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Technical Report No. SRH-2011-02

Hydrology, Hydraulics, and Sediment Transport Studies for the Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath River, Oregon and California
Mid-Pacific Region

U.S. Department of the Interior
Bureau of Reclamation

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Table of Contents

0. EXECUTIVE SUMMARY 0-1

1. INTRODUCTION 1-1

2. EXISTING HYDROLOGY CONDITIONS 2-1

- 2.1. RAINFALL AND TEMPERATURE 2-1
- 2.2. DAMS, WATER DIVERSION, AND HYDROPOWER FACILITIES 2-7
  - *2.2.1. Link Dam and Upper Klamath Lake 2-10*
  - *2.2.2. Klamath Irrigation Project 2-11*
  - *2.2.3. Keno Development 2-15*
  - *2.2.4. J.C. Boyle Development 2-15*
  - *2.2.5. Copco No. 1 Development 2-17*
  - *2.2.6. Copco No. 2 Development 2-18*
  - *2.2.7. Iron Gate Development 2-19*
- 2.3. REACH AND TRIBUTARY DESCRIPTIONS 2-24
  - *2.3.1. Upper Klamath Lake and Tributaries to Upper Klamath lake 2-25*
  - *2.3.2. J.C. Boyle to J.C. Boyle Powerplant (J.C. Boyle Bypassed Reach) 2-28*
  - *2.3.3. J.C. Boyle Powerplant to Copco Reservoir (J.C. Boyle Peaking Reach) 2-28*
  - *2.3.4. Copco to Iron Gate 2-30*
  - *2.3.5. Tributaries to Iron Gate 2-31*
  - *2.3.6. Downstream of Iron Gate Dam 2-32*
  - *2.3.7. Shasta River 2-35*
  - *2.3.8. Scott River 2-35*
  - *2.3.9. Klamath River near Seiad Valley 2-35*
  - *2.3.10. Salmon River 2-36*
  - *2.3.11. Klamath River at Orleans 2-37*
  - *2.3.12. Trinity River 2-38*
  - *2.3.13. Klamath River near Klamath 2-39*
- 2.4. PEAK FLOWS 2-41

3. EXISTING GROUNDWATER CONDITIONS 3-1

- 3.1. INTRODUCTION 3-1
- 3.2. PHYSIOGRAPHIC SETTING AND REGIONAL GEOLOGY 3-1
  - *3.2.1. Cascade Volcanics Province 3-1*
  - *3.2.2. Modoc Plateau Province 3-3*
- 3.3. LOCAL GEOLOGY 3-7
- 3.4. KLAMATH RIVER STUDY AREA 3-11
- 3.5. HYDROLOGY 3-11
  - *3.5.1. Generalized Surface Hydrology 3-11*
  - *3.5.2. Groundwater Hydrology 3-12*
- 3.6. EXISTING GROUNDWATER CONDITIONS 3-21
  - *3.6.1. Regional Groundwater Conditions 3-21*
  - *3.6.2. Sources of Groundwater in the Project Area 3-25*
  - *3.6.3. Groundwater Sinks in the Project Area 3-25*
  - *3.6.4. Local Groundwater Conditions 3-28*
    - 3.6.4.1. J.C. Boyle Reservoir 3-31
    - 3.6.4.2. Copco Reservoir 3-41
    - 3.6.4.3. Iron Gate Reservoir 3-53

4. EXISTING HYDRAULIC CONDITIONS 4-1

- 4.1. DEVELOPMENT OF HYDRAULIC MODEL 4-1

4.1.1. Hydraulic Model Upstream of Iron Gate Dam 4-2
4.1.2. Hydraulic Model Downstream of Iron Gate 4-4
4.2. CURRENT HYDRAULIC CONDITIONS 4-8

5. EXISTING GEOMORPHOLOGY AND SEDIMENT TRANSPORT CONDITIONS 5-1

5.1. GEOLOGICAL SETTING 5-1
5.2. GEOMORPHOLOGY 5-2
5.2.1. Data sources 5-3
5.2.2. Downstream of Iron Gate Dam 5-3
5.2.2.1. Iron Gate Dam to Hilt Mine (USGS RM 181-190) 5-5
5.2.2.2. Indian Girl Mine to Hilt Mine (USGS RM 174.6-181) 5-5
5.2.2.3. Scott River to Indian Girl Mine (USGS RM 143-174.6) 5-5
5.2.2.4. Scott River to China Point (USGS RM 118-143) 5-6
5.2.2.5. China Point to Trinity River (USGS RM 118-43.5) 5-7
5.2.2.6. Trinity River to Klamath River Estuary (USGS RM 43.5-0) 5-8
5.2.3. Comparisons to previous geomorphic mapping 5-9
5.2.4. Copco Reservoir high pool to Oregon-California state line 5-10
5.2.5. Reservoir areas 5-14
5.2.5.1. J.C. Boyle Reservoir 5-14
5.2.5.1. Copco 5-16
5.2.5.2. Iron Gate 5-18
5.2.6. Historical channel alignments vs. Bathymetric data 5-1
5.2.7. Comparison to vegetation restoration maps using bathymetric data 5-2
5.3. SEDIMENT LOADS 5-4
5.4. BED MATERIAL 5-11
5.5. FREQUENCY OF MOBILIZATION 5-15
5.5.1. Current Estimates of Mobilization 5-4
5.6. RESERVOIR SEDIMENT 5-9
5.6.1. Sediment Volume and Thickness 5-15
5.6.1.1. Previous Estimates 5-15
5.6.1.2. Current Estimates 5-18
5.6.2. Physical Properties 5-29
5.6.3. Cohesion and Shear strength 5-30
5.6.4. Erosive properties 5-31
5.6.5. Consolidation and desiccation 5-35
5.6.6. Fall Velocity 5-37

6. FUTURE HYDROLOGY CONDITIONS 6-1

6.1. NO ACTION ALTERNATIVE 6-1
6.1.1. Flood Frequency 6-1
6.1.2. Daily Flows 6-1
6.2. DAM REMOVAL ALTERNATIVE 6-1
6.2.1. Flood Frequency 6-1
6.2.2. Daily Flows 6-8

7. FUTURE GROUNDWATER CONDITIONS 7-1

7.1. NO ACTION ALTERNATIVE 7-1
7.2. DAM REMOVAL ALTERNATIVE 7-1

8. FUTURE HYDRAULIC CONDITIONS 8-1

8.1. NO ACTION ALTERNATIVE 8-1
8.2. DAM REMOVAL ALTERNATIVE 8-1

9. FUTURE GEOMORPHOLOGY AND SEDIMENT TRANSPORT CONDITIONS 9-1

9.1. NO ACTION ALTERNATIVE 9-1
9.2. DAM REMOVAL ALTERNATIVE 9-3
9.2.1. One-Dimensional Simulation of Reservoir Drawdown and Erosion of Reservoir sediment 9-3
9.2.1.1. Reservoir Elevations and Flows 9-8
9.2.1.2. Background Sediment Loads 9-14
9.2.1.3. Concentrations during Dam Removal 9-16
9.2.1.4. Erosion and Deposition after Dam Removal 9-33
9.2.1.5. Bed Material after Dam Removal 9-38
9.2.2. Two-dimensional analysis of Copco 1 drawdown 9-56
9.2.2.1. 2D Modeling Details 9-57
9.2.2.2. 2D Modeling Scenarios and Boundary Conditions 9-62
9.2.2.3. 2D Simulation Results and Discussion 9-65
9.2.3. Future Bed Mobilization Downstream of Iron Gate Dam 9-86
9.2.4. Water Quality Considerations during Drawdown 9-89
9.2.5. Suggested Monitoring 9-90
9.2.6. Summary 9-91

10. INFRASTRUCTURE IMPACTS OF DAM REMOVAL ALTERNATIVE 10-1

10.1. YREKA PIPELINE CROSSING 10-1
10.1.1. Scour Methods 10-2
10.1.2. Limiting Velocity 10-3
10.1.3. Scour Results 10-4
10.2. JENNY CREEK BRIDGE 10-7
10.3. HIGHWAY 66 BRIDGE 10-10
10.4. J.C. BOYLE BYPASS REACH BRIDGE 10-15
10.5. COPCO BRIDGE 10-17
10.6. COPCO NO. 2 ACCESS BRIDGE 10-19
10.7. ROAD CROSSINGS WITH CULVERTS 10-21

11. CLIMATE CHANGE EFFECTS 11-1

11.1. EFFECTS ON HYDROLOGY 11-1
11.2. EFFECT ON HYDRAULICS, SEDIMENT TRANSPORT AND GEOMORPHOLOGY 11-8

12. REFERENCES 12-1

13. APPENDIX A. FLOOD FREQUENCY REPORT 13-1

14. APPENDIX B. HYDRAULIC CONDITIONS DOWNSTREAM OF IRON GATE DAM 14-1

15. APPENDIX C. JET TEST RESULTS FROM TSC 15-1

16. APPENDIX D. REPORT ON ERODIBILITY CHARACTERISTICS OF RESERVOIR SEDIMENT BY AGRICULTURAL RESEARCH SERVICE 16-1

17. APPENDIX E. DOCUMENTATION OF HYDROLOGY SIMULATIONS FOR THE KLAMATH DAM REMOVAL STUDIES 17-1

17.1. HYDROLOGIC DATA DEVELOPMENT AND MANAGEMENT 17-3
17.2. CLIMATE CHANGE HYDROLOGY 17-5
17.3. BO 2010 OPERATIONS 17-7
17.4. KBRA OPERATIONS 17-9
17.5. OPERATIONS MODELS 17-11
17.6. FORECASTS FOR SYNTHETIC FLOWS AND DYNAMIC AGRICULTURAL DEMAND 17-13

18. APPENDIX F. EXCEEDANCE FLOWS FOR NO ACTION AND DAM REMOVAL ALTERNATIVES BASED UPON INDEX SEQUENTIAL HYDROLOGY 18-1

19. APPENDIX G. MAPPING OF 100-YEAR FLOOD PLAIN UNDER NO ACTION AND DAM REMOVAL ALTERNATIVES 19-1

20. APPENDIX H. GEOMORPHIC MAPPING 20-1

21. APPENDIX I. DRILL LOGS OF GROUNDWATER WELLS NEAR PACIFICORP RESERVOIRS 21-1

21.1. DRILL LOGS NEAR J.C. BOYLE RESERVOIR 21-1
21.2. DRILL LOGS NEAR COPCO RESERVOIR 21-8
21.3. DRILL LOGS NEAR IRON GATE RESERVOIR 21-20

22. APPENDIX J. REFERENCE SEDIMENT MOTION 22-1

23. APPENDIX K. OTHER DRAWDOWN SCENARIOS ANALYZED 23-1

23.1. SCENARIO 1 23-2
23.2. SCENARIO 2 23-9
23.3. SCENARIO 3 23-13
23.4. SCENARIO 4 23-17
23.5. SCENARIO 5 23-20
23.6. SCENARIO 6 23-24
23.7. SCENARIO 7 23-27
23.8. 1D MODEL SENSITIVITY 23-39
23.9. SUMMARY OF DRAWDOWN MODEL RESULTS 23-41

0. Executive Summary

The surface hydrology, groundwater hydrology, hydraulics, geomorphology, and sediment transport of the Klamath River Basin are analyzed as they pertain to the No Action and Dam Removal Alternatives of the Secretarial Determination on Klamath Dam Removal and Basin Restoration. The studies summarized in this document are consistent with those identified in the Project Management Plan for the Secretarial Determination on Klamath Dam Removal and Basin Restoration (PMP). The studies are intended to address the effects of the Klamath Basin Restoration Agreement (KBRA) and the Klamath Hydroelectric Settlement Agreement (KHSA).

Surface Water Hydrology

The No Action Alternative assumes that the current Klamath Project Operational conditions exist in the future. Several Section 7 Consultations and Biological Opinions (BO’s) have governed operation of Upper Klamath Lake (UKL) and the Klamath Project since the late 1990’s. The consultations involve the National Marine Fisheries Service (NMFS), also known as NOAA Fisheries, the U.S. Fish and Wildlife Service (FWS), and the Bureau of Reclamation (Reclamation). The latest FWS BO and the NMFS BO, dated March 15, 2010, are the basis of the operating criteria used by the Klamath Project Simulation Model (KPSIM) in the No Action Alternative.

The flows under the Dam Removal Alternative will be governed by the Klamath Basin Restoration Agreement (KBRA). The KBRA has the objective of restoring and sustaining fisheries while establishing reliable water and power supplies. The KBRA includes a potential operating scheme that was modeled based upon historical data and used a version of the Klamath Project Simulation Model (KPSIM). The hydrologic operations modeling under the Dam Removal Alternative are guided by this KBRA potential operating scheme.

The daily averaged reservoir elevations, water deliveries, and flows in the Klamath River were simulated under these two alternatives for a 50-yr period. The monthly average water surface elevations in UKL are higher under the Dam Removal Alternative than the No Action Alternative for every month of the year. In general, the average monthly flows at Iron Gate are relatively similar between the two alternatives. The exceptions to this are the months of October to December, where the average flows are about 200 to 400 cfs less under Dam Removal Alternative than under the No Action Alternative, and in April, where the flows are about 300 cfs higher under the Dam Removal Alternative than under the No Action Alternative. The differences in flow and lake elevations are due to differences in water deliveries to agriculture and wildlife refuges and to the flow releases at Link Dam. The PacifiCorp dams do not significantly affect average monthly flows because PacifiCorp operations do not remarkably alter the normal pool elevation throughout the year. The annual average flow at Iron Gate Dam under the Dam Removal Alternative is approximately 2% less.

The annual flow at Keno Dam is generally similar between the two alternatives except for the few driest years on record. In these dry years, the agricultural supply is significantly reduced under the No Action Alternative, whereas the agricultural supply is much less severely impacted under the Dam Removal Alternative; therefore, more flow is released to the Klamath River under the No Action Alternative than under the Dam Removal Alternative. At Iron Gate Dam from July through November, the flows are commonly around 800 cfs under the Dam Removal Alternative during these extremely dry years whereas the flows are more commonly between 1000 and 1300 cfs under the No Action Alternative.

The daily variability in flow is generally greater under the Dam Removal Alternative because of the ability to incorporate pulse flows into the operational rules under the KBRA. In addition, the natural variability in the tributary flow between J.C. Boyle and Iron Gate is not damped by the presence of the PacifiCorp Dams.

The removal of the Iron Gate and Copco No. 1 Dams will result in the removal of a relatively small storage volume that slightly attenuates floods. It is conservatively estimated that the discharge of 100-yr flood would increase by approximately 7% immediately downstream of Iron Gate after Dam Removal. This will slightly increase flood elevations immediately downstream of Iron Gate Dam.

The difference in streamflow between the No Action and Dam Removal Alternatives decreases in the downstream direction and the differences are not considered significant after the confluence with the Trinity River.

Groundwater Hydrology

Removal of the PacifiCorp Dams will not have a significant impact on the regional groundwater conditions. However, the removal of the dams may have a measureable impact on well immediately adjacent to the reservoirs. There are a significant number of private domestic wells exist in the river valley from upstream of Keno Dam to downstream of Iron Gate Dam. There are sixteen locatable wells within 2.5 miles of J.C. Boyle Reservoir, twenty-two locatable wells within 2.5 miles of Copco Reservoir, and twenty-five locatable wells within 2.5 miles of Iron Gate Reservoir – all are private domestic wells.

It does not appear that a significant number of private wells will be adversely impacted to any major degree. In most cases, the anticipated impacts will be negligible in the case of wells more than a ½ mile or more from the reservoir, or will only have minor lowering of the water elevations in the wells to a new baseline elevation. It is not anticipated that the new baseline will be significantly below the old river channel bed – which is likely to be the new baseline once the reservoirs are drained.

In cases where a well is anticipated to experience significant drops in water elevations, a recommended mitigation action would be to deepen an existing well or replace it if deepening is not an option.

Hydraulics

Because of the slight increase in peak flood flows immediately below Iron Gate Dam, there will be a slight increase in flood elevations. The most significant increase will occur just downstream of Iron Gate Dam from Bogus Creek to Willow Creek where the average increase in the 100- year flood elevations is expected to be about 1.5 feet. Downstream of the Humbug Creek (about 18 miles downstream of Iron Gate Dam), the increase in 100-year elevations are not considered significant because there will be attenuation effects in the channel and the peak flows in the tributaries will not perfectly coincide with the peak flow at Iron Gate.

Sediment Transport

The sediment stored in the PacifiCorp Reservoirs is predominantly silt, clay and organic material that is 80 to 90 % water and highly erodible. Drawdown of the four PacifiCorp Dams will release approximately 1/3 to 2/3 of the approximately 15 million yd^3 of sediment that will be stored in the reservoirs by 2020. If there is a wet year, more material will be eroded and if there is a dry year, less material will be eroded from the reservoirs. The river will return to its pre-dam alignment at each reservoir and have a similar width to pre-dam conditions. The sediment that is left behind in the reservoirs will raise the floodplain terraces above the pre-dam conditions and the floodplains are expected to be inundated less frequently than typical floodplains in the basin. High flows will gradually widen the floodplain, but this process is expected to occur slowly over several decades.

Over 80 % of the reservoir sediment is fine sediment (silt, clays, and organics). Most of this material will be transported to the ocean during the period of drawdown which will last from January 1, 2020 to mid March, 2020. The maximum sediment concentrations during this period may be more than 10,000 mg/l downstream of Iron Gate. The tributaries entering Klamath River will significantly reduce these concentrations to less than 2,000 mg/l at the mouth of the Klamath River.

If there is a wet year, it may take longer to drain Iron Gate Reservoir because of its limited outlet capacity and there may be sediment concentrations larger than 1,000 mg/l as late as June. If there is a dry year, the sediment concentration will be higher during the drawdown period because of less dilution of sediment by the flow.

Sediment concentrations are expected to resume to background levels by the end of the summer 2020 regardless of type of hydrology present. There will be aggressive hydro seeding of the reservoir material immediately following dam removal which will stabilize the sediment from erosion due to rainfall. In addition, the reservoir sediment dramatically increases its resistance to erosion once it dries out.

The bed material within the reservoirs and between Iron Gate to Cottonwood Creek is expected to have a high content (30 to 50 %) of sand immediately following reservoir drawdown until a flushing flow moves the sand sized material out of the reach. The flushing flow is expected to have to be at least 6,000 cfs and of several days to weeks to return the bed to bed dominated by cobble and gravel with a sand content less than 20%. After the flushing flow, the bed is expected to maintain fractions of sand, gravel, and cobble which would be expected under natural conditions.

The mobility of the bed downstream of Iron Gate Dam to Cottonwood Creek will be increased by the removal of the dams. The return of the natural gravel supply to this reach will increase the frequency of gravel mobilization from once every four years to once every other year.

Climate Change Effects

Five different Global Circulation Models were used to generate five different possible climate change scenarios. Three of the five climate change simulations show an increase in annual inflow while the other two show a decrease in annual inflow. However, all climate change simulations show a more rapid snow melt period. They all indicate a greater proportion of the annual inflow occurring during the months of November through March and a decrease in the proportion of inflow occurring May through October. The three wet climate change simulations have greater annual flow volumes, but the average flow in the summer and fall are similar to the simulations without climate change. Most all the increase in annual flows occurs from December to April. The dry climate change simulations show significantly smaller average flows throughout all months, except for March where the hotter climate can cause more precipitation to fall as rain and also cause faster snowmelt. The general expectation is that under climate change the flows entering UKL in the later winter and early spring (February to April) will be similar or higher than current flows, but that flows in May through October will be similar or lower than current flows. Flows into UKL during the winter may be either lower or higher than current conditions.

1. Introduction

The Reclamation Mid-Pacific Regional Office (MP) requested that the Reclamation Technical Service Center (TSC) perform hydrologic, hydraulic, and sediment transport studies to support the Secretarial Determination on Klamath Dam Removal and Basin Restoration. The studies summarized in this document are consistent with those identified in the Project Management Plan for the Secretarial Determination on Klamath Dam Removal and Basin Restoration (PMP). The studies are intended to address the effects of the Klamath Basin Restoration Agreement (KBRA) and the Klamath Hydroelectric Settlement Agreement (KHSA).

There are two alternatives analyzed in this document from the years 2012 to 2061: the "No Action" and "Dam Removal" Alternatives.

The No Action Alternatives includes the following features:

1. JC Boyle, Copco 1, Copco 2, and Iron Gate dams owned by PacifiCorp will remain and continue to generate hydropower on the Klamath River.
2. No additional fish passage will be installed at the PacifiCorp dams.
3. The Klamath Irrigation Project operations from 2012 to 2061 will be governed by the National Marine and Fisheries Service (NMFS) 2010 Biological Opinion.

The Dam Removal Alternatives includes the following features:

1. JC Boyle, Copco 1, Copco 2, and Iron Gate dams will be removed by December 31, 2020 and a free flowing river will be established by that date.
2. Reservoir drawdown of J.C. Boyle, Copco 1, and Iron Gate dams will begin on November 15, 2019 or January 1, 2020.
3. The sediment behind all dams will not be removed or stabilized by mechanical means prior to drawdown.
4. The Klamath Project operations from 2012 to 2061 will be governed by the KBRA settlement.

Chapters 1 through 5 of this report describe the current surface water hydrology, groundwater hydrology, stream hydraulics, geomorphology, and sediment characteristics of the Klamath River. Chapters 6 through 9 analyze the future conditions under the No Action and Dam Removal Alternatives. Chapter 10 presents some specific impacts to infrastructure caused by the Dam Removal Alternative. Chapter 11 presents the effects of Climate Change on the alternatives.

An overview of the entire Klamath River Basin is shown in Figure 1-1. The Klamath Basin is generally divided into Upper and Lower Basins. The Upper Basin (above Iron Gate Dam) is shown in Figure 1-2 and the Lower Basin (below Iron Gate Dam) is shown in Figure 1-3. The Upper Klamath River Basin is bordered by the Sacramento River Basin to the south, closed basins within the Great Basin to the east and north, and the Rogue River Basin to the northwest. Most of the precipitation occurs during the late fall, winter, and spring and is predominately in the form of snow above elevations of 5,000 feet. The Lower Klamath River Basin includes the river area downstream from Iron Gate Dam, flowing unimpeded by dam controls for 190 miles, which passes through the Klamath Estuary and into the Pacific Ocean. The major tributaries entering the river include the Shasta, Scott, Salmon, and Trinity Rivers. These four rivers provide 44 percent of the mean annual runoff, heavily influencing the hydrology of the Klamath River Basin. Flow for the entire Upper Klamath River Basin is recorded at the Klamath River gage below Keno Dam, Oregon.

An overview of the reach containing the four PacifiCorp dams being analyzed for removal is given in Figure 1-4. The four dams, J.C. Boyle, Copco No. 1, Copco No. 2, and Iron Gate dams, are located in the Upper Klamath Basin and downstream of Upper Klamath Lake (UKL). Upper Klamath Lake is fed by the Williamson, Sprague, and Wood Rivers. Upper Klamath Lake is now controlled by Link River Dam and empties into the Link River. The Klamath River begins at Lake Ewauna just south of Upper Klamath Lake and flows southwest into California. Lower Klamath Lake, once directly connected to the Klamath River, was cut off by 1924 and drained substantially by the Klamath Irrigation Project. The remaining marsh and lake areas are now managed primarily as Lower Klamath National Wildlife Refuge.

A water surface profile of the reach from above UKL on the Williamson River to the Ocean along the Klamath River is given in Figure 1-5. The slope upstream of Keno Dam is much smaller than the slope of the Klamath River below Keno Dam. Keno Reservoir is kept at approximately 4085 feet in elevation and the elevation of UKL is usually between 4136 and 4143 feet. These large reservoirs have profound effects on the hydrology and sediment transport of the basin. A profile of the Klamath River is given in Figure 1-6 from Keno Dam to Indian Creek. The bed profile is obtained from a bathymetric survey from Iron Gate Dam to Indian Creek and a LiDAR survey from Link Dam to Happy Camp, CA. The water surface slope is also shown in Figure 1-6. Discussion and details on the PacifiCorp dams on the Klamath River are given in section 2.2 - dams, Water Diversion, and Hydropower Facilities. (See also: Table 2-1).

Previous analyses of sediment impacts during dam removal have been conducted by GEC (Gathard Engineering Consulting) (2006), Stillwater Sciences (2008), and Phillip Williams and Associates, Ltd (2009). Water quality impacts of dam removal have been analyzed by Stillwater Sciences (2009a) and biological effects of dam removal have been analyzed by Stillwater Sciences (2009b).

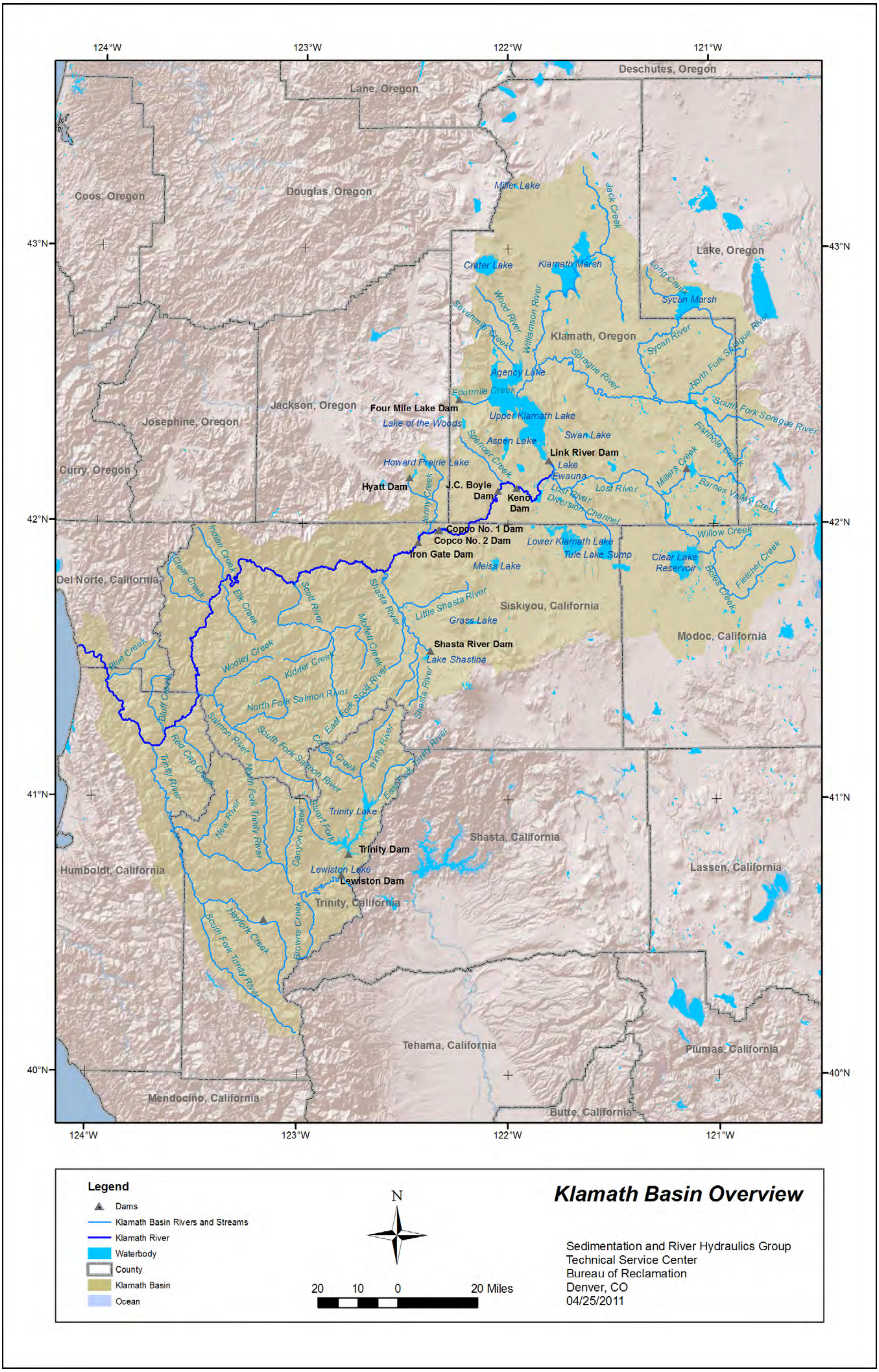


Figure 1-1. Overview of Klamath River Basin.

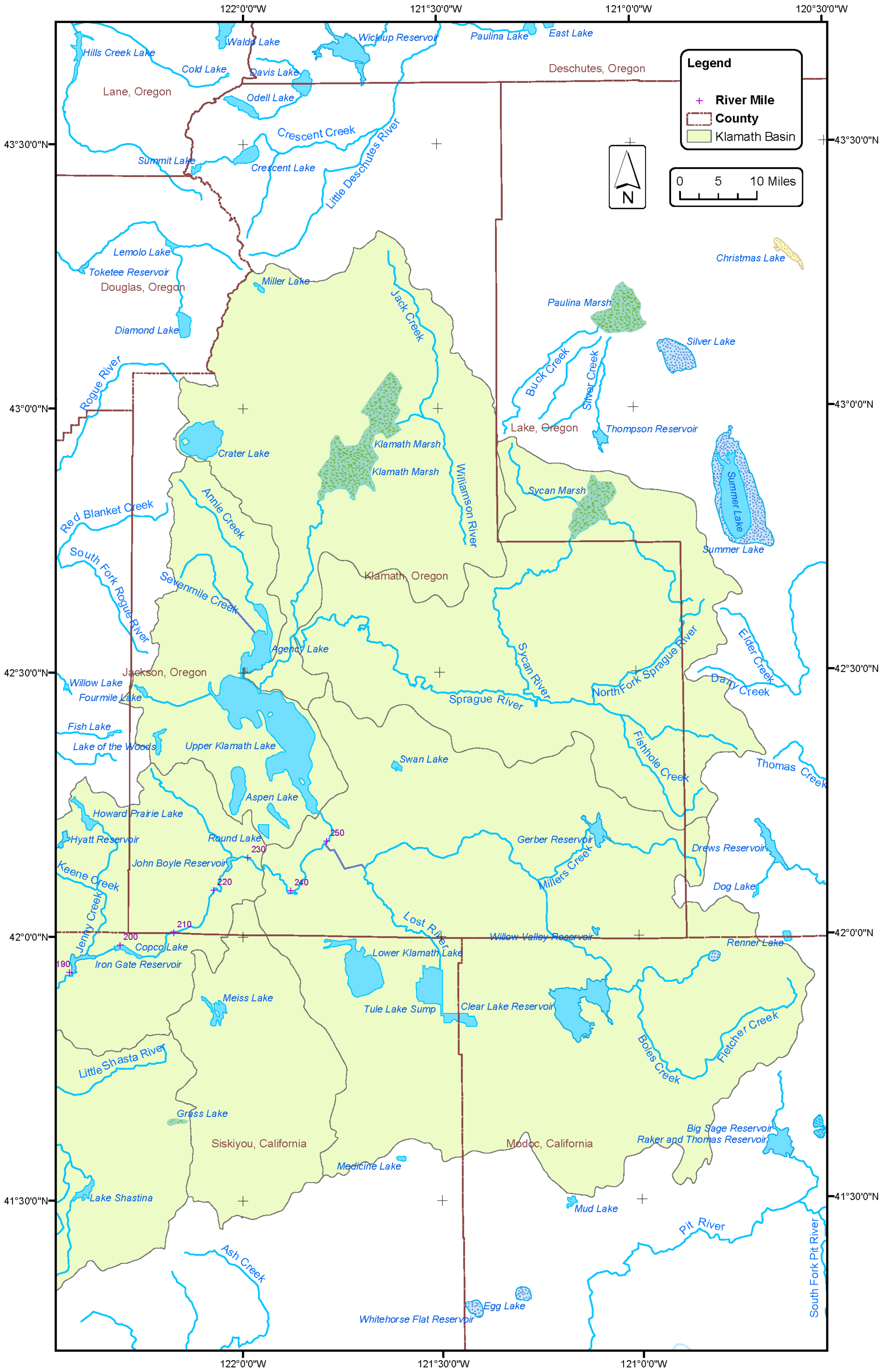


Figure 1-2. Overview of Upper Klamath Basin.

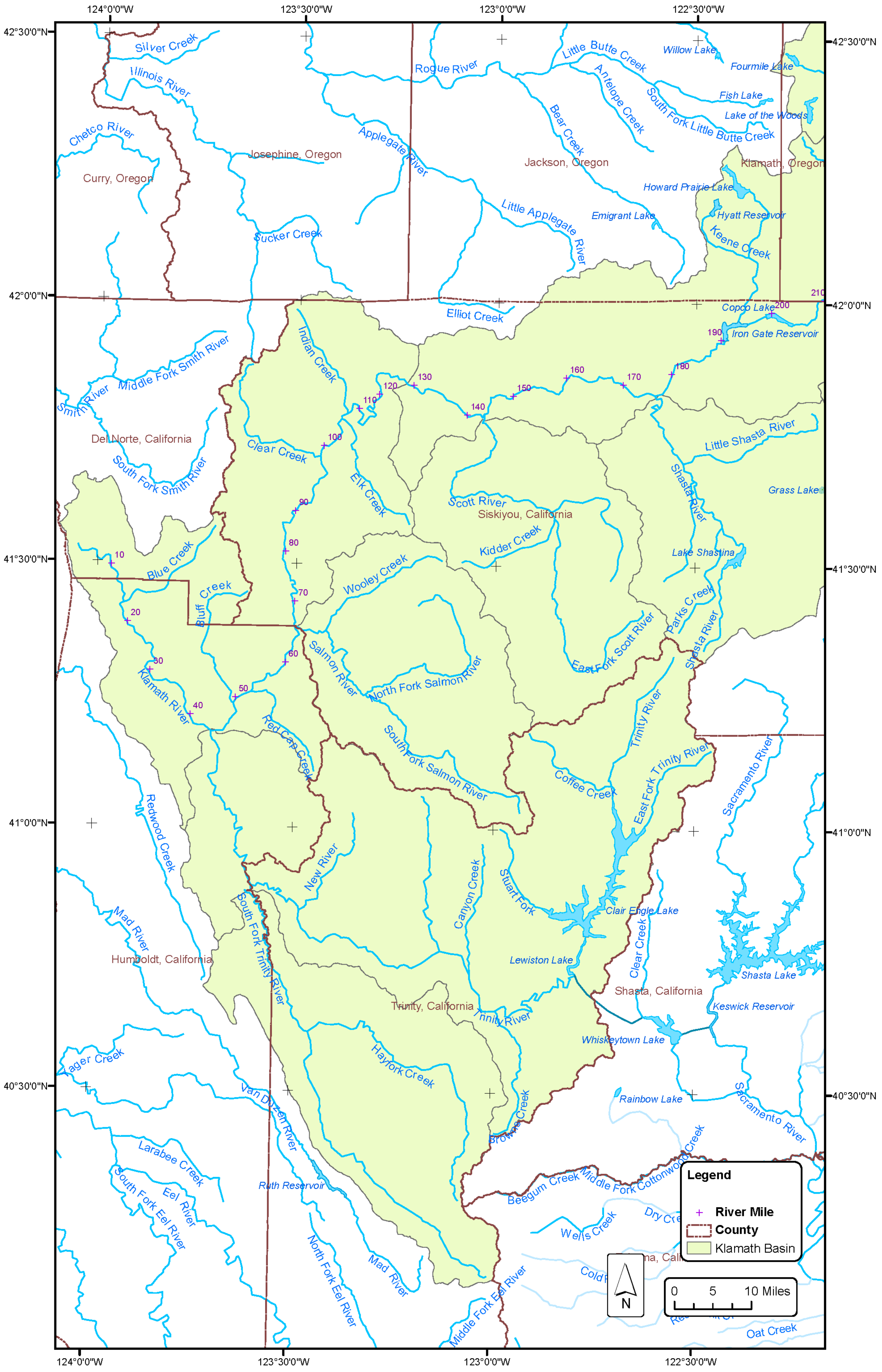


Figure 1-3. Overview of Lower Klamath Basin.

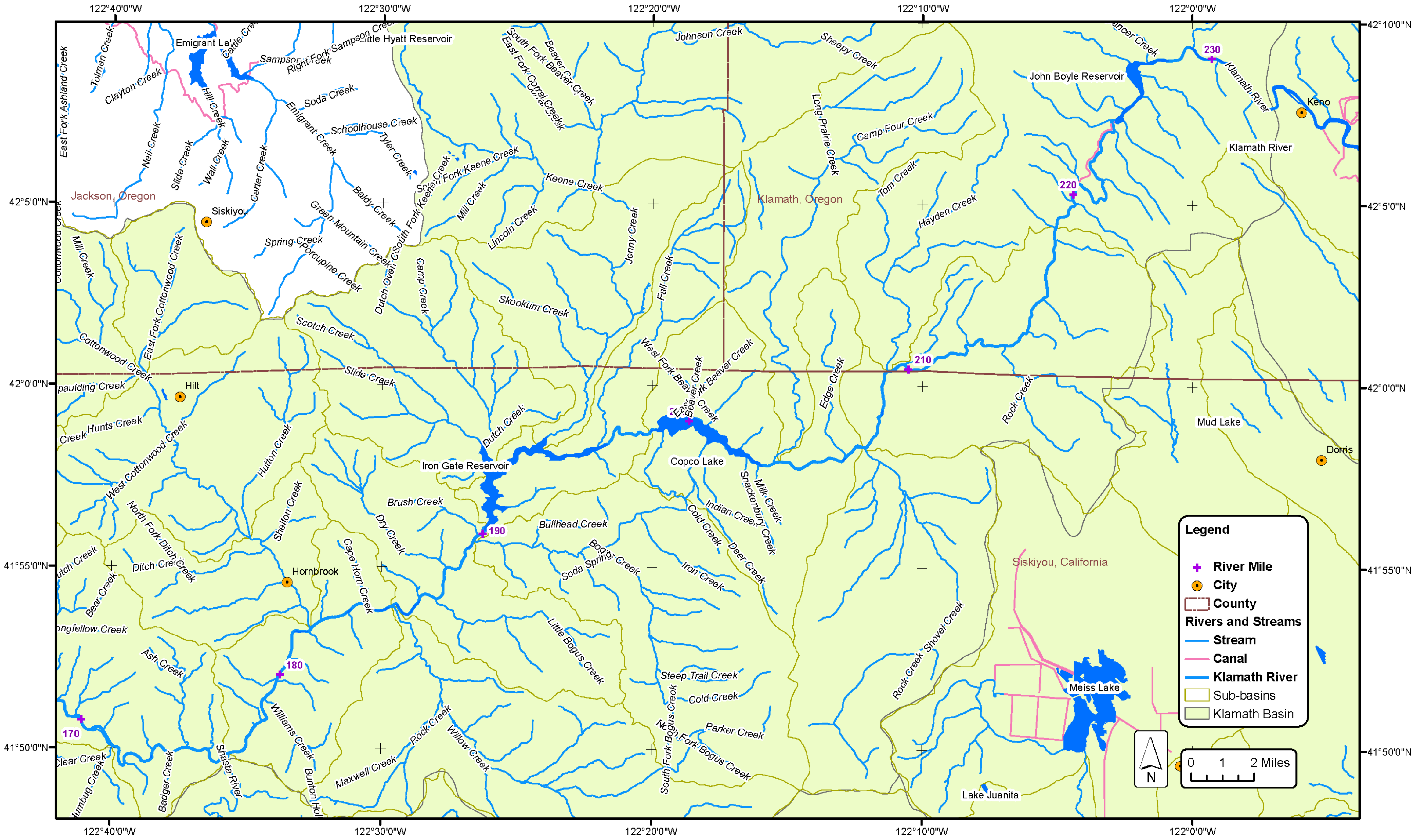


Figure 1-4. Overview of Klamath River from J.C. Boyle Reservoir to Shasta River.

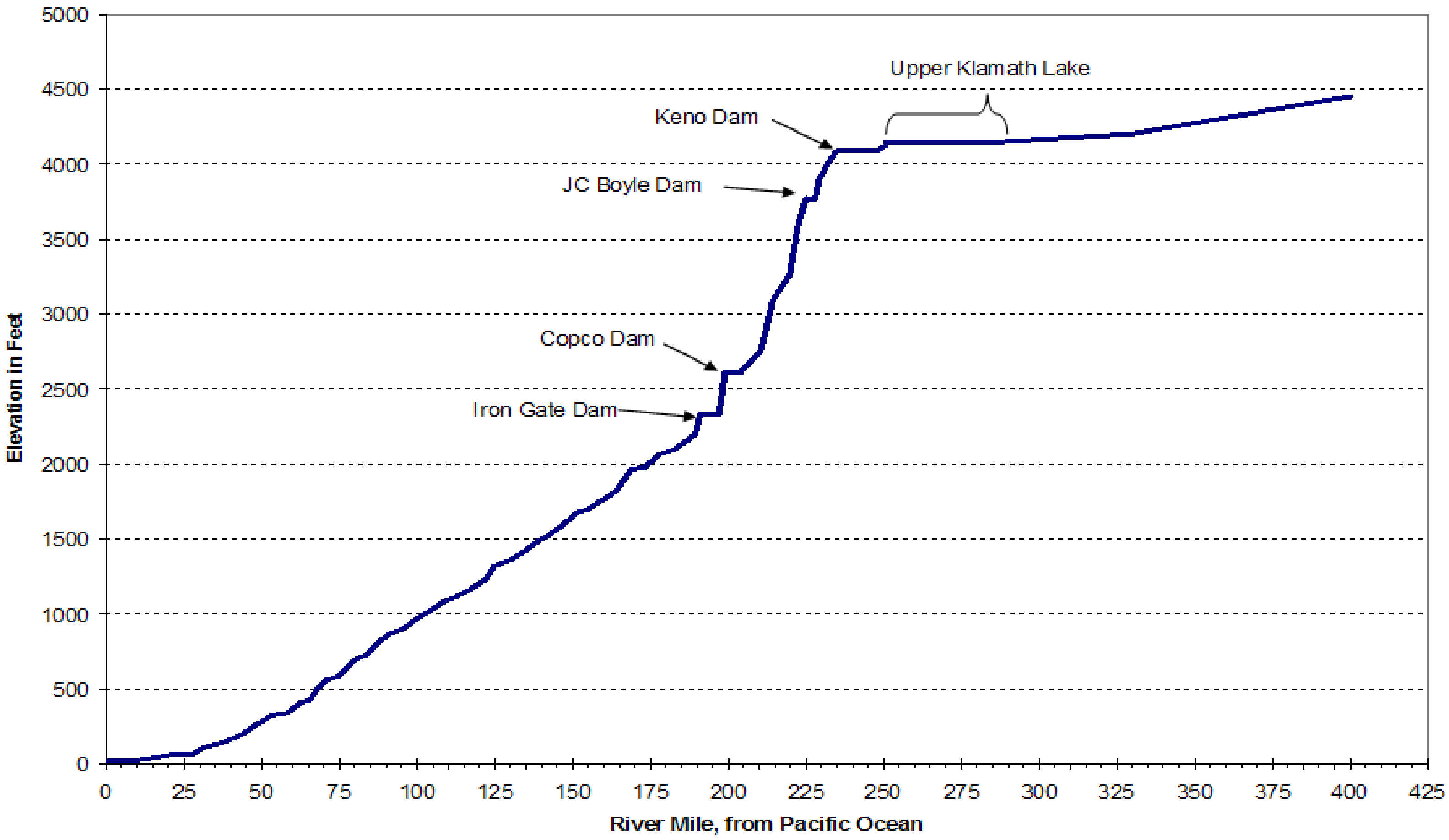


Figure 1-5. Water Surface Profile of Klamath and Williamson Rivers from ocean to above Upper Klamath Lake.

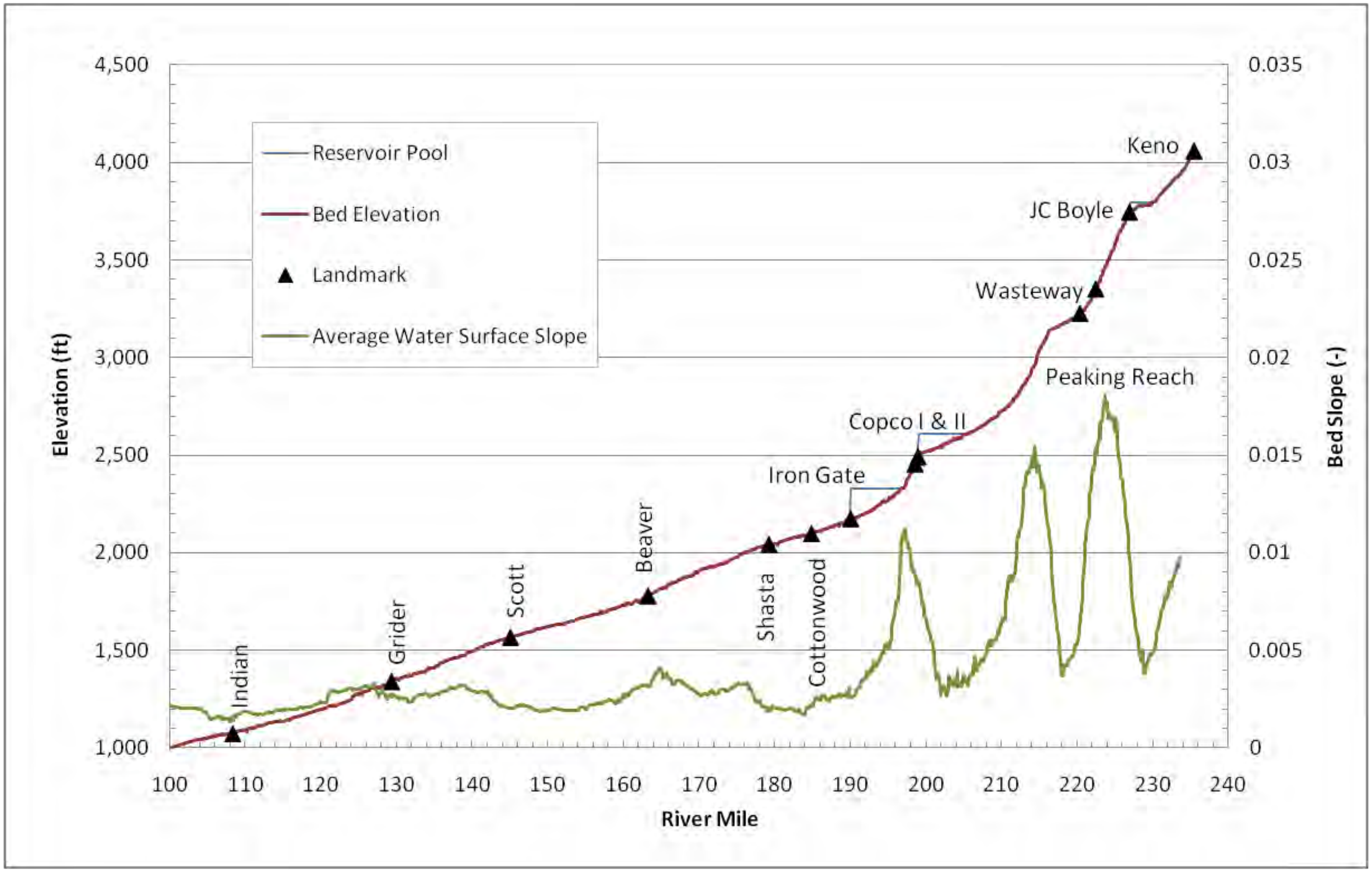


Figure 1-6. Bed elevation and water surface slope in reach from Keno to Happy Camp.

2. Existing Hydrology Conditions

Several studies of the hydrology were conducted and detailed reports were generated for each study. The following reports are attached as appendices to this report:

1. Current Flood Hydrology of the Klamath River – Appendix A: Analyzes the historical flow duration and flood frequency data of the Klamath River from Keno Dam to the Pacific Ocean.

2. Hydrologic Data Development and Management – Appendix E: Describes development of naturalized flows from historic data, an overview of synthetic hydrology, and an overview of data management system.

3. Upper Klamath Biological Opinion Operations – Appendix E: Describes how the 2010 Biological Operational criteria were implemented into the Klamath Project Simulation Model (KPSIM) without adjustments for the Klamath Dam Removal (KDR) study. These are the operations assumed under No Action Alternative.

4. Upper Klamath KBRA operations – Appendix E: Describes how the KBRA operation criteria were implemented into KPSIM without adjustments for the Dam Removal Study. These are the operations assumed under the Dam Removal Alternative.

5. Hydrology Operations – Appendix E: KBRA operation criteria and implementation in KPSIM without KDR adjustments. These are the operations assumed under the Dam Removal Alternative.

6. Forecast Generation and Demand Representation in Upstream Operation Models – Appendix E: Detailed description of forecast generation for synthetic hydrology for UKL operations and KBRA demand computations

7. Climate Change hydrology development – Appendix E: Describes development of Climate Change Hydrology

A brief summary on the current conditions of the Klamath basin hydrology is given in this chapter.

2.1. Rainfall and Temperature

Monthly average temperature and precipitation at Klamath Falls, OR and Yreka, CA are giving in Figure 2-1 and Figure 2-2, respectively. The months with the most precipitation are November to March. The least precipitation falls during the months of July through September.

The annual precipitation at Klamath Falls and at Copco 1 Dam is given in Figure 2-3 and Figure 2-4, respectively. The annual precipitation for the period from 1907 to 1997 at Klamath Falls is 13.4 inches and the annual precipitation from 1959 to 2009 at Copco 1 is about 20 inches. Additional statistics on monthly rainfall at Keno and Copco 1 are given Figure 2-5 and Figure 2-6.

The annual mean temperature and total precipitation for Jackson, Klamath, and Siskiyou Counties from 1900 to 2009 was reported in Reclamation (2011c) and their figure is reproduced in Figure 2-7. The 25-year moving average of the mean annual temperature has been increasing since the 1970s and is approximately 1° F higher now than in the 1930s to 1960s. The total precipitation is quite variable year to year and does not show a consistent trend since the 1950s.

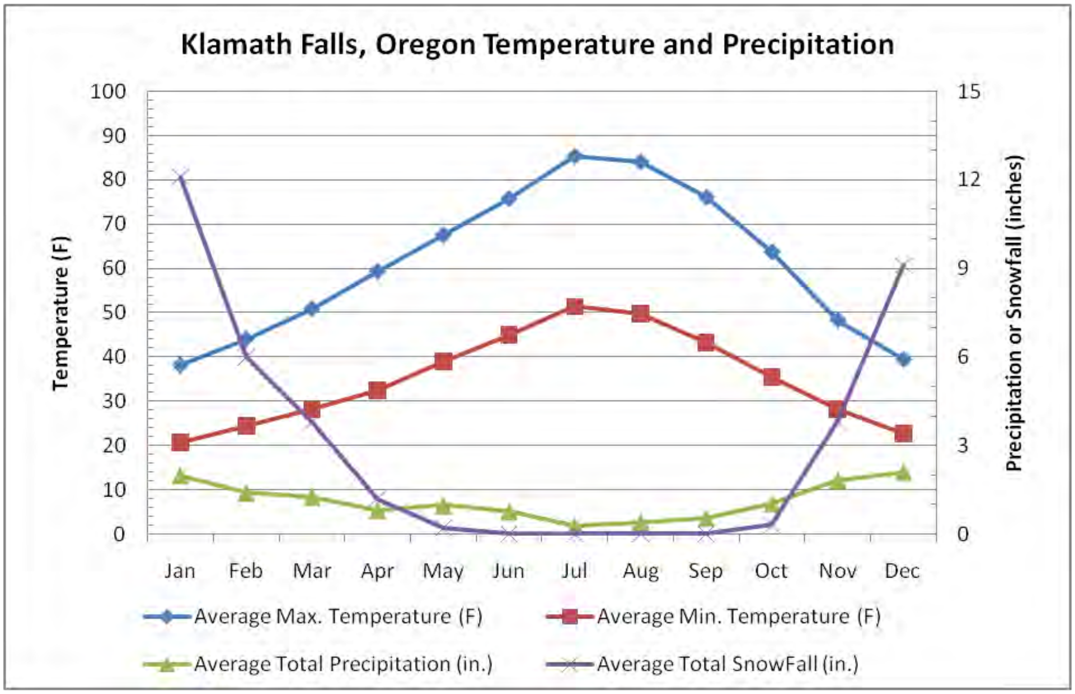


Figure 2-1. Average monthly temperatures and precipitation at Klamath Falls. (gage # 354506 at 41.97972 N, 1222.33778 W). Period of record is from 5/11/1887 to 5/31/2001. Data obtained from Western Regional Climate Center (http://www.wrcc.dri.edu/).

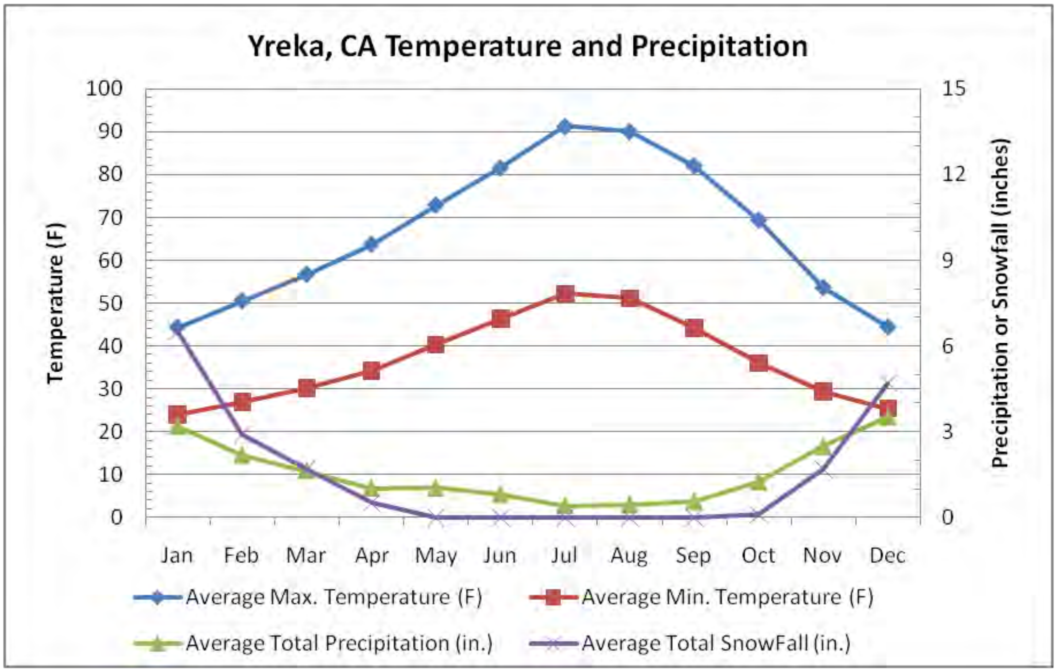


Figure 2-2. Average monthly temperatures and precipitation at Yreka, CA (gage # 049866). Period of record is from 2/ 1/1893 to 4/30/2010. Data obtained from Western Regional Climate Center (http://www.wrcc.dri.edu/).

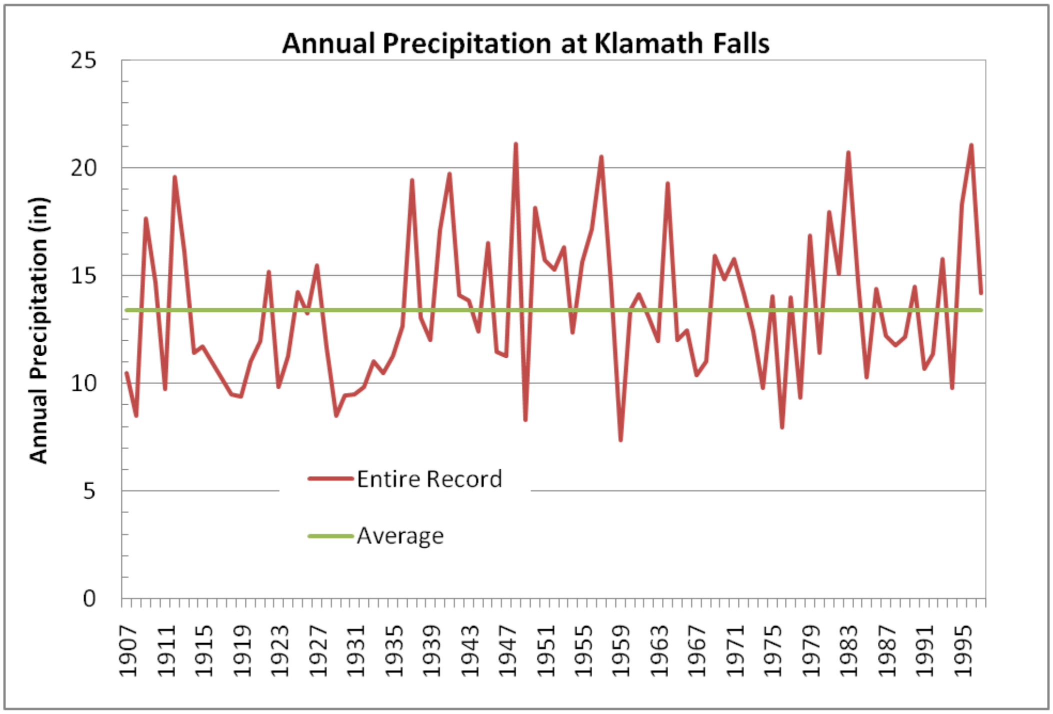


Figure 2-3. Annual precipitation at Klamath Falls. (gage # 041990 at 41.97972 N, 1222.33778 W). Data obtained from Western Regional Climate Center (http://www.wrcc.dri.edu/).

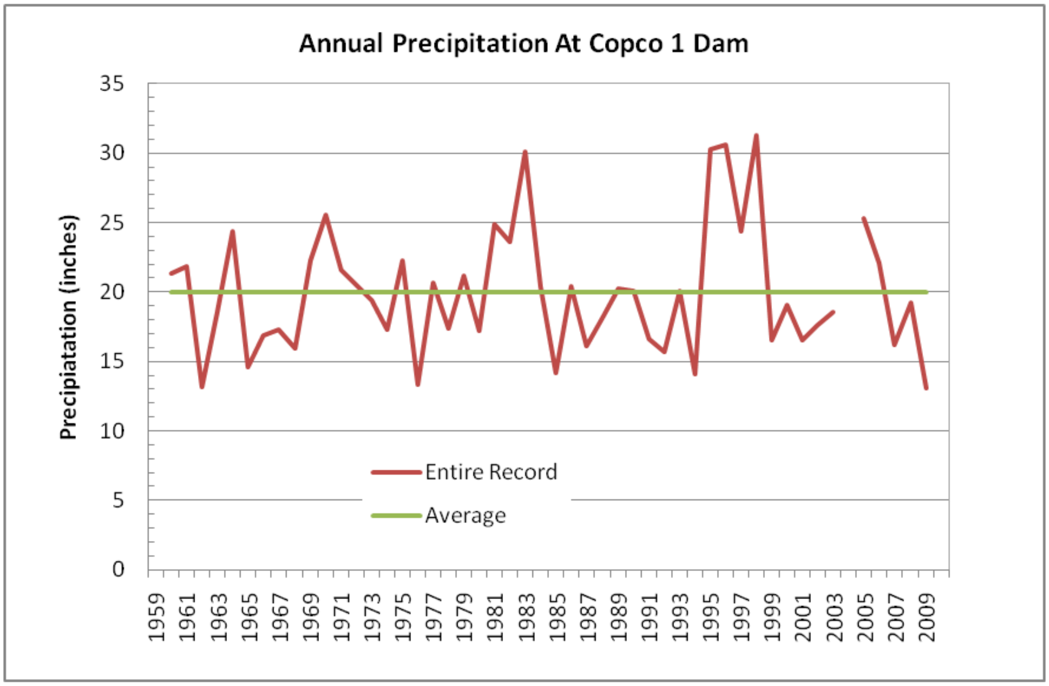


Figure 2-4. Annual precipitation at Copco 1 Dam (gage # 041990 at 41.97972 N, 1222.33778 W). Data obtained from Western Regional Climate Center (http://www.wrcc.dri.edu/).

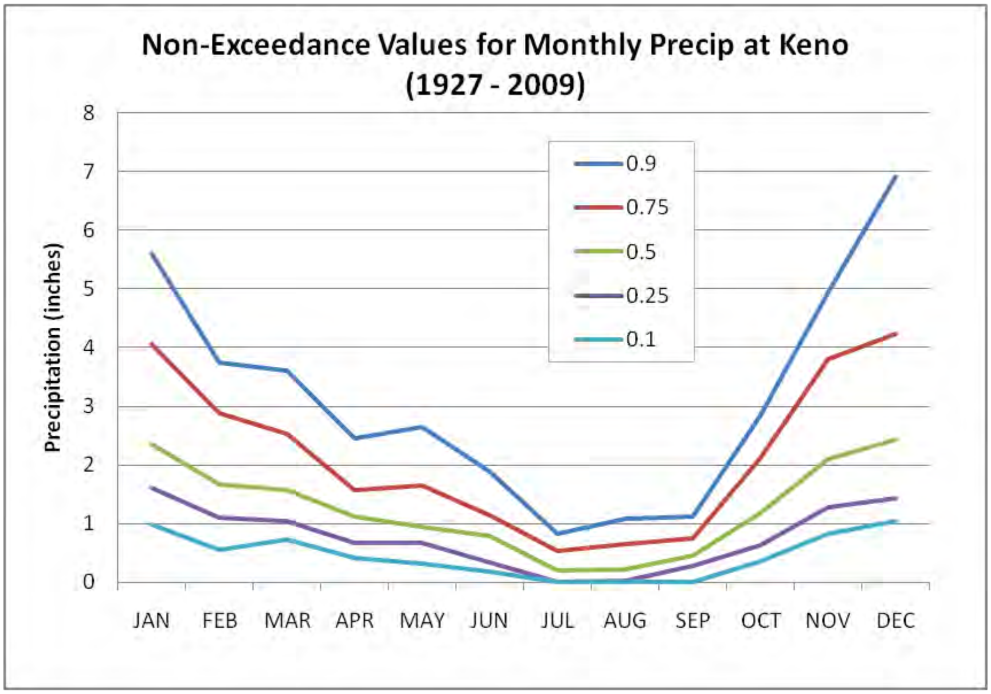


Figure 2-5. Rainfall statistics for rain gage located near Keno Dam (gage # 354403 at 42.12639 N, 121.93083 W). Data obtained from Western Regional Climate Center (http://www.wrcc.dri.edu/)

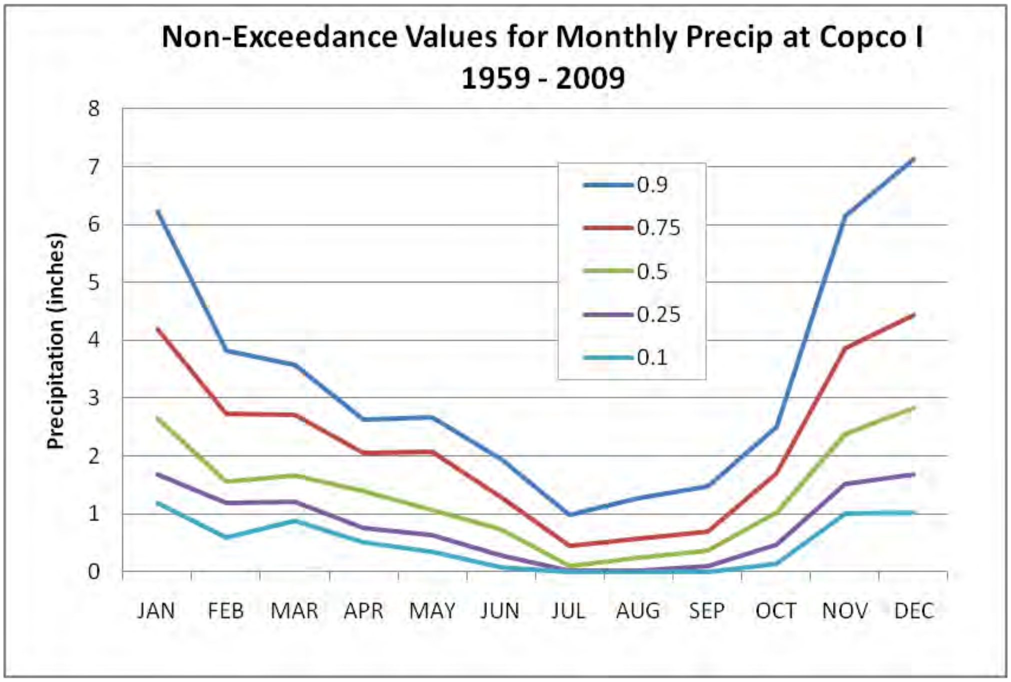


Figure 2-6. Rainfall statistics for rain gage located near Copco 1 Dam (gage # 041990 at 41.97972 N, 1222.33778 W). Data obtained from Western Regional Climate Center (http://www.wrcc.dri.edu/).

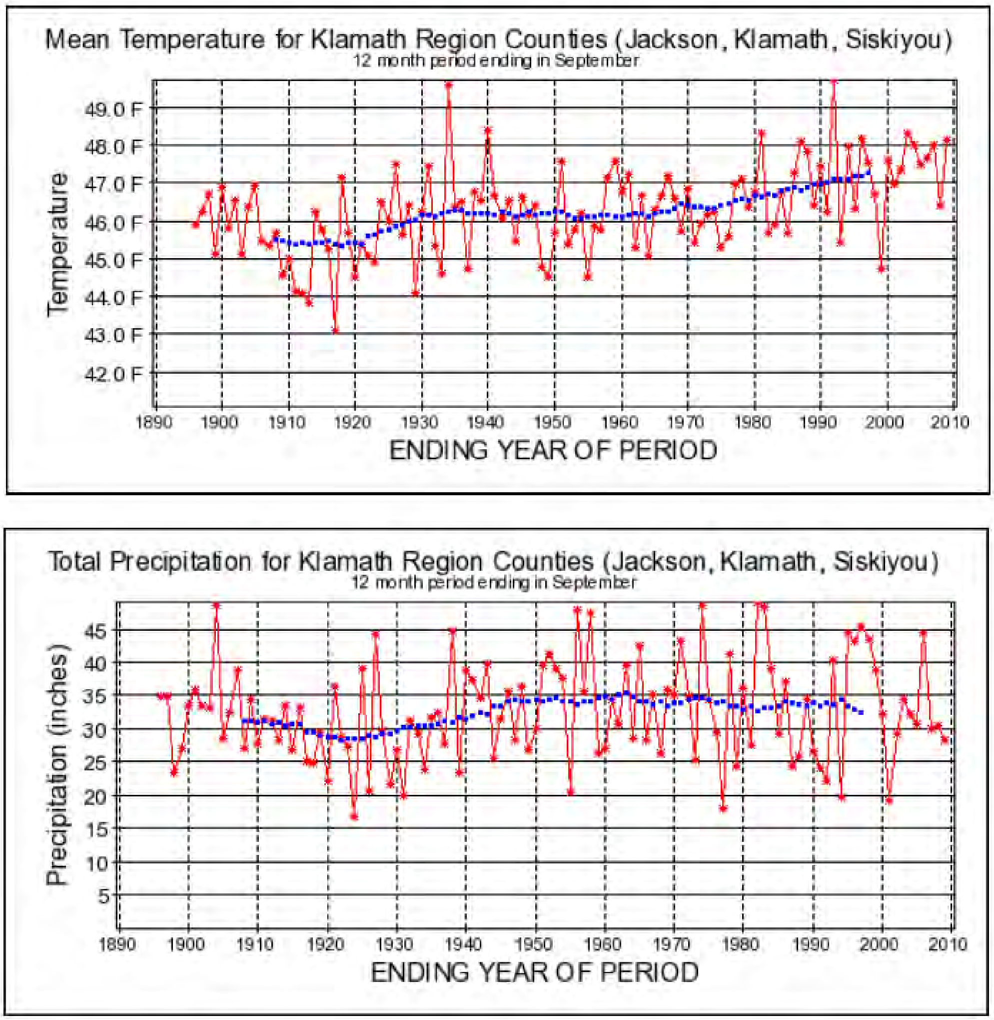


Figure 22. Observed annual (red) and moving-mean annual (blue) temperature and precipitation, averaged over the Klamath River Region.

Source: Western Climate Mapping Initiative (WestMap) available at: http://www.cefa.dri.edu/ Westmap/. Red line indicates annual time series for the given geographic region. Blue line indicates 25-year moving annual mean values, where each value is plotted on the center year of its respective 25-year period. WestMap data are derived from the PRISM climate mapping system (Daly et al. 2004; Gibson et al. 2002).

Figure 2-7. Historic annual mean temperature and total annual precipitation for Klamath Regional Counties from Reclamation, 2011c.

2.2. Dams, Water Diversion, and Hydropower Facilities

The storage capacities and details of the dams located on the Klamath River are given in Table 2-1 from PacifiCorp (2004a). Some of the details of their facilities are reproduced in this document. Upper Klamath Lake controlled by Link Dam has approximately 83% of the storage on the Klamath River, while the four PacifiCorp dams being analyzed for removal have 14% of the storage. These four dams are operated for hydropower and most often are operated as run-of-the-river facilities, whereas, Link Dam is operated primarily for water storage.

A flow schematic of the operations from Link Dam to Iron Gate is shown Figure 2-8 and a flow schematic of the Klamath Basin above Keno Dam is shown in Figure 2-9. A schematic of the Klamath Irrigation Project is shown in Figure 2-10.

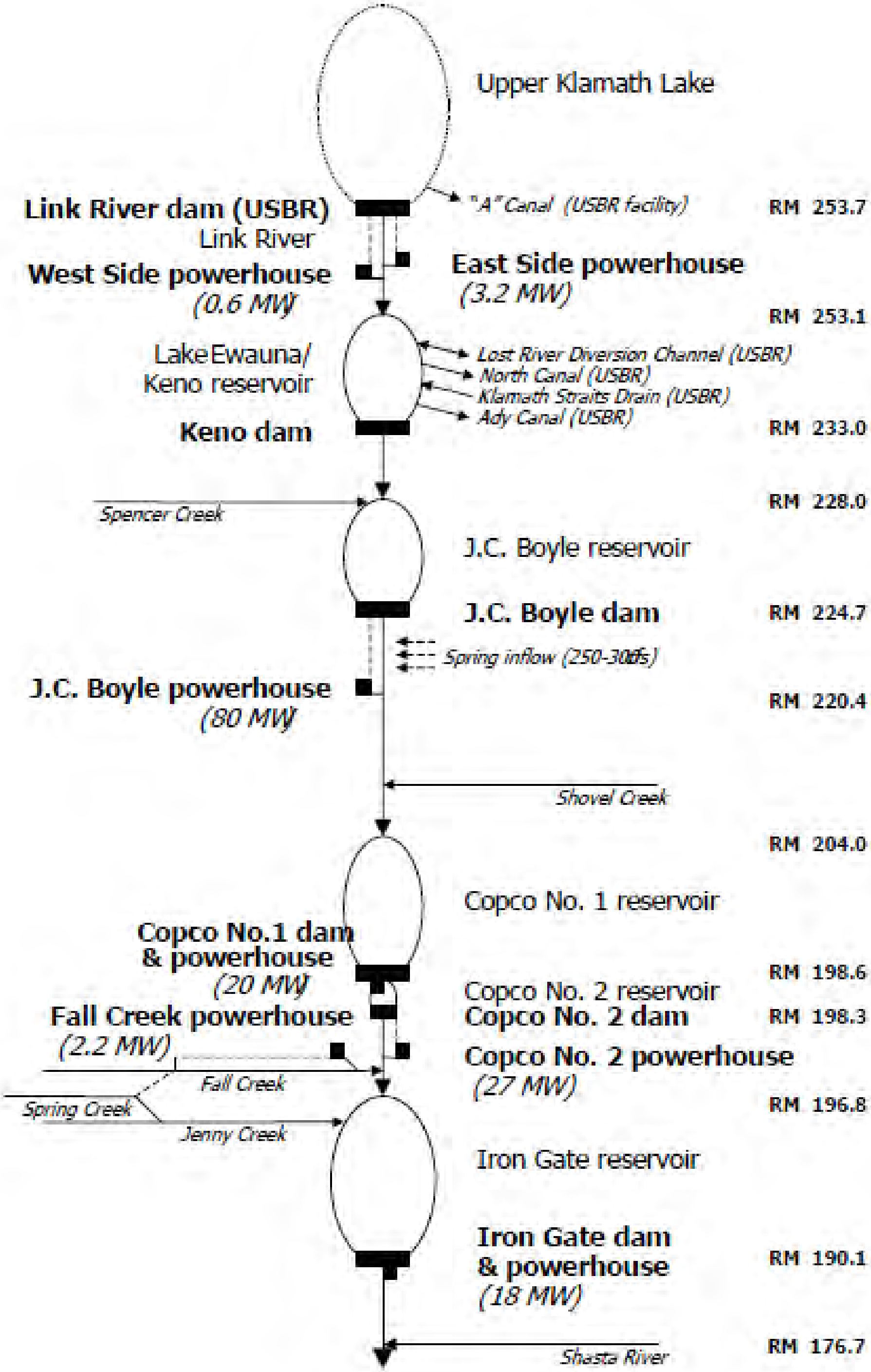


Figure 2-8. Schematic of Flow Operations in Klamath Basin (used by permission from PacifiCorp, Exhibit B, 2004).

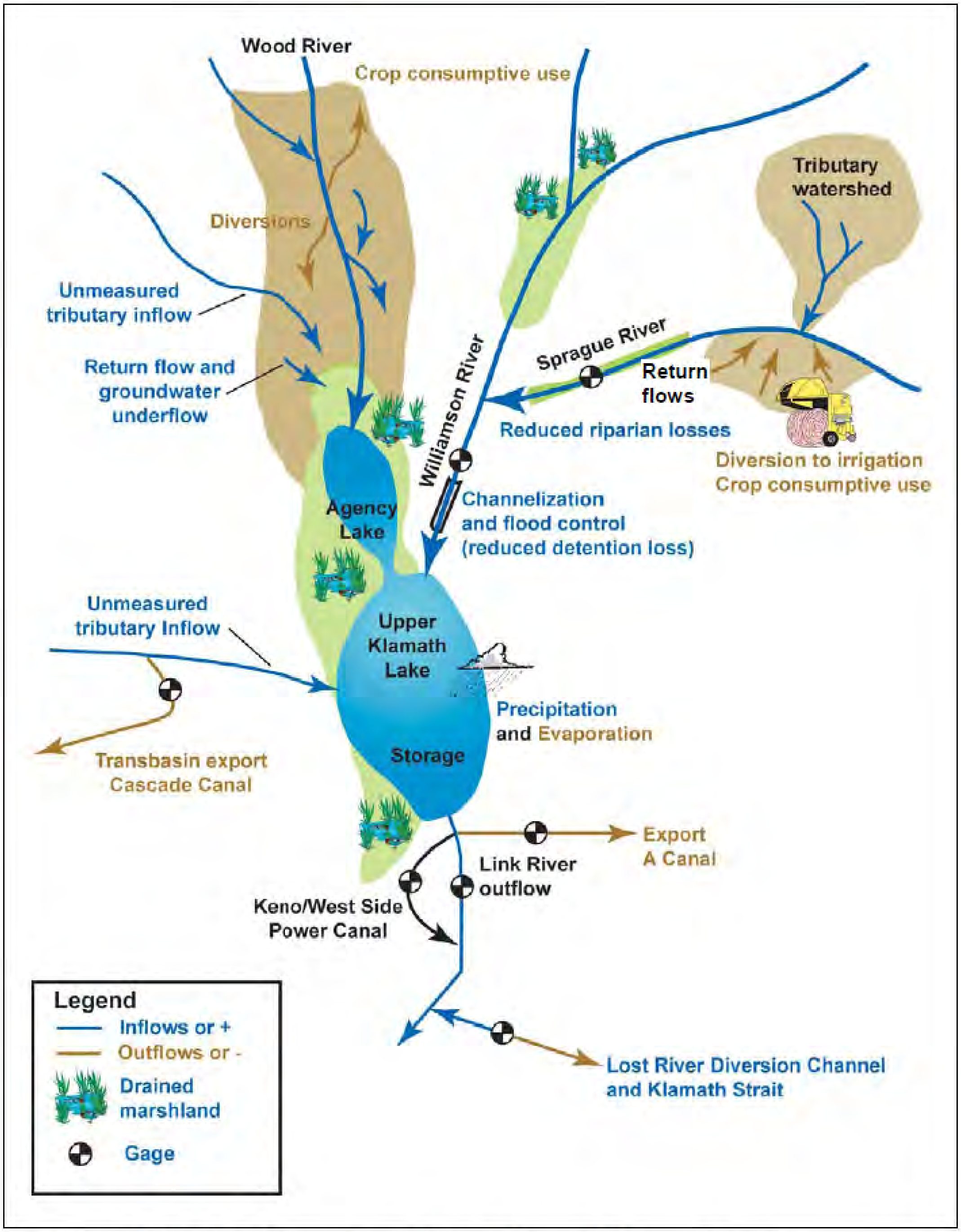


Figure 2-9. Upper Klamath Lake and Keno flow schematic (from Reclamation 2005).

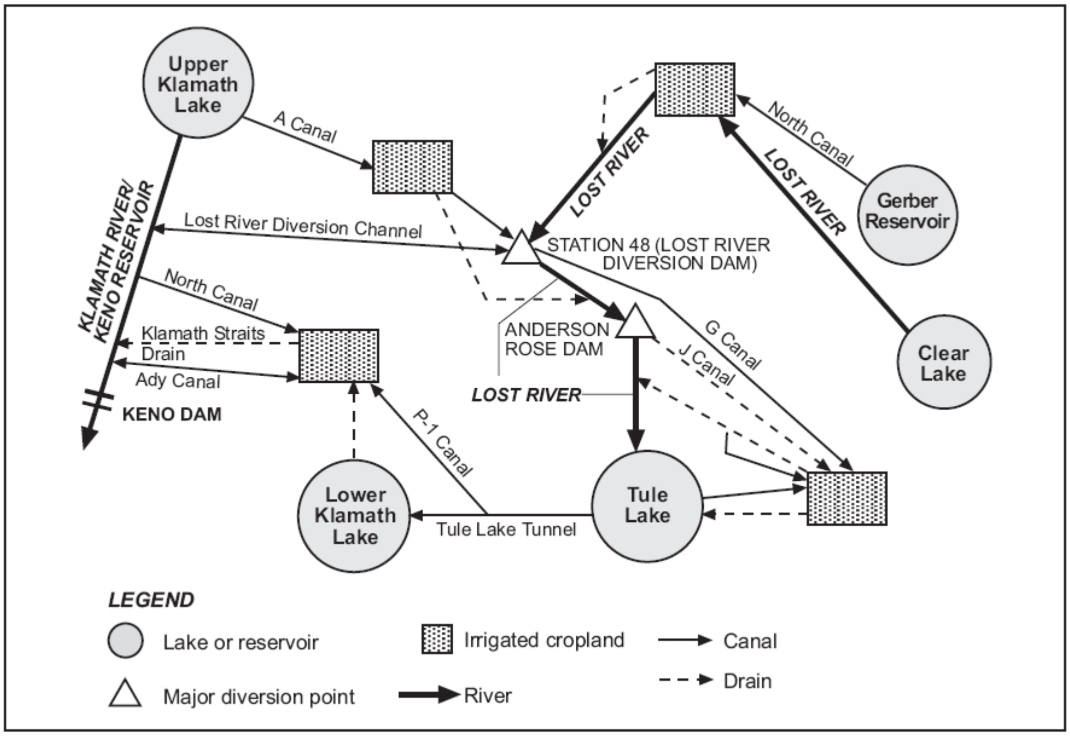


Figure 2-10. Schematic of Klamath Irrigation Project (from FWS, 2002 and FERC, 2007).

2.2.1. LINK DAM AND UPPER KLAMATH LAKE

Link River Dam on Link River at the head of Klamath River is just west of Klamath Falls, Oregon, and regulates flow from Upper Klamath Lake Reservoir. The dam is a reinforced concrete slab structure with a height of 22 feet and a crest length of 435 feet.

Upper Klamath/Agency Lake (UKL) is a shallow, hypereutrophic (high biological productivity) lake with extensive wetlands, and is fed by numerous shoreline springs, and several tributaries. This lake is the largest body of fresh water in Oregon and varies from 6 to 14 miles wide and is about 25 miles long. Upper Klamath/Agency Lake has a maximum surface area of approximately 83,000 acres and a active storage capacity between elevations 4136.0 and 4143.3, including Tulana and Goose Bays farms, of 515,400 acre-ft. The potential active capacity of a re-connected Agency Lake and Barnes Ranches between elevations 4136.0 and 4143.3 is 63,800 acre-ft. The “active” storage number is based upon the possible operational ranges of Link Dam, however, the current 2008 Biological Opinion sets a minimum lake elevation target of 4138.0 ft which reduces the active storage capacity of UKL and a re-connected Agency Lake and Barnes Ranches by approximately 127,700 acre-ft. Net inflow for the entire year averages 1.2 million acre-feet but ranges from 576,000 to 2.4 million acre-feet (Reclamation, 2005).

The Williamson River and Sprague River, a tributary to the Williamson River, drain the central and eastern part of the Upper Klamath River Basin into the Upper Klamath Lake, which empties to the Link River. The Klamath River begins at Lake Ewauna just south of Upper Klamath Lake and flows southwest into California. Flow for the entire Upper Klamath River Basin is recorded at the Klamath River gage at Keno, Oregon. The minimum flow release from Link Dam is 250 cfs June to Oct (USFWS, 2008) and 90 cfs otherwise (PacifiCorp, 2004).

2.2.2. KLAMATH IRRIGATION PROJECT

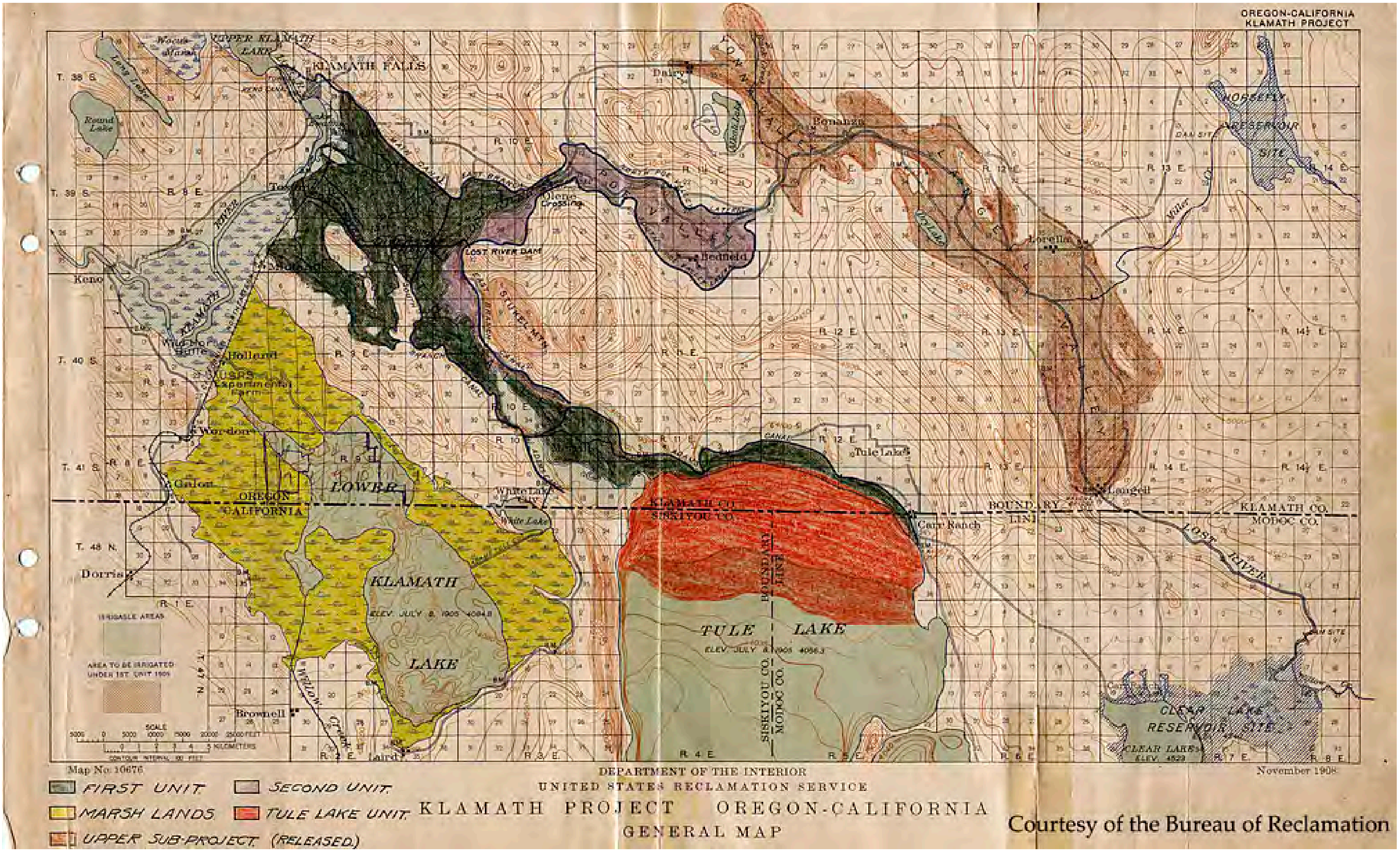
Reclamation’s Klamath Irrigation Project developed substantial water storage and distribution systems and drainage of lakes and wetlands, and it currently includes about 240,000 acres of irrigable lands. There are about 150,000 irrigated agricultural acres served by water withdrawn from the Upper Klamath Lake and the Klamath River. Reclamation states that, during a normal year, the net use of irrigation project water is 1.25 acre-feet per acre, including water used by FWS in the Tule Lake and Lower Klamath National Wildlife Refuges. The main sources of water for this system are Upper Klamath Lake via the A canal, the Klamath River from Keno reservoir, and the naturally closed Lost River Basin (see Figure 2-10).

Before development of the Klamath Irrigation Project in 1905, the surface area of Lower Klamath Lake was often larger than Upper Klamath Lake. Flows from the Klamath River, supplemented by springs around the lake, supported a complex of wetlands and open water covering about 80,000 to 94,000 acres in the spring, during high water, and 30,000 to 40,000 acres in late summer. By 1924, however, development in the Klamath Irrigation Project area eliminated more than 90 percent of the Lower Klamath Lake’s open water and marsh. Only about 4,700 acres of open water and wetland remain. Connections between the Klamath River and Lower Klamath Lake were severed by development, which changed the hydrology of both the lake and the river. Current connectivity between Lower Klamath Lake and the rest of the basin is limited to water pumped from Tule Lake and water from irrigation structures that lead to and from the present day Keno Reservoir (Reclamation, 2005).

Before the Klamath Irrigation Project, Tule Lake varied in surface area from 55,000 to more than 100,000 acres, averaging about 95,000 acres, at times larger than the former expanse of Upper Klamath Lake. Lost River was the main source of water to Tule Lake. Similar to Lower Klamath Lake, Tule Lake was connected seasonally to the Klamath River. During periods of high runoff, water from the Klamath River flowed into the Lost River slough and down the Lost River to Tule Lake. The direction of the river’s flow is now determined by operators of the Klamath Irrigation Project depending on water needs. Most of the former bed of Tule Lake has been drained for agriculture, leaving about 9,450 to 13,000 acres of shallow lake and marshland (FERC, 2007).

By 1924, the Lower Klamath Lake, once directly connected to the Klamath River, was cut off and drained substantially by the Klamath Irrigation Project. The remaining marsh and lake areas are now managed primarily as Lower Klamath National Wildlife Refuge. Primarily maintained for waterfowl and water dependent species, this 53,600 acre refuge contains 12 wetland units that are supplied with water on a seasonal basis. Only Unit 2 (about 2,200 acres), with an average depth of about 3 feet, is maintained as a permanently flooded lake. Private agricultural lands are within the boundary of the former lake, as well (FERC, 2007). Reclamation (2005) contains a more detailed history of Lower Klamath Lake.

The map of the Klamath Project in 1908 is shown in Figure 2-11 and the map of the Klamath Project in 1998 is shown in Figure 2-12. Of particular note are the much reduced sizes of Lower Klamath Lake and Tule Lake, as well as the replacement of marsh lands with agricultural lands.



Courtesy of the Bureau of Reclamation

Figure 2-11. Map of Klamath Project in 1908, prior to implementation of the Klamath Project.

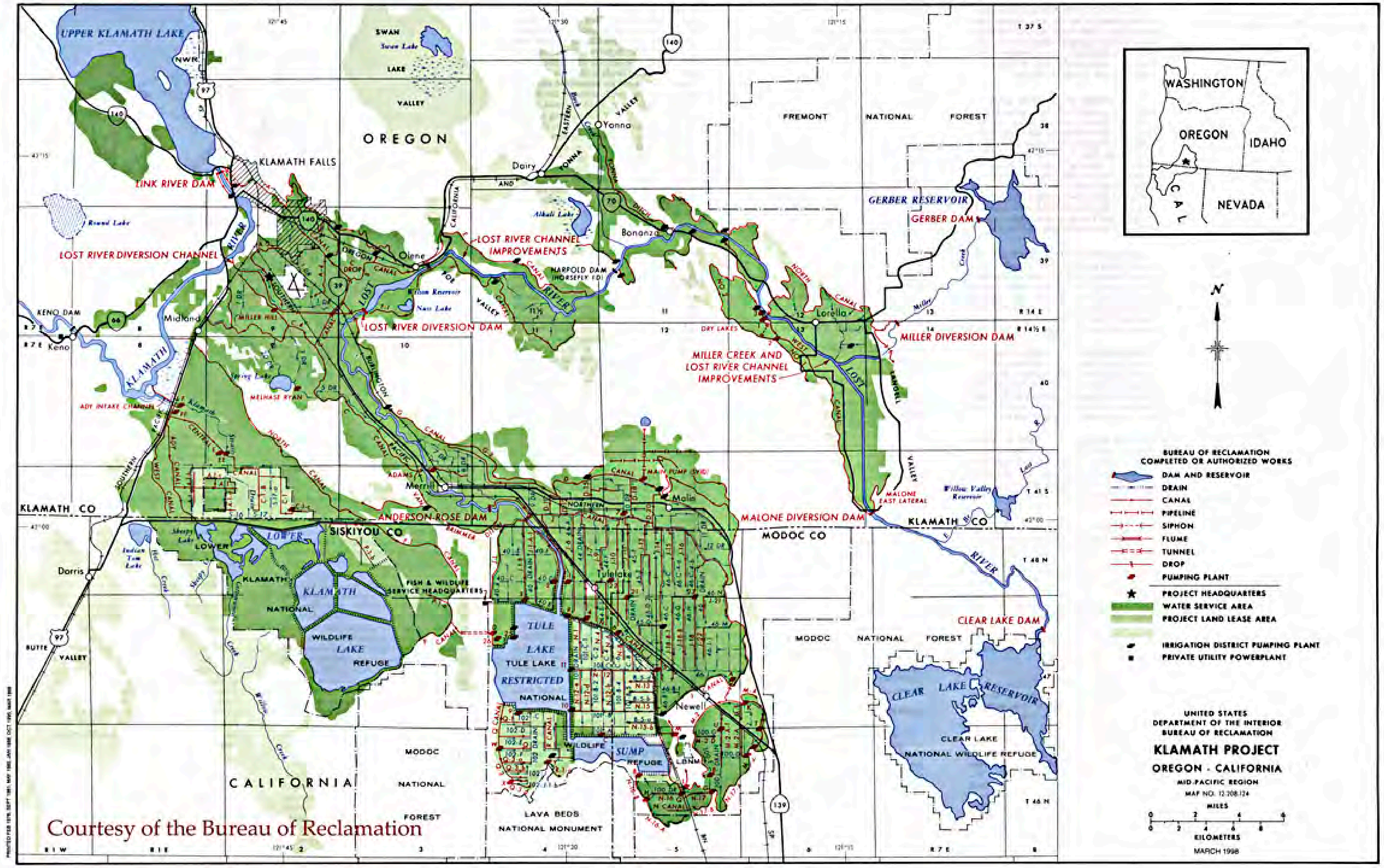


Figure 2-12. Map of Klamath Project in 1998.

2.2.3. KENO DEVELOPMENT

Information on the Keno Development is reproduced from PacifiCorp (2004a) below for convenience:

> *"Keno dam is a re-regulating facility located at approximately River mile (RM) 233, which is approximately 21 miles downstream of Link River dam (Figure B1.1-1). There is no power generating capability at this facility. The concrete dam has a height of 25 feet and a spillway section consisting of six 40-foot-wide spill gates. The impoundment upstream of the dam has a surface area of 2,475 acres and a total storage capacity of 18,500 acre-feet. There is a weir and orifice type fish ladder at the Keno dam.*
>
> *… In as much as possible, Keno dam is operated to maintain a steady reservoir elevation through all river flows and water year types, while continuing to provide enough water to meet flow requirements at Iron Gate dam. The steady reservoir elevation allows both the USBR and local irrigators to manage irrigation water. In operating Keno dam, PacifiCorp can more effectively schedule and plan load following operations at the J.C. Boyle powerhouse. Operating the reservoir in a re-regulating mode can result in river fluctuations below the dam, especially during high flow conditions.*
>
> *Flows from the USBR Project enter PacifiCorp's Project in Keno reservoir via the Klamath Straits Drain and Lost River diversion channel. These return flows can be highly variable and can be somewhat problematic for stable reservoir elevations. Flows from the USBR Project can vary approximately 775 cfs, each 200 cfs has the ability to affect the reservoir elevation approximately 0.2 feet in a 24-hour period. Hence, control of flows from the East Side Development and flow through Keno dam are crucial to maintain a constant elevation in Keno reservoir. In order to achieve a reservoir fluctuation within ± 0.1 feet, PacifiCorp and USBR coordinate and/or communicate their operations on a daily basis during periods of high flow fluctuation."*

2.2.4. J.C. BOYLE DEVELOPMENT

Information is reproduced from PacifiCorp (2004a) below for convenience

> *"The J.C. Boyle Development consists of a reservoir, a combination embankment and concrete dam, a water conveyance system, and a powerhouse on the Klamath River between about RM 228 and RM 220, which is downstream of the Keno dam and upstream of the Copco No. 1 dam. The purpose of the J.C. Boyle facility is to generate hydroelectric power.*
>
> ***DAM***
>
> *The embankment dam is a 68-foot-tall (at its maximum height above the original streambed) earthfill structure with a 15-foot side crest and a length of 413.5 feet at El. 3,800.0 feet msl. The concrete portion of the dam is 279 feet long and is composed of a spillway section, an intake structure, and a 115-foot-long gravity section of 23 feet maximum height between the intake block and the left abutment.*

The spillway is a concrete gravity ogee overflow section with three 36-foot-wide by 12-foot-high radial gates…The estimated spillway capacity at water surface El. 3,793 feet msl with all three gates open is 14,850 cfs. A 24-inch fish screen bypass pipe provides approximately 20 cfs of instream flow below the dam. The intake structure is located to the immediate left of the spillway and consists of a 40-foot-high reinforced concrete tower. It has four 11-foot, 2-inch-wide openings to the reservoir, each of which has a steel trash rack followed by a vertical traveling screen (0.25-inch mesh) with high pressure spray cleaners. Spray, along with any screened fish, are collected and diverted downstream of the dam...

A pool and weir fishway approximately 569 feet long with 63 pools is located at the dam for upstream fish passage. The fishway operates over a gross head range of approximately 55 to 60 feet.

The water conveyance infrastructure between the dam and the powerhouse has a total length of 2.56 miles. From the intake structure, the water flows through a 638-foot long, 14-foot-diameter, steel flowline. The flowline is supported on steel frames where it spans the Klamath River and discharges into an open power canal. The power canal is 2 miles long along a bench cut in the face of the river canyon. Depending on the terrain, the canal is either a double- or single-walled concrete flume. The power canal is provided with overflow structures at the upstream and downstream ends and terminates in a forebay. The forebay overflow section is equipped with float-operated gates, which release water during the hydraulic surge from the canal following any load rejection at the powerhouse. The released water discharges through a short, concrete-lined chute and returns to the bypass reach.

Water for power generation is drawn from the forebay through a 60-foot-wide and 17.9-foot-high trash rack with 2-inch bar spacing before entering a 15.5-foot-diameter, concrete-lined, horseshoe-section tunnel, which is 1,660 feet long. The last 57-foot length of the tunnel before the downstream portal is steel lined with the liner bifurcating into two 10.5-foot-diameter steel penstocks. The bifurcation is encased in a concrete anchor block, and a steel surge tank is mounted on the thrust block. Descending to the powerhouse, the penstocks reduce in two steps to 9 feet in diameter. Each penstock is 956 feet in length and is supported by ring girders seated on concrete footings.

RESERVOIR

The J.C. Boyle dam impounds a narrow reservoir of 420 surface acres (J.C. Boyle reservoir). The normal maximum and minimum operating levels are between El. 3,793 feet and El. 3,788 feet msl, a range of 5 feet. The reservoir contains approximately 3,495 acre-feet of total storage capacity and 1,724 acre-feet of active storage capacity.

POWERHOUSE

The conventional outdoor-type reinforced concrete powerhouse is located approximately 4.3 river miles downstream of the dam on the right bank of the river. There are two vertical-Francis turbines. Both have a rated discharge of 1,425 cfs and are rated 56,000 hp at 440 feet of net head. Both generators are rated at 42,500 kVA at 0.95 power factor (40 MW). Key information about J.C. Boyle powerhouse is summarized in Table A2.1-1. Two three-phase, 42,300-kVA, 11,000/236,000-V transformers step up the generator voltage for transmission interconnection.”

There is a 100 cfs minimum flow requirement immediately below J.C. Boyle Dam (PacifiCorp, 2004).

2.2.5. COPCO NO. 1 DEVELOPMENT

Information is reproduced from PacifiCorp (2004a) below for convenience:

> *"The Copco No. 1 Development consists of a reservoir, dam, spillway, intake, and outlet works and powerhouse located on the Klamath River between approximately RM 204 and RM 198 near the Oregon-California border. Copco No. 1 is downstream of the J.C. Boyle dam and upstream of Copco No. 2 dam. The purpose of the facility is to generate hydroelectric power.*
>
> ***DAM***
>
> *The Copco No. 1 dam is a concrete gravity arch structure with a 462-foot radius at the crest. As originally designed, the spillway crest was approximately 115 feet above the original river bed. After construction began, the river gravel was found to be over 100 feet deep at the dam site; this material was excavated and then backfilled with concrete, making the total height of the dam 230 feet, measured from the lowest depth of excavation to the spillway crest, and 250 feet to the top of the spillway deck.*
>
> *The crest length between the rock abutments is approximately 410 feet. The upstream face of the dam is vertical at the top, then battered at 1 horizontal to 15 vertical. The downstream face is stepped, with risers generally about 6.0 feet in height.*
>
> *The ogee-type spillway is located on the crest of the dam. It is divided into 13 bays controlled by 14-foot by 14-foot Tainter gates. The spillway crest is located at El. 2,593.5 feet msl. The normal operating reservoir water level is 1.5 feet below the top of the gates at El. 2,606.0 feet msl. The estimated spillway capacity at water surface El. 2,607.5 feet msl with all 13 gates open is 36,764 cfs.*
>
> *Two intake structures are located at approximately invert El. 2,575.0 feet msl in the dam near the right abutment. The left intake houses four vertical lift gates. Two 10-foot-diameter (reducing to 8-foot-diameter) steel penstocks feed Unit No. 1 in the powerhouse. The right intake houses four vertical-lift gates. A single, 14-foot-diameter (reducing to two 8-foot-diameter) steel penstock feeds Unit No. 2. Facilities exist at the intake for future expansion of the powerhouse, but there are no plans to expand the Project capacity. There are two side-by-side trash racks, which measure 44 feet wide, 12.5 feet high, and have bar spacings of 3 inches, in front of each intake.*
>
> *The low-level sluice outlet has been abandoned.*
>
> ***RESERVOIR***
>
> *The Copco No. 1 reservoir is approximately 1,000 acres in extent and contains approximately 15,200 acre-feet of total storage capacity at elevation 2,607.5 and approximately 6,235 acre-feet of active storage capacity. The normal maximum and minimum operating levels are between El. 2,607.5 and El. 2,601.0 feet, respectively, a range of 6.5 feet.*
>
> ***POWERHOUSE***

> *The Copco No. 1 powerhouse is a reinforced-concrete substructure with a concrete and steel superstructure enclosed by metal siding located at the base of Copco No. 1 dam on the right bank. The two turbines are double-runner, horizontal-Francis units, each with a rated discharge of 1,180 cfs, and rated at 18,600 hp at a net head of 125 feet. The generators are rated at 12,500 kVA at 0.8 power factor (10 MW). There are no turbine bypass valves. Unit 1 has three single-phase, 5,000-kVA, 2,300/72,000-V transformers to step-up the generator voltage for transmission interconnection. Unit 2 has three single-phase, 4,165-kVA,2,300/72,000-V transformers to step up the generator voltage for transmission interconnection."*

2.2.6. COPCO NO. 2 DEVELOPMENT

Information is reproduced from PacifiCorp (2004a) below for convenience:

> *"The Copco No. 2 Development consists of a diversion dam, small impoundment, a water conveyance system, and a powerhouse. The dam is located approximately 1/4 mile downstream of Copco No. 1 dam at RM 198.3. The purpose of the Copco No. 2 facilities is to generate hydroelectric power.*
>
> ***DAM***
>
> *The Copco No. 2 dam is a concrete gravity structure with an intake to the flowline on the left abutment and a 145-foot-long spillway section with five Tainter gates. The dam is 33 feet high, has an overall crest length of 335 feet and a crest width of 9 feet. The crest elevation is El.2,493 feet msl. The dam has a 132-foot-long earthen embankment with a gunite cutoff wall. The dam has a manual gate controlling a sluiceway adjacent to the intake. A corrugated metal flume provides approximately 5 cfs of instream flow in the bypass reach. The concrete gravity spillway section crest elevation is 2,473 feet msl. The estimated spillway capacity at water surface El.2,483 feet msl is 13,060 cfs with the five gates open.*
>
> *The intake structure incorporates trash racks and a roller-mounted (caterpillar) bulkhead gate. The trash rack is 36.5 feet by 48 feet and has 2-inch bar spacing.*
>
> *The flow line to the powerhouse consists of portions of 2,440 feet of concrete-lined tunnel, 1,313 feet of wood-stave pipeline, an additional 1,110 feet of concrete-lined tunnel, a surge tank, and two steel penstocks. The diameter of the tunnel and wood stave pipeline sections is a constant 16 feet. The two penstocks, one 405.5 feet long and one 410.6 feet long, range from 16 feet in diameter at the inlet to 8 feet in diameter at the turbine spiral cases.*
>
> ***RESERVOIR***
>
> *The reservoir created by the Copco No. 2 dam is approximately 1/4-mile long and has a storage capacity of 73 acre-feet. At the normal water surface elevation of El. 2483 feet msl, there is very minimal active storage. El. 2,483 feet msl is both the maximum and minimum normal water surface. As a result, Copco No. 2 generation tracks Copco No. 1 generation.*
>
> ***POWERHOUSE***

> *The powerhouse is a reinforced concrete structure that houses two vertical-Francis turbines. Each turbine has a rated discharge of 1,338 cfs and a rated capacity of 20,000 hp at 140 feet of net head. The synchronous generators are rated 15,000 kVA at 0.9 power factor (13.5 MW). There are three single-phase, 10/20-megavolt ampere (MVA), 6,600/72,000-V transformers for each generator to step up the voltage. There are also three single-phase, 10/20-MVA,73,800/230,00-V step-up transformers for interconnection to the transmission system."*

There is a 1.5-mile-long bypassed reach between Copco No. 2 reservoir and powerhouse. There is currently no minimum flow requirement at this bypassed reach, but PacifiCorp states it normally releases 5 to 10 cfs via a 24-inch-diameter pipe at the dam (FERC, 2007).

2.2.7. IRON GATE DEVELOPMENT

Information is reproduced from PacifiCorp (2004a) below for convenience:

> *"The Iron Gate Development consists of a reservoir, an earth embankment dam, an ungated side channel spillway, intakes for the diversion tunnel and penstock, a steel penstock from the dam to the powerhouse, and the powerhouse. It is located on the Klamath River between approximately RM 196.8 and RM 190, approximately 20 miles northeast of Yreka, California. It is the farthest downstream hydroelectric facility of the Klamath Hydroelectric Project. The purpose of the Iron Gate facilities is to generate hydroelectric power.*
>
> ***DAM***
>
> *Iron Gate Dam is a zoned earthfill embankment. The dam has a height of 189 feet from the rock foundation to the dam crest at El. 2.343.0 feet msl. The crest is 20 feet wide and approximately 740 feet long. It has a central, vertical-asymmetrical clay core. The dam is founded on a sound basalt rock foundation. There is a grout curtain in the bedrock beneath the impervious core.*
>
> *There are fish trapping and holding facilities located on the random fill area at the dam toe. The top of the random fill area is at El. 2,189.0 feet msl. High- (El. 2,310.0 feet msl) and low-level (El. 2,250 feet msl) intakes for the fish facility water are incorporated into the dam.*
>
> *In 2003, modifications were made to Iron Gate Dam to raise the dam crest elevation from El. 2343 feet msl to El. 2348 feet msl. The modifications included construction of a concrete wall extension along the dam crest, anchored into the existing dam structure….*
>
> *The spillway is excavated in rock at the right dam abutment. It is an ungated chute spillway with a side channel entrance. The spillway crest is at El. 2,328.0 feet msl, 15 feet below the dam crest. The spillway crest is 727 feet long and consists of a concrete ogee and slab placed over the excavated rock ridge. The upper part of the channel is partly lined with concrete. At the end of the chute, a flip-bucket terminal structure is located approximately 2,150 feet downstream of the toe of the dam.*

> *The diversion tunnel used during construction was driven through bedrock in the right abutment and is still in place. The tunnel terminates in a reinforced concrete outlet structure at the downstream toe of the dam. Control of the flow in the tunnel is provided by a slide gate approximately 112 feet upstream of the dam axis. The gate is housed in a reinforced concrete tower accessible by bridge from the dam crest. The intake is a reinforced concrete structure equipped with trash racks and is submerged on the floor of the reservoir approximately 380 feet upstream from the dam axis. Operation of the gate controlling flow through the tunnel is limited to emergency use during high flow events. If needed for such purposes, the tunnel can pass up to approximately 5,000 cfs.*
>
> *The intake structure for the powerhouse is a 45-foot-high, free-standing, reinforced-concrete tower, located in the reservoir immediately upstream of the left dam abutment. It is accessed by a foot bridge from the abutment. It houses a 14-foot by 17-foot slide gate, which controls the flow into a 12-foot-diameter, welded-steel penstock. The penstock is concrete-encased where it penetrates the dam approximately 35 feet below the normal maximum reservoir level. The penstock is supported on concrete supports down the dam abutment. There is a trash rack at the penstock entrance, which is 17.5 feet by 45 feet with 4-inch bar spacing.*
>
> ***RESERVOIR***
>
> *The reservoir formed upstream of the Iron Gate Dam is approximately 944 surface acres and contains approximately 58,794 acre-feet of total storage capacity (at El. 2,328.0 feet msl) and 3,790 acre-feet of active storage capacity. The normal maximum and minimum operating levels are between El. 2,328.0 feet msl and El. 2,324.0 feet msl, respectively, a range of 4 feet.*
>
> ***POWERHOUSE***
>
> *The powerhouse is located at the base of the dam on the left bank. The Iron Gate powerhouse consists of a single vertical Francis turbine. The turbine has a rated discharge capacity 1,735 cfs, with a rated output of 25,000 at a rated net head of 154 feet. The synchronous generator is rated 18.947 kVA at 0.95 power factor (18 MW). In the event of a turbine shutdown, a synchronized Howell-Bunger bypass valve located immediately upstream of the turbine diverts water around the turbine to maintain flows downstream of the dam.*
>
> *There is a single three-phase, 18,947-kVA, 6,600/69,000-V step-up transformer at the powerhouse to interconnect the PacifiCorp transmission system."*

Minimum flows requirements and flow targets at Iron Gate are currently governed by the NMFS 2010 Biological Opinion (NMFS, 2010).

Table 2-1. Information on dam characteristics from PacifiCorp (2004a).

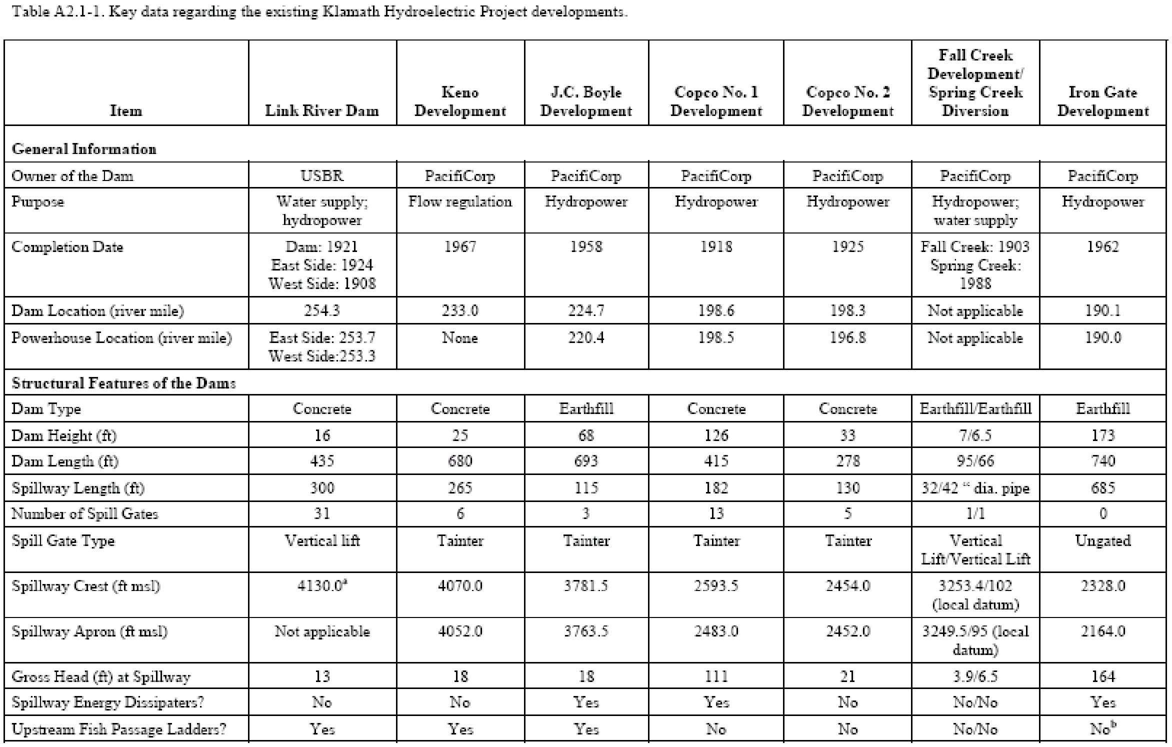


Table A2.1-1. Key data regarding the existing Klamath Hydroelectric Project developments.

Item	Link River Dam	Keno Development	J.C. Boyle Development	Copco No. 1 Development	Copco No. 2 Development	Fall Creek Development/ Spring Creek Diversion	Iron Gate Development
General Information							
Owner of the Dam	USBR	PacifiCorp	PacifiCorp	PacifiCorp	PacifiCorp	PacifiCorp	PacifiCorp
Purpose	Water supply; hydropower	Flow regulation	Hydropower	Hydropower	Hydropower	Hydropower; water supply	Hydropower
Completion Date	Dam: 1921 East Side: 1924 West Side: 1908	1967	1958	1918	1925	Fall Creek: 1903 Spring Creek: 1988	1962
Dam Location (river mile)	254.3	233.0	224.7	198.6	198.3	Not applicable	190.1
Powerhouse Location (river mile)	East Side: 253.7 West Side:253.3	None	220.4	198.5	196.8	Not applicable	190.0
Structural Features of the Dams							
Dam Type	Concrete	Concrete	Earthfill	Concrete	Concrete	Earthfill/Earthfill	Earthfill
Dam Height (ft)	16	25	68	126	33	7/6.5	173
Dam Length (ft)	435	680	693	415	278	95/66	740
Spillway Length (ft)	300	265	115	182	130	32/42 " dia. pipe	685
Number of Spill Gates	31	6	3	13	5	1/1	0
Spill Gate Type	Vertical lift	Tainter	Tainter	Tainter	Tainter	Vertical Lift/Vertical Lift	Ungated
Spillway Crest (ft msl)	4130.0[a]	4070.0	3781.5	2593.5	2454.0	3253.4/102 (local datum)	2328.0
Spillway Apron (ft msl)	Not applicable	4052.0	3763.5	2483.0	2452.0	3249.5/95 (local datum)	2164.0
Gross Head (ft) at Spillway	13	18	18	111	21	3.9/6.5	164
Spillway Energy Dissipaters?	No	No	Yes	Yes	No	No/No	Yes
Upstream Fish Passage Ladders?	Yes	Yes	Yes	No	No	No/No	No[b]

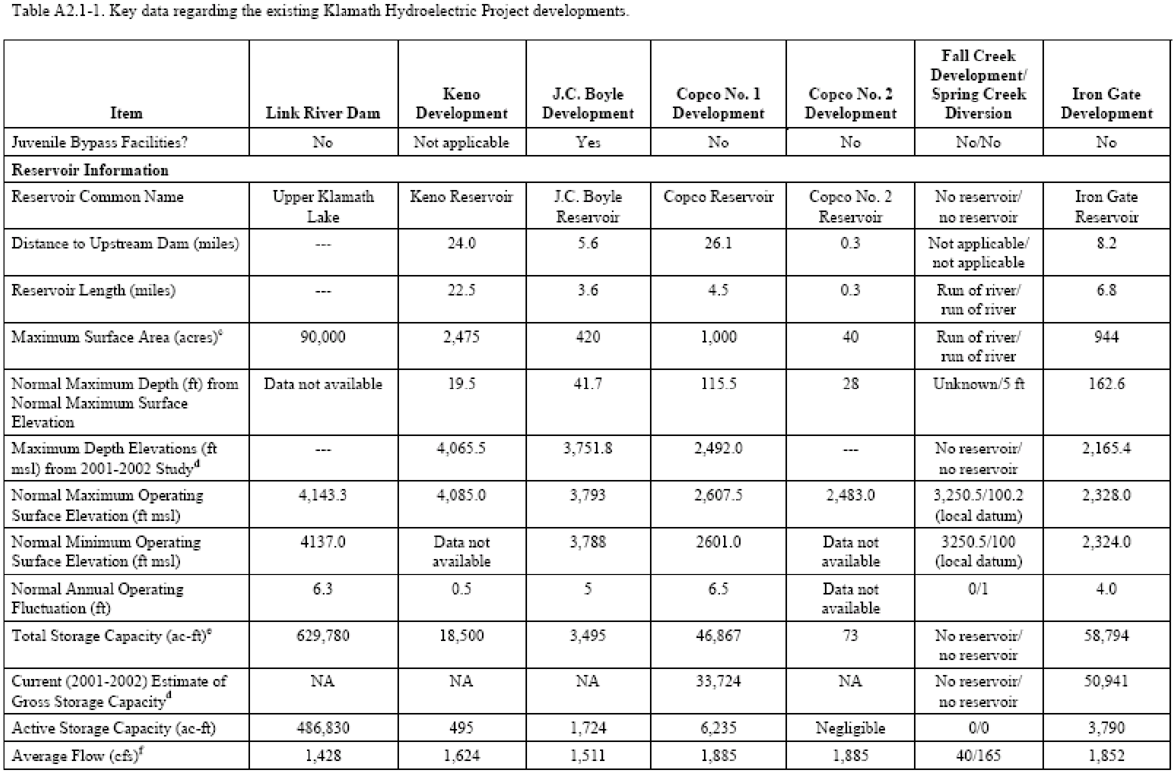
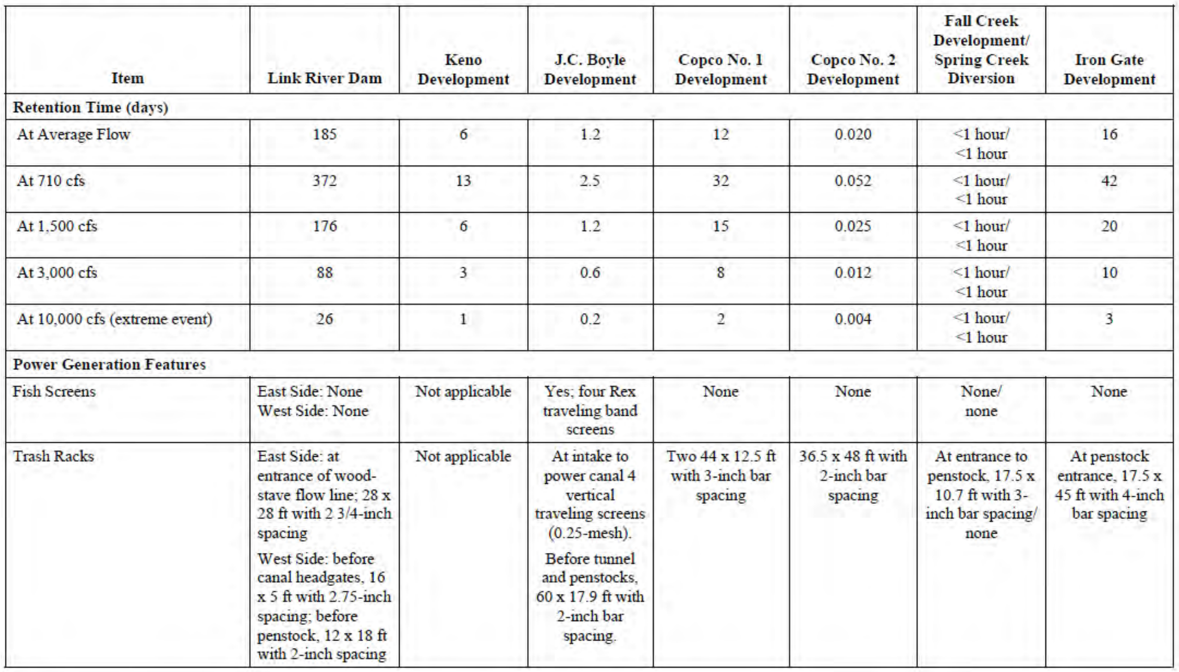


Table A2.1-1. Key data regarding the existing Klamath Hydroelectric Project developments.

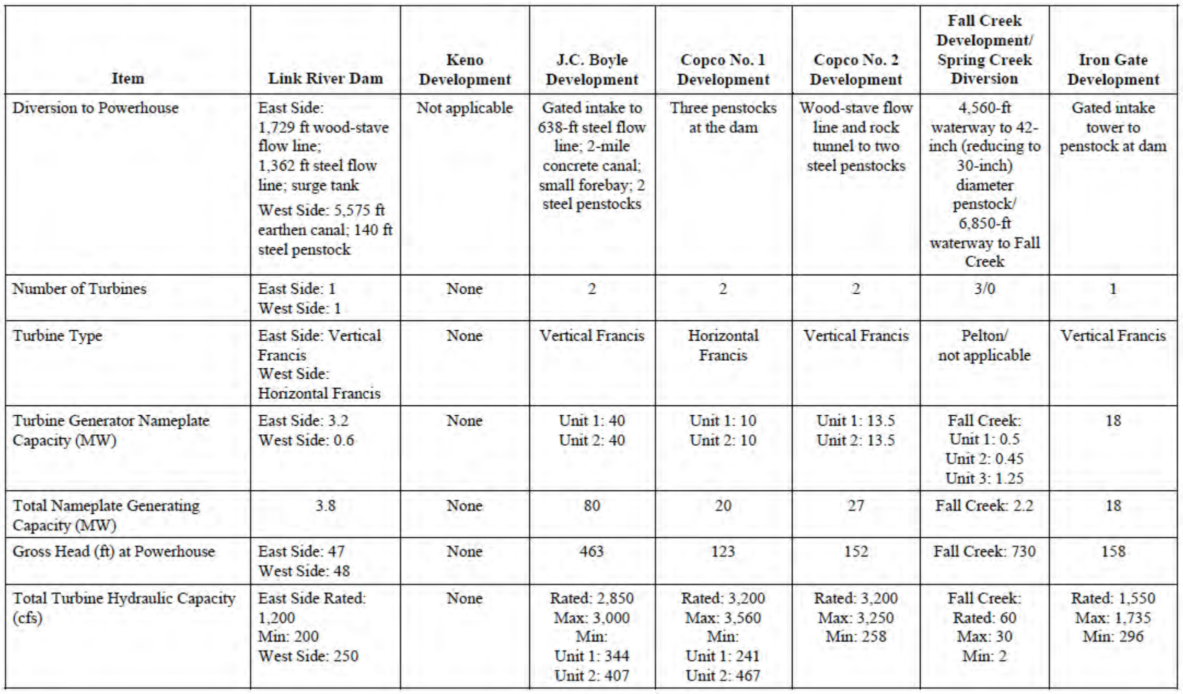
Item	Link River Dam	Keno Development	J.C. Boyle Development	Copco No. 1 Development	Copco No. 2 Development	Fall Creek Development/ Spring Creek Diversion	Iron Gate Development
Juvenile Bypass Facilities?	No	Not applicable	Yes	No	No	No/No	No
Reservoir Information							
Reservoir Common Name	Upper Klamath Lake	Keno Reservoir	J.C. Boyle Reservoir	Copco Reservoir	Copco No. 2 Reservoir	No reservoir/ no reservoir	Iron Gate Reservoir
Distance to Upstream Dam (miles)	---	24.0	5.6	26.1	0.3	Not applicable/ not applicable	8.2
Reservoir Length (miles)	---	22.5	3.6	4.5	0.3	Run of river/ run of river	6.8
Maximum Surface Area (acres)[c]	90,000	2,475	420	1,000	40	Run of river/ run of river	944
Normal Maximum Depth (ft) from Normal Maximum Surface Elevation	Data not available	19.5	41.7	115.5	28	Unknown/5 ft	162.6
Maximum Depth Elevations (ft msl) from 2001-2002 Study[d]	---	4,065.5	3,751.8	2,492.0	---	No reservoir/ no reservoir	2,165.4
Normal Maximum Operating Surface Elevation (ft msl)	4,143.3	4,085.0	3,793	2,607.5	2,483.0	3,250.5/100.2 (local datum)	2,328.0
Normal Minimum Operating Surface Elevation (ft msl)	4137.0	Data not available	3,788	2601.0	Data not available	3250.5/100 (local datum)	2,324.0
Normal Annual Operating Fluctuation (ft)	6.3	0.5	5	6.5	Data not available	0/1	4.0
Total Storage Capacity (ac-ft)[e]	629,780	18,500	3,495	46,867	73	No reservoir/ no reservoir	58,794
Current (2001-2002) Estimate of Gross Storage Capacity[d]	NA	NA	NA	33,724	NA	No reservoir/ no reservoir	50,941
Active Storage Capacity (ac-ft)	486,830	495	1,724	6,235	Negligible	0/0	3,790
Average Flow (cfs)[f]	1,428	1,624	1,511	1,885	1,885	40/165	1,852

Table A2.1-1. Key data regarding the existing Klamath Hydroelectric Project developments.



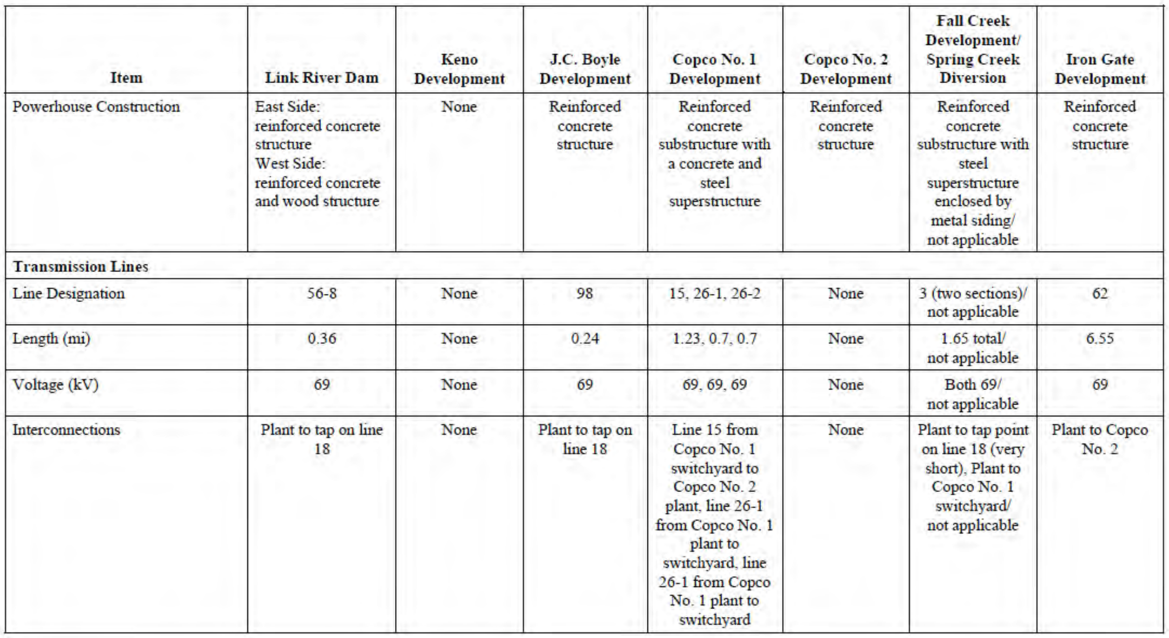
Item	Link River Dam	Keno Development	J.C. Boyle Development	Copco No. 1 Development	Copco No. 2 Development	Fall Creek Development/ Spring Creek Diversion	Iron Gate Development
Retention Time (days)							
At Average Flow	185	6	1.2	12	0.020	<1 hour/ <1 hour	16
At 710 cfs	372	13	2.5	32	0.052	<1 hour/ <1 hour	42
At 1,500 cfs	176	6	1.2	15	0.025	<1 hour/ <1 hour	20
At 3,000 cfs	88	3	0.6	8	0.012	<1 hour/ <1 hour	10
At 10,000 cfs (extreme event)	26	1	0.2	2	0.004	<1 hour/ <1 hour	3
Power Generation Features							
Fish Screens	East Side: None West Side: None	Not applicable	Yes; four Rex traveling band screens	None	None	None/ none	None
Trash Racks	East Side: at entrance of wood-stave flow line; 28 x 28 ft with 2 3/4-inch spacing West Side: before canal headgates, 16 x 5 ft with 2.75-inch spacing; before penstock, 12 x 18 ft with 2-inch spacing	Not applicable	At intake to power canal 4 vertical traveling screens (0.25-mesh). Before tunnel and penstocks, 60 x 17.9 ft with 2-inch bar spacing.	Two 44 x 12.5 ft with 3-inch bar spacing	36.5 x 48 ft with 2-inch bar spacing	At entrance to penstock, 17.5 x 10.7 ft with 3-inch bar spacing/ none	At penstock entrance, 17.5 x 45 ft with 4-inch bar spacing

Table A2.1-1. Key data regarding the existing Klamath Hydroelectric Project developments.



Item	Link River Dam	Keno Development	J.C. Boyle Development	Copco No. 1 Development	Copco No. 2 Development	Fall Creek Development/ Spring Creek Diversion	Iron Gate Development
Diversion to Powerhouse	East Side: 1,729 ft wood-stave flow line; 1,362 ft steel flow line; surge tank West Side: 5,575 ft earthen canal; 140 ft steel penstock	Not applicable	Gated intake to 638-ft steel flow line; 2-mile concrete canal; small forebay; 2 steel penstocks	Three penstocks at the dam	Wood-stave flow line and rock tunnel to two steel penstocks	4,560-ft waterway to 42-inch (reducing to 30-inch) diameter penstock/ 6,850-ft waterway to Fall Creek	Gated intake tower to penstock at dam
Number of Turbines	East Side: 1 West Side: 1	None	2	2	2	3/0	1
Turbine Type	East Side: Vertical Francis West Side: Horizontal Francis	None	Vertical Francis	Horizontal Francis	Vertical Francis	Pelton/ not applicable	Vertical Francis
Turbine Generator Nameplate Capacity (MW)	East Side: 3.2 West Side: 0.6	None	Unit 1: 40 Unit 2: 40	Unit 1: 10 Unit 2: 10	Unit 1: 13.5 Unit 2: 13.5	Fall Creek: Unit 1: 0.5 Unit 2: 0.45 Unit 3: 1.25	18
Total Nameplate Generating Capacity (MW)	3.8	None	80	20	27	Fall Creek: 2.2	18
Gross Head (ft) at Powerhouse	East Side: 47 West Side: 48	None	463	123	152	Fall Creek: 730	158
Total Turbine Hydraulic Capacity (cfs)	East Side Rated: 1,200 Min: 200 West Side: 250	None	Rated: 2,850 Max: 3,000 Min: Unit 1: 344 Unit 2: 407	Rated: 3,200 Max: 3,560 Min: Unit 1: 241 Unit 2: 467	Rated: 3,200 Max: 3,250 Min: 258	Fall Creek: Rated: 60 Max: 30 Min: 2	Rated: 1,550 Max: 1,735 Min: 296

Table A2.1-1. Key data regarding the existing Klamath Hydroelectric Project developments.



Item	Link River Dam	Keno Development	J.C. Boyle Development	Copco No. 1 Development	Copco No. 2 Development	Fall Creek Development/ Spring Creek Diversion	Iron Gate Development
Powerhouse Construction	East Side: reinforced concrete structure West Side: reinforced concrete and wood structure	None	Reinforced concrete structure	Reinforced concrete substructure with a concrete and steel superstructure	Reinforced concrete structure	Reinforced concrete substructure with steel superstructure enclosed by metal siding/ not applicable	Reinforced concrete structure
Transmission Lines							
Line Designation	56-8	None	98	15, 26-1, 26-2	None	3 (two sections)/ not applicable	62
Length (mi)	0.36	None	0.24	1.23, 0.7, 0.7	None	1.65 total/ not applicable	6.55
Voltage (kV)	69	None	69	69, 69, 69	None	Both 69/ not applicable	69
Interconnections	Plant to tap on line 18	None	Plant to tap on line 18	Line 15 from Copco No. 1 switchyard to Copco No. 2 plant, line 26-1 from Copco No. 1 plant to switchyard, line 26-1 from Copco No. 1 plant to switchyard	None	Plant to tap point on line 18 (very short), Plant to Copco No. 1 switchyard/ not applicable	Plant to Copco No. 2

[a] The spillway crest at Link River dam is adjustable with stop logs; normal full pool elevation is shown.

[b] Two existing fish ladders serve the Iron Gate fish hatchery, but do not allow passage past the dam.

[c] Pool elevations for these values are unknown.

[d] Data from the Draft Bathymetry and Sediment Classification of the Klamath Hydropower Project Impoundments, J.M. Eilers and C.P. Gubala of JC Headwaters, Inc. prepared for PacifiCorp, March 2003.

[e] Total storage capacity is at normal full pool.

[f] Data for Keno is from USGS Gage 11509500. All other data are average daily turbine flows plus spill flows for 1994 through 1997 provided by PacifiCorp.

2.3. Reach and Tributary Descriptions

Information for the current conditions hydrology is taken from The United States Geological Survey (USGS) stream gages on the Klamath River (Table 2-2) and the FERC 2007 EIS. The USGS gages on the Klamath River are listed in Table 2-2. A flow duration analysis based upon daily average flows at the PacifiCorp dams is given in Table 2-3.

Table 2-2.USGS gages on the Klamath River.

USGS Gaging Station	**Station Name**	**Drainage Area (mi^2)**	**Latitude**	**Longitude**	**Gage Elevation (feet)**	**Period of Record (Water Years)**
11509500	Klamath River at Keno, OR	3,920	42°08’00”	121°57’40”	3,961	1905-1913 1930-2009
11510700	Klamath River below John C. Boyle Power Plant near Keno, OR	4,080	42°05’05”	122°04’20”	3,275	1959-2009
11512500	Klamath River below Fall Creek near Copco, CA	4,370	41°58’20”	122°22’05”	2,310	1924-1961
11516530	Klamath River below Iron Gate Dam, CA	4,630	41°55’41”	122°26’35”	2,162	1961-2009
11520500	Klamath River near Seiad Valley, CA	6,940	41°51’14”	123°13’52”	1,320	1913-1925 1952-2009
11523000	Klamath River at Orleans, CA	8,475	41°18’13”	123°32’00”	356	1927-2009
11530500	Klamath River near Klamath, CA	12,100	41°30’40”	123°58’42”	5.6	1911-1927 1932-1994, 1996, 1998-2009

Table 2-3. Daily flow duration – annual and seasonal (July 1 – November 31), based upon historical data.

% of time equaled or exceeded	Discharge (ft^3/s)							
	Annual				Seasonal (July 1 – Nov 31)			
	Keno	Boyle	Copco	Iron Gate	Keno	Boyle	Copco	Iron Gate
99	152	331	290	528	147	325	294	441
95	297	522	529	716	292	473	524	701
90	431	635	643	741	417	592	604	725
80	645	802	882	955	621	725	823	846
70	821	962	1088	1040	737	856	973	1000
60	990	1130	1269	1320	901	960	1150	1030
50	1180	1260	1483	1360	1020	1060	1273	1130
40	1440	1480	1730	1700	1180	1180	1470	1320
30	1800	1810	2104	1977	1390	1280	1670	1350
20	2390	2660	2640	2980	1580	1490	1905	1510
10	3120	3200	3350	3870	1960	1890	2300	1840
5	4320	4530	4486	5500	2450	2710	2720	2920
1	6875	7660	7295	9167	3300	3970	3536	4350

2.3.1. UPPER KLAMATH LAKE AND TRIBUTARIES TO UPPER KLAMATH LAKE

Upper Klamath Lake (UKL) receives most of its water from the Williamson and Wood Rivers. The Williamson River watershed consists of two sub-basins drained by the Williamson and Sprague Rivers, which together provide about 75 percent of the drainage area to Upper Klamath Lake (FERC, 2007). The Sycan River, a major tributary to the Sprague River, drains much of the northeastern portion of the watershed. Both the Williamson and Sprague River sub-basins are primarily forested with some areas of shrub and grassland, agriculture, and wetland and are largely within the Winema and Fremont National Forests,. The Wood River drains an area northeast of Upper Klamath Lake. The Wood River watershed extends from the southern base of the eastern slopes of the Cascade Mountains near Crater Lake to its confluence with the northern arm of Upper Klamath Lake, which is often referred to as Agency Lake. Although primarily forested, the Wood River watershed also contains extensive agricultural lands and wetlands. The balance of the water reaching Upper Klamath Lake is derived from direct precipitation, flows from small streams, irrigation canals, and ground water from springs and agricultural pumps.

Historical UKL elevations are given in Figure 2-13. Lake elevations have varied between 4136.8 and 4143.3 feet and more typically vary between 4138 and 4143.2 feet in a given year.

The historical 1961 – 2009 annual inflows into Upper Klamath Lake (UKL) are graphed in Figure 2-14 showing significant variation in the yearly inflow into UKL. Also shown in the figure is the 5-year moving average of the annual inflows along with the average inflow over this period of record. A dry (1990), average (1961), and wet (1982) start year was identified based upon the 5-year moving average. The identification of the water year types is intended to be used to identify the sensitivity of a particular resource area to the dry and wet cycles that occur in the basin.

Figure 2-15 shows the autocorrelation of those yearly inflows and the approximate 95% confidence intervals of the autocorrelation coefficient. There is a significant positive correlation between one-year and the following year (lag 1). There is also significant negative correlation between years separated by 5 years (lag 5). This suggests that dry years occur more frequently after dry years and wet years occur more frequently after wet years.

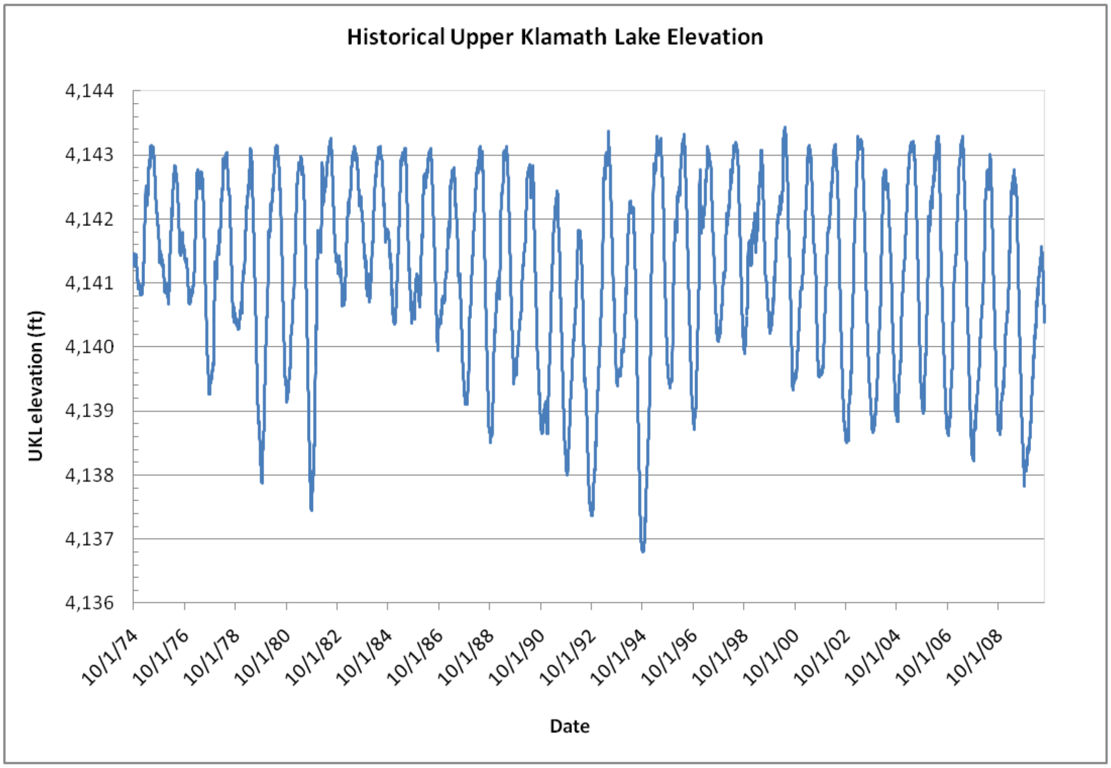


Figure 2-13. Daily UKL Elevations from Oct 1974 to July 2010.

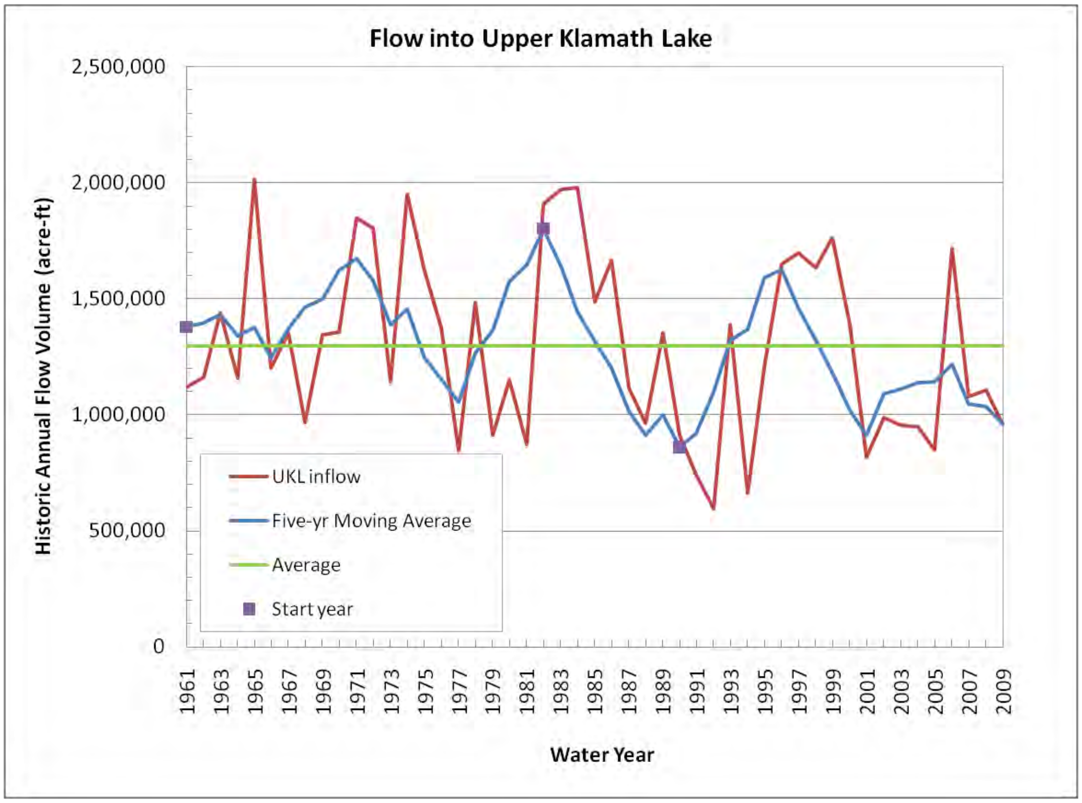


Figure 2-14. Annual inflows in UKL and representative start years based upon a 5-year moving average.

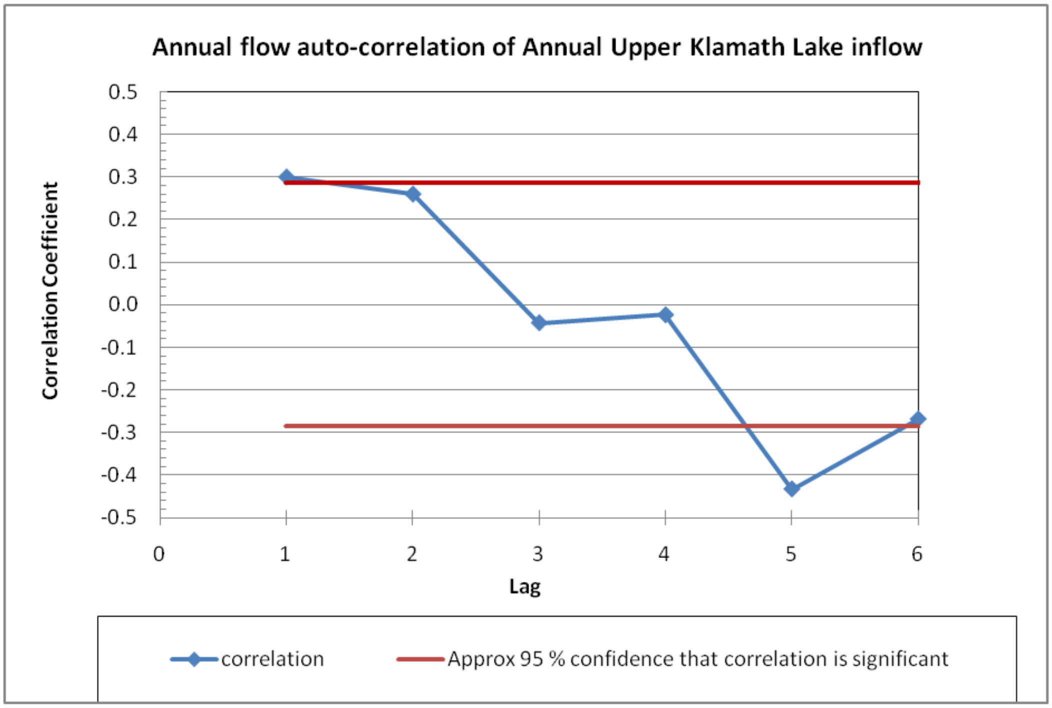


Figure 2-15. Autocorrelation of UKL inflows.

2.3.2. J.C. BOYLE TO J.C. BOYLE POWERPLANT (J.C. BOYLE BYPASSED REACH)

The 4.3-mile-long J.C. Boyle bypassed reach is a steep gradient section of the Klamath River from the dam to the powerhouse. Substantial groundwater enters the bypassed reach starting about 0.5 mile downstream of the dam. The average accretion in the bypassed reach is between 220 and 250 cfs and is relatively constant on a seasonal basis (FERC, 2007). The accretion is shown in the difference between the USGS Keno Gage and the USGS below J.C. Boyle Powerplant gage (Figure 2-16).

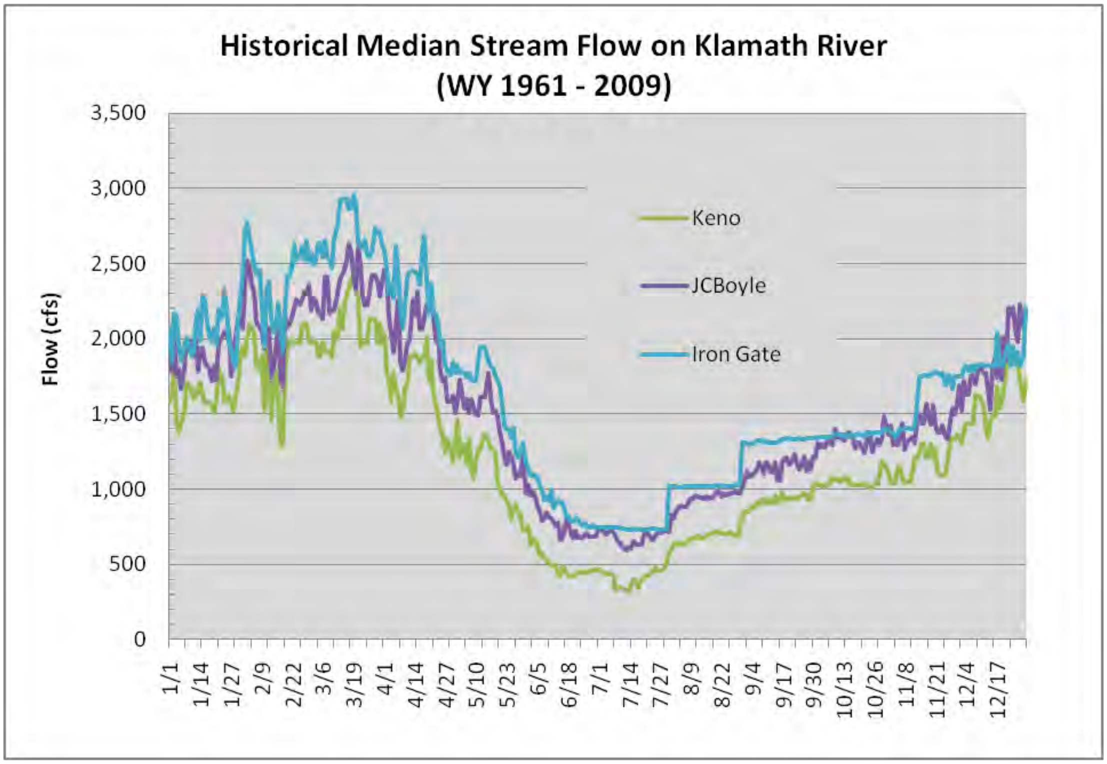


Figure 2-16. Median Flows at USGS stream gages from Keno to Iron Gate.

2.3.3. J.C. BOYLE POWERPLANT TO COPCO RESERVOIR (J.C. BOYLE PEAKING REACH)

Under current operations, when inflow to J.C. Boyle Reservoir is below 3,000 cfs, water is typically stored at night and flows during the day, the period of peak energy demand, are ramped up to either one unit operation (up to 1,500 cfs) or two unit operation (up to 3,000 cfs). PacifiCorp states that due to turbine efficiencies, the preferred flow through the powerhouse is 2,500 cfs, but this preferred flow is infrequently achieved on a daily average basis, during most months (FERC, 2007). When generation is not occurring and J.C. Boyle Dam is not spilling, normal flows in the peaking reach are about 320 to 350 cfs, com of

80 cfs from the fish ladder, 20 cfs from the juvenile fish bypass system, and the rest from spring accretion in the bypassed reach. Because of the popularity of whitewater boating on the J.C. Boyle reach, PacifiCorp considers the timing demands of commercial whitewater rafters as well as power demand, during May through mid October. The current license requires a ramping rate of 9 inches per hour for both up-ramping and down-ramping (FERC, 2007).

PacifiCorp has two direct diversion water rights along this reach for irrigation and stock watering at Copco ranch: 10 cfs and 2,300 acre-feet per year at the Owens ditch diversion and 5 cfs and 600 acre-feet per year at the Owens Island diversion -- both of which are gravity-fed diversions along the river (letter from R. Kanz, California State Water Resources Control Board, to the Commission, dated January 20, 2005).

Substantial tributaries in this reach include Rock Creek, at RM 213.9, and Shovel Creek at RM 206.5. PacifiCorp is currently diverting up to 15 cfs from Shovel Creek and Negro Creek (a tributary of Shovel Creek) during the summer for irrigation purposes (FERC, 2007).

The daily monthly flow duration data for each month for the Klamath River below J.C. Boyle Powerplant are given in “Appendix A. Flood Frequency Report” and shown Figure 2-17. The median daily average flow during the period 1961 to 2009 was between 1,800 and 2,200 cfs during the months of January through April, then decreasing to around 870 cfs for July. Historically, the median flows gradually increase back to 1,800 cfs by December. The minimum flow, during this period, was 320 cfs and occurred at least once in all months, though less frequently during the winter. The maximum daily average flow is around 10,000 cfs and has occurred during the months of January to March.

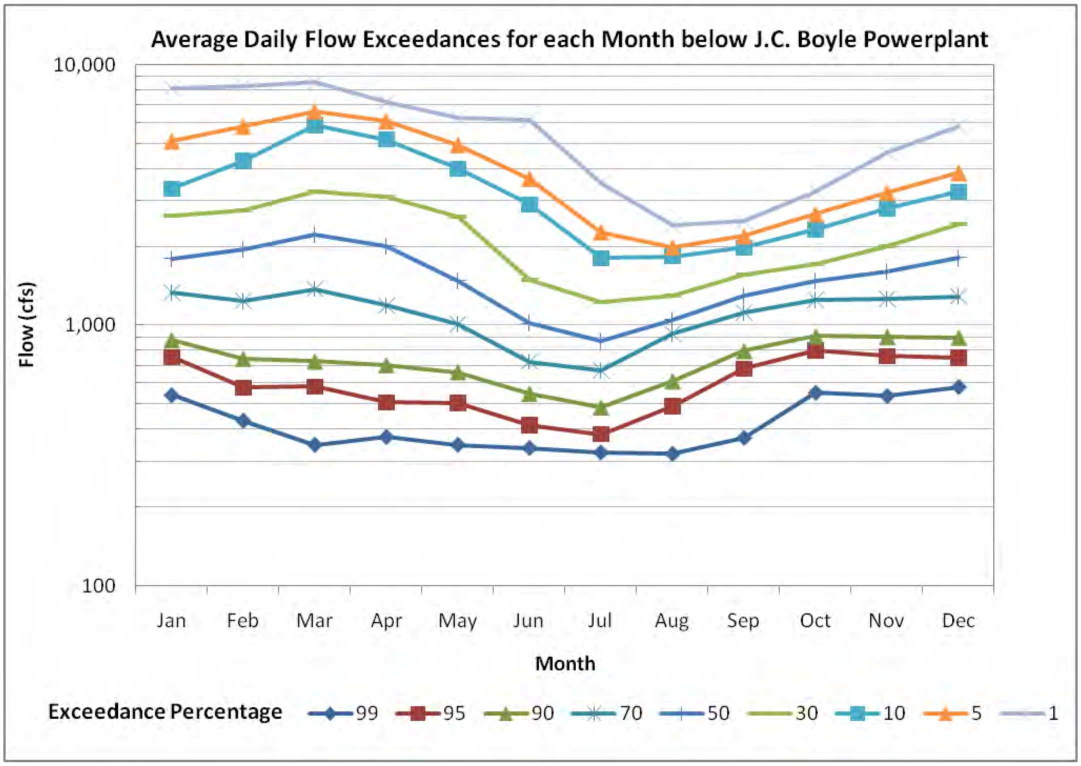


Figure 2-17. Daily flow exceedance percentages for J.C. Boyle Stream Gage below J.C. Boyle Powerplant for water years 1961 to 2010.

2.3.4. COPCO TO IRON GATE

The Copco No. 1 powerhouse can discharge up to 3,560 cfs directly into the 0.25-mile-long Copco No. 2 reservoir. PacifiCorp states that since the Copco No. 2 Reservoir has virtually no storage so the powerhouse acts as a virtual slave to discharge from Copco Reservoir and the water level within Copco No. 2 reservoir rarely fluctuates more than several inches. Spillage at Copco No. 2 dam would typically only occur when inflow exceeds the capacity of Copco No. 2 powerhouse, which occurs infrequently from November through April (FERC, 2007).

There is a 1.5-mile-long bypassed reach between Copco No. 2 reservoir and powerhouse. There is currently no minimum flow requirement for the bypassed reach, but PacifiCorp states it normally releases 5 to 10 cfs via a 24-inch-diameter pipe at the dam. PacifiCorp states that in this boulder-dominated, steeply-sloping bypassed reach accretion adds very little natural flow, unlike the J.C. Boyle bypassed reach (FERC, 2007). Discharge from Copco No. 2 powerhouse enters the upper reaches of the Iron Gate reservoir.

The daily average flows were recorded by USGS Gage #11512500 from water year (WY) 1923 to WY 1961 before the construction of Iron Gate Dam. An example of the flows is given in Figure 2-18. Copco 1 was operated as a peaking unit with flows during non-peak days of approximately 600 cfs. It is assumed that flows would fluctuate on a daily basis in the Klamath River before the construction of Iron Gate Dam.

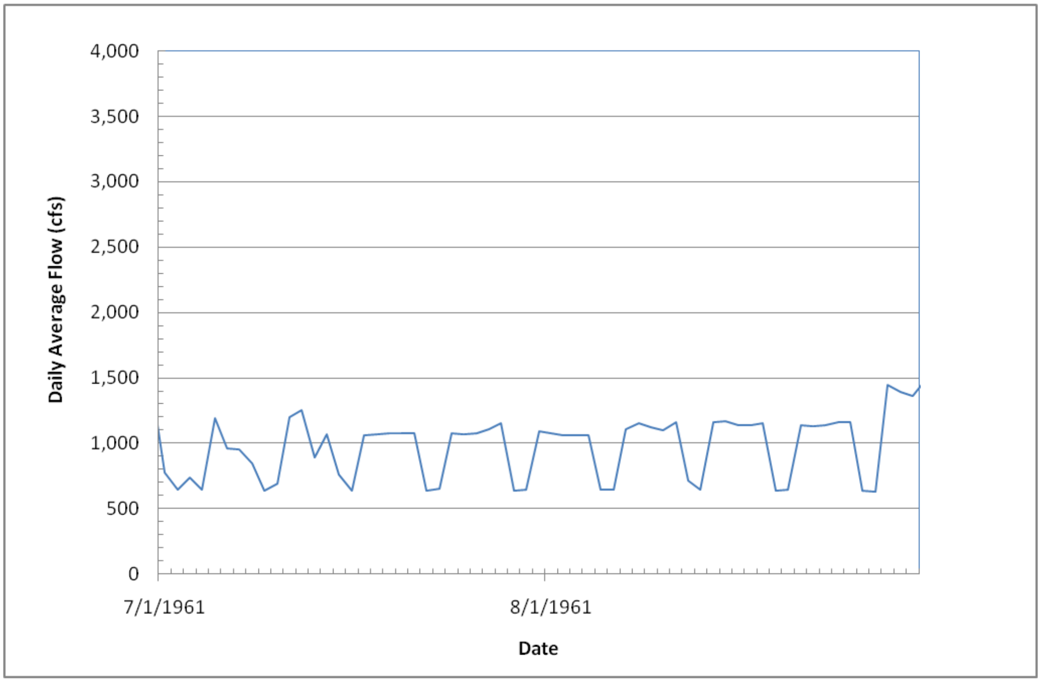


Figure 2-18. Typical daily average flows in Klamath River below Copco I before construction of Iron Gate Dam.

2.3.5. TRIBUTARIES TO IRON GATE

Two perennial tributaries, Jenny and Fall creeks, enter Iron Gate reservoir (see Figure 1-2). Spring Creek is a tributary to Jenny Creek, which flows for 1.2 miles from its source at Shoat Springs before it enters Jenny Creek at RM 5.5. Flow in Jenny Creek is altered by upstream Rogue River Irrigation Project reservoirs that store water during the high runoff season for irrigation. About 30 percent of the mean annual runoff (24,000 acre-feet) of the Jenny Creek watershed is diverted north into the Rogue River Basin. PacifiCorp estimates that inflow from Jenny Creek to Iron Gate Reservoir is normally between 30 and 500 cfs.

PacifiCorp operates a small diversion dam on Spring Creek to divert up to 16.5 cfs into Fall Creek. A Fall Creek dam diverts flow into a canal and penstock system leading to the Fall Creek powerhouse (FERC, 2007). PacifiCorp states that a water rights lawsuit with a local landowner precluded the Spring Creek diversions for most of the 1990s, but resumed diversions in 2003 when the lawsuit was decided in favor of PacifiCorp (FERC, 2007). The Spring Creek diversion, located 0.5 mile upstream of its confluence with Jenny Creek, diverts flow into a 1.3-mile-long canal until it enters Fall Creek about 1.7 miles upstream of the Fall Creek diversion. PacifiCorp estimates 5 cfs is the minimum observed flow in Spring Creek. The diversion dam on Fall Creek diverts up to 50 cfs of flow that bypasses 1.2 miles of a very steep gradient section of Fall Creek leading to the

Fall Creek powerhouse. The project's current license requires minimum flows of 0.5 cfs below the Fall Creek diversion and 15 cfs (or natural stream flow, whichever is less) downstream of the powerhouse.

USGS operated gage no. 11512000 on Fall Creek a short distance downstream of the Fall Creek powerhouse, the fish hatchery, and the city of Yreka intakes. During most of 1933 to 1959, the gage recorded a mean flow of 40 cfs and a minimum flow of 21 cfs. According to data from this gage, flow within Fall Creek does not vary much seasonally due to a reliable baseflow from groundwater springs that typically ranges from 30 to 50 cfs. The city of Yreka, California, operates a water supply intake downstream of the Fall Creek powerhouse and has water rights to withdraw up to 15 cfs. This facility is the sole normal water supply for the city and consists of two small impoundments, an intake structure, a pump and treatment plant, a cathodic protection field, and distribution pipelines, including the 24-inch diameter transmission main (letter from R. McNeil, Mayor, city of Yreka, California, to the Commission, dated November 29, 2006 as referenced by FERC, 2007). Intakes to the currently non-operating Fall Creek fish rearing facility are below the Yreka intake. Water rights include 10 cfs and 5,465 acre-feet per year between March 15 and December 15 for the Cal Fish & Game facility and 10 cfs from June 1 to November 1 for PacifiCorp (FERC, 2007).

2.3.6. DOWNSTREAM OF IRON GATE DAM

Downstream of Iron Gate dam, the Klamath River flows freely for 190 miles to its estuary and the Pacific Ocean. Four major tributaries enter this reach: the Shasta, Scott, Salmon, and Trinity rivers. These four tributaries contribute about 44 percent of the Klamath River Basin's mean annual runoff and have a substantial influence on the timing of peak and low flow rates within the Lower Klamath River (FERC, 2007).

The daily monthly flow duration data for each month for the Klamath River below Iron Gate Dam are given in "Appendix A. Flood Frequency Report" and shown in Figure 2-19. The median flows were between 1,900 and 2,600 cfs during the months of January through April, and between 700 cfs and 1,000 cfs for the months of June through August. The minimum flows recorded during the period 1961 to 2009 occurred in the summer and were as low as 400 cfs. Peak flows occur primarily from December through March.

The daily flows for the period of record are given in Figure 2-20. There is a substantial amount of variability in flow from year to year. It should be noted that the last 10 years have been a relatively dry period.

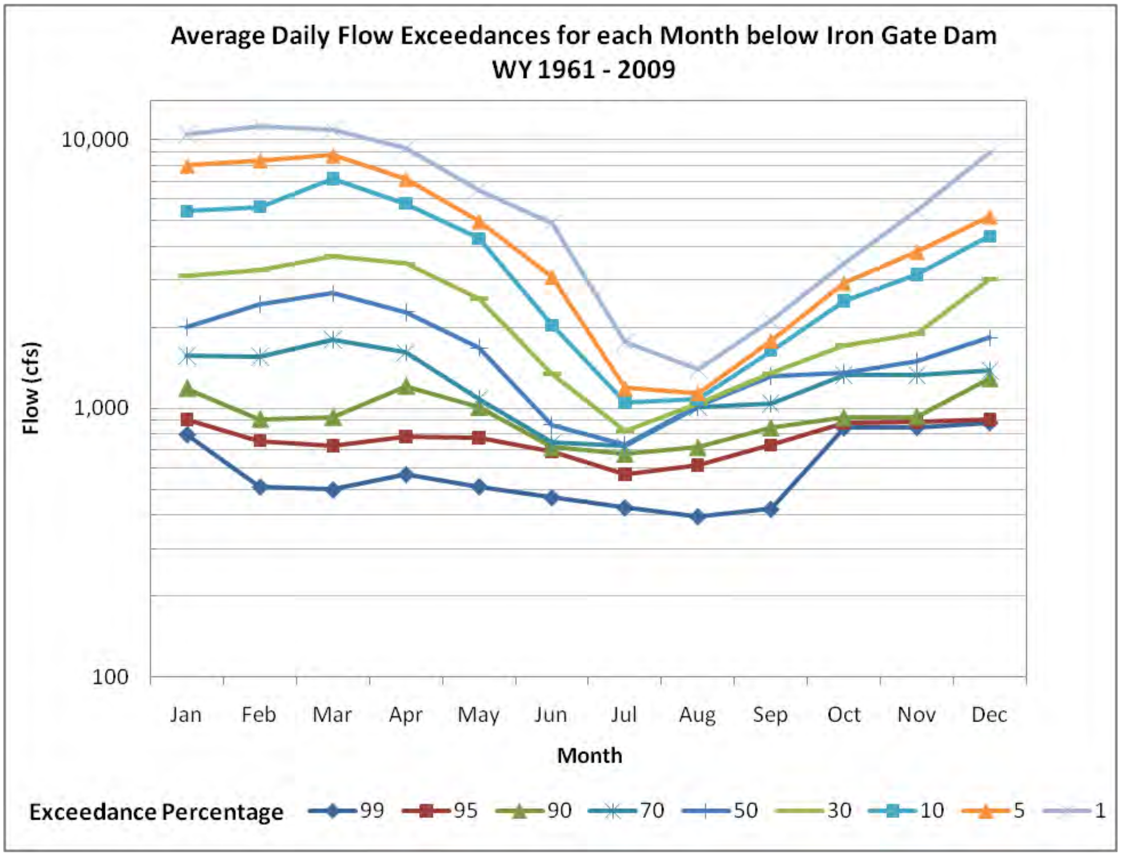


Figure 2-19. Daily flow exceedance percentages for each month below Iron Gate Dam for Period of Record WY 1961 – 2010 (USGS gage #11516530).

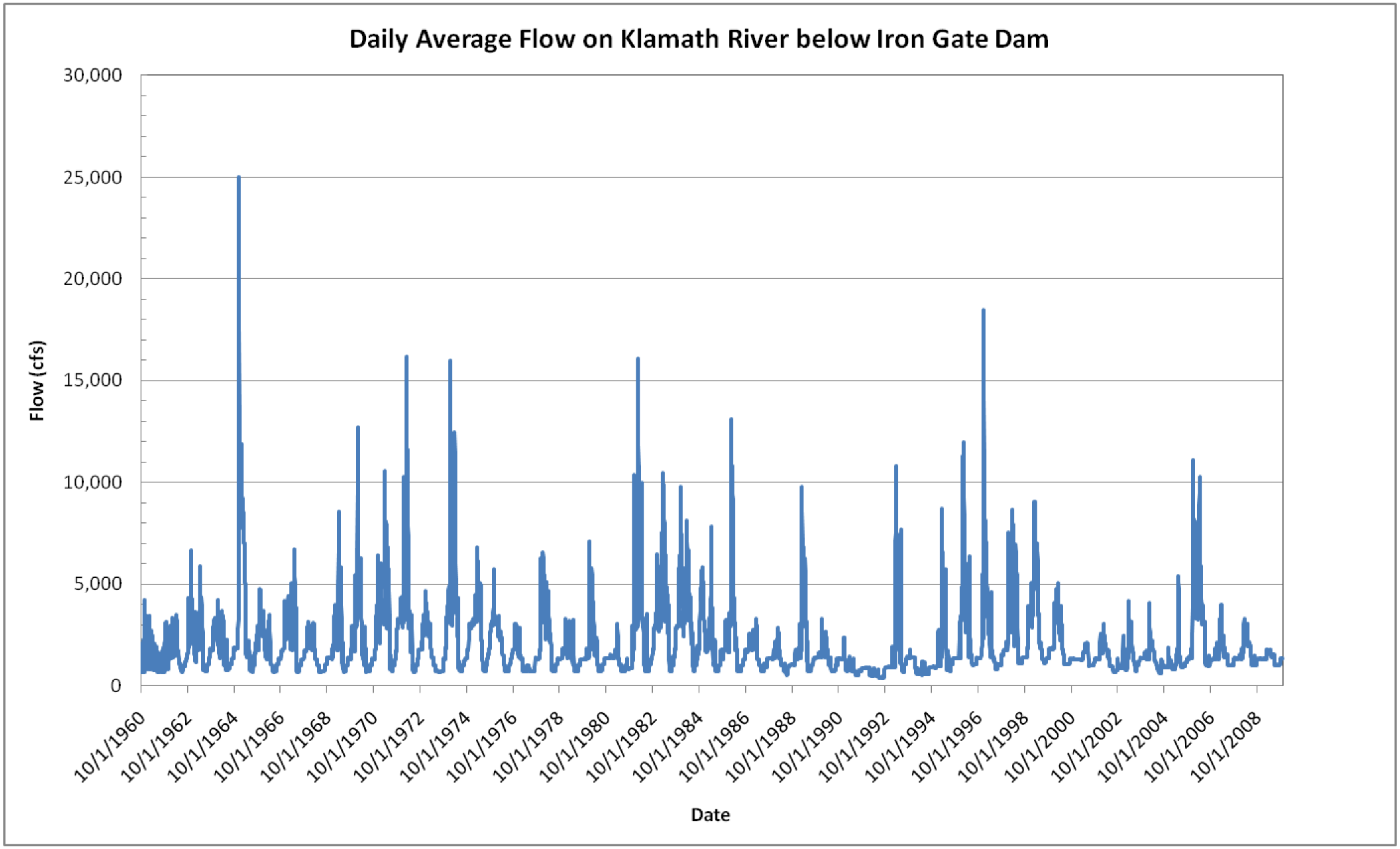


Figure 2-20. Plot of daily average flows below Iron Gate Dam from WY 1961 to 2009.

2.3.7. SHASTA RIVER

The Shasta River enters the Klamath River at RM 176.6, 13.5 miles downstream from Iron Gate dam. The Shasta River watershed includes the glaciated slopes of Mt Shasta, but is largely rangeland with substantial amounts of irrigated pastureland and agricultural area. The average precipitation in the watershed varies greatly with exposure and elevation, but is about 15 inches per year due to the rain shadow effect of the mountains to the west of the watershed. The hydrograph for the Shasta River near the confluence with the Klamath River shows a peak in the winter and minimum median flows under 40 cfs during July and August (FERC, 2007). The current hydrology of the Shasta River is affected by surface-water diversions, alluvial pumping, and the Dwinnell dam which creates Lake Shastina. Historically, springs and seeps dominated the hydrograph of the Shasta River resulting in a cool and stable river flow (NAS, 2004). Dwinnell dam, about 25 miles upstream from the Klamath River, controls 15 percent of the total drainage area of the Shasta River, The dam was constructed in 1928 and Lake Shastina has a normal storage capacity of 50,000 acre-feet. The majority of the water in Lake Shastina is retained during the winter and early spring for irrigation uses during the later spring and summer. Except for above average and wet water years, the only releases from Lake Shastina are to ensure sufficient flows to meet downstream water user requirements. Farther downstream, there are seven major diversion dams and numerous smaller dams or weirs on the Shasta River and its tributaries. When these diversions are in operation during the irrigation season, they substantially and rapidly reduce flows in the mainstem and completely dewater the main channel in some reaches of the river during the late summer of dry years (NAS, 2004).

2.3.8. SCOTT RIVER

The Scott River enters the Klamath River at RM 143, 47.1 miles downstream from Iron Gate dam. The Scott River watershed includes the heavily forested and relatively wet Salmon Mountains on its western divide, but these mountains create a rain shadow for the rest of the watershed. Similar to the Shasta River valley, many areas in the Scott River valley have been extensively altered for grazing and agriculture. Although the Scott River watershed is almost the same size as the Shasta River watershed, the hydrograph for the Scott River near the confluence with the Klamath River has 4 to 5 times higher median monthly flows in the winter and spring months (FERC, 2007). Somewhat similar to the Shasta River, the minimum monthly median flows near 50 cfs occur during August and September.

2.3.9. KLAMATH RIVER NEAR SEIAD VALLEY

The USGS gage Klamath River near Seiad Valley (#11520500) is located at RM 128.5, below the confluence of the Klamath River and Scott River. The daily flows at various exceedance values for each month near Seiad Valley on the Klamath are shown in Figure 2-21. The minimum flow during this period was near 400 cfs during the month of August; which is similar to the minimum recorded flow at Iron Gate, indicating that during the driest years there is very little contribution from tributaries between Iron Gate to Seiad Valley. The median flow is about 3,000 cfs to 5,000 for the months of December through May. The median flow decreases to about 1000 cfs during July and then gradually increases to 3,000 cfs by December. The 10 % exceedance flow is at or above 10,000 cfs at Seiad Valley for the months of January through April.

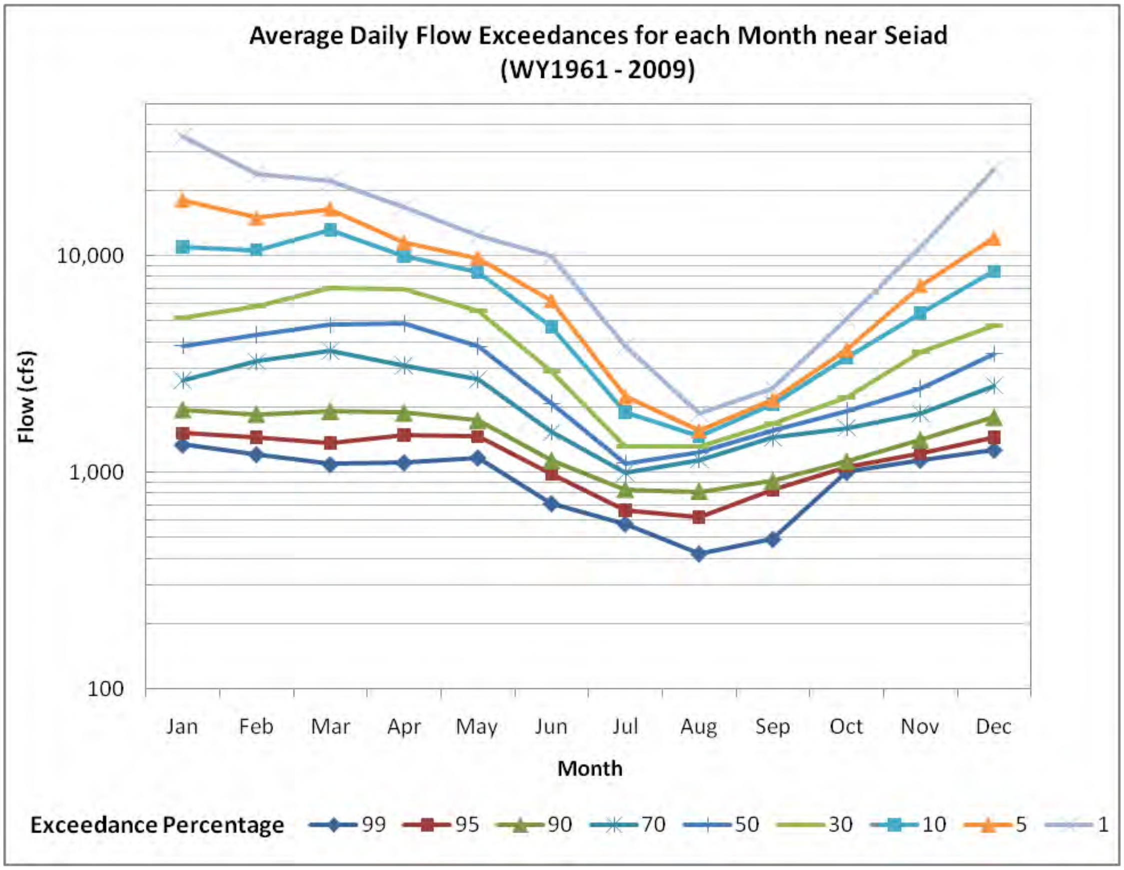


Figure 2-21. Daily flow exceedance percentages for each month near Seiad Valley for Period of Record WY 1961 – 2010 (USGS gage #11520500).

2.3.10. SALMON RIVER

The Salmon River enters the Klamath River at RM 66, 124.1 miles downstream from Iron Gate dam. The Salmon River watershed is generally steep, forested, and federally owned within the Klamath National Forest and several designated wilderness areas. The area is largely undisturbed except for logging, fires, and mining activity. The Salmon River hydrograph at the confluence with the Klamath River shows high average flows (3,375 cfs) during January, representing rain, or rain on snow events that are normally the peak flooding events during the winter. April and May have a more sustained and consistent spring high flow period (median flow, 2,660 and 2,630 cfs, respectively) representing snowmelt from the higher terrain where a deep snowpack accumulates. The minimum monthly median flow of about 200 cfs occurs during September (FERC, 2007).

2.3.11. KLAMATH RIVER AT ORLEANS

The daily flows at various exceedance values for each month at Orleans on the Klamath River are shown in Figure 2-22 (USGS Gage #11523000). This gage is located below the confluence of the Klamath and the Salmon Rivers at RM 60. The median flow is greater than 9,000 cfs for the months of January through near the end of May, and then the median flow gradually drops to less than 2,000 cfs during the months of August through September. The minimum flow during the period 1961 to 2009 was slightly less than 700 cfs during the drought of 1992. The 90% exceedance flow was approximately 1200 cfs during the month of August and September. The 90% exceedance flow reaches a maximum during the months of March and April of approximately 5,000 to 6,000 cfs. The maximum daily flows occur during the months of December through February and have been above 200,000 cfs during these months.

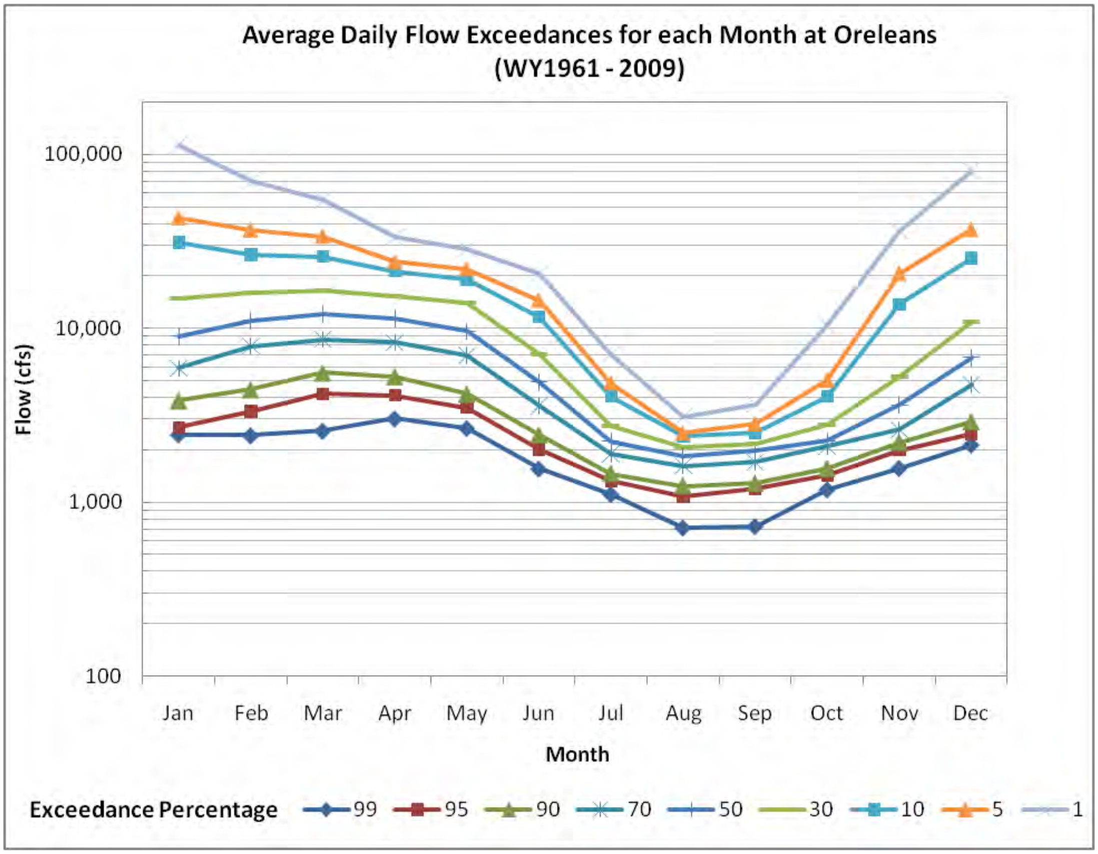


Figure 2-22. Historical stream flow statistics for every day of the year at Orleans on the Klamath River for WY 1961 – 2009, USGS gage #11523000.

2.3.12. TRINITY RIVER

The Trinity River enters the Klamath River at RM 40, 150 miles downstream of Iron Gate dam. The Trinity River is the largest tributary to the Klamath River. The Trinity watershed is generally wet, steep, forested, and federally owned within several national forests and wilderness areas. The Trinity River hydrograph at the confluence with the Klamath River show peak median monthly flows near 7,000 cfs occur in February and March, gradually declining to about 600 cfs in September (FERC, 2007).

A main feature of the Trinity River watershed is Trinity Lake. This reservoir has a storage capacity of 2.4 million acre-feet and is located 119 miles upstream from the Klamath River along the main branch of the Trinity River. Both Trinity Lake and, downstream, the much smaller Lewiston reservoir were constructed in the early 1960s as part of the Central Valley Project's Trinity River Division (TRD). During the first 10 years with these reservoirs and the TRD in full operation, an average of nearly 90 percent or 1.2 million acre-feet of the annual river flow at the Lewiston reservoir (drainage area of 692 square miles) was diverted via the Clear Creek Tunnel to Whiskeytown Lake and then into the Sacramento River system (Interior, 2000). About 1.1 million acre-feet per year were diverted during 1964 to 1986 and 0.73 million acre-feet during 1987 to 2000 (FERC, 2007).

The TRD has a substantial history of review and revisions to its flow regime. In 1973, the Cal Fish & Game requested that Reclamation release an annual volume of 315,000 acre-feet to reverse the steelhead and Chinook salmon declines. However, a combination of flood and drought resulted in a release of 705,000 acre-feet in 1974, 275,000 acre-feet in 1975, and 126,000 acre-feet in 1976; so Cal Fish & Game was not able to complete a formal evaluation of the effect of the flows (FWS and Hoopa Valley Tribe, 1999). In 1980, Interior prepared an EIS to address a proposal to increase stream flows in the Trinity for the goal of restoring steelhead and salmon populations. Based on this EIS, Interior issued a decision on January 14, 1981, to conduct the Trinity River Flow Evaluation to study the effects on fish habitat by increasing annual releases to 340,000 acre-feet in normal and wet years, and lesser releases of 220,000 acre-feet in dry years, and 140,000 acre-feet in critically dry years. In 1984, the Trinity River Basin Fish and Wildlife Management Act was signed by Congress, authorizing Interior to develop and implement a management program to restore the fish and wildlife populations in the Trinity River Basin to levels that existed prior to construction of the Trinity and Lewiston dams. The goals of the initial program (FWS and Hoopa Valley Tribe, 1999) included:

- Improve the capability of the Trinity River Hatchery to mitigate for salmon and steelhead fishery losses that have occurred above Lewiston dam.

- Restore natural (instream spawning) salmon and steelhead production in the mainstem and tributaries below Lewiston dam to pre-dam levels.

- Contribute to fish harvest management.

- Compensate for deer and other wildlife losses from flooding of habitat and reduced streamflow resulting from diversions to the Central Valley Project.

- Develop and implement land management activities to stabilize watersheds and reduce sediment yield to Trinity River tributaries.

The Central Valley Project Improvement Act of 1992 further supported restoration objectives and acknowledged the federal government's trust responsibilities by specifying minimum releases of 340,000 acre-feet per year pending completion of a flow evaluation study (FERC, 2007).

The current flow release program from Lewiston dam to the Trinity River is based on the Trinity River Mainstem Fishery Restoration EIS, completed in October 2000. In December 2000, Interior issued the Record of Decision (Trinity ROD) for the Trinity River Mainstem Fishery Restoration, but these flows did not go into full effect until November 2004.

Included in the Trinity ROD, which was based partly on the Trinity River Flow Evaluation (FWS and Hoopa Valley Tribe, 1999) and other studies, was a requirement for releases from Lewiston reservoir during the spring and early summer based on the water year type. Interior states that these flows are necessary to restore and maintain the Trinity River fishery resources by:

- providing physical fish habitat (i.e., appropriate depths and velocities) and suitable temperature regimes for anadromous salmonids; and

- restoring the riverine processes that create and maintain the structural integrity and spatial complexity of the fish habitats.

In addition, the Trinity ROD provides guidelines for mechanical channel rehabilitation, sediment management, watershed restoration, infrastructure improvement, adaptive environmental assessment and management programs, and measures to minimize and mitigate effects (Interior, 2000). The Trinity ROD flow release schedule is based on five different water year types, as they are determined on April 1 each year, and the total yearly releases are to be approximately 48 percent of the natural (pre-TRD) flow at Lewiston dam.

2.3.13. KLAMATH RIVER NEAR KLAMATH

The daily flows at various exceedance values for each month near Klamath on the Klamath River (USGS gage #11530500) are shown in Figure 2-23. This gage is sometimes affected by tidal influences during low flow periods. Releases from Iron Gate Dam still account for nearly 40 percent median flows of the low flow months of September and October -- close to the drainage area ratio of 38 percent between Iron Gate Dam and this location (FERC, 2007). During other months, especially during the winter and spring, over 85 percent of the hydrograph at this location is from sources other than releases from Iron Gate Dam. The median flows are at or above 20,000 cfs for most of January through April and decrease to approximately 2,000 cfs during August and September. The minimum flows recorded during the period of WY 1961 to 2009 were approximately 1,400 cfs and occurred during August and September. The 90% exceedance flows were approximately 2,000 cfs during August and September. The maximum daily average flows, as high as 400,000 cfs, occur during December through March.

Figure 2-24 compares median flows throughout the basin at USGS stream gages throughout the Klamath Bain for the period WY 1961 to 2009. The median flows at Keno were lowest in July and were between 300 and 500 cfs, increasing to approximately 700 cfs in August. The median flows at Iron Gate were lowest in July and were approximately 700 cfs, increasing to 1,000 cfs in August. The median flows at Orleans were the lowest in August and September and were approximately 2,000 cfs. The median flows at near Klamath were lowest in August and September and were approximately 3000 cfs.

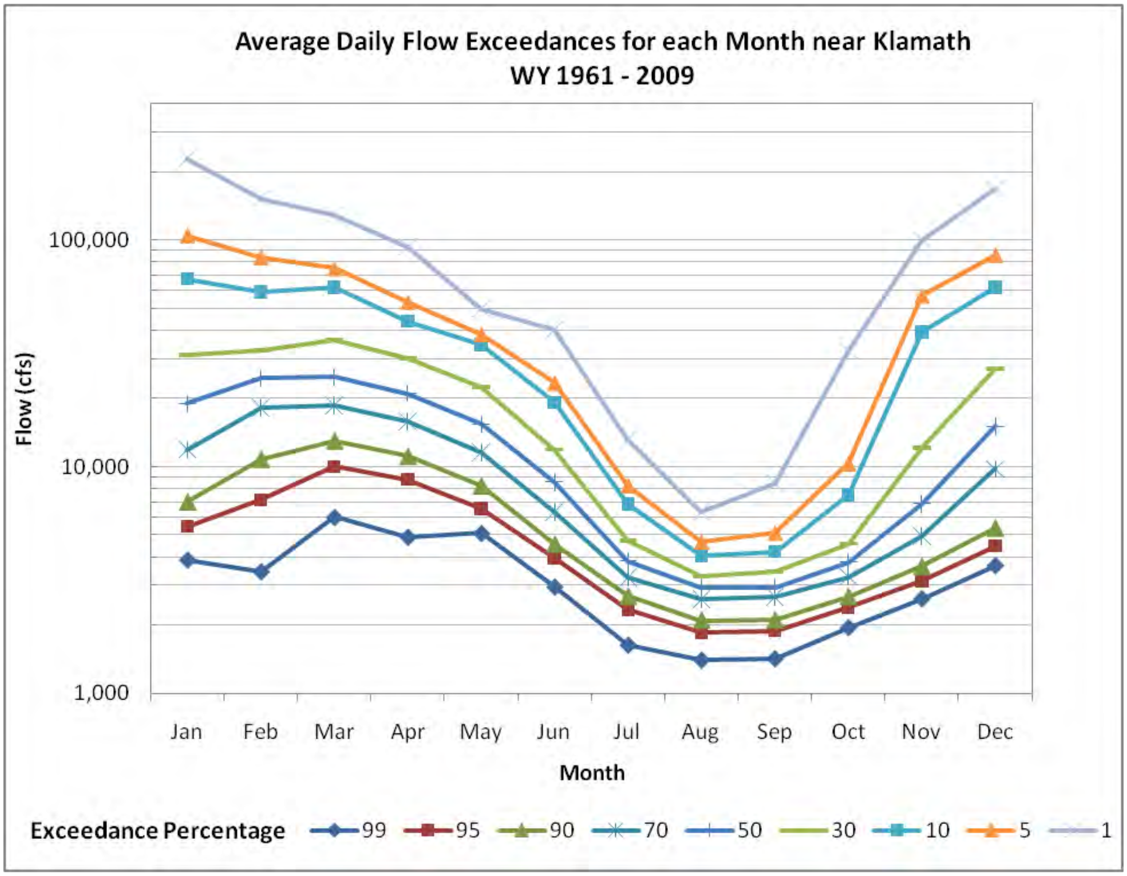


Figure 2-23. Historical stream flow statistics of the Klamath River at Klamath for WY 1961 – 2009, USGS gage #11530500.

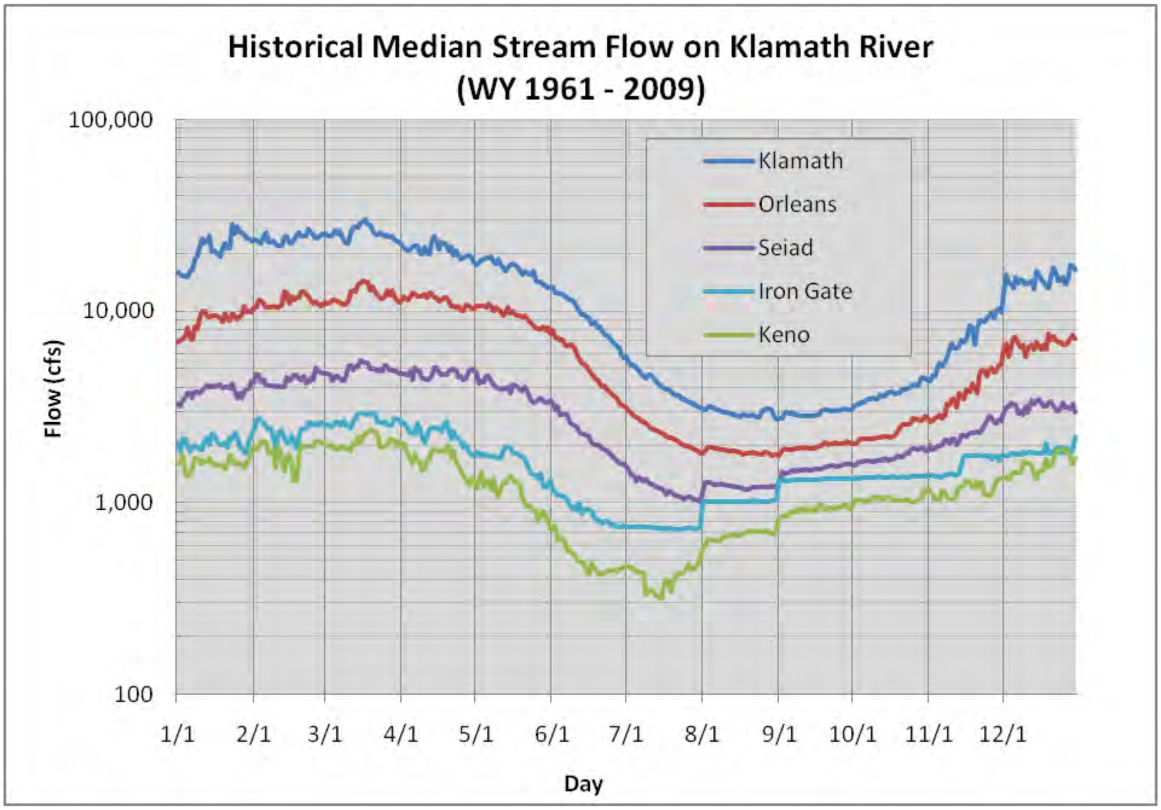


Figure 2-24. Median Flows at USGS stream gages on Klamath River for every day of the year at Keno, below Iron Gate, near Seiad Valley, at Orleans, and at Klamath.

2.4. Peak Flows

A flood frequency analysis at each of the gages and dams is described in “Appendix A. Flood Frequency Report” and discharge results are given in Table 2-4.

The peak flows at Iron Gate Dam are significantly greater than peak flows at J.C. Boyle Dam (Table 2-4) because of the tributaries that enter the Klamath River between the two dams. In particular, Jenny Creek contributes a large amount to the peak flow during the winter and spring months. The watershed area of Jenny Creek is 210 mi^2 and it is the largest single tributary between Keno Dam and Iron Gate Dam. Downstream of Iron Gate Dam, peak flows continue to increase substantially as tributaries enter the Klamath River. The 10-year discharge at Seiad Valley downstream of the Scott River is 56,500 cfs. The 10-year discharge at the mouth is estimated to be close to 300,000 cfs.

The 2-year and 5-year flood frequency discharges are given in Table 2-5 for the Klamath River and are graphed in Figure 2-26. The 2-year and 5-year flood computations for the period of record of 1961 – 2009 were based upon the exceedance values of 0.5 and 0.2, respectively. This period of record was chosen because all the gages used in the analysis had data for this period. The 5-year flood at J.C. Boyle and Keno reaches were slightly larger than the 10-year floods computed in the flood frequency analysis of the large floods. This is because a different period of record was used in the analysis. The larger flood frequency analysis used a longer period of record that included the 1930s and 1940s which was a relatively dry period with smaller peak flows.

A longer gage record is available for Orleans and Keno stream gages and the average peak flows for the periods 1927 to 1961 and 1962 to 2009 are given in Figure 2-27. The average peak flow was greater during the period 1962 to 2009 than from 1927 to 1961 for both gages. The period between the 1930s and 1940s was relatively dry in this basin and the river experienced correspondingly small peak flows.

Table 2-4. Flood Frequency analysis on Klamath River for 10-year to 100-year floods based upon full period of record of each gage.

Gaging Station	**Drainage Area (mi^2)**	**Discharge (ft^3/s)**				
		Gage Base	**10-yr Flood**	**25-yr Flood**	**50-yr Flood**	**100-yr Flood**
Keno	3,920	4,000	8,642	10,350	11,200	11,800
Boyle	4,080	4,000	9,058	11,050	12,220	13,150
Copco	4,370	5,400	10,750	12,720	13,730	14,470
Iron Gate	4,630	N/A	15,610	21,460	26,280	31,460
Seiad	6,940	N/A	56,540	93,400	131,000	179,300
Orleans	8,470	N/A	163,100	230,300	287,000	348,900
Klamath	12,100	N/A	298,300	392,900	466,900	543,300

Table 2-5. Flood Frequency on Klamath River for 2-year to 5-year floods for the period of record from 1961 – 2009.

Gaging Station	**Drainage Area (mi^2)**	**Discharge (ft^3/s)**				
		Median Flow	**Average Flood**	**1.5-yr Flood**	**2-yr Flood**	**5-yr Flood**
Keno	3,920	1,180	5,593	3,350	5,290	8,920
Boyle	4,080	1,250	6,049	3,520	5,100	9,396
Iron Gate	4,630	1,370	7,978	4,380	6,030	10,980
Seiad	6,940	2,700	28,569	11,000	17,600	39,960
Orleans	8,470	4,870	93,998	56,000	63,500	142,600
Klamath	12,100	9,980	183,802	116,318	154,000	273,600

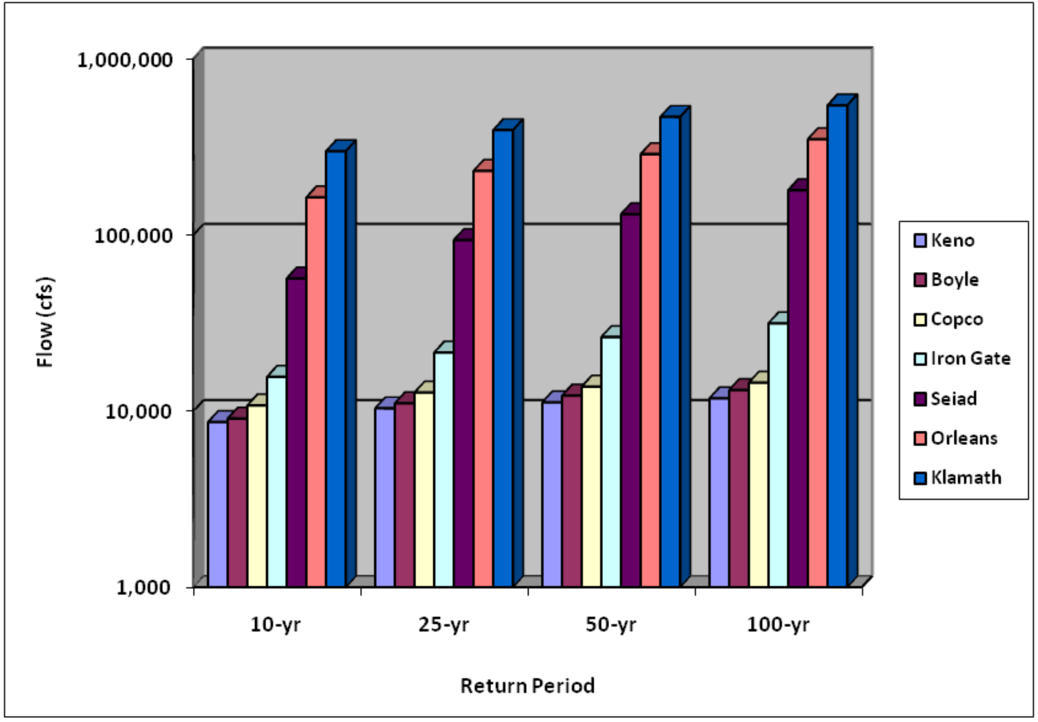


Figure 2-25. Flood-frequency recorded at USGS gages on Klamath River.

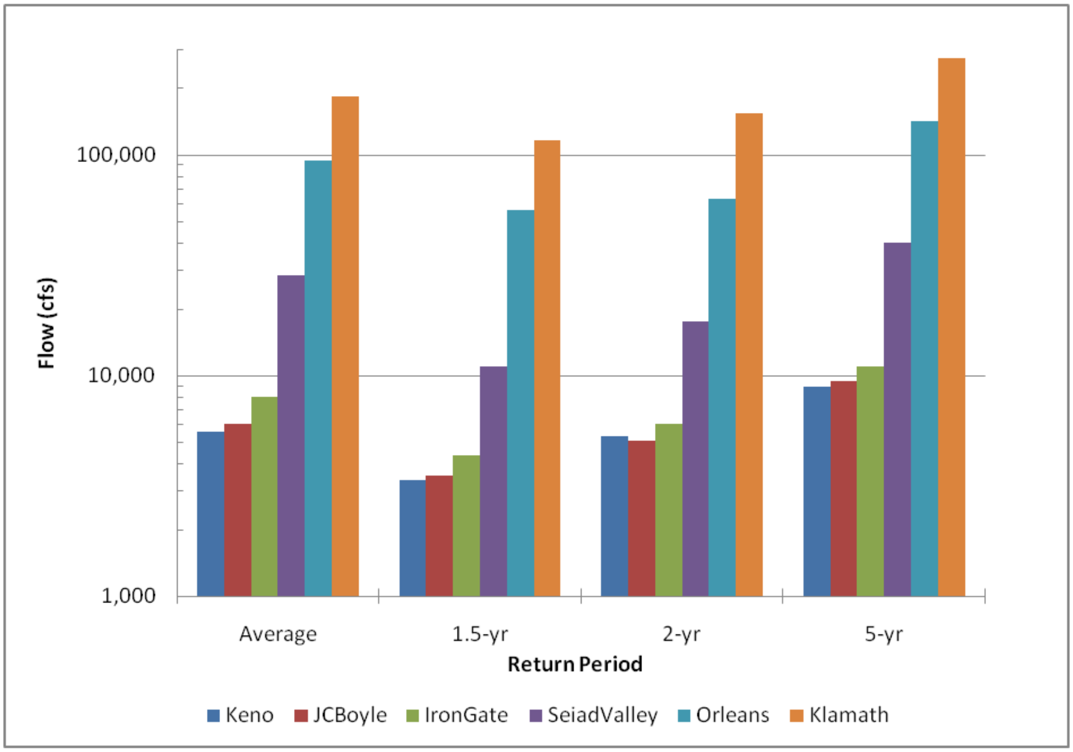


Figure 2-26. Flood frequency recorded at USGS gages on Klamath River for Floods with a Return Period of 5-years and less for the Period of Record 1961 – 2009.

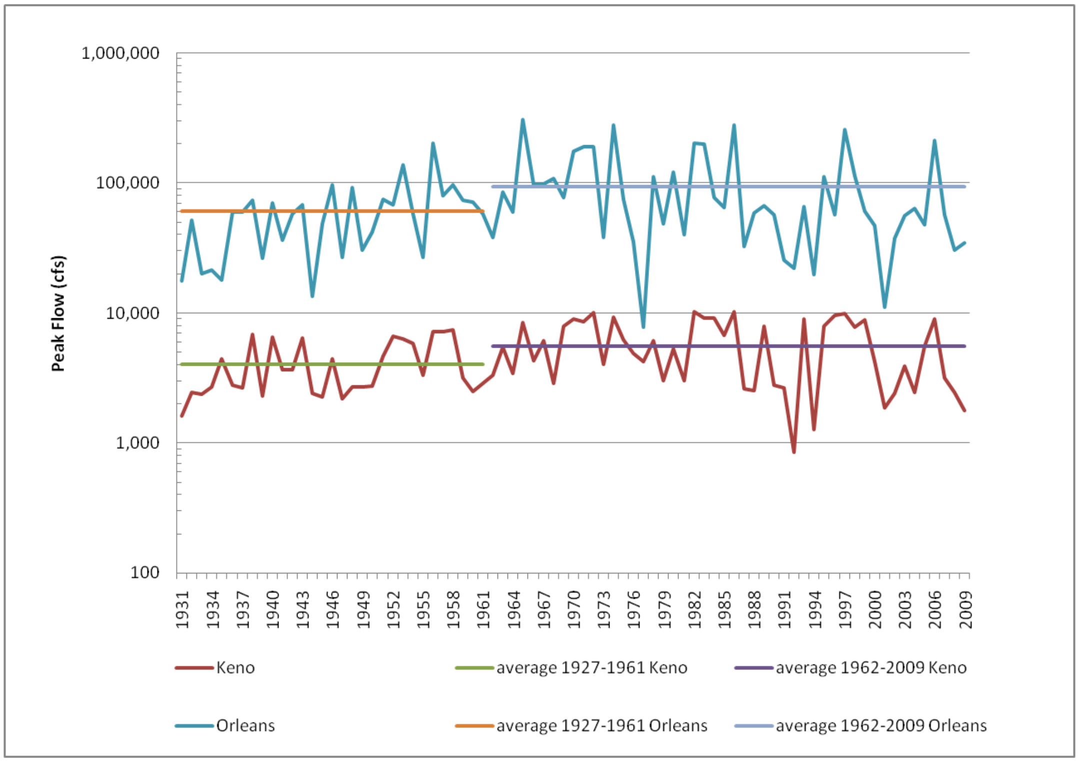


Figure 2-27. Historical peak flows at Keno and at Orleans on the Klamath River.

3. Existing Groundwater Conditions

3.1. Introduction

The goal of Chapter 3 is to review the potential for impacts to existing water wells in the vicinity of J.C. Boyle, Copco 1 & 2, and Iron Gate Dams, specifically impacts to static water levels (SWL) in the wells and potential increases in pumping head from the removal of the dams. There is no intent in this chapter to discuss potential changes in water quality in the wells or the river resulting from the removal of the dams. Nor is there any intent to discuss potential changes in water temperatures in the wells or river from the removal of the dams. It is assumed that the river and the groundwater system(s) were in equilibrium in terms of water chemistry and temperature before the dams were put into operation, and that they will return to near pre-dam equilibrium conditions once the dams are removed. The post-dam removal equilibrium will of course be modified by all the anthropogenic activities in the project area that have occurred and continue to occur since the dams went into operation.

3.2. Physiographic Setting and Regional Geology

The physiographic setting and regional geology of the Klamath River watershed as it pertains to groundwater is reviewed here. There is also a section on geological conditions as it relates to geomorphology in Section 5.

The Klamath River watershed covers four geomorphic provinces with distinctly different characteristics developed by, and indicative of, their geologic history. The head of the watershed begins in the Modoc Plateau Province (Figure 3-1), and abruptly transitions into the Cascade Volcanics Province (composed of the High Cascades sub-province and the Western Cascade sub-province) just west of Upper Klamath Lake (UKL). West of the Cascade Volcanics Province, in order, are the Klamath Mountains Province and the Coastal Range Province (Oakeshott, 1998). The three dams that are the subject of this report are all in the Cascade Volcanics Province. The Modoc Plateau Province has a strong influence on the character of the water, both surface and subsurface, in the Klamath Basin, and it will be discussed within this chapter as it relates to the occurrence and movement of subsurface water in the study area.

3.2.1. CASCADE VOLCANICS PROVINCE

Cascade Volcanics Province (CVP): is generally divided into two sub-provinces based on age and style of volcanism (Mertzman & Hazlett, 1997; Taylor, 1990): the Western Cascade Sub-Province (WCSP) and the High Cascades Sub-Province (HCSP).

The Western Cascade Sub-Province (WCSP) is the oldest and most eroded of the two sub-provinces (Figure 3-2). It is dominated by calc-alkaline continental margin andesites. The WCSP were extruded beginning some 40 Ma (mid-Tertiary; Oligocene time) in a back arc environment resulting from the subduction of the Juan de Fuca Plate under the North American Plate (Mertzman & Hazlett, 1997). USFS (2002a) describe the WCSP as:

> *The Western Cascades province is characterized as an older, deeply eroded volcanic range lying west of the more recent snow-covered High Cascade Range. They range in elevation from 1700 feet on the western margin to 5800 feet on the eastern margin. The Western Cascades began to form 40 million years ago with eruptions from a chain of volcanoes near the Eocene shoreline. Volcanic activity gradually shifted to the east in the Miocene and Pliocene.*
>
> *The Western Cascades are made up almost entirely of slightly deformed and partly altered volcanic flows and pyroclastic rocks which range in age from late Eocene to late Miocene. These rocks have been heavily dissected by erosion and the only evidence remaining of the many volcanoes from which they were erupted are occasional remnants of volcanic necks or plugs which mark former vents. There are also minor Pliocene to Pleistocene intracanyon lavas derived from the High Cascades or rare local vents (USFS, 2002a).*

The High Cascades Sub-Province (HCSP) is the younger of the two sub-provinces (Figure 3-2). The HCSP is of Quaternary age and is distinguished by lava flows, lava shields, pyroclastic flows, tuffs, cinder cones, and classic cone shaped stratovolcanoes. Volcanics consist primarily of basalt, andesite, and andesitic basalt with minor amounts of dacite and rhyolite although different volcanoes and even different eruptions from the same volcano can vary the proportions of the basalts, andesites, and andesitic basalts. Petrogrraphic analyusis indicates that all the volcanic are dominated primarily by olivine, plagioclase, clinopyroxene and opaques compositions (Robinson, 1995; Gaffney, 1994; Mertzman, 1995; Hill, 1995; Gravely, 1995). USFS (2002b) described the HCSP as:

> *The High Cascades province is characterized by a north-trending belt of upper Miocene to Quaternary volcanic rocks that were erupted on the east margin of the upper Eocene to Miocene Western Cascades province. The late Pleistocene record of this volcanic activity is well preserved on the crest of the High Cascades. The best exposed record of the early Pleistocene, Pliocene and late Miocene Cascade volcanism is found in volcanic and volcaniclastic deposits on the east flank of the range and in the adjacent Deschutes Basin.*
>
> *Upper Pliocene and Quaternary rocks of the High Cascades form a broad platform of chiefly basalt and basaltic andesite volcanoes that fill a structurally subsided zone in the older rocks of the High Cascades. Mt.*

> *Hood, Mt. Jefferson, Three Sisters-Broken Top, and Mt. Mazama (Crater Lake) are the four major Quaternary volcanic centers along this platform. These major volcanic centers have erupted lava flows and pyroclastic material that ranges in composition from basalt to dacite and with the exception of Mt. Hood have also erupted rhyolite (USFS, 2002b).*

3.2.2. MODOC PLATEAU PROVINCE

The Basin and Range Province in south-central and south-eastern Oregon, which includes the Modoc Plateau Province (Figure 3-1), is the northwestern-most extent of the Basin and Range Physiographic Province (Figure 3-3). The Basin and Range Province is dominated by NW-SE tending grabens and horsts resulting from normal faulting associated with extensional tectonics. The grabens are commonly interspersed with lake bed deposits, shield volcanoes, cinder cones, and/or lava flows.

The Modoc Plateau Province is located in north-eastern California and south-central Oregon and is primarily a Californian nomenclature. Although the topographic, geologic, and structural features of the Modoc Plateau extend into Oregon, Idaho, and Nevada it is generally not called the Modoc Plateau in any of those three states. It is bounded to the west by the Cascades Province and to the eastern escarpment of the Modoc Plateau forms the western boundary of the distinctly fault block topography of the Basin and Range Province. The Modoc Plateau structurally resembles the Basin and Range Province in that it consists of NW-SE trending horsts and grabens, but unlike the Basin and Range Province, the grabens of the Modoc Plateau have been essentially filled in with volcanic deposits. Like the Cascades, the area is dominated by volcanic activity, but the volcanics are typical of fissure eruptions and form broad level plains and low shield volcanoes and were generally less explosive than those in the Cascades. The volcanics of the Modoc Plateau lithologically resemble those of the Columbia Plateau more than those of the Cascades or the Basin and Range (Miles and Goudey, 1998). Thus the Modoc Plateau is considered to be a southern extension of the Columbia River plateaus of eastern Oregon and Washington (Michaelsen, 2009; Norris and Webb, 1976). The Modoc Plateau is considered a transitional zone between the upper extent of the Basin and Range Province in Nevada and the southern end of the Cascade Province in northern California and southern Oregon. Shallow lakes (Upper Klamath, Lower Klamath, and Tule lakes) and marshes (Klamath Marsh) are prominent features of the Modoc Plateau’s extent into Oregon.

Map layout: Bruce Gwynne, bgwynne@waterboards.ca.gov

Figure 3-1. Physiographic Provinces of the Klamath River Basin. (after Oakeshott, 1978).

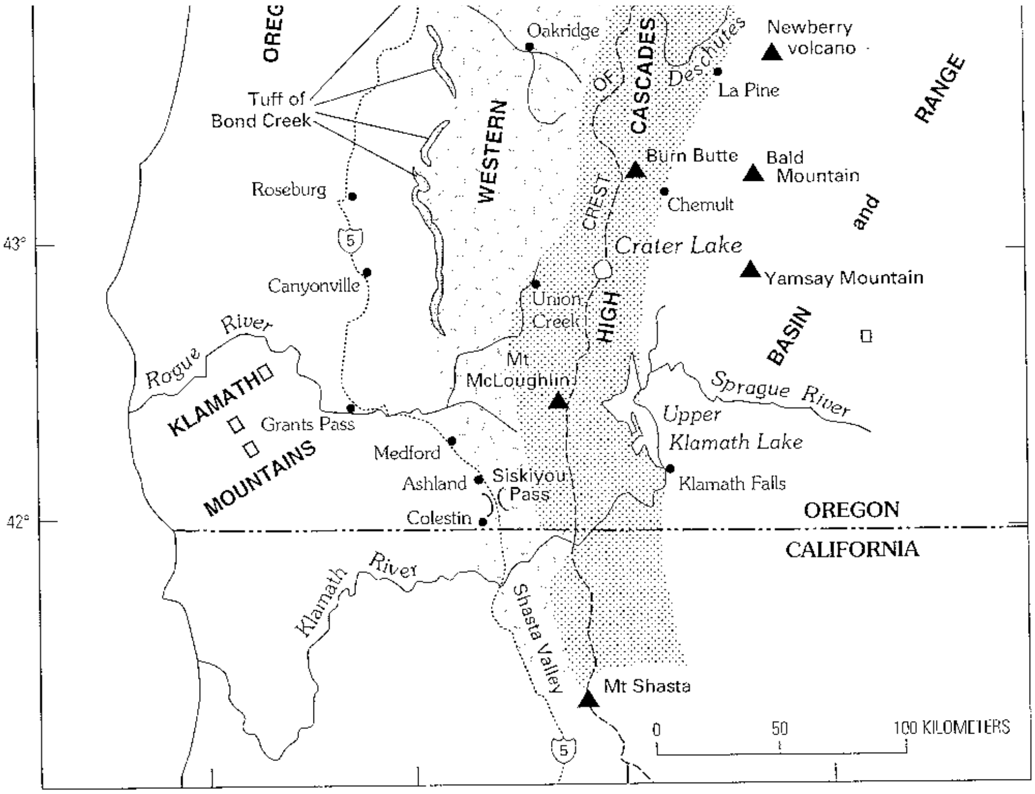


Figure 3-2. Map showing geographic locations, physiographic provinces, and subdivisions in the region of the Oregon-California border. Western and High Cascades sub-province extents are approximate. Modified from Sherrod and Smith, 2000 (Figure 1).

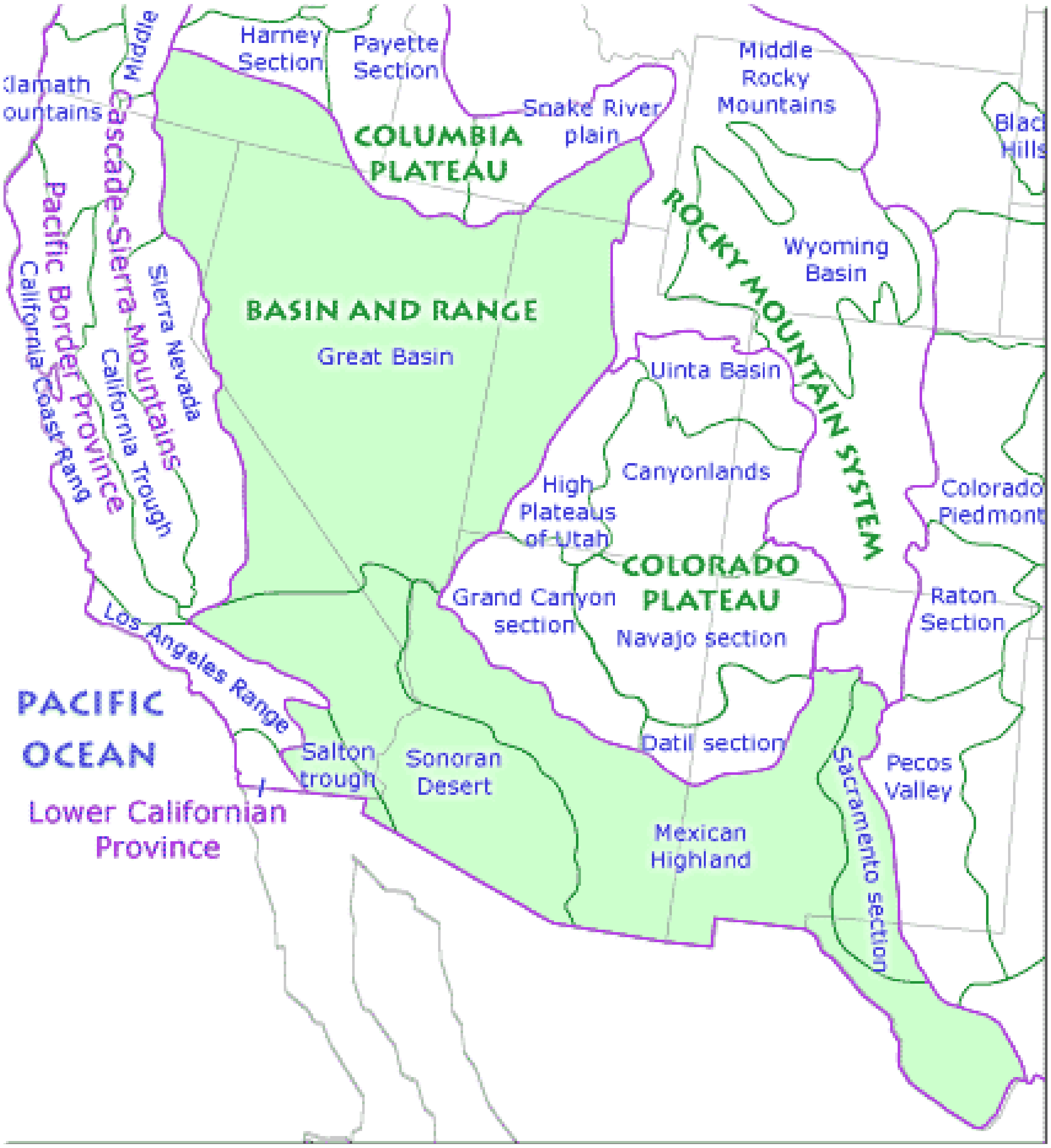


Figure 3-3. Index map of sub-provinces in the western United States. Downloaded from http://geomaps.wr.usgs.gov/parks/province/basinrange.html

3.3. Local Geology

Numerous geologic studies that include the reach of the Klamath River between Keno Dam and Iron Gate Dam were published in the 1970’s, 80’, and 90’s with a significant number also being published between 2002 and 2009. The region is a complex mixture of geologic units (Figure 3-4 and Figure 3-5) that are dominated by extensive volcanic terrains composed of several different and distinct chemical compositions. Sherrod and Smith (2000) state:

> “*The Cascade Range suite of volcanic, volcaniclastic, and nonvolcanic sedimentary rocks is stratigraphically complex compared to miogeoclinal or continental-shelf sedimentary rocks. The complexity results from the intricate way in which volcanic and volcaniclastic rocks were formed, deposited, and reworked in a subaerial arc environment. Hundreds of small overlapping and intertonguing volcanogenic and sedimentary units compose the range; thus, individual lithostratigraphic units are discontinuous and commonly intricately interbedded. In addition, the rocks are poorly exposed in many places, and distinctive widespread marker units are uncommon. Lithologic correlations, even of similar stratigraphic sequences, are unreliable without corroborating isotopic ages or detailed mapping.*”

They continue on to say:

> “*. . . volcaniclastic sediment derived from a major volcano laps onto an older eroded volcano and simultaneously interfingers with contemporaneous deposits that were derived from other volcanoes (fig. 2A). The resulting suite of volcaniclastic rocks represents many different depositional environments and volcanic sources. Intermittently erupted lava flows, highly mobile ash flows, and large-volume debris flows may travel long distances down valleys. Far downstream these flows become interlayered with fine-grained, thin-bedded volcaniclastic deposits that are characteristic of a low-energy depositional environment. Large andesitic to dacitic volcanoes construct aprons of pyroclastic and epiclastic debris derived from dome growth and eruptions higher on their flanks. Basaltic shield volcanoes overlap and interfinger with one another and with volcaniclastic sediment.*

Newcomb (1961) discusses the “Hydrology of Volcanic-Rock Terranes” in the Columbia River Basalt. As the volcanics of the Modoc Plateau have been related lithologically to the Columbia Basalts, Newcomb’s descriptions likely apply to the volcanics in the study area. Newcomb describes the average flow as a dense, nearly flintlike, partially fractured rock at the base and grading vertically to dense, massive columnar-jointed rock at its center; and often vesicular – and in some places rubbly at the top. Systems of cooling fractures create irregular columnar, cubical, and platy blocks ranging up to 60 inches across. Water moves through the sequence of flows primarily in the permeable zones at the top of flows which can be up to 10 feet thick. If a highly jointed flow connects two of these permeable zones then the water bearing unit may be quite thick.

The massive centers of many flows are relatively impermeable, and when several individual flows are stacked successively thick sections of non-water bearing zones are formed. These units can cause perched water tables above the regional water table, or can isolate water-bearing zones so that they have no interconnectivity which can result in water-bearing zones having significantly different piezometric levels.

Water that percolates into these materials will follow the path of least resistance which will be laterally through the permeable layers on the top of some flows and vertically through the highly fractured flows. Newcomb (1961) noted that where the strata are inclined, the water level will lie at or near the level of the principal streams. Water will travel laterally from anticlinal structures to synclinal structures where the water level may lie at or near the drainage level, or be under confined pressures.

Fault zones, vertical barriers such as dikes, termination of the permeable zone on the top of one flow by a later flow, or other processes that can alter or obliterate a permeable layer can impede or stop the flow of water completely. In such a situation, the groundwater will back up behind the barrier and a groundwater 'reservoir' may be created.

In addition to Sherrod and Smith (2000), several other investigators mention features similar to those described by Newcomb (1961). Gaffney (1994) mentions that in her study area "*Most of the units contain more than one flow, which can be seen in the field by a rubbly layer at the base and high vesicularity at the top of the flow*." Hill (1995) states that in her study area "*. . . exposes pyroclastic layers of fine ash, cinder/lapilli, and agglomerate layers with large clasts . . . blocks and bombs are also present and form a lag deposit on the surface where the finer material has weathered away. No lava flows were found . . .*" Norris and Webb (1975), when discussing the structure of the California Cascades, state "*Faulting has been important throughout the development of the California Cascades . . the lowest beds are folded and eroded but the highest are horizontal . . . During andesitic (earlier) volcanism, block faulting occurred, magma emerged along some of the faults, and cones and domes developed. Before and during basaltic (later) flow eruptions, ether was vertical faulting . . . young faults cut the basaltic sequences.*" Norris and Webb also state "*The block faulting that was more or less continuous during early Tuscan deposition produced enclosed drainages in which water collected. Alluvial fan, delta, and lake bed deposits, including water-laid ash, tuff, and diatomite accumulated in the lake basins. Sometimes deposition of the lake sediments was interrupted by lava flows. Many basaltic flows throughout the province show well –developed columnar jointing and possess weathered zones and fossil soils.*" All this suggests that in the study area it cannot be assumed that there is any extensive lateral or vertical connectivity within the volcanic materials, nor can it be assumed that there is no vertical connectivity between layers.

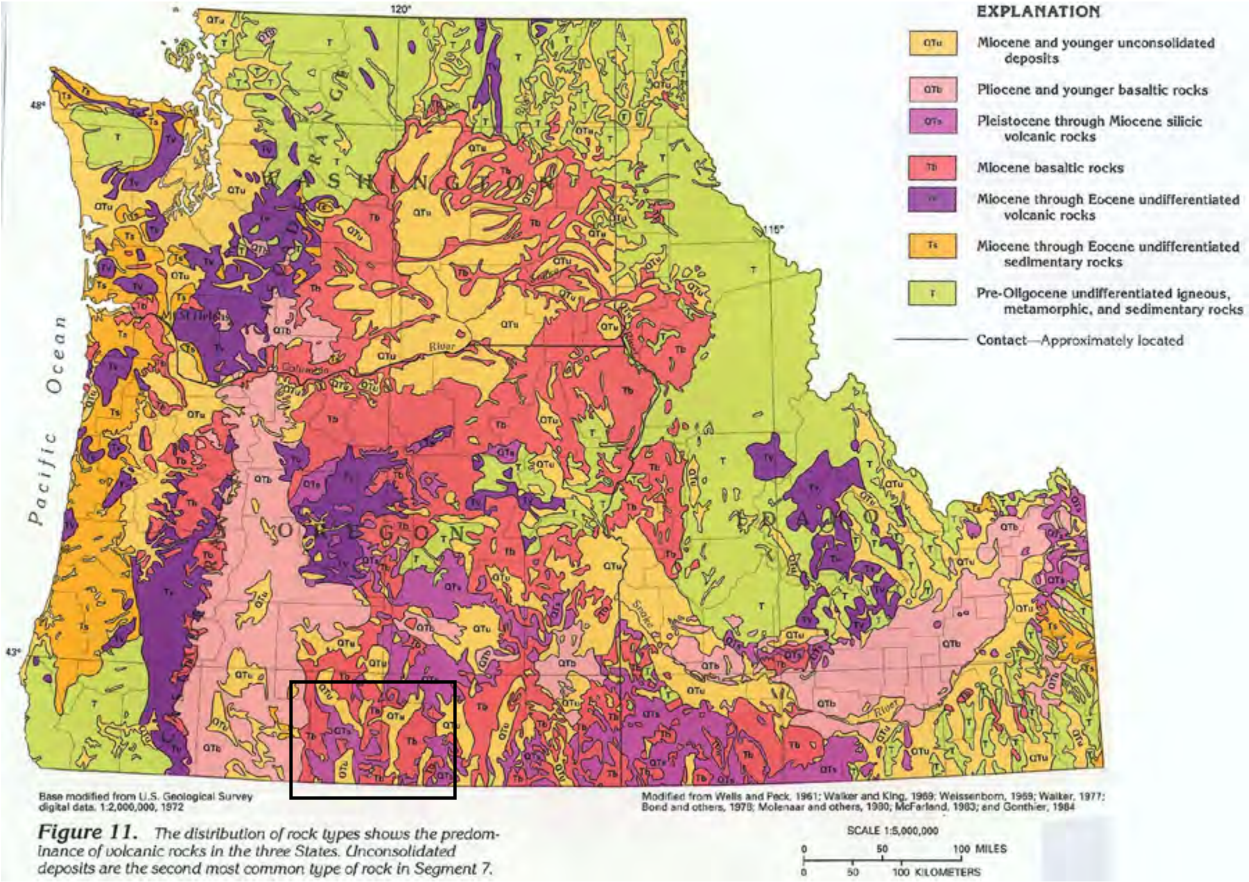


Figure 3-4. Generalized Geology for Washington, Oregon, and Idaho (after Figure 11, USGS Hydrologic Atlas Segment 8, HA 730-H). Box outlines the general region of the Upper Klamath Basin in Oregon in the vicinity of Upper Klamath Lake and Klamath Falls.

Figure 3-4a. Enlarged view of boxed area in above figure.

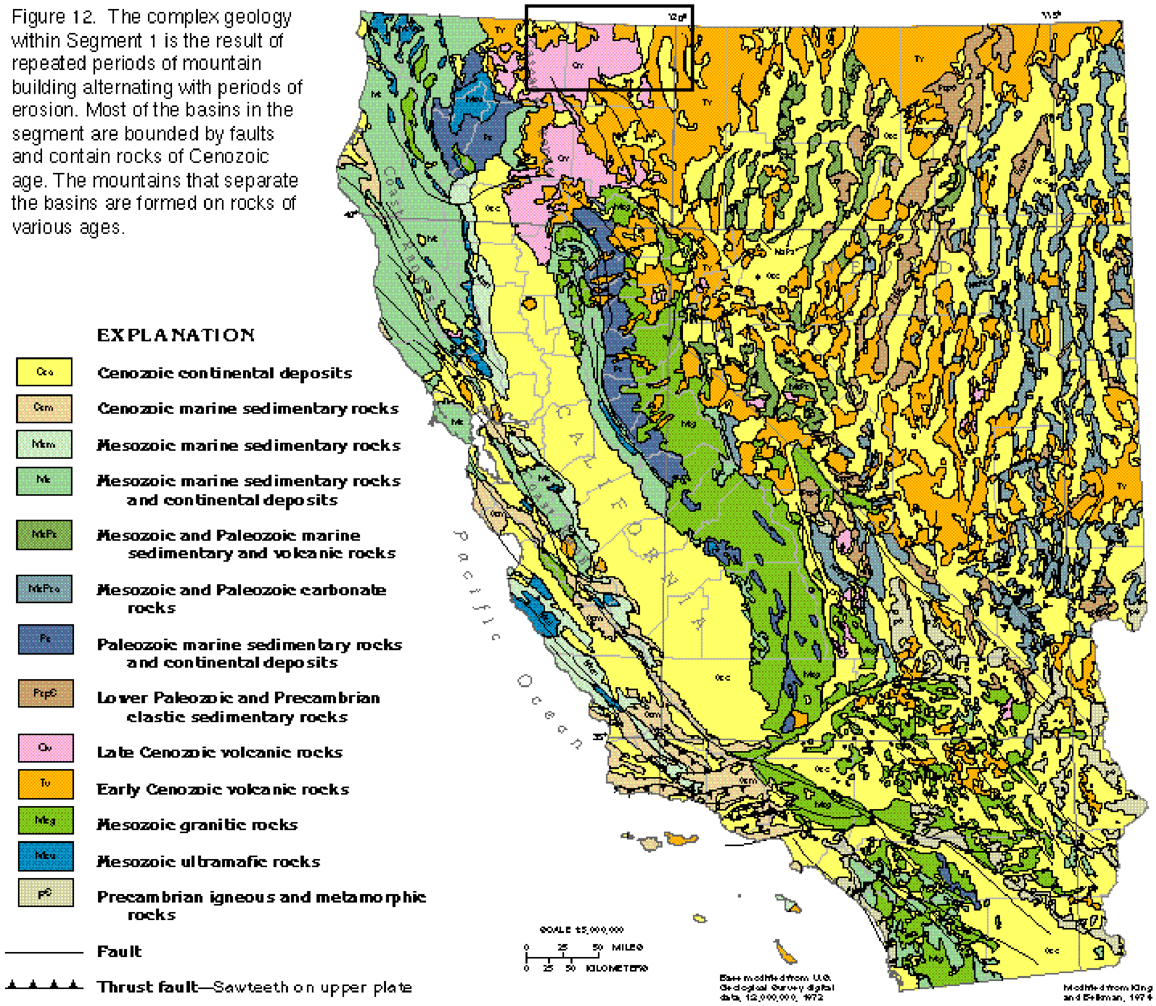


Figure 12. The complex geology within Segment 1 is the result of repeated periods of mountain building alternating with periods of erosion. Most of the basins in the segment are bounded by faults and contain rocks of Cenozoic age. The mountains that separate the basins are formed on rocks of various ages.

King, P.B., and Beikman, H.M., 1974, Geologic map of the United States: U.S. Geological Survey, scale 1:2,500,00, 3 sheets.

Figure 3-5. Generalized Geology of Nevada and California (after Figure 12, USGS Hydrologic Atlas Segment 1, HA 730-B). Box outlines the general region of the Upper Klamath Basin in California.

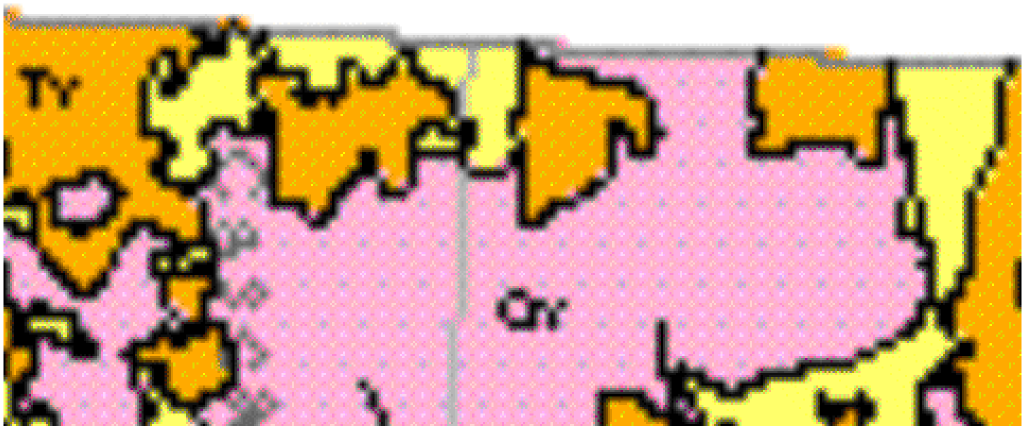


Figure 3-5a. Enlarged view of boxed area in above figure.

3.4. Klamath River Study Area

The river reach within the area that will likely be affected by the removal of the three dams consists of the river between Keno Dam, OR and Iron Gate Dam, CA. Within that reach, there is a section that is known as the Klamath River Gorge, which is generally between Keno and Copco Dams. While just about the entire length of the reach between Keno and Iron Gate Dams has exposures of bedrock it is the Klamath River Gorge section that is reported to have the best exposures (Gaffney, 1994). The best exposures are in a 2-3 km (1.2 – 1.8 miles) stretch identified as ‘Long Point’. Within the Klamath River Gorge area, the volcanics have been subdivided many different ways.

Walker (1985) divided the KRG volcanic into two units: an older unit of mildly alkaline basalts, which he informally referred to as the lower Outerson formation; and an overlying younger unit of calc-alkaline basalts, basaltic-andesites, and andesites referred to as the upper Outerson formation. Walker identified the basal contact between these Pliocene lavas and the underlying Western Cascade series as a prominent disconformity marked by a thick soil horizon; the upper contact with the overlying Pleistocene lavas is an angular unconformity. Walker differentiated the mildly alkaline lower Outerson lavas from the overlying calc-alkaline rocks by distinctly higher percentages of P_20_5, $Ti0_2$, iron, and alkalis.

As mentioned previously, Gaffney (1994) identified ten volcanic units in the KRG consisting of basalts and andesites. The most voluminous units come from the Hayden Mountain and Chase Mountain basaltic andesitic cones. The flows from these two volcanic centers interfinger spatially and temporally with flows from the other eight units in the area. Most of the units reportedly consist of more than one flow, where flows can be distinguished in the field by a rubbly layer at the base and high vesicularity at the top of the flow.

Robinson (1995) identified eight distinct units in the area – seven of volcanic origin and one Quaternary alluvium unit. Many if not most, of the studies along and across the river, including studies both upstream and downstream of ‘Long Point’, have focused on the geochemistry and petrology of the volcanics and generally only have rudimentary geologic descriptions of the units. Few of the studies have descriptions of unit thicknesses, bedding, jointing, faulting, orientation, or other common characteristics usually found in geologic reports.

3.5. Hydrology

3.5.1. GENERALIZED SURFACE HYDROLOGY

For a more detailed discussion of the surface hydrology, see Chapter 2. This chapter will only discuss the surface hydrology as it relates to the groundwater hydrology.

The Sprague and Williamson Rivers drain the Modoc Plateau portion of the upper Klamath Basin (KB) and merge some 10 river miles upstream of, and discharge into, Upper Klamath Lake (UKL). The Klamath River is generally considered to begin at the point of outflow from UKL (Gannett, et al, 2010). The KB is often divided into an upper and lower basin. The boundary between the upper and lower basin has variously been placed near Keno, Oregon or at Iron Gate Dam in California. Placing the boundary near Keno establishes the boundary at the point where the river crosses the transition zone from the relatively flat valleys of the Modoc Plateau Province to the more mountainous terrain of the High Cascades sub-province (Figure 3-1 and Figure 3-2). When placed at Iron Gate dam (Gannett, et al, 2010), the boundary would roughly coincide with where the Klamath River crosses the transition from the Cascade Volcanics Province (including the High Cascade and Western Cascade sub-provinces) to the Klamath Mountains Province (Figure 3-1 and Figure 3-2). This location also corresponds roughly to where the predominantly permeable volcanic terrain of the Cascade Volcanics Province transitions to older, less permeable rocks of the Klamath Mountains Province (Gannett, et al, 2010). By placing the boundary at Iron Gate Dam, the upper basin would include Reclamation's Klamath Project. The convention of placing the boundary between the upper and lower basins at Iron Gate Dam is followed in this chapter.

3.5.2. GROUNDWATER HYDROLOGY

Newcomb and Hart (1958) conducted the earliest investigation into the water resources of the Klamath Basin. The goals of the investigation were three-fold:

1. Recognition and inventory of the ground-water contributions to the surface water in the Klamath Basin and any significant diversions of surface water to the ground-water reservoirs, as well as significant diversions of water from or into the basin through percolation of ground water.

2. Recognition of the principal factors governing the ground-water regime and the water resources available for development.

3. Collection of geologic and hydrologic information pertinent to the development and use of the groundwater resources.

Accordingly, they summarized the primary factors that would influence a water budget including but not limited to: physiography of the basin, rocks composing the basin, surface water drainage, groundwater, population and settlement patterns, vegetation, climate, and geologic setting.
In terms of the hydrologic regime, they described the characteristics of the aquifers. They essentially had four aquifer types; 1) the lower lava rocks, 2) the upper lava rocks, 3) alluvium of Quaternary age, and 4) pumice of Quaternary age. As part of their database, they collected data on many of the springs and wells in the study area and indicated that the ". . . *regional body of ground water*

has a water level near the local base level of the major streams. Although this ground-water body is a single hydrologic unit, interstream divides separate it into four main segments which are treated below as hydrologic subunits. The areas constituting these subunits are (1) the Klamath Marsh area, (2) the Sprague River valley, (3) the Cascade Mountain slope south of Annie Creek valley, and (4) the valleys of the Lost River drainage system in Oregon."

Newcomb and Hart identified the source of the large springs as the upper and lower lava rocks and the pumice of Quaternary age – in the sense that the springs emerge from these units ". . . *where they are exposed at the land surface by faults, erosion, or other geologic conditions*." They also state ". . . *considerable flow is added to the Klamath River from numeroud spring in a 9 mile stretch of the river canyon below the Highway 66 bridge . . . undoubtedly many more springs occur in the river bed, where permeable water-bearing zones of the lower lava rock have been cut through be the canyon. Below that reach the river cuts into older rocks that are practically impermeable; therefore, little or no ground water is believed to enter the river in Oregon downstream from sec. 3, T. 41 S., R. 6 E.*" The Highway 66 Bridge is just upstream of J.C. Boyle Dam – which was completed in 1958. Sec. 3, T. 41 S., R. 6 E. is about four river miles downstream of the stretch of river known as 'Long Point' and roughly 3.5 river miles upstream of the Oregon-California border and so would be well upstream of Copco 1 & 2 Dams. Although the authors mention springs in the Klamath River in the reach known as Klamath River Gorge, they do not report any locations or flows for those springs. Likewise, none of the wells that they used for water level measurements were within the Klamath River Gorge downstream of Keno Dam. With the exception of a few wells in and around Keno, there were only two wells 'downstream' of Keno. One was about 1 mile north of the river near Oatman Lake and the other was about 3 miles south of the river just east of Chase Mountain. It would be unlikely that there would be much development around what would become J.C. Boyle Reservoir in 1954 when they collected their water level readings from wells as the dam was just not put into operation until 1958.

Gannett, et al, (2010) completed the first extensive investigation of the groundwater resources in the Upper Klamath Basin. The study area for Gannett, et al. included the entire Upper Klamath Basin above Iron Gate Dam in California (Figure 3-6). As described previously the volcanics in the Klamath River Gorge between Keno and Iron Gate Dams can be divided into many units based on their ages, composition, and style of eruption and/or deposition. That is all well and good for the geochemist or straight geologist – but to understand the hydrologic processes at work in the area, the hydrologic properties of the materials must be identified. Geologic units need to be regrouped according to their hydrologic properties – regardless of their geochemical, age, and/or depositional characteristics. Materials with vastly different characteristics can, and often do, have similar hydrologic properties. Gannett, et al. generalized the many distinct and mappable geologic units in the Upper Klamath Basin into eight hydrogeologic units as shown in Figure 3-7. Figure 3-7a is an enlargement of the area of the Klamath River downstream to Iron Gate Dam and significantly south of the Oregon-California border. The explanation of the map units is given in Figure 3-7b.

Table 3-1. Generalized hydrogeologic units in the upper Klamath Basin, Oregon and California (after Gannett, et al, 2010, Table 1, pg 12).

Hydrogeo-logic unit	Map symbol	Lithologic and hydrologic characteristics
Quaternary sedimentary deposits	Qs	Fine- to coarse-grained sediments deposited in stream valleys and major lake basins. Permeable coarse-grained deposits occur in stream valleys and locally in the lake basins. The lake basin deposits are, however, predominantly fine grained and have low permeability.
Quaternary volcaniclastic deposits	Qvp	Pyroclastic flows and air fall material (pumice, ash, and lapilli) deposited during the climactic eruption of Mt. Mazama that formed Crater Lake, and debris avalanche deposits of the Shasta River Valley. Air fall deposits are highly permeable. Pyroclastic flows and debris deposits may have low permeability.
Quaternary volcanic rocks	Qv	Basaltic and andesitic lavas and vent deposits occurring in the Cascade Range and around Medicine Lake Volcano. These materials are generally highly permeable, but may not be saturated at high elevations.
Quaternary to late Tertiary sedimentary rocks	QTs	Fine- to coarse-grained unconsolidated to moderately indurated sedimentary deposits. The hydraulic characteristics of this unit are not well known but lithologic descriptions on maps suggest it may be moderately permeable at some locations. This unit has very limited distribution.
Late Tertiary sedimentary rocks	Ts	Predominately fine-grained continental sedimentary deposits including bedded diatomite, mudstone, siltstone, and sandstone. This unit has generally low permeability but contains permeable strata at some locations.
Late Tertiary volcaniclastic rocks	Tvpt	Palagonitized basaltic ash and lapilli deposits associated with eruptive centers. The hydrologic characteristics of this unit are not well known, but springs are known to emerge from basal contact with unit Ts. This unit is most prominent in the Sprague River valley.
Late Tertiary volcanic rocks	Tv	Predominantly basaltic and andesitic lava flows and vent deposits with lesser amounts of silicic domes and flows. This unit has moderate to high permeability and is by far the most widely developed aquifer unit in the study area. Permeability is locally diminished by hydrothermal alteration and secondary mineralization.
Older Tertiary volcanic and sedimentary rocks	Tovs	Miocene and older volcanic and volcaniclastic deposits. The permeability of this unit is generally low due to weathering, hydrothermal alteration, and secondary mineralization. This unit is generally considered a boundary to the regional ground-water system of the upper Klamath Basin.

Gannett, et al (2010) further described the hydrogeologic units as:

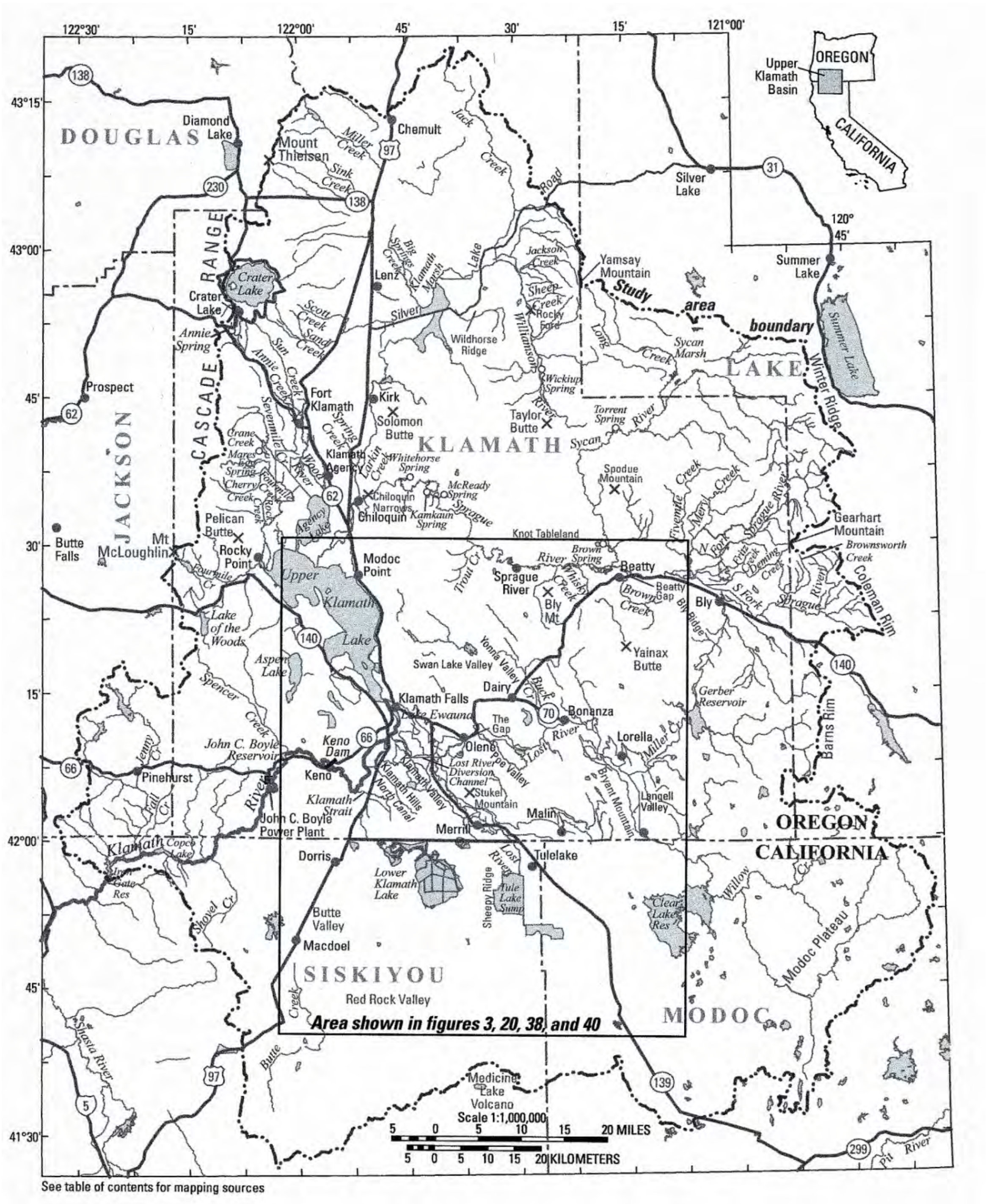
> *Early to mid-Tertiary volcanics and sediments (Tovs), the oldest hydrogeologic unit in the study area, comprises Miocene and older lava and volcaniclastic rocks of the Western Cascade subprovince along the western margin of the study area, as well as older volcanic deposits beneath late Tertiary lavas along the eastern margin. The unit also includes older rocks exposed in the Pit River Basin southeast of the study area. The permeability of this unit is generally low due to weathering, hydrothermal alteration, and secondary mineralization. This unit is herein considered a boundary to the regional ground-water system of the upper Klamath Basin.*
>
> *Late Tertiary volcaniclastic deposits (Tvpt) include palagonitized basaltic ash and lapilli deposits associated with eruptive centers. The hydrologic characteristics of this unit are not well known, but springs emerge from basal contact with unit Ts. This unit is most prominent in the Sprague River Valley.*
>
> *Late Tertiary sedimentary rocks (Ts) consist predominately of fine-grained continental sedimentary deposits that include bedded diatomite, mudstone, siltstone, and sandstone. This unit has generally low permeability. These deposits occur throughout the central part of the upper Klamath Basin. They are exposed in uplands in interior parts of the basin and penetrated by wells in the river valleys. Lithologic logs of wells in the Sprague River Valley indicate that the thickness of these sedimentary deposits there locally exceeds 1,500 ft.*
>
> *Late Tertiary volcanic rocks (Tv) consist predominately of basaltic and andesitic lava flows and vent deposits, but the unit includes local silicic domes and flows. This unit is locally affected by hydrothermal alteration and secondary mineralization. This is the most geographically extensive hydrogeologic unit, occurring throughout most of the upper Klamath Basin. The unit has moderate to high permeability and is by far the most widely developed aquifer unit in the study area.*
>
> *Quaternary to late Tertiary sedimentary rocks (QTs) consist of medium- to coarse-grained unconsolidated to moderately indurated sedimentary deposits. The hydraulic characteristics of this unit are not well known, but lithologic descriptions on maps suggest that it is moderately permeable at some locations. This unit occurs locally in the western Wood River Valley, south of Klamath Falls, and in the uppermost Williamson River sub-basin.*
>
> *Quaternary volcanics (Qv) consist primarily of basaltic and andesitic lavas and vent deposits occurring in the Cascade Range and around Medicine Lake Volcano. These materials are generally highly permeable.*

> *Quaternary volcaniclastic deposits (Qvp) consist primarily of pyroclastic flows and air-fall material (pumice ash and lapilli) deposited during the climactic eruption of Mt. Mazama that formed the caldera encompassing Crater Lake. This unit is most extensive in the Cascade Range around Crater Lake and in the upper Williamson River sub-basin. As mapped (fig. 4), the unit also includes debris avalanche deposits in the Shasta River Valley outside of the study area. Minor Quaternary pyroclastic deposits occur on Medicine Lake Volcano and in Butte Valley. Air-fall deposits are highly permeable.*
>
> *Quaternary sediments (Qs) include the alluvial deposits in principal stream valleys, glacial deposits in the Cascade Range, and basin-filling sediments in the major lake basins. The basin-filling deposits are generally fine grained and have low permeability. Coarse facies occur at some locations within the basin-filling deposits.*

Hydrogeologic unit descriptions from three sub-basins of the UKB (all within the Modoc Plateau Province) – Tule Lake, Lower Klamath Lake sub-basins, and the Butte Valley basin – have very similar descriptions (California Department of Water Resources, California Groundwater, Bulletin 118, 2004a, 2004b, 2004c) and are also similar to the descriptions of Gannett, et al. The principal water-bearing formations in the Tule Lake sub-basin include Tertiary to Quaternary lake deposits and volcanic. The principal water-bearing formations in the Lower Klamath Lake sub-basin include Quaternary alluvium, Tertiary sediments, Tertiary deposits of diatomite, and Tertiary to Quaternary lake deposits and volcanics. The principal water-bearing formations in the Butte Valley basin are Pleistocene to Holocene age alluvial fan, lake deposits, pyroclastic rocks, and Butte Valley Basalt, and Pliocene to Pleistocene volcanic rocks of the “High Cascades”. The water-bearing units and the wider spread confining units are summarized in Table 3-2. For a more detailed description of the units in the three sub-basins, the reader is referred to Bulletin 118.

Table 3-2. Summary of water-bearing and major confining units in the Tule Lake and Lower Klamath Lake sub-basins, and the Butte Valley Basin (after California Department of Water Resources, California Groundwater, Bulletin 118, 2004).

Period		Tule Lake Sub-Basin 1-2.01		Lower Klamath Lake Sub-Basin 1-2.02			Butte Valley Sub-Basin 1-3			
Holocene	Late		Lake Deposits: consist of sand, silt, clay, ash, lenses of diatomaceous earth, and semi-consolidated shale; poorly sorted, very low permeability	Upper Basalt : vesicular olivine flows; extensive fracturing, generally highly permeable	Quaternary Alluvium: consists of gravel, sand, clay, soil, and loess; moderately permeable			Pyroclastic Rock: typically well consolidated, massive to thin-bedded lapilli tuffs and cindery tuff breccias, generally cross-bedded, include abundant fragments of basalt and scoria	Alluvial Fan Deposits: poorly-sorted volcanic rock debris, cobbles, gravel, sand, and clay from Cascade Range; interfingers with lake deposits at depth	Lake Deposits: consist of sand, silt, clay, ash, lenses of diatomaceous earth, and local stringers of gravelly sand; highly variable permeabilities
	Early					Lake Deposits: consist of sand, silt, clay, ash, lenses of diatomaceous earth, and semi-consolidated shale; poorly sorted, very low permeability	Butte Valley Basalt: uniform sheet of vesicular basalt, highly permeable, interfingers with and overlies lakebed deposits			
Pleistocene	Late	Upper Basalt: unweathered, vesicular, olivine basalt; extensive fracturing, generally highly permeable		Intermediate Basalt: thin-bedded flows of diabasic olivine basalt; interfingers with lakebed deposits, columnar jointing, highly permeable						
	Early	Intermediate Basalt: thin-bedded flows of diabasic olivine basalt; interfingers with lake bed deposits, columnar jointing, highly permeable					High Cascade Volcanics: successive sheet of basalt, basaltic andesite, discontinuous layers of massive basaltic tuff and tuff breccias, some isolated lapilli tuff and cinder cones deposits			
Pliocene	Late	Lower Basalt: ophitic olivine basalt to porphyritic basalt, weakly jointed and fractured, highly permeable		Lower Basalt: ophitic olivine basalt to porphyritic basalt, weakly jointed and fractured, highly permeable	Diatomite: often includes interbedded sand, tuff breccia, volcanic ash; generally confining unit					
	Early				Continental Sediments: consist of clay, diatomaceous earth, interbedded fluvial sediments; may include the diatomite deposits					
Miocene	Late									
	Middle									
	Early									



See table of contents for mapping sources

Figure 3-6. Gannett, et al, 2010 study area. Original report dated 2007, revised in 2010.

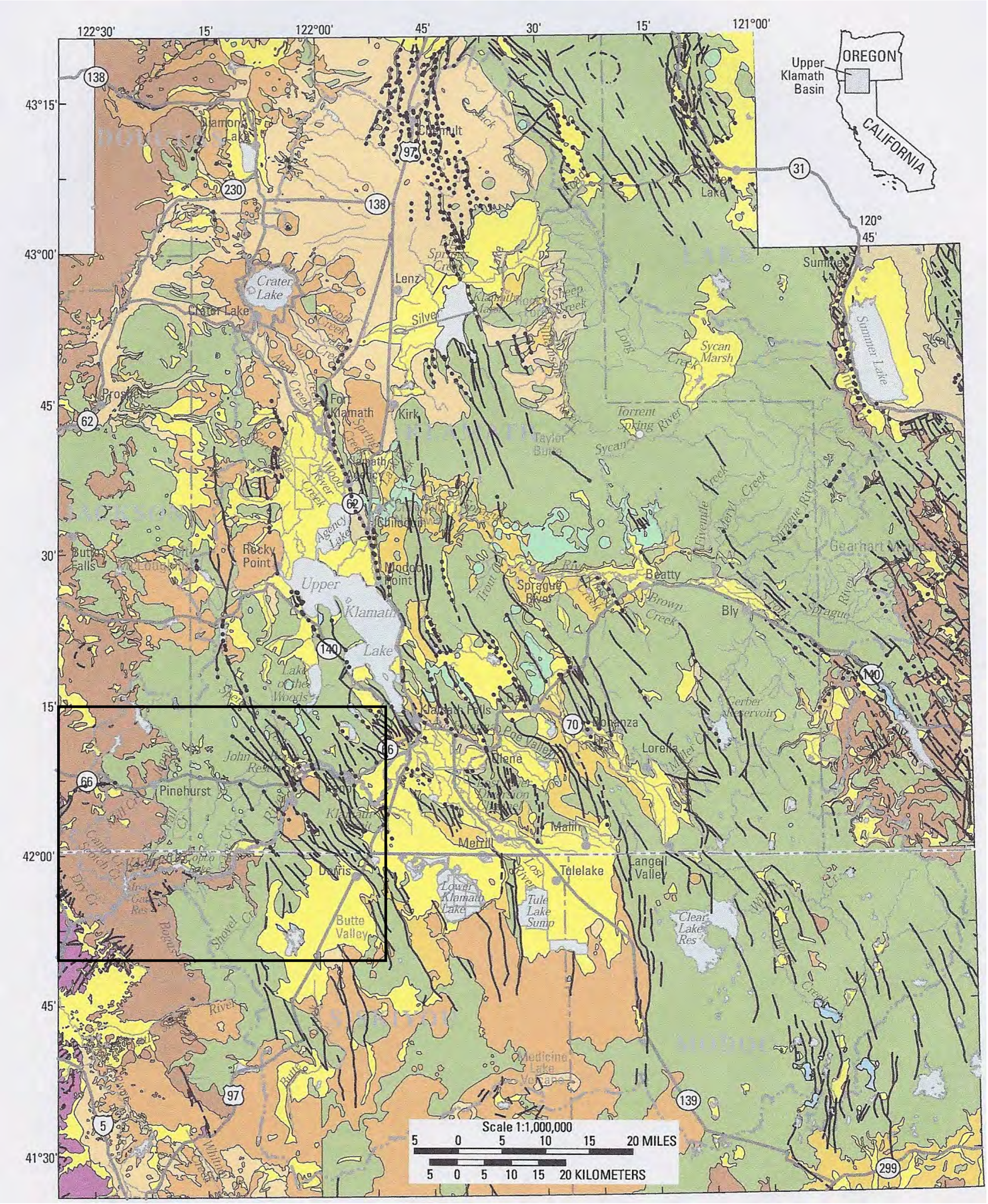


Figure 3-7. Hydrogeologic units of the Upper Klamath Basin, Oregon and California. Boxed area shown enlarged in Figure 3-7a. (after Gannett, et al., 2020, Figure 4).

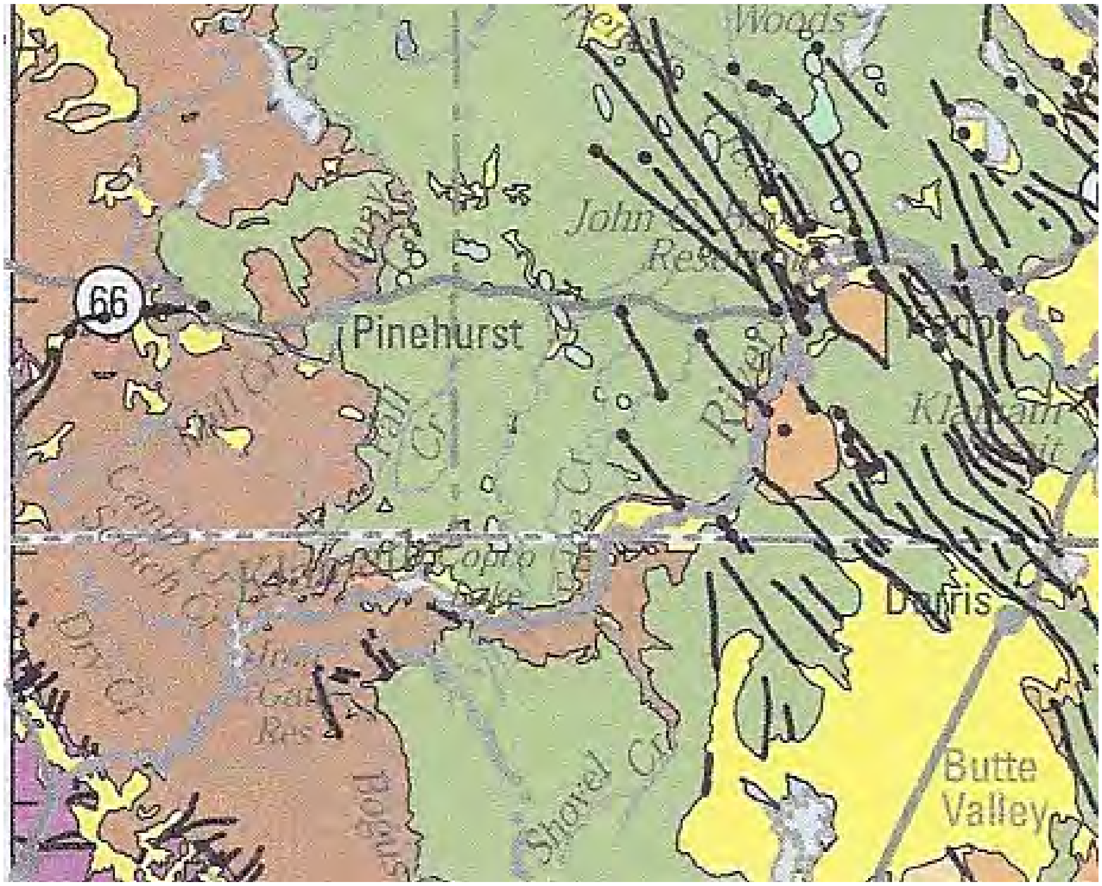
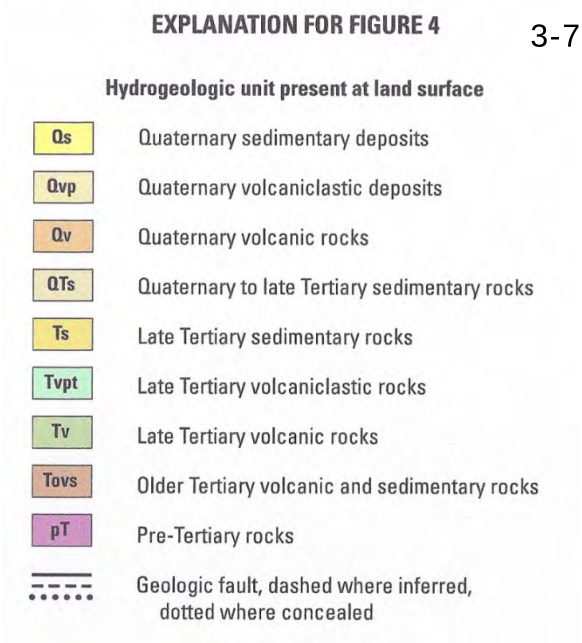


Figure 3-7a. Enlarged image of the hydrogeological units from above Keno Dam to below Iron Gate Dam. (after Gannett, et al, 2010, Figure 4).



EXPLANATION FOR FIGURE 4 3-7

Hydrogeologic unit present at land surface

Qs	Quaternary sedimentary deposits
Qvp	Quaternary volcaniclastic deposits
Qv	Quaternary volcanic rocks
QTs	Quaternary to late Tertiary sedimentary rocks
Ts	Late Tertiary sedimentary rocks
Tvpt	Late Tertiary volcaniclastic rocks
Tv	Late Tertiary volcanic rocks
Tovs	Older Tertiary volcanic and sedimentary rocks
pT	Pre-Tertiary rocks
---- ●●●●●●	Geologic fault, dashed where inferred, dotted where concealed

Figure 3-7b. Hydrogeologic Unit descriptions for Figure 3-7 and Figure 3-7a.

3.6. Existing Groundwater Conditions

3.6.1. REGIONAL GROUNDWATER CONDITIONS

The project area has few wells that completely characterize groundwater conditions. Gannett, et al, made the first regional attempt to estimate water level gradients and flow patterns in the Upper Klamath Basin – including the area of the Klamath River upstream and downstream of the three dam sites. Figure 3-8 and Figure 3-8a show a generalized groundwater map for the UKB and portions of the LKB. Figure 3-8a indicates that the regional groundwater flow patterns along the Klamath River downstream of Keno Dam are generally from the higher elevations (upland areas, mountain ranges, hills, etc.) toward the Klamath River, and from Keno Dam toward Iron Gate Dam. Gradients are steepest between the Mount Shasta uplands and the Klamath River. Figure 3-8a indicates that there is a possible groundwater divide running NNE-SSW thorough the area at about the Keno Dam. Gradients off the upland between Keno and UKL would trend towards the SE while gradients to the south of Keno coming off the mountain front along the west side of Butte Valley are trending towards the NE. If this groundwater divide exists, it would suggest that groundwater flow from the Modoc Plateau volcanics in Klamath Valley may be limited or restricted and that the hydrogeologic regime in the Modoc Plateau may not have a significant impact on the groundwater regime of the Klamath River as it flows through the Cascade Volcanics Province.

USGS Topographic 7-1/2 minute quadrangles around the reservoirs (Iron Gate and Copco Quadrangles in California, and Spencer Creek and Chicken Hills Quadrangles in Oregon) show varying numbers of springs on both sides of the reservoirs. The Iron Gate Quadrangle shows numerous springs all around Iron Gate reservoir ranging from several 10’s of feet to over 300 feet above the reservoir level. The Copco Quadrangle shows fewer springs around Copco reservoir – but the ones that are shown are again several 10’s of feet to over 800 feet above the reservoir level. Additionally, a number of the small drainages that empty into Copco reservoir have a spring at the headwater of the drainage. The Spencer Creek and Chicken Hills Quadrangles show very few springs in the vicinity of J.C. Boyle reservoir and those that are shown are only a few 10’s of feet above the reservoir level. However, many of the small drainages the empty into JCB reservoir have a spring at the headwater of the drainage (e.g., Spencer Creek (Gannett, et al., 2010). The presence of many springs in the area of the dam sites suggests local groundwater systems, and possibly a regional groundwater system, that are not receiving water from the reservoirs, or at least not directly. The water discharging from the springs above the reservoir levels is obviously not reservoir water. The flows from the springs and the location of the springs could be influenced indirectly by the presence of a reservoir in that the reservoir creates a local base line that in effect would ‘back up’ the groundwater upgradient of the reservoirs. This could result in a mounding effect near the reservoir that ‘artificially’ raises the groundwater levels in the local area to the point where spring flow increases, or new springs are created. Whether the spring systems are hydraulically connected to the reservoir is uncertain, but such a connection is a real possibility.

A spring complex about one mile below J.C. Boyle Dam contributes substantial flow to the River Gannett, et al., 2010). The water discharging at this site could be coming from the local groundwater system, or it could be influenced by seepage from the reservoir that is going around or under the dam and coming to the surface at the spring site. Probably, in this case, the flows from this spring complex are influenced by both the local groundwater system as well as leakage from the reservoir.

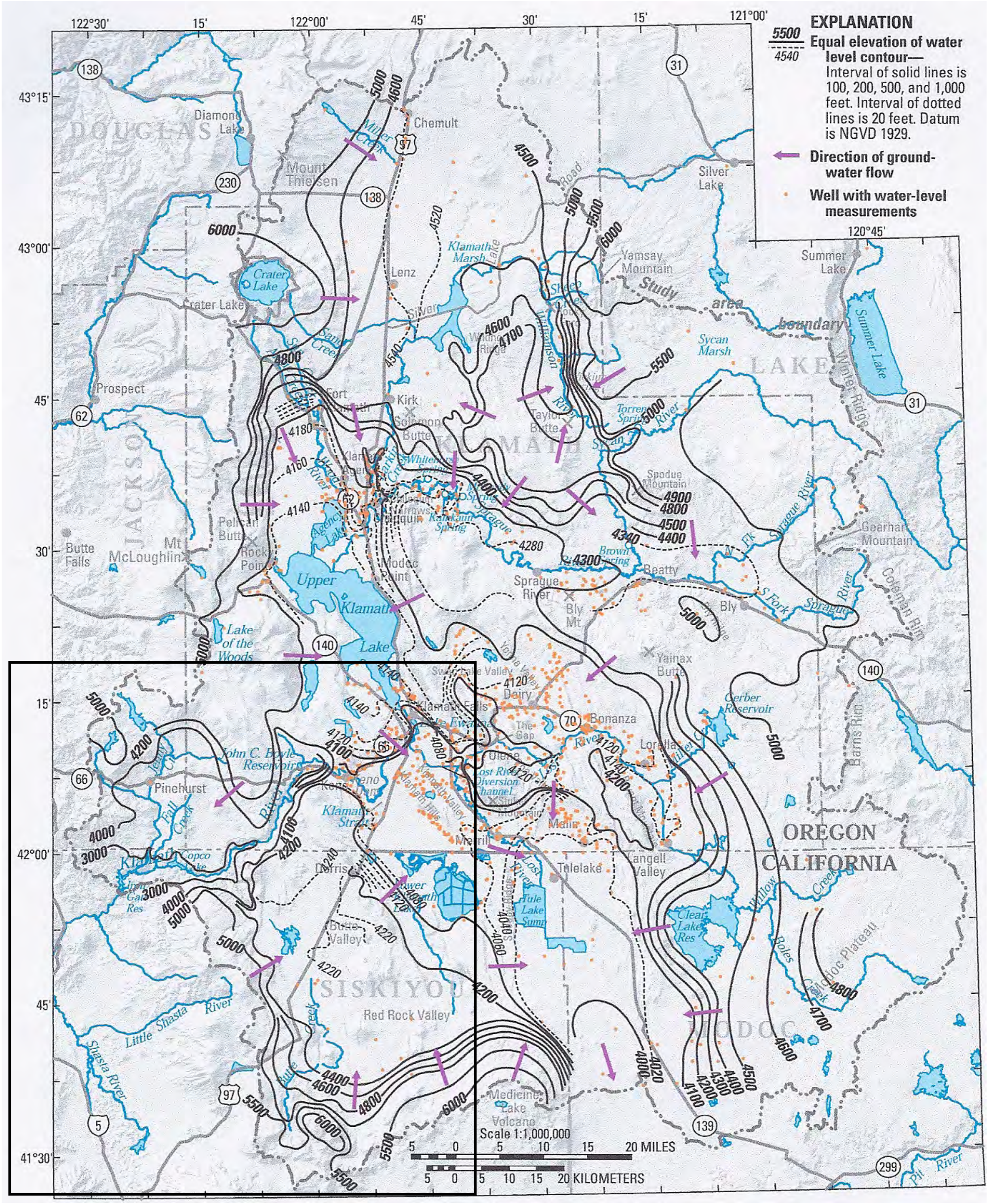


Figure 3-8. Generalized water-level contours and associated directions of regional groundwater flow patterns for the Upper Klamath Basin of Oregon and California. Box shows area enlarged in Figure 3-8a. (after Gannett, et al., 2010, Figure 21)

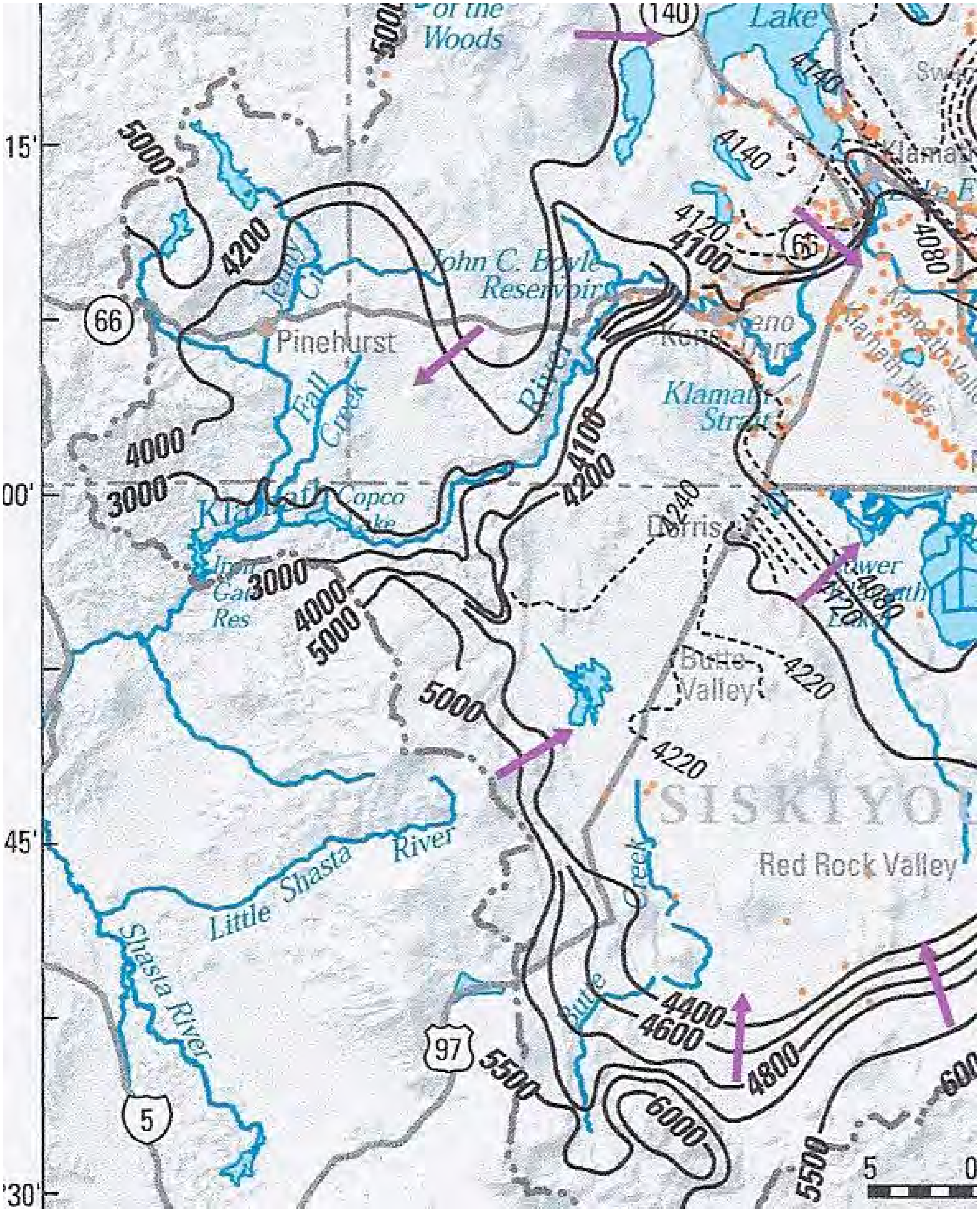


Figure 3-8a. Enlarged area of Figure 3-8 showing the generalized water-level contours and associated flow patterns in the vicinity of the three dam sites. (modified from Gannett, et al, 2010, Figure 21).

3.6.2. SOURCES OF GROUNDWATER IN THE PROJECT AREA

The lack of wells makes characterizing groundwater sources in the project area difficult. Groundwater in the project area is likely fed by percolation of precipitation through the surface materials to the bedrock units. As Figure 3-7a and Figure 3-7b show, groundwater at a regional scale appears to flow into the project area from upland areas toward the Klamath River and the reservoirs. Local groundwater in the project area is also fed by groundwater underflow from these upgradient areas. In the absence of barriers to vertical flow, surface water infiltration is a common source of recharge to groundwater systems. Rivers, lakes and other surface water bodies are common sources of site specific infiltration recharge. Areal precipitation is more of a dispersed, wide extent source of infiltration recharge. Given a regional groundwater flow direction toward the river and reservoirs in the project area, river reaches are more likely receiving water from the groundwater systems than they are losing water to the groundwater systems, while reservoirs are more likely to lose water to the groundwater. However, given the right conditions, the reservoirs could be gaining water from the groundwater system(s).

A large groundwater flow system exists in the Upper Klamath Basin (Gannett et al., 2010). Groundwater is recharged in areas in the Cascade Range and upland areas surrounding the basin. Groundwater flows from these areas toward the interior of the basin and subbasins (Figure 3-7a). Many of the streams in the interior of the basin are at least partially fed by groundwater discharge (Gannett et al., 2010). Some streams are fed predominately by groundwater (baseflow) at a consistent rate throughout the year.

3.6.3. GROUNDWATER SINKS IN THE PROJECT AREA

Locations where the bedrock comes into contact with surface water (e.g., rivers, streams, and reservoirs) can be sinks of groundwater to the surface water system if the surface water level is below the groundwater level. Gannett et al. 2010 estimates that groundwater adjacent to the Klamath River discharges to the river in the project area. The USGS estimates an average groundwater discharge of 190 cfs for the reach from Keno Dam to downstream of the J.C. Boyle Powerhouse and 92 cfs for the reach from there downstream to Iron Gate Dam. Based on gage data and changes in reservoir storage, these estimates are calculated for the length of each of these reaches and may include some ungaged tributary inflows.

Groundwater pumping is also a typical groundwater sink in the area. Domestic and some limited amount of irrigation use in the area are the primary uses of pumped groundwater in the project area. Most domestic wells around the reservoirs are probably seasonal residences (owner’s official address is different than the well location address) and are not expected to be a major groundwater sink in the project area. Average well yields in Siskiyou County, CA are just over 19 gpm while in Klamath County, OR the average yield is just over 22 gpm. Based on completion dates on well logs filed with Siskiyou County, an average of

5 new wells per year have been installed in the project area since 1963 (Figure 3-9). In Klamath County the average is about 3 new wells per year since 1976, including the area around Keno and Keno Dam, OR.

Groundwater is used in the Upper Basin to irrigate agricultural land. Groundwater is used as a primary source of irrigation water where surface water is not available and also as a supplemental source when surface supplies are limited (Gannett et al., 2010).

The USGS states that groundwater levels vary in response to both climatic and pumping conditions. Climatic variations can vary the groundwater level by five feet within the basin Gannett, et al., 2010). The typical drawdown and recovery cycles caused by groundwater pumping can be from one to ten feet Gannett, et al., 2010). Groundwater use in the Upper Basin has increased by 50 percent since 2001 Gannett, et al., 2010) primarily in the area surrounding Reclamation's Klamath Project. The increase in pumping has resulted in groundwater levels dropping 10 to 15 feet in portions of this area between 2001 and 2004 Gannett, et al., 2010)**.**

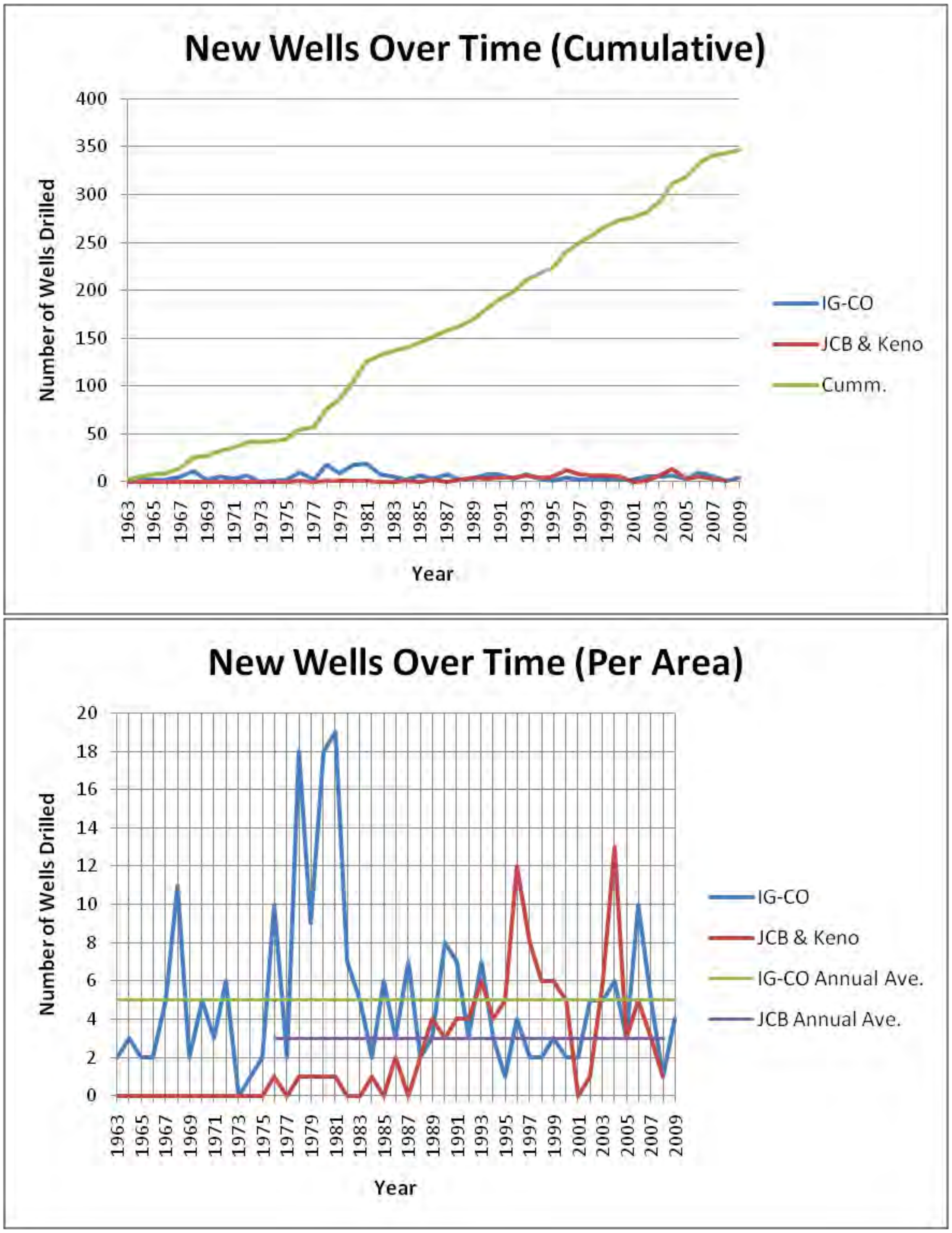


Figure 3-9. Cumulative and Times Series Graphs of new wells over time, by Reservoir based on well logs filed with Oregon and California.

3.6.4. LOCAL GROUNDWATER CONDITIONS

The California DWR *Bulletin 118 – Update 2003, California's Groundwater,* delineates 515 groundwater basins and subbasins throughout the state (DWR 2003). The area of analysis for the Proposed Action and alternatives does not fall within one of these delineated basins. The area is defined as a "groundwater source area" by the California DWR. A "groundwater source area" is "rocks that are significant in terms of being local groundwater sources, but do not fit the [typical] category of basin or subbasin" (DWR 2003). The Klamath River from the Oregon-California Stateline to downstream from Iron Gate Dam is a predominantly non-alluvial river flowing through mountainous terrain. Downstream from the Iron Gate Dam and for most of the river's length to the Pacific Ocean, the river maintains a relatively steep, high-energy, coarse-grained channel frequently confined by bedrock.

A search of wells in the databases of both the Oregon Water Resources Department and the California DWR retrieved well logs for known wells within several miles upstream and downstream of J.C. Boyle, Copco, and Iron Gate Reservoirs. Some of the well logs recorded the static water level at the time the well was completed, and a few logs recorded the well's estimated yield following completion. The drill logs are given in Appendix I. Drill Logs of Groundwater Wells near PacifiCorp Reservoirs.

Of all the retrieved logs for wells within several miles of any part of any of the three reservoirs roughly 83% (percent) of the logs (300 out of 360 logs) had sufficient information to be able to identify with a reasonable amount of certainty where those wells were physically located in relation to the reservoirs. Of the 300 logs where reasonable coordinates could be determined, only 63 were within 2.5 miles of one or more of the three reservoirs – as described below (Figure 3-10). 'Reliable' locations were obtained by comparing physical addresses on the driller logs against GoogleEarth© images of the regions to match an address with the image. When matches were obtained, the coordinates of the property were recorded from GoogleEarth©. When no physical address was included on the driller's log, location maps (if included) were used to locate the property in the same manner – by comparing the location map against the GoogleEarth images. In the absence of both a physical address and a location map, County tax roles were used to match owner's names on the well logs to obtain physical addresses or County/Developer's plat maps. All the data on the well logs were transferred to Excel spreadsheets which were then imported into ARCGIS and georeferenced.

Using the local topography, reservoir bathymetry, and lithologic descriptions on the well logs, representative cross-sections across various spans of the reservoirs were created such that each cross-section intersected at least one known well location. The cross-sections are presented under the discussion of each reservoir below. Each cross-section displays the topography, water surface elevation of the reservoir, well log ID, abbreviated well log lithology, and the static water level in the well. The water-bearing units in each well are presented in summary tables for each reservoir.

The discussions of potential or possible impacts to the local wells from the proposed action are predicated on the concept that in order to be impacted, the water-bearing unit that each well is tapping must be hydraulically connected to the reservoir – either by having the water-bearing unit daylighting within the reservoir walls or being hydraulically connected to the reservoir through a series of permeable layers between the reservoir and the water-bearing unit.

The potential for impacts to the wells is further predicated on the relative elevation differences between the static water level in the well(s) and the nominal surface elevation of the reservoir. Specifically, since the majority of units in the project area are relatively flat-laying, if the water-bearing unit being tapped by any given well is in hydraulic connection with a reservoir, then the static water level in the well should be similar or close to the water surface elevation in the reservoir. If the static water level is substantially higher or lower than the reservoir level, then it is likely that the water-bearing unit is reflecting a regional or local aquifer flow system as opposed to being influenced by the reservoir. If the water-bearing unit itself is substantially higher than the reservoir water levels, or is substantially deeper than the lowest portion of the reservoir, then it would likely not be in hydraulic connection with the reservoir.

Additionally, given the nature of the flow conditions in the volcanic materials in the region, it is not expected that influences from the reservoir levels would extend laterally very far from the reservoir and the direction in which those influences would likely develop would also be irregular and non uniform spatially.

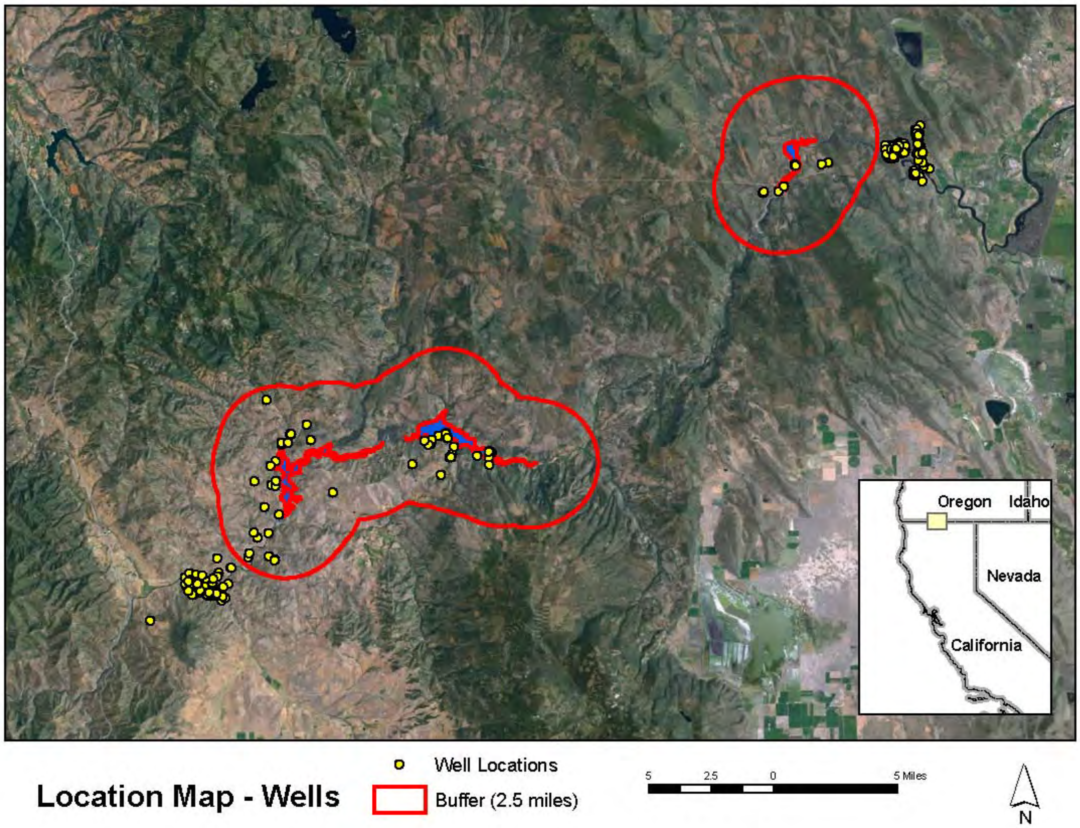


Figure 3-10. Location map showing locations of all the wells retrieved from the Counties' and States' databases of well logs. The red curved line represents a 'buffer zone' that is 2.5 miles from any point on any of the three reservoirs (ARCGIS map image).

3.6.4.1. J.C. Boyle Reservoir

A search of the Oregon Water Resources Department database retrieved 120 well logs around Keno and J.C. Boyle Reservoirs, 50 of which were within 2.5 miles of the reservoir based on T-R-S coordinates. Of those 120 logs, 108 had sufficient information to identify the approximate coordinates of the well, and of those 108 logs, 104 logs had a recorded static water level (SWL). Of the 108 logs, only sixteen were within 2.5 miles of the J.C. Boyle Reservoir (Figure 3-11) and two of those were downstream of the dam and in a tributary drainage basin to the Klamath River. Ten of the sixteen wells were shallow Oregon Department of Transportation borings near bridge footings and were abandoned after drilling. Two of the remaining six wells did not have a recorded SWL. Table 3-3 summarizes the lithology, depth, screened or open interval(s), SWL, and other pertinent data for each of the wells within the 2.5 mile buffer zone for J.C. Boyle Reservoir.

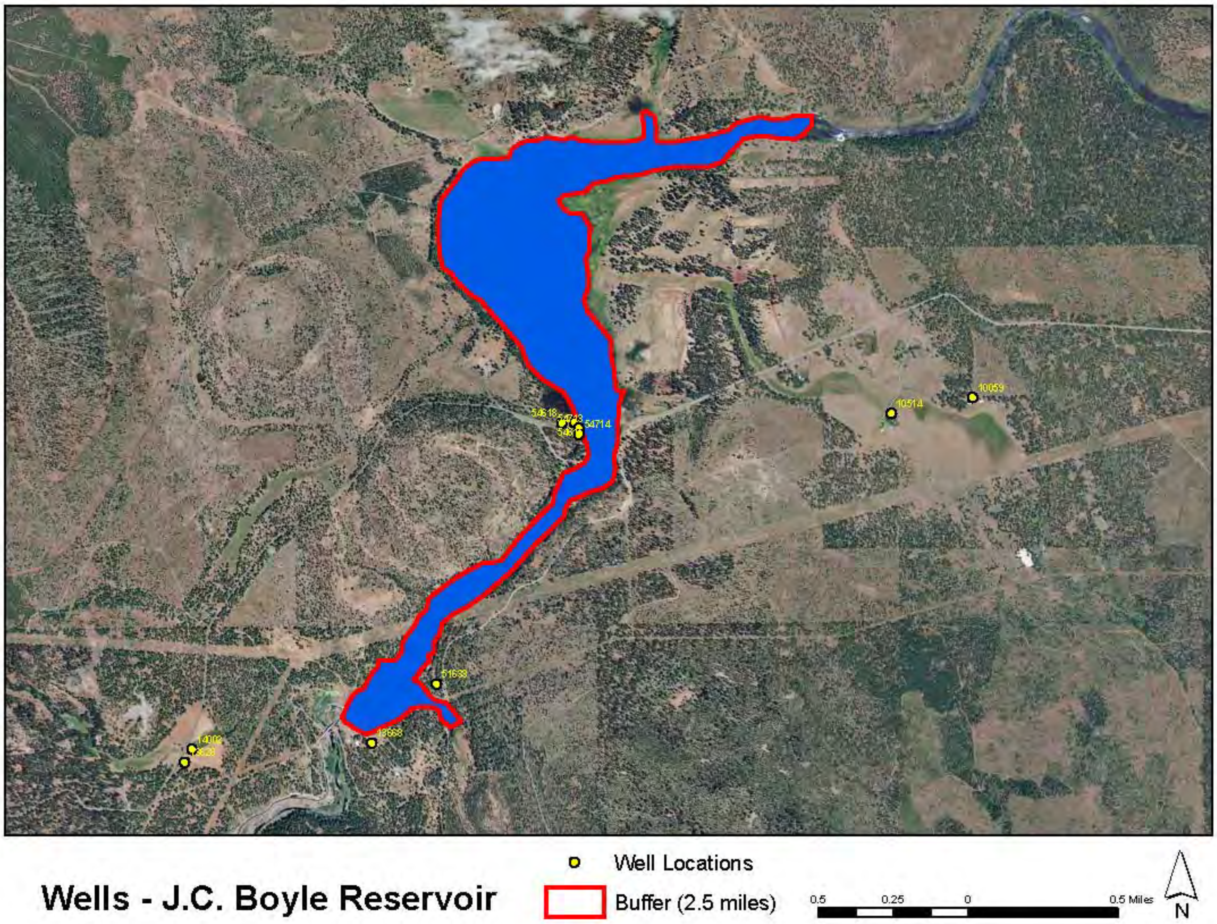


Figure 3-11. Location map showing locatable wells within 2.5 miles of J.C. Boyle Reservoir. Cross-section lines are shown and labeled on Figure 3-12.

Three cross-sections were constructed that intersected at least one of the six wells. These three cross-sections are labeled as J-J’, K-K’, and L-L’ on Figure 3-12 and are shown in Figure 3-13 thru Figure 3-15. The wells within the 2.5 mile zone of J. C. Boyle Reservoir that are along or near a cross-section line are summarized in the following table. In addition to the three cross-sections, a well profile for all the wells within 2.5 miles of J.C. Boyle is shown in Figure 3-16.

As can be seen on the x-sections (Figure 3-13 thru Figure 3-15) and in Table 21-1, the water-bearing units in the wells are below the bottom of the reservoir (3780’, 3750’, and 3690’ respectively) and the SWL in all the wells is 89’ to 106’ below the reservoir water level elevation of 3787’. In Figure 3-16, with the exception of one well that is 30 ft from the reservoir, all the remaining wells have SWLs below the reservoir water level suggesting that the local gradient is away from the reservoir. If the groundwater gradient is away from the reservoir one would expect to see some influence on the near-by wells. Well 54713 is obviously being influenced by the reservoir levels, but by the time the wells are several hundred feet away any signs of a reservoir influence becomes tenuous.

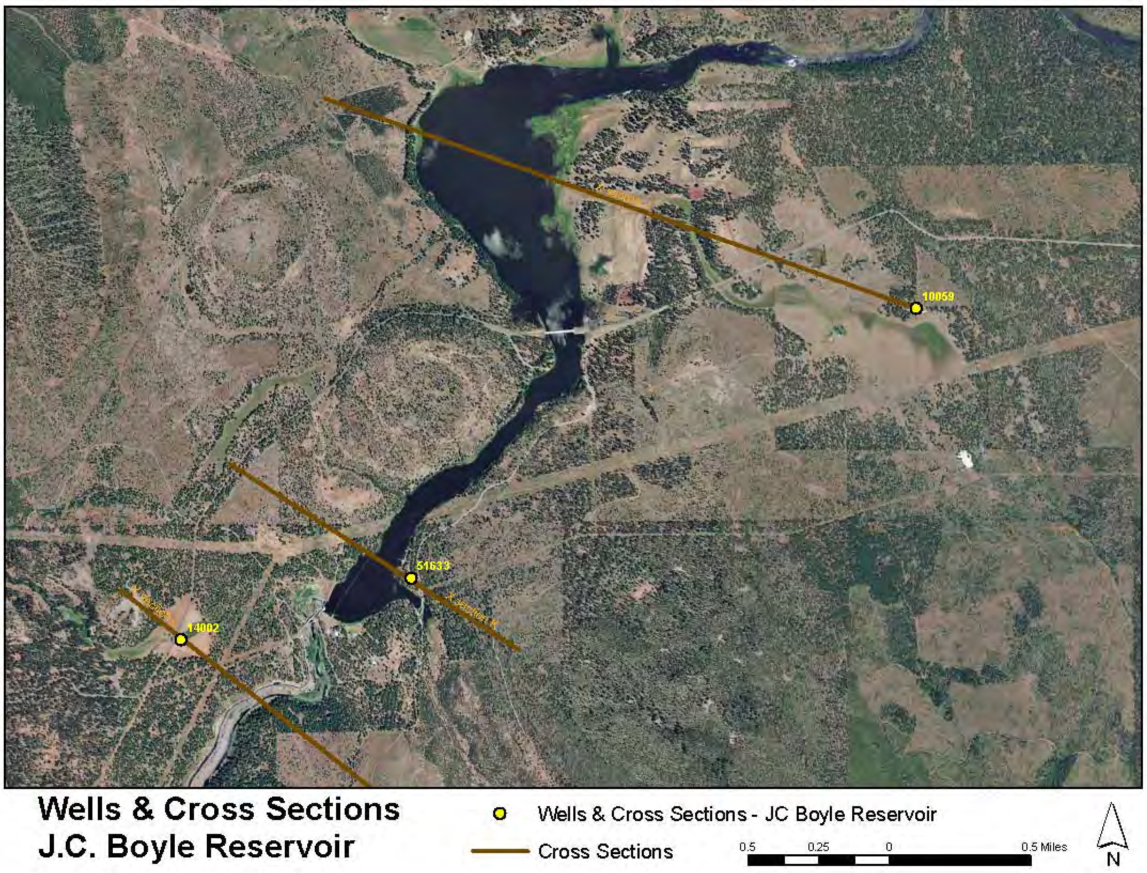


Figure 3-12. Location of cross-sections J – J’, K – K’, and L – L’ on J.C. Boyle Reservoir.

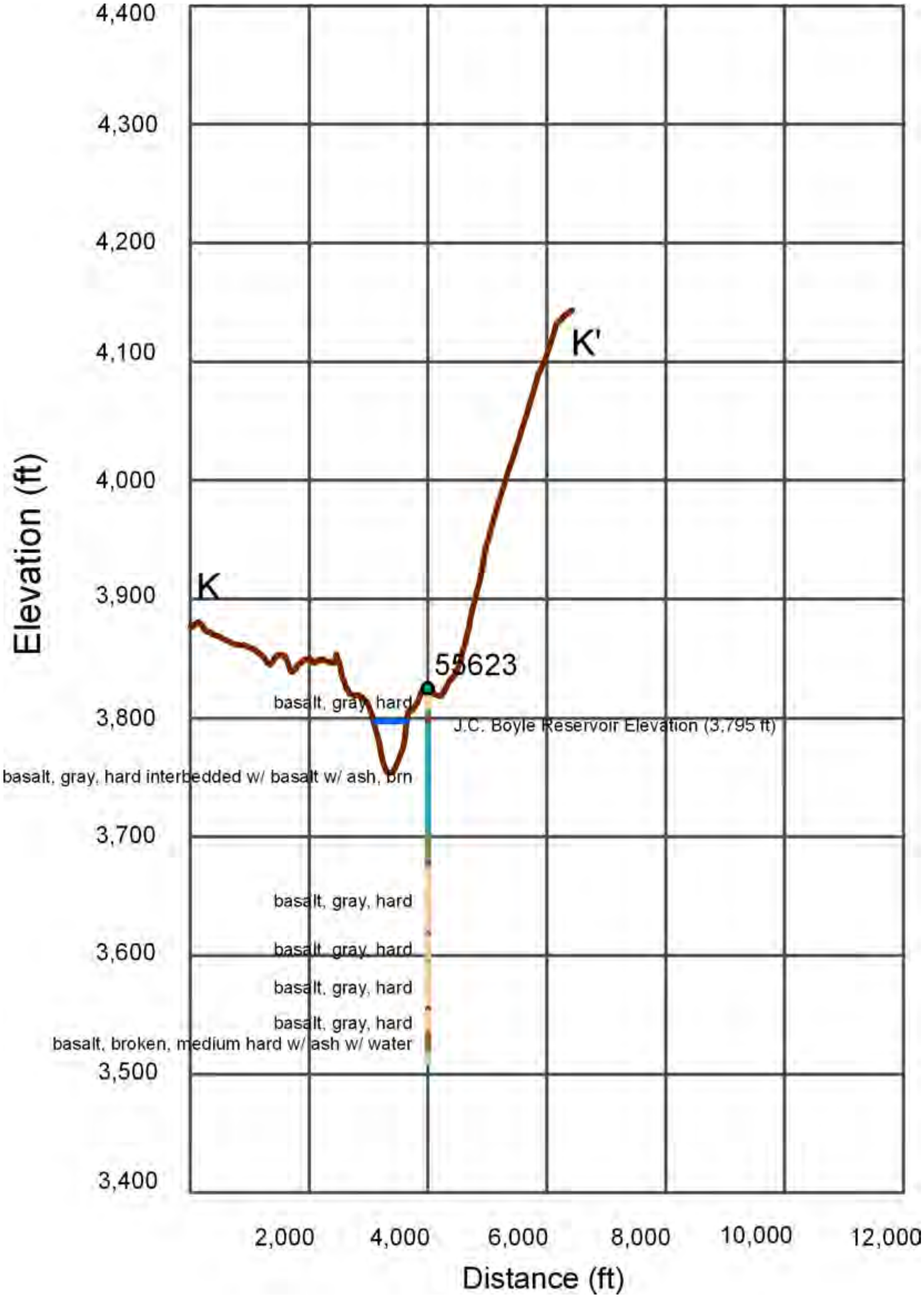


Figure 3-13. Cross section J – J'.

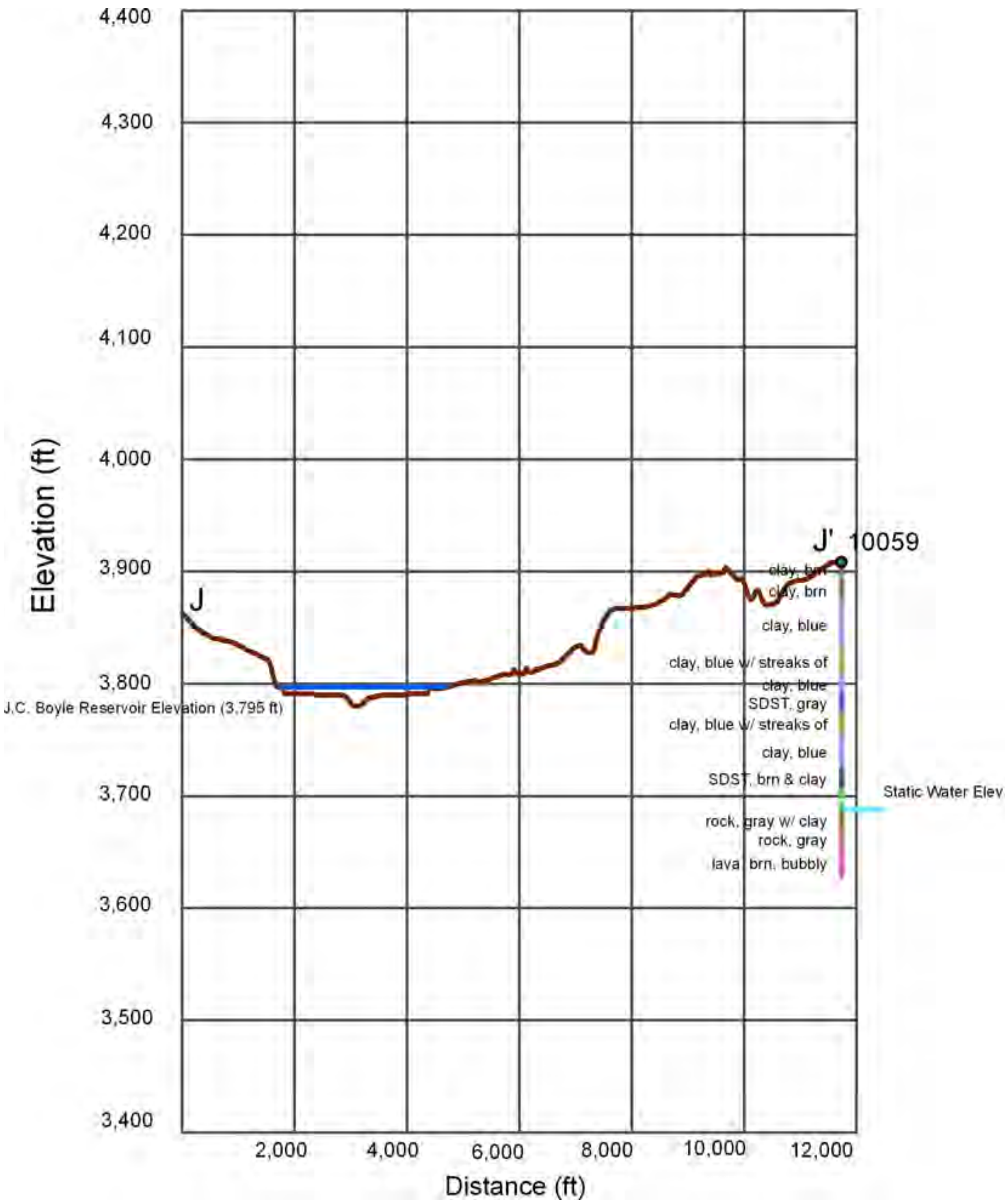


Figure 3-14. Cross-section K – K'.

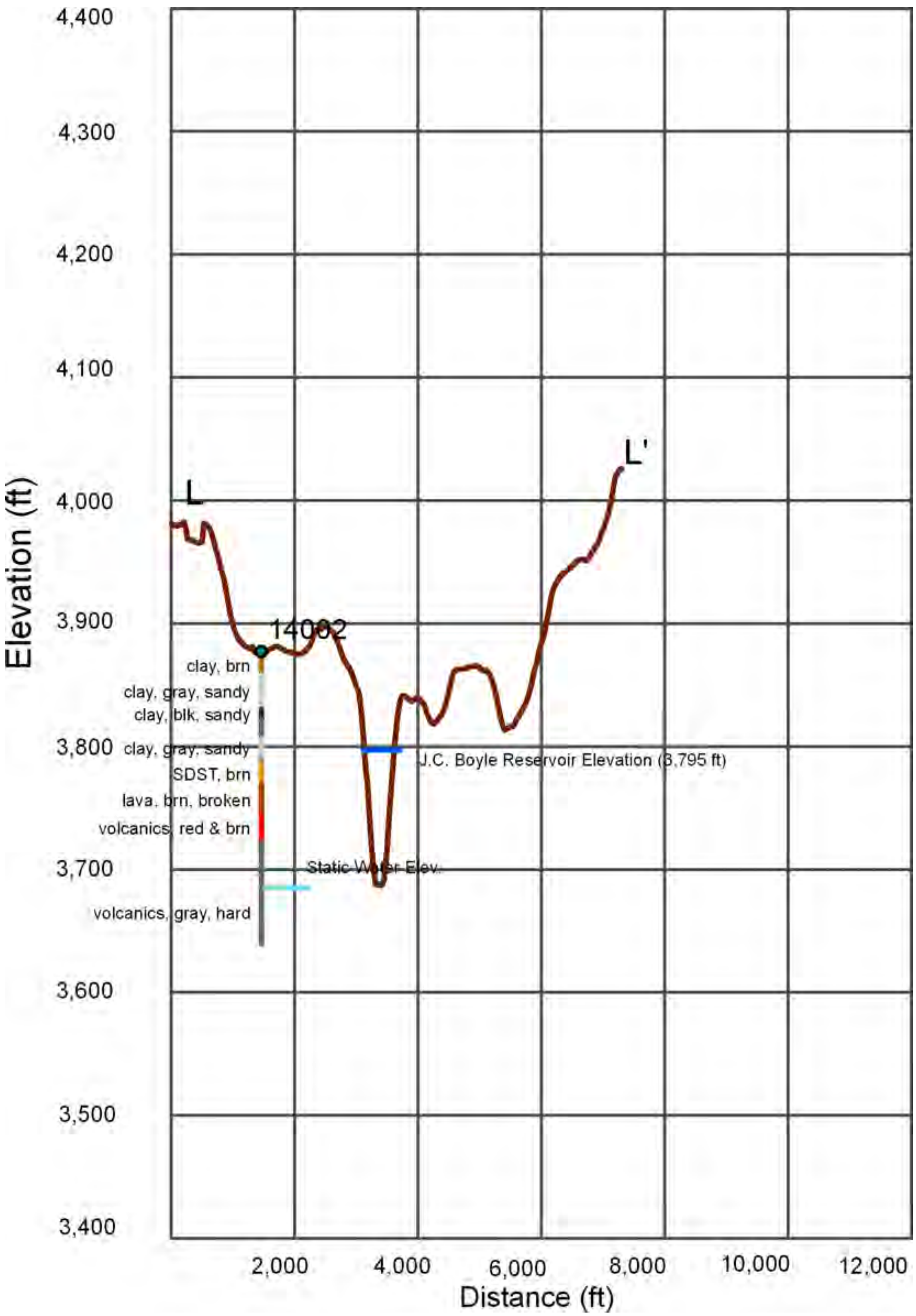


Figure 3-15. Cross-section L – L’.

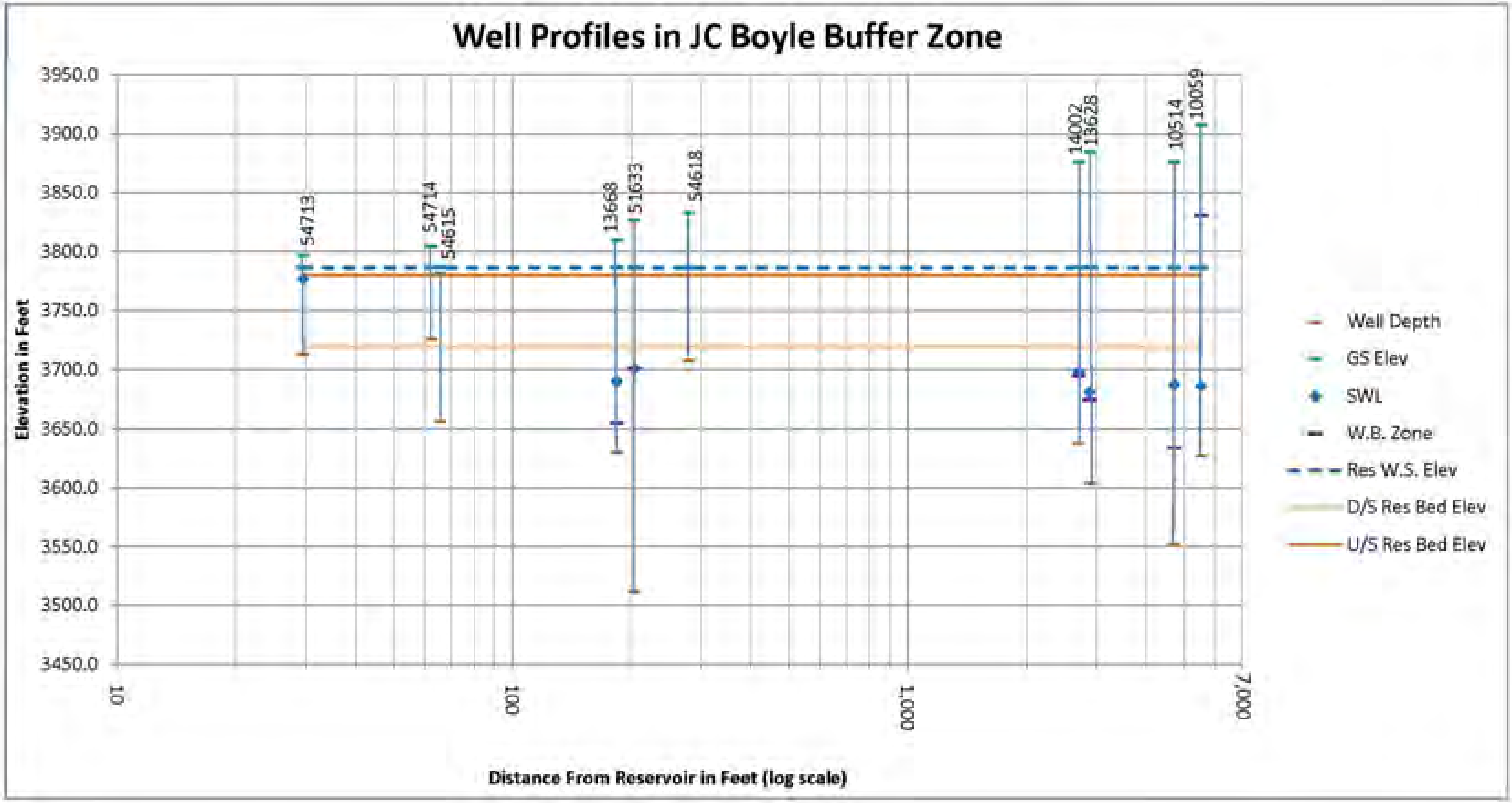


Figure 3-16. Well Profile graph for wells within 2.5 miles of J.C. Boyle Reservoir.

Table 3-3. Well Construction Information for Wells within 2.5 Miles of J.C. Boyle Reservoir (not including Oregon DOT boreholes for bridge footings) (Reservoir stage: 3787 feet AMSL; river bed elevation at dam site: 3720 feet AMSL)

Well ID	Drill Date	Use[1]	Well Diameter (in)	Depth to top of perforated zone or bottom of surface casing in an open well (ft)	Depth to bottom of perforated zone (ft)	Depth of Well (ft)	Depth to 1st Water (ft)	Pumping Rate (gpm)	Depth to Static Water (ft)
10059	06/29/1990	DOM	6	159 [2]	Open	281	77	12	222
10514	07/10/1992	DOM	6	275	315	324	242	40	189
13628	11/10/1989	DOM	4	201	241	281	204	30	204
14002	08/10/1988	DOM	6	99 [2]	Open	238	181	25	178
188972	10/19/2006	DOM	6	280 [2]	Open	315	126	55	126
16836	11/04/1976	DOM	6	22 [2]	Open	180	155	15	120

Notes:
1 - DOM: Domestic
2 - Depth to the bottom of the surface casing or sanitary seal in holes/wells that are open
Key:
in: inches
ft: feet
gpm: gallons per minute

Table 3-4. Water Level Compared to Water-Bearing Unit for Wells within 2.5 Miles of J.C. Boyle Reservoir (Reservoir stage: 3787 feet AMSL; river bed elevation at dam site: 3720 feet AMSL)

Well File #	Cross-Section Line	Static Water Elevation (ft)	Water-Bearing Unit	Elevation of Top of Water-Bearing Unit (ft)
10059	J-J’	3,686	Brown lava and clay from 203 to 223 feet bgs interspersed with black rock from 212 to 215 feet bgs, and gray rock and clay, and gray rock from 223 to 281 feet bgs with bubbly brown lava from 257 to 280 feet bgs	3,705
51633	K-K’	3,701	Gray and brown basalt from 126 to 315 feet bgs interspersed with hard gray baslalt, broken and fractured zones, and two ash layers	3,700
14002	L-L’	3,698	Hard gray volcanic rock from 181 to 238 feet bgs	3,695

The data in Table 3-4 suggests that the relatively flat lying, water-bearing units of volcanic materials are substantially deeper than the bottom elevation of the reservoir (i.e., the pre-reservoir river bed) in well #s 10059 and 51633. The SWL for each of these two wells is between 50 and 100 feet below the bottom of the reservoir. The top of the water bearing layer and the SWL in well # 14002 are just about at the elevation of the old river bed

As discussed in the EIS/EIR Section 3.11 – Geology, Soils, and Geologic Hazards, volcanic deposits in the region are highly variable in their lateral extent, homogeneity or inhomogeneity, degree of fracturing, and primary and secondary vertical permeability. It would be a conservative assumption that some degree of hydraulic connectivity exists between the reservoir and water bearing strata near the reservoir that allows downward migration of reservoir water. There would likely be a zone of similar horizontal hydraulic connectivity around the reservoir – but the extent and degree of connectivity is uncertain based on the limited well data. Both well #s 10059 and 14002 have significant amounts of clay recorded on the logs at depths between the top of their water bearing units and the equivalent depth of the old river bed that probably inhibits or significantly reduces the vertical migration of infiltration water from the reservoir. How extensive these clay units are is also uncertain.

Comparison of the elevations of the SWL in the six wells near J.C. Boyle reservoir shows that two wells downstream of the dam have SWL 20 to 40 feet below the pre-dam river bed elevation (at the dam site); the two wells furthest away from the reservoir (at 4,721 feet and 5,518 feet from the reservoir) have SWL elevations nearly 100 feet below the pre-dam upstream river bed elevation; and the two wells just about on the shore of the reservoir have SWL elevations 20 to 30 feet below the pre-dam river bed elevation at the dam site. The SWL elevations in the wells furthest from the reservoir are near or below the SWL elevations for the wells closer to the reservoir. No clear determination of any trends in vertical head gradients can be drawn from the data of these six wells.

3.6.4.2. Copco Reservoir

An estimated 80 percent of the reservoir area is on a portion of the Klamath River that was formerly a lower-gradient zone. The change in stream gradient resulted from previous geologic activities related to cinder cones and lava flows (See See Section 5.2). Thus, geologic conditions in Copco 1 Reservoir are different than those in J.C. Boyle Reservoir, even though the bedrock beneath and surrounding both reservoirs consists primarily of rocks formed from older volcanic flows overlain by younger lava flows. Sediment depositions and/or delta formations are present at the mouths of the larger streams in the reservoir (See Section 5.2).

Copco 2 Reservoir is a relatively short impoundment (extending just over 0.25 miles) that lies immediately downstream from Copco 1 Dam. The reservoir is narrow and confined by a narrow bedrock canyon formed by lava flow (See Section 5.2). Similar to Copco 1 Dam, rock at the Copco 2 Dam consists of a combination of lava flows and shallow intrusions. The bedrock surrounding and underlying the reservoir is comprised of basalt and andesite, steep slopes of volcanic cobbles and boulders lie along both sides.

A search of the California Department of Water Resources database retrieved 260 well logs around Copco and Iron Gate Reservoirs. Of those 260 logs, 192 had sufficient information to identify the approximate coordinates of the well, and of those 192 logs, 109 logs had a recorded static water level (SWL). Of the 192 logs, twenty-two were within 2.5 miles of the Copco Reservoir (Figure 3-17). Table 3-6 summarizes the well logs for wells within 2.5 miles of Copco Reservoir.

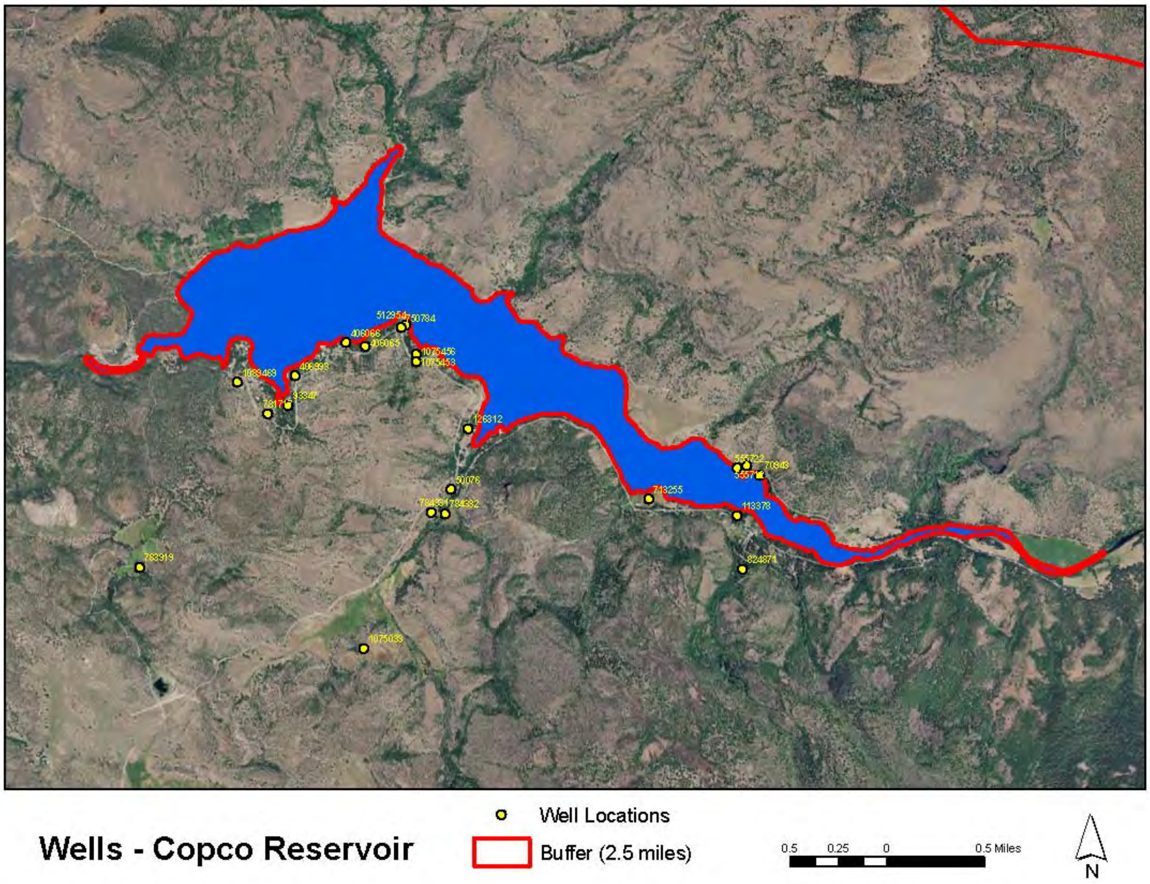


Figure 3-17. Location map showing locatable wells within 2.5 miles of Copco Reservoir. Cross-section lines are shown and labeled on Figure 3-18.

Four cross-sections were constructed on Copco Reservoir that intersected at least one of the six wells. These four cross-sections are labeled as A-A’, B-B’, C-C’, and D-D’ on Figure 3-18 and are shown in Figure 3-19 thru Figure 3-23. The wells within the 2.5 mile zone of Copco Reservoir used to generate the x-sections are summarized in the following table. Figure 3-24 shows a well profile of the wells within 2.5 miles of Copco Reservoir.

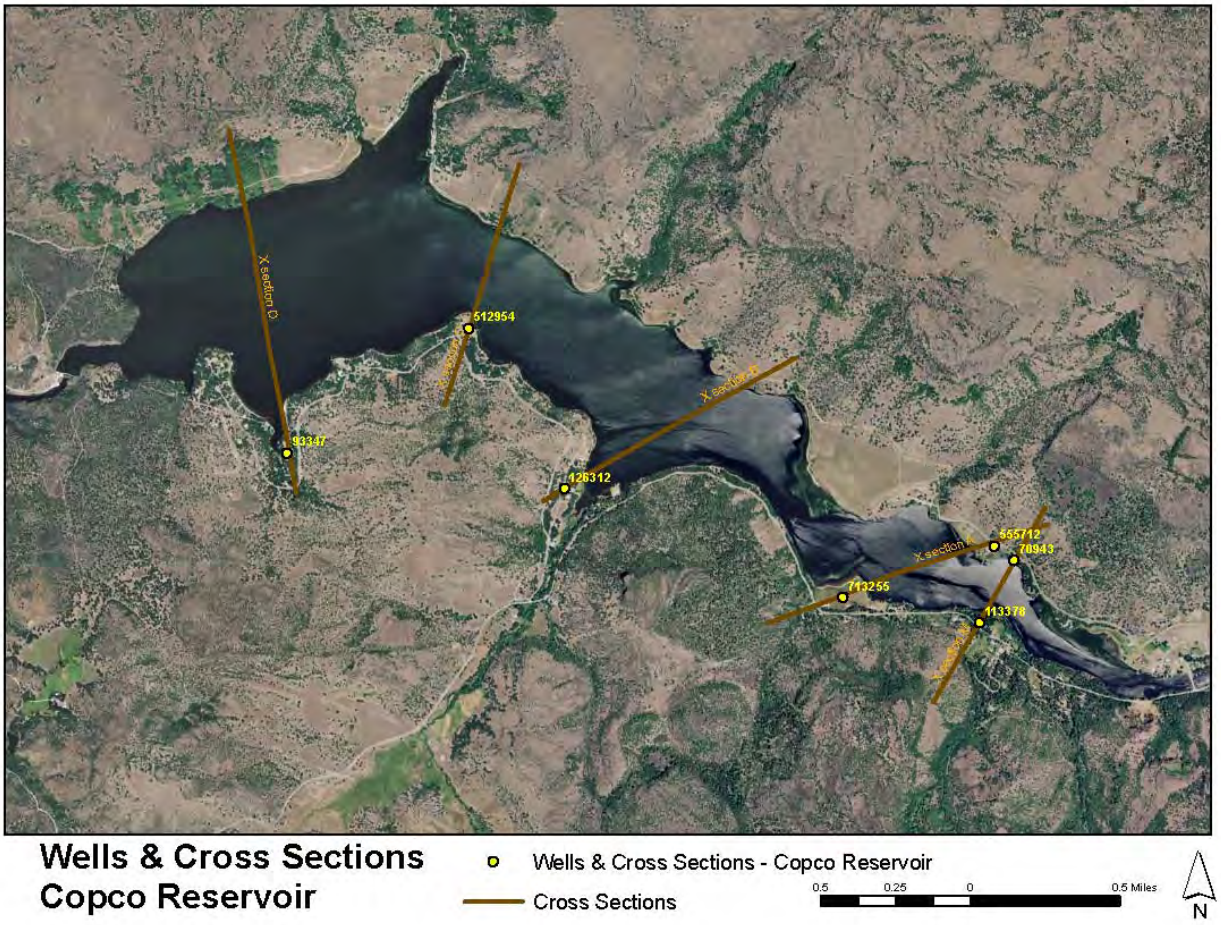


Figure 3-18. Location of cross-sections A – A’, B – B’, C – C’, D – D’, and M – M’ on Copco Reservoir.

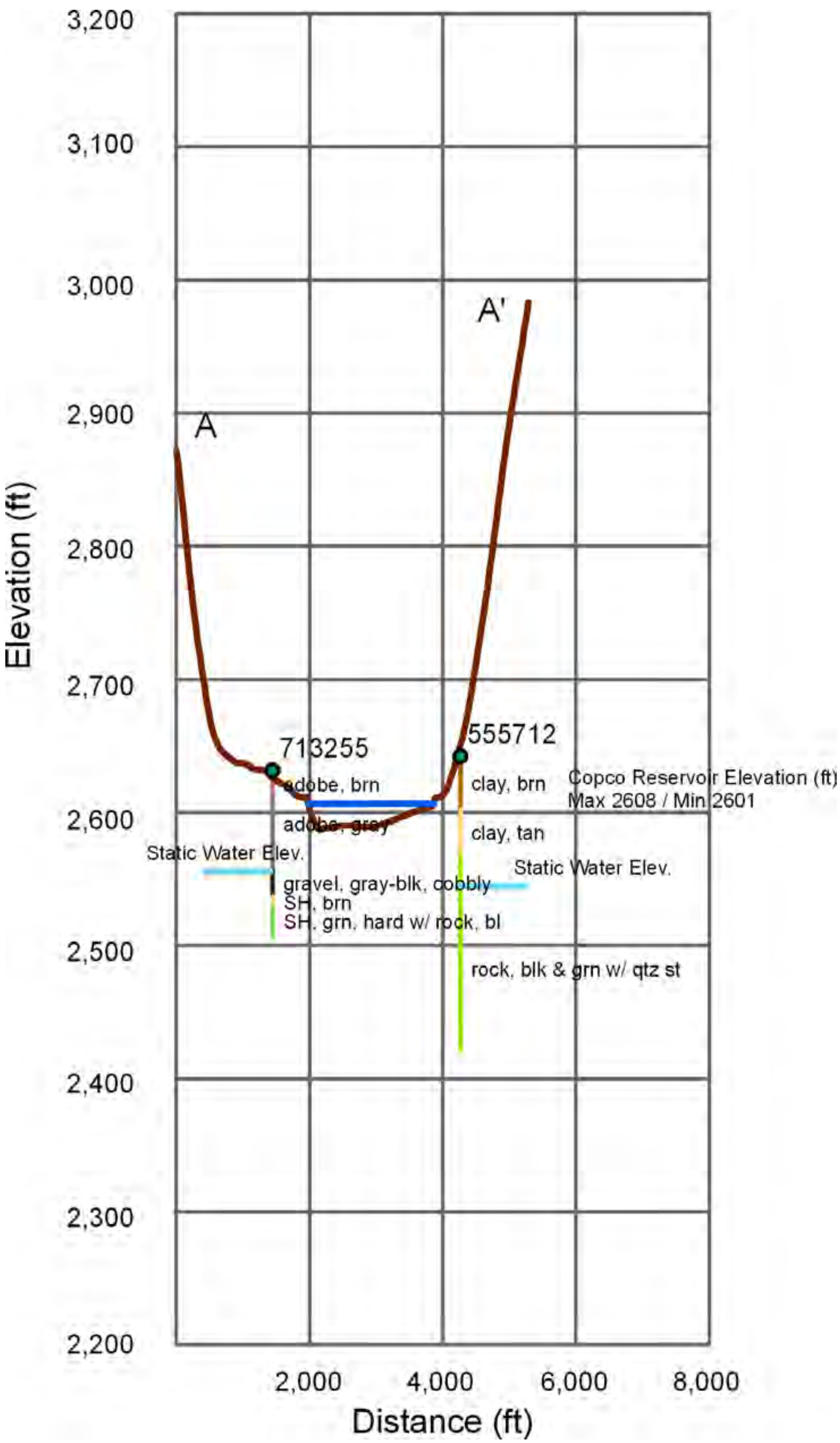


Figure 3-19. Cross-section A – A'.

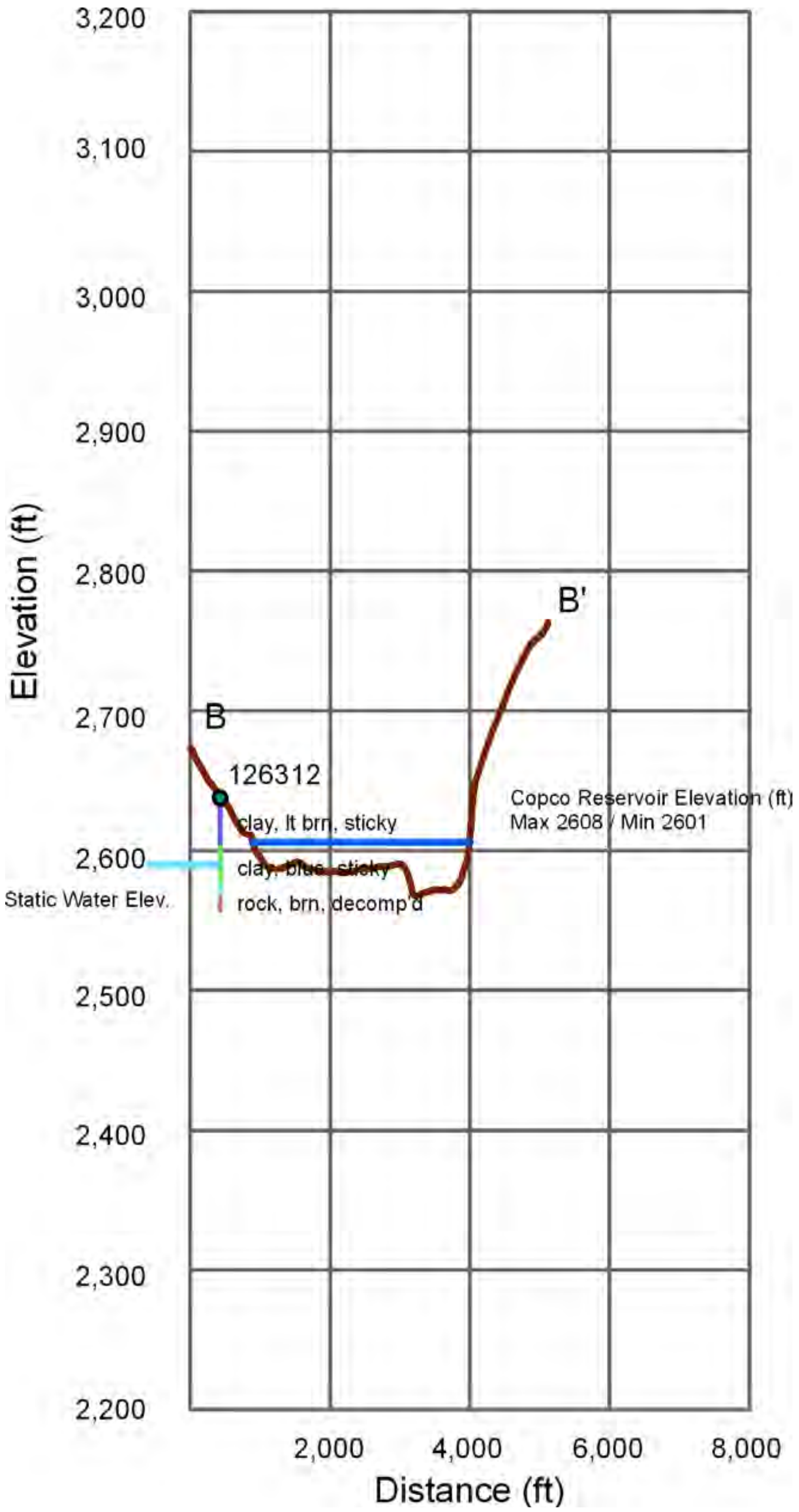


Figure 3-20. Cross-section B – B’.

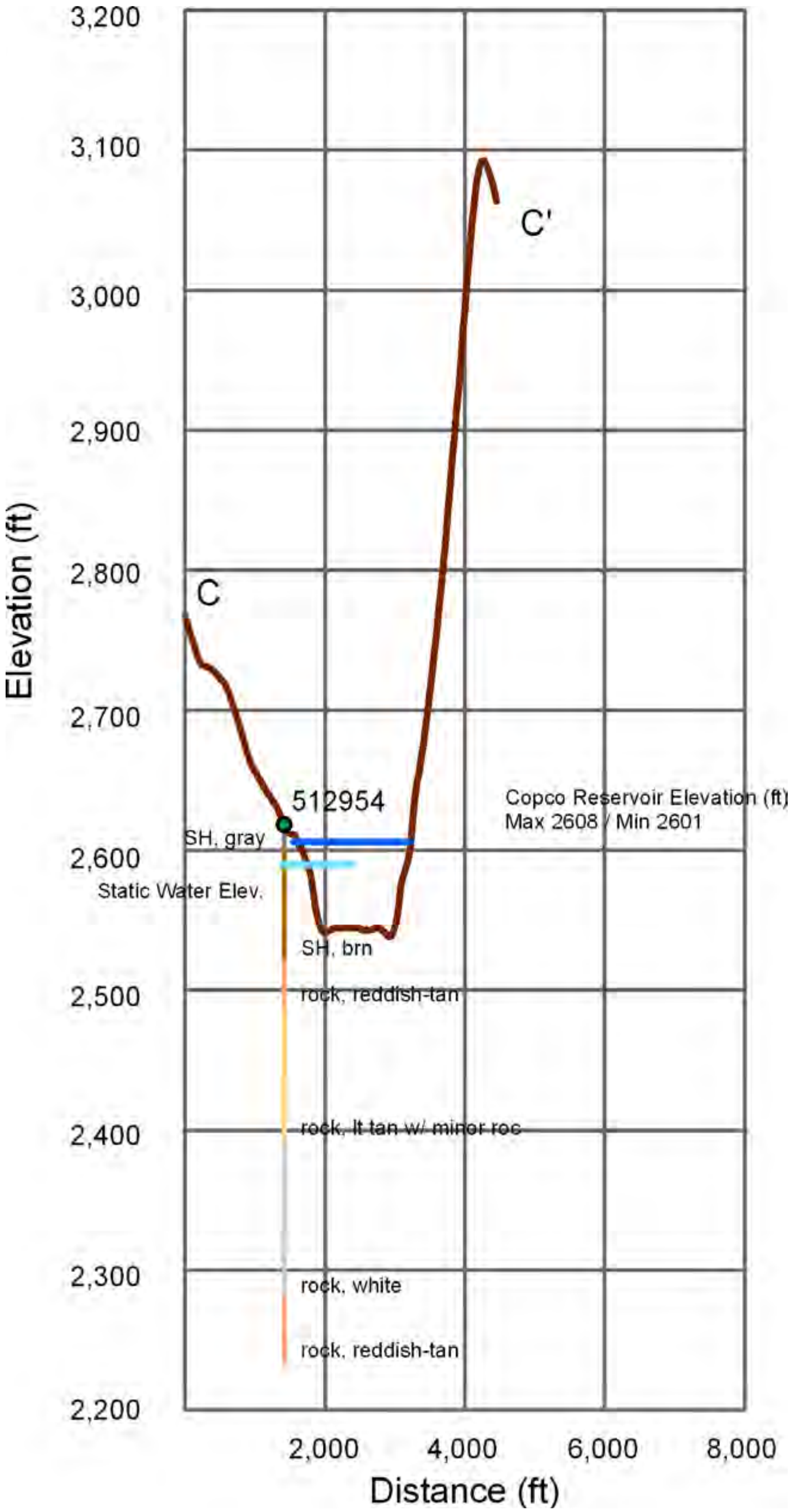


Figure 3-21. Cross-section C – C’.

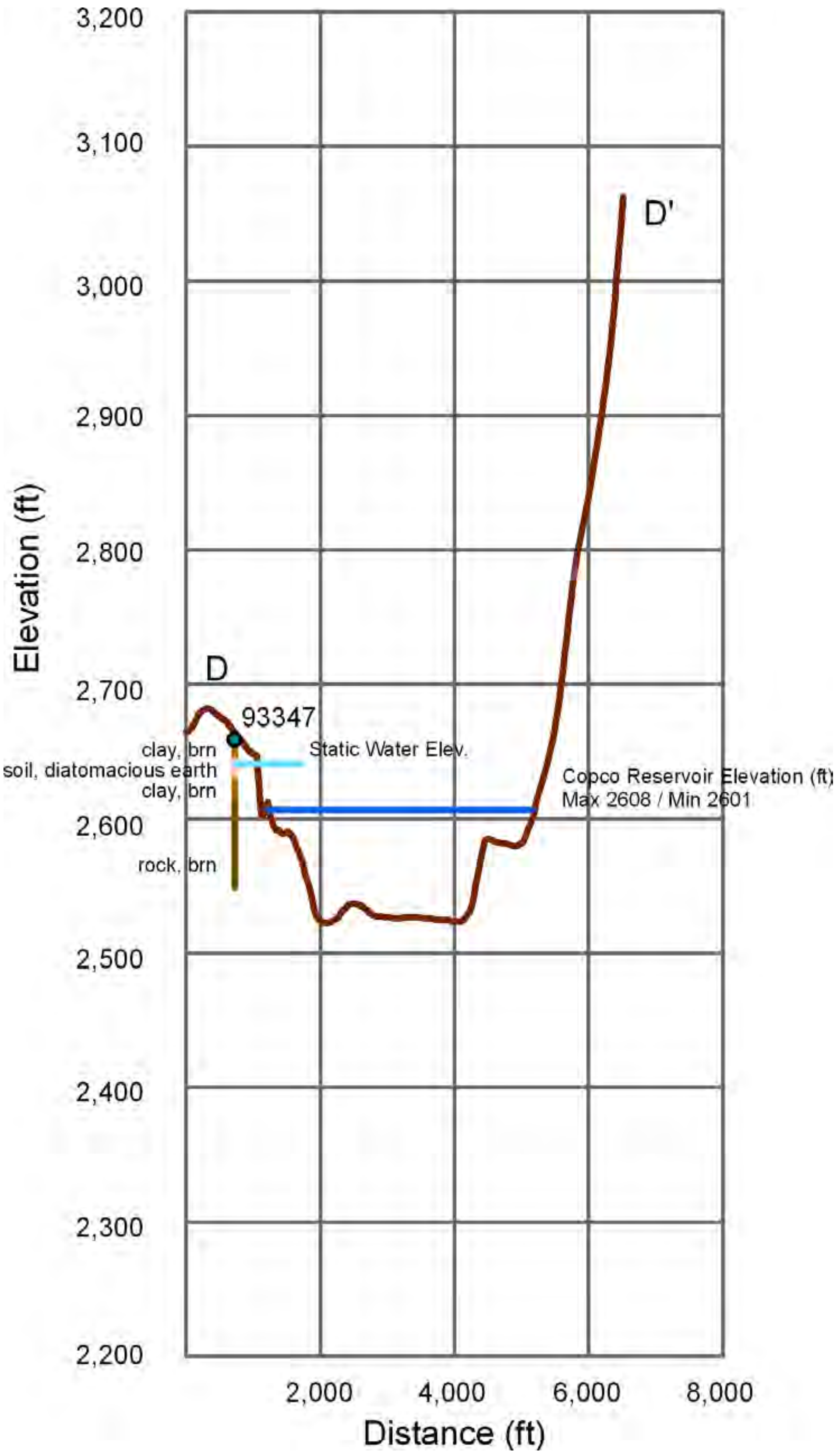


Figure 3-22. Cross-section D – D’.

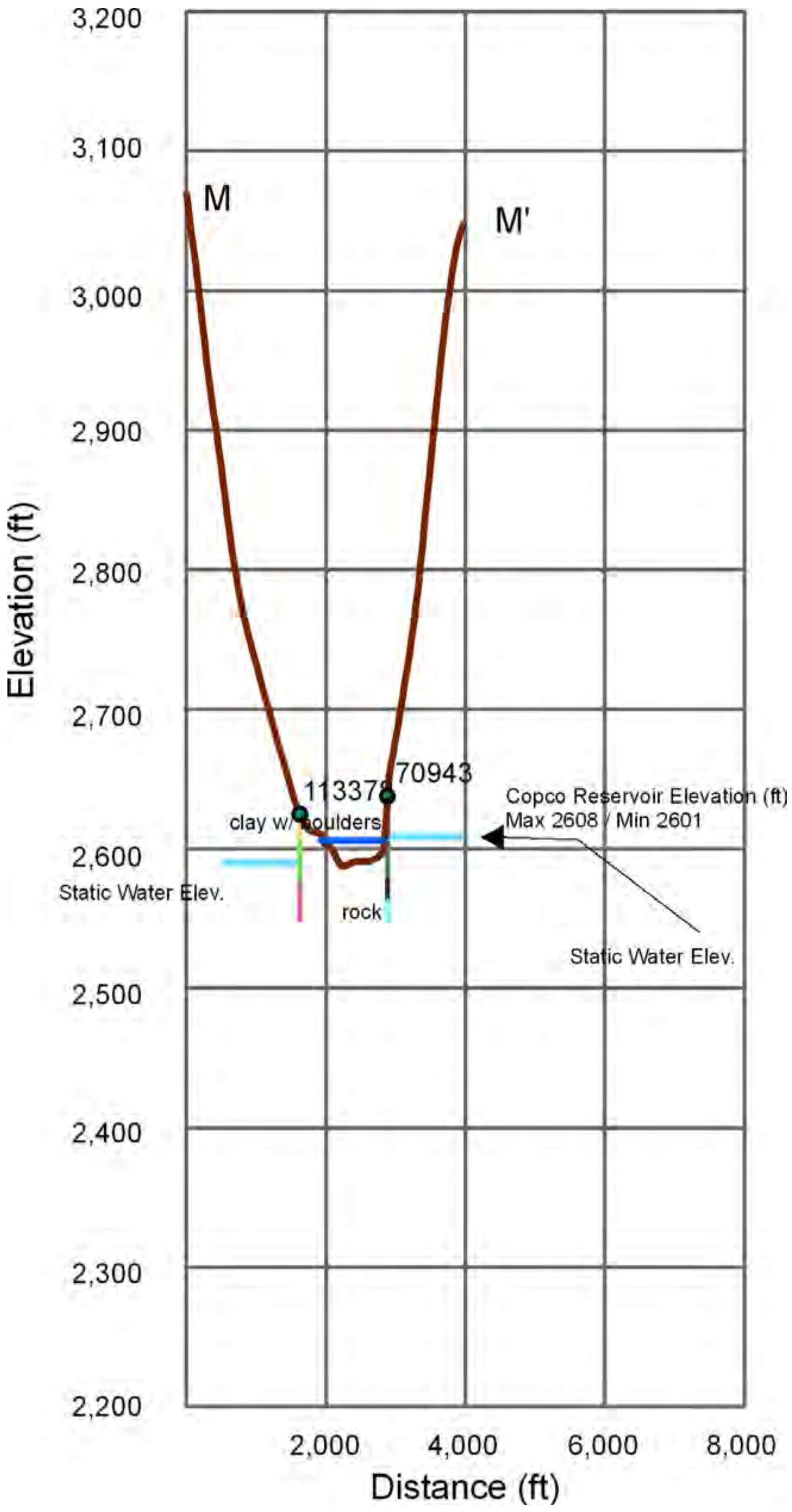


Figure 3-23. Cross-section M – M’.

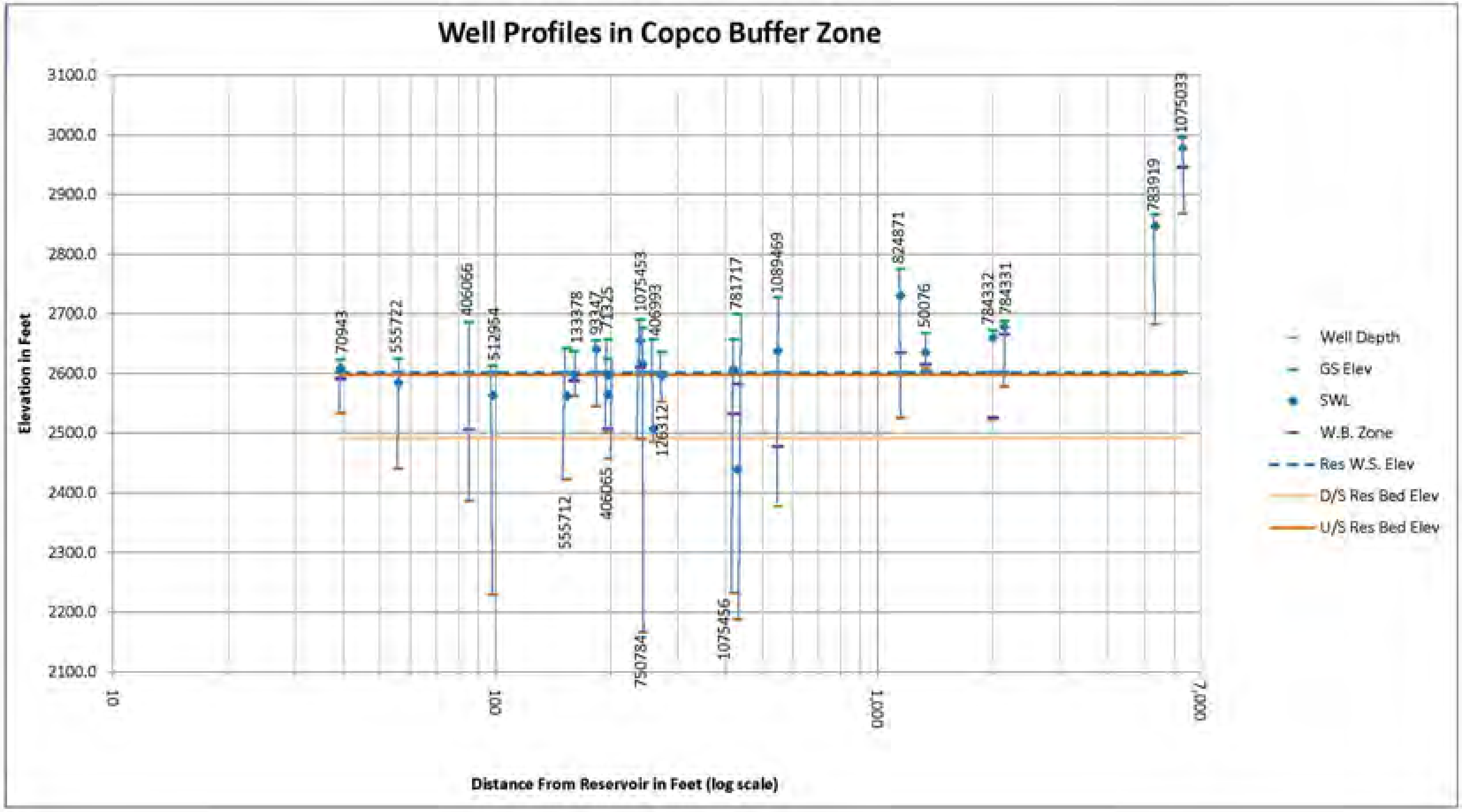


Figure 3-24. Well Profile graph for wells within 2.5 miles of Copco Reservoir.

Table 3-5. Well Construction Information for Wells within 2.5 Miles of Copco Reservoir (Reservoir Stage: 2,602 feet AMSL; River bed elevation at dam site: 2,493 feet AMSL)

Well ID	Drill Date	Use[1]	Well Diameter (in)	Depth to top of perforated zone or bottom of surface casing in an open well (ft)	Depth to bottom of perforated zone (ft)	Depth of Well (ft)	Depth to 1st Water (ft)	Pumping Rate (gpm)	Depth to Static Water (ft)
93347	08/05/1975	DOM	6	45 [2]	Open	110	N/R	20	15
126312	07/14/1976	DOM	6.625	63	83	83	55	10	40
512954	07/08/1998	DOM	6	75	225	384	N/R	2	50
555712	08/31/1994	DOM	6	100	120	220	N/R	15	80
713255	06/15/1999	DOM	6	104 [2]	Open	124	N/R	30	60
113378	08/01/1965	DOM	8	16	75	75	49	25	40
70943	06/20/1964	DOM	4.5	70	84	90	32	N/R	15

Notes:

1 - DOM: Domestic

2 - Depth to the bottom of the surface casing or sanitary seal in holes/wells that are open

Key:

in: inches

ft: feet

gpm: gallons per minute

Table 3-6. Water Level Compared to Water-Bearing Unit for Wells within 2.5 Miles of Copco 1 and Copco 2 Reservoirs (Reservoir Stage: 2,602 feet AMSL; River bed elevation at dam site: 2,493 feet AMSL)

Well File #	Cross-Section Line	Static Water Elevation (ft)	Water-Bearing Unit	Elevation of Top of Water-Bearing Unit (ft)
DWR-713255	Near A on A-A’	2,565	Hard green and black rock, 104 to 124 feet below ground surface (bgs)	2,521
DWR-555712	Near A’ on A-A’	2,564	Black/green rock w/quartz stringers, 100 to 120 feet bgs	2,544
DWR-126312	Near B on B-B’	2,597	Tight blue cemented sand, 55 to 70 feet bgs, brown decomposed rock, 70 to 80 feet bgs	2,582
DWR-512954	Near C on C-C’	2,566	Reddish tan rock, lighter tan rock, white rock, reddish tan rock	2,541
DWR-93347	Near D on D-D’	None recorded	Rock, 45 to 110 feet bgs	2,608 (est.)
DWR-113378	Near M on M-M’	2,597	Small boulders, 49 to 60 feet bgs	2,588
DWR-70943	Near M’ on M-M’	2,608	Gravel, 32 to 33 feet bgs	2,591

The data for the wells in the x-section indicate that the water-bearing unit is above the bottom of the reservoir at the dam site, as are the SWLs. In fact, all the wells near Copco Reservoir, with the exception of one, have SWLs that are below the reservoir stage but above the river bed elevation at the dam site. Similarly, all the wells but one has elevations for the top of the water bearing unit below the reservoir stage and above the river bed elevation at the dam site. The two exceptions are two different wells. In some cases, the top of the water bearing formation was not identified on the log, so the elevation at which water was first encountered in the drilling is used as a substitute for the top of the water bearing unit.

As can be seen on the x-sections A-A’, B-B’, and C-C’ (Figure 3-19 thru Figure 3-21) and in Table 3-4, the SWL in the wells is below the reservoir water level of 2602’, and the water bearing unit is below the bottom of the reservoir in x-sections A-A’ and B’B’ (2585’ and 2565’ respectively). In x-section C-C’ the top of the water-bearing unit is just about the same elevation as the bottom of the reservoir (2640’) although the SWL is some 36’ below the reservoir water level elevation of 2602’. So in the case of Well 512954 in x-section C-C’ it is uncertain if the water-bearing unit ‘daylights’ in the reservoir or is just below the original channel bed (or maybe the channel had started to incise into the unit).

In x-section D-D’ (Figure 3-22) the estimated top of the water-bearing unit (in this case the estimate is based on the bottom of the blank casing installed in the well) is well about the bottom of the reservoir at 2520’. Presumably, the water-bearing unit in this well is in direct contact with the reservoir – i.e. the unit ‘daylights’ in the reservoir. The case for a direct connection between the reservoir and the water-bearing unit could be verified if a SWL reading had been recorded.

The average SWL for all wells less than 300 feet from the reservoir is 2,591 feet while the average SWL for all wells greater than 400 feet from the reservoir is 2,680 feet. This suggests that there is a vertical downward head gradient component closer to the reservoir. This would also suggest that the reservoir does not have a significant lateral influence on groundwater levels.

The SWLs in the wells were recorded upon completion of the wells, which was in 1999, 1994, 1976, 1998, and 1975 respectively. Additionally, the water level elevation of Copco Reservoir is an average elevation over an unknown number of years, so there is little correlation between the reservoir level and the SWL in any of the wells. Even so, for any of these wells to be influenced by the water level in the reservoir the water-bearing unit in each well would have to have some connection with the reservoir. In case of Wells 713255, 555712, and 126312 (x-sections A-A’ and B-B’) the relatively flat laying or gently eastward dipping units of volcanic materials are deeper than the bottom elevation of the reservoir (the pre-reservoir river bed). The well profile for Copco Reservoir (Figure 3-24) suggests that the gradient near the reservoir is away from the reservoir – i.e. the reservoir is losing water and that far away from the reservoir the gradient is towards the reservoir, while at intermediate distances there are about as many SWLs above the reservoir level as there are below it. The wells more than about 1000 feet away from the reservoir appear to be responding to a regional or localized groundwater system that is higher than the reservoir level,

In the case of wells 512954 and 93347 that could have a connection to the reservoir, the lower SWL could simply reflect a lower water surface elevation in the reservoir when these two wells were completed. No subsequent SWL readings have been obtained that could be compared to the reservoir water surface elevation obtained at the same time in order to verify whether or not the water levels in these wells are responding to water levels in the reservoir.

3.6.4.3. Iron Gate Reservoir

Like Copco 1 Reservoir, Iron Gate Reservoir overlies the transition on the Klamath River with the upstream area being steeper. The downstream portion of Iron Gate Reservoir is a lower-gradient area where the valley floor widens, and the channel is less restricted by the localized basalt lava flows. The reservoir has relatively steep side-slopes and a narrow channel with numerous side drainages. Wells located within 2.5 miles are shown in Figure 3-25.

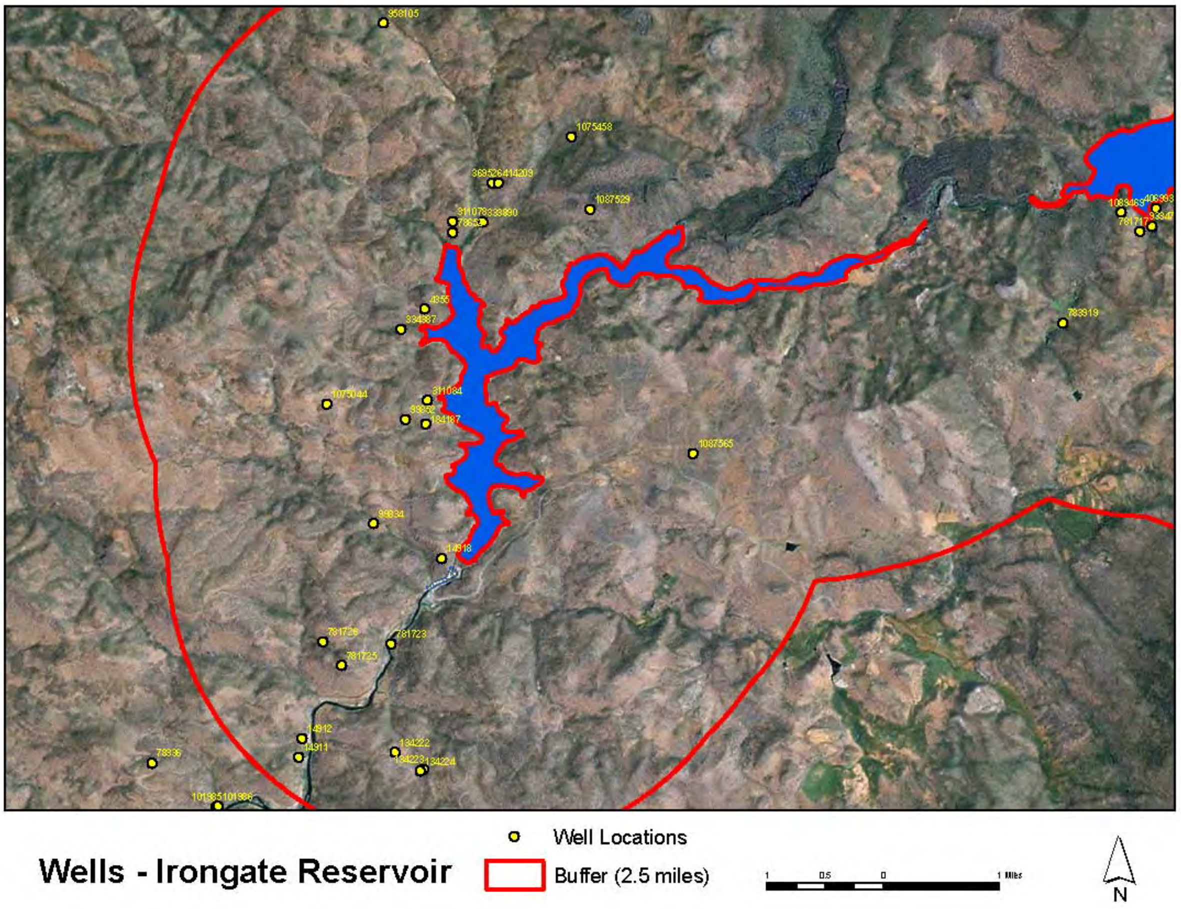


Figure 3-25. Location map showing locatable wells within 2.5 miles of Iron Gate Reservoir. Cross-section lines are shown and labeled on Figure 3-26.

Four cross-sections were constructed for Iron Gate Reservoir that intersected at least one of the twenty wells that are within 2.5 miles of the reservoir. These four cross-sections are labeled as E-E’, F-F’, G-G’, and H-H’ on Figure 3-26 and are shown in Figure 3-27 thru Figure 3-29. The wells within the 2.5 mile zone of Iron Gate Reservoir used for the x-sections are summarized in the following tables. Additionally, a well profile for Iron Gate was generated (Figure 3-30).

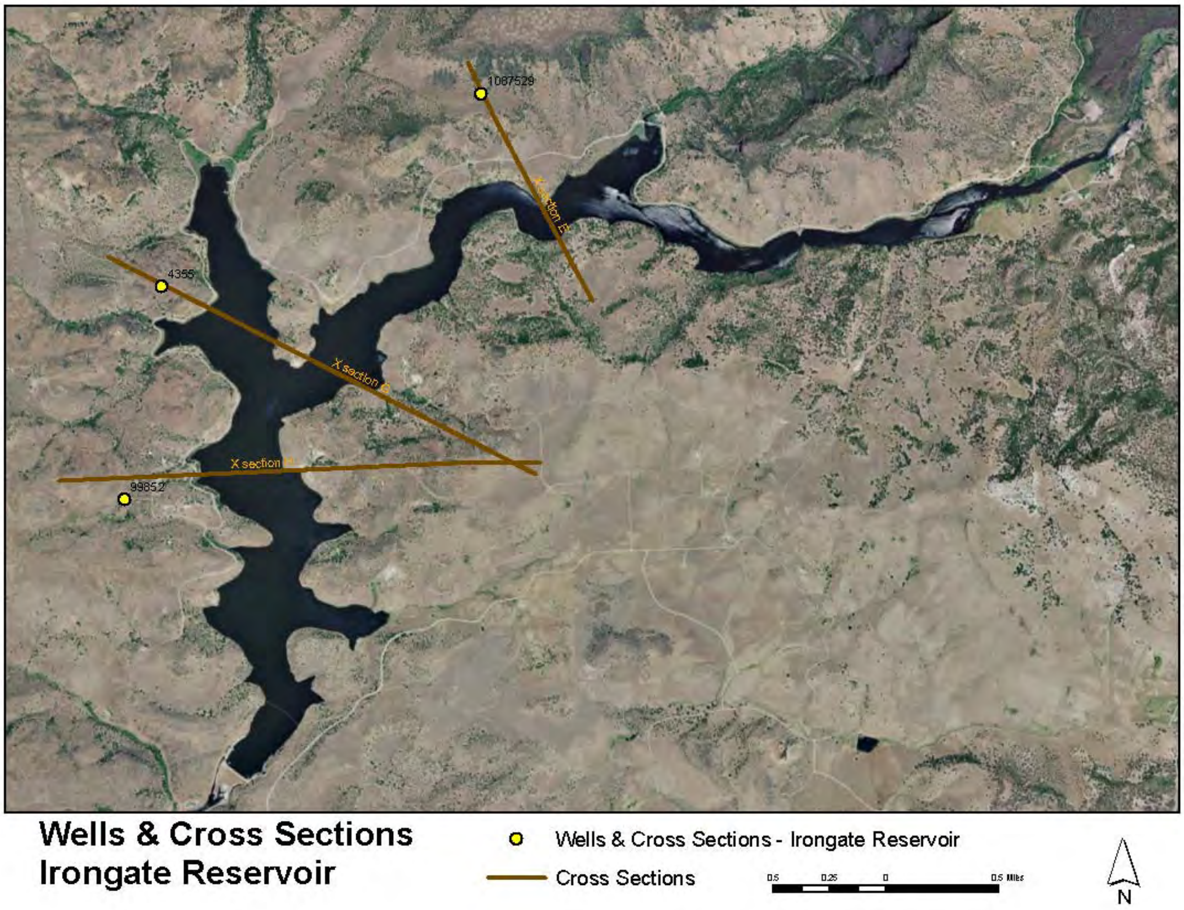


Figure 3-26. Location of cross-sections A – A’, B – B’, C – C’, and D – D’ on Copco Reservoir.

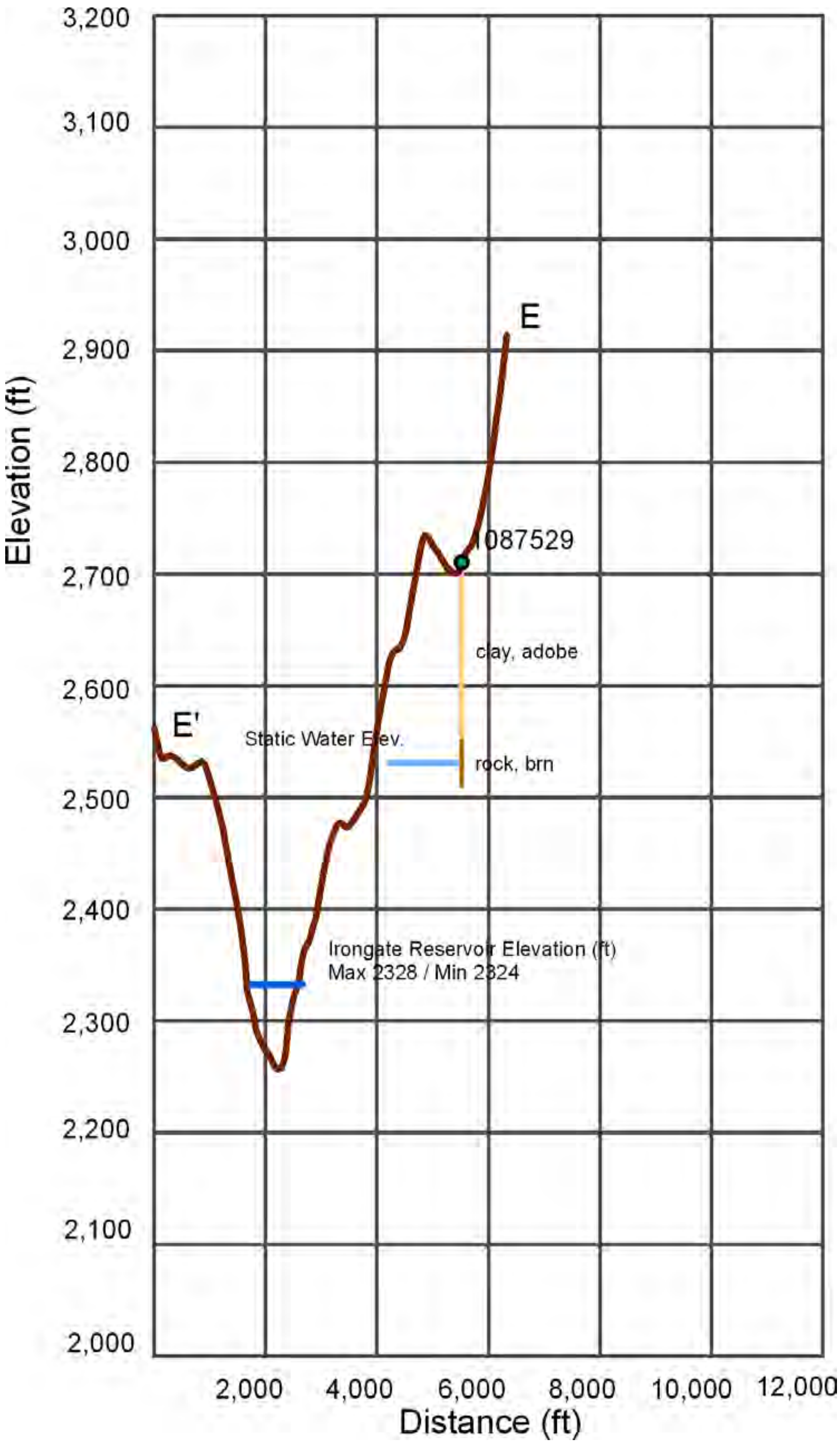


Figure 3-27. Cross-section E – E’.

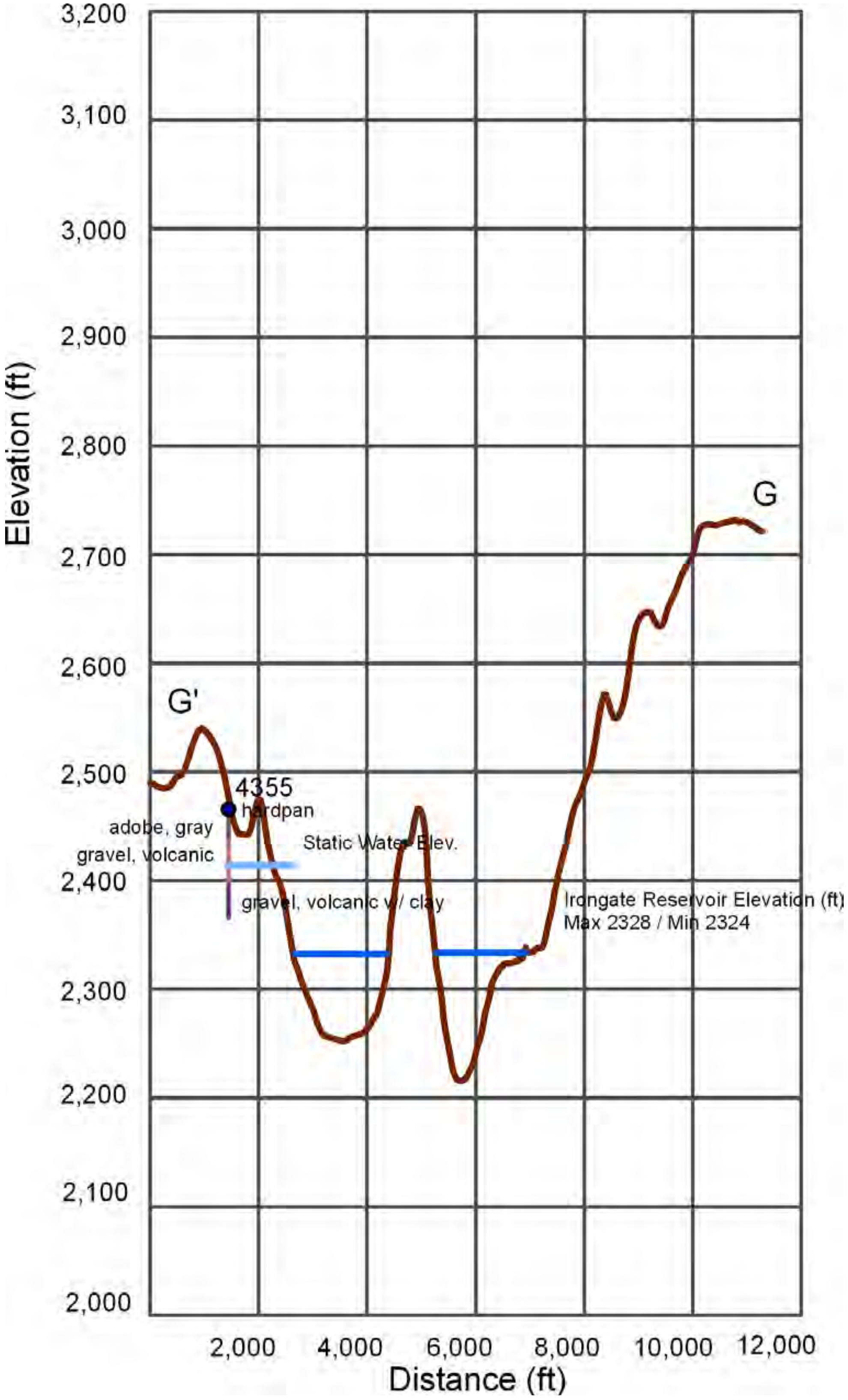


Figure 3-28. Cross-section G –G'.

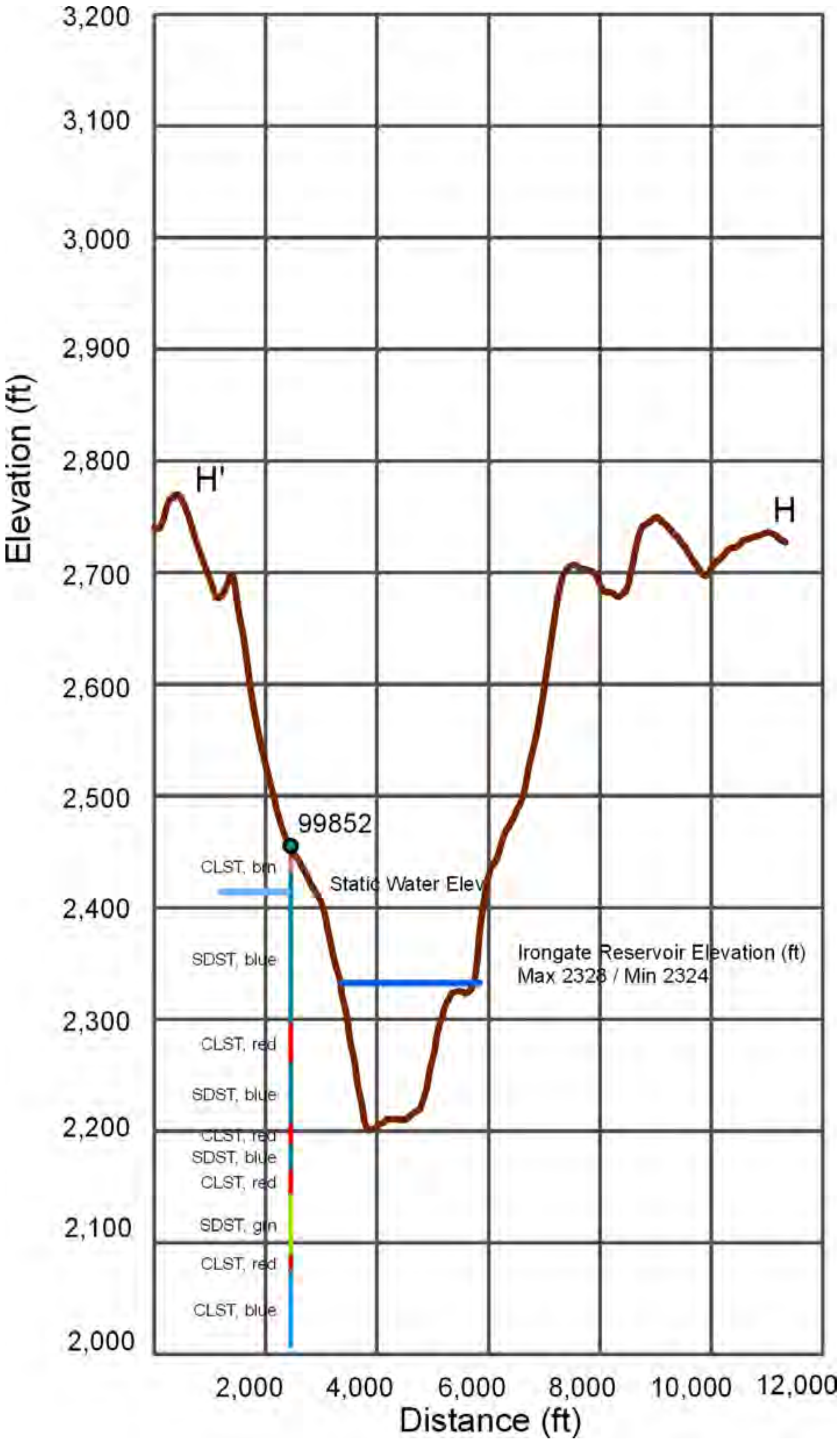


Figure 3-29. Cross-section H – H'.

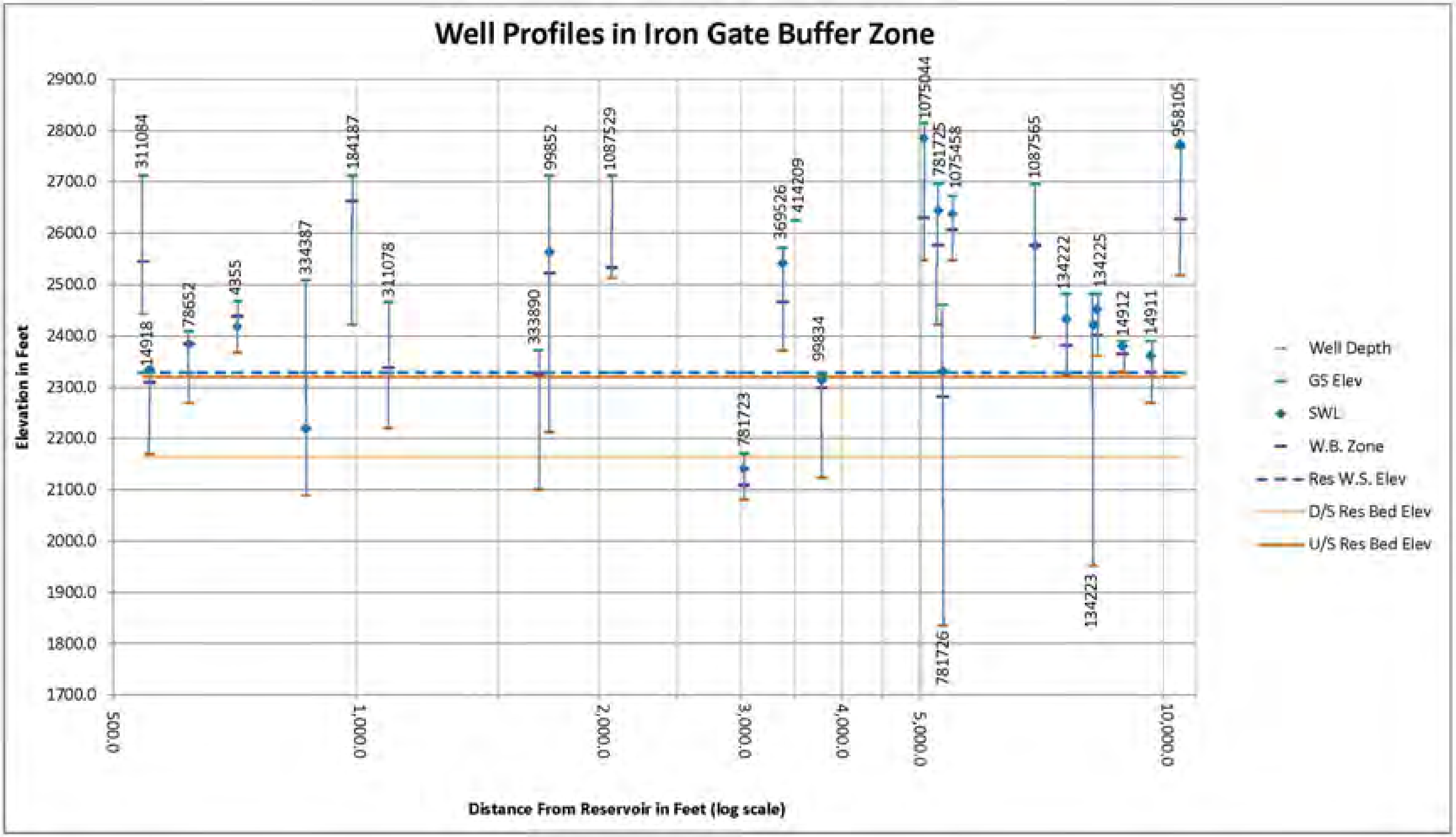


Figure 3-30. Well Profile graph for wells within 2.5 miles of Iron Gate Reservoir.

Table 3-7. Well Construction Information for Wells within 2.5 Miles of Iron Gate Reservoir (Reservoir stage – 2328 feet AMSL; river bed elevation at dam site – 2165 feet AMSL).

Well ID	Drill Date	Use[1]	Well Diameter (in)	Depth to top of perforated zone or bottom of surface casing in an open well (ft)	Depth to bottom of perforated zone (ft)	Depth of Well (ft)	Depth to 1st Water (ft)	Pumping Rate (gpm)	Depth to Static Water (ft)
4355	06/14/1966	DOM	8	12	70	100	30	10	50
14911	10/01/1980	DOM	6	100	120	120	N/R	50	28
14912	10/01/1980	DOM	6	40	60	60	N/R	50	10
14918	12/18/1980	DOM	6	40 [2]	Open	160	20	40	0
134222	09/01/1982	DOM	6	120	160	160	N/R	20	50
134223	09/01/1982	DOM	6	20 [2]	OPEN	530	N/R	1	60
78652	07/05/1983	DOM	4	80	140	140	25	6	25
99852	08/25/1981	DOM	6.625	30 [2]	Open	500	191	5	150
184187	04/13/1987	DOM	4	271 [2]	291	291	281	15	N/R
311078	05/09/1990	DOM	6	22 [2]	Open	246	N/R	12	N/R
134224	09/01/1982	DOM	6	80	120	120	N/R	15	30
311084	05/03/1990	DOM	6	52 [2]	Open	270	250	25	N/R
333890	07/09/1990	DOM	6	23 [2]	Open	271	N/R	12	N/R
334387	10/1201990	DOM	6	21 [2]	Open	420	N/R	0.125	290
369526	06/22/1991	DOM	6	36 [2]	Open	200	105	20	30
1075044	10/09/2008	DOM	4	52	260	268	185	30	30
1087529	07/18/2003	DOM/ IRR	8	100	200	200	180	25	N/R
1087565	09/06/2006	DOM	6	140	300	300	120	20	120
781223	02/03/2003	DOM	4	35	90	90	62	75	30
414209	06/22/1991	DOM	0	N/R	Open	0	N/R	0	0
1075458	11/17/2004	DOM	6	40	125	125	65	100	35
781725	01/06/2003	DOM	4	54	265	275	120	7	52
99834	07/28/1981	DOM	6.625	N/R	Open	200	N/R	25	10
781726	08/25/2002	DOM	4	55	530	625	180	12	130
958105	10/25/2006	DOM	4	30	247	250	140	N/R	0*

Notes:
1 - DOM: Domestic; IRR: Irrigation
2 - Depth to the bottom of the surface casing or sanitary seal in holes/wells that are open
Key:
in: inches
ft: feet
gpm: gallons per minute
N/R: Data not Recorded
* SWL at top of well casing, so depth to water is ‘0’.

Table 3-8. Water Level Compared to Water-Bearing Unit for Wells within 2.5 Miles of Iron Gate Reservoir (Reservoir stage – 2328 feet AMSL; river bed elevation at dam site – 2165 feet AMSL).

Well File #	Cross-Section Location	Static Water Elevation (ft)	Water-Bearing Unit	Elevation of Top of Water-Bearing Unit (ft)
1087529	Near E on E-E'	None recorded	Brown rock, 160 to 200 feet below ground surface (bgs)	2,532
4355	Near G' on G-G'	2,424	Volcanic gravels, 30 to 70 feet bgs	2,444
99852	Near H' on H-H'	2,563	Blue sandstone from 195 to 250 feet bgs	2,518

The data in Tables 3-10 and 3-11 show that the SWL (when recorded) is above the reservoir stage with only two exceptions (well #s 781723 and 99834). The SWL for all the wells is also above the elevation of the river bed at the dam site with only one exception (well # 781723). The tables also show that the estimated elevation of the top of the water bearing unit (recorded on 13 of the 25 logs) is above the reservoir stage (and by default also above the reservoir bottom) in 10 of the 13 wells. In two wells, the top of the water bearing unit is between the reservoir stage and the reservoir bottom. In only one well is the top of the water bearing unit below the reservoir bottom (well # 781723).

Wells further away from Iron Gate Reservoir have higher SWLs and generally higher top of water bearing unit elevations than well closer to the reservoir. This indicates a head gradient towards the reservoir which is in agreement with the regional groundwater gradients (Gannett, et al, 2010). Where recorded, wells within 2,000 feet of the reservoir have SWL very close to the reservoir stage or above (with one exception, well # 334387). The current well data is not sufficient to determine whether or not Iron Gate reservoir has any downward or horizontal seepage.

As can be seen on the x-sections E-E', G-G', and H-H' (Figures 3-27, -28, and -29) and in Table 3-7, both the SWL and the water-bearing units in the wells are significantly above the reservoir water level of 2328'. In fact, the bottom of each bore hole is also well above the reservoir level. It is obvious from these x-sections that the water-bearing units are in no way connected to the reservoir and thus definitely represent the regional groundwater system.

The well profile for Iron Gate Reservoir (Figure 3-30) would suggest that Iron Gate Reservoir has less of an influence on nearby wells than does Copco or J.C. Boyle. It also shows that many private wells are located on highlands overlooking the reservoir as opposed to near the shoreline. The four closest wells to the reservoir indicate that the local gradient is towards the reservoir so these wells are unlikely to be significantly impacted by the removal of the reservoir.

The SWLs in the wells were recorded upon completion of the wells, which was in 2003, 1966, 1980, and 1990 respectively. Summary
The four dams – J.C. Boyle, Copco #1 & #2, and Iron Gate – are in the High Cascades Province with J.C. Boyle Dam being in the transition zone between the Modoc Plateau and High Cascades Provinces and Iron Gate Dam being in the transition zone between the Western Cascades Sub-Province and the Klamath Mountains Province. The Modoc Plateau Province represents the northern most extent of the Basin and Range Physiographic Province while the Western Cascades and High Cascades Provinces represent volcanic arc processes related to subduction zones. Both processes, however, result in extensive volcanic activities extending back to at least the late Eocene Epoch some 35 - 40 Ma (million years before present).

The geology of the region of the Upper Klamath Basin is very complex with “. . . hundreds of distinct and mappable geologic units . . .” of volcanic and sedimentary processes. However, many of these “ . . . distinct and mappable geologic units . . .” have similar or identical origins and properties. As such, these hundreds of geologic units can be grouped into eight hydrologic units based on their hydrogeologic properties. These eight hydrologic units are: Quaternary sedimentary deposits, Quaternary volcaniclastic deposits, Quaternary volcanic rocks, Quaternary to late Tertiary sedimentary rocks, Late Tertiary sedimentary rocks, Late Tertiary volcaniclastic rocks, Late Tertiary volcanic rocks, and older Tertiary volcanic and sedimentary rocks (Gannett, et al., 2010).

Most of these hydrologic units are water-bearing and can form aquifers. The aquifers can consist of vast sheets of vesicular, fractured, and or columnar basalts, layers of weathered and/or reworked volcanic gravels and breccias, lake deposits, alluvial deposits, and loess deposits. Likewise, the aquifers can be restricted in areal extent, thickness, and capacity, or perched. They can also form confining units when they consist of fine-grained materials (such as lake bed clays) and/or are very tight (such as welded tuff, unfractured low vesicular basalts, cemented sandstones, etc). Each of these units can and often do overlay, underlay, and interfinger with all the other units in complex relationships.

Very little specific groundwater data exists for the areas of the three dams and reservoirs as there are no state or USGS monitoring wells in the reach of the Klamath River valley in which the dams are located. A significant number of private domestic wells exist in the river valley from upstream of Keno Dam to downstream of Iron Gate Dam. There are sixteen locatable wells within 2.5 miles of J.C. Boyle Reservoir, twenty-two locatable wells within 2.5 miles of Copco Reservoir, and twenty-five locatable wells within 2.5 miles of Iron Gate Reservoir – all are private domestic wells. No SWLs in any of the wells in the project area have been recorded more than once and no pre-dam SWL measurements were found.

The regional groundwater system generally flows from the higher landforms – hills, ridges, mountains, etc – toward the lower river valley with an overall regional gradient from upstream around Keno Dam downstream toward Iron Gate Dam. The gradients tend to be steepest on the south side of the valley between the Mount Shasta uplands and the Klamath River. Gradients near the reservoirs generally are away from the reservoir and/or vertically downward under the reservoirs – although cases where the gradients are towards the reservoirs or upwards under the reservoir are common.

4. Existing Hydraulic Conditions

A one-dimensional hydraulic model was developed in HEC-RAS 4.1 to simulate the hydraulic conditions of the Klamath River from upstream of J.C. Boyle (RM 230) to downstream of Indian Creek near Happy Camp (RM 105). The model is used to calculate the hydraulic condition before and after dam removal and the areas inundated by flood flows before and after dam removal. The model also serves as the basis for the sediment transport model used to calculate sediment transport under the No Action and Dam Removal Alternatives (Section 9).

This section describes the data necessary to build the model and a description of the current hydraulic conditions downstream of Iron Gate.

4.1. Development of Hydraulic Model

Woolpert, Inc obtained airborne LiDAR in February and March of 2010 for the Klamath River from Link Dam to approximately Happy Camp, CA. The LiDAR data was presented as full LAS data as well as a 3ft grid derived from the LAS. For the purposes of this study, the 3ft grid elevation data was used. LiDAR does not penetrate water, so the data representing the water surface was clipped so that the bathymetric data could be combined with the portion of the data representing the above-water land surface. This 3-ft grid, excluding the water surface data, was converted to points so that it could be used in developing the elevation model.

The 2001 bathymetric survey of the upstream reservoirs was used for generation of the cross sections in the reservoir pool (JC Headwaters, Inc., 2003). A 2009 bathymetry survey of the Klamath River from Iron Gate Dam to Happy Camp, CA was used for generation of the downstream cross sections. The downstream bathymetry survey was conducted in October, 2009 by Reclamation, with support from the USGS. The survey was conducted from two boats, each using a multi-beam ADCP interfaced with GPS. Data gaps exist in this dataset due to gaps in GPS coverage and/or data collection issues for the ADCP (aeration, shallow depth, etc.). One significant gap occurred within the 10 miles downstream of Iron Gate Dam. Woolpert was contracted to conduct a series of bathymetric cross sections to mitigate for a 3-mile gap in the reach from I-5 (near Hornbrook, CA) to the Shasta River confluence. In addition, a bathymetric survey was conducted by USGS for Happy Camp, CA, that included the Klamath River, Indian Creek, and the local confluence. This data was collected on April 21 – 22, 2009 and is part of an ongoing USGS water temperature study (pers. comm. Paul J. Kinzel).

A Geographic Information System (GIS) Triangulated Irregular Network (TIN) terrain model was used to create the surface elevation model. During triangulation of a TIN or terrain, a common misrepresentation of geometry can occur when relatively high land surface elevations on opposite sides of the river are "connected," essentially crafting a dam across the channel geometry. To avoid this, bank toes were developed by shifting the previously digitized bank lines toward the channel centerline by 15 feet. Elevation data from the three bathymetric data sources (Reclamation, USGS, Woolpert) were stationed along these channel centerline and two bank toe lines to represent locations of known bed topography. From this, a series of interpolated channel points were developed to represent the below-water bank toes and the channel center, placed at 3-foot intervals to match the frequency of the terrestrial elevation data. Elevations were assigned to these interpolation points as a linear function between points of known bed elevation.

4.1.1. HYDRAULIC MODEL UPSTREAM OF IRON GATE DAM

This section discusses the data and information used for the cross section setup of the 1D HEC-RAS model and the Sedimentation and River Hydraulics – One Dimensional model (SRH-1D) (Huang and Greimann, 2010) for analysis upstream of Iron Gate Dam.

The 2001 bathymetric survey of the reservoirs was used for generation of the cross sections in the reservoir pool (JC Headwaters, Inc., 2003). The 2010 LiDAR data was used for the generation of the cross sections between the reservoirs. An ArcGIS (ESRI, Inc) TIN terrain model was used to generate a three dimensional surface for each reservoir and the LiDAR. The LiDAR data were not manipulated to account for the flow in the channel at the time of the flight.

Banklines, a centerline, and 493 cross-sections were delineated in GIS for 45.9 river miles. Figure 4-1 shows a portion of the cross sections delineated in the reservoir. Figure 4-2 shows a portion of the cross section delineated in the river reaches. The GIS data was processed using HEC-GeoRAS, an interface that provides tools in ArcGIS to process geospatial data for import into HEC-RAS. Banklines were manually adjusted where necessary in HEC-RAS to ensure that the top of bank was captured.

The Mannings roughnesses were set to 0.04 for the main channel and 0.06 for the overbanks.

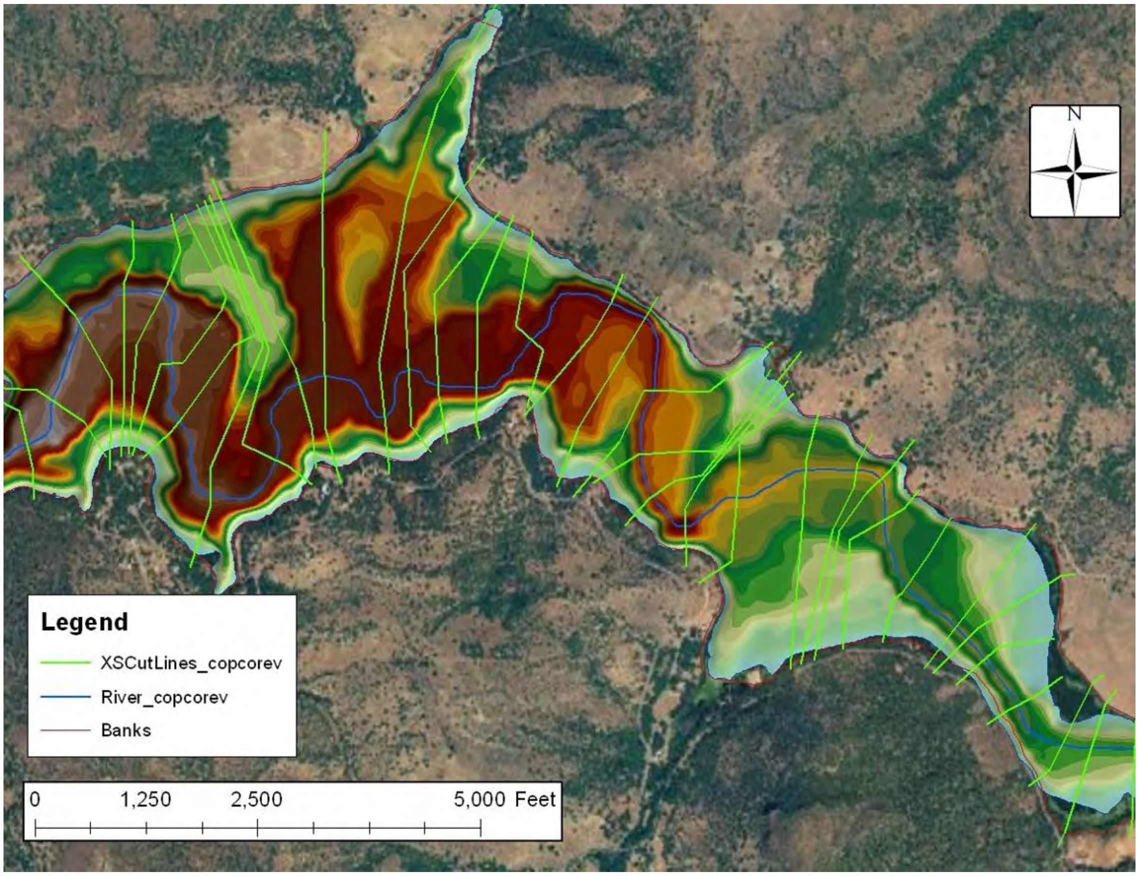


Figure 4-1. Cross sections in Copco Reservoir shown with bathymetric survey TIN and 2009 aerial photograph as background.

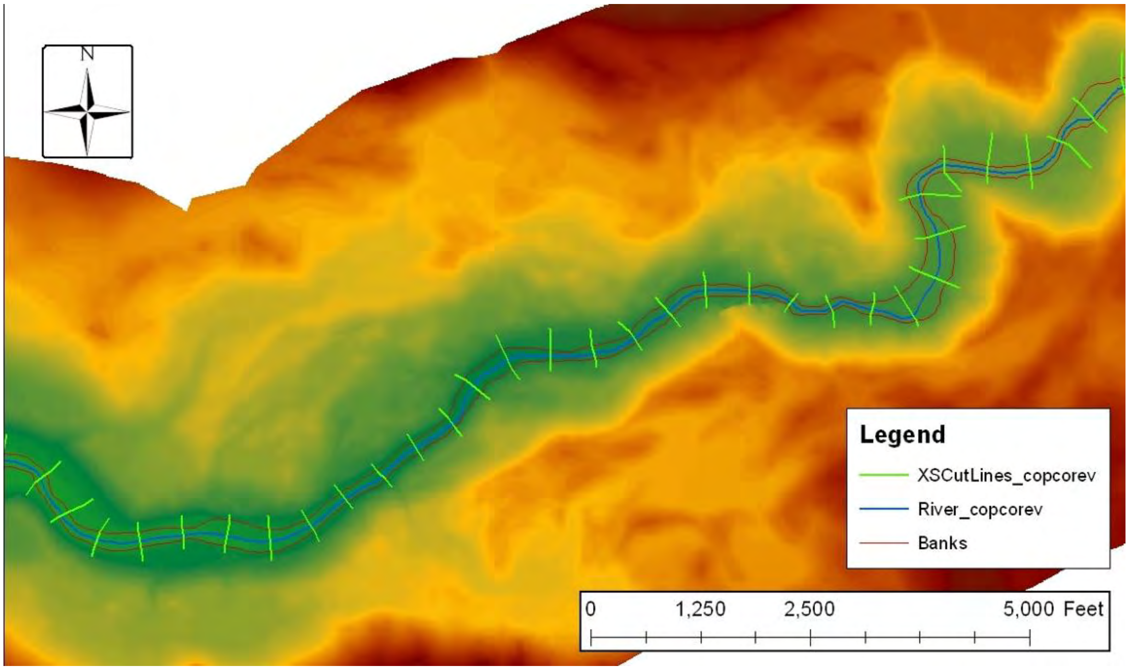


Figure 4-2. Cross sections in a river reach upstream of Copco Reservoir shown with LiDAR data TIN.

4.1.2. HYDRAULIC MODEL DOWNSTREAM OF IRON GATE

Bathymetric data was available from Iron Gate Dam to Happy Camp (RM 190 to 105) and this was merged with the 2010 LiDAR data. The wetting portion of the channel was eliminated from the LiDAR data and replace with the bathymetric data. A GIS TIN terrain model was then used to generate a three dimensional surface of the channel. Banklines, a centerline, and 692 cross sections, were delineated in GIS for 85 river miles. The terrain model was used to extract cross section elevations. The GIS data was processed using HEC-GeoRAS, an interface that provides tools in ArcGIS to process geospatial data for import into HEC-RAS. Banklines were manually adjusted where necessary in HEC-RAS to ensure that the top of bank was captured. The channel centerline and overbank flowpaths were digitized, and cross sections were automatically generated using HEC-GeoRAS at 1000 foot intervals along the digitized centerline. These cross sections were then modified in terms of spacing or extent to capture hydraulic controls and as well as to capture possible extent of inundation. In addition, cross sections were located more frequently in the reach from Iron Gate Dam to the Shasta River at approximately 500-ft spacing. This data was exported to HEC-RAS from HEC Geo-RAS where further model refinement could be conducted.

Ineffective flow areas and levees were added to cross sections where appropriate. A one-dimensional flow model such as HEC-RAS applies an averaged velocity to the entire wetted portion of a cross section. A reduced velocity can occur in a cross section if portions of a cross section are represented as providing conveyance where in reality little or no conveyance is provided by that portion of the cross section. In areas where no surface water connection will occur between two relatively low areas of a cross section until the intermediary high point is inundated (such as a much of the roadway in the valley) a levee was assigned. In areas where a cross section may get inundated from backwater, but where no surface connection exists from upstream (such as downstream of a bridge), an ineffective flow area was assigned.

Channel and overbank roughness was calibrated to two different datasets. Channel roughness was calibrated to longitudinal profile data, and the overbank roughness was calibrated to gage data.

Of the three bathymetric datasets (BOR, Woolpert, USGS), only the BOR dataset included water surface elevations along with the ground elevations. Daily flow data from the USGS gages (11516530, 11520500, 11517500, 11519500) corresponding to the data collection period (10/11/09 – 10/18/09) were run in the HEC-RAS model. A range of channel roughness values were applied to the geometry and the resulting water surface elevations were compared to the measured water surfaces from the survey. One value for channel roughness from Iron Gate Dam to Happy Camp was unable to match the surveyed water surfaces. A relationship between reach-average bed slope and roughness was developed such that the modeled water surface elevations matched the surveyed water surface elevations to an acceptable level. Figure 4-3 presents the reach averaged slopes and the resulting roughness values. Tributaries are shown for reference and not necessarily used to distinguish reaches used for slope averaging. Reaches were based on generic changes in geomorphology, typically changes between alluvial reaches and narrow bedrock reaches.

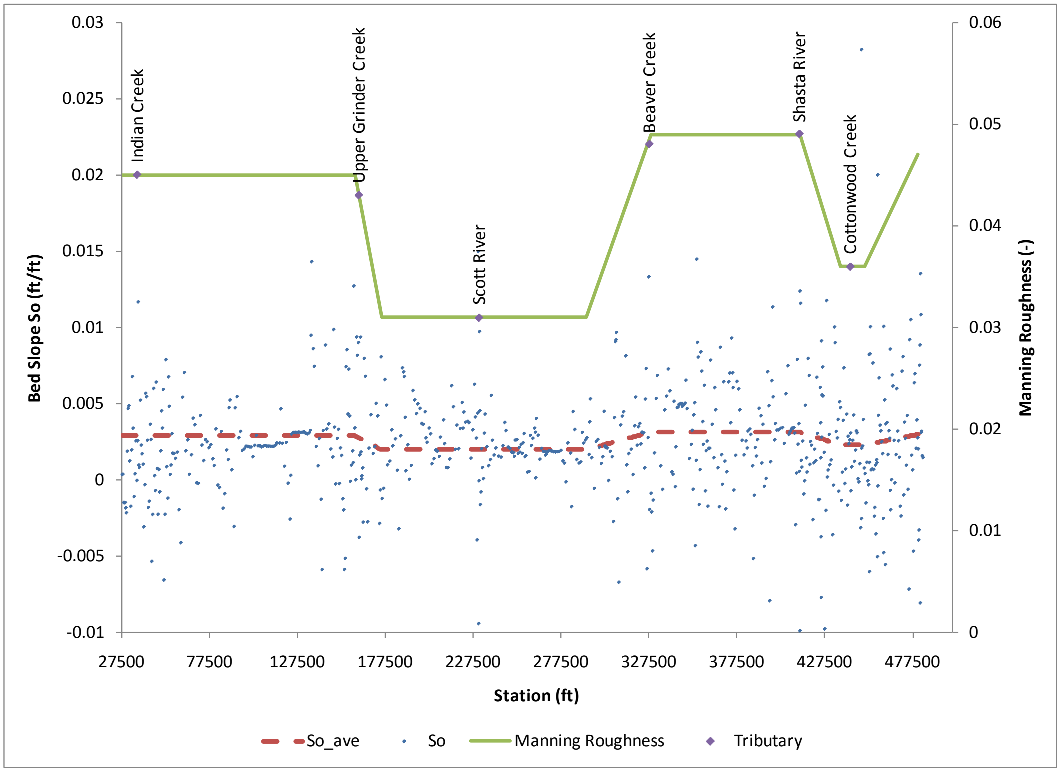


Figure 4-3. Calibrated Manning's Roughness for the main channel of the Klamath River.

Figure 4-4 presents the error in modeled water surface elevation relative to measured water surface for the data collected in October of 2009 by Reclamation. The measured water surface elevations were developed by locating all of the surveyed data that were within 5 ft of the model cross sections. Of the 792 cross sections used for the model from Iron Gate Dam to Happy Camp, 540 cross sections had data within 5 ft, giving 540 water surface elevations to be matched. The computed water surface elevations for the majority of the cross sections were within 1 foot of the measured and within 2 feet for most all of the cross sections.

The overbank roughness was calibrated by comparing modeled water surfaces to gage heights at Iron Gate Dam and at Seiad Valley (USGS 11516530, 11520500). A range of overbank roughness values from 0.055 to 0.08 were run in the model (with channel roughness as described above). Water surface elevations at the cross sections nearest the USGS gages were used for comparison. As can be seen in Figure 4-5 and Figure 4-6, the spread in measured values is on the order of, if not greater than, the spread in the modeled values based on varying overbank roughness. However, the lower roughness of 0.055 for the overbank areas more closely matches the high flow measured values.

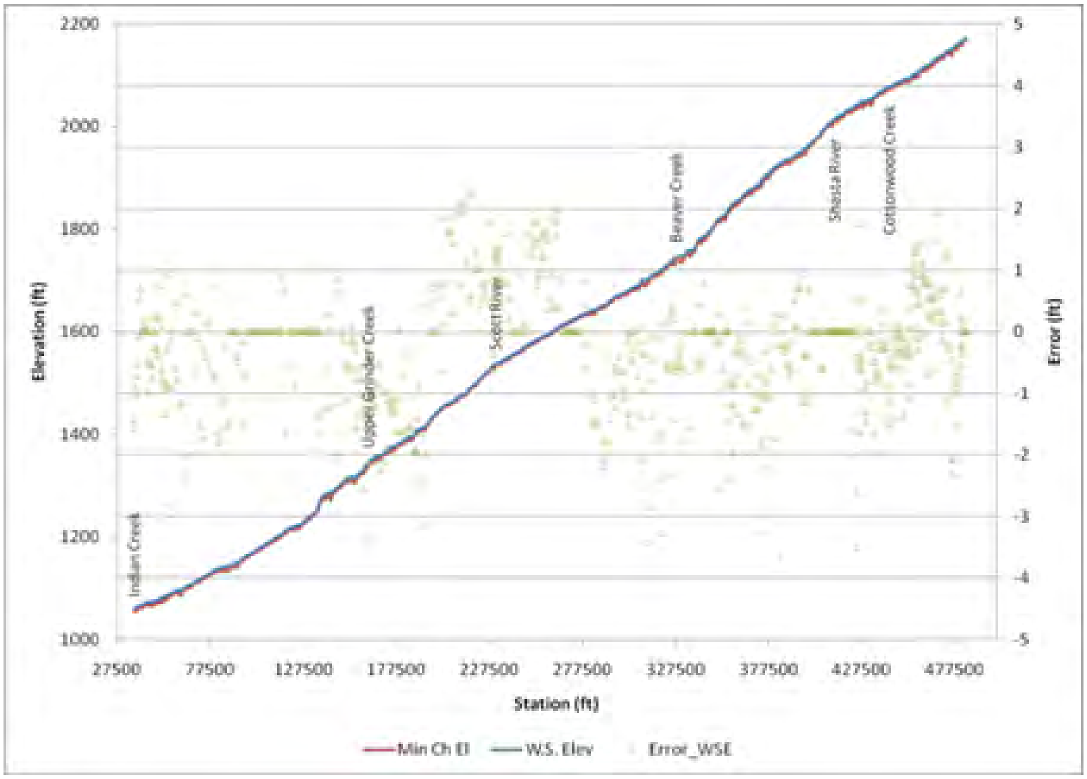


Figure 4-4. Comparison between measured and computed water surface elevations for the survey performed in October 2009.

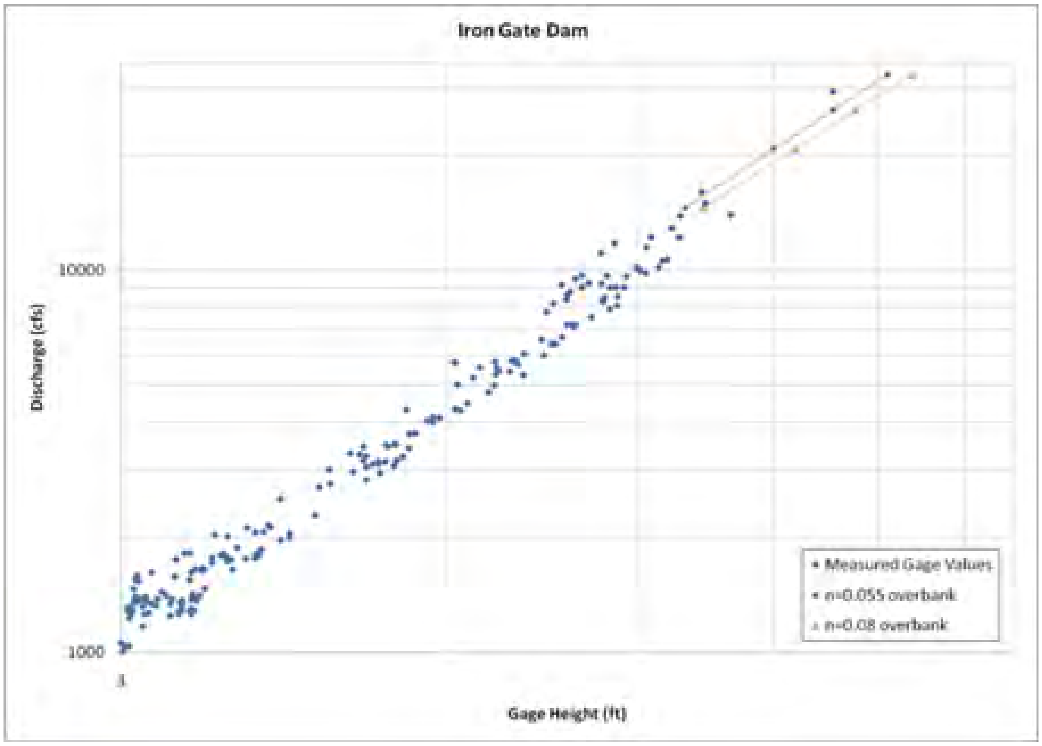


Figure 4-5. Calibration of HEC-RAS model to measurements at USGS gage below Iron Gate.

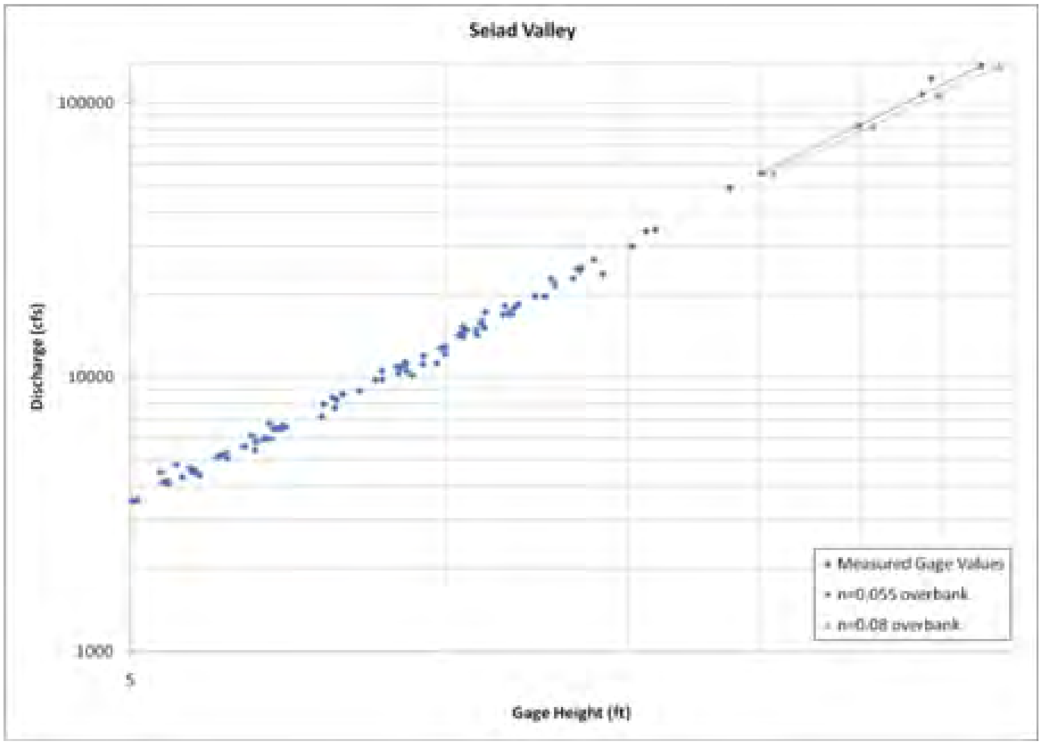


Figure 4-6. Calibration of HEC-RAS model to measurements at USGS gage near Seiad Valley.

4.2. Current Hydraulic Conditions

The bed profile and average water surface slope for the Reach from Keno Dam to Happy Camp, CA is shown in Figure 1-6. The HEC-RAS model was used to estimate reach average conditions from Iron Gate Dam to Indian Creek. The reaches are defined in Table 4-1. Results are limited to the reach from Iron Gate Dam to Indian Creek because this is the only reach where bathymetric data was collected to develop underwater cross sections. The average hydraulic properties for various stream flows are given in “Appendix B. Hydraulic Conditions Downstream of Iron Gate Dam”. The reach averaged hydraulic conditions are given in Figure 4-7 and Figure 4-8 for 2-year flood conditions. The properties for the median stream flow are given in Figure 4-9. Stream power is defined as γQS, where γ is the unit weight of water, Q is the flow rate, and S is the energy slope.

Table 4-1. Reaches for hydraulic and sediment analyses.

Reach	Approx Length (miles)	Upstream USGS RM
Iron Gate to Bogus Creek	0.5	190.1
Bogus Creek to Willow Creek	4.6	189.6
Willow Creek to Cottonwood Creek	2.7	185.0
Cottonwood Creek to Shasta River	5.4	182.1
Shasta River to Humbug Creek	5.5	176.7
Humbug Creek to Beaver Creek	10.5	171.5
Beaver Creek to Dona Creek	8.2	161.0
Dona Creek to Horse Creek	5.5	152.8
Horse Creek to Scott River	4.4	147.3
Scott River to Indian Creek	36.7	143.0
Indian Creek to Elk Creek	1.1	106.8
Elk Creek to Clear Creek	7.0	105.5
Clear Creek to Salmon River	33.5	98.6
Salmon River to Red Cap Creek	13.0	66.0
Red Cap Creek to Bluff Creek	3.2	53.6
Bluff Creek to Trinity River	6.0	49.5
Trinity River to Blue Creek	26.7	43.4
Blue Creek to Mouth	15.7	16.3

The reach averaged depth, channel velocity, and stream power decrease from Iron Gate Dam to Cottonwood Creek are given in Figure 4-7. The reach immediately downstream of Iron Gate Dam has a higher energy slope and narrower top width which increases the velocity relative to the next downstream reach. From Iron Gate Dam to Cottonwood Creek, the depth and velocity decrease as the top width increases and energy slope decreases. Depth, velocity, and stream power increase downstream of Cottonwood Creek as the flow and slope increases. There is another increase in velocity and stream power downstream of Shasta River caused by the increase in slope and stream flow rate. Downstream of the Shasta River to Beaver Creek, the channel is more confined and has a steeper slope than the reaches upstream or downstream of it. Downstream of Beaver Creek to Horse Creek, the energy slope decreases and top width increases causing a decrease in stream power. From Horse Creek to the Scott River, the energy slope stays relatively small and there is a slight decrease in top width which causes an increase in hydraulic depth and stream power. Downstream of Scott River, the flow and energy slope increase significantly causing an increase in stream power.

The results for the median flow show similar trends to the 2-year flood analysis, but the magnitude of the stream power is significantly less (Figure 4-9). The 2-year flood values are taken from Table 2-5.

The 100-year floodplain for the current conditions for the reach downstream of Iron Gate Dam to Happy Camp, CA is given in “Appendix G. Mapping of 100-year Flood Plain under No Action and Dam Removal Alternatives”. Based upon an analysis of the aerial photographs, there are several hundred structures within current 100-year floodplain downstream of Iron Gate Dam to Happy Camp.

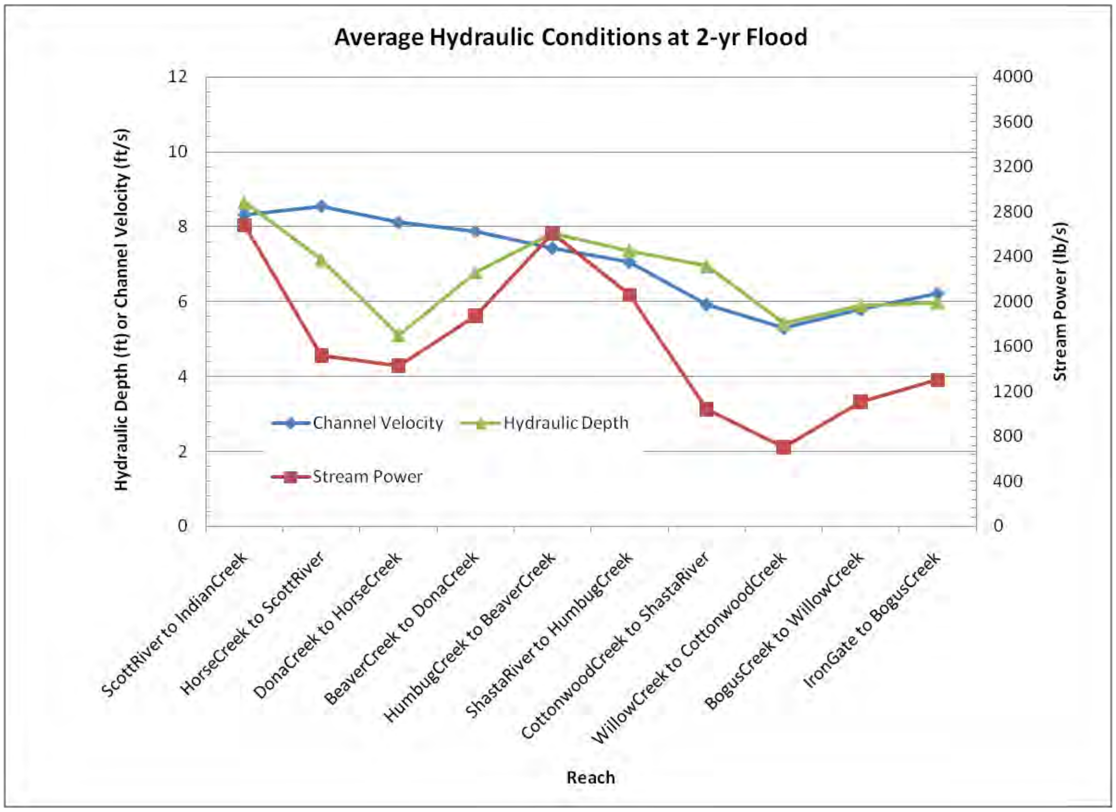


Figure 4-7. Reach averaged channel velocity, depth and stream power at 2-year flood conditions.

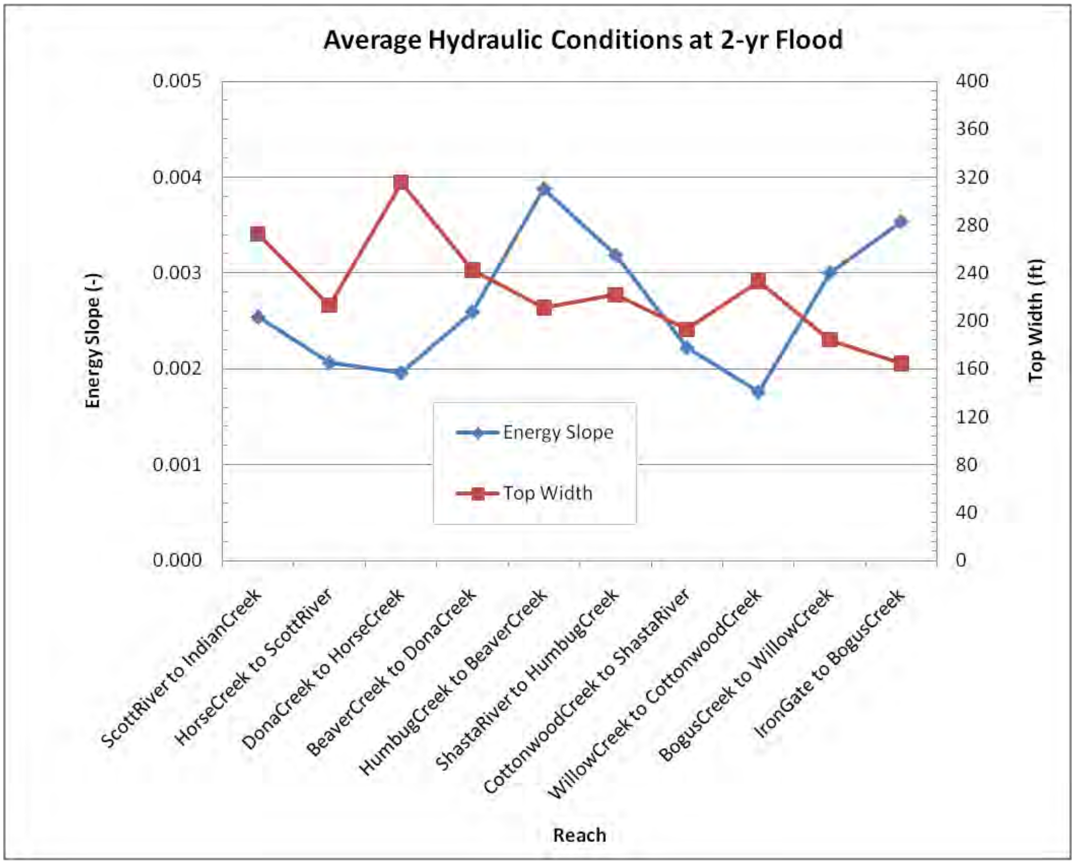


Figure 4-8. Reach averaged energy slope and top width at 2-year flood conditions.

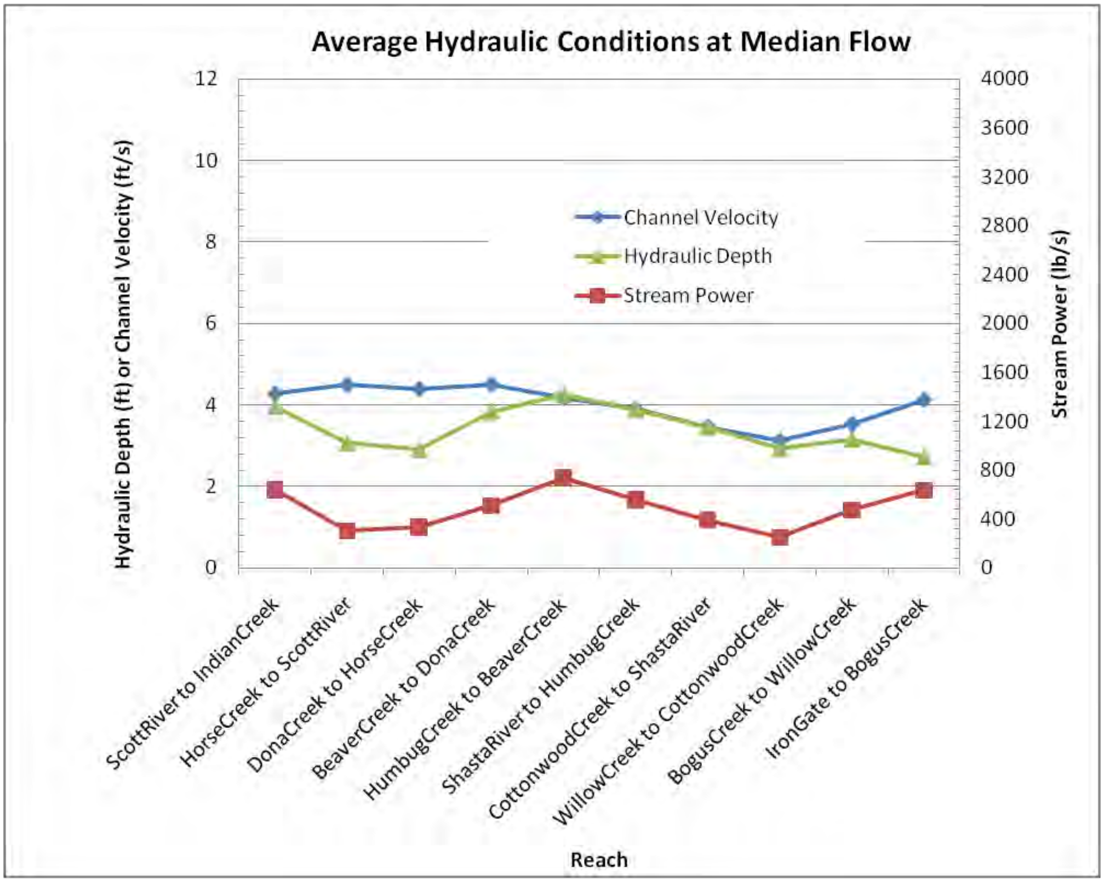


Figure 4-9. Reach averaged channel velocity, depth and stream power at median flow.

5. Existing Geomorphology and Sediment Transport Conditions

The existing conditions geomorphology and sediment transport of the Klamath River from J.C. Boyle Reservoir to the Ocean are described to give context for the changes that may occur as the result of the No Action and Dam Removal Alternatives.

5.1. Geological Setting

The geomorphic provinces along the Klamath River have a diverse geologic history of formation and deformation. In the upper watershed, from the Klamath Basin headwaters to Iron Gate Dam, the Basin and Range and Modoc Plateau geomorphic provinces have a physiography with subdued relief, low gradient streams, broad basins and many lakes and marshes. The Basin and Range province consists of Miocene age basalts with high permeability and internally drained basins. The ranges are block-faulted with intervening down dropped basins typical of the Basin and Range province in other areas. The Modoc Plateau Province consists of thick sequences of tuffs and basalt flows that form a relatively flat tableland physiography in part of the province. The region was extensively faulted during the late Miocene, forming a series of mountain ranges. Drainage systems were also disrupted, creating lakes in between the ranges. Quaternary age shield volcanoes and cinder cones also are common on the landscape and younger than the extensive basalt flows.

The Lower Klamath Basin, from Iron Gate Dam to the Klamath River mouth, consists of metamorphic and plutonic rocks that have a complex history of metamorphism and volcanism. Geomorphic provinces include the Cascade Range, Klamath Mountains, and Northern Coast Ranges. The Cascade Range Province consists of the Western Cascade and High Cascade volcanics. The western cascade rocks were formed during uplift and folding during the late Eocene to Pliocene. They include lava flows and pyroclastics and in places interbedded nonmarine and shallow marine sedimentary rocks. The composition of most of the rocks is andesitic, but ranges from olivine basalt to rhyolite. They are underlain by Eocene sedimentary rocks of the Hornbrook Formation or by pre-Cretaceous plutonic and metamorphic basement rocks. The Cretaceous Hornbrook Formation has about a 5,000-ft thickness near the California-Oregon border in the Hornbrook area and consists of conglomerate, sandstone, and siltstone. The High Cascade Range rocks overlie the Western Cascade rocks and are part of a time period of renewed volcanism, in which early flows in the group produced wide spreading flows and small shield volcanoes and fissures, being more basaltic. Later flows became more siliceous in composition, and thus, were more explosive, building large peaks in the Cascade Range.

The Klamath Mountains Province consists of rocks uplifted during the Nevadan orogeny in Late Jurassic time. These rocks are more resistant to weathering, and thus, form a major change from low-relief terrain to high-relief terrain with prominent peaks and ridges along the Klamath River near Cottonwood Creek. Rocks range in age from Ordovician to Late Jurassic and form a series of arcuate belts that are defined on the basis of lithology and have varying degrees of metamorphism. They include the Eastern Klamath belt, central Metamorphic belt, Western Paleozoic and Triassic belt and the Western Jurassic belt. The belts developed as accreted terranes during tectonic episodes of subduction along the continental margin.

Near the mouth of the Klamath River is the Northern Coast Range, which consists of a thick sequence of Mesozoic and Cenozoic sedimentary rocks that were deformed during the Cenozoic. Along the Klamath River, rocks of the Franciscan Formation dominate the landscape and are composed of metasedimentary and metavolcanic rocks as well as mélange, which form a hummocky landscape due to its tendency to develop landslides.

5.2. Geomorphology

This section provides geomorphic information relevant to the proposed dam removal on the Klamath River. Tasks include: (1) to provide baseline geomorphic data prior to the proposed dam removal for Iron Gate Dam to Happy Camp, CA; and (2) to interpret the geomorphology within the Iron Gate, Copco and J.C. Boyle Reservoir areas to help inform drawdown modeling scenarios and channel evolution following the dam removal.

In the upper watershed, from the Klamath Basin headwaters to Cottonwood Creek, physiography can be described as mostly subdued relief, low gradient streams, broad basins and many lakes and marshes (California Geological Survey, 2002). Sediment delivery from these areas to the reservoirs is low, due to a sparse drainage network, limited surface runoff, and the trapping of sediment in the basins, lakes and marshes of the upper watershed (FERC, 2004b; Stillwater Sciences, 2010). Near Cottonwood Creek, the watershed transitions into the Klamath Mountains Province that consists of rocks more resistant to weathering which have formed high-relief terrain with prominent peaks. Sediment delivery to the Klamath River is higher within this terrain due to the steep drainages that are able to mobilize, transport, and deliver more sediment during storms to the main stem (FERC, 2004b; Figure 5-1).

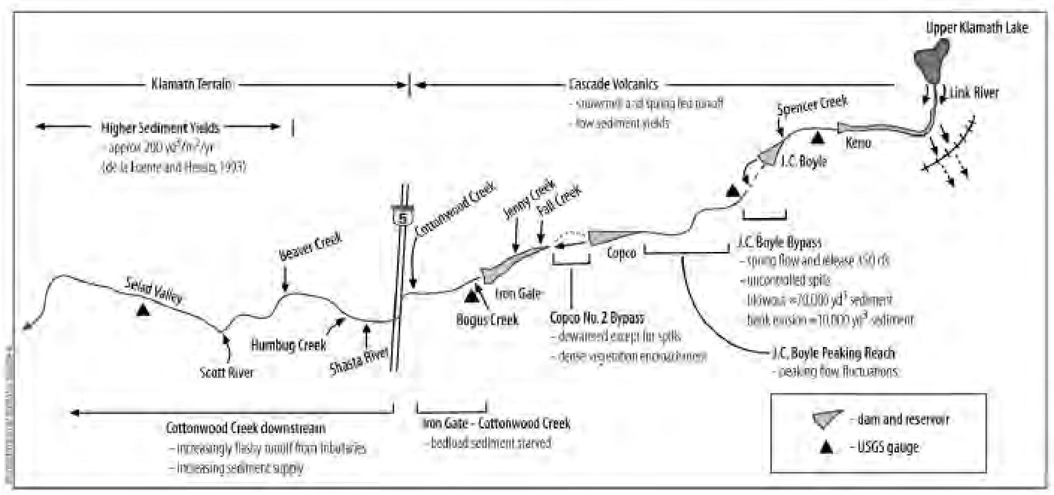


Figure 5-1. Reach Description from FERC (2004b).

5.2.1. DATA SOURCES

Several sources of existing data were used to develop geomorphic information for the study. Ayers (1999) produced geomorphic maps from the Klamath River estuary to Iron Gate Dam showing the extent of geomorphic features along the river corridor. Data from Happy Camp, CA to Iron Gate Dam were used most extensively and digitized in order to complement the extent of detailed modeling for the study. Rectified historical pre-dam aerial photography and topography were utilized from PacifiCorp, Inc., and JC Headwaters, Inc. (2002) to map pre-dam geomorphic features. These were compared to bathymetric data developed by JC Headwaters, Inc. (2002). Alluvial features mapped by CH2MHill as part of the FERC Fisheries Final Technical Report are also reviewed and discussed in the section, although they are not directly comparable to the geomorphic information developed in this study (PacifiCorp, 2004). PWA, Ltd. (2009) provided geomorphic descriptions of the pre-dam geomorphology and habitat, mostly related to the river channel and riparian vegetation. Information related to reservoir slope stability is also used in this section and was developed by PanGeo, Inc. as part of the PWA (2009) study.

The detailed geomorphic maps are located in Appendix H. Geomorphic Mapping.

5.2.2. DOWNSTREAM OF IRON GATE DAM

During 1997, Ayers (1999) conducted field work to map and interpret geomorphic features along the Klamath River from Iron Gate Dam to the Klamath River estuary. During the course of the study, features including unvegetated bars, floodplain, vegetated bars, stream terraces, landslides, bedrock, and tributary alluvial fans were mapped and described for each reach. Maps, produced for the USFWS, were not available and, therefore, were recreated in digital form for this study for the reach from Iron Gate Dam to Happy Camp, CA. To complete this task, the original draft mapping by Ayers (1999) was digitized using the USGS

7.5' topographic maps and digital terrain data produced by Woolpert, Inc. An initial reconnaissance was also conducted for this study reach to review the Ayers geomorphic mapping and determine if any features had changed along the river since the 1999 field mapping. Descriptions of the reach from Happy Camp, CA to the Klamath River estuary are derived entirely from Ayers work; field reconnaissance was not performed for this reach. Maps are provided in the Geo_Spatial Base Map Data Dictionary for this project (Reclamation, 2010b). Features depicted on the geomorphic maps are described below in sections 5.2.2.1 through 5.2.2.6. The reaches are shown Figure 5-2.

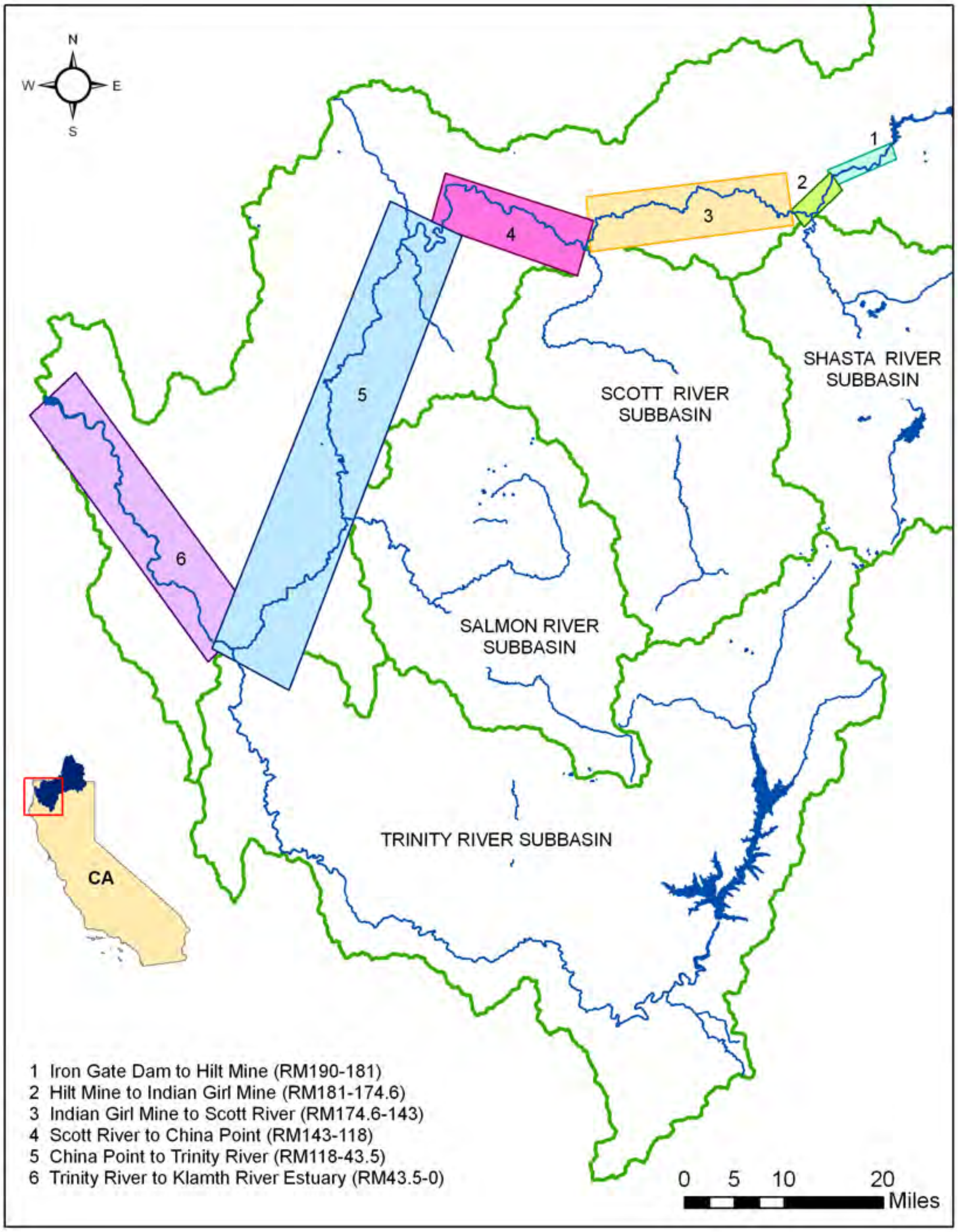


Figure 5-2. Map of Geomorphic Reaches.

5.2.2.1. Iron Gate Dam to Hilt Mine (USGS RM 181-190)

The first reach downstream from Iron Gate Dam consists of a narrow floodplain and terraces confined by bedrock hills of the Western Cascade Volcanics and sedimentary rocks of the Cretaceous Hornbrook Formation. The channel is mostly single thread with a few areas of split flow that form mid-channel bars and side channels of short length. Most of the bars are at least partially vegetated, leaving few areas of exposed bars in the reach. Main tributaries that enter the reach include Brush Creek, Bogus Creek, Little Bogus Creek, Willow Creek, and Cottonwood Creek. These tributaries form alluvial fans at their confluence with the Klamath River, which are all relatively small in area with the exception of Cottonwood Creek, which forms a large alluvial fan and terraces related to the tributary. Klamath River terraces are carved into the Cottonwood Creek alluvial fan deposits, suggesting that sediment input from Cottonwood Creek is limited to areas near and within the main channel of Cottonwood Creek.

5.2.2.2. Indian Girl Mine to Hilt Mine (USGS RM 174.6-181)

In this reach, the change in bedrock lithology marks a transition in channel confinement where the more resistant metasedimentary and metavolcaniclastic rocks of the Western Paleozoic and Triassic belt create a narrow canyon with narrow alternating terraces along the reach length. Few bars exist in this reach; at RM 179, a mid-channel bar appears to be associated with the Williams Creek alluvial fan, which enters at the upstream end of the high terrace of the Randolf Collier rest area. The Shasta River enters from the south near RM 177 and forms a small gravel bar at its confluence with the Klamath River. The lack of a large alluvial fan at the confluence or formation of bars downstream of the confluence indicates a limited coarse sediment supply from the Shasta River.

Ayers (1999) notes, however, that the supply of suspended sediment could be substantial. The only other notable tributary in the reach is Ash Creek, which forms a fan of negligible size at its confluence with the Klamath River. Ayers also notes many features associated with in stream mining, including low cobble-boulder benches and bars and a few wing-dam pits.

5.2.2.3. Scott River to Indian Girl Mine (USGS RM 143-174.6)

From Indian Girl Mine, the river valley broadens slightly within the canyon and allows for the preservation of broad, gravelly terraces that have been extensively mined. In areas not obscured by mining, overflow channels can be observed on the terrace surfaces. Unvegetated bars are more prevalent in this reach and exist as point bars along the inside bends of channel meanders as well as mid-channel bar and side channel complexes. The channel maintains a mostly single thread meandering morphology with some areas of split flow around mid-channel bars.

At Gottville, CA, several tributaries enter from the north and form a large alluvial fan complex that constricts the river and forms the Langley Falls rapid and associated large eddy directly upstream.

Downstream of Gottville, CA from RM 166 to 161.5, the river valley narrows to about half the width of that upstream and flows through ultramafic rocks of the Cretaceous Franciscan complex. Low terraces and point bars exist in this reach and have been extensively mined with tailings piles still visible on some of the surfaces. Channel morphology is less sinuous than that upstream and is single thread with a few small mid-channel bars. At the downstream end of this subreach, the Miller Gulch alluvial fan constricts the channel, forming an eddy between the upstream end of the Miller Gulch fan and a small tributary fan from the opposite bank.

From Miller Gulch (RM 161.5) to Horse Creek (near RM 147), the river valley broadens again to include terraces with at least two levels and gravel bars. In several locations, the channel pattern increases in sinuosity, which is closely related to large alluvial fans that force the channel to the opposite bank and form split flow around large alluvial bars. A narrow section exists in this reach from about RM154 to 150 and is confined by bedrock on both sides of the river or by the Kohl Creek alluvial fan near RM152. A few lateral bars exist in this reach; however, most are too small to be mapped. From RM150 to Horse Creek, the river returns to a broader valley with a large paleochannel in the Cherry Flat area that has been extensively placer mined.

From Horse Creek to Scott River (near RM 147 to 143), the river valley narrows and is confined by bedrock on both sides of the river. Terraces and bars are restricted to the insides of meander bends. Several small tributaries enter in this reach, forming steep alluvial fans at the confluence with the Klamath River, some of which have narrow terraces cut on their front edges. Channel morphology is single thread with a few small unvegetated mid-channel bars and point bars.

In this reach, major tributaries that provide sediment to the Klamath River include Horse Creek, Beaver Creek, Lumgrey Creek, Empire Creek, Dutch Creek, and Humbug Creek. Other minor tributaries include Sambo Gulch, Barkhouse Creek and Little Humbug Creek.

5.2.2.4. Scott River to China Point (USGS RM 118-143)

Downstream of Scott River from RM 143 to 132, the extent and height of unvegetated gravel bars increases and bars become more prevalent with discontinuous narrow alluvial terraces forming along the canyon margins. Large alluvial fans control river position from RM 141 to 139 along the south side of the river; sediment for these fans is generated from the Slinkard pluton, which are highly erodible plutonic rocks.

At Seiad Valley, large alluvial fans from Seiad Creek, Little Grider Creek, and Grider Creek form a wider alluvial valley in which terraces are cut on the front edges of the fans and large bars and riffles are formed along the river channel as a result of tributary sediment contributions to the Klamath River. Ayers and Associates (1999) noted that sediment deposition was significant from Grider Creek during the 1997 storm event and may have been at least partially mobilized from 1987 burned areas in the Grider Creek watershed. The 1997 peak flow at Iron Gate Dam was 20,500 cfs and was 117,000 cfs at Seiad Valley. From RM 130 to 121.5, the Klamath River flows through a sinuous bedrock canyon with unvegetated bars located on the insides of meander bends. Strath terraces and bedrock cored bars are prevalent in this reach.

From RM 121.5 to China Point, the canyon narrows as it enters bedrock of the Jurassic Galice Formation. Bedrock benches form along the channel margins. At China Point, an extensive unvegetated gravel bar is located on the inside of the bend along with a higher alluvial terrace. On the south side of the river, a paleochannel is elevated above the present channel. Major sediment contributing tributaries in this reach include: Thompson, Fort Goff, Portugese, Grider, Walker, O’Neil, and Macks Creeks. The tributaries are designated as major sediment contributors based on their large fans and recent observations of sediment contributions during the 1997 storm event (Ayers and Associates, 1999).

5.2.2.5. China Point to Trinity River (USGS RM 118-43.5)

Reaches from China Point to the Klamath River Estuary were not field checked during the course of this investigation. Observations for these reaches are summarized from Ayers and Associates (1999), who conducted an extensive field investigation of these reaches.

From China Point to Deason Flat (RM 118-104), the channel is narrow with numerous strath terraces that have been extensively mined. Well developed bars and riffles are formed at tributary confluences and meander bends, and in some areas, are also identified as relict mining features. The lower 3 miles of this reach (RM 107-104) contains a greater number of unvegetated bars, which are formed by sediment inputs from Elk and Indian creeks and channel constrictions downstream of RM 104. Tributaries in this reach contain large Quaternary landslides, with Indian Creek watershed containing the most of any tributary.

From Deason Flat to Dutch Creek (RM 104-92), the Klamath River flows through a narrow bedrock canyon with low bedrock benches and gravelly veneers. A narrow, inner bedrock channel is carved below the benches. Interspersed in this reach are wider sections having small strath terraces, that have been extensively mined, and unvegetated gravel bars formed by flow expansion as the river exits from more constricted reaches and backwater effects where the river again enters a more constricted reach. This reach also contains notable Quaternary landslides along the main stem, the largest of which is located on the west side of the river from RM 98.5 to 93. Major Sediment contributing tributaries include Independence and Clear Creeks -- both watersheds burned during the 1987 forest fire.

From Dutch Creek to Trinity River (RM92-43.5), the Klamath River is contained in a narrow bedrock canyon with intermittent alluvial reaches. This reach also includes the wider alluvial valley at Orleans (RM 58.5). Geomorphic features include strath terrace and bars, alluvial terraces and bars, bedrock benches and alluvial fans. Numerous Quaternary landslides are located along the river and interact with the river through sediment contributions and controlling channel position. This reach is the downstream limit of channel mining on the Klamath River. Major sediment contributing tributaries include: Salmon River, Trinity River, Bluff Creek, Camp Creek, and Ukonom Creek.

5.2.2.6. Trinity River to Klamath River Estuary (USGS RM 43.5-0)

From Trinity River to Cappell Flat (RM 43.5-35), a narrow bedrock canyon with few bars and no floodplain or terraces exists, and is primarily bedrock controlled. Landslides and alluvial fans are less common compared to upstream reaches, but locations still exist where these features have temporarily dammed the river based on remnant boulders in the channel and deposits on opposite banks.

From Cappell Flat to Starwein Flat (RM 35-10), The Klamath River flows through a narrow, confined valley with minimal floodplain and terraces. Terraces that are mapped are formed at tributary confluences or behind large bars. The bars are well developed and are either alternate bars formed in straighter reaches or point bars formed at meander bends. The extent of the bars increases in the downstream direction. Tributaries may create split flow channels, mid-channel bars, and riffles at their confluences with the main stem. Major sediment contributing tributaries include: Blue, Pecwan, Cappell, Bear, and Tectah Creeks.

From Starwein Flat to the mouth (RM10-0), the river transitions into a wide valley with floodplain surfaces and narrow terrace remnants. Well developed bars of variable height are located along the reach; several large pools and few riffles are formed in this reach. Turwar Creek is the only major sediment producer in this reach, contributing mostly fines to the Klamath River.

The Klamath River mouth experiences frequent flooding and has a spit formed across its mouth that is destroyed during floods and reformed by sediment reworking following floods. Ayers and Associates (1999) document several historical accounts that describe conditions similar to present day at the Klamath River mouth, which leads Ayers to conclude that present sediment deposition is similar to deposition during early settlement (mid-1880’s).

5.2.3. COMPARISONS TO PREVIOUS GEOMORPHIC MAPPING

Based on reconnaissance from Iron Gate to Happy Camp on the Klamath River, channel changes since 1999 along the road have been minor. Lateral channel positions have remained very similar due to the bedrock control that is prevalent throughout the Klamath River downstream of Iron Gate Dam. Bars have remained in similar locations for the most part since the channel mapping in 1999. Through historical photo analysis, Ayers (1999) observed that even over the historical period, channel changes were minimal and channel bars remained in similar locations. During the course of our field reconnaissance in 2009, most of the changes since 1999 are in the amount of vegetation on gravel bars. In 1999, Ayers described many bars as unvegetated while in 2009 these bars have young willows established on their surfaces. It is likely that in 1999, the bars had been recently scoured by the 1997 flood and had remained relatively vegetation free for the 1999 field work. A few areas had bars that had reduced in size or that had lost small side channels following bar attachment to stream banks or where multiple mid-channel bars had coalesced. A few other areas were modified in Ayers mapping based on field observations. For example, near RM155 and 156, an additional terrace was added to the mapping, splitting Ayers single terrace into 2 terraces.

Table 5-1. Changes made to Ayers (1999) mapping based on 2009-10 field observations and aerial photography

River mile	Description of changes
185	Added vegetated bar on right bank
184-183	Unvegetated bar is now vegetated
182-181	Unvegetated bar is now vegetated with young trees
181	Osburger Gulch: added small terrace cut on alluvial fan edge
173-172	Unvegetated bars are now vegetated
172-171	Humbug Creek: changed terrace to large bar
171-170	Some side channels filled in with islands attached to banks
169	Unvegetated bar has grown laterally
167	Low bar is only located along inside bend as a point bar, does not extend along slope in a narrow strip
164-163	Unvegetated bar is now vegetated
158-157	Island along left branch just downstream of split flow is gone
157	Bar on right bank is now vegetated
156	Bars are now vegetated with willows
156-155	Two terraces mapped on left bank rather than one
154	Extended bar on right bank further toward road
153	Unvegetated bar is now vegetated
151-150	Unvegetated bars are now vegetated
150	Split flow is gone, bar is now attached to bank and vegetated
147	New island developed
146	New island developed
146-145	Bars are now vegetated with willows
144	Clipped fan toe is now vegetated
143	More bars are unvegetated

River mile	Description of changes
142-141	Unvegetated bars are vegetated with willows
138-137	Island merged with point bar to form a single bar; side channel is filled in
135-134	Unvegetated bar has decreased in size
133	Uvegetated bar is now vegetated along left bank
133-132	Island downstream of Seiad Bridge has increased in size
131-130	Modified terrace mapping based on LiDAR
130	Island decreased in size since 1999
128	Bar is now vegetated with willows
127	Weak side channel and island developed since 1999
127-126	Bar near Fort Goff Creek is now vegetated with willows
125	Unvegetated bar is now vegetated
122	Small bar is now vegetated
118-117	Small island mapped in 1999 along left bank across from China Point is not present, other nearby bars remain unvegetated
109-108	Bar is now vegetated with willows
107	Portion of low bar on right bank is now vegetated

Alluvial features were mapped by CH2MHill from Iron Gate Dam to Seiad Valley. The alluvial areas correspond to areas that were observed to have little vegetation or linear alignments of young vegetation and scoured surfaces or clean sand, gravel and cobbles, indicating recent fluvial modification. These areas had to be located within the 2 to 5 year stage of flow events along the river. Submerged bars were also included in the mapped alluvial features when observed. The alluvial features mapped by CH2MHill and areas mapped as unvegetated bars in this study have similar extents in many locations from Iron Gate Dam to Seiad Valley. Some of CH2MHill's alluvial features are also mapped on Ayers (1999) terraces in places where the terraces are unvegetated or have young vegetation. Submerged bars were not mapped in this study; such that, none of CH2MHill's submerged alluvial features are included within the river channel mapping.

5.2.4. COPCO RESERVOIR HIGH POOL TO OREGON-CALIFORNIA STATE LINE

The mapped reach extends from RM 203 at the high pool of Copco Reservoir to RM 209 near the Oregon-California state line. Geomorphic surfaces were mapped in this reach in order to provide an analog to geomorphic surfaces that are currently inundated by the reservoirs. Channel planform is single thread with split flow around vegetated islands. The channel has a low sinuosity and is almost straight in some sections within this reach. Floodplain areas are about 2-5 feet above the channel and have irregular topography with grassy vegetation and some woody riparian vegetation. These surfaces typically have a dark brown soil that is mostly fine-grained with sandy and silty sediments (Figure 5-3; Figure 5-5). The most extensive surfaces within this reach are stream terraces adjacent to the channel. Terraces are grouped into younger and older map units. The younger terraces are about 5-10 feet above the channel with grasses and shrubs and relict channels or overflow channels on their surfaces (Figure 5-4). Soils have a dark brown sandy surface horizon while subsurface horizons are sandy with rounded pebbles and cobbles. The older terraces are about 15-20 feet above the modern channel and may have pines and other grasses on their surfaces. From soils that were observable, these surfaces also have dark brown soils with rounded cobbles and occasional boulders. Due to the narrowness of the valley, the terraces typically alternate as the channel traverses from side to side across the north-south trending valley. Klamath Hot Springs, near RM 206, is located along the east side of the Klamath River and forms a wetland area on the low terrace surface. Other springs are noted on the hillsides of the USGS 7.5’ topographic map.

Figure 5-3. Examples of geomorphic surfaces in reach from Copco high pool to Oregon-California state line; a) floodplain surface and b) younger terrace.

Alluvial fans from small drainages issue from the hillsides and deposit on the surfaces of many of the terraces in the reach; but the fans are located too far from the channel to contribute any significant amounts sediment to the river or to exert control on river morphology. Alluvial fans from larger drainages form more expansive deposits that extend to the river channel contributing sediment to the channel through debris flows and erosion by the Klamath River. There are also larger alluvial fan and terrace remnants that are about 40-50 feet above the channel and have been isolated from channel processes for thousands of years. These surfaces are largely vegetated by oaks and are composed of large cobbles and boulders. Steep scarps are formed along their margins. Debris flow processes are still active on the surfaces of these features, delivering sediment from hill slopes during intense rainstorms. In a few areas, channels are incised into these surfaces to the Klamath River, but for the most part the sediment is deposited in the upper part of the surfaces.

The major tributaries that enter this reach include Long Prairie Creek, Edge Creek, and Shovel Creek. Long Prairie Creek and Edge Creek enter from the north, and drop steeply into the Klamath River canyon to form alluvial fans at their confluence with the Klamath River. Shovel Creek is a larger, lower gradient drainage with a wide floodplain, riparian corridor, and multiple channels near the confluence with Klamath River. When stream terraces or alluvial fans are absent, the Klamath River flows against bedrock of the Western Cascade volcanic. Hill slopes are sparsely vegetated and have colluvial deposits that have formed on slopes.

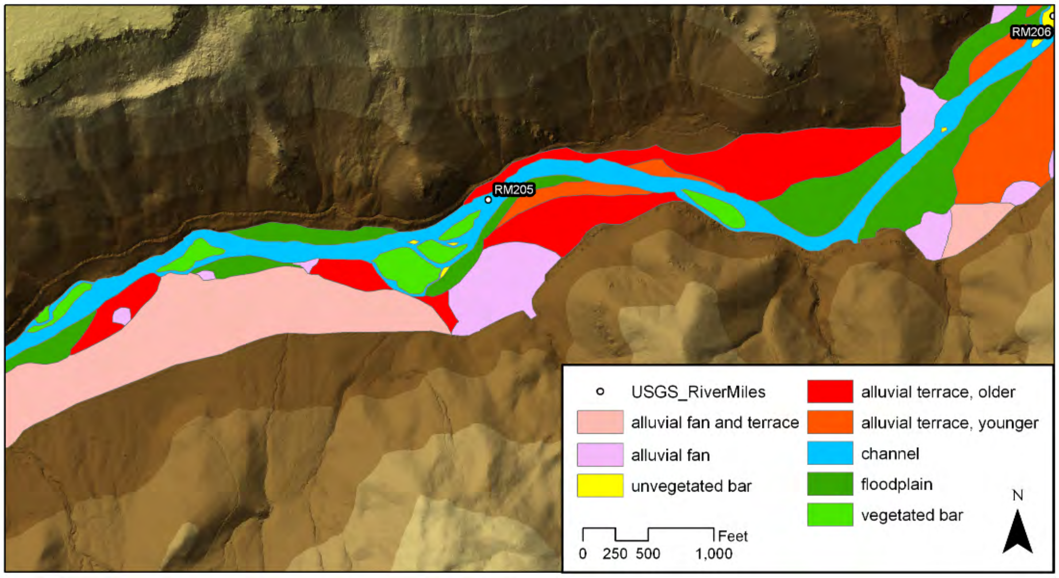


Figure 5-4. Example of mapping in the Copco analog reach from RM 203 to 209

Figure 5-5. Map unit descriptions, Copco Reservoir high pool to California-Oregon state line (RM 203-209)

Description	Map unit	Landscape Position	Materials
Channel	Qa3	same	Sand and cobbles
Unvegetated bar	Qa2	Adjacent to channel	Sand and cobbles
Vegetated bar	Qa1b	Adjacent to channel	Sand, silt and cobbles
floodplain	Qa1a	2-5 ft above channel	Sand and silt
Alluvial terrace, younger	Qt2	5-10 ft above channel	Sand, silt and cobbles
Alluvial terrace, older	Qt1	15-20 ft above channel	Sand, silt and cobbles
Alluvial fan	Qaf	Adjacent to hill slope, may or may not extend to river channel; height above channel varies	Cobbles and boulders in a sandy matrix
Alluvial fan and terrace	Qaf/Qt	Extends from hill slope to channel; height above channel varies	Ranges from cobbles and boulders in a sandy matrix to cobbly sand and silt

5.2.5. RESERVOIR AREAS

Geomorphology of the reservoir areas is delineated based on historical aerial photography and topographic maps that were rectified by Pacificorp (2004) and Eilers and Gubala, Inc (2003).

5.2.5.1. J.C. Boyle Reservoir

At J.C. Boyle Reservoir, pre-dam aerial photography from 1952 shows a flow expansion zone at the upper end of the reservoir where the river exits from a steep, narrow canyon with multiple rapids or riffles visible on the aerial photography. The river flows west, and then turns abruptly to the south as it encounters bedrock and alluvial fan deposits from an unnamed tributary. A large pool is formed at this location and remains in the bathymetric data collected in the reservoir area. Channel morphology was mostly single thread, with an area of split flow around a semi-vegetated island upstream of the Highway 21 Bridge and a few small side channels in the reach (Figure 5-6). From RM 228 to 226, the river corridor is wide enough to preserve some alluvial surfaces. Spencer Creek enters from the north and forms a large alluvial fan that extends to the river channel with, perhaps, a narrow floodplain surface cut on its edge. The tributary channel was multi-threaded in 1952 and probably supported wetland environments near its confluence with Klamath River. Downstream of Spencer Creek, extensive terrace surfaces less than 5 feet above the river channel were located on the left and right banks. Portions of these surfaces may be unvegetated bars that were modified frequently during larger peak discharges; however, the surfaces appear to be modified in 1952 photography and could not be delineated.

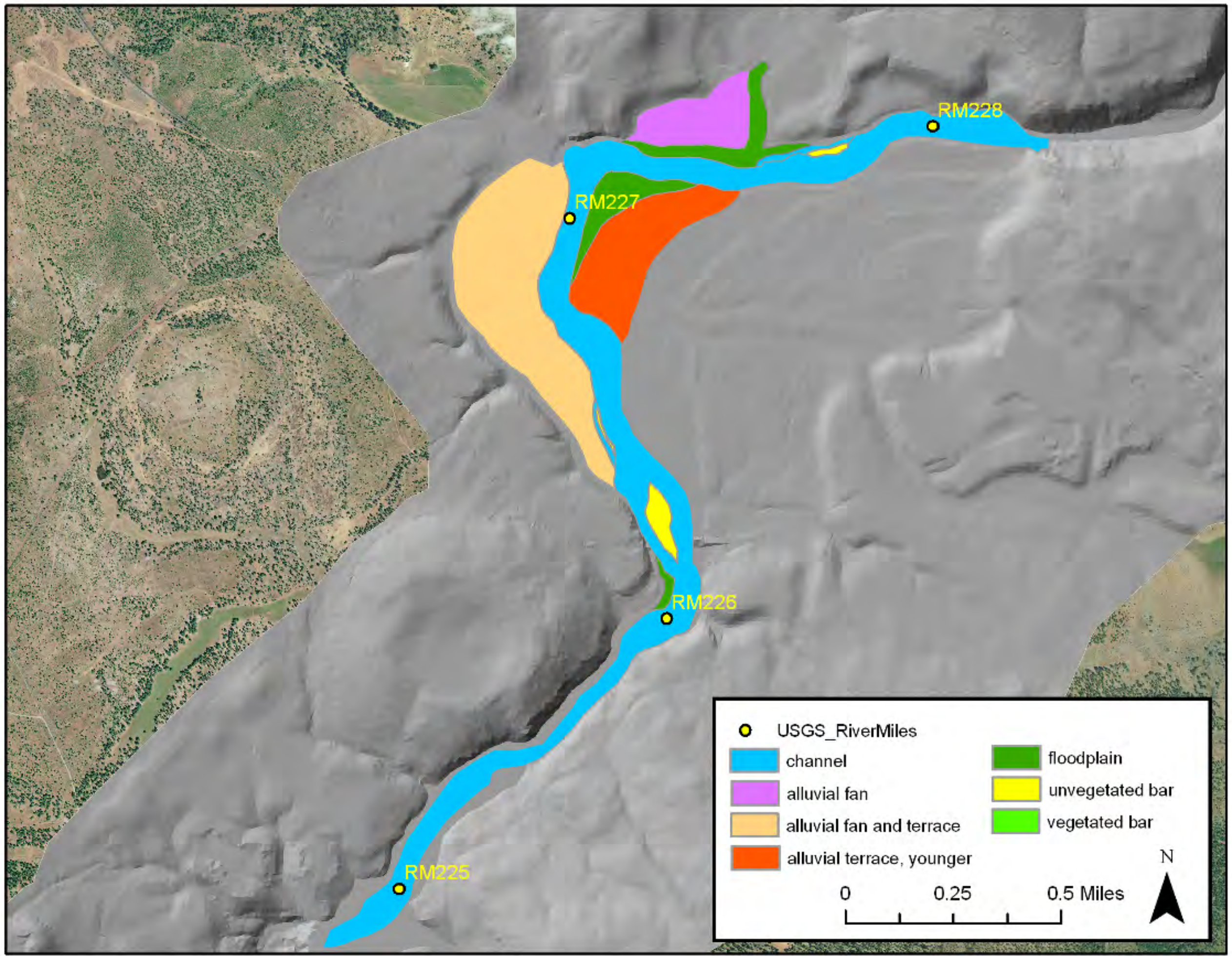


Figure 5-6. Geomorphic map of J.C. Boyle Reservoir.

5.2.5.1. Copco

Pre-dam geomorphology was interpreted using historical topographic maps of the reservoir area that were developed prior to inundation. The historical channel through Copco Reservoir consisted of asymmetrical meanders, controlled by bedrock on the outer bends. Deep pools were probably located in these bends; a couple of pools can still be observed in bathymetric data in the SW1/4 of section 27 and in the NW1/4 of section 35. In the upper portion of the reservoir from the high pool to about USGS RM 200, the channel was a mostly single-thread, sinuous channel with broad asymmetrical meanders. Terraces were located along most of the reach, and were mostly 5-10 feet above the river channel, which would correspond to the younger terrace in reaches mapped outside of the reservoir areas. In addition, there were areas designated with willow and brush vegetation, which could correspond to either floodplain areas or young alluvial terraces.

Downstream of RM 200 to about RM 199, the channel is more sinuous, perhaps due to the canyon constriction which begins near Copco 1 Dam. In this location, pyroclastic flows blocked the drainage, forming an ancient lake in the vicinity of Copco Reservoir. In this reach, the channel contained a greater number of vegetated islands, some abandoned channel meanders, and wetland or floodplain environments. Most surfaces in the reach were less than 5 feet above the river channel based on historical topography. A few terraces of 5-10 feet and 15-20 feet also exist in the reach, but are more limited in extent. A notable paleochannel, which was abandoned by the Klamath River prior to the historical period, is now partially occupied by Beaver Creek that enters Klamath River from the north. Downstream of RM 199 to the high pool of Iron Gate Reservoir, the Klamath River enters a narrow canyon incised into the pyroclastic deposits of the High Cascade Volcanics; only a few narrow terraces exist in this reach.

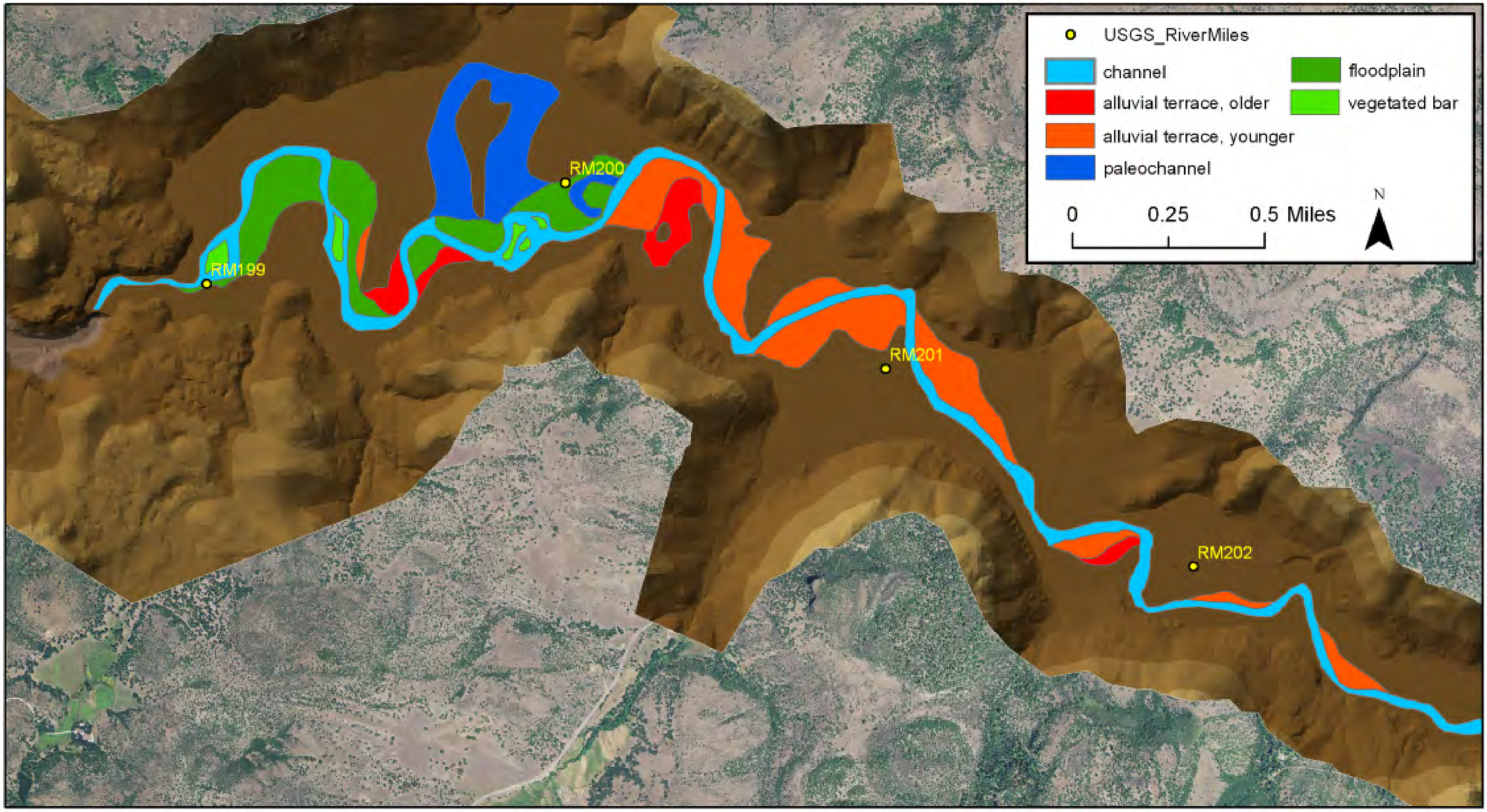


Figure 5-7. Geomorphic map of Copco Reservoir.

5.2.5.2. Iron Gate

The reach of the Klamath River through Iron Gate Reservoir consists of a confined bedrock canyon formed in andesite of the Western Cascade Volcanics. Based on 1955 aerial photography and pre-dam topography, terraces were located along the insides of meander bends and near tributary confluences and were typically less than 10 feet above the river channel based on the 10ft contours on the topographic map (Figure 5-8). These surfaces would correspond to younger terraces mapped in adjacent reaches without reservoirs and therefore would consist of an organic-rich, sandy surface horizon with gravelly materials below the surface horizon. Tributaries along this reach had mostly minor alluvial fans at their confluences with the Klamath River, likely indicating that the Klamath River was readily able to erode material in the main channel deposited by tributaries. A few alluvial fans exist that controlled the historical river position along this reach, but these are limited in extent.

Historical channel morphology is single thread with uncommon split flow areas and vegetated islands. A few unvegetated gravel bars are also visible in the 1955 aerial photography. Channel constrictions are located near RM 195 and 196, where large pools are formed behind the narrowed channel. It is likely that bedrock was visible in at least part of the channel bed in these locations. The presence of visible riffles in 1955 aerial photography indicate steeper reaches with higher velocities from RM 194 to RM 192 and from RM 197 to RM 195. Other reaches such as from RM 192 to Iron Gate Dam have riffles located near tributaries or gulches that contribute large sediment to the river, but for the most part likely contained pools or lower velocity sections.

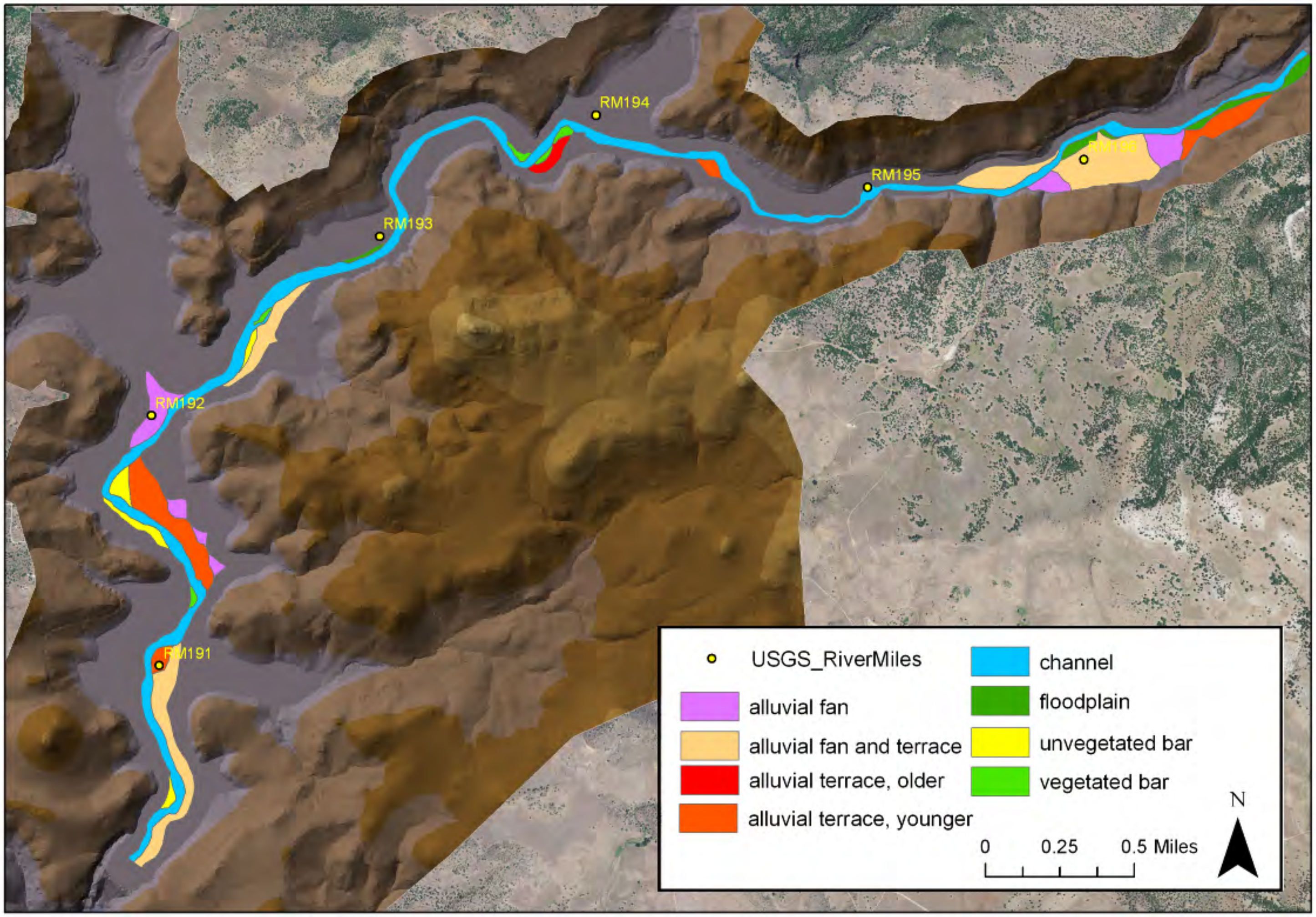


Figure 5-8. Geomorphic map of Iron Gate Reservoir.

5.2.6. HISTORICAL CHANNEL ALIGNMENTS VS. BATHYMETRIC DATA

Historical channel alignments were developed by Eilers and Gubala, Inc. from historical topographic maps of the reservoir areas. Comparison of the historical channel alignments with a hypothetical channel alignment following dam removal using bathymetric data was made to determine if there were any major changes to channel position from reservoir sedimentation or other effect. Comparisons at J.C. Boyle Reservoir and Iron Gate Reservoir revealed that there were no major changes between the low elevation points in the bathymetric data and historical channel position prior to dam construction. At Copco Reservoir, most of the channel alignments were similar with an exception in the vicinity of USGS RM 202 (Figure 5-9). The low elevations derived from bathymetric data at this location are in a much different location than the historical channel alignment. If the bathymetric data are correct, there may be some material that has slumped into the reservoir along the southern side, burying the location of the historical channel and shifting the low elevations to the north in the reservoir. In other locations within Copco Reservoir, bathymetric data and historical channel alignments match sedimentation.

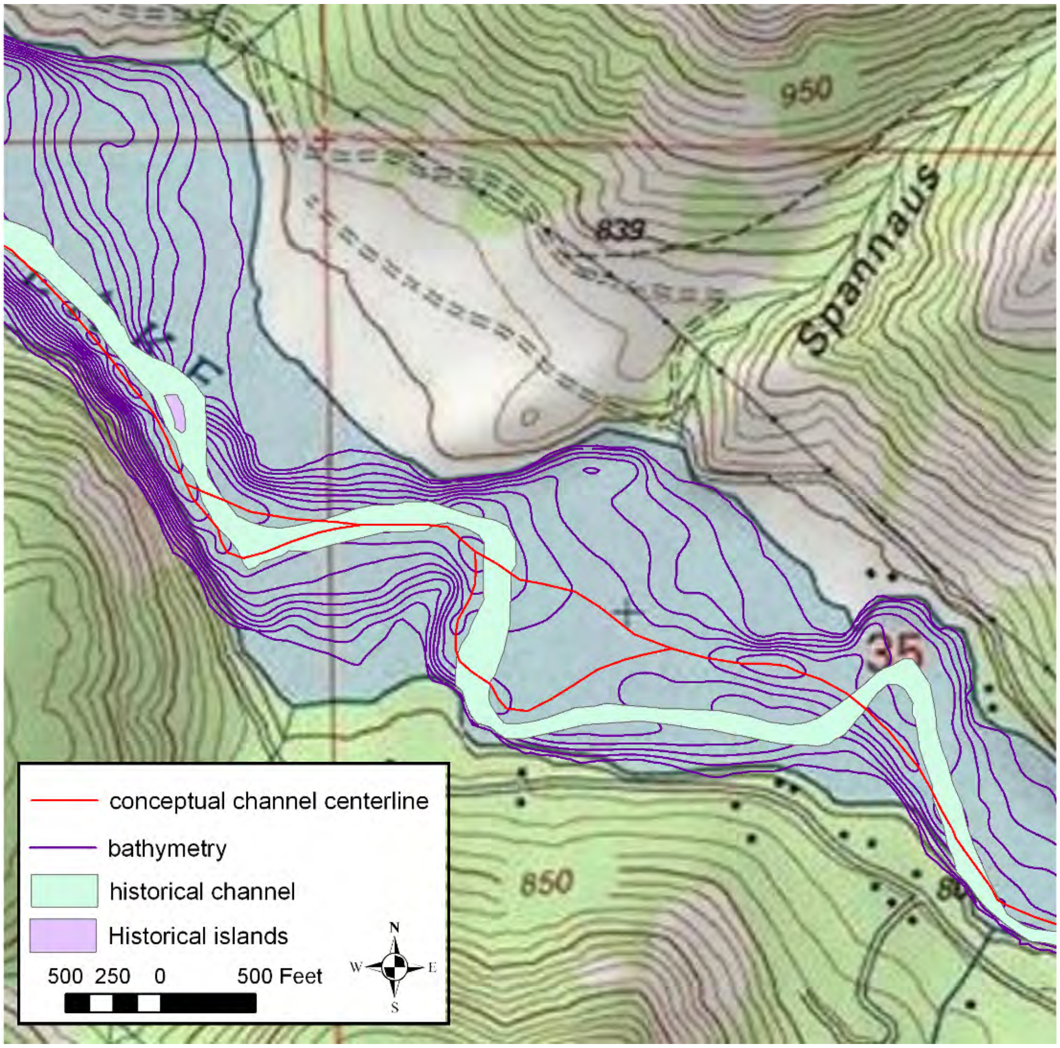


Figure 5-9. Comparison of historical channel alignment and bathymetric data near RM 202, Copco Reservoir.

5.2.7. COMPARISON TO VEGETATION RESTORATION MAPS USING BATHYMETRIC DATA

Geomorphic mapping is based on landform characteristics and the physical processes that created the landforms. Therefore, while the vegetation mapping and geomorphic mapping should be similar, some differences are to be expected. At Copco Reservoir, areas delineated as potential wetlands correspond to floodplain or young alluvial surfaces on the geomorphic map. Areas of active restoration may correspond to young alluvial terraces, but are also located on flat areas that are elevated above the pre-dam channel. Areas of passive restoration are located in upland areas or on older alluvial terraces. At Copco Reservoir, the large paleochannel mapped in the vicinity of Beaver Creek shows a wide variety of vegetation types due to changes in slope within the relict channel. Wetland vegetation is depicted in areas on the vegetation restoration map that are similarly located on the historical maps. These areas are mapped as part of the paleochannel landform, which can include wetland areas. In Iron Gate Reservoir, vegetation restoration areas are limited to small areas of expansion within the confined canyon, mainly along the major tributaries, and areas along the main channel, mapped as terraces or a combination of alluvial fans and terraces. At J.C. Boyle Reservoir, potential riparian areas are limited to banks and narrow sections along the channel. These areas roughly correspond to geomorphic mapping of floodplain and young alluvial terraces. Most of the areas within the reservoir are classified on the vegetation restoration maps as upland. These areas are mapped as terraces or alluvial fans on the geomorphic map, or may be located outside of areas that were mapped.

5.3. Sediment loads

Stillwater Sciences (2010) summarized several studies analyzing sediment loads in the basin and their results are given in Table 5-2. They used several reports to develop tributary sediment supplies to the Klamath River from Iron Gate Dam all the way to the ocean. They divided the estimates into the total sediment supply and the sediment supply of sediment sizes greater than 0.063 mm.

Based upon the work of Stillwater Sciences (2010), only a small fraction of the sediment load is supplied to the Klamath River from the watershed above Keno Dam. Because of its large surface area, Upper Klamath Lake traps practically all sediment entering it from its tributaries. From Keno Dam to Iron Gate Dam, the average annual sediment delivery was estimated to be approximately 150,000 ton/yr. The Scott River supplies approximately 607,000 tons/yr, the Salmon 320,000 tons/yr and the Trinity 3,300,000 tons/yr. The total annual delivery of sediment to the ocean from the Klamath River was estimated to be 5,800,000 tons/yr. The total annual delivery of sediment with a particle size greater than 0.063 mm was estimated to be 1,800,000 tons/yr. These estimates were based upon a variety of studies and data sets collected over different time periods. The Stillwater Study ignored temporal trends in the sediment load.

Suspended sediment data was collected by the USGS at the USGS gage on the Shasta River near Yreka, and on the Klamath River at Orleans and Klamath. The data is presented in Figure 5-10, Figure 5-11, and Figure 5-12, respectively. The data collected at the Yreka gage was from 1957 to 1960, the Orleans gage was from 1957 to 1979, and the Klamath gage was from 1974 to 1995. A simple power function was fit to the data as follows:

$$C = aQ^b$$

where, C = Suspended Sediment Concentration in mg/l
Q = flow rate in cfs
a, b = constants

The sum of the absolute value of the predicted and measured data was minimized to determine the value of a. A value of b was assumed to be 1.5 based upon visual fitting the data. The computed coefficients are given in Table 5-3. The sediment concentration during a 10-year flood (163,000 cfs) on the Klamath River at Orleans would be about 2,000 mg/l. A 2-year flood at Orleans is about 60,000 cfs and would have a suspended sediment concentration of about 800 mg/l. The data show considerable scatter about the best-fit line. Sediment concentrations commonly exceed 1,000 mg/l at Orleans, even at flows as small as 20,000 cfs.

The data from the Klamath gage from 1974 - 1984 was compared against the data from 1985 – 1995. A separate regression was fit to the data from 1985 – 1995 and there is a reduction in the a coefficient from 1.45E-5 to 1.1E-5, a reduction of

24%. The reduction in sediment loads could be caused by changes in land use or practices and the gradual recovery of the watershed from hydraulic mining.

There are no high flow suspended sediment data collected upstream of the Orleans gage. There are only low flow measurements of total suspended solids (TSS) collected by PacifiCorp downstream of their dams. The data collected downstream of Keno Dam and upstream of J.C. Boyle Dam are presented in Figure 5-14 and Figure 5-15. All the data was collected at flows less than 2,100 cfs and all the TSS measurements except those collected near 2,000 cfs were below 15 mg/l. Additional data on Total Suspended Solids is available from PacifiCorp on their website at: http://www.pacificorp.com/es/hydro/hl/kr.html#, and a list of their sampling sites is given in Table 5-4.

Because there is little information on sediment concentrations at high flows, the TSC attempted to synthesize a relationship between flow and sediment concentrations based upon the mass of sediment deposited behind the dams. An estimate of the volume and weight of deposition in the 3 reservoirs is given in Table 5-15. There is about 3.6 million tons of deposition in the three reservoirs. The fraction of the silt and clay sized material that is trapped by the three reservoirs is unknown, but assuming a trapping efficiency, it is possible to estimate the sediment concentration versus flow relationships necessary to deposit the measured volume behind the three dams. A flow duration curve is constructed at Iron Gate Dam based upon the 1962 – 2009 period of deposition in the reservoirs. This period is chosen because all three reservoirs have been in place during this period. The weight of deposited sediment since 1962 is estimated to be about 2.6 million tons. If the exponent b is assumed in the relationship between SSC and flow, then it is possible to solve for the constant a so that the weight of incoming sediment equals the weight of sediment deposited in the reservoirs. The values of the constant a were determined assuming two different exponents (0.7 and 1.5), and two different trap efficiencies (0.5 and 1.0). The results are shown in Figure 5-16. A 2-year flood is about 6,000 cfs at Iron Gate and the sediment concentration at this flow is estimated to be between 50 and 100 mg/l. There is considerable uncertainty in developing sediment concentration relationships from deposition data, but the main point behind this exercise is to demonstrate the likelihood that sediment concentrations will be higher at higher flows. This is also evidenced in a picture of the Confluence of the Klamath and Shasta Rivers at flood stage in January 2006 (Figure 5-17). The water in the photograph is noticeably laden with sediment.

Table 5-2. Annual sediment loads from Table 10 or Stillwater Sciences (2010). CWE refers to the Cumulative Watershed Effects assessment of the US Forest Service.

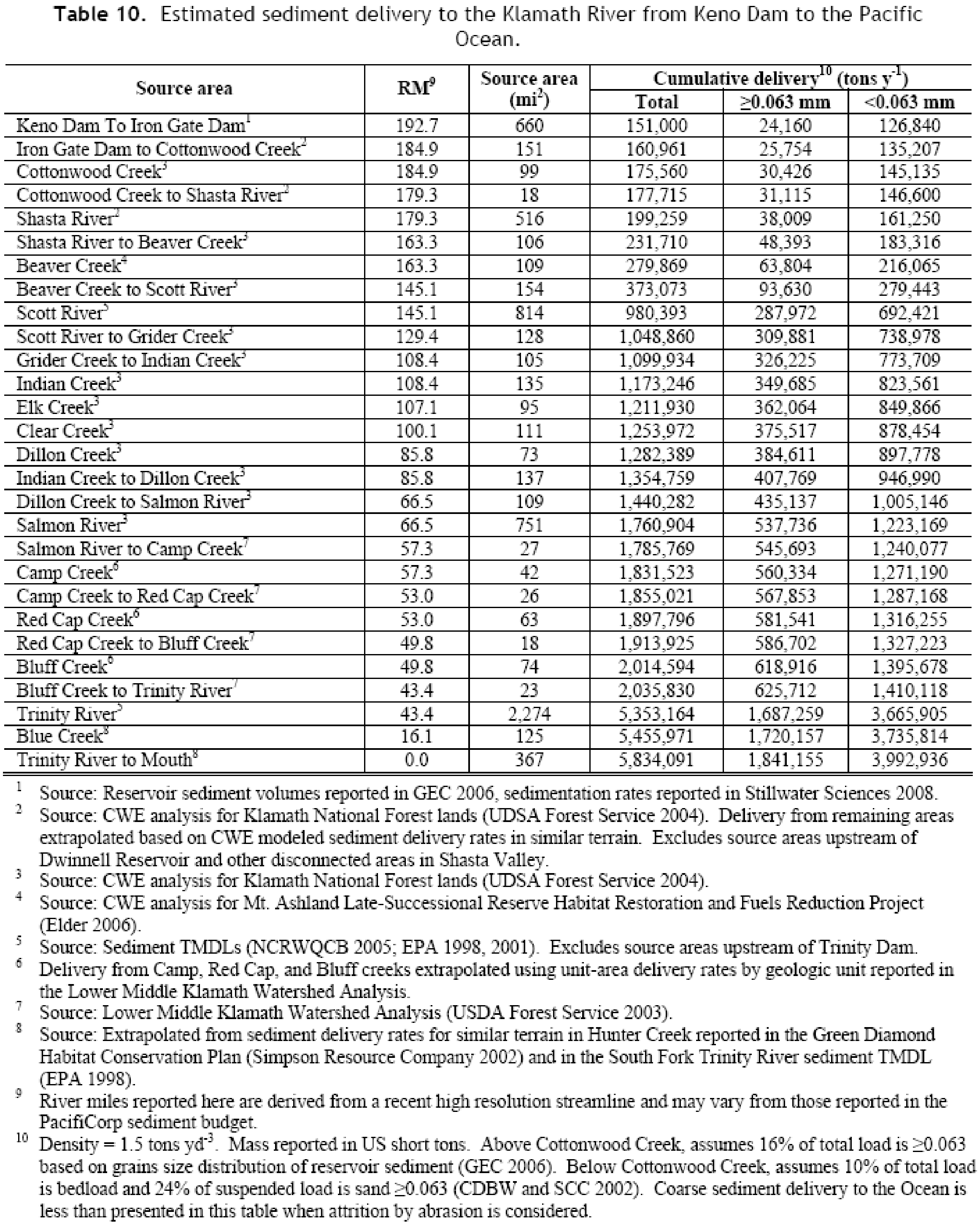


Table 10. Estimated sediment delivery to the Klamath River from Keno Dam to the Pacific Ocean.

Source area	RM[9]	Source area (mi^2)	Cumulative delivery[10] (tons y^{-1})		
			Total	≥0.063 mm	<0.063 mm
Keno Dam To Iron Gate Dam[1]	192.7	660	151,000	24,160	126,840
Iron Gate Dam to Cottonwood Creek[2]	184.9	151	160,961	25,754	135,207
Cottonwood Creek[3]	184.9	99	175,560	30,426	145,135
Cottonwood Creek to Shasta River[2]	179.3	18	177,715	31,115	146,600
Shasta River[2]	179.3	516	199,259	38,009	161,250
Shasta River to Beaver Creek[3]	163.3	106	231,710	48,393	183,316
Beaver Creek[4]	163.3	109	279,869	63,804	216,065
Beaver Creek to Scott River[3]	145.1	154	373,073	93,630	279,443
Scott River[5]	145.1	814	980,393	287,972	692,421
Scott River to Grider Creek[3]	129.4	128	1,048,860	309,881	738,978
Grider Creek to Indian Creek[3]	108.4	105	1,099,934	326,225	773,709
Indian Creek[3]	108.4	135	1,173,246	349,685	823,561
Elk Creek[3]	107.1	95	1,211,930	362,064	849,866
Clear Creek[3]	100.1	111	1,253,972	375,517	878,454
Dillon Creek[3]	85.8	73	1,282,389	384,611	897,778
Indian Creek to Dillon Creek[3]	85.8	137	1,354,759	407,769	946,990
Dillon Creek to Salmon River[3]	66.5	109	1,440,282	435,137	1,005,146
Salmon River[3]	66.5	751	1,760,904	537,736	1,223,169
Salmon River to Camp Creek[7]	57.3	27	1,785,769	545,693	1,240,077
Camp Creek[6]	57.3	42	1,831,523	560,334	1,271,190
Camp Creek to Red Cap Creek[7]	53.0	26	1,855,021	567,853	1,287,168
Red Cap Creek[6]	53.0	63	1,897,796	581,541	1,316,255
Red Cap Creek to Bluff Creek[7]	49.8	18	1,913,925	586,702	1,327,223
Bluff Creek[6]	49.8	74	2,014,594	618,916	1,395,678
Bluff Creek to Trinity River[7]	43.4	23	2,035,830	625,712	1,410,118
Trinity River[5]	43.4	2,274	5,353,164	1,687,259	3,665,905
Blue Creek[8]	16.1	125	5,455,971	1,720,157	3,735,814
Trinity River to Mouth[8]	0.0	367	5,834,091	1,841,155	3,992,936

[1] Source: Reservoir sediment volumes reported in GEC 2006, sedimentation rates reported in Stillwater Sciences 2008.

[2] Source: CWE analysis for Klamath National Forest lands (UDSA Forest Service 2004). Delivery from remaining areas extrapolated based on CWE modeled sediment delivery rates in similar terrain. Excludes source areas upstream of Dwinnell Reservoir and other disconnected areas in Shasta Valley.

[3] Source: CWE analysis for Klamath National Forest lands (UDSA Forest Service 2004).

[4] Source: CWE analysis for Mt. Ashland Late-Successional Reserve Habitat Restoration and Fuels Reduction Project (Elder 2006).

[5] Source: Sediment TMDLs (NCRWQCB 2005; EPA 1998, 2001). Excludes source areas upstream of Trinity Dam.

[6] Delivery from Camp, Red Cap, and Bluff creeks extrapolated using unit-area delivery rates by geologic unit reported in the Lower Middle Klamath Watershed Analysis.

[7] Source: Lower Middle Klamath Watershed Analysis (USDA Forest Service 2003).

[8] Source: Extrapolated from sediment delivery rates for similar terrain in Hunter Creek reported in the Green Diamond Habitat Conservation Plan (Simpson Resource Company 2002) and in the South Fork Trinity River sediment TMDL (EPA 1998).

[9] River miles reported here are derived from a recent high resolution streamline and may vary from those reported in the PacifiCorp sediment budget.

[10] Density = 1.5 tons yd^{-3}. Mass reported in US short tons. Above Cottonwood Creek, assumes 16% of total load is ≥0.063 based on grains size distribution of reservoir sediment (GEC 2006). Below Cottonwood Creek, assumes 10% of total load is bedload and 24% of suspended load is sand ≥0.063 (CDBW and SCC 2002). Coarse sediment delivery to the Ocean is less than presented in this table when attrition by abrasion is considered.

Table 5-3. Coefficients fit to all historical suspended sediment data.

	Shasta River		Orleans		Klamath	
Coefficient	Total	Sand	Total	Sand	Total	Sand
a	2.12E-01	-	5.26E-05	1.32E-05	1.45E-05	5.0E-06
b	0.7	-	1.5	1.5	1.5	1.5

Table 5-4. Additional PacifiCorp water quality sampling sites.

Site ID	River Mile	Site Name
KR15750	156.00	Klamath River at Walker Road Bridge
KR17923	176.00	Klamath River at I-5 Rest Area
KR18423	184.23	Klamath River at Klamathon Bridge
KR18973	189.73	Klamath River Iron Gate Dam outflow
KR19019	190.19	Iron Gate Reservoir near Dam
KR19645	196.45	Klamath River below Copco 2 Powerhouse
KR19874	198.74	Copco Reservoir near Dam
KR20642	206.42	Klamath River above Shovel Creek
KR22040	220.40	Klamath River at bottom of bypass
KR22460	224.60	Klamath River below J.C. Boyle dam
KR22822	228.22	Klamath River above J.C. Boyle reservoir
KR23334	233.34	Klamath River below Keno Dam
KR23435	234.35	Keno Reservoir at Highway 66 bridge
KR25312	253.12	Mouth of Link River

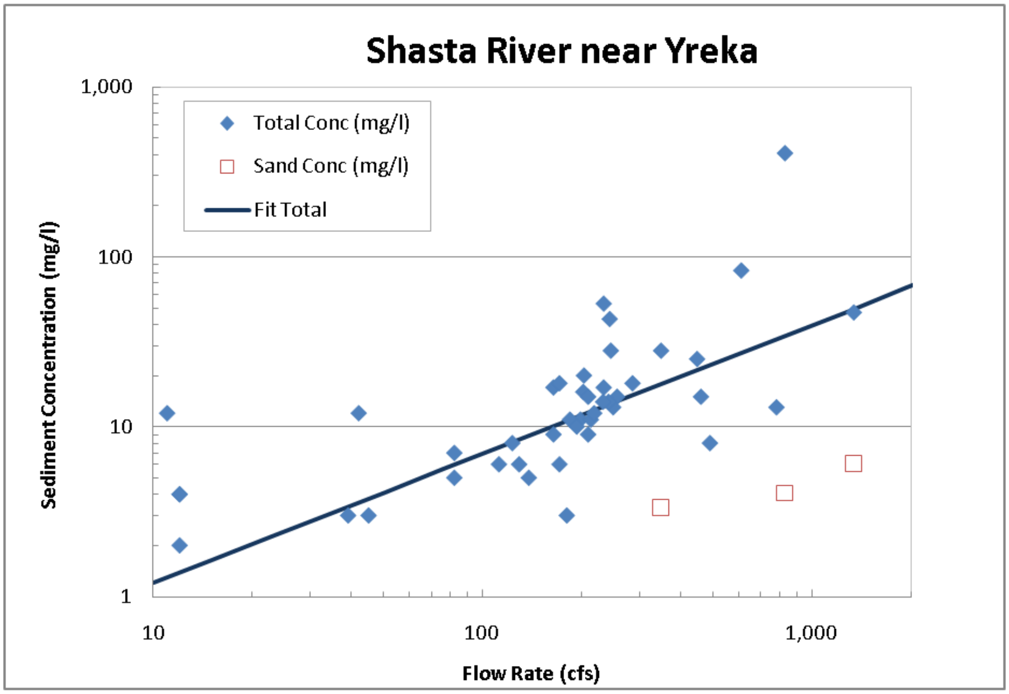


Figure 5-10. Suspended sediment data on Shasta River near Yreka.

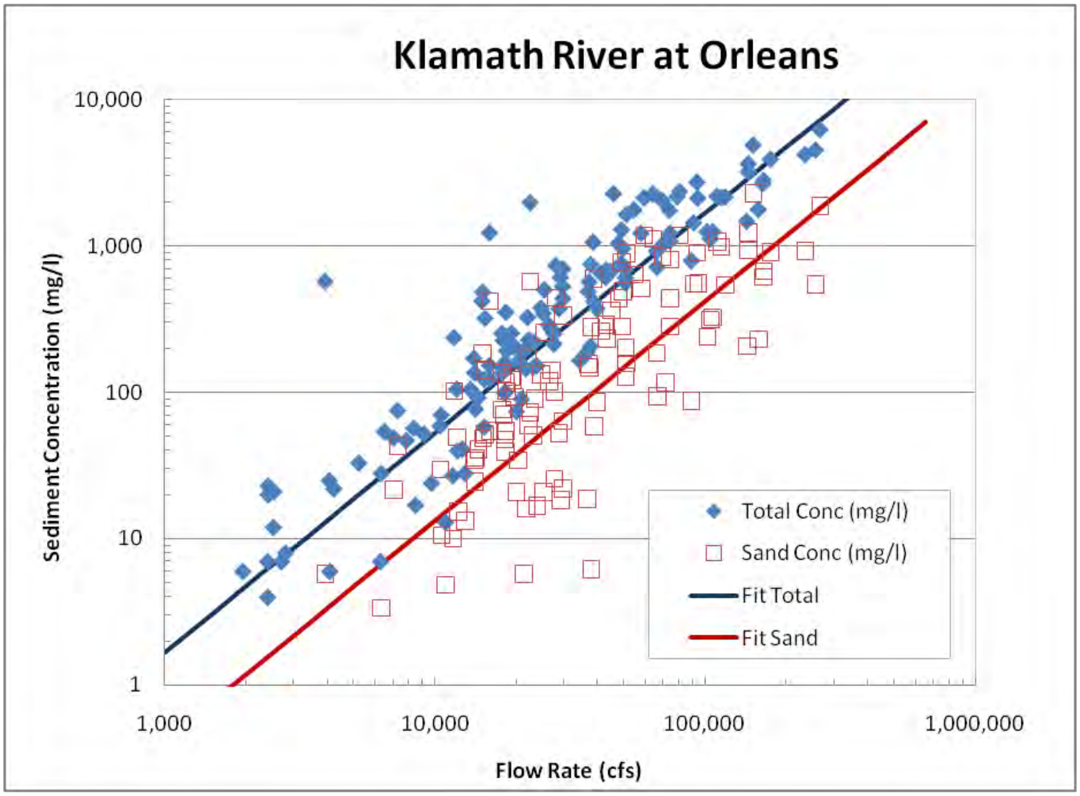


Figure 5-11. USGS Suspended sediment Data at Klamath River at Orleans.

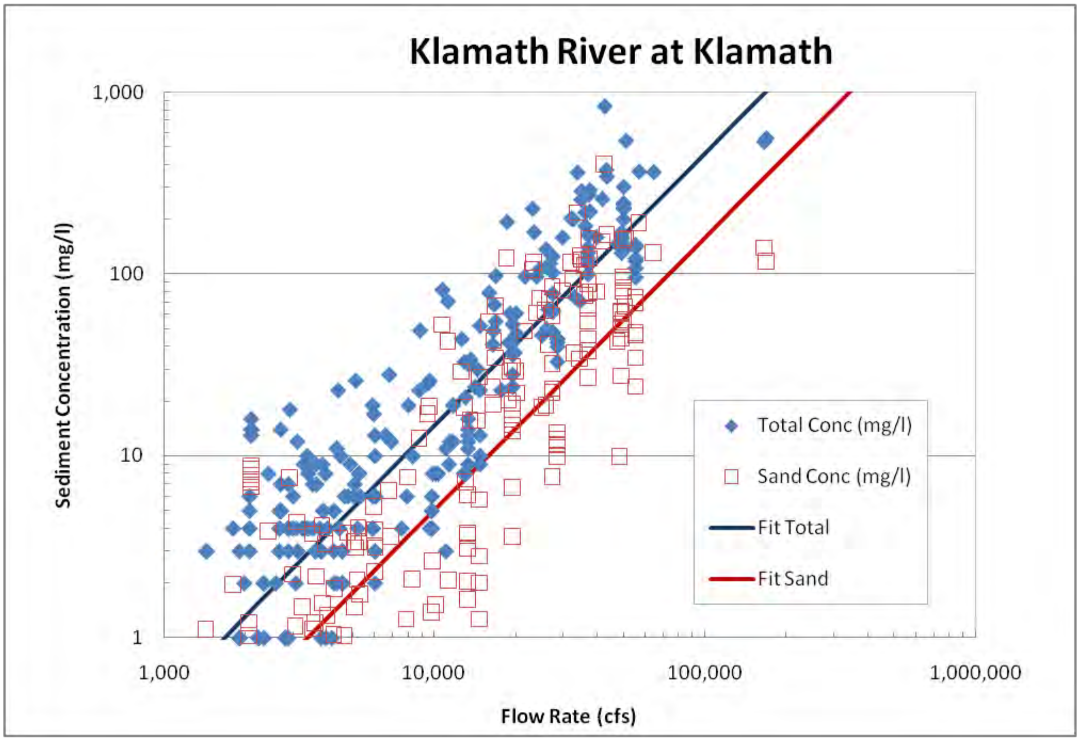


Figure 5-12. USGS Suspended sediment Data at Klamath River at Klamath.

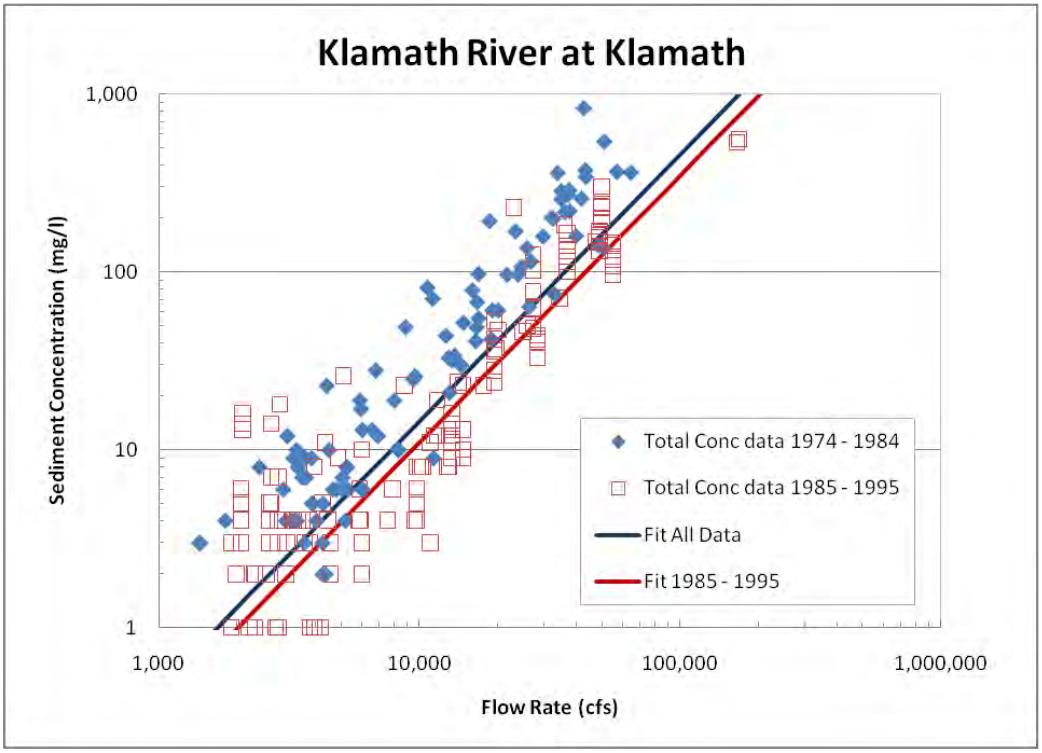


Figure 5-13. Comparison between rating curve fit to all data and that fit to data from 1985 to 1995.

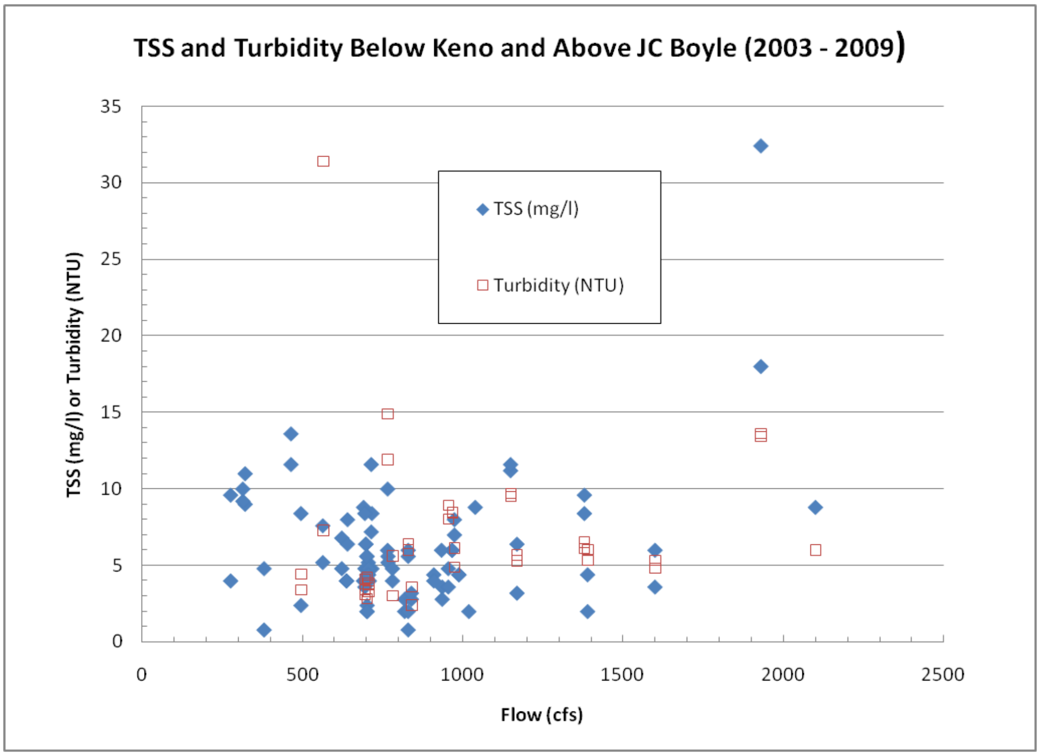


Figure 5-14. Total suspended solids (TSS) and turbidity data on Klamath River below Keno Dam and above J.C. Boyle Dam. Data collected by PacifiCorp from 2003 – 2009.

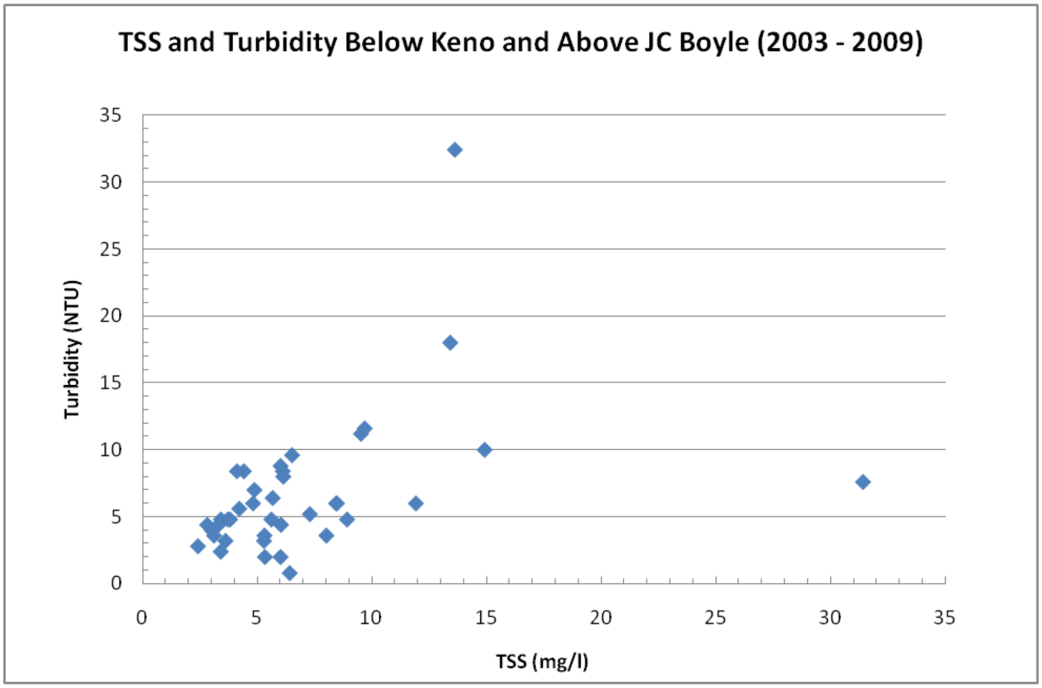


Figure 5-15. Relationship between suspended solids data and turbidity on Klamath River below Keno Dam and above J.C. Boyle Dam. Data collected by PacifiCorp from 2003 – 2009.

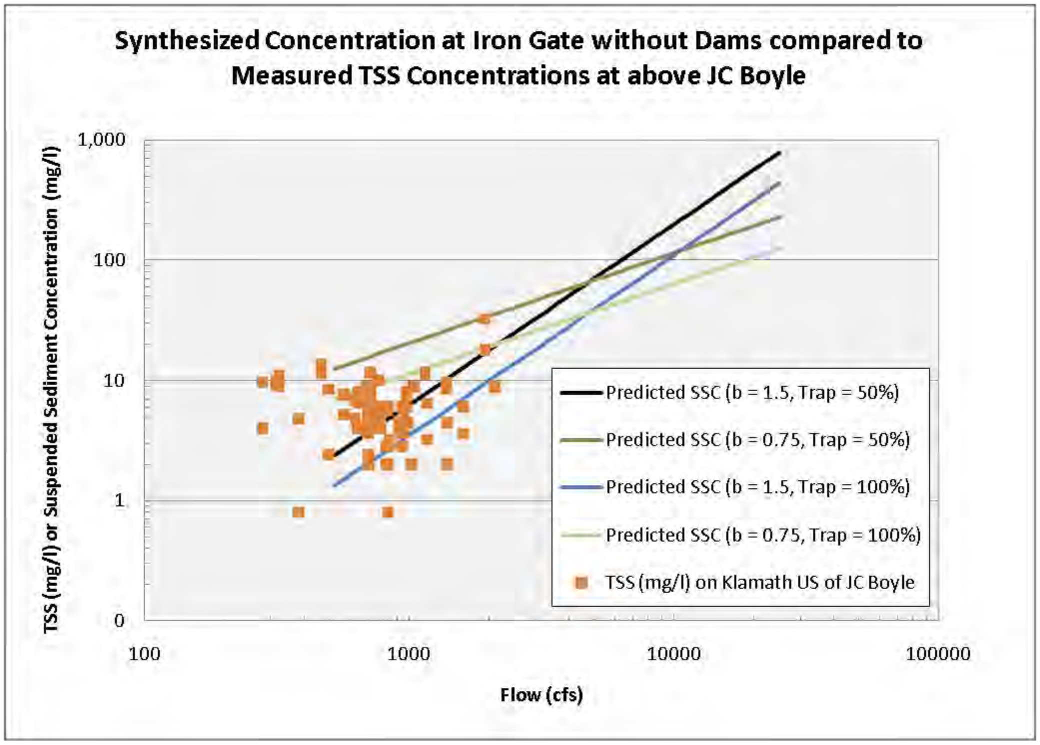


Figure 5-16. Sediment concentrations at Iron Gate synthesized from reservoir sedimentation rates.

Figure 5-17. Photograph of Klamath and Shasta River Confluence at flood stage in December 31, 2005 and the average daily flow for that day was 11,100 cfs. Looking upstream and Shasta River is coming in from the right.

5.4. Bed Material

Multiple measurements of bed material were performed between 1999 and 2008 by PacifiCorp, Ayers, and Reclamation on the Klamath River and the data were included for this study. Additional pebble count samples were collected as part of this project in October of 2009 to verify the previous sampling. These samples will be referred to as Reclamation 2009.

PacifiCorp (2004b) performed pebble counts between Link Dam and Seiad Valley (RM 254 to 128). The representative diameters are shown in Figure 5-18 for the D16, D50, and D84, where D16 refers to the 16% of material having a diameter that is finer than the diameters found in the total sample. Some of the samples were collected to intentionally sample the finer material deposited during floods on higher bars not exposed to lower flows, in locations protected by large boulders, or in pools. They are not representative of the bed material that would control the bed elevations or of the bed armor layer.

Ayres (1999) performed a geomorphic assessment of the Klamath River below Iron Gate Dam and collected pebble counts from RM 5 to 130. Reclamation (2008) collected pebble count data to support a salmon redd scour study from RM 147 to 185. The representative particle diameters for all data collected downstream of Iron Gate Dam are given in Figure 5-19, Figure 5-20, and Figure 5-21 for the D16, D50, and D84, respectively.

The reach averaged D50 and computed stream power for Iron Gate Dam to Indian Creek is shown in Figure 5-22. There is a strong correlation between reach average stream power and the median diameter. As stream power increases, the river can move larger sediment particles; therefore, the surface sediment sizes left in the bed are larger. There are some exceptions to this correlation if there are changes to the sediment supply. Downstream of the Beaver Creek and Scott River the ratio of stream power to sediment diameter is larger indicating that the bed material is relatively more mobile at these locations. This would be consistent with the large coarse sediment load supplied by these tributaries, in particular the coarse sediment supply of Scott River.

These observations are consistent with Lane's sediment balance (Lane, 1955), which can be written as:

$$QS \propto Q_s d_{50} \qquad \text{Equation 5-1}$$

where Q is flow rate, S is slope, Q_s is sediment supply, and d_{50} is the median particle diameter of bed material load. As the flow rate or slope increases, the sediment supply or median particle diameter will increase.

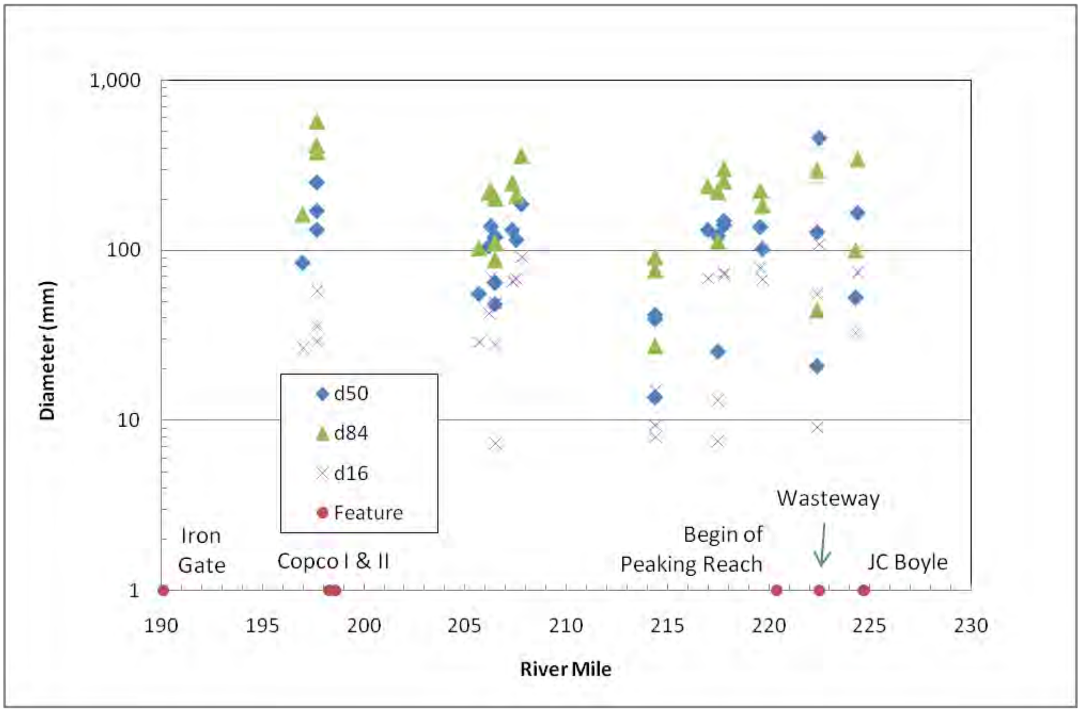


Figure 5-18. Measured representative bed material sizes in Klamath River downstream of J.C. Boyle and Upstream of Iron Gate reservoirs (PacifiCorp, 2004b).

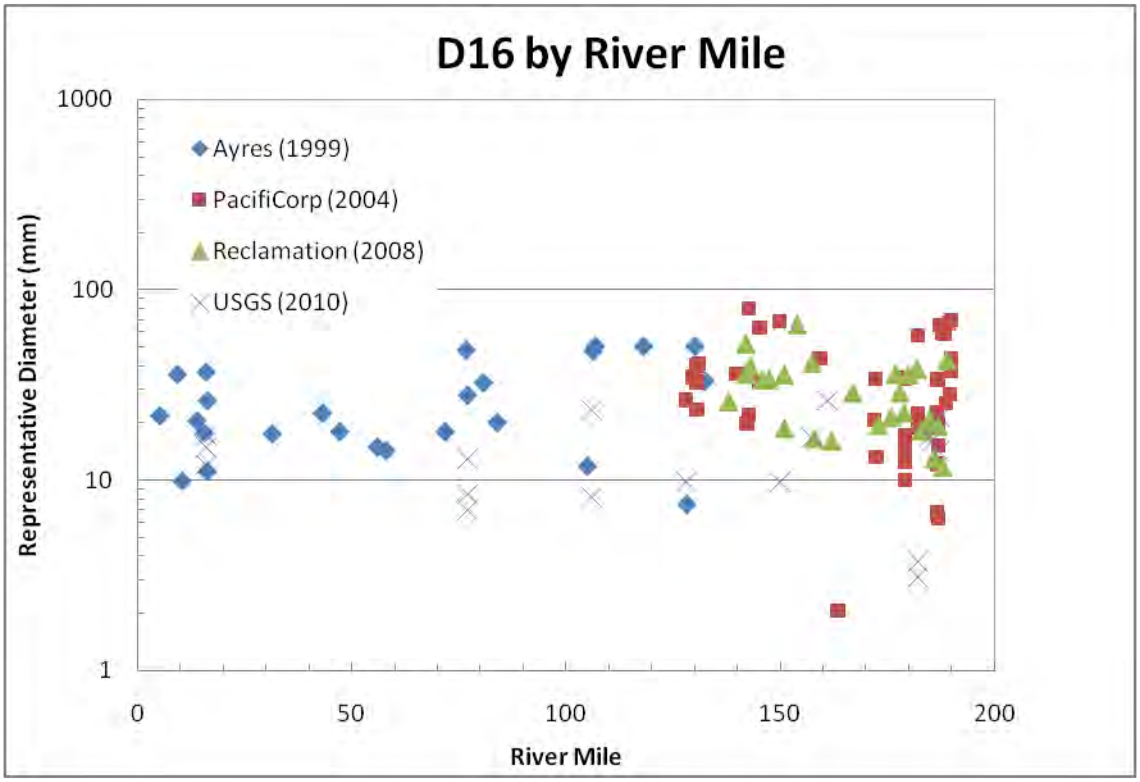


Figure 5-19. Measured D16 on Klamath River downstream of Iron Gate Reservoir.

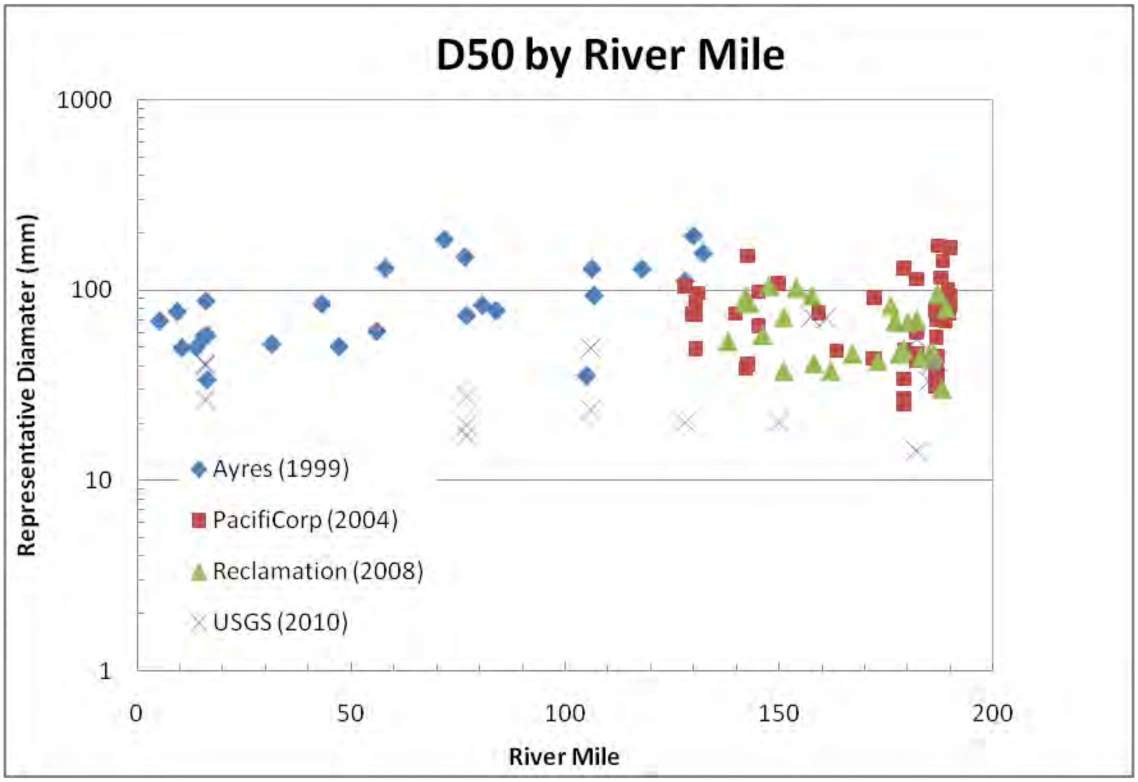


Figure 5-20. Measured D50 on Klamath River downstream of Iron Gate Reservoir.

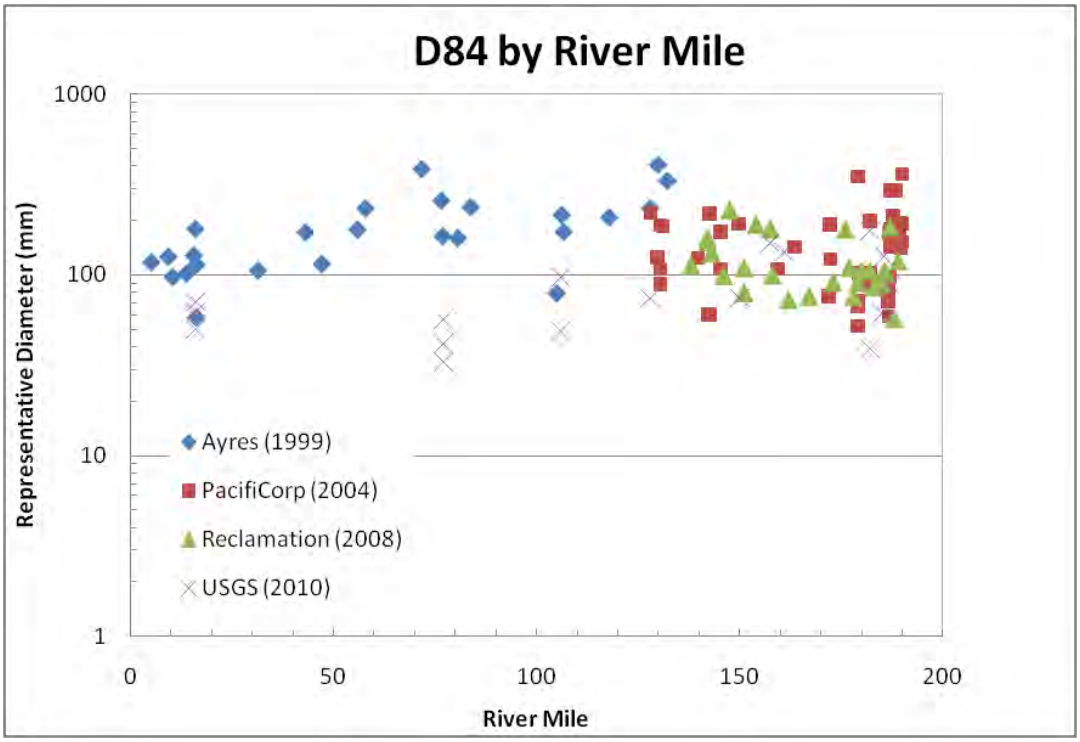


Figure 5-21. Measured D84 on Klamath River downstream of Iron Gate Reservoir.

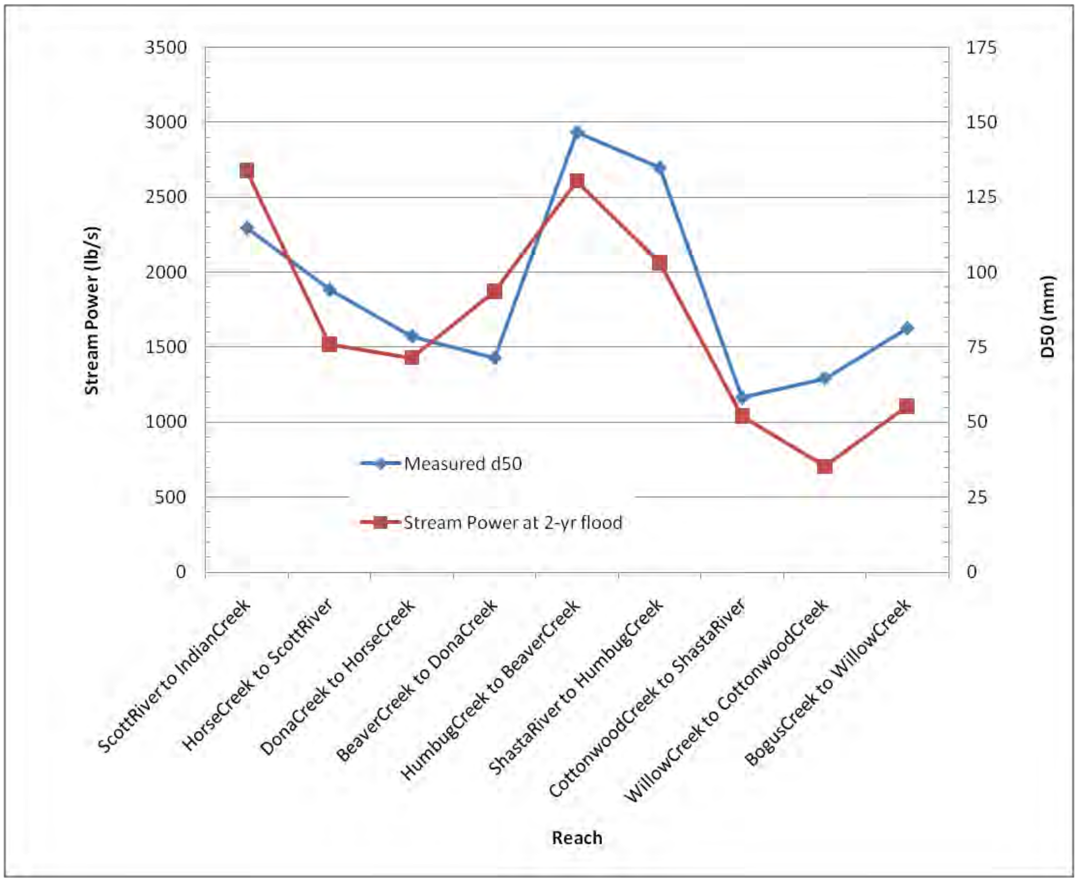


Figure 5-22. Average stream power and average D50 by reach.

5.5. Frequency of Mobilization

Several studies have estimated the magnitude of flow necessary to mobilize sediment in the Klamath River. All the studies used Shield’s criterion is used to estimate gravel mobilization. The Shield’s number, θ, is defined as:

$$\theta = \frac{\tau_g}{\gamma(s-1)D_{50}} \qquad \text{Equation 5-2}$$

where θ = dimensionless Shield’s number; τ_g = grain shear stress; γ = specific weight of water; s = relative specific density of sediment; and D_{50} = median sediment size.

Often, there is a specific value above which bed motion is assumed to begin. However, sediment motion is more accurately described as a stochastic process and exact initiation of motion is a qualitative term. Parker (1990) suggests that the concept of initiation of motion be replaced by a reference amount of sediment motion described by a specific amount of non-dimensional sediment transport:

$$W* = \frac{(s-1)gq_s}{\rho_s\left(\tau_g/\rho\right)^{1.5}} = 0.002 \qquad \text{Equation 5-3}$$

where s = relative specific density, g = acceleration of gravity, q_s = sediment transport rate, ρ_s = sediment density, τ_g = grain shear stress, ρ = water density. The Shields number that gives $W* = 0.002$ is termed the reference Shield’s stress (θ_r). It can be described as the condition when many particles are moving and there is a small, but measureable, sediment transport rate. The non-dimensional reference shear stress (θ_r) show considerable variation in the literature. A typical value for the reference Shield stress is about 0.02 to 0.04 (Parker, 1990; Buffington and Montgomery, 1998; Andrews, 2000; Wilcock and Crowe, 2003). However, there is significant variation and it has been found to vary between 0.01 and 0.1. Wilcock and Crowe (2003) use $\theta_r = 0.021$ if the fraction of sand in the surface layer is above 0.2 and $\theta_r = 0.036$ if the surface is devoid of sand. Lamb et al (2008) and Mueller et al. (2005) suggest that the critical or reference shear stress is dependent upon channel slope.

Appendix J. Reference Sediment Motion contains detailed information on the analytical methods used to compute Shields number at a variety of flows. Embedded in the method to compute the reference shear stress is the computation of the grain shear stress. The total shear stress is composed of the morphologic shear stress, the grain shear stress, and the wall shear stress (Lamb et al., 2008). The morphologic shear stress is that shear stress caused by bed forms and large channel features such as log jams or vegetation. A calculation of sediment mobilization should only include the grain shear stress.

If the shear stress is not increased beyond the reference shear stress, there will be only minimal disturbance of the armor layer. Many researchers suggest that a shear stress larger than the reference shear stress is necessary for significant disturbance of the armor layer. Hydraulic conductivity is a measure of the ability of water to travel through a permeable soil. Schälchi (1992) found that significant increases in hydraulic conductivity begin at $1.3\theta_r$. Higher hydraulic conductivities indicate a coarser bed that is flushed of fine material. Neill (1986) also suggests that significant mobilization occurs at $1.3\theta_r$. Holmquist-Johnson and Milhous (2010) also use the criteria proposing that the armor disturbance occurs at $1.3\theta_r$. The descriptions of slight mobilization, which is defined to occur at a $\theta = \theta_{r,}$ and significant mobilization, which is defined to occur at $\theta = 1.3\theta_{r,}$ is given in Table 5-5.

The exact definition of armor disturbance is somewhat artificial because the amount of transport will increase gradually and not as a step function, as shown in Figure 5-23 from Wilcock and Crowe (2003). Therefore, it is more accurate to analyze sediment transport as a continuum process rather than a process that has abrupt changes with flow rate. This implies the same amount of gravel movement would be accomplished by a high flow for a short duration as would be mobilized by a smaller flow for a longer duration. We suggest that the values definitions of slight mobilization and significant mobilization in Table 5-5 be used as general guidelines with the understanding that the mobilization of sediment is actually a gradual process, not marked by instantaneous jumps in transport with flow rate.

Table 5-5. Suggested general stages of sediment transport based upon Shield's number.

Relative Shield's Number	**Description**
θ_r	**Slight Mobilization**: There will be a small, but measurable, sediment transport rate. Armor layer is only minimally disturbed and there maybe flushing of sand to a depth of the D_{90}.
$1.3\ \theta_r$	**Significant Mobilization:** Many particles are moving and there is a significant sediment transport rate. Sand is mobilized in the interstitial spaces of the bed and to a depth of twice the D_{90}. The armor layer is significantly disturbed.

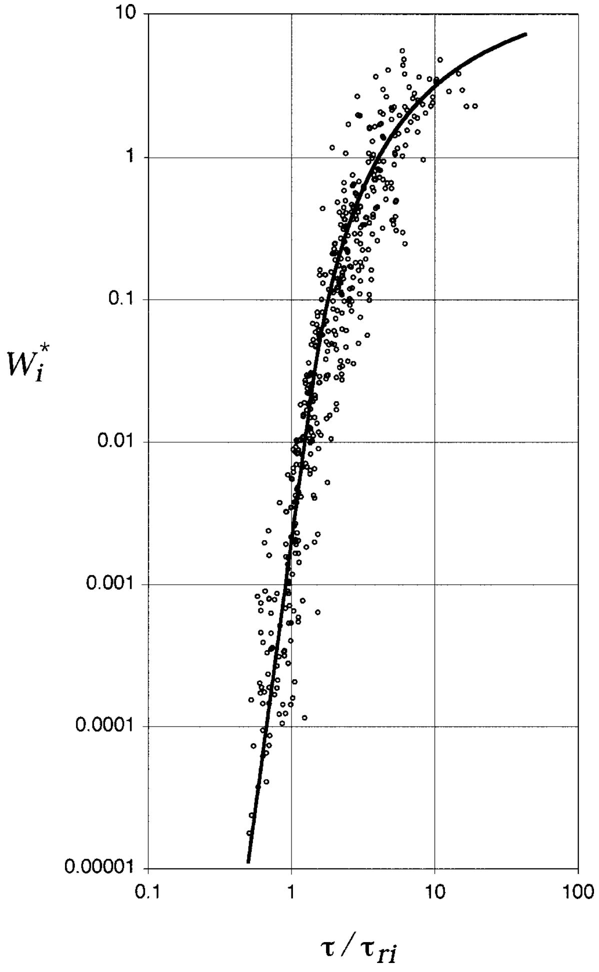


Figure 5-23. Figure 6 from Wilcock and Crowe (2003) showing relationship between non-dimensional transport rate (W_i*) and non-dimensional shear stress ($\theta/\theta_r = \tau/\ \tau_{ri}$) for a given size class *i*.

An issue related to the gravel mobilization is the mobilization of sandy material covering the bed or within the interstitial spaces of the gravel. The sandy material can move at much smaller shear stresses if it is exposed on the surface, but the sandy material located within the bed is protected by the larger gravels. Therefore, the depth of sand mobilization depends upon the mobilization of gravel. Wilcock et al. (1998) analyzed the sand mobilization on the Trinity River using measured data on sand transport and observations on sand coverage in the bed. Mobilization of sands within pools and the surface of the bed can occur at flows less than the flow required for mobilization of gravels. Wilcock et al. (1998) found that sands could be flushed to a depth of the D_{90} without gravel entrainment, but found that fully mobilized gravel would flush sands to a depth of approximately twice the D_{90}. Diplas and Parker (1985) also found that fine sediment can be entrained to a depth of two to three times the surface layer thickness.

To predict the exact fraction of sand remaining in the bed after a flushing event, it is necessary to simulate the sand budget and bed mixing during the event. It is also necessary to obtain measurement of the surface and subsurface sand fractions as well as the sand supply in the reach. Wu and Chou (2003) and Cui (2006) have developed models to predict the flux of sand from the subsurface to the surface. Future studies of mobilization could be done to quantify the flows necessary to accomplish a certain level of sand mobilization in the Klamath River. These studies could improve our understanding of the amount of sand content in the bed previous to and after the high flow event.

There have been several previous studies of gravel mobilization in the Klamath River. Holmquist-Johnson and Milhous (2010) defined various levels of mobilization, from flushing of fines from interstitial spaces to armor disturbance. The critical value of Shield’s parameter for armor disturbance was 0.045, and based upon their descriptions of motion, reference sediment motion is assumed to occur at 0.035. They also assumed that the morphologic and wall shear stress was zero. The main purpose of removing fine sediment in the Klamath River is to increase salmon habitat and decrease the occurrence of *C. shasta*, which is a bacteria that infects salmon. However, it is uncertain exactly how much habitat is destroyed from a specific mobilization flow and how much mobilization of fine material is necessary to control *C. shasta*.

Ayres (1999) measured bed material and cross sections at six locations on the Klamath River from Iron Gate Dam to the Pacific Ocean. They assumed that θ_r = 0.035. They assumed that the morphologic and wall shear stress was zero.

PacifiCorp (2004b) analyzed sediment motion at several other locations along the river as well. They used measured cross section data and bed material data to estimate mobilization under the No Action Alternative. They also computed mobilization flows under the Dam Removal Alternative by assuming a bed material size based upon tributary bed material sizes upstream of Iron Gate Dam. They also assumed that this bed material size would be the same for the entire length of the Klamath River below Iron Gate. PacifiCorp used θ_r = 0.047 and assumed that the morphologic and wall shear stress was zero.

Table 5-6. Previous estimates of the flow required to for Slight Mobilization ($\theta = \theta_r$) on the Klamath River.

		No Action			**Dam Removal**
Location (RM)	**Description**	**Ayres (1999)**	**PacifiCorp (2004b)**	**USGS (2010)**	**PacifiCorp (2004b)**
16.3	Below Blue Creek Confluence	147,000	-	-	-

77	Sandy Bar	59,000	-	-	-
106	Happy Camp	33,500	-	-	-
128	Portuguese Creek	16,500	68,000	-	27,000
161	Beaver Creek	13,000	-	-	-
172	Tree of Heaven	-	17,329	-	8,700
187	Little Bogus Creek	9,800	9,700	8,700	6,600

5.5.1. CURRENT ESTIMATES OF MOBILIZATION

Using the average hydraulic properties and averaged D50 of each reach, it is possible to estimate the reach averaged slight mobilization flow and the reach averaged significant mobilization flow. The return period of the initiation of flow is also calculated. The methods used to compute sediment mobilization are described in

Appendix J. Reference Sediment Motion. Mobilization is assumed to occur when the shear stress applied to the sediment particles of the bed exceeds the reference shear stress. There is considerable uncertainty in defining the mobilization flow without direct field measurements of sediment movement. One major uncertainty is the value of the reference shear stress. Based upon the previous studies, a range of 0.025 to 0.035 in shear stress is estimated for reference sediment motion to represent the probable range of potential mobilization on the Klamath River. Only the grain shear stress is used to compute shear stress applied to sediment mobilization. Previous studies have used the total shear stress and have not accounted for the inherent uncertainty in this estimate without measurements of sediment bedload movement.

Figure 5-24 shows the flow at which mobilization will occur on a reach average basis for the reaches defined in Section 4.2. The reach from Iron Gate Dam to Bogus Creek is not shown because there are no direct measurements of bed material size in this reach. It is expected that this reach is essentially fully armored because there has been no significant sediment supply to this reach for almost 50 years.

The median estimate of the slight mobilization flow from Bogus Creek to Willow Creek is about 9,500 cfs. This is consistent with the Ayres (2009) and USGS (2010) who found the mobilization flow to be 9,800 cfs and 8,700 cfs, respectively. The potential range of the mobilization flow in this reach is expected to be from 7,000 to 13,000 cfs. Field measurements of sediment mobilization are needed to reduce the uncertainty of this value. The range of the return period of the mobilization flow is between 2.6 to 7.5 years in the Bogus Creek to Willow Creek reach.

The reach between Cottonwood Creek and the Shasta River has a slightly smaller mobilization flow than the reaches upstream, corresponding to the supply of material from Cottonwood Creek. The return period of the mobilization flow is significantly less than the reaches between Iron Gate and Cottonwood Creek.

The mobilization flow increases substantially downstream of Shasta River to Beaver Creek. This reach is steeper than the reaches upstream or downstream of it. The bed elevations in this reach are primarily controlled by relatively immobile large cobbles, boulders, and bedrock. The sediment quickly moves through the reach, and therefore it is essentially a “pass through” reach.

At Beaver Creek, the tributary supply of peak flows and additional sediment in this reach decrease the mobilization flow substantially. The return period of slight mobilization is between 1.25 and 1.5 years. (A return period of 1.5 years is typical of gravel-bed rivers with unimpaired hydrology and sediment regimes).

At Scott River, the mobilization flow increases substantially, but the median return period for slight mobilization is still less than 2 years. Scott River supplies large amounts of sediment and also substantially increases the peak flow of the Klamath River.

Table 5-7. Low, median, and high estimates of bed material initiation of mobilization flow under current conditions ($\theta = \theta_r$).

Reach	Slight Bed Material Mobilization Flow Estimates (cfs)		
	Low	**Median**	**High**
Bogus Creek to Willow Creek	7,000	9,800	13,100
Willow Creek to Cottonwood Creek	7,700	10,700	14,200
Cottonwood Creek to Shasta River	5,900	8,400	11,300
Shasta River to Humbug Creek	14,000	20,000	27,400
Humbug Creek to Beaver Creek	13,500	19,100	26,400
Beaver Creek to Dona Creek	3,900	5,800	8,000
Dona Creek to Horse Creek	4,200	5,900	7,900
Horse Creek to Scott River	4,700	6,500	8,600
Scott River to Indian Creek	11,000	15,300	20,500

Table 5-8. Low, median, and high estimates of significant bed material mobilization flows under current conditions ($\theta = 1.3\theta_r$).

Reach	Significant Bed Material Mobilization Flow Estimates (cfs)		
	Low	**Median**	**High**
Bogus Creek to Willow Creek	11,500	15,900	21,300
Willow Creek to Cottonwood Creek	12,500	17,200	22,900
Cottonwood Creek to Shasta River	9,700	13,800	18,400
Shasta River to Humbug Creek	23,800	33,900	45,800
Humbug Creek to Beaver Creek	22,600	32,900	45,500
Beaver Creek to Dona Creek	6,900	10,100	13,900
Dona Creek to Horse Creek	6,900	9,700	13,200
Horse Creek to Scott River	7,500	10,400	13,900
Scott River to Indian Creek	17,900	25,500	34,100

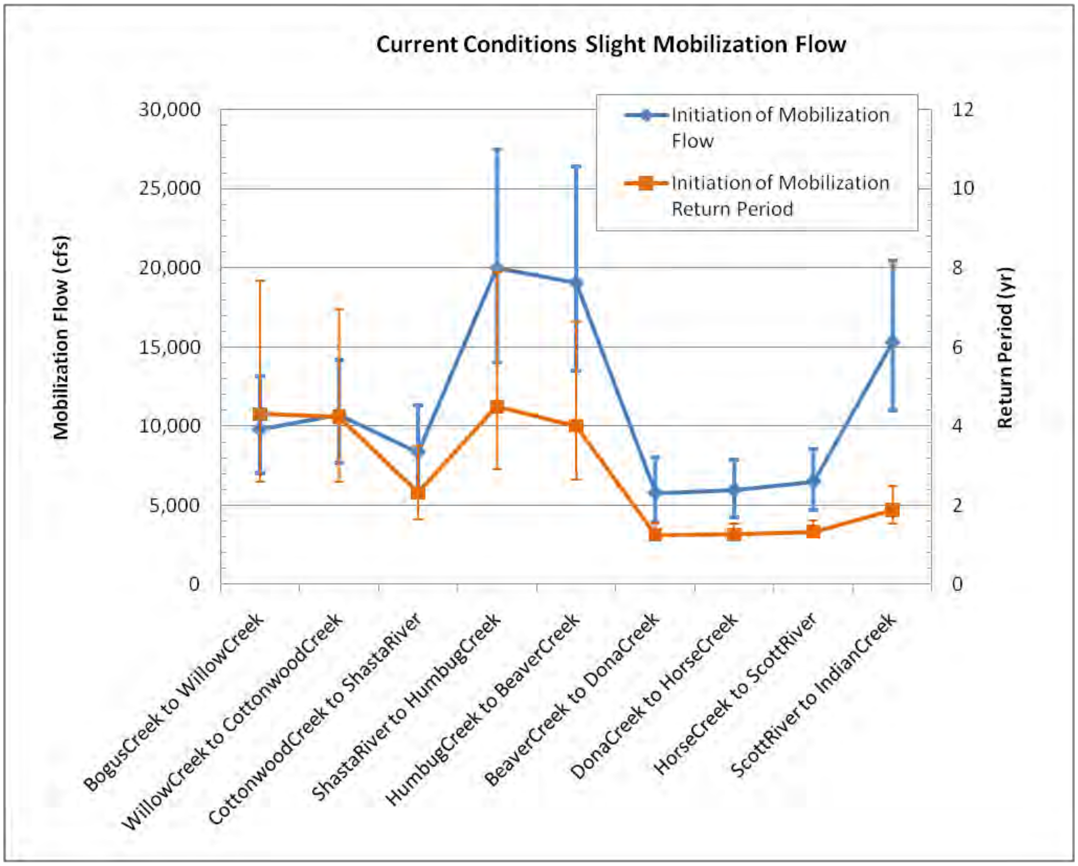


Figure 5-24. Slight bed material mobilization flow and return period for reaches downstream of Iron Gate Dam.

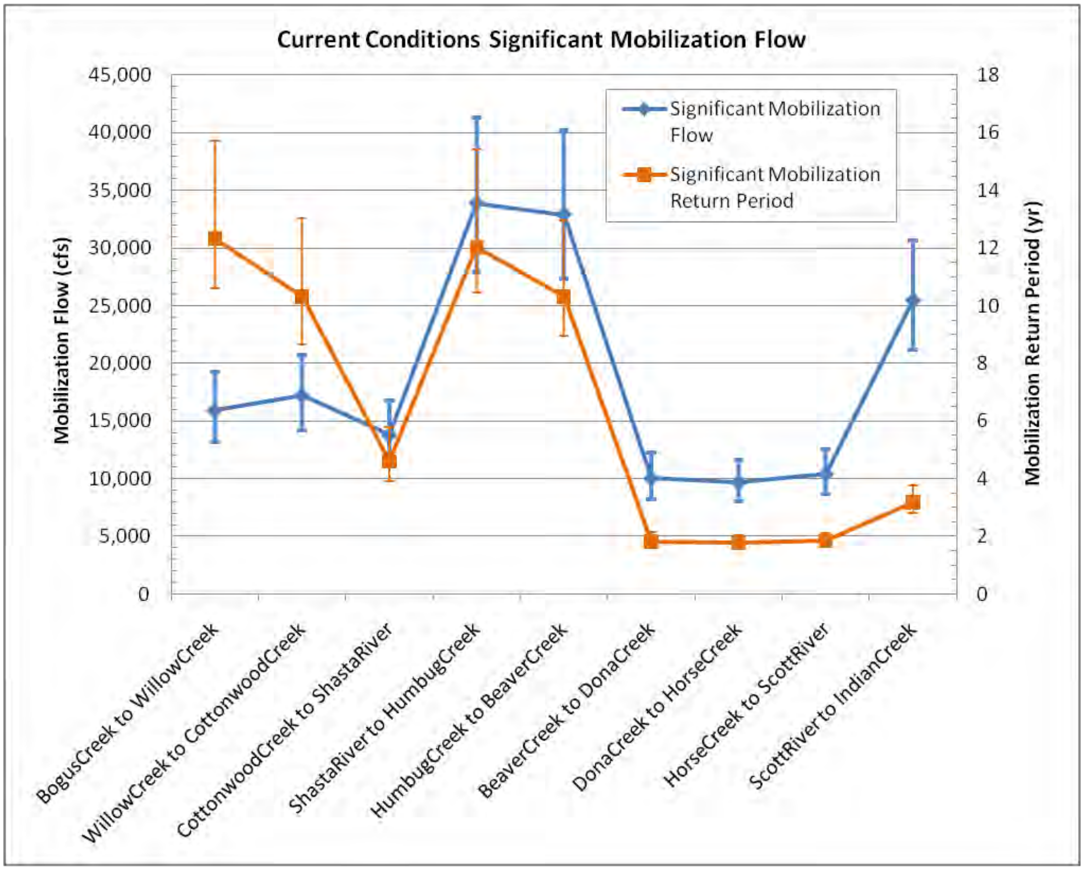


Figure 5-25. Significant bed material mobilization flow and return period on a reach averaged basis for reaches downstream of Iron Gate Dam.

5.6. Reservoir Sediment

A detailed reservoir investigation is documented in Reclamation (2010) and relevant results are reproduced here. Previous reservoir investigations have been performed by J.C. Headwaters, Inc. (2003), and Shannon and Wilson (2006).

Sediment in the reservoirs was characterized by soil properties, grain size, desiccation properties, and critical shear stress. The soil properties, including grain size and critical shear stress, were determined from field sampling and laboratory testing.

Field investigations were conducted at J.C. Boyle, Copco No. l, Copco No. 2, and Iron Gate dams/reservoirs, and in the Klamath River Estuary including about seven miles upstream from the mouth of the river. Maps of the reservoir and the sample site locations are given at the end of this section in Figure 5-26, Figure 5-27, and Figure 5-28, for J.C. Boyle, Copco 1, Iron Gate dams/reservoirs, and the Klamath River Estuary, respectively. Phase 1 of the geologic investigations included in-reservoir drilling to collect comprehensive suites of samples of reservoir sediment (Qr) behind each dam. There were three main purposes of this work:

1. To collect samples for screening-level analysis of organic and inorganic chemical compounds within the reservoir sediment and, where present, to determine the level and extent of contamination.

2. To collect samples of reservoir sediment to determine a standard suite of physical properties and to collect undisturbed samples for analyses of engineering properties.

3. To help determine the thickness of reservoir sediment throughout all major sections of each reservoir.

The in-reservoir geologic investigations consisted of:

- Barge and boat platforms for Auger Drilling and Sampling
- Barge and boat platforms for Push Tube Sampling
- A boat platform for Vibracore Drilling and Sampling
- A boat platform for Gravity Tube Sampling

Barge and boat-supported drilling/sampling took place at fifty-five locations in J.C. Boyle, Copco No.1, and Iron Gate reservoirs. Sixty-nine samples of reservoir sediment and pre-reservoir deposits were collected for gradation analysis, Atterberg limits, and field moisture content; seventy-three samples of reservoir sediment were collected for chemical analysis; and nineteen undisturbed samples of reservoir sediment were collected in Lexan liners for engineering properties, such as shear strength, testing. In Copco No. 2 Reservoir, boat-supported sampling of reservoir sediment was performed at sixteen locations, from the dam upstream for about 1,000 feet. In the Klamath River Estuary and up to seven miles upstream, boat-supported sampling took place at five locations, and characterization of fluvial deposits was conducted along seven miles of the river banks.

Fine-grained sediment in all of the reservoirs consisted primarily of Elastic Silt (MH), with lesser amounts of Elastic Silt with Fine Sand. The reservoir sediment is mostly an accumulation of silt-size particles of organic material, such as algae and diatoms, and silt-size particles of rock loosely arranged in an open water-filled structure. Reservoir sediment hosts a higher percentage of silt, sand, and gravel in the upper reaches of each reservoir. From the upper reaches to several thousand feet downstream, this coarse sediment transitions into deposits of sandy elastic silt, and then into elastic silt with trace sand.

Fine-grained reservoir sediment (Elastic Silt) throughout all the reservoirs has the consistency of pudding. The sediment captured in the sample tubes was very soft and indented with very light finger pressure. At 6 to 10 feet in the sample tubes, the sediment firmed up a little. On a microscopic scale, it has an open structure that holds a very high water content. Field moisture of samples of Elastic Silt were frequently 200% to 300% of the sample's dry weight, and ranged up to 700% moisture. Most reservoir sediment having this high water content that remains after the initial stage of dam removal will take some time to dry out.

Fine-grained reservoir sediment has a low cohesion and is highly erosive. In each reservoir, fine-grained reservoir sediment was thinnest in the upstream portion of the reservoir and thickest near the dam. Reservoir sediment was also thin to nonexistent in narrow channels of the reservoirs where water flow was greater than an estimated 2 to 4 miles per hour. This was attributed to the sediment either remaining in suspension or eroding from the active channel, or both.

These investigations demonstrated that sediment deposition throughout all four reservoirs follows well-understood principals of geology and of fluvio-lacustrine sedimentation. Geologic investigations did not encounter any unusual characteristics of the sediment or unique depositional environments requiring special consideration or explanations.

Methane gas is currently trapped in reservoir sediment behind each dam and this gas will escape during reservoir drawdown. A screening-level determination for all potential contaminants within the reservoir sediments is to be made by Reclamation in separate reports.

Surface geologic mapping and the installation of groundwater observation wells around each reservoir are planned for Phase 2 of the investigation program.

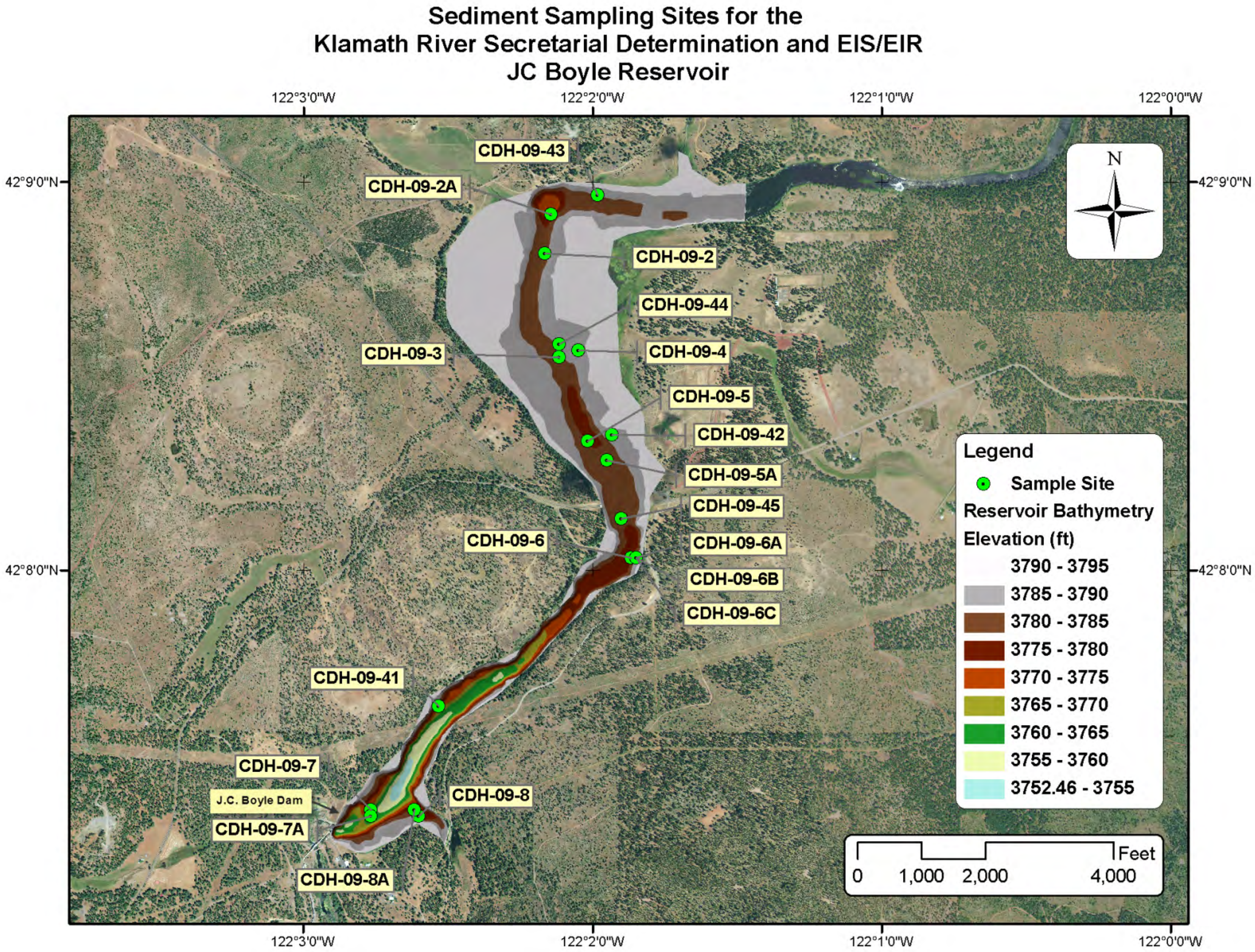


Figure 5-26. Bathymetry of J.C. Boyle Reservoir and 2009 drill hole locations.

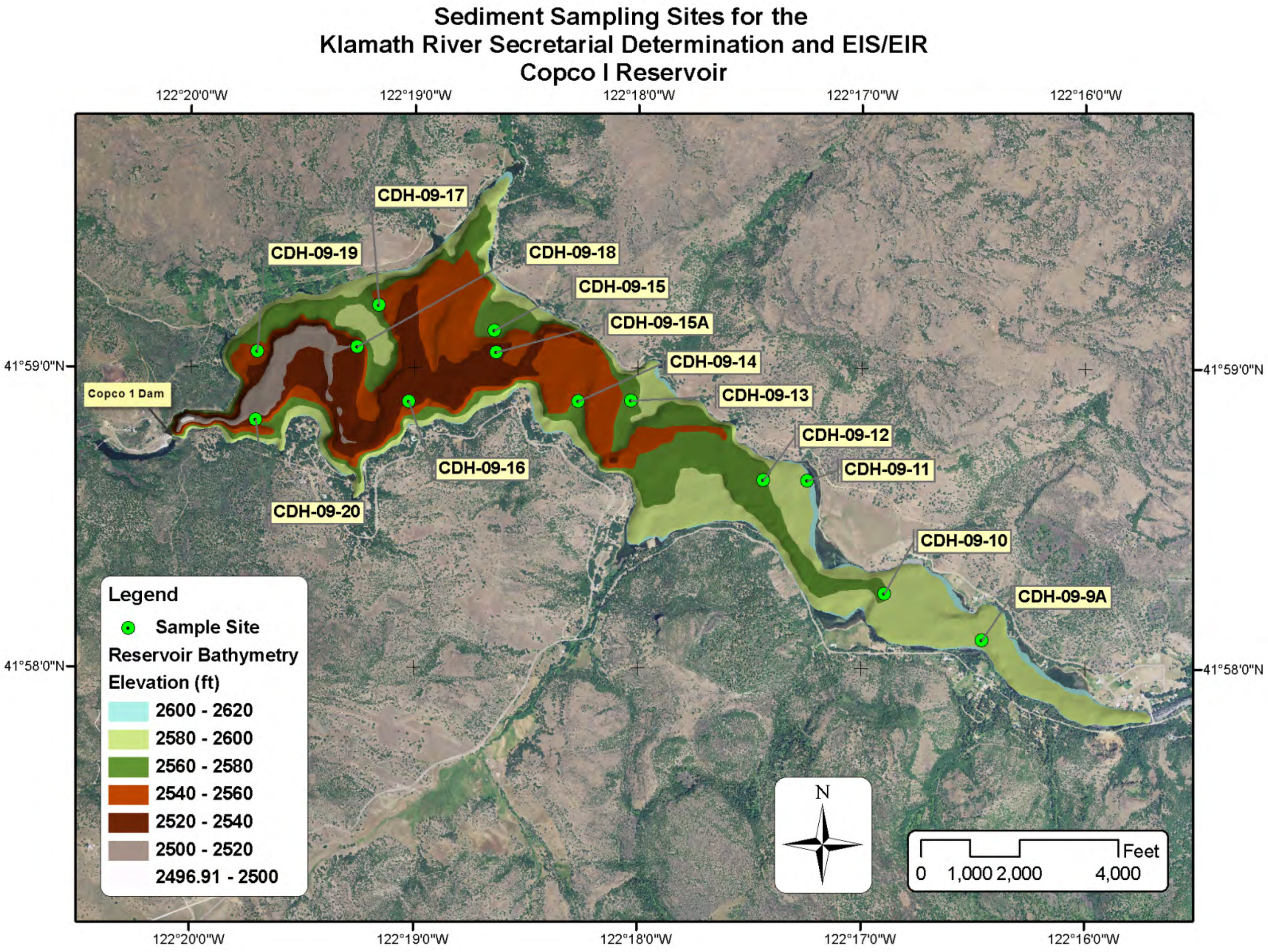
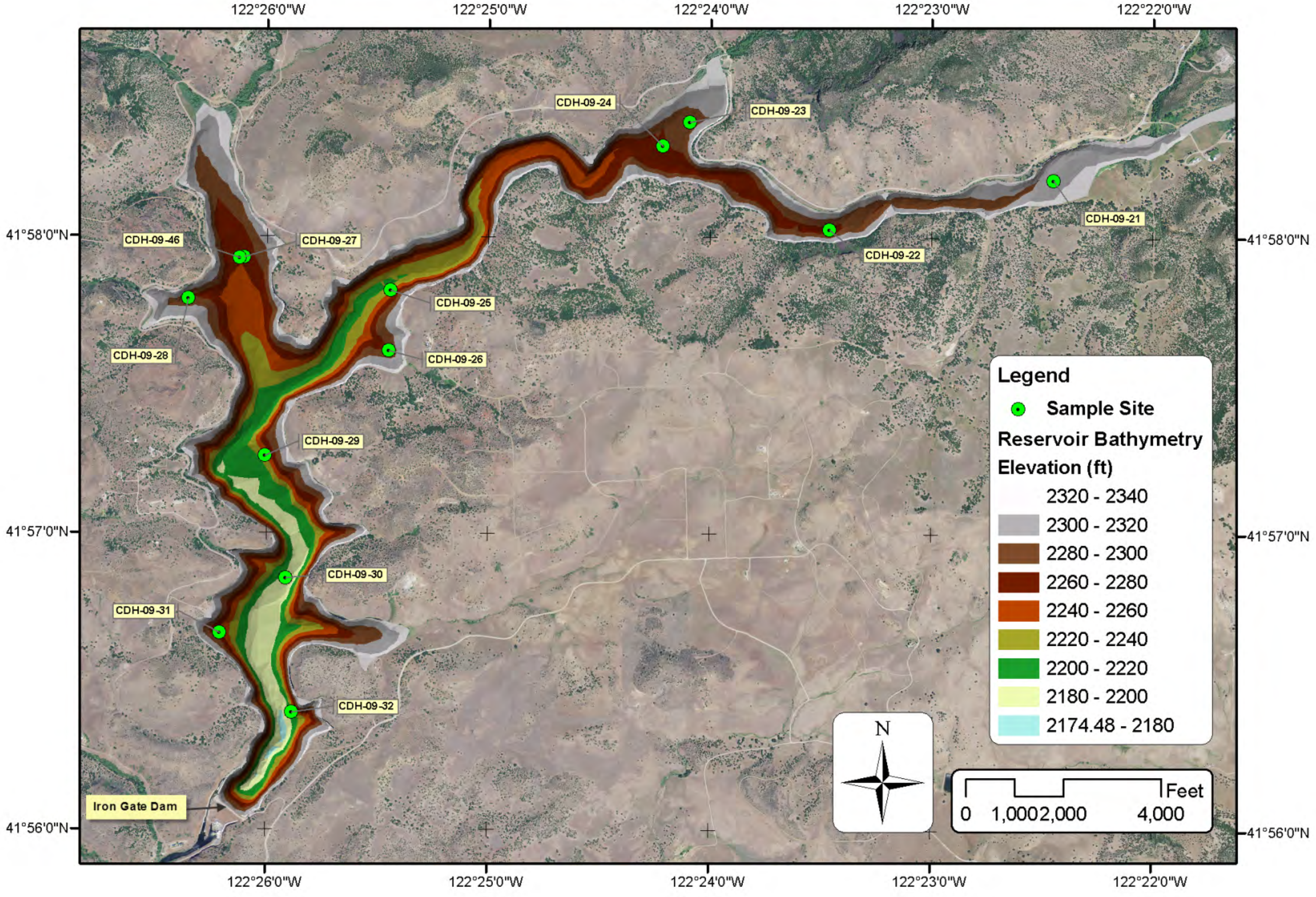


Figure 5-27. Bathymetry of Copco Reservoir and 2009 drill hole locations.



Sediment Sampling Sites for the
Klamath River Secretarial Determination and EIS/EIR
Iron Gate

Figure 5-28. Bathymetry of Iron Gate Reservoir and 2009 drill hole locations.

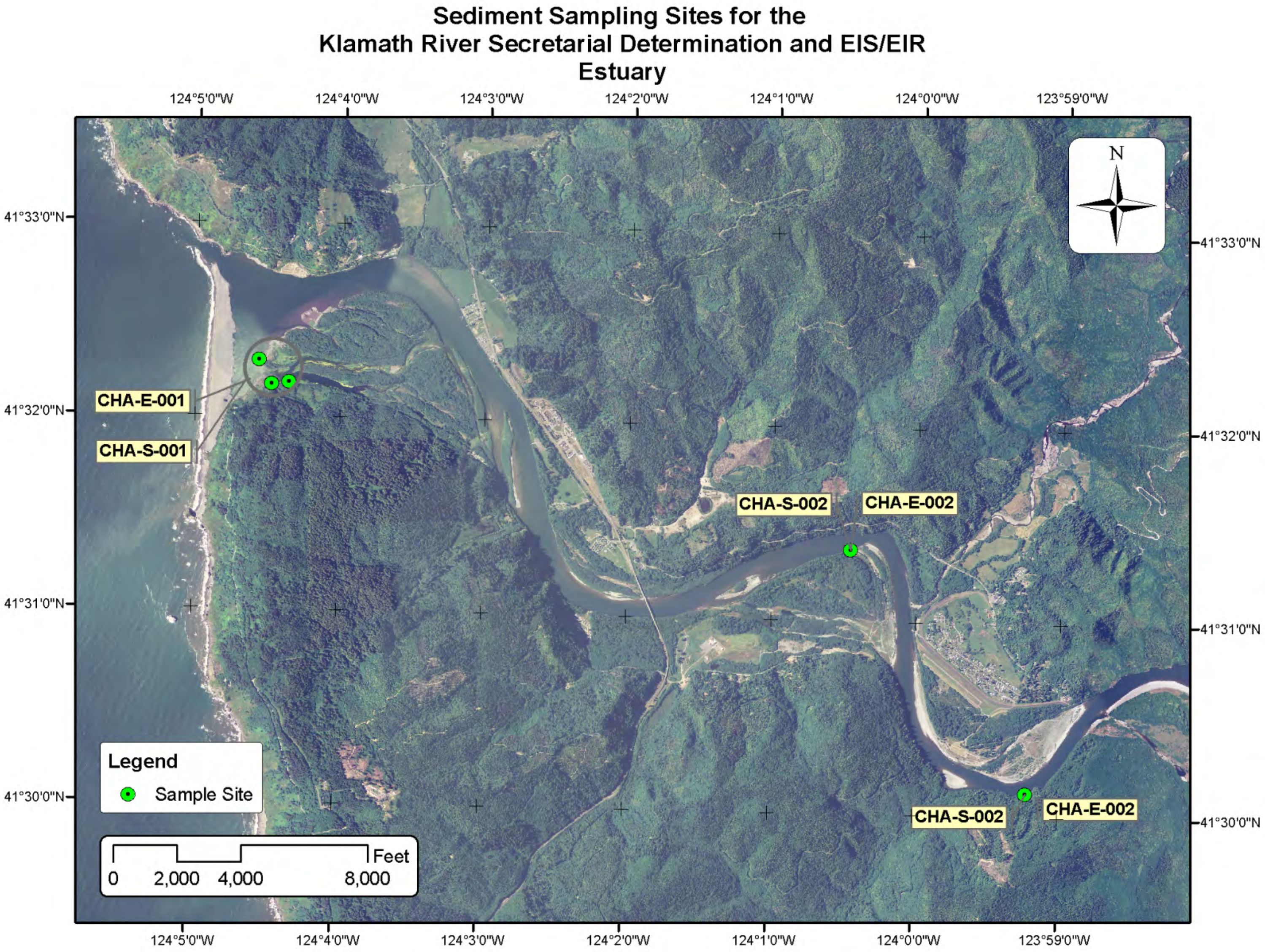


Figure 5-29. 2009 Sample site locations in the Klamath River Estuary.

5.6.1. SEDIMENT VOLUME AND THICKNESS

This section will detail the previous estimates of reservoir sediment volumes and explain the methodology for obtaining new volume estimates.

5.6.1.1. Previous Estimates

There have been two different estimates of the reservoir volumes. JC Headwaters, Inc. (2002) performed a bathymetric survey of J.C. Boyle, Copco No. 1, and Iron Gate reservoirs. JC Headwaters, Inc. (2002) then computed the relationships between reservoir storage volume and reservoir elevation. These were compared against the historical relationships based upon the pre-dam survey of each reservoir. The difference at full pool between the historical storage volume and the current storage volume was assumed to be the volume of sediment deposition. GEC (2006) estimated the reservoir volume based a difference between upon pre-dam surveys and the survey of JC Headwaters, Inc. (2002). The results of the two methods are given in Table 5-9.

Shannon and Wilson (2006a) collected sediment samples to characterize the physical and chemical properties of the sediment trapped behind the reservoirs. The reservoir sediment depth was recorded at 26 sites in J.C. Boyle, Copco 1, and Iron Gate reservoirs.

Table 5-9. Previous reservoir sediment volume estimates.

	Reservoir sediment (yd^3)			
Study	**J.C. Boyle**	**Copco No. 1**	**Copco No. 2**	**Iron Gate**
GEC (2006)	636,000	10,870,000	None	8,767,000
JC Headwaters, Inc. (2003)	22,222	9,629,000	None	4,818,000

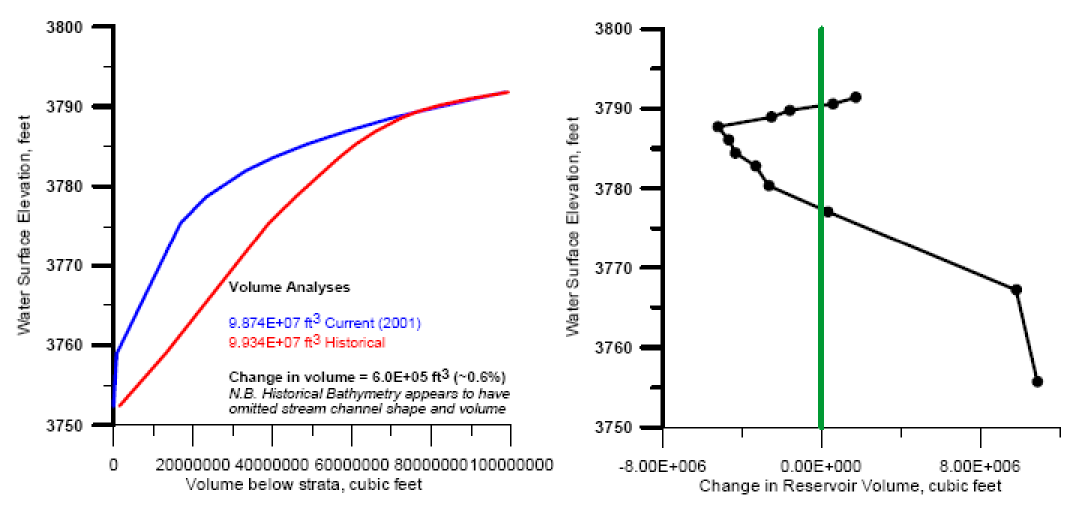


Figure 5-30. Volume – Elevation data for J.C. Boyle Reservoir. From J.C. Headwaters, Inc. (2003).

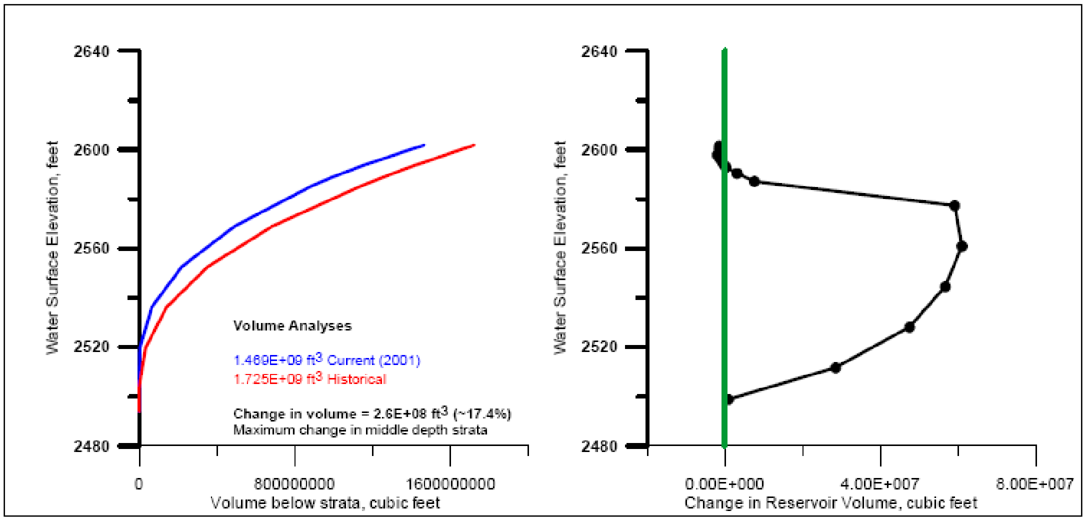


Figure 5-31. Volume – Elevation data for Copco No. 1 Reservoir. From J.C. Headwaters, Inc. (2003).

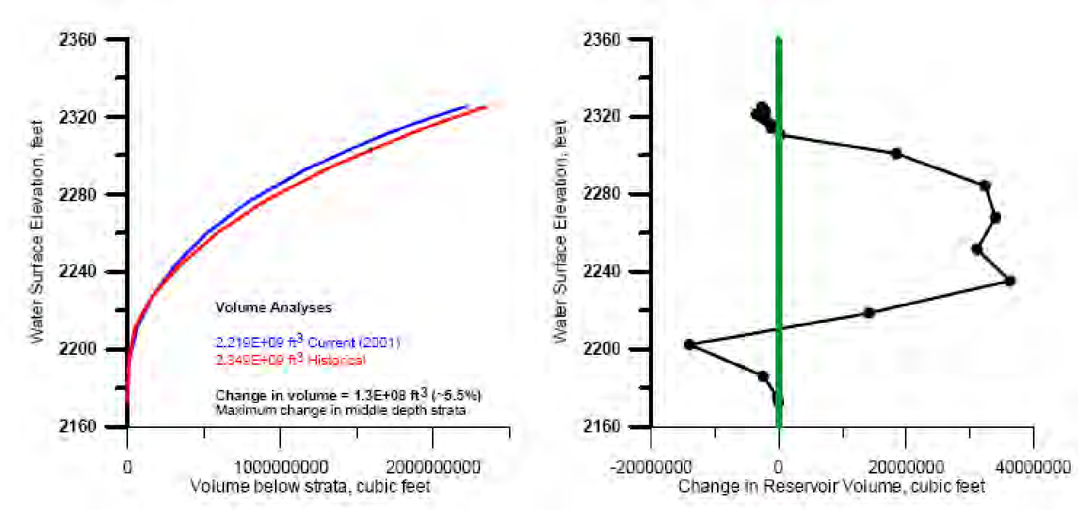


Figure 5-32. Volume – Elevation data for Iron Gate Reservoir. From J.C. Headwaters, Inc. (2003).

5.6.1.2. Current Estimates

A limitation of previous volume estimates is that they relied upon the pre-dam surveys. At Copco 1 Dam, the pre-dam contour interval was 5 feet. At Iron Gate and J.C. Boyle dams, the contour interval was 10 feet. The reservoir sediment thicknesses were generally less than 10 feet at Copco Reservoir, less than 5 feet at Iron Gate Reservoir and less than 20 feet at J.C. Boyle Reservoir. The sediment thicknesses were generally equivalent to the contour interval, making it difficult to obtain accurate estimates of the thickness through differencing of surveys. A much more direct way to estimate the sediment volumes is to rely upon the upon the drill holes, which are direct measurements of the sediment thickness. To develop sediment thickness measurements for the entire reservoir, measurements were extrapolated from the work of Shannon and Wilson (2006) and from Reclamation (2010).

JC Boyle

The sediment depth at J.C. Boyle Reservoir was determined by combining the sediment sample information with field observations. In the upper portions of the reservoir, little or no sediment was found during drilling except in one bend of the historical stream channel. An estimate of the extent and approximate location of this sediment deposition was drawn on the map to encompass the drill holes where the sediment was sampled. The extent of the deposition was limited to the historical stream channel.

In the lower portion of the reservoir, the sediment samples were used to determine the thickness. Holes CDH-09-07 (near the dam) and CDH-09-6 (near the state highway bridge) were near the dam and the sediment thickness was linearly interpolated between them. Table 5-10 shows the sediment samples used.

Figure 5-35, at the end of this section, shows the map of reservoir thickness and the locations of the Shannon and Wilson (2006a) and 2009 sediment samples. The volume of trapped sediment was estimated to be 990,000 yd^3. Limited samples available where the sediment was the deepest near the dam contributed to the considerable uncertainty in this estimate. It is expected that the uncertainty of the estimate is about +/- 30% or 300,000 yd^3. The previous GEC estimate was 600,000 yd^3 and it is likely that the true value is somewhere in between this estimate and the current one. Additional drill holes in the areas where significant sediment is present could reduce this uncertainty. Specifically, more samples could be taken in the 4,000 feet nearest the dam.

Table 5-10.Sediment sample locations and depths for J.C. Boyle Reservoir.

Year	Sample Number	Latitude	Longitude	Sediment Depth (ft)	Station (ft)	Bed Elevation (ft)
2006	J-1	N42 7.34	W122 2.782	13.2	191010.8	3766
2006	J-2	N42 8.921	W122 1.781	0	204732.9	3783
2006	J-3	N42 7.998	W122 1.968	0.5	196573.9	3776
2006	J-4	N42 8.926	W122 2.148	0.3	203054	3770
2006	J-5	N42 8.625	W122 2.197	0.3	201158.7	3779
2009	CDH-09-2	N42 08 49.6	W 122 02 10.8	5	202437.3	3779.02
2009	CDH-09-3	N42 08 33.7	W 122 02 07.5	6	200666.4	3781.4
2009	CDH-09-4	N42 08 34.2	W 122 02 03.3	9	200531	3785.7
2009	CDH-09-4A	N42 08 34.2	W 122 02 03.3	9.2	200531	3785.7
2009	CDH-09-5	N42 08 20.6	W 122 02 01.6	0.3	199182	3777.3
2009	CDH-09-5A	N42 08 02.1	W 122 01 51.8	0.3	197032.2	3777.3
2009	CDH-09-6	N42 08 02.5	W 122 01 52.6	0	197060.9	3777.6
2009	CDH-09-6A	N42 08 01.8	W 122 01 51.6	0	197030.4	3777.5
2009	CDH-09-6B	N42 08 02.1	W 122 01 51.8	0	197032.2	3777.5
2009	CDH-09-6C	N42 08 02.2	W 122 01 51.4	0	197047.8	3777.6
2009	CDH-09-7	N42 07 23.0	W 122 02 46.0	18.7	191256.4	3762.6
2009	CDH-09-7A	N42 07 22.9	W 122 02 46.0	21.7	191249	3762
2009	CDH-09-8	N42 07 22.4	W 122 02 36.8	1.7	191607.9	3779.8
2009	EDH-09-1	N42 08 49.5	W 122 02 11.0	3.2	202424.5	3779.1
2009	EDH-09-1A	N42 08 49.0	W 122 02 10.4	3.4	202384.3	3779.1
2009	EDH-09-2	N42 08 35.0	W 122 02 08.5	9	200797.6	3785.63
2009	EDH-09-2A	N42 08 34.1	W 122 02 09.3	9	200804.3	3785.8
2009	EDH-09-3	N42 07 26.2	W 122 02 41.0	14	191766	3756.3

Copco 1

To estimate the sediment depth throughout Copco 1 and Iron Gate reservoirs, a relationship was found between sediment depth and position within the reservoir for collected sediment samples. Samples were measured by Shannon and Wilson (2006a) and Reclamation (2009). For Copco Reservoir, 28 samples were used. Table 5-11 shows the samples used.

Table 5-11 Sediment sample locations and depths for Copco 1 Reservoir.

Year	Sample Number	Latitude	Longitude	Sediment Depth (ft)	Station (ft)	Bed Elevation (ft)	Relative Station	Relative Bed Elevation	Predicted Sediment Depth (ft)
2006	C-02	N41 58.154	W122 16.828	4.4	67610.69	2586.91	0.75	0.44	4.0
2006	C-03	N41 58.585	W122 17.88	5.7	61763.27	2575.96	0.50	0.45	4.3
2006	C-04	N41 58.829	W122 18.147	7.7	59876.47	2553.73	0.42	0.72	7.0
2006	C-05	N41 59.358	W122 18.781	5.8	56491.14	2555.35	0.27	0.58	5.8
2006	C-06	N41 58.921	W122 18.992	10	55386.44	2527.04	0.23	0.88	8.8
2006	C-07	N41 57.93	W122 16.244	5.8	70858.52	2590.68	0.89	0.54	4.8
2006	C-08	N41 58.373	W122 17.246	3.6	65168.13	2579.21	0.65	0.51	4.8
2006	C-09	N41 59.123	W122 18.277	3.5	58374.78	2561.33	0.36	0.56	5.5
2006	C-10	N41 58.908	W122 19.367	9.4	53632.49	2521.01	0.15	0.88	8.8
2006	C-12	N41 57.874	W122 16.04	6	71828.75	2588.39	0.93	0.77	6.8
2009	CDH-09-09A	N41 58.096	W 122 16.460	4.6	69356.10	2588.15	0.83	0.55	4.9
2009	CDH-09-10	N41 58.251	W 122 16.896	8	67052.88	2577.04	0.73	0.68	6.2
2009	CDH-09-11	N41 58.627	W 122 17.241	1.3	63999.20	2598.66	0.60	0.15	1.4
2009	CDH-09-12	N41 58.629	W 122 17.4403	5.4	63397.06	2573.55	0.57	0.58	5.5
2009	CDH-09-13	N41 58.892	W 122 18.031	5.7	60065.93	2566.99	0.43	0.55	5.3
2009	CDH-09-14	N41 58.889	W 122 18.268	5.3	59234.95	2562.94	0.39	0.34	3.3
2009	CDH-09-15	N41 59.124	W 122 18.642	3	57029.61	2569.58	0.30	0.50	4.9
2009	CDH-09-15A	N41 59.052	W 122 18.634	9.7	57070.02	2536.23	0.30	0.87	8.6
2009	CDH-09-16	N41 58.888	W 122 19.025	7.5	55224.26	2531.46	0.22	0.85	8.5
2009	CDH-09-17	N41 59.208	W 122 19.160	1.2	54706.02	2555.67	0.20	0.28	2.8
2009	CDH-09-18	N41 59.0680	W 122 19.256	9.2	54196.37	2523.17	0.18	0.92	9.2
2009	CDH-09-19	N41 59.053	W 122 19.704	4.8	51685.14	2552.44	0.07	0.50	5.1
2009	CDH-09-20	N41 58.825	W 122 19.711	7.4	51509.81	2534.69	0.06	0.78	8.0
2009	EDH-09-04	N41 58 12.2	W 122 16 42.1	3.5	67988.99	2590.08	0.77	0.57	5.2
2009	EDH-09-05	N41 58 53.4	W 122 17 51.8	1.9	60597.71	2579.53	0.45	0.31	3.0
2009	EDH-09-05A	N41 58 53.4	W 122 17 51.9	1.8	60597.71	2579.53	0.45	0.31	3.0
2009	EDH-09-06	N41 58 54.5	W 122 18 58.9	10	55429.45	2527.03	0.23	0.89	8.9
2009	EDH-09-07	N41 58 48.9	W 122 19 36.0	1.8	52387.33	2574.27	0.10	0.31	3.1

Beginning with the downstream end of the reservoir equivalent to zero and the upstream extent of the reservoir equivalent to one, a relative station was calculated for each sample. In addition, relative depth with respect to each station was calculated by setting the minimum bed = 1 and the highest elevation in the cross section = 0. The following function (equation 1) was fit to the data:

$$D = \left(a - bX^{c}\right)Y^{d}$$

where, D = sediment depth

X = relative stationing along reservoir

Y = relative depth within cross section

Constants: $a = 10.35$, $b = 1.69$, $c = d = 1$

For Copco Reservoir, the relationship yields an R^2 value of 0.84 and a root mean squared error of 1.1. Figure 5-33 shows the predicted sediment depths compared with the measured values. The largest difference between the predicted and measured values is 2 feet. The average difference is 1 foot.

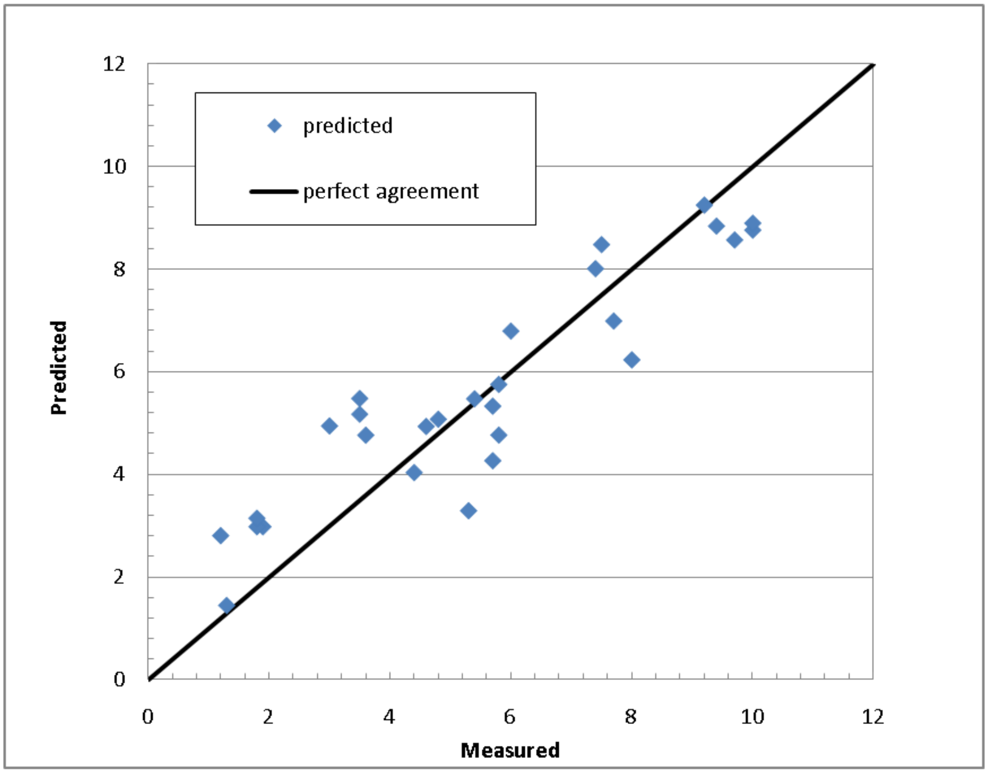


Figure 5-33. Comparison of measured sediment depth to predicted sediment depth from sediment samples collected in 2006 and 2009 in Copco Reservoir.

This relationship was applied to the entire reservoir. The extents were based on the area surveyed by J.C. Headwaters, Inc. (2003). Sediment depths were calculated using ArcMap's (ESRI, Inc.) ArcToolbox raster math functions. Figure 5-36, at the end of this section, shows the map of reservoir thickness and the locations of the 2009 sediment samples. Two areas were modified from the results of the regression function. Any location that produced a negative value was set at zero depth. This occurred in higher elevations around the reservoir edge and at the upstream-most area of the reservoir where sediment depths were higher than anticipated. However, measurements showed that no measureable sediment deposition exists in the upper end of the reservoir and a value of 0.5 feet of sediment as assigned to this area.

The total volume trapped in Copco 1 Reservoir was estimated to be 7.44 million yd^3. An estimate of the uncertainty of this volume was computed by multiplying the average error of the regression equation by the area of the reservoir. This equated to an uncertainty of 1.5 million yd^3, or 20 %.

Iron Gate Reservoir

The method for estimating the sediment depth in Iron Gate Reservoir was similar to that used for Copco 1 Reservoir. A relationship was found between sediment depth and position within the reservoir for collected sediment samples. Samples were measured by Shannon and Wilson (2006) and Reclamation (2009). For Iron Gate Reservoir, 18 samples were used (Table 5-12).

Table 5-12. Sediment sample locations and depths for Iron Gate Reservoir.

Year	Sample Number	Latitude	Longitude	Sediment Depth (ft)	Station (ft)	Bed Elevation (ft)	Relative Station	Relative Bed Elevation	Predicted Sediment Depth (ft)
2006	IG-03	N41 57.659	W122 25.629	2	16397.71	2222.96	0.36	1.02	3.7
2006	IG-04	N41 56.686	W122 25.777	2.5	7967.60	2230.06	0.11	0.72	4.0
2006	IG-05	N41 58.279	W122 22.421	0.5	35186.44	2306.55	0.93	1.24	0.6
2006	IG-07	N41 57.922	W122 25.235	5	18891.26	2232.27	0.44	1.02	3.4
2006	IG-08	N41 57.175	W122 26.039	4.3	11821.86	2198.06	0.23	1.07	4.0
2009	CDH-09-21	N41 58 11.7	W 122 22 26.9	1.5	34906.10	2311.01	0.92	0.58	0.6
2009	CDH-09-22	N41 58 01.7	W 122 23 27.6	1.4	29859.70	2271.78	0.77	1.09	1.8
2009	CDH-09-25	N41 57.820	W 122 25.440	5	17784.95	2235.39	0.40	1.02	3.6
2009	CDH-09-26	N41 57 36.9	W 122 25 26.8	2	17145.91	2283.76	0.39	0.29	3.1
2009	CDH-09-29	N41 57.262	W 122 26.006	4.8	12625.61	2237.78	0.25	0.77	3.8
2009	CDH-09-30	N41 56 50.8	W 122 25 54.6	2.9	9362.28	2193.36	0.15	0.98	4.1
2009	CDH-09-31	N41 56 39.7	W 122 26 12.5	4.8	7908.78	2263.37	0.11	0.37	3.7
2009	CDH-09-32	N41 56.396	W 122 25.882	4.3	6096.50	2216.72	0.05	0.85	4.1
2009	EDH-09-08	N41 58 03.4	W 122 23 21.1	0.3	30369.34	2282.99	0.78	0.91	1.6
2009	EDH-09-08A	N41 58 02.6	W 122 23 41.3	2.2	28775.45	2273.18	0.73	1.10	2.0
2009	EDH-09-09	N41 57 43.0	W 122 25 27.0	2	17435.53	2304.61	0.39	0.24	3.0
2009	EDH-09-09A	N41 57 43.0	W 122 25 30.0	3.8	17226.94	2280.93	0.39	0.24	3.0
2009	EDH-09-10	N41 57 14.5	W 122 25 58.6	4.5	12356.84	2251.67	0.24	0.54	3.7

The same function (equation 1) was used to fit the data at Iron Gate Reservoir. The best fit values for the constants are: $a = b = 4.208$, $c = 2.046$, $d = 0.125$. The relationship yields an R^2 value of 0.54 and a root mean squared error of 1.0. Figure 5-34 shows the predicted sediment depths compared with the measured values. The largest difference between the predicted and measured values is 1.7 feet. The average difference is 0.9 feet.

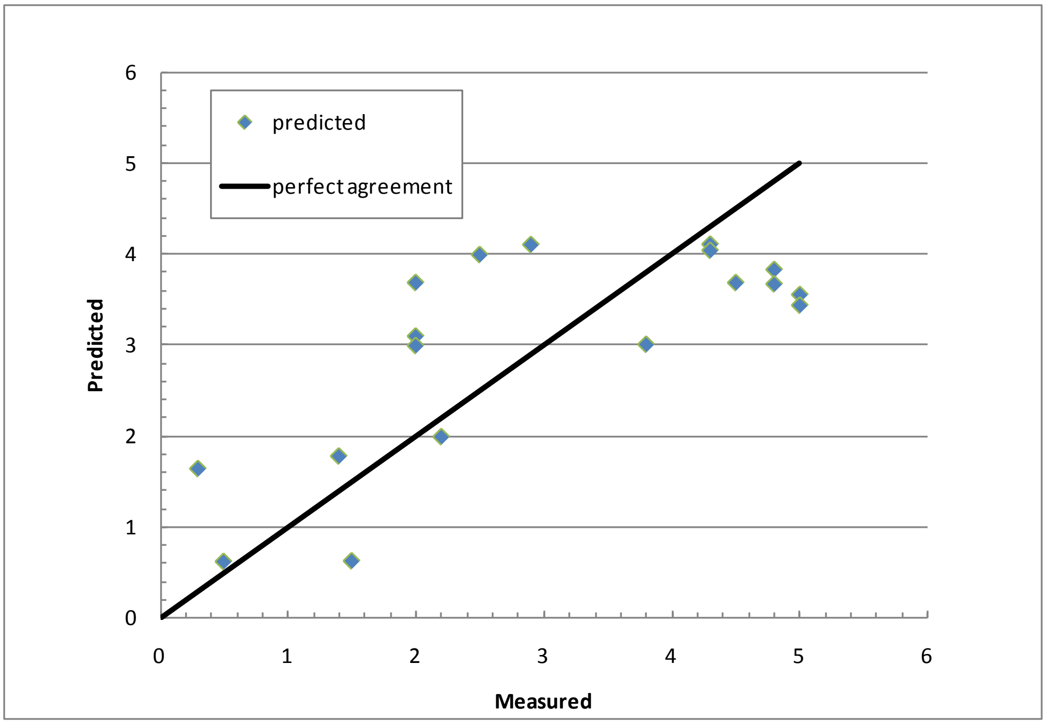


Figure 5-34. Comparison of measured sediment depth to predicted sediment depth from sediment samples collected in 2006 and 2009 in Iron Gate Reservoir.

This relationship was applied to the entire reservoir (the extents were based on the area surveyed by J.C. Headwaters, Inc. (2003). Sediment depths were calculated using ArcMap's (ESRI, Inc.) ArcToolbox raster math functions.

Figure 5-37, at the end of this section, shows the map of reservoir thickness and the locations of the 2009 sediment samples. Three areas were modified from the results of the regression function. Any location that produced a negative value was set at zero depth. This occurred in higher elevations around the reservoir edge. The other two areas were where tributaries enter into Iron Gate Reservoir from the north and influence the sediment deposition. Sediment samples collected in each of these areas were averaged and applied over the approximate area of influence. Jenny Creek is the tributary that enters from the north-east. The average sediment thickness was 6.0 feet. Scotch Creek and Camp Creek enter the reservoir from the north-west. The average sediment thickness in this area is 3.0 feet. See Table 5-13.

The total volume trapped in Iron Gate Reservoir was estimated to be 4.71 million yd^3. An estimate of the uncertainty of this volume was computed by multiplying the average error of the regression equation by the area of the reservoir. This equated to an uncertainty of 1.3 million yd^3 or 29 % (Tables 5-14 and 5-15).

Table 5-13. Sediment samples used to calculate the average thickness where Jenny Creek, Scotch Creek and Camp Creek enter Iron Gate Reservoir.

Year	Sample Number	Latitude	Longitude	Sediment Depth (ft)	Station (ft)	Bed Elevation (ft)
Jenny Creek						
2006	IG-1	N41 58.46	W122 24.001	7.0	26498.02	2306.00
2006	IG-9	N41 58.329	W122 24.277	6.5	25385.74	2270.00
2009	CDH-09-23	N41 58 23.3	W 122 24 05.5	9.2	26138.66	2298.70
2009	CDH-09-24	N41 58 18.6	W 122 24 12.7	4.1	25738.82	2282.40
2009	EDH-09-11	N41 58 17.3	W 122 24 10.9	3.1	25911.94	2281.60
		Average Depth		**6.0**		
Scotch Creek and Camp Creek						
2006	IG-2	N41 57.819	W122 26.16	1.9	14663.72	2254.00
2006	IG-6	N41 58.216	W122 26.255	2.0	17480.57	2299.00
2009	CDH-09-Add 1	N41 57 55.6	W 122 26 07.4	2.4	16822.33	2266.80
2009	CDH-09-27	N41 57 55.8	W 122 26 06.1	4.2	16887.17	2272.40
2009	CDH-09-28	N41 57 47.4	W 122 26 21.2	4.4	14321.23	2290.20
2009	EDH-09-091	N41 57 55.6	W 122 26 07.4	3.0	16822.33	2267.60
		Average Depth		**3.0**		

Table 5-14. Estimated reservoir volumes based upon drill holes.

Reservoir	# holes 2006	# holes 2009	# holes Total	Estimated Volume (yd^3)	Estimated Uncertainty (+/- yd^3)
JC Boyle	5	26	31	990,000	300,000
Copco I	12	17	29	7,440,000	1,500,000
Copco II	0	0	0	0	
Iron Gate	9	19	28	4,710,000	1,300,000

Table 5-15. Average reservoir physical characteristics based upon drill holes.

Reservoir	**Location**	**Volume (yd^3)**	**Silt and Clay (%)**	**Water Content (%)**	**Porosity (-)**	**Dry Bulk Density (lb/ft^3)**	**Estimated Dry Weight (tons)**
JC Boyle	Upper	380,000	44	172	0.82	29.5	151,000
	Lower	620,000	88	344	0.90	16.3	136,000
Copco I	Upper	810,000	73	287	0.88	19.2	210,000
	Lower	6,630,000	88	295	0.88	18.7	1,674,000
Iron Gate	Upper	830,000	78	192	0.83	27.0	303,000
	Lower	2,780,000	86	276	0.88	19.8	743,000
	Upper Trib	300,000	75	102	0.73	44.4	180,000
	Lower Trib	800,000	94	284	0.88	19.3	208,000
All		**13,150,000**	**84.8**	**278**	**0.87**	**20.3**	**3,605,000**

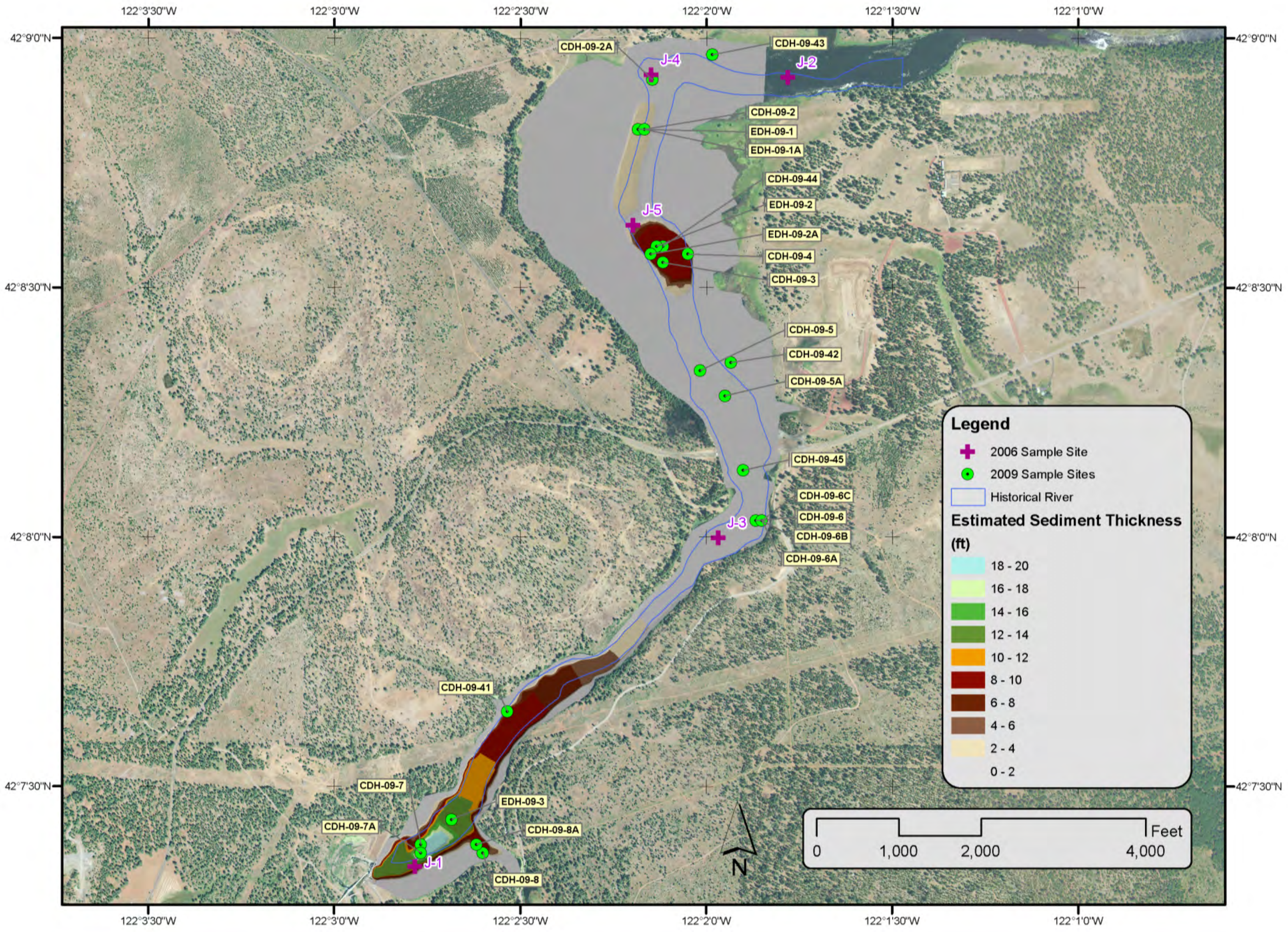


Figure 5-35. J.C. Boyle Reservoir estimated sediment thickness and sample site locations.

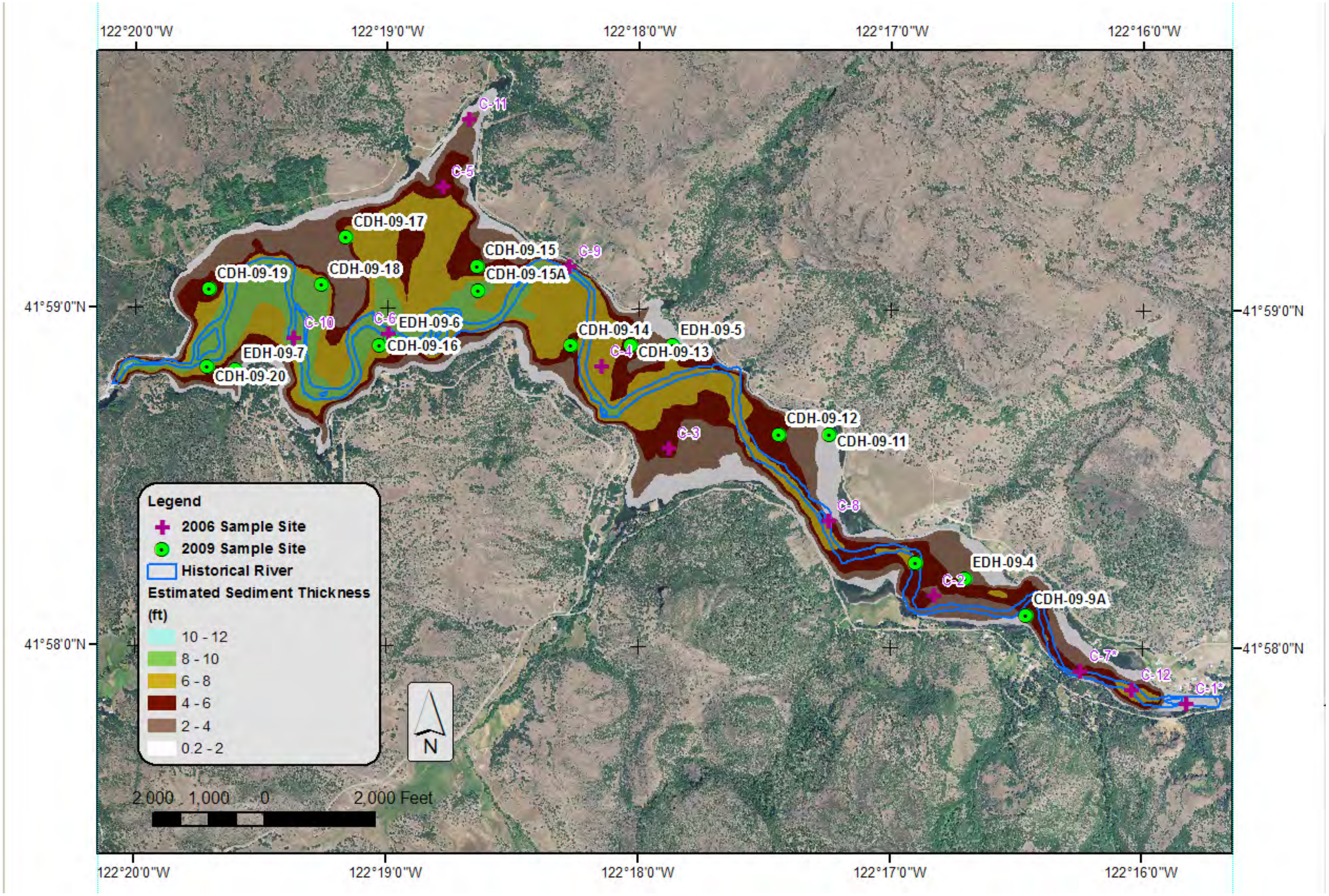


Figure 5-36. Copco 1 Reservoir estimated sediment thickness and sample site locations.

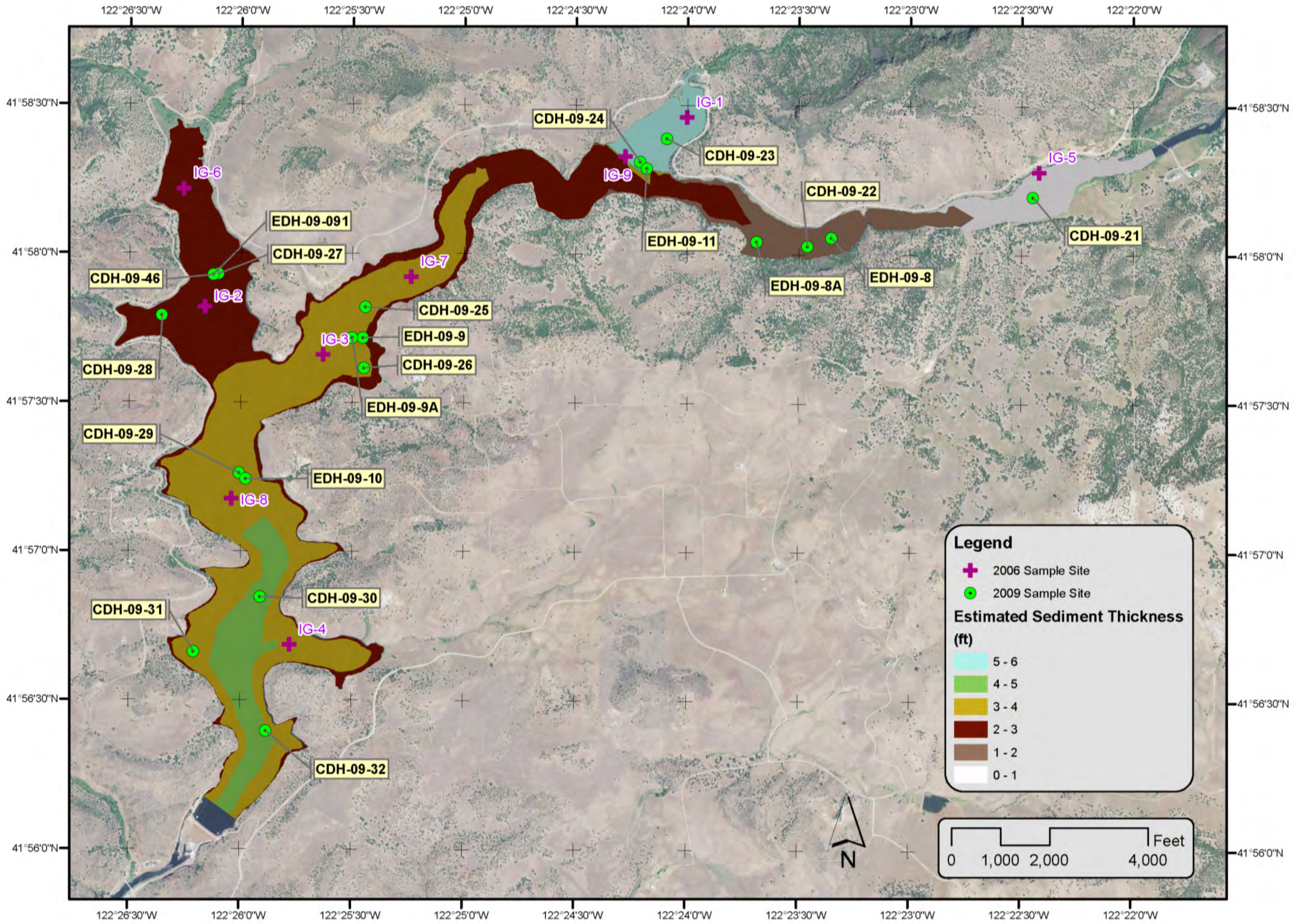


Figure 5-37. Iron Gate Reservoir estimated sediment thickness and sample site locations.

5.6.2. PHYSICAL PROPERTIES

Physical properties such as particle size, bulk density, and water content are important to defining the behavior of the reservoir sediment after dam removal. A particle size and basic engineering properties analyses were conducted on samples from each drill hole and details of the drilling investigation and laboratory analysis are given in Reclamation (2010). Average properties were computed for the upper and lower sections of each reservoir. In addition, the pre-reservoir sediment was averaged separately. At Iron Gate, the samples in the tributary arms were also averaged separately. The separation between upper and lower sections at J.C. Boyle Reservoir was between holes CDH-9-41 and CDH-9-6. At Copco 1 Reservoir, it was between samples CDH-9-11 and CDH-9-10 and at Iron Gate Reservoir, it was between samples CDH-9-25 and CDH-9-24. Results are summarized in Table 5-16.

To calculate the porosity, ε, of the sample the following equation was used:

$$\varepsilon = \left(1 + \frac{1}{\omega s}\right)^{-1}$$

Where ω = water content by mass and s = specific gravity of sediment. The dry bulk density of the sediment is

$$\rho_b = \gamma s(1-\varepsilon)$$

There were two samples classified as MH (Elastic silt) that were tested for specific gravity (s). The specific gravity of the material was 2.67 and 2.52, for an average specific gravity of 2.6 (Strauss, 2010).

Table 5-16. Average physical properties of reservoir sediment.

JC Boyle										
	#	Clay	Silt	Sand	Gravel	LL	PL	WC	η	ρ_d
		%	%	%	%	%	%	%	%	lb/ft^3
Upper Reservoir	12	17.3	26.2	56.5	0.0	45.5	14.7	173	0.82	29.5
Lower Reservoir	17	38.2	49.7	12.1	0.0	173	60.6	345	0.90	16.3
Pre-reservoir	2	3.7	9.5	28.4	58.5	44.9	12.7	23.4	0.38	101
Copco 1										
Upper Reservoir	4	27.9	46.8	25.1	0.2	109.3	49.3	287	0.88	19.2
Lower Reservoir	17	55.8	34.2	10.0	0.0	154.3	59.1	295	0.88	18.7
Pre-reservoir	6	35.6	42.2	22.2	0.0	105.0	41.5	153	0.80	32.6
Iron Gate										
Upper Reservoir	7	35.4	43.1	21.6	0.0	70.9	29.9	192	0.83	27.0
Lower Reservoir	10	60.7	25.5	13.5	0.4	118.7	51.4	276	0.88	19.8
Pre-reservoir	8	33.6	16.9	20.4	29.1	60.6	32.5	37.9	0.50	81.8
Upper Tributary	7	31.8	42.7	25.5	0.0	60.7	22.7	102	0.73	44.4
Lower Tributary	6	61.8	32.0	6.1	0.0	112.2	49.6	284	0.88	19.3

Clay = 0 to 0.005 mm
Silt = 0.005 to 0.075 mm
Sand = #200 to # 4 sieve
Gravel = #4 to 3 inch
LL = Liquid limit
PL = Plasticity Index
ω = Moisture Content = Weight Water / Weight Solids
η = porosity
ρ_d = dry bulk density

5.6.3. COHESION AND SHEAR STRENGTH

The shear strength of the reservoir sediment will be important to understanding the behavior of the sediment upon drawdown. Sediment with low shear strength will slump downslope as it will be unable to resist the force of gravity. The shear strength of the sediment can be computed as:

$$\tau_f = c' + (\sigma - \mu_w)\tan\phi'$$

where, τ_f = soil shear stress

c' = effective cohesion
σ = normal stress
μ_w = pore water pressure
ϕ' = effective angle of internal friction

Strauss (2010) performed direct shear tests on three drill core samples taken from each reservoir, holes EDH-9-3, EDH-9-6, and EDH-9-9A. The measured friction angles (ϕ') were 29.8º, 27.3º and 32.3º, respectively. The measured cohesion values (c') were 1.1, 0.8, and 0.7 lbf/in^2. Because the material is so soft, it was difficult to obtain accurate estimates of its shear strength and Strauss (2010) stated that actually shear strength may be less than measured.

If is possible to calculate the stable depth of an section of the deposit assuming infinite slope using the US Army Corps of Engineers Slope Stability Engineering Manual (EM-1110-2-1902, USACOE, 2003). The analysis is described in Appendix E of the manual and assumes that the soil rests on top of a firm base. It accounts for seepage. Table 5-17 contains the estimated stable depth of reservoir sediment assuming different values of the cohesion and different slope values. It is assumed that the sediment is fully saturated and draining. As a conservative assumption, it was assumed that the minimum effective cohesion value would be 50 % of the minimum measured value or 0.35 lbf/in^2. Therefore, on a slope of 10%, the stable depth is over 8 feet, which would encompass all of the sediment in Iron Gate and the most all of the off-channel sediment in Copco and J.C. Boyle.

Table 5-17. Stable depth of reservoir sediment assuming infinite slope and that the sediment is fully saturated. The minimum measured cohesion value was 0.7 lbf/in^2.

Slope	**Stable Depth for Different *c'* values**			
	***c'* (lbf/in^2)**			
	0.2	**0.35**	**0.7**	**1**
0.1	4.6	8.1	16.2	23.1
0.2	2.4	4.2	8.3	11.9
0.3	1.7	2.9	5.8	8.3
0.4	1.3	2.3	4.7	6.7

5.6.4. EROSIVE PROPERTIES

The most common equation used to predict the erosion of cohesive sediment erosion is:

$$E = k_d\left(\tau - \tau_c\right)$$

where E = erosion rate,
k_d = erosion rate constant,
τ = shear stress, and
τ_c = critical shear stress.

There were two sets of tests on the sediment. One set of tests was on samples from 3.5 inch acrylic tube samples. These samples were collected as part of the geological investigation described in Strauss (2010). These were analyzed by the Bureau of Reclamation in Denver, CO. The measured results of the jet tests on the drill cores are given in Appendix C. Jet Test Results from TSC and shown Figure 5-40.

Another set of samples were collected by a 9-inch Ponar sampler. These samples were repacked in the lab and tested using a jet test device described in Simons et al. (2010). The sample collected from the Ponar sampler is shown in Figure 5-38 and the sampling device is shown in Figure 5-39. The description of the testing procedure is given in Appendix D. Report on Erodibility Characteristics of Reservoir Sediment by Agricultural Research Service. The results are shown in Figure 5-41 and summary statistics are given in Table 5-18. Samples were tested under wet and dry conditions. The effects of drying on erosion resistance and erodibility (τ_c and k_d) were significant with reservoir-average values of τ_c increasing by at least an order of magnitude. Associated decreases in k_d also occurred with sample drying, but not to the extent of the increases in critical shear stress. The median value of the erodibility coefficient decreased by about 80%. The average erodibility of the moist reservoir sediment was similar to that of sand, while the average erodibility of the dried sediment was similar to that of gravel or cobbles.

Simulations of the sediment used the 25th, 50th, and 75th Percentiles of τ_c and k_d.

Table 5-18. Summary of jet tests on sediment from all reservoirs from Simons et al. (2010).

	τ_c (Pa)	k_d (cm^3/N-s)
Moist Sample		
Minimum	0.000	0.23
25th Percentile	0.032	0.57
50th Percentile	0.21	0.82
75th Percentile	1.18	1.23
Max	4.83	5.6
Average	0.94	1.4
Dry Samples		
Minimum	1.2	0.04
25th Percentile	2.7	0.12
50th Percentile	5.9	0.16
75th Percentile	17.8	0.32
Max	113.6	0.59
Average	24.7	0.23

Figure 5-38. Sample just after release from Ponar sampling device.

Figure 5-39. Ponar sampling device used to collected disturbed samples.

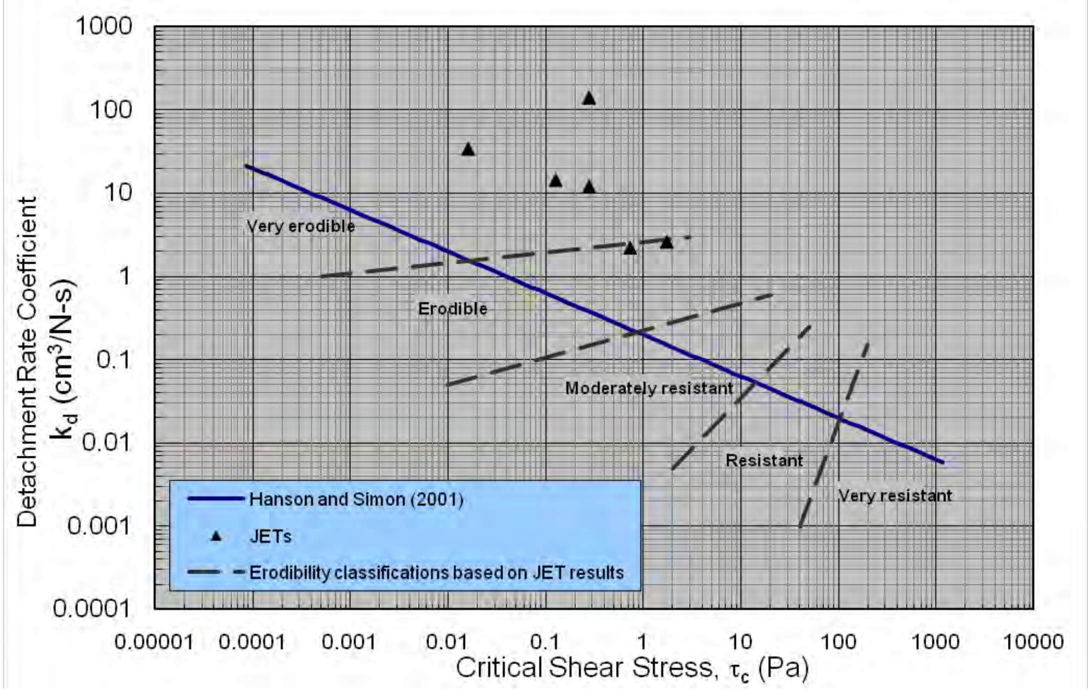


Figure 5-40. Results from jet tests on drill core samples. Details in Appendix C. Jet Test Results from TSC.

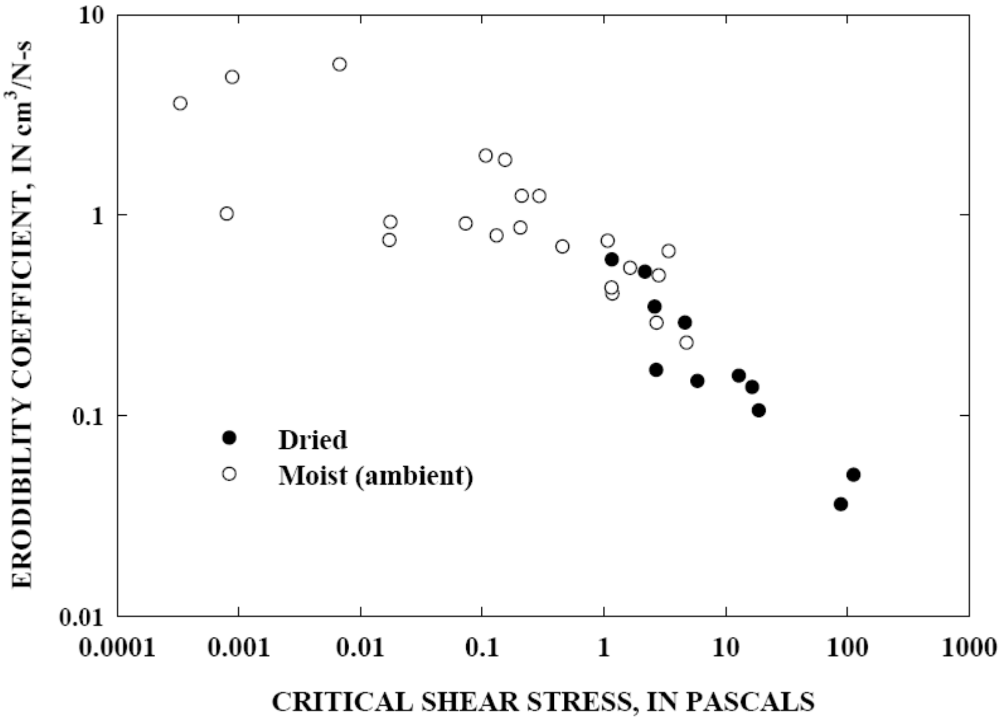


Figure 5-41. Measured critical shear stress (τ_c) and erodibility coefficient (k_d) for moist and dried samples (From Simon et al. 2010).

5.6.5. CONSOLIDATION AND DESICCATION

The sediment is primarily water with an average water content of over 80% by volume. After the reservoir is drawn down, the sediment will dry and decrease in thickness. A simple test of the sediment consolidation was performed by placing wet sediment into free draining plastic containers. Holes were cut into the bottom of the container and gravel placed on the bottom so that the sample could drain freely. The sample was allowed to dry outside, uncovered and exposed to the elements. The initial and final depths of the sample are given in Table 5-19. The desiccated depth of the sample was about 60% of the initial depth. In addition, deep cracks developed in the soil and the sampled pulled away from the container edges. We estimate that the volume of the sample decreased by approximately 66%. The porosity changed from 0.82 to approximately 0.46. The bulk density increased from 29.5 lb/ft^3 to approximately 87 lb/ft^3. The sample tested was taken from the upper portion of J.C. Boyle Reservoir and has a slightly higher bulk density than the sediment in the lower portions of the three reservoirs. The dry bulk density of the finer sediment located in the lower parts of the three reservoirs is expected to increase from its existing value of 16 – 20 lb/ft^3 to between 47 to 58 lb/ft^3.

Table 5-19. Change in depth of reservoir sediment after desiccated in an open air and freely draining container.

Container	Initial Depth (in)	Final Depth (in)	% of original depth
1	7.00	4.25	60
2	7.88	4.63	59
3	4.50	2.75	61

Figure 5-42. Picture of sediment from J.C. Boyle Reservoir immediately after placement.

Figure 5-43. Picture of sediment from J.C. Boyle Reservoir 15 days after placement.

5.6.6. FALL VELOCITY

The fall velocity of the sediment is important to defining the rate at which particles will settle in the riverine or reservoir environment. General relationships for fall velocity are available for non-cohesive sediment, which is generally defined as sediment with particle diameter greater than 62 µm (Mehta and Mcanally, 2008). The influence of cohesive forces relative to gravity forces generally increases with decreasing particle size, and when particles are 2 µm or less, cohesive forces will dominate (Mehta and Mcanally, 2008).

In the lower portion of Iron Gate Reservoir and Copco Reservoir where the bulk of the sediment is located, over 50% of the particles have diameters less than 5 µm and therefore cohesive forces will be important to the characteristics of the particles behavior. Deas et al (2010) collected samples of the sediment contained in the water column at one site upstream of Copco Reservoir, three sites within Copco Reservoir and one site downstream of Iron Gate Dam. The samples were taken to a lab where the fall velocity of the particles where measured with a Laser In-Situ Scattering and Transmissometry with Settling Tube (LISST-ST) in a bench top setting. The LISST-ST measures the settling rates and particle size distribution of the samples. The mean settling rate of the sediment sampled from the reservoir sites was 0.55 m/d and the average for the river sites was 2.7 m/d. The detention time of Copco and Iron Gate reservoirs under average flow conditions is 12 and 16 days (PacifiCorp, 2004). The ratio of annual inflow to storage volume for the reservoirs is 0.033 and 0.044. Based upon the Brune (1953) curve for fine-grained as modified by Morris and Fan (1998), the trap efficiency of the reservoirs would approximately about 60% at Copco Reservoir and about 70% Iron Gate Reservoir. The trap efficiency can also be based upon the methods used in Pemberton and Lara (1971) for settling basins:

$$\text{Trap Efficiency} = 1 - \exp\left(- \frac{l w_f}{V d} \right)$$

where l = length of basin
w_f = fall velocity
V = average flow velocity
D = basin depth

Rearranging the equation gives:

$$\text{Trap Efficiency} = 1 - \exp\left(- \frac{A w_f}{Q} \right)$$

where A = plan area of basin
w_f = fall velocity
Q = flow rate through basin

Using the fall velocity of 0.55 m/d and an average flow rate of 1885 cfs gives a trap efficiency of approximately 45% at Copco and Iron Gate reservoirs. Based upon these analyses, trap efficiencies of 50 to 75% are expected for each reservoir. The effective trap efficiencies of the reservoir in series would be between 75% and 94%.

The settling rate of particles can also depend upon the concentration (Figure 5-44). A study by Van Rijn (1993) using data collected in various rivers and estuaries concluded that the settling rates of sediment at a concentration of 1,000 to 10,000 mg/l can be an order of magnitude greater than the settling rates of sediment at a concentration of less than 100 mg/l. This is because cohesive sediment particles will tend to flocculate at higher concentrations and increase their diameter and settling velocity. As the concentrations exceeds around 10,000 mg/l, the concentration of particles is high enough to prevent settling because the particles basically run into each other and cannot settle.

The concentrations were not reported by Deas et al (2010), but the samples were collected during a period of relatively low flow and therefore the concentrations were most likely less than 100 mg/l. Therefore, the settling rates during periods of high concentration could be significantly higher.

Table 5-20. Measured settling rates from Table 2 of Deas et al (2010).

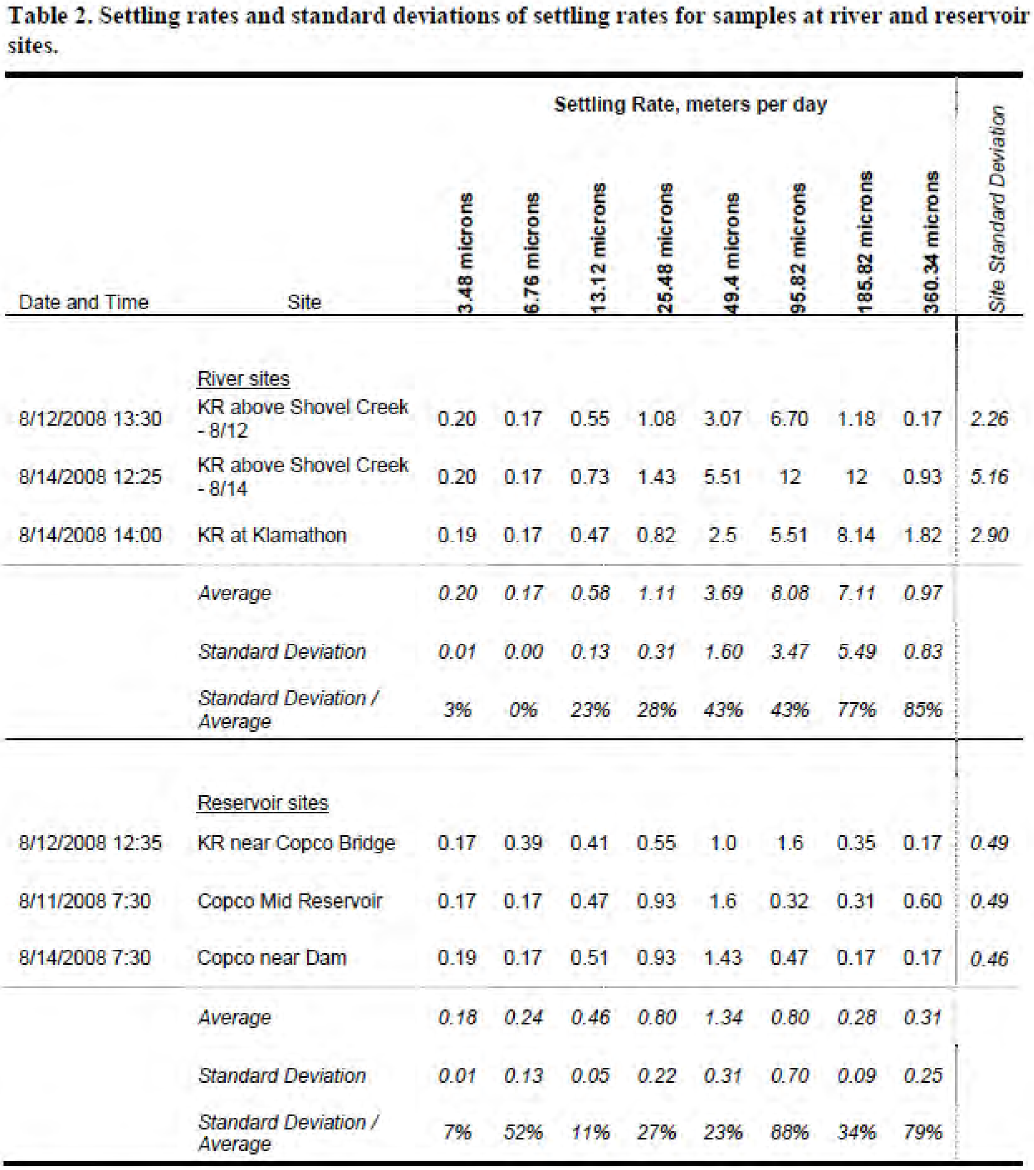


Table 2. Settling rates and standard deviations of settling rates for samples at river and reservoir sites.

		Settling Rate, meters per day								
Date and Time	Site	3.48 microns	6.76 microns	13.12 microns	25.48 microns	49.4 microns	95.82 microns	185.82 microns	360.34 microns	*Site Standard Deviation*
	River sites									
8/12/2008 13:30	KR above Shovel Creek - 8/12	0.20	0.17	0.55	1.08	3.07	6.70	1.18	0.17	*2.26*
8/14/2008 12:25	KR above Shovel Creek - 8/14	0.20	0.17	0.73	1.43	5.51	12	12	0.93	*5.16*
8/14/2008 14:00	KR at Klamathon	0.19	0.17	0.47	0.82	2.5	5.51	8.14	1.82	*2.90*
	Average	*0.20*	*0.17*	*0.58*	*1.11*	*3.69*	*8.08*	*7.11*	*0.97*	
	Standard Deviation	*0.01*	*0.00*	*0.13*	*0.31*	*1.60*	*3.47*	*5.49*	*0.83*	
	Standard Deviation / Average	*3%*	*0%*	*23%*	*28%*	*43%*	*43%*	*77%*	*85%*	
	Reservoir sites									
8/12/2008 12:35	KR near Copco Bridge	0.17	0.39	0.41	0.55	1.0	1.6	0.35	0.17	*0.49*
8/11/2008 7:30	Copco Mid Reservoir	0.17	0.17	0.47	0.93	1.6	0.32	0.31	0.60	*0.49*
8/14/2008 7:30	Copco near Dam	0.19	0.17	0.51	0.93	1.43	0.47	0.17	0.17	*0.46*
	Average	*0.18*	*0.24*	*0.46*	*0.80*	*1.34*	*0.80*	*0.28*	*0.31*	
	Standard Deviation	*0.01*	*0.13*	*0.05*	*0.22*	*0.31*	*0.70*	*0.09*	*0.25*	
	Standard Deviation / Average	*7%*	*52%*	*11%*	*27%*	*23%*	*88%*	*34%*	*79%*	

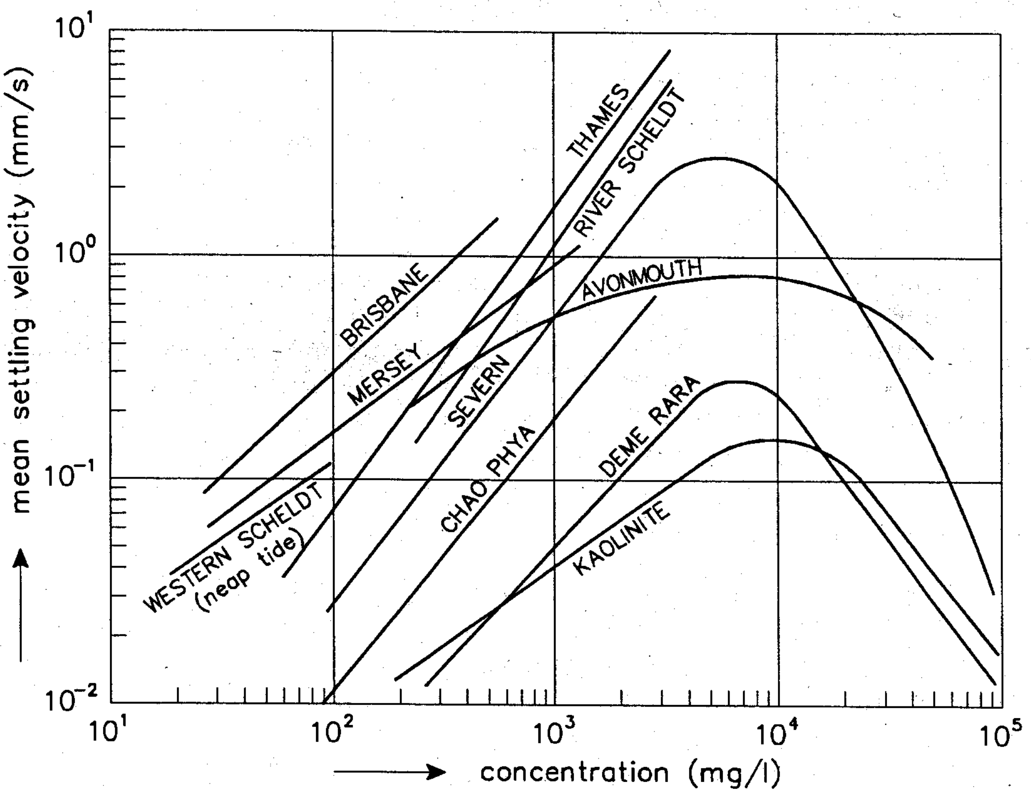


Figure 5-44. The influence of sediment concentration on the settling velocity for various rivers and estuaries (source: Van Rijn, 1993, figure 11.4.2).

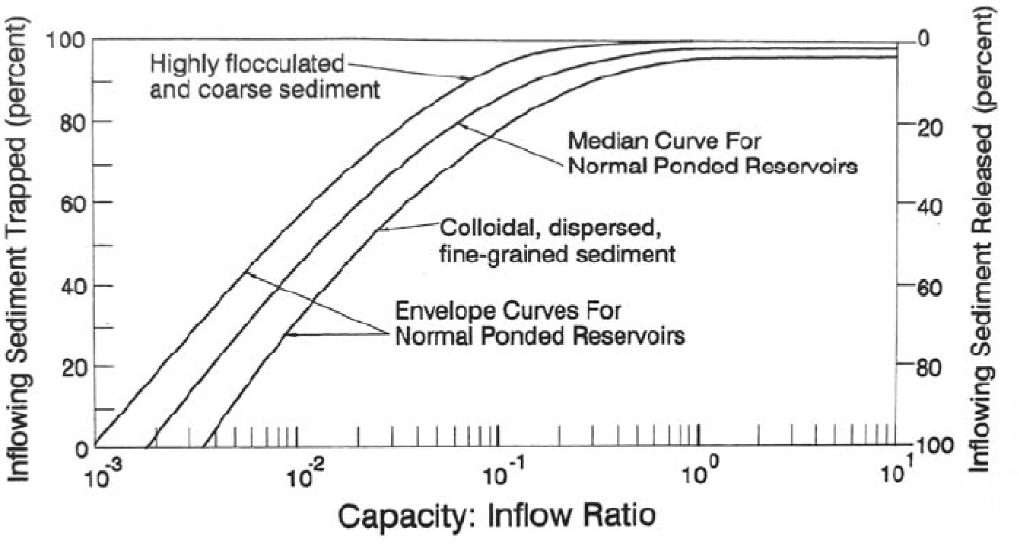


Figure 5-45. Trap efficiency for reservoirs (source: Morris and Fan, 1998, Figure 10.15).

6. Future Hydrology Conditions

6.1. No Action Alternative

The documentation for the flow operations under No Action Alternative is given in: Appendix E. Documentation of Hydrology Simulations for the Klamath Dam Removal . Several Section 7 Consultations and Biological Opinions (BO's) have governed operation of Upper Klamath Lake (UKL) and the Klamath Project (Project) since the late 1990's. The consultations involve the National Marine Fisheries Service (NMFS), also known as NOAA Fisheries, the U.S. Fish and Wildlife Service (FWS), and the Bureau of Reclamation (Reclamation). The latest FWS BO and the NMFS BO, dated March 15, 2010, are the basis of the operating criteria used by the Klamath Project Simulation Model (KPSIM) in the No Action Alternative. A comparison between the No Action Alternative and the KBRA is presented in Section 6.2.

6.1.1. FLOOD FREQUENCY

There are no significant changes to the flood frequency analysis presented in Section 2.

6.1.2. DAILY FLOWS

The daily flows under the No Action Alternative were generated assuming the 2010 National Marine and Fisheries (NMFS) biological opinion is in place. The details of the hydrologic simulation are given in Appendix E. Documentation of Hydrology Simulations for the Klamath Dam Removal Studies. The results of the simulations are described in the next section. More analysis of the daily flows is given in the following section.

6.2. Dam Removal Alternative

6.2.1. FLOOD FREQUENCY

PacifiCorp does not operate Iron Gate and Copco 1 dams primarily for flood control, but the reservoirs do exhibit minor flood control benefits because of the volume of flow required to overtop the spillway. There has been some confusion over the flood control benefit provided by the reservoirs and this in part can be explained because PacifiCorp makes the following two, somewhat contradictory, statements in their 2004 FERC license application:

> "The potential for high runoff conditions occurs each year from approximately November through April. Because the Project reservoirs provide little active storage, UKL provides the only meaningful storage in the basin to ameliorate high flow events." (Exhibit B 2-7, PacifiCorp, 2004).

> "During high runoff season, PacifiCorp will frequently draft down Copco and Iron Gate reservoirs by 4 to 7 vertical feet each. The vacant storage created by this draft is then available to manage all or some portion of the high flows as they accumulate from sub-basin tributaries downstream of the Link River dam. This vacant storage also allows for better management of flows below Iron Gate."
> (Exhibit B 2-8, PacifiCorp, 2004).

Based upon these statements, we conclude that flood control is not the primary purpose of Copco 1 and Iron Gate, but there may be small non-quantified ancillary benefits to flood control.

An attempt to estimate the flood control benefit provided by these reservoirs was modeled by performing a level pool routing of an estimated 100-year flood hydrograph through the reservoirs. The flood of record that occurred in Dec 1964 was used as a basis to develop the shape of the hydrograph.

First, an instantaneous hydrograph of the 1964 flood was developed based upon the daily average flows and the recorded peak flows. For all days except the day in which the peak occurred, the instantaneous flow was assumed to pass through the daily average flow at 12 pm of that day and the flow at the transition between days was computed as the average flow between the two days. For the day in which the peak occurred, the timing of the peak was determined to conserve the volume of the flow for that day. A plot of the daily average flow, the measured peak flow, and the estimated instantaneous flow is shown in Figure 6-1.

Then, this instantaneous hydrograph was routed through Iron Gate and Copco 1 reservoirs. The effect of J.C. Boyle Dam is ignored because it is approximately 35 miles upstream of Iron Gate Dam and is significantly smaller than either Iron Gate or Copco 1 dams. Level-pool routing was used to estimate the attenuation effects of Iron Gate and Copco 1 reservoirs, as described in the following equation:

$$\frac{S_{n+1} - S_n}{\Delta t} = \frac{I_{n+1} + I_n}{2} - \frac{O_{n+1} + O_n}{2}$$

where:

$\underline{S_n}$ = Storage within reservoir at time n
I_n = Inflow to reservoir at time n
O_n = Outflow from reservoir at time $n = CWH^{1.5}$
W = Width of spillway
H = Depth over spillway
C = Discharge coefficient

The storage vs. elevation relationships are taken from the hydrology simulations. The spillway elevations and widths are given in Table 2-1. A discharge coefficient, *C* = 3, is used in all simulations.

The ordinates of the Dec 1964 hydrograph were then multiplied by a constant fraction until the peak of the hydrograph downstream of Iron Gate equaled the 100-year flood peak estimated for the current conditions (Section 2). The 100-year flood peak after dam removal is the peak of the hydrograph before it is routed through the reservoirs. The synthetic 100-year flood is attenuated by about 7% by Copco and Iron Gate reservoirs (Table 6-1).

Fifteen minute data is available for the Iron Gate gage from 1988 until the present. The flood attenuation of floods in 1989, 1993, 1996, 1997, and 2005 were also simulated. The percent reduction in the peak was computed for each of the floods and the results are given in Table 6-1.

This assessment does not account for fact that Jenny Creek comes in downstream of Copco Reservoir. Jenny Creek is the largest tributary between Keno and Iron Gate dams. The attenuation reported in Table 6-1 are overestimates of the actual attenuation because a large portion of the peak flow events are due to the floods occurring on Jenny Creek and Copco Reservoir does not affect flows from Jenny Creek. A more detailed assessment of flood attenuation is recommended to quantify more accurately the attenuation of Copco and Iron Gate reservoirs.

The increase in the peak flow due to the removal of Iron Gate and Copco dams will decrease in the downstream direction because the of the flood routing in the channel and the timing of flood flows at Iron Gate do not perfectly correlate with the timing of flood flows in the tributaries. For example, if the peak flow is increased at Iron Gate Dam, but the peak flows at Seiad Valley are primarily due to the flood flows from the Scott River there may be no significant impact at Seiad Valley due to a small increase in peak flow at Iron Gate.

Table 6-1. Flood attenuation of Iron Gate and Copco 1 reservoirs below Iron Gate Dam.

Flood	**Peak Flow No Action**	**Peak Flow Dam Removal**	**% Reduction below Iron Gate Dam**
Synthetic 100-yr flood	31,460	33,800	6.9
1989	10,200	10,300	1.2
1993	11,100	11,400	2.7
1996	11,200	11,300	1.1
1997	20,500	21,400	4.0
2005	12,400	12,800	3.0

The National Weather Service (NWS) provides river stage forecasts for the Klamath River for the USGS gages at Seiad Valley, Orleans and Klamath. They currently do not publish a forecast provided at Iron Gate gage. However, they work with PacifiCorp to issue flood warnings to Siskiyou County. After removal of Copco and Iron Gate dams, it is likely that NWS will publish a forecast at the Iron Gate gage. The contact information for the NWS office responsible for the forecasting is:

National Weather Service
Medford Weather Forecast Office
4003 Cirrus Drive
Medford, OR 97504-4198
(541) 776-4303
http://www.wrh.noaa.gov/mfr/

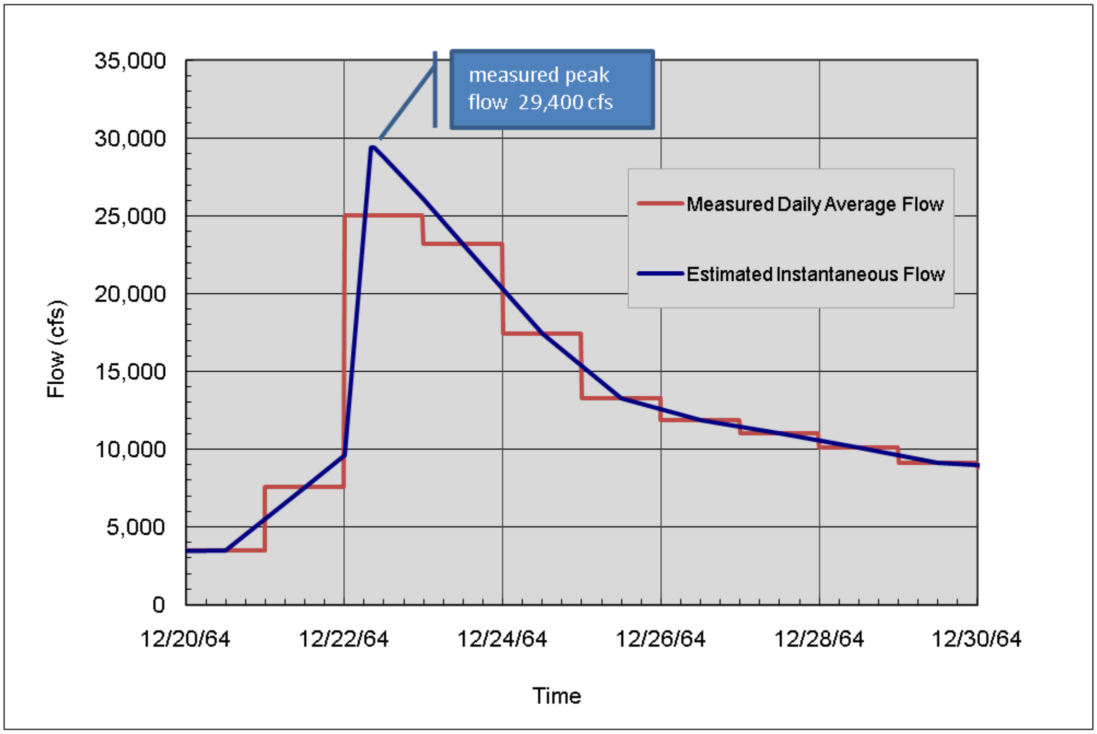


Figure 6-1. Daily average flows, measured peak flow, for Dec 1964 flood, peak of record for Iron Gate gage.

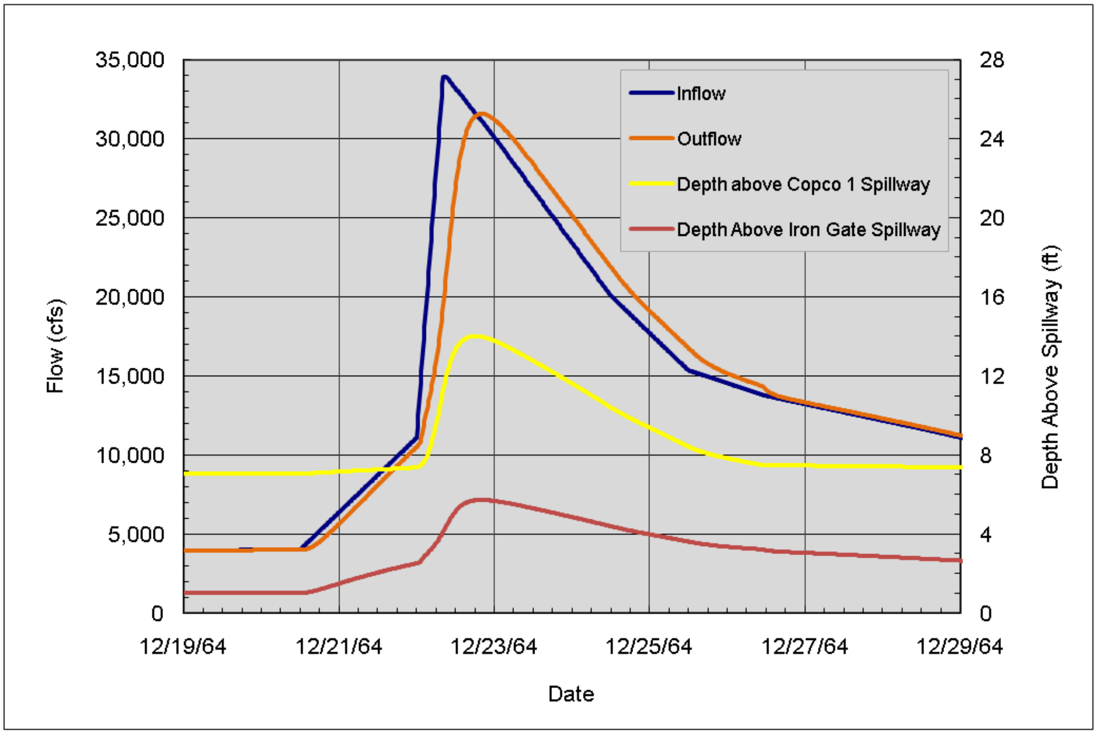


Figure 6-2. Inflow into Copco 1 Reservoir and outflow from Iron Gate dam for Dec 1964 flood.

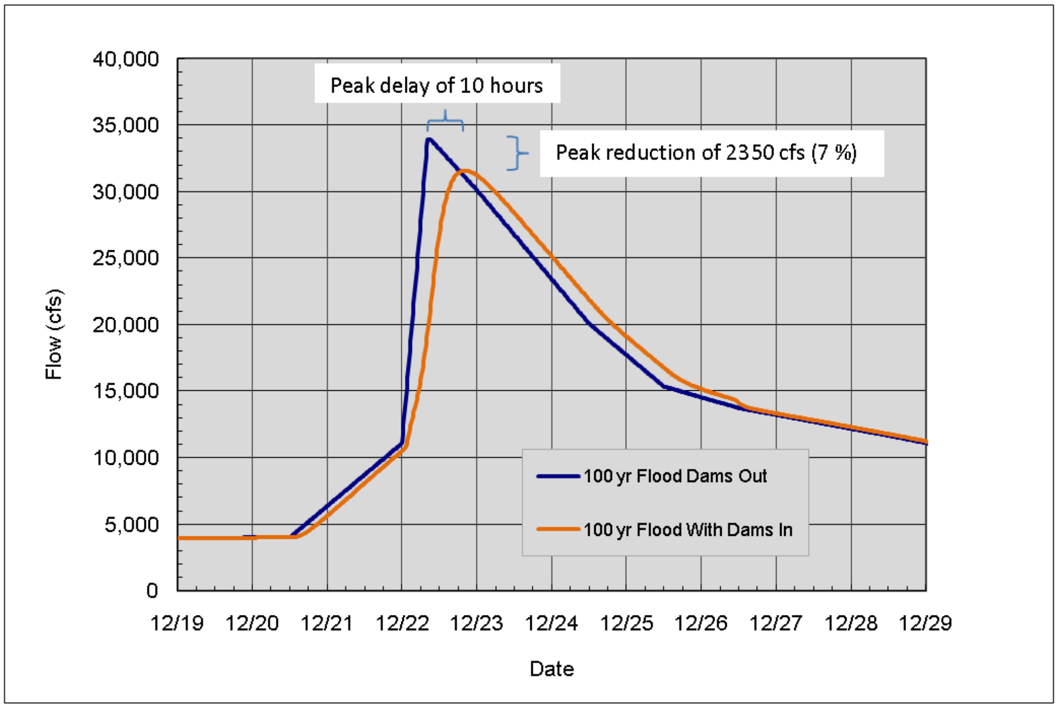


Figure 6-3. Difference between 100-year flood No Action and Dam Removal Alternatives.

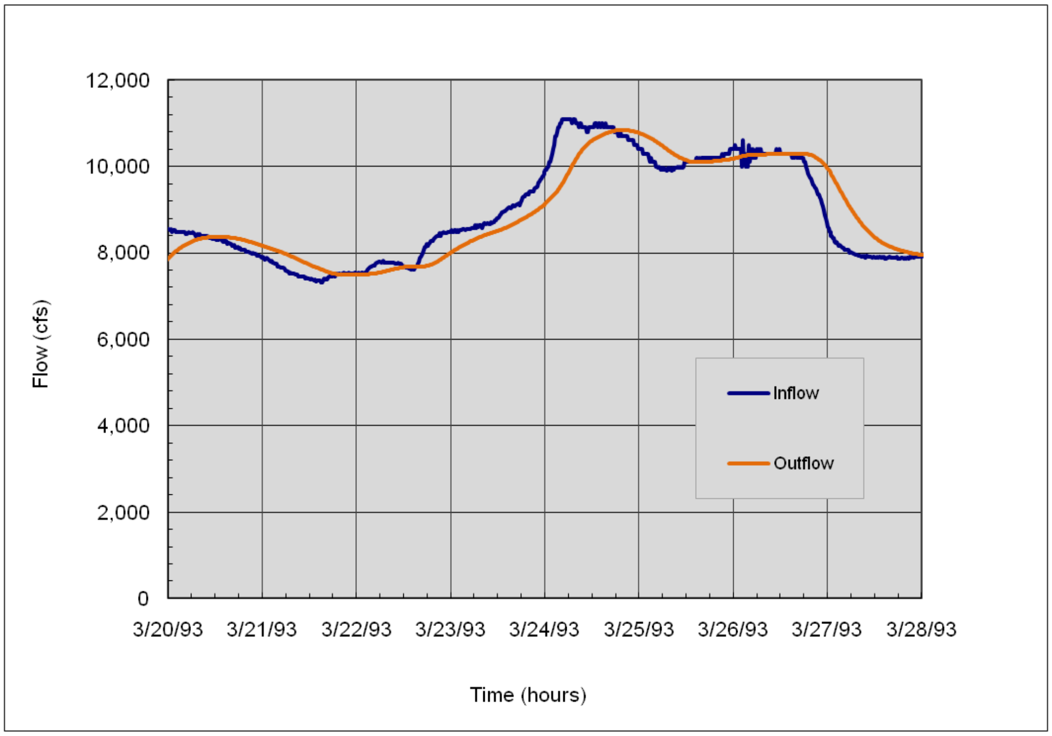


Figure 6-4. Inflow and outflow for March 1993 flood.

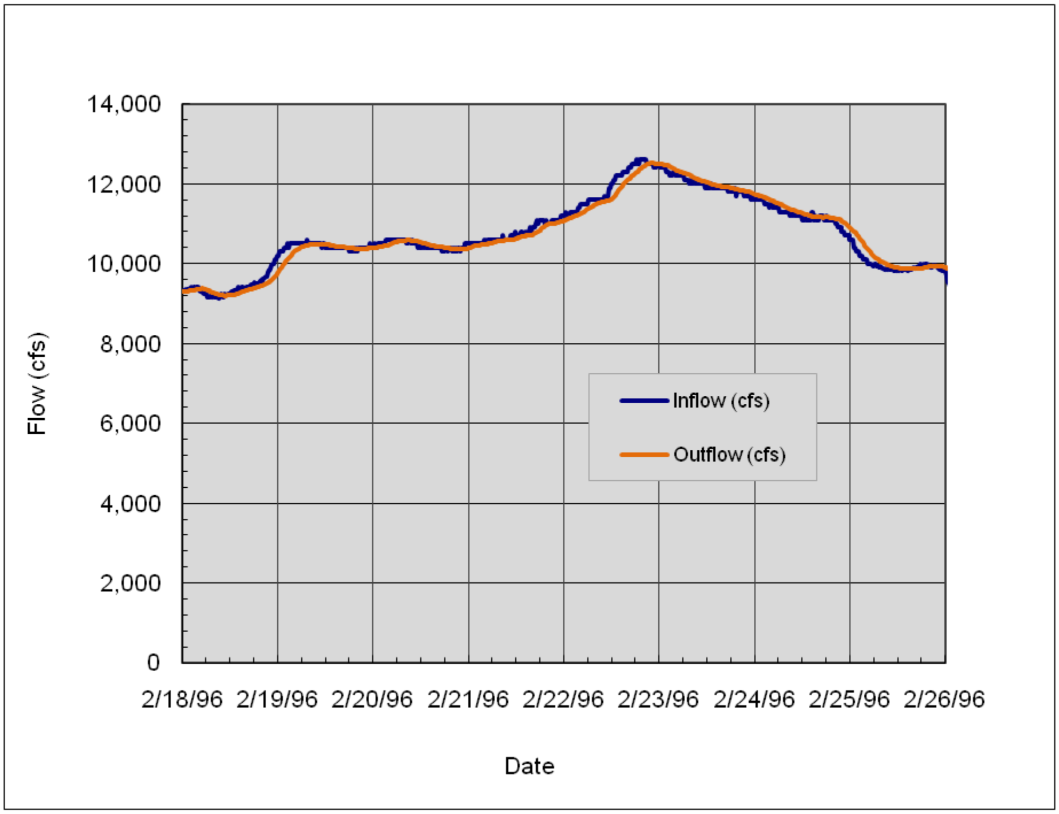


Figure 6-5. Inflow and outflow for Feb 1996 flood.

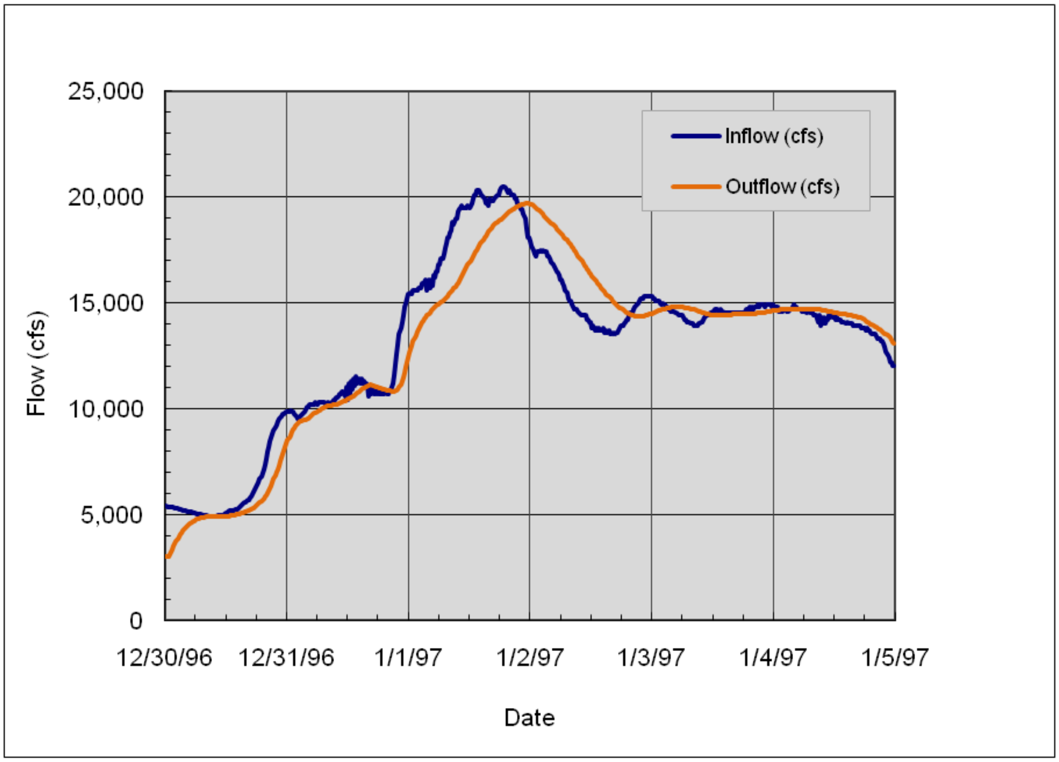


Figure 6-6. Flood routing through Copco I and Iron Gate dams for January 1997 flood.

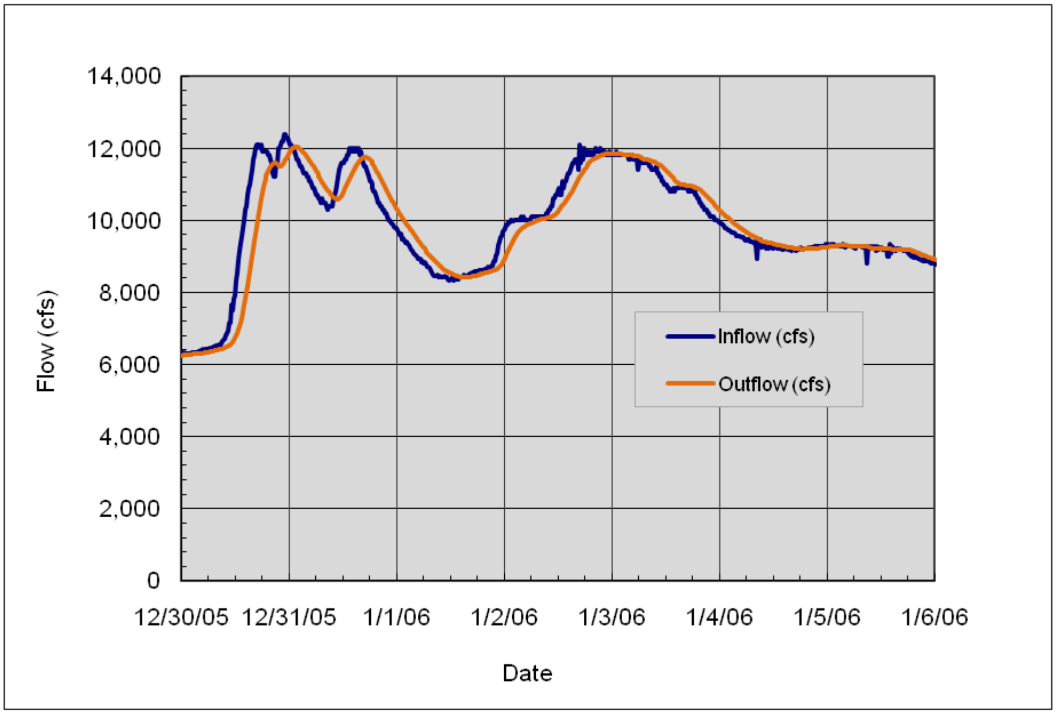


Figure 6-7. Flood routing through Copco I and Iron Gate dams for December 2005 flood.

6.2.2. DAILY FLOWS

The flows under the Dam Removal Alternative will be governed by the Klamath Basin Restoration Agreement (KBRA). The KBRA has the objective of restoring and sustaining fisheries while establishing reliable water and power supplies. The KBRA includes a potential operating scheme that was modeled based upon historical data and used a version of the Klamath Project Simulation Model (KPSIM). The hydrologic operations modeling under the Dam Removal Alternative are guided by this KBRA potential operating scheme. The details on the hydrologic modeling can be found in Appendix E. Documentation of Hydrology Simulations for the Klamath Dam Removal Studies. Flow duration data on the Klamath River at Keno Dam, Iron Gate Dam, and at Seiad Valley and Upper Klamath Lake elevations for the No Action and Dam Removal Alternatives are given in Appendix F. Exceedance Flows for No Action and Dam Removal Alternatives.

The flows discussed in this section were generated using the Index Sequential method (IS). The IS method relies upon historical flow data to generate a set of flows under future operational conditions. A 51-year hydrologic scenario from WY 2012 to WY 2062 was generated by using the historical flow record from 1961 – 2009 (49 years of data). The first two years are repeated to obtain a 51 water years and 50 calendar years. If a start year of 1961 is chosen, the hydrologic period from 1961 – 2009 is simulated followed by WYs 1961 and 1962. If a start year of 1982 is chosen, the period 1982 – 2009, then 1961 – 1983 is simulated.

The inflows to the UKL and Klamath River were computed based upon the historic stream flow measurements for the tributaries that have such measurements and computed inflows for other flow contributions that are not measured such as groundwater contributions and smaller tributaries. The KBRA flow operations were enforced in the Dam Removal Alternative to determine the monthly or biweekly lake elevations, water deliveries, and stream flows. The bi-weekly or monthly data was then disaggregated at Keno Dam into daily flows. These daily flows were routed down the Klamath River.

Results from Index Sequential (IS) method with a 1961 start year

UKL elevations for the Dam Removal Alternative are generally higher than under the No Action Alternative (Figure 6-8). The only exception is that for the 10% Exceedance level, the No Action Alternative has higher lake elevations for all months except June. Lake elevation exceedance curves for the entire year are shown in Figure 6-9. UKL elevations are generally higher at exceedance percentages of more than 10% under the Dam Removal Alternative than under the No Action Alternative. Under the Dam Removal Alternative, UKL will completely fill less often, but for most years, the elevations will be higher in the fall and winter.

The average flow at Iron Gate stream gage and the average Upper Klamath Lake (UKL) elevation are given at Figure 6-10 for both the No Action and Dam Removal Alternative. The average water surface elevations in UKL are higher under the Dam Removal Alternative than the No Action Alternative for every month of the year. In general, the average monthly flows at Iron Gate are relatively similar between the two alternatives. The exceptions are for the months of October to December, where the average flows are about 200 to 400 cfs less under Dam Removal Alternative than under the No Action Alternative and in April, where the flows are about 300 cfs higher under the Dam Removal Alternative than under the No Action Alternative. The differences in flow and lake elevations are due to differences in water deliveries to agriculture and wildlife refuges and to the flow releases at Link Dam. The PacifiCorp dams do not significantly affect average monthly flows because PacifiCorp operations do not remarkably alter the normal pool elevation throughout the year. The annual average flow at Iron Gate Dam under the Dam Removal Alternative is approximately 2% less.

Figure 6-11 contains the 10%, 50%, and 90% exceedance flows below Keno Dam for the No Action and Dam Removal Alternatives. The 10% exceedance flows under the Dam Removal Alternative are greater for the months of January through April and less for the months of November and December. Generally, the 50% exceedance flows are similar throughout most of the year. The No Action Alternative 90% exceedance flows are about 300 to 360 cfs larger during the months of October to December and about 175 cfs larger during the months of January and February.

The daily average flows below Iron Gate Dam for the 10%, 50%, and 90% exceedance levels are shown in Figure 6-12. The 10% exceedance flows under the Dam Removal Alternative are about 5 to 10 % greater for the months of January through March. The 50% exceedance flows under the Dam Removal Alternative are about 5 to 15 % greater for the months of April and June to August and about 15 to 20 % less for the months of October to December. The 90% exceedance flows are similar for the two alternatives from March to September, but for the months of October to February, the No Action Alternative 90% exceedance flows are about 20 to 30 % larger (290 to 360 cfs larger).

The higher flows for the Dam Removal Alternative during the months of January through April below Iron Gate Dam are partly due to the fact that the simulations include pulse flows that would be implemented under the KBRA. An example of the comparison between daily flows is shown Figure 6-13. Under the Dam Removal Alternative, more years have peak flows above 5,000 cfs. Based upon the 50 year hydrologic simulation of daily average flows, the 2-year flood was approximately 5,700 cfs under the Dam Removal Alternative and 3,500 cfs under the No Action Alternative. Under the Dam Removal Alternative, the 5-year flood was increased to 10,000 cfs from 8,700 cfs under the No Action Alternative.

The monthly flow at Iron Gate Dam and the monthly UKL elevation are given in Figure 6-14. The plot demonstrates the generally higher UKL elevations under the Dam Removal Alternative and the sometimes smaller fall flows under the Dam Removal Alternative.

The 50% exceedance flows at the Seiad Valley, Orleans, and Klamath stream gages are given in Figure 6-15. There is very little difference between the two simulations except for November and December at the Seiad Valley and Orleans. The 50% exceedance flows near the Klamath Mouth at Klamath are nearly identical between the alternatives. The 50% exceedance flows under the Dam Removal are approximately 20 to 25% smaller for the months of November and December at Seiad Valley and about 10% less for the months of November and December at Orleans. The 90% exceedance flows are shown in Figure 6-16. These follow a very similar pattern as the 50% exceedance flows.

Flow-duration curves for the entire year at Klamath River at Keno Dam, Iron Gate Dam, Seiad Valley, Orleans, and at Klamath are shown in Figure 6-17 and Figure 6-18. The annual flow duration curve at Iron Gate Dam is similar between the No Action and Dam Removal Alternatives, but the Dam Removal Alternative 90% exceedance flow is 960 cfs versus 1090 cfs for the No Action Alternative. The 50% exceedance flow is 1,330 cfs under the Dam Removal Alternative and 1,420 cfs under No Action Alternative at Iron Gate Dam. The flows for all exceedance values are within 10% at Seiad Valley, 7% at Orleans, and 3 % at Klamath.

The annual flow at Keno Dam and annual agricultural supply is shown in Figure 6-19. The annual flow at Keno Dam is generally similar between the two alternatives except for a few dry years (2042, 2043, and 2045). These correspond to dry years in the historical record (1991, 1992, and 1994). In these dry years, the agricultural supply is significantly reduced under the No Action Alternative; therefore, more flow is released to the Klamath River under the No Action Alternative than under the Dam Removal Alternative. At Iron Gate Dam from July through November, the flows are commonly around 800 cfs under the Dam Removal Alternative during these years. The flows under the No Action Alternative follow the requirements of the No Action Alternative (See Table 1 of “Upper Klamath 2010 Biological Opinion Operations”, Appendix E). The monthly average flows at Iron Gate under No Action and Dam Removal Alternatives for this dry period are shown in Figure 6-20.

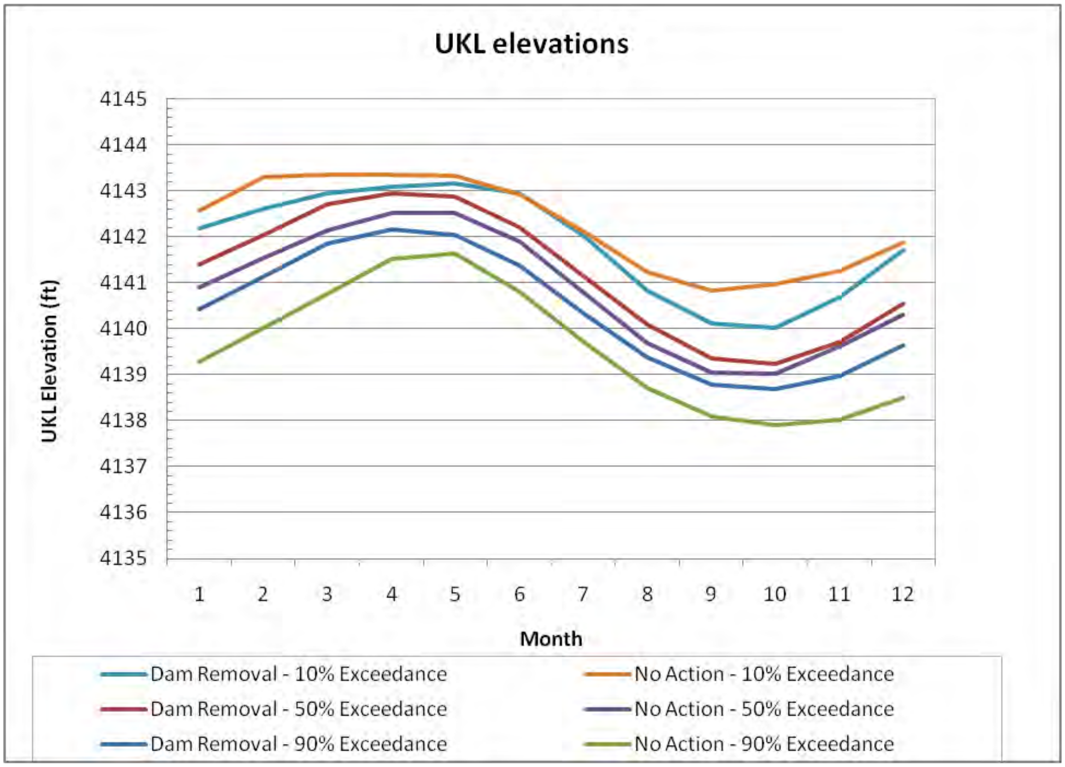


Figure 6-8. Lake elevations at various exceedance levels in Upper Klamath Lake.

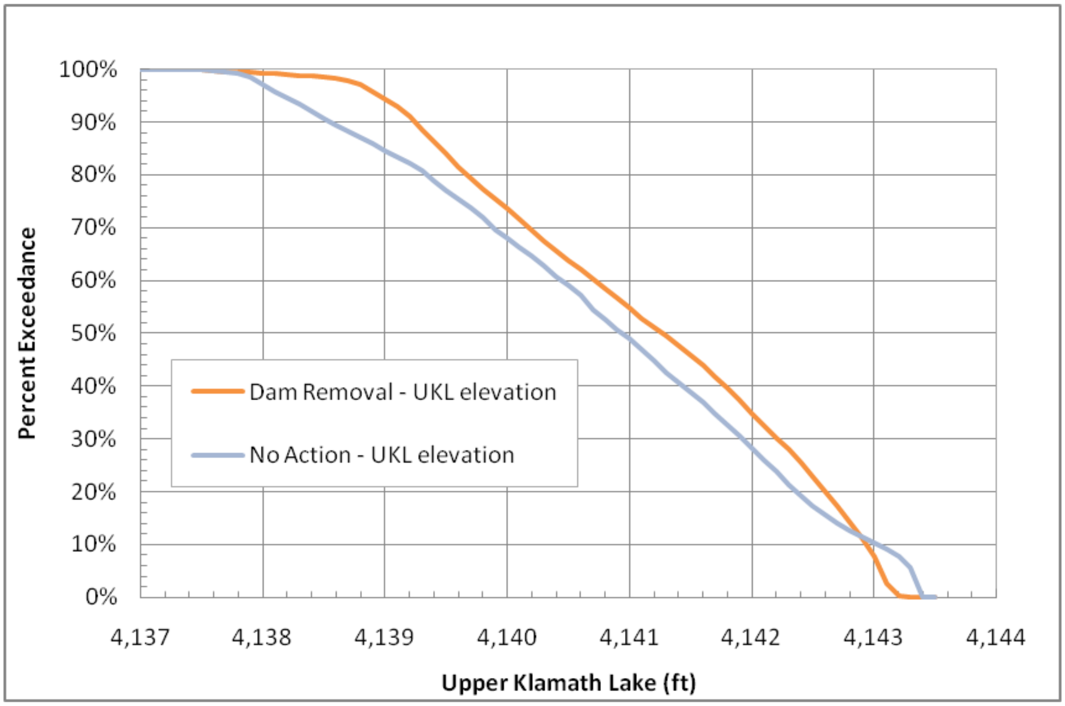


Figure 6-9. Upper Klamath Lake (UKL) elevations under No Action and Dam Removal Alternatives.

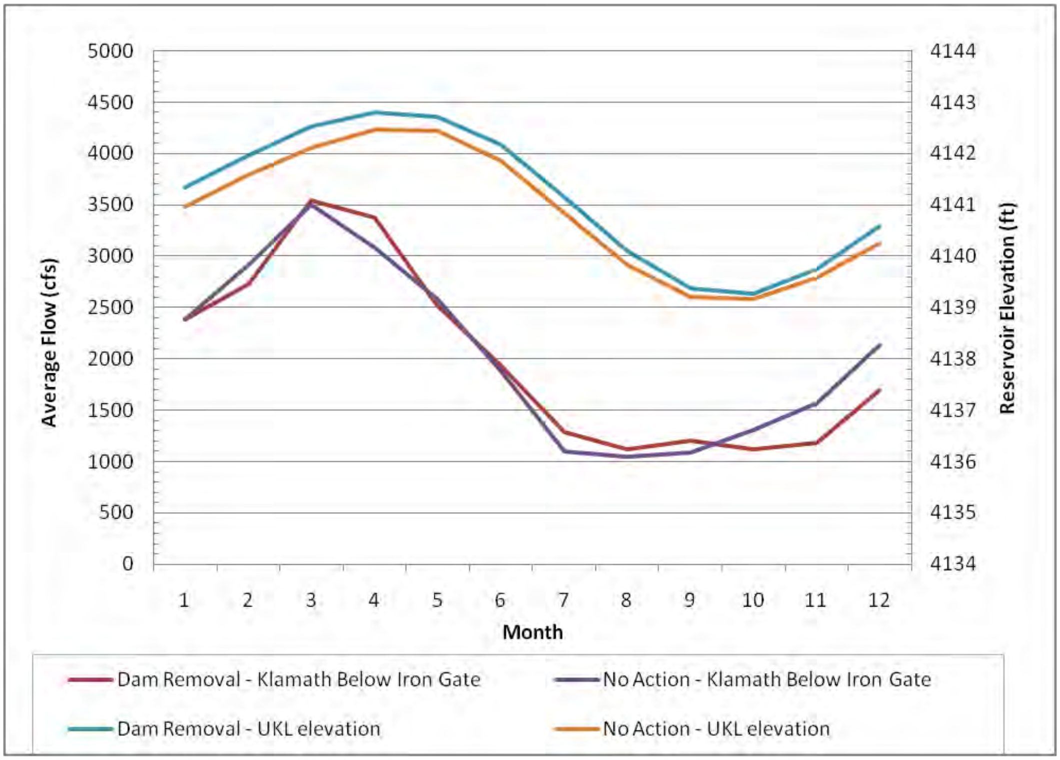


Figure 6-10. Average monthly flows at Iron Gate Dam and UKL elevations for No Action and Dam Removal Alternatives.

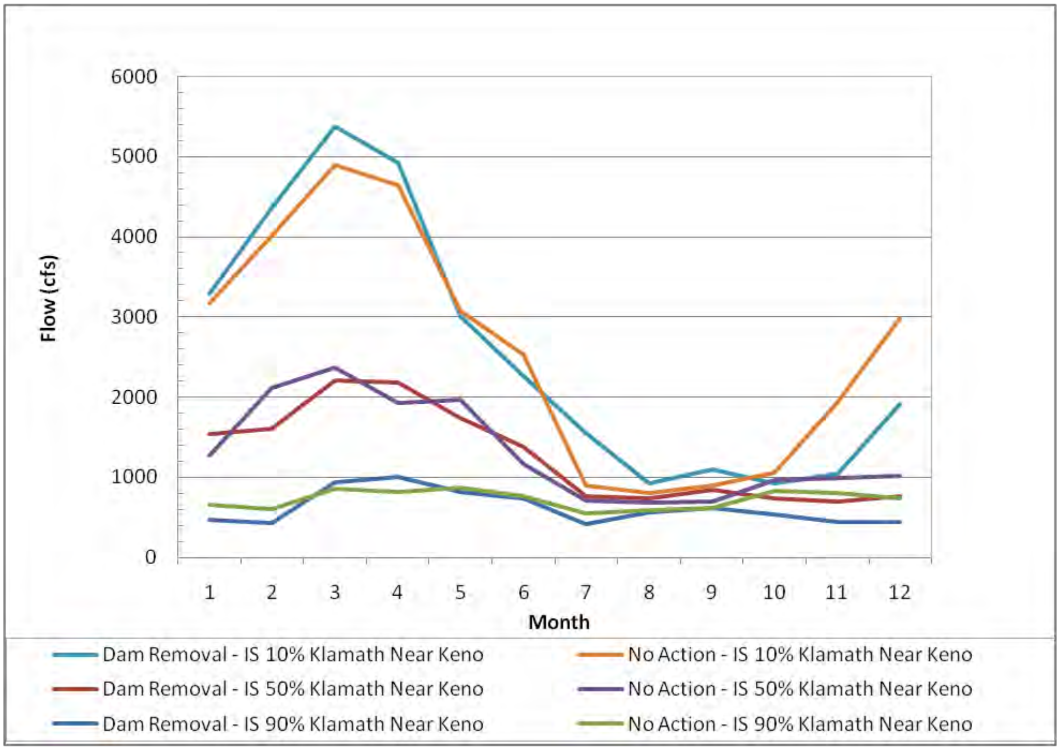


Figure 6-11. Dam Removal and No Action Alternatives exceedance flows below Keno.

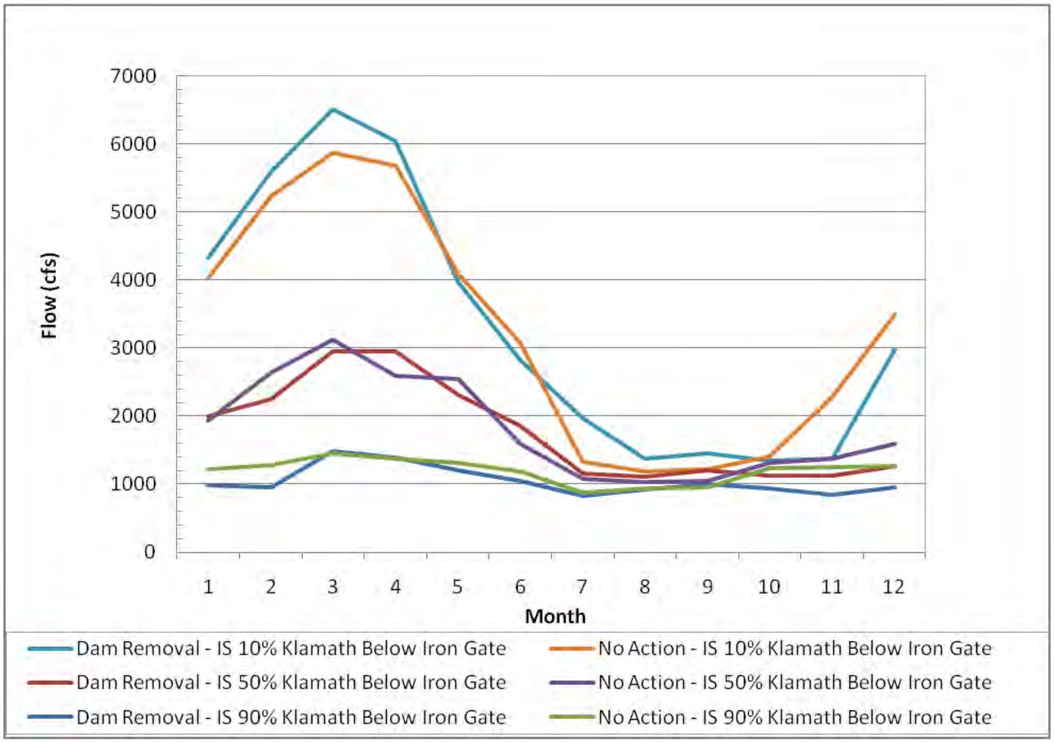


Figure 6-12. Exceedance flows below Iron Gate Dam for Dam Removal and No Action Alternatives.

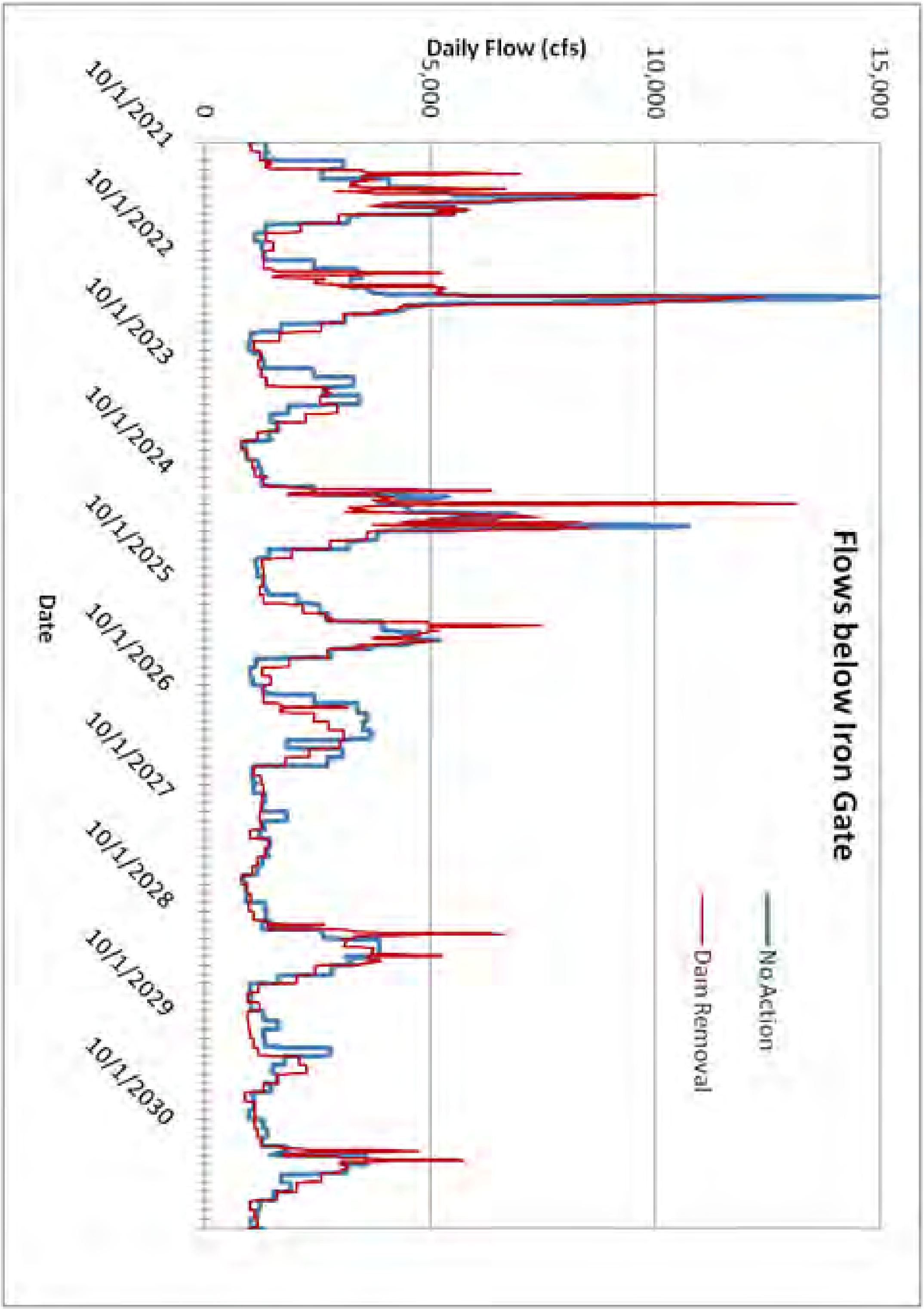


Figure 6-13. Daily flows during the Dam Removal and No Action Alternatives.

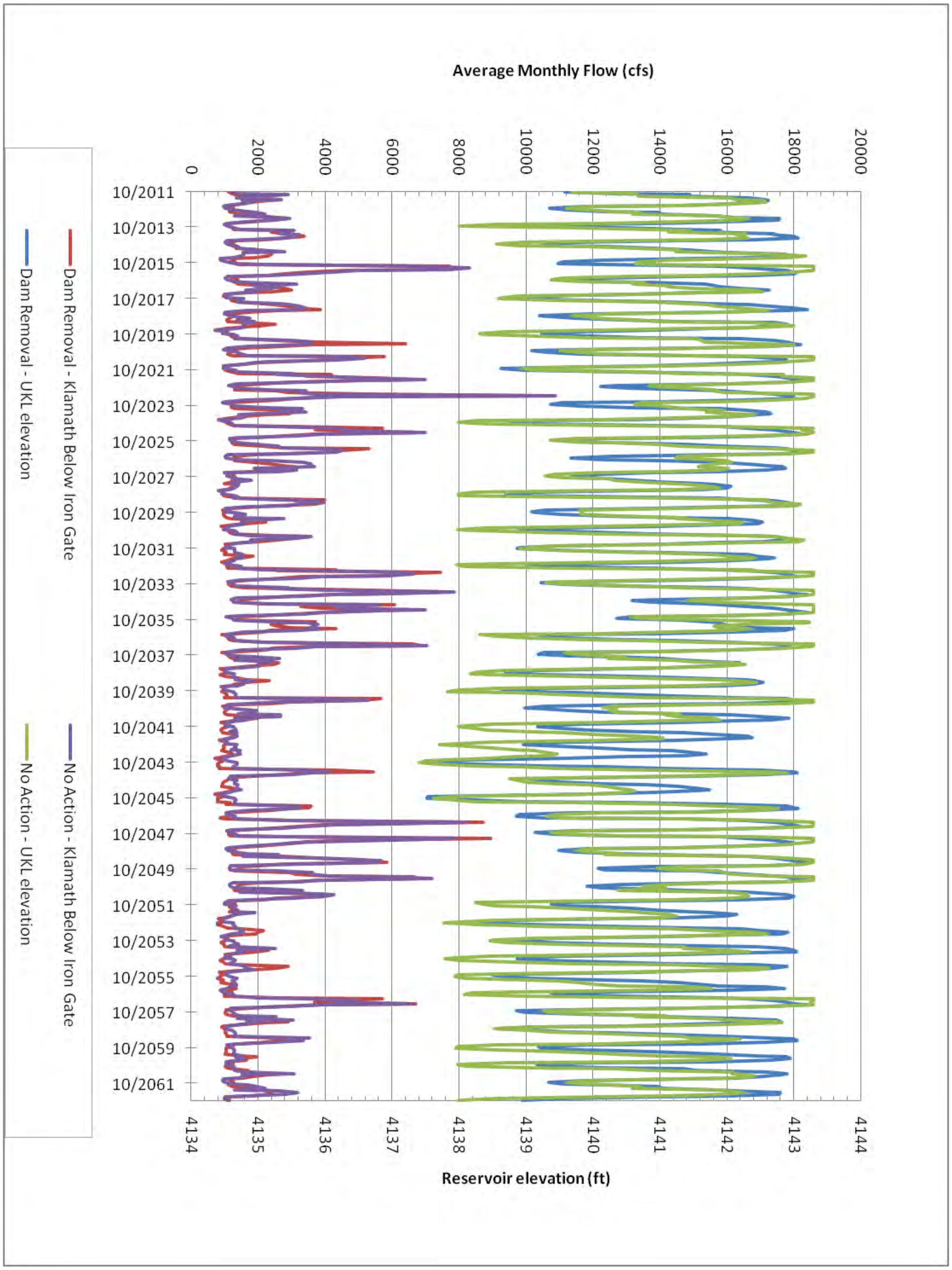


Figure 6-14. Comparison between monthly flows at Iron Gate dam and reservoir elevations for No Action and Dam Removal Alternatives.

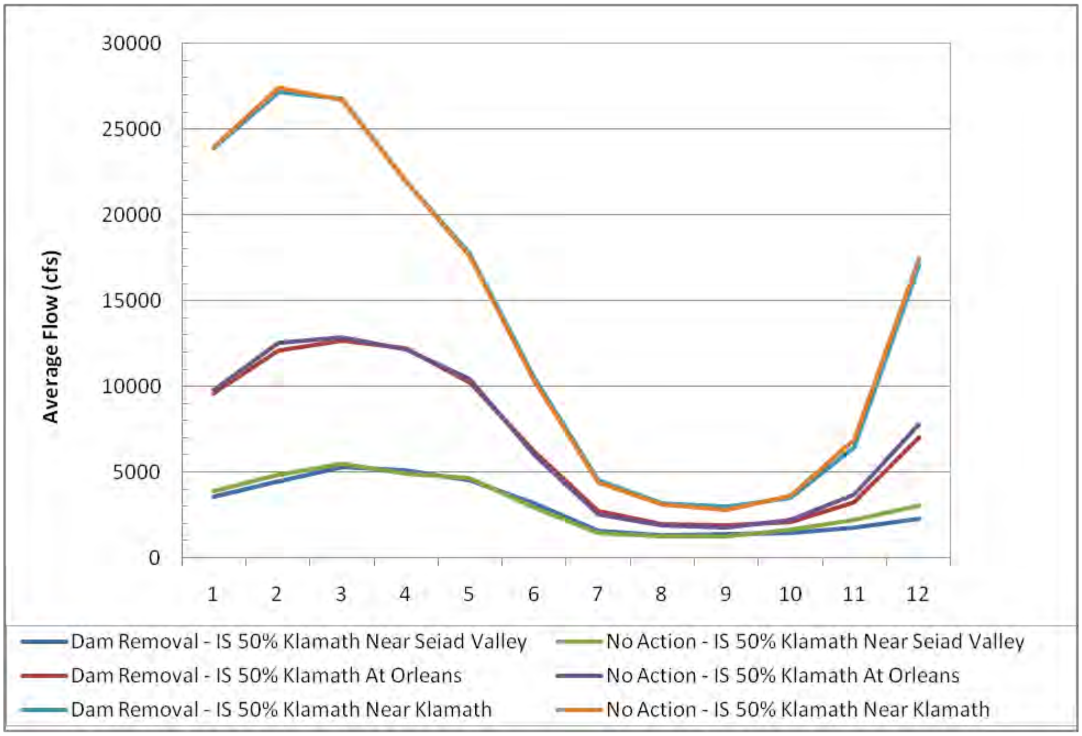


Figure 6-15. 50% Exceedance flows near Seiad Valley, Orleans, and Klamath for Dam Removal and No Action Alternatives.

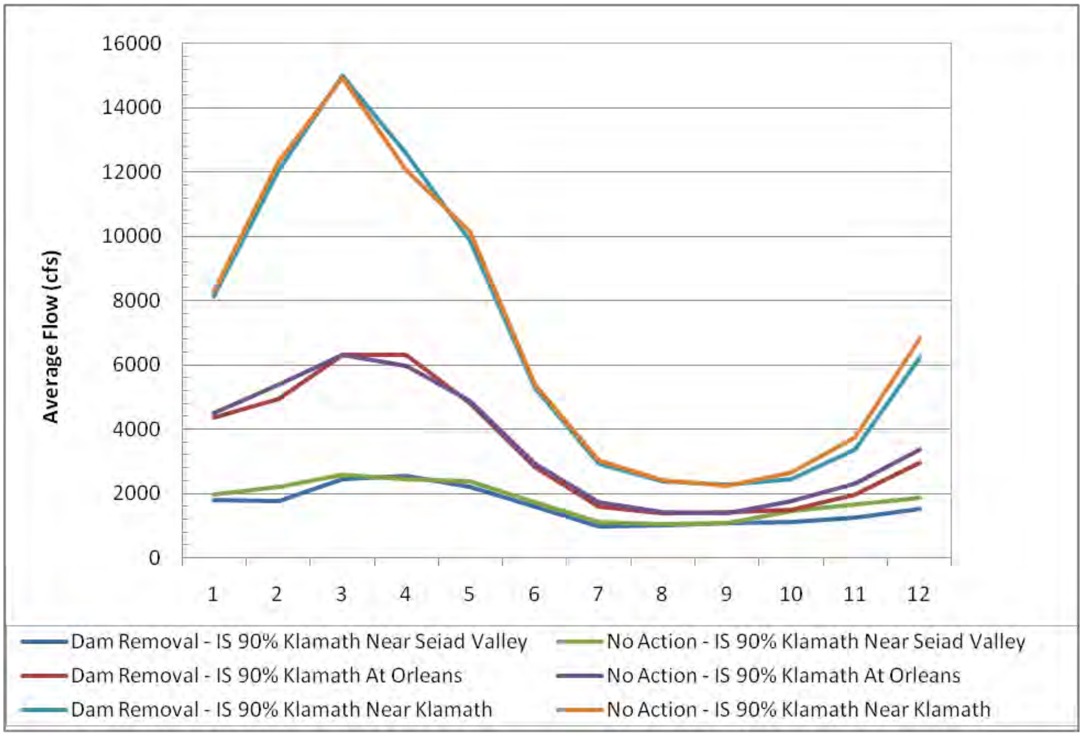


Figure 6-16. 90% Exceedance flows near Seiad Valley, Orleans, and Klamath for Dam Removal and No Action Alternatives.

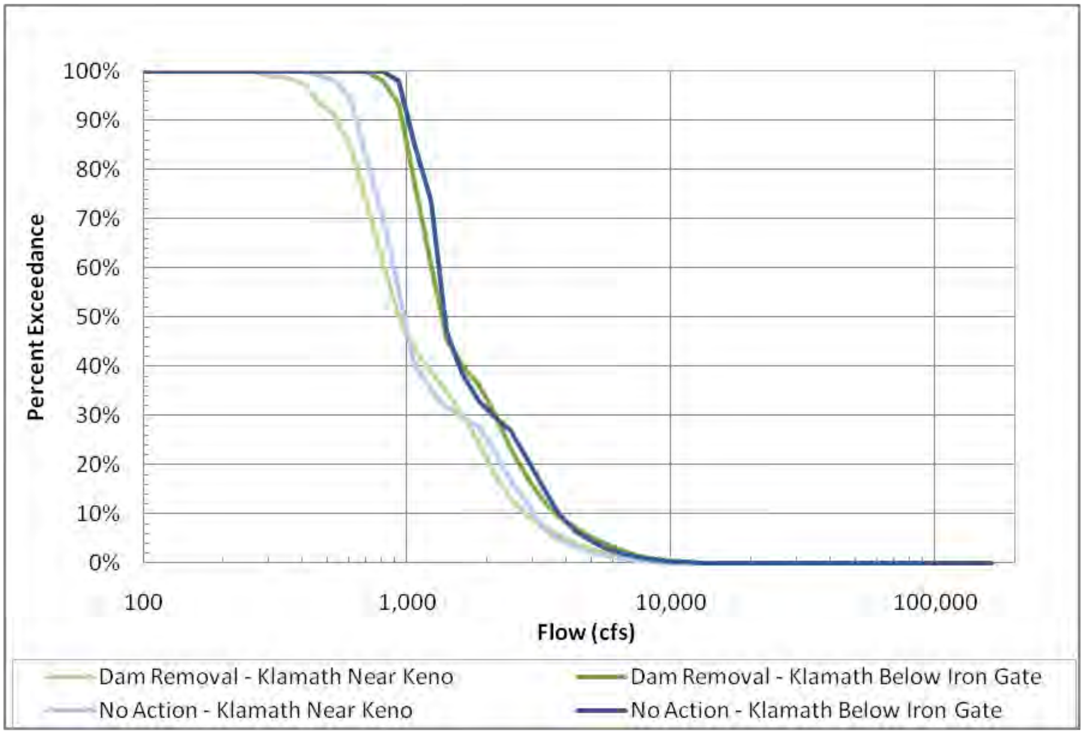


Figure 6-17. Flow duration at Keno Dam and below Iron Gate Dam under No Action and Dam Removal Alternatives.

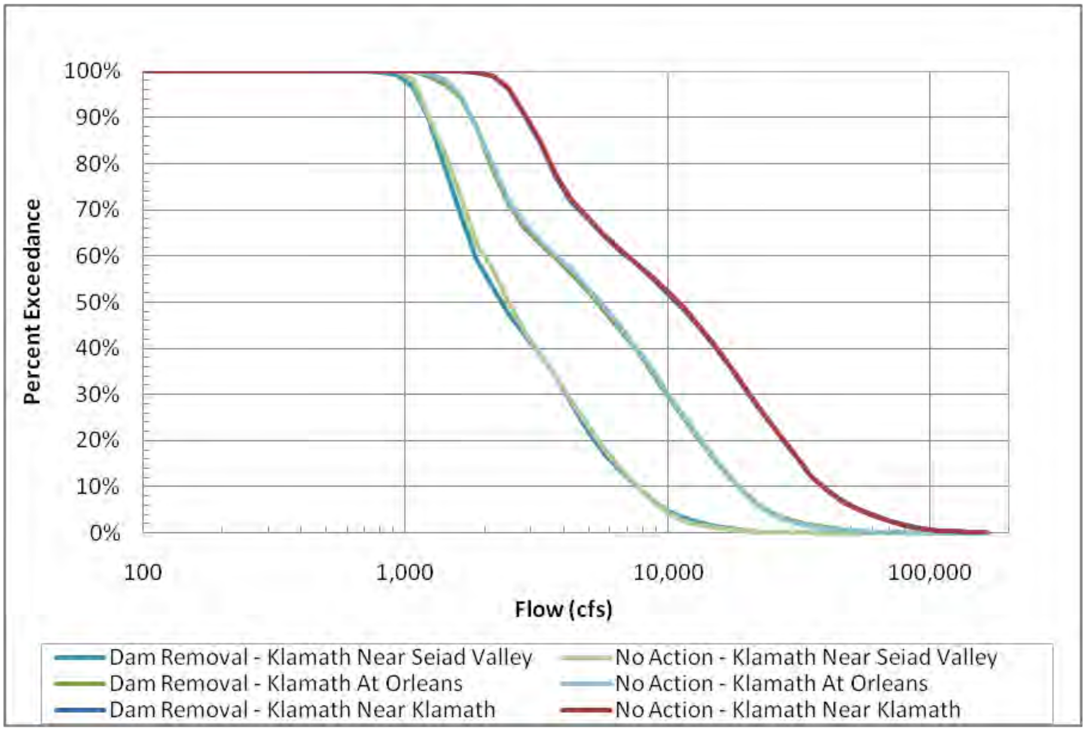


Figure 6-18. Flow duration at Seiad Valley, at Orleans, and at Klamath for the BO and KBRA.

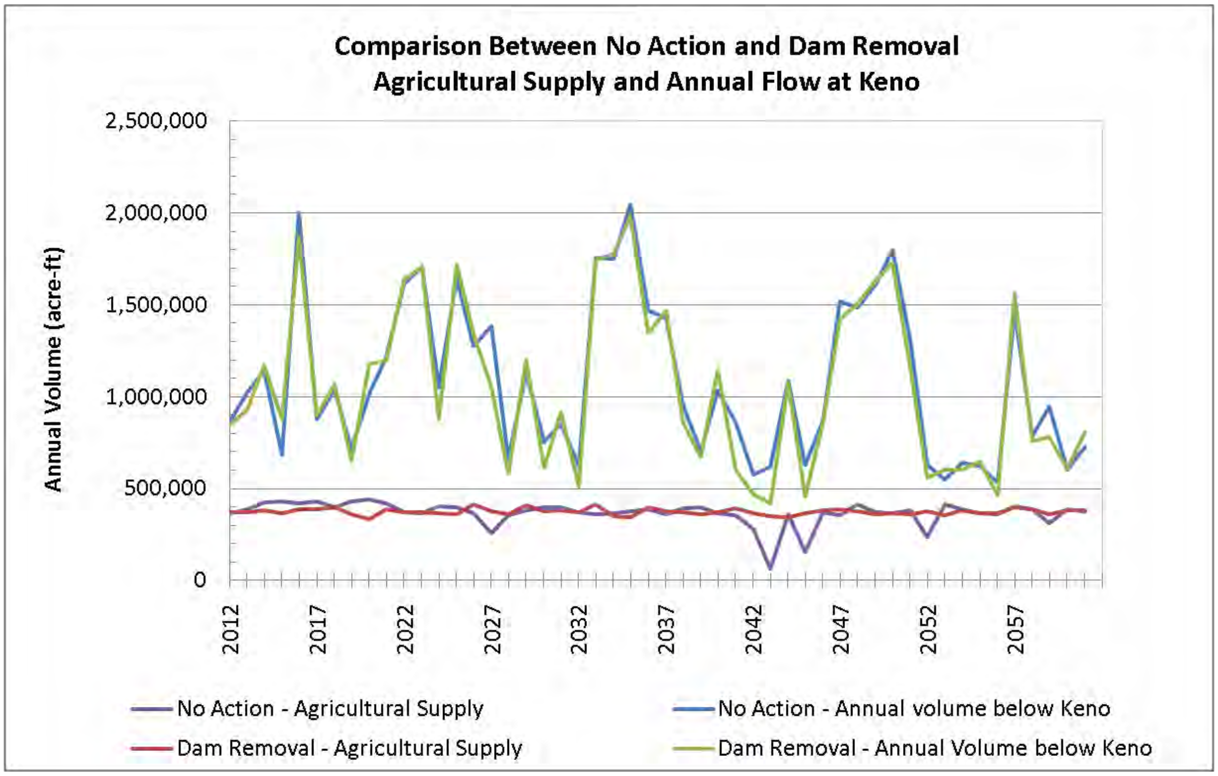


Figure 6-19. Annual flows under the No Action and Dam Removal Alternatives.

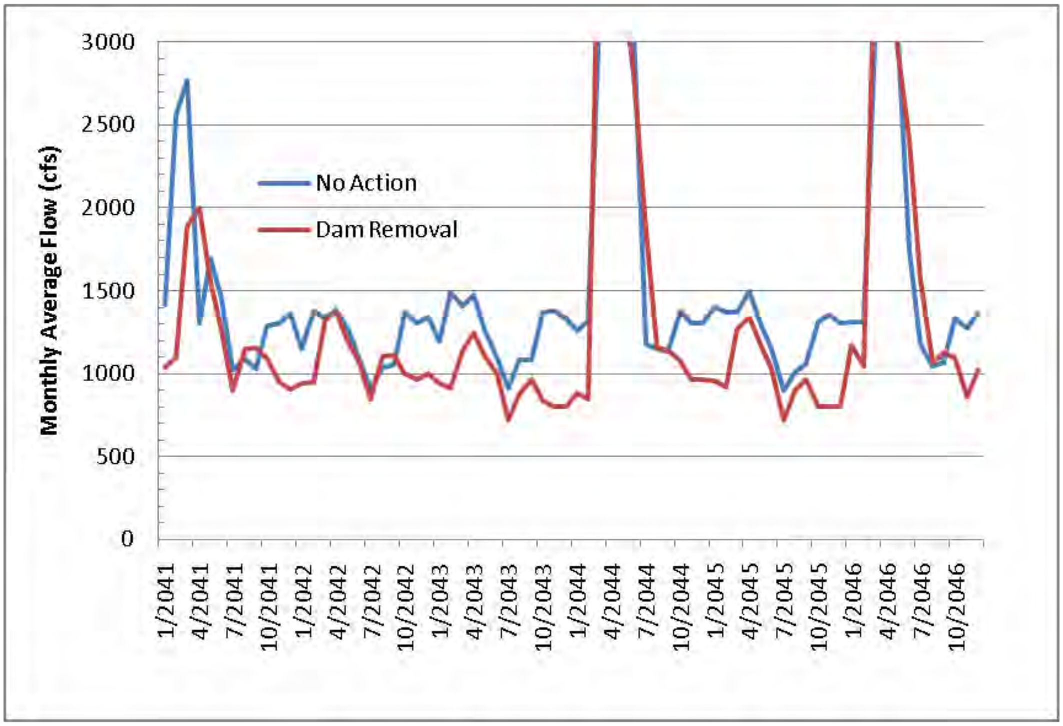


Figure 6-20. Monthly average flows at Iron Gate during period 2041 – 2046, which includes the driest period of the 50-yr simulation.

7. Future Groundwater Conditions

7.1. No Action Alternative

No significant changes to regional and local groundwater levels and aquifer systems are expected under the No Action Alternative if the dams and reservoirs are operated as they have been historically. If existing conditions change significantly – such as greatly lowered reservoir levels due to an extended drought period, or changes in the operational parameters of the dams and reservoirs, then significant changes to some of the local wells may occur. Any such changes to the local water levels and the potential impacts on nearby wells cannot be anticipated nor predicted.

7.2. Dam Removal Alternative

Based upon the characterization of the groundwater and well location, the impact to each well was estimated. The Table 7-1, Table 7-2, and Table 7-3 summarize an estimation of which wells are likely to be impacted and how much that impact might be. Additionally, the third table provides some estimate as to how much a well would have to be lowered if it is affected and the preferred mitigation action is to deepen, rehabilitate, or replace the well.

It does not appear that a significant number of private wells will be adversely impacted to any major degree. In most cases, the anticipated impacts will be negligible in the case of wells more than a ½ mile or more from the reservoir, or will only have minor lowering of the SWL in the wells to a new baseline elevation. It is not anticipated that the new baseline will be significantly below the old river channel bed – which is likely to be the new baseline once the reservoirs are drained.

In cases where a well is anticipated to experience significant drops in SWLs and the associated increased pumping heads (and costs associated with those increased pumping heads), one mitigation action would be to deepen an existing well, or replace it if deepening is not an option.

Table 7-1. Estimation of likelihood of impact to wells from removal of dams. Listing of all wells with reliable location data within 2.5 miles of a reservoir. Listing is grouped by reservoir and arranged from closest to furthest from the reservoir. Reason for the estimation is given under ‘Comments’.

WELL ID	**RESERVOIR**				**WELL**				**COMMENTS**
	Reservoir	Distance to (ft)	Elevati on (ft)	Bottom Elev. (ft) – ORC*	Bottom Elev. (ft)	1st Water Elev. (ft)	W.B. Zone Elev. (ft)	SWL Elev. (ft)	
311084	Iron Gate	544.6	2328.0	2165.0	2442.9	2544.9	2462.9	> 2442	Unlikely to be impacted: W.B. Zone, 1st water, and bottom of well all above reservoir’s influence zone.
14918	Iron Gate	554.5	2328.0	2165.0	2169.4	2309.4	2309.4	2334.4	Likely to be impacted: W.B. Zone is near the top of the reservoir elevation; SWL is above reservoir elevation.
78652	Iron Gate	620.1	2328.0	2165.0	2269.0	2384.0	2384.0	2384.0	Unlikely to be significantly impacted: SWL and W.B. Zone are both above reservoir elevation, and well is upgradient to the reservoir.
4335	Iron Gate	712.0	2328.0	2165.0	2397.7	2437.7	2417.7	2417.7	Unlikely to be impacted: 1st water, SWL and W.B. Zone are all above the reservoir elevation.
334387	Iron Gate	866.2	2328.0	2165.0	2088.8			2218.8	Insufficient information: likely to be impacted due to proximity to reservoir
184187	Iron Gate	987.6	2328.0	2165.0	2421.9	2662.9	2432.9		Unlikely to be significantly impacted: bottom of well, 1st water, and SWL are all above the reservoir elevation
311078	Iron Gate	1095.9	2328.0	2165.0	2219.9	2337.9	2337.9		Likely to be impacted due to proximity to reservoir: 1st water and W.B. Zone are both just above reservoir elevation, well is upgradient to the reservoir.
333890	Iron Gate	1683.2	2328.0	2165.0	2100.7	2325.7	2161.7		Likely to be impacted due to proximity to reservoir: 1st water is below reservoir elevation, W.B. Zone is about the same as the ORC, well is upgradient to the reservoir.

WELL ID	**RESERVOIR**				**WELL**				**COMMENTS**
	Reservoir	Distance to (ft)	Elevation (ft)	Bottom Elev. (ft) – ORC*	Bottom Elev. (ft)	1st Water Elev. (ft)	W.B. Zone Elev. (ft)	SWL Elev. (ft)	
99852	Iron Gate	1735.6	2328.0	2165.0	2212.9	2512.9		2562.9	Insufficient information: likely to be impacted due to proximity of reservoir and well 311084
1087529	Iron Gate	2073.6	2328.0	2165.0	2512.8	2532.8			Insufficient information: unlikely to be significantly impacted due to 1st water and bottom of well both well above reservoir elevation.
781723	Iron Gate	3025.1	2328.0	2165.0	2081.0	2109.0	2136.0	2141.0	Unlikely to be impacted: SWL below ORC, over 1/2 mile downstream of dam, and adjacent to the river.
369526	Iron Gate	3376.1	2328.0	2165.0	2371.2	2466.2	2466.2	2541.2	Unlikely to be significantly impacted: SWL and W.B. Zone are both above reservoir elevation, well is over ½ mile from reservoir, and is upgradient to the reservoir.
414209	Iron Gate	3507.4	2328.0	2165.0	2624.8				Insufficient information: Unlikely to be significantly impacted due to proximity to 369526
99834	Iron Gate	3776.4	2328.0	2165.0	2123.7	2298.7	2167.7	2313.7	Unlikely to be significantly impacted: W.B. Zone is near the ORC; SWL is well above ORC and just below the reservoir elevation, and well is nearly ¾ mile from the reservoir. Reservoir is unlikely to be the major source of water for the well.
1075044	Iron Gate	5049.5	2328.0	2165.0	2555.2	2630.2	2630.2	2785.2	Unlikely to be impacted: SWL and W.B. Zone are both well about the reservoir elevation, and well is nearly 1 mile from the reservoir.
781725	Iron Gate	5262.7	2328.0	2165.0	2431.6	2576.6	2576.6	2644.6	Unlikely to be impacted: over 1 mile downstream of dam
781726	Iron Gate	5331.6	2328.0	2165.0	1930.8	2280.8	2280.8	2330.8	Unlikely to be impacted: over 1 mile downstream of dam

WELL ID	**RESERVOIR**				**WELL**				**COMMENTS**
	Reservoir	Distance to (ft)	Elevation (ft)	Bottom Elev. (ft) – ORC*	Bottom Elev. (ft)	1st Water Elev. (ft)	W.B. Zone Elev. (ft)	SWL Elev. (ft)	
1075458	Iron Gate	5479.3	2328.0	2165.0	2547.5	2607.5	2607.5	2637.5	Unlikely to be impacted: SWL and W.B. Zone are both well about the reservoir elevation, and well is over 1 mile from the reservoir.
1087565	Iron Gate	6942.6	2328.0	2165.0	2396.1	2576.1	2556.1	2576.1	Unlikely to be impacted: SWL and W.B. Zone are both well about the reservoir elevation, and well is over 1 mile from the reservoir.
134222	Iron Gate	7585.7	2328.0	2165.0	2321.5	2381.5	2381.5	2431.5	Unlikely to be impacted: over 1 mile downstream of dam
134223	Iron Gate	8199.2	2328.0	2165.0	1951.5			2421.5	Unlikely to be impacted: over 1 mile downstream of dam
134224	Iron Gate	8271.4	2328.0	2165.0	2361.5	2401.5	2401.5	2451.5	Unlikely to be impacted: over 1 mile downstream of dam
14912	Iron Gate	8904.6	2328.0	2165.0	2329.6	2364.6	2364.6	2379.6	Unlikely to be impacted: over 1 mile downstream of dam
14911	Iron Gate	9649.4	2328.0	2165.0	2269.6	2329.6	2329.6	2361.6	Unlikely to be impacted: over 1 mile downstream of dam
958105	Iron Gate	10499.2	2328.0	2165.0	2520.5	2627.5	2627.5	2772.5	Unlikely to be impacted: SWL and W.B. Zone are both well about the reservoir elevation, and well is over 2 miles from the reservoir.
70943	Copco	39.4	2602.0	2493.0	2539.5	2591.5		2608.5	Likely to be impacted: 1st water, SWL, and bottom of well are likely within the reservoir influence zone.
555722	Copco	55.8	2602.0	2493.0	2440.8			2584.8	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.
406066	Copco	85.3	2602.0	2493.0	2386.4	2506.4			Likely to be impacted: 1st water is likely within reservoir's influence zone and bottom of well is below ORC

WELL ID	RESERVOIR				WELL				COMMENTS
	Reservoir	Distance to (ft)	Elevation (ft)	Bottom Elev. (ft) – ORC*	Bottom Elev. (ft)	1st Water Elev. (ft)	W.B. Zone Elev. (ft)	SWL Elev. (ft)	
512954	Copco	98.4	2602.0	2493.0	2388.4			2563.4	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.
555712	Copco	154.2	2602.0	2493.0	2522.7			2562.7	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.
113378	Copco	160.8	2602.0	2493.0	2562.3	2588.3		2597.3	Likely to be impacted: 1st water, SWL, and bottom of well are likely within the reservoir influence zone.
93347	Copco	183.7	2602.0	2493.0	2545.4			2640.4	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.
406065	Copco	196.9	2602.0	2493.0	2457.6	2507.6		2597.6	Likely to be impacted: 1st water, SWL, and bottom of well are likely within the reservoir influence zone.
713255	Copco	196.9	2602.0	2493.0	2500.9			2564.9	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.
1075453	Copco	239.5	2602.0	2493.0	2490.4	2610.4		2655.4	Likely to be impacted: 1st water is likely within the reservoir influence zone and bottom of well is coincident with ORC.
750784	Copco	242.8	2602.0	2493.0	2176.3			2616.3	Likely to be impacted: bottom of well is below ORC and SWL is likely within reservoir's influence zone.
406993	Copco	259.2	2602.0	2493.0	2485.6			2507.6	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.
126312	Copco	272.3	2602.0	2493.0	2553.1			2596.1	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.

WELL ID	**RESERVOIR**				**WELL**				**COMMENTS**
	Reservoir	Distance to (ft)	Elevation (ft)	Bottom Elev. (ft) – ORC*	Bottom Elev. (ft)	1st Water Elev. (ft)	W.B. Zone Elev. (ft)	SWL Elev. (ft)	
1075456	Copco	420.0	2602.0	2493.0	2232.6	2532.6		2607.6	Likely to be impacted: 1st water and SWL are likely within reservoir's influence zone, and bottom of well is below ORC.
781717	Copco	429.8	2602.0	2493.0	2188.1	2582.1		2439.1	Unlikely to be significantly impacted: SWL is already below the ORC.
1089469	Copco	547.9	2602.0	2493.0	2377.8	2477.8		2637.8	Likely to be impacted: 1st water and bottom of well are likely within the reservoir influence zone.
824871	Copco	1148.4	2602.0	2493.0	2571.5	2635.5		2730.5	Unlikely to be significantly impacted: 1st water and SWL are above the reservoir elevation, well is located near a tributary drainage channel.
50076	Copco	1335.4	2602.0	2493.0	2607.5	2615.5	2625.5	2635.5	Unlikely to be significantly impacted: 1st water, SWL, and W.B. Zone are all above the reservoir elevation, well is located near a tributary drainage channel.
784332	Copco	2004.7	2602.0	2493.0	2522.6	2526.6		2659.6	Likely to be slightly impacted: 1st water and bottom of well are both below the reservoir elevation, well is located in a tributary drainage channel.
784331	Copco	2142.5	2602.0	2493.0	2578.0	2666.0		2678.0	Unlikely to be significantly impacted: 1st water and SWL are both above the reservoir elevation, well is located in a tributary drainage channel.
783919	Copco	5327.1	2602.0	2493.0	2686.8			2846.8	Unlikely to be impacted: bottom of well and SWL are both well above the reservoir elevation, and well is over 1 mile away.
1075033	Copco	6276.6	2602.0	2493.0	2867.9	2945.9		2977.9	Unlikely to be impacted: bottom of well and SWL are both well above the reservoir elevation, and well is over 1 mile away.

WELL ID	RESERVOIR				WELL				COMMENTS
	Reservoir	Distance to (ft)	Elevation (ft)	Bottom Elev. (ft) – ORC*	Bottom Elev. (ft)	1st Water Elev. (ft)	W.B. Zone Elev. (ft)	SWL Elev. (ft)	
54713	J.C. Boyle	29.5	3787.0	3720.0	3712.6			3776.8	Likely to be impacted: proximity to reservoir, and similarity between SWL and reservoir elevation; SWL unlikely to decline below ORC.
54714	J.C. Boyle	62.3	3787.0	3720.0	3725.9				Insufficient information: Likely to be impacted due to proximity to 54713
54615	J.C. Boyle	65.6	3787.0	3720.0	3656.4				Insufficient information: Likely to be impacted due to proximity to 54713
13668	J.C. Boyle	183.7	3787.0	3720.0	3630.0	3655.0	3655.0	3690.0	Unlikely to be significantly impacted; SWL below ORC
51633	J.C. Boyle	203.4	3787.0	3720.0	3512.0	3701.0	3701.0	3701.0	Unlikely to be significantly impacted; SWL below ORC
54618	J.C. Boyle	278.9	3787.0	3720.0	3707.8				Insufficient information: Likely to be impacted due to proximity to 54713
14002	J.C. Boyle	2706.8	3787.0	3720.0	3638.0	3695.0	3695.0	3698.0	Unlikely to be impacted: 1st water, water bearing zone, and SWL are all below the lowest ORC; and the well is downstream of the dam.
13628	J.C. Boyle	2884.0	3787.0	3720.0	3644.0	3675.0	3675.0	3681.0	Unlikely to be impacted: 1st water, water bearing zone, and SWL are all below the lowest ORC; and the well is downstream of the dam.
10514	J.C. Boyle	4721.4	3787.0	3720.0	3561.0	3634.0	3646.0	3687.0	Unlikely to be impacted: SWL is below the lowest ORC, and the well is just under 1 mile away from the reservoir.
10059	J.C. Boyle	5518.6	3787.0	3720.0	3627.0	3831.0	3705.0	3686.0	Unlikely to be impacted: SWL is below the lowest ORC, and the well is over 1 mile away from the reservoir.

ORC – Elevation of **O**riginal **R**iver **C**hannel bed at the location of the dam

Table 7-2. Estimation of the amount of impact to wells within 2.5 miles of a reservoir, and an estimation of the amount of additional depth each well would have to be extended to in order to reasonably reach a reliable water supply. Wells estimated unlikely to be estimated in Table 7-1are not carried through to Table 7-2.

WELL ID	**RESERVOIR**			**WELL**			**COMMENTS**	**IMPACT CATEGORY**[1]
	Reservoir	Distance to (ft)	Bottom Elev. (ft) – ORC*	Bottom Elev. (ft)	Additional Drilling (ft)*	Replacement Drilling (ft)		
14918	Iron Gate	554.5	2165.0	2169.4	75	235	Likely to be impacted: W.B. Zone is near the top of the reservoir elevation; SWL is above reservoir elevation. Gradient is towards the reservoir.	IC-1
78652	Iron Gate	620.1	2165.0	2269.0	N/C	140	Unlikely to be significantly impacted: SWL and W.B. Zone are both above reservoir elevation, and well is upgradient to the reservoir	IC-2
334387	Iron Gate	866.2	2165.0	2088.8	N/A	420	Insufficient information: likely to be impacted due to proximity to reservoir. Gradient is away from the reservoir.	IC-3
184187	Iron Gate	987.6	2165.0	2421.9	N/C	291	Unlikely to be significantly impacted: bottom of well, 1st water, and SWL are all above the reservoir elevation. Gradient is towards the reservoir.	IC-2
311078	Iron Gate	1095.9	2165.0	2219.9	130	376	Likely to be impacted due to proximity to reservoir: 1st water and W.B. Zone are both just above reservoir elevation, well is upgradient to the reservoir. Gradient is towards the reservoir.	IC-4
333890	Iron Gate	1683.2	2165.0	2100.7	10	281	Likely to be impacted due to proximity to reservoir: 1st water is below reservoir elevation, W.B. Zone is about the same as the ORC, well is upgradient to the reservoir. SWL N/R.	IC-4
99852	Iron Gate	1735.6	2165.0	2212.9	125	625	Insufficient information: likely to be impacted due to proximity of reservoir. SWL N/R.	IC-3

WELL ID	RESERVOIR			WELL			COMMENTS	IMPACT CATEGORY[1]
	Reservoir	Distance to (ft)	Bottom Elev. (ft) – ORC*	Bottom Elev. (ft)	Additional Drilling (ft)*	Replacement Drilling (ft)		
1087529	Iron Gate	2073.6	2165.0	2512.8	N/C	200	Insufficient information: unlikely to be significantly impacted due to 1st water and bottom of well both well above reservoir elevation. SWL N/R, gradient likely towards the reservoir or similar to the local/regional gradient.	IC-1
70943	Copco	39.4	2493.0	2539.5	120***	210	Likely to be impacted: 1st water, SWL, and bottom of well are likely within the reservoir influence zone.	IC-4
555722	Copco	55.8	2493.0	2440.8	25	209	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone. Gradient is towards reservoir	IC-4
406066	Copco	85.3	2493.0	2386.4	N/A	300	Likely to be impacted: 1st water is likely within reservoir's influence zone and bottom of well is below ORC. SWL N/R. Gradient likely away from reservoir.	IC-4
512954	Copco	98.4	2493.0	2388.4	N/A	384	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.	IC-4
555712	Copco	154.2	2493.0	2522.7	80***	300	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.	IC-4
113378	Copco	160.8	2493.0	2562.3	145***	220	Likely to be impacted: 1st water, SWL, and bottom of well are likely within the reservoir influence zone.	IC-4
93347	Copco	183.7	2493.0	2545.4	100	210	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.	IC-4
406065	Copco	196.9	2493.0	2457.6	40	240	Likely to be impacted: 1st water, SWL, and bottom of well are likely within the reservoir influence zone.	IC-4
713255	Copco	196.9	2493.0	2500.9	75	199	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.	IC-4

WELL ID	**RESERVOIR**			**WELL**			**COMMENTS**	**IMPACT CATEGORY^1**
	Reservoir	Distance to (ft)	Bottom Elev. (ft) – ORC*	Bottom Elev. (ft)	Additional Drilling (ft)*	Replacement Drilling (ft)		
1075453	Copco	239.5	2493.0	2490.4	70***	270	Likely to be impacted: 1st water is likely within the reservoir influence zone and bottom of well is coincident with ORC.	IC-4
750784	Copco	242.8	2493.0	2176.3	N/A	510	Likely to be impacted: bottom of well is below ORC and SWL is likely within reservoir's influence zone.	IC-4
406993	Copco	259.2	2493.0	2485.6	65***	237	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.	IC-4
126312	Copco	272.3	2493.0	2553.1	135	218	Likely to be impacted: bottom of well and SWL are likely within reservoir's influence zone.	IC-4
1075456	Copco	420.0	2493.0	2232.6	N/A	425	Likely to be impacted: 1st water and SWL are likely within reservoir's influence zone, and bottom of well is below ORC.	IC-4
1089469	Copco	547.9	2493.0	2377.8	N/A	350	Likely to be impacted: 1st water and bottom of well are likely within the reservoir influence zone.	IC-4
784332	Copco	2004.7	2493.0	2522.6	100***	250	Likely to be slightly impacted: 1st water and bottom of well are both below the reservoir elevation, well is located in a tributary drainage channel.	IC-5
54713	J.C. Boyle	29.5	3720.0	3712.6	ABN	N/A	Likely to be impacted: proximity to reservoir, and similarity between SWL and reservoir elevation. Gradient is away from reservoir	IC-3
54714	J.C. Boyle	62.3	3720.0	3725.9	ABN	N/A	Insufficient information: Likely to be impacted due to proximity to 54713. SWL N/R.	IC-3
54615	J.C. Boyle	65.6	3720.0	3656.4	ABN	N/A	Insufficient information: Likely to be impacted due to proximity to 54713. SWL N/R	IC-3
13668	J.C. Boyle	183.7	3720.0	3630.0	N/A	180	Unlikely to be significantly impacted; SWL below ORC. Gradient is away from reservoir.	IC-5
51633	J.C. Boyle	203.4	3720.0	3512.0	ABN	N/A	Unlikely to be significantly impacted; SWL below ORC.	IC-5

WELL ID	**RESERVOIR**			**WELL**			**COMMENTS**	**IMPACT CATEGORY**[1]
	Reservoir	Distance to (ft)	Bottom Elev. (ft) – ORC*	Bottom Elev. (ft)	Additional Drilling (ft)*	Replacement Drilling (ft)		
54618	J.C. Boyle	278.9	3720.0	3707.8	ABN	N/A	Insufficient information: Likely to be impacted due to proximity to 54713	IC-3

* - Estimated by subtracting recorded drawdowns for wells with water bearing units at about the same elevation as the ORC from the ORC, and taking the difference between that value and the recorded bottom of the well, then adding 10 ft for a sump and rounding up to the next 10 ft increment. When no recorded drawdowns exist for wells with water bearing units at or about the elevation of the ORC, then a standard 70 feet was used [only one well remaining on the list for Iron Gate had a recorded drawdown – which was well 4335 @ 60 ft.]

** - N/A indicates that the bottom of the well is already more than 70 feet below the ORC, SWLs are not expected to drop significantly below the ORC so adequate saturated thickness will remain in the well. Pumping heads, and associated costs, will likely increase with a drop in SWLs. Insufficient information is available to estimate the actual drops in SWLs and associated pumping costs. N/C indicates that the impact will likely not be significant, only relatively minor drops in SWL are expected in the well along with associated minor increase in pumping heads (and costs).

[1/] Description of each 'impact category' is included in Table 3-16 at the end of the chapter.

*** - Indicates that these wells are currently screened and will likely have to be screened when deepened. The remaining wells either are open (unscreened) wells or are unlikely to need to be deepened.

Table 7-3. Estimated drilling lengths and screen lengths and associated estimated costs (drilling costs do not include mobilization and demobilization costs, material costs, or development and testing costs). Wells estimated to be unlikely to need deepening or replacement on Table 7-1are not carried through to Table 7-3.

WELL ID	RESERVOIR	ADDITIONAL DRILLING (LF)	ADDITIONAL SCREEN (LF)	ESTIMATED DRILLING ASSUMPTIONS*	ESTIMATED DRILLING COSTS*
14918	Iron Gate	75	0	2 days @ 50 ft/day @ $3,600.00/day	$7,200
311078	Iron Gate	130	0	3 days @ 50 ft/day @ $3,600.00/day	$10,800
333890	Iron Gate	10	0	1 day @ 50 ft/day @ $3,600.00/day	$3,600
99852	Iron Gate	125	0	3 days @ 50 ft/day @ $3,600.00/day	$10,800
70943	Copco	90 + 120	15 + 120	5 days @ 50 ft/day @ $3,600.00/day**	$18,000
555722	Copco	25	0	1day @ 50 ft/day @ $3,600.00/day	$3,600
555712	Copco	220 + 80	120 + 80	4 days @ 50 ft/day @ $3,600.00/day**	$14,400
113378	Copco	75 + 145	60 + 145	5 days @ 50 ft/day @ $3,600.00/day**	$18,000
93347	Copco	100	0	2 days @ 50 ft/day @ $3,600.00/day	$7,200
406065	Copco	40	0	1 day @ 50 ft/day @ $3,600.00/day	$3,600
713255	Copco	75	0	2 days @ 50 ft/day @ $3,600.00/day	$7,200
1075453	Copco	200 + 70	150 + 70	4 days @ 50 ft/day @ $3,600.00/day**	$14,400
406993	Copco	172 + 65	20 + 65	4 days @ 50 ft/day @ $3,600.00/day**	$14,400
126312	Copco	135	0	3 days @ 50 ft/day @ $3,600.00/day	$10,800
784332	Copco	100	100	4 days @ 50 ft/day @ $3,600.00/day	$14,400
All Wells	- - -	- - -	- - -	15 days @ 1/2 day/well to pull pump + ½ day/well to reset pump	$54,000
TOTALS		**2052**	**945**	**59 days @ 50 ft/day**	**$212,400**

* - Assumptions: Actual costs will vary and will be greater once all un-included services are factored in

- Drill Rig: down-hole hammer, conservatively estimated at 50 ft/day for 'hard rock' such as competent basalt and lava, and un-decomposed granite.
- Material type: basalt and/or granite
- Drill hole diameter: 6 inch to 8 inch
- Existing well conditions: uncased, open hole
- Rig Time: $3,600.00/day includes rig and crew charges (under current economic conditions)
- Mobilization and demobilization: not included
- Casing and Screen costs: not included

Site Prep and Clean-up (as necessary): not included
Drilling durations are rounded up to next whole 'day'.

** - Includes 2 days to set screen.

NOTES:

- Air Rotary, with or without water/foam, would be about the same as the down-hole hammer under the same assumptions.
- Smaller diameter boreholes will decrease the advancement rate, conservatively estimated at 30 ft/day – primarily due to the reduced weight of the drill string reducing the impact of the hammer or the down-hole ‘pressure’ on the rotary drill bit.
- Cased and/or screened holes will either have to have the casing pulled, or drill a smaller diameter borehole below the casing/screen bottom. The bottom cap will have to be pulled or drilled through.
- Softer materials, such as sandstones, claystones, cinders, ash, clays, broken or decomposed hard rock will allow for higher advancement rates of up to 100+/- ft/day.

Table 7-4. Table of lithology abbreviations used in well logs.

Abbreviations:		
MATERIALS	COLORS	OTHERS
SDST = sandstone	brn = brown	decomp'd = decomposed
CLST = claystone	lt = light	fract'd = fractured
BRNST = brownstone	grn = green	interm't = intermittent
GRST = graystone	dk = dark	crs = coarse
SH = shale	brnsh = brownish	am't = amount
CGLT = conglomerate	grnsh = greenish	med = medium
BDRK = bedrock	blk = black	lgr = large
SPTN = serpentine		sm = small
SLT = silt		comp'd = compacted
MDST = mudstone		N/R = No Recovery, No Log, or illegible log

Table 7-5. Impact Category descriptions.

Impact Category:

Current elevation of reservoir forms a local 'base line'* that impacts the groundwater levels and gradients upgradient of the reservoir and within the immediate vicinity of the reservoir. When the reservoir is drained and the dam removed, the local base line will be re-established at the elevation of the river channel as it was prior to construction of the dam. Initially, gradients will increase sharply between a well upgradient of the existing reservoir and the new base line. Over time, the groundwater system will establish equilibrium with the new (pre-dam) base line. Water levels in the upgradient wells will likely drop by varying amounts depending on a number of conditions, including:

- Distance from the existing reservoir site,
- Elevation of the water bearing zone relative to existing reservoir water levels,
- Degree of hydraulic connectivity between the water bearing unit in the well and the units that daylight in the reservoir walls, and
- Degree of hydraulic connectivity between the reservoir and the units within the reservoir's zone of influence – both horizontally and vertically.

IC-0: *SWL above reservoir elevation; W.B. Zone above reservoir elevation; 1st water is below reservoir elevation; and/or gradient is towards the reservoir*. Water bearing units upgradient of, and higher in elevation than, the reservoir are unlikely currently being significantly influenced by the reservoir, and after the reservoir is removed are unlikely to experience significant changes in existing water levels. Reduction in the well's SWL of several feet might be expected.

IC-1: *SWL above reservoir elevation; W.B. Zone near reservoir elevation; 1st water is above reservoir elevation; and/or gradient is towards the reservoir*. Water bearing units upgradient of, and at about the same elevation as, the reservoir are likely currently being influenced by the reservoir, and after the reservoir is removed are likely to experience significant changes in existing water levels. SWL in the well can be expected to drop. The SWL would be expected to drop to about the elevation of the nearest reach of the river channel. Regional gradient will likely keep the SWL above the base line.

IC-2: *SWL above reservoir elevation; W.B. Zone above reservoir elevation; 1st water is above reservoir elevation; and/or gradient is towards the reservoir*. Water bearing units upgradient of, and above the reservoir are unlikely currently being influenced by the reservoir, and after the reservoir is removed are unlikely to experience significant changes in existing water levels. SWL in the well can be expected to drop only a few feet at most as the local gradients adjust to the new base line.

IC-3: *SWL between reservoir elevation and ORC elevation.* Insufficient information, likely to be impacted due to elevation of SWL relative to the reservoir elevation, and proximity to the reservoir. SWL can be expected to drop to near or slightly below the ORC elevation.

IC-4: *SWL likely near reservoir elevation; W.B. Zone near reservoir elevation; 1st water near reservoir elevation; and/or gradient is away from the reservoir or flat*. Water bearing units at about the same elevation as the reservoir are likely currently being influenced by the reservoir, and after the reservoir is removed are likely to experience significant changes in existing water levels. SWL in the well can be expected to drop. The SWL would be expected to drop to about the elevation of the nearest reach of the river channel.

IC-5: *SWL below ORC, 1st Water below ORC, W.B. Zone below ORC, and/or gradient is away from reservoir.* SWL in well can be expected to decline slightly as the gradient between the reservoir zone and the well is reduced to the ORC elevation. The overall gradient would remain away from the reservoir.

8. Future Hydraulic Conditions

8.1. No Action Alternative

No significant changes to the river hydraulics are expected under the No Action Alternative.

8.2. Dam Removal Alternative

The reservoir pools of the four dams will be converted to a free flowing river. Free flowing conditions were estimated by simulating erosion of the reservoir sediment and then computing hydraulic properties after dam removal and the river has eroded a channel in the reservoir sediment. The details of the sediment modeling are given in Section 9.

A plot of the water surface elevations at 1,000 cfs is given in Figure 8-1 and Figure 8-2 for No Action and Dam Removal Alternatives. A plot of the water surface elevations at 3,000 cfs is given in Figure 8-5 and Figure 8-6. The average depths and velocities through the former reservoir pools will be similar to the reaches upstream and downstream of the reservoirs.

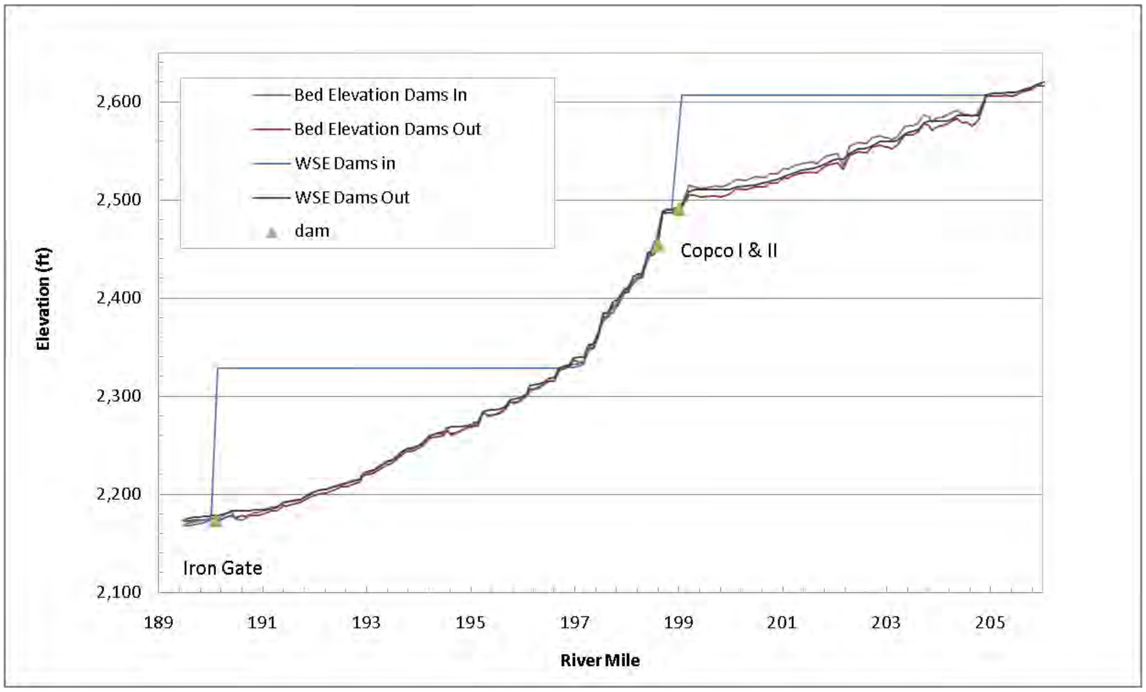


Figure 8-1. Bed and water surface profiles near Iron Gate and Copco 1 dams under No Action and Dam Removal Alternatives.

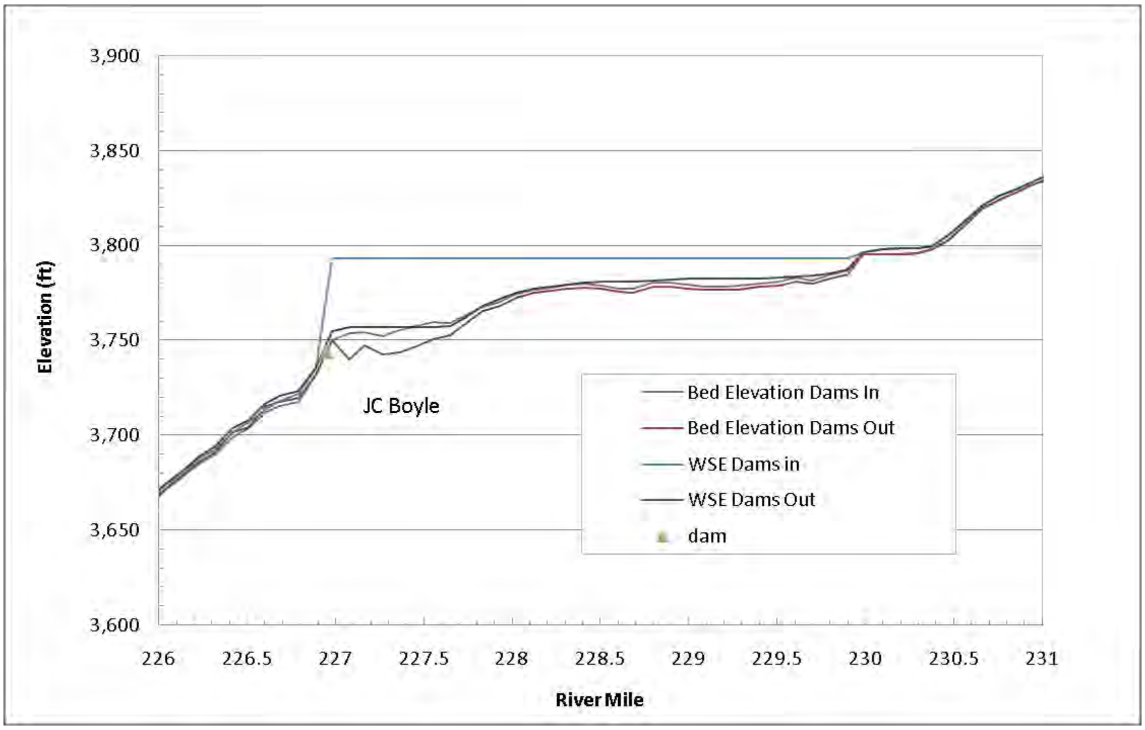


Figure 8-2. Bed and water surface profiles near J.C. Boyle Dam under No Action and Dam Removal Alternatives.

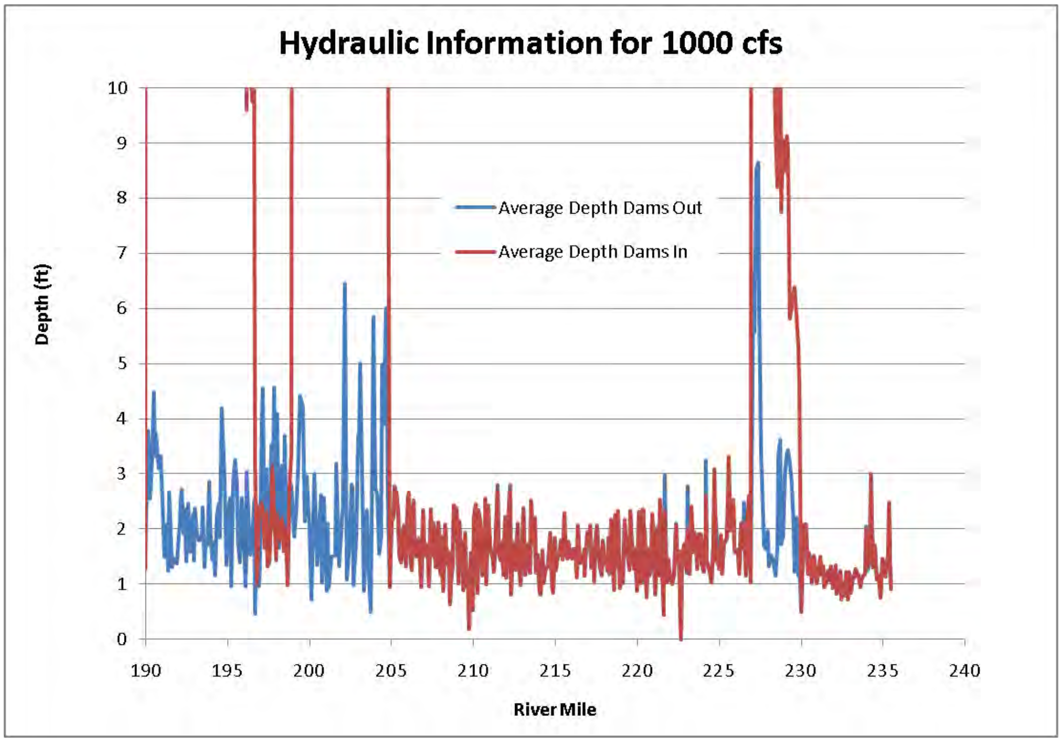


Figure 8-3. Average water depth in J.C. Boyle to Iron Gate reach for 1000 cfs under No Action and Dam Removal Alternatives.

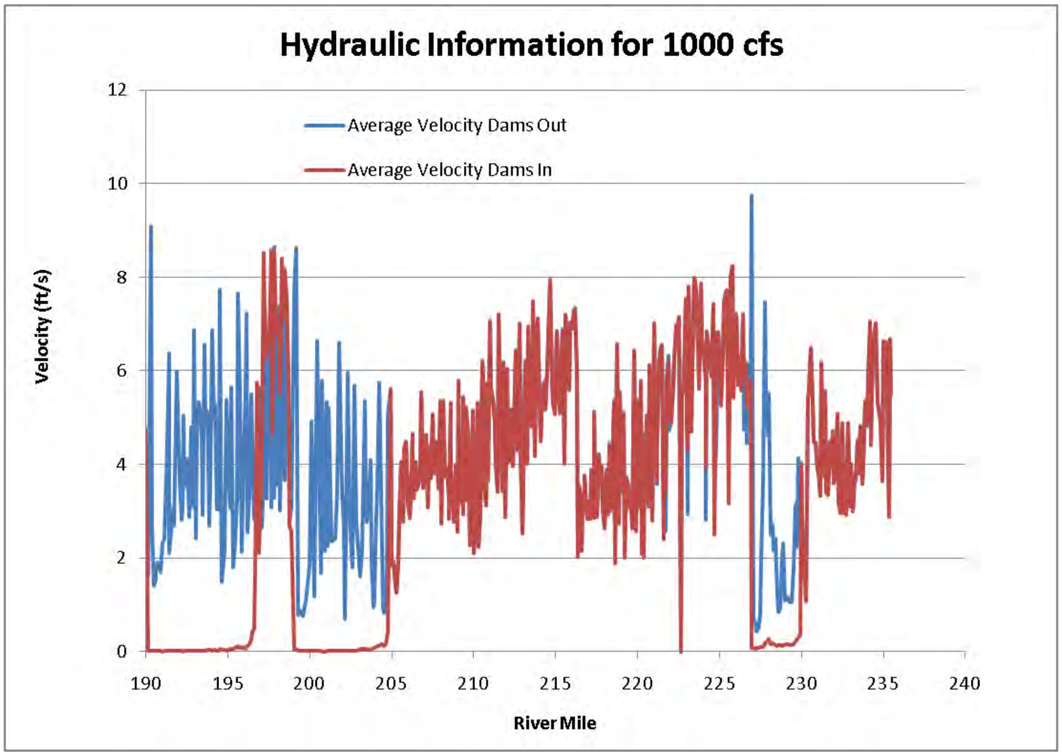


Figure 8-4. Average water velocity in J.C. Boyle to Iron Gate reach for 1000 cfs under No Action and Dam Removal Alternatives.

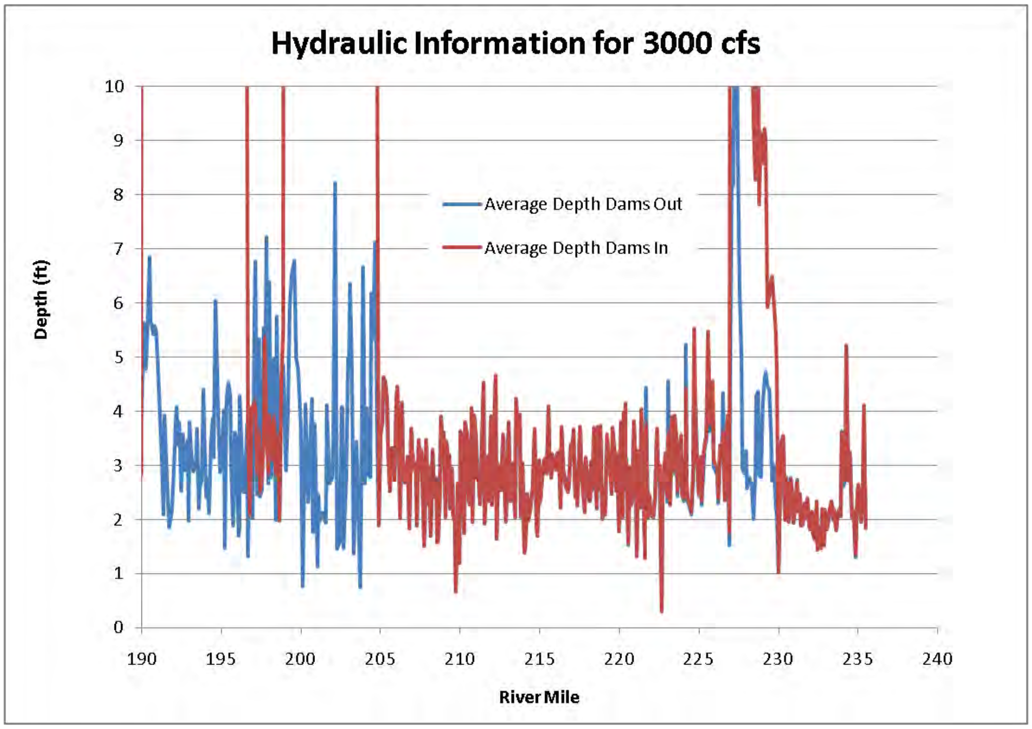


Figure 8-5. Average water depth in J.C. Boyle to Iron Gate reach for No Action and Dam Removal Alternatives at 3000 cfs.

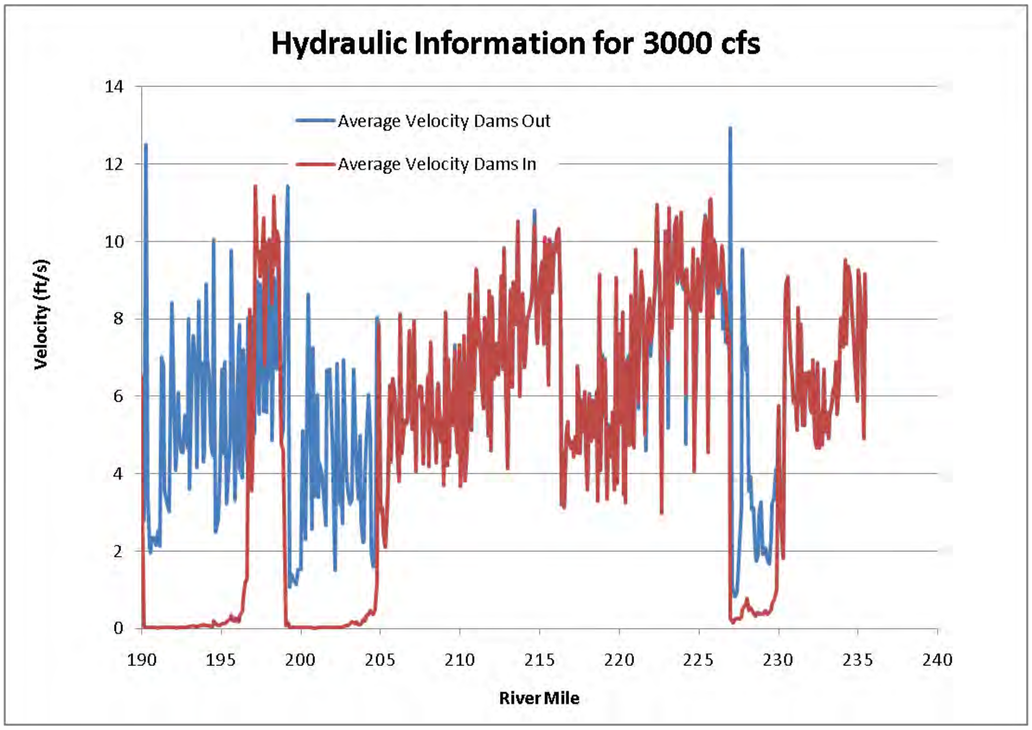


Figure 8-6. Average water velocity in J.C. Boyle to Iron Gate reach for No Action and Dam Removal Alternatives at 3000 cfs.

The 100-year floodplain may increase slightly as the result of dam removal. This is due to two affects: (1.) the removal of the attenuation of Iron Gate and Copco reservoirs, and (2.) the aggradation of the bed downstream of Iron Gate. The flood attenuation affects are quantified in Section 6 and the aggradation affects are quantified in Section 9. A plot of the 100-year floodplain for the Dam Removal and No Action Alternatives is given in "Appendix G. Mapping of 100-year Flood Plain under No Action and Dam Removal Alternatives". A plot of the increase in the 100-yr flood elevation levels is given in Figure 8-7.

It was assumed that the 100-yr flood discharge increases by 2,500 cfs for the entire length of the Klamath River downstream of Iron Gate Dam. This is an over estimate because it does not account for the fact the peak flow at Iron Gate Dam will not be perfectly timed with the peak flow from the tributaries. Therefore, the increase in the floodplain is considered to be a conservative estimate that will likely decrease as more detailed analysis is performed.

The most significant increase will occur near the dam from Bogus Creek to Willow Creek where the average increase in the 100- year flood elevations is expected to be about 1.5 feet. Downstream of the Humbug Creek, 100-year elevations are expected to increase less than 0.5 feet and the increase in flood elevations is not considered significant because there will be attenuation effects in the channel and the peak flows in the tributaries will not coincide with the peak flow from Iron Gate.

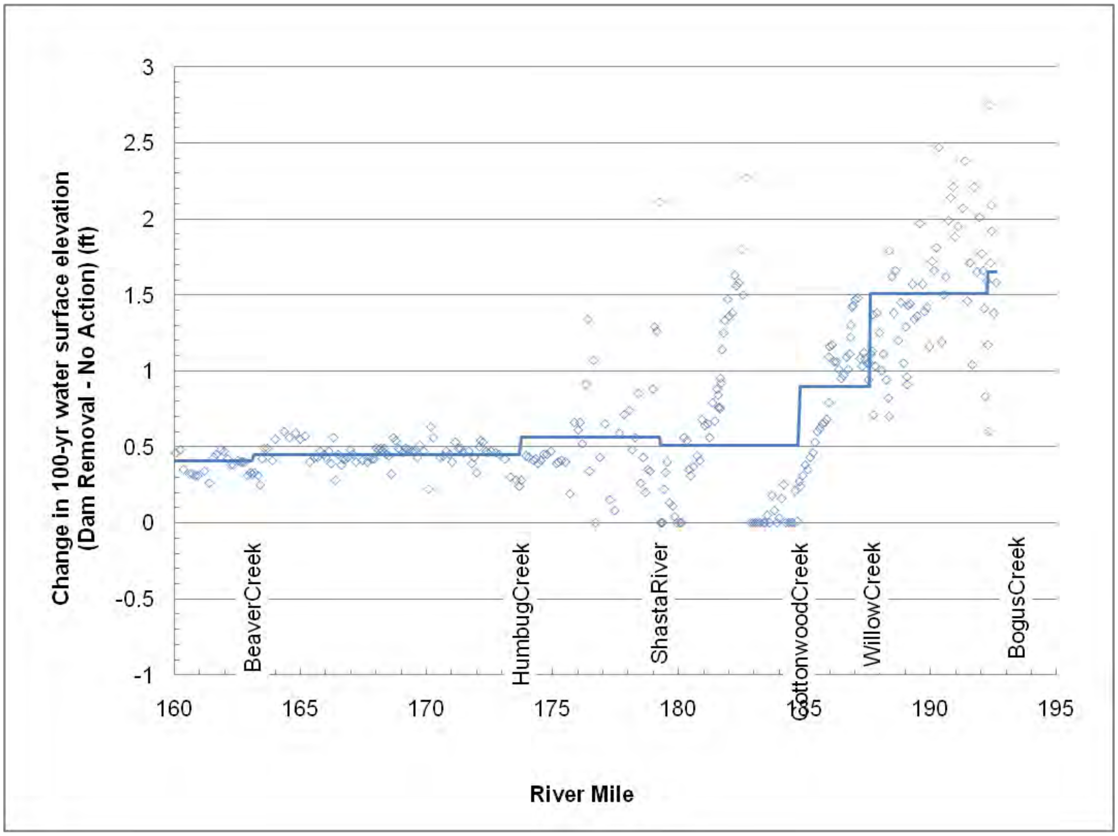


Figure 8-7. Estimate of the increase in 100-yr flood elevations as the result of Dam Removal. Below Humbug Creek, the increase in 100-yr flood elevation is not considered significant.

9. Future Geomorphology and Sediment Transport Conditions

9.1. No Action Alternative

Under the No Action Alternative, J.C. Boyle, Iron Gate, and Copco 1 reservoirs will continue to trap sediment at rates similar to historical levels. We estimate that approximately 23.5 million yd^3 of sediment will be stored behind the dams by 2061 (Table 9-1). The trapping efficiency of J.C. Boyle Reservoir may slightly decrease as the reservoir capacity decreases but the rate at which this happens is uncertain and is not likely to change significantly by 2061. Stillwater (2010) estimated that approximately 24,000 yd^3/yr of sediment coarser than 0.06 mm is being trapped in the PacifiCorp reservoirs. This volume of sediment will continue to be trapped under future conditions and it is expected that the reach downstream of Iron Gate Dam will continue to be depleted of sediment. In all reservoirs, the maximum sediment thicknesses are measured at the downstream ends and progressively decrease in thickness toward the upstream end of the reservoir to where the amount of reservoir sediment is too thin to measure. Thus, it is likely that while sediment will continue to deposit over the entire reservoir, measurable amounts of sediment will progress upstream into areas where there is negligible accumulation, currently. It is likely that after the storage capacity reduces to a certain level, the aggradation in the reservoirs will stop and sediment will begin to pass through the reservoir pools.

Table 9-1. Future Total Sedimentation Rate in reservoirs.

Reservoir	Year Completed	Original Storage Capacity (acre-ft)	Current Sediment Volume (yd^3)	Sedimentation Rate (yd^3/ yr)	2061 Sediment Volume (yd^3)	% reduction in Storage Capacity
JC Boyle	1958	3,495	990,000	19,600	2,020,000	36
Copco 1	1918	46,867	7,440,000	81,300	11,600,000	15
Copco 2	1925	73	0	0	0	0
Iron Gate	1962	58,794	4,710,000	100,000	9,900,000	10
Total	-	109,229	13,140,000	201,000	23,500,000	13

At J.C. Boyle Reservoir, sediment deposition is greatest at the downstream end of the reservoir, reaching a maximum of 18-20 feet near the dam and decreasing to 0 feet of depth between RM 225 and 226. Measureable amounts of reservoir sediment were also recorded near RM 227, amounting to 8-10 feet. It is likely that these areas will continue to accumulate sediment and the extent of sediment deposition will continue to progress upstream toward the state highway bridge.

At Copco Reservoir, sediment thicknesses mostly range from 6-10 feet with maximum values at the downstream end of the reservoir, while 2-6 feet thicknesses are common at the upstream end of the reservoir and along the reservoir margins. Several deep scour holes still exist that were part of the historical channel and are not expected to fill in within the near future.

At Iron Gate Reservoir, sediment thicknesses reach a maximum value of 10 feet in the vicinity of Jenny Creek delta while other parts of the reservoir have thicknesses of 3-5 feet near Iron Gate Dam. Thicknesses decrease with distance from the dam to where they are negligible near the reservoir high pool. Sediment deposition is predicted to continue at similar rates in Iron Gate Reservoir with progressive accumulation toward the upstream end of the reservoir and in the vicinity of Jenny Creek, Scotch Creek, and Camp Creek as these tributaries mobilize sediment into the reservoir from upland areas.

Under the No Action Alternative, no significant erosion is expected to occur downstream of any of the PacifiCorp dams in the future. Any significant adjustment in river elevations would have already occurred in previous floods. The river planform and elevation is largely controlled by boulders and bedrock and only limited adjustment is possible. PacifiCorp (2004b) was unable to determine any significant change in river morphology downstream of Iron Gate caused by the dams. PWA (2009) analyzed USGS stream gage below Iron Gate and also found no significant change to the relationship between flow elevation and flow discharge since the construction of Iron Gate Dam.

Under the No Action Alternative, continued sediment armoring occurs downstream of Iron Gate Dam. Bed mobilization from Iron Gate Dam to Cottonwood Creek is expected to continue to decrease in the future as sediment is stripped from the reach. The future bed mobilization under the No Action Alternative is discussed in 9.2.3. As the bed mobilization in the reach between Iron Gate Dam and Cottonwood Creek continues to decrease, the existing terraces and sediment bars are expected to continue to be stable and become more vegetated.

9.2. Dam Removal Alternative

There will be two major effects of the dam removal on sediment transport:

1. Short term release of fine sediment stored behind the dams.
2. Long term resupply of natural fine and coarse sediment to the Klamath River that was previously trapped by the dams.

We will analyze both effects of dam removal using both one-dimensional (1D) and two-dimensional (2D) models. The 1D model used in the simulation is SRH-1D (Huang and Greimann, 2010) and the 2D model used in the simulations is SRH-2D. Previous analyses of Klamath Dam Removal have been performed by Stillwater Sciences (2008) and PWA (2009).

9.2.1. ONE-DIMENSIONAL SIMULATION OF RESERVOIR DRAWDOWN AND EROSION OF RESERVOIR SEDIMENT

River flows will erode significant quantities of reservoir sediment as the reservoirs are drawn down. The rate of reservoir drawdown and the erosion of sediment are largely determined by the hydrology and low level outlet capacity. The outlet capacity of each reservoir is given in Figure 9-1, Figure 9-2, and Figure 9-3. The outlet capacity is consistent with that assumed in Reclamation (2010b). Hydrologic routing during dam removal was performed using the RiverWare model of the system described in Appendix E. Documentation of Hydrology Simulations for the Klamath Dam Removal . The operations under the KBRA are assumed to govern the releases of water at Link Dam and Keno Dam. For the purposes of discussion, representative dry, median, and wet water years were defined as the 90%, 50%, and 10% exceedance of the March to June flow volume at Keno Dam on the Klamath River. The dry, median, and wet water years were 2001, 1976, and 1984, respectively.

Two sets of simulations were performed.

1. Forty-eight 2-year simulations of the reservoir drawdown and following year. Forty-eight simulations were performed using every WY between 1961 and 2008.
2. Three 50-year simulations with the reservoir drawdown occurring the first year. Three simulations were performed using year 1976, 1984, and 2001 as the start years.

The short term release of fine sediment was simulated using SRH-1D (Huang and Greimann, 2010). There were two sediment models created: an upstream model extending from upstream of J.C. Boyle Dam to downstream of Iron Gate Dam, and a downstream model extending from Iron Gate Dam to the Pacific Ocean. The models were created from the respective HEC-RAS models of the same reaches. The reservoir sediment thicknesses where computed based upon the GIS maps in Figure 5-35, Figure 5-36, and Figure 5-37. The thicknesses were increased to estimate the thickness in 2020, when dam removal will occur. This increases the sediment volumes in the reservoirs by 24% at Iron Gate, 12% at Copco, and 22 % at J.C. Boyle. It is estimated that there will be 15 million yd^3 of sediment stored behind the three reservoirs by 2020.

There are several types of data and model parameters required in SHR-1D. They can be divided into the following categories:

1. **Model Parameters**: Both unsteady flow and sediment transport are simulated for the drawdown. Sensitivity to time step was performed and decreasing the time step below 0.1 hours did not significantly change the results, so a time step of 0.1 hours is used for all drawdown studies.
2. **Upstream Boundary Conditions**: Flow information at the upstream end of the model is taken from the hydrologic simulations.
3. **Downstream Boundary Conditions**: The downstream end of the model is approximately ½ mile downstream of Iron Gate Dam. A fixed rating curve is used at this point.
4. **Internal Flow Controls**: The reservoir elevations at the dams are specified based upon the hydrologic routing model.
5. **Lateral Inflows**: Lateral inflows were taken from the hydrologic routing model.
6. **Channel Geometry and Roughness**: The Channel geometry is taken from the HEC-RAS model described in Section 4.1.1. The channel roughness is set to 0.04.
7. **Sediment Model Parameters**: Sediment model parameters control the number of bed layers used to represent the river bed, the implicit factor for sediment transport computations, and the number of sediment time steps performed for each hydraulic time step. We used four bed layers. In the reservoir, the upper two layers represented the reservoir sediment and the bottom two layers represented the pre-reservoir sediment. The default for the implicit factor is 1. The number of sediment time steps default value is 1. The frequency of checking the angle of repose condition is set here too. The default is checking at every time step. Also in this data group, the sediment size classifications are given and the sixteen sediment size classes range from 0.00002 mm to 2048 mm in diameter. One size class is used to represent the silt/clay fractions, which is assumed to be all sediment smaller than 0.0625 mm. Sediment larger than 0.0625 mm is separated into size classes separated by powers of two starting at 0.0625 mm. The bulk density assumed for the fine material is 20 lb/ft^3, while the bulk density assumed for the non-cohesive material was 100 lb/ft^3.

   For non-cohesive sediment (assumed to be all sediment greater than 0.0625 mm) the Parker (1990) bedload equation is used to predict sediment transport movement is D50 is greater than 2 mm, while the

Engelund and Hansen (1972) formula is used to predict the movement if the D50 is less than 2 mm.

8. **Upstream Sediment Boundary Conditions**: No sediment is assumed to enter in from the upstream boundary.
9. **Lateral Sediment Discharge**: No lateral sediment discharge is modeled in the upstream reach for the deconstruction simulations. Tributary sediment supplies were computed from results of Stillwater (2010). The tributary loads were assigned as described in Section 9.2.1.29-14
10. **Sediment Bed Material**: Bed material gradations for the river reaches are taken from Reclamations sampling in 2009 downstream of Iron Gate and PacifiCorp's 2004 bed material information upstream of Iron Gate. The bed material gradations for the reservoir sediment are taken from Section 5.6.2.
11. **Water Temperature**: The assumed water temperature was 58º F. The sediment transport results are not sensitive to the water temperatures assumed in the model.
12. **Erosion and Deposition Limits**: No erosion and deposition limits are assumed in the model.
13. **Sediment Transport Parameters**: The Parker (1990) formula is used to compute gravel and larger sizes while the Engelund and Hansen (1972) formula is used to compute the sand sizes. The active layer thickness is set to 2 feet. The above water angle of repose is important to defining the stability of the reservoir sediment. The assumed angle of repose is 15º for most simulations, but some model sensitivity of this parameter is conducted.
14. **Cohesive Sediment Transport Parameters**: The erodibility parameters are described in Section 5.6.4. The 50th percentile values of the critical erosion shear stress and erosion rate coefficient are used in simulations. Model sensitivity of the erodibility parameter is conducted.
15. **Bedrock Geometry and Parameters**: SRH-1D allows the definition of bedrock and the pre-reservoir sediment in the reservoir reaches was assumed to be non-erodible bedrock.

Several drawdown scenarios were analyzed (Appendix K. Other Drawdown Scenarios Analyzed). The scenarios are largely determined by the start date of drawdown and whether or not Copco 1 Dam is notched at the beginning of drawdown or not until the dry summer months. The removal of Iron Gate and J.C. Boyle dams cannot begin before the dry summer months because of the risk of dam overtopping. Start dates of Nov 15, 2019 and January 1, 2020 were investigated.

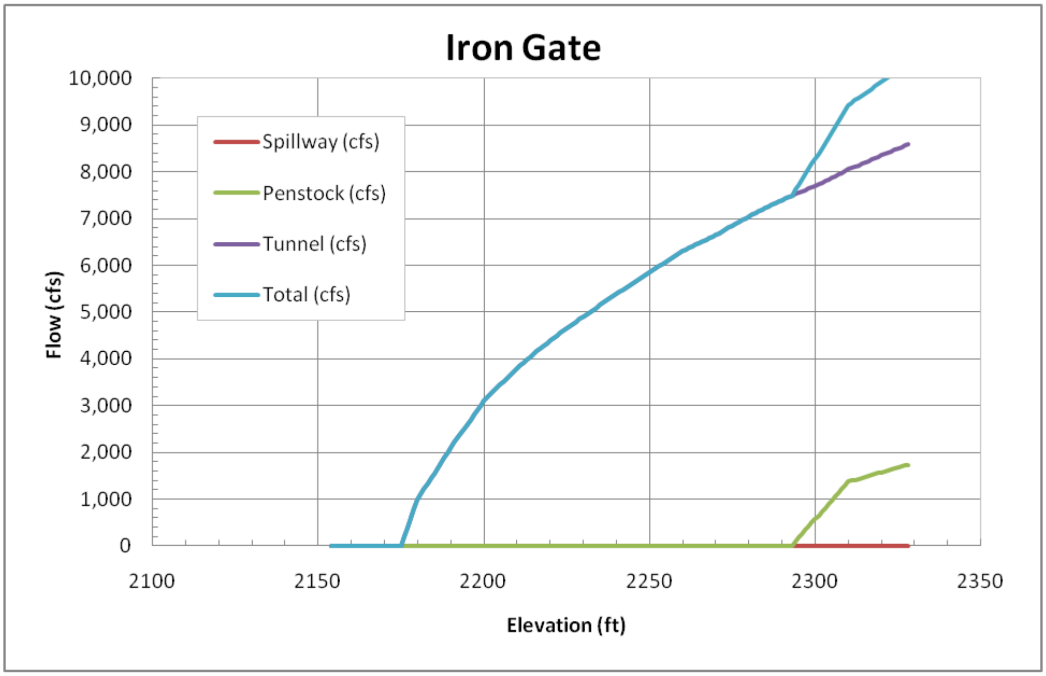


Figure 9-1. Outlet capacities at Iron Gate Dam.

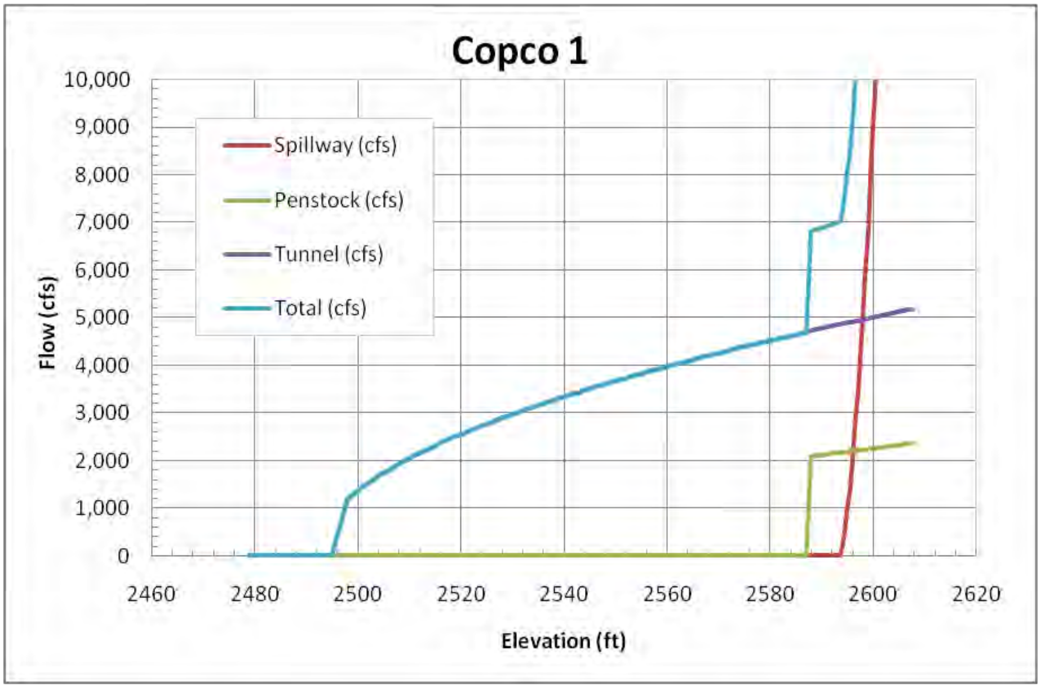


Figure 9-2. Outlet capacities at Copco 1 Dam.

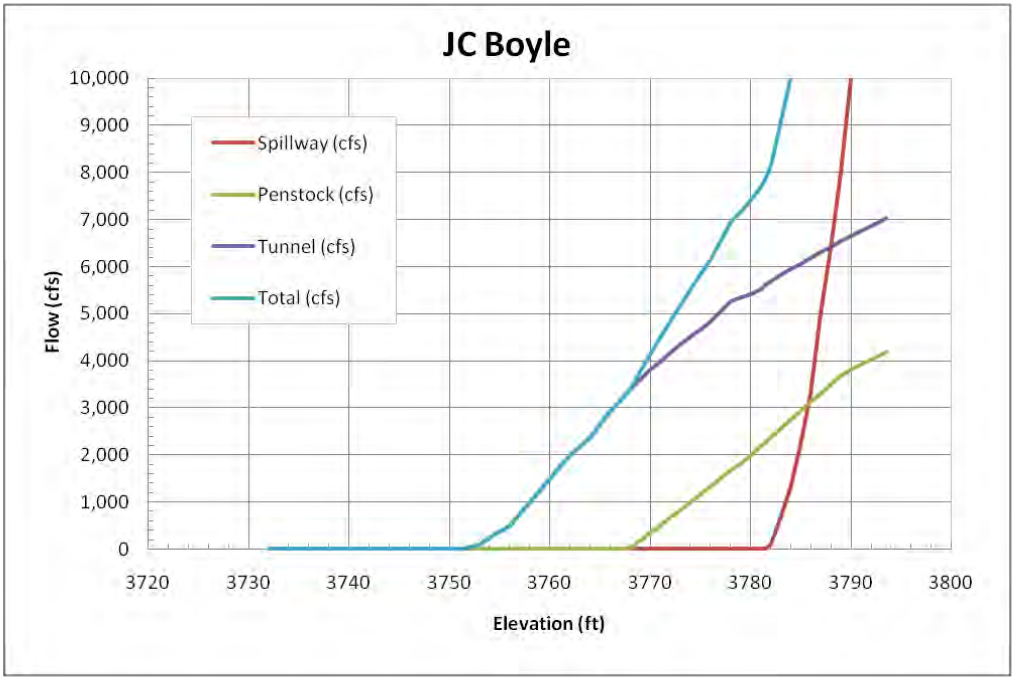


Figure 9-3. Outlet capacities at J.C. Boyle Dam.

The primary objective of the preferred drawdown scenario was to limit the period of high sediment concentrations to the months of January to early March. Details of the deconstruction can be found in the Detailed Plan Report (Reclamation, 2010). The preferred drawdown scenario has the following activities for each dam:

J.C. Boyle Dam

1. At J.C. Boyle Reservoir, the drawdown would also begin January 1, 2020 and would occur through the penstocks and gated spillway from a normal pool elevation of 3793 feet to 3780 feet at a rate not to exceed 3 ft/d. On January 13, one of the low level outlets of J.C. Boyle Dam would be opened by removing the concrete stoplogs that block the outlet and the reservoir would be drawdown to an elevation of 3770 feet. The second of the low level outlets would be opened January 20, 2020 and the reservoir would be drawdown to an elevation of 3762 feet.

2. The removal of the earthen embankment would begin July 1, 2020. The river level will be between 3758 and 3760 feet during this period as the flows pass through the low level outlets. The dam embankment would be removed to about 3760 feet elevation at the upstream face (over 100,000 yd^3) in July and August (about 23 feet above bedrock at upstream toe), or as low as reservoir level will allow, to create an upstream cofferdam to ensure flood protection for flows through left abutment. The embankment materials downstream of cofferdam would be removed to the pre-dam channel grade, including concrete cutoff wall. The excavated rockfill

(from stockpile) would be placed on the downstream face of the upstream cofferdam for controlled breach of cofferdam embankment to a streambed elevation of 3737 feet, by notching below the reservoir level. Final reservoir drawdown would be achieved by natural erosion of the armored cofferdam and impounded sediments to the original streambed level.

Copco 1 Dam

1. Initiate drawdown at Copco Reservoir beginning November 1, 2019 at rate of 1 ft/d from normal pool of about 2606 feet to 2590 feet, which is 3 feet below spillway crest. The spillway gates and superstructure would be removed once the pool is lowered below the crest and their removal would be complete by January 1, 2020. The original low level outlet used for stream diversion during the construction of Copco No.1 Dam would be used to bring the reservoir level below the spillway crest.

2. The drawdown of Copco Reservoir would resume January 1, at a rate of approximately 1.75 ft/d to an elevation of 2529. Below an elevation of 2529, the drawdown rate would be increased to 2.25 ft/d until it reaches the pre-dam river elevation. The drawdown at Copco Reservoir would primarily occur through the low level outlet. The dam would be notched by removing concrete sections and the spillway will be removed to ensure that the drawdown rates are accomplished and the reservoir does not refill.

Iron Gate Dam

1. Initiate drawdown at Iron Gate Dam on January 1, 2020 at a rate not to exceed 3 ft/d. The low level outlet at Iron Gate would be used to drawdown the reservoir. The outlet capacities for the low level at Iron Gate are given in Figure 9-1.

2. The earthen embankment would be removed in July and August of 2020. The reservoir would be drawdown to the maximum extent by September 1, 2020 and rockfill would be placed on the downstream face of the cofferdam, which would be at an elevation of 2202 feet or lower. The cofferdam would be allowed to natural erode to the pre-dam stream bed elevation of approximately 2165 feet by notching below reservoir elevation.

9.2.1.1. Reservoir Elevations and Flows

J.C. Boyle Reservoir elevations for WY 2001, 1976, 1984 are given in Figure 9-4. The drawdown begins January 1, and is performed through the penstock and spillway gates. The subsequent drawdown below elevation 3780 feet occur through the low level outlet. Some refill of J.C. Boyle Reservoir occurs during the wet year (1984) during the spring runoff. Figure 9-5 shows the reservoir elevation at various exceedance levels for every day of the year for all WY from 1961 – 2008. An elevation of 3770 feet is rarely exceeded after February 1.

Copco Reservoir elevations are shown in Figure 9-6. Because the dam is notched as it is drawdown, flows exceeding the low level outlet capacity overtop the notched dam and do not significantly fill the reservoir. During the wettest years, there is some refill of the reservoir in December and January because of the depth of water necessary to overtop the spillway during peak flow events.

Iron Gate Reservoir elevations are shown in Figure 9-8. The reservoir is drawdown below 2186 feet by mid February and remains below that elevation for the dry and median year. For the wet year, there is some refilling of the reservoir during the spring runoff. Figure 9-9 shows the reservoir elevations for various daily exceedance percentages based upon the simulated flows using WY 1961 - 2008. The 25% exceedance elevation is below 2220 feet after mid-February. The reservoir may almost completely refill during the spring runoff for the wettest years.

The flows for the drawdown downstream of Iron Gate Dam are shown in Figure 9-10 for the WY 1976, 2001, 1984, and Figure 9-11 shows the flows for various daily exceedance values. The median flow expected during the drawdown period from January to mid-February is between 6,000 to 8,000 cfs. During wet years, the flow may be much higher and the model is not sufficiently refined to simulate the operations during extreme floods. If a peak flow event occurs during drawdown then the notching of Copco 1 Dam would be halted and the outflow exiting each of the reservoirs would be less than the inflow entering them. Engineering precautions would be put in place to ensure that the peak flow would not be increased by the drawdown process.

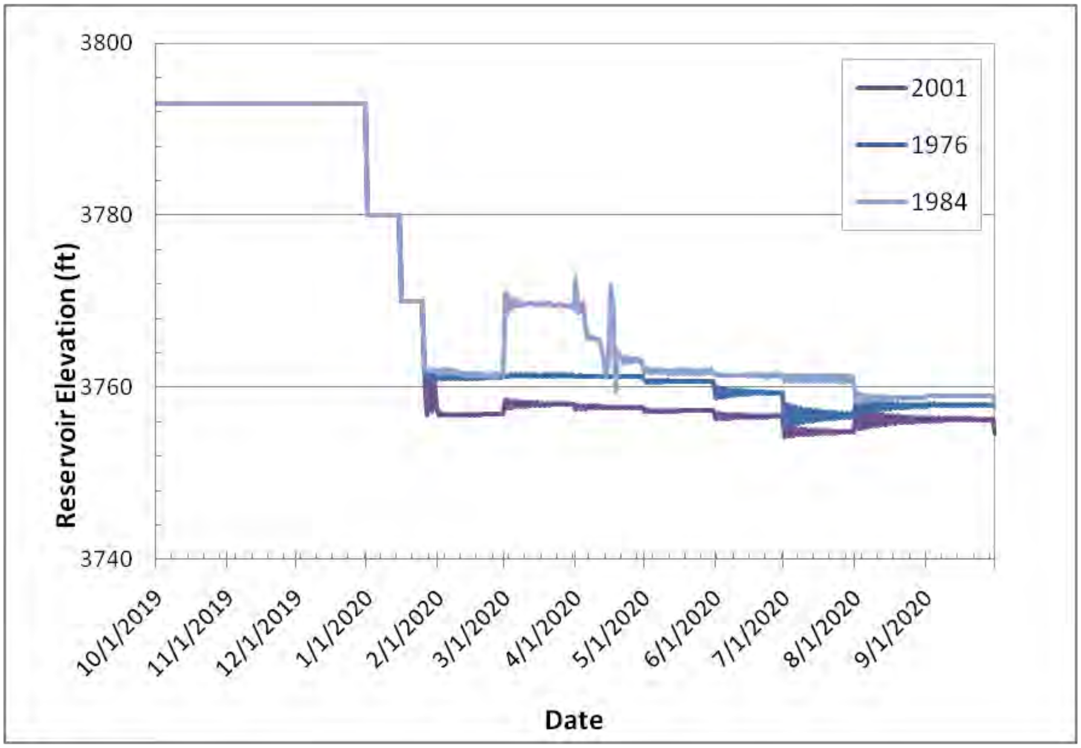


Figure 9-4. J.C. Boyle Reservoir elevation for typical Dry (2001), Median (1976), and Wet (1984) Years for Scenario 8.

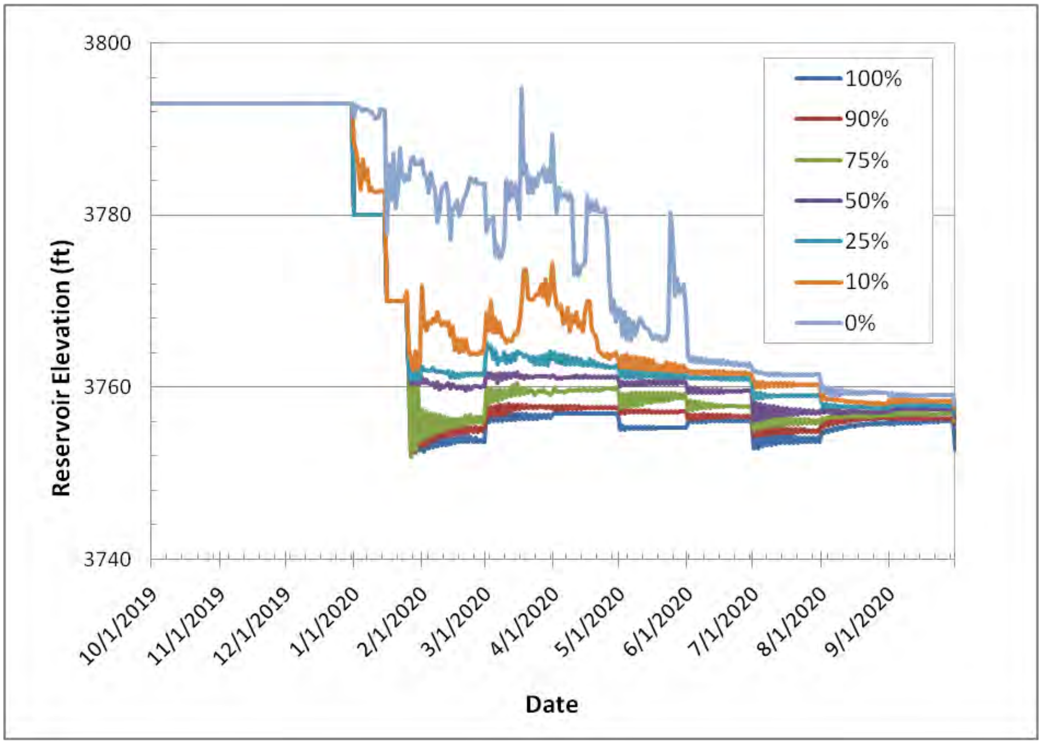


Figure 9-5. J.C. Boyle Reservoir exceedance elevations for WY 1961 to 2008 for Scenario 8.

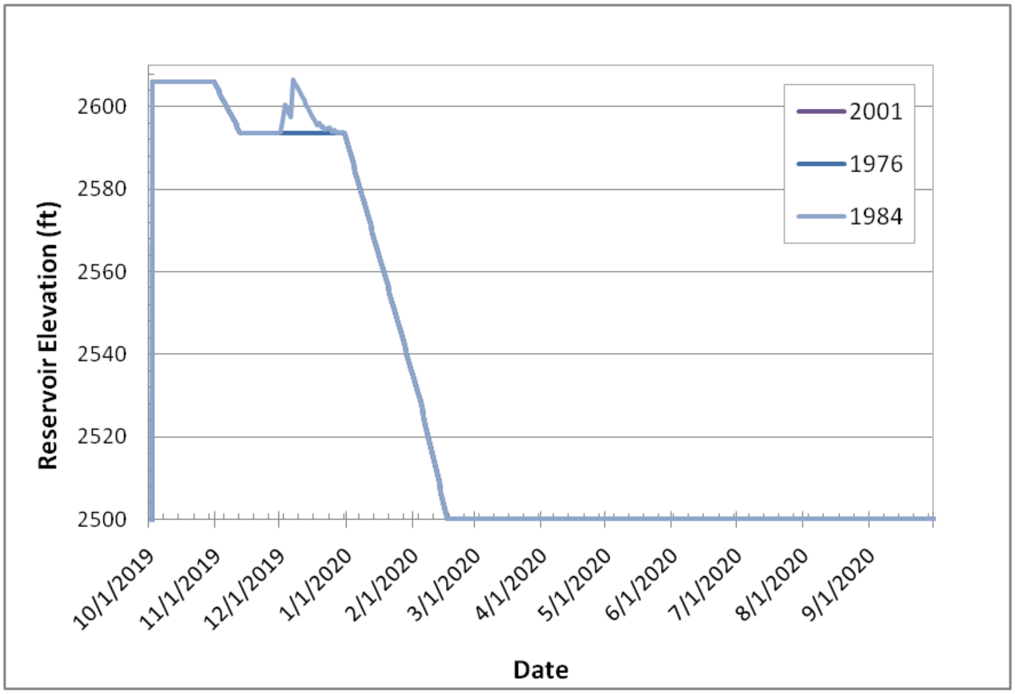


Figure 9-6. Copco Reservoir elevation for typical Dry (2001), Median (1976), and Wet (1984) years for Scenario 8.

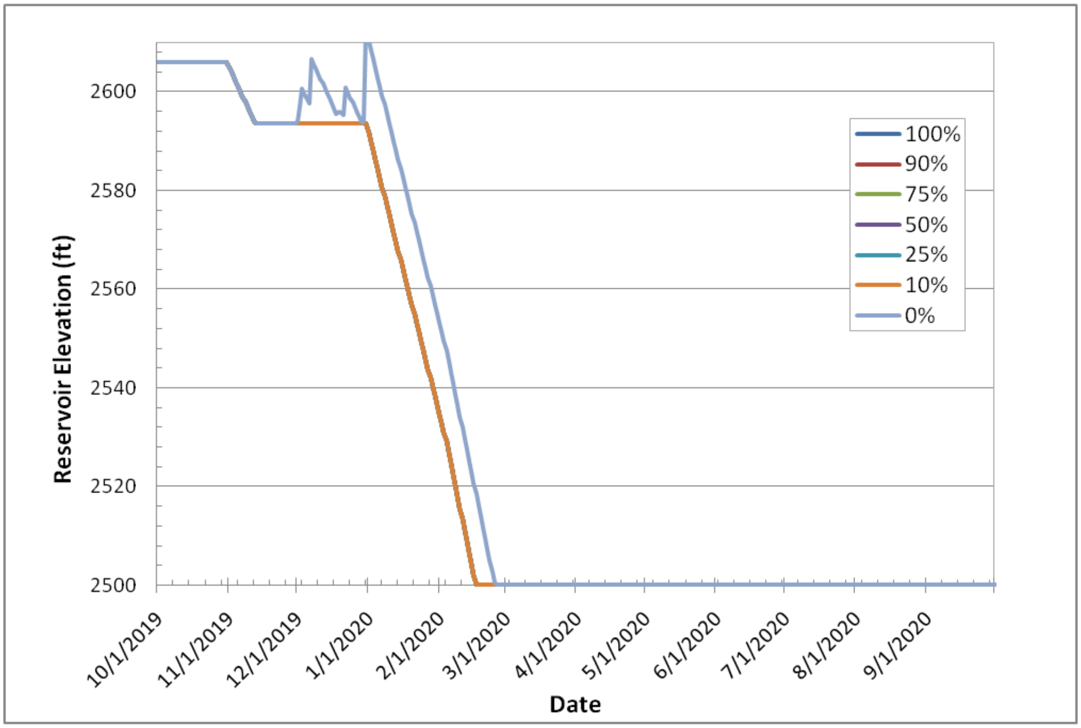


Figure 9-7. Copco Reservoir exceedance elevations for all years from 1961 to 2008 for Scenario 8.

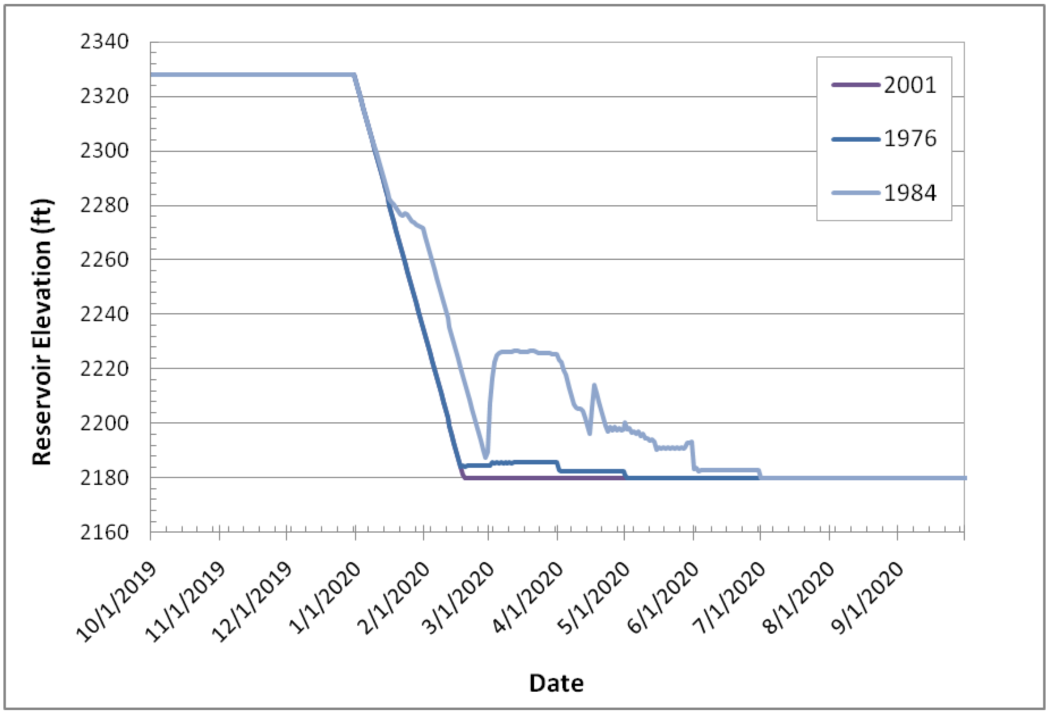


Figure 9-8. Iron Gate Reservoir elevations for typical dry (2001), median (1976), and wet (1984) years for Scenario 8.

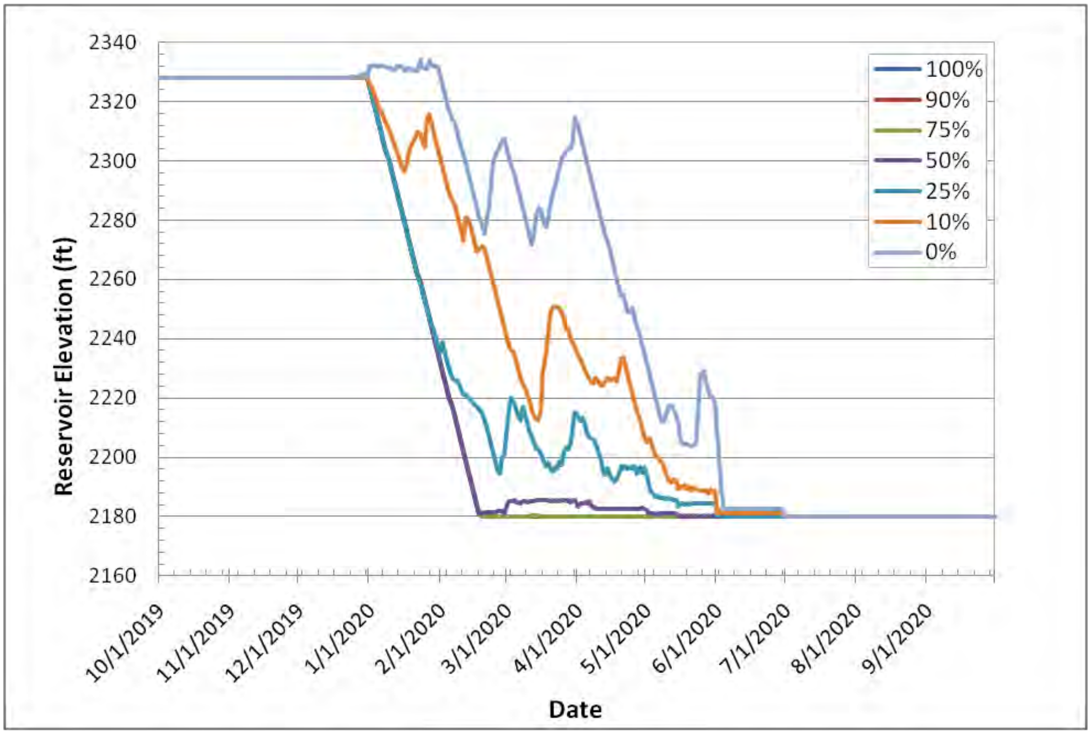


Figure 9-9. Iron Gate Reservoir exceedance elevations for all years from 1961 to 2008 for Scenario 8.

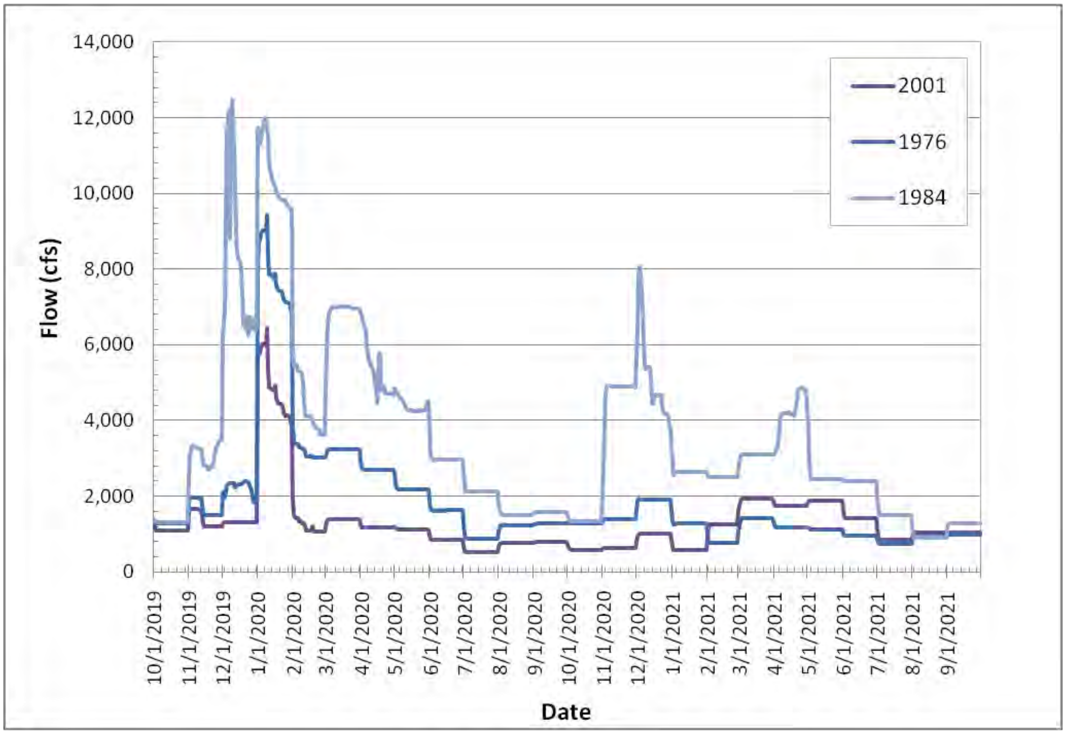


Figure 9-10. Flows downstream of Iron Gate Dam years 2001, 1976, and 1984 for Scenario 8.

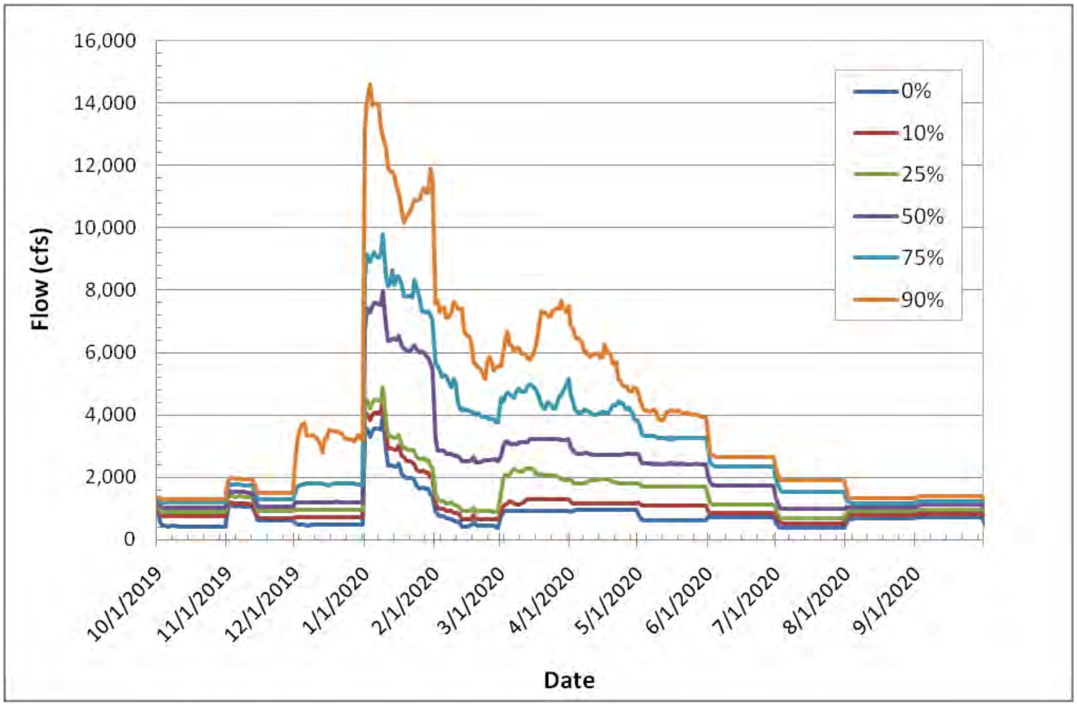


Figure 9-11. Iron Gate Reservoir exceedance elevations for all years from 1961 to 2008 for Scenario 8.

9.2.1.2. Background Sediment Loads

The sediment transport was simulated using SRH-1D for all the years between WY 1961 and 2008. Sediment concentrations were computed throughout the entire Klamath River from Iron Gate Dam to the Pacific Ocean and were compared against the “background” concentrations, which are the sediment concentrations that the river normally experiences. The incoming sediment concentrations supplied by tributaries downstream of Iron Gate Dam were computed using the sediment load information of Stillwater Sciences (2010). A sediment rating curve was developed in the form of $Q_s = aQ^b$ such that the annual loads as given in Table 5-2 are reproduced by the flow duration curve. The calculated value of $b = 2.3$ was based upon developing best matches to the observed sediment rating curves in the mainstem. The value of a was computed to match the annual sediment loads.

Comparison between the concentrations computed in SRH-1D with the assumed tributary contributions and those computed by using the sediment relationships in Table 5-3 is presented in Figure 9-12 for the Orleans gage and in Figure 9-13 for the Klamath gage. The values predicted with SRH-1D are generally lower than those from the sediment rating curves at the Orleans gage. Therefore, the SRH-1D model is generally expected to underestimate the background sediment concentrations.

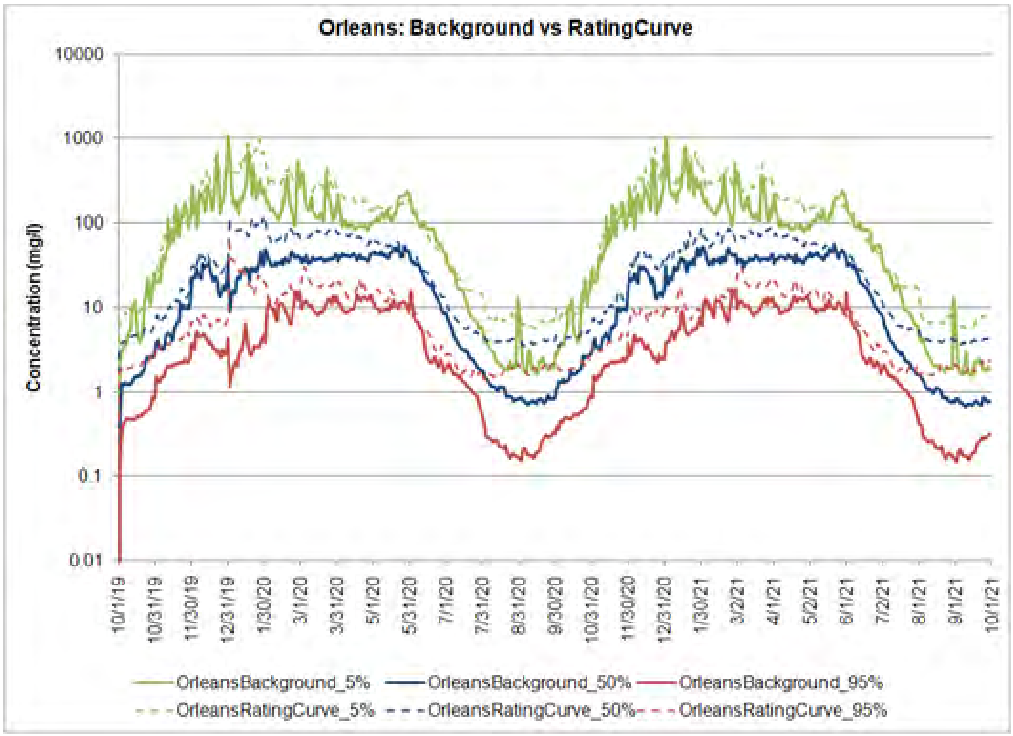


Figure 9-12. Comparison between sediment concentrations computed in SHR-1D for background conditions (Background) and those computed from the sediment rating curves at Orleans on the Klamath River (RatingCurve).

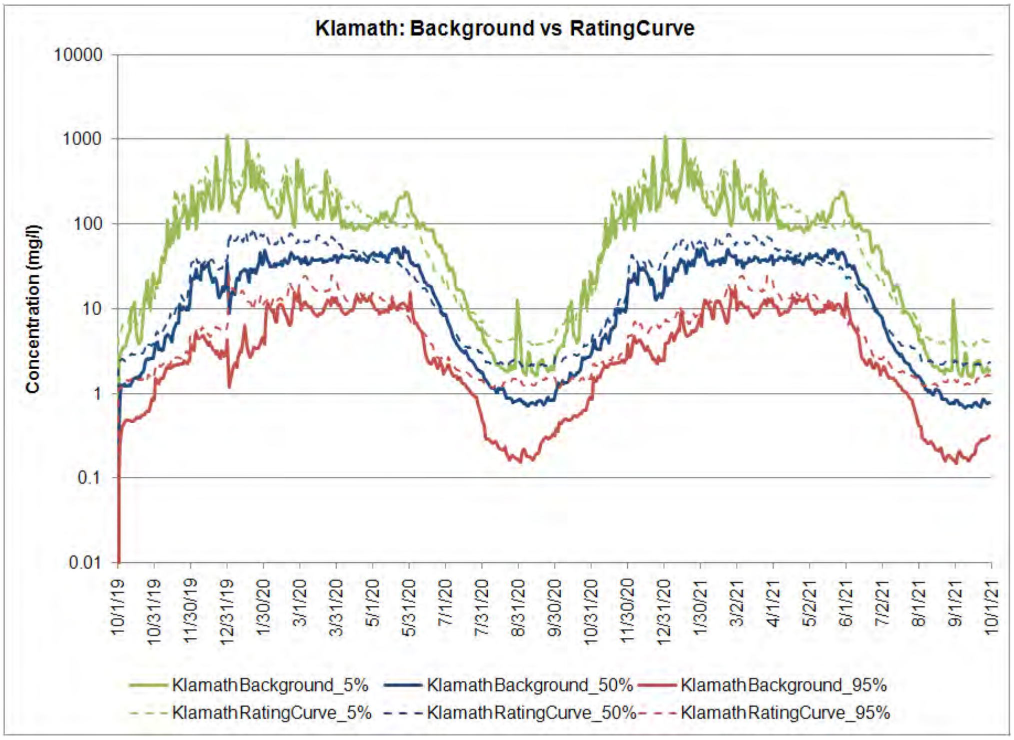


Figure 9-13. Comparison between sediment concentrations computed in SHR-1D for background conditions and those computed from the sediment rating curves at Klamath on the Klamath River.

9.2.1.3. Concentrations during Dam Removal

The concentrations for the drawdown scenarios are discussed below and for the purpose of this report, the following definitions are uses:

- **high** concentrations are greater than 1,000 mg/l.
- **medium** concentrations are between 100 and 1,000 mg/l.
- **low** concentrations refer to concentrations at or below 100 mg/l.

The sediment concentrations results below Iron Gate for the dry, median, and wet years are given in Figure 9-14, Figure 9-15, and Figure 9-16. It is expected that the maximum concentrations are under predicted because the model does not represent the variability that will existing during drawdown. For example, bank failure is assume to occur gradually during the drawdown process. In reality, a large bank failure may occur and suddenly add a large volume of sediment to the river. This high concentration will quickly dissipate but may cause a rapid spike in concentration. The concentrations in the plot are best interpreted as daily average concentrations that may vary significantly throughout the day.
Under a dry year, the initial drawdown of Copco 1 Reservoir beginning November 1 until January 1 will only produce low sediment concentrations downstream of Iron Gate Dam. There is little sediment that would be mobilized with a drawdown of only 16 ft. Also, the effective trap efficiency of Copco and Iron Gate reservoirs in series is between 75% and 94% (See Section 5.6.6). Therefore, the majority of the sediment mobilized during this initial drawdown of Copco will be trapped within Copco and Iron Gate reservoirs. When reservoir drawdown recommences on January 1, the concentrations will increase to around 3,000 to 5,000 mg/l and remain at that level through January. Beginning early February, as the reservoirs approach the low level outlets the concentrations will begin to increase and will reach nearly 14,000 mg/l in mid February as the reservoirs are almost fully drained. After this period, the concentrations will gradually decrease and be at low levels by the end of June. The recovery to low concentrations will take longer during a dry year then a wet year. This is because the silty/sandy material is more slowly mobilized under low flow conditions.

Under a median year, the response is qualitatively very similar to a dry year. The primary difference is that the additional flow will reduce concentration through dilution. The sediment concentrations in January at Iron Gate Dam are expected to be around 2,000 to 4,000 mg/l and the maximum concentration in February is expected to be around 10,000 mg/l. In addition, the system will recover to background concentration levels quicker and background concentrations will be reached by beginning of May.

Under a wet year, the concentrations downstream of Iron Gate Dam will rapidly increase to above 1,000 mg/l beginning January 1. The concentrations will likely be around 2,000 mg/l during the month of January and gradually increase to a maximum of 7,000 mg/l in mid to late February when the reservoirs are drawdown to their low level outlet elevations. In March, the concentrations will rapidly decrease to low levels until the wet spring runoff mobilized sediment and causes Iron Gate Reservoir to refill partially. The subsequent draining of the reservoir will create medium concentration levels and the concentration will gradually decrease to low levels after the spring runoff is complete.

A comparison between Scenario 8 and background concentrations for dry, median, and wet years at Iron Gate, Seiad Valley, Orleans, and Klamath stream gages is given in Figure 9-17, Figure 9-18, Figure 9-19, and Figure 9-20, respectively.

The maximum concentrations at Seiad Valley are near 9,000 mg/l for dry years, 6,000 mg/l for median years and 4,000 mg/l for wet years. The duration of high concentration is longest for the dry years where concentration remains above 100 mg/l until May, whereas, the concentrations decrease to below 100 mg/l by April for the median year and March for the wet year. The concentrations increase in May and June for the wet year, but this also corresponds to higher background concentrations and the increase above background is relatively minor.

The maximum concentrations at Orleans are approximately 2,000 mg/l for the median and wet years and about 5,000 mg/l for the dry years. The background concentrations at Orleans will typically be around 100 mg/l, but will spike to around 1,000 during high flow events.

The maximum concentrations at the Klamath gage are approximately 1,500 mg/l during a dry year and median year. The maximum concentration during a wet year is approximately 800 mg/l, which corresponds to typical concentrations during high flow. The concentrations are typically near background levels by March under a wet year and by May under a dry and median year.

The amount of sediment delivered to the estuary during Dam Removal and under Background Conditions (No Action) is given in Figure 9-21 for WY 1961 to 2008. There is between 1.1 to 2.7 million tons of sediment eroded from behind the PacifiCorp dams depending upon the type of water year. With the dams in place, there is between 100,000 tons of sediment to more than 16 million tons of sediment delivered to the ocean in a given year. Therefore, the relative importance of the dam removal on the sediment concentrations is entirely dependent upon the year type. If there is wet year, the additional sediment load from the dam removal at the estuary will be relatively small. If it is dry year, the additional sediment load from dam removal will be relatively large. The amount of sediment delivered to the ocean as the result of dam removal is expected to less than the average annual supply to the ocean.

The sediment concentration at a 50% and 10% percent exceedance level for every day of the year are given in Figure 9-23 and Figure 9-24, respectively, for the year of dam removal and the year after dam removal. The 50% and 10% exceedance levels for the background conditions are also given.

At the Iron Gate gage, the 50% exceedance levels reach approximately 10,000 mg/l in February and drop to below 500 mg/l by end of March. At Orleans, the 50% exceedance levels reach about 1,500 mg/l in February and drop to below 100 mg/l by April, which is near background levels. At Klamath, the 50% exceedance level reach 800 mg/l in February and drop to near background levels by April.

The 10% exceedance values under the Dam Removal Alternative Scenario 8 are around 13,000 mg/l at Iron Gate, 2,500 mg/l at Orleans, and 1,100 mg/l at Klamath. Background levels by April for the Orleans and Klamath locations are attached.

Sensitivity Analysis

A sensitivity analysis of the sediment concentration to various sediment transport parameters was conducted. The following simulations were performed in which a parameter or equation was altered:

1. The above water angle of repose is set equal to 5 degrees instead of 15.
2. The above water angle of repose is set equal to 10 degrees instead of 15
3. The cohesive sediment critical shear stress is increased to 0.025 lb/ft^2 (1.2 Pa) from 0.0042 (0.2 Pa).
4. The cohesive sediment critical shear stress is decreased to 0.0006 lb/ft^2 (0.03 Pa) from 0.0042 (0.2 Pa).
5. The non-cohesive sediment transport rates are calculated using the Wu et al. (2000) transport equations.
6. The non-cohesive bedload sediment transport rates are calculated using The Wilcock and Crowe (2004) equation instead of the Parker (1990).
7. The non-cohesive sediment transport rates are calculated using the maximum of the Parker (1990) transport equation and Engelund-Hansen transport equation for each size fraction.

The resulting fine sediment concentration is shown Figure 9-25 and the sand sediment concentration is shown in Figure 9-26.

Decreasing the angle of repose to 5 degrees decreases the maximum concentration and increases the duration of fine sediment concentration impacts. The period of fine sediment concentrations over 1,000 mg/l is not increased significantly, but the period that fine sediment concentrations are over 100 mg/l is increased by several months. The duration of sand concentration over 1,000 mg/l is increased by approximately two months. The response is somewhat complex and not entirely intuitive. However, the basic reason for this behavior is that Copco Reservoir contains a relatively large volume of sand that re-deposits in Iron Gate reservoir as both are drawdown. The sand then remobilizes as Iron Gate is completely emptied. If the angle of respose is very low, then almost all the sand is remobilized and enters the river channel. The carrying capacity during a median WY is relatively small and it takes a long time to empty the sand from the reservoir. This scenario is considered unlikely and this is why a very low angle of repose was not used for the simulations. The angle of respose of drained sand is typically 30 degrees or greater (Craig, 1987; Garcia, 2008). The model currently assumes one angle of repose for all material types throughout the duration of the simulation and therefore cannot simulate one angle of repose for saturated clay and one for sand. Because the model cannot simulate these detailed processes, the base simulation (angle of repose of 15 degrees) is considered more representative. PanGeo (2008) stated that the aggraded sediments at the edged of the river channel will likely remain stable on a slope of 18 degrees (3H:1V).

Decreasing the angle of repose to 10 degrees has a similar effect to reducing the angle of repose to 5 degrees, though the quantitative difference to the base simulation is much less.

Decreasing or increasing the critical shear stress of the fine sediment has little effect on the sediment concentrations. The 25th and 75th percentile of the measured critical shear stress of the moist samples was used and the resulting sediment concentrations downstream were essentially identical to the base simulation.

If the Wu et al. (2000) equation is used to compute the non-cohesive sediment transport, the simulated total concentration is very similar but the peak sand concentration is smaller and it take about a month longer for the sand concentrations to decrease below 100 mg/l. However, the differences are considered slight and the fine sediment concentrations are very similar. If the Wilcock and Crowe (2003) equation is used instead of the Parker (1990) equation, the results for the fine sediment are very similar, but there is overall less sand transport.

Using the maximum of Parker (1990) and Engelund-Hansen (1972) to compute the non-cohesive sediment transport rate for each size fraction did not show significant differences from using the Parker (1990) equation if the bed is composed of gravel and the Engelund-Hansen (1972) equation if the bed is composed of sand.

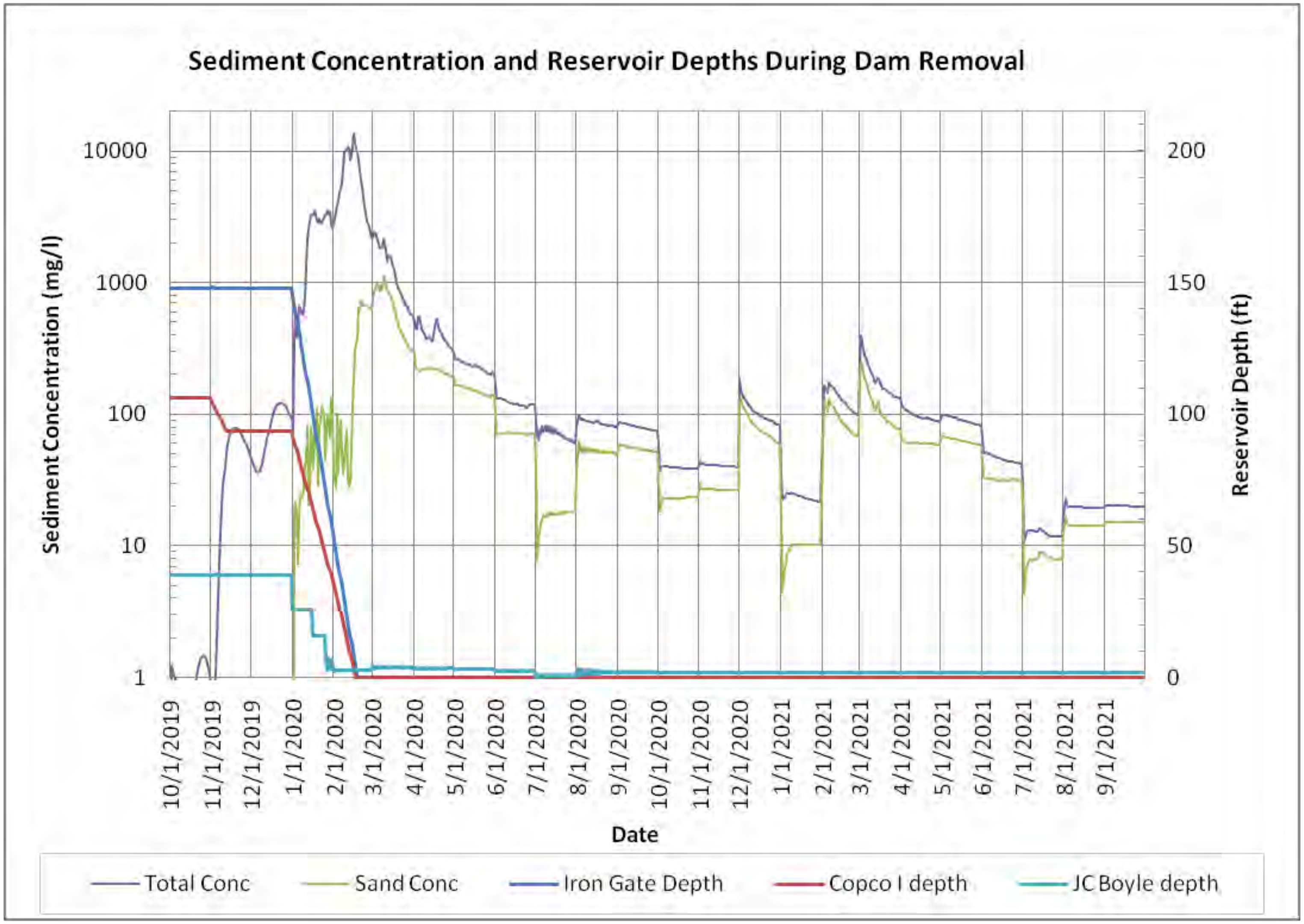


Figure 9-14. Simulated reservoir depths and sediment concentration below Iron Gate Dam for WY 2001 (Dry year) for Scenario 8.

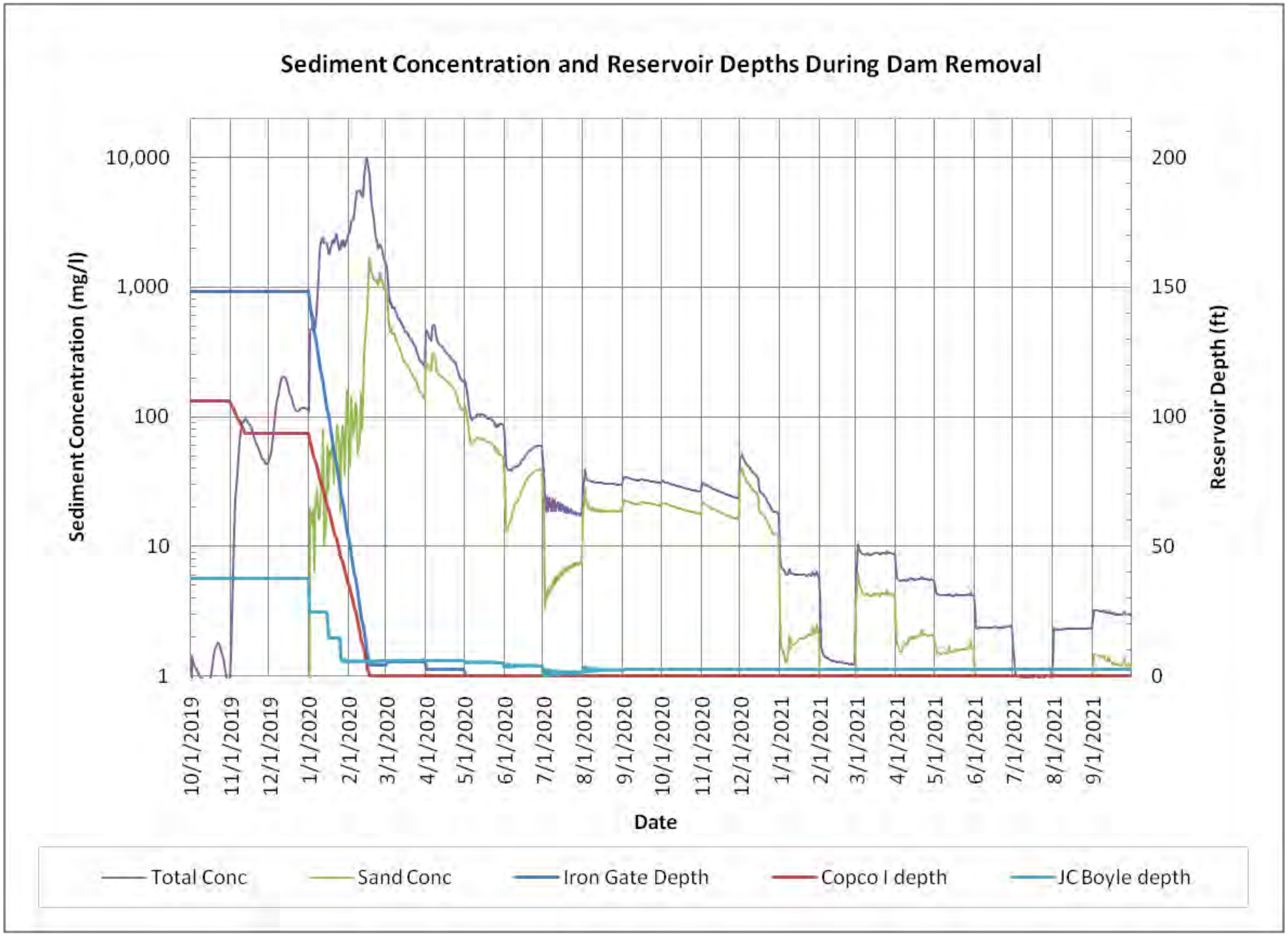


Figure 9-15. Simulated reservoir depths and sediment concentration below Iron Gate Dam for WY 1976 (Median year) for Scenario 8.

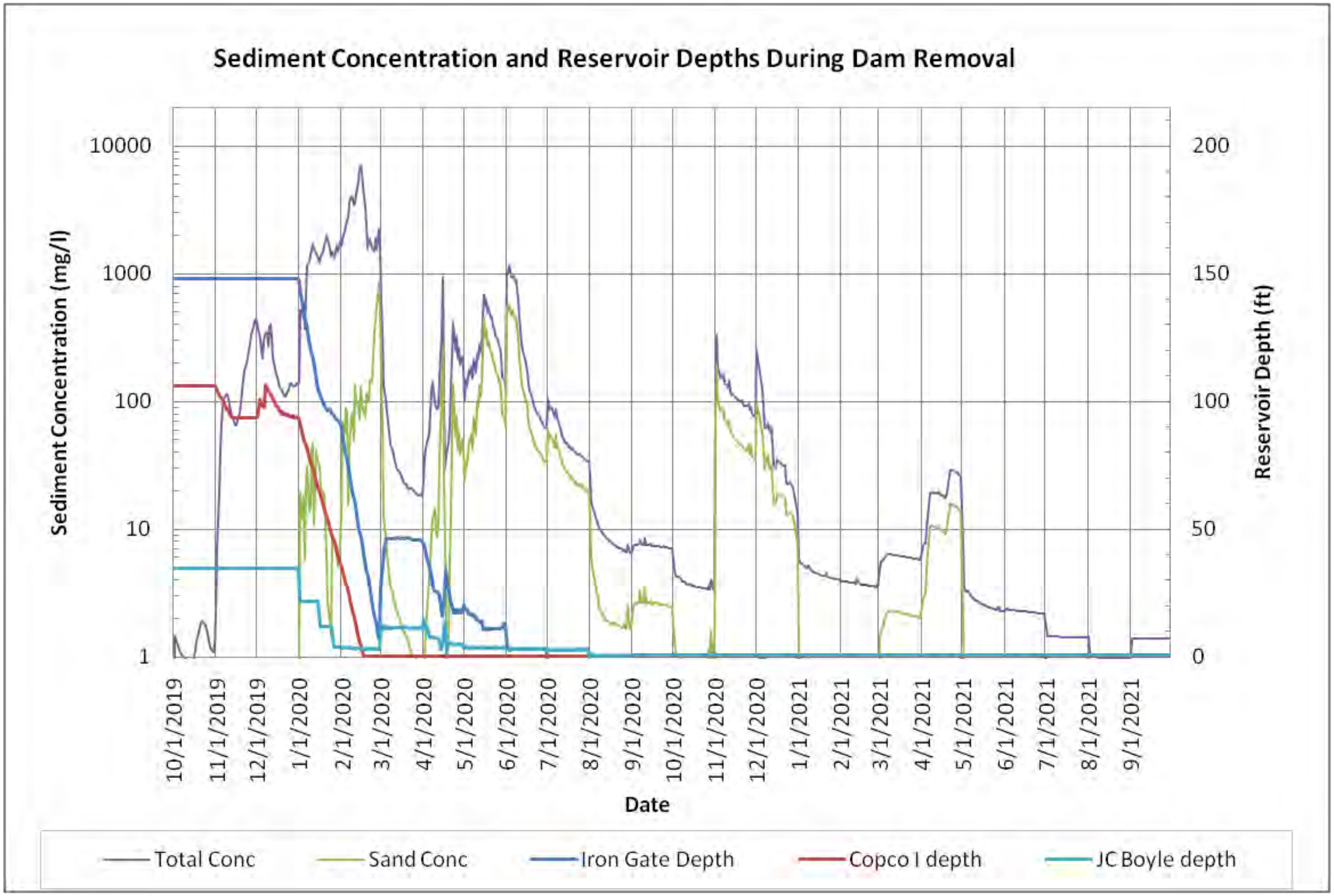


Figure 9-16. Simulated reservoir depths and sediment concentration below Iron Gate Dam for WY 1984 (Wet year) for Scenario 8.

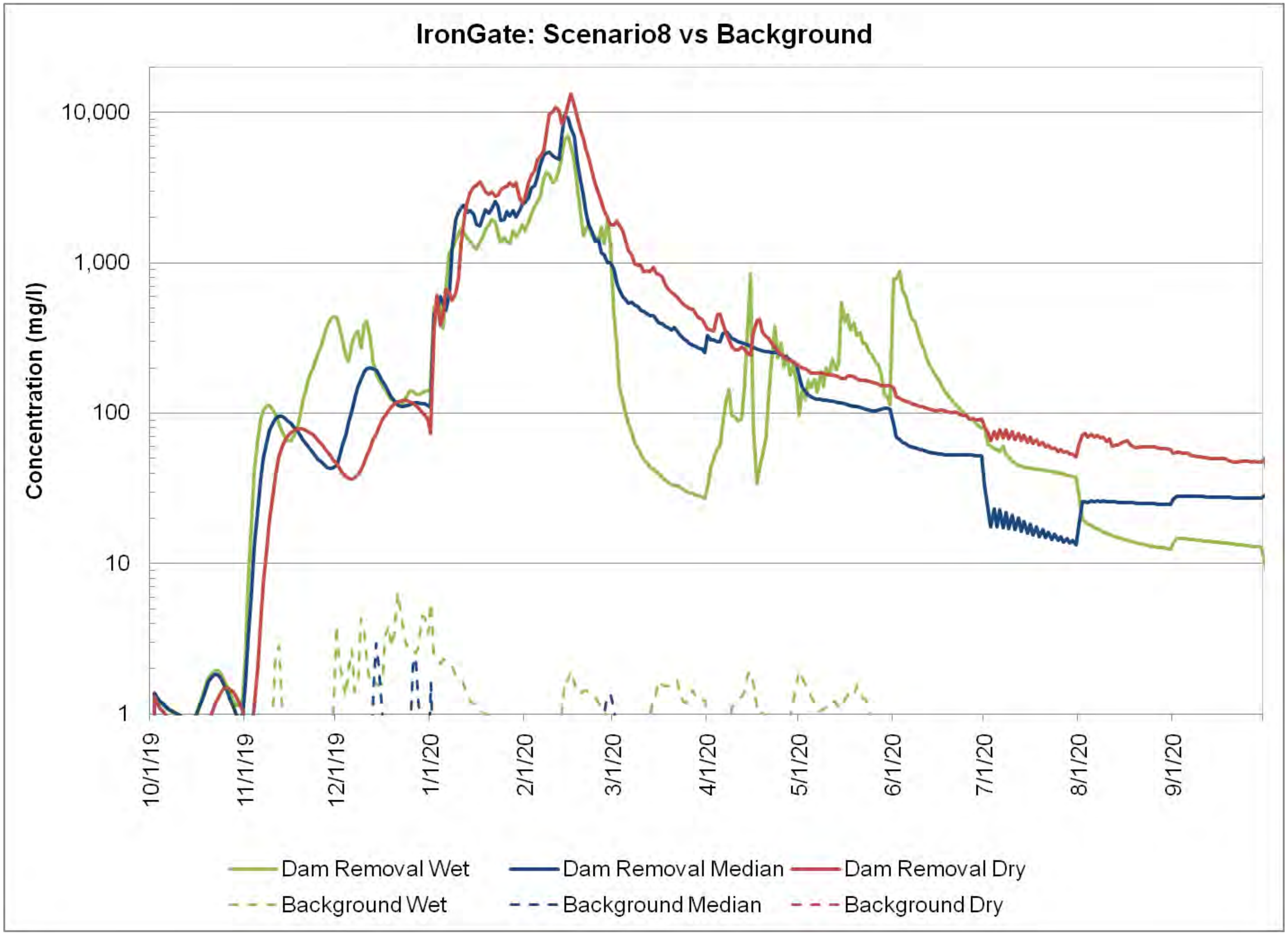


Figure 9-17. Sediment concentrations at the Iron Gate gage for Scenario 8 and for background conditions for dry, median and wet years.

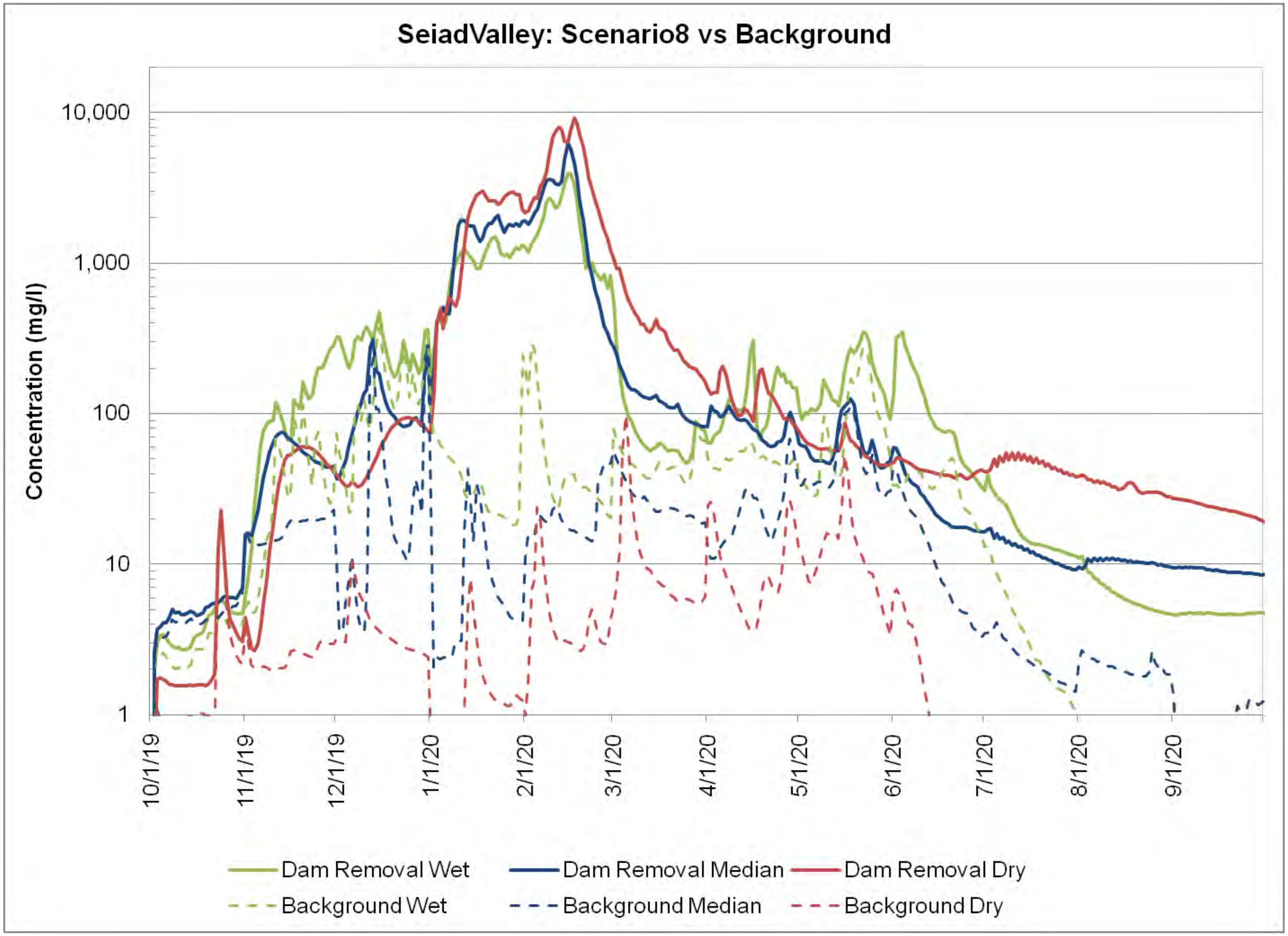


Figure 9-18. Sediment concentrations at Seiad Valley for Scenario 8 and for background conditions for dry, median and wet years.

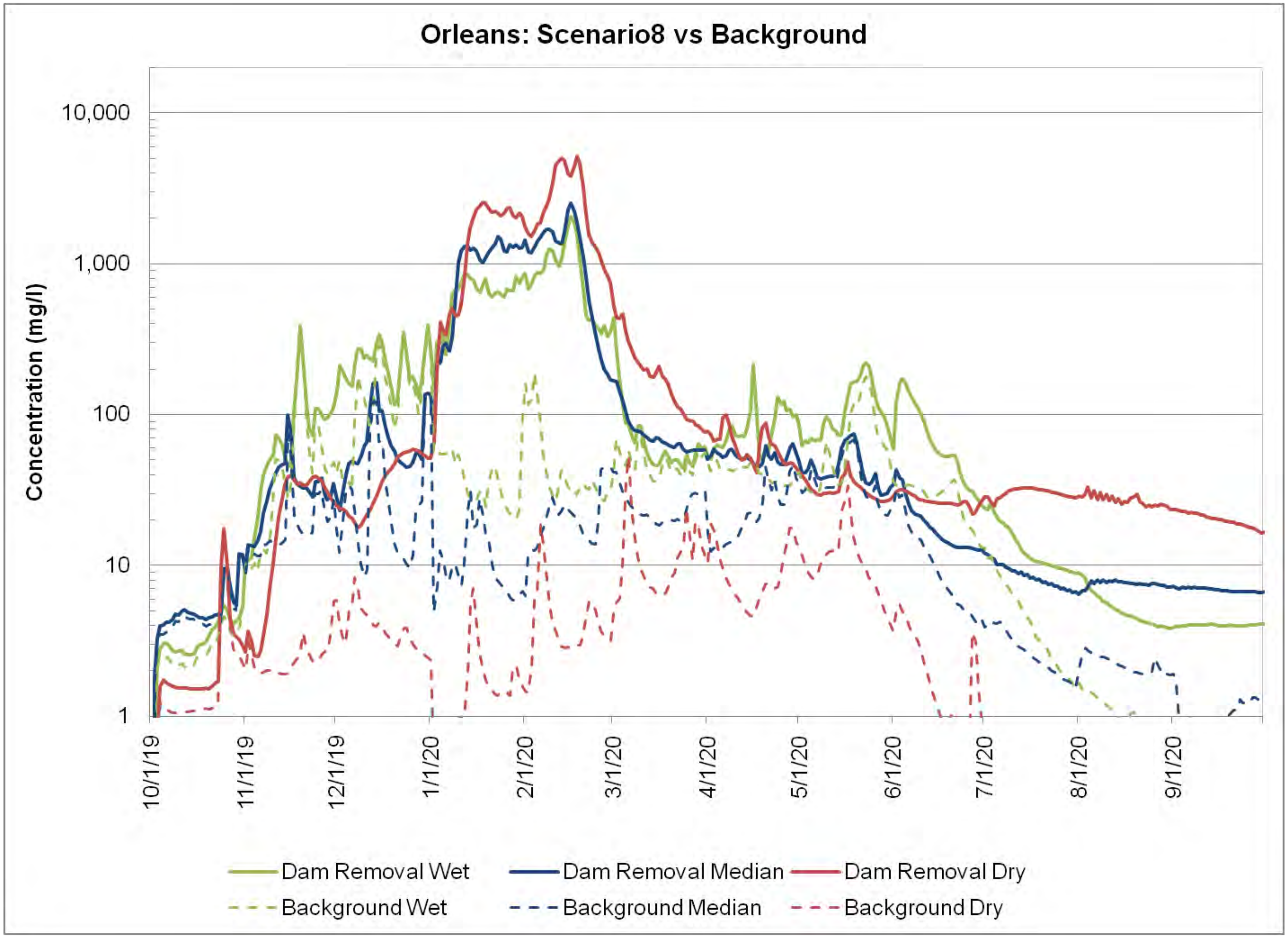


Figure 9-19. Sediment concentrations at Orleans for Scenario 8 and for background conditions for dry, median, and wet years.

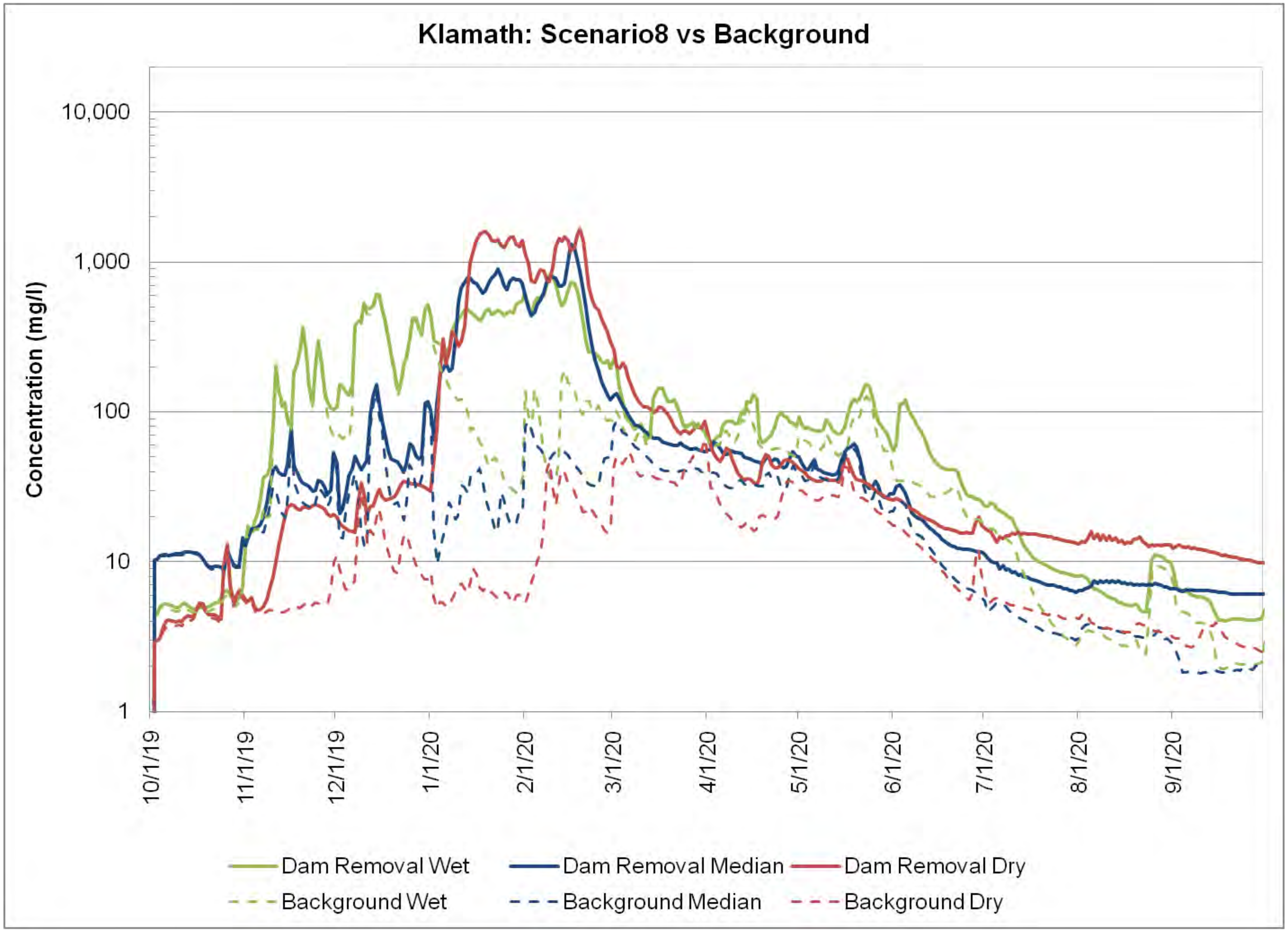


Figure 9-20. Sediment concentrations at the Klamath gage for Scenario 8 and for background conditions for dry, median, and wet years.

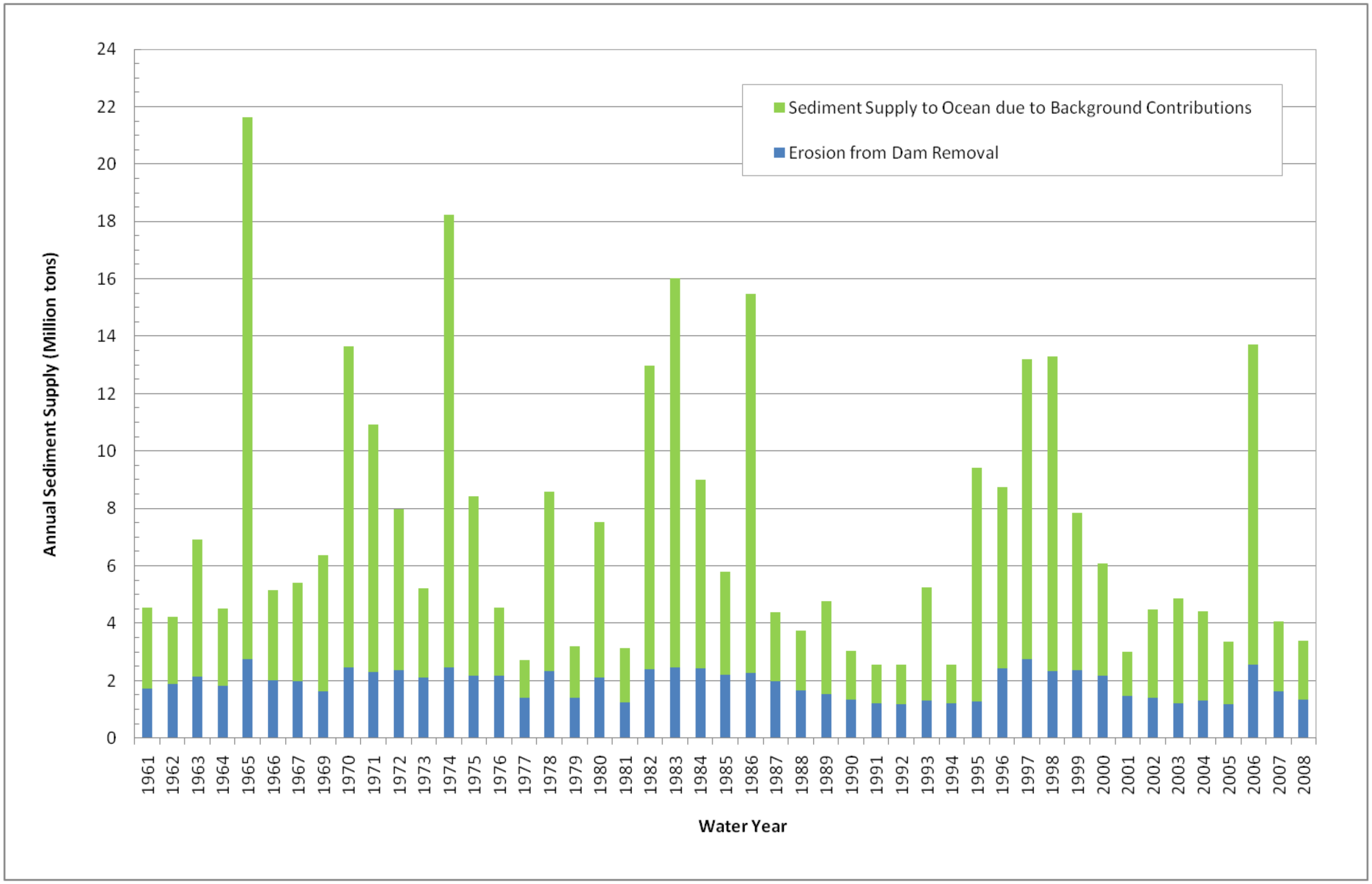


Figure 9-21. Sediment delivery to the ocean under Scenario 8 and with dams in place (No Action) for the year of dam removal. Note: these results are only valid for the year of dam removal. No significant increase in sediment loads is predicted for years following dam removal.

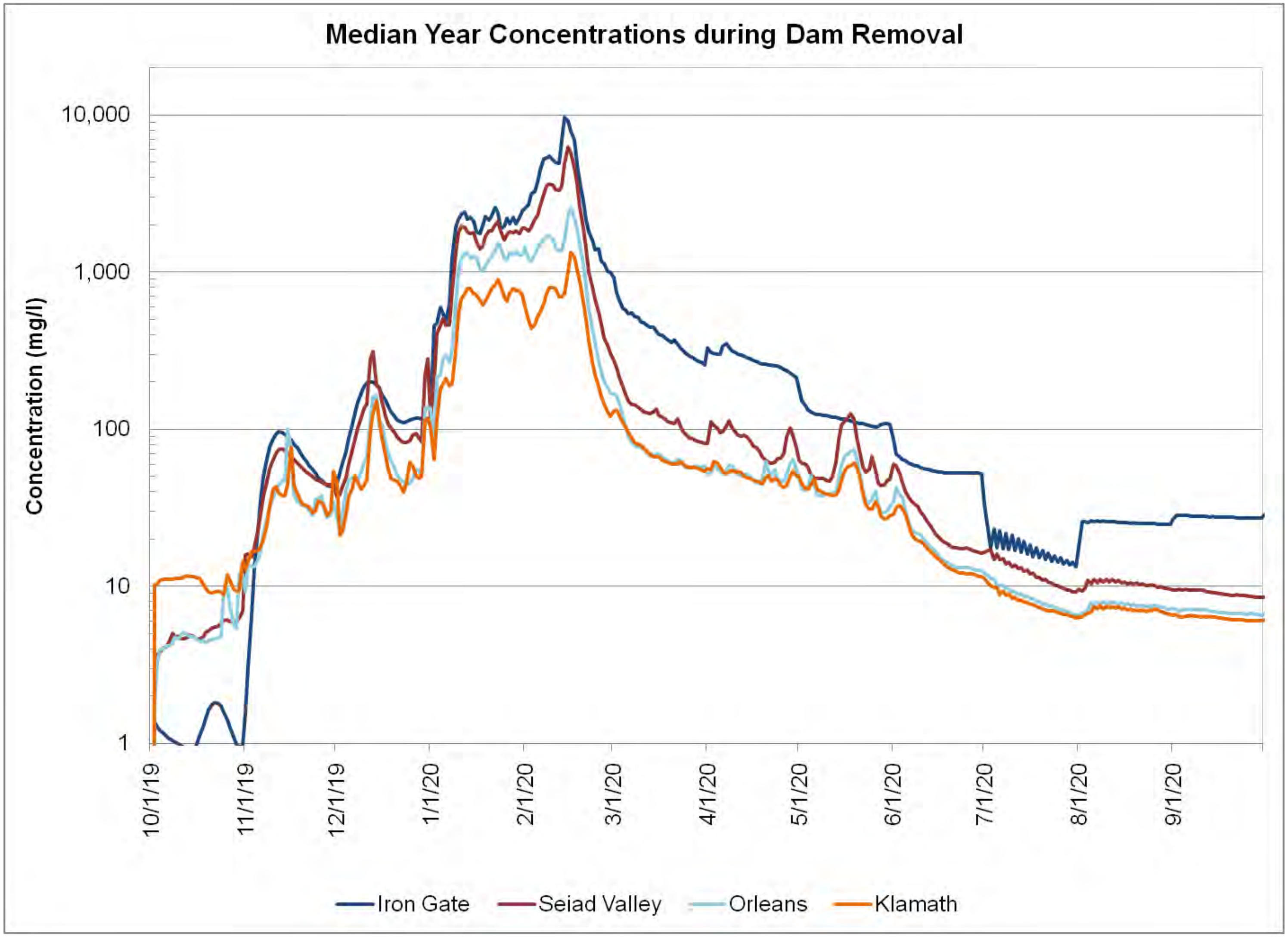


Figure 9-22. Sediment concentrations at stream gage locations for Scenario 8 for median year (1976).

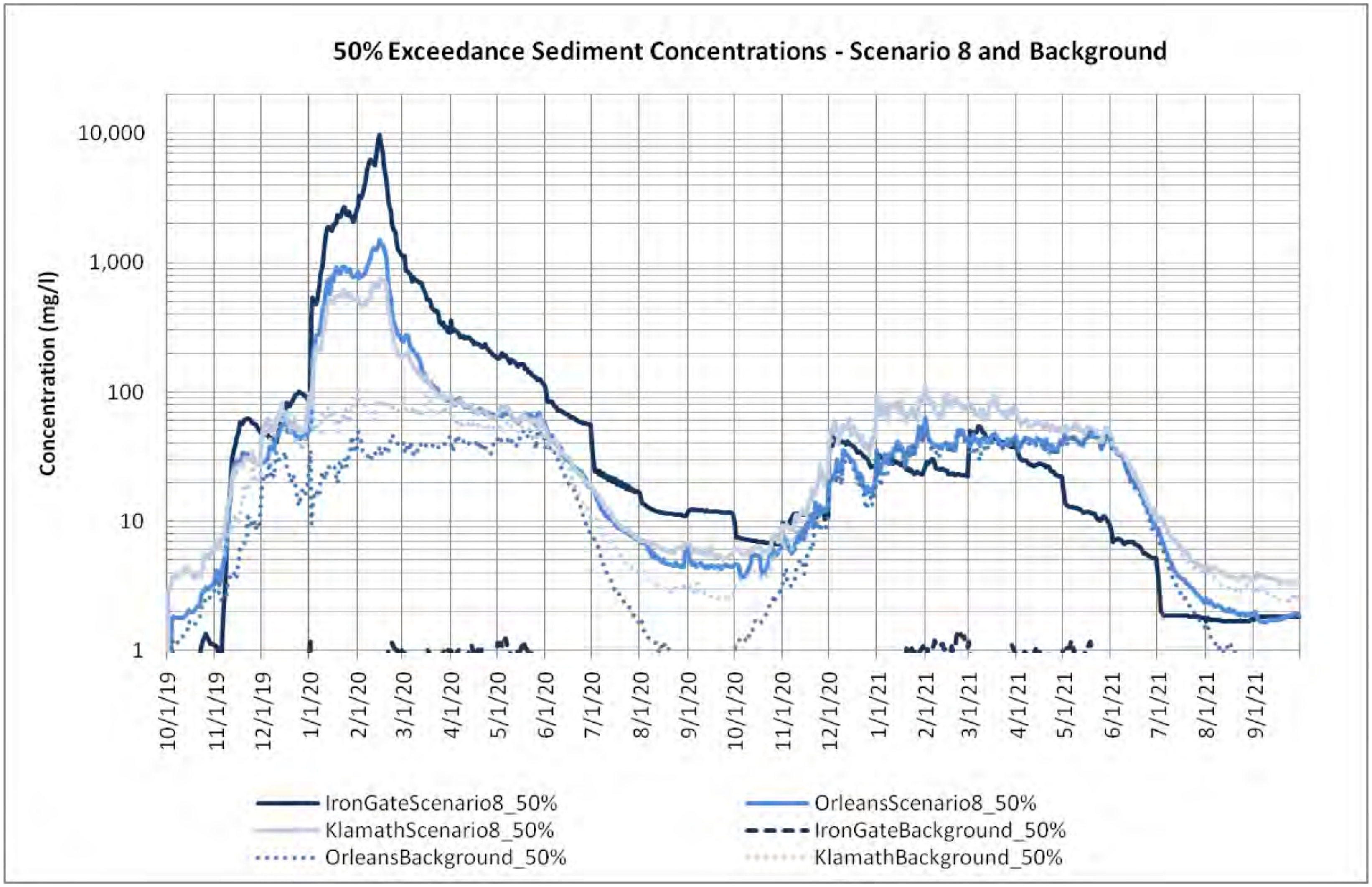


Figure 9-23. Sediment concentrations at a 50% exceedance level for below Iron Gate, at Orleans and at Klamath USGS gages.

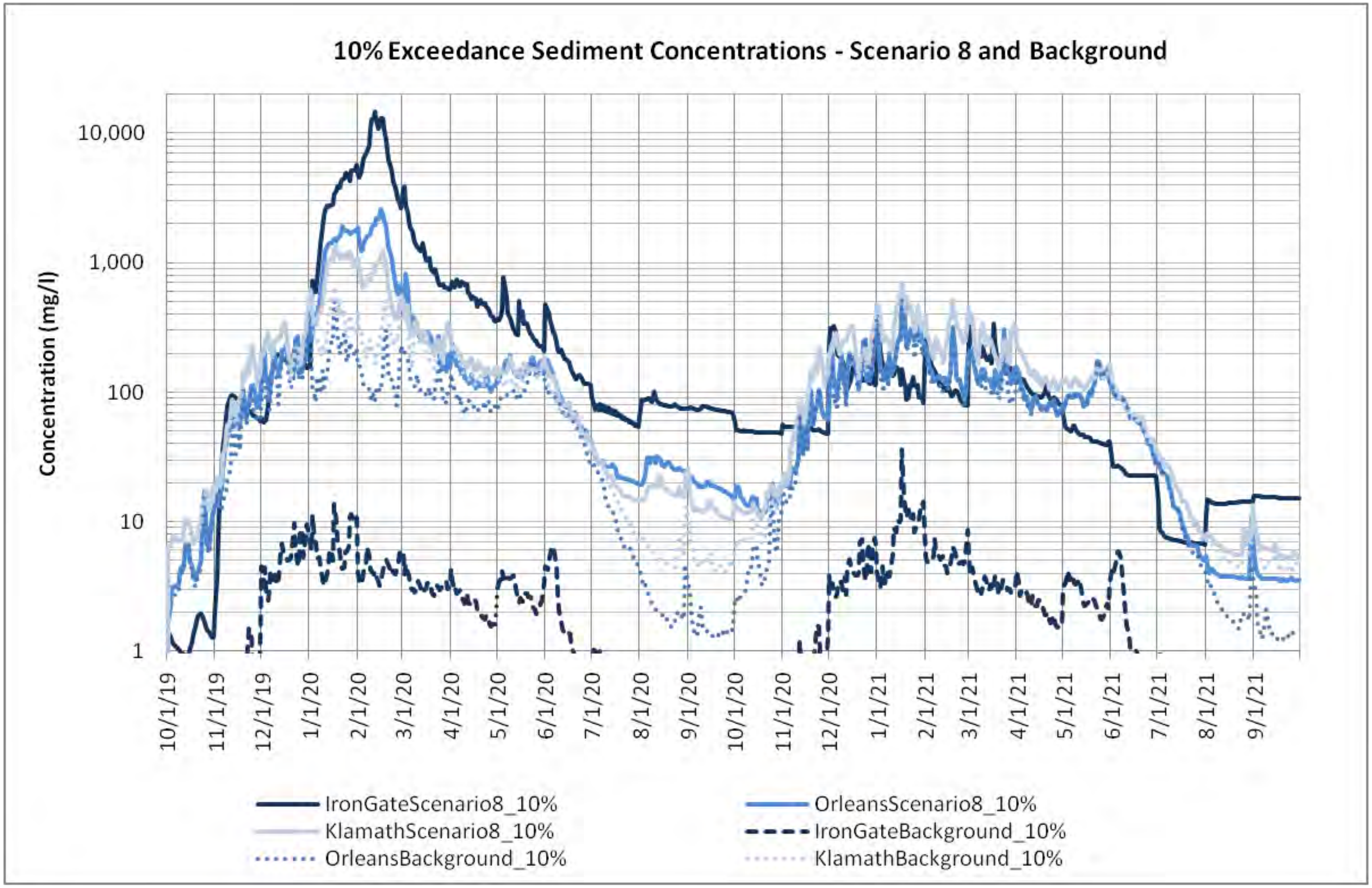


Figure 9-24. Sediment concentrations at a 10% exceedance level for below Iron Gate, at Orleans and at Klamath USGS gages.

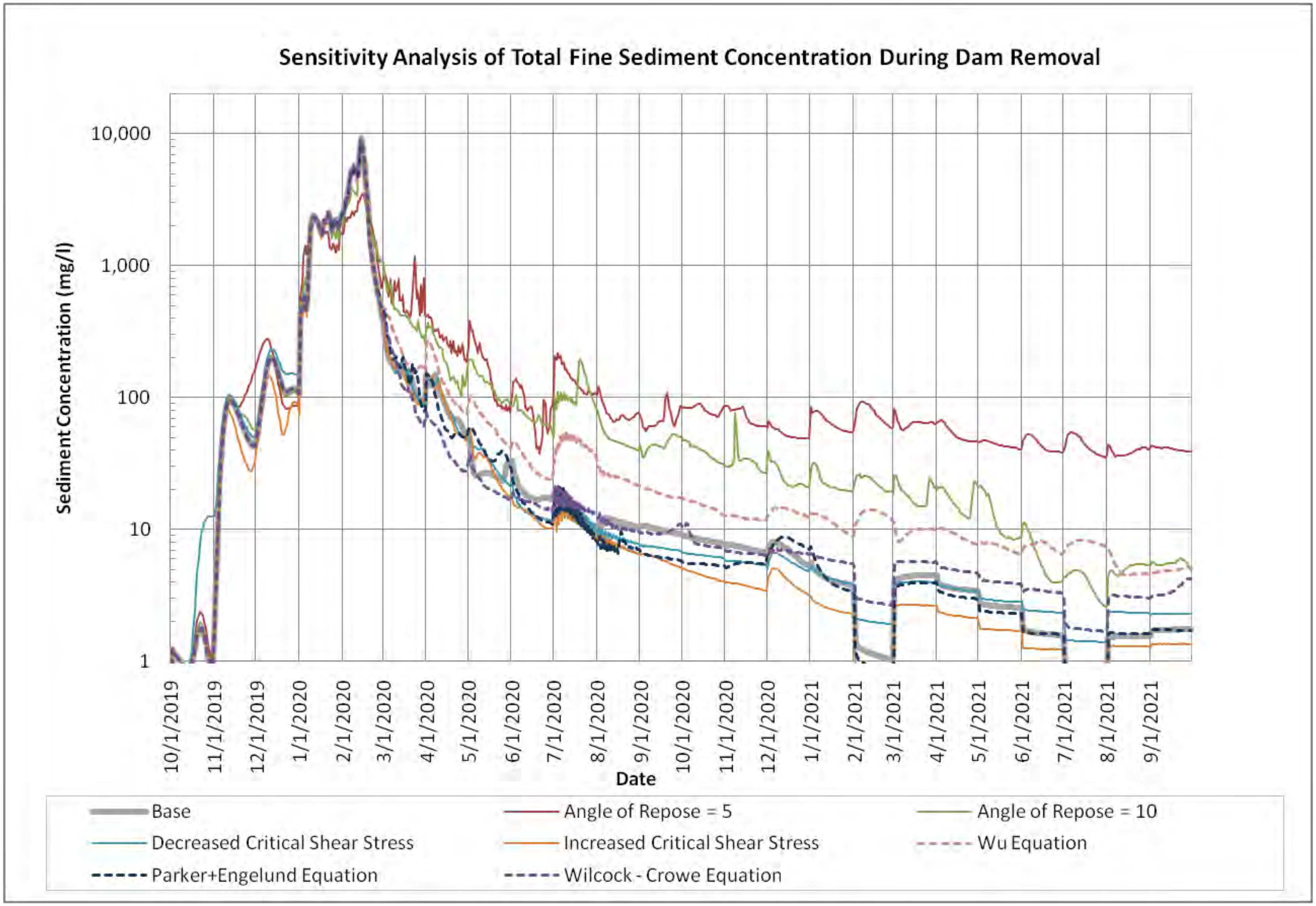


Figure 9-25. Sensitivity of Fine Sediment Concentration to Various Sediment Transport Parameters.

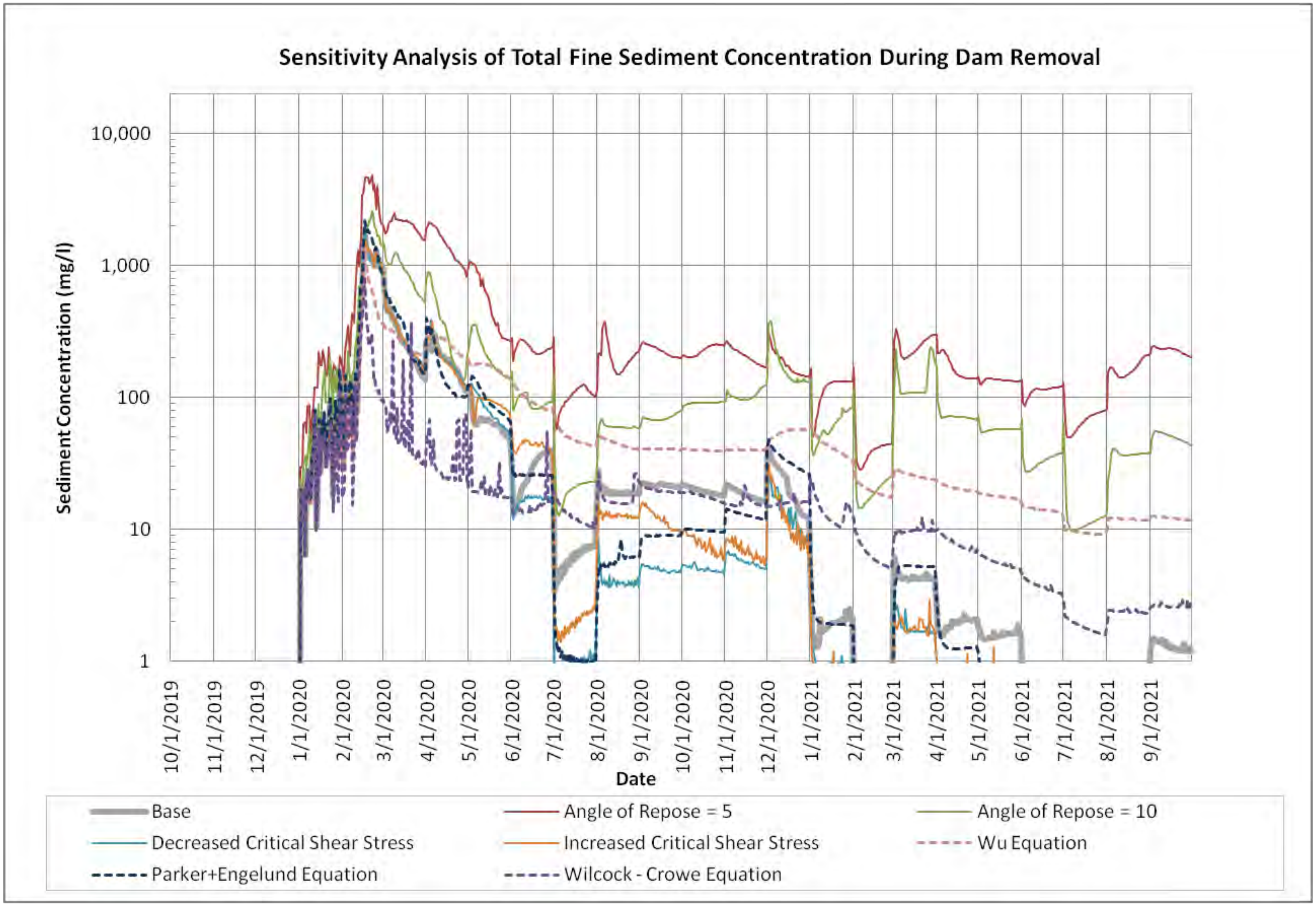


Figure 9-26. Sensitivity of Sand Concentration to Various Sediment Transport Parameters.

9.2.1.4. Erosion and Deposition after Dam Removal

The volume of erosion for dry, median, and wet years for each reservoir is given in Figure 9-27. There is between 5.4 and 8.6 million yd^3 of sediment eroded from behind the dams (41 and 66 %). Stated more loosely, approximately one to two thirds of the material will be removed depending on if it is a dry or wet year, respectively. Most of the erosion will occur during the drawdown process. During drawdown, direct hydraulic forces on the soft sediment will cause some of the erosion. There will also be slumping of sediment toward the river channel as the downslope force of sediment self-weight and the force of the draining water exceeds the shear strength of the sediment. However, as the excess water drains from the sediment, the sediment shear strength will quickly increase. The pore water pressure will decrease as the water drains from the sediment and the cohesion will increase as the sediment consolidates.

Initial stable slope estimates conservatively indicate that the stable slope of the reservoir sediment would be 10H:1V or about 6º (Shannon and Wilson, 2006). However, PanGeo (2008) estimated the stable slope would be 3H:1V. Laboratory measurements of the sediment drill cores estimate that the friction angle is between 27 and 32 degrees (2H:1V). However, because the sediments were so soft, it was difficult to obtain accurate measurement of the shear strengths. It is likely that the true value is close to the PanGeo (2008) estimate. The sediment located in the upper 1 foot will be soft, unconsolidated, and weak material that may wash away during drawdown or flow towards the river channel relatively quickly. The water content is above the liquid limit in many cases. The sediment located beneath this upper layer is expected to be relatively more consolidated but still very soft. The initial slumping process is expected to occur during the drawdown period under all scenarios. However, after drawdown, most of the sediment remaining on the terraces will be stable. The stable depth assuming an infinite slope was calculated in Section 5.6.3. Practically all the sediment on terraces of with slopes of 0.1 or less will be stable after drawdown. At a slope of 0.2, it is expected that the sediment will slump toward the river channel if the depth is greater than 3 or 4 feet. These unstable areas will include some sediment in Copco on the steeper slopes, but it will be localized to small areas.

After the initial slumping and draining of excess water from the sediment, the sediment will begin to dry as the result of evaporation. The remaining reservoir sediment volume will reduce by approximately two thirds and the depth of the sediment will decrease by about a third. Cracks will appear and the sediment will harden significantly. The drying process is expected to occur in the spring or early summer depending upon the balance of rain and evaporation rates. The resistance to erosion will increase markedly during this period and the sediment will progress from highly erodible to very resistant to erosion. Because of the cracking, some erosion will continue as gully formation occurs during rainstorms. However, the reservoir area will be mulched and seeded and this will limit significant surface erosion. It is not likely that there is any significant erosion of reservoir material after the drawdown period and the mulch has been applied. The revegetation plan is described in Reclamation (2011b).

The reach averaged erosion and deposition depths from J.C. Boyle to Iron Gate dams are shown in Figure 9-28 and Figure 9-29 for a dry and wet year, respectively. The entire reach was split into subreaches identified by the reservoirs and the reaches between the reservoirs. There is significant erosion of the reservoir sediment during the drawdown period from January 1, 2020 to March 1, 2020, after which the river bed in the reservoir reaches is expected to remain stable. The reaches between the reservoirs show very little change, with only some minor deposition occurring in the reach between Iron Gate to Copco 2 dams.

The bed profile downstream of Iron Gate Dam before dam removal and in the two years following dam removal is shown in Figure 9-30. After dam removal, some minor deposition is shown in the reach from Bogus Creek to Cottonwood Creek in the first year, but no additional deposition is indicated after the first year following dam removal. The reach averaged deposition downstream of Iron Gate Dam following dam removal is shown in Figure 9-31 for a median year of dam removal. There is no significant deposition in the reach from Iron Gate Dam to Bogus Creek. From Willow Creek to Bogus Creek, there is about 1.5 feet of deposition and from Cottonwood to Willow creeks there is less than 1 foot of deposition. Downstream of Cottonwood Creek, there is less than 0.25 feet of deposition but is considered not significant. The results for a dry start year (Figure 9-32) and wet start year (Figure 9-33) are very similar.

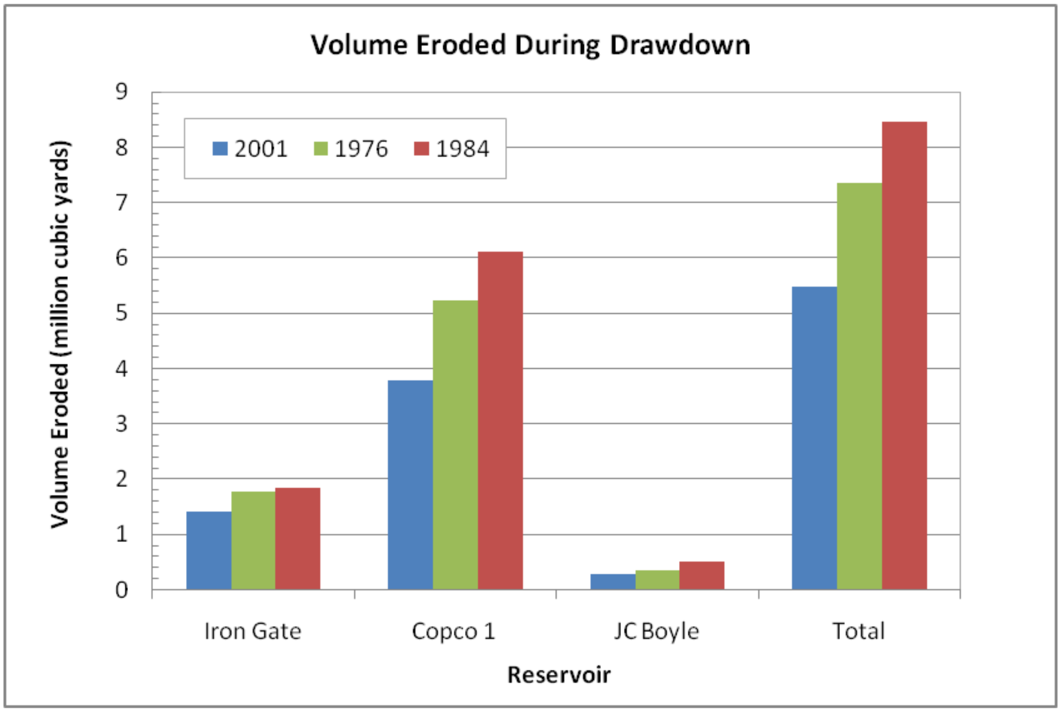


Figure 9-27. Volume of sediment erosion for preferred drawdown scenario.

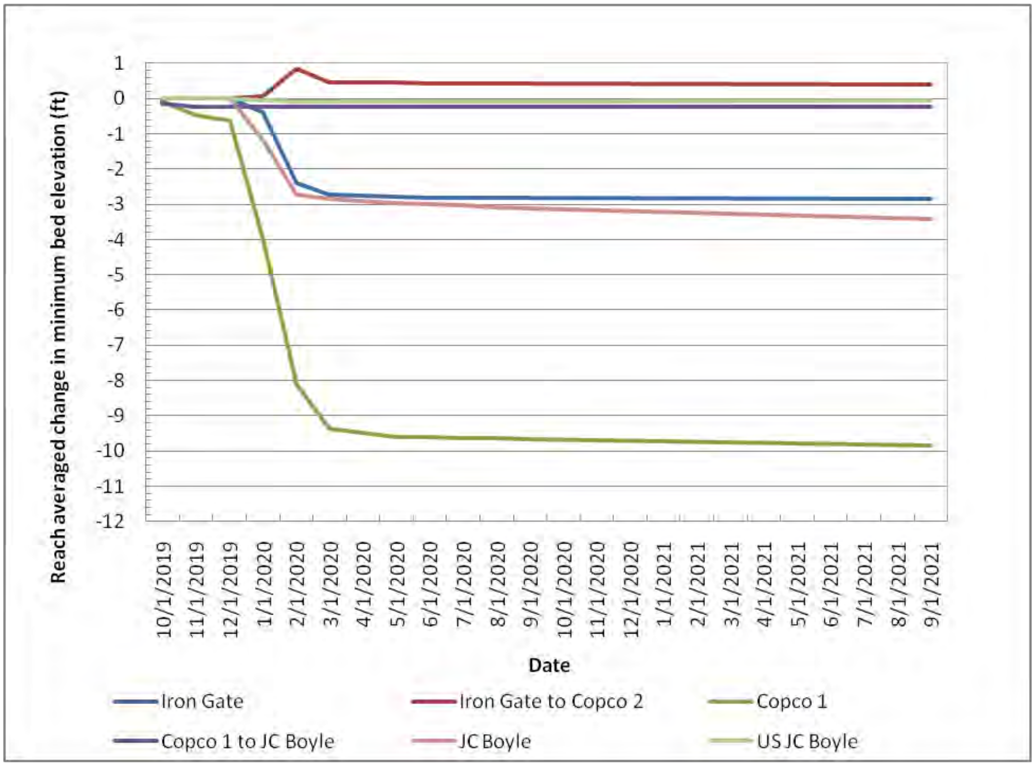


Figure 9-28. Reach averaged erosion for dry year (2001) for reaches from J.C. Boyle to Iron Gate Dam.

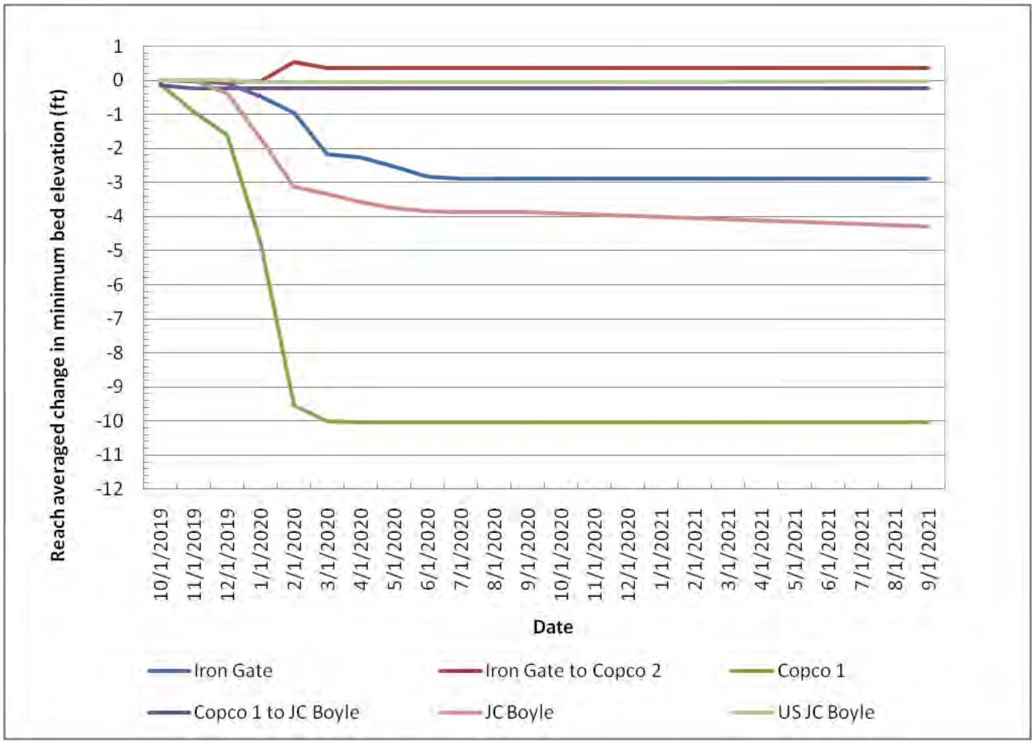


Figure 9-29. Reach averaged erosion for wet year (1984) for reaches from J.C. Boyle to Iron Gate Dam.

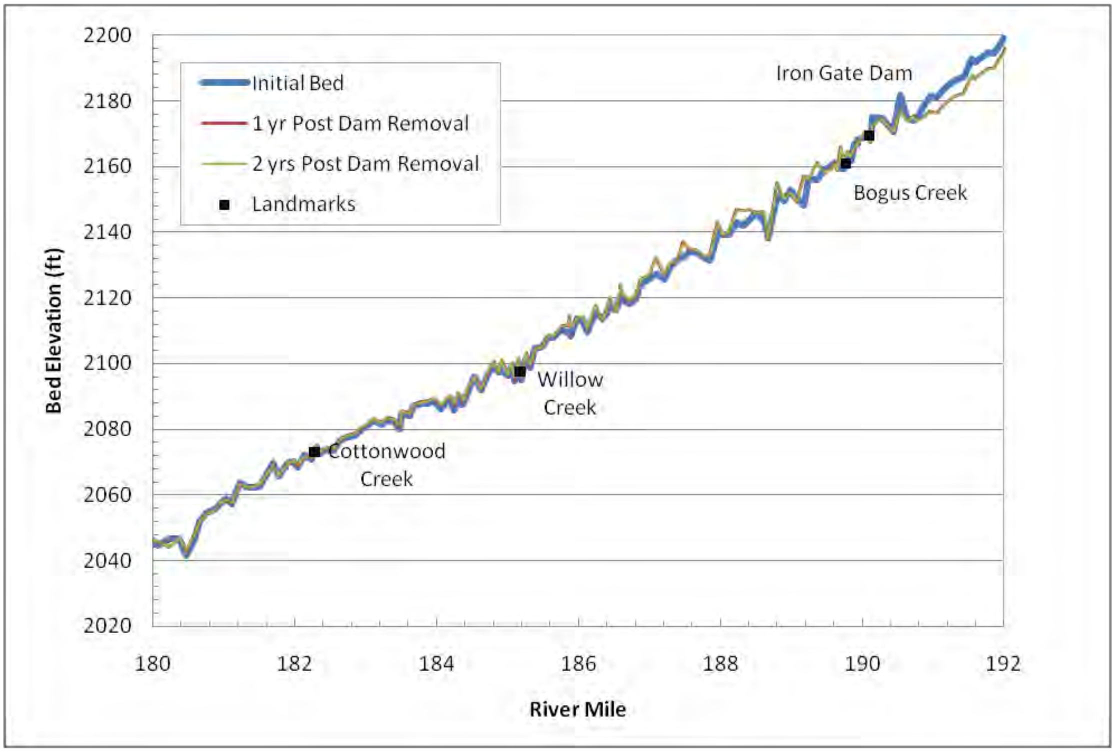


Figure 9-30. Bed profile downstream of Iron Gate Dam to Cottonwood Creek for two years following dam removal.

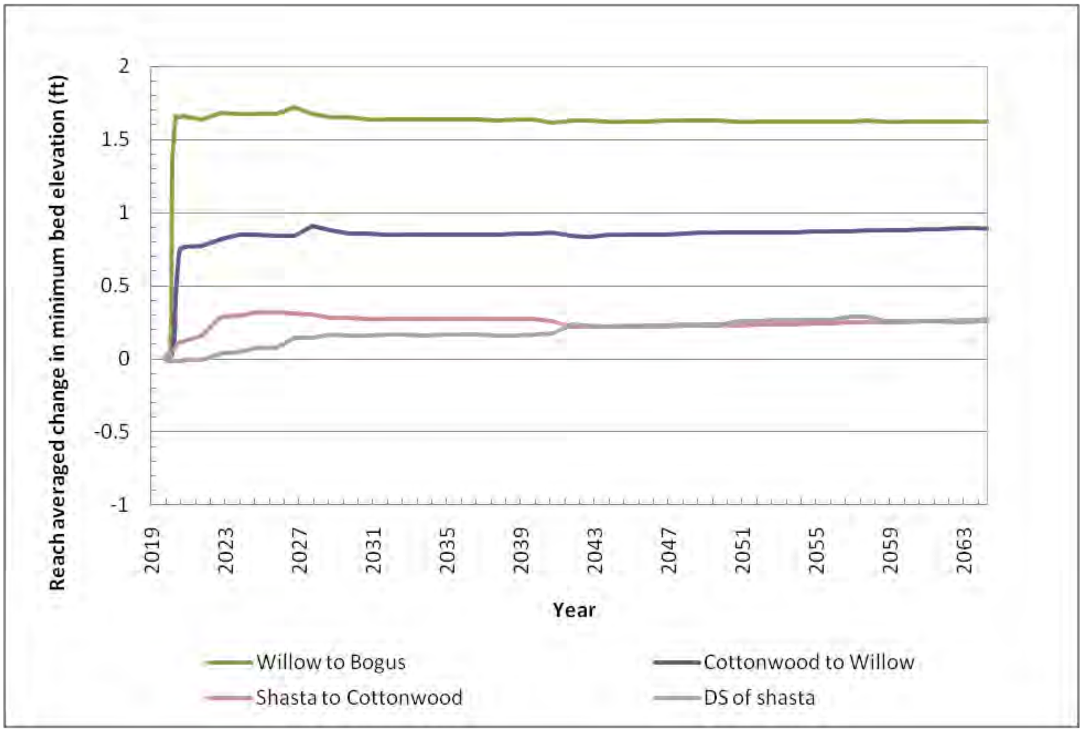


Figure 9-31. Reach averaged deposition from Iron Gate Dam to Shasta River for Scenario 8. Median start year.

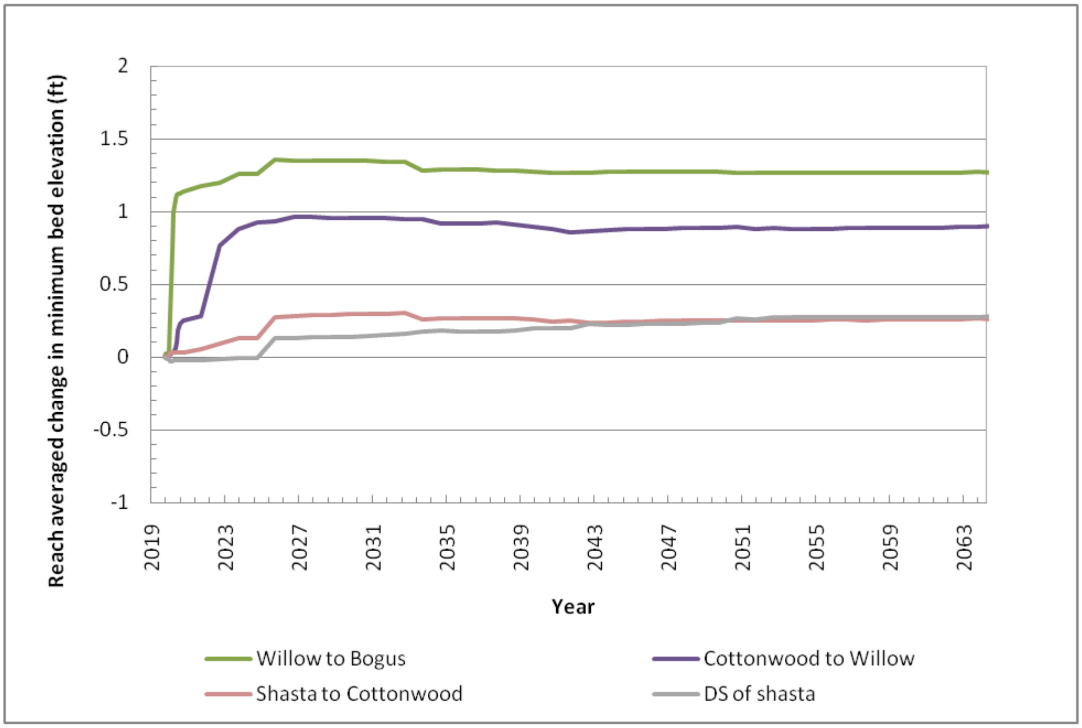


Figure 9-32. Reach averaged deposition from Iron Gate Dam to Shasta River for Scenario 8. Dry Start Year.

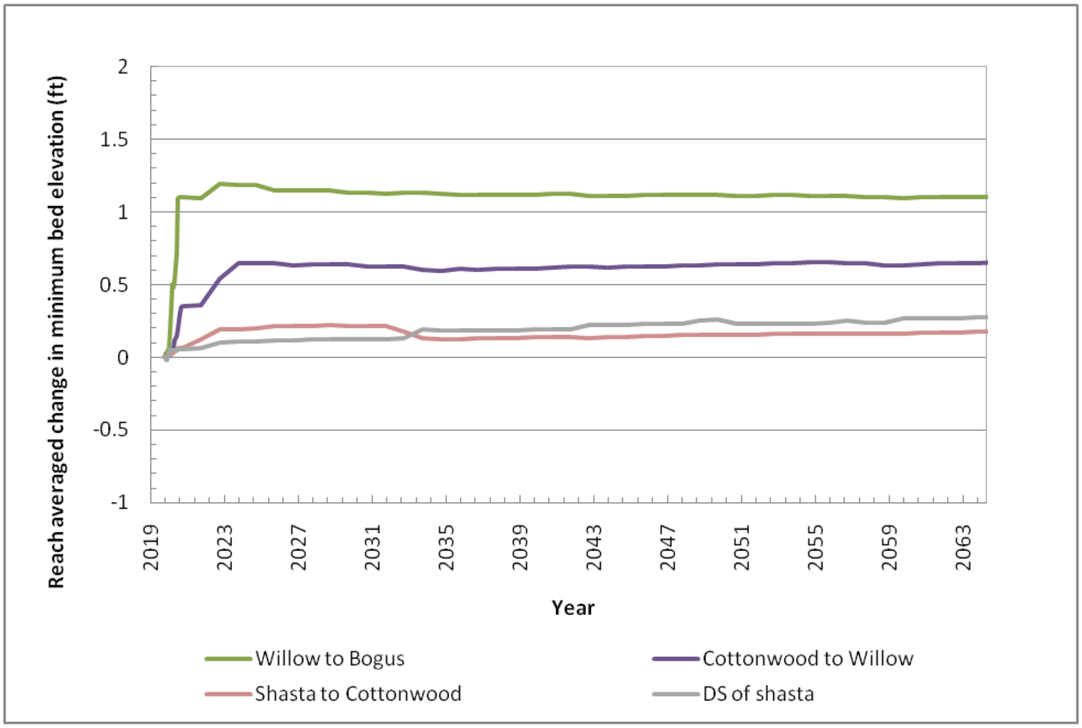


Figure 9-33. Reach averaged deposition from Iron Gate Dam to Shasta River for Scenario 8. Wet Start Year.

9.2.1.5. Bed Material after Dam Removal

SRH-1D was used to analyze the bed material fractions after dam removal. The reach average size gradation of the material in the active layer was analyzed to determine the fraction of fines (silts, clays, and organics), sand, gravel, and cobble. The active layer in the model was defined as the upper 1 foot of material in the bed. Therefore, it contains material below the visible surface. Most of the bed material data collected in the Klamath River used pebble count methods which only sample the material visible on the surface and cannot effectively sample the sand sized material. Therefore, very little sand size material was reported in these studies. Holmquist-Johnson and Milhous (2010) reported substrate data which was collected by removing the armor layer and taking bulk samples of the sediment beneath it. They reported sand contents ranging from 5% to 22 % in the substrate material at six different locations from Iron Gate Dam to the Pacific Ocean. The results reported form the active layer gradations of SRH-1D are most appropriately compared to a combination of the bulk substrate sample and the pebble count sample. We expect that if the simulated results of the sand content are in the range of 10% to 20% that this is an approximately a background level of sand within the bed under natural sediment supply conditions. Modeling the fraction of fines contained within the bed is difficult because it depends upon many factors. One of the main uncertainties is determining the sheltering effects that larger material has on the smaller material.

The fraction of fines, sand, gravel, and cobble in the bed for the J.C. Boyle Reservoir reach is shown in Figure 9-34 for wet, median, and dry hydrologic scenarios. Within the first month following drawdown, the bed is dominated by cobble and gravel sized sediment. The fraction of sand remaining in the bed will be dependent upon the hydrologic scenario. Immediately upon drawdown, there may be up to 30% to 40% sand remaining in the bed. There is also some silt, clay, and organics expected to remain in the bed, but in fairly low amounts depending upon their ability to adhere to larger particles. Under wet conditions, some of this sand and fine material will be flushed from the bed and by the second year, there is expected to be approximately 20% sand or less. Under median or dry conditions, the higher sand contents may remain until a high flow mobilizes the bed and flushes the sands from the bed. Regardless of the scenario, it is expected that by 2025, the bed is near equilibrium conditions with a small fraction of sand in the bed consistent with the reaches upstream and downstream.

Figure 9-35 shows the fraction of fines, sand, gravel, and cobble in the Copco Reservoir reach. Similar to the J.C. Boyle Reservoir reach, the bed is dominated by cobble and gravel sized sediment within the first month after drawdown. The sand is flushed from the bed quicker at Copco Reservoir than J.C. Boyle Reservoir, mostly likely because the upper part of J.C. Boyle Reservoir has a lesser slope than the slope through Copco Reservoir. For the Wet and Median Year, there is very little change after Year 1. The bed attains an equilibrium gradation typical of the upstream and downstream reaches within the first year. For the Dry Year, the response is slower and it is expected to take at least at median type of year to return the bed to equilibrium conditions. Based upon mobilization criteria presented in the Section 9.2.3 for the lower reaches, a flow of approximately 6,000 cfs will be required to mobilize the bed and flush the residual fines from the bed. It is expected that a similar flow will be required to obtain similar results in the Copco Reservoir reach.

Figure 9-36 shows the fraction of fines, sand, gravel, and cobble in the Iron Gate Reservoir reach. There is substantially more fine material expected at Iron Gate because it is downstream of Copco Reservoir. During a wet year scenario, the bed is restored to an equilibrium cobble and gravel bed stream with a small amount of sand after the spring runoff. For the median and dry year scenario, the bed remains over 30% sand for the first two years. By year 2025, the bed attains a near equilibrium cobble and gravel bed stream with a small amount of sand, similar to the wet year scenario.

Downstream of Iron Gate Dam, there will be a substantial increase in sand content immediately following reservoir drawdown in the Bogus Creek to Iron Gate reach (Figure 9-37). The percent of sand in the bed is expected to increase to up to 40% for the month immediately after reservoir drawdown. Under a wet scenario, it is expected that the percent sand would then decrease to below 20% by the end of spring runoff in 2020. Under a median or dry scenario, a subsequent wet year will be required to flush the sand material from the bed and return to an equilibrium level with a small amount of sand sized material in the bed.

The response of the reach from Willow Creek to Bogus Creek is expected to be similar to the reach above it (Figure 9-38). However, because the reach is longer, it may take slightly longer to flush the excess sand from the bed and move through the reach. Under a median or dry scenario, it may take 5 or 6 years to return sand content in the bed to equilibrium levels in this reach.

The reach from Cottonwood Creek to Willow Creek will respond slightly slower than the upstream reaches and the recovery to equilibrium levels may be slightly slower with the full return to equilibrium sand levels taking up to 10 years (Figure 9-39).

The bed material in the reach from Shasta River to Cottonwood Creek (Figure 9-40) will show a more gradual response and it is anticipated that it will be difficult to measure significant response. Sand contents are not expected to rise above typical levels in the Klamath River. Furthermore, downstream of the Shasta River, model results indicate there will be no significant effect of dam removal on bed material gradations.

The reach averaged D50 and D16 representative diameters for the same reaches are presented in Figure 9-41 to Figure 9-47. The same basic information is contained within these plots as the bed material percentage plots.

The fine fraction of the released sediment (silts, clays, and organics) is not expected to deposit in significant amounts in the river channel. The majority of this material will be transported to the ocean and not interact significantly with the river bed. However, there may be deposition of fine material along vegetated areas or in slack water areas. In particular, if removal occurs during a dry year, some bank lines and some of the slack water areas will be covered with a veneer of fine material. The fine material will typically not penetrate beyond twice the D90 of the bed material (Diplas and Parker, 1991; Schälchi, 1992).

Stewart et al (2002) documented a fine sediment release on the South Fork McKenzie River, Oregon. As part of the Willamette Valley Temperature Control Project, the U.S. Army Corps of Engineers (COE) modified the intake tower of Cougar Dam on the South Fork McKenzie River, Oregon. These modifications will allow operators to release colder water during the winter, and warmer water during the summer, to improve habitat conditions for bull trout and spring Chinook salmon. In order to carry out work on the intake tower, the COE lowered Cougar Reservoir below minimum pool elevation in April 2002, thereby exposing deltaic and lake bottom sediments to reworking by the South Fork McKenzie and other reservoir tributaries. The reworking of these sediments resulted in a prolonged discharge of turbid water from Cougar Reservoir that was highly visible for miles downstream and even affected the turbidity of the Willamette River below the confluence of the McKenzie. Although the COE had predicted in its Environmental Impact Statement (EIS) that turbidity would increase during the drawdown (predicted levels of 30 NTUs and spikes of 100 NTUs), they underestimated the magnitude, timing, and duration of the problem. Between April 1st and May 25th turbidity levels at the South Fork gauging station below the dam averaged 68 NTUs with spikes of up to 379 NTUs. The length of the high turbidity was approximately 2 months. The existing bed material downstream had a D50 of approximately 20 to 50 mm which is slightly smaller than the Klamath River bed material downstream of Iron Gate.

Stewart et al. (2010) stated that there was a relative enrichment in fines in the alluvial reaches below Cougar Reservoir as compared with the reaches above the reservoir. Upstream reaches and mainstem McKenzie sites have clay fractions representing 2.5% of the <2mm sample by weight as opposed to 9.5% in the South Fork below the dam. This increase in fines was not detectable below the confluence of the South Fork and the mainstem McKenzie River, which is located approximately 4 miles downstream. Because no in-situ sampling of gravels was conducted prior to the reservoir release in the spring of 2002, they were unable to discern whether this fines enrichment pre-dated the release, although high levels of fine sediment stored in channels downstream of dams is relatively uncommon.

Based upon the results of Stewart et al. (2010), if removal occurs in a dry year, we expect a measureable but small increase in the fine material (silts, clays, and organics) in the bed after dam removal. Stewart et al. (2010) reported an increase from 2.5% to 9% of clays within the < 2 mm size range, but this equated to less than 2% of the entire bed material sample which consistent primarily of gravels. We expect a similar type of result after dam removal on the Klamath River. The amount of fine deposition will also decrease with distance from the dam. Stewart et al. (2010) did not find any detectable increase in fine material after the confluence with a larger tributary. The tributaries downstream of Iron Gate Dam will have a similar dilution effect on the fine sediment release on the Klamath River. A longer distance of river will likely be affect on the Klamath River because of the higher sediment concentrations and duration expected. Downstream of the Shasta River, no significant deposits of reservoir material and no significant change to the bed material are expected.

The only reservoir material that will be transported to the estuary will be the fine material (silt, clays, and organics). The fine material will not deposit in significant quantities in the estuary. There are currently high concentrations of silt and clay transported through the estuary and the sediment sampling of Reclamation (2010) documented the absence of fine material in the estuary except in the backwater and vegetated areas. If removal occurs during a low flow year, there may be small amounts of deposition in these areas, but it will be relatively small volumes of material.

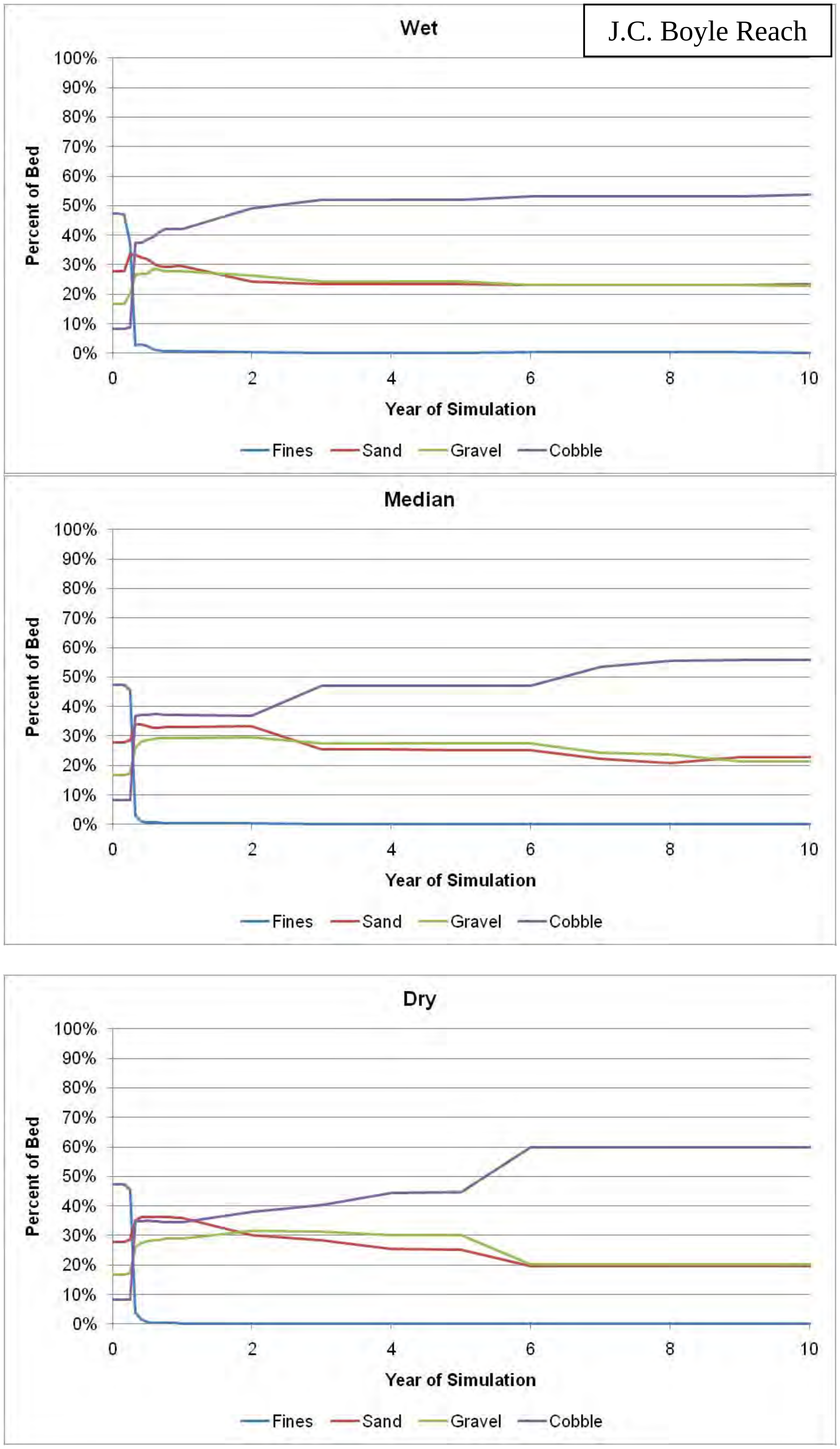


Figure 9-34. Bed material for the 10 years following dam removal for Wet, Median, and Dry Years for J.C. Boyle Reach

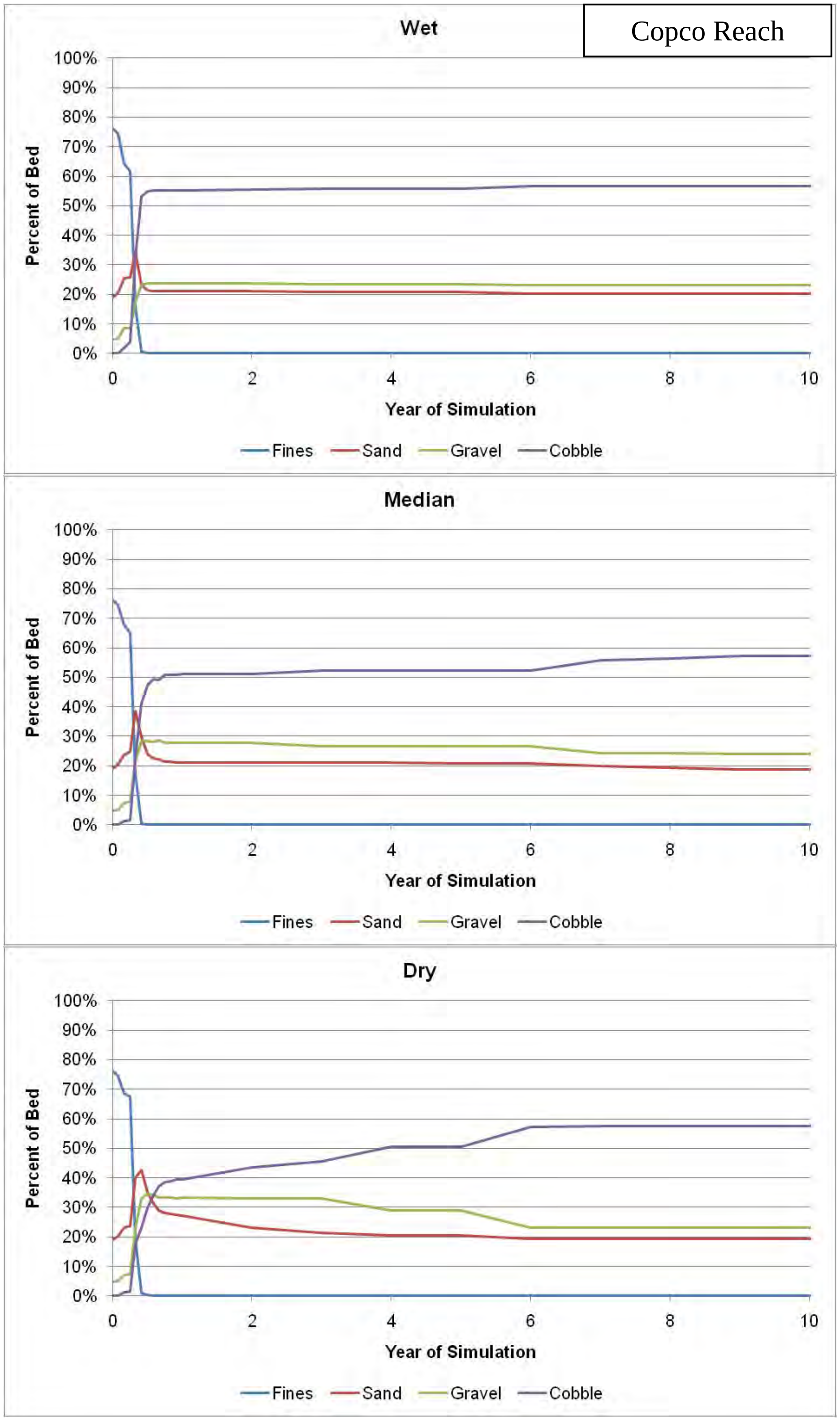


Figure 9-35. Bed material for the 10 years following dam removal for wet, median, and dry years for Copco Reach.

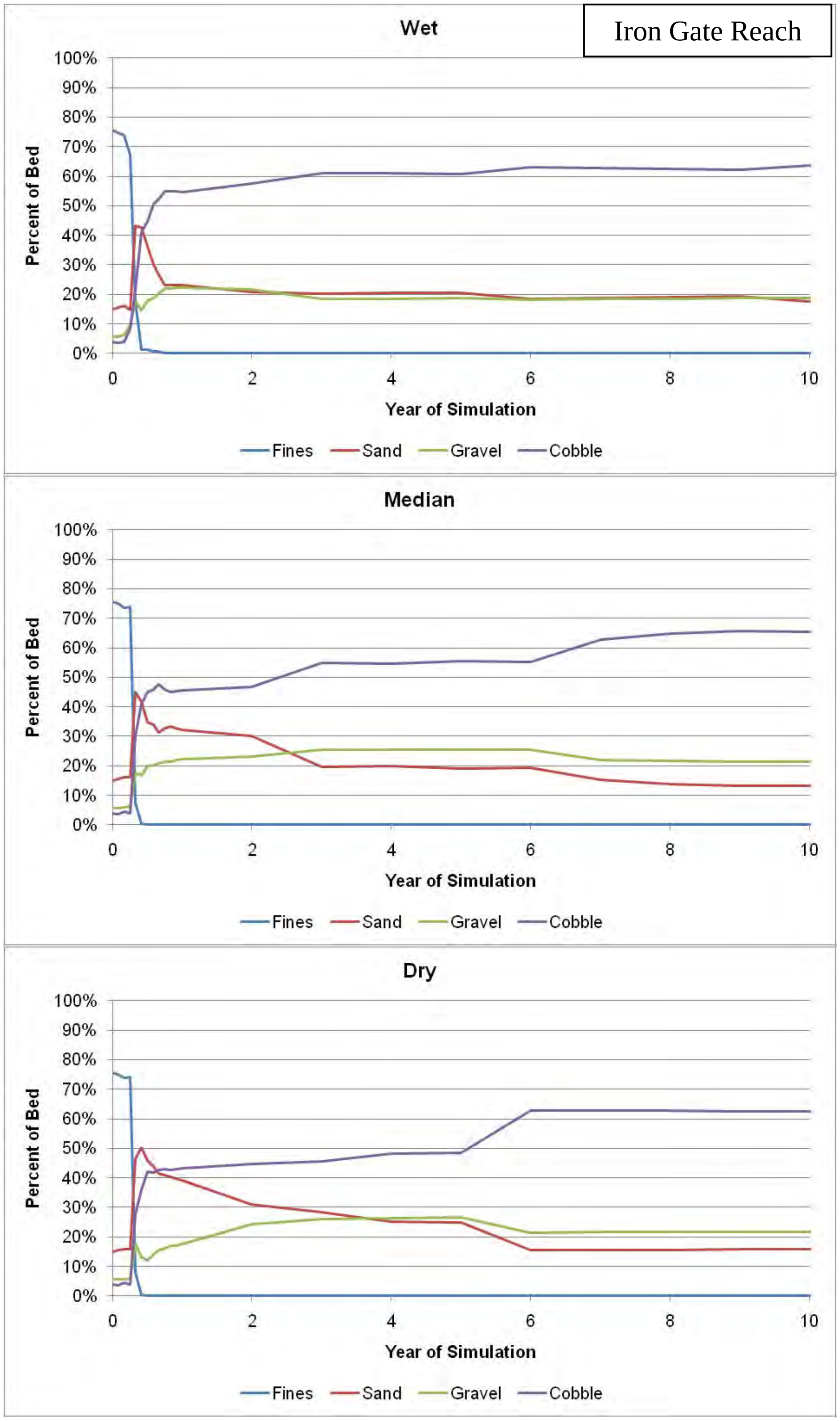


Figure 9-36. Bed material for the 10 years following dam removal for wet, median, and dry years for Iron Gate Reach.

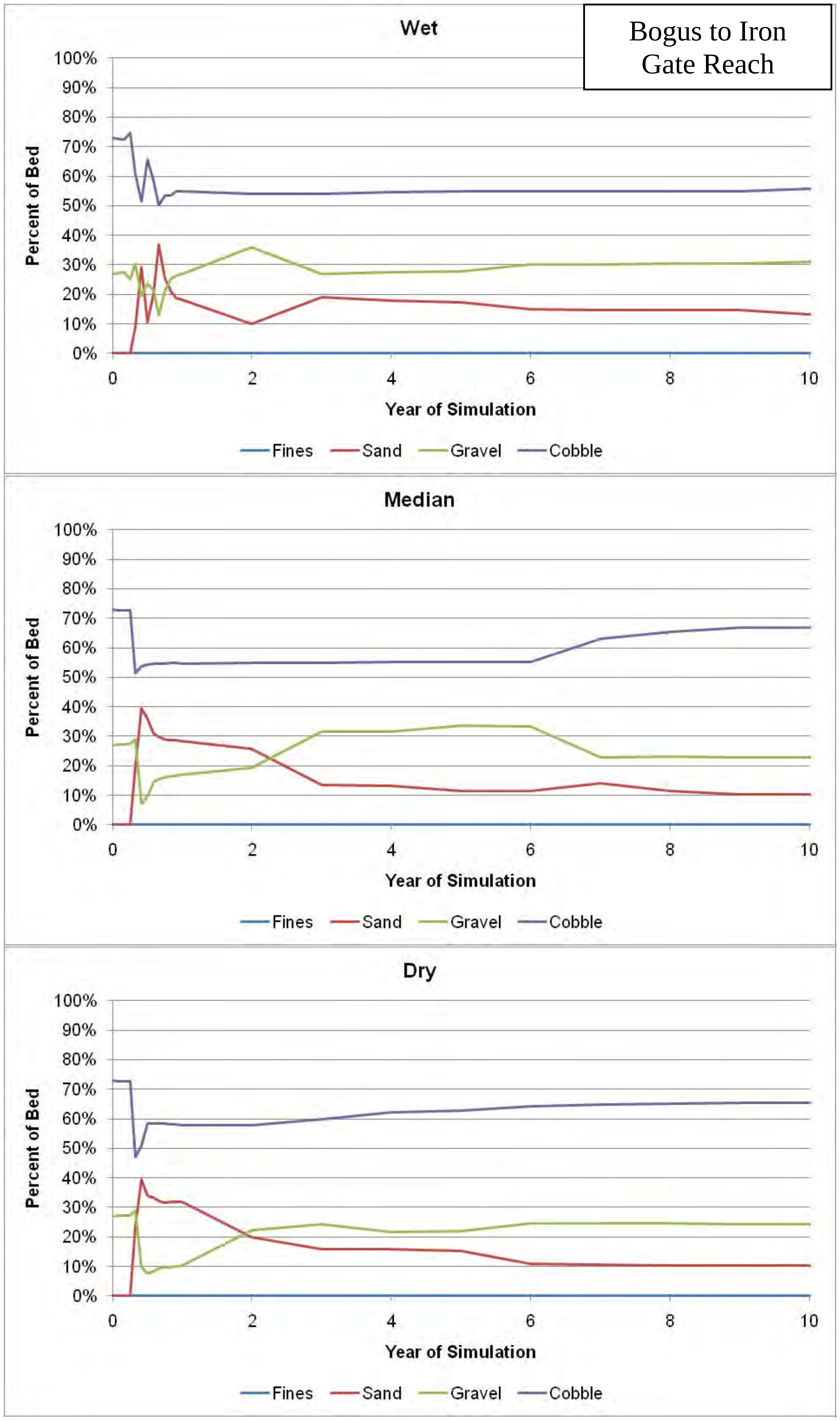


Figure 9-37. Bed material for the 10 years following dam removal for wet, median, and dry years for Bogus Creek to Iron Gate Reach.

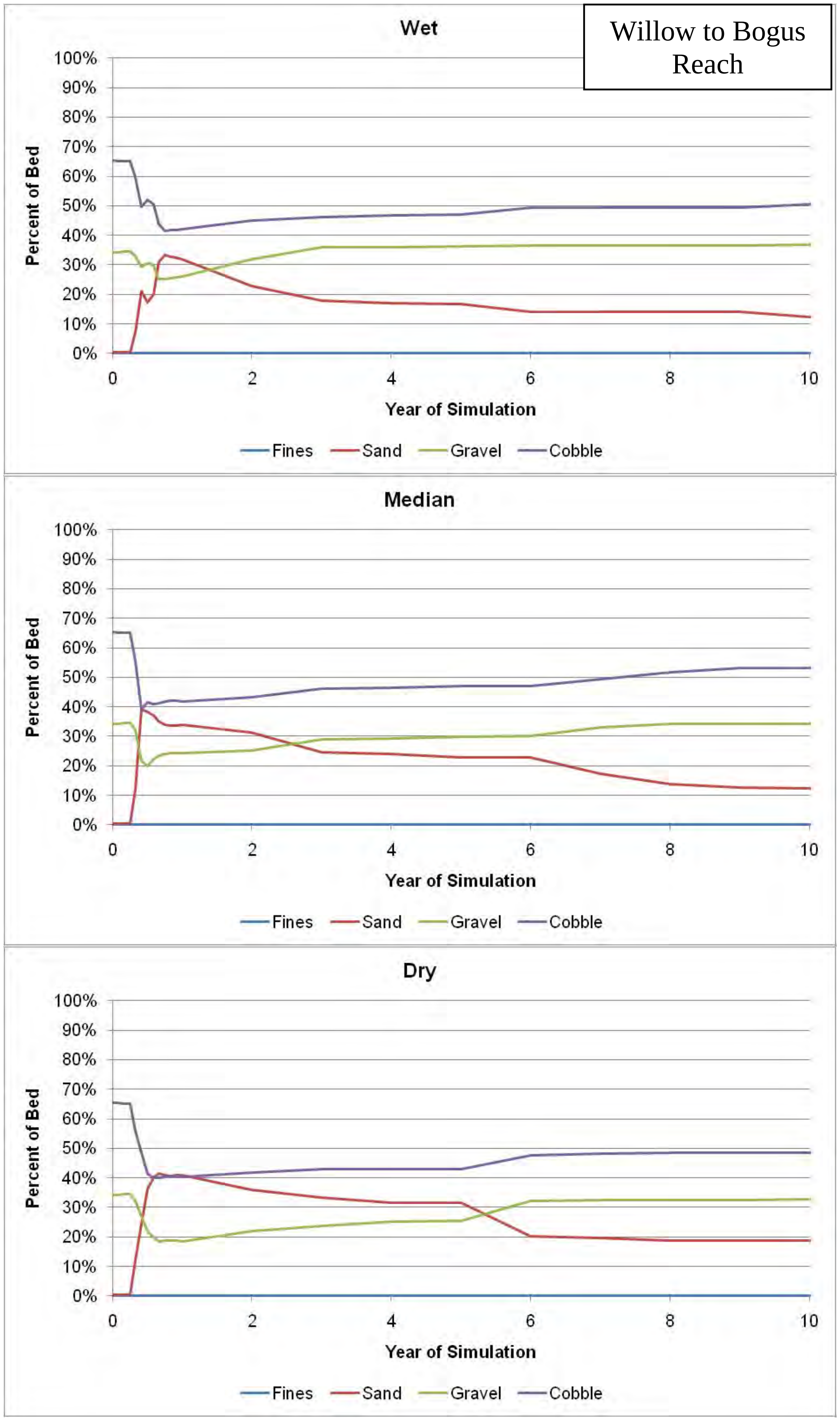


Figure 9-38. Bed material for the 10 years following dam removal for wet, median, and dry years for Willow Creek to Bogus Reach.

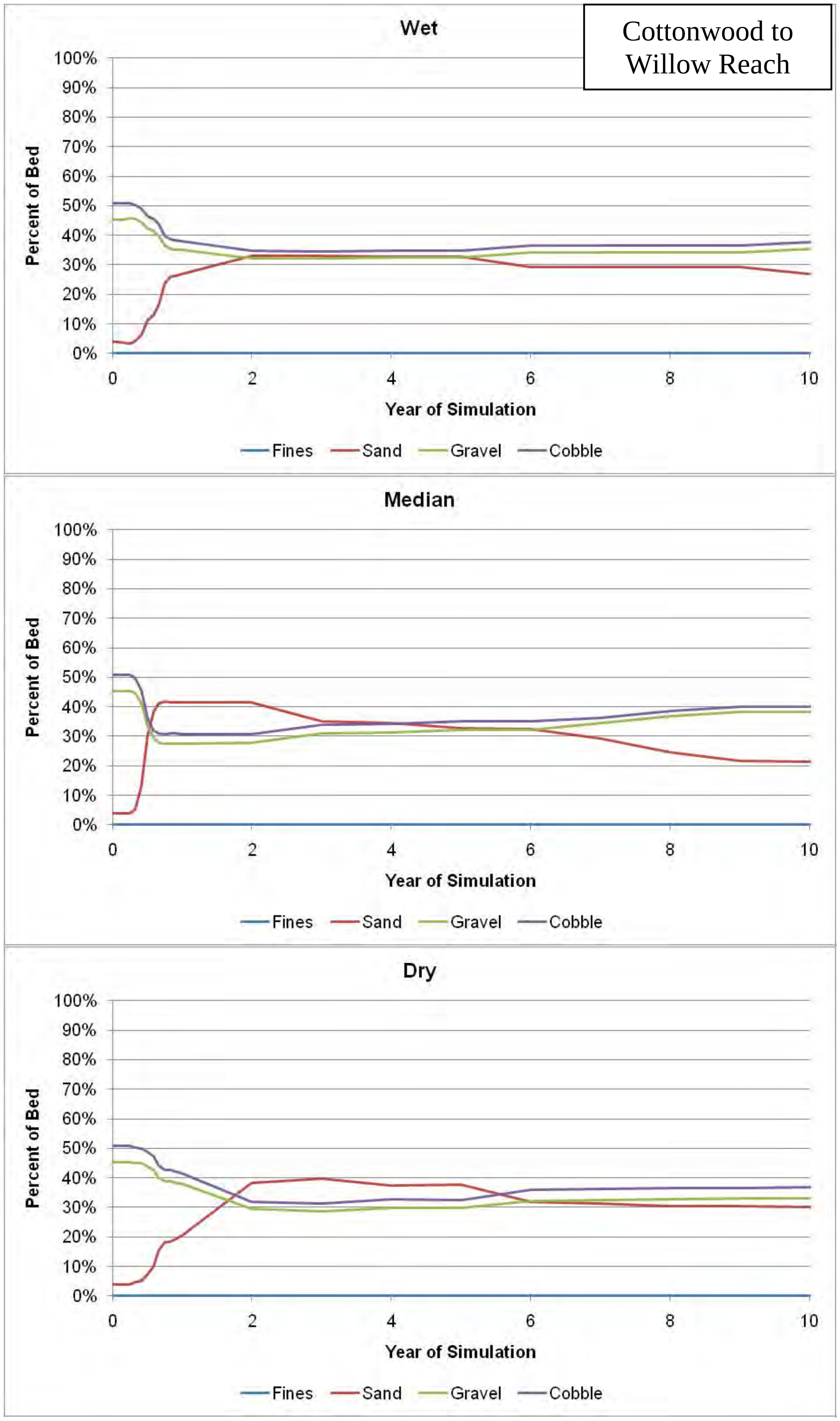


Figure 9-39. Bed material for the 10 years following dam removal for wet, median, and dry years for Cottonwood to Willow Creek Reach.

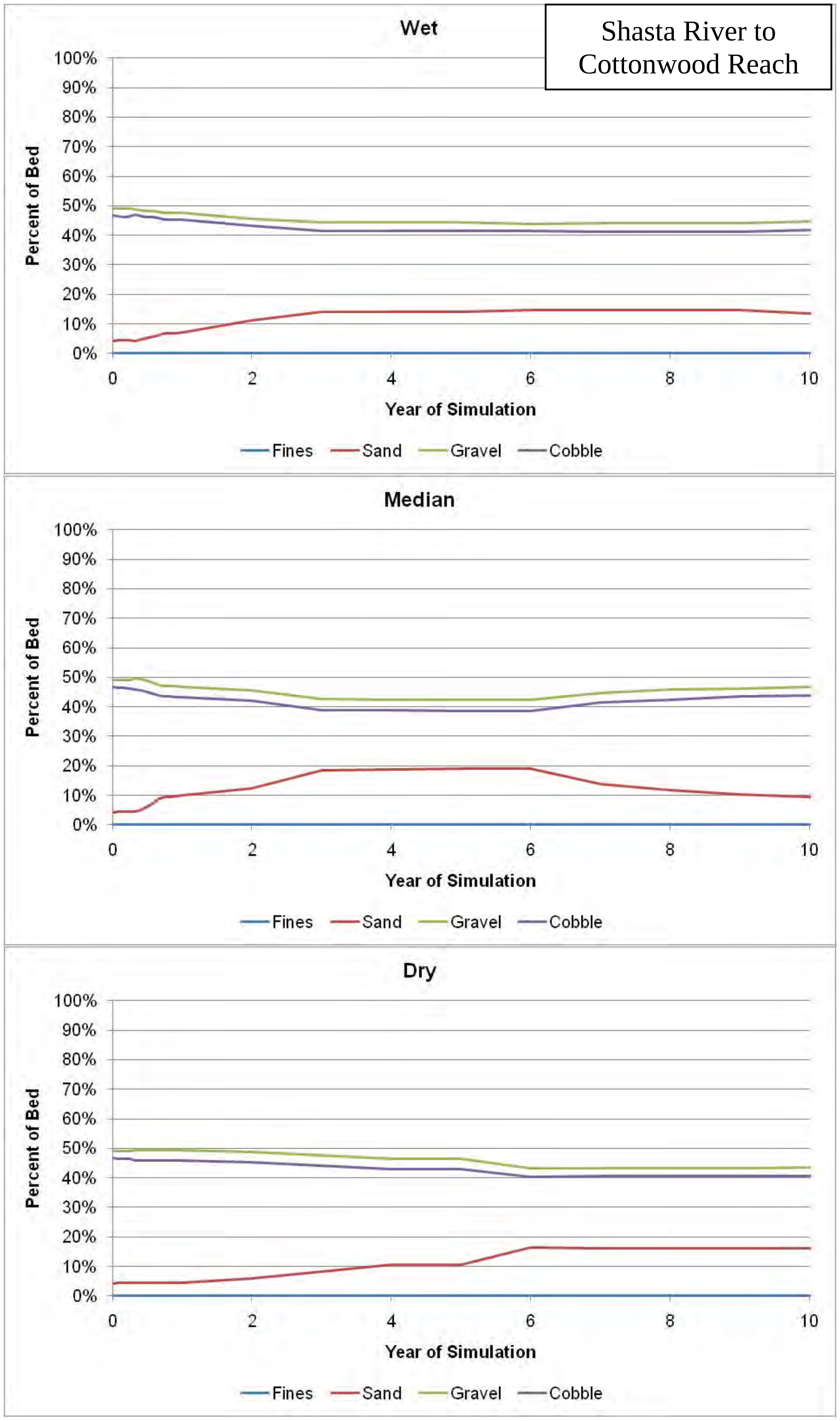


Figure 9-40. Bed material for the 10 years following dam removal for wet, median, and dry years for Shasta River to Cottonwood Creek reach.

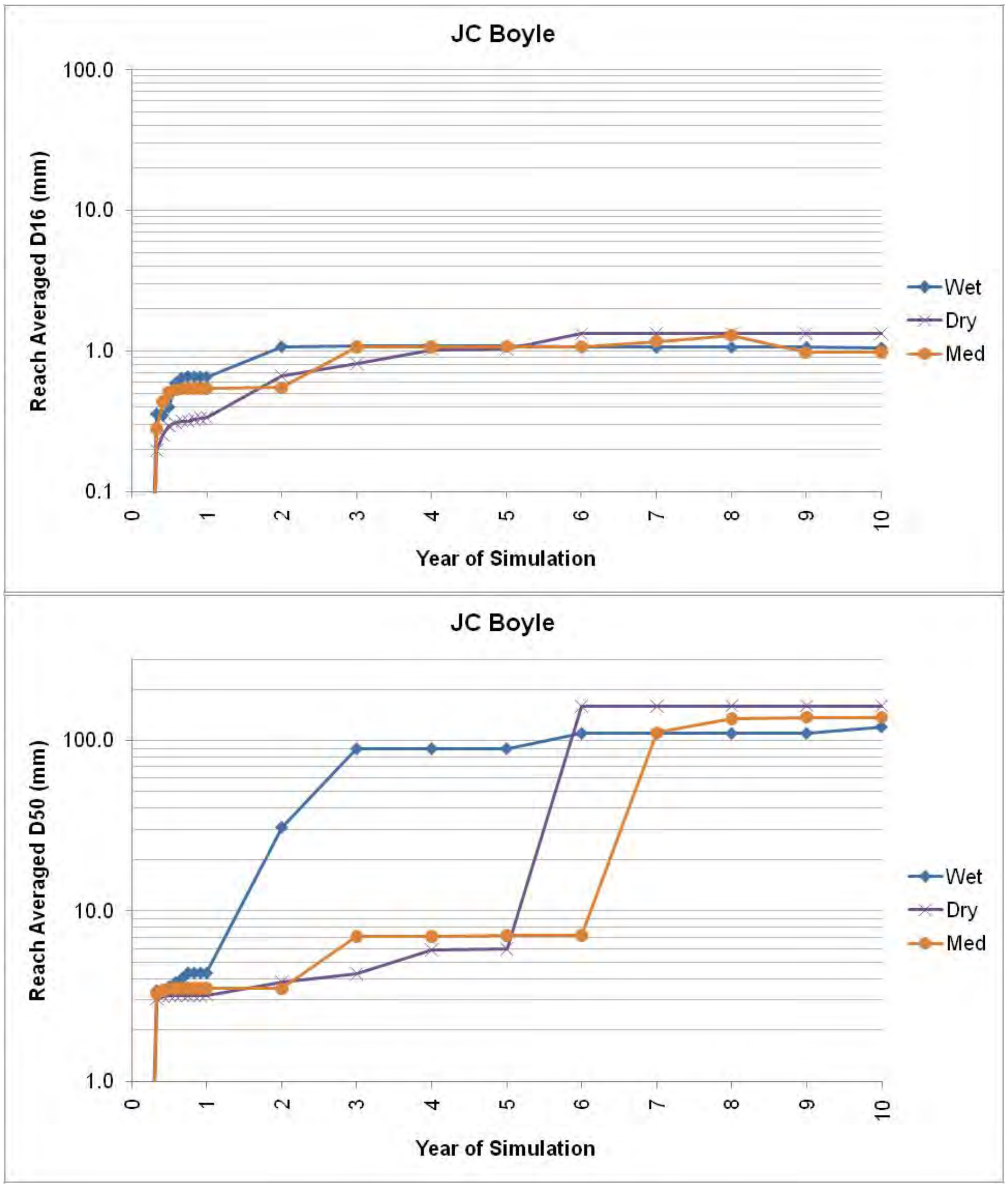


Figure 9-41. Reach averaged D16 and D50 in J.C. Boyle Reservoir reach following dam removal.

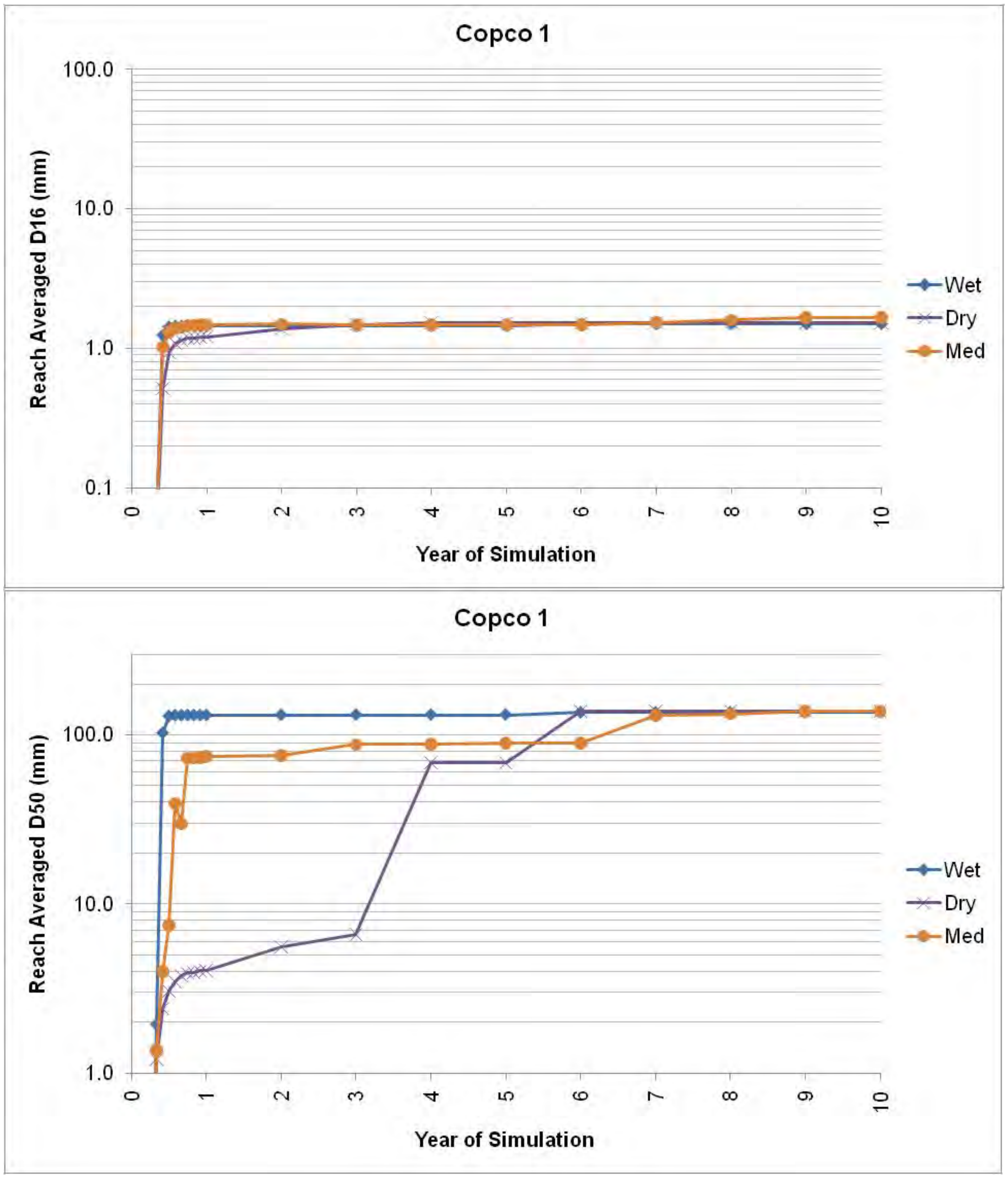


Figure 9-42. Reach averaged D16 and D50 in Copco Reservoir reach following dam removal.

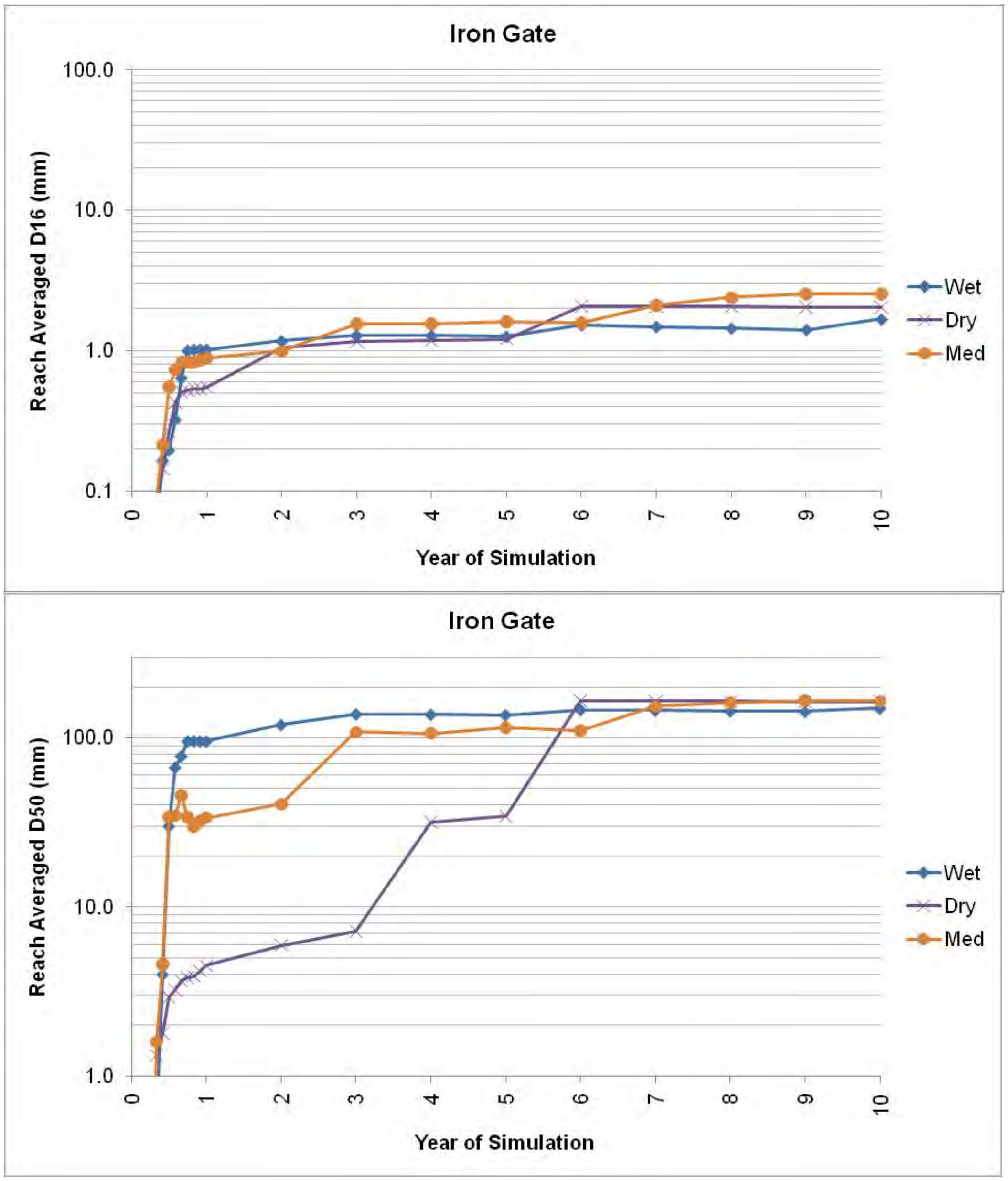


Figure 9-43. Reach averaged D16 and D50 in Iron Gate Reservoir reach following dam removal.

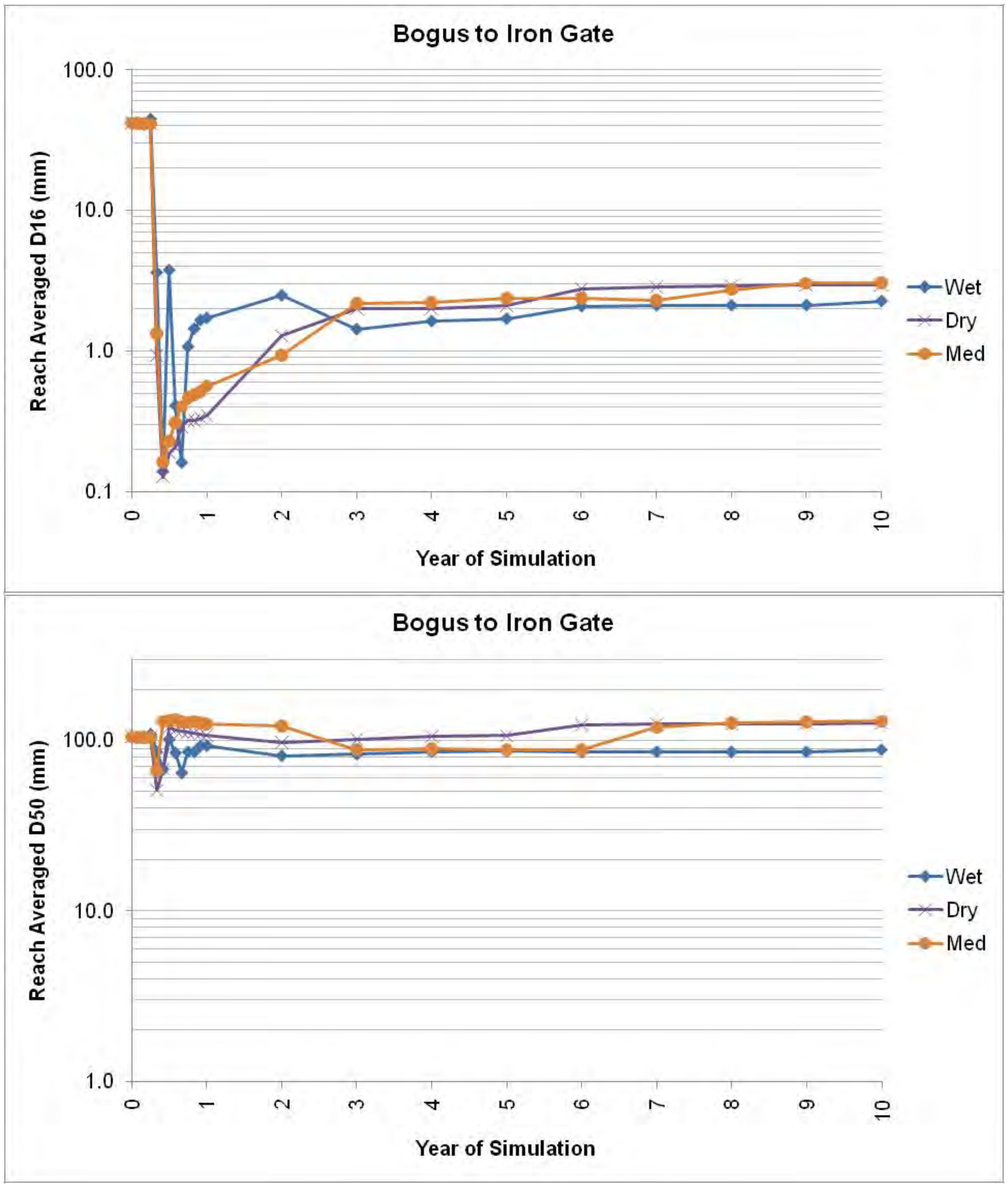


Figure 9-44. Reach averaged D16 and D50 in Bogus Creek to Iron Gate reach following dam removal.

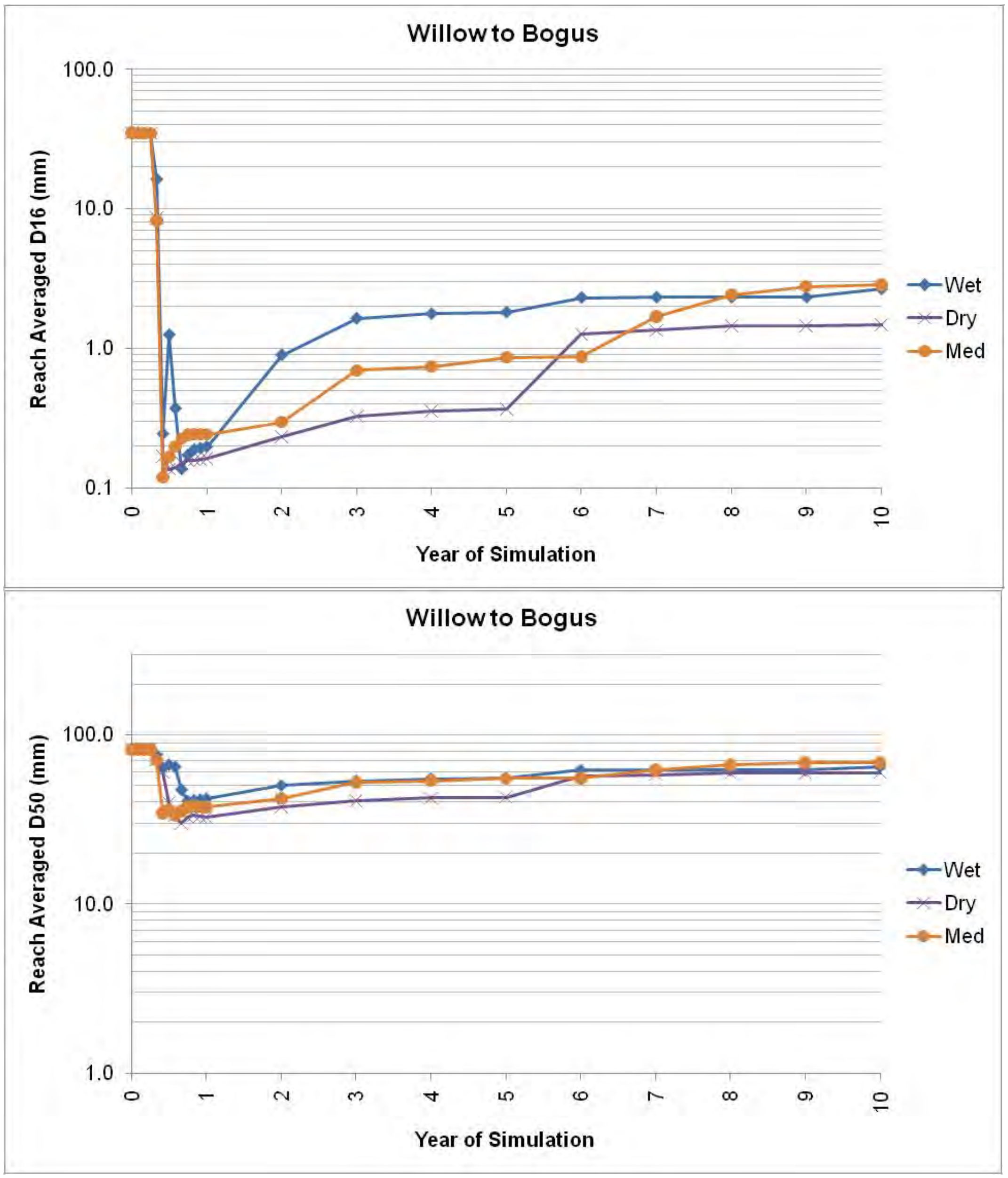


Figure 9-45. Reach averaged D16 and D50 in Willow Creek to Bogus Creek reach following dam removal.

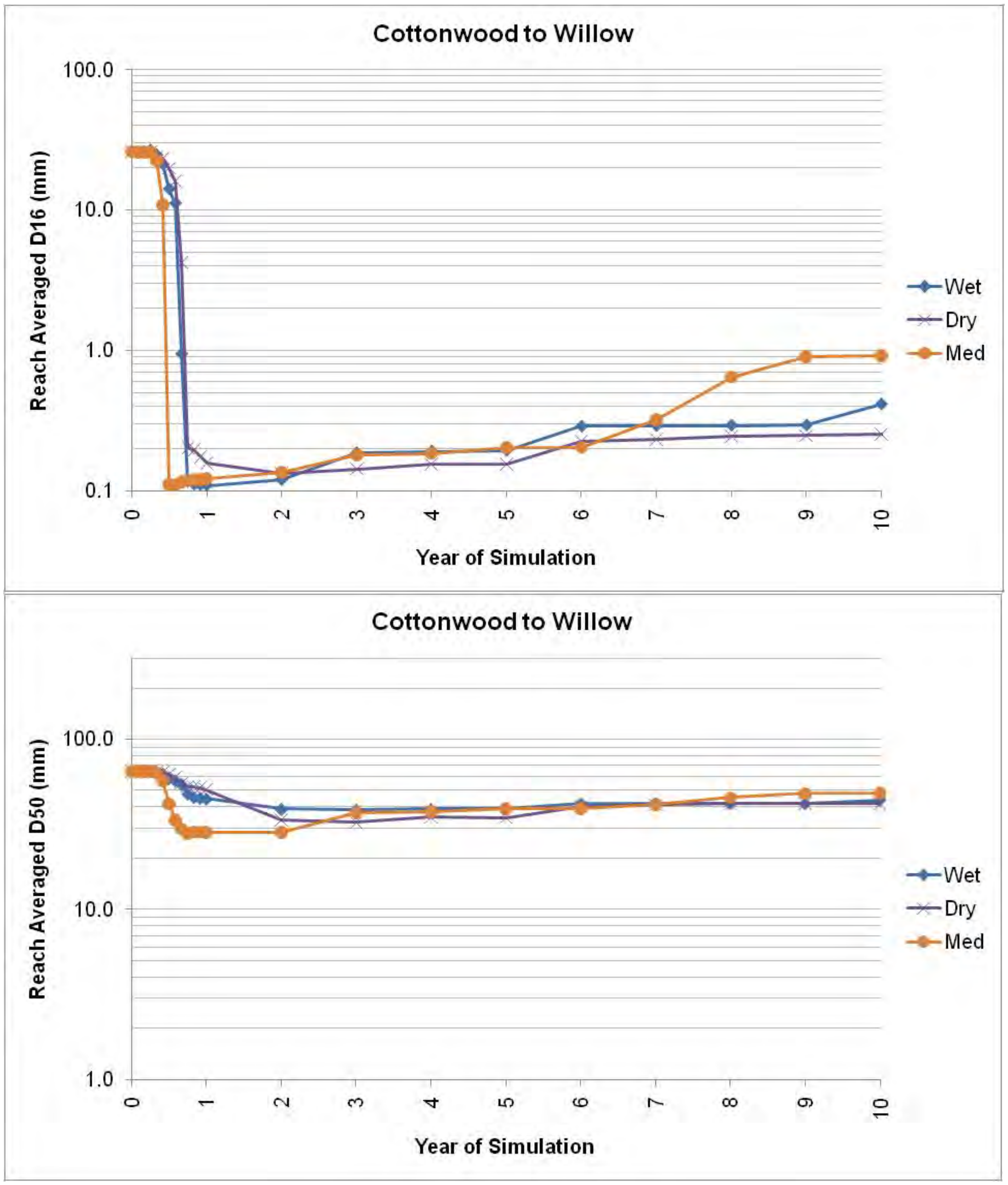


Figure 9-46. Reach averaged D16 and D50 in Cottonwood Creek to Willow Creek reach following dam removal.

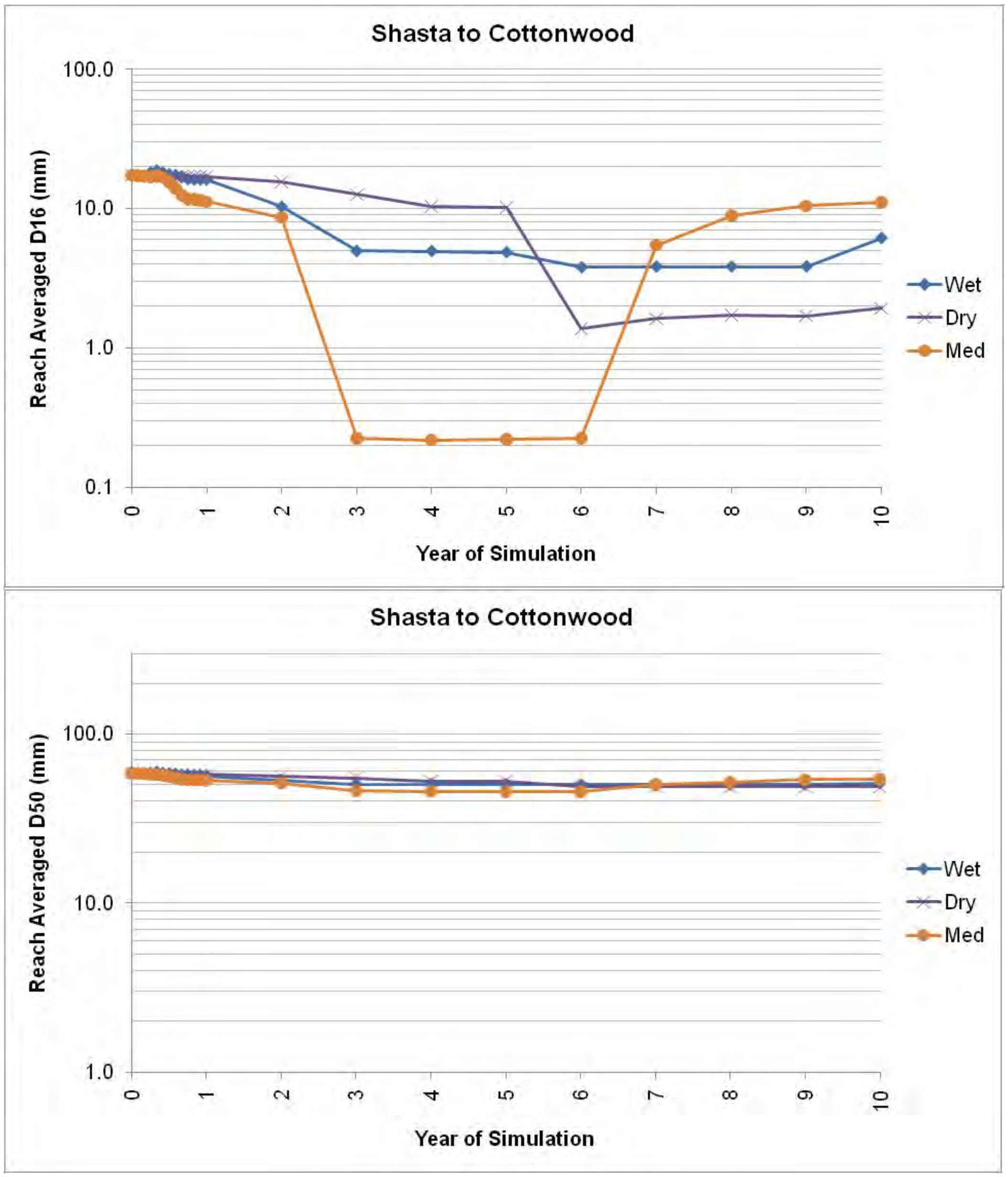


Figure 9-47. Reach averaged D16 and D50 in Shasta River to Cottonwood Creek reach following dam removal.

9.2.2. TWO-DIMENSIONAL ANALYSIS OF COPCO 1 DRAWDOWN

More detailed two-dimensional modeling of the erosion of sediment at Copco 1 was performed using a SRH-2D. This was done to verify the erosional patterns that may occur during reservoir drawdown and to verify the assumptions inherit in the 1D simulations.

SRH-2D v3 is a 2D, depth-averaged, hydraulic and sediment transport mobile-bed model for river systems and was developed at the Bureau of Reclamation. The hydraulic flow modeling module, documented by Lai (2008; 2010), is widely used; the mobile-bed sediment transport module is based on the Reclamation's latest sediment modeling methodology (Greimann et al. 2008), and is only used internally at present. The robustness and accuracy of SRH-2D have been proven with a range of Reclamation projects as well as with studies at many external institutions. Detailed technical information, selected application cases, and the SRH-2D version 2 model may be downloaded from the following Reclamation website: http://www.usbr.gov/pmts/sediment/. Sediment transport modeling details and applications may be found in a number of papers such as Greimann et al. (2008), Lai and Greimann (2007; 2008; 2010) and Lai et al. (2009), in addition to many project reports.

One of the major features of SRH-2D is the adoption of the arbitrarily shaped element method of Lai et al. (2003) for geometry representation. This allows use of the unstructured hybrid mesh for river modeling which has been shown to be flexible and led to increased accuracy and efficiency.

Major capabilities of SRH-2D are listed below:

- 2D depth-averaged solution of the dynamic wave equations for flow hydraulics.
- An implicit solution scheme for solution robustness and efficiency.
- Unstructured or structured meshes with arbitrary mesh cell shapes may be used. In most applications, a combination of quadrilateral and triangular meshes works the best.
- Steady or unsteady flows.
- All flow regimes: subcritical, supercritical, or transcritical flows.
- Unsteady, non-equilibrium, and non-uniform modeling of the sediment transport.
- Multi-size sediment transports, with bed sorting and armoring.
- Effects of gravity and secondary flows.
- Non-cohesive or cohesive sediments.

SRH-2D is a two-dimensional (2D) model, and it is particularly useful for problems where 2D effects are important. Examples include flows with in-stream structures (such as weirs, diversion dams, release gates, coffer dams, etc.), bends and point bars, perched rivers, and multi-channel systems. 2D models may also be needed if hydraulic characteristics are important, such as: flow recirculation and eddy patterns, lateral variations, flow overtopping over banks and levees, differential flow shears on river banks, and interaction between the main channel, vegetated areas, and floodplains. Some of the scenarios listed above may be modeled in 1D, but additional empirical models are used and extra calibration must be carried out with unknown accuracy.

9.2.2.1. 2D Modeling Details

A 2D analysis begins by defining a solution domain and then generating a mesh that covers the domain. The solution domain is determined based on the objectives of the project and most often it is constrained by available data. In this study, the solution domain includes the entire reservoir, as shown in Figure 9-48.

Figure 9-48. Solution domain used by the SRH-2D modeling.

A mesh is generated using the Surface Water Modeling System software (SMS). The following website link provides more information for the software: http://www.aquaveo.com. Additionally, the SRH-2D manual (Lai, 2008) and the theoretical discussion in Lai (2010) may be consulted for an in-depth discussion. The mesh consists of mixed quadrilaterals and triangles. A total of 10,504 mesh cells are used; an overall view of the mesh is displayed in Figure 9-49, while two close-up views of part of the mesh are in Figure 9-50.

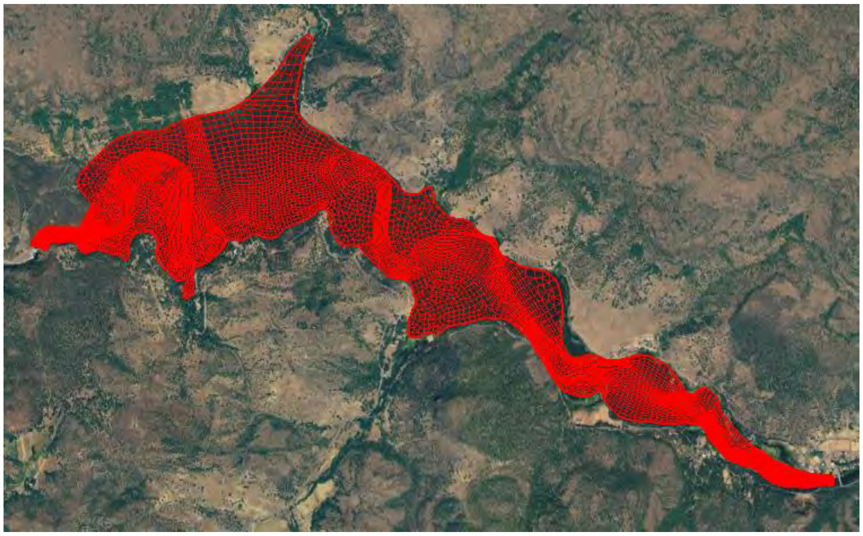
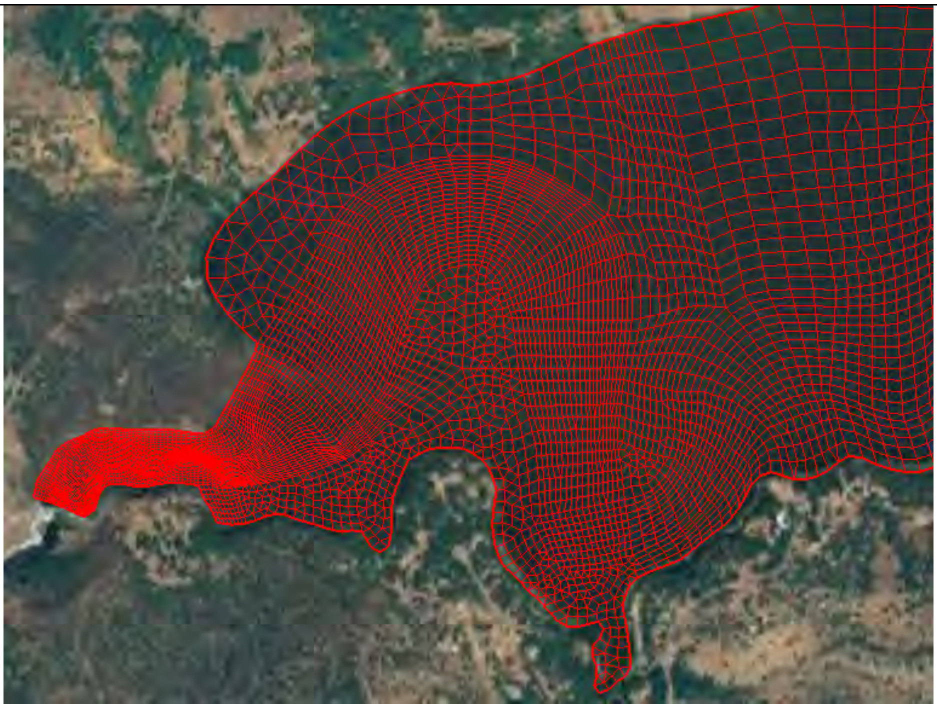
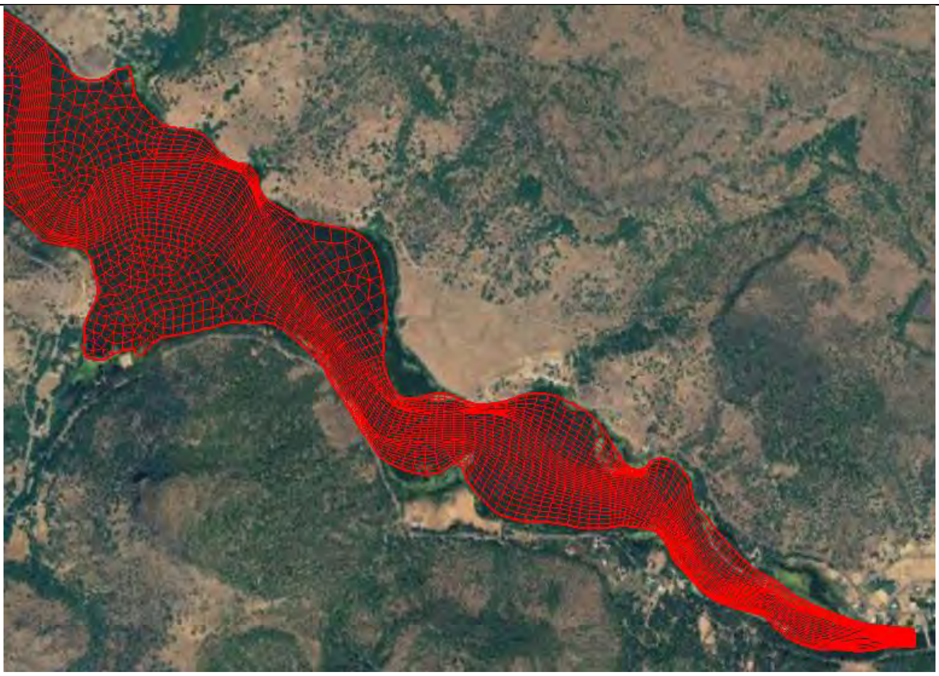


Figure 9-49. An overall view of the entire mesh.



(a) View of the mesh near the dam



(b) View of the mesh near the upstream boundary

Figure 9-50. A zoomed-in view of the mesh.

Topographic and bathymetric data are based on the survey data in the form of a digital elevation model (DEM). The DEM data were imported into SMS and interpolated to the mesh to represent the bed elevation. This bed elevation was used as the initial reservoir bed before drawdown. The contours of the initial bed elevation represented by the mesh are shown in Figure 9-51.

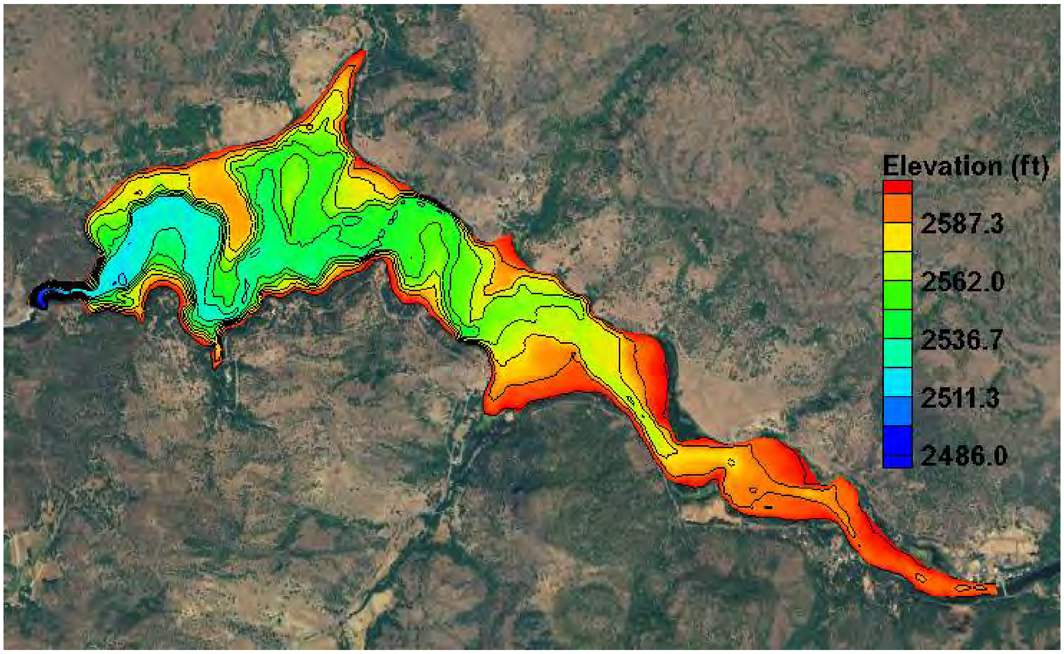


Figure 9-51. Bed contours represented by the mesh based on the survey data DEM and it is used as the initial bed elevation for the modeling.

Flow resistance is calculated with the Manning's roughness equation in which the Manning's coefficient (n) is used as one of the model inputs. In this study, a uniform Manning's coefficient of 0.03 is used.

The bed gradation distribution over the solution domain is also needed for the sediment transport analysis. In this study, all relevant data are based on available survey data discussed above. The solution domain is divided into an upstream and a downstream zone (Figure 9-52). Two bed layers are assumed in each zone. The top bed layer has uniform bed gradation (composition) specified in each zone, while the gradation of the bottom layer is the same over the entire solution domain. The cumulative distributions of the bed gradation for the top layer of the two zones, as well as the bottom layer, are plotted in Figure 9-53. The thickness of the top bed layer is based on the available survey data and it is shown in Figure 9-54.

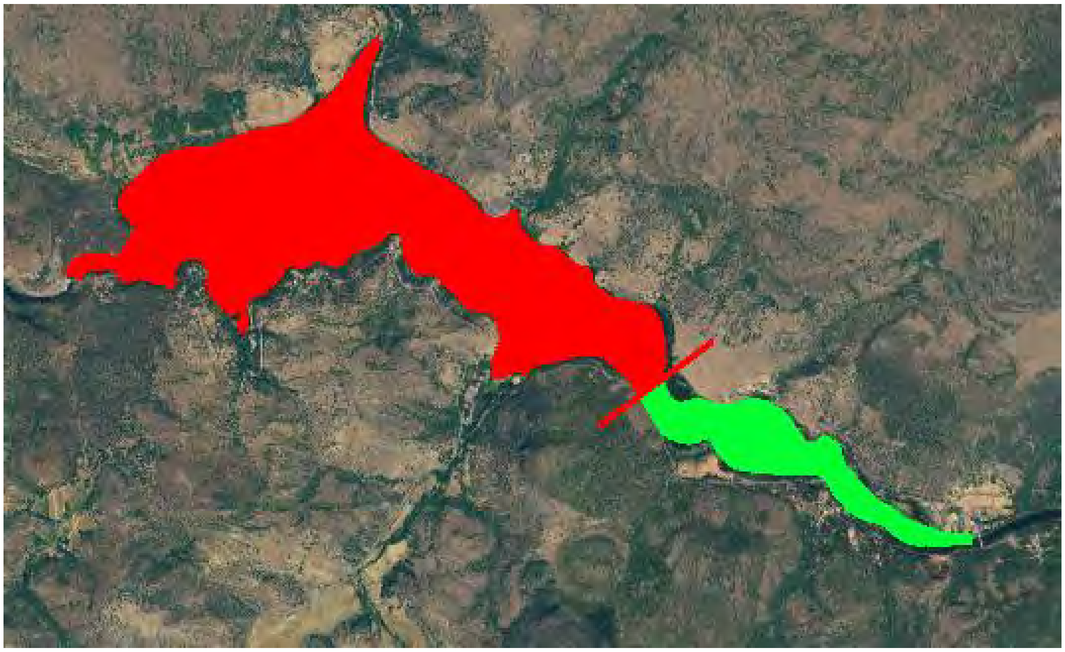


Figure 9-52. Two bed gradation zones, upstream and downstream zones, used to specify the bed sediment properties.

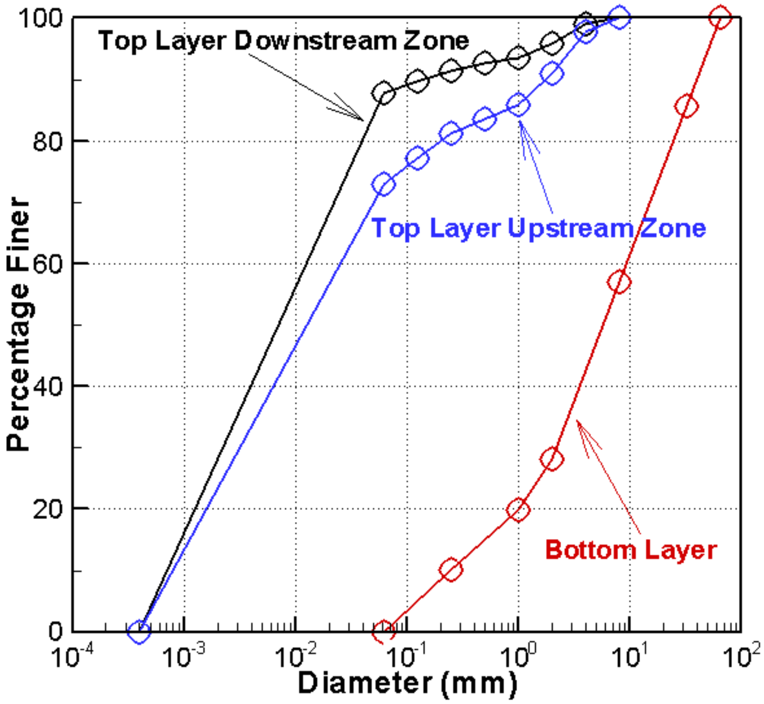


Figure 9-53. Cumulative distribution of the bed sediments for both the top and bottom layers of the Copco 1 Reservoir.

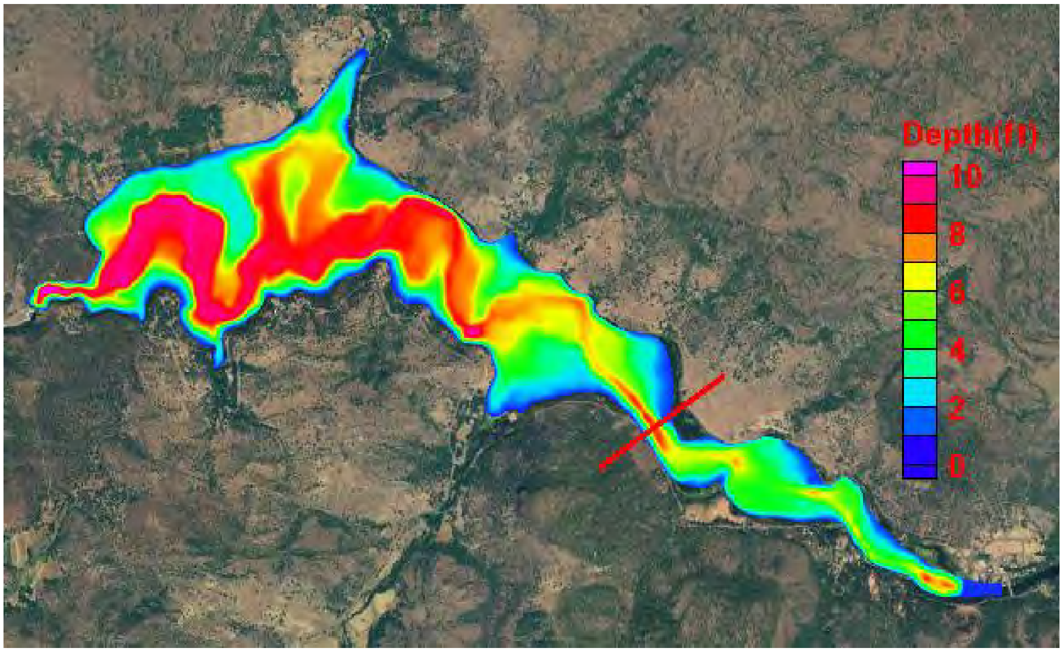


Figure 9-54. Distribution of thickness (ft) of the top bed layer.

9.2.2.2. 2D Modeling Scenarios and Boundary Conditions

Three hydrological scenarios are used for the drawdown simulation, and they represent the flow hydrograph for the Dry Year (2004), Average Year (1968), and Wet Year (1999). Simulation of each scenario starts at November 15 for a duration of six months. The flow discharges into the Copco 1 Reservoir for the three scenarios are shown in Figure 9-55. For the current modeling, the sediment input into the reservoir is assumed to be zero. This assumption is justified as majority of the sediment supply is in the form of the wash load that simply passes through the reservoir. Therefore, the total sediment released downstream may be estimated by simply adding the known sediment supply rate at Copco 1 Dam and the predicted sediment release by the present model together.

Initially, the reservoir is assumed to be filled with water at an elevation of 2,603 feet. Drawdown starts on November 15 through release of water at the exit gate. The release is at a maximum drawdown rate of 3.0 ft/day, subject to the constraint of the gate capacity as shown in Figure 9-56 for the discharge capacity curve. The drawdown discharge required to achieve the 3.0 ft/day rate is determined using the reservoir storage capacity curve as shown in Figure 9-57.

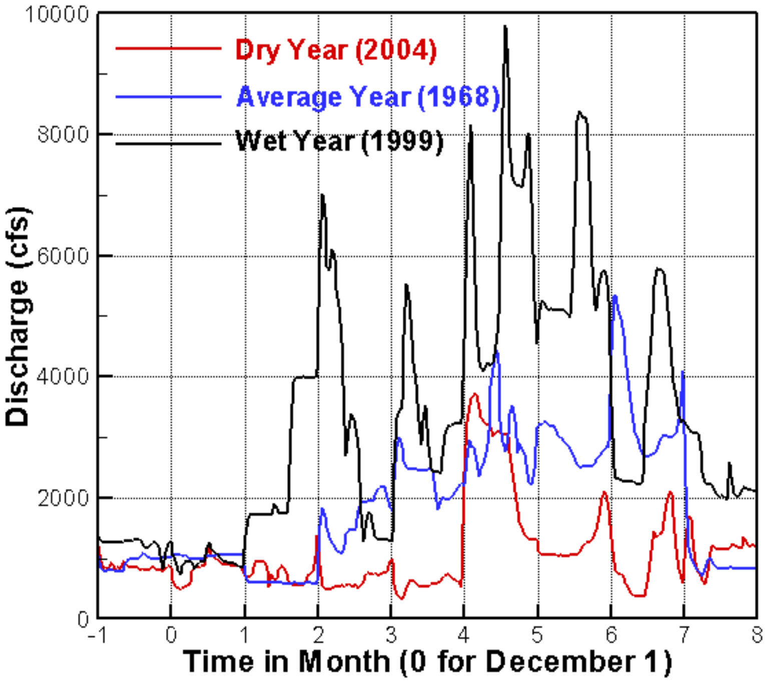


Figure 9-55. Flow discharges of three hydrological scenarios: Dry (2004), Average (1869) and Wet (1999) years for the Copco 1 Reservoir (-1 for November, 0 for December, etc.).

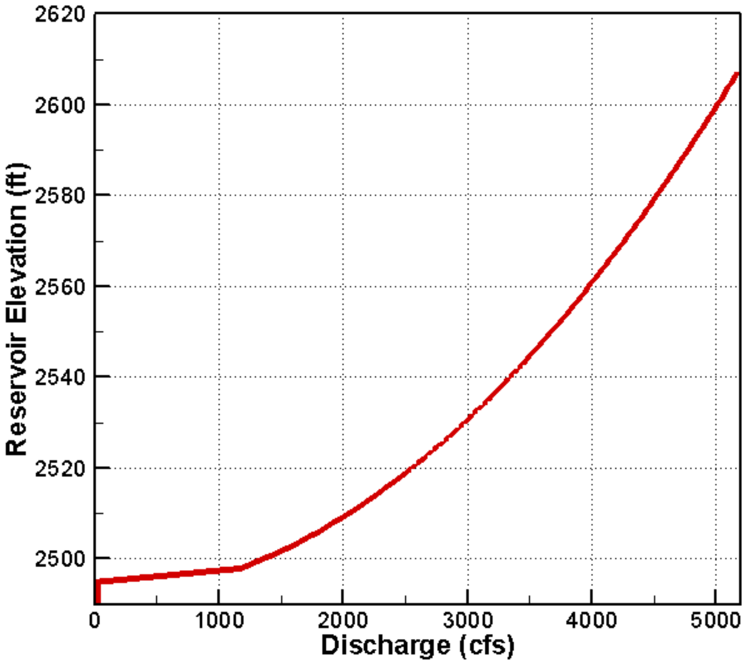


Figure 9-56. The discharge capacity curve of the gate at the exit for drawdown.

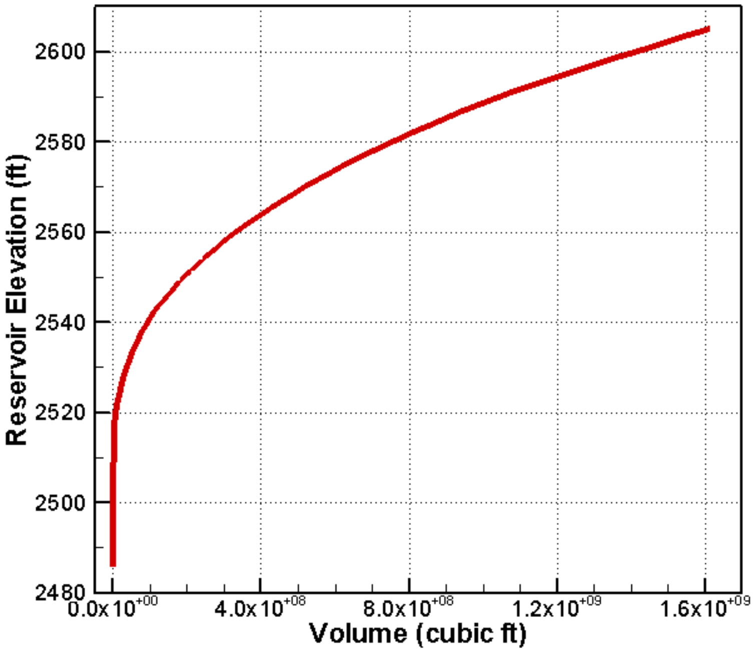


Figure 9-57. The storage capacity curve of the Copco 1 Reservoir.

A total of seven sediment size classes are used to represent the sediment and the partition is tabulated in Table 9-2. Note that size class 1 is reserved to model the cohesive material in the reservoir, while the remaining sediments are non-cohesive.

Table 9-2. Size ranges of each sediment size class

Sediment Size Class	Size Range (mm)
1	Cohesive
2	.0625 to .125
3	.125 to .5
4	.5 to 2
5	2 to 8
6	8 to 32
7	32 to 128

Each sediment size class (*k*) obeys the following mass conservation equation:

$$\frac{\partial hC}{\partial t}+\frac{\partial \cos(\alpha)V_t hC}{\partial x}+\frac{\partial \sin(\alpha)V_t hC}{\partial y}=S_E \qquad (1)$$

where C is the depth-averaged sediment concentration, *h* is water depth, *t* is time, *x* and *y* are two horizontal Cartesian coordinates, respectively, V_t is the depth-averaged total flow velocity, α is the angle of sediment transport direction relative to the *x*-axis, and S_E is the sediment exchange term between the total sediment load and the active layer. Specific models for a number of variables in the above equation will not be discussed, and they have been discussed by Greimann et al. (2008). Only the sediment exchange term needs some discussion. For a non-cohesive sediment size class, the exchange term is written as:

$$S_E = \frac{1}{L_{tot}}(q^*_{tot} - V_t hC) \qquad (2)$$

where L_{tot} is the adaptation length of the total load and q^*_{tot} is the equilibrium transport capacity for the total load transport rate. The Engelund-Hansen capacity equation was used for the current study. For the cohesive sediment class, sediment exchange between is affected through the following:

$$S_E = V_e\, p_k - V_d\, C \qquad (3)$$

where V_e and V_d are the rate of erosion and deposition, respectively, and p_k is the percentage of size class *k* on the bed.

In this study, the measured data are used for the parameters in the above equations. According to the measured data of the USDA Agricultural Research Service (Simon et al, 2010), the erosion rate may be computed by $V_e = k(\tau_b - \tau_{cri})$, with the measured k and τ_{cri} in the following range: $k(cm^3 / N - s) = 0.5, 2.0, 20.0$, respectively, for the minimum, medium, and maximum values; and $\tau_{cri}(Pa) = 0.2, 0.25, 2.0$, respectively, for the minimum, medium, and maximum values. Three sets of parameters are used for each hydrological scenario modeled, and they are designated as the easy-erode, medium-erode, and hard-erode cases. The parameter values are defined as follows: easy-erode case values are $\tau_{cri} = 0.2\,Pa$ and $k = 20.0\,cm^3 / N - s$; medium-erode case values are $\tau_{cri} = 0.25\,Pa$ and $k = 2.0\,cm^3 / N - s$; and hard-erode case values are $\tau_{cri} = 2.0\,Pa$ and $k = 0.5\,cm^3 / N - s$.

The deposition rate is based on the fall velocity of the cohesive sediment, and almost zero fall velocity is used in this study.

9.2.2.3. 2D Simulation Results and Discussion

A total of nine simulations are carried out, representing three hydrological scenarios and three reservoir bed material erodibility conditions for each hydrological scenario (i.e., the easy-erode, medium-erode, and hard-erode case). Each simulation starts on November 15 and runs for a duration of six months, ending on May 15 of the next year.

The simulated reservoir water surface elevation variations and flows into and out of the reservoir are displayed in Figure 9-58 through Figure 9-60 for the three hydrological scenarios. The differences between the three bed erodibility cases are so small that only the results from the medium-erode case are plotted. The following conclusions can be drawn:

- With the 3 ft/day maximum drawdown rate and the capacity of the gate at Copco 1 Dam (Figure 9-56), reservoir water elevation can be lowered to below 2,000 feet under all scenarios within one month. However, only under the relatively Dry Year (2004) scenario can the reservoir water level be maintained at the drawdown condition. The reservoir will be filled with water quickly given a Wet Year (1999) scenario.

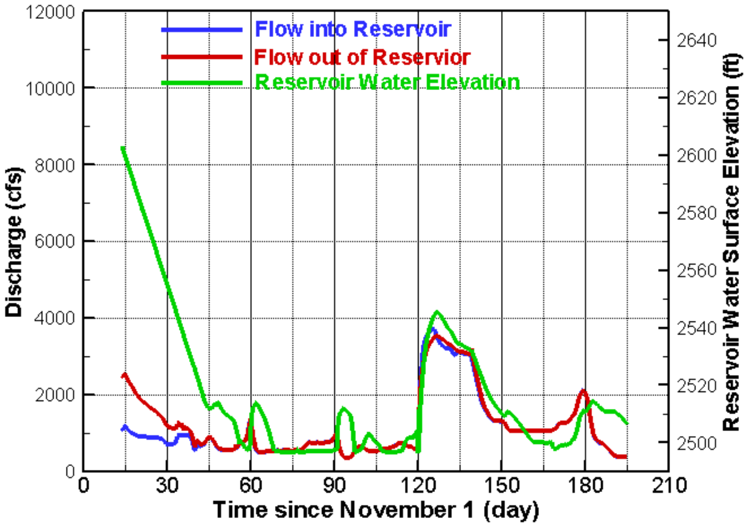


Figure 9-58. Predicted reservoir water elevation and discharge out of the reservoir for the dry year (2004) hydrology scenario and medium-erode case.

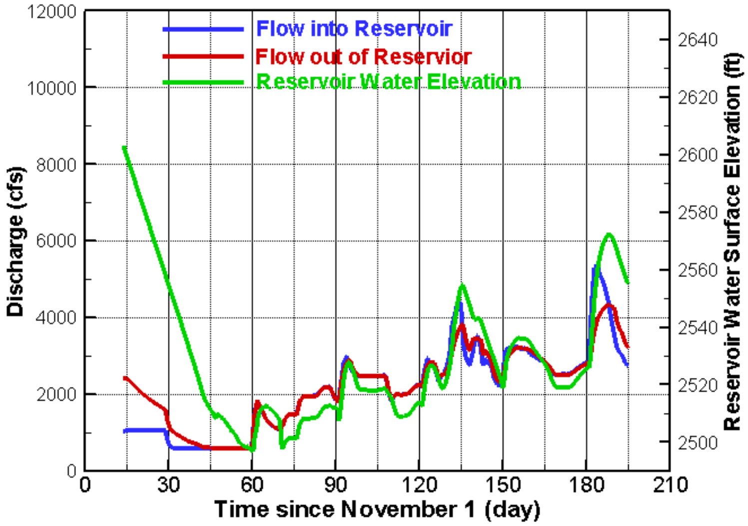


Figure 9-59. Predicted reservoir water elevation and discharge out of the reservoir for the average year (1968) hydrology scenario and medium-erode case.

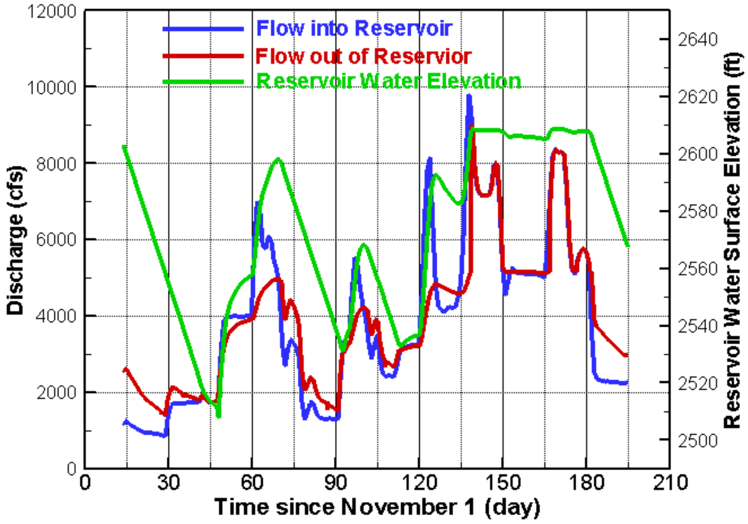


Figure 9-60.Predicted reservoir water elevation and discharge out of the reservoir for the wet year (1999) hydrology scenario and medium-erode case.

Next, the predicted sediment concentration delivered to the downstream out of the reservoir exit gate is plotted in Figure 9-61 for the three hydrological scenarios simulated. The sediment concentrations do not differ much between the dry and average year scenarios. The sediment pulse created by the drawdown has an average of about 6,000 ppm in concentration and duration of about 1.5 months for flows up to the average-year flow hydrograph. The maximum could reach more than 7,000 ppm. For the Wet Year (1999) flow, the average of the sediment pulse is about 4,000 ppm, with the maximum of about 6,000 ppm. After January 1, the sediment concentration falls to a relatively low level of about several hundreds of ppm.

The model results are not sensitive to the range of erodibility parameters used for the reservoir bed cohesive sediment, as demonstrated in the results in Figure 9-62.

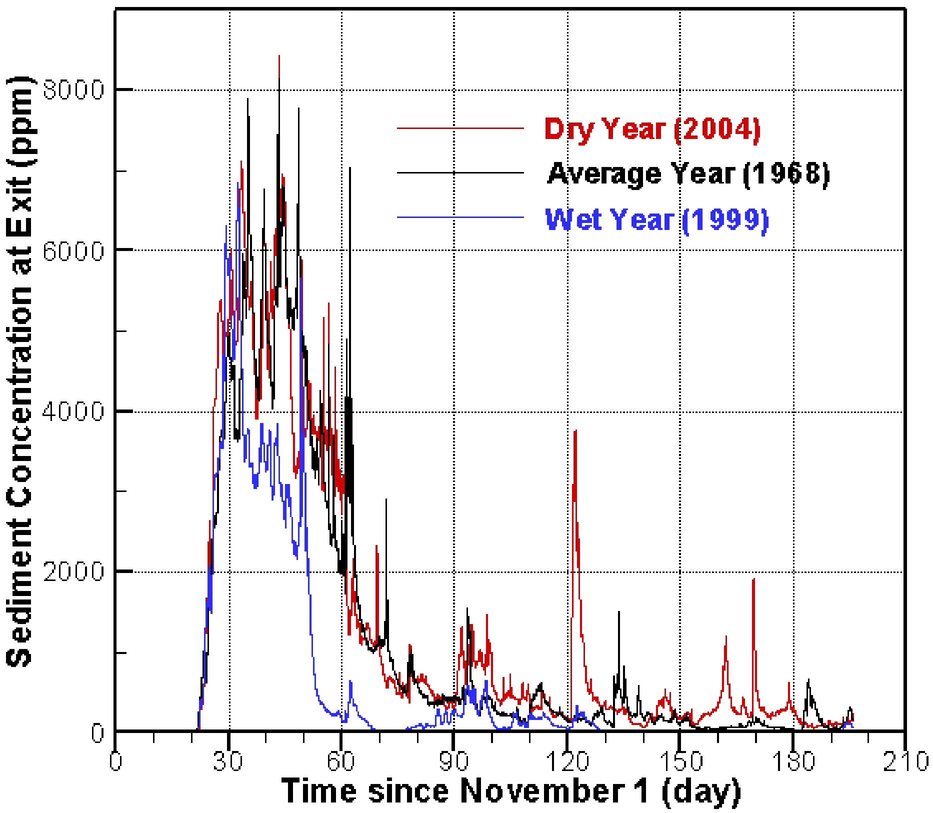


Figure 9-61. Predicted sediment concentration through the drawdown gate during the drawdown of Copco1 Reservoir under three hydrological scenarios.

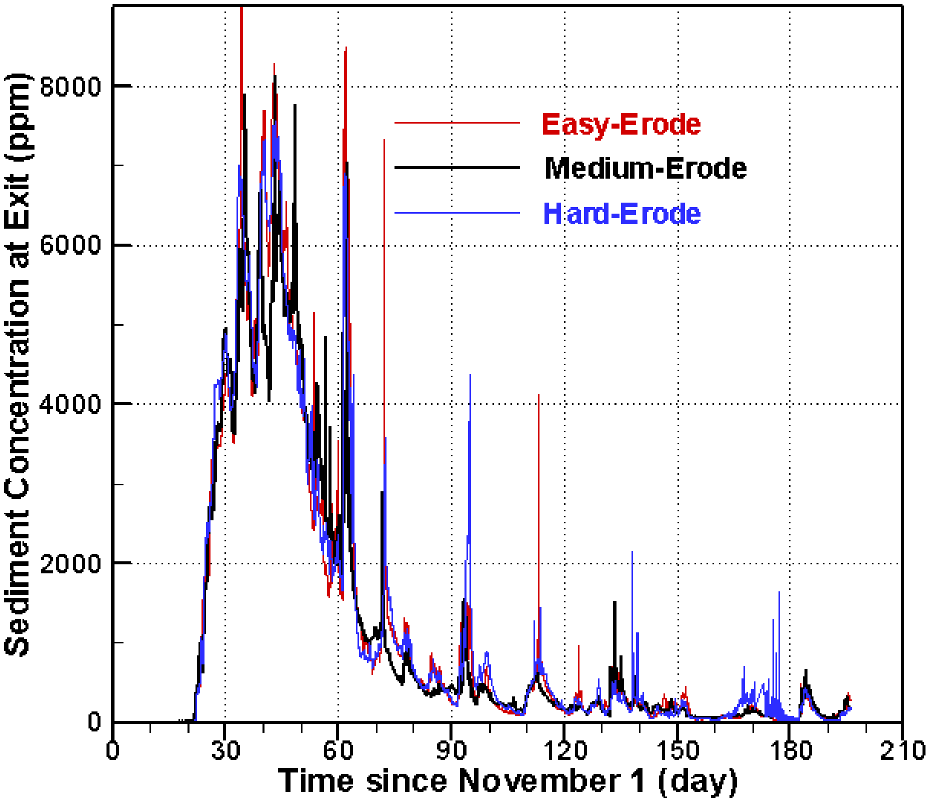


Figure 9-62. Predicted sediment concentration through the drawdown gate during the drawdown of Copco1 Reservoir under the average (1968) hydrological scenario with three bed erodibility cases.

A channel would cut through the reservoir deposit during drawdown as the example shown in Figure 9-63 for the Paonia Reservoir in Colorado. The model correctly predicts the general channel formation process during drawdown of the Copco 1 Reservoir. Two dates are selected to show the erosion, as well as the deposition, of the reservoir. The first date selected is December 29 when the reservoir pool level is approximately near its lowest level, and the second date selected is May 14 at the end of the model simulation (six months after the start of drawdown). The overall erosion pattern is displayed in Figure 9-64., Figure 9-65, and Figure 9-66 for the Dry (2004), Average (1968), and Wet (1999) flows. Furthermore, the solution domain of the Copco 1 Reservoir is divided into five zones, as marked in Figure 9-64. through Figure 9-66, for a more detailed zoom-in view of the model results. A zone-by-zone comparison of the predicted erosion and deposition patterns on December 29 and May 14 for the three hydrologic cases is shown in Figure 9-67 through Figure 9-76. The predicted eroded depth and bed elevation along the thalweg of the incised channel are compared with the initial top bed layer thickness and bed elevation in Figure 9-77 and Figure 9-78. The following conclusions can be drawn based on the model results:

- An incised channel would be formed as a result of the drawdown of the Copco 1 Reservoir. The channel alignment follows approximately the old channel.

- A major portion of the top bed layer deposit within the old channel alignment, which is the input to the model, is eroded during the drawdown period in the first one and half months. It is the case particularly for the upstream half of the solution domain (Figure 9-77). These top bed layer deposits provide most of the suspended sediment delivered to the downstream.

- It is predicted that incision does cut into the bottom bed layer for the upper half of the modeled reach (zone 4 to 6) six months later (Figure 9-77).

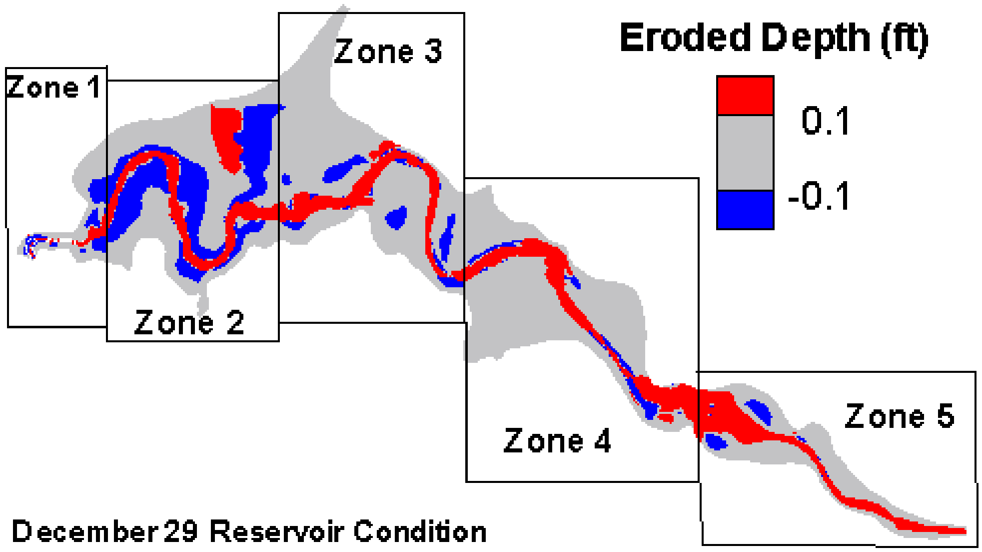
- Some deposition is predicted on the old floodplain area in the lower half of the modeled domain (zone 1 to 3), particularly in the wider area near the dam.

- For the area just upstream of the dam (e.g., zone 1 and 2), channel incision decreases with increasing flow into the reservoir; but the trend is reversed in zone 4 and 5 where incision increases with increasing flow.

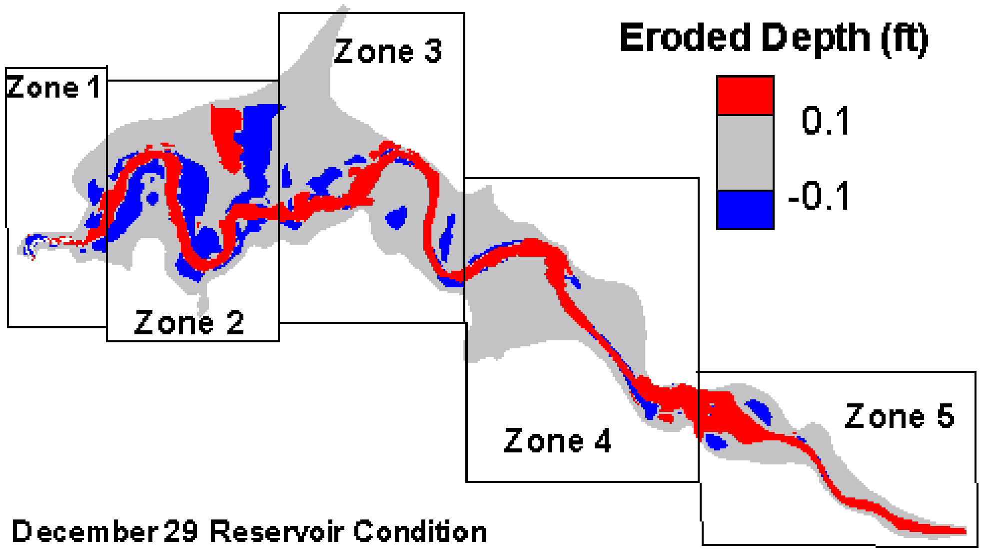
- The deposition near the drawdown gate in zone 1 may be unrealistic given that: (1) only a depth-averaged model is used, but flow is three-dimensional; and (2) flow at the gate is a type of “pressurized flow” while the model assumed an “open channel flow.” In fact, the bed near the gate is more probably erosional, not depositional. However, the inaccuracy of the erosion prediction in this area will not have much impact to the results upstream.

It is cautioned that there are uncertainties with regard to the model prediction. Major uncertainty is related to the bank erosion that is not included in the model. Therefore, the eroded material sent downstream may be underestimated. Also, the predicted channel may be narrower and deeper than what actually would happen, especially for upstream zones (e.g., zones 3 to 5).

Figure 9-63. A photo of Paonia Reservoir in Colorado after the reservoir is drawn down showing how a channel incised through a portion of the reservoir sediments .

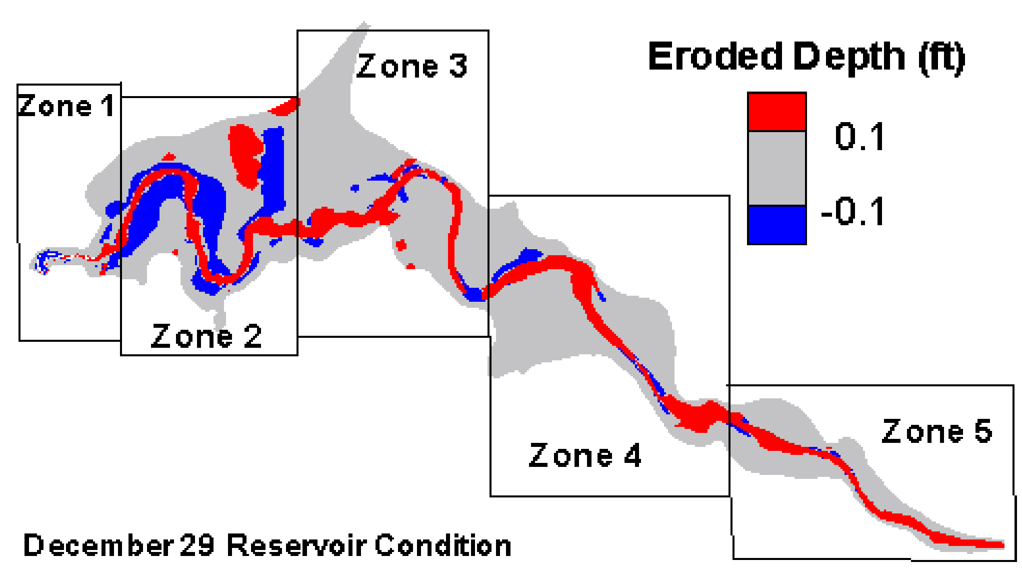


(a) On December 29

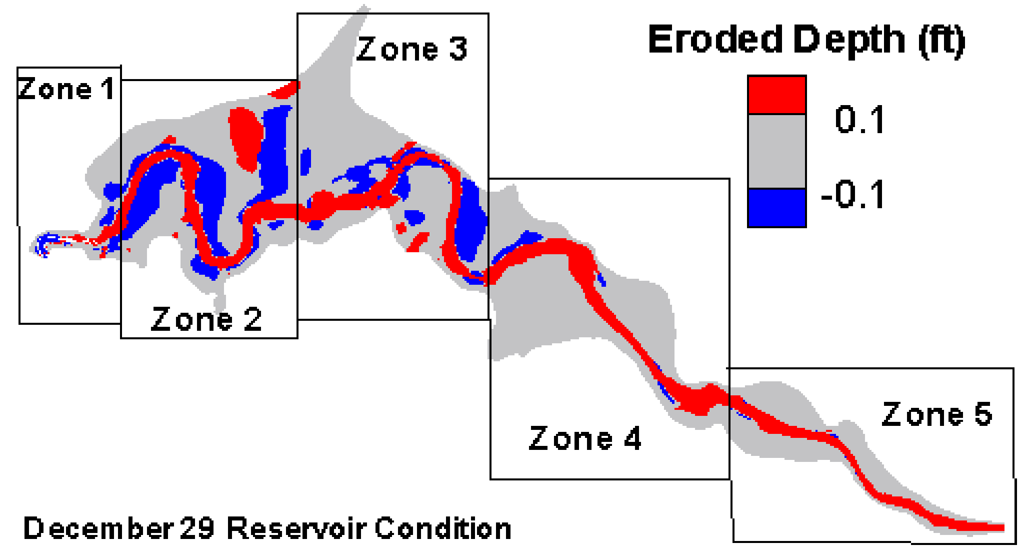


(b) On May 14

Figure 9-64. Predicted erosion/deposition pattern on two dates during the drawdown of Copco 1 Reservoir under the Dry (2004) hydrological scenario – overall view.

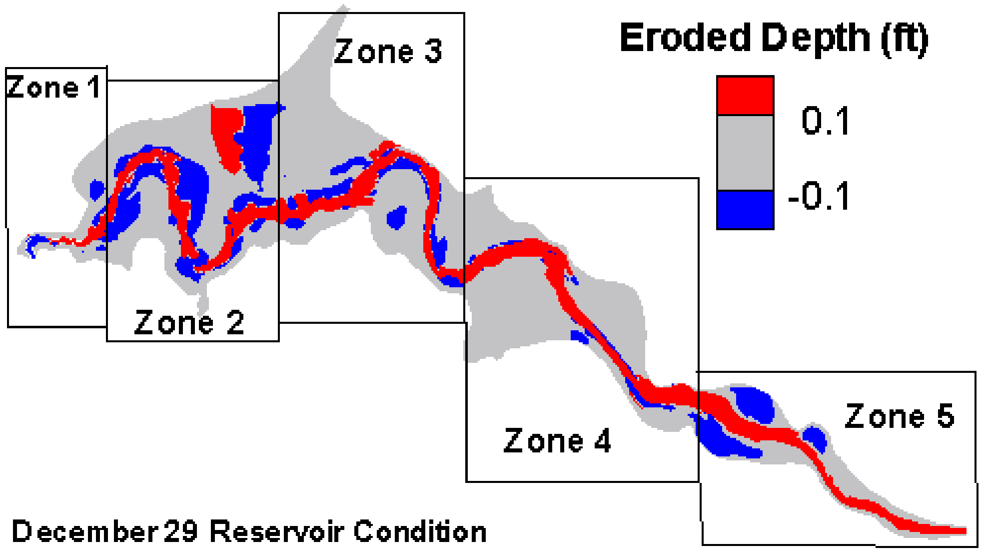


(a) On December 29

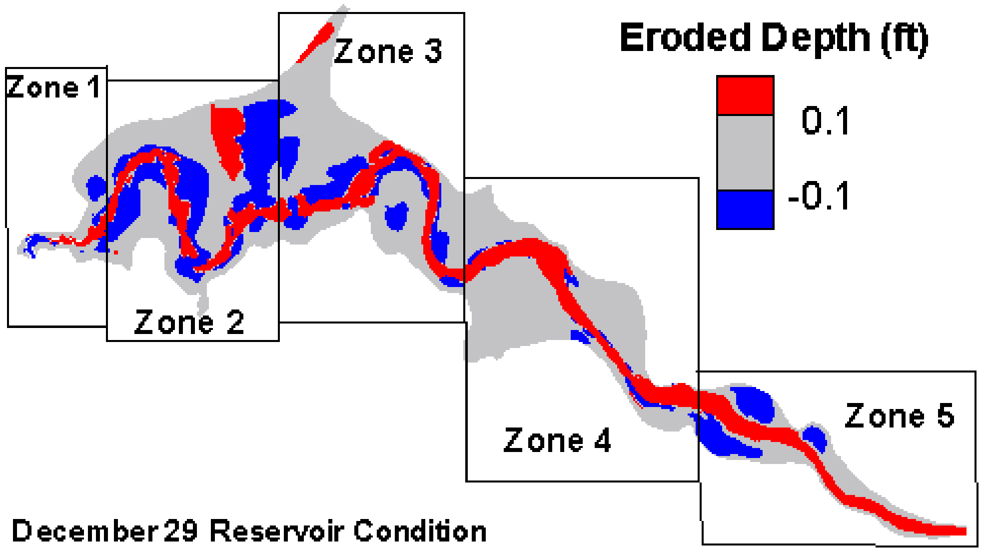


(b) On May 14

Figure 9-65. Predicted erosion/deposition pattern on two dates during the drawdown of Copco 1 Reservoir under the average (1968) hydrological scenario – overall view.

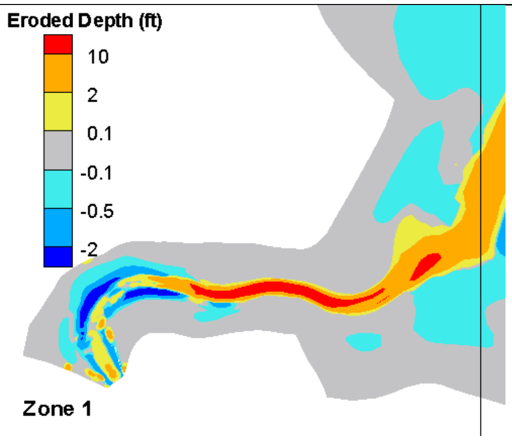


(a) On December 29

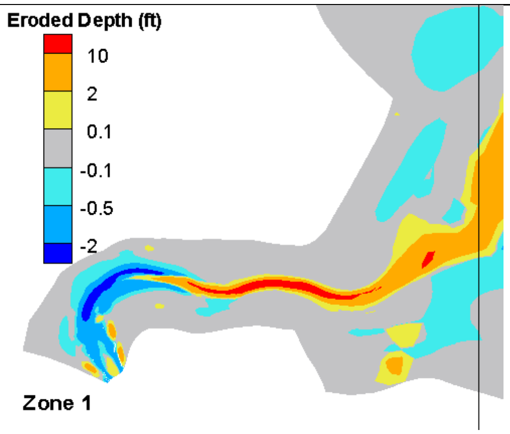


(b) On May 14

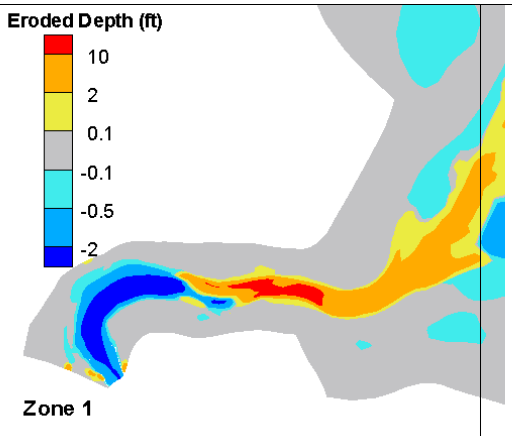
Figure 9-66. Predicted erosion/deposition pattern on two dates during the drawdown of Copco 1 Reservoir under the wet (1999) hydrological scenario – overall view.



(a) Dry Year (2004)

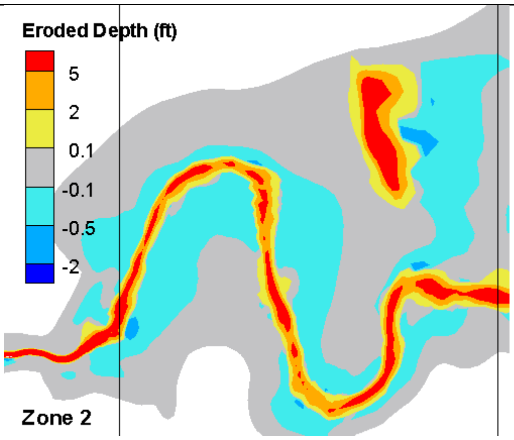


(b) Average Year (1968)

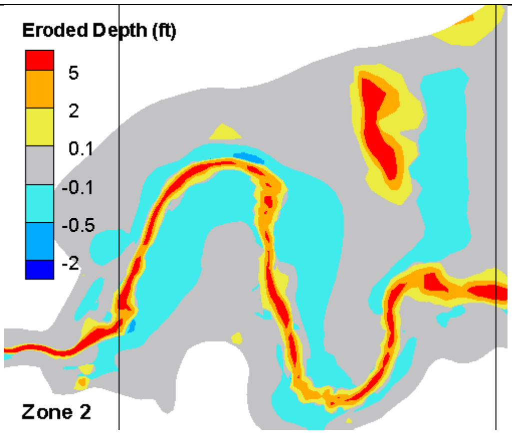


(c) Wet Year (1999)

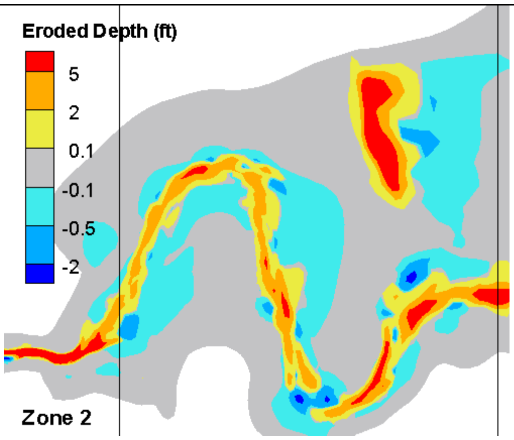
Figure 9-67. Predicted erosion/deposition pattern in zone 1 on December 29 during the drawdown of Copco 1 Reservoir under three hydrological scenarios.



(a) Dry Year (2004)

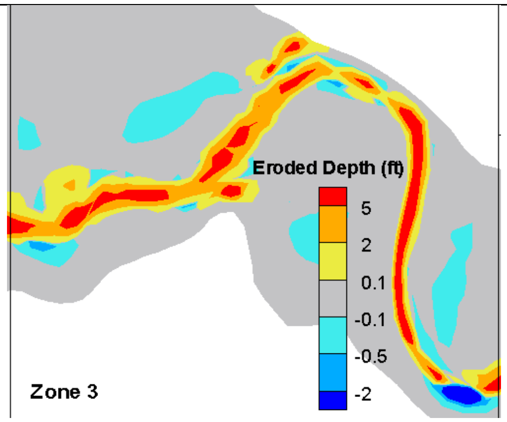


(b) Average Year (1968)

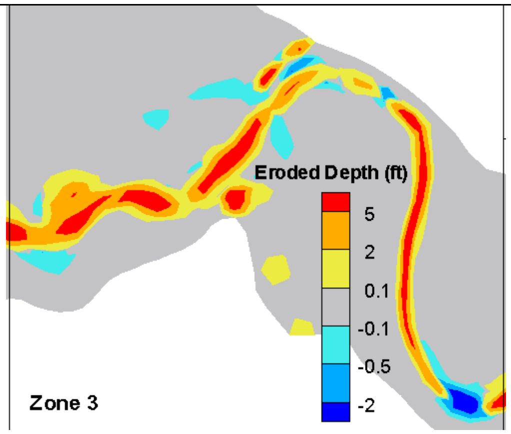


(c) Wet Year (1999)

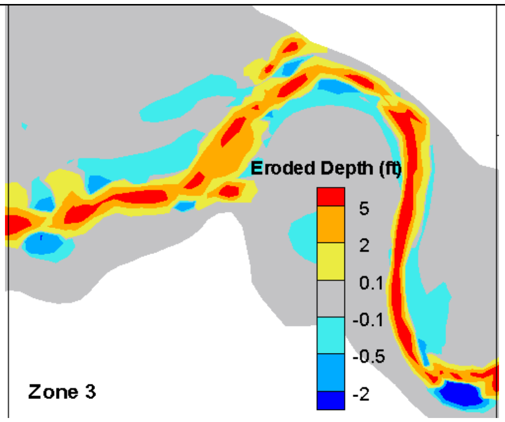
Figure 9-68. Predicted erosion/deposition pattern in zone 2 on December 29 during the drawdown of Copco 1 Reservoir under three hydrological scenarios.



(a) Dry Year (2004)

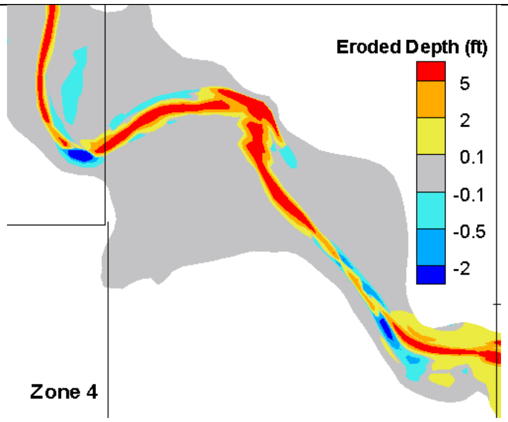


(b) Average Year (1968)

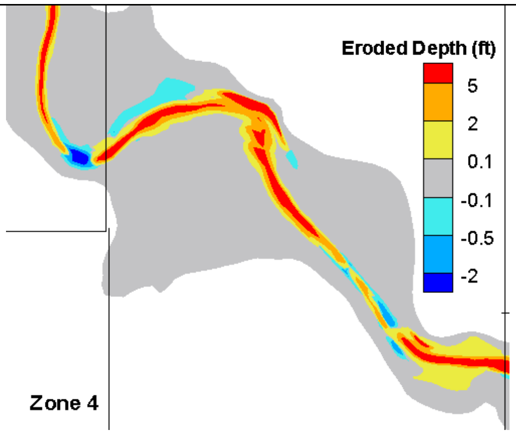


(c) Wet Year (1999)

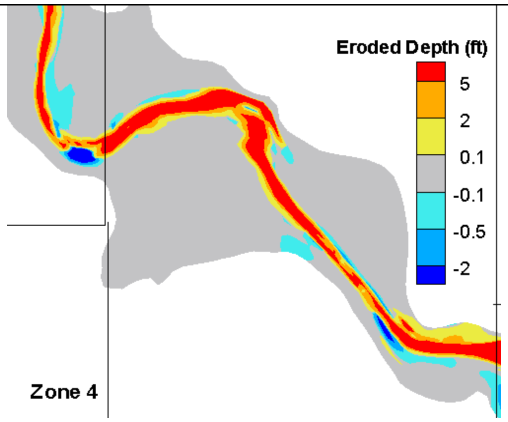
Figure 9-69. Predicted erosion/deposition pattern in zone 3 on December 29 during the drawdown of Copco 1 Reservoir under three hydrological scenarios.



(a) Dry Year (2004)

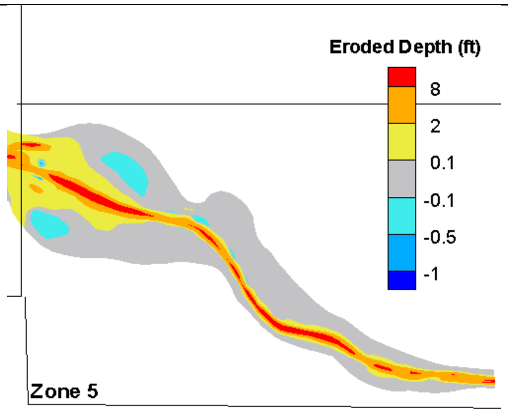


(b) Average (1968)

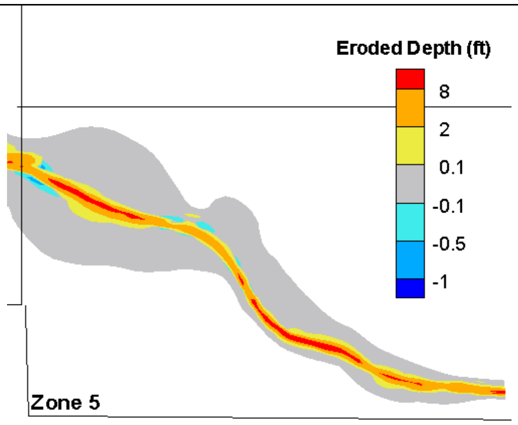


(c) Wet Year (1999)

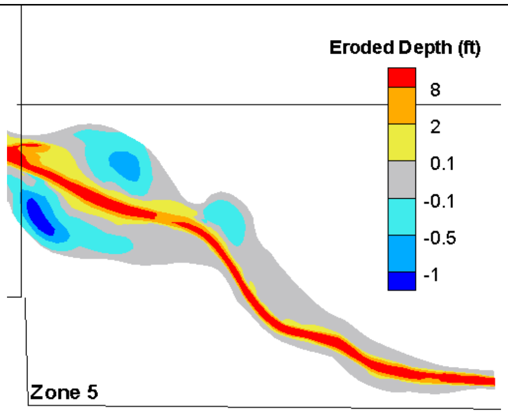
Figure 9-70. Predicted erosion/deposition pattern in zone 4 on December 29 during the drawdown of Copco 1 Reservoir under three hydrological scenarios.



(a) Dry Year (2004)

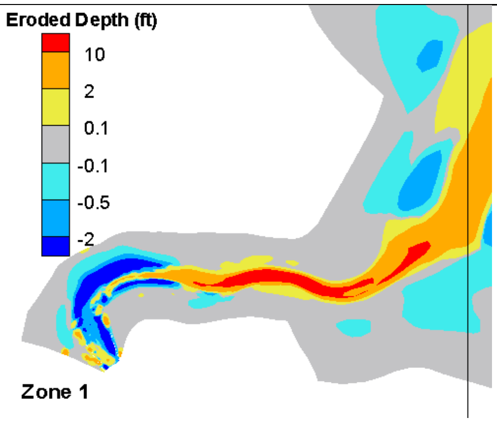


(b) Average Year (1968)

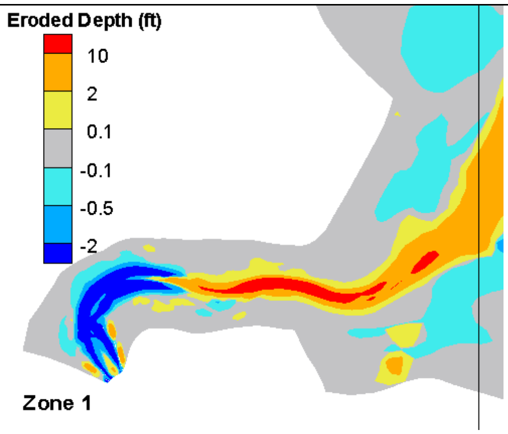


(c) Wet Year (1999)

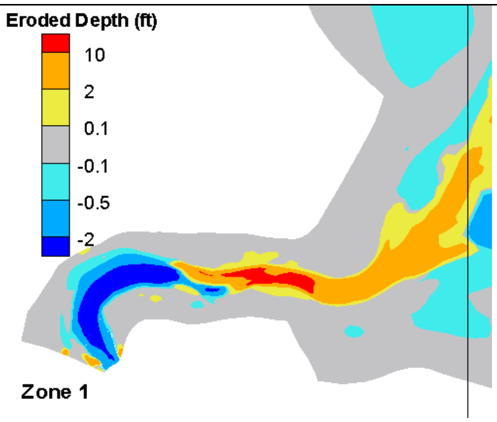
Figure 9-71. Predicted erosion/deposition pattern in zone 5 on December 29 during the drawdown of Copco 1 Reservoir under three hydrological scenarios.



(a) Dry Year (2004)

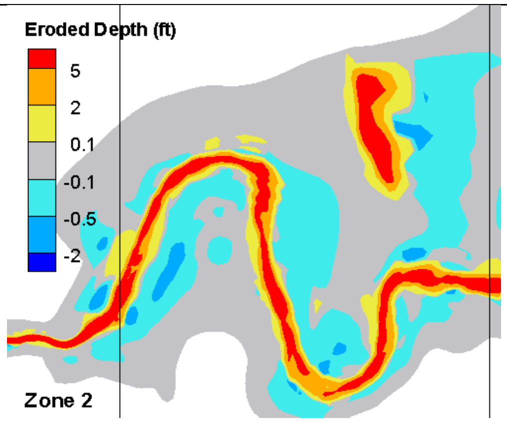


(b) Average Year (1968)

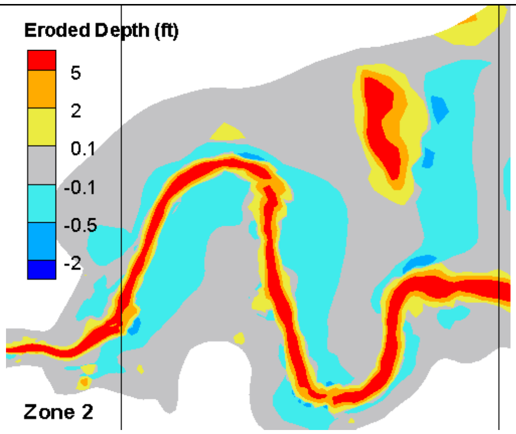


(c) Wet Year (1999)

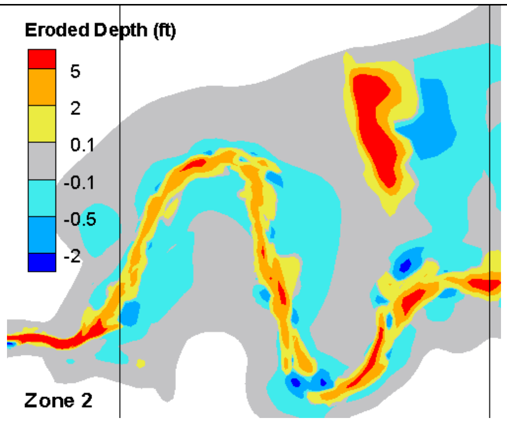
Figure 9-72. Predicted erosion/deposition pattern in zone 1 on May 14 during the drawdown of Copco 1 Reservoir under three hydrological scenarios.



(a) Dry Year (2004)

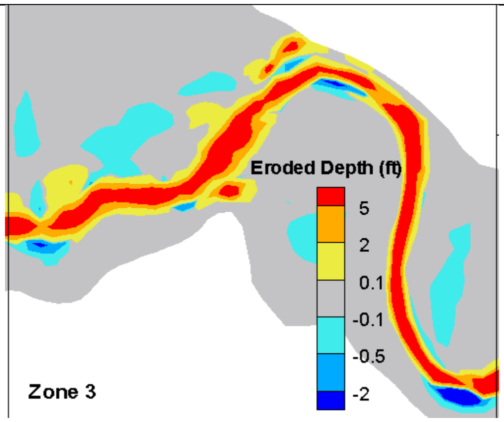


(b) Average Year (1968)

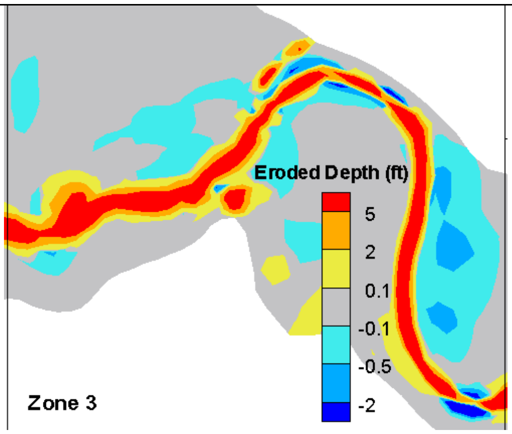


(c) Wet Year (1999)

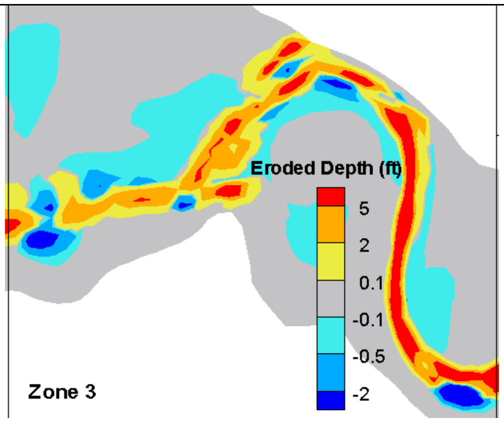
Figure 9-73. Predicted erosion/deposition pattern in zone 2 on May 14 during the drawdown of Copco 1 Reservoir under three hydrological scenarios.



(a) Dry Year (2004)

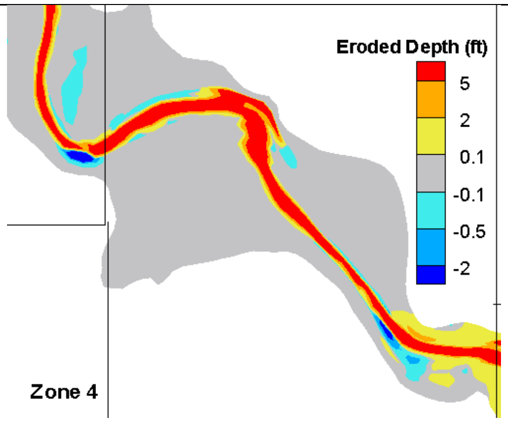


(b) Average Year (1968)

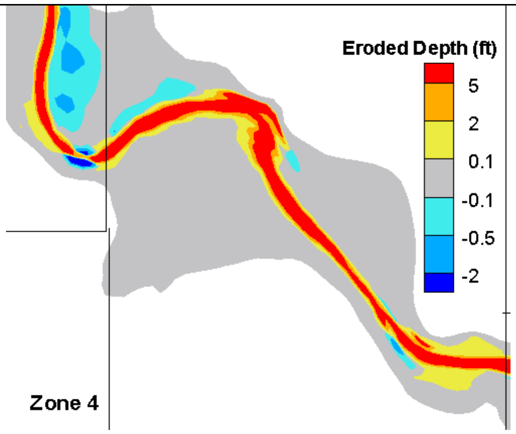


(c) Wet Year (1999)

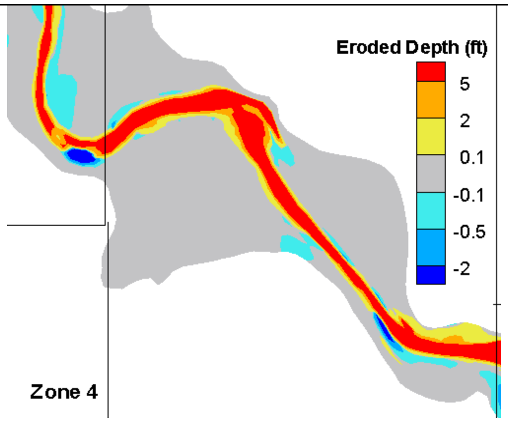
Figure 9-74. Predicted erosion/deposition pattern in zone 3 on May 14 during the drawdown of Copco 1 Reservoir under three hydrological scenarios.



(a) Dry Year (2004)

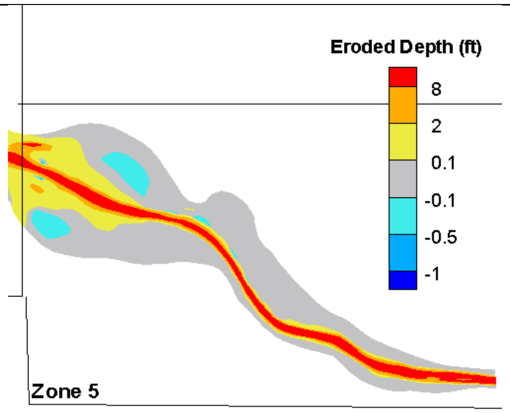


(b) Average Year (1968)

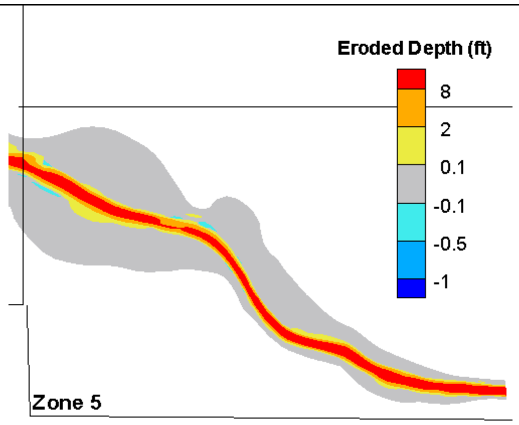


(c) Wet Year (1999)

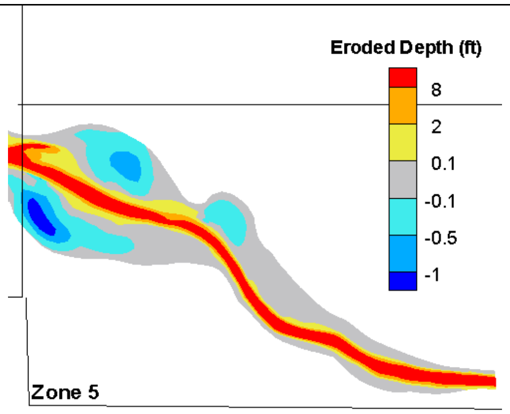
Figure 9-75. Predicted erosion/deposition pattern in zone 4 on May 14 during the drawdown of Copco 1 Reservoir under three hydrological scenarios.



(a) Dry Year (2004)



(b) Average Year (1968)



(c) Wet Year (1999).

Figure 9-76. Predicted erosion/deposition pattern in zone 5 on May 14 during the drawdown of Copco 1 Reservoir under three hydrological scenarios.

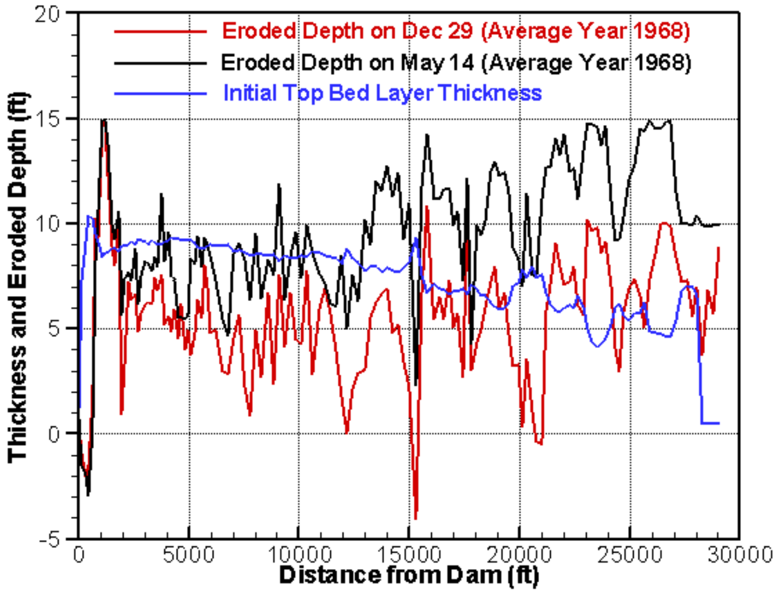


Figure 9-77. Predicted eroded depth along the thalweg of the incised channel on December 29 and May 1 (average year scenario and medium-erode case), which is compared with the initial thickness of the top bed layer deposit.

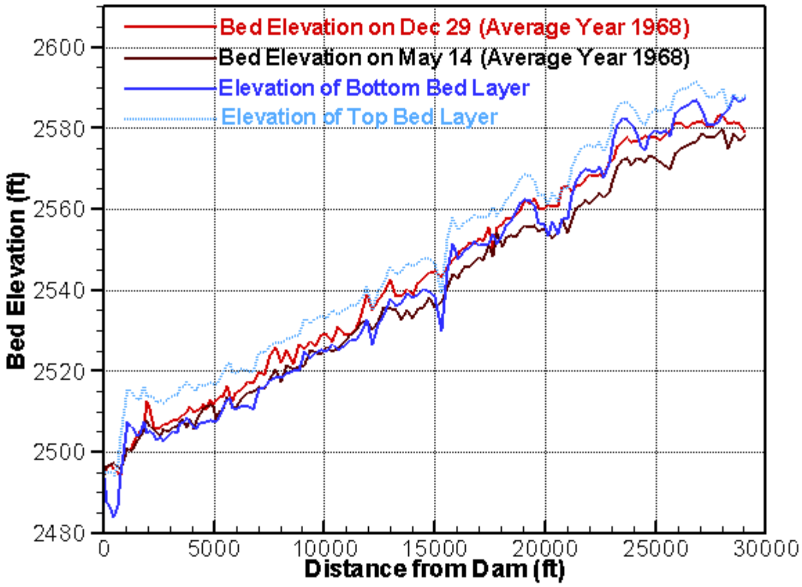


Figure 9-78. Predicted bed elevation along the thalweg of the incised channel on December 29 and May 14 (average year and medium-erode case), which is compared with the initial top and bottom bed layer elevations.

9.2.3. FUTURE BED MOBILIZATION DOWNSTREAM OF IRON GATE DAM

The bed material gradation results of the 50-year SRH-1D simulation were used to assess future bed mobility 10 years after dam removal in 2030 under the No Action and Dam Removal Alternatives. An identical analysis to that presented in Section 5.5 was performed using the predicted median particles size in year 2030 under the No Action and Dam Removal Alternatives. The only difference is that the median bed material sizes were altered based upon the 50-year simulations. The median particle sizes were given in the previous section. The resulting estimates of the initiation of bed mobilization flows and return period of those flows are given in Figure 9-79 and Figure 9-80. A range of estimates are given based upon the variation in the reference shear stress for mobilization being 0.025 to 0.035. It should be noted that when comparing alternatives, one should use the same reference shear stress in the comparison. For example, one should not use a reference shear stress of 0.025 for the No Action Alternative and a reference shear stress of 0.035 for the Dam Removal Alternative.

The comparison shows that the main effect of dam removal on bed mobilization will be from Iron Gate Dam to Cottonwood Creek (USGS RM 190 to RM 182). After Dam Removal, the median estimate of the mobilization flow will reduce from approximately 10,000 cfs to 6,000 cfs in the Bogus Creek to Willow Creek Reach (RM 189.7 to RM 185). In the Willow Creek to Cottonwood Creek reach, the median estimate of the mobilization from will reduce from about 11,000 cfs to 6,000 cfs. The return period of mobilization in this reach will decrease from 4 years to approximately 2 years. Downstream of Shasta River there will be essentially no effect of dam removal on bed mobilization.

Reduced mobilization of bed material under the No Action Alternative will generally result in more stable bed features and the existing bars will become more densely vegetated. More stable features also typically result in less complex habitat. As banks become more stable because of vegetation growth, the diversity of depth can be lost as the bars that create edge and fringe habitat become higher as the vegetation traps more sediment. This process has been documented on the adjacent Trinity River and gravel augmentation schemes are being implemented to increase bed mobilization. It is expected that the reach between Iron Gate and Cottonwood Creek will have improved habitat function under the Dam Removal Alternative than under the No Action Alternative.

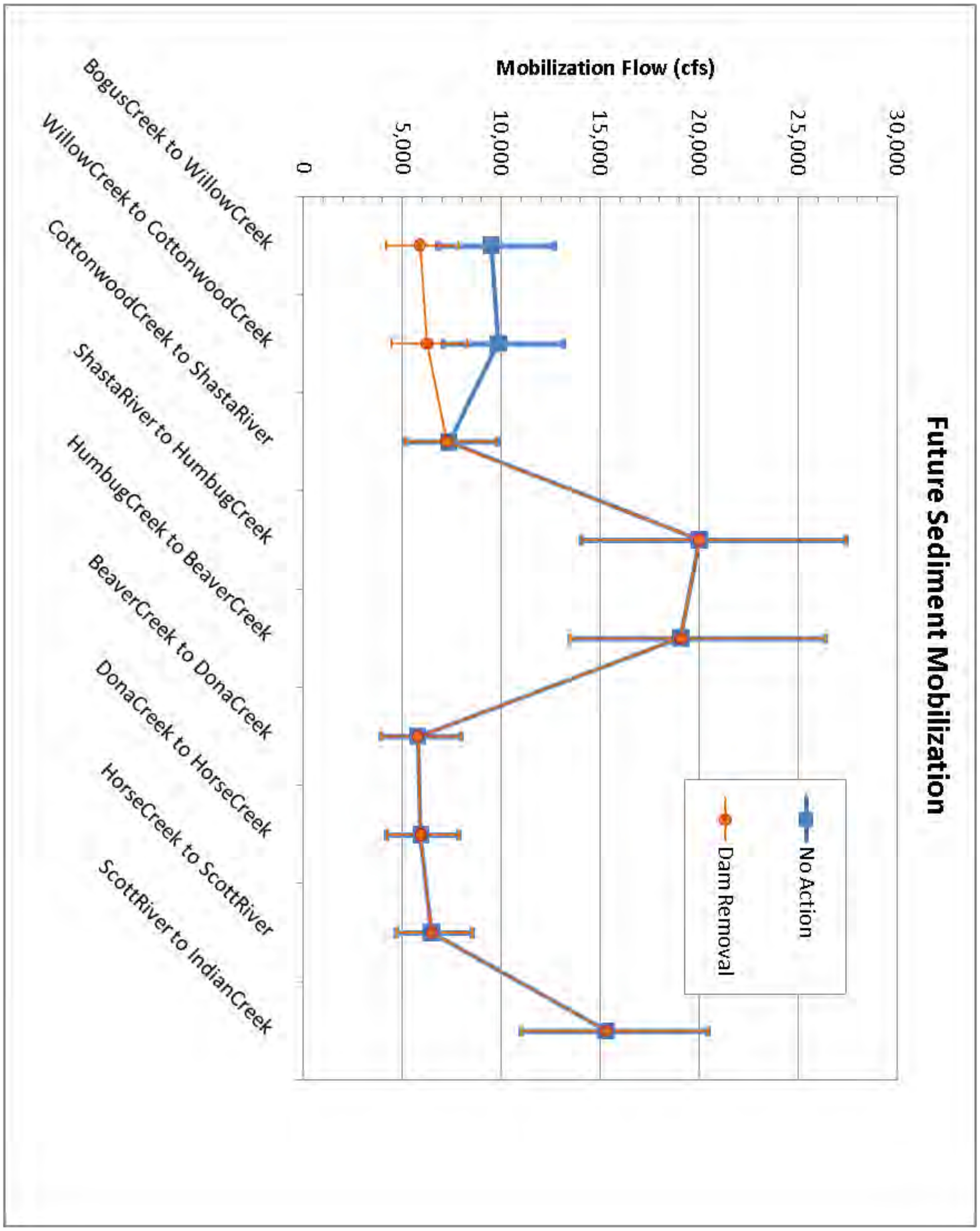


Figure 9-79. Future estimate of initiation of sediment mobilization flows under Dam Removal and No Action Alternatives.

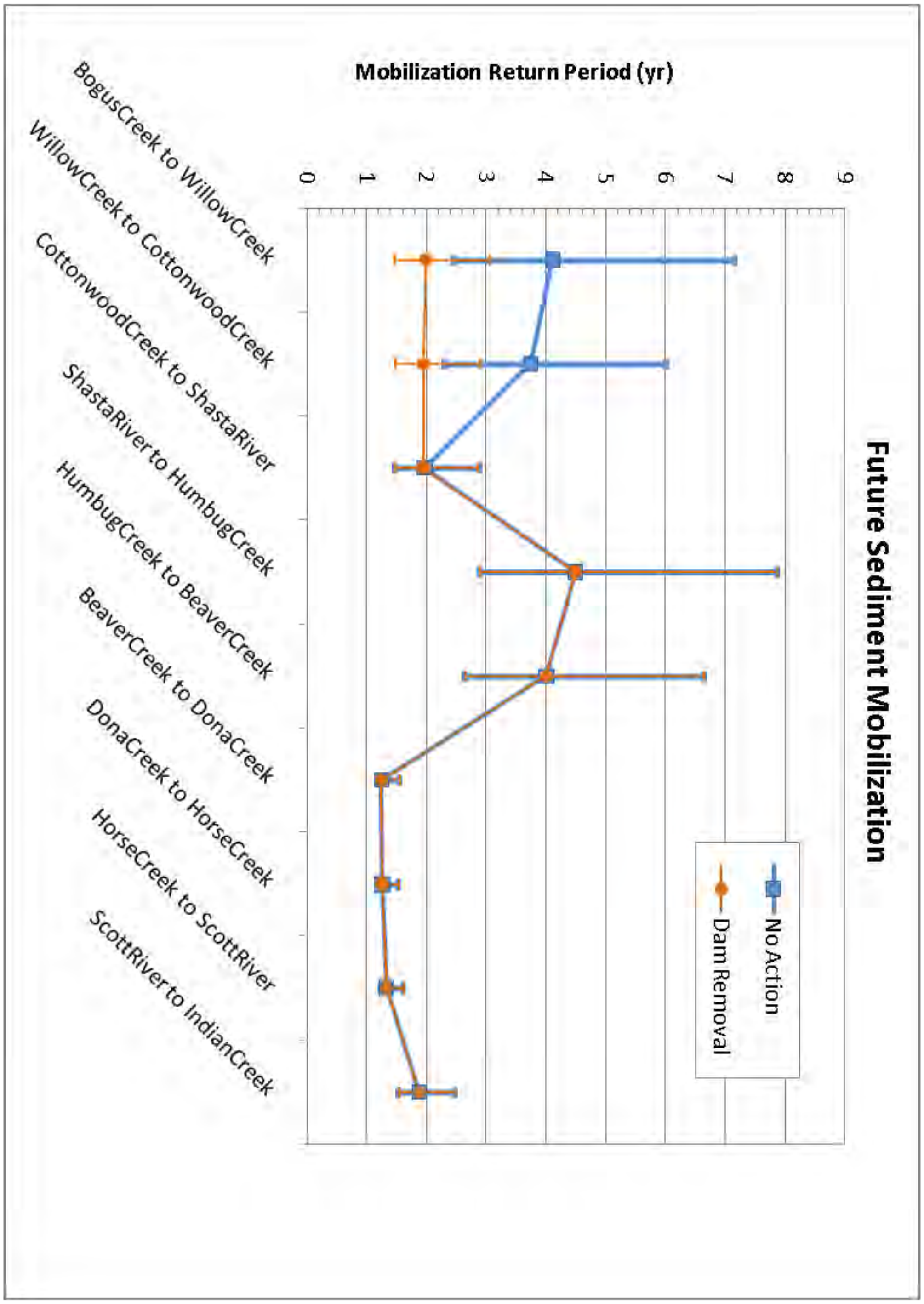


Figure 9-80. Return Period of Mobilization flow under No Action and Dam Removal Alternatives.

9.2.4. WATER QUALITY CONSIDERATIONS DURING DRAWDOWN

One consideration in the drawdown of the reservoirs is the water quality of the reservoirs at the time of drawdown. PacifiCorp (2004) states that Copco and Iron Gate reservoirs are stratified from March to Mid-November. Based upon the yearly water quality summary reports from Raymond (2007, 2008, and 2010) and Figure 3.8-5 in PacifiCorp (2004b), Copco Reservoir turns over in middle to late October and Iron Gate Reservoir in mid-November.

Table 9-3. Date of measured non-stratified conditions at Copco and Iron Gate reservoirs based upon Raymond (2008, 2009, 2010).

Year	Copco	Iron Gate
2009	Oct 13	Nov 17
2008	Oct 22	Nov 19
2007	Oct 23	Nov 28

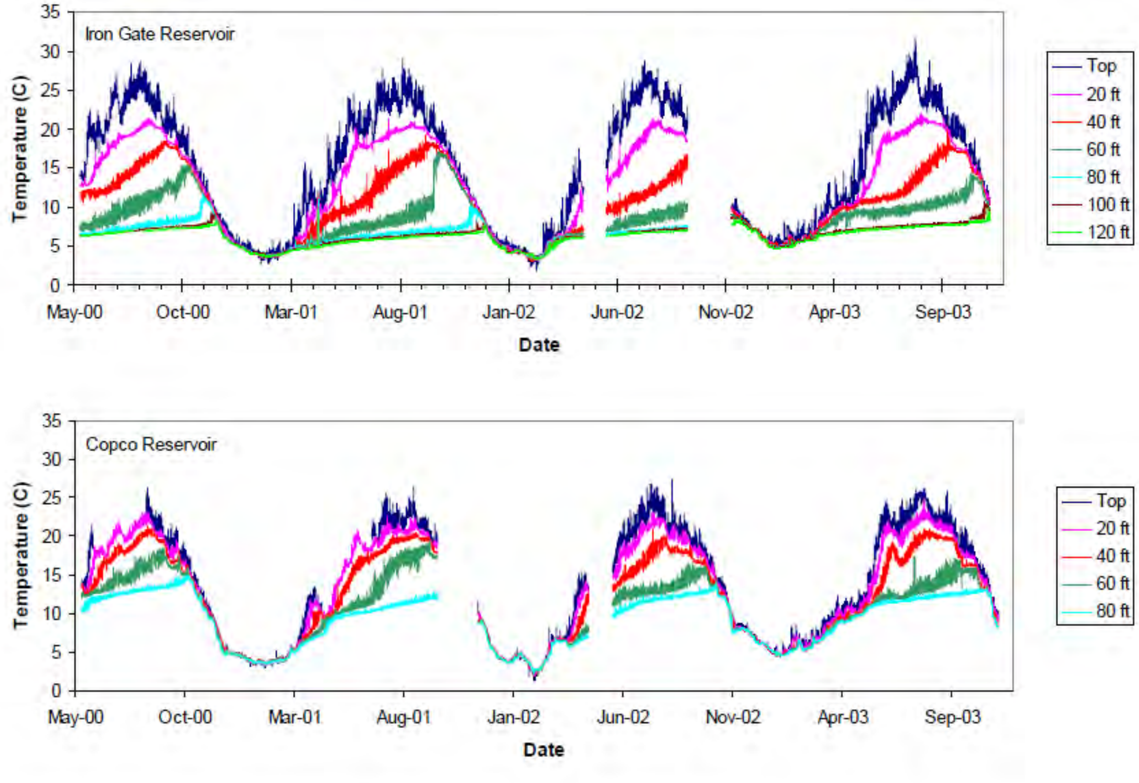


Figure 3.8-5. Hourly water temperature measurements from Copco (top) and Iron Gate (bottom) reservoirs.

Figure 9-81. Temperature profiles from PacifiCorp (Figure 3.8-5 in Water Resources Technical Appendix, PacifiCorp, 2004).

9.2.5. SUGGESTED MONITORING

The Dam Removal Alternative will require extensive monitoring of impacts to ensure that the impacts associated with removal are consistent with the expected impacts. A brief outline of the suggested monitoring objectives would be:

1. To determine the quantity and particle size distribution of sediment supplied to the downstream channel, the rate of downstream movement, and location of sediment accumulation in the channel and/or floodplain;

2. To determine the changes to the water surface elevation of a given discharge along the reach from Iron Gate Dam to Shasta River;

3. To determine the erosion and evolution of material in the reservoir region; and

4. Evaluate the condition of aquatic and riparian habitat in the Klamath River from J.C. Boyle Dam to the Ocean.

To meet these objectives the following activities are suggested:

1. Continued operation of all existing Klamath Basin stream gages to monitor flow discharge.

2. Suspended sediment measurements at the Keno, Iron Gate, Seiad Valley, Orleans and Klamath stream gages. This would begin 2 years prior to dam removal and continue at least 5 years after dam removal.

3. Bed material monitoring from upstream of J.C. Boyle to the Scott River. There would be at least one sampling trip prior to dam removal followed by every year after dam removal for 5 years. The purpose would be to monitor the content of fine material in the bed and to monitor changes to the coarse bed material.

4. Aerial Photography the year prior to dam removal and in years 1, 2, 5, and 10 after dam removal.

5. Detailed reservoir bathymetric surveys prior to dam removal followed by detailed topographic surveys in the reservoir in years 1, 2, and 5 after dam removal.

6. Channel bathymetric surveys from Iron Gate Dam to the Shasta River.

7. Monitoring of water surface elevations at several locations between Iron Gate Dam and the Shasta River.

9.2.6. SUMMARY

The sediment stored in the PacifiCorp Reservoirs is predominantly silt, clay and organic material that is 80 to 90 % water and highly erodible. Drawdown of the four PacifiCorp Dams will release approximately 1/3 to 2/3 of the approximately 15 million yd^3 of sediment that will be stored in the reservoirs by 2020. If there is a wet year, more material will be eroded and if there is a dry year, less material will be eroded from the reservoirs. The river will return to its pre-dam alignment at each reservoir and have a similar width to pre-dam conditions. The sediment that is left behind in the reservoirs will raise the floodplain terraces above the pre-dam conditions and the floodplains are expected to be inundated less frequently than typical floodplains. High flows will gradually widen the floodplain, but this process is expected to occur slowly over several decades.

Over 80 % of the reservoir sediment is fine sediment (silt, clays, and organics). Most of this material will be transported to the ocean during the period of drawdown which will last from January 1, 2020 to mid March, 2020. The maximum sediment concentrations during this period may be more than 10,000 mg/l downstream of Iron Gate. The tributaries entering Klamath River will significantly reduce these concentrations to less than 2,000 mg/l at the mouth of the Klamath River.

If there is a wet year, it may take longer to drain Iron Gate Reservoir because of its limited outlet capacity and there may be sediment concentrations larger than 1,000 mg/l as late as June. If there is a dry year, the sediment concentration will be higher during the drawdown period because of less dilution of sediment by the flow.

Sediment concentrations are expected to resume to background levels by the end of the summer 2020 regardless of type of hydrology present. There will be aggressive hydro seeding of the reservoir material immediately following dam removal which will stabilize the sediment from erosion due to rainfall. In addition, the reservoir sediment dramatically increases its resistance to erosion once it dries out.

The bed material within the reservoirs and between Iron Gate to Cottonwood Creek is expected to have a high content (30 to 50 %) of sand immediately following reservoir drawdown until a flushing flow moves the sand sized material out of the reach. The flushing flow is expected to have to be at least 6,000 cfs and of several days to weeks to return the bed to bed dominated by cobble and gravel with a sand content less than 20%. After the flushing flow, the bed is expected to maintain fractions of sand, gravel, and cobble which would be expected under natural conditions.

The mobility of the bed downstream of Iron Gate Dam to Cottonwood Creek will be increased by the removal of the dams. The return of the natural gravel supply to this reach will increase the frequency of gravel mobilization from once every four years to once every other year.

10. Infrastructure Impacts of Dam Removal Alternative

Immediate impacts of reservoir drawdown to infrastructure located within the reservoir areas are identified and analyzed.

10.1. Yreka Pipeline Crossing

The City of Yreka water supply pipeline crosses at the upstream end of Iron Gate Reservoir. Upon removal of the reservoir, the pipeline will be exposed to faster river flows that could damage the exposed pipeline. The pipeline will need to be relocated and this section analyzes the flood flows, hydraulics, and scour at this location to support the design of the new crossing. An aerial view of the reach at the pipelines crossing is given in Figure 10-1. The pipeline may be placed on a bridge over the river or it may be buried beneath the river bed. This section is intended to provided hydraulic and scour analysis for both alternatives.

The peak flows on the Klamath River are given in Table 2-4. The peak flows at the pipeline crossing were computed by developing a relationship between drainage area and peak flow at various return periods. The relationship between peak flows and drainage area is given in Figure 10-2. The estimated peak flows at the Yreka Pipeline Crossing are shown in Table 10-1.

A HEC-RAS model as described in section 4.1.1 is used to estimate the hydraulic properties at the pipe crossing after dam removal. Based upon the drill measurements, there is little deposition of material at the upper end of Iron Gate Reservoir. However, there is some uncertainty because no drill holes were at the pipeline location. Future studies should collect sediment information at the location of the pipe crossing before final designs are prepared. For the purposes of generating water surfaces, it is assumed that no significant erosion of the cross section will occur after dam removal. This will give a higher estimate for the water surface elevations. For the purposes of scour estimates, it is assumed that 2 feet of the channel bottom will eroded after dam removal. This will give a conservative estimate on scour.

The predicted water surface elevations are given in Table 10-2 and shown in Figure 10-3. These should be conservative estimates, but it is still recommended that any bridge or pipe crossing should be at least 3 feet above the 100-year water surface elevation.

Table 10-1. Flood flows at the Yreka pipeline crossing on the Klamath River.

Location	Drainage Area (mi^2)	10 yr (cfs)	25 yr (cfs)	50 yr (cfs)	100 yr (cfs)
Klamath River at Yreka Pipeline	4396	11,000	13,800	16,000	18,300

Table 10-2. Hydraulic properties at Yreka pipeline crossing

Profile	Q Total	W.S. Elev	E.G. Elev	E.G. Slope	Vel Chnl	Hydr Depth C	Top Width
	(cfs)	(ft)	(ft)	(ft/ft)	(ft/s)	(ft)	(ft)
100-yr	18300	2321.0	2323.1	0.00923	11.4	5.7	280
50-yr	16000	2320.4	2322.3	0.00972	11.2	5.4	267

10.1.1. SCOUR METHODS

If the pipeline is placed underneath the river bed, it should be placed at an elevation below the potential scour elevation. The scour elevations were estimated using several methods. It was assumed that the pipeline is on a moderate bend for the methods where a bend type is needed. The median bed material size at the site is computed based upon the average of the median bed material size from Iron Gate Dam to Cottonwood Creek.

Lacey

The scour equation of Lacey (1930) as reported in Reclamation (1984) is:

$$d_s = Z0.47\left(\frac{Q}{f}\right)^{1/3}$$

where:

Q = Flow rate in channel at design discharge (ft^3/s or m^3/s)

f = $1.76\sqrt{d_{50}}$

Z = 0.25 for straight reach, 0.5 for moderate bend, 1.25 for vertical rock bank

d_{50} = mean grain size in mm

Z = 1.25 was chosen for vertical rock bank.

Blench

The scour equation of Blench (1969) as reported in Reclamation (1984) is:

$$d_s = Z\frac{q_f^{2/3}}{F_{bo}^{1/3}}$$

where:

q_f = design discharge per unit width
F_{bo} = $1.75 d_{50}^{0.25}$
d_{50} = mean grain size in mm
Z = 0.6 for straight, 1.0 for moderate bend, 1.25 for vertical rock bank or wall.

Z = 1 was chosen for bends as recommended in Reclamation (1984).

10.1.2. LIMITING VELOCITY

The limiting velocity method as reported in Reclamation (1984) is:

$$d_s = d_m\left(\frac{V_m}{V_c} - 1\right)$$

where:

d_m = mean depth
V_m = mean channel velocity
V_c = minimum competent velocity

The competent velocity can be estimated using a shear stress based incipient motion criteria:

$$u_\tau = \theta_c \sqrt{g(s-1)D_c}$$

where:

u_τ = friction velocity = $nV_c\sqrt{g}\Big/\left(C_m R^{\frac{1}{6}}\right)$
V_c = minimum competent average channel velocity
n = Manning's roughness coefficient
g = acceleration of gravity
R = hydraulic radius
C_m = Manning's constant (1.0 for SI, 1.486 for English units)
θ_c = critical non-dimensional shear stress (often between 0.03 to 0.05)
s = specific weight of bed material
D_c = d_{50} of surface bed material

Alternatively, one could use the competent bottom velocity method as recommended in Reclamation (1984) Eq (3). That equation can be rewritten to be dimensionally consistent as:

$$V_c = 0.57\sqrt{g(s-1)D_c}$$

and this equation is used in the analysis in this report.

EM1601

The COE manual EM1601 (COE, 1994) recommends using the following equation:

$$d_s = S_f Z d_m - d_f$$

where:

d_m = average depth in the crossing upstream of the bend.
d_f = depth of thalweg at bend
S_f = Safety Factor = 1.14
Z = factor based upon radius of curvature to width ratio
= $3.37 - 0.66\ln(R/W)$ for sand bed
= $3.37 - 0.7\ln(R/W)$ for gravel bed

The correlation between *Z* and *R*/*W* for gravel bed rivers is very weak based upon Plate B-42 in Appendix B of EM1601. We recommend using the upper value of 3.37 for this design.

HEC 11

The scour method proposed by HEC-11 (Federal Highway Administration, 1989) is only a function of bed particle size:

$$d_s = \min\left(12, 6.5{d_{50}}^{-.11}\right)$$

10.1.3. SCOUR RESULTS

The results for each method are given in Table 10-3. The predicted scour ranges from 5 to 10 feet. There is considerable uncertainty regarding the site conditions because the site is currently within the reservoir. Therefore, the bed material and channel dimensions that will occur after dam removal are uncertain. There is also some uncertainty regarding the amount of sediment that will be eroded from the site after dam removal material. Therefore, the maximum scour depths are used in the recommendations. This equates to a scour elevation of 2399.5 feet.

Table 10-3. Reach scour estimates from each method at the Yreka pipeline crossing.

Bed Erosion (ft)	Design Scour (ft)					Final Design Scour Recommendation (ft)
	Lacey (1930)	Blench (1969)	Limiting Velocity	EM1601	HEC11	
2	6.4	9.5	5	9.8	9.7	10

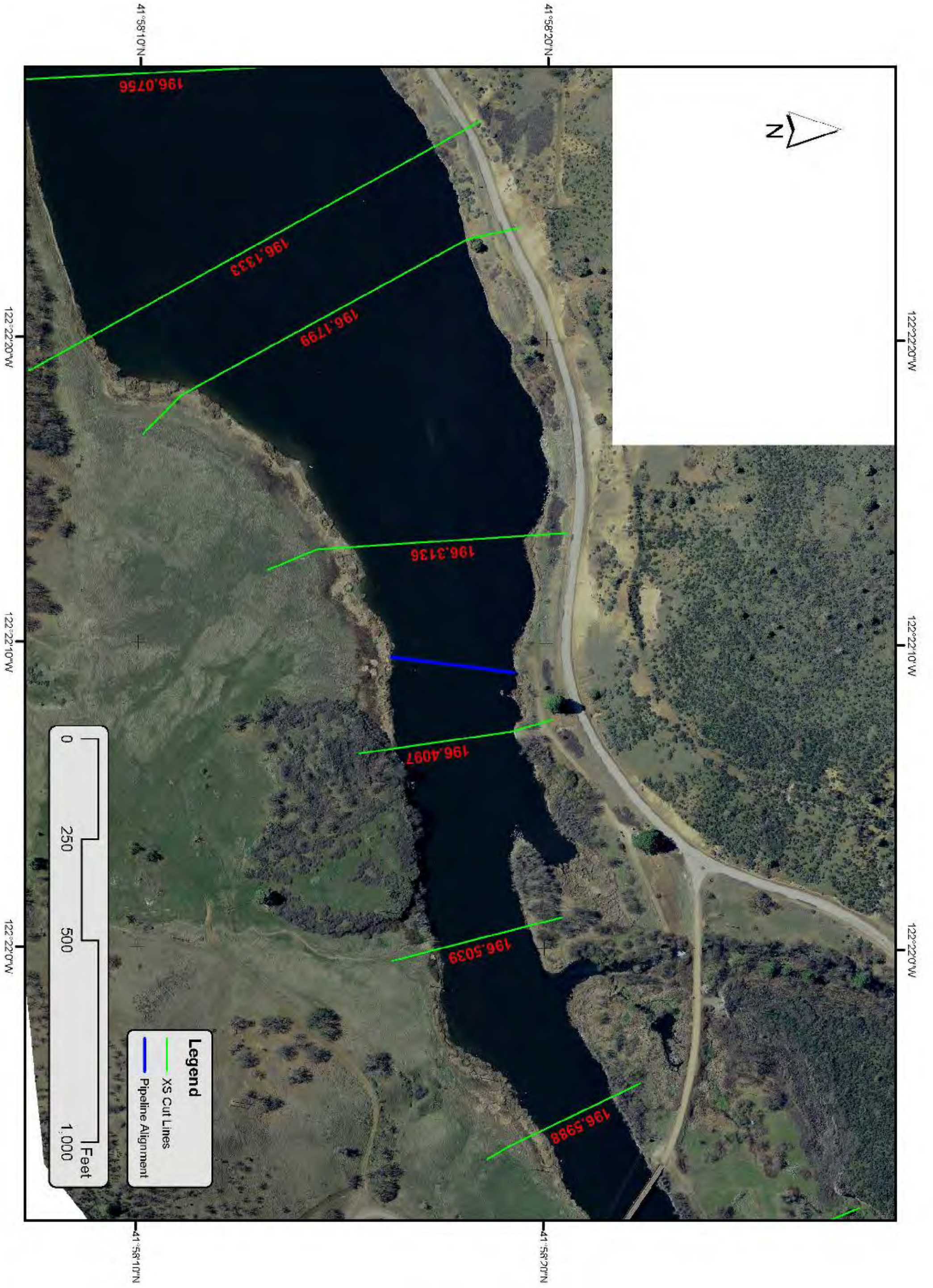


Figure 10-1. Overview map of the Yreka pipeline crossing.

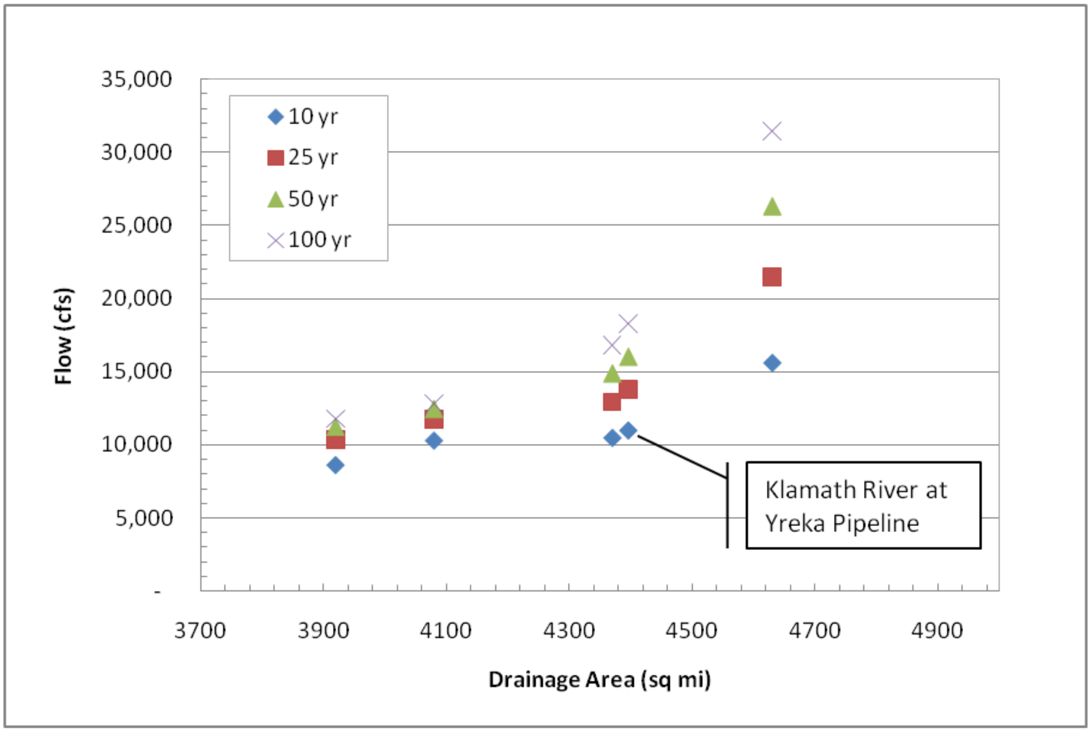


Figure 10-2. Drainage area and flood frequency at Yreka pipeline crossing on Klamath River.

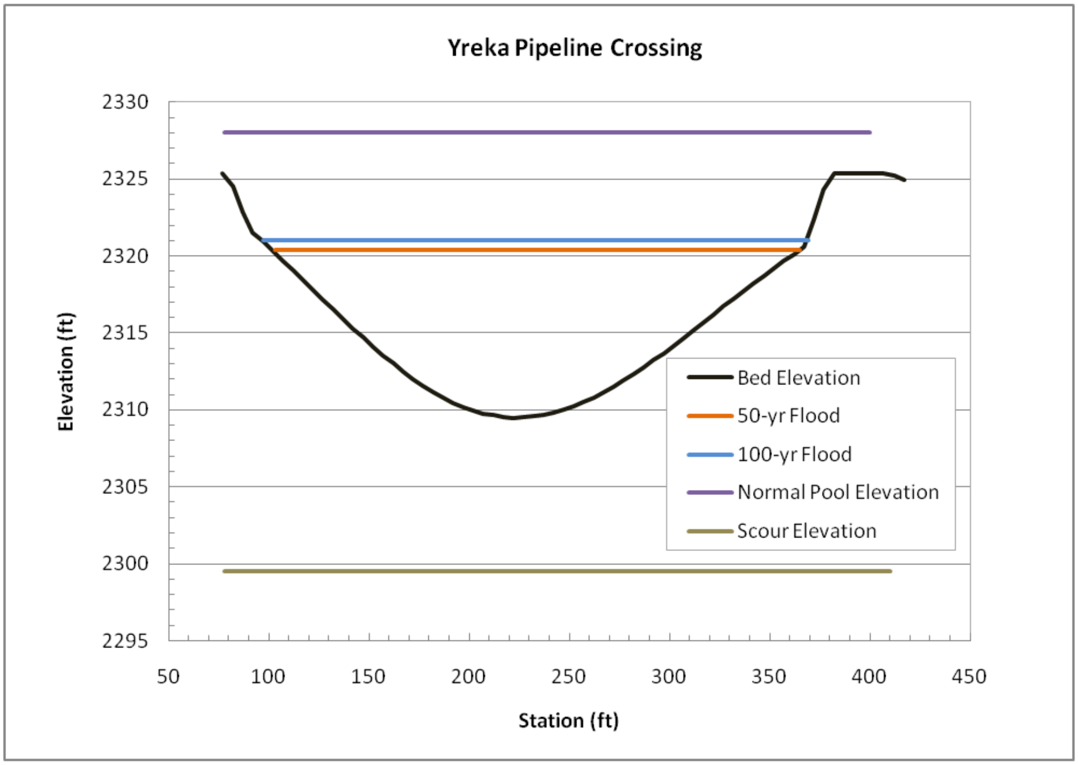


Figure 10-3. Cross section at Yreka pipeline crossing.

10.2. Jenny Creek Bridge

Jenny Creek Bridge is located on Iron Gate Reservoir. PWA (2008) identified this bridge as one that may be impacted by dam removal. The approach road and abutments are built upon material deposited since the construction of Iron Gate Dam (see Figure 5-7 of PWA, 2008). After dam removal, the channel will incise through the deposits and is expected to undermine the abutments of the bridge. To prevent this, a new bridge will be need upstream of the current bridge. The current alignment and a potential new alignment are shown in Figure 10-4 with the 2010 aerial photograph as a background. The same information is shown in Figure 10-5 with the 1960 (pre-dam) aerial photograph as a background.

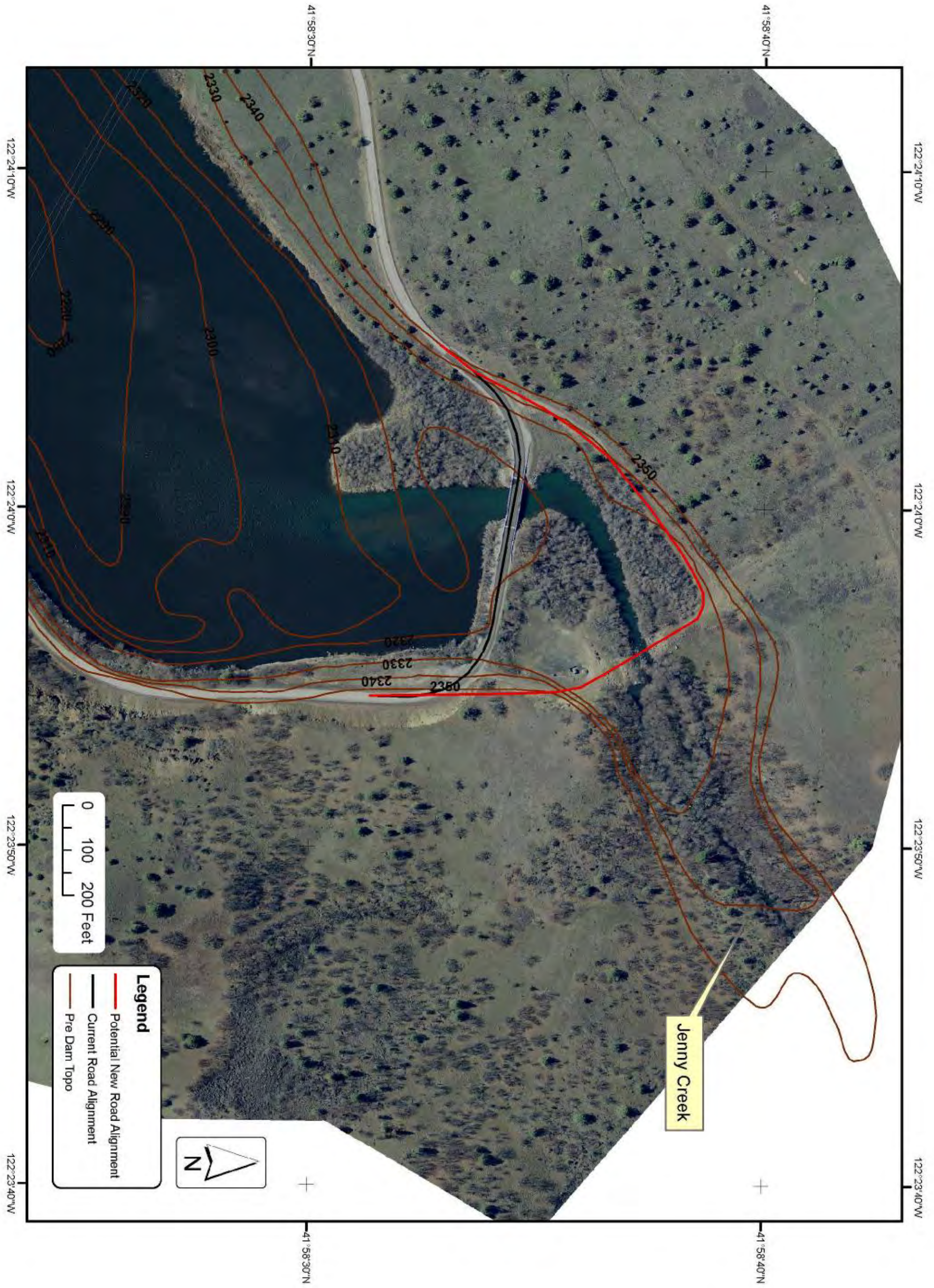


Figure 10-4. 2009 Aerial view of Jenny Creek Bridge on Iron Gate Reservoir with pre-dam topography shown.

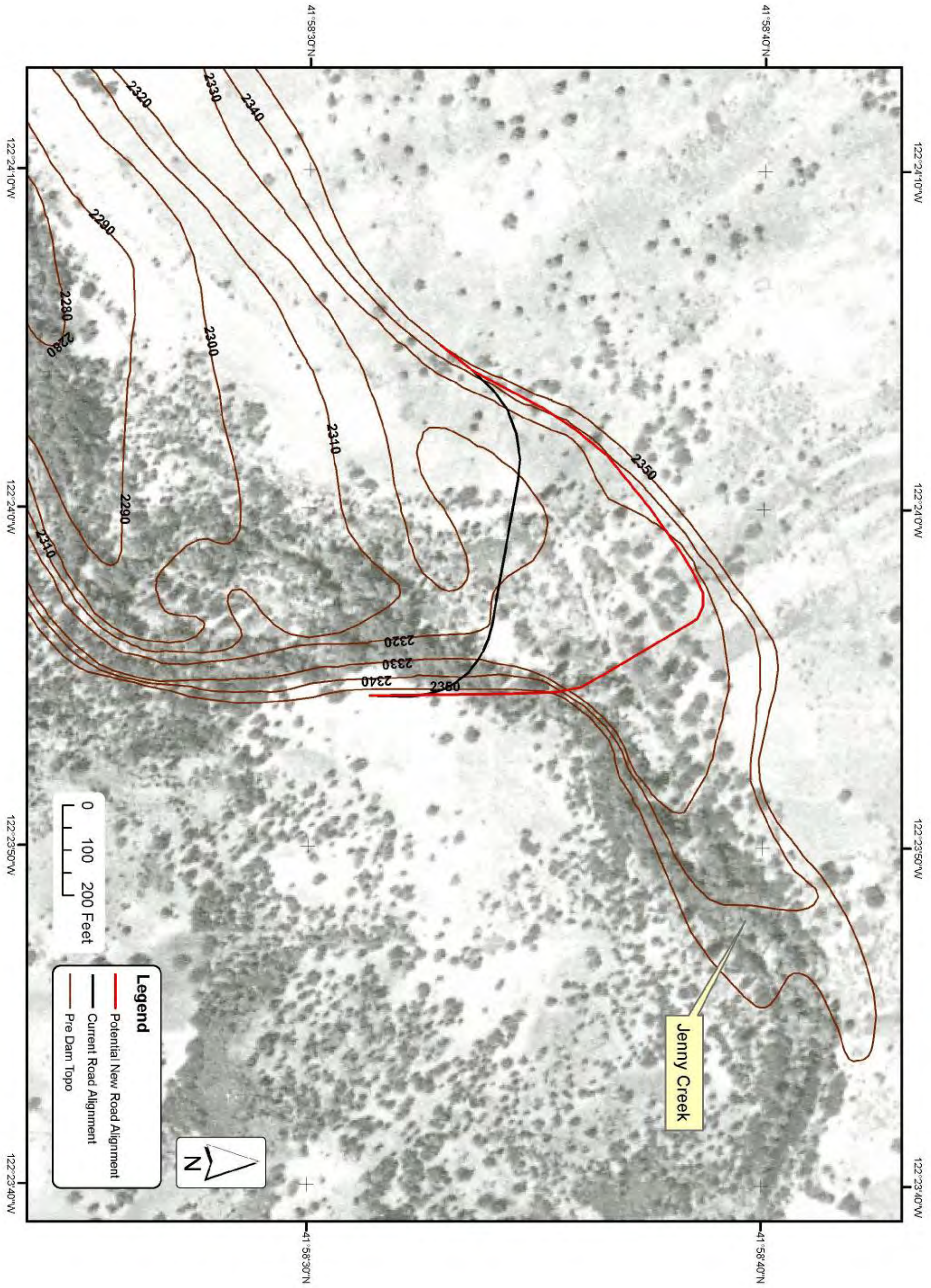


Figure 10-5. 1960 Aerial view of Jenny Creek Bridge site with pre-dam topography shown.

10.3. Highway 66 Bridge

State Highway 66 Bridge is located within J.C. Boyle Reservoir (Figure 10-6). Figure 10-7 shows the 2010 aerial photograph and the 1952 pre-dam photograph with the highway alignment shown on both. The left abutment and middle pier are located in the historical river channel, as evidenced by the 1952 aerial photograph. The sediment sampling holes are also shown in the figure. The reservoir sediment thicknesses vary between 0 and 1.5 feet in the holes shown in the figure (Reclamation, 2010). The minimum bed elevation according to the bathymetry information from Eilers and Gubala bathymetry survey is 3781.8 feet (NAVD 88). Therefore, the minimum pre-dam elevation could be as low as 3780 feet.

The historic river channel will quickly reestablish itself after dam removal. The bridge piers and east abutment will be subject to higher velocities and therefore subject to greater scour potential.

To determine the required protection at the pier, the as-built drawings were obtained from Oregon Department of Transportation. The bottom elevation of the 2 east piers is at 3763 feet and the bottom of the casing is at 3775.3 feet. The bottom elevations of the 2 west piers were 3768.7 feet and the bottom elevation of the casing around the pier was 3779.2 feet. The elevation of layer termed “Basalt B” at the east pier was approximately 3765.8 feet and the elevation at the west pier was 3775.6 feet.

Therefore, the minimum pier elevations are expected to be between 17 and 11.3 feet of the bed elevation after dam removal. The minimum pier elevations are about 3 feet below the “Basalt B” layer and about 8 feet below the top of the “Basalt A” layer. The descriptions of the Basalt Layers are below:

> *BASALT FLOW TOP - BASALT, gray. brown. and yellow brown. Moderately Weathered to Predominantly Decomposed. Very Soft to Soft (R1 to R2), Very Close to Close joints. RQD=O to 36, vesicular with vesicles forming planes of weakness, a few brecciated zones with green to green gray clay infilling up to 10 mm. This unit grades into Basalt A.*
>
> *BASALT UNIT A - BASALT - dark gray to brown gray, mostly Moderately Weathered but varies from Predominantly Decomposed to Slightly Weathered. Soft to Medium Hard (R2-R3), Very Close to Moderately Close joints, vesicles in very close near horizontal layers creating zones of weakness, joints near horizontal to 30 degrees and 45-60 degrees, light gray to green gray joint infilling up to 3 mm thick. RQD 47 to 83. Laboratory UCS is 19.4 to 45.1 MPa. This unit grades into Basalt B at the lower surface, and Basalt Flow Top at the upper contact.*
>
> *BASALT UNIT B - BASALT, dark gray to brown gray, mostly Slightly Weathered to Fresh, minor Moderately Weathered zones, mostly Medium Hard to Hard (R3 to R4) with minor Soft (R2) zones. Close to Wide*

> *jointing, joints stained and some have up to 2 mm of green gray clay infilling. RQD 62-100, Lab UCS is 88.4 MPa This unit is a local basalt flow and has a gradational upper contact with Basalt A.*

Based upon these classifications, pier scour should not extend below the Basalt Unit A layer and therefore the pier would have approximately 8 feet buried beneath into the basalt layer.

The abutment is located on the outside of a mild bend in the river and the river will create a scour pool at the left abutment. There is already a riprap along the east abutment and it is classified as “Riprap Class 1000”, which according to the Oregon Department of Transportation, has the gradations shown in Table 10-4. The size of material is sufficient to protect the abutment from scour, but it is uncertain if the riprap was place below grade to account for scour that can occur at the base of the riprap.

Table 10-4. Riprap size on east abutment of Highway 66 Bridge based upon as-built drawings from Oregon DOT.

Mass (kg)	**% by mass**
1000 – 650	20
650 – 300	30
300 – 20	40
20 -0	10

Figure 10-6. Spencer Bridge on State Highway 66 in J.C. Boyle Reservoir. Picture taken from the downstream side east abutment.

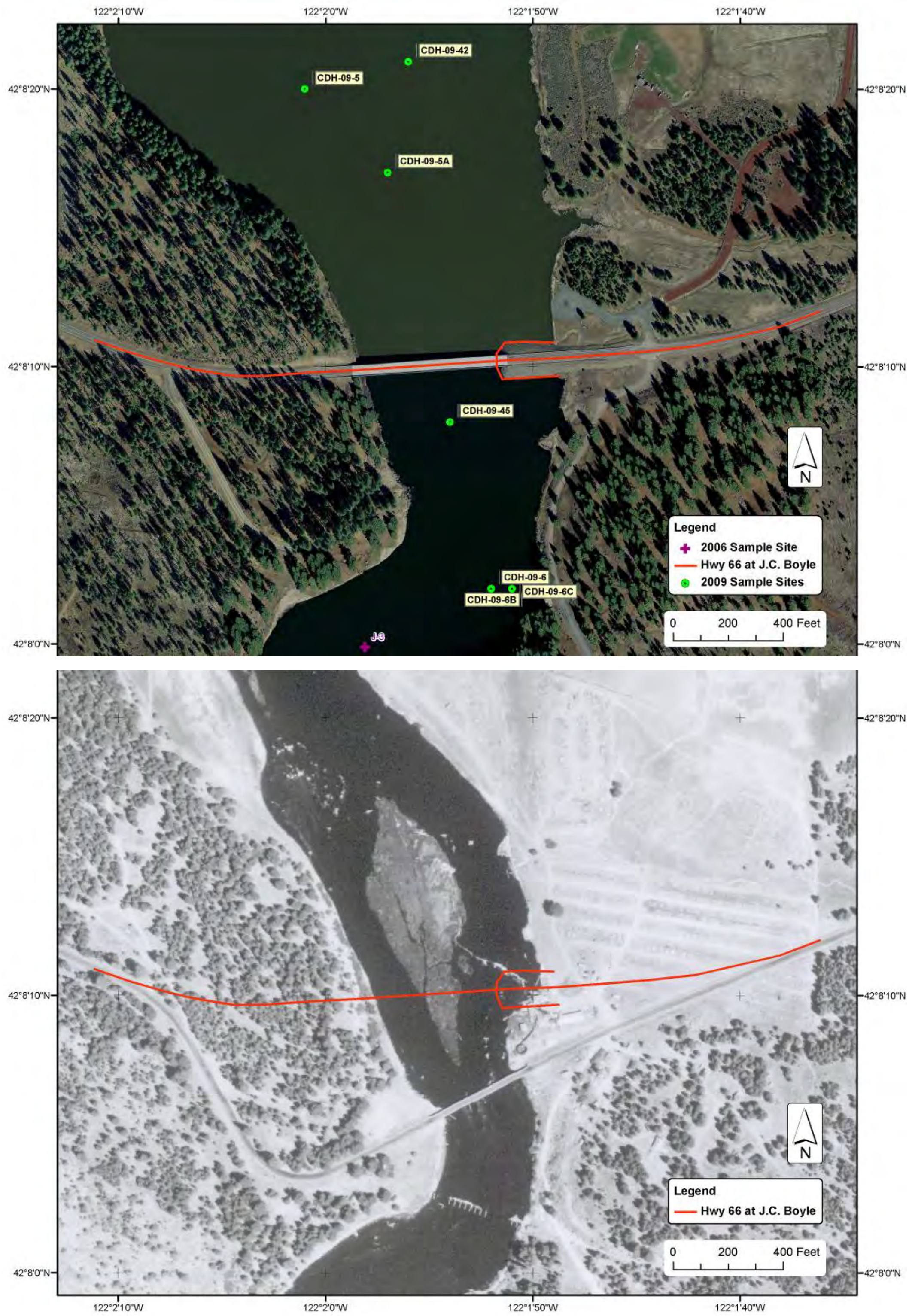


Figure 10-7. 2010 (above) and 1952 (below) Aerial photograph of State Highway 66 Bridge in J.C. Boyle Reservoir. The dam was complete in 1958.

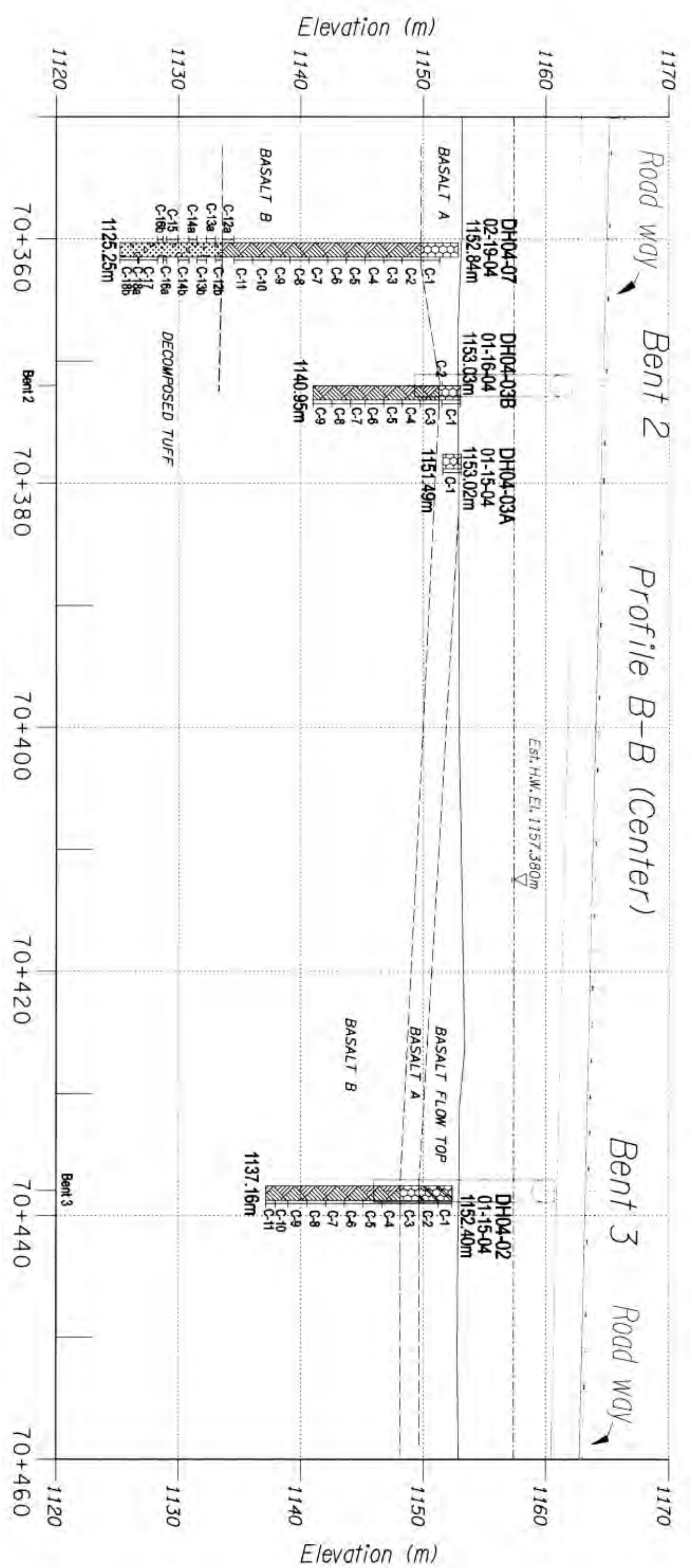


Figure 10-8. Pier location and drill log information from Oregon Department of Transportation.

10.4. J.C. Boyle Bypass Reach Bridge

The J.C. Boyle Bypass Reach Bridge is shown in Figure 10-9. The 2010 LiDAR information shows the bridge elevation as 3735 feet (NAVD88). The 100-year flood at J.C. Boyle Dam is 13,150 cfs (Table 2-4). The 100-year flood in the bypass reach under the No Action Alternative calculation assumes the powerhouse is at full capacity of 2,800 cfs is 10,350 cfs. A summary of the hydraulic characteristics for the bridge under No Action and Dam Removal Alternatives is given in Table 10-5. The 100-year water surface elevation for the No Action or Dam Removal Alternative will be below the bridge soffit elevation, and therefore, it will not be necessary to raise the bridge deck.

The median flow will increase substantially from the current minimum flow release of 100 cfs to 930 cfs under the Dam Removal Alternative. In addition, the river stage and velocities will be commonly higher under the Dam Removal Alternatives. The abutments consist of rock held in place by a wood crib structure (Figure 10-10). The abutment will experience higher flows for longer duration which may affect the lifespan of the current cribbing structure.

Table 10-5. Hydraulic conditions under No Action and Dam Removal Alternatives for J.C. Boyle Bypass Reach Bridge.

Item	**No Action**	**Dam Removal**
100-yr flood (cfs)	10,350	13,150
Median Flow (cfs)	100	930
Approximate 100-yr WSE (ft)	3726	3727
Approximate median flow WSE (ft)	3717.5	3720
Bridge Deck	3735	3735
Bridge Soffit	3731	3731

Figure 10-9. J.C. Boyle Bypass Reach Bridge.

Figure 10-10. Abutment of J.C. Boyle Bypass Reach Bridge.

10.5. Copco Bridge

Copco Bridge is located at the upstream end of Copco Reservoir. The cross section of the bridge is shown in Figure 10-11. The middle pier is located in the historical stream channel and extends to an elevation of 2560 feet. The bed elevation is at 2587.3 feet according to the drawings provided by Siskiyou County. After dam removal, there will be additional scour at this pier, but the pier rests upon bedrock and the additional scour will not destabilize the pier. There may be more exposure of the pier, so the pier may require additional protection from abrasion.

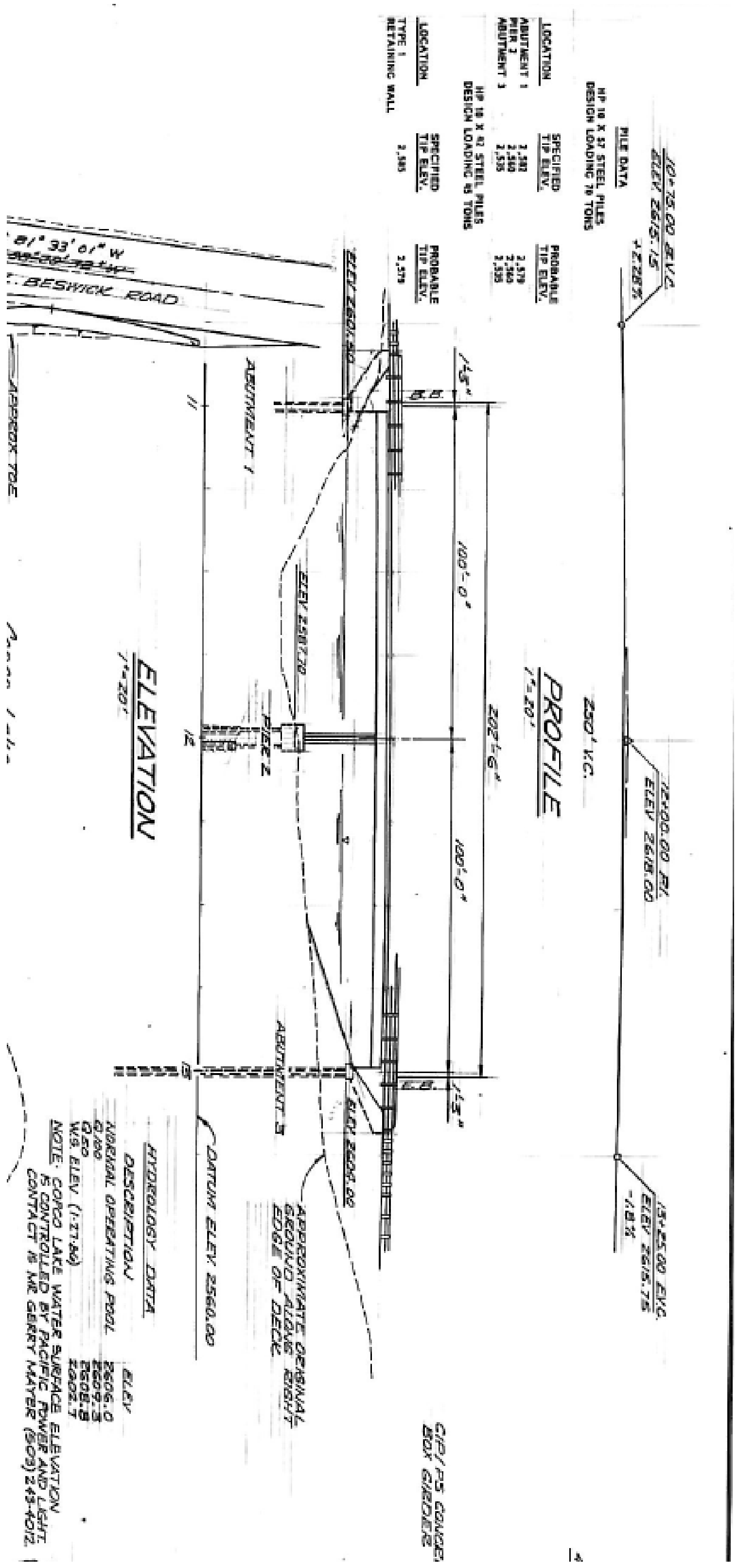


Figure 10-11. Pier elevations at Copco Bridge in upstream of Copco Reservoir.

10.6. Copco No. 2 Access Bridge

Copco No. 2 Access Bridge crosses the Klamath River in the upstream end of Iron Gate Reservoir. Information on the hydraulic conditions at the bridge for the No Action and Dam Removal Alternatives is given in Table 10-6. The 100-year flood information is from Table 2-4. The median flow is computed based upon the results listed in Appendix F. Exceedance Flows for No Action and Dam Removal Alternatives Based Upon Index Sequential Hydrology. The bridge deck elevation is taken from the 2010 LiDAR information. Based upon drawings from PacifiCorp, the bridge sofit is approximately 4 feet below the bridge deck. The bridge soffit is approximately 5 feet above the No Action Alternative 100-year WSE and 10 feet above the Dam Removal Alternative 100-year WSE. The hydraulic calculations are based upon the Iron Gate pre-dam survey having a 10-foot contour so the hydraulic calculations are expected to have a relatively large error associated with them. However, it is certain that the 100-year WSE under the Dam Removal Alternative conditions will be substantially lower than under the No Action Alternative. The bridge is shown in Figure 10-12 in the 2010 aerial photograph along with the pre-dam topography contours.

Because the water surface will decrease under the Dam Removal Alternative, the bridge will be exposed to higher velocities and greater scour potential. There are three piers located in the 100-year floodway. However, the bridge was built prior to the construction of Iron Gate reservoir and therefore would have been exposed to these high velocities at that time. The bridge and piers should be inspected to ensure they are in good condition. If they are in acceptable condition, additional protection should not be necessary.

Table 10-6. Hydraulic conditions under No Action and Dam Removal Alternatives for Copco No. 2 Access Bridge.

Item	**No Action**	**Dam Removal**
100-yr flood (cfs)	14,470	14,470
Median Flow (cfs)	1,390	1,360
Approximate 100-yr WSE (ft)	2,332	2,329
Approximate median flow WSE (ft)	2,328	2,323
Minimum Bridge Deck	2,341	2,341
Bridge Soffit	2,337	2,337

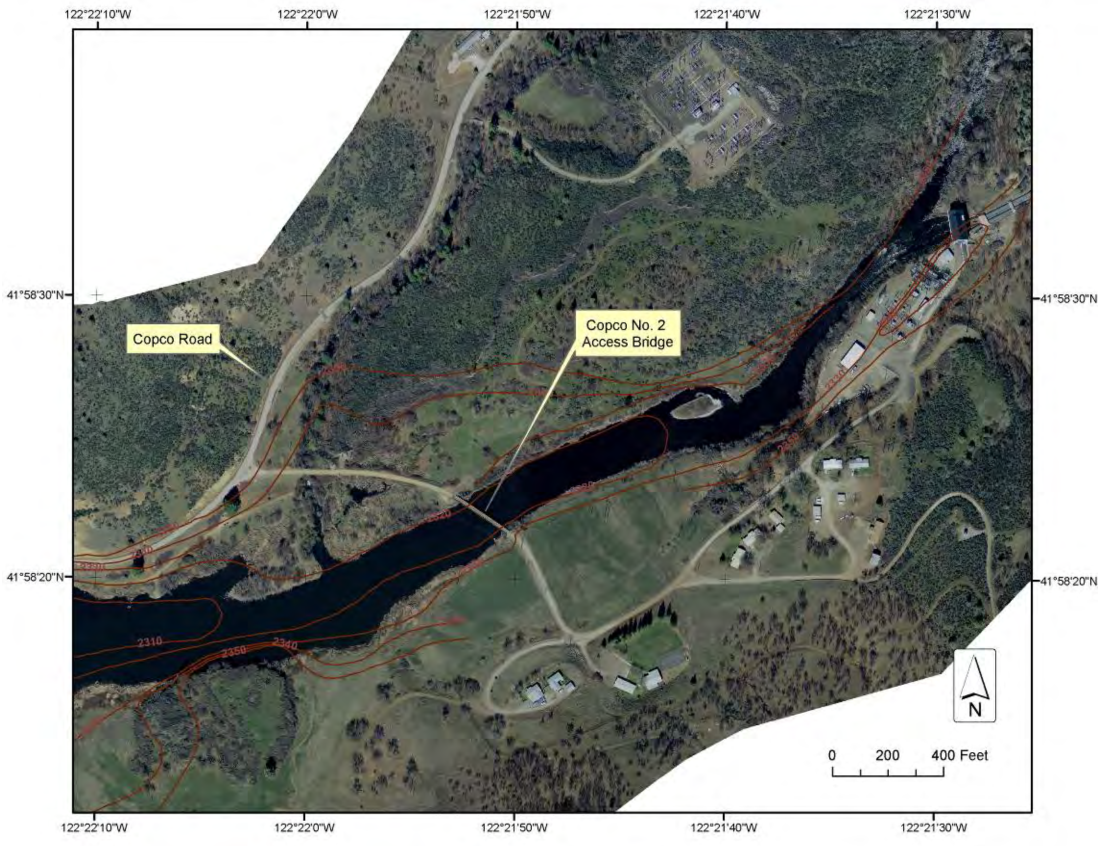


Figure 10-12. Copco No. 2 Access Bridge shown on 2010 aerial with pre-dam Iron Gate Reservoir survey contours.

10.7. Road Crossings with Culverts

Culverts are used to pass low flows under roads from several smaller tributaries into Iron Gate and Copco reservoirs. In some cases, these tributaries have created deltas perched above the pre-dam channel. After the reservoirs are emptied, the tributary channels will return to their pre-dam elevations and could possibly undermine the existing road crossings at these tributaries. At these road crossings, there would be two options to restore road access:

1. Prior to dam removal, move the crossing further upstream on the tributary.
2. Immediately after reservoir drawdown, grade a new road down to the elevation of the pre-dam channel. There may be a temporary interruption of access.

Scotch and Camp Creek at Iron Gate Reservoir

Copco Road intersects Scotch and Camp creeks and the crossings are shown in Figure 10-13 along with the pre-dam contours. The normal pool elevation of Iron Gate is 2328 feet and this can be compared against the pre-dam contours in the figure.

The current road elevation of the crossing at Scotch Creek is at an elevation of 2346 feet and the stream bed is currently at an elevation of 2336 feet based upon the 2010 LiDAR (NAVD88). The pre-dam elevation of the bed at this location was approximately 2334 feet (NAVD88). This indicates the bed should incise only a couple feet at this location. The current road alignment does not need to be altered, but a larger culvert will need to be installed to account for potential drop in bed elevation.

At Camp Creek, the current road elevation is at 2340 feet and the water surface elevation is at 2329.5 feet (NAVD88). The pre-dam bed elevation was approximately 2310 (NAVD88). Substantial erosion is expected at this location.

Fall Creek at Iron Gate Reservoir

The road crossing at Fall Creek at Iron Gate Reservoir is shown in Figure 10-14. The current road elevation at this crossing is 2348 feet and the water surface elevation is 2333 feet (NAVD88). The pre-dam elevation is estimated to be at approximately a normal pool elevation of 2331 feet (NAVD 88). Therefore, the incision expected at this site should be a couple feet.

Beaver Creek at Copco

Copco Rd crosses East Fork Beaver Creek and Beaver Creek along the north side of the reservoir (Figure 10-15). The road elevation is at approximately 2623 feet (NAVD88) and the gulch is at elevation 2616 feet just downstream of the crossing

(NAVD88). The normal pool elevation is at about 2606 feet (NAVD88) and the shoreline is about 430 feet from the road crossing. There is evidence of a substantial delta at this location and several feet of incision at the road crossing is possible.

Raymond Gulch at Copco

Figure 10-16 shows the crossing of Copco Rd over Raymond Gulch. The road elevation is at approximately 2631 feet (NAVD88) and the gulch is at elevation 2625 feet (NAVD88). The normal pool elevation is at 2606 feet (NAVD88) and the shoreline is about 450 feet from the road crossing. This crossing is elevated far enough above the reservoir, so that there should be no significant erosion at the crossing.

Tributary crossing Topsy Grade Road near J.C. Boyle Dam

Topsy Grade Road crosses an un-named tributary near J.C Boyle Dam. The watershed area of the tributary is approximately 5 square miles. The 2010 aerial photography and the pre-dam contours are shown in Figure 10-17. The elevation contour of 3793 feet (NAVD29) is the normal maximum pool elevation and defines the extent of the reservoir. A small delta has formed upstream of the road crossing, but this delta has not reached the road.

According to the pre-dam topographic map from PacifiCorp, there were three 24 inch culverts that pass flow underneath the road. The culverts are not aligned with the historical river channel and the road would act as a dam when high flows occur. The culverts will need to be aligned with the historical stream channel. The same number and size of culverts will be sufficient to maintain the same level of access for the road. The road will need armoring with riprap on the downstream face so that it does not erode away when overtopped. .

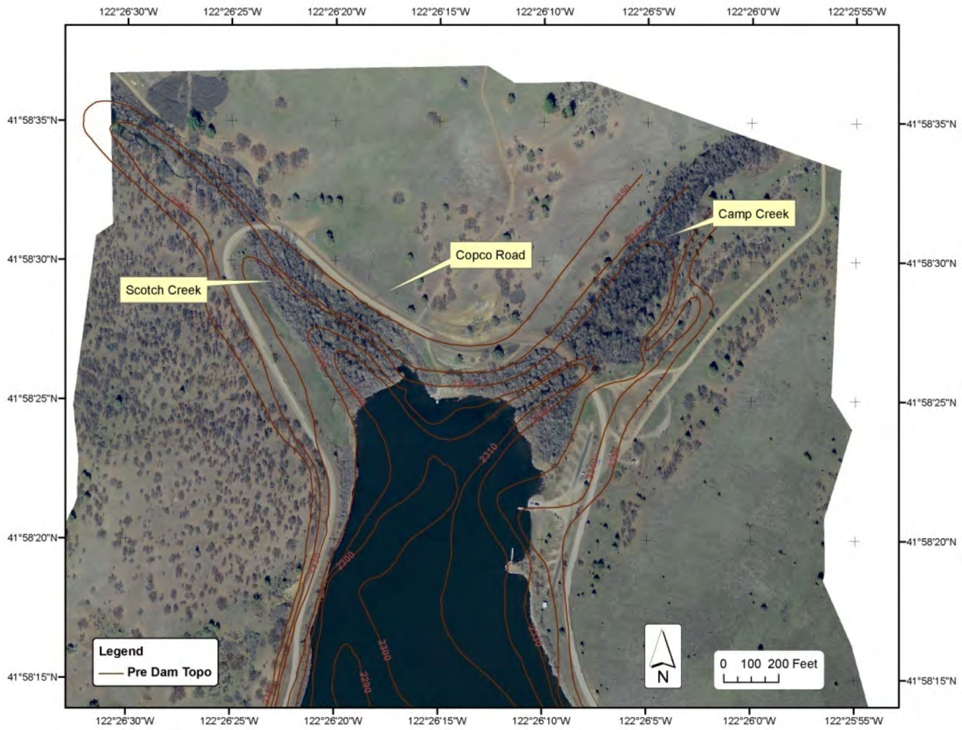


Figure 10-13. Road crossings at Scotch and Camp creeks. Pre-dam contours are in NGVD29 vertical datum.

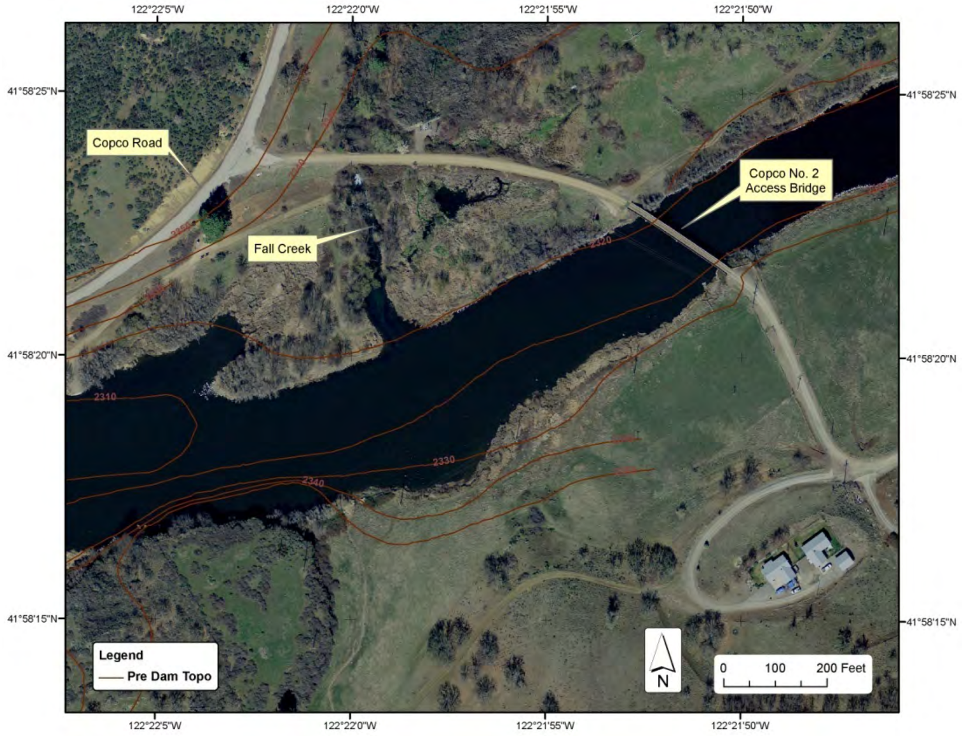


Figure 10-14. Fall Creek Road crossing at Iron Gate Reservoir. Pre-dam contours are in NGVD29 vertical datum.

Figure 10-15. Beaver Creek Road crossing at Copco Reservoir.

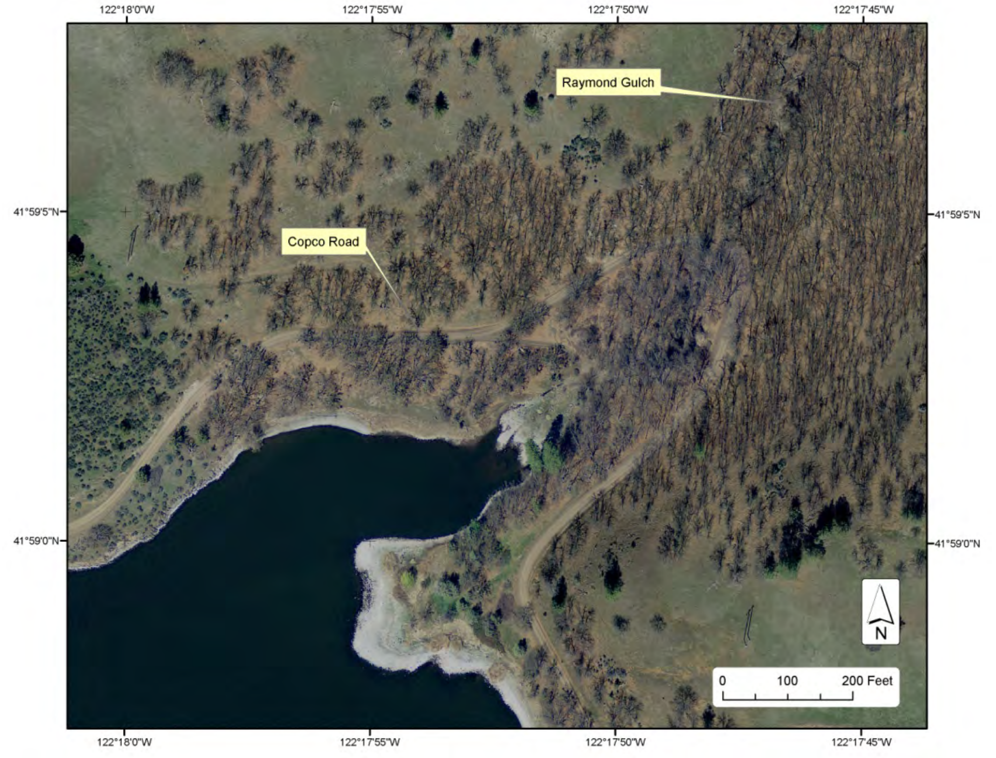


Figure 10-16. Raymond Gulch Road crossing at Copco Reservoir.

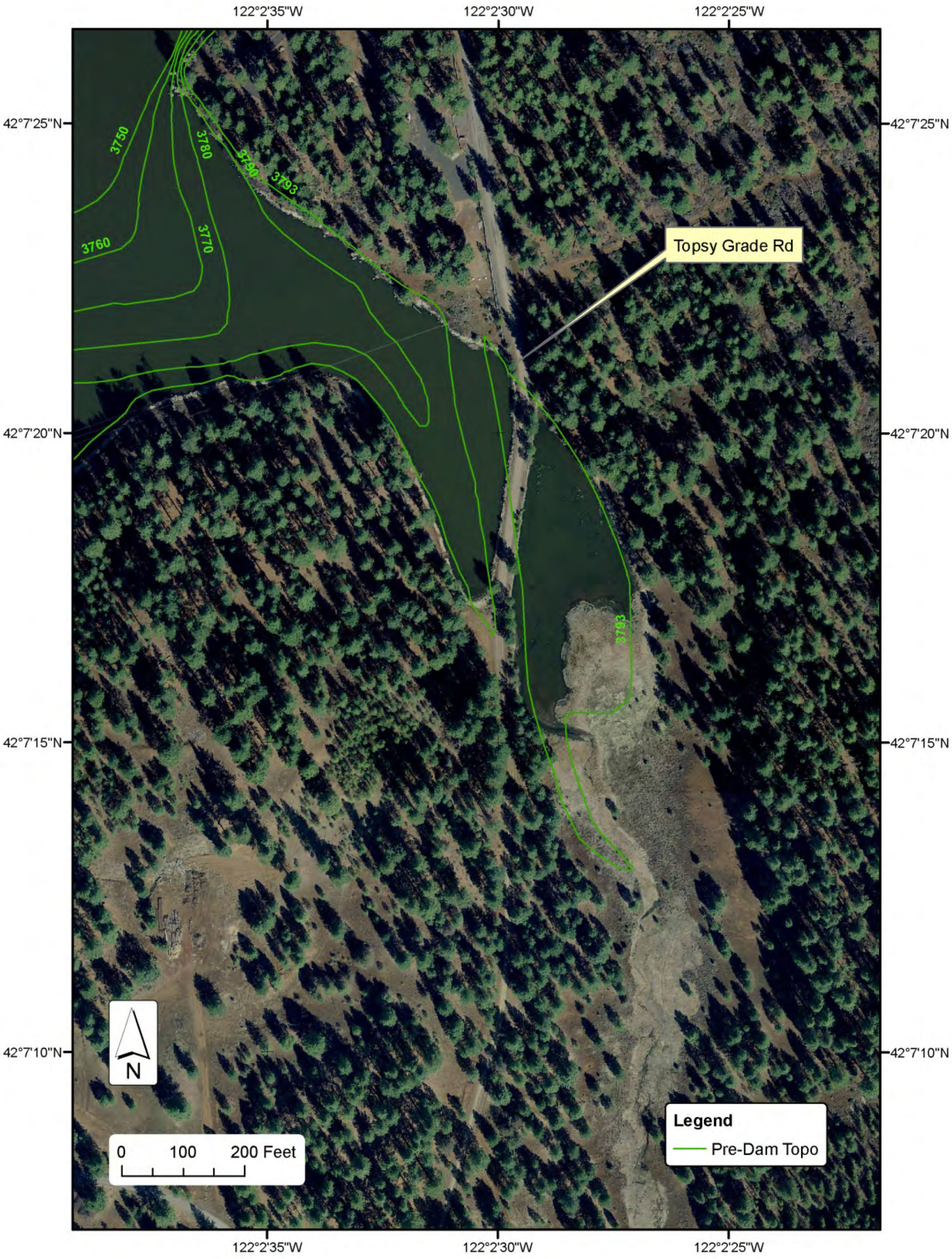


Figure 10-17. Crossing at Topsy Grade Road near J.C. Boyle Dam.

11. Climate Change Effects

Five different future climate scenarios were simulated as described in Appendix E. Documentation of Hydrology Simulations for the Klamath Dam Removal Studies. The scenarios were chosen to bracket the range of results predicted by Global Circulation Models (GCM). Four scenarios correspond to combinations of the 25th and 75th quantiles of the precipitation and temperature predicted by the GCMs for the Upper and Lower Klamath Basins. The fifth is the 50th quantile of the precipitation and temperature (Table 11-1). The precipitation and temperature predicted by the GCMs were downscaled to the Upper and Lower Klamath Basin. This precipitation and temperature provided input into a watershed scale hydrologic model, SAC-SMA. This section compares the hydrology results from the climate change scenarios (CC) to the Index Sequential simulations (IS) that were discussed in Section 6.

Table 11-1. Climate change scenarios.

Simulation ID	Climate Model	Temperature Quantile	Precipitation Quantile
6	cccma_cgcm3_1.4.sresa1b	75th	75th
11	gfdl_cm2_0.1.sresa2	50th	50th
24	miub_echo_g.3.sresa1b	75th	25th
37	mri_cgcm2_3_2a.3.sresa1b	25th	75th
45	ncar_pcm1.1.sresa2	25th	25th

All of the selected climate models predict increasing temperatures for the Upper Klamath Basin, while the climate models are split in terms of predicting increasing or decreasing precipitation. The 25th and 75th quantiles for the change in average temperature in the Upper Klamath Basin during the period 1950 to 1999 and from 2020 to 2069 are 1.4 to 2.2 degrees Celsius (2.5 to 4 degrees Fahrenheit). The same quantiles for the relative average annual precipitation for the same periods in the upper Klamath Basin are 0.95 and 1.05 inches (See Appendix E). Under the climate change scenarios, the average change in total precipitation ranges from a 5% decrease to a 5% increase.

11.1. Effects on Hydrology

The average flows entering UKL are given in Figure 11-1 for the No Action Alternative under the IS and CC scenarios. The Dam Removal Alternative includes an additional 30 acre-feet/yr of water being supplied to UKL, but otherwise is identical. Three of the five climate change simulations show an increase in annual inflow while the other two show a decrease in annual inflow. However, all climate change simulations show a more rapid snow melt period. They all indicate a greater proportion of the annual inflow occurring during the months of November through March and a decrease in the proportion of inflow occurring May through October. The three wet climate change simulations have greater annual flow volumes, but the average flow in the summer and fall are similar to the IS simulations. Most all the increase in annual flows occurs from December to April. The dry climate change simulations show significantly smaller average flows throughout all months, except for March where the hotter climate can cause more precipitation to fall as rain and also cause a faster snowmelt. The general expectation is that under climate change the flows entering UKL in the later winter and early spring (February to April) will be similar or higher than current flows, but that flows in May through October will be similar or lower than current flows. Flows into UKL during the winter may be either lower or higher than current conditions.

The flows at Iron Gate for the No Action and Dam Removal Alternatives are shown in Figure 11-2 and Figure 11-3 for the IS and CC scenarios. The effect of climate change on the No Action and Dam Removal Alternatives hydrology is similar at the Iron Gate stream gage. The shift in the spring snowmelt under climate change is still evident at Iron Gate, but it is somewhat amiliorated by UKL. Flows could be higher or lower during the months of November through April under climate change. During the months of May through October, the flows will likely be similar under median or wet climate scenarios and less under dry climate scenarios.

There is a more substantial shift in timing of flows at Seiad Valley under the climate change scenarios (Figure 11-4). The flows in Feburary and March are substantially higher under both wet and dry climate scenarios, whereas, the flows in May through July are lower under both wet and dry climate scenarios. The flows during the summer months of August through October are similar for the wet and median climate scenarios, but substantially less under the dry climate scenarios. This general shift in precipitation from late spring to winter is consistent with the study of Koopman et al. (2009) who analyzed the change in precipitation over the entire Klamath Basin for the period 2035 to 2045 relative to 1961 to 1991. They found that three climate models predicted between 4.1 to 2.7 mm less precipitation during the period June to August and a 1.5 to 14.4 mm more precipitation during the months of December through February.

A similar pattern of climate change appears at Orleans on the Klamath River, but the dry scenarios have smaller flows for all months of the year. In addition, most all climate scenarios have significantly smaller flows for April through November (Figure 11-5). The average flow under the IS scenarios in June is approximately 6,000 cfs, whereas, the average flow under the wet climate change scenario in June is approximately 3,700 cfs.

Figure 11-6 shows the IS and CC results for the Klamath River at Klamath under the Dam Removal Alternative. The flow pattern at Klamath is similar to that at Orleans. There is a distinct shift of flow to the winter months. For all climate scenarios, there is less flow during the months of April through November.

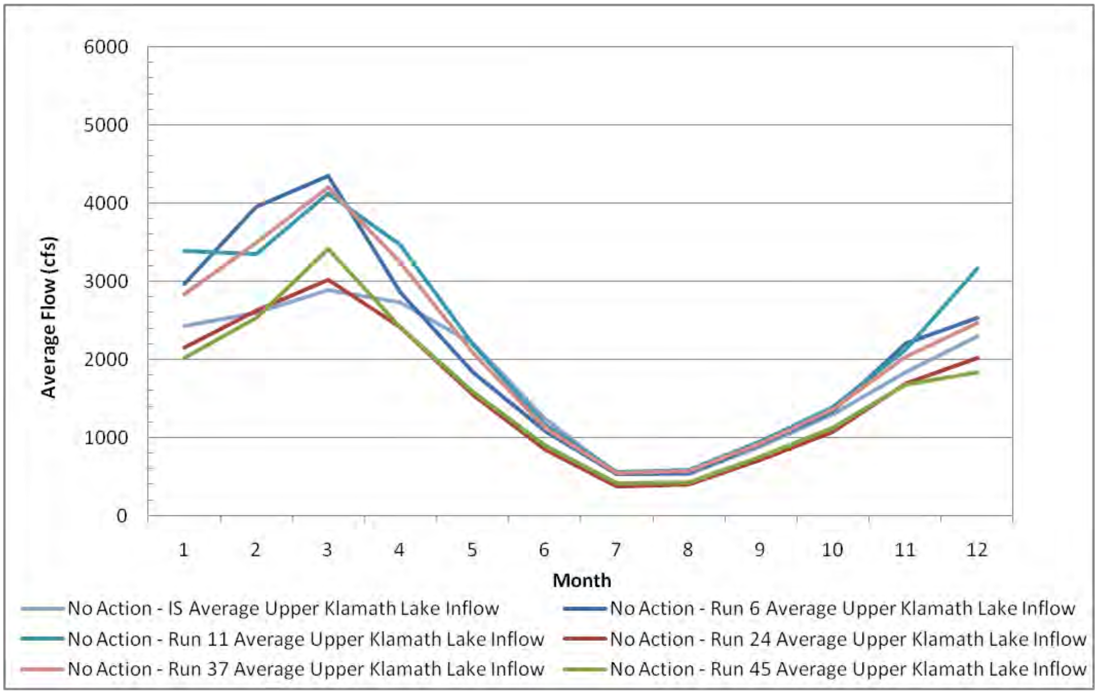


Figure 11-1. Average flows into UKL for the Index Sequential and Climate Change simulations for the No Action Alternative.

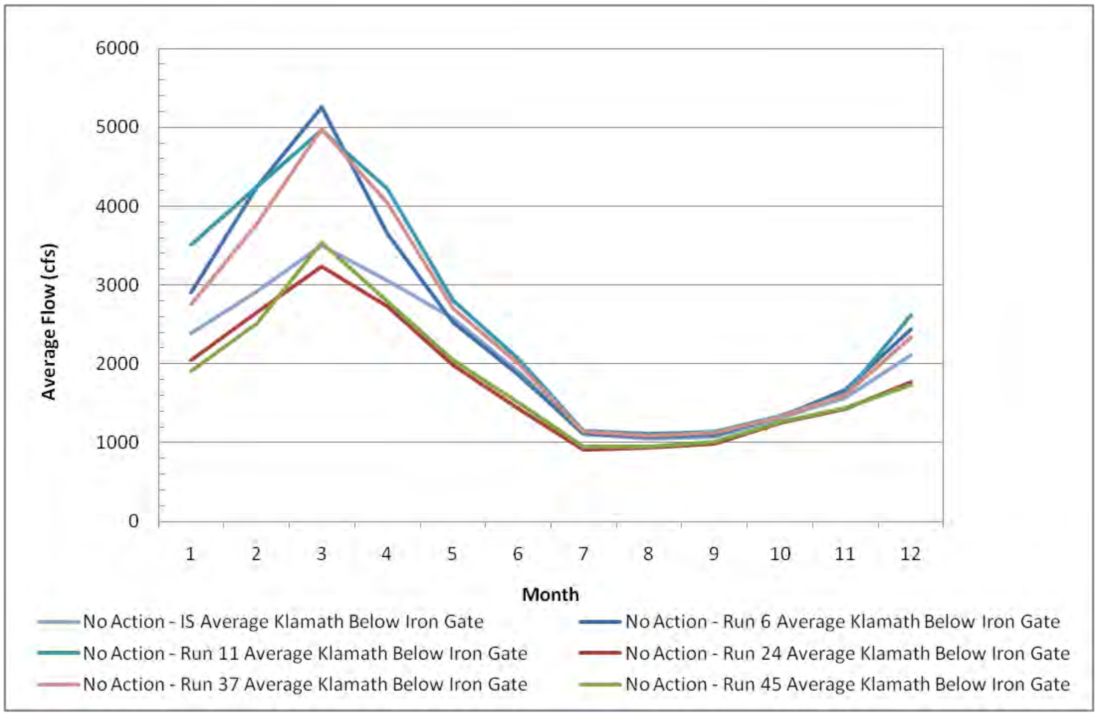


Figure 11-2. Average flows in the Klamath River below Iron Gate Dam for the Index Sequential and Climate Change simulations for the No Action Alternative.

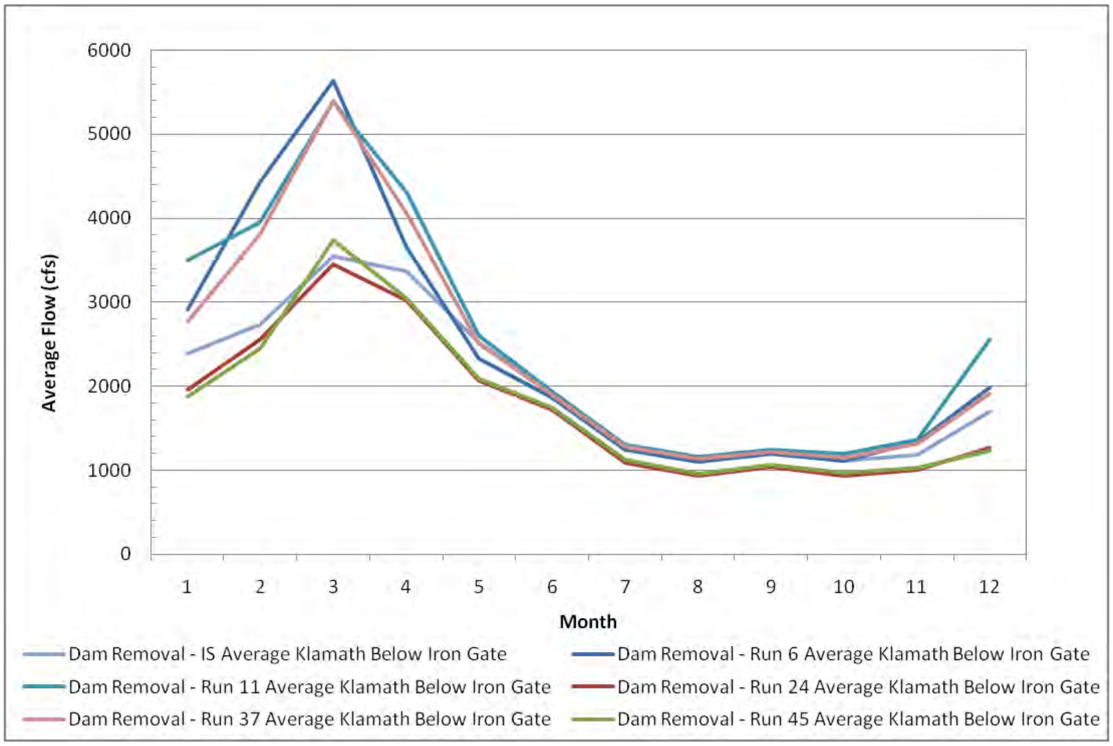


Figure 11-3. Average flows in the Klamath River below Iron Gate Dam for the Index Sequential and Climate Change simulations for the Dam Removal Alternative.

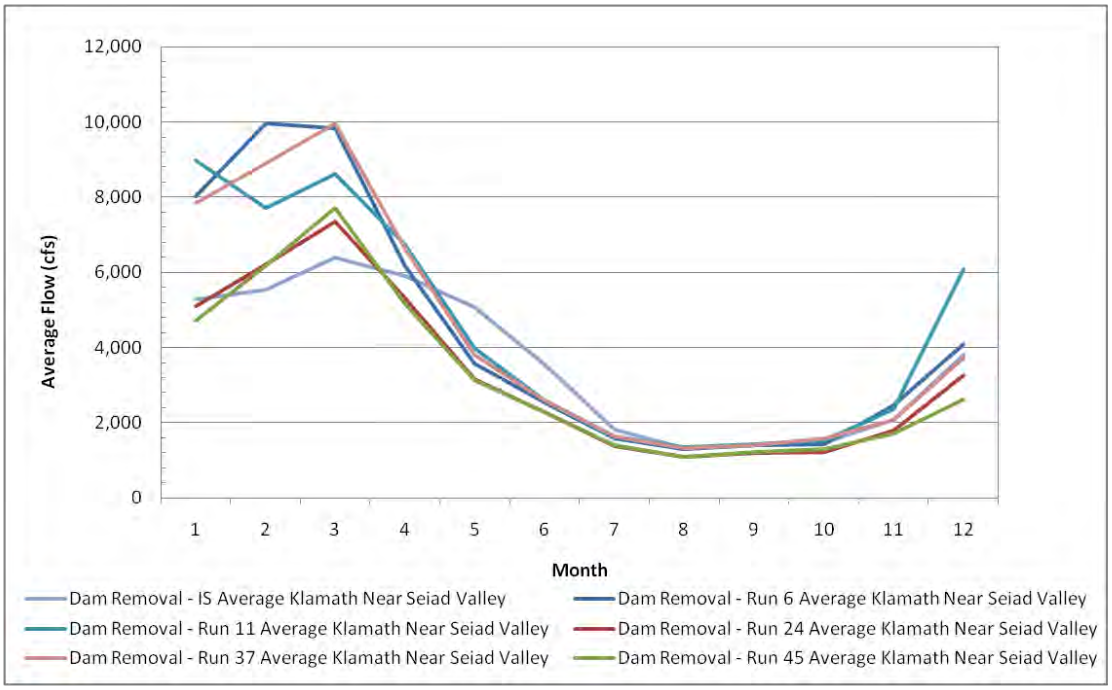


Figure 11-4. Average flows in the Klamath River near Seiad Valley for Dam Removal Alternative.

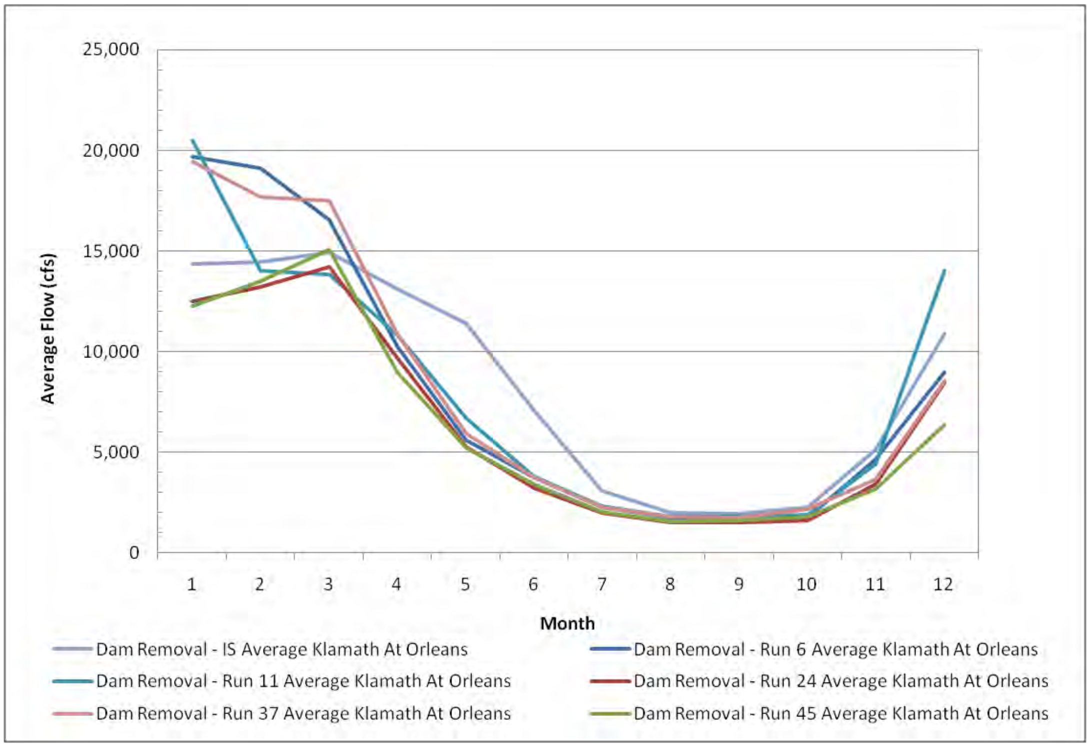


Figure 11-5. Average flows in the Klamath River at Orleans for Dam Removal Alternative

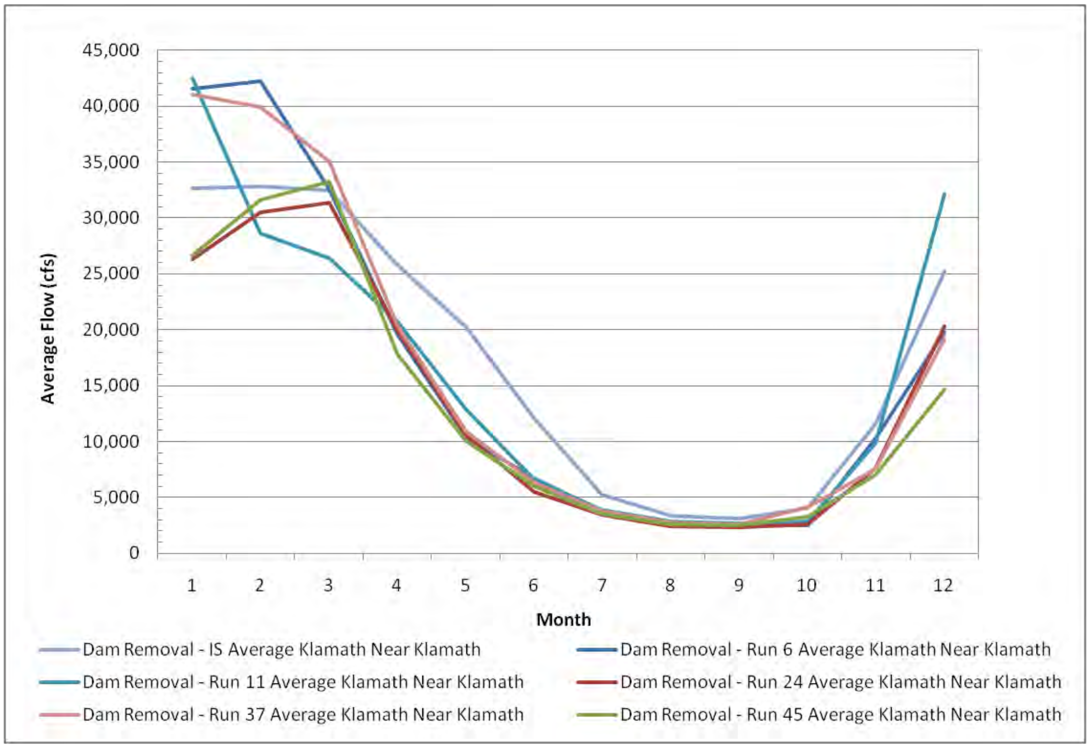


Figure 11-6. Average flows in the Klamath River at Klamath for Dam Removal Alternative.

These results are consistent with the findings of Reclamation (2011c, 2011d), which are reports intended to assess the effect of, and risk resulting from, global climate change with respect to the quantity of water resources located in each major Reclamation river basin. Some of the key findings of the Reclamation (2011c, 2011d) study are summarized in Figure 11-7 and Figure 11-8.

The technical assessment provided: (1) an analysis of changes in hydroclimate variables—namely, precipitation, temperature, snow water equivalent, and streamflow across the major Reclamation river basins—and the technical foundation for the SECURE report and (2) documentation for this new hydrologic projections dataset that will be made publicly available over the Western United States. The analysis involves developing hydrologic projections associated with World Climate Research Programme Coupled Model Intercomparison Project3 (WCRP CMIP3) climate projections that have been bias-corrected and spatially downscaled and served at the following Web site: http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections. In total, 112 hydrologic projections were developed, relying on watershed applications of the Variable Infiltration Capacity macroscale hydrology model. From these time-series climate and hydrologic projections (or hydroclimate projections), changes in hydroclimate variables were computed for three future decades: 2020s (water years 2020–2029), 2050s (water years 2050–2059) and 2070 (water years 2070–2079) from the reference 1990s' decade (water years 1990–1999). The reference 1990s are from the ensemble of simulated historical hydroclimates, not from the observed 1990s.

The annual mean temperature in the Upper and Lower basins of the Klamath River are predicted to increase over the next 90 years (Figure 11-7). The annual precipitation demonstrates no major increase or decrease over the next 90 years (Figure 11-7).

Reclamation (2011c) also indicates substantial shifts in the annual runoff from the months of April to July to the months of December to March. Figure 11-8 shows the percent change in runoff for the 2020, 2050, and 2070 decades relative to the 1990s for several points on the Klamath River. For many points within the basin by 2050, there is around a 15 to 50% increase in flow during the months of December to March and approximately a 10 to 20% decrease in flow for the months of April to July. This is consistent with results of this document that show the shift to stream flow late spring and summer months to winter and early spring months.

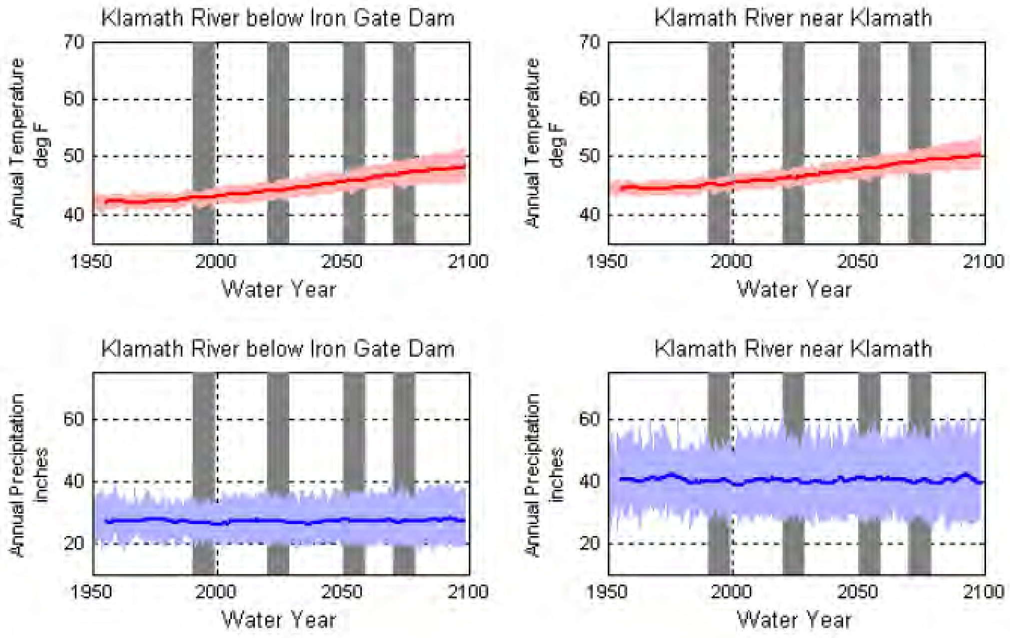


Figure 23. Simulated annual climate averaged over Klamath River subbasins.

Figure 23 displays the ensemble of temperature and precipitation projections from Bias Corrected and Spatially Downscaled WCRP CMIP3 Climate Projections (section 1.5.1). Annual conditions represent spatially averaged results over the basin. Darker colored lines indicate the median-annual condition through time, sampled from the ensemble of 112 climate simulations (section 1.5.1), and then smoothed using a 5-year running average. Lighter-colored areas represent the time-series range of 10th to 90th percentile annual values within the ensemble from simulated 1950 through simulated 2099.

Figure 11-7. Simulated annual climate averaged over Klamath River subbasins. Figure reproduced from Reclamation (2011c).

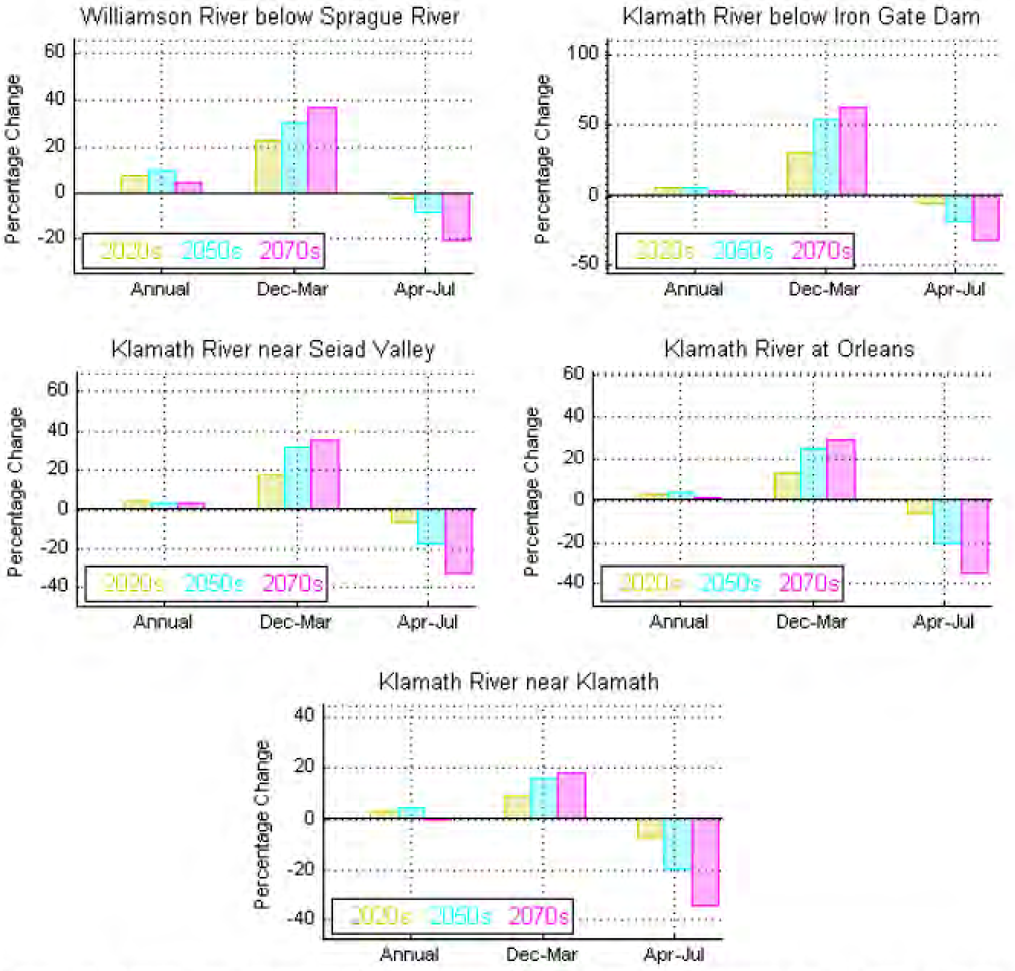


Figure 27. Simulated changes in decade-mean runoff for several subbasins in the Klamath River basin above Klamath, California.

Figure 27 presents Annual, December–March, and April–July runoff impacts for subbasins shown. Each panel shows percentage changes in mean runoff (annual or either season) for three future decades (2020s, 2050s, and 2070s) relative to baseline conditions (1990s). Development of runoff information is described in Reclamation (2011a) based on climate simulations previously discussed (section 1.5.1).

Figure 11-8. Changes in decade-mean runoff for several subbasins in Klamath River. Reproduced from Reclamation (2011c).

11.2. Effect on Hydraulics, Sediment Transport and Geomorphology

The climate change scenarios are not sufficiently refined to determine effects to peak flows. Therefore, it is difficult to determine if climate change will have a significant impact on flood risk, sediment transport, or geomorphology. However, if the future climate is wetter and more precipitation occurs as rainfall and/or there is a faster snowmelt runoff during the spring, then peak flows would likely increase as well. If the climate is overall drier, the peak flows may not be substantially higher.

If peak flows do indeed increase, higher peak flows will generally create a wider channel and floodplain. Higher flows would also tend to further armor the bed below Iron Gate Dam to Cottonwood Creek under the No Action Alternative, whereas, they would have much less effect on the Dam Removal Alternative because the gravel supply is restored to this reach.

The effect of climate change on geomorphology could be more pronounced if there is a change in riparian vegetation. For example, if the conifer species in the upper Klamath River are replaced by other species, such as willow, the bank properties may be slightly different. The difference in bank properties could translate into different rates of bank erosion and planform change. The quantification of this process is uncertain, however, and would affect both alternatives in a similar manner.

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13. Appendix A. Flood Frequency Report

RECLAMATION

Managing Water in the West

Hydrology Studies for the Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Official Use Only

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

March 2011

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Note: The previous version of this document was completed in October 2010. Additional frequency analyses and hydrographs were requested in January and February 2011 to support design and construction efforts. This March 2011 version of the document incorporates the additional information.

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Peer Review Certification: This document has been peer reviewed and is believed to be in accordance with the service agreement and standards of the proffessionl

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3/9/2011
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Table of Contents

1 Introduction 5
2 Peak Discharge Frequency Analysis 6
3 Streamflow Duration Analysis 13
4 Volume Frequency Estimates 18
5 Flood Frequency Hydrographs 23
6 Conclusions 35
7 References 36
8 Appendix A – Frequency Analysis 37
9 Appendix B – Monthly Flow Duration 74
10 Appendix C – 1961-2010 Average Daily Discharge 77
11 Appendix D – Hydrographs 82

1 Introduction

This report summarizes the flood frequency estimates for the Klamath River between Keno, OR and Klamath, CA (Figure 1) for the Secretary's Determination on Klamath River Dam Removal and Basin Restoration. This flood hydrology study is intended to provide hydrologic information to support hydraulic and sediment transport modeling efforts on the Klamath River and to determine the hydrologic conditions which would be expected during two construction seasons (July 1 to November 30 and June 1 to October 31) for the removal of Boyle, Copco 1, Copco 2 and Iron Gate dams. The Klamath River is regulated by numerous reservoirs upstream of the Keno gaging station. Annual flood frequency estimates were developed based on seven gaging stations on the Klamath River with long-term records. Annual, seasonal, and monthly flow duration values and seasonal flood frequency estimates were developed at the Keno, Boyle, Copco and Iron Gate gages. Using the calculated flood frequency values, frequency hydrographs were developed at the Keno, Boyle, Copco and Iron Gate gages. The Boyle, Copco, and Iron Gate gages are considered reasonable estimates of flood frequency values at Boyle, Copco1 and 2, and Iron Gate dams, respectively.

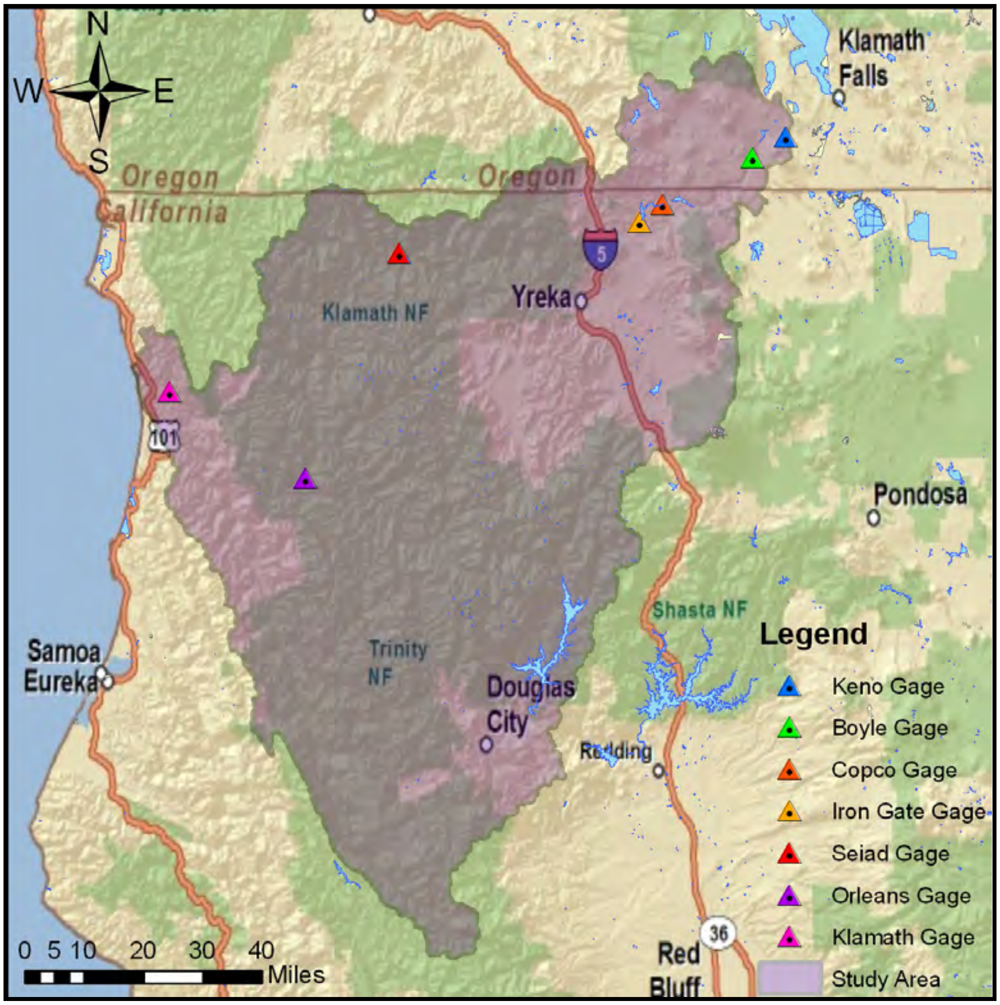


Figure 1 – Map of Klamath River Basin, OR & CA

2 Peak Discharge Frequency Analysis

U.S. Geological Survey (USGS) peak discharge estimates and mean daily flow records were available at seven locations and utilized to develop the flood frequency estimates for the Klamath River between Keno, OR and Klamath, CA [1]. The USGS streamflow gaging stations are listed in Table 1, and locations are shown in Figure 1.

Table 1 – U.S. Geological Survey Streamflow Gaging Stations Analyzed

USGS Gaging Station No.	Station Name	Drainage Area (mi^2)	Latitude	Longitude	Gage Elevation (feet, NGVD)	Period of Record (Water Years)
11509500	Klamath River at Keno, OR	3,920	42°08'00"	121°57'40"	3,961	1905-1913 1930-2009
11510700	Klamath River below John C. Boyle Power Plant near Keno, OR	4,080	42°05'05"	122°04'20"	3,275	1959-2009
11512500	Klamath River below Fall Creek near Copco, CA	4,370	41°58'20"	122°22'05"	2,310	1924-1961
11516530	Klamath River below Iron Gate Dam, CA	4,630	41°55'41"	122°26'35"	2,162	1961-2009
11520500	Klamath River near Seiad Valley, CA	6,940	41°51'14"	123°13'52"	1,320	1913-1925 1952-2009
11523000	Klamath River at Orleans, CA	8,475	41°18'13"	123°32'00"	356	1927-2009
11530500	Klamath River near Klamath, CA	12,100	41°30'40"	123°58'42"	5.6	1911-1927 1932-1994, 1996, 1998-2009

A Log-Pearson III distribution was fit to the annual peak flows using the method of moments. The USGS program PeakFQ [2] was used to analyze the station data. This process is consistent with the procedure described in the Guidelines for Determining Flood Flow Frequency, *Bulletin 17B* [3]. A regional skew value was not included in the calculations. Calculations based on the station skew are assumed sufficient due to the length of the gage records.

The Keno, Boyle and Copco gages are highly regulated by impoundments upstream of the Keno gage. To better model those effects and improve the fit of the frequency curve to the gage, the data was censored by applying a gage base discharge. This was done based on the assumption that the peak discharges above the gage base discharge represents what would be expected during unregulated conditions. The model does not include peaks below the gage base discharge to estimate the frequency curve statistics because they are regulated and cannot be modeled using the same distribution. Using the maximum censoring level allowed by PeakFQ (50 percent), the gage base discharges were set for Keno, Boyle, and Copco at 4,000 ft^3/s, 4,000 ft^3/s, and 5,400 ft^3/s respectively.

The station record at the Copco gage represents a lower flow period in the basin and is not indicative of the peak discharges that have been experienced in the basin. The record ends in 1961 before the basin flood of record which occurred in December 1964. Other large floods occurred in 1972, 1974, 1982, 1986, 1996, 1997, and 2006. The station record at the Boyle gage represents a higher to moderate flow period in the basin, but has a much shorter record than the record at the Keno gage. This can be shown by comparing the average peak discharge at Keno for the 89 years of record to the average peak discharge at Keno for the period of record that the Boyle and Copco gages were in operation. The Keno gage average peak discharge for the historic record is 4,860 ft^3/s. From 1930-1961 when the Copco gage was in operation, the average peak discharge at Keno is 3,960 ft^3/s. The average peak discharge at Keno for the period of 1961-2009 when the Boyle gage was in operation is 5,590 ft^3/s. Figure 2 displays the Keno historic record and the average discharge at Keno for the time periods when the Copco and Boyle gages were in operation.

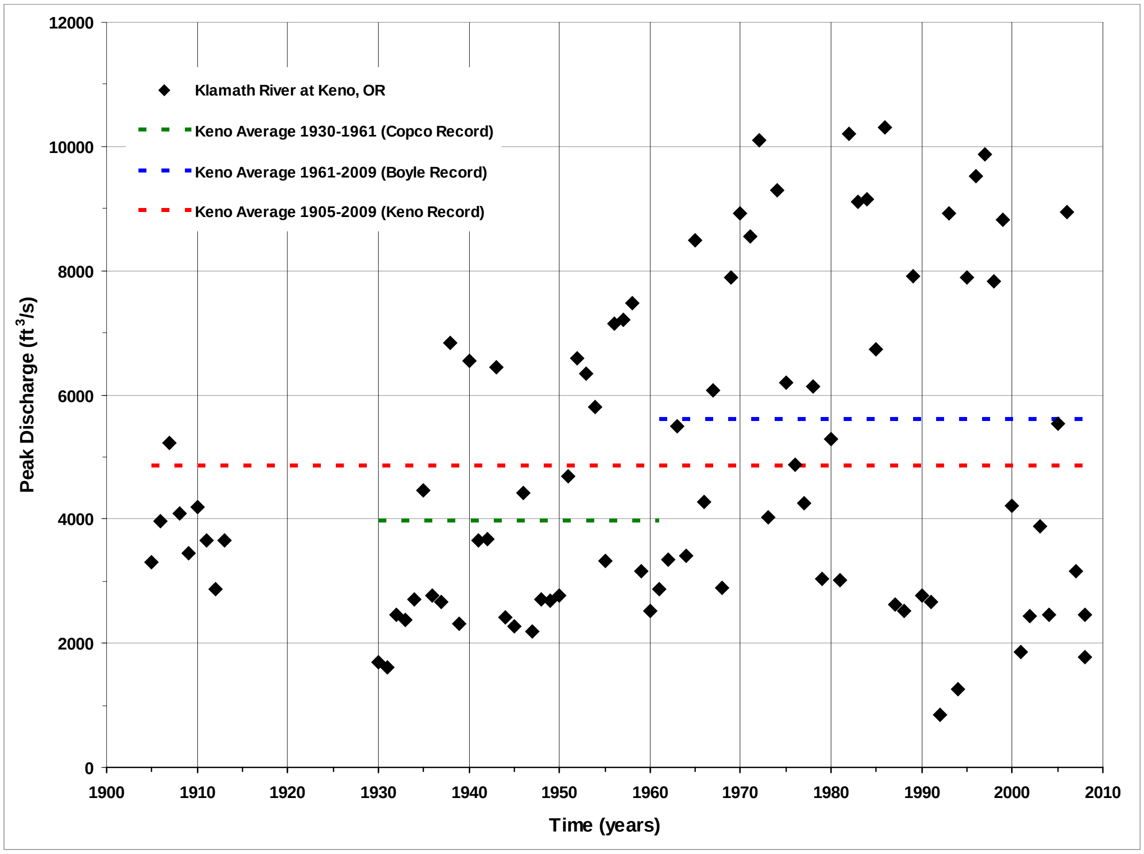


Figure 2 – Keno Annual Peak and Average Peak Discharge

In order to create a common time period for the peak discharge frequency analysis, the records at Boyle and Copco were extended based on a correlation to Keno. The station data at Keno was correlated to the Boyle and Copco data for the overlapping years of the record when the peak discharge at both stations were from the same flood event. Figure 3 shows the result of the gage correlation at both gages.

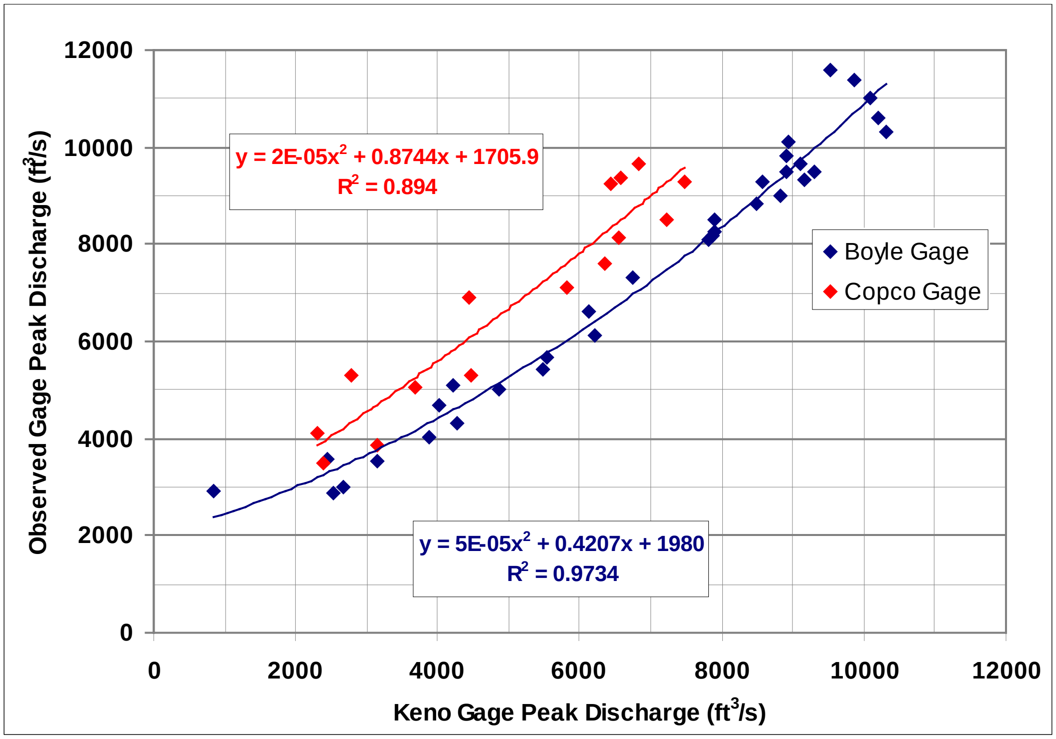


Figure 3 – Correlation of Keno to Boyle and Copco Observed Peak Discharges

Boyle and Copco peak discharge data was estimated by applying the following correlation equations:

$$Equation1: Q_{Boyle} = (5*10^{-5}*(Q_{Keno})^2) + (0.4207*Q_{Keno}) + 1980.0$$

$$Equation2: Q_{Copco} = (2*10^{-5}*(Q_{Keno})^2) + (0.8744*Q_{Keno}) + 1705.9$$

Where: Q_{Boyle} = Boyle Computed Peak Discharge (ft^3/s)
Q_{Keno} = Keno Gaged Peak Discharge (ft^3/s)
Q_{Copco} = Copco Computed Peak Discharge (ft^3/s)

The Boyle gaged record was extended using Equation 1 for the periods 1905-1913 and 1930-1960. The Copco gaged record was extended using Equation 2 for the periods 1905-1913 and 1962-2009. The extended records were combined with the gaged data at each gage and the peak discharges at each location were analyzed using PeakFQ and censored as described above. The list of annual peak discharges estimated at Boyle and Copco can be seen in Appendix A.

The gages at Iron Gate, Seiad, Orleans, and Klamath were not greatly influenced by the regulation above Keno and the data was not censored. Table 2 contains the results of the statistical analyses at each gage. Figures 4 through 10 present plots of the frequency data and the estimated frequency curve fit to the data. The data and statistical parameters of the LPIII distribution are shown in Appendix A.

Table 2 – Klamath River Annual Peak Discharge Frequency

Gaging Station	Drainage Area	Discharge (ft^3/s)				
		Gage Base	10-yr	25-yr	50-yr	100-yr
Keno	3,920	4,000	8,642	10,350	11,200	11,800
Boyle	4,080	4,000	9,058	11,050	12,220	13,150
Copco	5,370	5,400	10,750	12,720	13,730	14,470
Iron Gate	4,630	N/A	15,610	21,460	26,280	31,460
Seiad	6,940	N/A	56,540	93,400	131,000	179,300
Orleans	8,470	N/A	163,100	230,300	287,000	348,900
Klamath	12,100	N/A	298,300	392,900	466,900	543,300

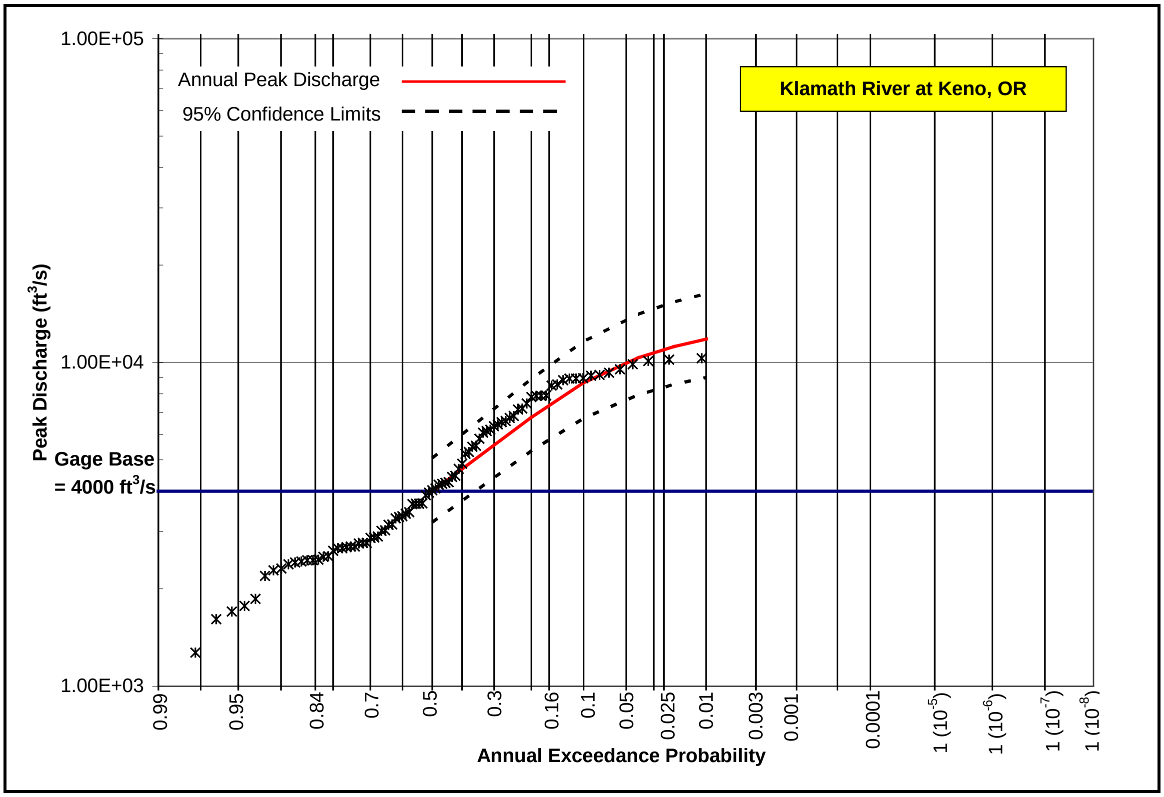


Figure 4 –Peak Discharge Frequency – Klamath River at Keno, OR

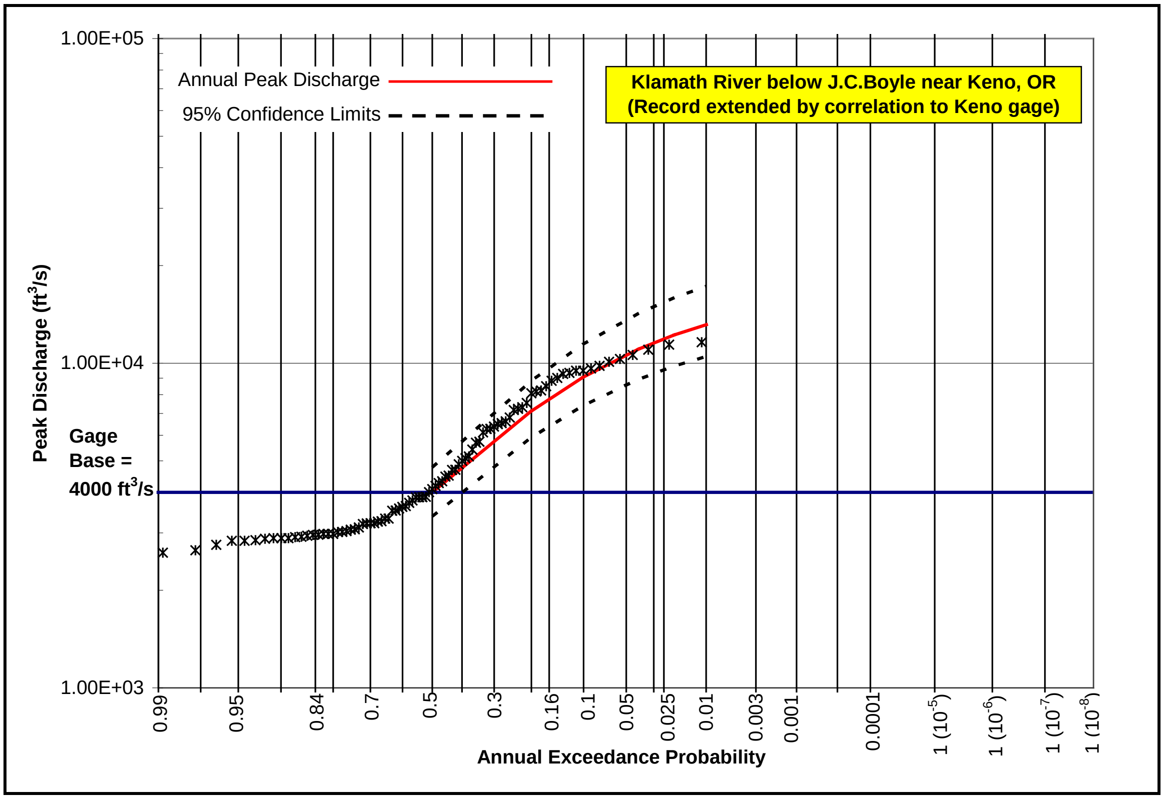


Figure 5 –Peak Discharge Frequency – Klamath River below J.C. Boyle Powerplant near Keno, OR

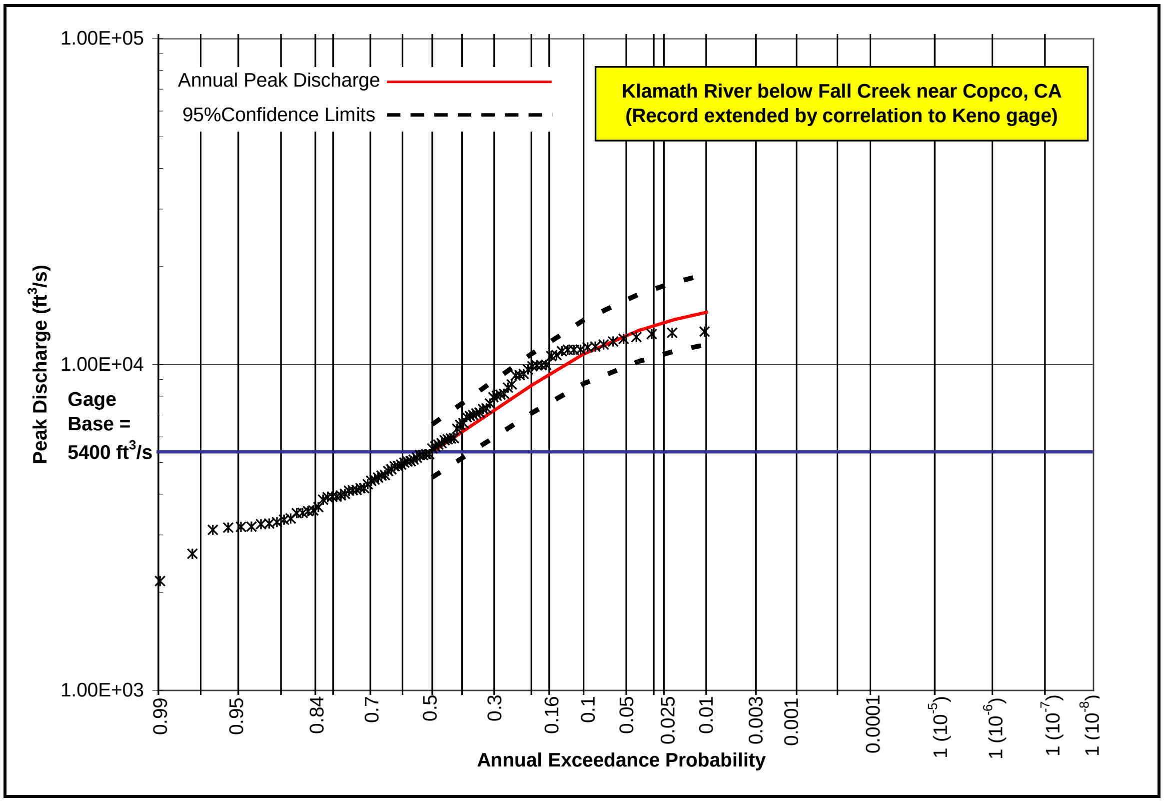


Figure 6 –Peak Discharge Frequency – Klamath River below Fall Creek near Copco, CA

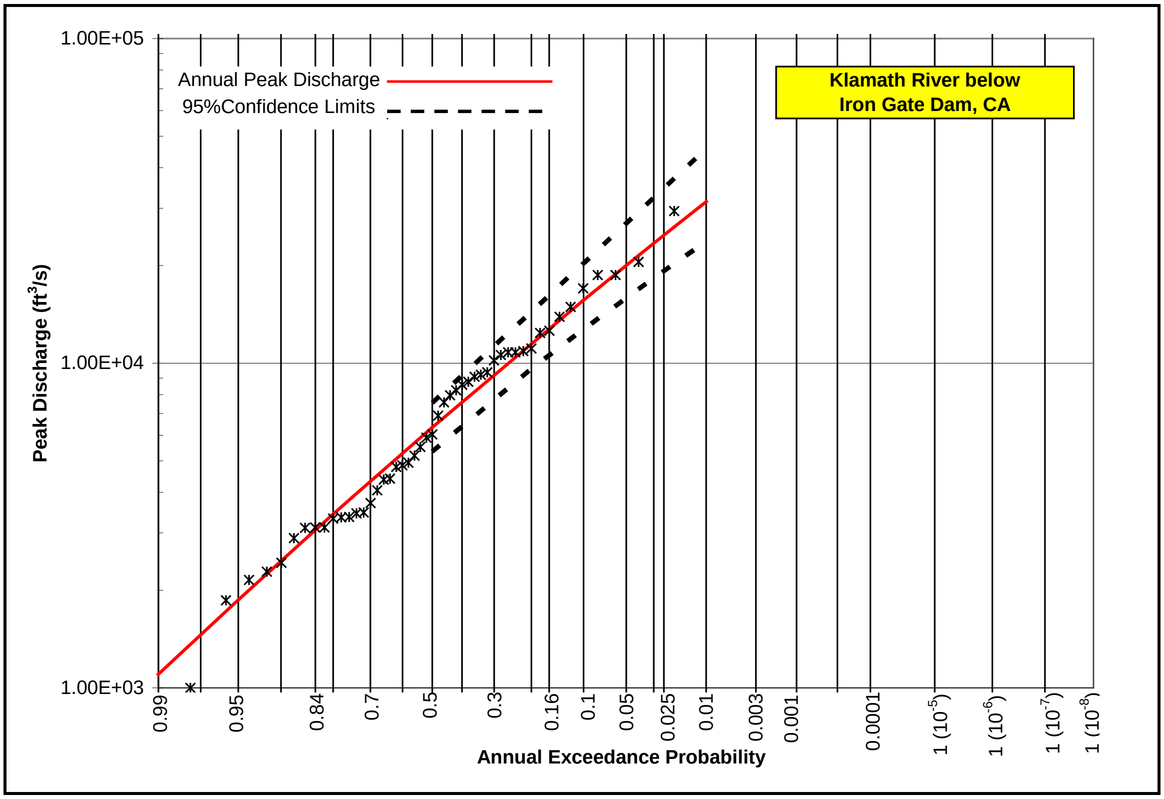


Figure 7 –Peak Discharge Frequency – Klamath River below Iron Gate Dam, CA

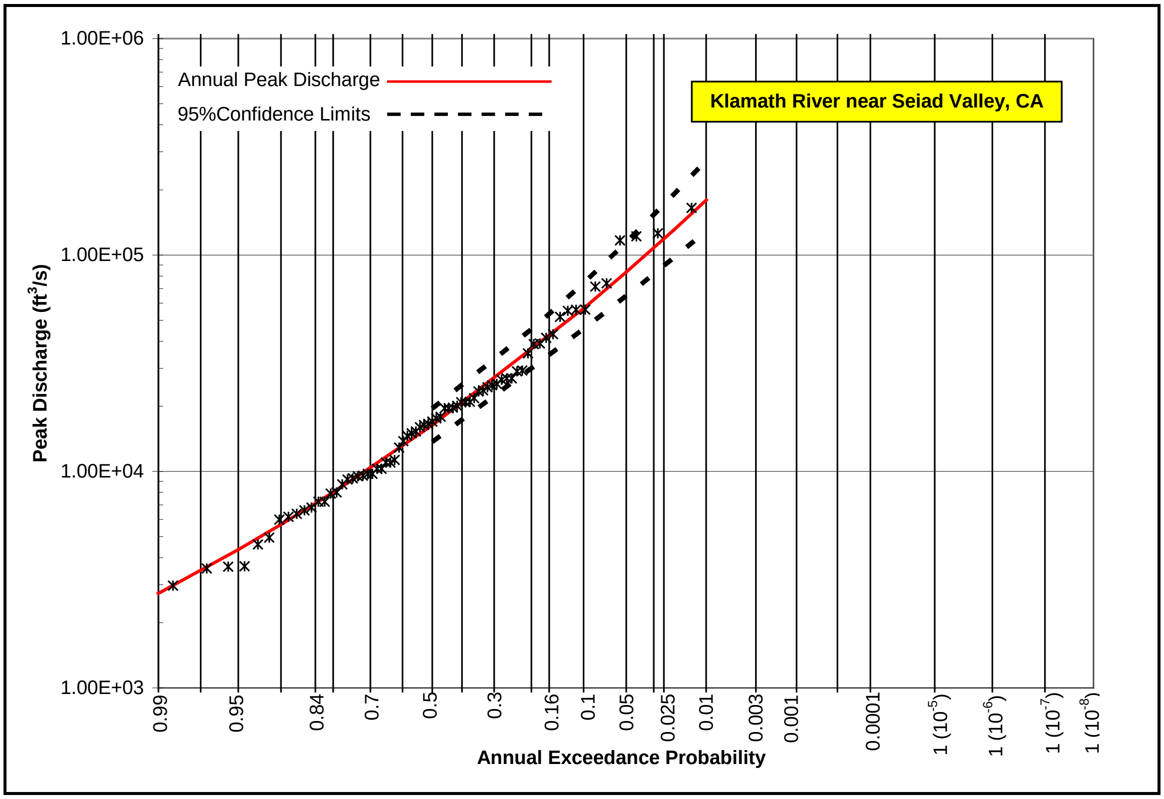


Figure 8 –Peak Discharge Frequency – Klamath River near Seiad Valley, CA

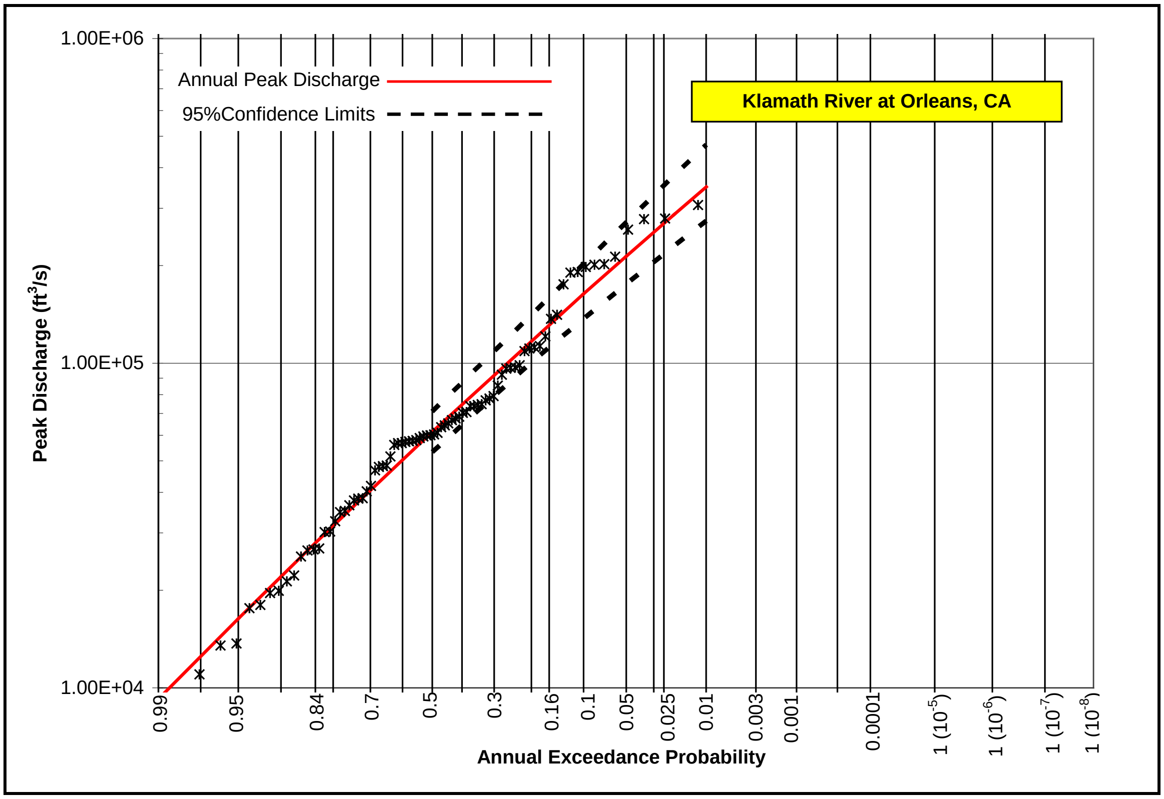


Figure 9 –Peak Discharge Frequency – Klamath River at Orleans, CA

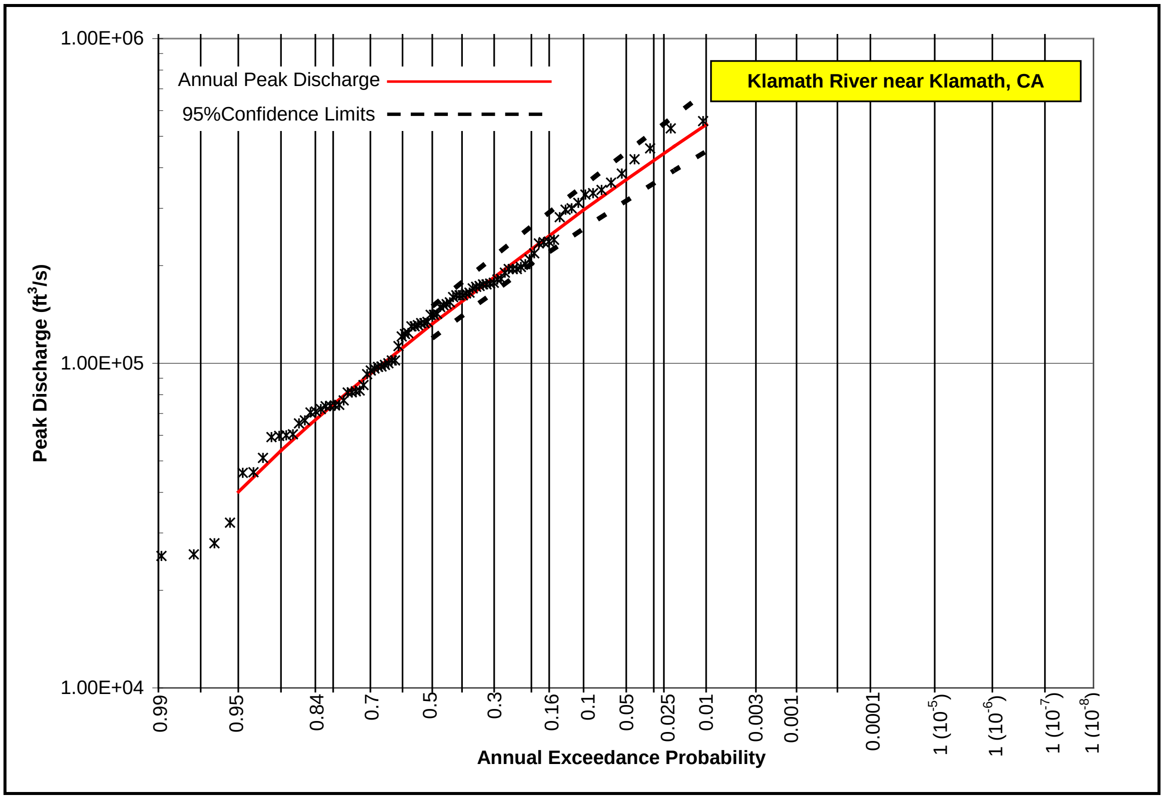


Figure 10 –Peak Discharge Frequency – Klamath River near Klamath, CA

3 Streamflow Duration Analysis

A streamflow duration analysis was performed for the Keno, Boyle, Copco, and Iron Gate daily gage data. This analysis presents the percentage of time that flows exceed various levels in the historic record. The data was also analyzed for the July 1 to November 30 and June 1 to October 31 seasons and for each month of the year.

In order to create a commom time period for the streamflow duration analysis, the daily discharge records at Boyle and Copco were extended based on a correlation to Keno. The station data at Keno was correlated to the Boyle and Copco data using a linear relationship for the overlapping years of daily record. Figures 11 and 12 present the results of the gage correlation.

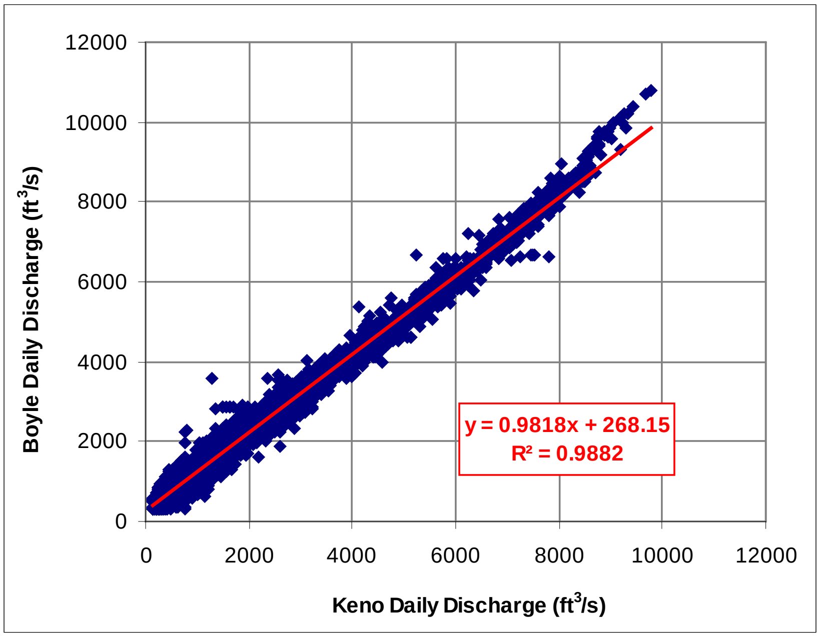


Figure 11 – Daily Discharge Correlation between Boyle and Keno gages

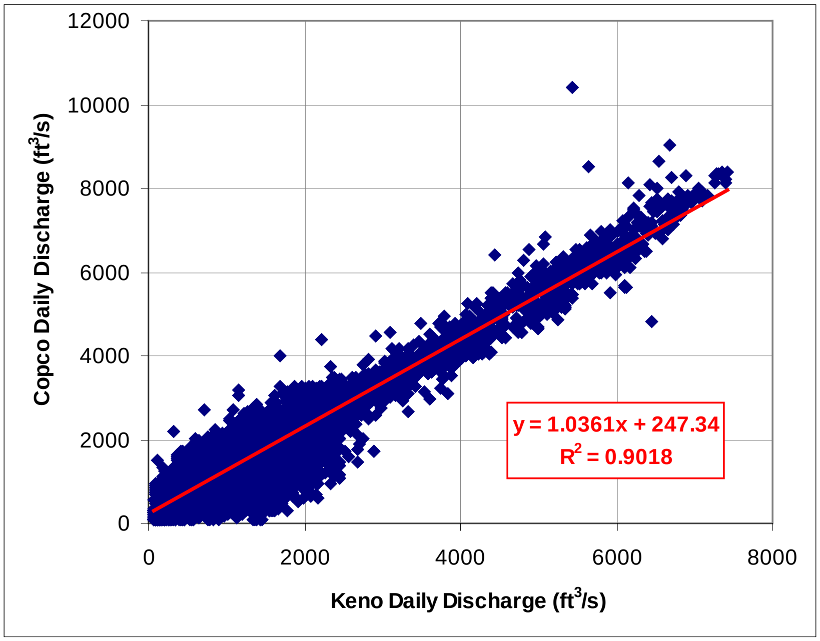


Figure 12 – Daily Discharge Correlation between Copco and Keno gages

Boyle and Copco peak discharge data was estimated by applying the following correlation equations:

$$Equation 3: Q_{Boyle} = (0.9818 * Q_{Keno}) + 268.15$$

$$Equation 4: Q_{Copco} = (1.0361 * Q_{Keno}) + 247.34$$

Where: Q_{Boyle} = Boyle Computed Daily Discharge (ft^3/s)
Q_{Keno} = Keno Gaged Daily Discharge (ft^3/s)
Q_{Copco} = Copco Computed DailyDischarge (ft^3/s)

The Boyle gaged daily discharge record was extended using Equation 3 for the periods 1905-1913 and 1930-1960. The Copco gaged record was extended using Equation 4 for the periods 1905-1913 and 1962-2009. The extended records were combined with the gaged data at each gage location. Annual and seasonal (July 1 to November 30 and June 1 to October 31) flow duration analyses were performed on the daily gage records at Keno and Iron Gate. The flow duration analyses were performed on the extended daily gage records at Boyle and Copco.

Tables 3 and 4 provide the tabular results of the flow duration analysis at each gage. Figures 13 to 16 present the annual and seasonal flow duration relationship at each gage location. The daily flow duration plots for each month and the tabular results can be found in Appendix B. Average daily discharges for each day of the year at each location were computed based on the fifty year period from 1961-2010. This data is presented in Appendix C.

Table 3 – Daily Flow Duration – Annual

% of time equaled or exceeded	Discharge (ft^3/s)			
	Annual			
	Keno	Boyle	Copco	Iron Gate
99	152	359	290	528
95	297	546	517	716
90	431	673	639	741
80	645	892	889	955
70	821	1080	1100	1040
60	990	1240	1290	1320
50	1180	1440	1500	1360
40	1440	1680	1760	1700
30	1800	2050	2130	1980
20	2390	2640	2690	2980
10	3120	3350	3400	3870
5	4320	4460	4600	5500
1	6880	6970	7480	9170

Table 4 – Daily Flow Duration –Seasonal

% of time equaled or exceeded	Discharge (ft^3/s)							
	July 1 – November 30				June 1 – October 31			
	Keno	Boyle	Copco	Iron Gate	Keno	Boyle	Copco	Iron Gate
99	147	352	294	441	145	338	285	435
95	292	526	509	701	270	482	496	675
90	417	656	597	725	336	600	555	717
80	621	854	827	846	500	748	717	739
70	737	1000	987	1000	663	913	907	852
60	901	1160	1170	1030	776	1040	1040	1000
50	1020	1270	1300	1130	938	1200	1219	1030
40	1180	1440	1480	1320	1070	1340	1367	1130
30	1390	1610	1700	1350	1270	1510	1584	1320
20	1580	1820	1930	1510	1500	1740	1843	1370
10	1960	2200	2310	1840	1850	2090	2247	1760
5	2450	2640	2820	2920	2340	2570	2710	1990
1	3300	3510	3620	4350	3730	3930	4010	3240

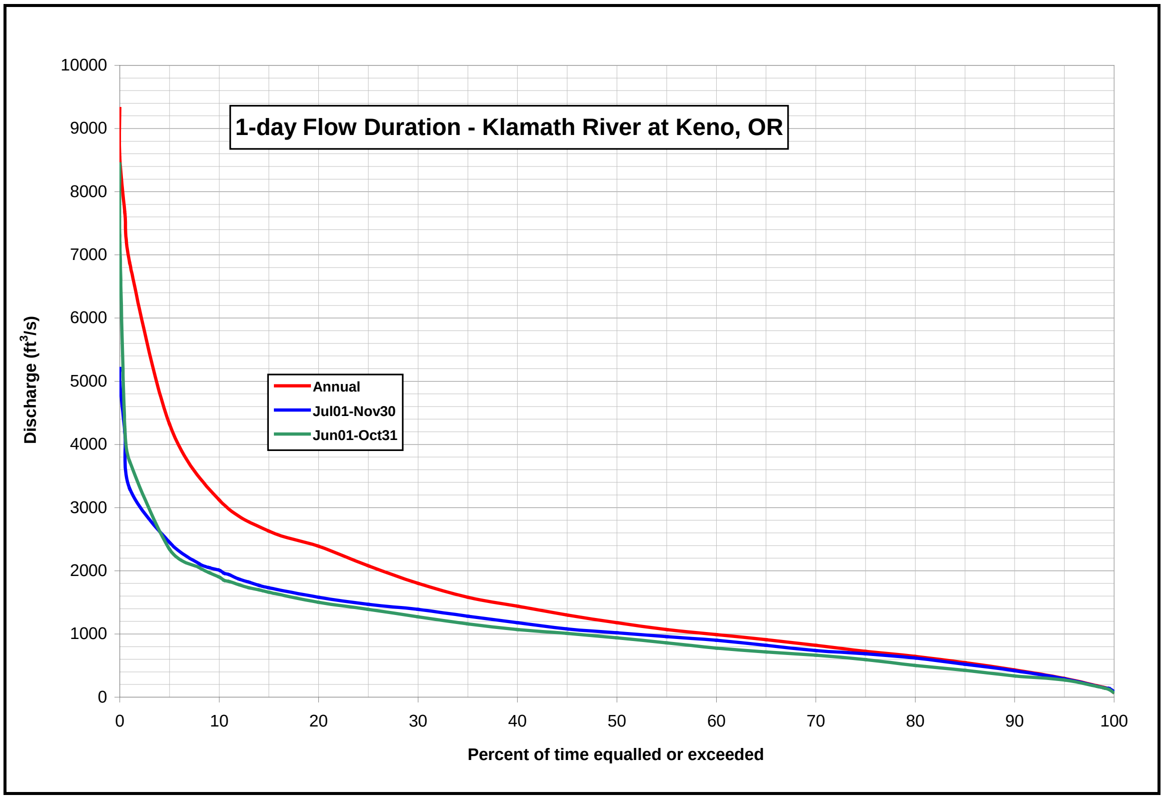


Figure 13 – Daily Flow Duration - Klamath River at Keno, OR

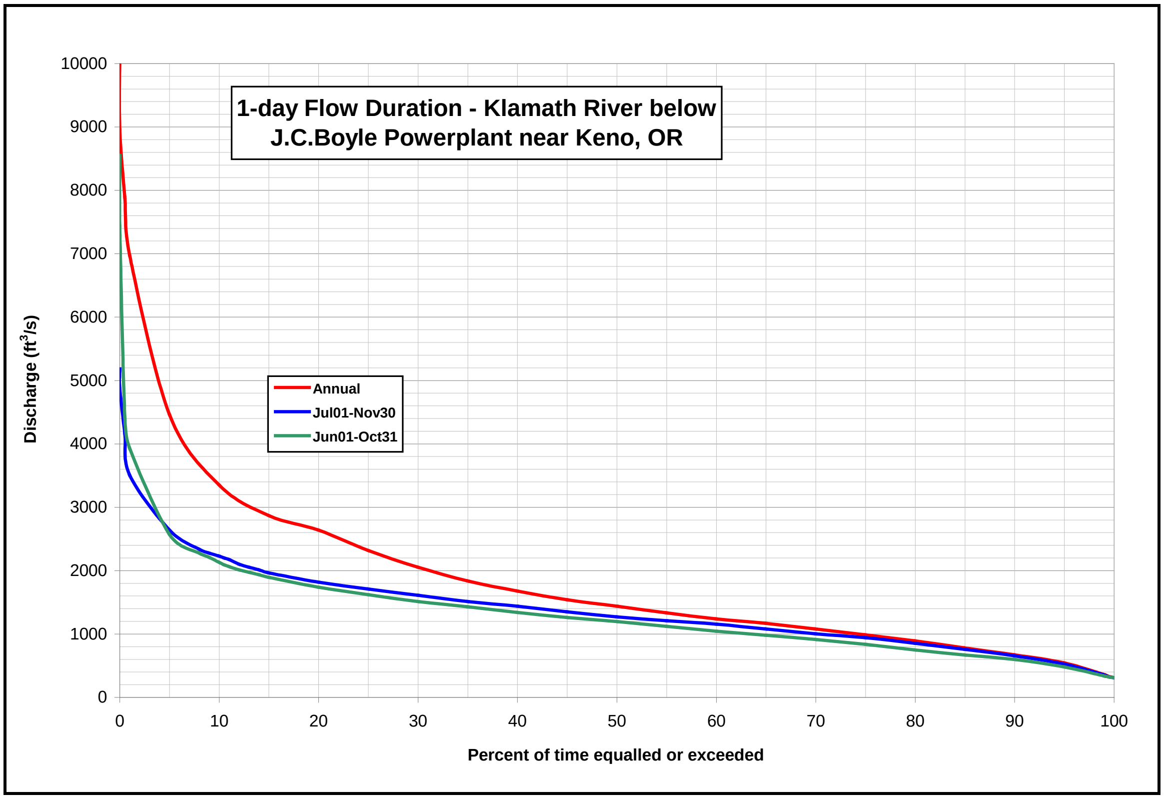


Figure 14 – Daily Flow Duration - Klamath River below J.C. Boyle Powerplant near Keno, OR

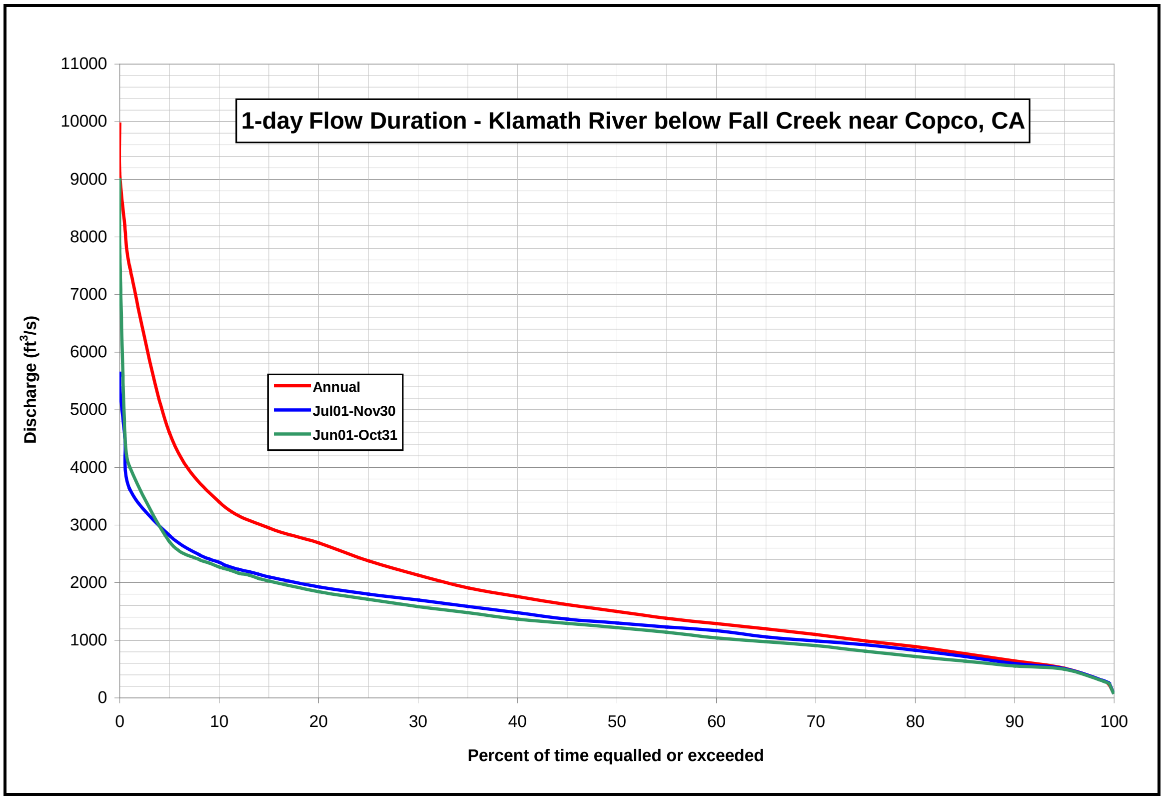


Figure 15 – Daily Flow Duration - Klamath River below Fall Creek near Copco, CA

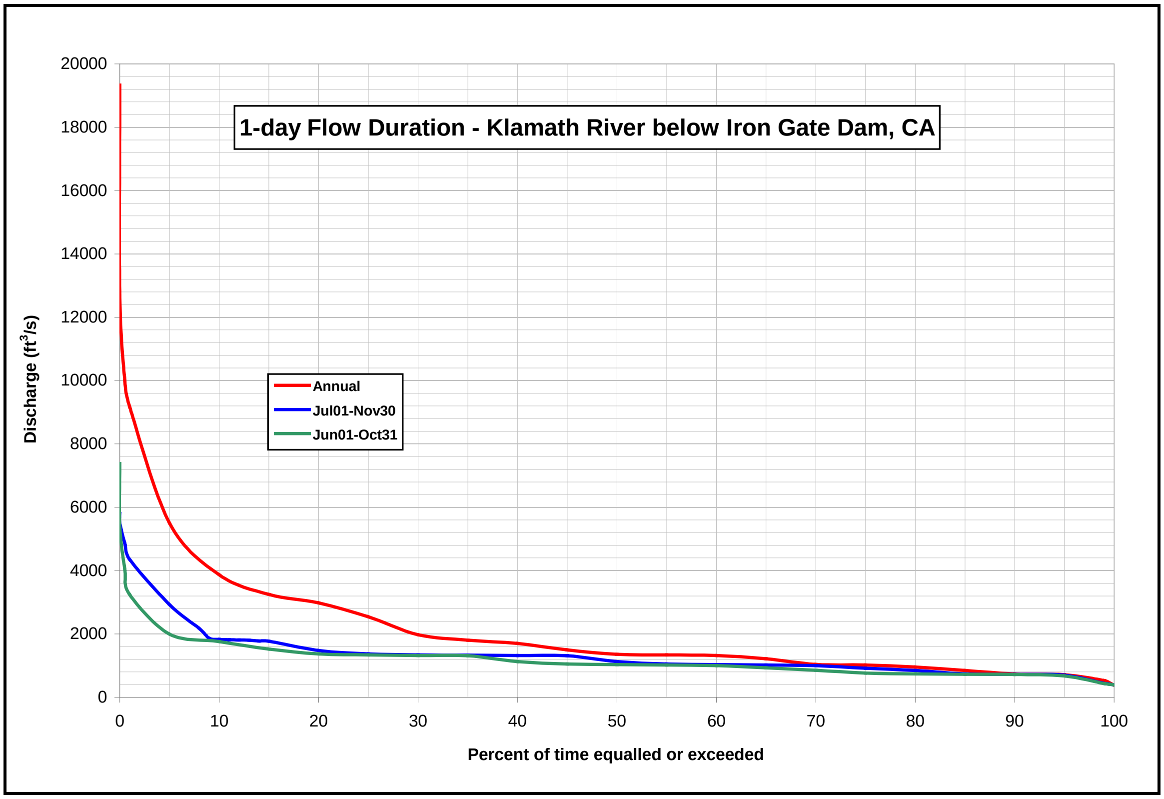


Figure 16 – Daily Flow Duration - Klamath River below Iron Gate Dam, CA

4 Volume Frequency Estimates

Volume frequency estimates were calculated for the 1-, 3-, 5-, 7-, and 15-day volumes at Keno, Boyle, Copco and Iron Gate gage locations. Boyle and Copco daily flow records were extended using Equations 3 and 4 respectively. A Log-Pearson III distribution was fit to the peak annual, seasonal (July 1 through November 30 and June 1 through October 31) and monthly (August and September) average discharges using the method of moments. The USGS program PeakFQ was used to analyze the station data. This process is consistent with the procedure described in the Guidelines for Determining Flood Flow Frequency, *Bulletin 17B*. A regional skew value was not included in the calculations. Calculations based on the station skew are assumed sufficient due to the length of the gage records. Tables 5 through 14 provide the results of the statistical analyses. The data and statistical parameters of the LPIII distribution are shown in Appendix A.

Table 5 – Annual Discharge Frequency

Gage Location	Duration (days)	Average Discharge (ft^3/s)				
		Gage Base	10-yr	25-yr	50-yr	100-yr
Keno	1	3700	8140	9660	10400	10900
	3	3550	7910	9340	10100	10700
	5	3500	7720	9120	9870	10400
	7	3300	7580	8970	9710	10300
	15	3250	7040	8400	9200	9800
Boyle	1	3900	8510	10300	11200	11800
	3	3750	8200	9830	10800	11500
	5	3600	7960	9530	10400	11100
	7	3500	7790	9310	10200	10900
	15	3500	7210	8660	9580	10400
Copco	1	4100	8750	10600	11500	12100
	3	3900	8440	10100	11000	11600
	5	3600	8190	9800	10700	11400
	7	3500	8080	9720	10500	11100
	15	3500	7550	9160	10000	10600
Iron Gate	1	N/A	14000	19000	22900	27100
	3	N/A	12800	17000	20400	23800
	5	N/A	11900	15600	18500	21400
	7	N/A	11300	14700	17300	19900
	15	N/A	9910	12700	14800	16900

Table 6 – Annual Volume Frequency

Gage Location	Duration (days)	Volume (acre-ft)			
		10-yr	25-yr	50-yr	100-yr
Keno	1	16200	19200	20600	28200
	3	47000	55500	10100	82500
	5	69800	83300	60000	135000
	7	105000	124000	135000	177000
	15	210000	250000	274000	358000
Boyle	1	16900	20300	22200	23500
	3	48800	58500	64000	68300
	5	71500	85900	95000	103000
	7	108000	129000	142000	152000
	15	214000	258000	285000	309000
Copco	1	17400	20900	22700	24000
	3	50200	60300	65300	68700
	5	74900	90800	99300	106000
	7	112000	135000	146000	154000
	15	225000	272000	298000	317000
Iron Gate	1	27800	37600	45500	53800
	3	76300	101000	121000	142000
	5	98300	126000	147000	168000
	7	157000	204000	240000	276000
	15	295000	378000	440000	503000

Table 7 – Seasonal Discharge Frequency (7/1-11/30)

Gage Location	Duration (days)	Average Discharge (ft^3/s)				
		Gage Base	10-yr	25-yr	50-yr	100-yr
Keno	1	1950	3290	4000	4570	5160
	3	1800	3230	3950	4510	5090
	5	1700	3180	3920	4490	5080
	7	1650	3150	3890	4450	5020
	15	1550	3010	3740	4300	4850
Boyle	1	2250	3440	4090	4580	5090
	3	2150	3390	4040	4530	5020
	5	2000	3350	4010	4500	4980
	7	1900	3320	3980	4470	4940
	15	1750	3180	3840	4320	4790
Copco	1	2400	3650	4350	4910	5510
	3	2250	3550	4260	4820	5420
	5	2200	3480	4230	4810	5410
	7	1950	3420	4200	4800	5400
	15	1850	3280	4050	4640	5230
Iron Gate	1	N/A	4060	5280	6290	7390
	3	N/A	3890	5060	6040	7110
	5	N/A	3800	4960	5940	7010
	7	N/A	3720	4860	5830	6910
	15	N/A	3470	4540	5460	6490

Table 8 – Seasonal Volume Frequency (7/1-11/30)

Gage Location	Duration (days)	Volume (acre-ft)			
		10-yr	25-yr	50-yr	100-yr
Keno	1	6520	7940	9060	10200
	3	19200	23500	26900	30300
	5	31500	38800	44500	50300
	7	43700	54000	61800	69700
	15	89400	111000	128000	144000
Boyle	1	6830	8110	9090	10100
	3	20100	24000	26900	29800
	5	33200	39800	44600	49400
	7	46000	55300	62000	68600
	15	94600	114000	129000	143000
Copco	1	7240	8620	9740	10900
	3	21100	25300	28700	32300
	5	34500	41900	47700	53700
	7	47500	58400	66600	74900
	15	97500	120600	138000	155000
Iron Gate	1	8050	10500	12500	14700
	3	23100	30100	35900	42300
	5	37700	49200	58900	69500
	7	51600	67500	81000	96000
	15	103000	135000	162400	193000

Table 9 – Seasonal Discharge Frequency (6/1-10/31)

Gage Location	Duration (days)	Average Discharge (ft^3/s)				
		Gage Base	10-yr	25-yr	50-yr	100-yr
Keno	1	1800	3750	5030	6090	7240
	3	1700	3690	4950	6010	7170
	5	1630	3590	4830	5850	6940
	7	1600	3480	4660	5610	6610
	15	1530	3100	4105	4950	5880
Boyle	1	2180	3950	5160	6190	7330
	3	1980	3870	5110	6130	7240
	5	1900	3790	4990	5970	7030
	7	1900	3690	4830	5750	6740
	15	1800	3310	4300	5130	6040
Copco	1	2280	4140	5370	6410	7560
	3	2170	4010	5260	6330	7520
	5	2060	3900	5130	6170	7330
	7	1910	3800	5000	5990	7040
	15	1820	3400	4440	5320	6280
Iron Gate	1	N/A	3940	5460	6860	8540
	3	N/A	3770	5200	6520	8090
	5	N/A	3660	5010	6260	7730
	7	N/A	3530	4790	5950	7300
	15	N/A	3000	3830	4530	5310

Table 10 – Seasonal Volume Frequency (6/1-10/31)

Gage Location	Duration (days)	Volume (acre-ft)			
		10-yr	25-yr	50-yr	100-yr
Keno	1	7438	9973	12079	14368
	3	21933	29478	35774	42659
	5	35643	47940	57997	68777
	7	48359	64631	77821	91831
	15	92083	122132	147273	174823
Boyle	1	7830	10200	12300	14500
	3	23100	30400	36500	43100
	5	37600	49400	59200	69700
	7	51200	67000	79800	93600
	15	98500	128000	153000	180000
Copco	1	8210	10600	12700	15000
	3	23900	31300	37700	44800
	5	38700	50900	61200	72700
	7	52700	69500	83100	97700
	15	101000	132000	158000	187000
Iron Gate	1	7820	10800	13600	16900
	3	22500	30900	38800	48100
	5	36200	49700	62100	76700
	7	49000	66600	82500	101000
	15	89300	114000	135000	158000

Table 11 – August Discharge Frequency

Gage Location	Duration (days)	Average Discharge (ft^3/s)				
		Gage Base	10-yr	25-yr	50-yr	100-yr
Boyle	1	1300	2070	2430	2680	2910
	3	1250	2030	2400	2650	2890
	5	1200	1990	2360	2610	2820
	7	1140	1960	2330	2570	2780
	15	1060	1870	2230	2470	2690
Iron Gate	1	N/A	1390	1530	1640	1740
	3	N/A	1360	1510	1610	1710
	5	N/A	1330	1460	1550	1650
	7	N/A	1310	1440	1530	1620
	15	N/A	1260	1370	1440	1510

Table 12 – August Volume Frequency

Gage Location	Duration (days)	Volume (acre-ft)			
		10-yr	25-yr	50-yr	100-yr
Boyle	1	4110	4830	5320	5780
	3	12100	14300	15800	17200
	5	19700	23400	25800	28000
	7	27200	32400	35700	38600
	15	55500	66300	73500	80000
Iron Gate	1	2750	3040	3250	3450
	3	8100	9000	9570	10200
	5	13200	14500	15410	16300
	7	18100	19900	21200	22500
	15	37500	40600	42800	44800

Table 13 – September Discharge Frequency

Gage Location	Duration (days)	Average Discharge (ft^3/s)				
		Gage Base	10-yr	25-yr	50-yr	100-yr
Boyle	1	1620	2310	2560	2690	2800
	3	1510	2210	2460	2610	2740
	5	1460	2140	2410	2570	2710
	7	1430	2110	2370	2540	2680
	15	1340	2020	2270	2440	2590
Iron Gate	1	N/A	1840	2060	2210	2360
	3	N/A	1820	2020	2160	2290
	5	N/A	1800	2000	2140	2270
	7	N/A	1770	1970	2100	2220
	15	N/A	1720	1870	1970	2060

Table 14 – September Volume Frequency

	Duration (days)	Volume (acre-ft)			
		10-yr	25-yr	50-yr	100-yr
Boyle	1	4580	5070	5340	5550
	3	13100	14600	15500	16300
	5	21300	23900	25500	26900
	7	29200	32900	35200	37300
	15	60000	67660	72600	77100
Iron Gate	1	3660	4080	4380	4670
	3	10800	12000	12800	13600
	5	17800	19800	21200	22500
	7	24600	27300	29100	30800
	15	51000	55700	58700	61400

5 Flood Frequency Hydrographs

Frequency hydrographs for Keno, Boyle, Copco and Iron Gate for the 10- to 100-year recurrence intervals were generated using a balanced hydrograph approach [4]. Under the balanced hydrograph approach, the annual maximum 1-, 3-, 5-, 7-, and 15-day duration average discharges are computed. The calculations for the duration average discharges are based on the gage records at Keno and Iron Gate and the extended records at Boyle and Copco. The 1-, 3-, 5-, 7-, and 15-day duration average discharges are computed by calculating moving averages of the mean daily flow data for specific durations and the annual maximums for each of the specified durations.

The above method was used for the July 1 to November 30 and June 1 to October 31 seasonal and the August and September monthly data for each year. The duration average discharge frequencies for the 10- to 100-year events were computed using a LPIII analysis as described above in section 2.

The July 1 to November 30 and June 1 to October 31 seasonal and August and September monthly peak flood frequency estimates were based on the linear relationship between the historic annual peak discharge and the annual daily discharge for the same day that the peak discharge occurred. This correlation equation was applied to the seasonal daily maximum value for each year to estimate the seasonal peak discharge. Figures 17 to 20 show the results of the gage correlation.

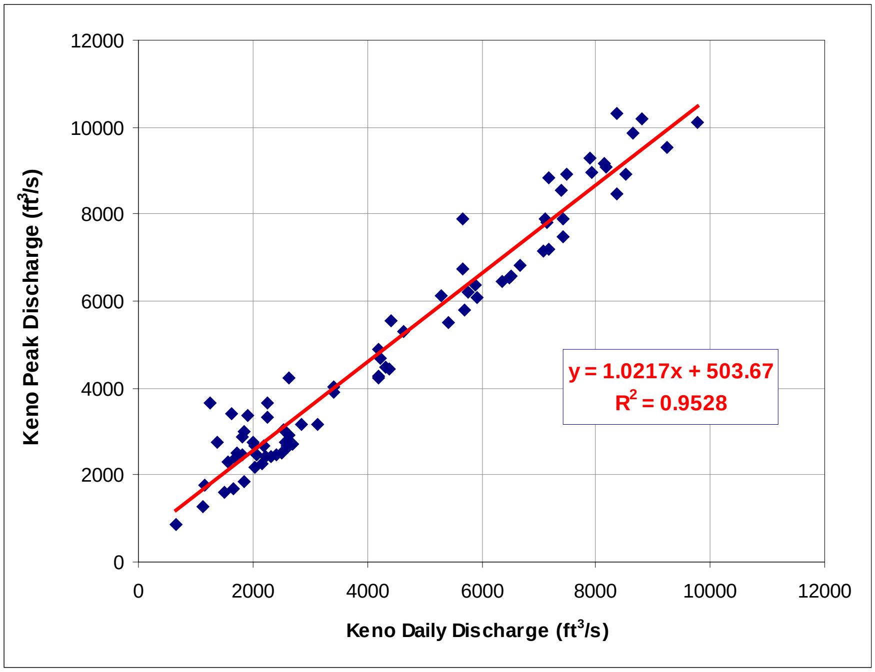


Figure 17 –Klamath River at Keno, OR

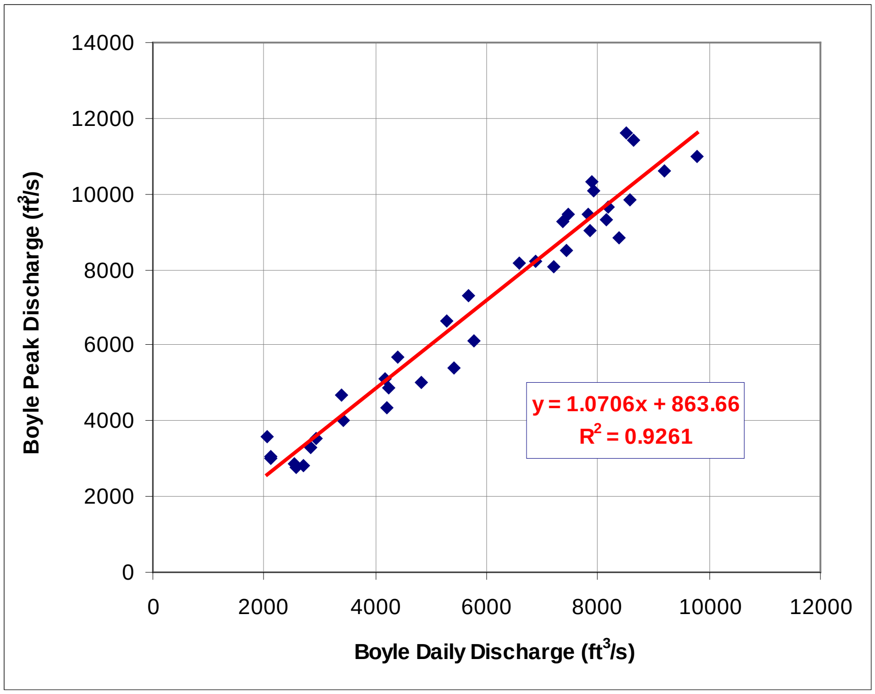


Figure 18 –Klamath River below J.C. Boyle Powerplant near Keno, OR

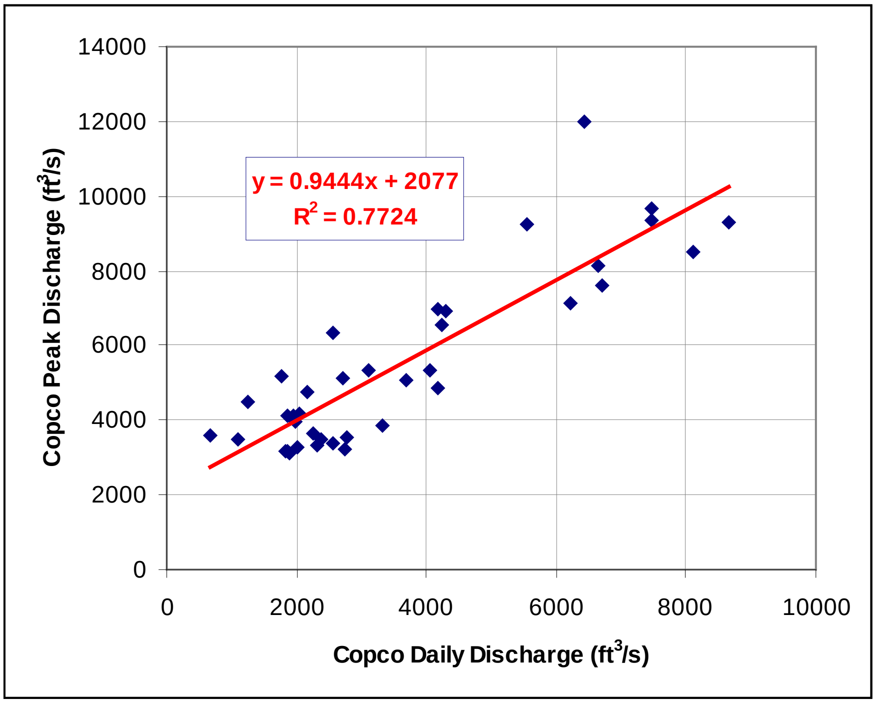


Figure 19 –Klamath River below Fall Creek near Copco, CA

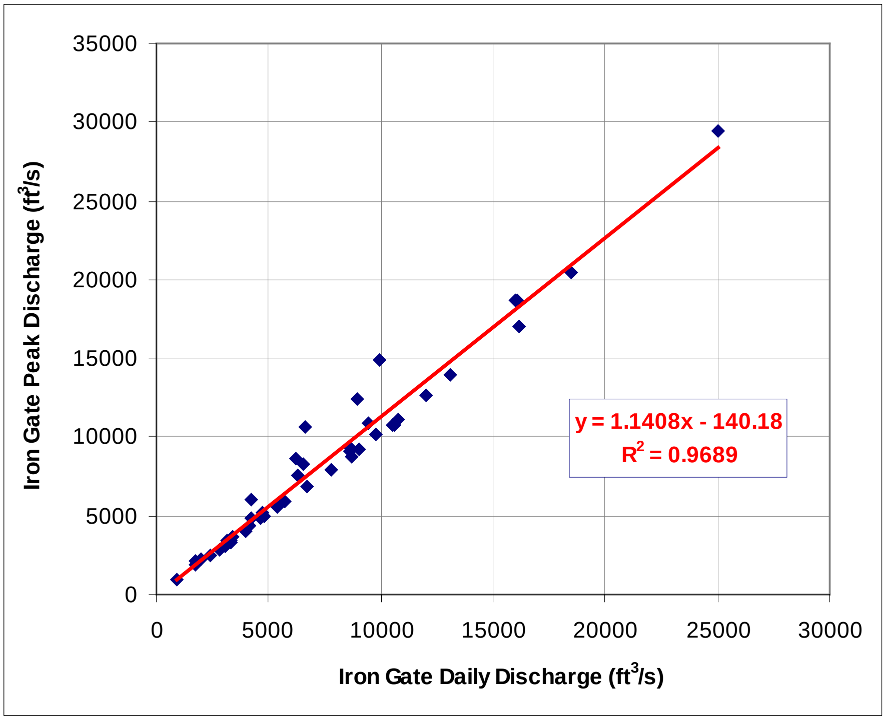


Figure 20 –Klamath River below Iron Gate Dam, CA

The following linear equations were derived from the correlation of the peak discharge to the daily discharge at each of the gage locations and applied to estimate the seasonal peak discharge for each year of the record.

$$Equation5 : QPeak_{Keno} = (1.0217 * QDaily_{Keno}) + 503.67$$

$$Equation6 : QPeak_{Boyle} = (1.0706 * QDaily_{Boyle}) + 863.66$$

$$Equation7 : QPeak_{Copco} = (0.9444 * QDaily_{Copco}) + 2077.0$$

$$Equation8 : QPeak_{IronGate} = (1.1408 * QDaily_{IronGate}) + 140.18$$

Where: $QPeak_{Keno} =$ Keno Computed Peak Discharge (ft^3/s)
$QDaily_{Keno} =$ Keno Gaged Daily Discharge (ft^3/s)
$QPeak_{Boyle} =$ Boyle Computed Peak Discharge (ft^3/s)
$QDaily_{Boyle} =$ Boyle Gaged Daily Discharge (ft^3/s)
$QPeak_{Copco} =$ Copco Computed Peak Discharge (ft^3/s)
$QDaily_{Copco} =$ Copco Gaged Daily Discharge (ft^3/s)
$QPeak_{IronGate} =$ Iron Gate Computed Peak Discharge (ft^3/s)
$QDaily_{IronGate} =$ Iron Gate Gaged Daily Discharge (ft^3/s)

The seasonal peak discharge frequencies for the 10- to 100-year events for each location were computed using a LPIII analysis as described above in section 4. Tables 15 and 16 present the results of the statistical analyses at each gage location for both seasons. Tables 17 and 18 present the results of the statistical analyses for August and September for Boyle and Iron Gate. The data and statistical parameters of the LPIII distribution are shown in Appendix A.

Table 15 – Klamath River Seasonal Peak Discharge Frequency (7/1-11/30)

Gaging Station	Discharge (ft^3/s)				
	Gage Base	10-yr	25-yr	50-yr	100-yr
Keno	2,550	3,870	4,610	5,180	5,760
Boyle	3,300	4,560	5,250	5,770	6,300
Copco	4,350	5,540	6,200	6,720	7,270
Iron Gate	N/A	4,500	5,910	7,100	8,390

Table 16 – Klamath River Seasonal Peak Discharge Frequency (6/1-10/31)

Gaging Station	Discharge (ft^3/s)				
	Gage Base	10-yr	25-yr	50-yr	100-yr
Keno	2,300	4,320	5,620	7,700	7,880
Boyle	3,150	5,070	6,370	7,470	8,680
Copco	4,190	6,070	7,240	8,180	9,190
Iron Gate	N/A	4,360	6,110	7,720	9,650

Table 17 – Klamath River August Peak Discharge Frequency

Gaging Station	Discharge (ft^3/s)				
	Gage Base	10-yr	25-yr	50-yr	100-yr
Boyle	2,250	3,080	3,460	3,720	3,970
Iron Gate	N/A	2,290	2,420	2,500	2,590

Table 18 – Klamath River September Peak Discharge Frequency

Gaging Station	Discharge (ft^3/s)				
	Gage Base	10-yr	25-yr	50-yr	100-yr
Boyle	2,600	3,340	3,590	3,730	3,840
Iron Gate	N/A	2,820	3,050	3,220	3,390

Frequency hydrographs for Keno, Boyle, Copco and Iron Gate for the 10- to 100-year recurrence intervals were generated using a balanced hydrograph approach [4]. Under the balanced hydrograph approach, the annual maximum 1-, 3-, 5-, 7-, and 15-day duration average discharges are computed. The calculations for the duration average discharges are based on the gage records at Keno and Iron Gate and the extended records at Boyle and Copco. The 1-, 3-, 5-, 7-, and 15-day duration average discharges are computed by calculating moving averages of the mean daily flow data for specific durations and the annual maximums for each of the specified durations.

The frequency hydrographs were generated assuming the peak occurs at the midpoint of the 15-day period, which is at hour 180. The annual and seasonal frequency hydrograph data for each gage is listed in Appendix D. The annual and seasonal frequency hydrographs for Keno, Boyle, Copco and Iron Gate are shown in Figures 21 to 32. The

August and September seasonal frequency hydrographs for Boyle and Iron Gate are presented in Figures 33 to 36.

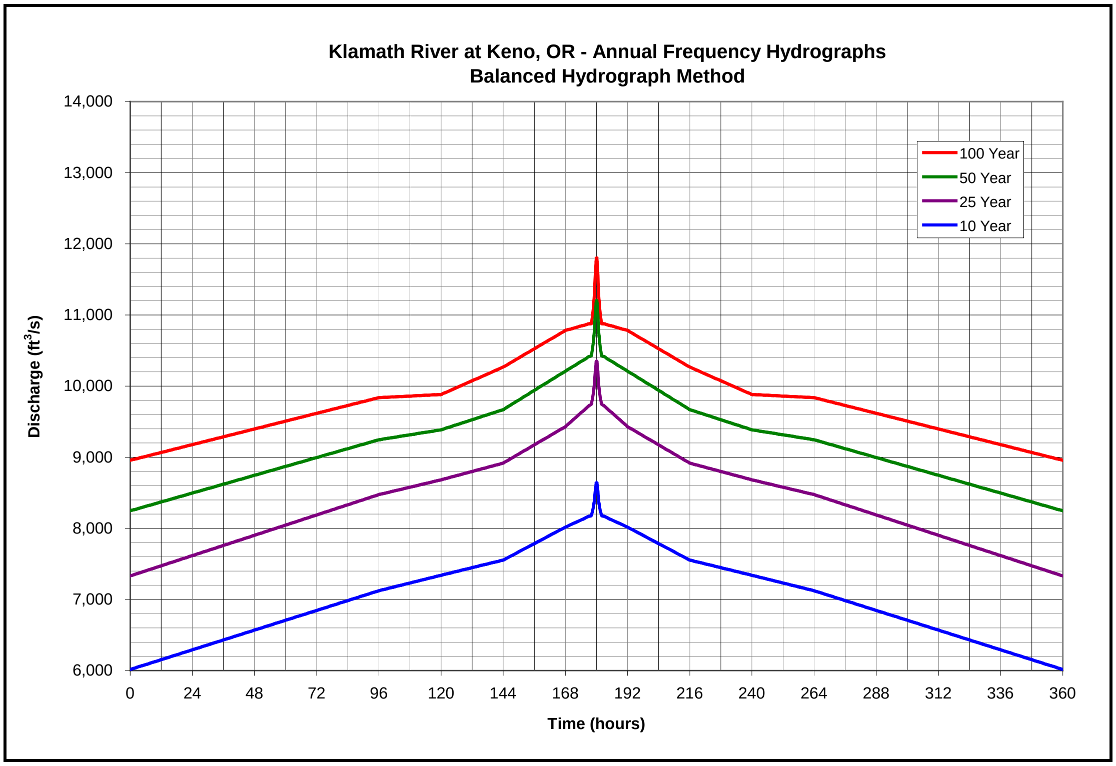


Figure 21 –Klamath River at Keno, OR – Annual Frequency Hydrographs

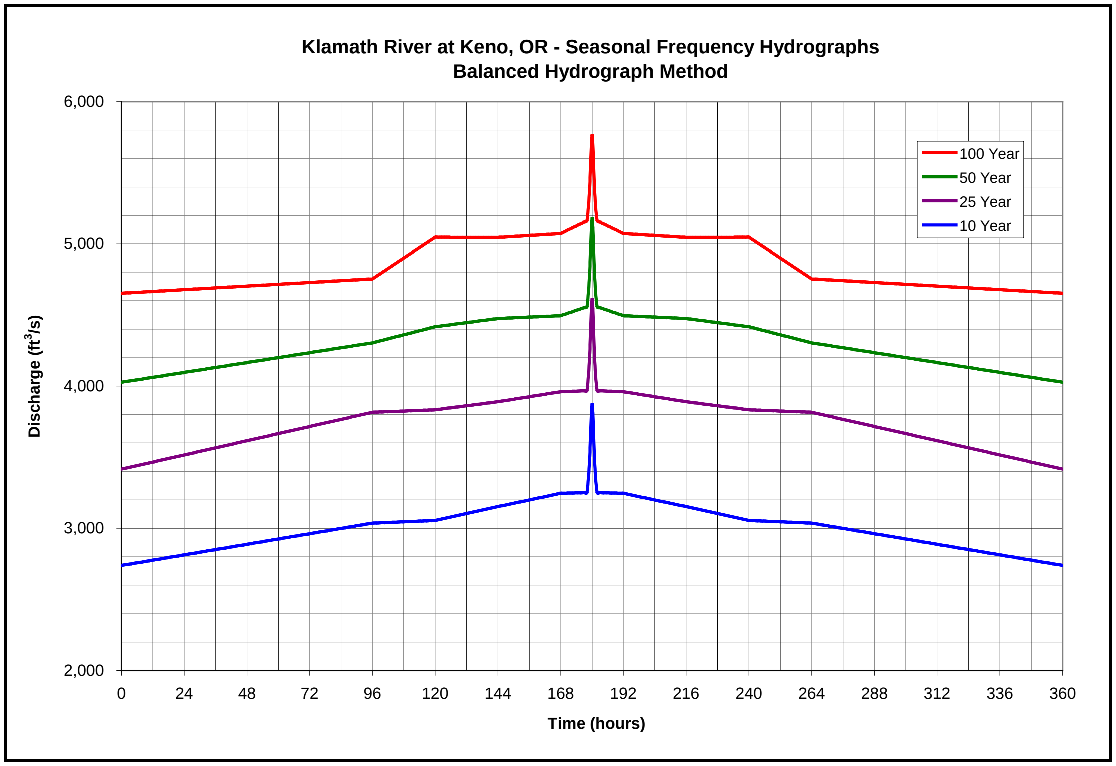


Figure 22 –Klamath River at Keno, OR – Seasonal Frequency Hydrographs

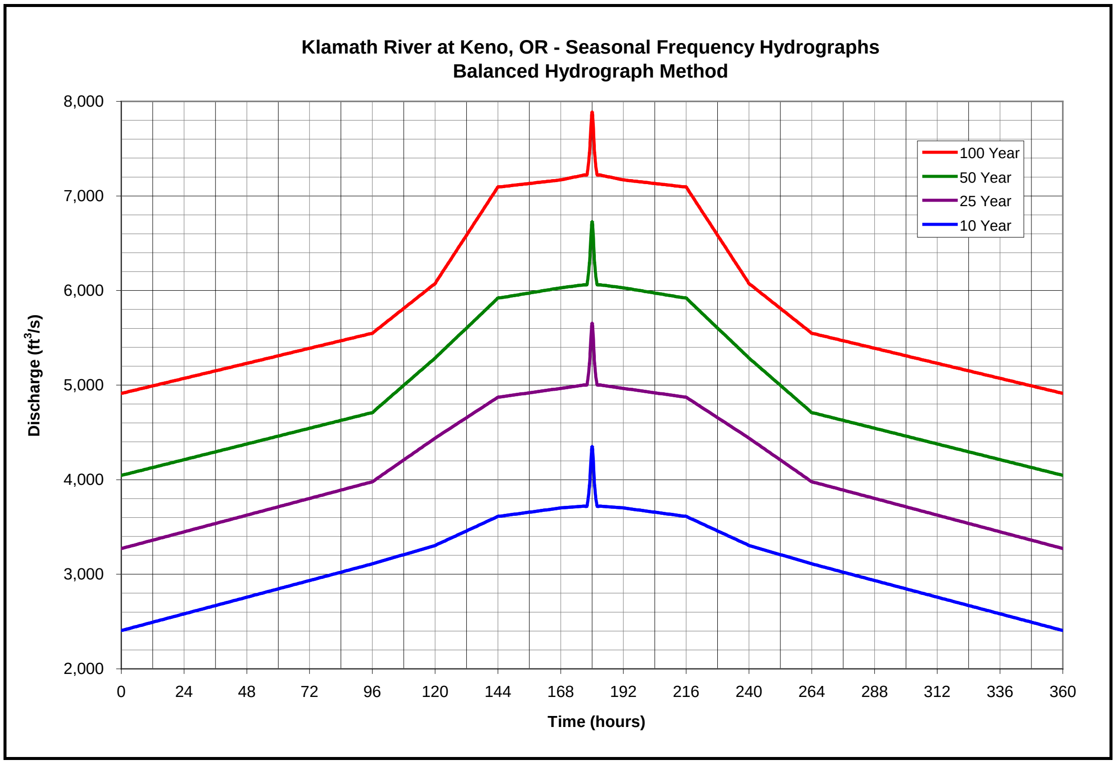


Figure 23 –Klamath River at Keno, OR – 6/1 to 10/31 Frequency Hydrographs

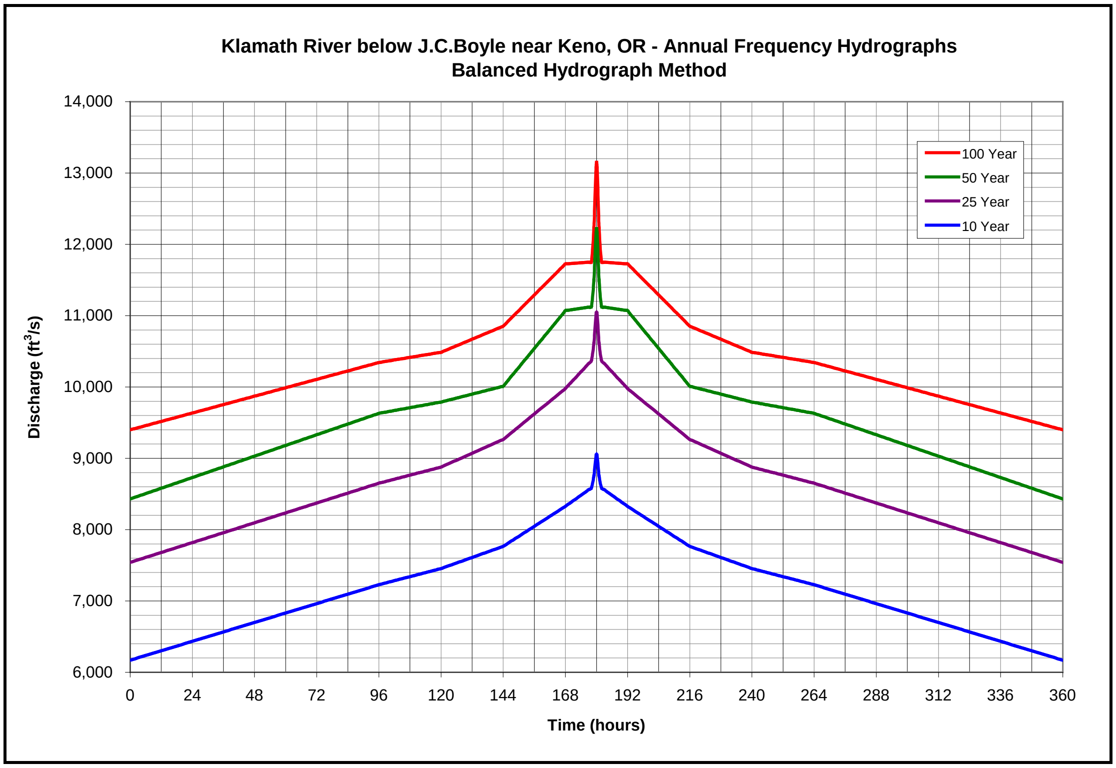


Figure 24 –Klamath River below J.C.Boyle near Keno, OR – Annual Frequency Hydrographs

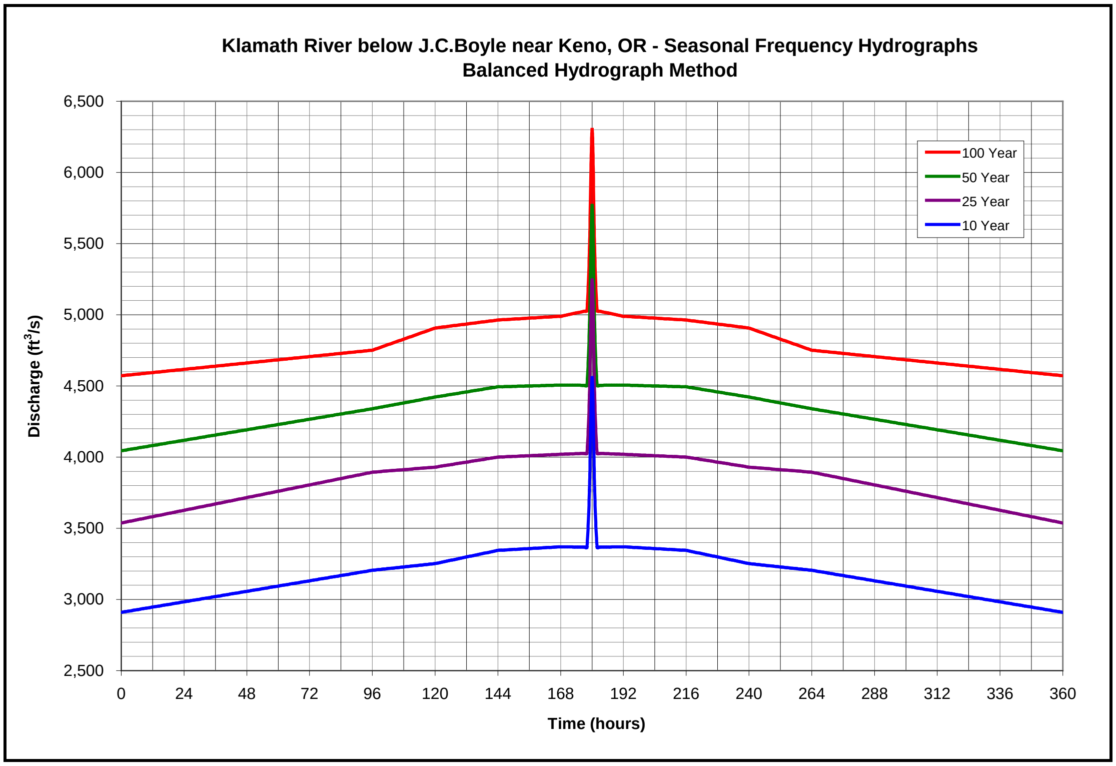


Figure 25 –Klamath River below J.C.Boyle near Keno, OR – Seasonal Frequency Hydrographs

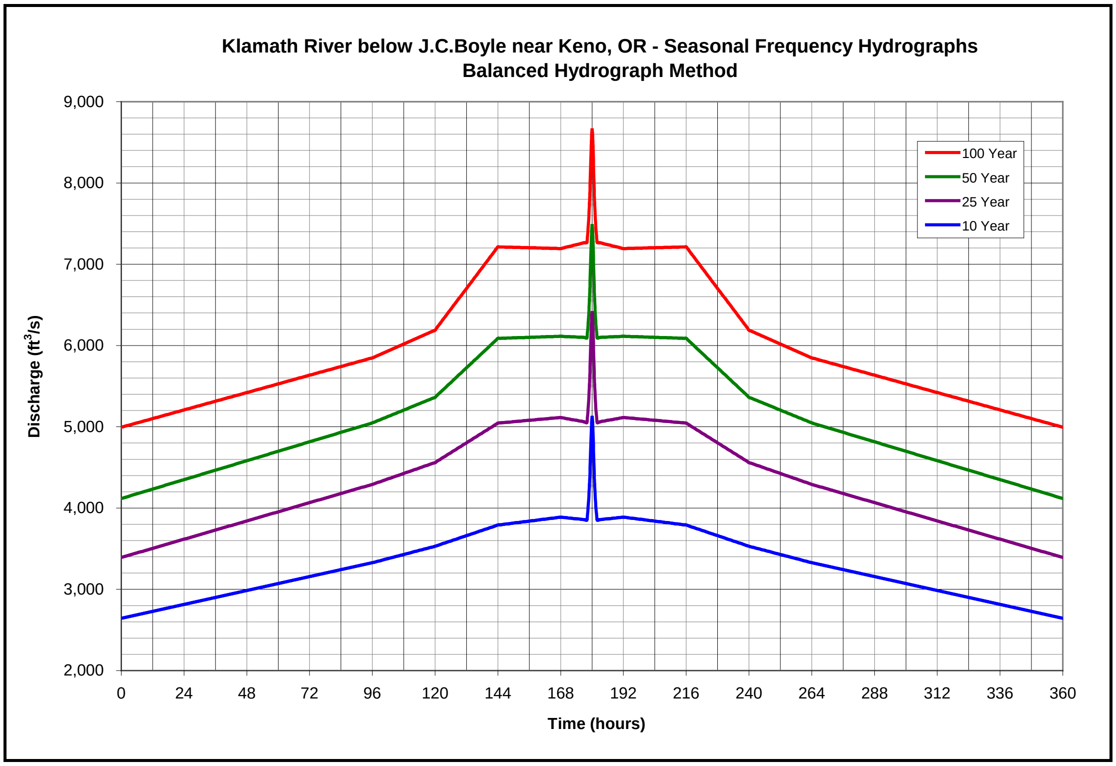


Figure 26 –Klamath River below J.C.Boyle near Keno, OR – 6/1 to 10/31 Frequency Hydrographs

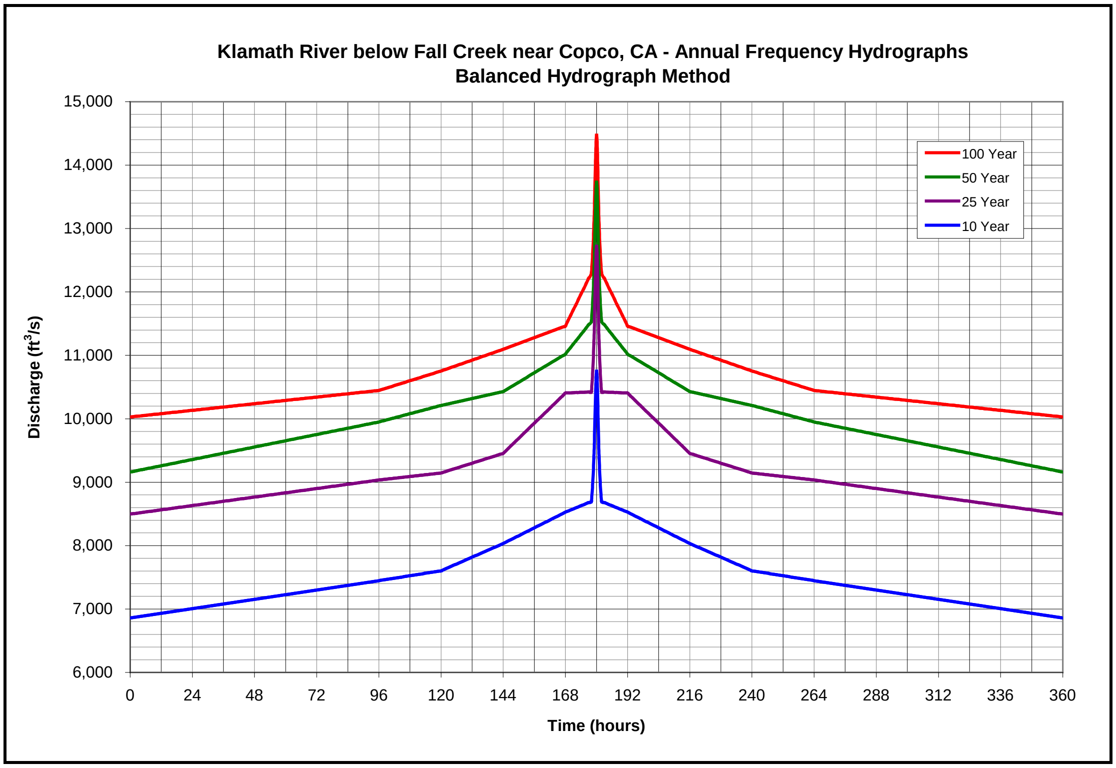


Figure 27 –Klamath River below Fall Creek near Copco, CA – Annual Frequency Hydrographs

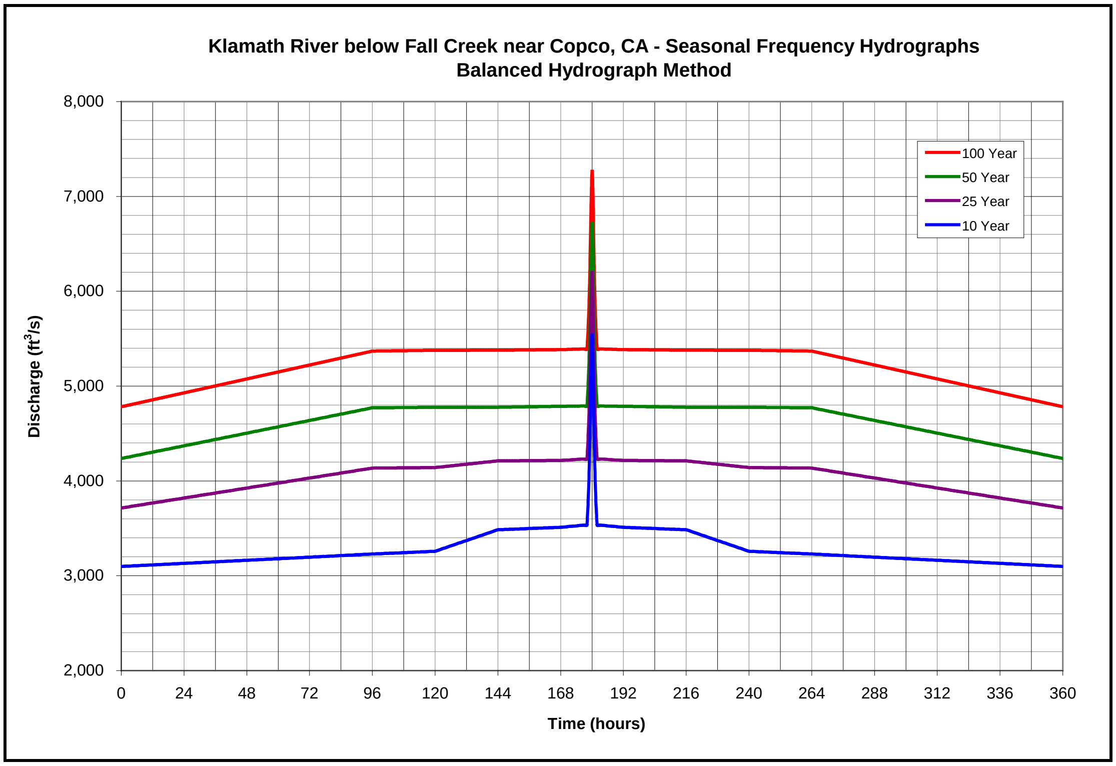


Figure 28 –Klamath River below Fall Creek near Copco, CA – Seasonal Frequency Hydrographs

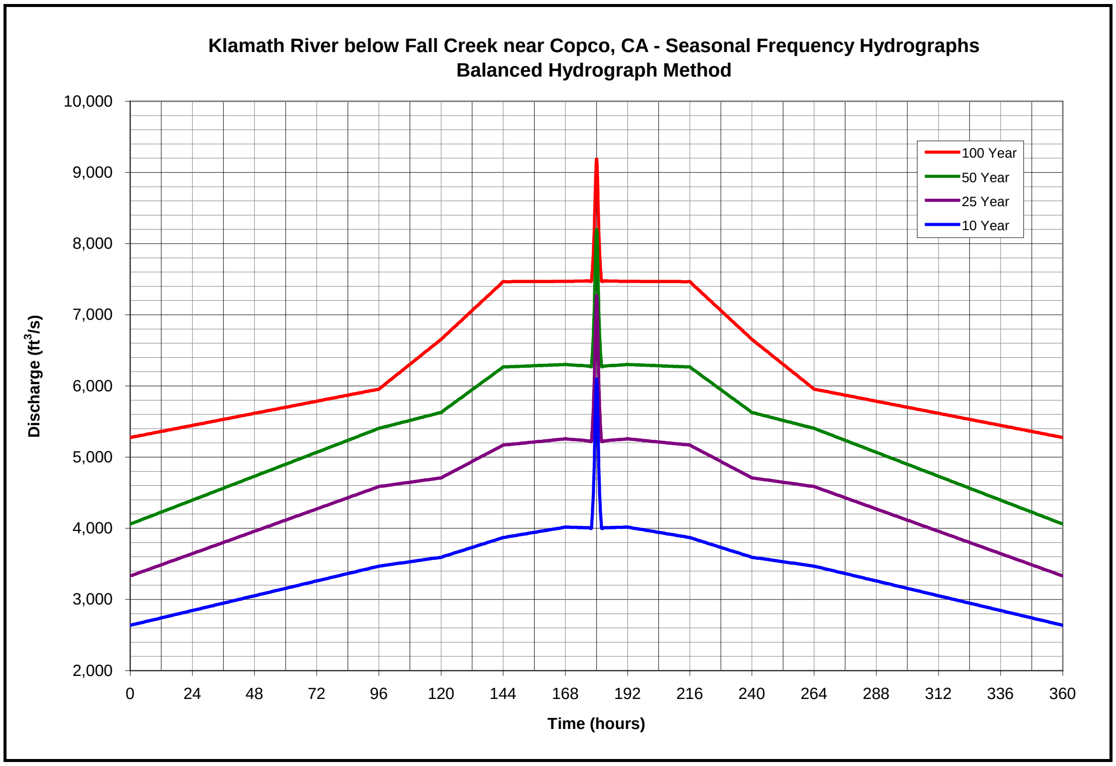


Figure 29 –Klamath River below Fall Creek near Copco, CA – 6/1 to 10/31 Frequency Hydrographs

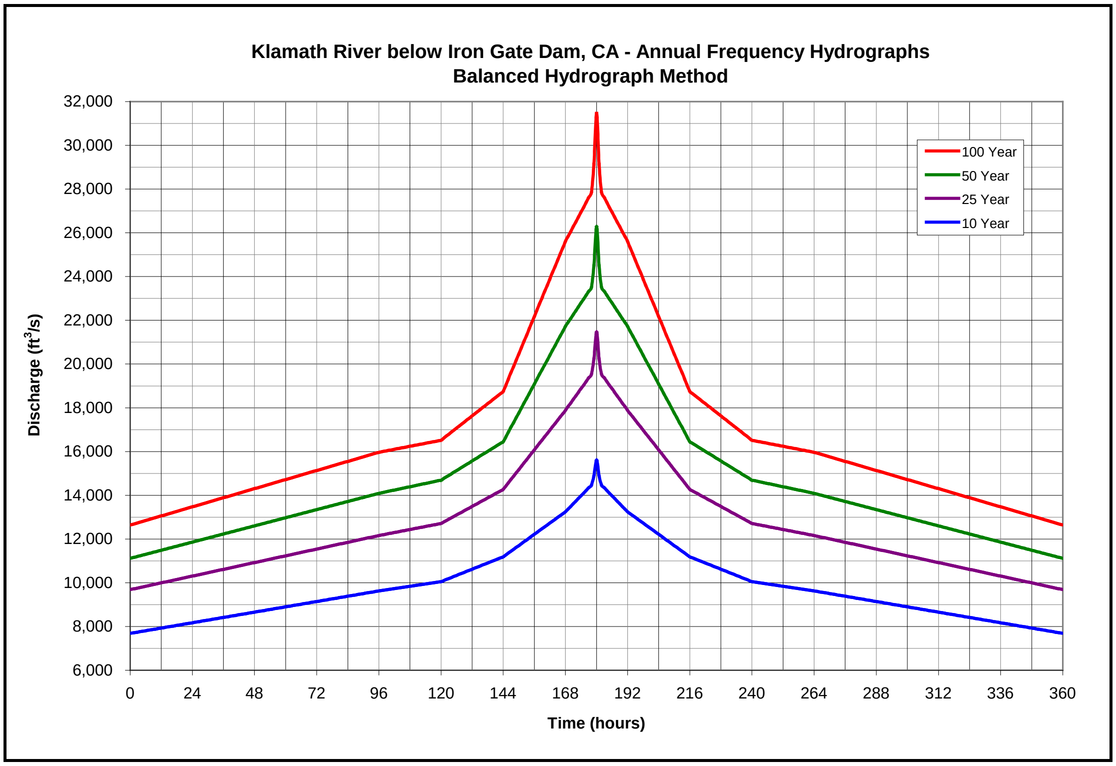


Figure 30 –Klamath River below Iron Gate Dam, CA – Annual Frequency Hydrographs

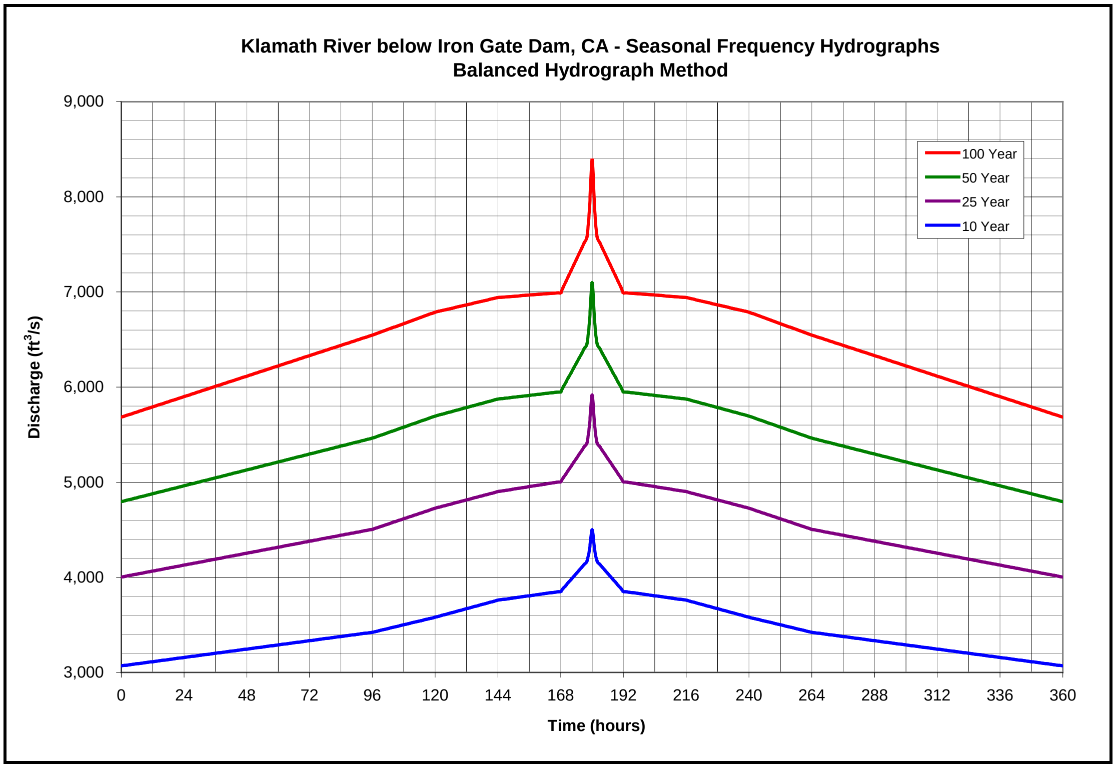


Figure 31 –Klamath River below Iron Gate Dam, CA – Seasonal Frequency Hydrographs

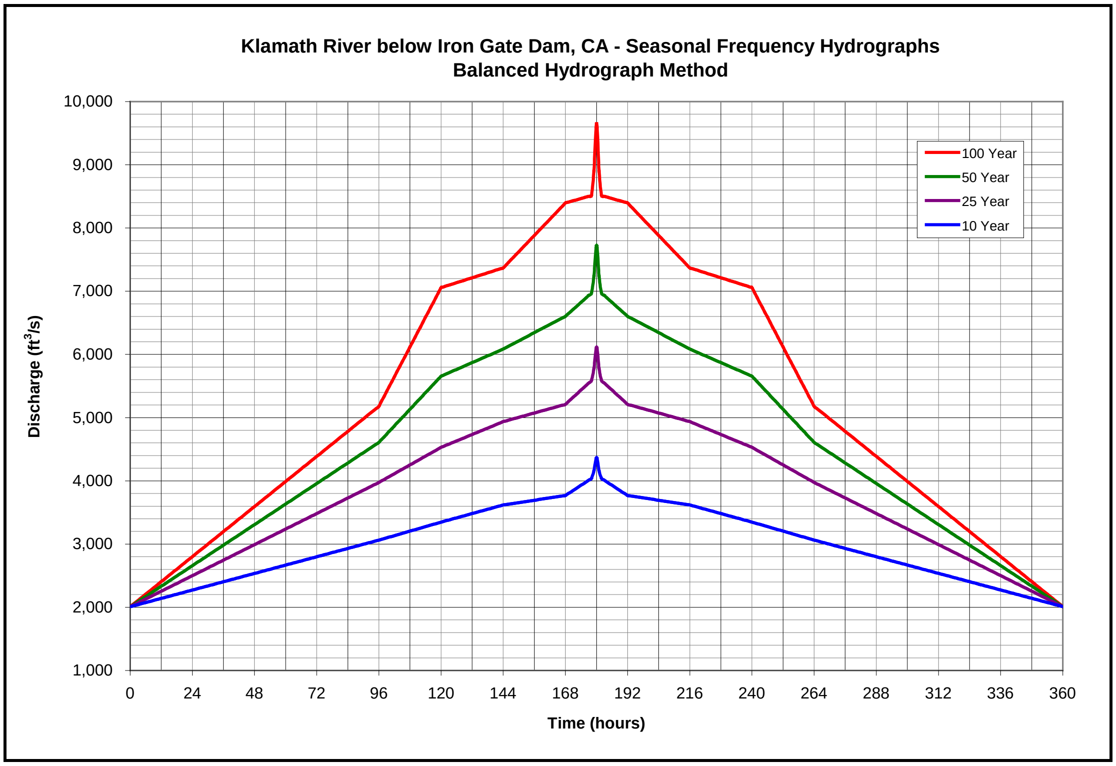


Figure 32 –Klamath River below Iron Gate Dam, CA – 6/1 to 10/31 Frequency Hydrographs

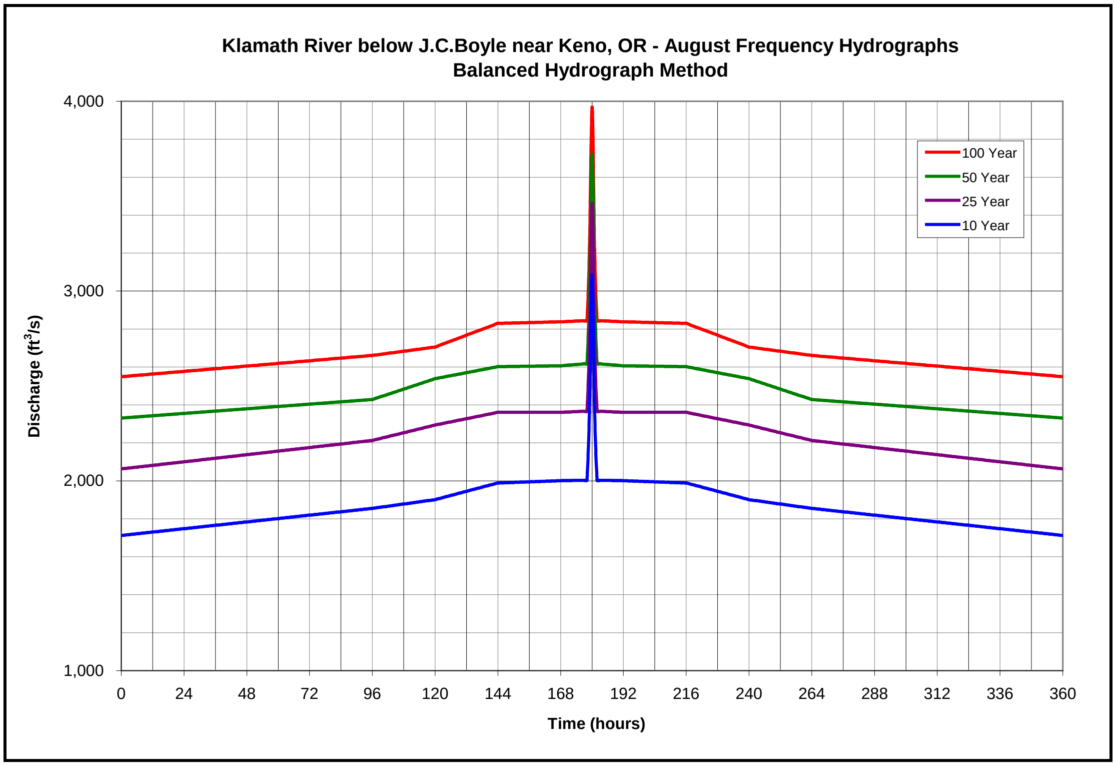


Figure 33 –Klamath River below J.C.Boyle near Keno, OR – August Frequency Hydrographs

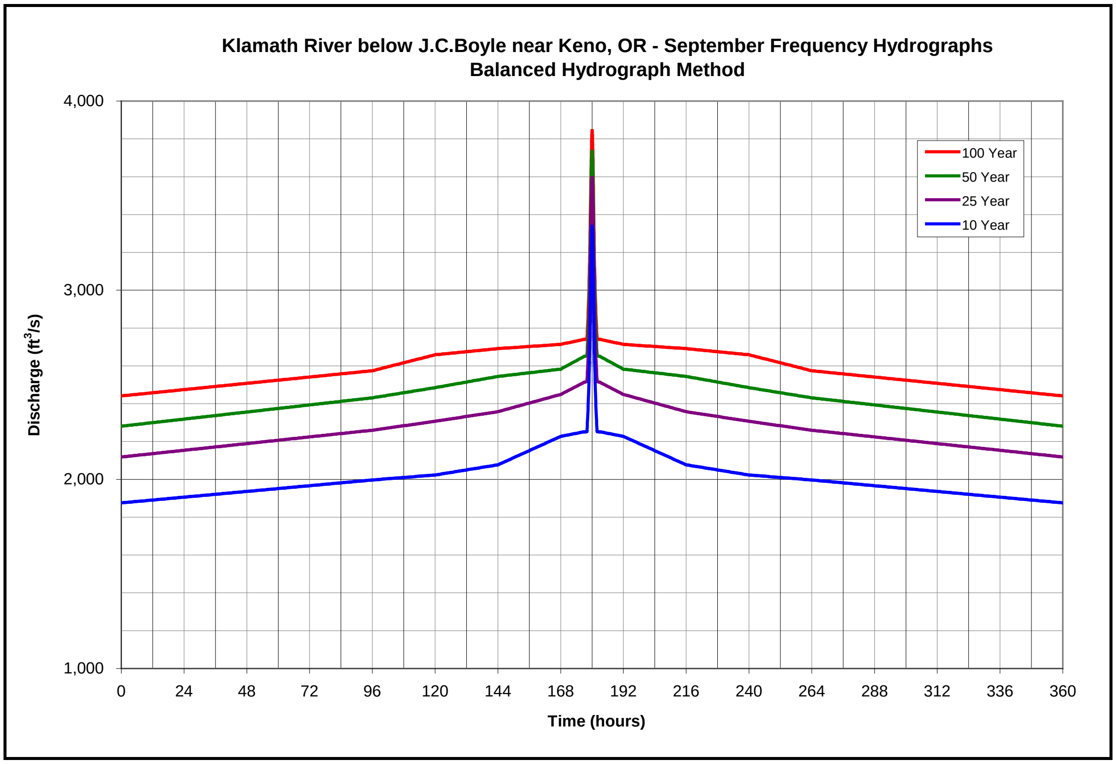


Figure 34 –Klamath River below J.C.Boyle near Keno, OR – September Frequency Hydrographs

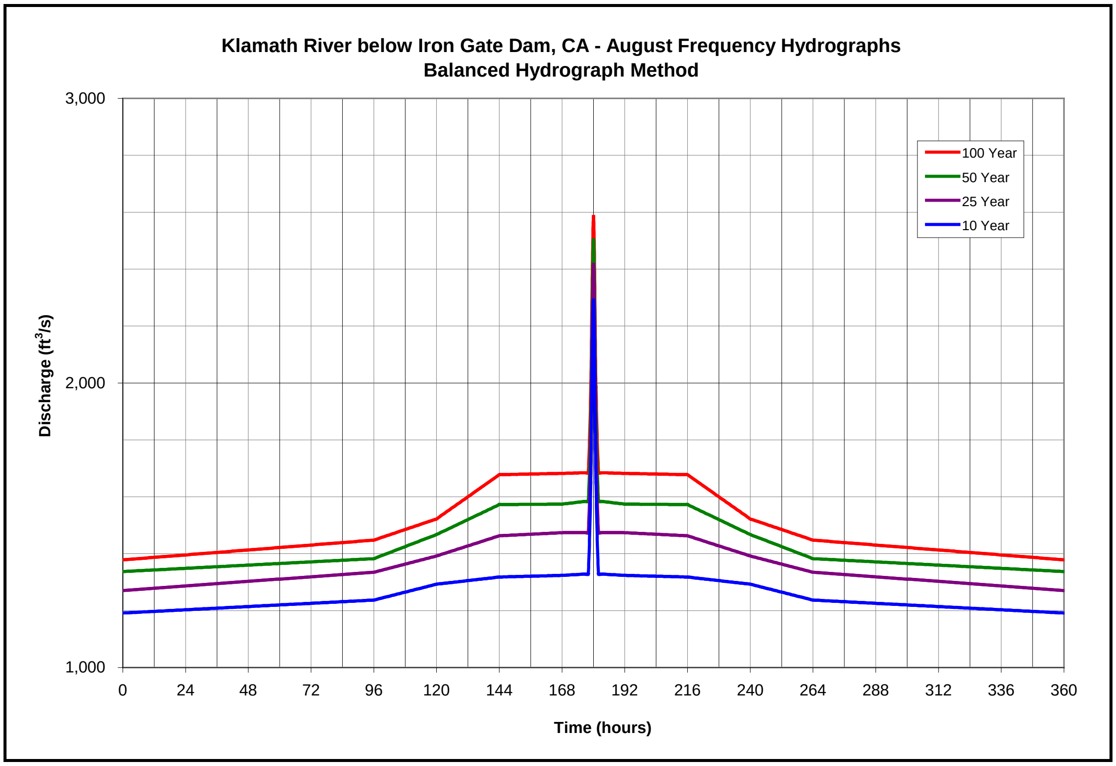


Figure 35 –Klamath River below Iron Gate Dam, CA – August Frequency Hydrographs

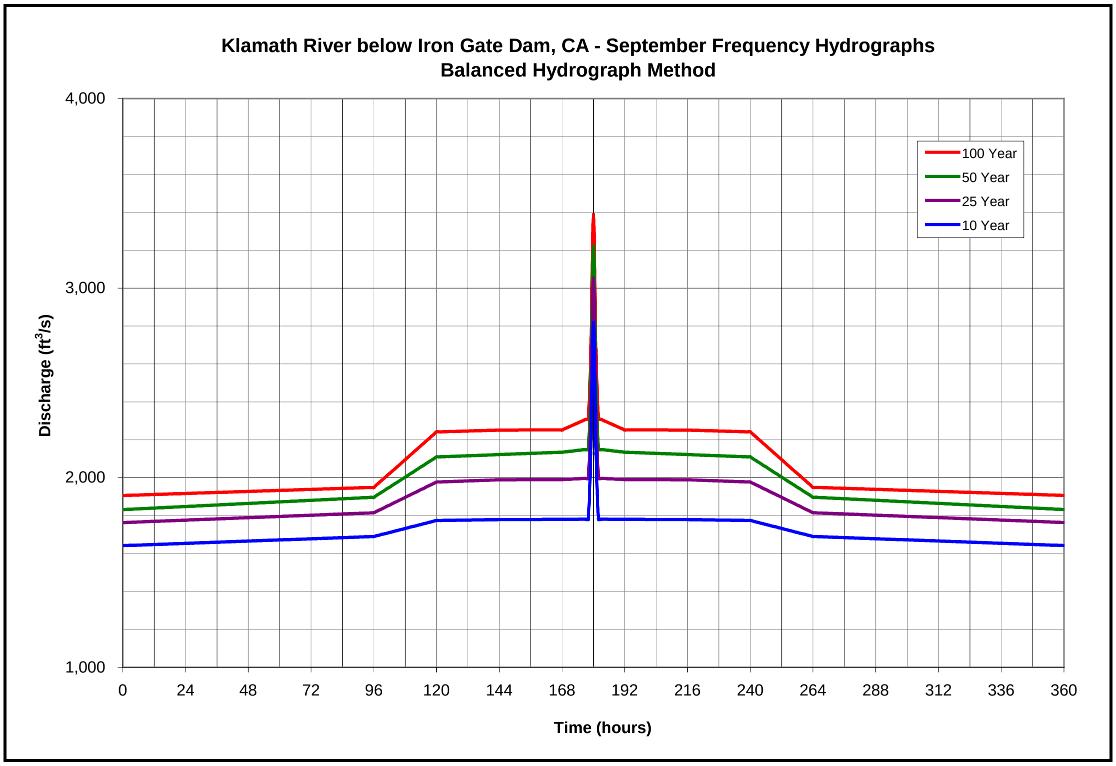


Figure 36 –Klamath River below Iron Gate Dam, CA – September Frequency Hydrographs

6 Conclusions

Flood frequency estimates for the Klamath River between Keno, OR and Klamath, CA were developed for the Secretary's Determination on Klamath River Dam Removal and Basin Restoration. This flood hydrology has provided hydrologic information to support hydraulic and sediment transport modeling efforts on the Klamath River and to determine the hydrologic conditions which would be expected during the potential construction seasons (July 1 to November 30 and June 1 to October 31) and for the removal of Boyle, Copco 1, Copco 2 and Iron Gate dams. Annual flood frequency estimates were developed based on seven gaging stations on the Klamath River with long-term records. Annual, seasonal, and monthly flow duration values and seasonal flood frequency estimates were developed at the Keno, Boyle, Copco and Iron Gate gages. Monthly flood frequency estimates were developed for August and September at Boyle and Iron Gate.

Using the calculated flood frequency values, annual and seasonal frequency hydrographs were developed at the Keno, Boyle, Copco and Iron Gate gages using a balanced hydrograph approach [4]. Monthly frequency hydrographs were also developed at Boyle and Iron Gate gages for August and September. The Boyle, Copco, and Iron Gate gages are considered reasonable estimates of flood frequency values at Boyle, Copco1 and 2, and Iron Gate dams, respectively. Tables 19 to 23 summarize the annual, seasonal, and monthly peak frequency estimates.

Table 19 – Klamath River Peak Discharge Frequency

Gaging Station	Discharge (ft^3/s)				
	Gage Base	**10-yr**	**25-yr**	**50-yr**	**100-yr**
Keno	4,000	8,642	10,350	11,200	11,800
Boyle	4,000	9,058	11,050	12,220	13,150
Copco	5,400	10,750	12,720	13,730	14,470
Iron Gate	N/A	15,610	21,460	26,280	31,460
Seiad	N/A	56,540	93,400	131,000	179,300
Orleans	N/A	163,100	230,300	287,000	348,900
Klamath	N/A	298,300	392,900	466,900	543,300

Table 20 – Klamath River Seasonal Peak Discharge Frequency (7/1 – 11/30)

Gaging Station	Discharge (ft^3/s)				
	Gage Base	**10-yr**	**25-yr**	**50-yr**	**100-yr**
Keno	2,550	3,870	4,610	5,180	5,760
Boyle	3,300	4,560	5,250	5,770	6,300
Copco	4,350	5,540	6,200	6,720	7,270
Iron Gate	N/A	4,500	5,910	7,100	8,390

Table 21 – Klamath River Seasonal Peak Discharge Frequency (6/1 – 10/31)

Gaging Station	Discharge (ft^3/s)				
	Gage Base	10-yr	25-yr	50-yr	100-yr
Keno	2,300	4,320	5,620	7,700	7,880
Boyle	3,150	5,070	6,370	7,470	8,680
Copco	4,190	6,070	7,240	8,180	9,190
Iron Gate	N/A	4,360	6,110	7,720	9,650

Table 22 – Klamath River August Peak Discharge Frequency

Gaging Station	Discharge (ft^3/s)				
	Gage Base	10-yr	25-yr	50-yr	100-yr
Boyle	2,250	3,080	3,460	3,720	3,970
Iron Gate	N/A	2,290	2,420	2,500	2,590

Table 23 – Klamath River September Peak Discharge Frequency

Gaging Station	Discharge (ft^3/s)				
	Gage Base	10-yr	25-yr	50-yr	100-yr
Boyle	2,600	3,340	3,590	3,730	3,840
Iron Gate	N/A	2,820	3,050	3,220	3,390

7 References

[1] USGS Surface-Water Data for the Nation. http://waterdata.usgs.gov/nwis/sw . United States Geological Survey. [Accessed 9/7/2010]

[2] Flynn, K.M., Kirby, W.H., and Hummel, P.R., User manual for PeakFQ, annual flood frequency analysis using Bulletin 17B Guidelines: U.S. Geological Survey Techniques and Methods Report Book 4, Chapter B4, 2006.

[3] Guidelines for Determining Flood Flow Frequency, *Bulletin #17B of the Hydrology Committee*, U.S. Department of the Interior, United States Water Resources Council, 1982.

[4] Cudworth, A.G., 1989, Flood Hydrology Manual: A Water Resources Technical Publication, U. S. Department of Interior, Bureau of Reclamation, Denver, CO, 1989.

8 Appendix A – Frequency Analysis

KLAMATH RIVER AT KENO, OR

ANNUAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.3796	3.3594	3.4449	3.4413	3.4369	3.4239
Std Deviation	0.5435	0.5435	0.4294	0.4217	0.4169	0.3911
Skew	-1.471	-1.515	-1.341	-1.324	-1.308	-1.199
Gage Base	4000	3700	3550	3500	3300	3250

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	8642	8144	7905	7722	7582	7061
25-Year	10350	9657	9335	9121	8966	8427
50-Year	11200	10390	10090	9865	9708	9199
100-Year	11800	10900	10650	10420	10260	9800

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1905	3300	3300	3300	3300	3300	3300
1906	3960	3960	3960	3960	3960	3960
1907	5220	5220	5143	5082	5056	5021
1908	4080	4080	3527	3352	3137	2850
1909	3450	3450	3317	3250	3250	3250
1910	4190	4190	4190	4190	4190	4168
1911	3660	3660	3590	3534	3510	3479
1912	2870	2870	2810	2762	2741	2714
1913	3660	3660	3590	3534	3510	3506
1930	1700	1670	1610	1506	1447	1369
1931	1610	1550	1550	1526	1511	1446
1932	2460	1910	1803	1706	1596	1350
1933	2380	2380	2010	1794	1713	1429
1934	2700	2700	2333	2010	1761	1528
1935	4470	4320	4270	4230	4191	3979
1936	2770	2670	2670	2650	2563	2098
1937	2670	2480	2327	2120	1936	1876
1938	6830	6830	6830	6830	6784	6553
1939	2310	2270	2243	2238	2196	1927
1940	6540	6490	6377	6224	6114	5654
1941	3650	2070	2020	1912	1864	1835
1942	3670	3500	3397	3364	3294	2408
1943	6440	6370	6347	6280	6200	5696
1944	2410	2330	2357	2352	2331	2312
1945	2280	2240	2173	2094	2051	1971
1946	4430	4390	4357	4328	4309	4251
1947	2190	2100	2073	2052	2040	1971

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1948	2700	2680	2580	2404	2323	2199
1949	2690	2660	2623	2510	2467	2232
1950	2760	2220	2210	2198	2200	2163
1951	4690	4500	4473	4376	4297	4005
1952	6590	6520	6397	6312	6227	5971
1953	6350	6210	6140	6060	5973	5655
1954	5810	5740	5667	5640	5644	5285
1955	3330	2820	2520	2484	2476	2449
1956	7150	7080	7050	7014	6981	6851
1957	7210	7170	7120	7064	7010	6752
1958	7470	7420	7370	7378	7351	7147
1959	3160	3140	3130	3126	3104	3058
1960	2510	1890	1857	1826	1799	1816
1961	2880	2920	2757	2630	2579	2483
1962	3350	3090	2927	2746	2654	2522
1963	5490	5410	5330	5180	4997	4117
1964	3410	2720	2700	2672	2656	2635
1965	8480	8370	8317	8248	8163	8027
1966	4270	3970	3970	3976	4001	4059
1967	6070	5910	5573	5036	4664	3745
1968	2900	2640	2603	2574	2546	2454
1969	7880	7210	7073	6948	6746	5646
1970	8920	8580	8470	8244	8103	7317
1971	8560	8190	8083	7820	7611	6361
1972	10100	9780	9623	9476	9269	9031
1973	4030	3800	3800	3760	3629	3160
1974	9300	8000	7743	7690	7689	7208
1975	6200	5800	5677	5512	5383	5007
1976	4870	4820	4803	4796	4664	4021
1977	4250	2650	2647	2644	2643	2643
1978	6140	5350	5240	5188	5094	4376
1979	3030	2770	2633	2516	2490	2418
1980	5290	4650	4647	4600	4539	4089
1981	3020	2640	2570	2522	2477	1947
1982	10200	9210	8937	8772	8641	8393
1983	9100	8470	8200	8034	7921	7183
1984	9150	8160	7337	6982	6737	6251
1985	6740	6520	6093	5904	5546	4899
1986	10300	9010	8893	8634	8556	8193
1987	2620	2600	2600	2590	2573	2544
1988	2520	2500	2497	2466	2424	2204
1989	7910	7430	6687	6362	6230	6074
1990	2770	2010	1920	1870	1847	1587
1991	2670	2190	2143	2140	2134	2115
1992	851	670	655	655	654	649
1993	8920	8580	8133	7796	7533	7043
1994	1270	1190	1133	1132	1131	1092
1995	7890	7210	6580	6100	5941	5483

Year	Discharge (ft^3/s)					
	Peak	**1-Day**	**3-Day**	**5-Day**	**7-Day**	**15-Day**
1996	9520	9250	8967	8688	8447	7741
1997	9870	9310	9050	8836	8729	8401
1998	7820	7210	6857	6766	6713	6473
1999	8820	8200	8080	8000	7854	7143
2000	4220	4200	4200	4198	4187	3807
2001	1860	1840	1837	1814	1796	1766
2002	2430	2390	2390	2386	2364	2130
2003	3890	3410	2913	2752	2623	2316
2004	2450	2240	2090	1878	1767	1498
2005	5530	4590	4227	3862	3686	3493
2006	8940	8380	8213	7968	7797	6849
2007	3150	2930	2893	2836	2810	2629
2008	2450	2410	2400	2378	2366	2246
2009	1770	1510	1363	1302	1274	1151

JULY-NOVEMBER SEASONAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.4012	3.3104	3.2822	3.2619	3.2339	3.1935
Std Deviation	0.1429	0.1575	0.175	0.1863	0.208	0.226
Skew	0.257	0.316	0.138	0.074	-0.113	-0.199
Gage Base	2550	1950	1800	1700	1650	1550

Return Period	Discharge (ft^3/s)					
	Peak	**1-Day**	**3-Day**	**5-Day**	**7-Day**	**15-Day**
10-Year	3871	3287	3228	3178	3147	3005
25-Year	4609	4004	3951	3915	3889	3743
50-Year	5176	4570	4513	4486	4450	4298
100-Year	5760	5163	5094	5075	5017	4853

Year	Discharge (ft^3/s)					
	Peak	**1-Day**	**3-Day**	**5-Day**	**7-Day**	**15-Day**
1904	5919	5300	5107	5040	4951	4673
1905	2373	1830	1743	1726	1684	1565
1906	3875	3300	3300	3220	3186	3064
1907	3630	3060	3007	2960	2903	2742
1908	2169	1630	1610	1574	1554	1469
1909	2598	2050	2027	1992	1941	1755
1910	2169	1630	1630	1618	1604	1450
1911	3078	2520	2413	2392	2337	2204
1912	2751	2200	2150	2110	2093	2001
1913	3078	2520	2467	2456	2429	2339
1930	1965	1430	1430	1430	1430	1426
1931	1893	1360	1323	1294	1243	1101
1932	1975	1440	1420	1346	1290	1163
1933	2098	1560	1517	1494	1490	1452

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1934	1944	1410	1370	1268	1211	1143
1935	2608	2060	2033	1990	1833	1513
1936	2946	2390	2233	2120	1936	1876
1937	2445	1900	1693	1598	1484	1432
1938	2537	1990	1787	1650	1584	1445
1939	2281	1740	1637	1580	1549	1465
1940	2608	2060	2020	1912	1864	1835
1941	2619	2070	1957	1886	1810	1723
1942	2547	2000	1950	1944	1939	1905
1943	2935	2380	2377	2352	2331	2315
1944	2568	2020	2017	2016	2014	1863
1945	2792	2240	2187	2136	2074	1992
1946	2649	2100	2073	2052	2040	1971
1947	2189	1650	1633	1626	1620	1584
1948	2353	1810	1787	1784	1773	1736
1949	2772	2220	2210	2198	2200	2163
1950	2966	2410	2393	2380	2370	2285
1951	2179	1640	1627	1594	1590	1586
1952	3089	2530	2487	2438	2384	2325
1953	3610	3040	3007	2988	2989	2949
1954	3385	2820	2520	2484	2476	2449
1955	2670	2120	2023	1902	1886	1871
1956	4059	3480	3453	3444	3446	3427
1957	3916	3340	3333	3304	3287	3097
1958	3640	3070	3063	3044	3026	2974
1959	2455	1910	1897	1884	1873	1816
1960	2568	2020	1830	1584	1473	1346
1961	3487	2920	2757	2630	2579	2483
1962	3661	3090	2927	2746	2654	2522
1963	3232	2670	2663	2660	2656	2608
1964	2118	1580	1570	1558	1554	1548
1965	4805	4210	4137	4122	4109	4069
1966	2506	1960	1807	1552	1550	1534
1967	3129	2570	2410	1939	1661	1522
1968	2271	1730	1600	1524	1312	1222
1969	3242	2680	2660	2630	2607	2515
1970	3426	2860	2790	2768	2763	2663
1971	3610	3040	2803	2704	2674	2645
1972	3620	3050	3043	3038	2991	2805
1973	3293	2730	2697	2674	2661	2142
1974	3099	2540	2523	2512	2507	2501
1975	3855	3280	3280	3264	3209	2897
1976	3262	2700	2667	2660	2656	2647
1977	1842	1310	1303	1302	1286	1169
1978	2363	1820	1717	1594	1550	1485
1979	1883	1350	1131	1047	1033	1016
1980	1546	1020	1013	1012	1011	1011
1981	2741	2190	1653	1230	1016	816

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1982	3640	3070	3023	3012	3009	2754
1983	5827	5210	5183	5146	5056	4879
1984	5745	5130	5127	5080	5017	4899
1985	3497	2930	2877	2832	2634	2171
1986	2659	2110	2110	1968	1824	1651
1987	1791	1260	1163	1064	1044	1039
1988	1489	964	962	959	946	831
1989	1822	1290	1283	1276	1230	1096
1990	1576	1050	1030	1028	1026	1015
1991	1188	670	641	638	636	632
1992	1173	655	655	655	654	652
1993	1730	1200	1187	1170	1159	1156
1994	1213	694	682	680	681	675
1995	1597	1070	1070	1068	1066	956
1996	1638	1110	1087	1086	1074	1068
1997	1863	1330	1330	1330	1326	1313
1998	3313	2750	2743	2730	2727	2094
1999	2087	1550	1547	1538	1523	1445
2000	1873	1340	1074	1052	1049	1029
2001	2108	1570	1433	1259	1178	1034
2002	1607	1080	981	947	886	757
2003	1965	1430	1273	1196	1170	1115
2004	1485	960	880	761	723	684
2005	1781	1250	1137	1102	1071	1068
2006	3272	2710	2557	2146	1830	1198
2007	1638	1110	1063	1005	941	936
2008	1893	1360	1145	1106	1090	1020
2009	1648	1120	1107	1104	1058	970

JUNE-OCTOBER SEASONAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.3504	3.2383	3.2316	3.1968	3.1860	3.1832
Std Deviation	0.2209	0.2602	0.2591	0.2810	0.2796	0.2361
Skew	0.200	0.085	0.112	-0.046	-0.077	0.213
Gage Base	2300	1800	1700	1630	1600	1530

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	4344	3750	3686	3594	3483	3095
25-Year	5649	5028	4954	4834	4655	4105
50-Year	6722	6090	6012	5848	5605	4950
100-Year	7882	7244	7169	6935	6614	5876

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1904	9127	8440	8440	8322	8244	7864
1905	3119	2560	2560	2560	2514	2403
1906	4550	3960	3960	3960	3960	3899
1907	4713	4120	4080	4038	3993	3857
1908	2598	2050	2050	2050	2047	2023
1909	4029	3450	3317	3148	2990	2724
1910	3078	2520	2520	2472	2440	2323
1911	4029	3450	3450	3410	3364	3227
1912	2915	2360	2360	2360	2360	2328
1913	3436	2870	2870	2834	2793	2762
1930	1965	1430	1430	1430	1430	1426
1931	1750	1220	1150	1126	1107	907
1932	2261	1720	1480	1416	1389	1082
1933	2098	1560	1517	1494	1490	1452
1934	1944	1410	1370	1268	1211	1143
1935	2036	1500	1480	1476	1407	1335
1936	2690	2140	2087	2004	1904	1812
1937	2445	1900	1693	1598	1484	1432
1938	2864	2310	2270	2246	2141	1714
1939	2281	1740	1637	1580	1549	1465
1940	2608	2060	2020	1912	1864	1835
1941	2619	2070	1957	1886	1784	1723
1942	2639	2090	1950	1944	1939	1905
1943	3630	3060	3000	2924	2866	2573
1944	2410	1740	1733	1726	1723	1683
1945	2280	2240	2187	2136	2074	1992
1946	2598	2050	2017	1964	1919	1847
1947	2189	1650	1633	1626	1620	1584
1948	2700	2680	2580	2404	2323	2199
1949	2731	2180	2170	2154	2143	2067
1950	2241	1700	1697	1606	1579	1527
1951	2149	1610	1607	1594	1583	1467
1952	4253	3670	3507	3240	3041	2549
1953	6624	5990	5787	5424	4979	4549
1954	2956	2400	2367	2352	2350	2208
1955	2159	1620	1620	1552	1510	1308
1956	4366	3780	3597	3454	3321	3185
1957	2986	2430	2360	2270	2214	2112
1958	4979	4380	4317	4280	4276	3972
1959	2455	1910	1897	1884	1873	1816
1960	1740	1210	1203	1190	1179	1151
1961	2711	2160	2140	2070	2037	1899
1962	3661	3090	2927	2746	2654	2522
1963	2098	1560	1513	1508	1497	1479
1964	2118	1580	1570	1558	1554	1548
1965	3589	3020	2817	2712	2639	2558
1966	2057	1520	1520	1518	1517	1510
1967	3548	2980	2873	2838	2589	1538

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1968	1954	1420	1413	1262	1052	1045
1969	3242	2680	2660	2630	2607	2042
1970	2302	1760	1717	1576	1325	1162
1971	4958	4360	4350	4276	4164	2645
1972	2496	1950	1940	1908	1886	1729
1973	1771	1240	1150	1103	1050	1019
1974	2271	1730	1670	1646	1610	1517
1975	3129	2570	2567	2566	2564	2477
1976	2792	2240	2240	2018	1864	1659
1977	1822	1290	1253	1234	1224	1110
1978	1566	1040	1040	1040	1040	1035
1979	1566	1040	1040	1034	1033	1016
1980	1546	1020	1013	1012	1011	1011
1981	1536	1010	1010	964	892	795
1982	3313	2750	2730	2584	2464	1843
1983	3998	3420	3363	3360	3356	2834
1984	4805	4210	4207	4202	4201	3947
1985	2414	1870	1790	1604	1497	1484
1986	2057	1520	1520	1520	1520	1505
1987	1576	1050	1047	1044	1044	1039
1988	1489	964	962	959	946	831
1989	2792	2240	1777	1366	1230	1096
1990	1576	1050	1030	1028	1026	1015
1991	1163	645	641	638	636	632
1992	1170	652	652	651	650	649
1993	7288	6640	6553	6126	5300	3187
1994	1270	694	682	680	681	675
1995	1863	1330	1227	1155	1108	956
1996	2179	1640	1600	1326	1167	1143
1997	1852	1320	1317	1312	1311	1245
1998	5776	5160	5073	4982	4741	3885
1999	2261	1720	1683	1664	1593	1511
2000	1873	1340	1230	1230	1226	1156
2001	1860	1840	1837	1814	1796	1766
2002	1607	1080	981	947	886	757
2003	1985	1450	1437	1386	1361	1293
2004	1576	1050	1015	931	810	667
2005	1822	1290	1270	1150	1071	1028
2006	3272	2710	2710	2710	2710	2704
2007	1730	1200	1193	1192	1190	1186
2008	2220	1680	1623	1554	1481	1447
2009	1699	1170	1170	1168	1166	1151

KLAMATH RIVER BELOW J.C.BOYLE NEAR KENO, OR

ANNUAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.4939	3.3969	3.4763	3.4739	3.4712	3.4557
Std Deviation	0.423	0.5106	0.4031	0.3925	0.3854	0.3638
Skew	-1.159	-1.391	-1.204	-1.19	-1.17	-1.081
Gage Base	4000	3900	3750	3600	3550	3500

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	9058	8508	8200	7964	7802	7244
25-Year	11050	10250	9831	9527	9336	8716
50-Year	12220	11170	10750	10410	10210	9589
100-Year	13150	11830	11470	11110	10910	10300

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1905	3610	3505	3505	3505	3505	3505
1906	4094	4153	4153	4153	4153	4153
1907	5163	5390	5315	5255	5229	5194
1908	4188	4271	3728	3556	3345	3063
1909	3715	3652	3521	3456	3456	3456
1910	4275	4379	4379	4379	4379	4357
1911	3867	3859	3790	3735	3711	3681
1912	3322	3083	3024	2977	2957	2930
1913	3867	3859	3790	3735	3711	3707
1930	2653	1905	1846	1744	1686	1609
1931	2608	1787	1787	1763	1749	1685
1932	3069	2140	2036	1940	1832	1590
1933	3022	2602	2239	2026	1947	1668
1934	3215	2916	2556	2239	1995	1765
1935	4504	4507	4457	4418	4380	4171
1936	3259	2887	2887	2867	2781	2325
1937	3196	2700	2549	2347	2166	2107
1938	6807	6971	6971	6971	6926	6699
1939	2981	2494	2468	2462	2421	2157
1940	6488	6637	6526	6376	6268	5816
1941	3860	2297	2248	2142	2096	2066
1942	3875	3701	3600	3568	3499	2629
1943	6380	6519	6496	6431	6352	5857
1944	3040	2553	2579	2574	2554	2535
1945	2964	2464	2399	2321	2279	2201
1946	4471	4575	4543	4514	4495	4439
1947	2913	2327	2301	2280	2268	2200
1948	3215	2896	2798	2625	2546	2424
1949	3209	2877	2841	2729	2687	2457
1950	3252	2445	2435	2423	2425	2388

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1951	4690	4683	4657	4562	4484	4198
1952	6542	6666	6545	6462	6379	6127
1953	6285	6362	6293	6215	6129	5818
1954	5730	5901	5829	5803	5807	5454
1955	3631	3034	2739	2704	2696	2670
1956	7171	7216	7187	7151	7120	6991
1957	7241	7305	7256	7201	7148	6894
1958	7547	7550	7501	7509	7483	7282
1959	3514	3348	3338	3334	3313	3267
1960	2980	2340	2133	2054	1986	2001
1961	3320	2810	2803	2782	2749	2631
1962	3080	3410	3217	3100	3016	2829
1963	5420	5310	5217	5052	4859	4101
1964	2960	2740	2740	2738	2739	2734
1965	8830	8730	8710	8650	8561	8337
1966	4330	3990	4003	3996	4030	4077
1967	6270	6060	5690	5184	4753	3901
1968	2760	2720	2680	2672	2669	2507
1969	8180	7080	6953	6854	6626	5615
1970	9480	8930	8763	8538	8377	7431
1971	9270	8510	8447	8074	7757	6363
1972	11000	10800	10633	10440	10226	9911
1973	4700	4140	4090	4040	3934	3476
1974	9480	8660	8257	8174	8167	7577
1975	6120	5630	5453	5300	5183	4844
1976	5000	5000	5000	5000	4886	4267
1977	2840	2810	2810	2810	2810	2811
1978	6620	5210	5053	5000	4920	4313
1979	2840	2810	2787	2752	2707	2599
1980	4880	4500	4480	4444	4403	4046
1981	2850	2800	2760	2720	2661	2134
1982	10600	10000	9530	9282	9160	8758
1983	9640	8920	8563	8338	8200	7350
1984	9340	8260	7417	6976	6701	6374
1985	7320	6680	6253	6008	5654	4625
1986	10300	9630	9513	9122	9001	8516
1987	2940	2920	2920	2888	2866	2836
1988	2880	2810	2810	2778	2734	2497
1989	8500	7780	6843	6474	6329	6158
1990	2980	2500	2217	2186	2173	1909
1991	3020	2630	2450	2394	2389	2307
1992	2920	1090	959	913	896	890
1993	9820	9120	8750	8238	7930	7391
1994	2890	1560	1547	1528	1489	1397
1995	8240	7710	6850	6308	6140	5647
1996	11600	10200	9837	9396	9063	8189
1997	11400	9860	9480	9120	8981	8577
1998	8080	7550	7237	6950	6893	6687

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1999	9010	8460	8367	8296	8106	7355
2000	5100	4460	4400	4380	4371	4040
2001	3120	2200	2163	2078	2041	1989
2002	3780	2870	2870	2870	2870	2595
2003	4010	3850	3367	3216	3089	2790
2004	3570	2930	2430	2164	2049	1797
2005	5690	4880	4477	4104	3930	3741
2006	10100	8650	8440	8134	7946	6969
2007	3520	3500	3463	3390	3359	3160
2008	2890	2740	2733	2726	2696	2564
2009	2890	1830	1617	1580	1554	1446

JULY-NOVEMBER SEASONAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.5177	3.3515	3.3169	3.3013	3.2812	3.2511
Std Deviation	0.1071	0.1421	0.1664	0.1764	0.1907	0.2005
Skew	0.421	0.239	-0.032	-0.109	-0.221	-0.25
Gage Base	3300	2250	2150	2000	1900	1750

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	4559	3443	3386	3351	3316	3178
25-Year	5245	4089	4041	4013	3982	3840
50-Year	5768	4584	4528	4500	4466	4320
100-Year	6301	5092	5015	4983	4939	4791

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1904	6718	5469	5279	5213	5126	4853
1905	3071	2062	1977	1960	1919	1801
1906	4616	3505	3505	3427	3393	3273
1907	4364	3269	3217	3171	3115	2957
1908	2861	1865	1846	1811	1791	1708
1909	3302	2278	2255	2221	2171	1988
1910	2861	1865	1865	1854	1840	1689
1911	3796	2739	2635	2614	2560	2429
1912	3460	2425	2376	2337	2320	2230
1913	3796	2739	2687	2676	2650	2562
1930	2651	1669	1669	1669	1669	1665
1931	2577	1600	1564	1536	1485	1346
1932	2661	1679	1659	1587	1532	1407
1933	2787	1797	1754	1732	1728	1691
1934	2630	1649	1610	1510	1455	1388
1935	3313	2288	2261	2219	2065	1750
1936	3660	2612	2458	2347	2166	2107

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1937	3145	2131	1928	1834	1722	1671
1938	3239	2219	2019	1885	1821	1684
1939	2976	1973	1872	1816	1786	1704
1940	3313	2288	2248	2142	2096	2066
1941	3323	2297	2186	2117	2042	1957
1942	3250	2229	2180	2174	2168	2135
1943	3649	2602	2599	2574	2554	2538
1944	3271	2248	2245	2244	2243	2094
1945	3502	2464	2412	2362	2302	2221
1946	3355	2327	2301	2280	2268	2200
1947	2882	1885	1869	1862	1856	1820
1948	3050	2042	2019	2017	2006	1970
1949	3481	2445	2435	2423	2425	2388
1950	3681	2631	2615	2602	2592	2508
1951	2871	1875	1862	1830	1826	1822
1952	3807	2749	2707	2659	2606	2548
1953	4343	3250	3217	3199	3199	3161
1954	4112	3034	2739	2704	2696	2670
1955	3376	2347	2252	2133	2117	2102
1956	4805	3682	3656	3646	3648	3630
1957	4658	3544	3538	3509	3492	3306
1958	4374	3279	3273	3254	3236	3185
1959	3369	2340	2200	2158	2064	2001
1960	3476	2440	2143	1794	1699	1599
1961	3915	2850	2830	2782	2749	2631
1962	4514	3410	3217	3100	3016	2829
1963	3797	2740	2733	2732	2731	2727
1964	2823	1830	1760	1736	1686	1671
1965	5382	4220	4163	4132	4116	4077
1966	3347	2320	2080	1772	1743	1721
1967	3594	2550	2430	2006	1813	1676
1968	2759	1770	1720	1668	1483	1415
1969	3754	2700	2650	2640	2634	2576
1970	3893	2830	2827	2822	2813	2737
1971	4504	3400	3060	2946	2897	2833
1972	4322	3230	3227	3226	3193	3021
1973	4011	2940	2933	2928	2926	2405
1974	3829	2770	2770	2754	2731	2712
1975	4718	3600	3600	3520	3407	3046
1976	3883	2820	2813	2812	2811	2811
1977	2598	1620	1593	1550	1519	1388
1978	3037	2030	1847	1736	1691	1641
1979	2470	1500	1320	1258	1241	1217
1980	2448	1480	1293	1258	1243	1217
1981	3529	2490	1963	1537	1299	1087
1982	4322	3230	3213	3204	3207	2999
1983	6324	5100	5057	5022	4930	4758
1984	5831	4640	4640	4640	4640	4625

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1985	4118	3040	3017	2976	2804	2392
1986	3390	2360	2327	2170	2064	1868
1987	2641	1660	1470	1354	1303	1291
1988	2255	1300	1223	1200	1190	1074
1989	2630	1650	1477	1426	1401	1317
1990	2619	1640	1410	1364	1339	1300
1991	1901	969	897	886	880	865
1992	2031	1090	959	913	896	890
1993	2566	1590	1487	1460	1453	1434
1994	1882	951	916	897	886	868
1995	2480	1510	1470	1392	1361	1335
1996	3273	2250	1780	1616	1529	1415
1997	3101	2090	1860	1730	1671	1653
1998	4236	3150	3143	3136	3133	2483
1999	2941	1940	1850	1822	1827	1739
2000	2470	1500	1390	1336	1331	1319
2001	2737	1750	1670	1566	1479	1292
2002	2480	1510	1306	1251	1151	997
2003	2598	1620	1460	1408	1387	1348
2004	2148	1200	1073	1018	973	887
2005	2448	1480	1400	1332	1334	1288
2006	4150	3070	2870	2582	2250	1595
2007	2373	1410	1320	1294	1267	1234
2008	2662	1680	1457	1396	1364	1278
2009	2341	1380	1333	1314	1269	1232

JUNE-OCTOBER SEASONAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.4987	3.3212	3.2839	3.2665	3.2549	3.2509
Std Deviation	0.1580	0.2090	0.2341	0.2413	0.2418	0.2047
Skew	0.630	0.379	0.185	0.107	0.062	0.362
Gage Base	3200	2180	1980	1900	1860	1800

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	5115	3946	3874	3788	3685	3311
25-Year	6403	5163	5107	4985	4825	4300
50-Year	7476	6190	6130	5968	5750	5127
100-Year	8654	7326	7244	7027	6739	6036

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1904	10019	8552	8552	8436	8359	7986
1905	3838	2779	2779	2779	2734	2625
1906	5310	4153	4153	4153	4153	4093
1907	5478	4310	4271	4230	4185	4052
1908	3302	2278	2278	2278	2275	2252
1909	4774	3652	3521	3356	3201	2940
1910	3796	2739	2739	2692	2661	2546
1911	4774	3652	3652	3613	3568	3434
1912	3628	2582	2582	2582	2582	2551
1913	4164	3083	3083	3048	3007	2977
1930	2651	1669	1669	1669	1669	1665
1931	2430	1463	1394	1371	1352	1155
1932	2955	1954	1718	1655	1628	1328
1933	2787	1797	1754	1732	1728	1691
1934	2630	1649	1610	1510	1455	1388
1935	2724	1738	1718	1714	1646	1576
1936	3397	2366	2314	2233	2135	2044
1937	3145	2131	1928	1834	1722	1671
1938	3576	2533	2494	2470	2368	1948
1939	2976	1973	1872	1816	1786	1704
1940	3313	2288	2248	2142	2096	2066
1941	3323	2297	2186	2117	2017	1957
1942	3344	2317	2180	2174	2168	2135
1943	4364	3269	3211	3136	3079	2791
1944	2976	1973	1967	1960	1957	1918
1945	3502	2464	2412	2362	2302	2221
1946	3302	2278	2245	2193	2149	2079
1947	2882	1885	1869	1862	1856	1820
1948	3965	2896	2798	2625	2546	2424
1949	3439	2405	2396	2380	2369	2295
1950	2934	1934	1931	1842	1815	1764
1951	2840	1846	1843	1830	1819	1705
1952	5005	3868	3708	3446	3251	2768
1953	7444	6146	5946	5590	5153	4732
1954	3670	2621	2589	2574	2572	2433
1955	2850	1856	1856	1789	1748	1549
1956	5121	3976	3796	3656	3526	3392
1957	3702	2651	2582	2494	2439	2339
1958	5751	4565	4503	4467	4463	4165
1959	3369	2340	2200	2158	2064	2001
1960	2980	1840	1550	1520	1458	1411
1961	3455	2420	2260	2230	2227	2111
1962	4514	3410	3217	3100	3016	2829
1963	2941	1940	1813	1756	1696	1672
1964	2791	1800	1760	1736	1686	1671
1965	4225	3140	2920	2838	2791	2687
1966	3347	2320	1823	1772	1737	1701

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1967	4247	3160	3070	3026	2824	1823
1968	2737	1750	1603	1532	1275	1270
1969	3754	2700	2650	2640	2634	2140
1970	3101	2090	1867	1736	1467	1350
1971	5649	4470	4437	4366	4287	2796
1972	3647	2600	2263	2140	2107	1936
1973	2448	1480	1463	1400	1274	1256
1974	3080	2070	1933	1940	1904	1811
1975	3808	2750	2750	2728	2714	2619
1976	3465	2430	2343	2156	1990	1789
1977	2480	1510	1510	1510	1499	1388
1978	2470	1500	1337	1298	1279	1252
1979	2191	1240	1227	1222	1221	1217
1980	2448	1480	1293	1258	1243	1217
1981	2180	1230	1227	1186	1091	1011
1982	4065	2990	2920	2848	2703	2080
1983	4921	3790	3677	3654	3637	3166
1984	5328	4170	4170	4170	4167	3947
1985	3198	2180	2010	1834	1749	1711
1986	3091	2080	1837	1776	1756	1705
1987	2320	1360	1313	1312	1291	1288
1988	2255	1300	1223	1200	1190	1074
1989	3476	2440	2057	1620	1406	1317
1990	2619	1640	1410	1364	1339	1300
1991	1840	912	892	876	872	865
1992	2031	1090	959	913	893	877
1993	8080	6740	6640	6244	5519	3485
1994	2890	908	901	884	875	868
1995	2641	1660	1470	1456	1404	1335
1996	3273	2250	1963	1688	1529	1490
1997	2737	1750	1707	1660	1649	1558
1998	6613	5370	5250	5158	4964	4160
1999	3058	2050	1983	1960	1943	1878
2000	2577	1600	1557	1546	1527	1461
2001	3219	2200	2163	2078	2041	1989
2002	2480	1510	1306	1251	1151	997
2003	2791	1800	1733	1684	1644	1569
2004	2202	1250	1213	1138	1025	892
2005	2823	1830	1627	1466	1316	1269
2006	4161	3080	3073	3068	3066	3063
2007	2523	1550	1523	1510	1506	1482
2008	2890	2080	1977	1856	1769	1749
2009	2890	1550	1437	1406	1411	1401

AUGUST MONTHLY FREQUENCY ANALYSIS

Statical Parameters	**Peak**	**1-Day**	**3-Day**	**5-Day**	**7-Day**	**15-Day**
Log Mean	3.3423	3.0758	3.0555	3.0093	2.9836	2.9776
Std Deviation	0.1163	0.1967	0.2065	0.2448	0.2635	0.2462
Skew	-0.167	-0.473	-0.491	-0.704	-0.778	-0.661
Gage Base	2250	1300	1250	1200	1140	1060

Return Period	**Discharge (ft^3/s)**					
	Peak	**1-Day**	**3-Day**	**5-Day**	**7-Day**	**15-Day**
10-Year	3084	2070	2027	1990	1958	1865
25-Year	3460	2433	2398	2362	2331	2228
50-Year	3720	2682	2652	2606	2571	2469
100-Year	3967	2912	2888	2823	2783	2688

Year	**Discharge (ft^3/s)**					
	Peak	**1-Day**	**3-Day**	**5-Day**	**7-Day**	**15-Day**
1904	4406	3309	3309	3234	3177	2987
1905	2346	1384	1384	1384	1359	1325
1906	3208	2189	2189	2189	2171	2096
1907	3071	2062	1996	1960	1931	1863
1908	2262	1306	1306	1306	1300	1249
1909	2409	1443	1430	1416	1403	1344
1910	2220	1267	1239	1240	1234	1200
1911	2672	1689	1689	1665	1630	1560
1912	2735	1748	1748	1724	1697	1631
1913	3302	2278	2278	2278	2278	2127
1930	1550	641	635	631	624	608
1931	1499	593	580	571	567	539
1932	2451	1483	1453	1420	1376	1318
1933	2430	1463	1414	1213	1180	1035
1934	2346	1384	1296	1267	1166	1088
1935	2609	1630	1496	1507	1474	1397
1936	2913	1915	1888	1856	1801	1693
1937	2567	1591	1541	1490	1494	1457
1938	2693	1708	1689	1618	1570	1493
1939	2640	1659	1551	1492	1463	1351
1940	2703	1718	1715	1710	1687	1602
1941	3323	2297	2186	2013	1948	1818
1942	3250	2229	2180	2125	2045	1996
1943	3292	2268	2206	2144	2121	2087
1944	2924	1924	1918	1893	1894	1868
1945	3481	2445	2376	2296	2220	2076
1946	3124	2111	2104	2074	2048	1981
1947	2808	1816	1800	1781	1760	1693
1948	2913	1915	1862	1812	1787	1759
1949	2083	1139	1137	1136	1131	1099
1950	2230	1276	1270	1265	1257	1225
1951	2051	1109	1087	1082	1084	1066

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1952	2966	1964	1898	1881	1857	1844
1953	3302	2278	2111	2026	1972	1920
1954	3145	2131	2121	2115	2117	2034
1955	2514	1541	1541	1522	1471	1263
1956	2945	1944	1921	1887	1856	1797
1957	2524	1551	1548	1543	1540	1534
1958	3460	2425	2396	2368	2327	2253
1959	3048	2040	1930	1834	1763	1499
1960	2191	1240	1170	1144	1081	1069
1961	2245	1290	1230	1141	1095	1018
1962	2191	1240	1090	1016	943	874
1963	2138	1190	1120	1090	1069	1030
1964	2138	1190	1080	1041	964	909
1965	2630	1650	1617	1564	1506	1275
1966	2341	1380	1273	1188	1133	1111
1967	2384	1420	1267	1254	1057	946
1968	2031	1090	1083	969	885	779
1969	2213	1260	1253	1210	1097	993
1970	2448	1480	1377	1324	1267	1189
1971	2555	1580	1577	1574	1507	1240
1972	2373	1410	1148	1073	1059	997
1973	1988	1050	825	821	687	649
1974	2148	1200	1087	1048	1004	983
1975	2191	1240	1200	1164	1120	1010
1976	2395	1430	1360	1234	1164	1105
1977	1571	661	661	661	661	660
1978	2073	1130	1077	1048	1025	1018
1979	1966	1030	993	991	984	972
1980	2191	1240	1157	1112	1064	1024
1981	2159	1210	1030	983	974	962
1982	2084	1140	1110	1096	1096	1033
1983	2106	1160	1160	1158	1144	1135
1984	2148	1200	1004	962	956	948
1985	2213	1260	1083	1052	1033	1000
1986	2180	1230	1177	1069	1076	1019
1987	2180	1230	1016	1004	998	974
1988	2116	1170	1093	1058	1054	1039
1989	2116	1170	1160	1123	1079	1055
1990	2255	1300	1287	1198	1159	1055
1991	1717	797	792	791	745	697
1992	1424	523	390	361	348	357
1993	2491	1520	1300	1232	1203	1122
1994	1738	817	766	748	701	584
1995	2063	1120	1037	1026	1022	1008
1996	2277	1320	1257	1216	1207	1059
1997	2031	1090	1028	1013	1015	983
1998	2373	1410	1293	1256	1210	1139
1999	2320	1360	1263	1264	1196	1123

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
2000	2373	1410	1223	1086	1034	1000
2001	2009	1070	983	966	939	927
2002	1774	850	735	699	661	631
2003	2170	1220	991	983	959	944
2004	2148	1200	1073	1018	973	778
2005	2170	1220	989	968	950	929
2006	2073	1130	1042	1030	1033	990
2007	2106	1160	1052	1037	1026	1009
2008	2084	1140	1130	1120	1107	1039
2009	2095	1150	1037	1020	1012	973

SEPTEMBER MONTHLY FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.3642	3.1362	3.1504	3.1334	3.1225	3.1123
Std Deviation	0.1429	0.2060	0.1658	0.1677	0.1697	0.1597
Skew	-1.065	-1.113	-0.806	-0.726	-0.702	-0.594
Gage Base	2600	1620	1510	1460	1430	1340

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	3338	2311	2205	2143	2105	2015
25-Year	3594	2558	2455	2406	2371	2274
50-Year	3734	2694	2607	2570	2538	2441
100-Year	3843	2800	2735	2711	2684	2590

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1904	3355	2327	2235	2217	2191	2088
1905	2346	1384	1355	1331	1321	1308
1906	2567	1591	1591	1591	1591	1562
1907	2672	1689	1649	1634	1616	1588
1908	2030	1090	1088	1085	1082	1064
1909	2167	1217	1208	1205	1204	1199
1910	2130	1183	1183	1183	1183	1158
1911	2262	1306	1280	1258	1258	1235
1912	2482	1512	1512	1512	1512	1505
1913	2735	1748	1748	1701	1680	1614
1930	2451	1483	1473	1471	1462	1437
1931	1690	772	741	733	730	702
1932	2619	1640	1551	1481	1438	1328
1933	2756	1767	1754	1732	1728	1668
1934	2588	1610	1525	1475	1455	1309
1935	2630	1649	1649	1620	1606	1576
1936	3313	2288	2117	1776	1787	1728
1937	3145	2131	1928	1834	1722	1671

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1938	2934	1934	1849	1781	1731	1677
1939	2976	1973	1872	1816	1786	1704
1940	3166	2150	2062	2005	1929	1830
1941	3050	2042	2019	1997	1982	1957
1942	3187	2170	2137	2103	2100	2031
1943	3649	2602	2599	2568	2551	2538
1944	2976	1973	1967	1960	1957	1918
1945	3502	2464	2399	2321	2279	2201
1946	3271	2248	2242	2193	2149	2068
1947	2882	1885	1869	1862	1856	1820
1948	3040	2032	2019	2001	1948	1911
1949	2609	1630	1630	1620	1610	1508
1950	2388	1424	1375	1349	1347	1335
1951	2356	1394	1358	1345	1344	1341
1952	3481	2445	2445	2441	2435	2399
1953	3765	2710	2582	2559	2544	2488
1954	3481	2445	2412	2388	2362	2182
1955	2630	1649	1617	1476	1433	1273
1956	3649	2602	2582	2549	2474	2146
1957	3250	2229	2144	2040	1992	1935
1958	3407	2376	2373	2370	2348	2298
1959	3251	2230	2200	2158	2064	1985
1960	2587	1610	1427	1392	1315	1299
1961	2630	1650	1610	1568	1463	1375
1962	3208	2190	1583	1468	1411	1348
1963	2834	1840	1780	1728	1689	1642
1964	2684	1700	1700	1592	1554	1458
1965	3315	2290	2263	2162	2121	2033
1966	2545	1570	1377	1362	1251	1215
1967	2427	1460	1453	1450	1450	1449
1968	2213	1260	1103	1004	993	944
1969	3016	2010	1917	1812	1761	1660
1970	3101	2090	1797	1604	1426	1350
1971	2598	1620	1607	1602	1600	1494
1972	3647	2600	2263	2140	2107	1936
1973	2009	1070	1063	978	946	848
1974	2619	1640	1567	1454	1390	1283
1975	2876	1880	1863	1842	1820	1680
1976	2502	1530	1443	1442	1436	1395
1977	2384	1420	1227	1158	1134	988
1978	2191	1240	1237	1212	1207	1140
1979	2191	1240	1227	1222	1221	1211
1980	2448	1480	1293	1258	1243	1217
1981	2180	1230	1227	1138	1024	871
1982	2951	1950	1920	1890	1790	1447
1983	3219	2200	2120	1944	1889	1703
1984	3305	2280	1927	1818	1683	1650
1985	3091	2080	1750	1688	1666	1634

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1986	2502	1530	1487	1400	1364	1334
1987	2255	1300	1297	1292	1284	1259
1988	2180	1230	1207	1200	1190	1074
1989	2630	1650	1440	1392	1341	1317
1990	2587	1610	1410	1364	1339	1241
1991	1716	796	777	756	749	699
1992	1724	804	758	651	632	567
1993	2566	1590	1443	1394	1360	1331
1994	1833	905	901	884	875	866
1995	2480	1510	1360	1330	1317	1279
1996	2662	1680	1510	1408	1404	1366
1997	2041	1100	1093	1088	1087	1045
1998	2630	1650	1470	1420	1421	1366
1999	2705	1720	1673	1518	1489	1313
2000	2373	1410	1303	1207	1205	1102
2001	1966	1030	958	954	949	945
2002	1869	939	837	828	821	763
2003	2437	1470	1367	1220	1138	1079
2004	1821	894	878	873	870	827
2005	2277	1320	1170	1152	1140	1079
2006	2116	1170	1087	1086	1081	1067
2007	2009	1070	1040	1022	1015	975
2008	2095	1150	1117	1098	1063	1008
2009	2073	1130	1026	1008	1001	933

KLAMATH RIVER BELOW FALL CREEK NEAR COPCO, CA

ANNUAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.5527	3.3563	3.3363	3.4732	3.328	3.3381
Std Deviation	0.4583	0.573	0.5806	0.4072	0.5672	0.5148
Skew	-1.388	-1.481	-1.509	-1.223	-1.486	-1.369
Gage Base	5400	4100	3900	3600	3500	3400

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	10750	8754	8438	8192	8079	7548
25-Year	12720	10560	10140	9804	9715	9155
50-Year	13730	11460	10970	10710	10530	10010
100-Year	14470	12090	11550	11400	11100	10640

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1905	4877	3666	3666	3666	3666	3666
1906	5608	4350	4350	4350	4350	4350
1907	7003	5656	5576	5513	5486	5449
1908	5741	4475	3901	3720	3498	3200
1909	5043	3822	3684	3615	3615	3615
1910	5862	4589	4589	4589	4589	4566
1911	5276	4039	3967	3909	3884	3852
1912	4401	3221	3159	3109	3088	3059
1913	5276	4039	3967	3909	3884	3880
1924	4880	4190	3033	2506	2383	2339
1925	4100	2750	2497	2322	2280	2116
1926	3970	2890	2837	2826	2679	2468
1927	6350	4210	3903	3640	3496	3347
1928	6950	4190	3637	3406	3399	3266
1929	3180	2610	2423	2324	2048	2016
1930	3110	2300	2143	2076	1926	1723
1931	3160	2220	2053	1902	1760	1637
1932	3370	2560	2260	2200	1977	1691
1933	3510	2610	2273	2130	1775	1712
1934	3650	2640	2387	2182	1944	1833
1935	5310	4170	4113	4074	4059	3873
1936	5310	3100	3020	2990	2899	2472
1937	3240	2810	2637	2484	2131	2117
1938	9660	7740	7740	7740	7703	7460
1939	4120	2950	2870	2782	2536	2289
1940	8140	7090	6897	6742	6569	6081
1941	3250	2480	2360	2248	2073	2010
1942	5050	3900	3567	3422	3394	2610
1943	9260	6560	6507	6442	6373	5861
1944	3340	2700	2640	2630	2596	2581
1945	4500	2530	2503	2474	2316	2238
1946	6900	4720	4477	4418	4357	4238
1947	3570	2420	2343	2316	2190	2118
1948	4770	2890	2700	2620	2549	2413
1949	4180	2960	2927	2836	2650	2449
1950	5180	2830	2650	2498	2357	2349
1951	6530	4630	4600	4526	4461	4189
1952	9360	8130	7890	7490	7273	6885
1953	7600	6840	6783	6690	6610	6310
1954	7120	6240	6180	6096	6123	5843
1955	3500	3270	3100	2960	2784	2741
1956	12000	10400	8603	8038	7841	7697
1957	8500	8100	7870	7800	7770	7479
1958	9280	8650	8410	8386	8376	8221
1959	3850	3990	3360	3356	3351	3345
1960	5110	3060	2780	2410	2064	2091
1961	3550	3273	3104	2972	2919	2820
1962	4932	3449	3280	3092	2997	2860

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1963	7302	5853	5770	5614	5425	4513
1964	4999	3066	3045	3016	2999	2977
1965	10612	8919	8864	8793	8705	8564
1966	5951	4361	4361	4367	4393	4453
1967	7944	6371	6022	5465	5080	4127
1968	4434	2983	2945	2914	2885	2790
1969	9948	7718	7576	7446	7237	6097
1970	11099	9137	9023	8789	8643	7828
1971	10701	8733	8622	8350	8134	6838
1972	12406	10380	10218	10065	9851	9605
1973	5685	4185	4185	4143	4007	3521
1974	11520	8536	8270	8215	8213	7716
1975	8088	6257	6129	5958	5825	5435
1976	6615	5241	5224	5216	5080	4413
1977	5929	2993	2990	2987	2986	2985
1978	8021	5790	5677	5623	5526	4781
1979	4578	3117	2976	2854	2827	2753
1980	7080	5065	5062	5013	4950	4484
1981	4567	2983	2910	2860	2814	2264
1982	12517	9790	9507	9336	9201	8943
1983	11299	9023	8743	8571	8455	7689
1984	11354	8702	7849	7481	7228	6724
1985	8686	7003	6561	6364	5993	5324
1986	12627	9583	9462	9193	9112	8736
1987	4124	2941	2941	2931	2913	2883
1988	4013	2838	2834	2802	2759	2531
1989	9981	7946	7175	6839	6702	6541
1990	4290	2330	2237	2185	2161	1892
1991	4179	2516	2468	2465	2459	2439
1992	2167	942	926	926	925	920
1993	11099	9137	8674	8325	8052	7545
1994	2629	1480	1422	1420	1420	1379
1995	9959	7718	7065	6568	6403	5929
1996	11764	9831	9538	9249	8999	8268
1997	12151	9893	9624	9402	9291	8951
1998	9882	7718	7352	7258	7203	6954
1999	10989	8743	8619	8536	8385	7649
2000	5896	4599	4599	4597	4586	4192
2001	3283	2154	2150	2127	2108	2077
2002	3914	2724	2724	2719	2697	2454
2003	5530	3780	3266	3099	2965	2647
2004	3936	2568	2413	2193	2078	1799
2005	7346	5003	4627	4249	4066	3867
2006	11122	8930	8757	8503	8326	7344
2007	4711	3283	3245	3186	3159	2971
2008	3936	2744	2734	2711	2698	2574
2009	3183	1812	1660	1596	1568	1440

JULY-NOVEMBER SEASONAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.6552	3.4011	3.3725	3.3292	3.2857	3.25
Std Deviation	0.0658	0.121	0.134	0.1627	0.195	0.2096
Skew	1.172	0.676	0.52	0.216	-0.051	-0.127
Gage Base	4350	2400	2250	2200	1950	1850

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	5539	3650	3548	3477	3424	3278
25-Year	6197	4348	4258	4225	4204	4053
50-Year	6718	4909	4824	4808	4796	4637
100-Year	7265	5506	5423	5412	5396	5225

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1904	7497	5739	5538	5469	5378	5089
1905	4101	2143	2054	2036	1992	1868
1906	5540	3666	3666	3584	3548	3422
1907	5305	3418	3363	3314	3255	3088
1908	3906	1936	1915	1878	1858	1770
1909	4316	2371	2347	2311	2259	2065
1910	3906	1936	1936	1924	1910	1750
1911	4776	2858	2748	2726	2669	2531
1912	4463	2527	2475	2434	2416	2321
1913	4776	2858	2803	2792	2764	2671
1924	4136	2180	2073	1960	1907	1779
1925	4674	2750	2497	2226	2097	1899
1926	4211	2260	1677	1722	1516	1463
1927	4617	2690	2567	2410	2153	2109
1928	4684	2760	2473	2324	2159	2016
1929	3852	1880	1817	1804	1597	1544
1930	4079	2120	1920	1864	1629	1637
1931	3900	1930	1673	1584	1534	1444
1932	4117	2160	1750	1724	1539	1382
1933	4542	2610	2197	2092	1775	1715
1934	4051	2090	1890	1712	1449	1418
1935	4362	2420	2253	2254	2040	1730
1936	4731	2810	2637	2484	2131	2117
1937	4192	2240	2223	2198	1798	1673
1938	4306	2360	2273	1966	1765	1652
1939	4362	2420	2263	1996	1776	1737
1940	4362	2420	2307	2248	2073	2010
1941	4485	2550	2390	2220	2018	1918
1942	4514	2580	2533	2378	2121	2075
1943	4636	2710	2680	2630	2597	2581

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1944	4230	2280	2233	2186	2116	2023
1945	4466	2530	2503	2474	2316	2238
1946	4325	2380	2343	2316	2190	2118
1947	4126	2170	2073	2028	1826	1781
1948	4306	2360	2280	2206	1975	1934
1949	4750	2830	2650	2498	2357	2349
1950	4910	3000	2960	2820	2603	2524
1951	4221	2270	2237	2076	1934	1887
1952	5118	3220	3050	2970	2783	2743
1953	5250	3360	3330	3320	3321	3273
1954	5165	3270	3100	2960	2784	2741
1955	4731	2810	2603	2452	2163	2151
1956	5713	3850	3827	3800	3781	3739
1957	5288	3400	3400	3364	3337	3201
1958	5241	3350	3313	3312	3299	3243
1959	5845	3990	3023	2448	2206	2091
1960	4627	2700	2137	1858	1700	1573
1961	5168	3273	3104	2972	2919	2820
1962	5334	3449	3280	3092	2997	2860
1963	4923	3014	3007	3003	2999	2949
1964	3857	1884	1874	1862	1858	1851
1965	6430	4609	4533	4518	4504	4463
1966	4228	2278	2119	1855	1853	1837
1967	4825	2910	2744	2257	1969	1824
1968	4003	2040	1905	1826	1607	1513
1969	4933	3024	3003	2972	2949	2853
1970	5109	3211	3138	3115	3110	3007
1971	5285	3397	3152	3049	3018	2988
1972	5295	3407	3401	3395	3347	3153
1973	4982	3076	3041	3018	3005	2466
1974	4796	2879	2862	2850	2845	2839
1975	5520	3646	3646	3629	3572	3249
1976	4953	3045	3010	3003	2999	2990
1977	3592	1605	1598	1596	1579	1459
1978	4091	2133	2026	1899	1853	1786
1979	3632	1646	1419	1332	1317	1300
1980	3309	1304	1297	1296	1295	1294
1981	4453	2516	1960	1522	1300	1093
1982	5315	3428	3380	3368	3365	3101
1983	7409	5645	5618	5579	5486	5303
1984	7330	5563	5559	5511	5446	5324
1985	5178	3283	3228	3182	2977	2496
1986	4375	2434	2434	2286	2137	1958
1987	3543	1553	1453	1350	1329	1324
1988	3254	1246	1244	1241	1227	1108
1989	3573	1584	1577	1569	1521	1383
1990	3338	1335	1315	1312	1310	1299
1991	2966	942	912	908	906	903

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1992	2952	926	926	926	925	922
1993	3485	1491	1477	1460	1448	1445
1994	2990	966	954	952	953	946
1995	3358	1356	1356	1354	1352	1238
1996	3397	1397	1373	1373	1360	1354
1997	3612	1625	1625	1625	1621	1608
1998	5001	3097	3090	3076	3073	2417
1999	3827	1853	1850	1841	1825	1744
2000	3622	1636	1360	1337	1334	1313
2001	3847	1874	1732	1552	1468	1319
2002	3367	1366	1264	1229	1166	1031
2003	3710	1729	1567	1487	1460	1402
2004	3250	1242	1159	1036	996	956
2005	3534	1542	1425	1389	1357	1353
2006	4962	3055	2896	2471	2143	1489
2007	3397	1397	1349	1289	1223	1217
2008	3641	1656	1434	1393	1377	1305
2009	3406	1408	1394	1391	1343	1252

JUNE-OCTOBER SEASONAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.6182	3.3658	3.3725	3.3063	3.2525	3.2518
Std Deviation	0.1255	0.1897	0.1340	0.2167	0.2545	0.2131
Skew	0.588	0.525	0.520	0.347	0.015	0.325
Gage Base	4190	2280	2250	2060	1910	1820

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	6094	4141	3548	3898	3793	3398
25-Year	7264	5366	4258	5132	5004	4442
50-Year	8197	6407	4824	6174	5986	5317
100-Year	9183	7564	5423	7327	7035	6278

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1904	10569	8992	8992	8870	8789	8395
1905	4816	2900	2900	2900	2852	2737
1906	6185	4350	4350	4350	4350	4287
1907	6342	4516	4475	4431	4384	4243
1908	4316	2371	2371	2371	2368	2344
1909	5686	3822	3684	3509	3345	3070
1910	4776	2858	2858	2809	2775	2654
1911	5686	3822	3822	3780	3733	3591
1912	4620	2693	2693	2693	2693	2659
1913	5119	3221	3221	3184	3141	3109

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1924	4136	2180	2073	1960	1907	1760
1925	4100	2750	2497	2322	2166	2116
1926	3758	1780	1677	1558	1516	1463
1927	6350	2790	2627	2606	2653	2496
1928	4684	2760	2473	2324	2159	2008
1929	3110	1880	1817	1804	1597	1544
1930	3160	2300	2130	1928	1655	1637
1931	3409	1410	1377	1354	1290	1118
1932	4183	2230	2150	1918	1859	1410
1933	3650	2610	2197	2092	1775	1715
1934	4051	2090	1890	1712	1449	1418
1935	4221	2270	2050	1972	1676	1592
1936	3240	2740	2577	2432	2047	1984
1937	4192	2240	2223	2198	1798	1673
1938	4863	2950	2720	2604	2556	2027
1939	4362	2420	2263	1996	1776	1737
1940	4362	2420	2307	2248	2073	2010
1941	3250	2480	2360	2220	1991	1874
1942	4514	2580	2533	2378	2121	2075
1943	5401	3520	3410	3246	3169	2901
1944	4230	2280	2153	2084	1944	1890
1945	4466	2530	2503	2474	2316	2238
1946	4296	2350	2300	2278	2063	2047
1947	4126	2170	2073	2018	1826	1781
1948	4806	2890	2700	2620	2549	2413
1949	4589	2660	2513	2482	2307	2260
1950	4315	2370	2077	2032	1984	1859
1951	4221	2270	2237	2060	1844	1757
1952	6147	4310	4170	3822	3609	3080
1953	8301	6590	6420	6084	5679	5197
1954	5165	3270	3010	2856	2683	2626
1955	3500	2300	2080	2038	1804	1571
1956	5817	3960	3863	3804	3760	3579
1957	5165	3270	2713	2596	2549	2397
1958	6544	4730	4623	4592	4576	4253
1959	5845	3990	3023	2448	2206	2091
1960	3994	2030	1877	1786	1495	1467
1961	4424	2485	2465	2392	2358	2215
1962	5334	3449	3280	3092	2997	2860
1963	3837	1864	1815	1810	1799	1780
1964	3857	1884	1874	1862	1858	1851
1965	5266	3376	3166	3057	2981	2898
1966	3798	1822	1822	1820	1819	1812
1967	5226	3335	3224	3188	2929	1841
1968	3700	1719	1712	1555	1338	1330
1969	4933	3024	3003	2972	2949	2363
1970	4033	2071	2026	1880	1620	1451
1971	6577	4765	4754	4678	4562	2988

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1972	4219	2268	2257	2224	2201	2039
1973	3524	1532	1439	1391	1335	1303
1974	4003	2040	1978	1953	1915	1819
1975	4825	2910	2907	2906	2904	2814
1976	4502	2568	2568	2338	2179	1966
1977	3573	1584	1546	1526	1516	1397
1978	3328	1325	1325	1325	1325	1320
1979	3328	1325	1325	1319	1317	1300
1980	3309	1304	1297	1296	1295	1294
1981	3299	1294	1294	1246	1171	1071
1982	5001	3097	3076	2925	2801	2157
1983	5657	3791	3732	3729	3724	3184
1984	6430	4609	4606	4601	4600	4337
1985	4140	2185	2102	1909	1799	1785
1986	3798	1822	1822	1822	1822	1806
1987	3338	1335	1332	1329	1329	1324
1988	3254	1246	1244	1241	1227	1108
1989	4502	2568	2088	1662	1521	1383
1990	3338	1335	1315	1312	1310	1299
1991	2942	916	912	908	906	903
1992	2949	923	923	921	921	920
1993	8808	7127	7037	6594	5739	3549
1994	2990	966	954	952	953	946
1995	3612	1625	1518	1444	1395	1238
1996	3915	1947	1905	1621	1457	1431
1997	3602	1615	1612	1607	1606	1537
1998	7360	5594	5504	5409	5160	4272
1999	3994	2029	1991	1971	1898	1813
2000	3622	1636	1522	1522	1517	1445
2001	4111	2154	2150	2127	2108	2077
2002	3367	1366	1264	1229	1166	1031
2003	3729	1750	1736	1683	1658	1587
2004	3338	1335	1299	1212	1086	938
2005	3573	1584	1563	1438	1357	1313
2006	4962	3055	3055	3055	3055	3049
2007	3485	1491	1484	1482	1480	1476
2008	3954	1988	1929	1857	1782	1747
2009	3455	1460	1460	1458	1455	1440

KLAMATH RIVER BELOW IRON GATE DAM, CA

ANNUAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.7965	3.7626	3.7355	3.7171	3.7026	3.6619
Std Deviation	0.313	0.3046	0.2965	0.2881	0.2824	0.268
Skew	-0.116	-0.166	-0.22	-0.272	-0.291	-0.288
Gage Base	N/A	N/A	N/A	N/A	N/A	N/A

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	15610	14030	12820	11940	11340	9909
25-Year	21460	18970	17040	15620	14710	12690
50-Year	26280	22940	20370	18450	17290	14790
100-Year	31460	27140	23830	21350	19890	16910

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1961	6030	4230	3427	3024	2861	2657
1962	3710	3490	3433	3408	3363	3263
1963	10600	6660	5833	5754	5566	4779
1964	4850	4250	3843	3662	3524	3179
1965	29400	25000	21867	18160	15986	11983
1966	4940	4780	4727	4646	4590	4502
1967	6890	6730	6453	6000	5603	4773
1968	3470	3170	3050	3032	3023	2950
1969	9090	8590	8120	7872	7540	6449
1970	14900	12700	11400	10848	10477	9379
1971	10800	10600	10137	9908	9619	8085
1972	17000	16200	15500	14680	14086	12707
1973	4790	4680	4513	4468	4397	3797
1974	18700	16000	12307	10904	10489	9484
1975	8260	6810	6443	6112	6050	5934
1976	5900	5730	5487	5366	5206	4503
1977	3120	3080	3067	3060	3061	3044
1978	7580	6590	6430	6268	6133	5255
1979	3320	3300	3227	3144	3009	2953
1980	8580	7120	6193	6216	5994	5033
1981	3120	3080	3007	2958	2810	2292
1982	18700	16100	14100	12940	12229	10922
1983	10800	10500	10080	9736	9524	8488
1984	10900	9810	9673	9212	8683	7515
1985	7970	7830	7200	6862	6539	5487
1986	13900	13100	12267	11600	11034	10014
1987	3350	3310	3293	3272	3259	3145
1988	2890	2870	2850	2798	2767	2633
1989	10200	9780	8817	8060	7664	7171
1990	3360	3310	2810	2552	2447	2205

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1991	2430	2400	2400	2398	2399	2257
1992	1000	920	893	892	891	890
1993	11100	10800	10333	9586	9114	8470
1994	2150	1780	1540	1482	1459	1435
1995	9380	8740	8227	7482	7229	6466
1996	12600	12000	11733	11300	10981	9861
1997	20500	18500	16067	14700	13614	11477
1998	8770	8680	8420	7952	7646	7478
1999	9220	9070	8963	8880	8740	8041
2000	5190	5060	4827	4758	4711	4441
2001	2280	2120	2113	2108	2104	2099
2002	3110	3070	3037	3014	2969	2730
2003	4410	4180	3963	3678	3503	3123
2004	4380	4110	3607	3338	3099	2618
2005	5520	5380	5080	4882	4673	4479
2006	12400	11100	10457	10252	9906	8611
2007	4060	4010	3997	3956	3900	3737
2008	3450	3310	3217	3104	2967	2937
2009	1860	1780	1773	1772	1770	1763

JULY-NOVEMBER SEASONAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.3578	3.3294	3.3152	3.3068	3.2984	3.2774
Std Deviation	0.2262	0.2134	0.2096	0.2079	0.2062	0.198
Skew	0.24	0.275	0.322	0.368	0.414	0.52
Gage Base	N/A	N/A	N/A	N/A	N/A	N/A

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	4497	4058	3890	3802	3716	3465
25-Year	5914	5276	5061	4962	4863	4538
50-Year	7095	6286	6037	5936	5834	5458
100-Year	8387	7386	7107	7010	6912	6487

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1961	3442	3140	2977	2842	2779	2640
1962	4799	4330	3803	3666	3419	3067
1963	3590	3270	3157	3158	3014	2983
1964	2027	1900	1897	1894	1890	1883
1965	5313	4780	4727	4646	4590	4502
1966	1982	1860	1847	1842	1839	1835
1967	2826	2600	2117	1998	1947	1869
1968	1468	1410	1400	1392	1389	1383
1969	3248	2970	2950	2940	2921	2911

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1970	4389	3970	3767	3758	3717	3385
1971	3682	3350	3330	3306	3260	3210
1972	3830	3480	3393	3364	3341	3191
1973	4206	3810	3497	3408	3403	2869
1974	3362	3070	3010	2964	2949	2931
1975	4012	3640	3583	3536	3467	3233
1976	3373	3080	3067	3060	3061	3044
1977	1879	1770	1757	1716	1611	1464
1978	1947	1830	1830	1830	1824	1821
1979	1515	1450	1387	1368	1357	1350
1980	1411	1360	1360	1360	1357	1353
1981	3248	2970	2523	2242	2017	1737
1982	3955	3590	3507	3442	3434	3212
1983	6476	5800	5657	5566	5494	5269
1984	6511	5830	5647	5594	5561	5487
1985	3567	3250	3223	3164	3004	2475
1986	2792	2570	2567	2352	2189	1961
1987	1434	1380	1350	1350	1347	1344
1988	1902	1790	1707	1610	1549	1310
1989	1548	1480	1430	1418	1413	1407
1990	1411	1360	1360	1356	1350	1349
1991	890	890	890	890	888	881
1992	940	940	925	921	920	918
1993	1890	1780	1540	1482	1459	1435
1994	962	962	961	960	958	952
1995	1411	1360	1353	1352	1351	1351
1996	1913	1800	1800	1780	1723	1575
1997	1879	1770	1763	1762	1760	1760
1998	4343	3930	3873	3792	3690	2792
1999	1947	1830	1830	1830	1830	1825
2000	1400	1350	1350	1350	1341	1336
2001	1400	1350	1347	1344	1340	1337
2002	1400	1350	1350	1350	1350	1302
2003	1548	1480	1400	1384	1377	1369
2004	1366	1320	1283	1194	1116	1006
2005	1491	1430	1397	1380	1367	1359
2006	3294	3010	2787	2558	2330	1763
2007	1525	1460	1350	1342	1336	1333
2008	1594	1520	1500	1420	1346	1331
2009	1480	1420	1330	1330	1330	1325

JUNE-OCTOBER SEASONAL FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.3354	3.3100	3.2986	3.2871	3.2768	3.2468
Std Deviation	0.2282	0.2137	0.2078	0.2062	0.2023	0.1735
Skew	0.730	0.824	0.860	0.37	0.812	0.602
Gage Base	N/A	N/A	N/A	N/A	N/A	N/A

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	4364	3942	3773	3655	3526	3001
25-Year	6110	5460	5200	5012	4794	3831
50-Year	7724	6863	6516	6257	5945	4533
100-Year	9647	8535	8085	7733	7299	5310

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1961	3385	3090	2730	2558	2406	2237
1962	4799	4330	3803	3666	3419	3067
1963	1970	1850	1850	1840	1831	1787
1964	2438	2260	1967	1894	1887	1878
1965	3294	3010	2980	2978	2971	2928
1966	1833	1730	1723	1720	1717	1713
1967	4229	3830	3730	3598	3433	2337
1968	1468	1410	1400	1392	1389	1383
1969	3202	2930	2917	2876	2844	2203
1970	1879	1770	1760	1700	1584	1442
1971	5769	5180	5120	5044	4957	3353
1972	1913	1800	1800	1800	1800	1795
1973	1411	1360	1353	1344	1340	1339
1974	1925	1810	1810	1810	1810	1809
1975	3362	3070	3070	3046	3034	2897
1976	2643	2440	2347	2128	2034	1909
1977	1434	1380	1363	1354	1350	1344
1978	1400	1350	1350	1346	1344	1339
1979	1388	1340	1323	1318	1319	1315
1980	1411	1360	1360	1360	1357	1353
1981	1423	1370	1370	1286	1214	1120
1982	3932	3570	3480	3286	3004	2278
1983	4971	4480	4257	4170	4121	3545
1984	5050	4550	4507	4482	4481	4211
1985	2484	2300	2193	2030	1893	1807
1986	1925	1810	1810	1806	1804	1802
1987	1400	1350	1350	1350	1347	1344
1988	1126	1110	1110	1090	1053	1047
1989	2370	2200	2013	1776	1513	1406
1990	1446	1390	1373	1356	1350	1349
1991	890	890	890	890	888	881
1992	940	920	917	916	915	913

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1993	8655	7710	7357	6826	6097	3883
1994	962	1180	1130	971	955	950
1995	1856	1750	1720	1656	1619	1373
1996	2176	2030	1850	1762	1663	1538
1997	1868	1760	1663	1602	1579	1546
1998	7127	6370	5947	5724	5497	4495
1999	2301	2140	2057	2022	2013	2002
2000	1719	1630	1600	1578	1566	1551
2001	2278	2120	2113	2108	2104	2099
2002	1400	1350	1350	1350	1350	1302
2003	1811	1710	1663	1654	1614	1509
2004	1366	1320	1283	1194	1137	1070
2005	1617	1540	1520	1486	1460	1362
2006	3545	3230	3153	3140	3141	3130
2007	1651	1570	1557	1554	1554	1551
2008	2278	2120	2067	2048	2051	2019
2009	1617	1540	1540	1536	1534	1531

AUGUST MONTHLY FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.3003	3.0267	3.0190	3.0139	3.0092	2.9987
Std Deviation	0.0492	0.0972	0.0996	0.0967	0.0952	0.0926
Skew	-0.419	-0.657	-0.995	-1.201	-1.256	-1.478
Gage Base	N/A	N/A	N/A	N/A	N/A	N/A

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	2291	1387	1361	1328	1307	1259
25-Year	2416	1533	1505	1460	1436	1365
50-Year	2503	1638	1608	1554	1527	1437
100-Year	2585	1740	1710	1646	1617	1505

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1961	2566	3140	1490	1306	1205	1125
1962	1988	4330	1003	1001	995	981
1963	2106	3270	1093	1078	1076	1068
1964	2084	1900	1113	1104	1094	1078
1965	2630	4780	1637	1634	1633	1397
1966	2041	1860	1070	1066	1069	1061
1967	1988	2600	1043	1034	1029	1021
1968	1689	1410	759	758	758	757
1969	2020	2970	1047	1036	1031	1026
1970	1977	1590	1040	1040	1033	1021
1971	2009	1050	1070	1056	1047	1037

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1972	1656	1160	732	729	726	722
1973	1988	1140	1047	1042	1039	1033
1974	2320	1650	1350	1342	1293	1199
1975	2095	1100	1137	1134	1134	1106
1976	1643	1050	726	726	724	721
1977	2009	771	1057	1054	1053	1050
1978	1998	1080	1050	1048	1043	1029
1979	2009	1040	1057	1054	1053	1051
1980	1977	1070	1040	1040	1040	1036
1981	2020	740	1060	1052	1049	1045
1982	1998	1050	1040	1032	1029	1016
1983	2159	1360	1090	1062	1050	1034
1984	1977	1150	1027	1022	1020	1015
1985	1988	728	1030	1026	1026	1019
1986	1956	1070	1013	1012	985	949
1987	1966	1060	1023	1022	1021	1021
1988	1998	1070	1053	1044	1040	1039
1989	2298	1040	1317	1228	1171	1099
1990	1669	1080	746	741	740	737
1991	1382	1060	426	415	411	404
1992	2020	1210	1060	1060	1057	1051
1993	1833	1040	905	904	836	698
1994	2009	1050	1050	1046	1044	1043
1995	2020	1020	1080	1080	1080	1074
1996	2020	1030	1073	1070	1070	1066
1997	2073	1060	1123	1122	1121	1121
1998	2266	1340	1283	1218	1190	1158
1999	2020	752	1080	1080	1080	1075
2000	1966	484	1030	1030	1030	1027
2001	1591	1080	673	673	672	669
2002	1934	905	1000	1000	999	998
2003	2277	1070	1283	1194	1116	913
2004	1956	1080	1010	1010	1010	1009
2005	1988	1080	1020	1012	1007	1002
2006	1977	1130	1040	1036	1034	1032
2007	2491	1310	1500	1420	1346	1180
2008	1934	1080	998	997	997	997
2009	1860	1030	1330	1860	1860	1860

SEPTEMBER MONTHLY FREQUENCY ANALYSIS

Statical Parameters	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
Log Mean	3.3645	3.1337	3.1271	3.1210	3.1150	3.1026
Std Deviation	0.0650	0.1033	0.1040	0.1059	0.1065	0.1080
Skew	0.296	-0.027	-0.130	-0.145	-0.215	-0.487
Gage Base	N/A	N/A	N/A	N/A	N/A	N/A

Return Period	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
10-Year	2816	1844	1815	1799	1773	1715
25-Year	3052	2059	2016	2000	1965	1873
50-Year	3221	2210	2155	2139	2095	1974
100-Year	3386	2355	2286	2270	2217	2064

Year	Discharge (ft^3/s)					
	Peak	1-Day	3-Day	5-Day	7-Day	15-Day
1961	2983	1980	1933	1898	1595	1527
1962	2587	1610	1607	1588	1527	1413
1963	2844	1850	1850	1840	1831	1763
1964	2330	1370	1370	1370	1370	1370
1965	3540	2500	2387	2342	2321	2189
1966	2309	1350	1337	1326	1321	1315
1967	2277	1320	1317	1314	1313	1312
1968	2020	1080	1063	1058	1059	1054
1969	2352	1390	1387	1368	1357	1336
1970	2288	1330	1327	1326	1323	1311
1971	2780	1790	1790	1790	1787	1779
1972	1725	805	745	734	731	728
1973	2320	1360	1350	1346	1344	1340
1974	2812	1820	1820	1820	1810	1717
1975	2587	1610	1603	1602	1601	1516
1976	2341	1380	1363	1350	1349	1318
1977	2298	1340	1340	1340	1337	1333
1978	2277	1320	1320	1316	1316	1312
1979	2320	1360	1360	1360	1357	1353
1980	2330	1370	1370	1254	1146	988
1981	2405	1440	1407	1388	1376	1357
1982	2834	1840	1817	1814	1811	1712
1983	2994	1990	1920	1884	1849	1684
1984	2801	1810	1810	1810	1809	1796
1985	2780	1790	1727	1676	1664	1486
1986	2309	1350	1343	1342	1341	1341
1987	2009	1070	1057	1054	1053	1046
1988	2341	1380	1353	1348	1344	1340
1989	2320	1360	1360	1356	1350	1305
1990	1795	870	870	825	803	765
1991	1806	880	877	839	777	657
1992	2405	1440	1417	1386	1374	1367

Year	Discharge (ft^3/s)					
	Peak	**1-Day**	**3-Day**	**5-Day**	**7-Day**	**15-Day**
1993	1846	918	916	915	915	910
1994	2309	1350	1350	1350	1350	1350
1995	2341	1380	1377	1372	1371	1362
1996	1988	1050	1043	1044	1043	1039
1997	2373	1410	1410	1410	1410	1405
1998	2341	1380	1360	1358	1356	1354
1999	2309	1350	1350	1350	1341	1324
2000	1977	1040	1033	1032	1031	1027
2001	2309	1350	1290	1080	989	867
2002	2352	1390	1383	1378	1373	1320
2003	1850	921	920	918	917	914
2004	2138	1190	1183	1182	1181	1180
2005	2448	1480	1310	1216	1157	1080
2006	2148	1200	1080	1056	1050	1045
2007	1998	1060	1037	1030	1027	1025
2008	1988	1050	1020	1014	1008	999
2009	1860	1860	1860	1860	1860	1860

KLAMATH RIVER NEAR SEIAD VALLEY, CA

ANNUAL PEAK FREQUENCY ANALYSIS

Statical Parameters	
Log Mean	4.2383
Std Deviation	0.3909
Skew	0.374
Gage Base	N/A

Return Period	Peak Discharge (ft^3/s)
10-Year	56540
25-Year	93400
50-Year	131000
100-Year	179300

Year	Peak Discharge (ft^3/s)
1913	9190
1914	26500
1915	14600
1916	16600
1917	9760
1918	6380
1919	15300
1920	3650
1921	21800
1922	9760
1923	7250
1924	6170
1925	23700
1952	25400
1953	55200
1954	20900
1955	5990
1956	122000
1957	25000
1958	38800
1959	11000
1960	19600
1961	17000
1962	7910
1963	35100
1964	20100
1965	165000
1966	15000
1967	19600
1968	23400
1969	16000
1970	56000
1971	51800
1972	55800
1973	10300
1974	126000

Year	Peak Discharge (ft^3/s)
1975	26900
1976	10300
1977	3630
1978	29300
1979	9310
1980	41400
1981	7250
1982	71500
1983	29000
1984	24500
1985	13800
1986	43100
1987	6820
1988	8720
1989	19700
1990	12900
1991	4950
1992	4600
1993	20900
1994	2970
1995	26900
1996	21000
1997	117000
1998	39000
1999	17900
2000	11300
2001	3560
2002	9500
2003	16400
2004	17600
2005	11000
2006	74000
2007	9570
2008	8000
2009	6610

KLAMATH RIVER AT ORLEANS, CA

ANNUAL PEAK FREQUENCY ANALYSIS

Statical Parameters	
Log Mean	4.7821
Std Deviation	0.3391
Skew	-0.112
Gage Base	N/A

Return Period	Peak Discharge (ft^3/s)
10-Year	163100
25-Year	230300
50-Year	287000
100-Year	348900

Year	Peak Discharge (ft^3/s)
1927	141000
1928	60300
1929	13700
1931	17600
1932	51600
1933	19900
1934	21300
1935	18000
1936	60000
1937	59500
1938	73700
1939	26500
1940	70300
1941	36500
1942	58000
1943	68400
1944	13500
1945	48400
1946	97000
1947	26700
1948	92200
1949	30200
1950	41900
1951	74400
1952	67600
1953	137000
1954	57500
1955	26900

Year	Peak Discharge (ft^3/s)
1956	202000
1957	79200
1958	96800
1959	73700
1960	70700
1961	57600
1962	38300
1963	85300
1964	59900
1965	307000
1966	96200
1967	98600
1968	109000
1969	77800
1970	175000
1971	190000
1972	191000
1973	38400
1974	279000
1975	74800
1976	35100
1977	7800
1978	111000
1979	48200
1980	121000
1981	40300
1982	201000

Year	Peak Discharge (ft^3/s)
1983	198000
1984	76800
1985	64400
1986	278000
1987	32600
1988	58800
1989	66800
1990	56700
1991	25400
1992	22200
1993	65300
1994	19600
1995	112000
1996	56700
1997	258000
1998	113000
1999	61000
2000	46800
2001	11000
2002	37800
2003	56000
2004	63500
2005	47900
2006	213000
2007	57200
2008	30300
2009	34800

KLAMATH RIVER NEAR KLAMATH, CA

ANNUAL FREQUENCY ANALYSIS

Statical Parameters	
Log Mean	5.1148
Std Deviation	0.2865
Skew	-0.218
Gage Base	N/A

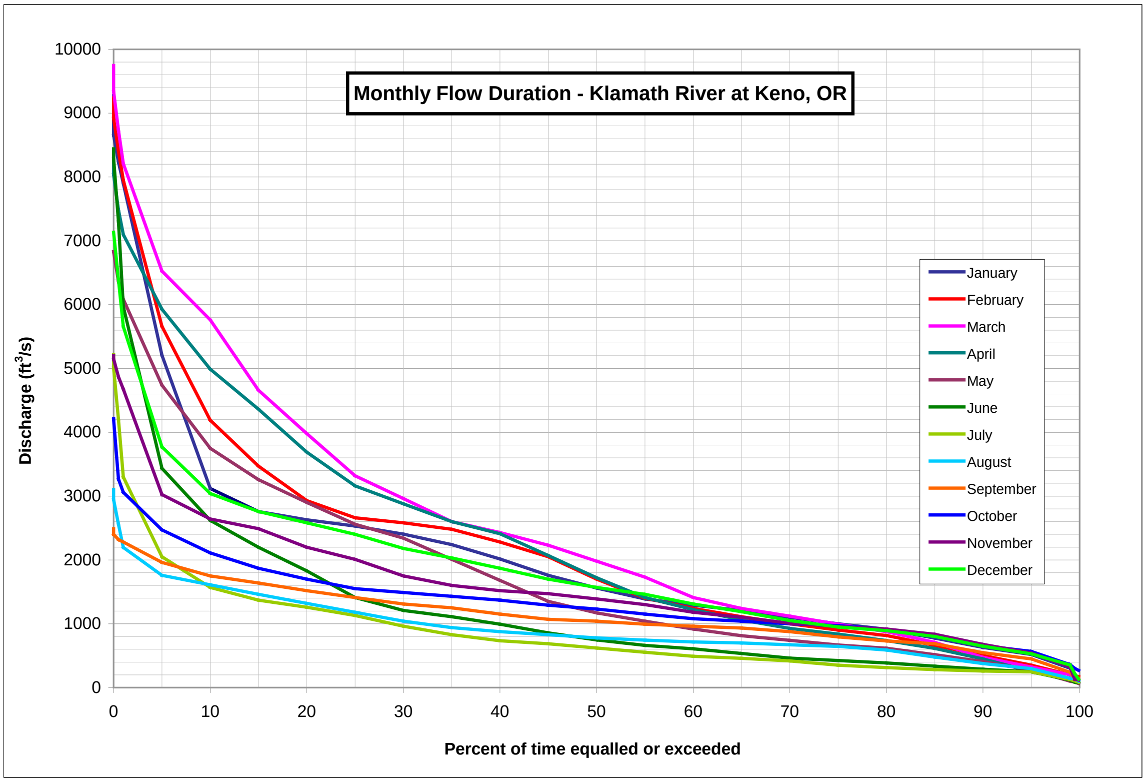
Return Period	Peak Discharge (ft^3/s)
10-Year	298300
25-Year	392900
50-Year	466900
100-Year	543300

Year	Peak Discharge (ft^3/s)
1862	450000
1881	360000
1890	425000
1911	66700
1912	142000
1913	74500
1914	130000
1915	182000
1916	85700
1917	73700
1918	65300
1919	133000
1920	27900
1921	130000
1922	59700
1923	60400
1924	25800
1925	175000
1926	102000
1927	300000
1932	96400
1933	46200
1934	51100
1935	60000
1936	162000
1937	121000
1938	218000
1939	71000
1940	237000
1941	124000
1942	151000
1943	162000

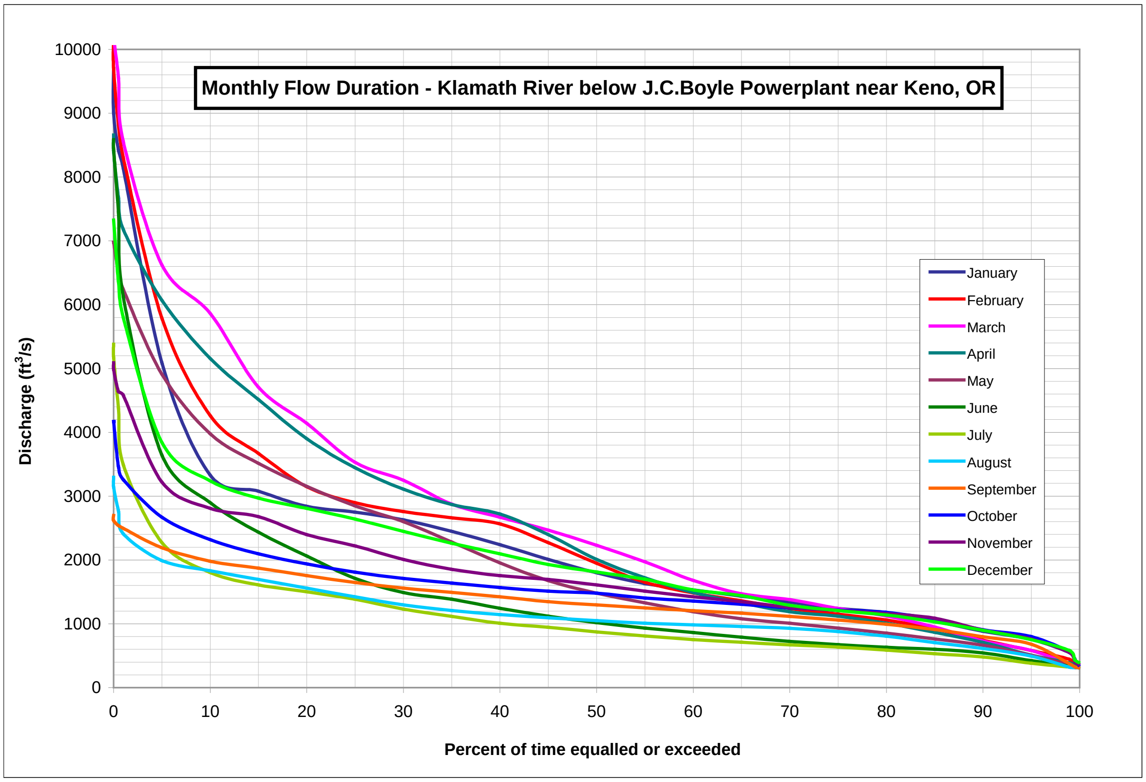
Year	Peak Discharge (ft^3/s)
1944	32300
1945	102000
1946	209000
1947	73900
1948	202000
1949	95000
1950	92600
1951	173000
1952	195000
1953	297000
1954	133000
1955	74200
1956	425000
1957	160000
1958	236000
1959	175000
1960	195000
1961	123000
1962	82000
1963	176000
1964	162000
1965	557000
1966	152000
1967	170000
1968	190000
1969	177000
1970	331000
1971	334000
1972	360000
1973	97800
1974	529000
1975	198000

Year	Peak Discharge (ft^3/s)
1976	76900
1977	15200
1978	312000
1979	98800
1980	234000
1981	81400
1982	384000
1983	282000
1984	172000
1985	149000
1986	459000
1987	81300
1988	113000
1989	154000
1990	131000
1991	70500
1992	59200
1993	164000
1994	46000
1996	165000
1998	240000
1999	141000
2000	141000
2001	25500
2002	134000
2003	181000
2004	195000
2005	100000
2006	342000
2007	97400
2008	72300
2009	82400

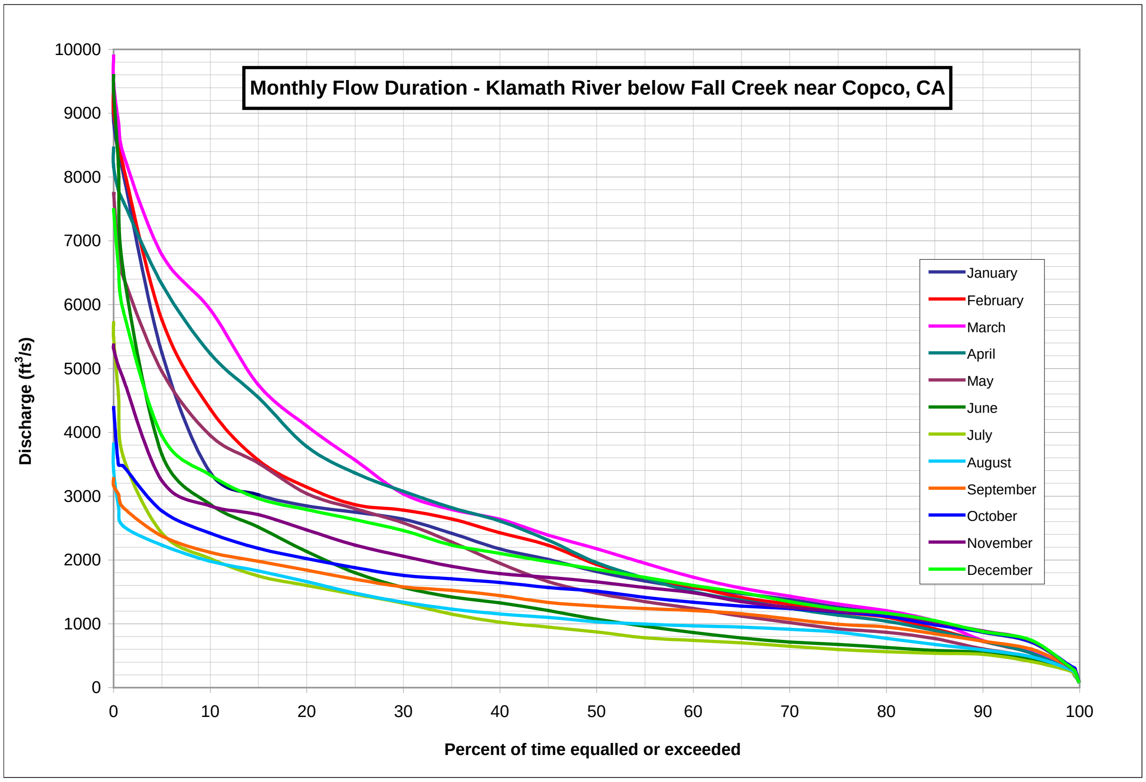
9 Appendix B – Monthly Flow Duration



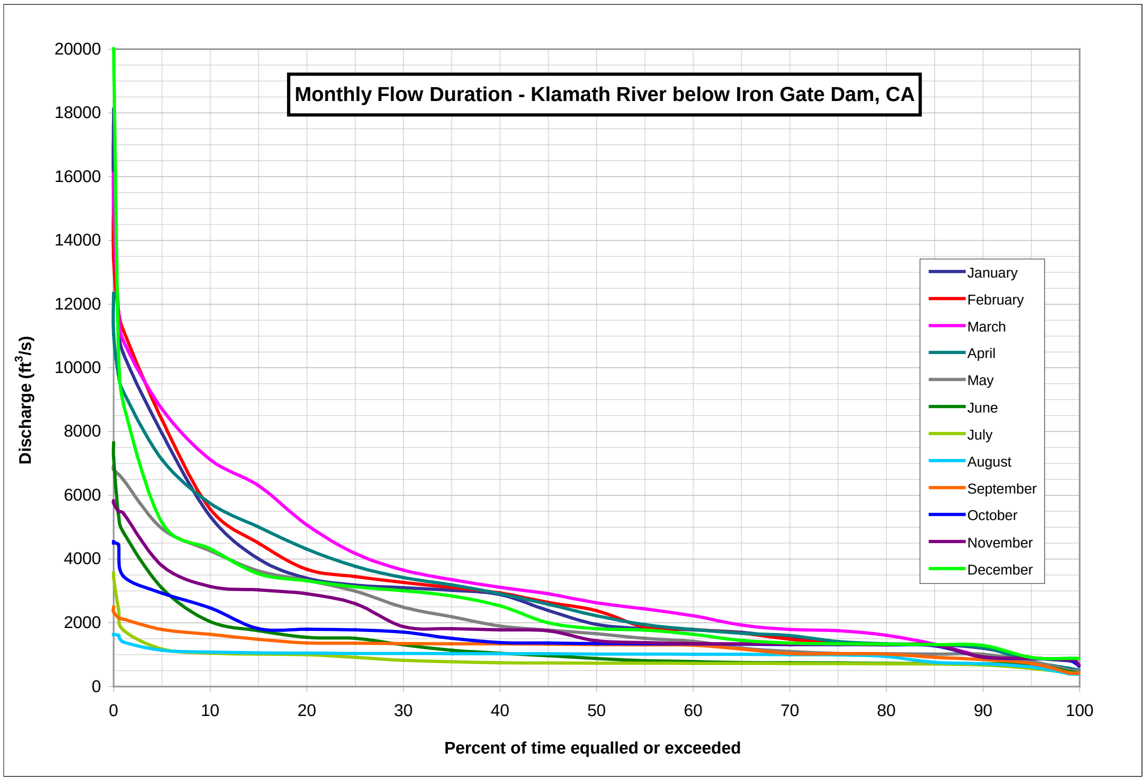
% of time equaled or exceeded	Keno Discharge (ft^3/s)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
99	304	201	204	145	101	118	127	145	243	361	327	356
95	520	352	324	254	273	247	246	296	450	567	540	528
90	628	503	473	448	409	289	259	377	557	658	678	649
80	913	815	875	739	618	385	312	588	734	911	919	891
70	1100	1000	1120	928	740	461	417	672	860	1000	1010	1050
60	1290	1240	1410	1220	917	606	490	716	959	1080	1180	1310
50	1560	1700	1980	1720	1170	747	619	779	1030	1230	1390	1570
40	2014	2280	2430	2410	1680	993	733	875	1140	1370	1520	1870
30	2403	2580	2960	2880	2340	1210	962	1040	1310	1490	1750	2180
20	2630	2930	3980	3690	2900	1830	1260	1320	1510	1700	2200	2580
10	3120	4188	5761	4990	3750	2620	1570	1610	1750	2110	2640	3040
5	5206	5660	6526	5930	4740	3436	2050	1760	1960	2470	3026	3770
1	7900	7951	8210	7100	6082	5970	3300	2194	2280	3060	4677	5658



% of time equaled or exceeded	**Boyle Discharge (ft^3/s)**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
99	539	430	347	372	347	337	324	320	369	551	535	580
95	753	575	581	505	502	414	381	488	680	800	760	750
90	877	744	726	703	660	545	482	609	802	907	902	897
80	1174	1055	1119	1008	854	632	585	806	980	1180	1160	1140
70	1335	1238	1378	1190	1010	724	671	930	1103	1250	1260	1290
60	1530	1483	1680	1491	1190	861	752	984	1200	1355	1424	1532
50	1800	1954	2230	2011	1480	1016	870	1050	1290	1480	1610	1816
40	2240	2567	2670	2720	1954	1242	1010	1142	1420	1571	1757	2101
30	2630	2760	3250	3110	2602	1490	1230	1296	1560	1710	2013	2450
20	2840	3152	4153	3900	3160	2065	1502	1561	1750	1940	2400	2810
10	3338	4269	5862	5164	3987	2906	1807	1836	1983	2327	2810	3250
5	5086	5787	6620	6068	4919	3652	2278	1993	2199	2670	3226	3840
1	8132	8302	8553	7167	6238	6126	3505	2419	2504	3269	4580	5800



% of time equaled or exceeded	Copco Discharge (ft^3/s)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
99	339	301	290	272	273	278	263	287	325	347	320	325
95	710	533	540	538	475	453	396	476	599	719	737	743
90	870	724	736	726	602	535	505	582	730	881	894	885
80	1180	1125	1220	1051	874	623	549	772	961	1135	1181	1190
70	1390	1330	1460	1260	1030	713	647	925	1063	1272	1281	1366
60	1584	1590	1760	1540	1250	870	739	984	1221	1352	1490	1622
50	1846	1950	2233	2009	1491	1080	879	1046	1304	1532	1688	1874
40	2216	2466	2724	2693	1988	1346	1040	1169	1449	1677	1812	2140
30	2693	2889	3143	3125	2651	1580	1330	1340	1605	1812	2061	2485
20	2962	3208	4143	3884	3120	2170	1600	1660	1840	2030	2520	2910
10	3400	4450	6065	5376	4050	2950	2030	1983	2130	2425	2972	3350
5	5356	5919	7005	6445	5021	3718	2428	2250	2376	2858	3300	4116
1	8401	8441	8736	7833	6480	6381	3666	2579	2820	3470	5083	6193



% of time equaled or exceeded	Iron Gate Discharge (ft^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
99	801	511	498	568	513	466	428	396	422	847	851	886
95	909	761	726	790	793	690	569	615	730	880	890	910
90	1200	914	952	1220	1010	715	676	715	849	924	932	1290
80	1330	1322	1610	1340	1030	731	715	942	1020	1310	1320	1330
70	1520	1490	1790	1600	1100	745	723	1000	1040	1320	1330	1370
60	1780	1790	2220	1790	1420	782	731	1010	1286	1340	1350	1640
50	1950	2380	2630	2220	1660	883	736	1020	1320	1350	1440	1820
40	2890	2936	3114	2910	1900	1044	750	1030	1334	1380	1780	2530
30	3100	3267	3653	3420	2490	1310	822	1040	1350	1710	1883	3010
20	3402	3680	5072	4314	3332	1542	1000	1050	1370	1800	2910	3320
10	5341	5569	7121	5750	4260	2040	1050	1080	1630	2471	3140	4321
5	7948	8370	8711	7121	4960	3090	1180	1140	1790	2930	3791	5150
1	10451	11178	10851	9251	6490	4842	1770	1400	2110	3460	5440	8881

10 Appendix C – 1961-2010 Average Daily Discharge

Klamath River at Keno, OR – Water Year 1961-2010 – Average Daily Discharge (ft^3/s)

Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge
1-Jan	2108	1-Mar	2375	1-May	1744	1-Jul	597	1-Sep	795	1-Nov	1372
2-Jan	2132	2-Mar	2417	2-May	1731	2-Jul	584	2-Sep	836	2-Nov	1420
3-Jan	2163	3-Mar	2499	3-May	1727	3-Jul	573	3-Sep	842	3-Nov	1386
4-Jan	2128	4-Mar	2477	4-May	1677	4-Jul	547	4-Sep	853	4-Nov	1393
5-Jan	2104	5-Mar	2475	5-May	1660	5-Jul	539	5-Sep	834	5-Nov	1415
6-Jan	2102	6-Mar	2475	6-May	1643	6-Jul	512	6-Sep	825	6-Nov	1450
7-Jan	2128	7-Mar	2519	7-May	1642	7-Jul	487	7-Sep	843	7-Nov	1454
8-Jan	2123	8-Mar	2546	8-May	1727	8-Jul	485	8-Sep	856	8-Nov	1434
9-Jan	2104	9-Mar	2577	9-May	1702	9-Jul	463	9-Sep	878	9-Nov	1433
10-Jan	2044	10-Mar	2641	10-May	1682	10-Jul	445	10-Sep	878	10-Nov	1438
11-Jan	1985	11-Mar	2705	11-May	1697	11-Jul	439	11-Sep	891	11-Nov	1426
12-Jan	1937	12-Mar	2713	12-May	1727	12-Jul	427	12-Sep	879	12-Nov	1454
13-Jan	1975	13-Mar	2713	13-May	1757	13-Jul	407	13-Sep	842	13-Nov	1508
14-Jan	2009	14-Mar	2775	14-May	1805	14-Jul	410	14-Sep	852	14-Nov	1538
15-Jan	2022	15-Mar	2786	15-May	1787	15-Jul	419	15-Sep	876	15-Nov	1550
16-Jan	2028	16-Mar	2763	16-May	1712	16-Jul	424	16-Sep	900	16-Nov	1561
17-Jan	2038	17-Mar	2801	17-May	1692	17-Jul	433	17-Sep	937	17-Nov	1576
18-Jan	2079	18-Mar	2807	18-May	1665	18-Jul	441	18-Sep	952	18-Nov	1583
19-Jan	2101	19-Mar	2770	19-May	1525	19-Jul	448	19-Sep	933	19-Nov	1591
20-Jan	2100	20-Mar	2719	20-May	1437	20-Jul	445	20-Sep	930	20-Nov	1614
21-Jan	2115	21-Mar	2682	21-May	1409	21-Jul	439	21-Sep	947	21-Nov	1620
22-Jan	2200	22-Mar	2621	22-May	1385	22-Jul	446	22-Sep	943	22-Nov	1618
23-Jan	2275	23-Mar	2551	23-May	1360	23-Jul	451	23-Sep	941	23-Nov	1602
24-Jan	2305	24-Mar	2560	24-May	1317	24-Jul	453	24-Sep	948	24-Nov	1604
25-Jan	2282	25-Mar	2627	25-May	1273	25-Jul	463	25-Sep	970	25-Nov	1611
26-Jan	2264	26-Mar	2651	26-May	1276	26-Jul	472	26-Sep	976	26-Nov	1634
27-Jan	2261	27-Mar	2653	27-May	1276	27-Jul	473	27-Sep	963	27-Nov	1670
28-Jan	2295	28-Mar	2659	28-May	1256	28-Jul	472	28-Sep	980	28-Nov	1691
29-Jan	2265	29-Mar	2607	29-May	1210	29-Jul	475	29-Sep	976	29-Nov	1731
30-Jan	2253	30-Mar	2574	30-May	1159	30-Jul	501	30-Sep	967	30-Nov	1738
31-Jan	2213	31-Mar	2633	31-May	1101	31-Jul	520	1-Oct	1004	1-Dec	1737
1-Feb	2187	1-Apr	2599	1-Jun	1090	1-Aug	549	2-Oct	1040	2-Dec	1741
2-Feb	2181	2-Apr	2615	2-Jun	1106	2-Aug	555	3-Oct	1033	3-Dec	1759
3-Feb	2145	3-Apr	2602	3-Jun	1134	3-Aug	568	4-Oct	1037	4-Dec	1812
4-Feb	2168	4-Apr	2523	4-Jun	1128	4-Aug	590	5-Oct	1102	5-Dec	1837
5-Feb	2172	5-Apr	2497	5-Jun	1108	5-Aug	588	6-Oct	1144	6-Dec	1804
6-Feb	2203	6-Apr	2489	6-Jun	1078	6-Aug	588	7-Oct	1143	7-Dec	1812
7-Feb	2150	7-Apr	2399	7-Jun	1003	7-Aug	580	8-Oct	1140	8-Dec	1887
8-Feb	2075	8-Apr	2346	8-Jun	944	8-Aug	583	9-Oct	1194	9-Dec	1923
9-Feb	2068	9-Apr	2307	9-Jun	897	9-Aug	602	10-Oct	1187	10-Dec	1920
10-Feb	2012	10-Apr	2269	10-Jun	848	10-Aug	614	11-Oct	1192	11-Dec	1912
11-Feb	1999	11-Apr	2261	11-Jun	816	11-Aug	627	12-Oct	1199	12-Dec	1870
12-Feb	1990	12-Apr	2294	12-Jun	804	12-Aug	630	13-Oct	1244	13-Dec	1800
13-Feb	1974	13-Apr	2376	13-Jun	800	13-Aug	635	14-Oct	1254	14-Dec	1796
14-Feb	1982	14-Apr	2389	14-Jun	806	14-Aug	644	15-Oct	1236	15-Dec	1885
15-Feb	2051	15-Apr	2368	15-Jun	774	15-Aug	629	16-Oct	1233	16-Dec	1945
16-Feb	2103	16-Apr	2315	16-Jun	752	16-Aug	648	17-Oct	1216	17-Dec	1926
17-Feb	2120	17-Apr	2263	17-Jun	751	17-Aug	653	18-Oct	1199	18-Dec	1927
18-Feb	2191	18-Apr	2226	18-Jun	730	18-Aug	669	19-Oct	1223	19-Dec	1913
19-Feb	2318	19-Apr	2190	19-Jun	690	19-Aug	682	20-Oct	1234	20-Dec	1945
20-Feb	2381	20-Apr	2136	20-Jun	663	20-Aug	682	21-Oct	1228	21-Dec	1947
21-Feb	2393	21-Apr	2009	21-Jun	633	21-Aug	686	22-Oct	1229	22-Dec	1943
22-Feb	2417	22-Apr	1986	22-Jun	618	22-Aug	692	23-Oct	1259	23-Dec	1979
23-Feb	2445	23-Apr	1984	23-Jun	611	23-Aug	699	24-Oct	1240	24-Dec	2004
24-Feb	2436	24-Apr	1926	24-Jun	607	24-Aug	699	25-Oct	1235	25-Dec	1997
25-Feb	2406	25-Apr	1885	25-Jun	613	25-Aug	698	26-Oct	1261	26-Dec	2018
26-Feb	2376	26-Apr	1870	26-Jun	609	26-Aug	711	27-Oct	1277	27-Dec	2024
27-Feb	2344	27-Apr	1831	27-Jun	611	27-Aug	719	28-Oct	1304	28-Dec	2029
28-Feb	2336	28-Apr	1810	28-Jun	621	28-Aug	699	29-Oct	1338	29-Dec	2019
29-Feb	2508	29-Apr	1814	29-Jun	604	29-Aug	695	30-Oct	1370	30-Dec	2025
		30-Apr	1808	30-Jun	601	30-Aug	693	31-Oct	1355	31-Dec	2097
						31-Aug	722				

Klamath River below J.C. Boyle near Keno, OR – Water Year 1961-2010 – Average Daily Discharge (ft^3/s)

Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge
1-Jan	2324	1-Mar	2577	1-May	2044	1-Jul	852	1-Sep	1046	1-Nov	1594
2-Jan	2373	2-Mar	2638	2-May	2026	2-Jul	871	2-Sep	1068	2-Nov	1645
3-Jan	2376	3-Mar	2746	3-May	2042	3-Jul	816	3-Sep	1072	3-Nov	1599
4-Jan	2374	4-Mar	2705	4-May	1983	4-Jul	785	4-Sep	1085	4-Nov	1618
5-Jan	2352	5-Mar	2735	5-May	1946	5-Jul	808	5-Sep	1081	5-Nov	1617
6-Jan	2332	6-Mar	2688	6-May	1920	6-Jul	800	6-Sep	1068	6-Nov	1672
7-Jan	2341	7-Mar	2781	7-May	1909	7-Jul	748	7-Sep	1081	7-Nov	1700
8-Jan	2347	8-Mar	2788	8-May	2004	8-Jul	739	8-Sep	1100	8-Nov	1638
9-Jan	2342	9-Mar	2827	9-May	2021	9-Jul	708	9-Sep	1085	9-Nov	1636
10-Jan	2288	10-Mar	2861	10-May	1992	10-Jul	674	10-Sep	1130	10-Nov	1664
11-Jan	2215	11-Mar	2957	11-May	1972	11-Jul	660	11-Sep	1140	11-Nov	1633
12-Jan	2197	12-Mar	2943	12-May	2019	12-Jul	650	12-Sep	1116	12-Nov	1686
13-Jan	2202	13-Mar	2965	13-May	2035	13-Jul	648	13-Sep	1082	13-Nov	1712
14-Jan	2249	14-Mar	3018	14-May	2074	14-Jul	667	14-Sep	1092	14-Nov	1755
15-Jan	2282	15-Mar	3006	15-May	2076	15-Jul	650	15-Sep	1094	15-Nov	1757
16-Jan	2273	16-Mar	3019	16-May	2011	16-Jul	674	16-Sep	1116	16-Nov	1777
17-Jan	2284	17-Mar	3033	17-May	1961	17-Jul	686	17-Sep	1192	17-Nov	1780
18-Jan	2297	18-Mar	3040	18-May	1962	18-Jul	687	18-Sep	1203	18-Nov	1801
19-Jan	2292	19-Mar	2984	19-May	1840	19-Jul	699	19-Sep	1204	19-Nov	1785
20-Jan	2335	20-Mar	2958	20-May	1714	20-Jul	691	20-Sep	1191	20-Nov	1812
21-Jan	2308	21-Mar	2918	21-May	1691	21-Jul	703	21-Sep	1188	21-Nov	1813
22-Jan	2385	22-Mar	2849	22-May	1666	22-Jul	700	22-Sep	1192	22-Nov	1815
23-Jan	2468	23-Mar	2806	23-May	1608	23-Jul	667	23-Sep	1183	23-Nov	1806
24-Jan	2498	24-Mar	2788	24-May	1606	24-Jul	691	24-Sep	1182	24-Nov	1822
25-Jan	2469	25-Mar	2841	25-May	1551	25-Jul	709	25-Sep	1218	25-Nov	1837
26-Jan	2464	26-Mar	2894	26-May	1564	26-Jul	716	26-Sep	1228	26-Nov	1832
27-Jan	2435	27-Mar	2875	27-May	1554	27-Jul	724	27-Sep	1161	27-Nov	1867
28-Jan	2497	28-Mar	2903	28-May	1547	28-Jul	736	28-Sep	1212	28-Nov	1923
29-Jan	2484	29-Mar	2828	29-May	1499	29-Jul	732	29-Sep	1185	29-Nov	1929
30-Jan	2481	30-Mar	2837	30-May	1467	30-Jul	762	30-Sep	1236	30-Nov	1957
31-Jan	2450	31-Mar	2845	31-May	1344	31-Jul	744	1-Oct	1233	1-Dec	1962
1-Feb	2414	1-Apr	2839	1-Jun	1380	1-Aug	804	2-Oct	1275	2-Dec	1924
2-Feb	2413	2-Apr	2836	2-Jun	1352	2-Aug	798	3-Oct	1279	3-Dec	1983
3-Feb	2414	3-Apr	2847	3-Jun	1393	3-Aug	817	4-Oct	1276	4-Dec	2012
4-Feb	2391	4-Apr	2751	4-Jun	1389	4-Aug	820	5-Oct	1347	5-Dec	2028
5-Feb	2397	5-Apr	2745	5-Jun	1376	5-Aug	827	6-Oct	1373	6-Dec	2014
6-Feb	2395	6-Apr	2717	6-Jun	1359	6-Aug	844	7-Oct	1391	7-Dec	2003
7-Feb	2384	7-Apr	2691	7-Jun	1285	7-Aug	825	8-Oct	1351	8-Dec	2066
8-Feb	2289	8-Apr	2594	8-Jun	1196	8-Aug	849	9-Oct	1446	9-Dec	2119
9-Feb	2284	9-Apr	2545	9-Jun	1184	9-Aug	836	10-Oct	1420	10-Dec	2080
10-Feb	2243	10-Apr	2505	10-Jun	1107	10-Aug	853	11-Oct	1443	11-Dec	2101
11-Feb	2191	11-Apr	2506	11-Jun	1094	11-Aug	879	12-Oct	1446	12-Dec	2059
12-Feb	2193	12-Apr	2553	12-Jun	1088	12-Aug	851	13-Oct	1468	13-Dec	2021
13-Feb	2185	13-Apr	2602	13-Jun	1064	13-Aug	887	14-Oct	1467	14-Dec	1987
14-Feb	2191	14-Apr	2611	14-Jun	1091	14-Aug	891	15-Oct	1491	15-Dec	2069
15-Feb	2265	15-Apr	2613	15-Jun	1028	15-Aug	875	16-Oct	1460	16-Dec	2175
16-Feb	2301	16-Apr	2530	16-Jun	1015	16-Aug	923	17-Oct	1456	17-Dec	2116
17-Feb	2333	17-Apr	2517	17-Jun	1008	17-Aug	891	18-Oct	1418	18-Dec	2137
18-Feb	2402	18-Apr	2489	18-Jun	1007	18-Aug	891	19-Oct	1450	19-Dec	2108
19-Feb	2555	19-Apr	2436	19-Jun	950	19-Aug	940	20-Oct	1504	20-Dec	2137
20-Feb	2578	20-Apr	2412	20-Jun	919	20-Aug	935	21-Oct	1459	21-Dec	2143
21-Feb	2629	21-Apr	2328	21-Jun	894	21-Aug	930	22-Oct	1466	22-Dec	2190
22-Feb	2662	22-Apr	2232	22-Jun	872	22-Aug	923	23-Oct	1522	23-Dec	2240
23-Feb	2655	23-Apr	2265	23-Jun	880	23-Aug	930	24-Oct	1499	24-Dec	2277
24-Feb	2668	24-Apr	2244	24-Jun	858	24-Aug	933	25-Oct	1458	25-Dec	2238
25-Feb	2642	25-Apr	2172	25-Jun	851	25-Aug	928	26-Oct	1497	26-Dec	2280
26-Feb	2580	26-Apr	2126	26-Jun	869	26-Aug	943	27-Oct	1506	27-Dec	2271
27-Feb	2573	27-Apr	2137	27-Jun	861	27-Aug	957	28-Oct	1535	28-Dec	2281
28-Feb	2584	28-Apr	2097	28-Jun	881	28-Aug	963	29-Oct	1551	29-Dec	2275
29-Feb	2717	29-Apr	2094	29-Jun	863	29-Aug	972	30-Oct	1609	30-Dec	2286
		30-Apr	2095	30-Jun	856	30-Aug	929	31-Oct	1582	31-Dec	2345
						31-Aug	980				

Klamath River blw Fall Creek near Copco, CA – Water Year 1961-2010 – Average Daily Discharge (ft^3/s)

Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge
1-Jan	2411	1-Mar	2721	1-May	2063	1-Jul	862	1-Sep	1078	1-Nov	1669
2-Jan	2437	2-Mar	2765	2-May	2041	2-Jul	846	2-Sep	1105	2-Nov	1730
3-Jan	2490	3-Mar	2834	3-May	2038	3-Jul	837	3-Sep	1111	3-Nov	1691
4-Jan	2456	4-Mar	2799	4-May	1986	4-Jul	809	4-Sep	1122	4-Nov	1704
5-Jan	2431	5-Mar	2813	5-May	1969	5-Jul	811	5-Sep	1119	5-Nov	1702
6-Jan	2421	6-Mar	2813	6-May	1950	6-Jul	778	6-Sep	1109	6-Nov	1732
7-Jan	2444	7-Mar	2853	7-May	1944	7-Jul	752	7-Sep	1130	7-Nov	1760
8-Jan	2432	8-Mar	2884	8-May	2037	8-Jul	748	8-Sep	1137	8-Nov	1734
9-Jan	2431	9-Mar	2919	9-May	2013	9-Jul	722	9-Sep	1145	9-Nov	1739
10-Jan	2367	10-Mar	2982	10-May	1992	10-Jul	704	10-Sep	1145	10-Nov	1743
11-Jan	2307	11-Mar	3034	11-May	2007	11-Jul	708	11-Sep	1179	11-Nov	1729
12-Jan	2263	12-Mar	3044	12-May	2038	12-Jul	696	12-Sep	1162	12-Nov	1743
13-Jan	2295	13-Mar	3055	13-May	2068	13-Jul	668	13-Sep	1124	13-Nov	1791
14-Jan	2316	14-Mar	3136	14-May	2118	14-Jul	675	14-Sep	1134	14-Nov	1842
15-Jan	2330	15-Mar	3141	15-May	2099	15-Jul	678	15-Sep	1159	15-Nov	1857
16-Jan	2349	16-Mar	3128	16-May	2022	16-Jul	681	16-Sep	1168	16-Nov	1864
17-Jan	2356	17-Mar	3168	17-May	2000	17-Jul	698	17-Sep	1208	17-Nov	1887
18-Jan	2404	18-Mar	3141	18-May	1973	18-Jul	706	18-Sep	1238	18-Nov	1894
19-Jan	2427	19-Mar	3096	19-May	1828	19-Jul	714	19-Sep	1222	19-Nov	1889
20-Jan	2424	20-Mar	3083	20-May	1740	20-Jul	711	20-Sep	1219	20-Nov	1901
21-Jan	2429	21-Mar	3025	21-May	1711	21-Jul	705	21-Sep	1233	21-Nov	1930
22-Jan	2506	22-Mar	2962	22-May	1685	22-Jul	704	22-Sep	1230	22-Nov	1931
23-Jan	2605	23-Mar	2890	23-May	1654	23-Jul	709	23-Sep	1209	23-Nov	1897
24-Jan	2642	24-Mar	2899	24-May	1610	24-Jul	720	24-Sep	1211	24-Nov	1889
25-Jan	2617	25-Mar	2971	25-May	1565	25-Jul	730	25-Sep	1259	25-Nov	1943
26-Jan	2593	26-Mar	2995	26-May	1567	26-Jul	739	26-Sep	1264	26-Nov	1940
27-Jan	2589	27-Mar	2997	27-May	1570	27-Jul	741	27-Sep	1251	27-Nov	1962
28-Jan	2610	28-Mar	3005	28-May	1546	28-Jul	740	28-Sep	1269	28-Nov	1999
29-Jan	2585	29-Mar	2953	29-May	1499	29-Jul	733	29-Sep	1265	29-Nov	2045
30-Jan	2584	30-Mar	2922	30-May	1453	30-Jul	760	30-Sep	1234	30-Nov	2044
31-Jan	2545	31-Mar	2986	31-May	1395	31-Jul	789	1-Oct	1273	1-Dec	2057
1-Feb	2525	1-Apr	2931	1-Jun	1378	1-Aug	820	2-Oct	1312	2-Dec	2067
2-Feb	2520	2-Apr	2957	2-Jun	1403	2-Aug	825	3-Oct	1318	3-Dec	2055
3-Feb	2468	3-Apr	2945	3-Jun	1420	3-Aug	838	4-Oct	1336	4-Dec	2105
4-Feb	2480	4-Apr	2861	4-Jun	1420	4-Aug	862	5-Oct	1398	5-Dec	2155
5-Feb	2480	5-Apr	2834	5-Jun	1399	5-Aug	851	6-Oct	1441	6-Dec	2121
6-Feb	2539	6-Apr	2827	6-Jun	1368	6-Aug	851	7-Oct	1437	7-Dec	2124
7-Feb	2496	7-Apr	2734	7-Jun	1291	7-Aug	852	8-Oct	1419	8-Dec	2203
8-Feb	2431	8-Apr	2677	8-Jun	1230	8-Aug	856	9-Oct	1471	9-Dec	2243
9-Feb	2378	9-Apr	2633	9-Jun	1182	9-Aug	875	10-Oct	1487	10-Dec	2219
10-Feb	2317	10-Apr	2604	10-Jun	1125	10-Aug	887	11-Oct	1490	11-Dec	2213
11-Feb	2312	11-Apr	2592	11-Jun	1085	11-Aug	901	12-Oct	1499	12-Dec	2186
12-Feb	2310	12-Apr	2626	12-Jun	1080	12-Aug	895	13-Oct	1541	13-Dec	2113
13-Feb	2300	13-Apr	2711	13-Jun	1081	13-Aug	899	14-Oct	1542	14-Dec	2110
14-Feb	2316	14-Apr	2725	14-Jun	1086	14-Aug	919	15-Oct	1509	15-Dec	2203
15-Feb	2392	15-Apr	2693	15-Jun	1053	15-Aug	903	16-Oct	1509	16-Dec	2266
16-Feb	2427	16-Apr	2627	16-Jun	1031	16-Aug	923	17-Oct	1506	17-Dec	2232
17-Feb	2448	17-Apr	2596	17-Jun	1019	17-Aug	928	18-Oct	1498	18-Dec	2232
18-Feb	2500	18-Apr	2562	18-Jun	993	18-Aug	944	19-Oct	1528	19-Dec	2234
19-Feb	2637	19-Apr	2519	19-Jun	964	19-Aug	948	20-Oct	1533	20-Dec	2273
20-Feb	2720	20-Apr	2467	20-Jun	935	20-Aug	948	21-Oct	1528	21-Dec	2270
21-Feb	2720	21-Apr	2332	21-Jun	904	21-Aug	962	22-Oct	1505	22-Dec	2260
22-Feb	2756	22-Apr	2301	22-Jun	887	22-Aug	968	23-Oct	1537	23-Dec	2295
23-Feb	2789	23-Apr	2286	23-Jun	882	23-Aug	975	24-Oct	1537	24-Dec	2311
24-Feb	2774	24-Apr	2239	24-Jun	879	24-Aug	976	25-Oct	1535	25-Dec	2313
25-Feb	2726	25-Apr	2209	25-Jun	873	25-Aug	975	26-Oct	1562	26-Dec	2320
26-Feb	2690	26-Apr	2192	26-Jun	884	26-Aug	976	27-Oct	1573	27-Dec	2353
27-Feb	2678	27-Apr	2155	27-Jun	886	27-Aug	984	28-Oct	1607	28-Dec	2357
28-Feb	2667	28-Apr	2126	28-Jun	897	28-Aug	979	29-Oct	1616	29-Dec	2349
29-Feb	2846	29-Apr	2115	29-Jun	880	29-Aug	973	30-Oct	1649	30-Dec	2350
		30-Apr	2106	30-Jun	875	30-Aug	971	31-Oct	1656	31-Dec	2422
						31-Aug	1003				

Klamath River below Iron Gate Dam, CA – Water Year 1961-2010 – Average Daily Discharge (ft^3/s)

Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge	Day	Discharge
1-Jan	2886	1-Mar	3142	1-May	2414	1-Jul	918	1-Sep	1189	1-Nov	1728
2-Jan	2830	2-Mar	3205	2-May	2389	2-Jul	890	2-Sep	1176	2-Nov	1740
3-Jan	2858	3-Mar	3299	3-May	2352	3-Jul	898	3-Sep	1172	3-Nov	1747
4-Jan	2793	4-Mar	3256	4-May	2327	4-Jul	894	4-Sep	1173	4-Nov	1726
5-Jan	2754	5-Mar	3255	5-May	2336	5-Jul	898	5-Sep	1187	5-Nov	1713
6-Jan	2680	6-Mar	3240	6-May	2308	6-Jul	889	6-Sep	1192	6-Nov	1737
7-Jan	2623	7-Mar	3249	7-May	2293	7-Jul	870	7-Sep	1205	7-Nov	1818
8-Jan	2624	8-Mar	3290	8-May	2329	8-Jul	853	8-Sep	1212	8-Nov	1845
9-Jan	2636	9-Mar	3361	9-May	2362	9-Jul	840	9-Sep	1207	9-Nov	1860
10-Jan	2567	10-Mar	3401	10-May	2340	10-Jul	835	10-Sep	1210	10-Nov	1871
11-Jan	2556	11-Mar	3455	11-May	2332	11-Jul	832	11-Sep	1221	11-Nov	1839
12-Jan	2547	12-Mar	3456	12-May	2337	12-Jul	827	12-Sep	1219	12-Nov	1852
13-Jan	2613	13-Mar	3483	13-May	2399	13-Jul	811	13-Sep	1219	13-Nov	1849
14-Jan	2692	14-Mar	3544	14-May	2386	14-Jul	795	14-Sep	1221	14-Nov	1896
15-Jan	2755	15-Mar	3588	15-May	2404	15-Jul	790	15-Sep	1225	15-Nov	1952
16-Jan	3028	16-Mar	3546	16-May	2343	16-Jul	784	16-Sep	1215	16-Nov	1969
17-Jan	2984	17-Mar	3550	17-May	2317	17-Jul	791	17-Sep	1234	17-Nov	1984
18-Jan	2885	18-Mar	3641	18-May	2271	18-Jul	799	18-Sep	1264	18-Nov	1997
19-Jan	2822	19-Mar	3531	19-May	2160	19-Jul	805	19-Sep	1274	19-Nov	1982
20-Jan	2839	20-Mar	3487	20-May	2076	20-Jul	798	20-Sep	1284	20-Nov	1982
21-Jan	2835	21-Mar	3391	21-May	2037	21-Jul	795	21-Sep	1289	21-Nov	2014
22-Jan	2963	22-Mar	3330	22-May	1980	22-Jul	781	22-Sep	1287	22-Nov	2042
23-Jan	2989	23-Mar	3323	23-May	1927	23-Jul	784	23-Sep	1276	23-Nov	2066
24-Jan	2957	24-Mar	3354	24-May	1858	24-Jul	794	24-Sep	1277	24-Nov	2086
25-Jan	2862	25-Mar	3377	25-May	1842	25-Jul	795	25-Sep	1311	25-Nov	2143
26-Jan	2848	26-Mar	3401	26-May	1813	26-Jul	799	26-Sep	1313	26-Nov	2130
27-Jan	2921	27-Mar	3294	27-May	1835	27-Jul	801	27-Sep	1314	27-Nov	2115
28-Jan	2889	28-Mar	3366	28-May	1779	28-Jul	803	28-Sep	1327	28-Nov	2111
29-Jan	2877	29-Mar	3378	29-May	1764	29-Jul	789	29-Sep	1338	29-Nov	2115
30-Jan	2871	30-Mar	3411	30-May	1714	30-Jul	789	30-Sep	1328	30-Nov	2130
31-Jan	2853	31-Mar	3409	31-May	1652	31-Jul	821	1-Oct	1368	1-Dec	2177
1-Feb	2860	1-Apr	3433	1-Jun	1552	1-Aug	959	2-Oct	1401	2-Dec	2232
2-Feb	2877	2-Apr	3377	2-Jun	1534	2-Aug	958	3-Oct	1411	3-Dec	2221
3-Feb	2835	3-Apr	3348	3-Jun	1521	3-Aug	956	4-Oct	1429	4-Dec	2276
4-Feb	2824	4-Apr	3267	4-Jun	1565	4-Aug	958	5-Oct	1448	5-Dec	2328
5-Feb	2780	5-Apr	3232	5-Jun	1578	5-Aug	947	6-Oct	1471	6-Dec	2324
6-Feb	2795	6-Apr	3199	6-Jun	1570	6-Aug	945	7-Oct	1468	7-Dec	2338
7-Feb	2807	7-Apr	3190	7-Jun	1513	7-Aug	956	8-Oct	1458	8-Dec	2335
8-Feb	2800	8-Apr	3102	8-Jun	1426	8-Aug	958	9-Oct	1510	9-Dec	2372
9-Feb	2732	9-Apr	3036	9-Jun	1359	9-Aug	957	10-Oct	1544	10-Dec	2353
10-Feb	2672	10-Apr	3002	10-Jun	1291	10-Aug	958	11-Oct	1548	11-Dec	2349
11-Feb	2672	11-Apr	2983	11-Jun	1250	11-Aug	963	12-Oct	1591	12-Dec	2377
12-Feb	2649	12-Apr	2993	12-Jun	1233	12-Aug	956	13-Oct	1600	13-Dec	2400
13-Feb	2617	13-Apr	3096	13-Jun	1218	13-Aug	954	14-Oct	1561	14-Dec	2467
14-Feb	2686	14-Apr	3155	14-Jun	1235	14-Aug	964	15-Oct	1543	15-Dec	2437
15-Feb	2740	15-Apr	3088	15-Jun	1230	15-Aug	967	16-Oct	1572	16-Dec	2471
16-Feb	2794	16-Apr	3018	16-Jun	1216	16-Aug	973	17-Oct	1576	17-Dec	2479
17-Feb	2875	17-Apr	2953	17-Jun	1173	17-Aug	972	18-Oct	1582	18-Dec	2360
18-Feb	2966	18-Apr	2918	18-Jun	1121	18-Aug	972	19-Oct	1599	19-Dec	2443
19-Feb	3062	19-Apr	2863	19-Jun	1097	19-Aug	963	20-Oct	1616	20-Dec	2499
20-Feb	3172	20-Apr	2786	20-Jun	1063	20-Aug	971	21-Oct	1613	21-Dec	2579
21-Feb	3262	21-Apr	2711	21-Jun	1039	21-Aug	989	22-Oct	1581	22-Dec	2839
22-Feb	3200	22-Apr	2624	22-Jun	1025	22-Aug	992	23-Oct	1605	23-Dec	2787
23-Feb	3206	23-Apr	2634	23-Jun	1026	23-Aug	997	24-Oct	1657	24-Dec	2677
24-Feb	3130	24-Apr	2626	24-Jun	1000	24-Aug	1000	25-Oct	1657	25-Dec	2589
25-Feb	3081	25-Apr	2619	25-Jun	970	25-Aug	1002	26-Oct	1669	26-Dec	2561
26-Feb	3054	26-Apr	2529	26-Jun	975	26-Aug	1004	27-Oct	1672	27-Dec	2609
27-Feb	3039	27-Apr	2468	27-Jun	966	27-Aug	1011	28-Oct	1653	28-Dec	2602
28-Feb	3092	28-Apr	2439	28-Jun	958	28-Aug	1028	29-Oct	1643	29-Dec	2590
29-Feb	3413	29-Apr	2455	29-Jun	975	29-Aug	1025	30-Oct	1700	30-Dec	2694
		30-Apr	2450	30-Jun	980	30-Aug	1018	31-Oct	1705	31-Dec	2825
						31-Aug	1034				

11 Appendix D – Hydrographs

KLAMATH RIVER AT KENO, OR

Annual	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
0	6016	7331	8247	8957
1	6027	7343	8257	8966
2	6039	7355	8268	8976
3	6050	7367	8278	8985
4	6062	7379	8288	8994
5	6073	7391	8299	9003
6	6085	7403	8309	9012
7	6096	7414	8320	9021
8	6108	7426	8330	9031
9	6120	7438	8340	9040
10	6131	7450	8351	9049
11	6143	7462	8361	9058
12	6154	7474	8372	9067
13	6166	7486	8382	9076
14	6177	7498	8392	9086
15	6189	7510	8403	9095
16	6200	7522	8413	9104
17	6212	7534	8424	9113
18	6223	7545	8434	9122
19	6235	7557	8444	9131
20	6246	7569	8455	9141
21	6258	7581	8465	9150
22	6270	7593	8476	9159
23	6281	7605	8486	9168
24	6293	7617	8496	9177
25	6304	7629	8507	9187
26	6316	7641	8517	9196
27	6327	7653	8528	9205
28	6339	7665	8538	9214
29	6350	7677	8548	9223
30	6362	7688	8559	9232
31	6373	7700	8569	9242
32	6385	7712	8580	9251
33	6396	7724	8590	9260
34	6408	7736	8600	9269
35	6420	7748	8611	9278
36	6431	7760	8621	9287
37	6443	7772	8632	9297
38	6454	7784	8642	9306
39	6466	7796	8652	9315
40	6477	7808	8663	9324
41	6489	7819	8673	9333
42	6500	7831	8684	9342

Annual	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
181	8343	9963	10697	11194
182	8185	9753	10435	10885
183	8168	9720	10412	10875
184	8151	9688	10390	10865
185	8134	9656	10367	10854
186	8118	9624	10345	10844
187	8101	9591	10323	10834
188	8084	9559	10300	10823
189	8067	9527	10278	10813
190	8050	9495	10255	10803
191	8033	9463	10233	10792
192	8017	9430	10210	10782
193	7997	9409	10188	10761
194	7978	9388	10165	10739
195	7959	9366	10143	10718
196	7940	9345	10120	10696
197	7920	9324	10098	10675
198	7901	9302	10075	10654
199	7882	9281	10053	10632
200	7863	9259	10030	10611
201	7843	9238	10008	10589
202	7824	9217	9985	10568
203	7805	9195	9963	10546
204	7786	9174	9940	10525
205	7766	9153	9917	10504
206	7747	9131	9895	10482
207	7728	9110	9872	10461
208	7708	9089	9850	10439
209	7689	9067	9827	10418
210	7670	9046	9805	10396
211	7651	9025	9782	10375
212	7631	9003	9760	10354
213	7612	8982	9737	10332
214	7593	8960	9715	10311
215	7574	8939	9692	10289
216	7554	8918	9670	10268
217	7545	8908	9658	10252
218	7537	8898	9646	10236
219	7528	8888	9634	10220
220	7519	8878	9622	10204
221	7510	8869	9610	10187
222	7501	8859	9599	10171
223	7492	8849	9587	10155

Annual	**Keno Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
43	6512	7843	8694	9352
44	6523	7855	8705	9361
45	6535	7867	8715	9370
46	6546	7879	8725	9379
47	6558	7891	8736	9388
48	6570	7903	8746	9398
49	6581	7915	8757	9407
50	6593	7927	8767	9416
51	6604	7939	8777	9425
52	6616	7951	8788	9434
53	6627	7962	8798	9443
54	6639	7974	8809	9453
55	6650	7986	8819	9462
56	6662	7998	8829	9471
57	6673	8010	8840	9480
58	6685	8022	8850	9489
59	6696	8034	8861	9498
60	6708	8046	8871	9508
61	6719	8058	8881	9517
62	6731	8070	8892	9526
63	6743	8082	8902	9535
64	6754	8093	8913	9544
65	6766	8105	8923	9553
66	6777	8117	8933	9563
67	6789	8129	8944	9572
68	6800	8141	8954	9581
69	6812	8153	8965	9590
70	6823	8165	8975	9599
71	6835	8177	8985	9608
72	6846	8189	8996	9618
73	6858	8201	9006	9627
74	6869	8213	9017	9636
75	6881	8225	9027	9645
76	6893	8236	9037	9654
77	6904	8248	9048	9664
78	6916	8260	9058	9673
79	6927	8272	9069	9682
80	6939	8284	9079	9691
81	6950	8296	9089	9700
82	6962	8308	9100	9709
83	6973	8320	9110	9719
84	6985	8332	9121	9728
85	6996	8344	9131	9737
86	7008	8356	9141	9746
87	7019	8367	9152	9755
88	7031	8379	9162	9764
89	7043	8391	9173	9774
90	7054	8403	9183	9783
91	7066	8415	9194	9792

Annual	**Keno Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
224	7483	8839	9575	10139
225	7474	8829	9563	10123
226	7465	8820	9551	10107
227	7456	8810	9539	10091
228	7448	8800	9528	10075
229	7439	8790	9516	10059
230	7430	8780	9504	10043
231	7421	8771	9492	10027
232	7412	8761	9480	10011
233	7403	8751	9468	9995
234	7394	8741	9456	9979
235	7385	8731	9445	9963
236	7376	8722	9433	9946
237	7367	8712	9421	9930
238	7358	8702	9409	9914
239	7350	8692	9397	9898
240	7341	8682	9385	9882
241	7332	8674	9380	9880
242	7323	8665	9374	9878
243	7314	8656	9368	9877
244	7304	8648	9362	9875
245	7295	8639	9356	9873
246	7286	8630	9350	9871
247	7277	8622	9345	9869
248	7268	8613	9339	9867
249	7259	8604	9333	9866
250	7250	8596	9327	9864
251	7241	8587	9321	9862
252	7232	8579	9316	9860
253	7223	8570	9310	9858
254	7214	8561	9304	9856
255	7205	8553	9298	9854
256	7196	8544	9292	9853
257	7187	8535	9286	9851
258	7178	8527	9281	9849
259	7169	8518	9275	9847
260	7160	8509	9269	9845
261	7150	8501	9263	9843
262	7141	8492	9257	9842
263	7132	8483	9251	9840
264	7123	8475	9246	9838
265	7112	8463	9235	9829
266	7100	8451	9225	9819
267	7089	8439	9214	9810
268	7077	8427	9204	9801
269	7066	8415	9194	9792
270	7054	8403	9183	9783
271	7043	8391	9173	9774
272	7031	8379	9162	9764

Annual	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
92	7077	8427	9204	9801
93	7089	8439	9214	9810
94	7100	8451	9225	9819
95	7112	8463	9235	9829
96	7123	8475	9246	9838
97	7132	8483	9251	9840
98	7141	8492	9257	9842
99	7150	8501	9263	9843
100	7160	8509	9269	9845
101	7169	8518	9275	9847
102	7178	8527	9281	9849
103	7187	8535	9286	9851
104	7196	8544	9292	9853
105	7205	8553	9298	9854
106	7214	8561	9304	9856
107	7223	8570	9310	9858
108	7232	8579	9316	9860
109	7241	8587	9321	9862
110	7250	8596	9327	9864
111	7259	8604	9333	9866
112	7268	8613	9339	9867
113	7277	8622	9345	9869
114	7286	8630	9350	9871
115	7295	8639	9356	9873
116	7304	8648	9362	9875
117	7314	8656	9368	9877
118	7323	8665	9374	9878
119	7332	8674	9380	9880
120	7341	8682	9385	9882
121	7350	8692	9397	9898
122	7358	8702	9409	9914
123	7367	8712	9421	9930
124	7376	8722	9433	9946
125	7385	8731	9445	9963
126	7394	8741	9456	9979
127	7403	8751	9468	9995
128	7412	8761	9480	10011
129	7421	8771	9492	10027
130	7430	8780	9504	10043
131	7439	8790	9516	10059
132	7448	8800	9528	10075
133	7456	8810	9539	10091
134	7465	8820	9551	10107
135	7474	8829	9563	10123
136	7483	8839	9575	10139
137	7492	8849	9587	10155
138	7501	8859	9599	10171
139	7510	8869	9610	10187
140	7519	8878	9622	10204

Annual	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
273	7019	8367	9152	9755
274	7008	8356	9141	9746
275	6996	8344	9131	9737
276	6985	8332	9121	9728
277	6973	8320	9110	9719
278	6962	8308	9100	9709
279	6950	8296	9089	9700
280	6939	8284	9079	9691
281	6927	8272	9069	9682
282	6916	8260	9058	9673
283	6904	8248	9048	9664
284	6893	8236	9037	9654
285	6881	8225	9027	9645
286	6869	8213	9017	9636
287	6858	8201	9006	9627
288	6846	8189	8996	9618
289	6835	8177	8985	9608
290	6823	8165	8975	9599
291	6812	8153	8965	9590
292	6800	8141	8954	9581
293	6789	8129	8944	9572
294	6777	8117	8933	9563
295	6766	8105	8923	9553
296	6754	8093	8913	9544
298	6743	8082	8902	9535
297	6731	8070	8892	9526
298	6719	8058	8881	9517
299	6708	8046	8871	9508
300	6696	8034	8861	9498
301	6685	8022	8850	9489
302	6673	8010	8840	9480
303	6662	7998	8829	9471
304	6650	7986	8819	9462
305	6639	7974	8809	9453
306	6627	7962	8798	9443
307	6616	7951	8788	9434
308	6604	7939	8777	9425
309	6593	7927	8767	9416
310	6581	7915	8757	9407
311	6570	7903	8746	9398
312	6558	7891	8736	9388
313	6546	7879	8725	9379
314	6535	7867	8715	9370
315	6523	7855	8705	9361
316	6512	7843	8694	9352
317	6500	7831	8684	9342
318	6489	7819	8673	9333
319	6477	7808	8663	9324
320	6466	7796	8652	9315

Annual	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
141	7528	8888	9634	10220
142	7537	8898	9646	10236
143	7545	8908	9658	10252
144	7554	8918	9670	10268
145	7574	8939	9692	10289
146	7593	8960	9715	10311
147	7612	8982	9737	10332
148	7631	9003	9760	10354
149	7651	9025	9782	10375
150	7670	9046	9805	10396
151	7689	9067	9827	10418
152	7708	9089	9850	10439
153	7728	9110	9872	10461
154	7747	9131	9895	10482
155	7766	9153	9917	10504
156	7786	9174	9940	10525
157	7805	9195	9963	10546
158	7824	9217	9985	10568
159	7843	9238	10008	10589
160	7863	9259	10030	10611
161	7882	9281	10053	10632
162	7901	9302	10075	10654
163	7920	9324	10098	10675
164	7940	9345	10120	10696
165	7959	9366	10143	10718
166	7978	9388	10165	10739
167	7997	9409	10188	10761
168	8017	9430	10210	10782
169	8033	9463	10233	10792
170	8050	9495	10255	10803
171	8067	9527	10278	10813
172	8084	9559	10300	10823
173	8101	9591	10323	10834
174	8118	9624	10345	10844
175	8134	9656	10367	10854
176	8151	9688	10390	10865
177	8168	9720	10412	10875
178	8185	9753	10435	10885
179	8343	9963	10697	11194
180	8642	10350	11200	11800

Annual	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
321	6454	7784	8642	9306
322	6443	7772	8632	9297
323	6431	7760	8621	9287
324	6420	7748	8611	9278
325	6408	7736	8600	9269
326	6396	7724	8590	9260
327	6385	7712	8580	9251
328	6373	7700	8569	9242
329	6362	7688	8559	9232
330	6350	7677	8548	9223
331	6339	7665	8538	9214
332	6327	7653	8528	9205
333	6316	7641	8517	9196
334	6304	7629	8507	9187
335	6293	7617	8496	9177
336	6281	7605	8486	9168
337	6270	7593	8476	9159
338	6258	7581	8465	9150
339	6246	7569	8455	9141
340	6235	7557	8444	9131
341	6223	7545	8434	9122
342	6212	7534	8424	9113
343	6200	7522	8413	9104
344	6189	7510	8403	9095
345	6177	7498	8392	9086
346	6166	7486	8382	9076
347	6154	7474	8372	9067
348	6143	7462	8361	9058
349	6131	7450	8351	9049
350	6120	7438	8340	9040
351	6108	7426	8330	9031
352	6096	7414	8320	9021
353	6085	7403	8309	9012
354	6073	7391	8299	9003
355	6062	7379	8288	8994
356	6050	7367	8278	8985
357	6039	7355	8268	8976
358	6027	7343	8257	8966
359	6016	7331	8247	8957
360	6016	7331	8247	8957

7/01-11/30	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
0	2738	3415	4026	4652
1	2741	3419	4029	4653
2	2744	3423	4032	4654
3	2747	3428	4035	4655
4	2750	3432	4038	4656
5	2754	3436	4041	4657
6	2757	3440	4044	4658
7	2760	3444	4047	4660
8	2763	3449	4050	4661
9	2766	3453	4052	4662
10	2769	3457	4055	4663
11	2772	3461	4058	4664
12	2775	3465	4061	4665
13	2778	3469	4064	4666
14	2781	3474	4067	4667
15	2785	3478	4070	4668
16	2788	3482	4073	4669
17	2791	3486	4076	4670
18	2794	3490	4078	4671
19	2797	3494	4081	4672
20	2800	3499	4084	4673
21	2803	3503	4087	4674
22	2806	3507	4090	4675
23	2809	3511	4093	4676
24	2812	3515	4096	4677
25	2816	3519	4099	4678
26	2819	3524	4102	4679
27	2822	3528	4104	4680
28	2825	3532	4107	4682
29	2828	3536	4110	4683
30	2831	3540	4113	4684
31	2834	3544	4116	4685
32	2837	3549	4119	4686
33	2840	3553	4122	4687
34	2843	3557	4125	4688
35	2847	3561	4127	4689
36	2850	3565	4130	4690
37	2853	3569	4133	4691
38	2856	3574	4136	4692
39	2859	3578	4139	4693
40	2862	3582	4142	4694
41	2865	3586	4145	4695
42	2868	3590	4148	4696
43	2871	3594	4151	4697
44	2874	3599	4153	4698
45	2878	3603	4156	4699
46	2881	3607	4159	4700
47	2884	3611	4162	4701

6/01-10/31	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
0	2403	3271	4045	4912
1	2410	3278	4051	4919
2	2418	3285	4058	4925
3	2425	3293	4065	4932
4	2432	3300	4072	4939
5	2440	3307	4079	4945
6	2447	3315	4086	4952
7	2454	3322	4093	4959
8	2462	3329	4100	4965
9	2469	3337	4107	4972
10	2476	3344	4114	4978
11	2484	3351	4121	4985
12	2491	3359	4128	4992
13	2498	3366	4135	4998
14	2506	3374	4141	5005
15	2513	3381	4148	5012
16	2520	3388	4155	5018
17	2528	3396	4162	5025
18	2535	3403	4169	5031
19	2542	3410	4176	5038
20	2550	3418	4183	5045
21	2557	3425	4190	5051
22	2564	3432	4197	5058
23	2572	3440	4204	5065
24	2579	3447	4211	5071
25	2587	3454	4218	5078
26	2594	3462	4225	5084
27	2601	3469	4231	5091
28	2609	3477	4238	5098
29	2616	3484	4245	5104
30	2623	3491	4252	5111
31	2631	3499	4259	5118
32	2638	3506	4266	5124
33	2645	3513	4273	5131
34	2653	3521	4280	5137
35	2660	3528	4287	5144
36	2667	3535	4294	5151
37	2675	3543	4301	5157
38	2682	3550	4308	5164
39	2689	3558	4315	5171
40	2697	3565	4321	5177
41	2704	3572	4328	5184
42	2711	3580	4335	5190
43	2719	3587	4342	5197
44	2726	3594	4349	5204
45	2733	3602	4356	5210
46	2741	3609	4363	5217
47	2748	3616	4370	5224

7/01-11/30	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
48	2887	3615	4165	4703
49	2890	3619	4168	4704
50	2893	3624	4171	4705
51	2896	3628	4174	4706
52	2899	3632	4177	4707
53	2902	3636	4179	4708
54	2905	3640	4182	4709
55	2909	3644	4185	4710
56	2912	3649	4188	4711
57	2915	3653	4191	4712
58	2918	3657	4194	4713
59	2921	3661	4197	4714
60	2924	3665	4200	4715
61	2927	3669	4203	4716
62	2930	3674	4205	4717
63	2933	3678	4208	4718
64	2936	3682	4211	4719
65	2940	3686	4214	4720
66	2943	3690	4217	4721
67	2946	3694	4220	4722
68	2949	3699	4223	4723
69	2952	3703	4226	4725
70	2955	3707	4228	4726
71	2958	3711	4231	4727
72	2961	3715	4234	4728
73	2964	3719	4237	4729
74	2967	3724	4240	4730
75	2971	3728	4243	4731
76	2974	3732	4246	4732
77	2977	3736	4249	4733
78	2980	3740	4252	4734
79	2983	3744	4254	4735
80	2986	3749	4257	4736
81	2989	3753	4260	4737
82	2992	3757	4263	4738
83	2995	3761	4266	4739
84	2998	3765	4269	4740
85	3002	3769	4272	4741
86	3005	3774	4275	4742
87	3008	3778	4278	4743
88	3011	3782	4280	4744
89	3014	3786	4283	4745
90	3017	3790	4286	4747
91	3020	3794	4289	4748
92	3023	3799	4292	4749
93	3026	3803	4295	4750
94	3029	3807	4298	4751
95	3033	3811	4301	4752
96	3036	3815	4304	4753

6/01-10/31	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
48	2756	3624	4377	5230
49	2763	3631	4384	5237
50	2770	3638	4391	5244
51	2778	3646	4398	5250
52	2785	3653	4405	5257
53	2792	3661	4411	5263
54	2800	3668	4418	5270
55	2807	3675	4425	5277
56	2814	3683	4432	5283
57	2822	3690	4439	5290
58	2829	3697	4446	5297
59	2836	3705	4453	5303
60	2844	3712	4460	5310
61	2851	3719	4467	5316
62	2858	3727	4474	5323
63	2866	3734	4481	5330
64	2873	3741	4488	5336
65	2880	3749	4495	5343
66	2888	3756	4501	5350
67	2895	3764	4508	5356
68	2902	3771	4515	5363
69	2910	3778	4522	5369
70	2917	3786	4529	5376
71	2924	3793	4536	5383
72	2932	3800	4543	5389
73	2939	3808	4550	5396
74	2947	3815	4557	5403
75	2954	3822	4564	5409
76	2961	3830	4571	5416
77	2969	3837	4578	5422
78	2976	3845	4585	5429
79	2983	3852	4591	5436
80	2991	3859	4598	5442
81	2998	3867	4605	5449
82	3005	3874	4612	5456
83	3013	3881	4619	5462
84	3020	3889	4626	5469
85	3027	3896	4633	5475
86	3035	3903	4640	5482
87	3042	3911	4647	5489
88	3049	3918	4654	5495
89	3057	3925	4661	5502
90	3064	3933	4668	5509
91	3071	3940	4675	5515
92	3079	3948	4681	5522
93	3086	3955	4688	5529
94	3093	3962	4695	5535
95	3101	3970	4702	5542
96	3108	3977	4709	5548

7/01-11/30	**Keno Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
97	3036	3816	4308	4765
98	3037	3817	4313	4777
99	3038	3818	4318	4790
100	3039	3818	4322	4802
101	3040	3819	4327	4814
102	3040	3820	4332	4826
103	3041	3820	4336	4839
104	3042	3821	4341	4851
105	3043	3822	4346	4863
106	3043	3823	4351	4875
107	3044	3823	4355	4888
108	3045	3824	4360	4900
109	3046	3825	4365	4912
110	3047	3825	4369	4925
111	3047	3826	4374	4937
112	3048	3827	4379	4949
113	3049	3828	4384	4961
114	3050	3828	4388	4974
115	3050	3829	4393	4986
116	3051	3830	4398	4998
117	3052	3830	4402	5010
118	3053	3831	4407	5023
119	3054	3832	4412	5035
120	3054	3833	4416	5047
121	3058	3835	4419	5047
122	3062	3837	4421	5047
123	3066	3840	4424	5047
124	3071	3842	4426	5047
125	3075	3844	4429	5047
126	3079	3847	4431	5047
127	3083	3849	4433	5047
128	3087	3852	4436	5047
129	3091	3854	4438	5047
130	3095	3856	4441	5047
131	3099	3859	4443	5047
132	3103	3861	4446	5047
133	3107	3863	4448	5046
134	3111	3866	4450	5046
135	3115	3868	4453	5046
136	3119	3870	4455	5046
137	3123	3873	4458	5046
138	3127	3875	4460	5046
139	3131	3878	4462	5046
140	3135	3880	4465	5046
141	3140	3882	4467	5046
142	3144	3885	4470	5046
143	3148	3887	4472	5046
144	3152	3889	4475	5046
145	3156	3892	4475	5047

6/01-10/31	**Keno Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
97	3116	3996	4733	5570
98	3124	4015	4757	5592
99	3132	4035	4781	5614
100	3141	4054	4805	5636
101	3149	4073	4829	5658
102	3157	4092	4853	5680
103	3165	4111	4877	5702
104	3173	4131	4901	5724
105	3181	4150	4925	5746
106	3189	4169	4949	5768
107	3197	4188	4973	5790
108	3206	4208	4998	5812
109	3214	4227	5022	5833
110	3222	4246	5046	5855
111	3230	4265	5070	5877
112	3238	4284	5094	5899
113	3246	4304	5118	5921
114	3254	4323	5142	5943
115	3262	4342	5166	5965
116	3270	4361	5190	5987
117	3279	4380	5214	6009
118	3287	4400	5238	6031
119	3295	4419	5262	6053
120	3303	4438	5286	6075
121	3316	4456	5312	6117
122	3328	4474	5339	6160
123	3341	4492	5365	6202
124	3354	4510	5391	6244
125	3367	4528	5418	6287
126	3379	4546	5444	6329
127	3392	4564	5470	6372
128	3405	4582	5497	6414
129	3418	4600	5523	6457
130	3430	4618	5549	6499
131	3443	4636	5576	6542
132	3456	4654	5602	6584
133	3469	4672	5628	6626
134	3482	4690	5655	6669
135	3494	4708	5681	6711
136	3507	4726	5707	6754
137	3520	4744	5734	6796
138	3533	4762	5760	6839
139	3545	4780	5786	6881
140	3558	4798	5813	6924
141	3571	4816	5839	6966
142	3584	4834	5865	7008
143	3596	4852	5892	7051
144	3609	4870	5918	7093
145	3613	4874	5923	7097

7/01-11/30	**Keno Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
146	3159	3895	4476	5048
147	3163	3898	4477	5049
148	3167	3901	4478	5050
149	3171	3904	4479	5052
150	3175	3907	4480	5053
151	3179	3910	4480	5054
152	3183	3913	4481	5055
153	3187	3916	4482	5056
154	3191	3919	4483	5057
155	3195	3922	4484	5058
156	3199	3925	4485	5060
157	3202	3927	4485	5061
158	3206	3930	4486	5062
159	3210	3933	4487	5063
160	3214	3936	4488	5064
161	3218	3939	4489	5065
162	3222	3942	4489	5066
163	3226	3945	4490	5067
164	3230	3948	4491	5069
165	3234	3951	4492	5070
166	3238	3954	4493	5071
167	3241	3957	4494	5072
168	3245	3960	4494	5073
169	3246	3960	4501	5082
170	3246	3961	4507	5091
171	3247	3962	4513	5100
172	3247	3963	4520	5109
173	3248	3963	4526	5118
174	3248	3964	4532	5127
175	3249	3965	4538	5136
176	3249	3965	4545	5145
177	3250	3966	4551	5154
178	3250	3967	4557	5163
179	3457	4181	4766	5365
180	3871	4609	5176	5760
181	3457	4181	4766	5365
182	3250	3967	4557	5163
183	3250	3966	4551	5154
184	3249	3965	4545	5145
185	3249	3965	4538	5136
186	3248	3964	4532	5127
187	3248	3963	4526	5118
188	3247	3963	4520	5109
189	3247	3962	4513	5100
190	3246	3961	4507	5091
191	3246	3960	4501	5082
192	3245	3960	4494	5073
193	3241	3957	4494	5072
194	3238	3954	4493	5071

6/01-10/31	**Keno Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
146	3617	4878	5927	7100
147	3620	4882	5932	7103
148	3624	4886	5936	7106
149	3628	4890	5941	7109
150	3632	4893	5946	7112
151	3635	4897	5950	7116
152	3639	4901	5955	7119
153	3643	4905	5959	7122
154	3647	4909	5964	7125
155	3650	4913	5968	7128
156	3654	4917	5973	7132
157	3658	4921	5978	7135
158	3661	4925	5982	7138
159	3665	4929	5987	7141
160	3669	4933	5991	7144
161	3673	4937	5996	7147
162	3676	4941	6000	7151
163	3680	4944	6005	7154
164	3684	4948	6010	7157
165	3688	4952	6014	7160
166	3691	4956	6019	7163
167	3695	4960	6023	7166
168	3699	4964	6028	7170
169	3701	4968	6031	7175
170	3703	4972	6035	7181
171	3705	4976	6039	7187
172	3707	4980	6042	7192
173	3709	4984	6046	7198
174	3711	4988	6049	7204
175	3713	4992	6053	7209
176	3715	4996	6056	7215
177	3717	5000	6060	7221
178	3719	5004	6064	7226
179	3928	5221	6284	7447
180	4344	5649	6722	7882
181	3928	5221	6284	7447
182	3719	5004	6064	7226
183	3717	5000	6060	7221
184	3715	4996	6056	7215
185	3713	4992	6053	7209
186	3711	4988	6049	7204
187	3709	4984	6046	7198
188	3707	4980	6042	7192
189	3705	4976	6039	7187
190	3703	4972	6035	7181
191	3701	4968	6031	7175
192	3699	4964	6028	7170
193	3695	4960	6023	7166
194	3691	4956	6019	7163

7/01-11/30	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
195	3234	3951	4492	5070
196	3230	3948	4491	5069
197	3226	3945	4490	5067
198	3222	3942	4489	5066
199	3218	3939	4489	5065
200	3214	3936	4488	5064
201	3210	3933	4487	5063
202	3206	3930	4486	5062
203	3202	3927	4485	5061
204	3199	3925	4485	5060
205	3195	3922	4484	5058
206	3191	3919	4483	5057
207	3187	3916	4482	5056
208	3183	3913	4481	5055
209	3179	3910	4480	5054
210	3175	3907	4480	5053
211	3171	3904	4479	5052
212	3167	3901	4478	5050
213	3163	3898	4477	5049
214	3159	3895	4476	5048
215	3156	3892	4475	5047
216	3152	3889	4475	5046
217	3148	3887	4472	5046
218	3144	3885	4470	5046
219	3140	3882	4467	5046
220	3135	3880	4465	5046
221	3131	3878	4462	5046
222	3127	3875	4460	5046
223	3123	3873	4458	5046
224	3119	3870	4455	5046
225	3115	3868	4453	5046
226	3111	3866	4450	5046
227	3107	3863	4448	5046
228	3103	3861	4446	5047
229	3099	3859	4443	5047
230	3095	3856	4441	5047
231	3091	3854	4438	5047
232	3087	3852	4436	5047
233	3083	3849	4433	5047
234	3079	3847	4431	5047
235	3075	3844	4429	5047
236	3071	3842	4426	5047
237	3066	3840	4424	5047
238	3062	3837	4421	5047
239	3058	3835	4419	5047
240	3054	3833	4416	5047
241	3054	3832	4412	5035
242	3053	3831	4407	5023
243	3052	3830	4402	5010

6/01-10/31	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
195	3688	4952	6014	7160
196	3684	4948	6010	7157
197	3680	4944	6005	7154
198	3676	4941	6000	7151
199	3673	4937	5996	7147
200	3669	4933	5991	7144
201	3665	4929	5987	7141
202	3661	4925	5982	7138
203	3658	4921	5978	7135
204	3654	4917	5973	7132
205	3650	4913	5968	7128
206	3647	4909	5964	7125
207	3643	4905	5959	7122
208	3639	4901	5955	7119
209	3635	4897	5950	7116
210	3632	4893	5946	7112
211	3628	4890	5941	7109
212	3624	4886	5936	7106
213	3620	4882	5932	7103
214	3617	4878	5927	7100
215	3613	4874	5923	7097
216	3609	4870	5918	7093
217	3596	4852	5892	7051
218	3584	4834	5865	7008
219	3571	4816	5839	6966
220	3558	4798	5813	6924
221	3545	4780	5786	6881
222	3533	4762	5760	6839
223	3520	4744	5734	6796
224	3507	4726	5707	6754
225	3494	4708	5681	6711
226	3482	4690	5655	6669
227	3469	4672	5628	6626
228	3456	4654	5602	6584
229	3443	4636	5576	6542
230	3430	4618	5549	6499
231	3418	4600	5523	6457
232	3405	4582	5497	6414
233	3392	4564	5470	6372
234	3379	4546	5444	6329
235	3367	4528	5418	6287
236	3354	4510	5391	6244
237	3341	4492	5365	6202
238	3328	4474	5339	6160
239	3316	4456	5312	6117
240	3303	4438	5286	6075
241	3295	4419	5262	6053
242	3287	4400	5238	6031
243	3279	4380	5214	6009

7/01-11/30	**Keno Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
244	3051	3830	4398	4998
245	3050	3829	4393	4986
246	3050	3828	4388	4974
247	3049	3828	4384	4961
248	3048	3827	4379	4949
249	3047	3826	4374	4937
250	3047	3825	4369	4925
251	3046	3825	4365	4912
252	3045	3824	4360	4900
253	3044	3823	4355	4888
254	3043	3823	4351	4875
255	3043	3822	4346	4863
256	3042	3821	4341	4851
257	3041	3820	4336	4839
258	3040	3820	4332	4826
259	3040	3819	4327	4814
260	3039	3818	4322	4802
261	3038	3818	4318	4790
262	3037	3817	4313	4777
263	3036	3816	4308	4765
264	3036	3815	4304	4753
265	3033	3811	4301	4752
266	3029	3807	4298	4751
267	3026	3803	4295	4750
268	3023	3799	4292	4749
269	3020	3794	4289	4748
270	3017	3790	4286	4747
271	3014	3786	4283	4745
272	3011	3782	4280	4744
273	3008	3778	4278	4743
274	3005	3774	4275	4742
275	3002	3769	4272	4741
276	2998	3765	4269	4740
277	2995	3761	4266	4739
278	2992	3757	4263	4738
279	2989	3753	4260	4737
280	2986	3749	4257	4736
281	2983	3744	4254	4735
282	2980	3740	4252	4734
283	2977	3736	4249	4733
284	2974	3732	4246	4732
285	2971	3728	4243	4731
286	2967	3724	4240	4730
287	2964	3719	4237	4729
288	2961	3715	4234	4728
289	2958	3711	4231	4727
290	2955	3707	4228	4726
291	2952	3703	4226	4725
292	2949	3699	4223	4723

6/01-10/31	**Keno Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
244	3270	4361	5190	5987
245	3262	4342	5166	5965
246	3254	4323	5142	5943
247	3246	4304	5118	5921
248	3238	4284	5094	5899
249	3230	4265	5070	5877
250	3222	4246	5046	5855
251	3214	4227	5022	5833
252	3206	4208	4998	5812
253	3197	4188	4973	5790
254	3189	4169	4949	5768
255	3181	4150	4925	5746
256	3173	4131	4901	5724
257	3165	4111	4877	5702
258	3157	4092	4853	5680
259	3149	4073	4829	5658
260	3141	4054	4805	5636
261	3132	4035	4781	5614
262	3124	4015	4757	5592
263	3116	3996	4733	5570
264	3108	3977	4709	5548
265	3101	3970	4702	5542
266	3093	3962	4695	5535
267	3086	3955	4688	5529
268	3079	3948	4681	5522
269	3071	3940	4675	5515
270	3064	3933	4668	5509
271	3057	3925	4661	5502
272	3049	3918	4654	5495
273	3042	3911	4647	5489
274	3035	3903	4640	5482
275	3027	3896	4633	5475
276	3020	3889	4626	5469
277	3013	3881	4619	5462
278	3005	3874	4612	5456
279	2998	3867	4605	5449
280	2991	3859	4598	5442
281	2983	3852	4591	5436
282	2976	3845	4585	5429
283	2969	3837	4578	5422
284	2961	3830	4571	5416
285	2954	3822	4564	5409
286	2947	3815	4557	5403
287	2939	3808	4550	5396
288	2932	3800	4543	5389
289	2924	3793	4536	5383
290	2917	3786	4529	5376
291	2910	3778	4522	5369
292	2902	3771	4515	5363

7/01-11/30	**Keno Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
293	2946	3694	4220	4722
294	2943	3690	4217	4721
295	2940	3686	4214	4720
296	2936	3682	4211	4719
298	2933	3678	4208	4718
297	2930	3674	4205	4717
298	2927	3669	4203	4716
299	2924	3665	4200	4715
300	2921	3661	4197	4714
301	2918	3657	4194	4713
302	2915	3653	4191	4712
303	2912	3649	4188	4711
304	2909	3644	4185	4710
305	2905	3640	4182	4709
306	2902	3636	4179	4708
307	2899	3632	4177	4707
308	2896	3628	4174	4706
309	2893	3624	4171	4705
310	2890	3619	4168	4704
311	2887	3615	4165	4703
312	2884	3611	4162	4701
313	2881	3607	4159	4700
314	2878	3603	4156	4699
315	2874	3599	4153	4698
316	2871	3594	4151	4697
317	2868	3590	4148	4696
318	2865	3586	4145	4695
319	2862	3582	4142	4694
320	2859	3578	4139	4693
321	2856	3574	4136	4692
322	2853	3569	4133	4691
323	2850	3565	4130	4690
324	2847	3561	4127	4689
325	2843	3557	4125	4688
326	2840	3553	4122	4687
327	2837	3549	4119	4686
328	2834	3544	4116	4685
329	2831	3540	4113	4684
330	2828	3536	4110	4683
331	2825	3532	4107	4682
332	2822	3528	4104	4680
333	2819	3524	4102	4679
334	2816	3519	4099	4678
335	2812	3515	4096	4677
336	2809	3511	4093	4676
337	2806	3507	4090	4675
338	2803	3503	4087	4674
339	2800	3499	4084	4673
340	2797	3494	4081	4672

6/01-10/31	**Keno Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
293	2895	3764	4508	5356
294	2888	3756	4501	5350
295	2880	3749	4495	5343
296	2873	3741	4488	5336
298	2866	3734	4481	5330
297	2858	3727	4474	5323
298	2851	3719	4467	5316
299	2844	3712	4460	5310
300	2836	3705	4453	5303
301	2829	3697	4446	5297
302	2822	3690	4439	5290
303	2814	3683	4432	5283
304	2807	3675	4425	5277
305	2800	3668	4418	5270
306	2792	3661	4411	5263
307	2785	3653	4405	5257
308	2778	3646	4398	5250
309	2770	3638	4391	5244
310	2763	3631	4384	5237
311	2756	3624	4377	5230
312	2748	3616	4370	5224
313	2741	3609	4363	5217
314	2733	3602	4356	5210
315	2726	3594	4349	5204
316	2719	3587	4342	5197
317	2711	3580	4335	5190
318	2704	3572	4328	5184
319	2697	3565	4321	5177
320	2689	3558	4315	5171
321	2682	3550	4308	5164
322	2675	3543	4301	5157
323	2667	3535	4294	5151
324	2660	3528	4287	5144
325	2653	3521	4280	5137
326	2645	3513	4273	5131
327	2638	3506	4266	5124
328	2631	3499	4259	5118
329	2623	3491	4252	5111
330	2616	3484	4245	5104
331	2609	3477	4238	5098
332	2601	3469	4231	5091
333	2594	3462	4225	5084
334	2587	3454	4218	5078
335	2579	3447	4211	5071
336	2572	3440	4204	5065
337	2564	3432	4197	5058
338	2557	3425	4190	5051
339	2550	3418	4183	5045
340	2542	3410	4176	5038

7/01-11/30	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
341	2794	3490	4078	4671
342	2791	3486	4076	4670
343	2788	3482	4073	4669
344	2785	3478	4070	4668
345	2781	3474	4067	4667
346	2778	3469	4064	4666
347	2775	3465	4061	4665
348	2772	3461	4058	4664
349	2769	3457	4055	4663
350	2766	3453	4052	4662
351	2763	3449	4050	4661
352	2760	3444	4047	4660
353	2757	3440	4044	4658
354	2754	3436	4041	4657
355	2750	3432	4038	4656
356	2747	3428	4035	4655
357	2744	3423	4032	4654
358	2741	3419	4029	4653
359	2738	3415	4026	4652
360	2738	3415	4026	4652

6/01-10/31	Keno Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
341	2535	3403	4169	5031
342	2528	3396	4162	5025
343	2520	3388	4155	5018
344	2513	3381	4148	5012
345	2506	3374	4141	5005
346	2498	3366	4135	4998
347	2491	3359	4128	4992
348	2484	3351	4121	4985
349	2476	3344	4114	4978
350	2469	3337	4107	4972
351	2462	3329	4100	4965
352	2454	3322	4093	4959
353	2447	3315	4086	4952
354	2440	3307	4079	4945
355	2432	3300	4072	4939
356	2425	3293	4065	4932
357	2418	3285	4058	4925
358	2410	3278	4051	4919
359	2403	3271	4045	4912
360	2403	3271	4045	4912

KLAMATH RIVER BELOW J.C. BOYLE NEAR KENO, OR

Annual	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
0	6170	7541	8431	9399
1	6181	7552	8443	9409
2	6192	7564	8456	9419
3	6203	7576	8468	9429
4	6214	7587	8481	9439
5	6225	7599	8493	9448
6	6236	7610	8506	9458
7	6247	7622	8518	9468
8	6258	7633	8531	9478
9	6269	7645	8543	9488
10	6280	7656	8556	9498
11	6291	7668	8568	9507
12	6302	7680	8581	9517
13	6313	7691	8593	9527
14	6324	7703	8606	9537
15	6335	7714	8618	9547
16	6346	7726	8631	9557
17	6357	7737	8643	9566
18	6368	7749	8656	9576
19	6379	7761	8668	9586
20	6390	7772	8681	9596

Annual	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
181	8751	10609	11491	12220
182	8585	10368	11124	11754
183	8559	10329	11119	11751
184	8533	10290	11113	11748
185	8508	10251	11108	11746
186	8482	10212	11102	11743
187	8456	10173	11097	11740
188	8430	10134	11091	11738
189	8404	10095	11086	11735
190	8378	10056	11080	11732
191	8352	10017	11075	11730
192	8327	9978	11069	11727
193	8303	9948	11025	11690
194	8280	9919	10981	11654
195	8256	9889	10937	11618
196	8233	9859	10893	11581
197	8210	9830	10849	11545
198	8186	9800	10805	11508
199	8163	9770	10761	11472
200	8140	9740	10716	11436
201	8116	9711	10672	11399

Annual	**Boyle Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
21	6401	7784	8693	9606
22	6412	7795	8706	9616
23	6423	7807	8718	9625
24	6434	7818	8731	9635
25	6445	7830	8743	9645
26	6456	7841	8756	9655
27	6467	7853	8768	9665
28	6478	7865	8781	9675
29	6489	7876	8793	9684
30	6500	7888	8806	9694
31	6511	7899	8818	9704
32	6522	7911	8831	9714
33	6533	7922	8843	9724
34	6544	7934	8856	9734
35	6555	7946	8868	9743
36	6566	7957	8881	9753
37	6577	7969	8893	9763
38	6588	7980	8906	9773
39	6599	7992	8918	9783
40	6610	8003	8931	9793
41	6621	8015	8943	9802
42	6632	8026	8956	9812
43	6643	8038	8968	9822
44	6654	8050	8981	9832
45	6665	8061	8993	9842
46	6676	8073	9006	9852
47	6687	8084	9018	9861
48	6699	8096	9031	9871
49	6710	8107	9043	9881
50	6721	8119	9056	9891
51	6732	8131	9068	9901
52	6743	8142	9081	9911
53	6754	8154	9093	9920
54	6765	8165	9106	9930
55	6776	8177	9118	9940
56	6787	8188	9131	9950
57	6798	8200	9143	9960
58	6809	8212	9156	9970
59	6820	8223	9168	9979
60	6831	8235	9181	9989
61	6842	8246	9193	9999
62	6853	8258	9206	10009
63	6864	8269	9218	10019
64	6875	8281	9231	10029
65	6886	8292	9243	10038
66	6897	8304	9256	10048
67	6908	8316	9268	10058
68	6919	8327	9281	10068
69	6930	8339	9293	10078

Annual	**Boyle Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
202	8093	9681	10628	11363
203	8069	9651	10584	11326
204	8046	9622	10540	11290
205	8023	9592	10496	11254
206	7999	9562	10452	11217
207	7976	9532	10408	11181
208	7952	9503	10364	11144
209	7929	9473	10319	11108
210	7906	9443	10275	11072
211	7882	9413	10231	11035
212	7859	9384	10187	10999
213	7836	9354	10143	10962
214	7812	9324	10099	10926
215	7789	9295	10055	10890
216	7765	9265	10011	10853
217	7753	9249	10001	10838
218	7740	9233	9992	10823
219	7727	9216	9983	10807
220	7714	9200	9974	10792
221	7701	9184	9965	10777
222	7688	9168	9955	10762
223	7675	9152	9946	10746
224	7662	9136	9937	10731
225	7649	9119	9928	10716
226	7636	9103	9918	10701
227	7623	9087	9909	10685
228	7610	9071	9900	10670
229	7597	9055	9891	10655
230	7584	9039	9882	10639
231	7571	9023	9872	10624
232	7558	9006	9863	10609
233	7545	8990	9854	10594
234	7532	8974	9845	10578
235	7519	8958	9835	10563
236	7506	8942	9826	10548
237	7493	8926	9817	10533
238	7480	8909	9808	10517
239	7467	8893	9799	10502
240	7455	8877	9789	10487
241	7445	8868	9783	10481
242	7436	8858	9776	10475
243	7426	8849	9770	10469
244	7417	8839	9763	10463
245	7407	8830	9756	10457
246	7398	8821	9750	10451
247	7388	8811	9743	10445
248	7379	8802	9736	10439
249	7369	8792	9730	10433
250	7360	8783	9723	10427

Annual	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
70	6941	8350	9306	10088
71	6952	8362	9318	10097
72	6963	8373	9331	10107
73	6974	8385	9343	10117
74	6985	8397	9356	10127
75	6996	8408	9368	10137
76	7007	8420	9381	10147
77	7018	8431	9393	10156
78	7029	8443	9406	10166
79	7040	8454	9418	10176
80	7051	8466	9431	10186
81	7062	8477	9443	10196
82	7073	8489	9456	10206
83	7084	8501	9468	10215
84	7095	8512	9481	10225
85	7106	8524	9493	10235
86	7117	8535	9506	10245
87	7128	8547	9518	10255
88	7139	8558	9531	10265
89	7150	8570	9543	10274
90	7161	8582	9556	10284
91	7172	8593	9568	10294
92	7183	8605	9581	10304
93	7194	8616	9593	10314
94	7205	8628	9606	10323
95	7216	8639	9618	10333
96	7227	8651	9631	10343
97	7237	8660	9637	10349
98	7246	8670	9644	10355
99	7256	8679	9650	10361
100	7265	8689	9657	10367
101	7275	8698	9664	10373
102	7284	8707	9670	10379
103	7294	8717	9677	10385
104	7303	8726	9684	10391
105	7313	8736	9690	10397
106	7322	8745	9697	10403
107	7332	8755	9703	10409
108	7341	8764	9710	10415
109	7350	8773	9717	10421
110	7360	8783	9723	10427
111	7369	8792	9730	10433
112	7379	8802	9736	10439
113	7388	8811	9743	10445
114	7398	8821	9750	10451
115	7407	8830	9756	10457
116	7417	8839	9763	10463
117	7426	8849	9770	10469
118	7436	8858	9776	10475

Annual	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
251	7350	8773	9717	10421
252	7341	8764	9710	10415
253	7332	8755	9703	10409
254	7322	8745	9697	10403
255	7313	8736	9690	10397
256	7303	8726	9684	10391
257	7294	8717	9677	10385
258	7284	8707	9670	10379
259	7275	8698	9664	10373
260	7265	8689	9657	10367
261	7256	8679	9650	10361
262	7246	8670	9644	10355
263	7237	8660	9637	10349
264	7227	8651	9631	10343
265	7216	8639	9618	10333
266	7205	8628	9606	10323
267	7194	8616	9593	10314
268	7183	8605	9581	10304
269	7172	8593	9568	10294
270	7161	8582	9556	10284
271	7150	8570	9543	10274
272	7139	8558	9531	10265
273	7128	8547	9518	10255
274	7117	8535	9506	10245
275	7106	8524	9493	10235
276	7095	8512	9481	10225
277	7084	8501	9468	10215
278	7073	8489	9456	10206
279	7062	8477	9443	10196
280	7051	8466	9431	10186
281	7040	8454	9418	10176
282	7029	8443	9406	10166
283	7018	8431	9393	10156
284	7007	8420	9381	10147
285	6996	8408	9368	10137
286	6985	8397	9356	10127
287	6974	8385	9343	10117
288	6963	8373	9331	10107
289	6952	8362	9318	10097
290	6941	8350	9306	10088
291	6930	8339	9293	10078
292	6919	8327	9281	10068
293	6908	8316	9268	10058
294	6897	8304	9256	10048
295	6886	8292	9243	10038
296	6875	8281	9231	10029
298	6864	8269	9218	10019
297	6853	8258	9206	10009
298	6842	8246	9193	9999

Annual	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
119	7445	8868	9783	10481
120	7455	8877	9789	10487
121	7467	8893	9799	10502
122	7480	8909	9808	10517
123	7493	8926	9817	10533
124	7506	8942	9826	10548
125	7519	8958	9835	10563
126	7532	8974	9845	10578
127	7545	8990	9854	10594
128	7558	9006	9863	10609
129	7571	9023	9872	10624
130	7584	9039	9882	10639
131	7597	9055	9891	10655
132	7610	9071	9900	10670
133	7623	9087	9909	10685
134	7636	9103	9918	10701
135	7649	9119	9928	10716
136	7662	9136	9937	10731
137	7675	9152	9946	10746
138	7688	9168	9955	10762
139	7701	9184	9965	10777
140	7714	9200	9974	10792
141	7727	9216	9983	10807
142	7740	9233	9992	10823
143	7753	9249	10001	10838
144	7765	9265	10011	10853
145	7789	9295	10055	10890
146	7812	9324	10099	10926
147	7836	9354	10143	10962
148	7859	9384	10187	10999
149	7882	9413	10231	11035
150	7906	9443	10275	11072
151	7929	9473	10319	11108
152	7952	9503	10364	11144
153	7976	9532	10408	11181
154	7999	9562	10452	11217
155	8023	9592	10496	11254
156	8046	9622	10540	11290
157	8069	9651	10584	11326
158	8093	9681	10628	11363
159	8116	9711	10672	11399
160	8140	9740	10716	11436
161	8163	9770	10761	11472
162	8186	9800	10805	11508
163	8210	9830	10849	11545
164	8233	9859	10893	11581
165	8256	9889	10937	11618
166	8280	9919	10981	11654
167	8303	9948	11025	11690

Annual	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
299	6831	8235	9181	9989
300	6820	8223	9168	9979
301	6809	8212	9156	9970
302	6798	8200	9143	9960
303	6787	8188	9131	9950
304	6776	8177	9118	9940
305	6765	8165	9106	9930
306	6754	8154	9093	9920
307	6743	8142	9081	9911
308	6732	8131	9068	9901
309	6721	8119	9056	9891
310	6710	8107	9043	9881
311	6699	8096	9031	9871
312	6687	8084	9018	9861
313	6676	8073	9006	9852
314	6665	8061	8993	9842
315	6654	8050	8981	9832
316	6643	8038	8968	9822
317	6632	8026	8956	9812
318	6621	8015	8943	9802
319	6610	8003	8931	9793
320	6599	7992	8918	9783
321	6588	7980	8906	9773
322	6577	7969	8893	9763
323	6566	7957	8881	9753
324	6555	7946	8868	9743
325	6544	7934	8856	9734
326	6533	7922	8843	9724
327	6522	7911	8831	9714
328	6511	7899	8818	9704
329	6500	7888	8806	9694
330	6489	7876	8793	9684
331	6478	7865	8781	9675
332	6467	7853	8768	9665
333	6456	7841	8756	9655
334	6445	7830	8743	9645
335	6434	7818	8731	9635
336	6423	7807	8718	9625
337	6412	7795	8706	9616
338	6401	7784	8693	9606
339	6390	7772	8681	9596
340	6379	7761	8668	9586
341	6368	7749	8656	9576
342	6357	7737	8643	9566
343	6346	7726	8631	9557
344	6335	7714	8618	9547
345	6324	7703	8606	9537
346	6313	7691	8593	9527
347	6302	7680	8581	9517

Annual	**Boyle Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
168	8327	9978	11069	11727
169	8352	10017	11075	11730
170	8378	10056	11080	11732
171	8404	10095	11086	11735
172	8430	10134	11091	11738
173	8456	10173	11097	11740
174	8482	10212	11102	11743
175	8508	10251	11108	11746
176	8533	10290	11113	11748
177	8559	10329	11119	11751
178	8585	10368	11124	11754
179	8751	10609	11491	12220
180	9058	11050	12220	13150

Annual	**Boyle Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
348	6291	7668	8568	9507
349	6280	7656	8556	9498
350	6269	7645	8543	9488
351	6258	7633	8531	9478
352	6247	7622	8518	9468
353	6236	7610	8506	9458
354	6225	7599	8493	9448
355	6214	7587	8481	9439
356	6203	7576	8468	9429
357	6192	7564	8456	9419
358	6181	7552	8443	9409
359	6170	7541	8431	9399
360	6170	7541	8431	9399

7/01-11/30	**Boyle Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
0	2910	3537	4044	4572
1	2913	3541	4048	4574
2	2916	3545	4051	4576
3	2919	3548	4054	4577
4	2922	3552	4057	4579
5	2925	3556	4060	4581
6	2928	3560	4063	4583
7	2931	3563	4066	4585
8	2934	3567	4069	4587
9	2937	3571	4072	4589
10	2940	3574	4075	4590
11	2943	3578	4078	4592
12	2946	3582	4081	4594
13	2950	3586	4084	4596
14	2953	3589	4088	4598
15	2956	3593	4091	4600
16	2959	3597	4094	4602
17	2962	3600	4097	4604
18	2965	3604	4100	4605
19	2968	3608	4103	4607
20	2971	3612	4106	4609
21	2974	3615	4109	4611
22	2977	3619	4112	4613
23	2980	3623	4115	4615
24	2983	3627	4118	4617
25	2986	3630	4121	4619
26	2990	3634	4125	4620
27	2993	3638	4128	4622
28	2996	3641	4131	4624
29	2999	3645	4134	4626
30	3002	3649	4137	4628

6/01-10/30	**Boyle Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
0	2641	3391	4117	4994
1	2648	3400	4126	5003
2	2655	3410	4136	5012
3	2662	3419	4146	5020
4	2670	3428	4155	5029
5	2677	3438	4165	5038
6	2684	3447	4175	5047
7	2691	3456	4185	5056
8	2698	3466	4194	5065
9	2705	3475	4204	5074
10	2712	3485	4214	5083
11	2720	3494	4223	5092
12	2727	3503	4233	5100
13	2734	3513	4243	5109
14	2741	3522	4252	5118
15	2748	3531	4262	5127
16	2755	3541	4272	5136
17	2762	3550	4281	5145
18	2770	3560	4291	5154
19	2777	3569	4301	5163
20	2784	3578	4311	5172
21	2791	3588	4320	5181
22	2798	3597	4330	5189
23	2805	3606	4340	5198
24	2812	3616	4349	5207
25	2820	3625	4359	5216
26	2827	3634	4369	5225
27	2834	3644	4378	5234
28	2841	3653	4388	5243
29	2848	3663	4398	5252
30	2855	3672	4407	5261

7/01-11/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
31	3005	3653	4140	4630
32	3008	3656	4143	4632
33	3011	3660	4146	4633
34	3014	3664	4149	4635
35	3017	3667	4152	4637
36	3020	3671	4155	4639
37	3023	3675	4158	4641
38	3026	3679	4161	4643
39	3030	3682	4165	4645
40	3033	3686	4168	4647
41	3036	3690	4171	4648
42	3039	3693	4174	4650
43	3042	3697	4177	4652
44	3045	3701	4180	4654
45	3048	3705	4183	4656
46	3051	3708	4186	4658
47	3054	3712	4189	4660
48	3057	3716	4192	4662
49	3060	3719	4195	4663
50	3063	3723	4198	4665
51	3066	3727	4201	4667
52	3070	3731	4205	4669
53	3073	3734	4208	4671
54	3076	3738	4211	4673
55	3079	3742	4214	4675
56	3082	3745	4217	4676
57	3085	3749	4220	4678
58	3088	3753	4223	4680
59	3091	3757	4226	4682
60	3094	3760	4229	4684
61	3097	3764	4232	4686
62	3100	3768	4235	4688
63	3103	3772	4238	4690
64	3106	3775	4242	4691
65	3110	3779	4245	4693
66	3113	3783	4248	4695
67	3116	3786	4251	4697
68	3119	3790	4254	4699
69	3122	3794	4257	4701
70	3125	3798	4260	4703
71	3128	3801	4263	4704
72	3131	3805	4266	4706
73	3134	3809	4269	4708
74	3137	3812	4272	4710
75	3140	3816	4275	4712
76	3143	3820	4278	4714
77	3146	3824	4282	4716
78	3150	3827	4285	4718
79	3153	3831	4288	4719

6/01-10/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
31	2862	3681	4417	5270
32	2870	3691	4427	5278
33	2877	3700	4436	5287
34	2884	3709	4446	5296
35	2891	3719	4456	5305
36	2898	3728	4466	5314
37	2905	3738	4475	5323
38	2912	3747	4485	5332
39	2919	3756	4495	5341
40	2927	3766	4504	5350
41	2934	3775	4514	5359
42	2941	3784	4524	5367
43	2948	3794	4533	5376
44	2955	3803	4543	5385
45	2962	3813	4553	5394
46	2969	3822	4562	5403
47	2977	3831	4572	5412
48	2984	3841	4582	5421
49	2991	3850	4592	5430
50	2998	3859	4601	5439
51	3005	3869	4611	5448
52	3012	3878	4621	5456
53	3019	3887	4630	5465
54	3027	3897	4640	5474
55	3034	3906	4650	5483
56	3041	3916	4659	5492
57	3048	3925	4669	5501
58	3055	3934	4679	5510
59	3062	3944	4688	5519
60	3069	3953	4698	5528
61	3077	3962	4708	5537
62	3084	3972	4718	5545
63	3091	3981	4727	5554
64	3098	3991	4737	5563
65	3105	4000	4747	5572
66	3112	4009	4756	5581
67	3119	4019	4766	5590
68	3127	4028	4776	5599
69	3134	4037	4785	5608
70	3141	4047	4795	5617
71	3148	4056	4805	5626
72	3155	4066	4814	5634
73	3162	4075	4824	5643
74	3169	4084	4834	5652
75	3177	4094	4844	5661
76	3184	4103	4853	5670
77	3191	4112	4863	5679
78	3198	4122	4873	5688
79	3205	4131	4882	5697

7/01-11/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
80	3156	3835	4291	4721
81	3159	3838	4294	4723
82	3162	3842	4297	4725
83	3165	3846	4300	4727
84	3168	3850	4303	4729
85	3171	3853	4306	4731
86	3174	3857	4309	4733
87	3177	3861	4312	4734
88	3180	3864	4315	4736
89	3183	3868	4318	4738
90	3186	3872	4322	4740
91	3190	3876	4325	4742
92	3193	3879	4328	4744
93	3196	3883	4331	4746
94	3199	3887	4334	4747
95	3202	3891	4337	4749
96	3205	3894	4340	4751
97	3207	3896	4343	4758
98	3209	3897	4347	4764
99	3211	3899	4350	4771
100	3213	3900	4354	4777
101	3215	3902	4357	4784
102	3217	3903	4361	4790
103	3219	3905	4364	4797
104	3221	3906	4367	4803
105	3223	3908	4371	4810
106	3225	3909	4374	4816
107	3227	3911	4378	4823
108	3229	3912	4381	4829
109	3230	3913	4384	4835
110	3232	3915	4388	4842
111	3234	3916	4391	4848
112	3236	3918	4395	4855
113	3238	3919	4398	4861
114	3240	3921	4401	4868
115	3242	3922	4405	4874
116	3244	3924	4408	4881
117	3246	3925	4412	4887
118	3248	3927	4415	4894
119	3250	3928	4419	4900
120	3252	3930	4422	4907
121	3256	3933	4425	4909
122	3260	3936	4428	4912
123	3264	3939	4431	4914
124	3268	3942	4434	4916
125	3271	3944	4437	4919
126	3275	3947	4440	4921
127	3279	3950	4443	4923
128	3283	3953	4446	4926

6/01-10/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
80	3212	4140	4892	5706
81	3219	4150	4902	5715
82	3227	4159	4911	5723
83	3234	4169	4921	5732
84	3241	4178	4931	5741
85	3248	4187	4940	5750
86	3255	4197	4950	5759
87	3262	4206	4960	5768
88	3269	4215	4970	5777
89	3276	4225	4979	5786
90	3284	4234	4989	5795
91	3291	4244	4999	5804
92	3298	4253	5008	5812
93	3305	4262	5018	5821
94	3312	4272	5028	5830
95	3319	4281	5037	5839
96	3326	4290	5047	5848
97	3335	4302	5060	5862
98	3343	4313	5073	5877
99	3352	4324	5087	5891
100	3360	4335	5100	5905
101	3369	4346	5113	5919
102	3377	4358	5126	5934
103	3385	4369	5139	5948
104	3394	4380	5152	5962
105	3402	4391	5166	5976
106	3411	4403	5179	5991
107	3419	4414	5192	6005
108	3428	4425	5205	6019
109	3436	4436	5218	6033
110	3444	4447	5231	6047
111	3453	4459	5244	6062
112	3461	4470	5258	6076
113	3470	4481	5271	6090
114	3478	4492	5284	6104
115	3486	4504	5297	6119
116	3495	4515	5310	6133
117	3503	4526	5323	6147
118	3512	4537	5337	6161
119	3520	4548	5350	6176
120	3529	4560	5363	6190
121	3539	4580	5393	6233
122	3550	4600	5423	6275
123	3561	4620	5453	6318
124	3572	4640	5484	6360
125	3583	4661	5514	6403
126	3594	4681	5544	6446
127	3605	4701	5574	6488
128	3616	4721	5604	6531

7/01-11/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
129	3287	3956	4449	4928
130	3291	3959	4452	4930
131	3295	3962	4455	4933
132	3299	3965	4458	4935
133	3302	3968	4461	4937
134	3306	3971	4464	4940
135	3310	3974	4467	4942
136	3314	3977	4470	4944
137	3318	3980	4473	4947
138	3322	3983	4476	4949
139	3326	3986	4479	4951
140	3329	3988	4482	4954
141	3333	3991	4485	4956
142	3337	3994	4488	4958
143	3341	3997	4491	4961
144	3345	4000	4494	4963
145	3346	4001	4495	4964
146	3347	4002	4495	4965
147	3348	4003	4496	4967
148	3349	4003	4496	4968
149	3350	4004	4497	4969
150	3351	4005	4497	4970
151	3352	4006	4498	4971
152	3353	4007	4498	4972
153	3354	4008	4499	4973
154	3355	4008	4499	4974
155	3356	4009	4500	4975
156	3358	4010	4500	4977
157	3359	4011	4500	4978
158	3360	4012	4501	4979
159	3361	4012	4501	4980
160	3362	4013	4502	4981
161	3363	4014	4502	4982
162	3364	4015	4503	4983
163	3365	4016	4503	4984
164	3366	4017	4504	4985
165	3367	4017	4504	4986
166	3368	4018	4505	4988
167	3369	4019	4505	4989
168	3370	4020	4506	4990
169	3370	4020	4506	4994
170	3370	4021	4506	4998
171	3369	4022	4505	5001
172	3369	4023	4505	5005
173	3369	4023	4505	5009
174	3368	4024	4505	5013
175	3368	4025	4505	5017
176	3368	4025	4505	5021
177	3368	4026	4505	5025

6/01-10/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
129	3626	4741	5634	6574
130	3637	4762	5665	6616
131	3648	4782	5695	6659
132	3659	4802	5725	6702
133	3670	4822	5755	6744
134	3681	4842	5785	6787
135	3692	4863	5816	6829
136	3702	4883	5846	6872
137	3713	4903	5876	6915
138	3724	4923	5906	6957
139	3735	4943	5936	7000
140	3746	4964	5966	7043
141	3757	4984	5997	7085
142	3768	5004	6027	7128
143	3779	5024	6057	7170
144	3789	5044	6087	7213
145	3794	5047	6088	7212
146	3798	5050	6089	7211
147	3802	5053	6090	7211
148	3806	5056	6091	7210
149	3810	5059	6092	7209
150	3814	5062	6094	7208
151	3818	5065	6095	7207
152	3822	5067	6096	7206
153	3826	5070	6097	7206
154	3830	5073	6098	7205
155	3834	5076	6099	7204
156	3838	5079	6100	7203
157	3842	5082	6101	7202
158	3846	5085	6102	7201
159	3850	5088	6103	7200
160	3854	5091	6104	7200
161	3858	5093	6105	7199
162	3862	5096	6106	7198
163	3866	5099	6108	7197
164	3870	5102	6109	7196
165	3874	5105	6110	7195
166	3878	5108	6111	7195
167	3882	5111	6112	7194
168	3887	5114	6113	7193
169	3883	5108	6111	7201
170	3880	5102	6110	7209
171	3877	5096	6108	7217
172	3873	5090	6107	7225
173	3870	5084	6105	7233
174	3867	5078	6104	7241
175	3863	5072	6102	7249
176	3860	5066	6101	7257
177	3857	5060	6099	7264

7/01-11/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
178	3367	4027	4504	5028
179	3765	4433	4926	5454
180	4559	5245	5768	6301
181	3765	4433	4926	5454
182	3367	4027	4504	5028
183	3368	4026	4505	5025
184	3368	4025	4505	5021
185	3368	4025	4505	5017
186	3368	4024	4505	5013
187	3369	4023	4505	5009
188	3369	4023	4505	5005
189	3369	4022	4505	5001
190	3370	4021	4506	4998
191	3370	4020	4506	4994
192	3370	4020	4506	4990
193	3369	4019	4505	4989
194	3368	4018	4505	4988
195	3367	4017	4504	4986
196	3366	4017	4504	4985
197	3365	4016	4503	4984
198	3364	4015	4503	4983
199	3363	4014	4502	4982
200	3362	4013	4502	4981
201	3361	4012	4501	4980
202	3360	4012	4501	4979
203	3359	4011	4500	4978
204	3358	4010	4500	4977
205	3356	4009	4500	4975
206	3355	4008	4499	4974
207	3354	4008	4499	4973
208	3353	4007	4498	4972
209	3352	4006	4498	4971
210	3351	4005	4497	4970
211	3350	4004	4497	4969
212	3349	4003	4496	4968
213	3348	4003	4496	4967
214	3347	4002	4495	4965
215	3346	4001	4495	4964
216	3345	4000	4494	4963
217	3341	3997	4491	4961
218	3337	3994	4488	4958
219	3333	3991	4485	4956
220	3329	3988	4482	4954
221	3326	3986	4479	4951
222	3322	3983	4476	4949
223	3318	3980	4473	4947
224	3314	3977	4470	4944
225	3310	3974	4467	4942
226	3306	3971	4464	4940

6/01-10/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
178	3854	5054	6097	7272
179	4273	5502	6556	7736
180	5115	6403	7476	8654
181	4273	5502	6556	7736
182	3854	5054	6097	7272
183	3857	5060	6099	7264
184	3860	5066	6101	7257
185	3863	5072	6102	7249
186	3867	5078	6104	7241
187	3870	5084	6105	7233
188	3873	5090	6107	7225
189	3877	5096	6108	7217
190	3880	5102	6110	7209
191	3883	5108	6111	7201
192	3887	5114	6113	7193
193	3882	5111	6112	7194
194	3878	5108	6111	7195
195	3874	5105	6110	7195
196	3870	5102	6109	7196
197	3866	5099	6108	7197
198	3862	5096	6106	7198
199	3858	5093	6105	7199
200	3854	5091	6104	7200
201	3850	5088	6103	7200
202	3846	5085	6102	7201
203	3842	5082	6101	7202
204	3838	5079	6100	7203
205	3834	5076	6099	7204
206	3830	5073	6098	7205
207	3826	5070	6097	7206
208	3822	5067	6096	7206
209	3818	5065	6095	7207
210	3814	5062	6094	7208
211	3810	5059	6092	7209
212	3806	5056	6091	7210
213	3802	5053	6090	7211
214	3798	5050	6089	7211
215	3794	5047	6088	7212
216	3789	5044	6087	7213
217	3779	5024	6057	7170
218	3768	5004	6027	7128
219	3757	4984	5997	7085
220	3746	4964	5966	7043
221	3735	4943	5936	7000
222	3724	4923	5906	6957
223	3713	4903	5876	6915
224	3702	4883	5846	6872
225	3692	4863	5816	6829
226	3681	4842	5785	6787

7/01-11/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
227	3302	3968	4461	4937
228	3299	3965	4458	4935
229	3295	3962	4455	4933
230	3291	3959	4452	4930
231	3287	3956	4449	4928
232	3283	3953	4446	4926
233	3279	3950	4443	4923
234	3275	3947	4440	4921
235	3271	3944	4437	4919
236	3268	3942	4434	4916
237	3264	3939	4431	4914
238	3260	3936	4428	4912
239	3256	3933	4425	4909
240	3252	3930	4422	4907
241	3250	3928	4419	4900
242	3248	3927	4415	4894
243	3246	3925	4412	4887
244	3244	3924	4408	4881
245	3242	3922	4405	4874
246	3240	3921	4401	4868
247	3238	3919	4398	4861
248	3236	3918	4395	4855
249	3234	3916	4391	4848
250	3232	3915	4388	4842
251	3230	3913	4384	4835
252	3229	3912	4381	4829
253	3227	3911	4378	4823
254	3225	3909	4374	4816
255	3223	3908	4371	4810
256	3221	3906	4367	4803
257	3219	3905	4364	4797
258	3217	3903	4361	4790
259	3215	3902	4357	4784
260	3213	3900	4354	4777
261	3211	3899	4350	4771
262	3209	3897	4347	4764
263	3207	3896	4343	4758
264	3205	3894	4340	4751
265	3202	3891	4337	4749
266	3199	3887	4334	4747
267	3196	3883	4331	4746
268	3193	3879	4328	4744
269	3190	3876	4325	4742
270	3186	3872	4322	4740
271	3183	3868	4318	4738
272	3180	3864	4315	4736
273	3177	3861	4312	4734
274	3174	3857	4309	4733
275	3171	3853	4306	4731

6/01-10/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
227	3670	4822	5755	6744
228	3659	4802	5725	6702
229	3648	4782	5695	6659
230	3637	4762	5665	6616
231	3626	4741	5634	6574
232	3616	4721	5604	6531
233	3605	4701	5574	6488
234	3594	4681	5544	6446
235	3583	4661	5514	6403
236	3572	4640	5484	6360
237	3561	4620	5453	6318
238	3550	4600	5423	6275
239	3539	4580	5393	6233
240	3529	4560	5363	6190
241	3520	4548	5350	6176
242	3512	4537	5337	6161
243	3503	4526	5323	6147
244	3495	4515	5310	6133
245	3486	4504	5297	6119
246	3478	4492	5284	6104
247	3470	4481	5271	6090
248	3461	4470	5258	6076
249	3453	4459	5244	6062
250	3444	4447	5231	6047
251	3436	4436	5218	6033
252	3428	4425	5205	6019
253	3419	4414	5192	6005
254	3411	4403	5179	5991
255	3402	4391	5166	5976
256	3394	4380	5152	5962
257	3385	4369	5139	5948
258	3377	4358	5126	5934
259	3369	4346	5113	5919
260	3360	4335	5100	5905
261	3352	4324	5087	5891
262	3343	4313	5073	5877
263	3335	4302	5060	5862
264	3326	4290	5047	5848
265	3319	4281	5037	5839
266	3312	4272	5028	5830
267	3305	4262	5018	5821
268	3298	4253	5008	5812
269	3291	4244	4999	5804
270	3284	4234	4989	5795
271	3276	4225	4979	5786
272	3269	4215	4970	5777
273	3262	4206	4960	5768
274	3255	4197	4950	5759
275	3248	4187	4940	5750

7/01-11/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
276	3168	3850	4303	4729
277	3165	3846	4300	4727
278	3162	3842	4297	4725
279	3159	3838	4294	4723
280	3156	3835	4291	4721
281	3153	3831	4288	4719
282	3150	3827	4285	4718
283	3146	3824	4282	4716
284	3143	3820	4278	4714
285	3140	3816	4275	4712
286	3137	3812	4272	4710
287	3134	3809	4269	4708
288	3131	3805	4266	4706
289	3128	3801	4263	4704
290	3125	3798	4260	4703
291	3122	3794	4257	4701
292	3119	3790	4254	4699
293	3116	3786	4251	4697
294	3113	3783	4248	4695
295	3110	3779	4245	4693
296	3106	3775	4242	4691
298	3103	3772	4238	4690
297	3100	3768	4235	4688
298	3097	3764	4232	4686
299	3094	3760	4229	4684
300	3091	3757	4226	4682
301	3088	3753	4223	4680
302	3085	3749	4220	4678
303	3082	3745	4217	4676
304	3079	3742	4214	4675
305	3076	3738	4211	4673
306	3073	3734	4208	4671
307	3070	3731	4205	4669
308	3066	3727	4201	4667
309	3063	3723	4198	4665
310	3060	3719	4195	4663
311	3057	3716	4192	4662
312	3054	3712	4189	4660
313	3051	3708	4186	4658
314	3048	3705	4183	4656
315	3045	3701	4180	4654
316	3042	3697	4177	4652
317	3039	3693	4174	4650
318	3036	3690	4171	4648
319	3033	3686	4168	4647
320	3030	3682	4165	4645
321	3026	3679	4161	4643
322	3023	3675	4158	4641
323	3020	3671	4155	4639

6/01-10/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
276	3241	4178	4931	5741
277	3234	4169	4921	5732
278	3227	4159	4911	5723
279	3219	4150	4902	5715
280	3212	4140	4892	5706
281	3205	4131	4882	5697
282	3198	4122	4873	5688
283	3191	4112	4863	5679
284	3184	4103	4853	5670
285	3177	4094	4844	5661
286	3169	4084	4834	5652
287	3162	4075	4824	5643
288	3155	4066	4814	5634
289	3148	4056	4805	5626
290	3141	4047	4795	5617
291	3134	4037	4785	5608
292	3127	4028	4776	5599
293	3119	4019	4766	5590
294	3112	4009	4756	5581
295	3105	4000	4747	5572
296	3098	3991	4737	5563
298	3091	3981	4727	5554
297	3084	3972	4718	5545
298	3077	3962	4708	5537
299	3069	3953	4698	5528
300	3062	3944	4688	5519
301	3055	3934	4679	5510
302	3048	3925	4669	5501
303	3041	3916	4659	5492
304	3034	3906	4650	5483
305	3027	3897	4640	5474
306	3019	3887	4630	5465
307	3012	3878	4621	5456
308	3005	3869	4611	5448
309	2998	3859	4601	5439
310	2991	3850	4592	5430
311	2984	3841	4582	5421
312	2977	3831	4572	5412
313	2969	3822	4562	5403
314	2962	3813	4553	5394
315	2955	3803	4543	5385
316	2948	3794	4533	5376
317	2941	3784	4524	5367
318	2934	3775	4514	5359
319	2927	3766	4504	5350
320	2919	3756	4495	5341
321	2912	3747	4485	5332
322	2905	3738	4475	5323
323	2898	3728	4466	5314

7/01-11/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
324	3017	3667	4152	4637
325	3014	3664	4149	4635
326	3011	3660	4146	4633
327	3008	3656	4143	4632
328	3005	3653	4140	4630
329	3002	3649	4137	4628
330	2999	3645	4134	4626
331	2996	3641	4131	4624
332	2993	3638	4128	4622
333	2990	3634	4125	4620
334	2986	3630	4121	4619
335	2983	3627	4118	4617
336	2980	3623	4115	4615
337	2977	3619	4112	4613
338	2974	3615	4109	4611
339	2971	3612	4106	4609
340	2968	3608	4103	4607
341	2965	3604	4100	4605
342	2962	3600	4097	4604
343	2959	3597	4094	4602
344	2956	3593	4091	4600
345	2953	3589	4088	4598
346	2950	3586	4084	4596
347	2946	3582	4081	4594
348	2943	3578	4078	4592
349	2940	3574	4075	4590
350	2937	3571	4072	4589
351	2934	3567	4069	4587
352	2931	3563	4066	4585
353	2928	3560	4063	4583
354	2925	3556	4060	4581
355	2922	3552	4057	4579
356	2919	3548	4054	4577
357	2916	3545	4051	4576
358	2913	3541	4048	4574
359	2910	3537	4044	4572
360	2910	3537	4044	4572

6/01-10/30	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
324	2891	3719	4456	5305
325	2884	3709	4446	5296
326	2877	3700	4436	5287
327	2870	3691	4427	5278
328	2862	3681	4417	5270
329	2855	3672	4407	5261
330	2848	3663	4398	5252
331	2841	3653	4388	5243
332	2834	3644	4378	5234
333	2827	3634	4369	5225
334	2820	3625	4359	5216
335	2812	3616	4349	5207
336	2805	3606	4340	5198
337	2798	3597	4330	5189
338	2791	3588	4320	5181
339	2784	3578	4311	5172
340	2777	3569	4301	5163
341	2770	3560	4291	5154
342	2762	3550	4281	5145
343	2755	3541	4272	5136
344	2748	3531	4262	5127
345	2741	3522	4252	5118
346	2734	3513	4243	5109
347	2727	3503	4233	5100
348	2720	3494	4223	5092
349	2712	3485	4214	5083
350	2705	3475	4204	5074
351	2698	3466	4194	5065
352	2691	3456	4185	5056
353	2684	3447	4175	5047
354	2677	3438	4165	5038
355	2670	3428	4155	5029
356	2662	3419	4146	5020
357	2655	3410	4136	5012
358	2648	3400	4126	5003
359	2641	3391	4117	4994
360	2641	3391	4117	4994

August	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
0	1712	2063	2331	2549
1	1714	2064	2332	2550
2	1715	2066	2333	2551
3	1717	2068	2334	2552
4	1718	2069	2335	2554
5	1720	2071	2336	2555
6	1721	2072	2337	2556

September	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
0	1876	2118	2281	2441
1	1877	2120	2283	2442
2	1878	2121	2284	2444
3	1879	2123	2286	2445
4	1881	2124	2287	2447
5	1882	2126	2289	2448
6	1883	2127	2290	2449

August	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
7	1723	2074	2338	2557
8	1724	2075	2339	2558
9	1726	2077	2340	2559
10	1727	2078	2341	2561
11	1729	2080	2342	2562
12	1730	2082	2343	2563
13	1732	2083	2344	2564
14	1733	2085	2345	2565
15	1735	2086	2346	2566
16	1736	2088	2347	2568
17	1738	2089	2348	2569
18	1739	2091	2349	2570
19	1741	2093	2350	2571
20	1742	2094	2351	2572
21	1744	2096	2352	2573
22	1745	2097	2353	2575
23	1746	2099	2354	2576
24	1748	2100	2355	2577
25	1749	2102	2356	2578
26	1751	2103	2357	2579
27	1752	2105	2358	2580
28	1754	2107	2359	2582
29	1755	2108	2360	2583
30	1757	2110	2361	2584
31	1758	2111	2362	2585
32	1760	2113	2363	2586
33	1761	2114	2364	2587
34	1763	2116	2365	2589
35	1764	2118	2366	2590
36	1766	2119	2367	2591
37	1767	2121	2369	2592
38	1769	2122	2370	2593
39	1770	2124	2371	2594
40	1772	2125	2372	2596
41	1773	2127	2373	2597
42	1775	2128	2374	2598
43	1776	2130	2375	2599
44	1778	2132	2376	2600
45	1779	2133	2377	2601
46	1781	2135	2378	2603
47	1782	2136	2379	2604
48	1784	2138	2380	2605
49	1785	2139	2381	2606
50	1787	2141	2382	2607
51	1788	2143	2383	2608
52	1790	2144	2384	2610
53	1791	2146	2385	2611
54	1793	2147	2386	2612
55	1794	2149	2387	2613

September	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
7	1885	2129	2292	2451
8	1886	2130	2294	2452
9	1887	2132	2295	2454
10	1888	2133	2297	2455
11	1890	2135	2298	2456
12	1891	2136	2300	2458
13	1892	2138	2301	2459
14	1893	2139	2303	2461
15	1895	2140	2305	2462
16	1896	2142	2306	2463
17	1897	2143	2308	2465
18	1898	2145	2309	2466
19	1900	2146	2311	2467
20	1901	2148	2312	2469
21	1902	2149	2314	2470
22	1903	2151	2315	2472
23	1905	2152	2317	2473
24	1906	2154	2319	2474
25	1907	2155	2320	2476
26	1908	2157	2322	2477
27	1910	2158	2323	2479
28	1911	2160	2325	2480
29	1912	2161	2326	2481
30	1914	2163	2328	2483
31	1915	2164	2330	2484
32	1916	2166	2331	2486
33	1917	2167	2333	2487
34	1919	2168	2334	2488
35	1920	2170	2336	2490
36	1921	2171	2337	2491
37	1922	2173	2339	2492
38	1924	2174	2340	2494
39	1925	2176	2342	2495
40	1926	2177	2344	2497
41	1927	2179	2345	2498
42	1929	2180	2347	2499
43	1930	2182	2348	2501
44	1931	2183	2350	2502
45	1932	2185	2351	2504
46	1934	2186	2353	2505
47	1935	2188	2355	2506
48	1936	2189	2356	2508
49	1938	2191	2358	2509
50	1939	2192	2359	2511
51	1940	2194	2361	2512
52	1941	2195	2362	2513
53	1943	2196	2364	2515
54	1944	2198	2366	2516
55	1945	2199	2367	2517

August	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
56	1796	2150	2388	2614
57	1797	2152	2389	2615
58	1798	2154	2390	2617
59	1800	2155	2391	2618
60	1801	2157	2392	2619
61	1803	2158	2393	2620
62	1804	2160	2394	2621
63	1806	2161	2395	2622
64	1807	2163	2396	2624
65	1809	2164	2397	2625
66	1810	2166	2398	2626
67	1812	2168	2399	2627
68	1813	2169	2400	2628
69	1815	2171	2401	2629
70	1816	2172	2402	2631
71	1818	2174	2403	2632
72	1819	2175	2404	2633
73	1821	2177	2405	2634
74	1822	2179	2406	2635
75	1824	2180	2407	2636
76	1825	2182	2408	2637
77	1827	2183	2409	2639
78	1828	2185	2410	2640
79	1830	2186	2411	2641
80	1831	2188	2412	2642
81	1833	2189	2413	2643
82	1834	2191	2414	2644
83	1836	2193	2415	2646
84	1837	2194	2417	2647
85	1839	2196	2418	2648
86	1840	2197	2419	2649
87	1842	2199	2420	2650
88	1843	2200	2421	2651
89	1845	2202	2422	2653
90	1846	2204	2423	2654
91	1847	2205	2424	2655
92	1849	2207	2425	2656
93	1850	2208	2426	2657
94	1852	2210	2427	2658
95	1853	2211	2428	2660
96	1855	2213	2429	2661
97	1857	2216	2433	2663
98	1859	2220	2438	2664
99	1861	2223	2442	2666
100	1863	2226	2447	2668
101	1865	2230	2452	2670
102	1866	2233	2456	2672
103	1868	2237	2461	2674
104	1870	2240	2465	2676

September	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
56	1946	2201	2369	2519
57	1948	2202	2370	2520
58	1949	2204	2372	2522
59	1950	2205	2373	2523
60	1951	2207	2375	2524
61	1953	2208	2376	2526
62	1954	2210	2378	2527
63	1955	2211	2380	2529
64	1956	2213	2381	2530
65	1958	2214	2383	2531
66	1959	2216	2384	2533
67	1960	2217	2386	2534
68	1961	2219	2387	2536
69	1963	2220	2389	2537
70	1964	2222	2391	2538
71	1965	2223	2392	2540
72	1967	2225	2394	2541
73	1968	2226	2395	2542
74	1969	2227	2397	2544
75	1970	2229	2398	2545
76	1972	2230	2400	2547
77	1973	2232	2401	2548
78	1974	2233	2403	2549
79	1975	2235	2405	2551
80	1977	2236	2406	2552
81	1978	2238	2408	2554
82	1979	2239	2409	2555
83	1980	2241	2411	2556
84	1982	2242	2412	2558
85	1983	2244	2414	2559
86	1984	2245	2416	2561
87	1985	2247	2417	2562
88	1987	2248	2419	2563
89	1988	2250	2420	2565
90	1989	2251	2422	2566
91	1990	2253	2423	2567
92	1992	2254	2425	2569
93	1993	2255	2426	2570
94	1994	2257	2428	2572
95	1996	2258	2430	2573
96	1997	2260	2431	2574
97	1998	2262	2433	2578
98	1999	2264	2436	2581
99	2000	2266	2438	2585
100	2001	2268	2440	2588
101	2002	2270	2442	2592
102	2003	2272	2445	2595
103	2004	2274	2447	2599
104	2006	2276	2449	2602

August	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
105	1872	2243	2470	2677
106	1874	2247	2474	2679
107	1876	2250	2479	2681
108	1878	2254	2484	2683
109	1880	2257	2488	2685
110	1882	2260	2493	2687
111	1884	2264	2497	2689
112	1886	2267	2502	2690
113	1888	2270	2506	2692
114	1890	2274	2511	2694
115	1891	2277	2515	2696
116	1893	2281	2520	2698
117	1895	2284	2525	2700
118	1897	2287	2529	2702
119	1899	2291	2534	2703
120	1901	2294	2538	2705
121	1905	2297	2541	2710
122	1908	2300	2544	2716
123	1912	2302	2546	2721
124	1916	2305	2549	2726
125	1919	2308	2551	2731
126	1923	2311	2554	2736
127	1927	2314	2557	2742
128	1930	2316	2559	2747
129	1934	2319	2562	2752
130	1938	2322	2565	2757
131	1941	2325	2567	2762
132	1945	2328	2570	2768
133	1949	2330	2573	2773
134	1952	2333	2575	2778
135	1956	2336	2578	2783
136	1960	2339	2581	2788
137	1963	2341	2583	2793
138	1967	2344	2586	2799
139	1971	2347	2589	2804
140	1974	2350	2591	2809
141	1978	2353	2594	2814
142	1982	2355	2596	2819
143	1985	2358	2599	2825
144	1989	2361	2602	2830
145	1989	2361	2602	2830
146	1990	2361	2602	2830
147	1990	2361	2602	2831
148	1991	2361	2603	2831
149	1991	2361	2603	2832
150	1992	2361	2603	2832
151	1992	2361	2603	2832
152	1993	2361	2603	2833
153	1993	2361	2603	2833

September	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
105	2007	2278	2451	2606
106	2008	2280	2454	2609
107	2009	2282	2456	2613
108	2010	2284	2458	2617
109	2011	2285	2460	2620
110	2012	2287	2462	2624
111	2013	2289	2465	2627
112	2014	2291	2467	2631
113	2016	2293	2469	2634
114	2017	2295	2471	2638
115	2018	2297	2474	2641
116	2019	2299	2476	2645
117	2020	2301	2478	2648
118	2021	2303	2480	2652
119	2022	2305	2483	2655
120	2023	2307	2485	2659
121	2025	2309	2487	2660
122	2028	2311	2490	2661
123	2030	2313	2492	2663
124	2032	2316	2495	2664
125	2034	2318	2497	2665
126	2037	2320	2500	2667
127	2039	2322	2502	2668
128	2041	2324	2505	2670
129	2043	2326	2507	2671
130	2046	2328	2510	2672
131	2048	2330	2512	2674
132	2050	2333	2515	2675
133	2052	2335	2517	2676
134	2054	2337	2519	2678
135	2057	2339	2522	2679
136	2059	2341	2524	2680
137	2061	2343	2527	2682
138	2063	2345	2529	2683
139	2066	2347	2532	2685
140	2068	2349	2534	2686
141	2070	2352	2537	2687
142	2072	2354	2539	2689
143	2075	2356	2542	2690
144	2077	2358	2544	2691
145	2083	2362	2546	2692
146	2089	2366	2547	2693
147	2096	2369	2549	2694
148	2102	2373	2551	2695
149	2108	2377	2552	2696
150	2114	2381	2554	2697
151	2121	2385	2555	2698
152	2127	2388	2557	2699
153	2133	2392	2559	2700

August	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
154	1994	2361	2604	2833
155	1994	2361	2604	2834
156	1995	2361	2604	2834
157	1996	2361	2604	2834
158	1996	2361	2604	2835
159	1997	2361	2605	2835
160	1997	2361	2605	2835
161	1998	2361	2605	2836
162	1998	2361	2605	2836
163	1999	2361	2605	2836
164	1999	2361	2605	2837
165	2000	2361	2606	2837
166	2000	2361	2606	2838
167	2001	2361	2606	2838
168	2001	2361	2606	2838
169	2001	2362	2607	2839
170	2002	2362	2609	2839
171	2002	2363	2610	2840
172	2002	2364	2611	2841
173	2002	2364	2612	2841
174	2002	2365	2613	2842
175	2003	2365	2614	2843
176	2003	2366	2616	2843
177	2003	2367	2617	2844
178	2003	2367	2618	2844
179	2364	2732	2986	3219
180	3084	3460	3720	3967
181	2364	2732	2986	3219
182	2003	2367	2618	2844
183	2003	2367	2617	2844
184	2003	2366	2616	2843
185	2003	2365	2614	2843
186	2002	2365	2613	2842
187	2002	2364	2612	2841
188	2002	2364	2611	2841
189	2002	2363	2610	2840
190	2002	2362	2609	2839
191	2001	2362	2607	2839
192	2001	2361	2606	2838
193	2001	2361	2606	2838
194	2000	2361	2606	2838
195	2000	2361	2606	2837
196	1999	2361	2605	2837
197	1999	2361	2605	2836
198	1998	2361	2605	2836
199	1998	2361	2605	2836
200	1997	2361	2605	2835
201	1997	2361	2605	2835
202	1996	2361	2604	2835

September	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
154	2139	2396	2560	2701
155	2146	2400	2562	2702
156	2152	2404	2564	2703
157	2158	2407	2565	2703
158	2165	2411	2567	2704
159	2171	2415	2568	2705
160	2177	2419	2570	2706
161	2183	2422	2572	2707
162	2190	2426	2573	2708
163	2196	2430	2575	2709
164	2202	2434	2576	2710
165	2208	2438	2578	2711
166	2215	2441	2580	2712
167	2221	2445	2581	2713
168	2227	2449	2583	2714
169	2230	2456	2590	2717
170	2233	2463	2598	2720
171	2235	2470	2605	2723
172	2238	2478	2613	2726
173	2241	2485	2620	2729
174	2244	2492	2628	2732
175	2246	2499	2635	2735
176	2249	2506	2643	2738
177	2252	2513	2650	2741
178	2255	2520	2658	2744
179	2617	2881	3019	3111
180	3338	3594	3734	3843
181	2617	2881	3019	3111
182	2255	2520	2658	2744
183	2252	2513	2650	2741
184	2249	2506	2643	2738
185	2246	2499	2635	2735
186	2244	2492	2628	2732
187	2241	2485	2620	2729
188	2238	2478	2613	2726
189	2235	2470	2605	2723
190	2233	2463	2598	2720
191	2230	2456	2590	2717
192	2227	2449	2583	2714
193	2221	2445	2581	2713
194	2215	2441	2580	2712
195	2208	2438	2578	2711
196	2202	2434	2576	2710
197	2196	2430	2575	2709
198	2190	2426	2573	2708
199	2183	2422	2572	2707
200	2177	2419	2570	2706
201	2171	2415	2568	2705
202	2165	2411	2567	2704

August	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
203	1996	2361	2604	2834
204	1995	2361	2604	2834
205	1994	2361	2604	2834
206	1994	2361	2604	2833
207	1993	2361	2603	2833
208	1993	2361	2603	2833
209	1992	2361	2603	2832
210	1992	2361	2603	2832
211	1991	2361	2603	2832
212	1991	2361	2603	2831
213	1990	2361	2602	2831
214	1990	2361	2602	2830
215	1989	2361	2602	2830
216	1989	2361	2602	2830
217	1985	2358	2599	2825
218	1982	2355	2596	2819
219	1978	2353	2594	2814
220	1974	2350	2591	2809
221	1971	2347	2589	2804
222	1967	2344	2586	2799
223	1963	2341	2583	2793
224	1960	2339	2581	2788
225	1956	2336	2578	2783
226	1952	2333	2575	2778
227	1949	2330	2573	2773
228	1945	2328	2570	2768
229	1941	2325	2567	2762
230	1938	2322	2565	2757
231	1934	2319	2562	2752
232	1930	2316	2559	2747
233	1927	2314	2557	2742
234	1923	2311	2554	2736
235	1919	2308	2551	2731
236	1916	2305	2549	2726
237	1912	2302	2546	2721
238	1908	2300	2544	2716
239	1905	2297	2541	2710
240	1901	2294	2538	2705
241	1899	2291	2534	2703
242	1897	2287	2529	2702
243	1895	2284	2525	2700
244	1893	2281	2520	2698
245	1891	2277	2515	2696
246	1890	2274	2511	2694
247	1888	2270	2506	2692
248	1886	2267	2502	2690
249	1884	2264	2497	2689
250	1882	2260	2493	2687
251	1880	2257	2488	2685

September	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
203	2158	2407	2565	2703
204	2152	2404	2564	2703
205	2146	2400	2562	2702
206	2139	2396	2560	2701
207	2133	2392	2559	2700
208	2127	2388	2557	2699
209	2121	2385	2555	2698
210	2114	2381	2554	2697
211	2108	2377	2552	2696
212	2102	2373	2551	2695
213	2096	2369	2549	2694
214	2089	2366	2547	2693
215	2083	2362	2546	2692
216	2077	2358	2544	2691
217	2075	2356	2542	2690
218	2072	2354	2539	2689
219	2070	2352	2537	2687
220	2068	2349	2534	2686
221	2066	2347	2532	2685
222	2063	2345	2529	2683
223	2061	2343	2527	2682
224	2059	2341	2524	2680
225	2057	2339	2522	2679
226	2054	2337	2519	2678
227	2052	2335	2517	2676
228	2050	2333	2515	2675
229	2048	2330	2512	2674
230	2046	2328	2510	2672
231	2043	2326	2507	2671
232	2041	2324	2505	2670
233	2039	2322	2502	2668
234	2037	2320	2500	2667
235	2034	2318	2497	2665
236	2032	2316	2495	2664
237	2030	2313	2492	2663
238	2028	2311	2490	2661
239	2025	2309	2487	2660
240	2023	2307	2485	2659
241	2022	2305	2483	2655
242	2021	2303	2480	2652
243	2020	2301	2478	2648
244	2019	2299	2476	2645
245	2018	2297	2474	2641
246	2017	2295	2471	2638
247	2016	2293	2469	2634
248	2014	2291	2467	2631
249	2013	2289	2465	2627
250	2012	2287	2462	2624
251	2011	2285	2460	2620

August	**Boyle Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
252	1878	2254	2484	2683
253	1876	2250	2479	2681
254	1874	2247	2474	2679
255	1872	2243	2470	2677
256	1870	2240	2465	2676
257	1868	2237	2461	2674
258	1866	2233	2456	2672
259	1865	2230	2452	2670
260	1863	2226	2447	2668
261	1861	2223	2442	2666
262	1859	2220	2438	2664
263	1857	2216	2433	2663
264	1855	2213	2429	2661
265	1853	2211	2428	2660
266	1852	2210	2427	2658
267	1850	2208	2426	2657
268	1849	2207	2425	2656
269	1847	2205	2424	2655
270	1846	2204	2423	2654
271	1845	2202	2422	2653
272	1843	2200	2421	2651
273	1842	2199	2420	2650
274	1840	2197	2419	2649
275	1839	2196	2418	2648
276	1837	2194	2417	2647
277	1836	2193	2415	2646
278	1834	2191	2414	2644
279	1833	2189	2413	2643
280	1831	2188	2412	2642
281	1830	2186	2411	2641
282	1828	2185	2410	2640
283	1827	2183	2409	2639
284	1825	2182	2408	2637
285	1824	2180	2407	2636
286	1822	2179	2406	2635
287	1821	2177	2405	2634
288	1819	2175	2404	2633
289	1818	2174	2403	2632
290	1816	2172	2402	2631
291	1815	2171	2401	2629
292	1813	2169	2400	2628
293	1812	2168	2399	2627
294	1810	2166	2398	2626
295	1809	2164	2397	2625
296	1807	2163	2396	2624
298	1806	2161	2395	2622
297	1804	2160	2394	2621
298	1803	2158	2393	2620
299	1801	2157	2392	2619

September	**Boyle Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
252	2010	2284	2458	2617
253	2009	2282	2456	2613
254	2008	2280	2454	2609
255	2007	2278	2451	2606
256	2006	2276	2449	2602
257	2004	2274	2447	2599
258	2003	2272	2445	2595
259	2002	2270	2442	2592
260	2001	2268	2440	2588
261	2000	2266	2438	2585
262	1999	2264	2436	2581
263	1998	2262	2433	2578
264	1997	2260	2431	2574
265	1996	2258	2430	2573
266	1994	2257	2428	2572
267	1993	2255	2426	2570
268	1992	2254	2425	2569
269	1990	2253	2423	2567
270	1989	2251	2422	2566
271	1988	2250	2420	2565
272	1987	2248	2419	2563
273	1985	2247	2417	2562
274	1984	2245	2416	2561
275	1983	2244	2414	2559
276	1982	2242	2412	2558
277	1980	2241	2411	2556
278	1979	2239	2409	2555
279	1978	2238	2408	2554
280	1977	2236	2406	2552
281	1975	2235	2405	2551
282	1974	2233	2403	2549
283	1973	2232	2401	2548
284	1972	2230	2400	2547
285	1970	2229	2398	2545
286	1969	2227	2397	2544
287	1968	2226	2395	2542
288	1967	2225	2394	2541
289	1965	2223	2392	2540
290	1964	2222	2391	2538
291	1963	2220	2389	2537
292	1961	2219	2387	2536
293	1960	2217	2386	2534
294	1959	2216	2384	2533
295	1958	2214	2383	2531
296	1956	2213	2381	2530
298	1955	2211	2380	2529
297	1954	2210	2378	2527
298	1953	2208	2376	2526
299	1951	2207	2375	2524

August	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
300	1800	2155	2391	2618
301	1798	2154	2390	2617
302	1797	2152	2389	2615
303	1796	2150	2388	2614
304	1794	2149	2387	2613
305	1793	2147	2386	2612
306	1791	2146	2385	2611
307	1790	2144	2384	2610
308	1788	2143	2383	2608
309	1787	2141	2382	2607
310	1785	2139	2381	2606
311	1784	2138	2380	2605
312	1782	2136	2379	2604
313	1781	2135	2378	2603
314	1779	2133	2377	2601
315	1778	2132	2376	2600
316	1776	2130	2375	2599
317	1775	2128	2374	2598
318	1773	2127	2373	2597
319	1772	2125	2372	2596
320	1770	2124	2371	2594
321	1769	2122	2370	2593
322	1767	2121	2369	2592
323	1766	2119	2367	2591
324	1764	2118	2366	2590
325	1763	2116	2365	2589
326	1761	2114	2364	2587
327	1760	2113	2363	2586
328	1758	2111	2362	2585
329	1757	2110	2361	2584
330	1755	2108	2360	2583
331	1754	2107	2359	2582
332	1752	2105	2358	2580
333	1751	2103	2357	2579
334	1749	2102	2356	2578
335	1748	2100	2355	2577
336	1746	2099	2354	2576
337	1745	2097	2353	2575
338	1744	2096	2352	2573
339	1742	2094	2351	2572
340	1741	2093	2350	2571
341	1739	2091	2349	2570
342	1738	2089	2348	2569
343	1736	2088	2347	2568
344	1735	2086	2346	2566
345	1733	2085	2345	2565
346	1732	2083	2344	2564
347	1730	2082	2343	2563
348	1729	2080	2342	2562

September	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
300	1950	2205	2373	2523
301	1949	2204	2372	2522
302	1948	2202	2370	2520
303	1946	2201	2369	2519
304	1945	2199	2367	2517
305	1944	2198	2366	2516
306	1943	2196	2364	2515
307	1941	2195	2362	2513
308	1940	2194	2361	2512
309	1939	2192	2359	2511
310	1938	2191	2358	2509
311	1936	2189	2356	2508
312	1935	2188	2355	2506
313	1934	2186	2353	2505
314	1932	2185	2351	2504
315	1931	2183	2350	2502
316	1930	2182	2348	2501
317	1929	2180	2347	2499
318	1927	2179	2345	2498
319	1926	2177	2344	2497
320	1925	2176	2342	2495
321	1924	2174	2340	2494
322	1922	2173	2339	2492
323	1921	2171	2337	2491
324	1920	2170	2336	2490
325	1919	2168	2334	2488
326	1917	2167	2333	2487
327	1916	2166	2331	2486
328	1915	2164	2330	2484
329	1914	2163	2328	2483
330	1912	2161	2326	2481
331	1911	2160	2325	2480
332	1910	2158	2323	2479
333	1908	2157	2322	2477
334	1907	2155	2320	2476
335	1906	2154	2319	2474
336	1905	2152	2317	2473
337	1903	2151	2315	2472
338	1902	2149	2314	2470
339	1901	2148	2312	2469
340	1900	2146	2311	2467
341	1898	2145	2309	2466
342	1897	2143	2308	2465
343	1896	2142	2306	2463
344	1895	2140	2305	2462
345	1893	2139	2303	2461
346	1892	2138	2301	2459
347	1891	2136	2300	2458
348	1890	2135	2298	2456

August	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
349	1727	2078	2341	2561
350	1726	2077	2340	2559
351	1724	2075	2339	2558
352	1723	2074	2338	2557
353	1721	2072	2337	2556
354	1720	2071	2336	2555
355	1718	2069	2335	2554
356	1717	2068	2334	2552
357	1715	2066	2333	2551
358	1714	2064	2332	2550
359	1712	2063	2331	2549
360	1712	2063	2331	2549

September	Boyle Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
349	1888	2133	2297	2455
350	1887	2132	2295	2454
351	1886	2130	2294	2452
352	1885	2129	2292	2451
353	1883	2127	2290	2449
354	1882	2126	2289	2448
355	1881	2124	2287	2447
356	1879	2123	2286	2445
357	1878	2121	2284	2444
358	1877	2120	2283	2442
359	1876	2118	2281	2441
360	1876	2118	2281	2441

KLAMATH RIVER BELOW FALL CREEK NEAR COPCO, CA

Annual	Copco Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
0	6858	8497	9160	10028
1	6864	8502	9168	10033
2	6870	8508	9177	10037
3	6876	8514	9185	10041
4	6882	8519	9193	10046
5	6888	8525	9201	10050
6	6895	8530	9210	10055
7	6901	8536	9218	10059
8	6907	8542	9226	10063
9	6913	8547	9234	10068
10	6919	8553	9242	10072
11	6925	8558	9251	10076
12	6931	8564	9259	10081
13	6938	8570	9267	10085
14	6944	8575	9275	10089
15	6950	8581	9284	10094
16	6956	8586	9292	10098
17	6962	8592	9300	10102
18	6968	8598	9308	10107
19	6974	8603	9317	10111
20	6981	8609	9325	10116
21	6987	8614	9333	10120
22	6993	8620	9341	10124
23	6999	8626	9349	10129
24	7005	8631	9358	10133
25	7011	8637	9366	10137
26	7017	8642	9374	10142
27	7024	8648	9382	10146
28	7030	8654	9391	10150

Annual	Copco Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
181	9386	11190	12284	13051
182	8695	10424	11535	12299
183	8678	10422	11484	12215
184	8661	10421	11432	12132
185	8644	10419	11381	12048
186	8628	10417	11329	11965
187	8611	10415	11278	11881
188	8594	10413	11226	11798
189	8577	10411	11175	11714
190	8560	10409	11123	11630
191	8544	10407	11072	11547
192	8527	10405	11020	11463
193	8506	10366	10996	11448
194	8486	10326	10971	11433
195	8465	10287	10946	11418
196	8445	10247	10922	11402
197	8424	10207	10897	11387
198	8403	10168	10873	11372
199	8383	10128	10848	11356
200	8362	10088	10823	11341
201	8342	10049	10799	11326
202	8321	10009	10774	11311
203	8301	9970	10750	11295
204	8280	9930	10725	11280
205	8259	9890	10700	11265
206	8239	9851	10676	11249
207	8218	9811	10651	11234
208	8198	9772	10627	11219
209	8177	9732	10602	11204

Annual	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
29	7036	8659	9399	10155
30	7042	8665	9407	10159
31	7048	8670	9415	10163
32	7054	8676	9423	10168
33	7060	8682	9432	10172
34	7067	8687	9440	10177
35	7073	8693	9448	10181
36	7079	8698	9456	10185
37	7085	8704	9465	10190
38	7091	8710	9473	10194
39	7097	8715	9481	10198
40	7103	8721	9489	10203
41	7110	8726	9497	10207
42	7116	8732	9506	10211
43	7122	8738	9514	10216
44	7128	8743	9522	10220
45	7134	8749	9530	10224
46	7140	8754	9539	10229
47	7146	8760	9547	10233
48	7153	8766	9555	10238
49	7159	8771	9563	10242
50	7165	8777	9571	10246
51	7171	8782	9580	10251
52	7177	8788	9588	10255
53	7183	8794	9596	10259
54	7189	8799	9604	10264
55	7195	8805	9613	10268
56	7202	8810	9621	10272
57	7208	8816	9629	10277
58	7214	8822	9637	10281
59	7220	8827	9645	10285
60	7226	8833	9654	10290
61	7232	8838	9662	10294
62	7238	8844	9670	10298
63	7245	8850	9678	10303
64	7251	8855	9687	10307
65	7257	8861	9695	10312
66	7263	8866	9703	10316
67	7269	8872	9711	10320
68	7275	8878	9719	10325
69	7281	8883	9728	10329
70	7288	8889	9736	10333
71	7294	8894	9744	10338
72	7300	8900	9752	10342
73	7306	8906	9761	10346
74	7312	8911	9769	10351
75	7318	8917	9777	10355
76	7324	8922	9785	10359
77	7331	8928	9793	10364

Annual	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
210	8157	9692	10577	11188
211	8136	9653	10553	11173
212	8115	9613	10528	11158
213	8095	9573	10504	11142
214	8074	9534	10479	11127
215	8054	9494	10454	11112
216	8033	9455	10430	11097
217	8015	9442	10421	11082
218	7997	9429	10411	11068
219	7979	9416	10402	11054
220	7961	9403	10393	11039
221	7944	9390	10384	11025
222	7926	9377	10375	11011
223	7908	9364	10366	10997
224	7890	9352	10357	10982
225	7872	9339	10347	10968
226	7854	9326	10338	10954
227	7836	9313	10329	10939
228	7818	9300	10320	10925
229	7800	9287	10311	10911
230	7782	9274	10302	10896
231	7764	9261	10293	10882
232	7746	9248	10283	10868
233	7728	9236	10274	10853
234	7710	9223	10265	10839
235	7692	9210	10256	10825
236	7675	9197	10247	10811
237	7657	9184	10238	10796
238	7639	9171	10229	10782
239	7621	9158	10219	10768
240	7603	9145	10210	10753
241	7596	9141	10199	10741
242	7590	9136	10189	10728
243	7583	9132	10178	10715
244	7577	9127	10167	10702
245	7570	9122	10156	10689
246	7564	9118	10145	10677
247	7557	9113	10134	10664
248	7551	9108	10123	10651
249	7544	9104	10113	10638
250	7538	9099	10102	10626
251	7531	9095	10091	10613
252	7525	9090	10080	10600
253	7519	9085	10069	10587
254	7512	9081	10058	10574
255	7506	9076	10047	10562
256	7499	9072	10037	10549
257	7493	9067	10026	10536
258	7486	9062	10015	10523

Annual	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
78	7337	8934	9802	10368
79	7343	8939	9810	10373
80	7349	8945	9818	10377
81	7355	8950	9826	10381
82	7361	8956	9835	10386
83	7367	8962	9843	10390
84	7374	8967	9851	10394
85	7380	8973	9859	10399
86	7386	8979	9868	10403
87	7392	8984	9876	10407
88	7398	8990	9884	10412
89	7404	8995	9892	10416
90	7410	9001	9900	10420
91	7417	9007	9909	10425
92	7423	9012	9917	10429
93	7429	9018	9925	10434
94	7435	9023	9933	10438
95	7441	9029	9942	10442
96	7447	9035	9950	10447
97	7454	9039	9961	10459
98	7460	9044	9971	10472
99	7467	9048	9982	10485
100	7473	9053	9993	10498
101	7480	9058	10004	10511
102	7486	9062	10015	10523
103	7493	9067	10026	10536
104	7499	9072	10037	10549
105	7506	9076	10047	10562
106	7512	9081	10058	10574
107	7519	9085	10069	10587
108	7525	9090	10080	10600
109	7531	9095	10091	10613
110	7538	9099	10102	10626
111	7544	9104	10113	10638
112	7551	9108	10123	10651
113	7557	9113	10134	10664
114	7564	9118	10145	10677
115	7570	9122	10156	10689
116	7577	9127	10167	10702
117	7583	9132	10178	10715
118	7590	9136	10189	10728
119	7596	9141	10199	10741
120	7603	9145	10210	10753
121	7621	9158	10219	10768
122	7639	9171	10229	10782
123	7657	9184	10238	10796
124	7675	9197	10247	10811
125	7692	9210	10256	10825
126	7710	9223	10265	10839

Annual	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
259	7480	9058	10004	10511
260	7473	9053	9993	10498
261	7467	9048	9982	10485
262	7460	9044	9971	10472
263	7454	9039	9961	10459
264	7447	9035	9950	10447
265	7441	9029	9942	10442
266	7435	9023	9933	10438
267	7429	9018	9925	10434
268	7423	9012	9917	10429
269	7417	9007	9909	10425
270	7410	9001	9900	10420
271	7404	8995	9892	10416
272	7398	8990	9884	10412
273	7392	8984	9876	10407
274	7386	8979	9868	10403
275	7380	8973	9859	10399
276	7374	8967	9851	10394
277	7367	8962	9843	10390
278	7361	8956	9835	10386
279	7355	8950	9826	10381
280	7349	8945	9818	10377
281	7343	8939	9810	10373
282	7337	8934	9802	10368
283	7331	8928	9793	10364
284	7324	8922	9785	10359
285	7318	8917	9777	10355
286	7312	8911	9769	10351
287	7306	8906	9761	10346
288	7300	8900	9752	10342
289	7294	8894	9744	10338
290	7288	8889	9736	10333
291	7281	8883	9728	10329
292	7275	8878	9719	10325
293	7269	8872	9711	10320
294	7263	8866	9703	10316
295	7257	8861	9695	10312
296	7251	8855	9687	10307
298	7245	8850	9678	10303
297	7238	8844	9670	10298
298	7232	8838	9662	10294
299	7226	8833	9654	10290
300	7220	8827	9645	10285
301	7214	8822	9637	10281
302	7208	8816	9629	10277
303	7202	8810	9621	10272
304	7195	8805	9613	10268
305	7189	8799	9604	10264
306	7183	8794	9596	10259

Annual	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
127	7728	9236	10274	10853
128	7746	9248	10283	10868
129	7764	9261	10293	10882
130	7782	9274	10302	10896
131	7800	9287	10311	10911
132	7818	9300	10320	10925
133	7836	9313	10329	10939
134	7854	9326	10338	10954
135	7872	9339	10347	10968
136	7890	9352	10357	10982
137	7908	9364	10366	10997
138	7926	9377	10375	11011
139	7944	9390	10384	11025
140	7961	9403	10393	11039
141	7979	9416	10402	11054
142	7997	9429	10411	11068
143	8015	9442	10421	11082
144	8033	9455	10430	11097
145	8054	9494	10454	11112
146	8074	9534	10479	11127
147	8095	9573	10504	11142
148	8115	9613	10528	11158
149	8136	9653	10553	11173
150	8157	9692	10577	11188
151	8177	9732	10602	11204
152	8198	9772	10627	11219
153	8218	9811	10651	11234
154	8239	9851	10676	11249
155	8259	9890	10700	11265
156	8280	9930	10725	11280
157	8301	9970	10750	11295
158	8321	10009	10774	11311
159	8342	10049	10799	11326
160	8362	10088	10823	11341
161	8383	10128	10848	11356
162	8403	10168	10873	11372
163	8424	10207	10897	11387
164	8445	10247	10922	11402
165	8465	10287	10946	11418
166	8486	10326	10971	11433
167	8506	10366	10996	11448
168	8527	10405	11020	11463
169	8544	10407	11072	11547
170	8560	10409	11123	11630
171	8577	10411	11175	11714
172	8594	10413	11226	11798
173	8611	10415	11278	11881
174	8628	10417	11329	11965
175	8644	10419	11381	12048

Annual	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
307	7177	8788	9588	10255
308	7171	8782	9580	10251
309	7165	8777	9571	10246
310	7159	8771	9563	10242
311	7153	8766	9555	10238
312	7146	8760	9547	10233
313	7140	8754	9539	10229
314	7134	8749	9530	10224
315	7128	8743	9522	10220
316	7122	8738	9514	10216
317	7116	8732	9506	10211
318	7110	8726	9497	10207
319	7103	8721	9489	10203
320	7097	8715	9481	10198
321	7091	8710	9473	10194
322	7085	8704	9465	10190
323	7079	8698	9456	10185
324	7073	8693	9448	10181
325	7067	8687	9440	10177
326	7060	8682	9432	10172
327	7054	8676	9423	10168
328	7048	8670	9415	10163
329	7042	8665	9407	10159
330	7036	8659	9399	10155
331	7030	8654	9391	10150
332	7024	8648	9382	10146
333	7017	8642	9374	10142
334	7011	8637	9366	10137
335	7005	8631	9358	10133
336	6999	8626	9349	10129
337	6993	8620	9341	10124
338	6987	8614	9333	10120
339	6981	8609	9325	10116
340	6974	8603	9317	10111
341	6968	8598	9308	10107
342	6962	8592	9300	10102
343	6956	8586	9292	10098
344	6950	8581	9284	10094
345	6944	8575	9275	10089
346	6938	8570	9267	10085
347	6931	8564	9259	10081
348	6925	8558	9251	10076
349	6919	8553	9242	10072
350	6913	8547	9234	10068
351	6907	8542	9226	10063
352	6901	8536	9218	10059
353	6895	8530	9210	10055
354	6888	8525	9201	10050
355	6882	8519	9193	10046

Annual	Copco Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
176	8661	10421	11432	12132
177	8678	10422	11484	12215
178	8695	10424	11535	12299
179	9386	11190	12284	13051
180	10750	12720	13730	14470

Annual	Copco Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
356	6876	8514	9185	10041
357	6870	8508	9177	10037
358	6864	8502	9168	10033
359	6858	8497	9160	10028
360	6858	8497	9160	10028

7/01-11/30	Copco Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
0	3097	3714	4236	4781
1	3098	3718	4242	4787
2	3100	3723	4247	4793
3	3101	3727	4253	4800
4	3102	3732	4259	4806
5	3104	3736	4264	4812
6	3105	3740	4270	4818
7	3107	3745	4275	4824
8	3108	3749	4281	4830
9	3109	3753	4286	4836
10	3111	3758	4292	4842
11	3112	3762	4297	4849
12	3113	3767	4303	4855
13	3115	3771	4309	4861
14	3116	3775	4314	4867
15	3117	3780	4320	4873
16	3119	3784	4325	4879
17	3120	3789	4331	4885
18	3122	3793	4336	4892
19	3123	3797	4342	4898
20	3124	3802	4348	4904
21	3126	3806	4353	4910
22	3127	3810	4359	4916
23	3128	3815	4364	4922
24	3130	3819	4370	4928
25	3131	3824	4375	4934
26	3132	3828	4381	4941
27	3134	3832	4387	4947
28	3135	3837	4392	4953
29	3137	3841	4398	4959
30	3138	3846	4403	4965
31	3139	3850	4409	4971
32	3141	3854	4414	4977
33	3142	3859	4420	4983
34	3143	3863	4426	4990
35	3145	3867	4431	4996
36	3146	3872	4437	5002
37	3147	3876	4442	5008
38	3149	3881	4448	5014

6/01-10/31	Copco Discharge (ft^3/s) by Return Period (years)			
Time(hr)	10	25	50	100
0	2637	3330	4059	5276
1	2646	3343	4073	5283
2	2654	3356	4087	5290
3	2663	3369	4101	5297
4	2672	3383	4115	5304
5	2680	3396	4129	5311
6	2689	3409	4143	5318
7	2698	3422	4157	5325
8	2706	3435	4171	5332
9	2715	3448	4185	5339
10	2724	3461	4199	5347
11	2732	3474	4213	5354
12	2741	3487	4227	5361
13	2750	3500	4241	5368
14	2758	3513	4255	5375
15	2767	3526	4269	5382
16	2775	3540	4283	5389
17	2784	3553	4297	5396
18	2793	3566	4311	5403
19	2801	3579	4325	5410
20	2810	3592	4339	5417
21	2819	3605	4353	5424
22	2827	3618	4367	5432
23	2836	3631	4381	5439
24	2845	3644	4395	5446
25	2853	3657	4409	5453
26	2862	3670	4423	5460
27	2871	3683	4437	5467
28	2879	3697	4451	5474
29	2888	3710	4465	5481
30	2897	3723	4480	5488
31	2905	3736	4494	5495
32	2914	3749	4508	5502
33	2923	3762	4522	5509
34	2931	3775	4536	5516
35	2940	3788	4550	5524
36	2949	3801	4564	5531
37	2957	3814	4578	5538
38	2966	3827	4592	5545

7/01-11/30	Copco Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
39	3150	3885	4453	5020
40	3152	3889	4459	5026
41	3153	3894	4465	5032
42	3154	3898	4470	5039
43	3156	3902	4476	5045
44	3157	3907	4481	5051
45	3158	3911	4487	5057
46	3160	3916	4492	5063
47	3161	3920	4498	5069
48	3163	3924	4504	5075
49	3164	3929	4509	5082
50	3165	3933	4515	5088
51	3167	3938	4520	5094
52	3168	3942	4526	5100
53	3169	3946	4531	5106
54	3171	3951	4537	5112
55	3172	3955	4542	5118
56	3173	3959	4548	5124
57	3175	3964	4554	5131
58	3176	3968	4559	5137
59	3178	3973	4565	5143
60	3179	3977	4570	5149
61	3180	3981	4576	5155
62	3182	3986	4581	5161
63	3183	3990	4587	5167
64	3184	3994	4593	5173
65	3186	3999	4598	5180
66	3187	4003	4604	5186
67	3188	4008	4609	5192
68	3190	4012	4615	5198
69	3191	4016	4620	5204
70	3193	4021	4626	5210
71	3194	4025	4632	5216
72	3195	4030	4637	5222
73	3197	4034	4643	5229
74	3198	4038	4648	5235
75	3199	4043	4654	5241
76	3201	4047	4659	5247
77	3202	4051	4665	5253
78	3203	4056	4671	5259
79	3205	4060	4676	5265
80	3206	4065	4682	5271
81	3208	4069	4687	5278
82	3209	4073	4693	5284
83	3210	4078	4698	5290
84	3212	4082	4704	5296
85	3213	4086	4710	5302
86	3214	4091	4715	5308
87	3216	4095	4721	5314

6/01-10/31	Copco Discharge (ft^3/s) by Return Period (years)			
Time(hr)	10	25	50	100
39	2974	3840	4606	5552
40	2983	3853	4620	5559
41	2992	3867	4634	5566
42	3000	3880	4648	5573
43	3009	3893	4662	5580
44	3018	3906	4676	5587
45	3026	3919	4690	5594
46	3035	3932	4704	5601
47	3044	3945	4718	5609
48	3052	3958	4732	5616
49	3061	3971	4746	5623
50	3070	3984	4760	5630
51	3078	3997	4774	5637
52	3087	4010	4788	5644
53	3096	4024	4802	5651
54	3104	4037	4816	5658
55	3113	4050	4830	5665
56	3122	4063	4844	5672
57	3130	4076	4858	5679
58	3139	4089	4872	5686
59	3148	4102	4886	5694
60	3156	4115	4900	5701
61	3165	4128	4914	5708
62	3174	4141	4928	5715
63	3182	4154	4942	5722
64	3191	4167	4956	5729
65	3199	4181	4970	5736
66	3208	4194	4984	5743
67	3217	4207	4998	5750
68	3225	4220	5012	5757
69	3234	4233	5026	5764
70	3243	4246	5040	5771
71	3251	4259	5054	5778
72	3260	4272	5068	5786
73	3269	4285	5082	5793
74	3277	4298	5096	5800
75	3286	4311	5110	5807
76	3295	4324	5124	5814
77	3303	4337	5138	5821
78	3312	4351	5152	5828
79	3321	4364	5166	5835
80	3329	4377	5180	5842
81	3338	4390	5194	5849
82	3347	4403	5208	5856
83	3355	4416	5222	5863
84	3364	4429	5236	5871
85	3373	4442	5250	5878
86	3381	4455	5264	5885
87	3390	4468	5278	5892

7/01-11/30	Copco Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
88	3217	4100	4726	5321
89	3218	4104	4732	5327
90	3220	4108	4737	5333
91	3221	4113	4743	5339
92	3223	4117	4748	5345
93	3224	4122	4754	5351
94	3225	4126	4760	5357
95	3227	4130	4765	5363
96	3228	4135	4771	5370
97	3229	4135	4771	5370
98	3230	4135	4771	5370
99	3232	4135	4771	5371
100	3233	4136	4772	5371
101	3234	4136	4772	5371
102	3235	4136	4772	5372
103	3236	4136	4772	5372
104	3238	4137	4773	5372
105	3239	4137	4773	5373
106	3240	4137	4773	5373
107	3241	4137	4773	5373
108	3243	4138	4774	5374
109	3244	4138	4774	5374
110	3245	4138	4774	5374
111	3246	4138	4774	5374
112	3247	4138	4774	5375
113	3249	4139	4775	5375
114	3250	4139	4775	5375
115	3251	4139	4775	5376
116	3252	4139	4775	5376
117	3253	4140	4776	5376
118	3255	4140	4776	5377
119	3256	4140	4776	5377
120	3257	4140	4776	5377
121	3266	4143	4776	5378
122	3276	4146	4776	5378
123	3285	4149	4776	5378
124	3295	4152	4776	5378
125	3304	4155	4776	5378
126	3314	4158	4776	5378
127	3323	4161	4776	5378
128	3333	4164	4776	5378
129	3342	4167	4776	5378
130	3352	4170	4776	5378
131	3361	4173	4776	5378
132	3371	4176	4777	5378
133	3380	4178	4777	5378
134	3389	4181	4777	5378
135	3399	4184	4777	5378
136	3408	4187	4777	5378

6/01-10/31	Copco Discharge (ft^3/s) by Return Period (years)			
Time(hr)	**10**	**25**	**50**	**100**
88	3398	4481	5292	5899
89	3407	4494	5306	5906
90	3416	4508	5320	5913
91	3424	4521	5334	5920
92	3433	4534	5348	5927
93	3442	4547	5362	5934
94	3450	4560	5376	5941
95	3459	4573	5390	5948
96	3468	4586	5404	5956
97	3473	4591	5413	5985
98	3478	4596	5423	6014
99	3483	4601	5432	6043
100	3489	4607	5441	6072
101	3494	4612	5451	6101
102	3499	4617	5460	6130
103	3504	4622	5469	6159
104	3510	4627	5479	6189
105	3515	4632	5488	6218
106	3520	4637	5497	6247
107	3525	4642	5507	6276
108	3531	4648	5516	6305
109	3536	4653	5525	6334
110	3541	4658	5535	6363
111	3546	4663	5544	6392
112	3551	4668	5553	6421
113	3557	4673	5563	6451
114	3562	4678	5572	6480
115	3567	4683	5581	6509
116	3572	4688	5591	6538
117	3578	4694	5600	6567
118	3583	4699	5609	6596
119	3588	4704	5619	6625
120	3593	4709	5628	6654
121	3605	4728	5655	6688
122	3616	4747	5681	6722
123	3628	4766	5708	6756
124	3639	4786	5735	6790
125	3651	4805	5761	6823
126	3662	4824	5788	6857
127	3674	4843	5814	6891
128	3685	4862	5841	6925
129	3697	4881	5868	6959
130	3708	4901	5894	6992
131	3720	4920	5921	7026
132	3732	4939	5948	7060
133	3743	4958	5974	7094
134	3755	4977	6001	7128
135	3766	4997	6027	7161
136	3778	5016	6054	7195

7/01-11/30	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
137	3418	4190	4777	5378
138	3427	4193	4777	5378
139	3437	4196	4777	5378
140	3446	4199	4777	5378
141	3456	4202	4777	5378
142	3465	4205	4777	5378
143	3475	4208	4777	5378
144	3484	4211	4777	5379
145	3485	4211	4777	5379
146	3486	4211	4778	5379
147	3487	4211	4778	5379
148	3488	4211	4778	5380
149	3489	4212	4779	5380
150	3490	4212	4779	5380
151	3492	4212	4780	5380
152	3493	4212	4780	5381
153	3494	4212	4780	5381
154	3495	4213	4781	5381
155	3496	4213	4781	5381
156	3497	4213	4782	5382
157	3498	4213	4782	5382
158	3499	4213	4782	5382
159	3500	4214	4783	5382
160	3501	4214	4783	5382
161	3502	4214	4783	5383
162	3504	4214	4784	5383
163	3505	4214	4784	5383
164	3506	4215	4785	5383
165	3507	4215	4785	5384
166	3508	4215	4785	5384
167	3509	4215	4786	5384
168	3510	4215	4786	5384
169	3513	4217	4787	5385
170	3515	4219	4787	5386
171	3518	4220	4787	5387
172	3520	4222	4788	5388
173	3523	4224	4788	5388
174	3525	4225	4789	5389
175	3528	4227	4789	5390
176	3530	4229	4789	5391
177	3533	4230	4790	5391
178	3535	4232	4790	5392
179	4204	4888	5433	6017
180	5539	6197	6718	7265
181	4204	4888	5433	6017
182	3535	4232	4790	5392
183	3533	4230	4790	5391
184	3530	4229	4789	5391
185	3528	4227	4789	5390

6/01-10/31	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time(hr)	**10**	**25**	**50**	**100**
137	3789	5035	6081	7229
138	3801	5054	6107	7263
139	3812	5073	6134	7297
140	3824	5092	6160	7330
141	3835	5112	6187	7364
142	3847	5131	6214	7398
143	3858	5150	6240	7432
144	3870	5169	6267	7466
145	3876	5173	6268	7466
146	3882	5176	6270	7466
147	3888	5180	6271	7466
148	3894	5184	6273	7466
149	3900	5187	6274	7466
150	3906	5191	6275	7467
151	3912	5195	6277	7467
152	3919	5198	6278	7467
153	3925	5202	6280	7467
154	3931	5206	6281	7467
155	3937	5209	6283	7467
156	3943	5213	6284	7468
157	3949	5217	6285	7468
158	3955	5220	6287	7468
159	3961	5224	6288	7468
160	3967	5228	6290	7468
161	3974	5231	6291	7468
162	3980	5235	6293	7468
163	3986	5239	6294	7469
164	3992	5242	6295	7469
165	3998	5246	6297	7469
166	4004	5250	6298	7469
167	4010	5253	6300	7469
168	4016	5257	6301	7469
169	4015	5254	6299	7470
170	4014	5251	6296	7471
171	4013	5248	6294	7471
172	4012	5244	6291	7472
173	4011	5241	6289	7473
174	4010	5238	6287	7473
175	4009	5235	6284	7474
176	4008	5232	6282	7475
177	4007	5229	6280	7475
178	4006	5226	6277	7476
179	4702	5904	6916	8045
180	6094	7264	8197	9183
181	4702	5904	6916	8045
182	4006	5226	6277	7476
183	4007	5229	6280	7475
184	4008	5232	6282	7475
185	4009	5235	6284	7474

7/01-11/30	Copco Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
186	3525	4225	4789	5389
187	3523	4224	4788	5388
188	3520	4222	4788	5388
189	3518	4220	4787	5387
190	3515	4219	4787	5386
191	3513	4217	4787	5385
192	3510	4215	4786	5384
193	3509	4215	4786	5384
194	3508	4215	4785	5384
195	3507	4215	4785	5384
196	3506	4215	4785	5383
197	3505	4214	4784	5383
198	3504	4214	4784	5383
199	3502	4214	4783	5383
200	3501	4214	4783	5382
201	3500	4214	4783	5382
202	3499	4213	4782	5382
203	3498	4213	4782	5382
204	3497	4213	4782	5382
205	3496	4213	4781	5381
206	3495	4213	4781	5381
207	3494	4212	4780	5381
208	3493	4212	4780	5381
209	3492	4212	4780	5380
210	3490	4212	4779	5380
211	3489	4212	4779	5380
212	3488	4211	4778	5380
213	3487	4211	4778	5379
214	3486	4211	4778	5379
215	3485	4211	4777	5379
216	3484	4211	4777	5379
217	3475	4208	4777	5378
218	3465	4205	4777	5378
219	3456	4202	4777	5378
220	3446	4199	4777	5378
221	3437	4196	4777	5378
222	3427	4193	4777	5378
223	3418	4190	4777	5378
224	3408	4187	4777	5378
225	3399	4184	4777	5378
226	3389	4181	4777	5378
227	3380	4178	4777	5378
228	3371	4176	4777	5378
229	3361	4173	4776	5378
230	3352	4170	4776	5378
231	3342	4167	4776	5378
232	3333	4164	4776	5378
233	3323	4161	4776	5378
234	3314	4158	4776	5378

6/01-10/31	Copco Discharge (ft^3/s) by Return Period (years)			
Time(hr)	10	25	50	100
186	4010	5238	6287	7473
187	4011	5241	6289	7473
188	4012	5244	6291	7472
189	4013	5248	6294	7471
190	4014	5251	6296	7471
191	4015	5254	6299	7470
192	4016	5257	6301	7469
193	4010	5253	6300	7469
194	4004	5250	6298	7469
195	3998	5246	6297	7469
196	3992	5242	6295	7469
197	3986	5239	6294	7469
198	3980	5235	6293	7468
199	3974	5231	6291	7468
200	3967	5228	6290	7468
201	3961	5224	6288	7468
202	3955	5220	6287	7468
203	3949	5217	6285	7468
204	3943	5213	6284	7468
205	3937	5209	6283	7467
206	3931	5206	6281	7467
207	3925	5202	6280	7467
208	3919	5198	6278	7467
209	3912	5195	6277	7467
210	3906	5191	6275	7467
211	3900	5187	6274	7466
212	3894	5184	6273	7466
213	3888	5180	6271	7466
214	3882	5176	6270	7466
215	3876	5173	6268	7466
216	3870	5169	6267	7466
217	3858	5150	6240	7432
218	3847	5131	6214	7398
219	3835	5112	6187	7364
220	3824	5092	6160	7330
221	3812	5073	6134	7297
222	3801	5054	6107	7263
223	3789	5035	6081	7229
224	3778	5016	6054	7195
225	3766	4997	6027	7161
226	3755	4977	6001	7128
227	3743	4958	5974	7094
228	3732	4939	5948	7060
229	3720	4920	5921	7026
230	3708	4901	5894	6992
231	3697	4881	5868	6959
232	3685	4862	5841	6925
233	3674	4843	5814	6891
234	3662	4824	5788	6857

7/01-11/30	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
235	3304	4155	4776	5378
236	3295	4152	4776	5378
237	3285	4149	4776	5378
238	3276	4146	4776	5378
239	3266	4143	4776	5378
240	3257	4140	4776	5377
241	3256	4140	4776	5377
242	3255	4140	4776	5377
243	3253	4140	4776	5376
244	3252	4139	4775	5376
245	3251	4139	4775	5376
246	3250	4139	4775	5375
247	3249	4139	4775	5375
248	3247	4138	4774	5375
249	3246	4138	4774	5374
250	3245	4138	4774	5374
251	3244	4138	4774	5374
252	3243	4138	4774	5374
253	3241	4137	4773	5373
254	3240	4137	4773	5373
255	3239	4137	4773	5373
256	3238	4137	4773	5372
257	3236	4136	4772	5372
258	3235	4136	4772	5372
259	3234	4136	4772	5371
260	3233	4136	4772	5371
261	3232	4135	4771	5371
262	3230	4135	4771	5370
263	3229	4135	4771	5370
264	3228	4135	4771	5370
265	3227	4130	4765	5363
266	3225	4126	4760	5357
267	3224	4122	4754	5351
268	3223	4117	4748	5345
269	3221	4113	4743	5339
270	3220	4108	4737	5333
271	3218	4104	4732	5327
272	3217	4100	4726	5321
273	3216	4095	4721	5314
274	3214	4091	4715	5308
275	3213	4086	4710	5302
276	3212	4082	4704	5296
277	3210	4078	4698	5290
278	3209	4073	4693	5284
279	3208	4069	4687	5278
280	3206	4065	4682	5271
281	3205	4060	4676	5265
282	3203	4056	4671	5259
283	3202	4051	4665	5253

6/01-10/31	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time(hr)	**10**	**25**	**50**	**100**
235	3651	4805	5761	6823
236	3639	4786	5735	6790
237	3628	4766	5708	6756
238	3616	4747	5681	6722
239	3605	4728	5655	6688
240	3593	4709	5628	6654
241	3588	4704	5619	6625
242	3583	4699	5609	6596
243	3578	4694	5600	6567
244	3572	4688	5591	6538
245	3567	4683	5581	6509
246	3562	4678	5572	6480
247	3557	4673	5563	6451
248	3551	4668	5553	6421
249	3546	4663	5544	6392
250	3541	4658	5535	6363
251	3536	4653	5525	6334
252	3531	4648	5516	6305
253	3525	4642	5507	6276
254	3520	4637	5497	6247
255	3515	4632	5488	6218
256	3510	4627	5479	6189
257	3504	4622	5469	6159
258	3499	4617	5460	6130
259	3494	4612	5451	6101
260	3489	4607	5441	6072
261	3483	4601	5432	6043
262	3478	4596	5423	6014
263	3473	4591	5413	5985
264	3468	4586	5404	5956
265	3459	4573	5390	5948
266	3450	4560	5376	5941
267	3442	4547	5362	5934
268	3433	4534	5348	5927
269	3424	4521	5334	5920
270	3416	4508	5320	5913
271	3407	4494	5306	5906
272	3398	4481	5292	5899
273	3390	4468	5278	5892
274	3381	4455	5264	5885
275	3373	4442	5250	5878
276	3364	4429	5236	5871
277	3355	4416	5222	5863
278	3347	4403	5208	5856
279	3338	4390	5194	5849
280	3329	4377	5180	5842
281	3321	4364	5166	5835
282	3312	4351	5152	5828
283	3303	4337	5138	5821

7/01-11/30	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
284	3201	4047	4659	5247
285	3199	4043	4654	5241
286	3198	4038	4648	5235
287	3197	4034	4643	5229
288	3195	4030	4637	5222
289	3194	4025	4632	5216
290	3193	4021	4626	5210
291	3191	4016	4620	5204
292	3190	4012	4615	5198
293	3188	4008	4609	5192
294	3187	4003	4604	5186
295	3186	3999	4598	5180
296	3184	3994	4593	5173
298	3183	3990	4587	5167
297	3182	3986	4581	5161
298	3180	3981	4576	5155
299	3179	3977	4570	5149
300	3178	3973	4565	5143
301	3176	3968	4559	5137
302	3175	3964	4554	5131
303	3173	3959	4548	5124
304	3172	3955	4542	5118
305	3171	3951	4537	5112
306	3169	3946	4531	5106
307	3168	3942	4526	5100
308	3167	3938	4520	5094
309	3165	3933	4515	5088
310	3164	3929	4509	5082
311	3163	3924	4504	5075
312	3161	3920	4498	5069
313	3160	3916	4492	5063
314	3158	3911	4487	5057
315	3157	3907	4481	5051
316	3156	3902	4476	5045
317	3154	3898	4470	5039
318	3153	3894	4465	5032
319	3152	3889	4459	5026
320	3150	3885	4453	5020
321	3149	3881	4448	5014
322	3147	3876	4442	5008
323	3146	3872	4437	5002
324	3145	3867	4431	4996
325	3143	3863	4426	4990
326	3142	3859	4420	4983
327	3141	3854	4414	4977
328	3139	3850	4409	4971
329	3138	3846	4403	4965
330	3137	3841	4398	4959
331	3135	3837	4392	4953

6/01-10/31	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time(hr)	**10**	**25**	**50**	**100**
284	3295	4324	5124	5814
285	3286	4311	5110	5807
286	3277	4298	5096	5800
287	3269	4285	5082	5793
288	3260	4272	5068	5786
289	3251	4259	5054	5778
290	3243	4246	5040	5771
291	3234	4233	5026	5764
292	3225	4220	5012	5757
293	3217	4207	4998	5750
294	3208	4194	4984	5743
295	3199	4181	4970	5736
296	3191	4167	4956	5729
298	3182	4154	4942	5722
297	3174	4141	4928	5715
298	3165	4128	4914	5708
299	3156	4115	4900	5701
300	3148	4102	4886	5694
301	3139	4089	4872	5686
302	3130	4076	4858	5679
303	3122	4063	4844	5672
304	3113	4050	4830	5665
305	3104	4037	4816	5658
306	3096	4024	4802	5651
307	3087	4010	4788	5644
308	3078	3997	4774	5637
309	3070	3984	4760	5630
310	3061	3971	4746	5623
311	3052	3958	4732	5616
312	3044	3945	4718	5609
313	3035	3932	4704	5601
314	3026	3919	4690	5594
315	3018	3906	4676	5587
316	3009	3893	4662	5580
317	3000	3880	4648	5573
318	2992	3867	4634	5566
319	2983	3853	4620	5559
320	2974	3840	4606	5552
321	2966	3827	4592	5545
322	2957	3814	4578	5538
323	2949	3801	4564	5531
324	2940	3788	4550	5524
325	2931	3775	4536	5516
326	2923	3762	4522	5509
327	2914	3749	4508	5502
328	2905	3736	4494	5495
329	2897	3723	4480	5488
330	2888	3710	4465	5481
331	2879	3697	4451	5474

7/01-11/30	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
332	3134	3832	4387	4947
333	3132	3828	4381	4941
334	3131	3824	4375	4934
335	3130	3819	4370	4928
336	3128	3815	4364	4922
337	3127	3810	4359	4916
338	3126	3806	4353	4910
339	3124	3802	4348	4904
340	3123	3797	4342	4898
341	3122	3793	4336	4892
342	3120	3789	4331	4885
343	3119	3784	4325	4879
344	3117	3780	4320	4873
345	3116	3775	4314	4867
346	3115	3771	4309	4861
347	3113	3767	4303	4855
348	3112	3762	4297	4849
349	3111	3758	4292	4842
350	3109	3753	4286	4836
351	3108	3749	4281	4830
352	3107	3745	4275	4824
353	3105	3740	4270	4818
354	3104	3736	4264	4812
355	3102	3732	4259	4806
356	3101	3727	4253	4800
357	3100	3723	4247	4793
358	3098	3718	4242	4787
359	3097	3714	4236	4781
360	3097	3714	4236	4781

6/01-10/31	**Copco Discharge (ft^3/s) by Return Period (years)**			
Time(hr)	**10**	**25**	**50**	**100**
332	2871	3683	4437	5467
333	2862	3670	4423	5460
334	2853	3657	4409	5453
335	2845	3644	4395	5446
336	2836	3631	4381	5439
337	2827	3618	4367	5432
338	2819	3605	4353	5424
339	2810	3592	4339	5417
340	2801	3579	4325	5410
341	2793	3566	4311	5403
342	2784	3553	4297	5396
343	2775	3540	4283	5389
344	2767	3526	4269	5382
345	2758	3513	4255	5375
346	2750	3500	4241	5368
347	2741	3487	4227	5361
348	2732	3474	4213	5354
349	2724	3461	4199	5347
350	2715	3448	4185	5339
351	2706	3435	4171	5332
352	2698	3422	4157	5325
353	2689	3409	4143	5318
354	2680	3396	4129	5311
355	2672	3383	4115	5304
356	2663	3369	4101	5297
357	2654	3356	4087	5290
358	2646	3343	4073	5283
359	2637	3330	4059	5276
360	2637	3330	4059	5276

KLAMATH RIVER BELOW IRON GATE DAM, CA

Annual	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
0	7686	9686	11115	12640
1	7706	9712	11146	12674
2	7727	9737	11177	12709
3	7747	9763	11208	12743
4	7767	9789	11239	12778
5	7787	9815	11270	12813
6	7808	9840	11301	12847
7	7828	9866	11332	12882
8	7848	9892	11363	12917
9	7868	9918	11394	12951
10	7888	9944	11425	12986
11	7909	9969	11456	13021
12	7929	9995	11487	13055

Annual	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
181	14884	20228	24486	29116
182	14461	19529	23501	27832
183	14339	19364	23323	27609
184	14217	19200	23145	27387
185	14095	19035	22967	27164
186	13973	18870	22789	26941
187	13852	18705	22611	26718
188	13730	18540	22433	26496
189	13608	18375	22255	26273
190	13486	18211	22077	26050
191	13364	18046	21899	25827
192	13243	17881	21720	25605
193	13157	17730	21501	25319

Annual	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
13	7949	10021	11518	13090
14	7969	10047	11549	13125
15	7990	10072	11580	13159
16	8010	10098	11611	13194
17	8030	10124	11642	13228
18	8050	10150	11673	13263
19	8070	10175	11704	13298
20	8091	10201	11735	13332
21	8111	10227	11766	13367
22	8131	10253	11797	13402
23	8151	10278	11828	13436
24	8172	10304	11859	13471
25	8192	10330	11890	13506
26	8212	10356	11921	13540
27	8232	10381	11952	13575
28	8252	10407	11983	13610
29	8273	10433	12014	13644
30	8293	10459	12045	13679
31	8313	10485	12076	13714
32	8333	10510	12107	13748
33	8354	10536	12138	13783
34	8374	10562	12169	13817
35	8394	10588	12200	13852
36	8414	10613	12231	13887
37	8434	10639	12262	13921
38	8455	10665	12293	13956
39	8475	10691	12324	13991
40	8495	10716	12355	14025
41	8515	10742	12386	14060
42	8536	10768	12417	14095
43	8556	10794	12448	14129
44	8576	10819	12479	14164
45	8596	10845	12510	14199
46	8616	10871	12541	14233
47	8637	10897	12572	14268
48	8657	10923	12603	14303
49	8677	10948	12633	14337
50	8697	10974	12664	14372
51	8718	11000	12695	14406
52	8738	11026	12726	14441
53	8758	11051	12757	14476
54	8778	11077	12788	14510
55	8798	11103	12819	14545
56	8819	11129	12850	14580
57	8839	11154	12881	14614
58	8859	11180	12912	14649
59	8879	11206	12943	14684
60	8900	11232	12974	14718
61	8920	11257	13005	14753

Annual	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
194	13071	17580	21281	25033
195	12986	17429	21062	24747
196	12900	17279	20842	24461
197	12814	17128	20622	24176
198	12729	16978	20403	23890
199	12643	16827	20183	23604
200	12558	16677	19963	23318
201	12472	16526	19744	23032
202	12386	16376	19524	22747
203	12301	16225	19305	22461
204	12215	16075	19085	22175
205	12129	15925	18865	21889
206	12044	15774	18646	21603
207	11958	15624	18426	21318
208	11872	15473	18207	21032
209	11787	15323	17987	20746
210	11701	15172	17767	20460
211	11616	15022	17548	20174
212	11530	14871	17328	19889
213	11444	14721	17108	19603
214	11359	14570	16889	19317
215	11273	14420	16669	19031
216	11187	14269	16450	18745
217	11140	14204	16376	18653
218	11093	14139	16303	18560
219	11046	14074	16230	18467
220	10998	14009	16156	18374
221	10951	13944	16083	18281
222	10904	13880	16010	18188
223	10856	13815	15936	18095
224	10809	13750	15863	18002
225	10762	13685	15790	17909
226	10715	13620	15717	17816
227	10667	13555	15643	17723
228	10620	13490	15570	17630
229	10573	13425	15497	17537
230	10525	13360	15423	17444
231	10478	13295	15350	17351
232	10431	13230	15277	17258
233	10384	13165	15204	17165
234	10336	13100	15130	17072
235	10289	13036	15057	16979
236	10242	12971	14984	16886
237	10194	12906	14910	16793
238	10147	12841	14837	16700
239	10100	12776	14764	16607
240	10053	12711	14690	16515
241	10035	12688	14665	16492
242	10017	12665	14640	16469

Annual	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
62	8940	11283	13036	14788
63	8960	11309	13067	14822
64	8980	11335	13098	14857
65	9001	11360	13129	14891
66	9021	11386	13160	14926
67	9041	11412	13191	14961
68	9061	11438	13222	14995
69	9082	11464	13253	15030
70	9102	11489	13284	15065
71	9122	11515	13315	15099
72	9142	11541	13346	15134
73	9162	11567	13377	15169
74	9183	11592	13408	15203
75	9203	11618	13439	15238
76	9223	11644	13470	15273
77	9243	11670	13501	15307
78	9264	11695	13532	15342
79	9284	11721	13563	15377
80	9304	11747	13594	15411
81	9324	11773	13625	15446
82	9344	11798	13656	15480
83	9365	11824	13687	15515
84	9385	11850	13718	15550
85	9405	11876	13749	15584
86	9425	11901	13780	15619
87	9445	11927	13811	15654
88	9466	11953	13842	15688
89	9486	11979	13873	15723
90	9506	12005	13904	15758
91	9526	12030	13935	15792
92	9547	12056	13966	15827
93	9567	12082	13997	15862
94	9587	12108	14028	15896
95	9607	12133	14059	15931
96	9627	12159	14090	15965
97	9645	12182	14115	15988
98	9663	12205	14140	16011
99	9681	12228	14165	16034
100	9698	12251	14190	16057
101	9716	12274	14215	16080
102	9734	12297	14240	16103
103	9751	12320	14265	16126
104	9769	12343	14290	16148
105	9787	12366	14315	16171
106	9805	12389	14340	16194
107	9822	12412	14365	16217
108	9840	12435	14390	16240
109	9858	12458	14415	16263
110	9875	12481	14440	16286

Annual	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
243	9999	12642	14615	16446
244	9982	12619	14590	16423
245	9964	12596	14565	16400
246	9946	12573	14540	16377
247	9929	12550	14515	16354
248	9911	12527	14490	16332
249	9893	12504	14465	16309
250	9875	12481	14440	16286
251	9858	12458	14415	16263
252	9840	12435	14390	16240
253	9822	12412	14365	16217
254	9805	12389	14340	16194
255	9787	12366	14315	16171
256	9769	12343	14290	16148
257	9751	12320	14265	16126
258	9734	12297	14240	16103
259	9716	12274	14215	16080
260	9698	12251	14190	16057
261	9681	12228	14165	16034
262	9663	12205	14140	16011
263	9645	12182	14115	15988
264	9627	12159	14090	15965
265	9607	12133	14059	15931
266	9587	12108	14028	15896
267	9567	12082	13997	15862
268	9547	12056	13966	15827
269	9526	12030	13935	15792
270	9506	12005	13904	15758
271	9486	11979	13873	15723
272	9466	11953	13842	15688
273	9445	11927	13811	15654
274	9425	11901	13780	15619
275	9405	11876	13749	15584
276	9385	11850	13718	15550
277	9365	11824	13687	15515
278	9344	11798	13656	15480
279	9324	11773	13625	15446
280	9304	11747	13594	15411
281	9284	11721	13563	15377
282	9264	11695	13532	15342
283	9243	11670	13501	15307
284	9223	11644	13470	15273
285	9203	11618	13439	15238
286	9183	11592	13408	15203
287	9162	11567	13377	15169
288	9142	11541	13346	15134
289	9122	11515	13315	15099
290	9102	11489	13284	15065
291	9082	11464	13253	15030

Annual	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
111	9893	12504	14465	16309
112	9911	12527	14490	16332
113	9929	12550	14515	16354
114	9946	12573	14540	16377
115	9964	12596	14565	16400
116	9982	12619	14590	16423
117	9999	12642	14615	16446
118	10017	12665	14640	16469
119	10035	12688	14665	16492
120	10053	12711	14690	16515
121	10100	12776	14764	16607
122	10147	12841	14837	16700
123	10194	12906	14910	16793
124	10242	12971	14984	16886
125	10289	13036	15057	16979
126	10336	13100	15130	17072
127	10384	13165	15204	17165
128	10431	13230	15277	17258
129	10478	13295	15350	17351
130	10525	13360	15423	17444
131	10573	13425	15497	17537
132	10620	13490	15570	17630
133	10667	13555	15643	17723
134	10715	13620	15717	17816
135	10762	13685	15790	17909
136	10809	13750	15863	18002
137	10856	13815	15936	18095
138	10904	13880	16010	18188
139	10951	13944	16083	18281
140	10998	14009	16156	18374
141	11046	14074	16230	18467
142	11093	14139	16303	18560
143	11140	14204	16376	18653
144	11187	14269	16450	18745
145	11273	14420	16669	19031
146	11359	14570	16889	19317
147	11444	14721	17108	19603
148	11530	14871	17328	19889
149	11616	15022	17548	20174
150	11701	15172	17767	20460
151	11787	15323	17987	20746
152	11872	15473	18207	21032
153	11958	15624	18426	21318
154	12044	15774	18646	21603
155	12129	15925	18865	21889
156	12215	16075	19085	22175
157	12301	16225	19305	22461
158	12386	16376	19524	22747
159	12472	16526	19744	23032

Annual	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
292	9061	11438	13222	14995
293	9041	11412	13191	14961
294	9021	11386	13160	14926
295	9001	11360	13129	14891
296	8980	11335	13098	14857
298	8960	11309	13067	14822
297	8940	11283	13036	14788
298	8920	11257	13005	14753
299	8900	11232	12974	14718
300	8879	11206	12943	14684
301	8859	11180	12912	14649
302	8839	11154	12881	14614
303	8819	11129	12850	14580
304	8798	11103	12819	14545
305	8778	11077	12788	14510
306	8758	11051	12757	14476
307	8738	11026	12726	14441
308	8718	11000	12695	14406
309	8697	10974	12664	14372
310	8677	10948	12633	14337
311	8657	10923	12603	14303
312	8637	10897	12572	14268
313	8616	10871	12541	14233
314	8596	10845	12510	14199
315	8576	10819	12479	14164
316	8556	10794	12448	14129
317	8536	10768	12417	14095
318	8515	10742	12386	14060
319	8495	10716	12355	14025
320	8475	10691	12324	13991
321	8455	10665	12293	13956
322	8434	10639	12262	13921
323	8414	10613	12231	13887
324	8394	10588	12200	13852
325	8374	10562	12169	13817
326	8354	10536	12138	13783
327	8333	10510	12107	13748
328	8313	10485	12076	13714
329	8293	10459	12045	13679
330	8273	10433	12014	13644
331	8252	10407	11983	13610
332	8232	10381	11952	13575
333	8212	10356	11921	13540
334	8192	10330	11890	13506
335	8172	10304	11859	13471
336	8151	10278	11828	13436
337	8131	10253	11797	13402
338	8111	10227	11766	13367
339	8091	10201	11735	13332

Annual	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
160	12558	16677	19963	23318
161	12643	16827	20183	23604
162	12729	16978	20403	23890
163	12814	17128	20622	24176
164	12900	17279	20842	24461
165	12986	17429	21062	24747
166	13071	17580	21281	25033
167	13157	17730	21501	25319
168	13243	17881	21720	25605
169	13364	18046	21899	25827
170	13486	18211	22077	26050
171	13608	18375	22255	26273
172	13730	18540	22433	26496
173	13852	18705	22611	26718
174	13973	18870	22789	26941
175	14095	19035	22967	27164
176	14217	19200	23145	27387
177	14339	19364	23323	27609
178	14461	19529	23501	27832
179	14884	20228	24486	29116
180	15610	21460	26280	31460

Annual	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
340	8070	10175	11704	13298
341	8050	10150	11673	13263
342	8030	10124	11642	13228
343	8010	10098	11611	13194
344	7990	10072	11580	13159
345	7969	10047	11549	13125
346	7949	10021	11518	13090
347	7929	9995	11487	13055
348	7909	9969	11456	13021
349	7888	9944	11425	12986
350	7868	9918	11394	12951
351	7848	9892	11363	12917
352	7828	9866	11332	12882
353	7808	9840	11301	12847
354	7787	9815	11270	12813
355	7767	9789	11239	12778
356	7747	9763	11208	12743
357	7727	9737	11177	12709
358	7706	9712	11146	12674
359	7686	9686	11115	12640
360	7686	9686	11115	12640

7/01-11/30	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
0	3069	4003	4795	5684
1	3073	4008	4802	5693
2	3076	4013	4809	5702
3	3080	4018	4816	5711
4	3084	4023	4823	5720
5	3087	4029	4830	5729
6	3091	4034	4837	5738
7	3095	4039	4844	5747
8	3098	4044	4851	5756
9	3102	4050	4858	5765
10	3106	4055	4865	5774
11	3109	4060	4872	5783
12	3113	4065	4878	5792
13	3117	4071	4885	5801
14	3120	4076	4892	5810
15	3124	4081	4899	5819
16	3128	4086	4906	5828
17	3131	4091	4913	5837
18	3135	4097	4920	5845
19	3139	4102	4927	5854
20	3142	4107	4934	5863
21	3146	4112	4941	5872
22	3150	4118	4948	5881

6/01-10/31	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	**10**	**25**	**50**	**100**
0	2005	2005	2007	2009
1	2016	2026	2034	2042
2	2027	2046	2061	2075
3	2038	2067	2088	2108
4	2049	2087	2115	2141
5	2060	2108	2142	2174
6	2071	2128	2169	2207
7	2082	2149	2196	2240
8	2093	2169	2223	2273
9	2104	2190	2250	2306
10	2114	2210	2277	2339
11	2125	2231	2304	2372
12	2136	2251	2331	2405
13	2147	2272	2359	2438
14	2158	2292	2386	2471
15	2169	2313	2413	2504
16	2180	2333	2440	2537
17	2191	2354	2467	2570
18	2202	2374	2494	2603
19	2213	2394	2521	2636
20	2224	2415	2548	2669
21	2235	2435	2575	2702
22	2246	2456	2602	2735

7/01-11/30	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
23	3153	4123	4955	5890
24	3157	4128	4962	5899
25	3161	4133	4969	5908
26	3165	4139	4976	5917
27	3168	4144	4983	5926
28	3172	4149	4990	5935
29	3176	4154	4997	5944
30	3179	4159	5004	5953
31	3183	4165	5011	5962
32	3187	4170	5018	5971
33	3190	4175	5025	5980
34	3194	4180	5032	5989
35	3198	4186	5039	5998
36	3201	4191	5045	6007
37	3205	4196	5052	6016
38	3209	4201	5059	6025
39	3212	4207	5066	6034
40	3216	4212	5073	6043
41	3220	4217	5080	6052
42	3223	4222	5087	6061
43	3227	4227	5094	6070
44	3231	4233	5101	6079
45	3234	4238	5108	6088
46	3238	4243	5115	6097
47	3242	4248	5122	6106
48	3245	4254	5129	6115
49	3249	4259	5136	6124
50	3253	4264	5143	6133
51	3256	4269	5150	6142
52	3260	4275	5157	6151
53	3264	4280	5164	6160
54	3267	4285	5171	6169
55	3271	4290	5178	6178
56	3275	4295	5185	6187
57	3278	4301	5192	6196
58	3282	4306	5199	6205
59	3286	4311	5206	6214
60	3289	4316	5213	6223
61	3293	4322	5219	6232
62	3297	4327	5226	6241
63	3301	4332	5233	6250
64	3304	4337	5240	6259
65	3308	4343	5247	6268
66	3312	4348	5254	6277
67	3315	4353	5261	6286
68	3319	4358	5268	6295
69	3323	4363	5275	6304
70	3326	4369	5282	6313
71	3330	4374	5289	6322

6/01-10/31	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	**10**	**25**	**50**	**100**
23	2257	2476	2629	2768
24	2268	2497	2656	2801
25	2279	2517	2683	2834
26	2290	2538	2711	2867
27	2301	2558	2738	2900
28	2312	2579	2765	2933
29	2323	2599	2792	2966
30	2334	2620	2819	2999
31	2345	2640	2846	3032
32	2356	2661	2873	3065
33	2367	2681	2900	3098
34	2378	2702	2927	3131
35	2389	2722	2954	3164
36	2400	2743	2981	3198
37	2411	2763	3008	3231
38	2422	2784	3035	3264
39	2433	2804	3063	3297
40	2444	2825	3090	3330
41	2454	2845	3117	3363
42	2465	2865	3144	3396
43	2476	2886	3171	3429
44	2487	2906	3198	3462
45	2498	2927	3225	3495
46	2509	2947	3252	3528
47	2520	2968	3279	3561
48	2531	2988	3306	3594
49	2542	3009	3333	3627
50	2553	3029	3360	3660
51	2564	3050	3387	3693
52	2575	3070	3415	3726
53	2586	3091	3442	3759
54	2597	3111	3469	3792
55	2608	3132	3496	3825
56	2619	3152	3523	3858
57	2630	3173	3550	3891
58	2641	3193	3577	3924
59	2652	3214	3604	3957
60	2663	3234	3631	3990
61	2674	3255	3658	4023
62	2685	3275	3685	4056
63	2696	3296	3712	4089
64	2707	3316	3739	4122
65	2718	3337	3767	4155
66	2729	3357	3794	4188
67	2740	3377	3821	4221
68	2751	3398	3848	4254
69	2762	3418	3875	4287
70	2773	3439	3902	4320
71	2784	3459	3929	4353

7/01-11/30	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
72	3334	4379	5296	6331
73	3337	4384	5303	6340
74	3341	4390	5310	6349
75	3345	4395	5317	6358
76	3348	4400	5324	6367
77	3352	4405	5331	6376
78	3356	4411	5338	6385
79	3359	4416	5345	6394
80	3363	4421	5352	6403
81	3367	4426	5359	6412
82	3370	4431	5366	6421
83	3374	4437	5373	6430
84	3378	4442	5380	6439
85	3381	4447	5386	6448
86	3385	4452	5393	6457
87	3389	4458	5400	6466
88	3392	4463	5407	6475
89	3396	4468	5414	6484
90	3400	4473	5421	6493
91	3403	4479	5428	6502
92	3407	4484	5435	6511
93	3411	4489	5442	6520
94	3414	4494	5449	6529
95	3418	4499	5456	6538
96	3422	4505	5463	6547
97	3428	4514	5473	6557
98	3435	4523	5482	6567
99	3442	4532	5492	6577
100	3448	4542	5502	6587
101	3455	4551	5511	6597
102	3461	4560	5521	6607
103	3468	4569	5531	6617
104	3475	4579	5540	6627
105	3481	4588	5550	6637
106	3488	4597	5560	6647
107	3494	4606	5569	6657
108	3501	4616	5579	6667
109	3508	4625	5589	6677
110	3514	4634	5598	6687
111	3521	4643	5608	6697
112	3527	4652	5618	6707
113	3534	4662	5627	6717
114	3541	4671	5637	6727
115	3547	4680	5647	6737
116	3554	4689	5656	6747
117	3560	4699	5666	6757
118	3567	4708	5676	6767
119	3574	4717	5685	6777
120	3580	4726	5695	6787

6/01-10/31	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	**10**	**25**	**50**	**100**
72	2794	3480	3956	4386
73	2805	3500	3983	4419
74	2816	3521	4010	4452
75	2827	3541	4037	4485
76	2838	3562	4064	4518
77	2849	3582	4092	4551
78	2860	3603	4119	4584
79	2871	3623	4146	4617
80	2882	3644	4173	4650
81	2893	3664	4200	4683
82	2904	3685	4227	4716
83	2915	3705	4254	4749
84	2926	3726	4281	4782
85	2937	3746	4308	4816
86	2948	3767	4335	4849
87	2959	3787	4362	4882
88	2970	3808	4389	4915
89	2981	3828	4416	4948
90	2992	3849	4444	4981
91	3003	3869	4471	5014
92	3014	3889	4498	5047
93	3025	3910	4525	5080
94	3036	3930	4552	5113
95	3047	3951	4579	5146
96	3058	3971	4606	5179
97	3070	3995	4650	5257
98	3081	4018	4693	5335
99	3093	4041	4737	5413
100	3105	4064	4781	5492
101	3117	4087	4824	5570
102	3129	4110	4868	5648
103	3141	4133	4912	5726
104	3153	4156	4955	5805
105	3164	4180	4999	5883
106	3176	4203	5043	5961
107	3188	4226	5086	6039
108	3200	4249	5130	6118
109	3212	4272	5174	6196
110	3224	4295	5217	6274
111	3236	4318	5261	6352
112	3247	4342	5305	6430
113	3259	4365	5348	6509
114	3271	4388	5392	6587
115	3283	4411	5436	6665
116	3295	4434	5479	6743
117	3307	4457	5523	6822
118	3319	4480	5567	6900
119	3330	4503	5610	6978
120	3342	4527	5654	7056

7/01-11/30	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
121	3588	4734	5702	6794
122	3595	4741	5710	6800
123	3603	4748	5717	6807
124	3610	4755	5725	6813
125	3618	4763	5732	6820
126	3625	4770	5740	6826
127	3633	4777	5747	6832
128	3640	4784	5755	6839
129	3648	4792	5762	6845
130	3655	4799	5770	6852
131	3663	4806	5777	6858
132	3670	4814	5785	6865
133	3677	4821	5792	6871
134	3685	4828	5799	6877
135	3692	4835	5807	6884
136	3700	4843	5814	6890
137	3707	4850	5822	6897
138	3715	4857	5829	6903
139	3722	4864	5837	6909
140	3730	4872	5844	6916
141	3737	4879	5852	6922
142	3745	4886	5859	6929
143	3752	4893	5867	6935
144	3760	4901	5874	6942
145	3764	4905	5877	6944
146	3768	4909	5880	6946
147	3771	4914	5884	6948
148	3775	4918	5887	6950
149	3779	4923	5890	6952
150	3783	4927	5893	6955
151	3787	4931	5896	6957
152	3791	4936	5900	6959
153	3794	4940	5903	6961
154	3798	4945	5906	6963
155	3802	4949	5909	6965
156	3806	4954	5913	6968
157	3810	4958	5916	6970
158	3814	4962	5919	6972
159	3818	4967	5922	6974
160	3821	4971	5925	6976
161	3825	4976	5929	6978
162	3829	4980	5932	6980
163	3833	4984	5935	6983
164	3837	4989	5938	6985
165	3841	4993	5941	6987
166	3844	4998	5945	6989
167	3848	5002	5948	6991
168	3852	5006	5951	6993
169	3884	5047	6001	7052

6/01-10/31	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	10	25	50	100
121	3354	4544	5672	7069
122	3365	4561	5690	7082
123	3376	4577	5708	7095
124	3388	4594	5726	7108
125	3399	4611	5743	7121
126	3410	4628	5761	7134
127	3421	4645	5779	7147
128	3433	4662	5797	7160
129	3444	4679	5815	7173
130	3455	4696	5833	7186
131	3467	4713	5851	7199
132	3478	4730	5869	7213
133	3489	4747	5886	7226
134	3501	4764	5904	7239
135	3512	4781	5922	7252
136	3523	4798	5940	7265
137	3535	4815	5958	7278
138	3546	4832	5976	7291
139	3557	4849	5994	7304
140	3568	4866	6011	7317
141	3580	4883	6029	7330
142	3591	4899	6047	7343
143	3602	4916	6065	7356
144	3614	4933	6083	7369
145	3620	4945	6105	7412
146	3626	4956	6126	7454
147	3632	4968	6148	7497
148	3639	4979	6169	7540
149	3645	4990	6191	7583
150	3651	5002	6213	7626
151	3657	5013	6234	7668
152	3664	5024	6256	7711
153	3670	5036	6278	7754
154	3676	5047	6299	7797
155	3682	5059	6321	7840
156	3689	5070	6343	7883
157	3695	5081	6364	7925
158	3701	5093	6386	7968
159	3707	5104	6407	8011
160	3713	5116	6429	8054
161	3720	5127	6451	8097
162	3726	5138	6472	8139
163	3732	5150	6494	8182
164	3738	5161	6516	8225
165	3745	5172	6537	8268
166	3751	5184	6559	8311
167	3757	5195	6580	8353
168	3763	5207	6602	8396
169	3790	5244	6638	8408

7/01-11/30	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
170	3915	5087	6051	7110
171	3947	5128	6102	7168
172	3978	5169	6152	7226
173	4010	5209	6202	7284
174	4041	5250	6252	7343
175	4073	5290	6302	7401
176	4104	5331	6353	7459
177	4136	5371	6403	7517
178	4167	5412	6453	7575
179	4288	5593	6684	7865
180	4497	5914	7095	8387
181	4288	5593	6684	7865
182	4167	5412	6453	7575
183	4136	5371	6403	7517
184	4104	5331	6353	7459
185	4073	5290	6302	7401
186	4041	5250	6252	7343
187	4010	5209	6202	7284
188	3978	5169	6152	7226
189	3947	5128	6102	7168
190	3915	5087	6051	7110
191	3884	5047	6001	7052
192	3852	5006	5951	6993
193	3848	5002	5948	6991
194	3844	4998	5945	6989
195	3841	4993	5941	6987
196	3837	4989	5938	6985
197	3833	4984	5935	6983
198	3829	4980	5932	6980
199	3825	4976	5929	6978
200	3821	4971	5925	6976
201	3818	4967	5922	6974
202	3814	4962	5919	6972
203	3810	4958	5916	6970
204	3806	4954	5913	6968
205	3802	4949	5909	6965
206	3798	4945	5906	6963
207	3794	4940	5903	6961
208	3791	4936	5900	6959
209	3787	4931	5896	6957
210	3783	4927	5893	6955
211	3779	4923	5890	6952
212	3775	4918	5887	6950
213	3771	4914	5884	6948
214	3768	4909	5880	6946
215	3764	4905	5877	6944
216	3760	4901	5874	6942
217	3752	4893	5867	6935
218	3745	4886	5859	6929

6/01-10/31	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time(hr)	**10**	**25**	**50**	**100**
170	3817	5282	6675	8419
171	3844	5319	6711	8431
172	3871	5357	6747	8442
173	3898	5394	6784	8454
174	3925	5432	6820	8465
175	3952	5469	6856	8477
176	3978	5507	6893	8489
177	4005	5544	6929	8500
178	4032	5582	6966	8512
179	4152	5770	7230	8894
180	4364	6110	7724	9647
181	4152	5770	7230	8894
182	4032	5582	6966	8512
183	4005	5544	6929	8500
184	3978	5507	6893	8489
185	3952	5469	6856	8477
186	3925	5432	6820	8465
187	3898	5394	6784	8454
188	3871	5357	6747	8442
189	3844	5319	6711	8431
190	3817	5282	6675	8419
191	3790	5244	6638	8408
192	3763	5207	6602	8396
193	3757	5195	6580	8353
194	3751	5184	6559	8311
195	3745	5172	6537	8268
196	3738	5161	6516	8225
197	3732	5150	6494	8182
198	3726	5138	6472	8139
199	3720	5127	6451	8097
200	3713	5116	6429	8054
201	3707	5104	6407	8011
202	3701	5093	6386	7968
203	3695	5081	6364	7925
204	3689	5070	6343	7883
205	3682	5059	6321	7840
206	3676	5047	6299	7797
207	3670	5036	6278	7754
208	3664	5024	6256	7711
209	3657	5013	6234	7668
210	3651	5002	6213	7626
211	3645	4990	6191	7583
212	3639	4979	6169	7540
213	3632	4968	6148	7497
214	3626	4956	6126	7454
215	3620	4945	6105	7412
216	3614	4933	6083	7369
217	3602	4916	6065	7356
218	3591	4899	6047	7343

7/01-11/30	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
219	3737	4879	5852	6922
220	3730	4872	5844	6916
221	3722	4864	5837	6909
222	3715	4857	5829	6903
223	3707	4850	5822	6897
224	3700	4843	5814	6890
225	3692	4835	5807	6884
226	3685	4828	5799	6877
227	3677	4821	5792	6871
228	3670	4814	5785	6865
229	3663	4806	5777	6858
230	3655	4799	5770	6852
231	3648	4792	5762	6845
232	3640	4784	5755	6839
233	3633	4777	5747	6832
234	3625	4770	5740	6826
235	3618	4763	5732	6820
236	3610	4755	5725	6813
237	3603	4748	5717	6807
238	3595	4741	5710	6800
239	3588	4734	5702	6794
240	3580	4726	5695	6787
241	3574	4717	5685	6777
242	3567	4708	5676	6767
243	3560	4699	5666	6757
244	3554	4689	5656	6747
245	3547	4680	5647	6737
246	3541	4671	5637	6727
247	3534	4662	5627	6717
248	3527	4652	5618	6707
249	3521	4643	5608	6697
250	3514	4634	5598	6687
251	3508	4625	5589	6677
252	3501	4616	5579	6667
253	3494	4606	5569	6657
254	3488	4597	5560	6647
255	3481	4588	5550	6637
256	3475	4579	5540	6627
257	3468	4569	5531	6617
258	3461	4560	5521	6607
259	3455	4551	5511	6597
260	3448	4542	5502	6587
261	3442	4532	5492	6577
262	3435	4523	5482	6567
263	3428	4514	5473	6557
264	3422	4505	5463	6547
265	3418	4499	5456	6538
266	3414	4494	5449	6529
267	3411	4489	5442	6520

6/01-10/31	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	10	25	50	100
219	3580	4883	6029	7330
220	3568	4866	6011	7317
221	3557	4849	5994	7304
222	3546	4832	5976	7291
223	3535	4815	5958	7278
224	3523	4798	5940	7265
225	3512	4781	5922	7252
226	3501	4764	5904	7239
227	3489	4747	5886	7226
228	3478	4730	5869	7213
229	3467	4713	5851	7199
230	3455	4696	5833	7186
231	3444	4679	5815	7173
232	3433	4662	5797	7160
233	3421	4645	5779	7147
234	3410	4628	5761	7134
235	3399	4611	5743	7121
236	3388	4594	5726	7108
237	3376	4577	5708	7095
238	3365	4561	5690	7082
239	3354	4544	5672	7069
240	3342	4527	5654	7056
241	3330	4503	5610	6978
242	3319	4480	5567	6900
243	3307	4457	5523	6822
244	3295	4434	5479	6743
245	3283	4411	5436	6665
246	3271	4388	5392	6587
247	3259	4365	5348	6509
248	3247	4342	5305	6430
249	3236	4318	5261	6352
250	3224	4295	5217	6274
251	3212	4272	5174	6196
252	3200	4249	5130	6118
253	3188	4226	5086	6039
254	3176	4203	5043	5961
255	3164	4180	4999	5883
256	3153	4156	4955	5805
257	3141	4133	4912	5726
258	3129	4110	4868	5648
259	3117	4087	4824	5570
260	3105	4064	4781	5492
261	3093	4041	4737	5413
262	3081	4018	4693	5335
263	3070	3995	4650	5257
264	3058	3971	4606	5179
265	3047	3951	4579	5146
266	3036	3930	4552	5113
267	3025	3910	4525	5080

7/01-11/30	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
268	3407	4484	5435	6511
269	3403	4479	5428	6502
270	3400	4473	5421	6493
271	3396	4468	5414	6484
272	3392	4463	5407	6475
273	3389	4458	5400	6466
274	3385	4452	5393	6457
275	3381	4447	5386	6448
276	3378	4442	5380	6439
277	3374	4437	5373	6430
278	3370	4431	5366	6421
279	3367	4426	5359	6412
280	3363	4421	5352	6403
281	3359	4416	5345	6394
282	3356	4411	5338	6385
283	3352	4405	5331	6376
284	3348	4400	5324	6367
285	3345	4395	5317	6358
286	3341	4390	5310	6349
287	3337	4384	5303	6340
288	3334	4379	5296	6331
289	3330	4374	5289	6322
290	3326	4369	5282	6313
291	3323	4363	5275	6304
292	3319	4358	5268	6295
293	3315	4353	5261	6286
294	3312	4348	5254	6277
295	3308	4343	5247	6268
296	3304	4337	5240	6259
298	3301	4332	5233	6250
297	3297	4327	5226	6241
298	3293	4322	5219	6232
299	3289	4316	5213	6223
300	3286	4311	5206	6214
301	3282	4306	5199	6205
302	3278	4301	5192	6196
303	3275	4295	5185	6187
304	3271	4290	5178	6178
305	3267	4285	5171	6169
306	3264	4280	5164	6160
307	3260	4275	5157	6151
308	3256	4269	5150	6142
309	3253	4264	5143	6133
310	3249	4259	5136	6124
311	3245	4254	5129	6115
312	3242	4248	5122	6106
313	3238	4243	5115	6097
314	3234	4238	5108	6088
315	3231	4233	5101	6079

6/01-10/31	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	**10**	**25**	**50**	**100**
268	3014	3889	4498	5047
269	3003	3869	4471	5014
270	2992	3849	4444	4981
271	2981	3828	4416	4948
272	2970	3808	4389	4915
273	2959	3787	4362	4882
274	2948	3767	4335	4849
275	2937	3746	4308	4816
276	2926	3726	4281	4782
277	2915	3705	4254	4749
278	2904	3685	4227	4716
279	2893	3664	4200	4683
280	2882	3644	4173	4650
281	2871	3623	4146	4617
282	2860	3603	4119	4584
283	2849	3582	4092	4551
284	2838	3562	4064	4518
285	2827	3541	4037	4485
286	2816	3521	4010	4452
287	2805	3500	3983	4419
288	2794	3480	3956	4386
289	2784	3459	3929	4353
290	2773	3439	3902	4320
291	2762	3418	3875	4287
292	2751	3398	3848	4254
293	2740	3377	3821	4221
294	2729	3357	3794	4188
295	2718	3337	3767	4155
296	2707	3316	3739	4122
298	2696	3296	3712	4089
297	2685	3275	3685	4056
298	2674	3255	3658	4023
299	2663	3234	3631	3990
300	2652	3214	3604	3957
301	2641	3193	3577	3924
302	2630	3173	3550	3891
303	2619	3152	3523	3858
304	2608	3132	3496	3825
305	2597	3111	3469	3792
306	2586	3091	3442	3759
307	2575	3070	3415	3726
308	2564	3050	3387	3693
309	2553	3029	3360	3660
310	2542	3009	3333	3627
311	2531	2988	3306	3594
312	2520	2968	3279	3561
313	2509	2947	3252	3528
314	2498	2927	3225	3495
315	2487	2906	3198	3462

7/01-11/30	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
316	3227	4227	5094	6070
317	3223	4222	5087	6061
318	3220	4217	5080	6052
319	3216	4212	5073	6043
320	3212	4207	5066	6034
321	3209	4201	5059	6025
322	3205	4196	5052	6016
323	3201	4191	5045	6007
324	3198	4186	5039	5998
325	3194	4180	5032	5989
326	3190	4175	5025	5980
327	3187	4170	5018	5971
328	3183	4165	5011	5962
329	3179	4159	5004	5953
330	3176	4154	4997	5944
331	3172	4149	4990	5935
332	3168	4144	4983	5926
333	3165	4139	4976	5917
334	3161	4133	4969	5908
335	3157	4128	4962	5899
336	3153	4123	4955	5890
337	3150	4118	4948	5881
338	3146	4112	4941	5872
339	3142	4107	4934	5863
340	3139	4102	4927	5854
341	3135	4097	4920	5845
342	3131	4091	4913	5837
343	3128	4086	4906	5828
344	3124	4081	4899	5819
345	3120	4076	4892	5810
346	3117	4071	4885	5801
347	3113	4065	4878	5792
348	3109	4060	4872	5783
349	3106	4055	4865	5774
350	3102	4050	4858	5765
351	3098	4044	4851	5756
352	3095	4039	4844	5747
353	3091	4034	4837	5738
354	3087	4029	4830	5729
355	3084	4023	4823	5720
356	3080	4018	4816	5711
357	3076	4013	4809	5702
358	3073	4008	4802	5693
359	3069	4003	4795	5684
360	3069	4003	4795	5684

6/01-10/31	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	10	25	50	100
316	2476	2886	3171	3429
317	2465	2865	3144	3396
318	2454	2845	3117	3363
319	2444	2825	3090	3330
320	2433	2804	3063	3297
321	2422	2784	3035	3264
322	2411	2763	3008	3231
323	2400	2743	2981	3198
324	2389	2722	2954	3164
325	2378	2702	2927	3131
326	2367	2681	2900	3098
327	2356	2661	2873	3065
328	2345	2640	2846	3032
329	2334	2620	2819	2999
330	2323	2599	2792	2966
331	2312	2579	2765	2933
332	2301	2558	2738	2900
333	2290	2538	2711	2867
334	2279	2517	2683	2834
335	2268	2497	2656	2801
336	2257	2476	2629	2768
337	2246	2456	2602	2735
338	2235	2435	2575	2702
339	2224	2415	2548	2669
340	2213	2394	2521	2636
341	2202	2374	2494	2603
342	2191	2354	2467	2570
343	2180	2333	2440	2537
344	2169	2313	2413	2504
345	2158	2292	2386	2471
346	2147	2272	2359	2438
347	2136	2251	2331	2405
348	2125	2231	2304	2372
349	2114	2210	2277	2339
350	2104	2190	2250	2306
351	2093	2169	2223	2273
352	2082	2149	2196	2240
353	2071	2128	2169	2207
354	2060	2108	2142	2174
355	2049	2087	2115	2141
356	2038	2067	2088	2108
357	2027	2046	2061	2075
358	2016	2026	2034	2042
359	2005	2005	2007	2009
360	2005	2005	2007	2009

August	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
0	1192	1271	1337	1378
1	1192	1271	1338	1379
2	1193	1272	1338	1380
3	1193	1273	1339	1381
4	1194	1273	1339	1381
5	1194	1274	1340	1382
6	1194	1275	1340	1383
7	1195	1275	1341	1384
8	1195	1276	1341	1384
9	1196	1277	1342	1385
10	1196	1277	1342	1386
11	1197	1278	1343	1386
12	1197	1279	1343	1387
13	1198	1279	1343	1388
14	1198	1280	1344	1389
15	1199	1281	1344	1389
16	1199	1281	1345	1390
17	1200	1282	1345	1391
18	1200	1283	1346	1391
19	1201	1283	1346	1392
20	1201	1284	1347	1393
21	1202	1285	1347	1394
22	1202	1285	1348	1394
23	1203	1286	1348	1395
24	1203	1287	1349	1396
25	1203	1287	1349	1397
26	1204	1288	1350	1397
27	1204	1289	1350	1398
28	1205	1289	1351	1399
29	1205	1290	1351	1399
30	1206	1291	1351	1400
31	1206	1291	1352	1401
32	1207	1292	1352	1402
33	1207	1293	1353	1402
34	1208	1294	1353	1403
35	1208	1294	1354	1404
36	1209	1295	1354	1404
37	1209	1296	1355	1405
38	1210	1296	1355	1406
39	1210	1297	1356	1407
40	1211	1298	1356	1407
41	1211	1298	1357	1408
42	1212	1299	1357	1409
43	1212	1300	1358	1410
44	1212	1300	1358	1410
45	1213	1301	1359	1411
46	1213	1302	1359	1412
47	1214	1302	1360	1412
48	1214	1303	1360	1413

September	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	**10**	**25**	**50**	**100**
0	1640	1762	1831	1906
1	1641	1763	1832	1907
2	1641	1763	1833	1907
3	1642	1764	1833	1907
4	1642	1764	1834	1908
5	1643	1765	1835	1908
6	1643	1765	1835	1909
7	1644	1766	1836	1909
8	1644	1767	1837	1910
9	1645	1767	1837	1910
10	1645	1768	1838	1911
11	1646	1768	1839	1911
12	1646	1769	1839	1911
13	1647	1769	1840	1912
14	1647	1770	1841	1912
15	1648	1770	1841	1913
16	1648	1771	1842	1913
17	1649	1771	1843	1914
18	1649	1772	1843	1914
19	1650	1772	1844	1915
20	1650	1773	1845	1915
21	1651	1774	1845	1915
22	1651	1774	1846	1916
23	1652	1775	1847	1916
24	1652	1775	1847	1917
25	1653	1776	1848	1917
26	1653	1776	1849	1918
27	1654	1777	1849	1918
28	1654	1777	1850	1919
29	1655	1778	1851	1919
30	1655	1778	1852	1919
31	1656	1779	1852	1920
32	1656	1780	1853	1920
33	1657	1780	1854	1921
34	1657	1781	1854	1921
35	1658	1781	1855	1922
36	1658	1782	1856	1922
37	1659	1782	1856	1923
38	1659	1783	1857	1923
39	1660	1783	1858	1923
40	1660	1784	1858	1924
41	1661	1784	1859	1924
42	1661	1785	1860	1925
43	1662	1785	1860	1925
44	1662	1786	1861	1926
45	1663	1787	1862	1926
46	1663	1787	1862	1927
47	1664	1788	1863	1927
48	1664	1788	1864	1928

August	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
49	1215	1304	1360	1414
50	1215	1304	1361	1415
51	1216	1305	1361	1415
52	1216	1306	1362	1416
53	1217	1306	1362	1417
54	1217	1307	1363	1417
55	1218	1308	1363	1418
56	1218	1308	1364	1419
57	1219	1309	1364	1420
58	1219	1310	1365	1420
59	1220	1310	1365	1421
60	1220	1311	1366	1422
61	1221	1312	1366	1423
62	1221	1312	1367	1423
63	1221	1313	1367	1424
64	1222	1314	1368	1425
65	1222	1314	1368	1425
66	1223	1315	1369	1426
67	1223	1316	1369	1427
68	1224	1316	1369	1428
69	1224	1317	1370	1428
70	1225	1318	1370	1429
71	1225	1318	1371	1430
72	1226	1319	1371	1430
73	1226	1320	1372	1431
74	1227	1320	1372	1432
75	1227	1321	1373	1433
76	1228	1322	1373	1433
77	1228	1322	1374	1434
78	1229	1323	1374	1435
79	1229	1324	1375	1436
80	1230	1324	1375	1436
81	1230	1325	1376	1437
82	1230	1326	1376	1438
83	1231	1326	1377	1438
84	1231	1327	1377	1439
85	1232	1328	1377	1440
86	1232	1328	1378	1441
87	1233	1329	1378	1441
88	1233	1330	1379	1442
89	1234	1330	1379	1443
90	1234	1331	1380	1443
91	1235	1332	1380	1444
92	1235	1332	1381	1445
93	1236	1333	1381	1446
94	1236	1334	1382	1446
95	1237	1334	1382	1447
96	1237	1335	1383	1448
97	1239	1337	1386	1451

September	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time(hr)	**10**	**25**	**50**	**100**
49	1665	1789	1864	1928
50	1665	1789	1865	1928
51	1666	1790	1866	1929
52	1666	1790	1866	1929
53	1667	1791	1867	1930
54	1667	1791	1868	1930
55	1668	1792	1869	1931
56	1668	1792	1869	1931
57	1669	1793	1870	1932
58	1669	1794	1871	1932
59	1670	1794	1871	1932
60	1670	1795	1872	1933
61	1671	1795	1873	1933
62	1671	1796	1873	1934
63	1672	1796	1874	1934
64	1672	1797	1875	1935
65	1673	1797	1875	1935
66	1673	1798	1876	1936
67	1674	1798	1877	1936
68	1674	1799	1877	1936
69	1675	1799	1878	1937
70	1675	1800	1879	1937
71	1676	1801	1879	1938
72	1676	1801	1880	1938
73	1677	1802	1881	1939
74	1677	1802	1881	1939
75	1678	1803	1882	1940
76	1678	1803	1883	1940
77	1679	1804	1883	1940
78	1679	1804	1884	1941
79	1680	1805	1885	1941
80	1680	1805	1885	1942
81	1681	1806	1886	1942
82	1681	1806	1887	1943
83	1682	1807	1888	1943
84	1682	1808	1888	1944
85	1683	1808	1889	1944
86	1683	1809	1890	1944
87	1684	1809	1890	1945
88	1684	1810	1891	1945
89	1685	1810	1892	1946
90	1685	1811	1892	1946
91	1686	1811	1893	1947
92	1686	1812	1894	1947
93	1687	1812	1894	1948
94	1687	1813	1895	1948
95	1688	1813	1896	1948
96	1688	1814	1896	1949
97	1692	1821	1905	1961

August	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
98	1242	1340	1390	1454
99	1244	1342	1393	1457
100	1246	1344	1397	1460
101	1249	1347	1400	1463
102	1251	1349	1404	1466
103	1253	1352	1407	1469
104	1256	1354	1411	1473
105	1258	1356	1414	1476
106	1260	1359	1418	1479
107	1263	1361	1421	1482
108	1265	1364	1425	1485
109	1267	1366	1429	1488
110	1270	1368	1432	1491
111	1272	1371	1436	1494
112	1274	1373	1439	1497
113	1277	1375	1443	1501
114	1279	1378	1446	1504
115	1281	1380	1450	1507
116	1284	1383	1453	1510
117	1286	1385	1457	1513
118	1288	1387	1460	1516
119	1291	1390	1464	1519
120	1293	1392	1467	1522
121	1294	1395	1472	1529
122	1295	1398	1476	1535
123	1296	1401	1480	1542
124	1297	1404	1485	1548
125	1298	1407	1489	1555
126	1299	1410	1494	1561
127	1300	1413	1498	1568
128	1301	1416	1502	1574
129	1302	1419	1507	1581
130	1303	1422	1511	1587
131	1304	1425	1516	1594
132	1306	1428	1520	1600
133	1307	1430	1524	1606
134	1308	1433	1529	1613
135	1309	1436	1533	1619
136	1310	1439	1538	1626
137	1311	1442	1542	1632
138	1312	1445	1546	1639
139	1313	1448	1551	1645
140	1314	1451	1555	1652
141	1315	1454	1560	1658
142	1316	1457	1564	1665
143	1317	1460	1568	1671
144	1318	1463	1573	1678
145	1318	1463	1573	1678
146	1319	1464	1573	1678

September	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time(hr)	**10**	**25**	**50**	**100**
98	1695	1827	1914	1973
99	1699	1834	1923	1985
100	1702	1841	1932	1998
101	1706	1848	1941	2010
102	1709	1854	1949	2022
103	1713	1861	1958	2034
104	1716	1868	1967	2046
105	1720	1875	1976	2058
106	1723	1881	1985	2071
107	1727	1888	1994	2083
108	1731	1895	2003	2095
109	1734	1902	2011	2107
110	1738	1909	2020	2119
111	1741	1915	2029	2132
112	1745	1922	2038	2144
113	1748	1929	2047	2156
114	1752	1936	2056	2168
115	1755	1942	2064	2180
116	1759	1949	2073	2192
117	1762	1956	2082	2205
118	1766	1963	2091	2217
119	1769	1969	2100	2229
120	1773	1976	2109	2241
121	1773	1977	2109	2241
122	1773	1977	2110	2242
123	1773	1978	2110	2242
124	1773	1978	2111	2243
125	1774	1979	2111	2243
126	1774	1979	2112	2244
127	1774	1980	2112	2244
128	1774	1980	2113	2244
129	1774	1981	2113	2245
130	1775	1981	2114	2245
131	1775	1982	2114	2246
132	1775	1982	2115	2246
133	1775	1982	2116	2246
134	1775	1983	2116	2247
135	1776	1983	2117	2247
136	1776	1984	2117	2248
137	1776	1984	2118	2248
138	1776	1985	2118	2248
139	1776	1985	2119	2249
140	1777	1986	2119	2249
141	1777	1986	2120	2250
142	1777	1987	2120	2250
143	1777	1987	2121	2251
144	1777	1988	2121	2251
145	1777	1988	2122	2251
146	1777	1988	2122	2251

August	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time (hr)	**10**	**25**	**50**	**100**
147	1319	1464	1573	1678
148	1319	1465	1573	1679
149	1319	1465	1573	1679
150	1320	1466	1573	1679
151	1320	1466	1573	1679
152	1320	1467	1573	1679
153	1320	1467	1573	1679
154	1321	1468	1573	1680
155	1321	1468	1573	1680
156	1321	1469	1574	1680
157	1321	1469	1574	1680
158	1321	1469	1574	1680
159	1322	1470	1574	1681
160	1322	1470	1574	1681
161	1322	1471	1574	1681
162	1322	1471	1574	1681
163	1323	1472	1574	1681
164	1323	1472	1574	1681
165	1323	1473	1574	1682
166	1323	1473	1574	1682
167	1324	1474	1574	1682
168	1324	1474	1574	1682
169	1324	1474	1575	1682
170	1325	1474	1576	1683
171	1325	1474	1578	1683
172	1326	1474	1579	1683
173	1326	1474	1580	1684
174	1327	1474	1581	1684
175	1327	1474	1582	1684
176	1328	1474	1583	1684
177	1328	1474	1584	1685
178	1329	1474	1585	1685
179	1650	1788	1891	1985
180	2291	2416	2503	2585
181	1650	1788	1891	1985
182	1329	1474	1585	1685
183	1328	1474	1584	1685
184	1328	1474	1583	1684
185	1327	1474	1582	1684
186	1327	1474	1581	1684
187	1326	1474	1580	1684
188	1326	1474	1579	1683
189	1325	1474	1578	1683
190	1325	1474	1576	1683
191	1324	1474	1575	1682
192	1324	1474	1574	1682
193	1324	1474	1574	1682
194	1323	1473	1574	1682
195	1323	1473	1574	1682

September	**Iron Gate Discharge (ft^3/s) by Return Period (years)**			
Time(hr)	**10**	**25**	**50**	**100**
147	1777	1988	2123	2251
148	1778	1988	2123	2251
149	1778	1988	2124	2251
150	1778	1988	2124	2251
151	1778	1988	2125	2251
152	1778	1988	2125	2251
153	1778	1988	2126	2251
154	1778	1988	2126	2251
155	1778	1988	2127	2251
156	1778	1989	2128	2252
157	1778	1989	2128	2252
158	1778	1989	2129	2252
159	1778	1989	2129	2252
160	1778	1989	2130	2252
161	1778	1989	2130	2252
162	1778	1989	2131	2252
163	1778	1989	2131	2252
164	1778	1989	2132	2252
165	1779	1989	2132	2252
166	1779	1989	2133	2252
167	1779	1989	2133	2252
168	1779	1989	2134	2252
169	1779	1990	2135	2258
170	1779	1990	2137	2264
171	1779	1991	2138	2270
172	1779	1992	2140	2276
173	1779	1992	2142	2283
174	1779	1993	2143	2289
175	1779	1994	2145	2295
176	1779	1994	2146	2301
177	1780	1995	2148	2307
178	1780	1996	2150	2313
179	2125	2348	2507	2673
180	2816	3052	3221	3386
181	2125	2348	2507	2673
182	1780	1996	2150	2313
183	1780	1995	2148	2307
184	1779	1994	2146	2301
185	1779	1994	2145	2295
186	1779	1993	2143	2289
187	1779	1992	2142	2283
188	1779	1992	2140	2276
189	1779	1991	2138	2270
190	1779	1990	2137	2264
191	1779	1990	2135	2258
192	1779	1989	2134	2252
193	1779	1989	2133	2252
194	1779	1989	2133	2252
195	1779	1989	2132	2252

August	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
196	1323	1472	1574	1681
197	1323	1472	1574	1681
198	1322	1471	1574	1681
199	1322	1471	1574	1681
200	1322	1470	1574	1681
201	1322	1470	1574	1681
202	1321	1469	1574	1680
203	1321	1469	1574	1680
204	1321	1469	1574	1680
205	1321	1468	1573	1680
206	1321	1468	1573	1680
207	1320	1467	1573	1679
208	1320	1467	1573	1679
209	1320	1466	1573	1679
210	1320	1466	1573	1679
211	1319	1465	1573	1679
212	1319	1465	1573	1679
213	1319	1464	1573	1678
214	1319	1464	1573	1678
215	1318	1463	1573	1678
216	1318	1463	1573	1678
217	1317	1460	1568	1671
218	1316	1457	1564	1665
219	1315	1454	1560	1658
220	1314	1451	1555	1652
221	1313	1448	1551	1645
222	1312	1445	1546	1639
223	1311	1442	1542	1632
224	1310	1439	1538	1626
225	1309	1436	1533	1619
226	1308	1433	1529	1613
227	1307	1430	1524	1606
228	1306	1428	1520	1600
229	1304	1425	1516	1594
230	1303	1422	1511	1587
231	1302	1419	1507	1581
232	1301	1416	1502	1574
233	1300	1413	1498	1568
234	1299	1410	1494	1561
235	1298	1407	1489	1555
236	1297	1404	1485	1548
237	1296	1401	1480	1542
238	1295	1398	1476	1535
239	1294	1395	1472	1529
240	1293	1392	1467	1522
241	1291	1390	1464	1519
242	1288	1387	1460	1516
243	1286	1385	1457	1513
244	1284	1383	1453	1510

September	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	10	25	50	100
196	1778	1989	2132	2252
197	1778	1989	2131	2252
198	1778	1989	2131	2252
199	1778	1989	2130	2252
200	1778	1989	2130	2252
201	1778	1989	2129	2252
202	1778	1989	2129	2252
203	1778	1989	2128	2252
204	1778	1989	2128	2252
205	1778	1988	2127	2251
206	1778	1988	2126	2251
207	1778	1988	2126	2251
208	1778	1988	2125	2251
209	1778	1988	2125	2251
210	1778	1988	2124	2251
211	1778	1988	2124	2251
212	1778	1988	2123	2251
213	1777	1988	2123	2251
214	1777	1988	2122	2251
215	1777	1988	2122	2251
216	1777	1988	2121	2251
217	1777	1987	2121	2251
218	1777	1987	2120	2250
219	1777	1986	2120	2250
220	1777	1986	2119	2249
221	1776	1985	2119	2249
222	1776	1985	2118	2248
223	1776	1984	2118	2248
224	1776	1984	2117	2248
225	1776	1983	2117	2247
226	1775	1983	2116	2247
227	1775	1982	2116	2246
228	1775	1982	2115	2246
229	1775	1982	2114	2246
230	1775	1981	2114	2245
231	1774	1981	2113	2245
232	1774	1980	2113	2244
233	1774	1980	2112	2244
234	1774	1979	2112	2244
235	1774	1979	2111	2243
236	1773	1978	2111	2243
237	1773	1978	2110	2242
238	1773	1977	2110	2242
239	1773	1977	2109	2241
240	1773	1976	2109	2241
241	1769	1969	2100	2229
242	1766	1963	2091	2217
243	1762	1956	2082	2205
244	1759	1949	2073	2192

August	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	**10**	**25**	**50**	**100**
245	1281	1380	1450	1507
246	1279	1378	1446	1504
247	1277	1375	1443	1501
248	1274	1373	1439	1497
249	1272	1371	1436	1494
250	1270	1368	1432	1491
251	1267	1366	1429	1488
252	1265	1364	1425	1485
253	1263	1361	1421	1482
254	1260	1359	1418	1479
255	1258	1356	1414	1476
256	1256	1354	1411	1473
257	1253	1352	1407	1469
258	1251	1349	1404	1466
259	1249	1347	1400	1463
260	1246	1344	1397	1460
261	1244	1342	1393	1457
262	1242	1340	1390	1454
263	1239	1337	1386	1451
264	1237	1335	1383	1448
265	1237	1334	1382	1447
266	1236	1334	1382	1446
267	1236	1333	1381	1446
268	1235	1332	1381	1445
269	1235	1332	1380	1444
270	1234	1331	1380	1443
271	1234	1330	1379	1443
272	1233	1330	1379	1442
273	1233	1329	1378	1441
274	1232	1328	1378	1441
275	1232	1328	1377	1440
276	1231	1327	1377	1439
277	1231	1326	1377	1438
278	1230	1326	1376	1438
279	1230	1325	1376	1437
280	1230	1324	1375	1436
281	1229	1324	1375	1436
282	1229	1323	1374	1435
283	1228	1322	1374	1434
284	1228	1322	1373	1433
285	1227	1321	1373	1433
286	1227	1320	1372	1432
287	1226	1320	1372	1431
288	1226	1319	1371	1430
289	1225	1318	1371	1430
290	1225	1318	1370	1429
291	1224	1317	1370	1428
292	1224	1316	1369	1428
293	1223	1316	1369	1427

September	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	**10**	**25**	**50**	**100**
245	1755	1942	2064	2180
246	1752	1936	2056	2168
247	1748	1929	2047	2156
248	1745	1922	2038	2144
249	1741	1915	2029	2132
250	1738	1909	2020	2119
251	1734	1902	2011	2107
252	1731	1895	2003	2095
253	1727	1888	1994	2083
254	1723	1881	1985	2071
255	1720	1875	1976	2058
256	1716	1868	1967	2046
257	1713	1861	1958	2034
258	1709	1854	1949	2022
259	1706	1848	1941	2010
260	1702	1841	1932	1998
261	1699	1834	1923	1985
262	1695	1827	1914	1973
263	1692	1821	1905	1961
264	1688	1814	1896	1949
265	1688	1813	1896	1948
266	1687	1813	1895	1948
267	1687	1812	1894	1948
268	1686	1812	1894	1947
269	1686	1811	1893	1947
270	1685	1811	1892	1946
271	1685	1810	1892	1946
272	1684	1810	1891	1945
273	1684	1809	1890	1945
274	1683	1809	1890	1944
275	1683	1808	1889	1944
276	1682	1808	1888	1944
277	1682	1807	1888	1943
278	1681	1806	1887	1943
279	1681	1806	1886	1942
280	1680	1805	1885	1942
281	1680	1805	1885	1941
282	1679	1804	1884	1941
283	1679	1804	1883	1940
284	1678	1803	1883	1940
285	1678	1803	1882	1940
286	1677	1802	1881	1939
287	1677	1802	1881	1939
288	1676	1801	1880	1938
289	1676	1801	1879	1938
290	1675	1800	1879	1937
291	1675	1799	1878	1937
292	1674	1799	1877	1936
293	1674	1798	1877	1936

August	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time (hr)	10	25	50	100
294	1223	1315	1369	1426
295	1222	1314	1368	1425
296	1222	1314	1368	1425
298	1221	1313	1367	1424
297	1221	1312	1367	1423
298	1221	1312	1366	1423
299	1220	1311	1366	1422
300	1220	1310	1365	1421
301	1219	1310	1365	1420
302	1219	1309	1364	1420
303	1218	1308	1364	1419
304	1218	1308	1363	1418
305	1217	1307	1363	1417
306	1217	1306	1362	1417
307	1216	1306	1362	1416
308	1216	1305	1361	1415
309	1215	1304	1361	1415
310	1215	1304	1360	1414
311	1214	1303	1360	1413
312	1214	1302	1360	1412
313	1213	1302	1359	1412
314	1213	1301	1359	1411
315	1212	1300	1358	1410
316	1212	1300	1358	1410
317	1212	1299	1357	1409
318	1211	1298	1357	1408
319	1211	1298	1356	1407
320	1210	1297	1356	1407
321	1210	1296	1355	1406
322	1209	1296	1355	1405
323	1209	1295	1354	1404
324	1208	1294	1354	1404
325	1208	1294	1353	1403
326	1207	1293	1353	1402
327	1207	1292	1352	1402
328	1206	1291	1352	1401
329	1206	1291	1351	1400
330	1205	1290	1351	1399
331	1205	1289	1351	1399
332	1204	1289	1350	1398
333	1204	1288	1350	1397
334	1203	1287	1349	1397
335	1203	1287	1349	1396
336	1203	1286	1348	1395
337	1202	1285	1348	1394
338	1202	1285	1347	1394
339	1201	1284	1347	1393
340	1201	1283	1346	1392
341	1200	1283	1346	1391

September	Iron Gate Discharge (ft^3/s) by Return Period (years)			
Time(hr)	10	25	50	100
294	1673	1798	1876	1936
295	1673	1797	1875	1935
296	1672	1797	1875	1935
298	1672	1796	1874	1934
297	1671	1796	1873	1934
298	1671	1795	1873	1933
299	1670	1795	1872	1933
300	1670	1794	1871	1932
301	1669	1794	1871	1932
302	1669	1793	1870	1932
303	1668	1792	1869	1931
304	1668	1792	1869	1931
305	1667	1791	1868	1930
306	1667	1791	1867	1930
307	1666	1790	1866	1929
308	1666	1790	1866	1929
309	1665	1789	1865	1928
310	1665	1789	1864	1928
311	1664	1788	1864	1928
312	1664	1788	1863	1927
313	1663	1787	1862	1927
314	1663	1787	1862	1926
315	1662	1786	1861	1926
316	1662	1785	1860	1925
317	1661	1785	1860	1925
318	1661	1784	1859	1924
319	1660	1784	1858	1924
320	1660	1783	1858	1923
321	1659	1783	1857	1923
322	1659	1782	1856	1923
323	1658	1782	1856	1922
324	1658	1781	1855	1922
325	1657	1781	1854	1921
326	1657	1780	1854	1921
327	1656	1780	1853	1920
328	1656	1779	1852	1920
329	1655	1778	1852	1919
330	1655	1778	1851	1919
331	1654	1777	1850	1919
332	1654	1777	1849	1918
333	1653	1776	1849	1918
334	1653	1776	1848	1917
335	1652	1775	1847	1917
336	1652	1775	1847	1916
337	1651	1774	1846	1916
338	1651	1774	1845	1915
339	1650	1773	1845	1915
340	1650	1772	1844	1915
341	1649	1772	1843	1914

August	Iron Gate Discharge (ft³/s) by Return Period (years)			
Time (hr)	10	25	50	100
342	1200	1282	1345	1391
343	1199	1281	1345	1390
344	1199	1281	1344	1389
345	1198	1280	1344	1389
346	1198	1279	1343	1388
347	1197	1279	1343	1387
348	1197	1278	1343	1386
349	1196	1277	1342	1386
350	1196	1277	1342	1385
351	1195	1276	1341	1384
352	1195	1275	1341	1384
353	1194	1275	1340	1383
354	1194	1274	1340	1382
355	1194	1273	1339	1381
356	1193	1273	1339	1381
357	1193	1272	1338	1380
358	1192	1271	1338	1379
359	1192	1271	1337	1378
360	1192	1271	1337	1378

September	Iron Gate Discharge (ft³/s) by Return Period (years)			
Time(hr)	10	25	50	100
342	1649	1771	1843	1914
343	1648	1771	1842	1913
344	1648	1770	1841	1913
345	1647	1770	1841	1912
346	1647	1769	1840	1912
347	1646	1769	1839	1911
348	1646	1768	1839	1911
349	1645	1768	1838	1911
350	1645	1767	1837	1910
351	1644	1767	1837	1910
352	1644	1766	1836	1909
353	1643	1765	1835	1909
354	1643	1765	1835	1908
355	1642	1764	1834	1908
356	1642	1764	1833	1907
357	1641	1763	1833	1907
358	1641	1763	1832	1907
359	1640	1762	1831	1906
360	1640	1762	1831	1906

14. Appendix B. Hydraulic Conditions Downstream of Iron Gate Dam

Reach	**Variable**	**Flow Rate (cfs)**																
		1000	2000	3000	4000	5000	6000	8000	10000	15000	20000	30000	40000	50000	60000	80000	100000	130000
IronGate to BogusCreek	E.G. Slope	0.00848	0.00580	0.00453	0.00398	0.00369	0.00352	0.00334	0.00326	0.00323	0.00324	0.00346	0.00356	0.00367	0.00378	0.00388	0.00369	0.00314
	Vel Chnl (ft/s)	3.9	4.6	5.1	5.5	5.9	6.3	6.9	7.4	8.6	9.7	11.5	12.9	14.2	15.3	17.0	18.0	18.2
	Flow Area (ft^2)	291	460	610	748	875	996	1213	1408	1835	2215	2844	3428	3992	4581	5791	7458	10396
	Top Width (ft)	126	136	144	152	159	165	171	177	192	201	213	227	250	292	373	529	633
	Froude #	0.49	0.46	0.44	0.44	0.43	0.43	0.44	0.44	0.46	0.47	0.51	0.53	0.55	0.56	0.58	0.58	0.54
BogusCreek to WillowCreek	E.G. Slope	0.00597	0.00491	0.00376	0.00344	0.00324	0.00298	0.00283	0.00273	0.00258	0.00255	0.00249	0.00246	0.00242	0.00240	0.00234	0.00225	0.00211
	Vel Chnl (ft/s)	3.2	4.1	4.6	5.1	5.5	5.8	6.4	7.0	8.1	8.9	10.3	11.3	12.1	12.7	13.6	14.4	15.2
	Flow Area (ft^2)	382	561	713	850	978	1098	1326	1537	2031	2507	3475	4461	5445	6375	8227	9983	12628
	Top Width (ft)	137	148	157	167	176	185	199	211	244	281	371	441	483	513	555	593	640
	Froude #	0.41	0.41	0.40	0.41	0.41	0.41	0.42	0.43	0.44	0.45	0.47	0.47	0.48	0.48	0.48	0.48	0.47
WillowCreek to CottonwoodCreek	E.G. Slope	0.00325	0.00223	0.00201	0.00190	0.00183	0.00177	0.00171	0.00169	0.00166	0.00165	0.00164	0.00163	0.00165	0.00167	0.00167	0.00163	0.00151
	Vel Chnl (ft/s)	2.8	3.5	4.1	4.5	4.9	5.2	5.7	6.2	7.2	8.0	9.3	10.3	11.1	11.8	12.9	13.5	13.9
	Flow Area (ft^2)	422	611	776	928	1071	1208	1461	1695	2281	2830	3952	5103	6252	7411	9956	12851	17858
	Top Width (ft)	166	177	189	202	219	231	242	259	294	338	457	540	631	717	839	954	1099
	Froude #	0.36	0.36	0.37	0.37	0.38	0.38	0.39	0.40	0.41	0.42	0.44	0.45	0.46	0.47	0.47	0.47	0.45

Reach	**Variable**	**Flow Rate (cfs)**																
		1000	2000	3000	4000	5000	6000	8000	10000	15000	20000	30000	40000	50000	60000	80000	100000	130000
CottonwoodCreek to ShastaRiver	E.G. Slope	0.00468	0.00354	0.00277	0.00255	0.00238	0.00230	0.00220	0.00215	0.00209	0.00205	0.00200	0.00194	0.00189	0.00184	0.00177	0.00171	0.00165
	Vel Chnl (ft/s)	3.0	3.8	4.3	4.8	5.2	5.5	6.1	6.5	7.6	8.4	9.6	10.6	11.3	12.0	12.9	13.7	14.6
	Flow Area (ft^2)	409	594	754	899	1032	1160	1399	1619	2126	2592	3496	4421	5400	6386	8301	10210	12989
	Top Width (ft)	142	152	162	171	179	185	195	202	222	240	295	355	406	436	467	498	536
	Froude #	0.37	0.38	0.37	0.38	0.38	0.38	0.39	0.40	0.41	0.42	0.43	0.43	0.43	0.43	0.43	0.42	0.42
ShastaRiver to HumbugCreek	E.G. Slope	0.00496	0.00478	0.00434	0.00409	0.00393	0.00359	0.00330	0.00320	0.00309	0.00306	0.00305	0.00306	0.00304	0.00305	0.00308	0.00309	0.00311
	Vel Chnl (ft/s)	3.1	4.0	4.6	5.1	5.5	5.9	6.5	7.0	8.0	8.8	10.1	11.1	12.0	12.8	14.0	15.1	16.5
	Flow Area (ft^2)	370	556	714	855	988	1117	1361	1594	2146	2655	3559	4382	5187	5956	7391	8707	10418
	Top Width (ft)	125	138	149	161	172	182	200	219	257	283	305	336	365	397	441	465	486
	Froude #	0.35	0.38	0.39	0.39	0.40	0.40	0.40	0.41	0.42	0.43	0.45	0.46	0.46	0.47	0.48	0.49	0.51
HumbugCreek to BeaverCreek	E.G. Slope	0.00711	0.00608	0.00512	0.00471	0.00434	0.00419	0.00399	0.00391	0.00370	0.00362	0.00347	0.00336	0.00334	0.00332	0.00332	0.00328	0.00325
	Vel Chnl (ft/s)	3.3	4.2	4.8	5.3	5.7	6.1	6.7	7.3	8.3	9.2	10.5	11.5	12.3	13.0	14.3	15.2	16.4
	Flow Area (ft^2)	402	578	728	866	994	1118	1351	1572	2091	2577	3514	4374	5170	5945	7473	8888	10892
	Top Width (ft)	123	133	145	155	164	174	190	205	245	282	334	364	384	407	453	479	512
	Froude #	0.39	0.41	0.40	0.41	0.41	0.42	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.48	0.49	0.50	0.51

Reach	**Variable**	**Flow Rate (cfs)**																
		1000	2000	3000	4000	5000	6000	8000	10000	15000	20000	30000	40000	50000	60000	80000	100000	130000
BeaverCreek to DonaCreek	E.G. Slope	0.00552	0.00408	0.00352	0.00333	0.00314	0.00294	0.00268	0.00261	0.00256	0.00250	0.00241	0.00234	0.00229	0.00223	0.00212	0.00204	0.00192
	Vel Chnl (ft/s)	3.6	4.5	5.1	5.6	6.1	6.4	7.0	7.5	8.6	9.4	10.7	11.6	12.3	12.9	13.8	14.4	15.0
	Flow Area (ft^2)	351	513	651	778	899	1019	1248	1477	2025	2563	3638	4717	5791	6869	9089	11205	14282
	Top Width (ft)	127	134	142	153	162	175	199	226	278	327	426	497	566	619	694	738	798
	Froude #	0.45	0.44	0.45	0.45	0.45	0.46	0.46	0.46	0.48	0.48	0.49	0.50	0.50	0.50	0.49	0.49	0.48
DonaCreek to HorseCreek	E.G. Slope	0.00284	0.00264	0.00240	0.00217	0.00209	0.00205	0.00200	0.00197	0.00193	0.00190	0.00186	0.00184	0.00181	0.00179	0.00172	0.00162	0.00148
	Vel Chnl (ft/s)	3.4	4.4	5.0	5.6	6.0	6.4	7.1	7.7	8.9	9.8	11.2	12.3	13.2	13.9	15.1	15.7	16.5
	Flow Area (ft^2)	322	491	634	767	889	1004	1223	1434	1945	2441	3402	4327	5260	6166	7987	10340	13743
	Top Width (ft)	155	170	186	198	209	230	274	297	351	396	475	532	571	599	645	694	768
	Froude #	0.44	0.46	0.47	0.48	0.48	0.49	0.50	0.50	0.52	0.53	0.54	0.55	0.55	0.56	0.56	0.54	0.53
HorseCreek to ScottRiver	E.G. Slope	0.00290	0.00240	0.00222	0.00215	0.00211	0.00209	0.00208	0.00207	0.00205	0.00202	0.00203	0.00200	0.00196	0.00198	0.00200	0.00202	0.00203
	Vel Chnl (ft/s)	3.5	4.5	5.2	5.7	6.2	6.7	7.4	8.1	9.4	10.4	12.1	13.3	14.3	15.3	17.0	18.5	20.2
	Flow Area (ft^2)	316	480	617	740	853	960	1162	1354	1804	2216	2988	3708	4444	5077	6289	7444	9142
	Top Width (ft)	145	158	166	172	177	183	195	204	229	246	281	298	318	327	355	375	401
	Froude #	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.55	0.57	0.58	0.59	0.60	0.61	0.63	0.64

Reach	**Variable**	**Flow Rate (cfs)**																
		1000	2000	3000	4000	5000	6000	8000	10000	15000	20000	30000	40000	50000	60000	80000	100000	130000
ScottRiver to IndianCreek	E.G. Slope	0.00515	0.00414	0.00374	0.00343	0.00321	0.00307	0.00288	0.00276	0.00257	0.00249	0.00239	0.00233	0.00228	0.00225	0.00217	0.00213	0.00207
	Vel Chnl (ft/s)	3.1	3.9	4.5	5.0	5.4	5.7	6.4	6.9	8.0	8.9	10.2	11.3	12.1	12.9	14.0	15.0	16.2
	Flow Area (ft^2)	426	622	784	930	1066	1193	1431	1653	2172	2659	3582	4451	5292	6129	7864	9621	12176
	Top Width (ft)	167	178	185	194	202	209	222	234	262	289	334	366	399	435	525	599	672
	Froude #	0.41	0.41	0.42	0.42	0.43	0.43	0.44	0.44	0.45	0.46	0.48	0.49	0.49	0.50	0.50	0.51	0.51

15. Appendix C. Jet Test Results from TSC

			Critical shear stress	Detachment rate coefficient			
			τ_c	k_d			
Sample	Description	Sample Depth, ft	Pa	$cm^3/(N\text{-}s)$	Notes	Water Content, %	Dry Density, lb/ft^3
EDH-09-4 (71X-9)	undisturbed tube sample cut from larger sample	3	0.016	34	Very soft. Sample could only be tested for about 2 minutes. Depth of hole caused material to start falling back into the hole after t=2 min.	-	-
EDH-09-5 (71X-10)	Remolded sample from bottom of tube…remolded with spoon, no compaction	1.9	0.28	12	Better test. Very erodible, but sample seemed to erode in consistent, controlled manner.	276.9	19.25
EDH-09-6 (71X-12)	Remolded sample from top of tube…remolded with spoon, no compaction	1.5	0.28	140	Very soft, and material seemed to erode along seams. Got only a couple of good data points before scour hole got very deep and it was impossible to accurately measure depth.	286.7	18.76

EDH-09-7, ~1.4 ft depth (71X-15)	Tube sample	1.4	1.76	2.6	This sample appears from documentation to be above the top of existing pre-reservoir sediment, but may actually be below. Color of material seen in tube seems backward…brown material at bottom and very black at top.	-	-
EDH-09-7, ~2.1 ft depth (71X-15)	Tube sample	2.1	0.74	2.2	Companion sample to test 4, supposedly below the pre-reservoir sediment interface, but may come from above the interface. Very good test. Consistent erosion.	-	-
EDH-09-6, ~5 ft depth (71X-13)	Tube sample	5	0.127	14.3	Short test. Hole deviated off to side and it became impossible to accurately measure depth of scour..	-	-

16. Appendix D. Report on Erodibility Characteristics of Reservoir Sediment by Agricultural Research Service

Erodibility Characteristics of Bottom Deposits from Three Klamath River Reservoirs, California and Oregon

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INTRODUCTION

Dam decommissioning has become an important aspect of restoring the nation's streams and rivers. The U.S. Bureau of Reclamation among other federal agencies and entities such as the U.S. Army Corps of Engineers are responsible for these types of projects while minimizing off-site impacts such as erosion of reservoir deposits and the potential for damage to downstream water quality and aquatic habitat. To minimize potential adverse effects of dam decommissioning, it is critical to understand and quantify the dominant processes and rates of erosion during dam removal and reservoir drawdown.

Studies are underway to support the Secretarial Determination on Klamath Dam Removal and Basin Restoration. The dams and associated reservoirs are Copco 1 1, John C. Boyle and Iron Gate.

Predicting of rates of erosion under given hydrologic and hydraulic conditions is in part a function of determining the erodibility characteristics of the reservoir deposits. As most of these deposits are fine grained silts and clays, conventional analytic methods used for non-cohesive materials which are based on particle size and weight may not valid for predicting incipient motion criteria in these cohesive deposits. The resistance of cohesive materials to erosion is a function of the strength of the electro-chemical bonds between charged clay particles. Still, to analyze the potential for and magnitude of hydraulic erosion, results must be parameterized using variables that can be associated to equations that rely on comparison of resistance values to the applied hydraulic shear stress. These variables are critical shear stress (τ_c) and the erodibility coefficient (k) and can be obtained from direct testing of the deposits with a submerged jet-test apparatus (Hanson, 1990).

Information obtained from testing the erodibility characteristics of the reservoir deposits will then be used with the Bureau's two-dimension flow and sediment transport model SRH-2D to predict incipient motion and erosion of the deposits. The model has been recently enhanced to include the National Sedimentation Laboratory's (NSL) Bank-Stability and Toe Erosion Model (BSTEM).

Erosion by Hydraulic Shear

Whether sediment is entrained by a moving fluid depends on both the properties of the fluid (i.e. its density, viscosity and velocity) and the physical properties of the sediment, such as its size, shape, density and arrangement (Knighton, 1998). A basic distinction exists between the entrainment of non-cohesive sediment (usually coarse silt, sand, gravel and boulders or cobbles) and cohesive sediments, because the entrainment of the latter is complicated by the presence of cohesion (Knighton, 1998). In both cases, most approaches to sediment transport have relied upon the concept of a critical value of some parameter. The present paper utilizes the applied shear stress, τ_o as the independent variable.

Mechanisms of Cohesive Sediment Erosion: Mechanistically, the detachment and erosion of cohesive (silt- and clay-sized) material by gravity and/or flowing water is controlled by a variety of physical, electrical, and chemical forces. Identification of all of these forces and the role they play in determining detachment, incipient motion, and erodibility, of cohesive materials is incomplete and still relatively poorly understood (Winterwerp and van Kesteren, 2004). Assessing the erosion resistance of cohesive materials by flowing water is complex due to the difficulties in characterizing the strength of the electro-chemical bonds that define the resistance of cohesive materials. The many studies that have been conducted on cohesive materials have observed that numerous soil properties influence erosion resistance including antecedent moisture, clay mineralogy and proportion, density, soil structure, organic content, as well as pore and water chemistry (Grissinger, 1982). For example, Arulanandan (1975) described how the erodibility of a soil decreases with increasing salt concentration of the eroding fluid, inducing weakening of inter-particle bonds. Kelly and Gularte (1981) showed that for cohesive sediments, increasing temperature increases erosion rates, particularly at low salinity, while at high salinity, there is less of an effect on erosion.

Cohesive materials can be eroded in three contrasting ways (Mehta 1991): (1) surface erosion of bed aggregates; (2) mass erosion of the bed; and (3) entrainment of fluid mud. Partheniades (1965) showed that clay resistance to erosion seemed to be independent of the macroscopic shear strength of the bed, provided that the bed shear stresses did not exceed the macroscopic shear strength of the material. Once the bed shear stress exceeds some critical value, then following Ariathurai and Arulanandan (1978) the rate of erosion, ε, of cohesive materials can be predicted by:

$$\varepsilon = k_d \left(\frac{\tau_o}{\tau_c} - 1 \right)^a \qquad (\text{for } \tau_o > \tau_c)$$

$$\varepsilon = 0 \qquad (\text{for } \tau_o \leq \tau_c) \qquad (1)$$

where k_d = erosion rate coefficient (m s^{-1}), τ_o = bed shear stress (Pa), τ_c = critical shear stress (Pa), and a = exponent assumed to equal 1.0. Equation 1 may also be written as (Partheniades, 1965):

$$\varepsilon = \frac{k_d}{\tau_c}\left(\tau_o - \tau_c\right) = k\left(\tau_o - \tau_c\right) \qquad (\text{for } \tau_o > \tau_c)$$

$$\varepsilon = 0 \qquad (\text{for } \tau_o \leq \tau_c) \qquad (2)$$

where k = erodibility coefficient (m^3/N-s). Note, however, that this simple approach does not differentiate between the different modes of erosion.

OBJECTIVES and SCOPE

The overall objective of the study was to determine erodibility characteristics of reservoir deposits from Copco 1 1, John C Boyle and Iron Gate Reservoirs in the upper Klamath River System, California and Oregon (Figure 1). An attempt was to be made to determine how these characteristics varied under different moisture contents and degrees of compaction.

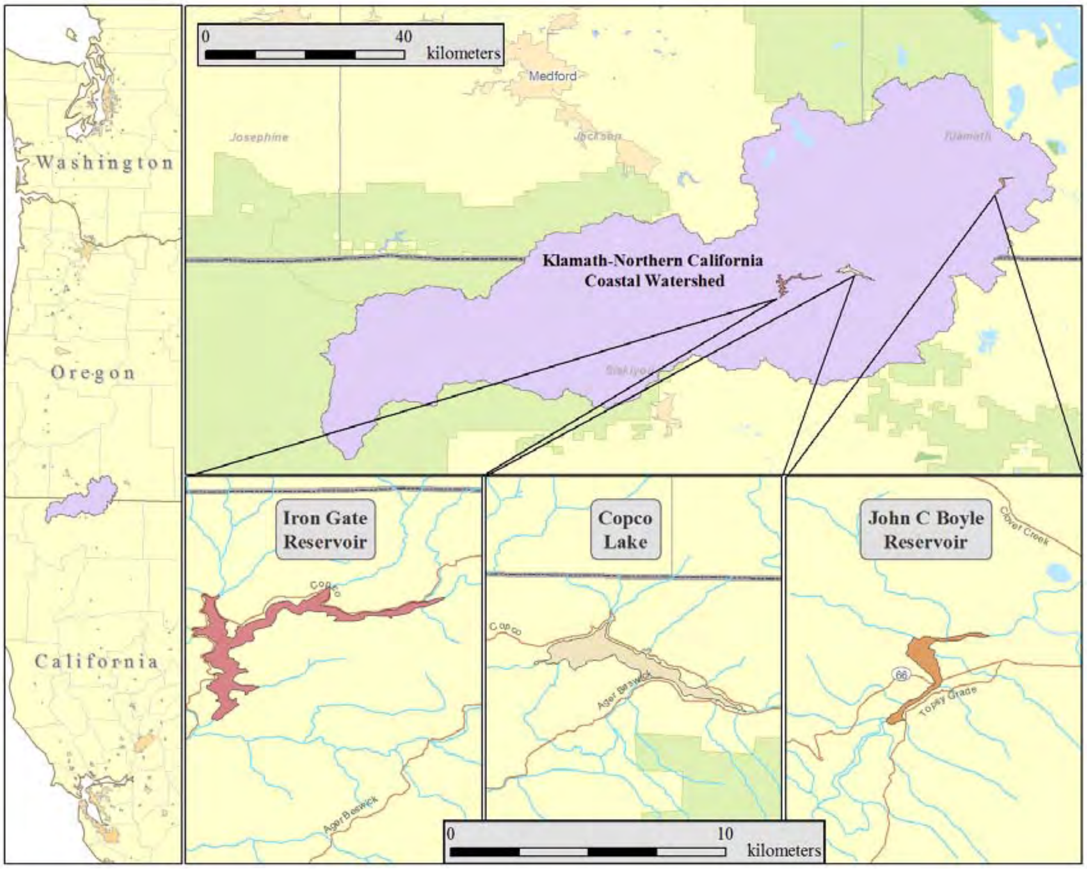

Figure 1- Location map of Iron Gate, Copco 1 1 and John C. Boyle Reservoirs in the Klamath River System.

METHODS

The methods employed in this study can be classified as field and analytic. Field methods were restricted to sample collection as all sample testing was conducted in a laboratory setting.

Sample Collection

Field-data collection of reservoir deposits was carried out on November 18 and 19, 2009 from a boat. Samples collection was attempted at three locations in each reservoir as determined by the Bureau. A spring-loaded Ponar grab sampler was lowered by cable through the water column to the bed and retrieved by winching the sampler back up into the sampling boat. Material was then dumped into 5-gallon buckets, labeled and sealed for shipment back to NSL. In total 15 buckets were retrieved from the nine sampling locations (Table 1). A particularly firm or coarse-grained bed was identified at sampling location 486 in Iron Gate Reservoir making sample recovery difficult. Ultimately, an insufficient sample mass (5.2 kg) was obtained from this location to conduct erodibility tests. In general however, the bulk samples flowed easily from out of the Ponar sampler into the buckets.

Table 1. Summary of bulk samples obtained from the reservoirs on November 18-19, 2009. [1]Site identification numbers provided by the Bureau.

Reservoir	**Site Number[1]**	**Number of Buckets**	**Total Weight (kg)**
Copco 1	489	2	41.9
Copco 1	490	2	41.9
Copco 1	491	2	44.1
Iron Gate	485	2	44.3
Iron Gate	486	1	5.2
Iron Gate	488	1	17.5
John C Boyle	482	2	40.8
John C Boyle	483	1	22.0
John C Boyle	484	2	41.4

Sample Preparation

Initial data provided by the Bureau and observations of material exhumed from the Ponar sampler indicated that the reservoir deposits were generally highly organic and too soft for erosion testing. It was, therefore, understood that the samples would have to undergo a certain degree of drying and compaction to make them conducive to testing. Before this could take place however, an initial sample density was required to determine how much compaction would be required to produce a sample, bulk unit weight of 12 kN/m^3, representing the initial testing condition. An initial sample density (ρ_s) was obtained by determining the weight of the soil-water mixture and dividing by the volume of the sample within each bucket ($\pi r^2 h$; where r = radius of the bucket and h = the height of the sample in the bucket). Bulk unit weight of the material (γ_s) was then obtained by multiplying (ρ_s) by 9.81/1000.

Initial unit weights were remarkably consistent, ranging from 10.5 to 11.6 kN/m^3 with an average of 11.0 kN/m^3 (standard error = 0.0868). Table 2 shows the initial, calculated bulk unit weights for each bucket.

Compaction of samples: 20.3 centimeter by 40.6 centimeter boxes were constructed and prepared to permit sample drainage during application of a vertical load. The box was constructed of this size to be able to accommodate two submerged jet tests as well as other instruments to characterize erodibility. A flat metal plate was also constructed to fit just inside the top box and on top of the sample while compaction occurred. The initial volume that the sample filled within the each box was calculated to determine the volume required to reach 12 kN/m^3.

Each sample was poured into a separate box and the height of the sample in the box was recorded. Initial compaction was carried out using static weights placed on top of the metal insert. This allowed the sample to shed some of it’s water in preparation for more aggressive compaction with a hydraulic press. The static load used was 40.8 kg and was kept on the samples from 2 to 5 days and sometimes longer depending on the availability of the hydraulic press.

Table 2. Initial bulk unit weights (γ_s) of samples obtained with the Ponar sampler. [1]Site identification numbers provided by the Bureau.

Reservoir	Site Number[1]	Bucket #	Bulk unit weight (kN/m^3)
Copco 1	489	1	10.8
Copco 1	489	2	10.8
Copco 1	490	1	11.1
Copco 1	490	2	10.8
Copco 1	491	1	11.3
Copco 1	491	2	11.3
Iron Gate	485	1	11.5
Iron Gate	485	2	11.2
Iron Gate	486	1	11.2
Iron Gate	488	1	11.2
John C Boyle	482	1	10.6
John C Boyle	482	2	10.5
John C Boyle	483	1	11.6
John C Boyle	484	1	10.7
John C Boyle	484	2	10.7

To shorten the time required to obtain the desired bulk unit weight, a hydraulic press was used. An initial load of 136 kg was applied to the samples coming from the static load press. Over time, the sample absorbed the load from the hydraulic press as the sample compacted and reduced in volume and the hydraulic arm of the press remained at the same position. For this reason, the load was reapplied over a period of 3 to 5 days by periodically lowering the hydraulic arm. As the sample became more difficult to compact, the load was increased to approximately 295 kg, depending on the integrity of the box the sample was contained in. The volume of the sample was continuously monitored during the period of compaction permitting back-calculation of bulk unit weights as the sample volume decreased. The target bulk unit weight of 12 kN/m^3 was achieved using the hydraulic press.

Given an average, initial bulk unit weight of 11.0 kN/m^3, it was somewhat surprising that attaining the target bulk unit weight of 12 kN/m^3 (a 9% increase) took 3-5 days under a load of up to 295 kg. This was attributed to the generally organic nature of the deposits and delayed erosion testing copnsiderably.

Sample drying: Given that one of the objectives of this research was to determine to what degree erosion parameters varied between moist and dried conditions, several methods were tested by which samples could be dried efficiently while minimizing surface cracks. They were:

- Air drying—spreading the sample out evenly in a pre-fabricated box and allowing it to dry inside the laboratory;
- Oven-assisted drying—spreading the sample out evenly in a pre-fabricated box and drying it out in a convection oven set to a temperature of 60^{o}C;
- Heat lamp assisted drying—spreading the sample out evenly in a prefabricated box and placing a heat lamp over the sample at various heights;
- Pressing then air drying—spreading the sample out evenly in a prefabricated box, pressing it to a unit weight of 12 kN/m^3 then allowing it to air dry for several days.

Although air drying tended to take the most time, it was a more effective method in reducing surface cracking. Moisture contents (by volume) were obtained with a digital moisture meter using time-domain reflectometry (TDR) technology at various stages of the drying process. As erosion testing with the jet-test apparatus and other instruments was destructive to the prepared sample, the compaction and drying process had to be repaeated after samples were remixed and brought to moisture contents similar to the initial.

Characterization of Erodibility

To characterize the erodibility of the reservoir deposits several types of tests were carried out on the prepared samples. The most important were those used to determine values of the hydraulic-erosion parameters τ_c and k. Ancillary data on moisture content, bulk unit weight, total shear strength and compressive strength were also collected.

Erosion Testing with Jet-Test Device: A submerged jet-test was developed by the Agricultural Research Service (Hanson, 1990; Figure 2) for testing the *in situ* erodibility of surface materials (ASTM, 1995). This device was developed based on knowledge of the hydraulic characteristics of a submerged jet and the characteristics of soil-material erodibility. In an attempt to remove empiricism and to obtain direct measurements of τ_c and k, Hanson and Cook (1997) developed analytical procedures for determining soil k based on the diffusion principles of a submerged circular jet and the corresponding scour produced by the jet. These procedures are based on analytical techniques developed by Stein et al. (1993) for a planar jet at an overfall and extended by Stein and Nett (1997). Stein and Nett (1997) validated this approach in the laboratory using six different soil types.

As the scour depth increases with time, the applied shear stress decreases due to increasing dissipation of jet energy within the plunge pool. Detachment rate is initially high and asymptotically approaches zero as shear stress approaches the critical shear stress of the bed material. The difficulty in determining equilibrium scour depth is that the length of time required to reach equilibrium can be large. Blaisdell *et al*. (1981) observed during studies on pipe outlets that scour in cohesionless sands continued to progress even after 14 months. They developed a function to compute the equilibrium scour depth that assumes that the relation between scour and time follows a logarithmic-hyperbolic function. Fitting the jet-test data to the logarithmic-hyperbolic method described in Hanson and Cook (1997) can predetermine τ_c. k is then estimated by curve-fitting measured values of scour depth versus time and minimizing the error of the measured time versus the predicted time. Both k and τ_c are treated as soil properties and the former does not generally correlate well with standard soil mechanical indices such as Atterberg limits. Instead, k is dependent on the physio-chemical parameters that determine the inter-particle forces characteristic of cohesive sediment (Parchure and Mehta, 1985; Mehta, 1991).

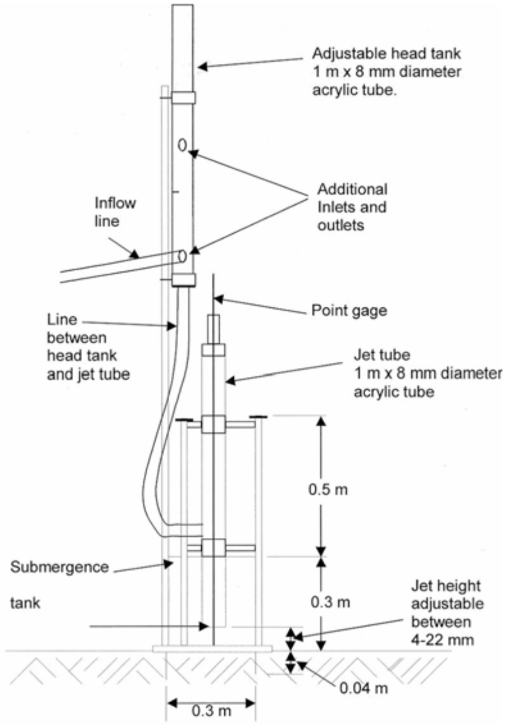

Figure 2. Schematic of jet-test device (from Hanson and Simon, 2001).

To provide an erosion-testing apparatus that could be used in remote field locations as well as in smaller laboratory setups, the National Sedimentation Laboratory, requested to Dr. Greg Hanson of the Agricultural Research Service in Stillwater, OK to design and construct a miniature version of the jet-test device. This was developed in 2008 (Figure 3) and extensively used by NSL in various field locations across the United States. The mini-jet apparatus consists of an electric submersible 60 liters/second pump powered by a portable generator, a scaled-down 0.12 m- diameter submergence tank with an integrated, rotatable 3.18 mm-diameter nozzle, depth gauge, and delivery hoses. This was the instrument used for erosion testing in this study. An example of test results are shown in Figure 4.

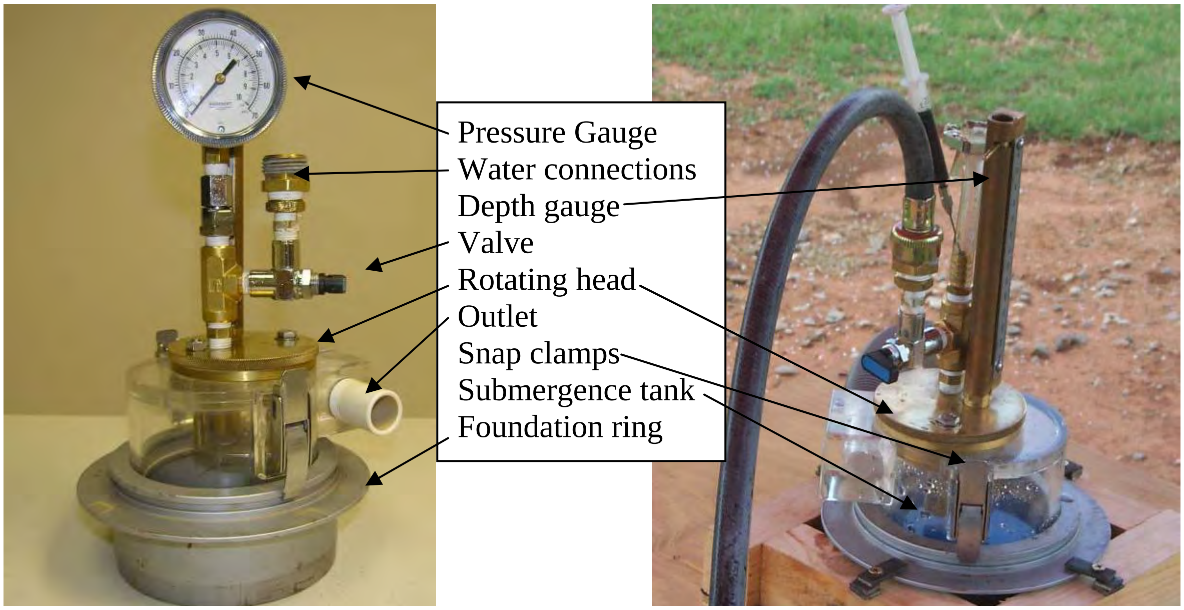

Figure 3. Mini-Jet (~0.12 m diameter) including foundation ring, submergence tank, rotating head, outlet, water delivery connections, gauge, valve, outlet, snap clamps, and depth gauge.

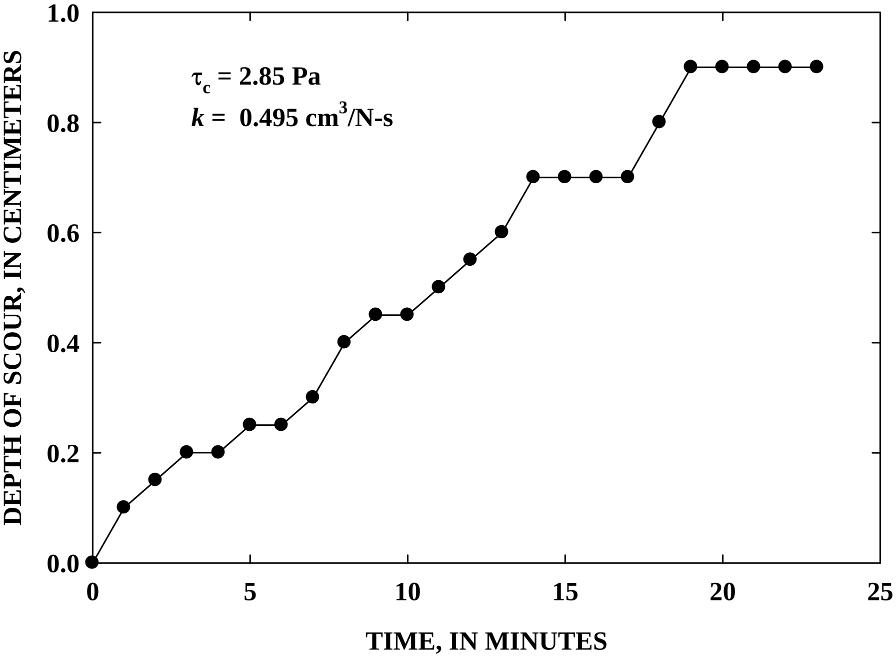

Figure 4. Example of erosion-test results for Iron Gate 488 using the mini-jet device.

Geotechnical measurements: Although we rely on erosion tests that provide hydraulic-resistance parameters (as with the jet-test device), geotechnical forces actually control the resistance of cohesive materials. Rapid geotechnical measurements that minimize sample disturbance or additional sample preparation were conducted to test whether relations could developed between shear strength and τ_c and k. Measurements of geotechnical shear strength (τ_f) were obtained with a Torvane shear device. A cylindrical vane was inserted vertically into the sample to the depth of the vanes. The head of the device was then rotated until the material encompassing the vane shears (fails). As the head of the device is spring loaded, a needle points to the maximum shear strength value (in kg/cm^2) that was resisted prior to failure. Values are then converted to kPa by multiplying by 98.0665.

A pocket penetrometer was used to measure the unconfined compressive strength of the samples. The tip of the spring-loaded instrument was pushed vertically into the sample until it has been embedded a distance of 6.35 mm. Compressive strength (in kg/cm^2) is then read directly off the shaft of the instrument. These tests were conducted before the samples were tested with the mini-jet device and throughout the drying process.

RESULTS OF MATERIAL and EROSION TESTING

Laboratory tests were conducted by the Bureau from core samples and were provided to NSL as background information on the nature of the reservoir deposits. The soft, and semi-fluid nature of the materials can be identified by both the average moisture contents (by weight) which ranged from 176 to 297%, and by the fact that these moisture contents generally exceeded the liquid limit of the materials by almost a factor of two (Table 3). Because moisture contents exceeded the liquid limit of the sample materials (Table 3), erosion tests that were attempted prior to any compaction failed because the materials were far too soft and fluidized to create a seal around the base of the jet-test device.

Table 3. Average values of reservoir-deposit characteristics. Original data provided by the U.S. Bureau of Reclamation.

Reservoir	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Liquid Limit (%)	Plasticity Index	Moisture content (% by weight)
Copco 1	51.1	42.5	6.4	0.0	152	71.0	297
Iron Gate	45.8	31.2	16.0	7.0	88.3	43.7	176
John C Boyle	29.7	40.0	25.4	4.9	152	58.5	265

Hydraulic-Erosion Test Results

A total of 33 tests at a sample bulk unit weight of 12 kN/m^3 were conducted with the mini-jet device during the study. Tests were conducted at moisture contents ranging from 48 to 82% (by volume). Samples that had not been dried (per se) but only compacted had moisture contents greater than 67% and were considered “moist” for the purposes of this study. Samples with moisture contents less than this and were subjected to drying, were considered “dried”.

For all tests, critical shear stresses (τ_c) ranged over six orders of magnitude, from 0.0008 to 114 Pa. Generally, however, reservoir average (τ_c) for moist samples at 12 kN/m^3 were equivalent to sand-sized materials, ranging from 0.58 to 1.1 Pa (Table 4). Erodibility coefficients (*k*) ranged from 0.05 to about 5.6 cm^3/N-s with moist, reservoir-average values being very consistent at 0.90 to 2.2 cm^3/N-s. An example of sample material post jet test is shown in Figure 5.

Table 4. Summary of reservoir-average erosion-testing results.

Reservoir	Total number of tests	τ_c (Pa)		k (cm^3/N-s)		Average τ_c (Pa)			Average k (cm^3/N-s)		
		Average	Median	Average	Median	Moist	Dried	% difference	Moist	Dried	% difference
Copco 1	10	3.26	1.18	0.741	0.555	0.578	5.93	926	1.11	0.370	-66.8
Iron Gate	11	20.8	2.72	1.43	0.654	0.934	55.7	5860	2.19	0.098	-95.5
John C Boyle	12	2.51	0.815	0.778	0.614	1.12	9.47	743	0.903	0.152	-83.2

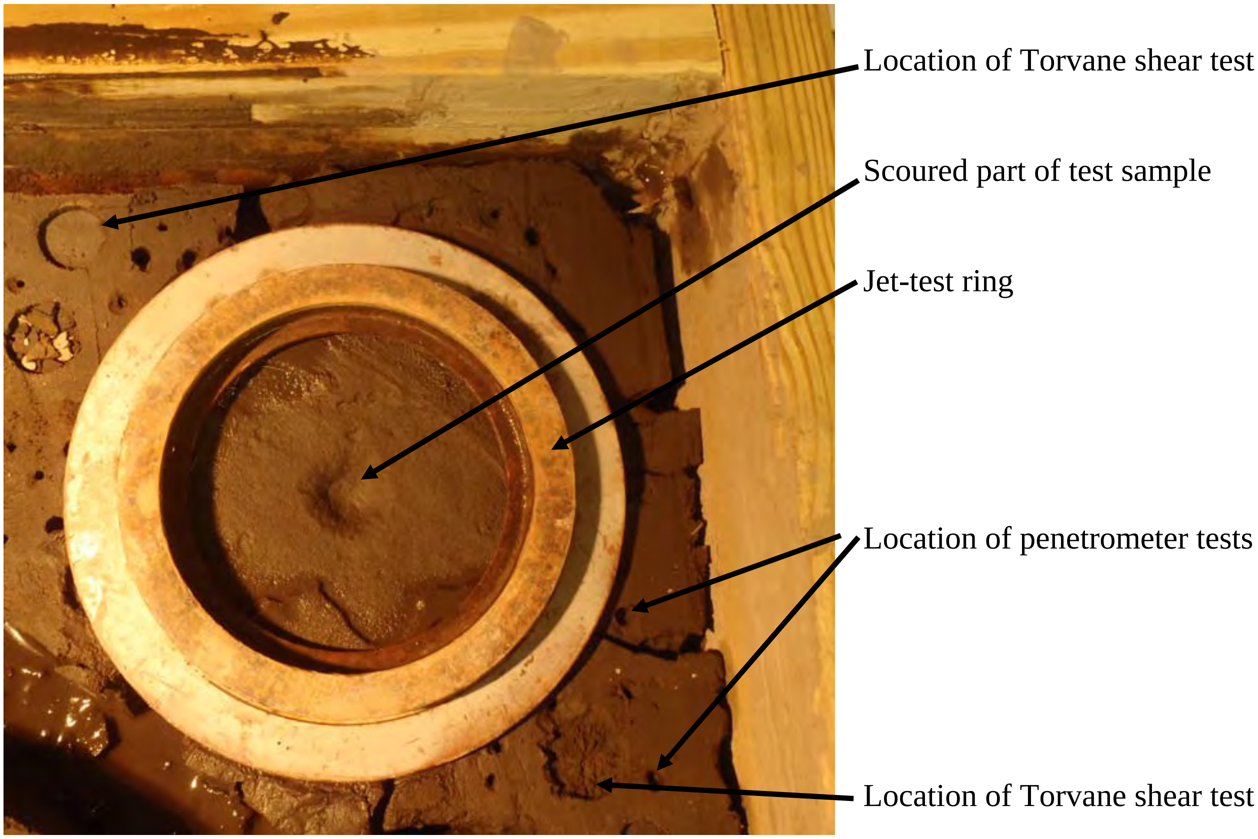

Figure 5. Photograph of surface of test sample after completion of a mini-jet test. The depression in the center of the sample surface represents the material scoured by the jet.

The effects of drying on erosion resistance and erodibility (τ_c and k) were significant with reservoir-average values of τ_c increasing by at least an order of magnitude (743 to 5860%) (Table 4). Associated decreases in k also occurred with sample drying, but not to the extent of the increases in critical shear stress. Reservoir-average values of the erodibility coefficient decreased between 67 and 96% (Table 4). This increase in resistance for dried samples equates to τ_c-values equivalent to those of gravel and cobbles (5.9 for Copco 1 to 56 Pa for Iron Gate), indicating that if the drawdown of the reservoir was very slow and the deposits were left to dry, resistance of the materials would increase considerably and erosion rates would be reduced.

Erosion-testing results of cohesive sediments are often disseminated as a relation between τ_c and *k* for the purpose of being able to estimate *k* from tests or estimates of critical shear stress. Results from the mini-jet testing of the Klamath River reservoir deposits shows a typical relation between these two variables with the relation flattening off at τ_c-values less than about 0.1 Pa (Figure 6) (Simon *et al.*, 2010). The form of this relation has been observed in data sets collected in cohesive deposits from diverse regions. These findings imply that *k* does not vary by an inverse power function under conditions of very high excess shear stress (in the range of 100 to 1,000), but reaches a maximum value as a function of the nature of the eroding materials.This can be attributed to: (1) the mass erosion and/or (2) entrainment of fluid mud erosion mechanisms proposed by Mehta (1991). Truncating the relation shown in Figure 6 at a critical shear stress of 0.1 Pa provides a significant relation ($r^2 = 0.89$) between these two important erosion-rate variables that can be used to predict *k* from τ_c (Figure 7). In fact, the strength of the relation as indicated by the r^2-value is better than any other relation the authors have developed for other field locations (Simon et al., 2010).

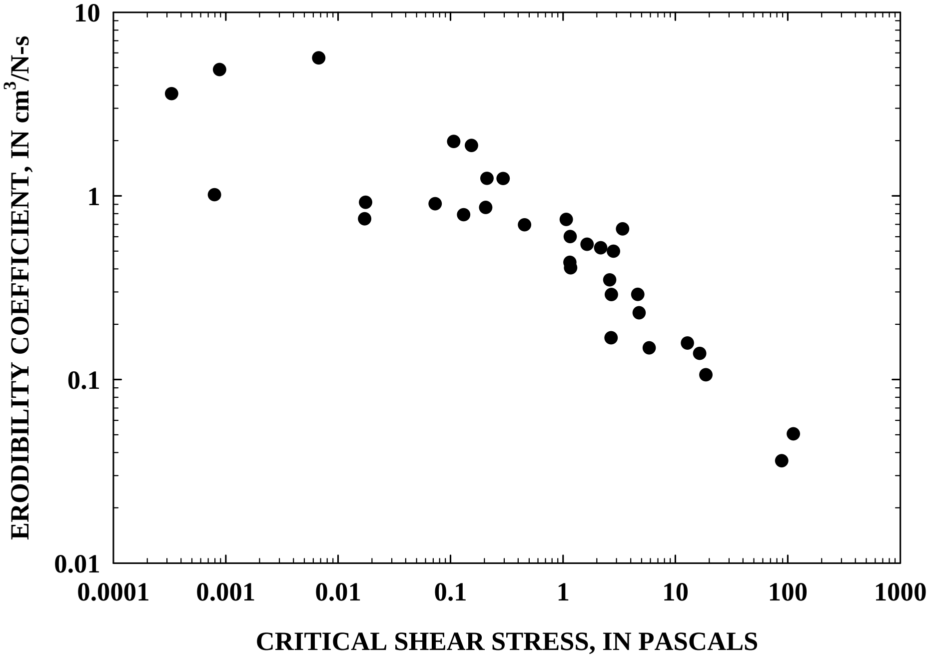

Figure 6. Relation between critical shear stress and the erodibility coefficient for mini-jet tests at 12 kN/m^3 on Klamath River reservoir deposits.

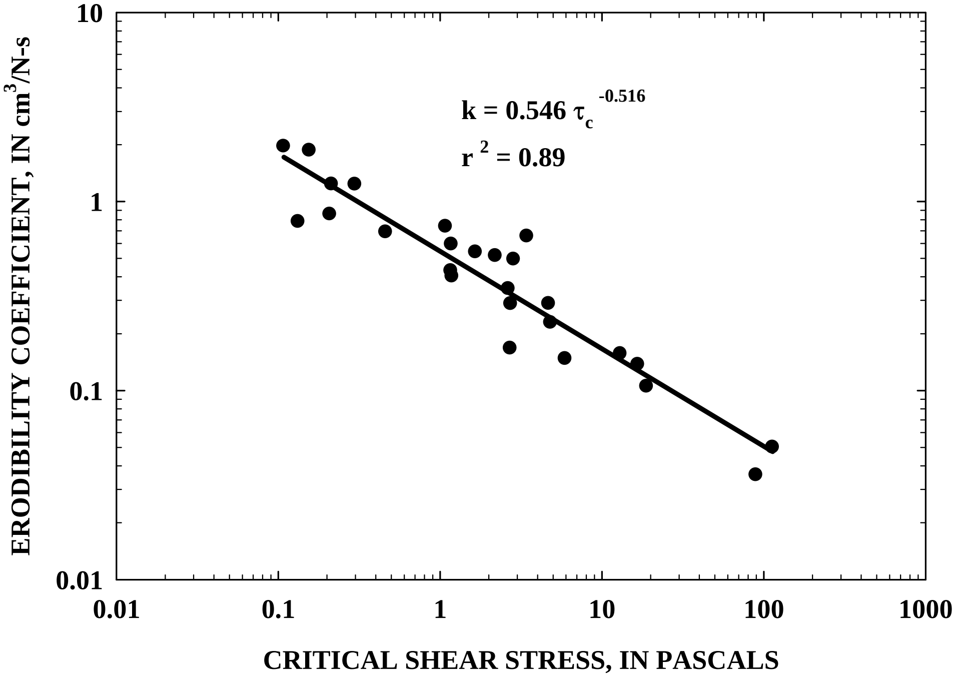

Figure 7. Relation between critical shear stress (τ_c) and the erodibility coefficient (k) for mini-jet tests on Klamath River reservoir deposits. Data truncated at τ_c-values less than 0.1 Pa after Simon et al. (2010).

Further investigation of the original relation with all test points at 12 kN/m^3 (Figure 6) provides clear evidence of the effect of sample drying on values of the erosion variables (Figure 8). The majority of the more resistant tests are those that have been dried to less than 67% moisture

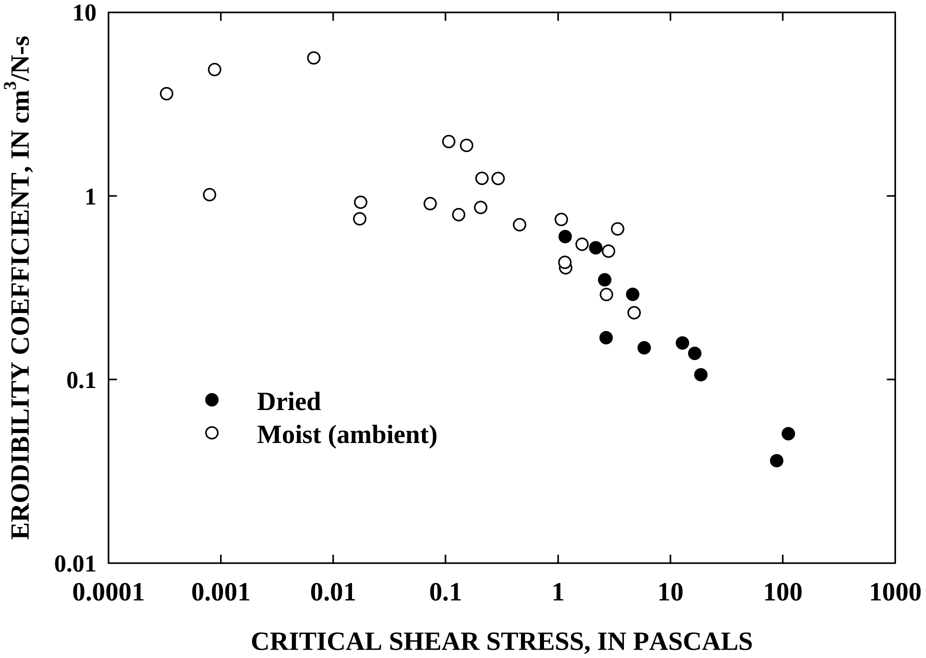

Figure 8. Original relation between critical shear stress and the erodibility coefficient showing that most of the more resistant samples are representative of dried conditions.

content, with the most resistant tests ($\tau_c > 5$ Pa) all having been dried. This effect is further substantiated in investigating the relation between the hydraulic-erosion variables and the associated geotechnical variables that theoretically control resistance to erosion.

Geotechnical Test Results

The geotechnical tests conducted by NSL as part of this study were meant to be rapid, reproducible procedures to be used as ancillary data to the hydraulic-erosion testing. They were not meant to replace the direct shear or triaxial shear tests being conducted by the Bureau for use as model input in bank-stability algorithms. Still, results provided by the Torvane shear device in particular have been useful in understanding the nature of the reservoir deposits. Analysis of the geotechnical tests was again relative to compaction to 12 kN/m^3 and represents both “moist” and “dried” samples. A summary of test results is provided in Table 5.

Table 5. Results of geotechnical tests on Klamath River reservoir samples compacted to 12 kN/m^3.

Reservoir	**Total number of tests**	**Total shear strength (kPa)**		**Compressive strength (kPa)**		**Average shear strength (kPa)**			**Average compressive strength (kPa)**		
		Average	Median	Average	Median	Moist	Dried	% difference	Moist	Dried	% difference
Copco 1	10*5	12.2	9.81	15.6	6.36	3.78	22.8	503	4.73	22.6	377
Iron Gate	11*5	15.0	0.67	28.7	4.52	0.516	39.1	7478	3.07	71.5	2231
John C Boyle	12*5	6.75	1.59	21.2	12.1	5.78	10.2	76	24.4	9.90	-59.4

Reservoir-average values of shear strength range from 6.75 to 15.0 kPa while compressive strength values range from 15.6 to 28.7 kPa. As with the hydraulic-erosion variables there were distinct differences between moist and dried samples, with the dried samples showing greater geotechnical strength. The one exception was the apparent decrease in compressive strength with drying for samples from John C Boyle Reservoir (Table 5). This may have bee due to dilatancy and cracking just below the surface in the dried condition. Shear strength values obtained with the Torvane device seem reasonable given the composition of the reservoir deposits (on average, 30 – 51% clay). Reservoir-average values for moist tests ranged from 0.52 to 5.8 kPa in comparison to 10 to 39 kPa for dried tests. The increase in shearing resistance can probably be attributed to the development of matric suction within

To test whether the measured variations in critical shear stress and the erodibility coefficient could be related to the geotechnical characteristics that theoretically control erosion rates in cohesive materials, the two data sets were combined. Results show a reasonably good relation ($r^2 = 0.64$) indicating that values of critical shear stress can be potentially estimated from total shear strength (τ_f) (Figure 9). Similarly, a relation between total shear strength and k ($r^2 = 0.65$) was developed from the data (Figure 10) again indicating that k could be estimated from τ_f. The advantage of this is that the Torvane shear tests are (1) far less destructive, (2) take much less sample area, and (3) can be conducted considerably quicker than tests with the mini-jet device.

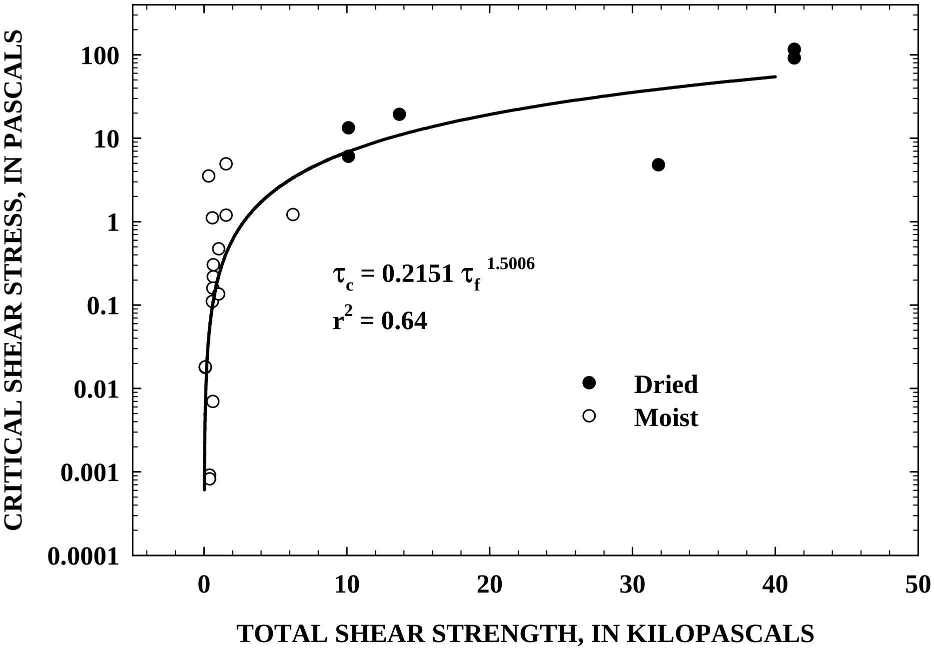

Figure 9. Relation between total shear strength (τ_f) as measured with the Torvane shear device and critical shear stress (τ_c) as measured with the mini-jest device.

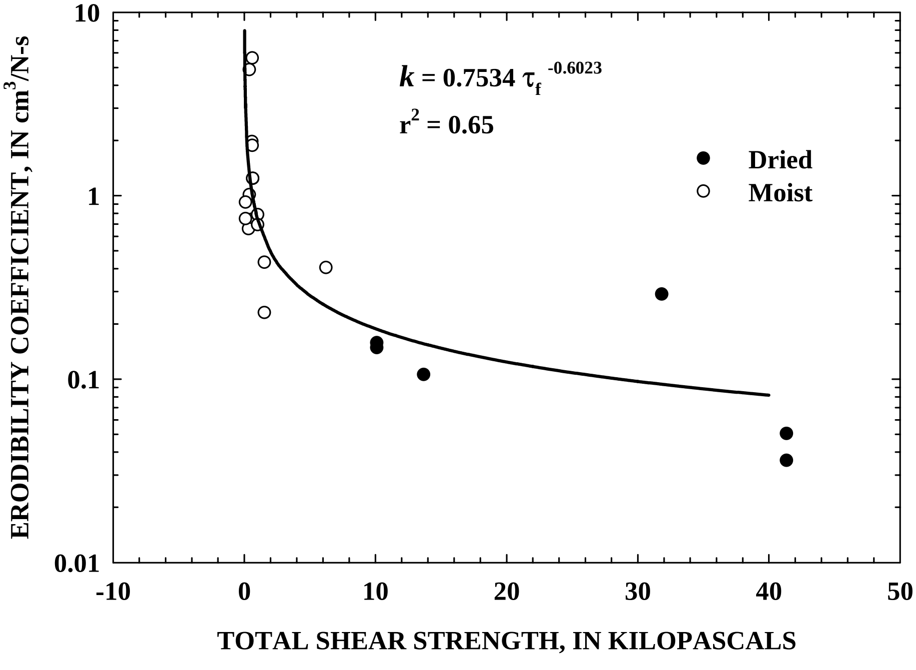

Figure 10. Relation between total shear strength (τ_f) as measured with the Torvane shear device and the erodibility coefficient (k) as measured with the mini-jest device.

SUMMARY and CONCLUSIONS

Hydraulic and geotechnical tests were conducted on samples obtained with a Ponar grab sampler from three reservoirs in the Upper Klamath River System, California and Oregon. In general, the materials were particularly fine grained (silts and clays) that in their in situ state, had moisture contents that exceeded their liquid limits by about a factor of two. In order to conduct tests on these materials, it was agreed that the samples would be compacted to a bulk unit weight of $12kN/m^3$. A total of 33 hydraulic-erosion tests were carried out over a range of moisture contents with a mini jet-test device. A significant regression relation was developed between critical shear stress and the erodibility coefficient that can be used to calculate the erodibility coefficient from critical shear stress.

Reservoir-average values of critical shear stress under moist conditions ranged from 0.58 to 1.1 Pa, equivalent to the stress required to entrain sand-sized particles. Upon drying to moisture contents less than 67%, hydraulic shearing resistance increased dramatically with reservoir-average values ranging from 5.9 to 56 Pa. Critical shear stresses of this magnitude are equivalent to those for gravels and cobbles. Similarly, reservoir-average erodibility values decreased from 67 to 96% with drying. The increase in erosion resistance was probably due to the development of matric suction in the materials as they dried out. This was further supported by the identification of substantial increases in total shear strength (measured with a Torvane shear device). Reservoir-average shear-strength values for moist conditions ranged from 0.52 to 5.8 kPa compared to 10 to 39 kPa under dried conditions. These shear-strength values are completely reasonable given that reservoir-average clay contents ranged from 30 to 51%.

Data provided from this study will be used by the Bureau as inputs into SRH-2D, a two-dimensional flow and sediment transport model to conduct simulations of possible erosion rates and channel adjustments. To provide data for sensitivity analysis the Bureau will “bracket” erosion parameters to test for the effects of uncertainty of the input variables. For this reason, statistics for the erosion parameters, critical shear stress and the erodibility coefficient are provided that represent the central tendency of the data distribution (Table 6).

The hydraulic and geotechnical data sets were successfully combined to develop relations between total shear strength and both critical shear stress and the erodibility coefficient. This signifies that these two hydraulic-erosion parameters can be estimated with measurements of shear strength as obtained with the Torvane device. This potentially has a great advantage as the Torvane device can be deployed easily and rapidly.

Table 6. Distribution of critical shear stress and erodibility coefficient for each reservoir.

Reservoir	**Condition**	**τ_c (Pa)**		***k* (cm^3/N-s)**	
		25th Percentile	75th Percentile	25th Percentile	75th Percentile
Copco 1	All tests	0.494	2.53	0.360	1.110
	Moist	0.214	1.08	0.736	1.23
	Dried	2.20	4.69	0.288	0.516
Iron Gate	All tests	0.0405	10.1	0.152	1.43
	Moist	0.00386	1.51	0.776	3.34
	Dried	13.2	95.6	0.0465	0.145
John C Boyle	All tests	0.104	3.26	0.273	0.800
	Moist	0.0470	1.54	0.457	0.838
	Dried	7.70	11.2	0.149	0.154

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APPENDIX

Appendix 1. Raw test data. * Refers to average moisture content for "moist" samples.

Test date	Reservoir	Site	Unit weight in kN/m^3	Jet test id	Dried or Moist	τ_c in Pa	*k* in $cm^3/N\text{-}s$	Torvane (total shear strength) in kPa	Penetrometer (compressive strength) in kPa	Avg. moisture content (% vol.)
8/12/2010	**Copco 1**	489	12.0	1	M	1.188	0.402	6.28	6.13	71.9
7/26/2010	**Copco 1**	490	12.0	1	D	18.96	0.11	13.7	0.01	57.8
7/26/2010	**Copco 1**	490	12.0	-	-	-	-	13.7	0.01	80.2
7/26/2010	**Copco 1**	490	12.0	1a	D	4.69	0.29	31.9	45.1	57.8
7/26/2010	**Copco 1**	490	12.0	-	-	-	-	13.3	20.6	64.0
6/7/2010	**Copco 1**	491	12.0	1b	M	0.298	1.23	0.70	6.59	*77.2
6/7/2010	**Copco 1**	491	12.0	2	M	0.214	1.23	0.70	6.59	*77.2
6/7/2010	**Copco 1**	491	12.0	-	M	-	-	40.5	61.8	73.7
8/26/2010	**Copco 1**	491	10.6	1c	D	2.65	0.345	-	-	Dried
8/26/2010	**Copco 1**	491	10.6	2	D	1.177	0.594	-	-	Dried
8/27/2010	**Copco 1**	491	10.6	3	D	2.201	0.516	-	-	Dried
9/9/2010	**Copco 1**	491	10.1	1	M	1.084	0.736	0.63	4.52	72.3
9/9/2010	**Copco 1**	491	10.1	2	M	0.108	1.957	0.63	4.52	72.3
6/24/2010	**Iron Gate**	488	12.0	1	M	0.000894	4.82	0.44	2.66	*77.7
6/24/2010	**Iron Gate**	488	12.0	2a	M	0.000807	1.004	0.44	2.66	*77.7
6/24/2010	**Iron Gate**	488	12.0	1	M	0.0741	0.897	-	-	72.4
6/24/2010	**Iron Gate**	488	12.0	2	M	2.85	0.495	-	-	72.1
6/4/2010	**Iron Gate**	485	12.0	1c	M	3.45	0.654	0.37	0.98	*77.7
7/23/2010	**Iron Gate**	485	12.0	1	D	114	0.0501	41.38	89.2	54.8
7/23/2010	**Iron Gate**	485	12.0	2	D	89.7	0.04	41.38	89.2	54.8
7/23/2010	**Iron Gate**	485	12.0	-	-	-	-	34.62	36.0	71.2
8/30/2010	**Iron Gate**	485	10.8	1	D	16.7	0.137	-	-	Dried
8/31/2010	**Iron Gate**	485	10.8	2	D	2.72	0.167	-	-	Dried
9/9/2010	**Iron Gate**	485	9.7	1	M	0.007	5.579	0.67	4.52	69.1
9/9/2010	**Iron Gate**	485	9.7	2	M	0.156	1.862	0.67	4.52	69.1
6/8/2010	**John C Boyle**	482	12.0	1	M	0.0003	3.57	-	-	*71.3
6/8/2010	**John C Boyle**	482	12.0	2	M	0.208	0.856	-	-	*71.3
6/28/2010	**John C Boyle**	482	12.0	-	M	-	-	34.81	49.03	50.7
6/28/2010	**John C Boyle**	482	12.0	1	M	1.66	0.539	-	-	69.7
6/28/2010	**John C Boyle**	482	12.0	2	M	2.74	0.288	-	-	71.3
8/18/2010	**John C Boyle**	482	9.8	1	D	5.93	0.147	10.16	9.90	50.1
8/18/2010	**John C Boyle**	482	9.8	3	D	13.00	0.156	10.16	9.90	50.1
9/9/2010	**John C Boyle**	482	9.9	1	M	0.133	0.781	1.07	12.1	67.4
9/9/2010	**John C Boyle**	482	9.9	2	M	0.462	0.688	1.07	12.1	67.4
6/23/2010	**John C Boyle**	483	12.0	1c	M	0.0175	0.742	0.15	1.30	*71.3
6/23/2010	**John C Boyle**	483	12.0	2b	M	0.0178	0.913	0.15	1.30	*71.3
7/8/2010	**John C Boyle**	484	12.0	1	M	4.83	0.229	1.59	47.4	67.9
7/8/2010	**John C Boyle**	484	12.0	2	M	1.17	0.430	1.59	47.4	68.9

17. Appendix E. Documentation of Hydrology Simulations for the Klamath Dam Removal Studies

Document	**Description**
Hydrologic Data Development And Management	Describes development of naturalized flows from historic data, an overview of synthetic hydrology, and an overview of data management system.
Climate Change Hydrology	Describes development of Climate Change Hydrology
BO 2010 Operations	BO2010 operation criteria and implementation in KPSIM without KDR adjustments. These are the operations assumed under No Action Alternative.
KBRA Operations	KBRA operation criteria and implementation in KPSIM without KDR adjustments. These are the operations assumed under the Dam Removal Alternative.
Operations Models	BO 2010 and KBRA operation criteria and implementation in KPSIM as implemented for KDR, daily operations model, and other operations specific to the KDR study.
Forecasts For Synthetic Flows and Dynamic Agricultural Demand	Detailed description of forecast generation for synthetic hydrology for UKL operations and KBRA demand computations.

17.1. Hydrologic Data Development and Management

Hydrologic Data Development and Management to support Klamath Dam Removal Study

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02/24/2011

Introduction

The study to determine the feasibility of removing four dams on the Klamath River required development of historic hydrology to support hydrologic and other analyzes related to the study. Available historic USGS and PacifiCorp data were obtained for water years 1961 through 2009, extended to fill in missing periods, and used to compute hydrologic inflows to the basin. The primary developed data for the study are the historic gains, also known as accretions or local inflows. Historic data are used with the historic period for model development and for deconstruction scenarios. Historic data from water years 1961 through 2009 were used to develop three synthetic types of hydrology for dams-in and dams-out planning scenarios. The types of synthetic hydrology are:

1. Indexed sequential – A hydrograph created by repetition of historic hydrology.
2. Stochastic – Hydrographs created using statistical software reflecting statistics from historical hydrology.
3. Climate change – Hydrographs created using a watershed model forced with weather conditions consistent with several climate change scenarios.

Documentation of the stochastic and climate change data is available elsewhere. The stochastic data set was not actually used because it did not include temperature data needed by other modeling efforts. The indexed sequential traces use all 49 years of historic data as a starting year. All traces are processed through a monthly upstream WRIMS model (KPSIM) and a daily downstream RiverWare model (Klamath Dam Removal Model - KDRM). Because of the large amounts of data, the processes were automated to the extent possible. These pages document historic hydrologic data development and data management applications.

Data Inventory

Historic monthly data upstream of Iron Gate Reservoir are developed by the Klamath Basin Area Office (KBAO). These data are used as hydrologic input data to the KPSIM. The downstream model required development of daily data downstream of Keno Reservoir. USGS streamflow records are mostly complete. Availability of reservoir elevations and releases varies considerably. Table 1 is a summary of available historic data downstream of Keno Reservoir.

KDRM Hydrology Nodes

The KPSIM has existed for a number of years and no modifications to its nodes were made. The KDRM was created for this study. The KDRM include hydrology nodes, routing nodes, confluences, and for the dams-in operations, power plants and reservoirs. A list of the primary hydrologic nodes in the KDRM is listed in Table 2. Additional nodes exist between these nodes which correspond to SALMOD fisheries model nodes. These nodes correspond to additional tributary inflows. Note that the Hoopa to Klamath gains are all gains from the Trinity At Hoopa and Klamath At Orleans gages to the Klamath Near

Klamath gage. Primary gains developed from historic data are spatially disaggregated to the SALMOND

Data Item	Source	Available Data
Klamath Near Keno Flow	USGS	1961 – 2009
JC Boyle Pool Elevation	PacifiCorp	1961 – 2009 with a few missing days.
JC Boyle Reservoir Spill	PacifiCorp	1979 - 2009 with some missing periods.
JC Boyle PP Turbine Release	PacifiCorp	1979 - 1982 and 1988 – 2009
Klamath Below JC Boyle PP Flow	USGS	1961 – 2009
Copco 1 Monthly Pool Elevation	USGS	1968 – 2002
Copco 1 Daily Pool Elevation	PacifiCorp	1979 - 2009 with some missing periods.
Copco 1 Outflow	PacifiCorp	1979 - 2009 with some missing periods.
Iron Gate Monthly Pool Elevation	USGS	1968 – 2002
Iron Gate Daily Pool Elevation	PacifiCorp	1979 – 2009 with some missing periods.
Klamath Below Iron Gate Flow	USGS	1961 – 2009
Shasta Near Yreka Flow	USGS	1961 – 2009
Scott Near Ft Jones Flow	USGS	1961 – 2009
Klamath Near Seiad Valley Flow	USGS	1961 – 2009
Indian Creek Near Happy Camp Flow	USGS	1961 – 2009
Salmon River At Somes Bar Flow	USGS	1961 – 2009
Seiad to Orleans Gain Reach	USGS	1961 – 2009
Klamath At Orleans Flow	USGS	1961 – 2009
Trinity At Hoopa Flow	USGS	1961 – 2009
Klamath Near Klamath Flow	USGS	1961-1994 and 1998 – 2009

Table 1. Downstream Klamath River Hydrologic Data Inventory.

Klamath River Near Keno
Keno to Boyle Reservoir Gain
JC Boyle Reservoir
Boyle Reservoir To Boyle Gage Gain
Boyle Gage To Copco Gain
Copco 1 Reservoir
Copco 2 Reservoir
Copco To Iron Gate Gain
Iron Gate Reservoir
Iron Gate to Seiad Gain
Seiad to Orleans Gain
Scott Near Ft Jones
Salmon At Somes Bar
Indian Creek Near Happy Camp
Shasta Near Yreka
Hoopa to Klamath Gains
Trinity At Hoopa

Table 2. Primary Downstream Model Hydrology Nodes.

nodes. KDRM uses temporally disaggregated monthly flows produced by KPSIM for Keno Reservoir releases. The temporal disaggregation process is described in a later section.

Data Development

Because of the file sizes involved, individual workbooks were created for data in the reservoir reaches and data downstream of the reservoir reaches. The downstream workbook consists entirely of USGS streamflow data and is self contained. The reservoir reaches workbook consists of USGS and PacifiCorp data and is supported by several other workbooks. The reservoir reaches workbook includes USGS streamflow data, Boyle spills, Boyle power plant flows, and change in storage for Boyle, Copco 1, and Iron Gate reservoirs expressed as flow. The computation of change in storage and conversion to flow is done in a separate workbook that has all end-of-period data obtained for the study. These data include a mix of USGS and PacifiCorp daily and monthly data.

A Reclamation developed Excel Add-In called the Data Utilities Toolkit (DUT) was used to move data between workbooks, between workbooks and HEC Data Storage System (DSS) files, and other data stores. The DUT also includes temporal aggregation utilities. The DUT is available at:

ftp://ftp.usbr.gov/tsc/jrieker/warsmp/dmiutils/dutaddin.zip

A DUT data management interface (DMI) exists in both primary historic data workbooks to pull USGS streamflow data. Except for two missing days for Klamath Below JC Boyle PP and three missing years for Klamath Near Klamath, these data are complete. The two missing days for Klamath Below JC Boyle PP were linearly interpolated. The missing data for Klamath Near Klamath were filled using regressions of monthly data. For instance, if a January value was missing, the January regression was used to fill that value.

A number of regression combinations were investigated to fill the missing Klamath Near Klamath period. The most satisfactory combination was a regression of the Hoopa to Klamath gain to the sum of Trinity At Hoopa plus Klamath At Orleans flow. Although the R^2's range from 0.16 to 0.78, the filled data are believed to be sufficient for this study because these flows do not affect the reservoir reaches.

Because of temporal and data quality issues, gains computed using historic streamflow data often have unnatural spikes including negative values. While negative gains can exist, they would typically not include large spikes. A smoothing method was applied to all gains downstream of Iron Gate reservoir that consisted of applying the flow pattern of the next downstream gage to the monthly gain. This approach maintains continuity on a monthly basis while computing a more natural hydrograph on a daily basis.

As seen in Table 1, data availability was problematic in the reservoir reaches. The record for the total hydrologic gain from Keno to Iron Gate is complete, so the missing data only affects the estimation of the total natural gain and the distribution of those gains between Keno and Iron Gate. Evaporation and other losses were not computed because insufficient data on evaporation rates was available, because insufficient knowledge of future river profiles for the dams-out scenario exists, and because a sensitivity analysis showed that evaporation is an insignificant portion of the gain. The results of the sensitivity analysis are shown in Table 3. Because evaporation and other losses were not computed, the computed gains in the reservoir reaches should be described as pseudo natural gains or developed gains. Furthermore, the gains below the reservoirs do not account for historic diversions and reservoir storage. The basic equation to compute pseudo natural gains is:

Pseudo natural gain = hydrologic gain + change in storage

Estimated reservoir evaporation @ 5.0 feet/year using historic average areas.								
Reservoir	Average Pool Elevation (feet)	Average Surface Area (acres)	Evaporation Volume (acre-feet/year)	Evaporation Volume (cfs)	PacifiCorp Maximum Surface Area (acres)	Evaporation Volume (acre-feet/year)	Evaporation Volume (cfs)
JC Boyle	3791.20	197	985	1.360	220	1100	1.518
Copco 1	2603.84	935	4675	6.453	980	4900	6.764
Copco 2	N/A	6	30	0.041	6	30	0.041
Iron Gate	2326.61	921	4607	6.359	1000	5000	6.902
Total	N/A	2059	10296	14.212	2206	11030	15.225
Average Annual Gain Volume			418297			418297	
Percent of Average Ann Gain			2.46%			2.64%	
1/2 Average Annual Evaporation			5148			5515	
Percent of Average Annual Gain			1.23%			1.32%	

Table 3. Evaporation Sensitivity Analysis.

Boyle pool elevation data were obtained but not storage values. An area-capacity table for Boyle reservoir was developed from an area-capacity curve provided by PacifiCorp. Historic Copco 1 and Iron Gate data include USGS end-of-month pool elevations and contents from 1968 through 2002. These data were used with PacifiCorp area-capacity curves to develop area-capacity tables for Copco 1 and Iron Gate reservoirs.

Missing reservoir data were handled in a number of ways. Small periods of 1 to 4 days were linearly interpolated. Periods where monthly elevations existed but daily values did not, a straight line interpolation of the monthly storage values was used. Missing change in storage for longer periods for Copco 1 and Iron Gate were computed using monthly regressions to Boyle's change in storage. Although these regressions are poor, they only affect data before 1968. Since these estimates only affect pseudo natural gain computations before 1968 and those data are only used for the deconstruction scenarios and model development, it was decided that these estimates are sufficient for this study.

Three additional adjustments of the daily data were made. First, PacifiCorp has periodically measured the gain from spring inflows between Boyle Reservoir and the gage below the power plant. The average flow of 220 cfs was incorporated as the minimum gain in this reach, also known as the bypass reach. Second, the years that Copco reservoir releases are available were used to compute the average monthly spatial distribution of gains between the Klamath River Below JC Boyle Power Plant gage and Iron Gate reservoir upstream and downstream of Copco reservoir. These distributions were applied to total gain when the measured distribution was unavailable. The monthly spatial distribution pattern is shown in Table 4.

The third adjustment was to compute a provisional change in storage for the regressed and interpolated periods, then adjust the change in storage if it produced negative reservoir inflows. When negative inflows are computed, they were set to zero. Then the change in storage was recomputed using the adjusted inflow. This adjustment mostly affects computations before 1979. However, it can affect the distribution of gains between reservoirs on any day if bad recorded data exists.

Month	Fraction
January	0.240
February	0.208
March	0.144
April	0.093
May	0.144
June	0.175
July	0.303
August	0.349
September	0.292
October	0.178
November	0.165
December	0.067
Annual	0.183

Table 4. Klamath Below JC Boyle PP to Copco Gain To Total Gain Monthly Distribution.

The Trinity at Hoopa case is problematic in that this reach is highly regulated and is affected by transbasin operations which have changed over time. Therefore, historic flows for Trinity at Hoopa were noted used. Instead, the flows used for this study are based on CALSIM output for Trinity at Lewiston. CALSIM is a WRIMS model for the central valley of California. These data are available through 2003. CALSIM output for 2004 through 2009 was estimated by regressing CALSIM Trinity at Lewiston to CDEC natural flow for Trinity at Lewiston. The actual and estimated CALSIM flows were extended to Trinity at Hoopa by adding the historic hydrologic gain between the two gages.

The developed gains are consolidated in another workbook and posted to a DSS. The consolidated workbook computes daily to monthly ratios that support the disaggregations that are used by the KDRM. Monthly data from KPSIM and the synthetic monthly data traces are disaggregated to daily by the KDRM.

Synthetic Hydrology Development

Historic monthly data upstream of Iron Gate Reservoir are developed annually by the Klamath Basin Area Office (KBAO) in workbook MODSUM. Data from MODSUM are used as hydrologic input data to the KPSIM for planning studies using two primary operation scenarios:

BO – Current operations based on various biological opinions
KBRA – Klamath Basin Restoration Agreement

A 100-year repeated historic data set was created with 2012 as the starting year using 1961 through 2009 historic data for all hydrology nodes used by the KDRM and for Upper Klamath Lake (UKL) inflow and Keno to Iron Gate gain of the KPSIM. This trace was mostly intended for calibration purposes. It was intended that KDR analyzes use the indexed sequential, stochastic, or climate change scenarios. In actual implementation, it was not possible to use the stochastic data because it was problematic to compute stochastic climate data to support fisheries modeling.

Initially, the synthetic hydrologies were based upon historic 1977 through 2009 data based from a study by Dr. Tim Mayer of the U.S. Fish and Wildlife Service (Mayer, 2008)[1]. This study analyzed trends in hydrology for the Klamath basin. Subsequently, it was decided to base all hydrologies on the 1961 through 2009 historic record. It was decided that hydrologic variation was more important than hydrologic trends to the KDR analyzes.

Temporal Disaggregations

The KDRM requires daily data. Disaggregations of monthly to daily data are based on historic daily to monthly relations. As previously noted, the disaggregation fractions are computed using the filled historic daily data and equivalent monthly data. The disaggregations are computed by the KDRM. In addition to the disaggregation fractions, the KDRM needs rankings of the historic data by season. The rankings are computed in a workbook as a pre-process. Before a model run, synthetic monthly flows from the hydrologic traces are imported into the KDRM. At the beginning of each month, the disaggregation rules compute the seasonal volume, find the closest match to historic seasonal volume, and use the disaggregation fractions from the matched season to compute the daily flows for the month. Seasonal matching was used in lieu of monthly matching to reduce unnatural transitions between disaggregation periods.

The KDRM Keno daily flows are treated differently because those flows are regulated and because of the overlap with the KPSIM model. Both operating scenarios of the KPSIM attempt to meet an instream flow requirement (IFR) at Iron Gate[2]. Because Iron Gate is downstream of the beginning of the KDRM, Keno daily flow is computed as daily Iron Gate flow without the reservoirs less Keno to Iron Gate daily gain. The IFR is subtracted from the total KPSIM flow at Iron Gate and only the excess water is disaggregated. The daily flow at Iron Gate is the sum of the disaggregated excess water and the IFR. If the KPSIM flow for the month is less than the IFR, the average daily flow is used.

Gains between Keno and Iron Gate use the pattern of disaggregated Keno flow. This was done to enable the KDRM to better meet Iron Gate IFR’s. In actual operations, additional water is released from UKL to meet Iron Gate IFR’s. However, this not possible with the KDRM because it does not model UKL. Using Keno’s daily pattern is a virtual emulation of supplemental releases of UKL.

Spatial Disaggregations

The temporally disaggregated data downstream of Iron Gate Dam are spatially disaggregated to a number of tributaries. The spatial distribution factors were estimated as a function of the drainage area at the tributary and the drainage area of the next downstream gage. This approach produces similarly shaped hydrographs for all the tributaries between gages but maintains mass balance with respect to the total daily gain of the reach.

Streamflow Routing

Hourly data from the gages downstream of Keno were used to estimate travel times between gages as a function of flow. These were used in the KDRM to lag flows down the river. More sophisticated routing methods require more data than were available for this study.

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[1] Mayer, T. F., 2008. Analysis of Trends and Changes in Upper Klamath Lake Hydroclimatology, U.S. Fish and Wildlife Service.

[2] The criteria for the Iron Gate IFR vary between the BO and KBRA operations.

Data Management

The data development and the numerous steps to generate model input and process model output require considerable data management. Most of the hydrologic workbooks used for the study include DMI's managed by the DUT. Each DMI requires a header worksheet which is basically a mapping of the workbook's data for one time-series worksheet to another data store. These DMI's are usually ran interactively using the DUT. Automated management of the multiple models, operating scenarios, and hydrologic traces was facilitated by creating Excel macro based workbook for managing the runs. Using user provided file specifications, number of years, number of traces, and other data, the runs manager runs appropriate DUT DMI's and the models in batch mode. The runs manager uses an input data workbook that includes the input DMI headers and templates for the spatial disaggregations. It also includes knowledge of how to adjust UKL inflows for the KBRA KPSIM operating scenario. All monthly model input data are retained in the input data workbook. A user manual for the data manager is available.

17.2. Climate Change Hydrology

Klamath Dam Removal Study

Climate Change Hydrology Development

David King, David Sutley, and David Raff

02/24/2011

Introduction

The Klamath Dam Removal (KDR) study used two hydrologic models to assist in analyzing several hydrologic scenarios. The two hydrologic models consist of an upstream monthly model and a downstream daily model. Output of the upstream model becomes part of the input to the downstream model. The upstream monthly timestep was sufficient to allocate water supplies in the upper basin and a reasonable estimate of Klamath River flows available to the downstream model. The daily timestep of the downstream model provided better computations of power production and streamflows in critical river reaches. To analyze a wide range of potential future hydrologic scenarios, three synthetic hydrologies were developed:

1. Indexed sequential – A hydrograph created by repetition of historic hydrology.
2. Stochastic – Hydrographs created using statistical software reflecting statistics from historical hydrology.
3. Climate change – Hydrographs created using a watershed model forced with weather conditions consistent with several climate change scenarios.

The following pages describe the definition of regional climate change scenarios in a larger process of identifying the potential impact of climate change on the water resources management of the Klamath Basin, the use of these data into a Sacramento Soil Moisture Accounting (SAC-SMA**)** watershed model, and the incorporation of the hydrology produced by the watershed model in the KDR models.

Climate Change Data Development

The regional climate change scenario selection described here builds upon two recent studies performed in support of the 2008 Central Valley Project/State Water Project Operations Criteria and Plan (Reclamation 2008) and the San Joaquin River Restoration Program Supplemental Hydrologic and Water Operations Analyses (Reclamation 2009), respectively. The selection criteria described here is similar to Reclamation 2008 and Reclamation 2009 in that the first four regional scenarios were chosen for how they bracket a range of possible regional climates. Similar to Reclamation 2009, a fifth scenario is chosen for how it represents a centrally projected climate change over the region. And similar to Reclamation 2008 and Reclamation 2009, the possible regional climates are defined by paired precipitation-temperature conditions. Projection information is surveyed for changes in these conditions given four selection factors:

1. Historical and future climate periods
2. Climate change metrics
3. Location of climate change
4. Change-range of interest.

The climate change information used throughout the selection procedure is through the Bureau of Reclamation (Reclamation) in cooperation with the Lawrence Livermore National Laboratories, Santa Clara University and The Institute for Research on Climate Change and its Societal Impacts have developed and host a downscaled climate projection archive:

http://gdodcp.ucllnl.org/downscaled_cmip3_projections/

Within that archive are housed 112 climate projections from 1950 through 2099. These represent three emissions paths, A1B, A2, and B1 (IPCC 2000) for sixteen general circulation models (GCMS) with different initial conditions for different model simulations. The GCMS represent various climate modeling groups coordinating through the World Climate Research Programme Working Group on Coupled Modeling through the CMIP3 effort (Meehl et al. 2007). The sixteen GCMs represent a spatial scale that is too coarse for most impact studies. Therefore, a downscaling methodology (Wood et al. 2004) has been applied to these projections to provide information at an1/8° resolution that can be used to study potential climate change impacts. In addition, GSM data require bias corrections to adjust the data to historic climate of a selected location. Therefore, data obtained from this archive have also been bias corrected.

Location of Climate Change

The Klamath Basin was divided into two regions for analysis of climate change. These regions were selected for consistency with the tools and methods that were used for the impact analyzes as well as to evaluate potential different climate change effects in the upper and lower basin, given the possibility of change different dynamics in these distinct geographic regions. The first region encompasses the Upper Klamath basin and roughly corresponds to the geographic extent (***Upper*** basin) of the upstream monthly WRIMS model (KPSIM). That is the Klamath Basin above Iron Gate.

The second region (***Lower*** basin) is located below Iron Gate and encompasses three regions that correspond to availability of National Weather Service forecast points on the Klamath River and their operational SAC-SMA hydrologic tool availability. These forecast points are Seiad, Klamath, and Orleans. The downstream daily RiverWare model (KDRM) covers this area plus the power reservoirs upstream of Iron Gate and therefore, overlaps the KPSIM.

These two regions were used to provide climate information for the ***Upper*** basin in order to evaluate operations and the ***Lower*** basin to provide intervening effects at Seiad, Klamath, and Orleans as shown on Figure 1.

Historical and Future Climate Periods and Climate Change Metrics

Temporally, the 75 projections were divided into two equal length periods, the base period defined as 1950 – 1999 and a lookahead period defined as 2020 – 2069. The lookahead period was chosen based on the analysis period defined for the KDR Study. A fifty year base and lookahead period were used to encompass the full time period of effects analysis that would lead to a single set of projections, desired for ease in evaluation. Using a shorter time period to define selection criteria could result in selection of different model projections for different lookahead horizons and some reconciliation would then have to take place. The 39 projections for each of the Upper and Lower portions of the Klamath Basin, as shown in Table 1, were averaged spatially and temporally. The result of this averaging is a single value of temperature and precipitation for each projection within the base period and the lookahead period for temperature and precipitation, respectively.

The three emissions scenarios within the downscaled archive 75 projections were extracted representing all of the projections following A1B and the A2 emissions paths. The A1B and A2 emissions paths are greater than the B1 emissions path. The B1 emissions path was not included because global emissions are already known to exceed all SRES scenarios to present and therefore the B1 projections were considered less likely future projections than the A1B and A2 paths (Figure 2). The metrics of climate change to be evaluated are changes in precipitation and temperature described as a net change from future to base for temperature and a ratio from future to base for precipitation. The rationale for these metrics is that ultimately it will be precipitation and temperature that will be used to drive the hydrologic tool and therefore the metrics evaluated should then define a range of hydrologic outputs.

Figure 1. Klamath Basin downscaled climate projection data extraction regions.

Change-Range of Interest

The four bracketing climate scenarios were defined by the distribution of the climate change projection metrics. The climate change metrics (net change temp, ratio of precip) are evaluated by their Weibull plotting positions as shown on Figure 3. The bracketing criteria were set as the 25th and 75th quantiles of the empirical distributions of precipitation and temperature. These are then used to define a quantile plot for the joint distribution of the temperature and precipitation ratios as shown on Figure 4. The 25th and 75th quantiles are used because they represent a range about the central tendency that is assumed to describe climatic drift as opposed to interdecadal

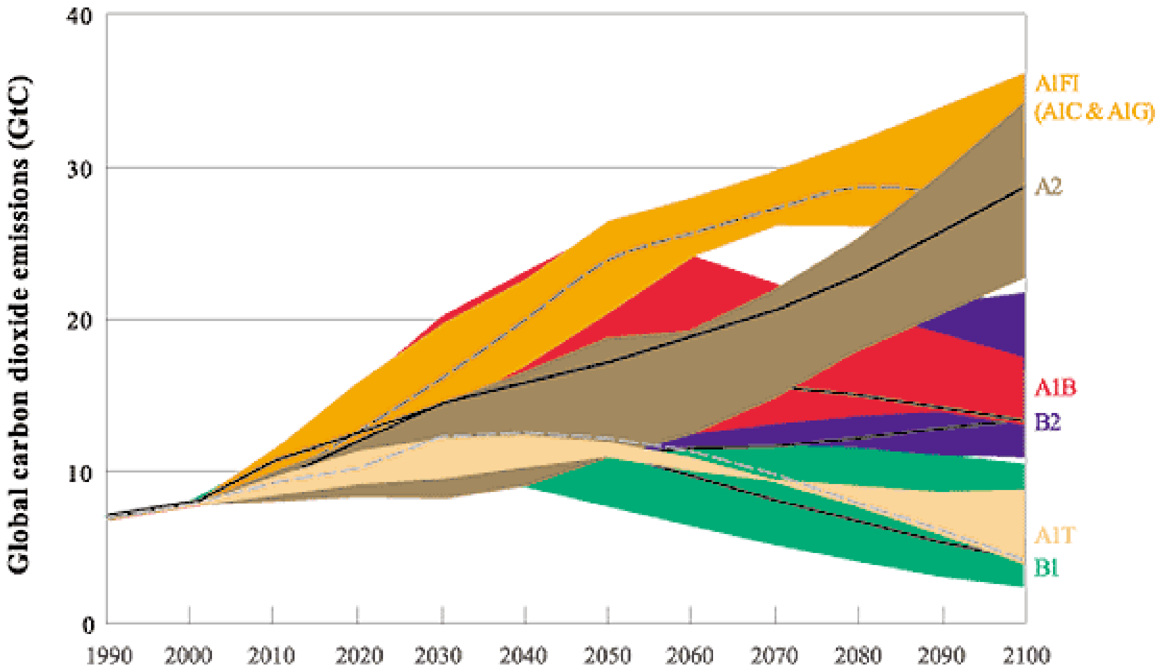


Figure 2. Emissions Paths. Paths A1B and A2 were used as selection criteria for data extraction.

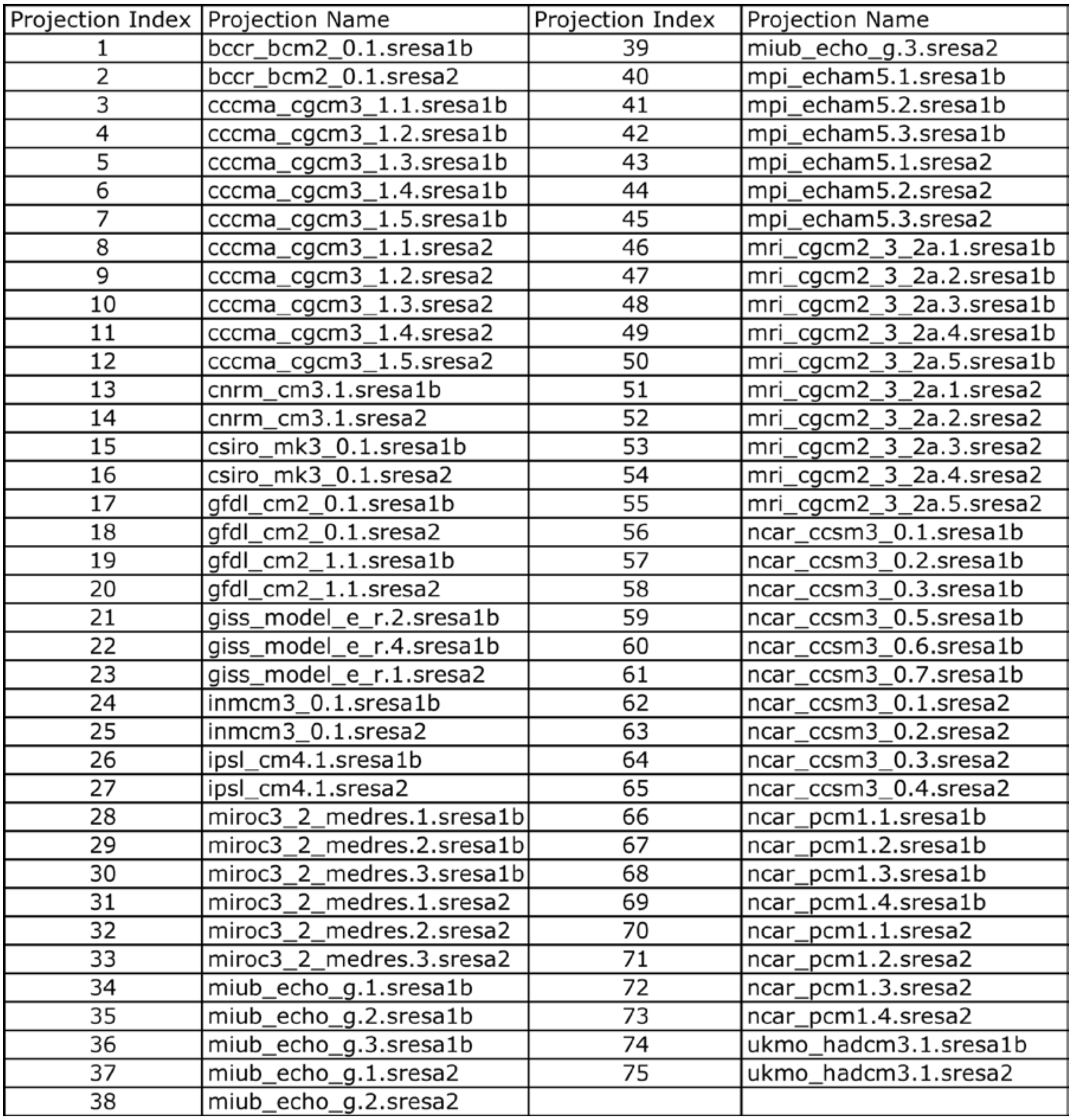
variability that would be more described by 10th and 90th quantiles as learned through Reclamation 2009. The central tendency was defined as the mean of the climate change metrics. Therefore, on the joint distribution plot (Figure 4) the scenarios are defined as being nearest to the vertices:

- Vertice 1: 25th quantile Temperature paired with 25th quantile Precipitation
- Vertice 2: 25th quantile Temperature paired with 75th quantile Precipitation
- Vertice 3: 75th quantile Temperature paired with 25th quantile Precipitation
- Vertice 4: 75th quantile Temperature paired with 75th quantile Precipitation

and the centrally projected vertice

- Vertice 5: 50th quantile Temperature paired with the 50th quantile Precipitation

Each region are shown on Figure 4 as highlighted by the blue boxes. The selection criteria for the Upper and Lower basins are shown in Table 2, respectively. For consistency between the Upper and Lower basins it is desirable to use the same set of projections. Therefore the differences between Table 2a and Table 2b must be resolved. The resolution criteria employed here was to reevaluate the projection distances from each of the five vertices and determine the projections whose distance is shortest from both the Upper and Lower basins. These projections are shown in yellow in Figure 4 and are listed in Table 3.



Projection Index	Projection Name	Projection Index	Projection Name
1	bccr_bcm2_0.1.sresa1b	39	miub_echo_g.3.sresa2
2	bccr_bcm2_0.1.sresa2	40	mpi_echam5.1.sresa1b
3	cccma_cgcm3_1.1.sresa1b	41	mpi_echam5.2.sresa1b
4	cccma_cgcm3_1.2.sresa1b	42	mpi_echam5.3.sresa1b
5	cccma_cgcm3_1.3.sresa1b	43	mpi_echam5.1.sresa2
6	cccma_cgcm3_1.4.sresa1b	44	mpi_echam5.2.sresa2
7	cccma_cgcm3_1.5.sresa1b	45	mpi_echam5.3.sresa2
8	cccma_cgcm3_1.1.sresa2	46	mri_cgcm2_3_2a.1.sresa1b
9	cccma_cgcm3_1.2.sresa2	47	mri_cgcm2_3_2a.2.sresa1b
10	cccma_cgcm3_1.3.sresa2	48	mri_cgcm2_3_2a.3.sresa1b
11	cccma_cgcm3_1.4.sresa2	49	mri_cgcm2_3_2a.4.sresa1b
12	cccma_cgcm3_1.5.sresa2	50	mri_cgcm2_3_2a.5.sresa1b
13	cnrm_cm3.1.sresa1b	51	mri_cgcm2_3_2a.1.sresa2
14	cnrm_cm3.1.sresa2	52	mri_cgcm2_3_2a.2.sresa2
15	csiro_mk3_0.1.sresa1b	53	mri_cgcm2_3_2a.3.sresa2
16	csiro_mk3_0.1.sresa2	54	mri_cgcm2_3_2a.4.sresa2
17	gfdl_cm2_0.1.sresa1b	55	mri_cgcm2_3_2a.5.sresa2
18	gfdl_cm2_0.1.sresa2	56	ncar_ccsm3_0.1.sresa1b
19	gfdl_cm2_1.1.sresa1b	57	ncar_ccsm3_0.2.sresa1b
20	gfdl_cm2_1.1.sresa2	58	ncar_ccsm3_0.3.sresa1b
21	giss_model_e_r.2.sresa1b	59	ncar_ccsm3_0.5.sresa1b
22	giss_model_e_r.4.sresa1b	60	ncar_ccsm3_0.6.sresa1b
23	giss_model_e_r.1.sresa2	61	ncar_ccsm3_0.7.sresa1b
24	inmcm3_0.1.sresa1b	62	ncar_ccsm3_0.1.sresa2
25	inmcm3_0.1.sresa2	63	ncar_ccsm3_0.2.sresa2
26	ipsl_cm4.1.sresa1b	64	ncar_ccsm3_0.3.sresa2
27	ipsl_cm4.1.sresa2	65	ncar_ccsm3_0.4.sresa2
28	miroc3_2_medres.1.sresa1b	66	ncar_pcm1.1.sresa1b
29	miroc3_2_medres.2.sresa1b	67	ncar_pcm1.2.sresa1b
30	miroc3_2_medres.3.sresa1b	68	ncar_pcm1.3.sresa1b
31	miroc3_2_medres.1.sresa2	69	ncar_pcm1.4.sresa1b
32	miroc3_2_medres.2.sresa2	70	ncar_pcm1.1.sresa2
33	miroc3_2_medres.3.sresa2	71	ncar_pcm1.2.sresa2
34	miub_echo_g.1.sresa1b	72	ncar_pcm1.3.sresa2
35	miub_echo_g.2.sresa1b	73	ncar_pcm1.4.sresa2
36	miub_echo_g.3.sresa1b	74	ukmo_hadcm3.1.sresa1b
37	miub_echo_g.1.sresa2	75	ukmo_hadcm3.1.sresa2
38	miub_echo_g.2.sresa2		

Table 1. 39 projections analyzed for possible selection for climate change analysis. Numbers correspond to quartile scatter plot with Figure 4. The Projection naming convention is <model>.<run>.<path>.

Vertice	Projection Index	Projection Name
1	22	giss_model_e_r.4.sresa1b
2	48	mri_cgcm2_3_2a.3.sresa1b
3	39	miub_echo_g.3.sresa2
4	6	cccma_cgcm3_1.4.sresa1b
5	41	mpi_echam5.2.sresa1b

Table 2a. Upper Basin.

Vertice	Projection Index	Projection Name
1	14	cnrm_cm3.1.sresa2
2	48	mri_cgcm2_3_2a.3.sresa1b
3	36	miub_echo_g.3.sresa1b
4	6	cccma_cgcm3_1.4.sresa1b
5	43	mpi_echam5.1.sresa2

Table 2b. Lower Basin.

Table 2. Projections nearest to selection criteria vertices.

Vertice	Projection Index	Projection Name
1	70	ncar_pcm1.1.sresa2
2	48	mri_cgcm2_3_2a.3.sresa1b
3	36	miub_echo_g.3.sresa1b
4	6	cccma_cgcm3_1.4.sresa1b
5	18	gfdl_cm2_0.1.sresa2

Table 3. Projections nearest to vertices 1-5 for both Upper and Lower Basin.

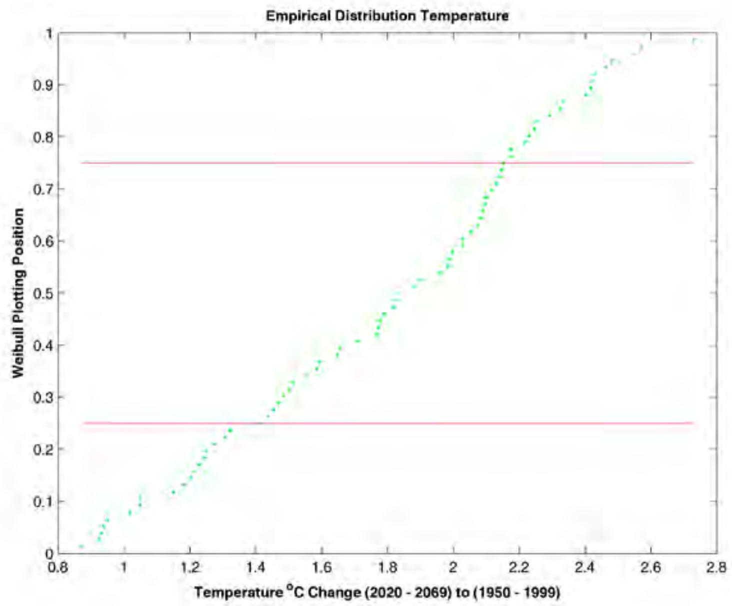
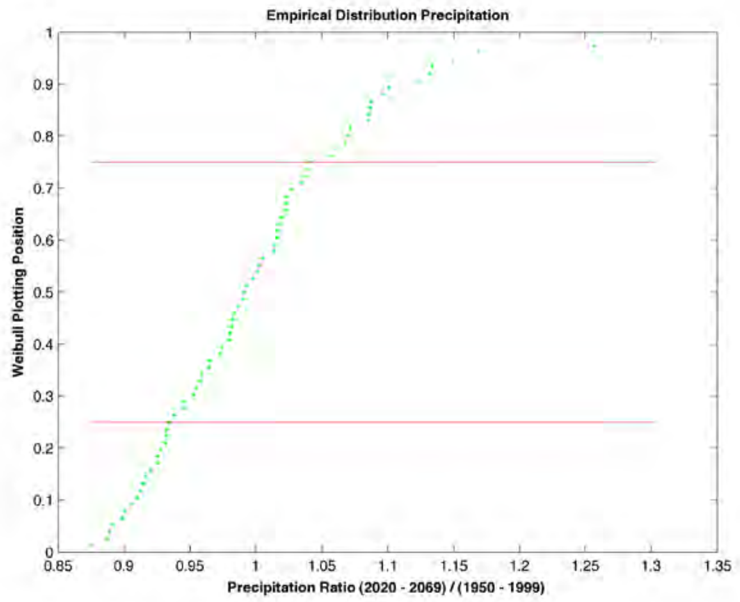
Temperature	
Precipitation	

Figure 3a. Upper Basin.

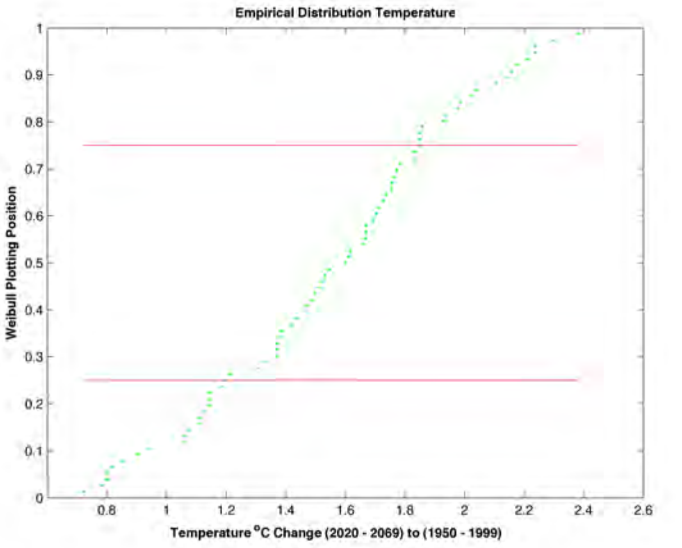
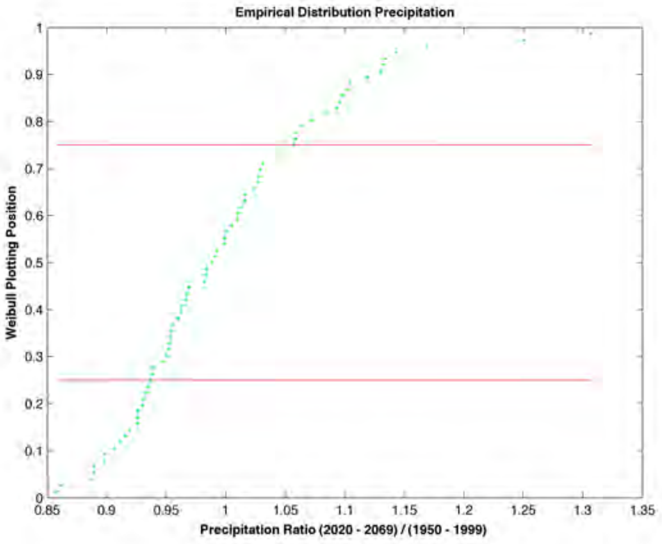
Temperature	
Precipitation	

Figure 3b. Lower Basin.

Figure 3. Weibull plotting positions for temperature and precipitation projections. Red horizontal lines represent 25th and 75th quantiles, respectively.

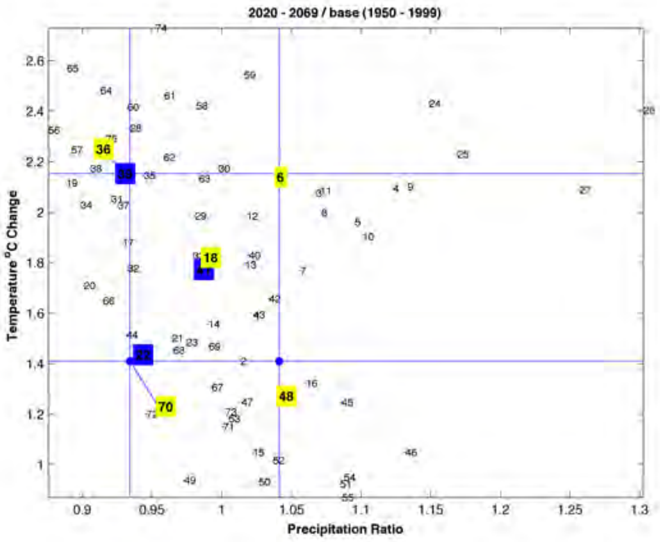
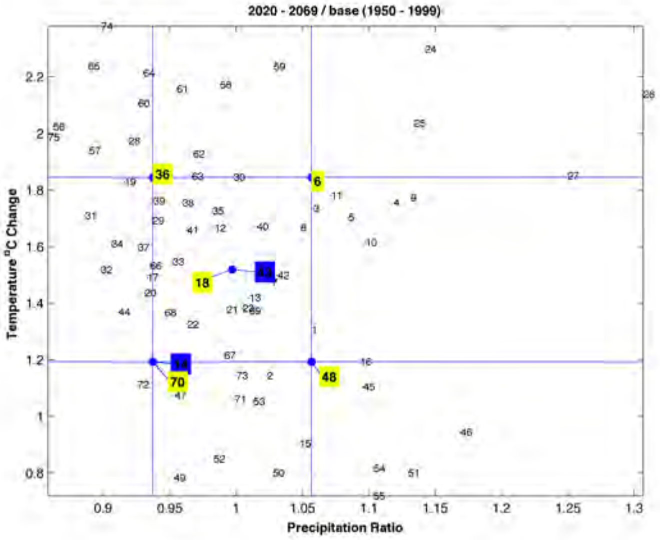
Upper Basin	
Lower Basin	

Figure 4. Quartile Maps of 39 projections. Projections selected for climate change analysis are those highlighted by blue box closest to quartile vertices.

Watershed Model

Climate change implications for hydrology were evaluated using the SacSMA/Snow17 hydrology model. A set of subbasin-specific SacSMA/Snow17 model-applications spanning the Klamath River Basin were obtained from the NOAA-NWS California Nevada River Forecast Center (CNRFC). The SAC-SMA/Snow17 hydrologic application were used to translate the regional climate change scenarios into hydrologic runoff scenarios to drive the WRIMs operational tool for the Upper Klamath Basin and to define intervening flows at Seiad, Klamath, and Orleans (Figure 1).

As described in Reclamation 2009, the SAC-SMASnow17 is a coupling of the Sacramento Soil Moisture Accounting model (Burnash et al. 1973) coupled to the Snow17 snow accumulation and ablation model (Anderson 1973). SacSMA/Sno17 applications have been applied to support numerous studies on climate change implications (i.e. Miller et al. 2003, Brekke et al. 2004, Zhu et al. 2005, Reclamation 2008, Brekke et al. 2009). Structurally, SacSMA/ Snow 17 applications depict a water balance evolving through time, where accumulated precipitation eventually leaves the watershed as either runoff or evapotranspiration. SacSMA/Snow17 is driven by information of temperature and precipitation at 6-hourly time steps. The models are calibrated to reproduce historical runoff given historical streamflow and weather station observations (Brazil and Hudlow 1981, Burnash et al 1973, Burnash 1995, and Finnerty et al. 1997).

One issue of uncertainty is to what degree warming over the Klamath basin would increase actual and potential evapotranspiration (AET and PET) over the watershed. Conceivably, warmer air can hold more moisture, so it might be expected that PET could increase under warming, thus raising the limits on AET. Even without raising PET limits, AET should increase when summed over the water year if snow-covered fraction is reduced in area extent and in time.

SacSMA/Snow17 does not compute PET internally. However, it does feature input PET values to constrain AET. These input PET values reflect historical climatological (mean-monthly) PET and vary by month. These inputs were not adjusted for the SacSMA/Snow17 simultions under climate change. Thus, the simulated runoff estimates may be slightly greater than they would have been had some scheme been used to increase PET limits relative to the degree of warming in each climate change scenario. However, the omission of elevated PET with warming may be minor matter with the SacSMA/Snow17 applications in the Klamath basin, particularly if the basin behaves similarly to the Sacramento above Shasta or N.F. American. In the latter two basins, climate change impacts on runoff were found to be largely similar when simulated by a model featuring internally computed PET and increased PET for warming, and SacSMA/Snow17 applications also obtained from the California Nevada River Forecast Center (Maurer et al. 2010).

Decision Modeling

As previously noted, the KDR study used two hydrologic decision models to assist in analyzing the impacts of study alternatives and hydrologic scenarios, a monthly upstream model (KPSIM) and a daily downstream model (KDRM). Although 6-hour values were available from the watershed model, these data were not biased corrected and were not available for all nodes needed by the decision models. In addition, KDR study modelers did not have sufficient resources to use all 50 traces generated by the SAC-SMA. Based upon these considerations, the realization closest to the median of the ten realizations per climate change model was used for each of the five climate change scenarios. This narrowed the used scenarios to the five listed in Table 4.

Model	Realization
cccma_cgcm3_1.4.sresa1b - Realization 7	7
gfdl_cm2_0.1.sresa2 - Realization 2	2
miub_echo_g.3.sresa1b - Realization 5	5
mri_cgcm2_3_2a.3.sresa1b - Realization 8	8
ncar_pcm1.1.sresa2 - Realization 6	6

Table 4. Climate change scenarios.

Bias correction of watershed model output is computationally intensive and would have required considerable time to implement. In addition, bias corrected flows would still have required spatial transformation into KDR nodes. Subsequently, it was decided to use a more direct approach to translate climate change scenario streamflows into equivalent flows for KDR analyzes.

For the five used scenarios, daily output of used SAC-SMA nodes were aggregated to monthly and used to perturbate historic hydrology for KPSIM and KDR nodes. The perturbation factors are the ratio of scenario's average monthly flows to the historic average monthly flows. These are multiplied by the historic monthly flows to compute the climate change flows as:

Decision model scenario flow = Decision model historic flow * SAC SMA monthly ratio

Subsequently, the climate change hydrologies used by the decision model have a dependency upon historic hydrology. Because the KPSIM input data includes precipitation, the SAC-SMA's precipitation upstream of UKL was also used to compute climate change precipitation for the KPSIM using the same approach. Example flow perturbation data are shown in Table 5.

The KPSIM model uses the monthly climate change data generated by this process directly. The downstream model uses a combination of those data and data from the KPSIM. All monthly values are disaggregated to daily in the KDRM using methods discussed elsewhere.

Average Monthly SAC SMA Scenario to Calibration Ratios For 39 years of calibration

Month		Hoopa to Klamath Gains	Total Iron Gate to Seiad Gain	Total Seiad to Orleans Gain	Williamson Near Klamath Agency	Sprague Near Chiloquin	UKL Inflow	Trinity At Hoopa Flow	Upstream UKL Precipitation
January	1	0.7903	0.9767	0.8372	0.6109	0.6391	0.8329	0.7868	0.8594
February	2	0.8863	1.3559	0.8272	0.7244	0.9646	0.9757	1.0722	1.3120
March	3	0.9651	1.3998	0.8733	0.8811	1.2191	1.1793	1.1002	1.1970
April	4	0.7225	0.8037	0.5022	0.5622	0.9088	0.8853	0.6747	0.8665
May	5	0.7244	0.3882	0.3161	0.4469	0.6109	0.7185	0.4154	0.9412
June	6	0.7066	0.3377	0.3205	0.5066	0.6537	0.7242	0.4089	0.8878
July	7	0.7659	0.5283	0.5139	0.5770	0.6625	0.7696	0.6507	0.7237
August	8	0.8196	0.6548	0.7206	0.6264	0.5801	0.7862	0.7058	0.3973
September	9	0.7224	0.7918	0.7248	0.6895	0.7077	0.8633	0.7288	1.0469
October	10	0.9330	0.8744	0.6117	0.6937	0.7245	0.8689	0.7374	0.9282
November	11	0.6158	0.7559	0.4702	0.7118	0.8069	0.9097	0.5937	0.8198
December	12	0.6338	0.6579	0.5316	0.6112	0.5983	0.8008	0.5221	0.8849
Annual Total		0.7833	0.8787	0.6512	0.6355	0.7932	0.8758	0.7714	0.9398

Average Monthly SAC SMA Scenario Flows

Month		Hoopa to Klamath Gain	Total Iron Gate to Seiad Gain	Total Seiad to Orleans Gain	Williamson Near Klamath Agency	Sprague Near Chiloquin	UKL Inflow	Trinity At Hoopa Flow	Upstream UKL Precipitation
January	1	451416	165636	452691	44732	11535	117216	596103	3.26
February	2	458846	229829	459152	58741	18987	142843	822618	3.55
March	3	498745	265707	513160	98641	36295	222623	925681	3.20
April	4	220549	122792	199999	66070	32333	161331	400465	1.51
May	5	109958	65806	101999	46712	24301	125717	192747	1.62
June	6	51814	31583	52612	32411	13997	88716	101328	1.20
July	7	22395	15747	30549	21279	6567	56823	56179	0.42
August	8	12627	9198	22639	19295	4158	48786	34406	0.33
September	9	8281	11072	18679	23316	5282	62600	26026	0.94
October	10	31762	22215	33886	28409	6867	76784	42477	1.71
November	11	154667	43278	110036	32016	8559	92668	139973	3.17
December	12	342028	87210	259880	38686	9750	107568	309716	3.61
Annual Total		2363089	1070073	2255280	510309	178632	1303675	3647720	24.54

Average Monthly SAC SMA Historic Flows

Month		Hoopa to Klamath Gain	Total Iron Gate to Seiad Gain	Total Seiad to Orleans Gain	Williamson Near Klamath Agency	Sprague Near Chiloquin	UKL Inflow	Trinity At Hoopa Flow	Upstream UKL Precipitation
January	1	571232	169580	540704	73227	18048	140739	757607	3.79
February	2	517688	169507	555061	81091	19684	146401	767224	2.71
March	3	516775	189818	587610	111952	29771	188780	841402	2.67
April	4	305260	152777	398273	117527	35577	182233	593515	1.74
May	5	151783	169506	322661	104533	39776	174962	463947	1.72
June	6	73331	93515	164163	63973	21412	122503	247808	1.35
July	7	29239	29808	59445	36876	9911	73838	86335	0.58
August	8	15407	14048	31416	30805	7168	62057	48746	0.84
September	9	11462	13983	25771	33816	7464	72509	35709	0.90
October	10	34044	25407	55400	40951	9478	88373	57608	1.85
November	11	251170	57254	234017	44978	10608	101861	235777	3.87
December	12	539624	132560	488887	63298	16296	134325	593235	4.08
Annual Total		3017015	1217763	3463409	803026	225193	1488581	4728914	26.11

Average Monthly Historic Flows

Month		Hoopa to Klamath Gain	Total Iron Gate to Seiad Gain	Total Seiad to Orleans Gain	Williamson Near Klamath Agency	Sprague Near Chiloquin	UKL Inflow	Trinity At Hoopa Flow	Upstream UKL Precipitation
January	1	539324	186139	580698	10507	39213	150716	625254	1.95
February	2	474214	157758	500242	12853	42488	146596	557031	1.25
March	3	490600	177892	520940	20811	62892	179463	593761	1.26
April	4	347098	149108	423154	21233	71382	163385	407886	0.93
May	5	221370	157636	389118	12351	70218	136523	326511	1.01
June	6	119578	92679	200394	5262	35942	74485	176509	0.70
July	7	51349	30606	76194	1659	16265	32946	80172	0.26
August	8	33274	12896	40405	467	11930	32493	47488	0.50
September	9	32041	12321	30412	411	13333	52317	40381	0.44
October	10	60020	23283	50131	1147	18462	79756	54168	0.98
November	11	233068	54363	190512	4450	21294	109057	162474	2.02
December	12	467861	134484	449100	9739	31528	141232	429981	2.18
Annual Total		3069797	1189164	3451300	100892	434948	1298968	3501616	13.51

Table 5. Example climate change flow perturbations.

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17.3. BO 2010 Operations

Upper Klamath Biological Opinion Operations

David King and Nancy Parker

Bureau of Reclamation

01/04/2011

Introduction

Several Section 7 Consultations and Biological Opinions (BO's) have governed operation of Upper Klamath Lake (UKL) and the Klamath Project (Project) since the late 1990's. The consultations involve the National Marine Fisheries Service (NMFS), also known as NOAA Fisheries, the U.S. Fish and Wildlife Service (FWS), and the Bureau of Reclamation (Reclamation). The latest FWS BO and the NMFS BO, dated March 15, 2010, are the basis of the operating criteria used by the Klamath Project Simulation Model (KPSIM) in the setup known as the "BO 2010" or "BO" operation. The following sections document the BO 2010 operation as implemented in the KPSIM.

Modeling Software

Modeling has been conducted using the Water Resources Integrated Modeling System (WRIMS) – general purpose river and reservoir planning and operations modeling software developed and maintained by the California Department of Water Resources Modeling Support Branch. The Klamath Project Simulation Model (KPSIM) was originally a spreadsheet model. Development of the WRIMS KPSIM model began in 2004 and by 2006 had replaced the KPSIM spreadsheet model as the analytical tool of choice to address increasingly complex water management scenarios and strategies in the basin.

WRIMS uses a mixed integer linear programming solver to route water through a network. Policies and priorities for water routing are implemented through user-defined weights applied to flow arcs and storage nodes in the network. System variables and the constraints on them are specified with a scripting language called the "water resources engineering simulation language" (wresl). Wresl code is developed in simple ascii text files. Time series input data and model results are stored in HEC-DSS files. Relational data (lookup tables) is stored in ascii text files.

Hydrology Data

Current representation of the Klamath Project uses a 49-year period of hydrology, encompassing water years 1961 through 2009. A full set of data is available from the USGS for key streamflow gages for this period, and it includes the dry period of record as well as some of the wettest years in the Upper Klamath Basin. Hydrologic input to the model includes historical records for net inflow to Upper Klamath Lake, Lost River Diversion Canal spills to the Klamath River, local gains between Link River and Keno Dam, runoff from agricultural lands above Lower Klamath Lake, gains between USGS gages at Keno and Iron Gate, and returns from the Klamath Straits Drain.

Each water year is divided into 17 timesteps – full months in August-February and half-months in March through July. This temporal scale is necessary to represent some operational requirements for lake elevation and flow.

System Description and Model Network

Figure 1 shows the schematic diagram of the model. Headwaters inflows are represented for Upper Klamath Lake, Gerber Reservoir, and Clear Lake. Local gains and other inflows are represented by Lake Ewauna gain, Lost River Diversion Channel Spill, Area A2 Winter Runoff, Klamath Straits Drain inflows, and Keno to Iron Gate Gain. Diversions to Project demands are represented at A Canal, Lost River Diversion Channel, North Canal, and Ady Canal. Although it is included in the model, the Lost River portion of the system is not germane to the outcome of the KPSIM runs. Lost River inflow and operations for Gerber Reservoir, Clear Lake, and Area C delivery are completely separate and have no hydrologic impact on Klamath River operations in the model.

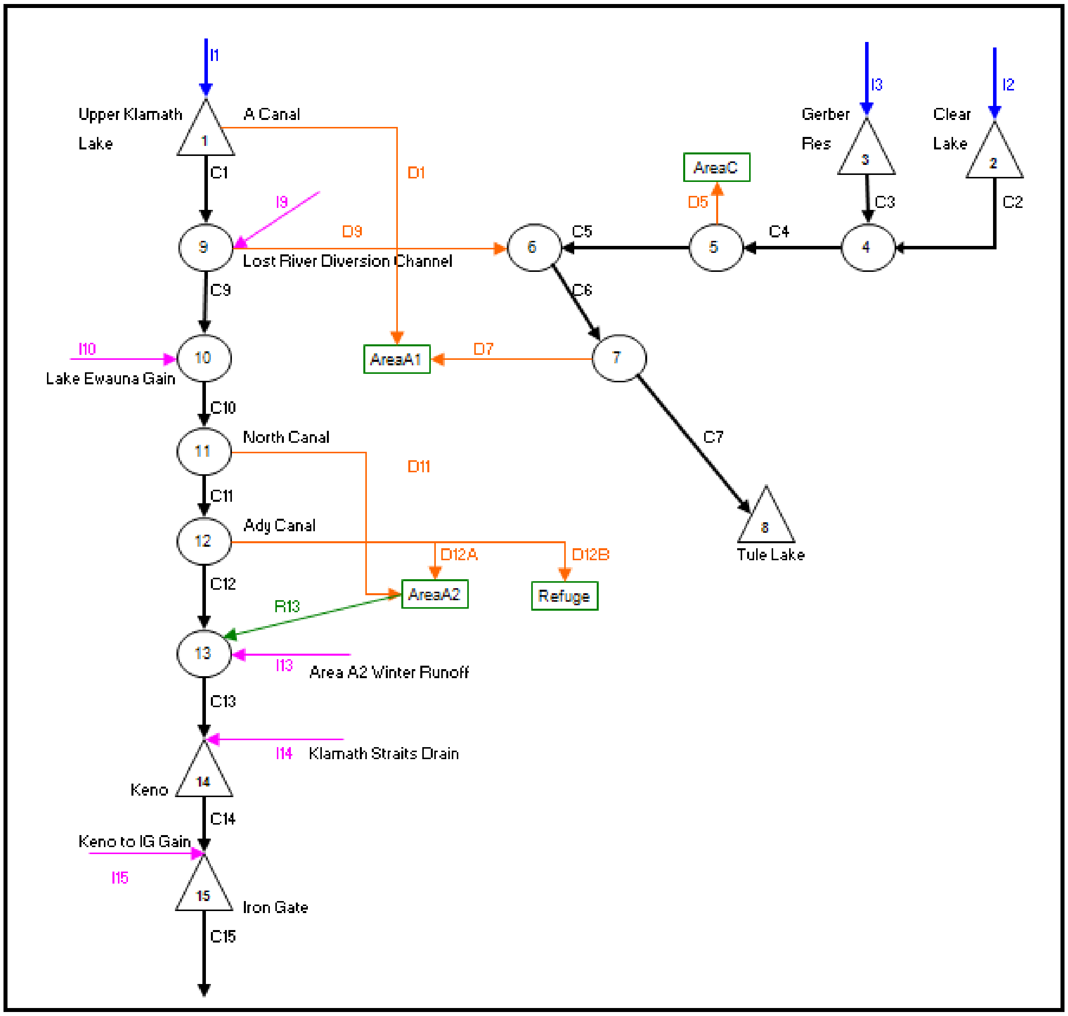

Figure 1. Schematic Network of the Klamath Project Planning Model,

Operations Criteria

Upper Klamath Biological Opinion Operations

Input data and operating rules for BO 2010 operation of the KPSIM are described below. Priorities for water use are:

- Meet Iron Gate base flows.
- Meet BO minimums for UKL elevations.
- Meet full RPA flow targets at Iron Gate Dam.
- Deliver water to Klamath Project irrigators.
- Deliver water to satisfy National Wildlife Refuge demands
- Meet UKL Refill Targets.

Target flows at Iron Gate are comprised of two parts – a base flow and an augmentation flow. Base flows were taken from the 95% exceedence level described by NMFS in the 2010 BO. The flow augmentation portion of the flow target is based on water supply conditions in the basin under the assumption that wetter conditions enable higher flows. In the fall and winter months, without an established forecast for upcoming inflows, the water supply index is based solely on the storage in Upper Klamath Lake. Water supply for spring and summer months is described by a combination of storage volume, forecasted April through September inflow, and desired end-of-September UKL carryover storage. Unique relationships were developed for each month or half-month timestep, implementing flow augmentation targets as a function of the water supply expression. The relationships were refined so that the model results achieved by their use produced a set of output flows whose probability distribution matched as closely as possible that described by NMFS in the 2010 BO.

Iron Gate base flows are shown in Table 1. Table 2 shows the definition of the water supply index as it is calculated for each timestep in the KPSIM. Tables 3A through 3C show the relationships between the water supply index and flow augmentation targets in thousands of acre-feet (TAF) for each timestep in the model. Interpolation is used to determine flow augmentation for values of the WSI that are not precisely represented by values in the table. In some months, no flow augmentation is targeted at the lowest WSI levels. If the flow augmentation target is zero, total target flow at Iron Gate is the base flow value. Flow augmentation targets are substantial at high WSI levels. No flow augmentation target exists in October.

Klamath Project demands for irrigation and refuge water users are based on precipitation indices that define annual demand and its monthly distribution. A1 deliveries include diversion from UKL to the A Canal and diversion from Lake Ewauna to the Lost River Diversion Channel. A2 deliveries include diversions from the Klamath River to irrigation uses through the North and Ady Canals. Refuge deliveries as modeled are the Ady Canal deliveries to the Lower Klamath Lake National Wildlife Refuge. Tule Lake National Wildlife Refuge, D-pump operations, and distribution of Lost River water is not explicitly represented in the model. Annual demands are based on precipitation conditions are shown in Table 4.

The BO operation includes criteria for minimum elevations in UKL per the FWS 2008 BO. Criteria used by the KPSIM are shown in Table 2.

UKL can be run with existing capacity or with existing capacity plus expanded storage capacity that includes Agency Lake, Barnes Ranch, Tulana Farms, and Goose Bay areas. Evaporation and changes to consumptive use for these new storage areas are represented specifically in the model.

Flood control rules are adjusted from the original Pacific Power and Light levels to reflect the same amount of available storage space given the modified storage capacity. Flood control targets are shown in Table 1.

KPSIM Timestep	Iron Gate Target Flow (cfs)	UKL BO Elevation Minimum (feet)	UKL Refill and Carryover Targets(Feet)	UKL Flood Control Rules (feet)
Oct	1300		4139.10	4141.80
Nov	1300		4139.90	4141.39
Dec	1260		4140.80	4141.70
Jan	1130		4141.70	4142.30
Feb	1300	4141.50	4142.50	4142.70
Mar 1-15	1275	4141.85	4143.00	4142.90
Mar 16-31	1275	4142.20		4143.15
Apr 1-15	1325	4142.20		4143.30
Apr 16-30	1325	4142.20		4143.30
May 1-15	1175	4141.90		4143.30
May 16-31	1175	4141.60		4143.30
JUN 1-15	1025	4141.05		4143.30
JUN 16-30	1025	4140.50		4143.30
JUL 1-15	805	4140.10		4143.30
JUL 16-31	805	4139.30		4143.30
Aug	942	4138.10		4143.30
Sep	1000	4137.50	4138.00	4143.05

Table 1. Iron Gate Base Flow and UKL Elevation Criteria.

November - February	Beginning of Month (End of Previous Month) UKL Storage Volume
March 1	(End of February UKL Storage) +(March 1st April-September 50% UKL Inflow Forecast) – (End-of-September Carryover Storage Target)
March 16	(March 15 UKL Storage) + (March 1st April-September 50% UKL Inflow Forecast) – (End-of-September Carryover Storage Target)
April 1	(End of March UKL Storage) + (April 1st April-September 50% UKL Inflow Forecast) – (End-of-September Carryover Storage Target)
April 16	(April 15 UKL Storage) + (April 1st April-September 50% UKL Inflow Forecast) –(End-of-September Carryover Storage Target)
May 1 - Sept	Use the index value computed for the previous April 16th

Table 2. Planning model definitions of Water Supply Index.

November		December		January		February	
Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation
0	0	0	0	0	0	0	0
104	0	132	0	176	0	246	0
117	0	143	2.46	210	7.07	273	0
124	0	175	2.46	222	10.45	293	0
133	0	187	2.46	254	10.45	312	0
147	0	195	2.46	275	10.45	314	0
150	0	210	2.46	286	10.45	328	0
152	0	216	2.46	312	10.45	349	1.28
160	0	269	2.46	323	11.01	373	32.21
180	0	277	5.23	326	32.34	377	65.15
190	0	289	9.22	333	38.18	383	70.92
213	0	302	29.08	340	54.6	398	79.31
238	0	307	35.48	348	68.37	416	100.24
260	0	315	50.36	351	87.25	430	122.46
265	7.97	320	74.46	377	89.03	488	129.51
270	17.26	335	101.33	404	92.05	508	140.06
290	31.6	345	106.8	421	109.32	522	147.73
320	44.03	356	111.78	454	145.6	550	161.61
379	66.35	362	124.2	488	166.32	555	165.78
416	69.02	463	130.66	545	175.85	556	176.33

Table 3A. Augmentation Flow Volumes in TAF as a function of WSI and timestep.

March 1-15		March 16-31		April 1-15		April 16-30	
Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation
0	0	0	0	0	0	0	0
432	0	453	0	480	0	489	0
502	4.02	546	4.28	517	5.21	528	5.21
552	5.21	564	5.55	607	5.21	625	5.21
599	12.14	641	12.95	632	5.21	642	5.21
645	23.06	676	24.6	699	5.21	720	5.21
649	31.98	691	34.12	729	5.21	734	5.21
677	40.28	725	42.97	740	7.85	772	7.85
721	48.05	761	51.25	779	37.64	789	37.64
757	55.79	799	59.5	798	41.59	825	41.59
783	56.59	808	60.36	824	50.73	862	50.73
812	65.19	818	69.53	860	57.12	881	57.12
861	71.7	861	76.48	909	64.26	900	64.26
914	74.14	918	79.08	943	70.81	937	70.81
952	79.29	958	84.58	952	77.5	978	77.5
981	80.78	1004	86.16	986	81.52	1036	81.52
1053	85.83	1061	91.56	1043	86.43	1067	86.43
1075	89.55	1087	95.52	1142	92.23	1145	92.23
1115	91.64	1115	97.75	1177	96.99	1174	96.99
1199	94.76	1196	101.08	1243	103.09	1235	103.09

Table 3B. Augmentation Flow Volumes in TAF as a function of WSI and timestep.

Water Supply Index	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August	September
	Flow Augmentation	Flow Augmentation	Flow Augmentation	Flow Augmentation	Flow Augmentation	Flow Augmentation	Flow Augmentation	Flow Augmentation
0	0	0	0	0	0	0	0	0
489	0	0	0	0	0	0	0	0
528	1.34	1.43	1.64	1.64	1.04	1.11	0.45	0
625	7.14	7.62	4.02	4.02	2.98	3.17	0.92	0
642	12.73	13.58	8.78	8.78	4.17	4.44	1.8	0.36
720	14.67	15.65	12.79	12.79	6.28	6.7	3.08	0.77
734	18.68	19.93	14.07	14.07	6.66	7.11	4.16	1.43
772	20.86	22.25	14.73	14.73	6.84	7.3	4.62	1.79
789	25.41	27.1	16.19	16.19	7.29	7.78	5.05	2.44
825	27.97	29.83	16.93	16.93	7.47	7.97	5.29	2.86
862	43.65	46.56	18.27	18.27	7.88	8.41	5.72	3.57
881	48.79	52.05	19.16	19.16	8.09	8.63	5.91	3.93
900	53.11	56.65	19.55	19.55	8.24	8.79	6.09	4.22
937	57.72	61.57	20.05	20.05	8.78	9.36	6.64	5.06
978	60.99	65.06	21.36	21.36	9.31	9.93	6.83	5.3
1036	65.9	70.29	50.64	50.64	9.88	10.54	7.14	5.77
1067	68.58	73.15	54.3	54.3	10.32	11.01	7.63	8.03
1145	72.6	77.43	58.02	58.02	12.44	13.27	9.29	9.64
1174	75.42	80.45	60.4	60.4	16.81	17.93	11.32	14.64
1235	79.44	84.73	64.26	64.26	18.6	19.83	12.61	16.72

Table 3C. Augmentation Flow Volumes in TAF as a function of WSI and timestep.

Feb-Mar Precipitation Index (in)	A1 Demand Apr-Mar (TAF)	Refuge Demand Apr-Mar (TAF)	Oct-Jan Precipitation Index (in)	A2 Demand Apr-Mar (TAF)
0.00 - 1.999	340	30	0.00 - 3.99	105
2.00 - 2.749	310	25	4.00 - 6.99	95
2.75 - 3.299	300	20	7.00 - 9.99	90
>= 3.30	275	15	>= 10.00	80

Table 4. Project demand as a function of precipitation.

17.4. KBRA Operations

Upper Klamath KBRA Operations

David King and Nancy Parker
Bureau of Reclamation
01/03/2011

Introduction

The Klamath Basin Restoration Agreement (KBRA) among stakeholders in the Klamath River basin has the objective of restoring and sustaining fisheries while establishing reliable water and power supplies. The KBRA includes specific hydrologic criteria that were implemented using a version of the Klamath Project Simulation Model (KPSIM). This documentation describes the operating criteria and implementation in the KBRA version of the Klamath Project Simulation Model (KPSIM).

Modeling Software

Modeling has been conducted using the Water Resources Integrated Modeling System (WRIMS) – general purpose river and reservoir planning and operations modeling software developed and maintained by the California Department of Water Resources Modeling Support Branch. The Klamath Project Simulation Model (KPSIM) was originally a spreadsheet model. Development of the WRIMS KPSIM model began in 2004 and by 2006 had replaced the KPSIM spreadsheet model as the analytical tool of choice to address increasingly complex water management scenarios and strategies in the basin.

WRIMS uses a mixed integer linear programming solver to route water through a network. Policies and priorities for water routing are implemented through user-defined weights applied to flow arcs and storage nodes in the network. System variables and the constraints on them are specified with a scripting language called the “water resources engineering simulation language” (wresl). Wresl code is developed in simple ascii text files. Time series input data and model results are stored in HEC-DSS files. Relational data (lookup tables) is stored in ascii text files.

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Each water year is divided into 17 timesteps – full months in August-February and half-months in March through July. This temporal scale is necessary to represent some operational requirements for lake elevation and flow.

System Description and Model Network

Figure 1 shows the schematic diagram of the model. Headwaters inflows are represented for Upper Klamath Lake (UKL), Gerber Reservoir, and Clear Lake. Local gains and other inflows are represented by Lake Ewauna gain, Lost River Diversion Channel Spill, Area A2 Winter Runoff, Klamath Straits Drain inflows, and Keno to Iron Gate Gain. Diversions to Project demands are represented at A Canal, Lost River Diversion Channel, North Canal, and Ady Canal. Although it is included in the model, the Lost River portion of the system is not germane to the outcome of the KPSIM runs. Lost River inflow and operations for Gerber Reservoir, Clear Lake, and Area C delivery are completely separate and have no hydrologic impact on Klamath River operations in the model.

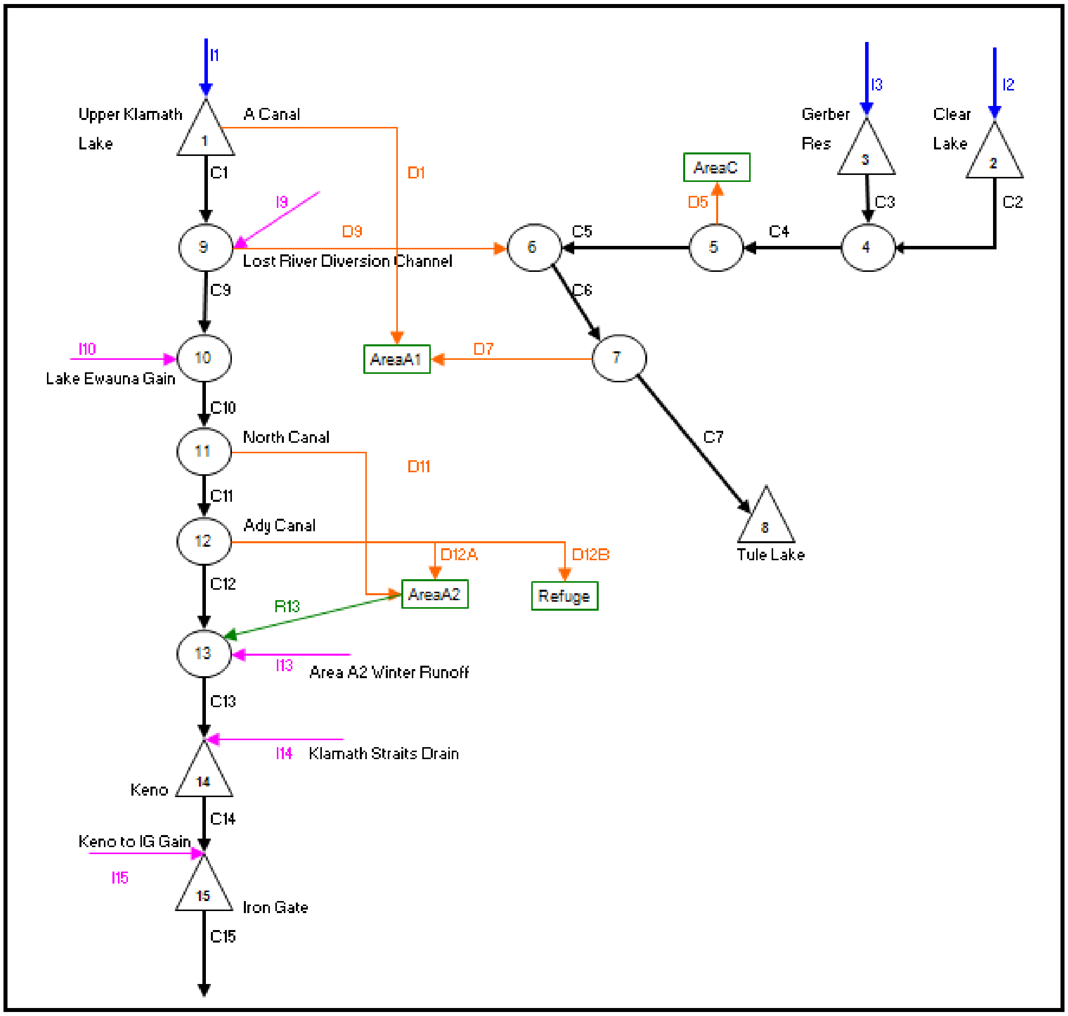

Figure 1. Schematic Network of the Klamath Project Planning Model.

Operations Criteria

Input data and operating rules for KBRA operation of the KPSIM are described below. The fundamental modeling approach is:

- Deliver Project Irrigation allocation and meet National Wildlife Refuge demands
- Balance Iron Gate Flow and UKL elevation conditions – set targets and balance any shortage or surplus

- If Iron Gate Flow or UKL elevation would fall short of an environmental baseline under the above operation, first reduce Refuge delivery to no more than 24,000 acre-feet (24 TAF) April-October and then decrease Irrigation deliveries.

The specific operating criteria are:

Net Inflow to UKL is augmented by 30,000 acre-feet (30 TAF) per year distributed between March and October.

March through October Project demand from UKL and Klamath River is computed as a function of inflow forecast using following criteria:

330 TAF when March 1 inflow forecast is <= 287 TAF
385 TAF when forecast is > 569 TAF
Linear interpolation between 330 TAF and 385 TAF for forecasts between 287 TAF and 569 TAF

November through February project demand is based on historic delivery.

March through October refuge demand from UKL and Klamath River is computed as a function of inflow forecast using the following criteria:

48 TAF when Mar 1 inflow forecast is <= 287 TAF
60 TAF when forecast is > 569 TAF
Linear interpolation between forecasts of 287 TAF and 567 TAF.

November through February refuge demand is based on historic delivery. Demand for diversions from the Klamath River are reduced by estimated D Plant pumping.

Target flows at Iron Gate are selected based on cumulative winter or summer inflows to UKL through the previous time step, using the Inflow Exceedence Index (IEI). Values are interpolated between exceedence levels. The targets used in the model are shown in Table 1.

UKL level targets are selected based on cumulative winter or summer inflows to UKL through the previous time step, using the Inflow Exceedence Index (IEI). Values are interpolated between exceedence levels. The targets used in the model are shown in Table 2.

During shortage years, irrigation and refuge supplies are redistributed to reflect KBRA language. KPSIM does adjustments on an annual basis as a post process. Monthly adjustments are done as a post process in a workbook.

UKL can be run with existing capacity or with existing capacity plus expanded storage capacity that includes Agency Lake, Barnes Ranch, Tulana Farms, Goose Bay, and Wood River areas. Evaporation and changes to consumptive use for these new storage areas are represented specifically in the model.

Flood control rules are adapted from the original Pacific Power and Light levels to reflect the same amount of available storage space given the modified storage capacity. Flood control targets are shown in Table 2.

Probability	100%	98%	97%	90%	70%	50%	30%	10%	0%
Oct	970	970	1000	1000	1100	1300	1300	1300	1300
Nov	1000	1000	1000	1000	1100	1300	1300	1300	1300
Dec	1000	1000	1000	1000	1100	1300	1300	1300	1300
Jan	1000	1000	1000	1000	1100	2024	2223	2421	2421
Feb	1000	1000	1000	1000	1100	2353	2592	2831	2831
Mar 1-15	1100	1175	1398	1398	2085	2721	2988	3224	3224
Mar 16-31	1200	1250	1446	1446	2149	2932	3220	3458	3458
Apr 1-15	1250	1325	1494	1494	2212	3030	3335	3620	3620
Apr 16-30	1250	1325	1542	1542	2276	3015	3334	3710	3710
May 1-15	1100	1175	1240	1240	2090	2739	3306	3728	3728
May 16-31	1100	1175	1182	1182	1936	2559	3063	3675	3675
Jun 1-15	1000	1022	1109	1109	1746	2315	2782	3147	3147
Jun 16-30	1000	1022	1022	1022	1522	2008	2463	2781	2781
Jul 1-15	700	700	840	840	1070	1330	1830	2140	2140
Jul 16-31	700	700	840	840	1070	1330	1830	2140	2140
Aug	880	880	1110	1110	1260	1305	1430	1545	1545
Sep	970	970	1110	1110	1260	1305	1430	1545	1545

Table 1. **KBRA Iron Gate Flow Targets (cfs).**

Probability	100%	98%	97%	90%	70%	25%	0%	Flood
Oct	4137.80	4137.80	4138.85	4138.90	4139.20	4139.95	4140.20	4141.80
Nov	4138.80	4138.80	4139.61	4139.74	4140.02	4140.65	4141.00	4141.70
Dec	4139.80	4139.80	4140.21	4140.33	4140.59	4141.15	4141.50	4141.90
Jan	4140.80	4140.80	4140.91	4141.01	4141.23	4141.73	4142.00	4142.30
Feb	4141.60	4141.60	4141.61	4141.69	4141.87	4142.28	4142.50	4142.70
Mar 1-15	4141.70	4141.70	4142.20	4142.44	4142.52	4142.70	4142.80	4142.90
Mar 16-31	4141.80	4141.80	4142.40	4142.72	4142.76	4142.85	4142.90	4143.00
Apr 1-15	4141.30	4141.50	4142.80	4142.82	4142.86	4142.95	4143.00	4143.00
Apr 16-30	4141.20	4141.50	4142.90	4142.92	4142.96	4143.05	4143.10	4143.10
May 1-15	4141.00	4141.30	4143.00	4143.02	4143.06	4143.15	4143.20	4143.20
May 16-31	4140.70	4141.10	4141.60	4142.40	4142.70	4143.10	4143.10	4143.20
Jun 1-15	4140.40	4140.60	4141.20	4142.00	4142.40	4142.85	4142.85	4143.30
Jun 16-30	4139.80	4140.10	4140.80	4141.55	4142.10	4142.60	4142.60	4143.30
Jul 1-15	4139.60	4139.60	4140.32	4141.02	4141.57	4142.02	4142.02	4143.30
Jul 16-31	4139.10	4139.10	4139.80	4140.40	4141.00	4141.40	4141.40	4143.30
Aug	4138.10	4138.10	4139.14	4139.65	4139.80	4140.84	4140.84	4143.30
Sep	4137.50	4137.50	4138.50	4139.00	4139.05	4139.60	4140.30	4143.30

Table 2. KBRA UKL Target and Flood Control Elevations (feet).

The KBRA process intends to develop a drought plan in which shortage criteria and minimum flows in the river are explicitly defined. However, at the time this document was complete, no such drought plan was available. The following assumptions were made in place of the drought plan:

1. Incorporation of a minimum flow of 100 cfs at Link River to provide adequate passage through the fish ladder and stream channel.

2. Incorporation of a minimum flow at Keno Dam of 300 cfs to provide adequate fish passage.

3. Minor adjustment of KBRA flow targets for use in the hydrology model for the time steps from July 1 through the end of September to improve flow conditions for adult migration and reduce the potential for fish die off. The changes that were implemented include reducing the target from 921 to 840 cfs for July 1 to 15, increasing the target from 806 to 840 cfs for July 16 to 31, increasing the target from 895 to 1110 cfs in August, and increasing the targets from 1010 to 1110 cfs in September.

4. Incorporation of minimum Ecological Base Flow levels during the periods from March 1 through June 30 and during the months of August and September. The EBF volumes would be represented by the Hardy Phase II 95% exceedence flow levels.

5. Minor adjustment to the flow targets for the month of March for water years represented by the 70% Exceedence. These adjustments include reductions in the targets from 2358 to 2085 cfs (March 1-15) and from 2343 to 2149 cfs (March 16-31). The change is consistent with rate of change for wetter water years.

6. Incorporation of minimum base flows of 800 cfs during the months of October through February. The minimum of 800 cfs is considered to be necessary to prevent adverse impacts to salmonids during the winter months.

7. Redistribution of irrigation and refuge supplies during shortage years to reflect KBRA language. KPSIM does adjustments on annual basis as a post process. Monthly adjustments are done as a post process in a workbook by the data manager which runs both models.

8. Minor adjustments were made to UKL elevation criteria in association with shortage adjustments.

17.5. Operations Models

Klamath Dam Removal - Hydrologic Operations

David King and Nancy Parker

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01/04/2011

Introduction

The Klamath Dam Removal (KDR) study used two hydrologic models to assist in analyzing several hydrologic scenarios and two basin operating criteria. The two basin operating criteria are the Biologic Opinion (BO) and Klamath Basin Restoration Agreement (KBRA). These operations correspond to the Dams In and Dams Out KDR scenarios, also known as the No Action and Dam Removal Alternative scenarios. The two hydrologic models consist of an upstream monthly model and a downstream daily model. Output of the upstream model becomes part of the input to the downstream model. The upstream monthly timestep was sufficient to allocate water supplies in the upper basin and a reasonable estimate of Klamath River flows available to the downstream model. The daily timestep of the downstream model provided better computations of power production and streamflows in critical river reaches. The following pages document the KDR hydrologic models.

Modeling Software

Recent upstream modeling has been conducted using the Water Resources Integrated Modeling System (WRIMS) – general purpose river and reservoir planning and operations modeling software developed and maintained by the California Department of Water Resources Modeling Support Branch. The Klamath Project Simulation Model (KPSIM) was originally a spreadsheet model. Development of the WRIMS KPSIM model began in 2004 and by 2006 had replaced the KPSIM spreadsheet model as the analytical tool of choice to address increasingly complex water management scenarios and strategies in the basin.

WRIMS uses a mixed integer linear programming solver to route water through a network. Policies and priorities for water routing are implemented through user-defined weights applied to flow arcs and storage nodes in the network. System variables and the constraints on them are specified with a scripting language called the “water resources engineering simulation language” (wresl). Wresl code is developed in simple ascii text files. Time series input data and model results are stored in HEC-DSS files. Relational data (lookup tables) is stored in ascii text files.

The downstream model, known as the Klamath Dam Removal Model (KDRM), was developed using RiverWare. RiverWare is a generic hydrologic modeling tool developed by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) located at the University of Colorado. Reclamation is a co-owner of RiverWare. RiverWare has several controllers - the KDRM uses the rule based simulation controller. Rules in RiverWare are written using RiverWare Policy Language (RPL), a user-friendly language that includes a debugger and other tools for implementing and troubleshooting operating criteria.

Hydrology Data

The KDR uses hydrology based on a 49-year period of historic hydrology, encompassing water years 1961 through 2009. A mostly full set of data is available from the USGS for key streamflow gages for this period which includes the dry period of record as well as some of the wettest years in the Upper Klamath Basin. Hydrologic input to the KPSIM includes net inflow to Upper Klamath Lake, Lost River Diversion Canal spills to the Klamath River, local gains between Link River and Keno Dam, runoff from agricultural lands above Lower Klamath Lake, gains between USGS gages at Keno and Iron Gate, and returns from the Klamath Straits Drain. Input to the KDRM are monthly flow that includes output of the KPSIM at Keno and Iron Gate, four gains between Keno and Iron Gate, and major gains downstream of Iron Gate.

Historic data were developed from USGS daily streamflow records, USGS monthly reservoir records (partial record) and reservoir data obtained from PacifiCorp. Reservoir data were incomplete but were extended by interpolation and other methods. Additional documentation of downstream data development is available. The Klamath Basin Area Office (KBAO) develops data used by the KPSIM annually.

Historic data from water years 1961 through 2009 were used to develop three synthetic types of hydrology for dams-in and dams-out planning scenarios. The types of synthetic hydrology are:

1. Indexed sequential – A hydrograph created by repetition of historic hydrology.
2. Stochastic – Hydrographs created using statistical software from the historic hydrology.
3. Climate change – Hydrographs created using a watershed model with climate variation.

Development of synthetic hydrologies is discussed in detail in other documents. In the end, the stochastic data were not used because it was problematic to create climate data stochastically. In addition, the climate change traces used for KDR analyzes were reduced to five. All scenario runs use a simulation period starting date 10/1/2011, water year 2012 and are 51 water years to obtain 50 calendar years for the economic analyzes. The indexed sequential scenarios consist of 49 traces using every historic year as a starting year. The five climate change traces were run with three starting years representing median (1961), wet (1982), and dry (1990) periods of the historic record.

Each water year of the KPSIM is divided into 17 timesteps – full months in August-February and half-months in March through July. This temporal scale is necessary to represent some operational requirements for lake elevation and flow. The 17 timesteps of the upstream model are temporally aggregated for the monthly input data used by the KDRM. All monthly data are temporally disaggregated to daily by the KDRM as explained in more detailed in the KDRM operations section.

System Description and Model Network

Figure 1 shows the schematic diagram of the KPSIM. Headwaters inflows are represented for Upper Klamath Lake, Gerber Reservoir, and Clear Lake. Local gains and other inflows are represented by Lake Ewauna gain, Lost River Diversion Channel Spill, Area A2 Winter Runoff, Klamath Straits Drain inflows, and Keno to Iron Gate Gain. Diversions to Project demands are represented at A Canal, Lost River Diversion Channel, North Canal, and Ady Canal. Note that although the diagram shows Keno and Iron Gate reservoirs, the KPSIM does not explicitly model these reservoirs.

The KDRM model begins just downstream of Keno Reservoir and ends at the ocean as shown on Figure 2. A list of the primary hydrologic nodes in the KDRM is listed in Table 1. Additional nodes exist between these nodes which correspond to SALMOD fisheries model nodes. These nodes correspond to additional tributary inflows. Note that the Hoopa to Klamath gains are all gains from the Trinity At Hoopa and Klamath At Orleans gages to the Klamath Near Klamath gage. Primary gains developed from historic data are spatially disaggregated to the SALMOD nodes.

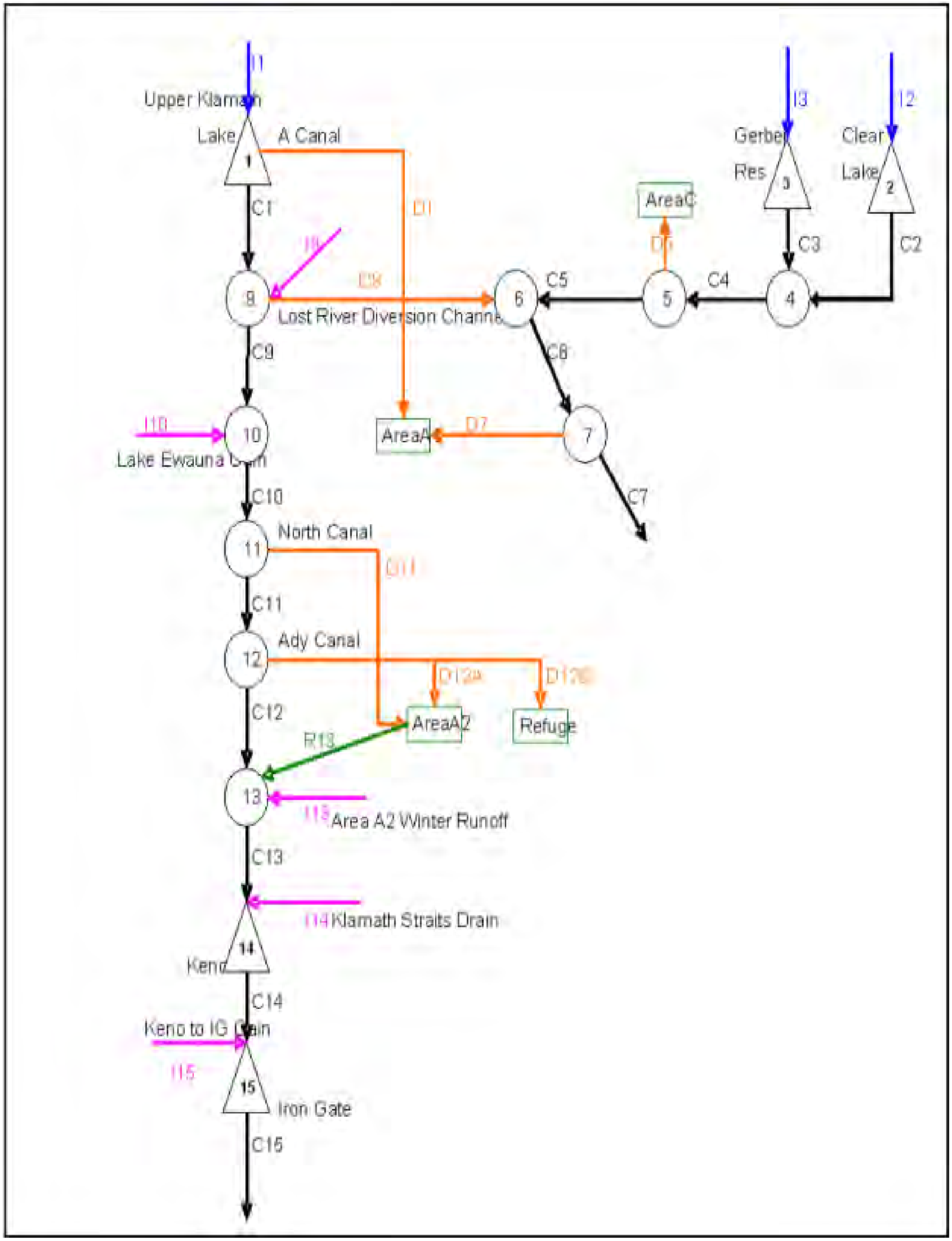


Figure 1. Schematic network of the upstream model.

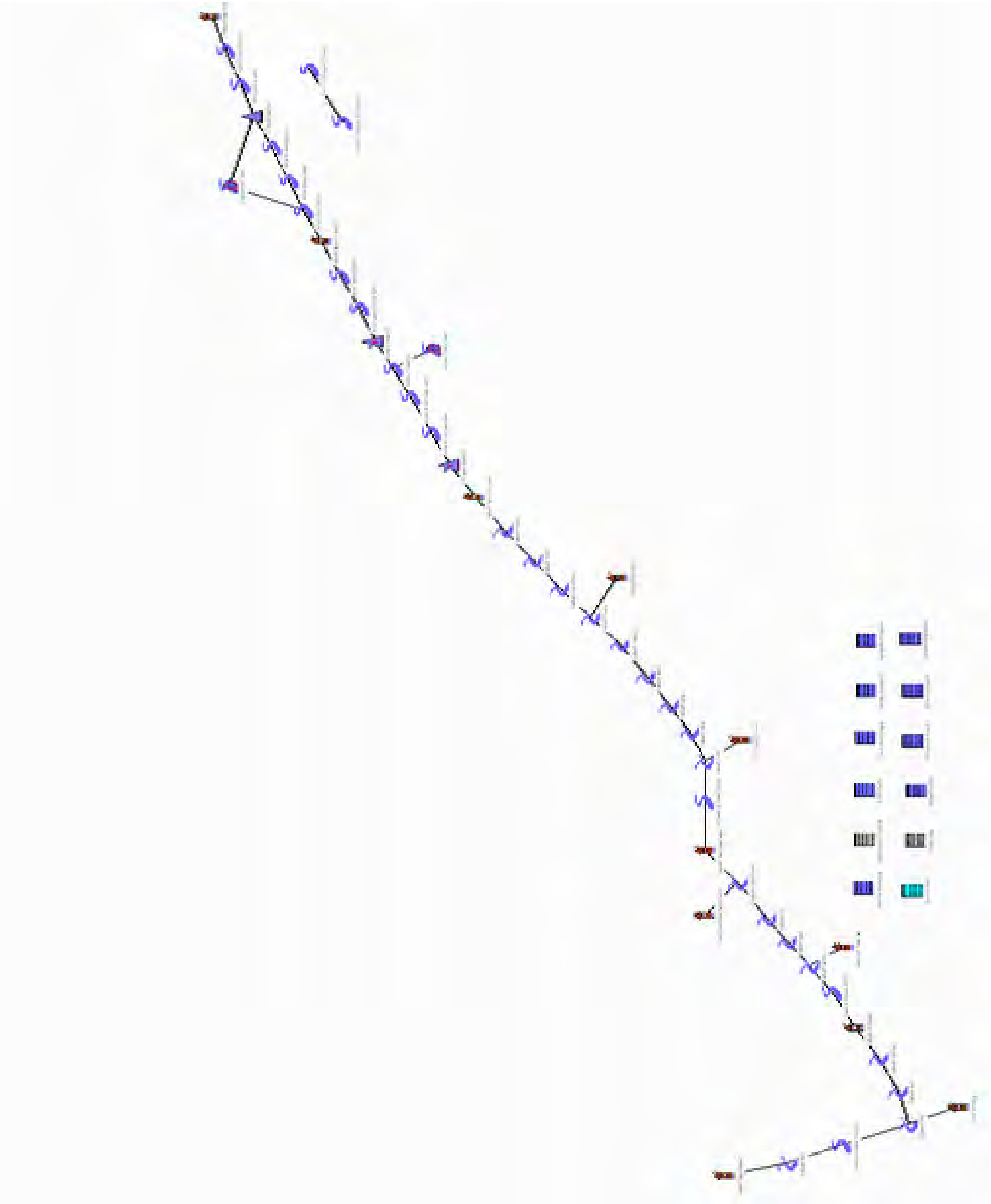


Figure 2. Schematic network of the downstream model.

Klamath River Near Keno
Keno to Boyle Reservoir Gain
JC Boyle Reservoir
Boyle Reservoir To Boyle Gage Gain
Boyle Gage To Copco Gain
Copco 1 Reservoir
Copco 2 Reservoir
Copco To Iron Gate Gain
Iron Gate Reservoir
Iron Gate to Seiad Gain
Seiad to Orleans Gain
Scott Near Ft Jones
Salmon At Somes Bar
Indian Creek Near Happy Camp
Shasta Near Yreka
Hoopa to Klamath Gains
Trinity At Hoopa

Table 1. Primary Downstream Model Hydrology Nodes.

KPSIM Biological Opinion Operations

Several Section 7 Consultations and Biological Opinions (BO's) have governed operation of Upper Klamath Lake (UKL) and the Klamath Project (Project) since the late 1990's. The consultations involve the National Marine Fisheries Service (NMFS), also known as NOAA Fisheries, the U.S. Fish and Wildlife Service (FWS), and the Bureau of Reclamation (Reclamation). The latest FWS BO and the NMFS BO, dated March 15, 2010, are the basis of the operating criteria used by the Klamath Project Simulation Model (KPSIM) in the setup known as the "BO 2010" or "BO" operation. The following sections document the BO 2010 operation as implemented in the KPSIM.

Input data and operating rules for BO 2010 operation of the KPSIM are described below. Priorities for water use are:

- Meet Iron Gate base flows.
- Meet BO minimums for UKL elevations.
- Meet full RPA flow targets at Iron Gate Dam.
- Deliver water to Klamath Project irrigators.
- Deliver water to satisfy National Wildlife Refuge demands
- Meet UKL Refill Targets.

Target flows at Iron Gate are comprised of two parts – a base flow and an augmentation flow. Base flows were taken from the 95% exceedence level described by NMFS in the 2010 BO. The flow augmentation portion of the flow target is based on water supply conditions in the basin under the assumption that wetter conditions enable higher flows. In the fall and winter months, without an established forecast for upcoming inflows, the water supply index is based solely on the storage in Upper Klamath Lake. Water supply for spring and summer months is described by a combination of storage volume, forecasted April through September inflow, and desired end-of-September UKL carryover storage. Unique relationships were developed for each month or half-month timestep, implementing flow augmentation targets as a function of the water supply expression. The relationships were refined so that the model results achieved by their use produced a set of output flows whose probability distribution matched as closely as possible that described by NMFS in the 2010 BO.

Iron Gate base flows are shown in Table 2. Table 3 shows the definition of the water supply index as it is calculated for each timestep in the KPSIM. Tables 4A through 4C show the relationships between the water supply index and flow augmentation targets in thousands of acre-feet (TAF) for each timestep in the model. Interpolation is used to determine flow augmentation for values of the WSI that are not precisely represented by values in the table. In some months, no flow augmentation is targeted at the lowest WSI levels. If the flow augmentation target is zero, total target flow at Iron Gate is the base flow value. Flow augmentation targets are substantial at high WSI levels. No flow augmentation target exists in October.

KPSIM Timestep	Iron Gate Target Flow (cfs)	UKL BO Elevation Minimum (feet)	UKL Refill and Carryover Targets(Feet)	UKL Flood Control Rules (feet)
Oct	1300		4139.10	4141.80
Nov	1300		4139.90	4141.39
Dec	1260		4140.80	4141.70
Jan	1130		4141.70	4142.30
Feb	1300	4141.50	4142.50	4142.70
Mar 1-15	1275	4141.85	4143.00	4142.90
Mar 16-31	1275	4142.20		4143.15
Apr 1-15	1325	4142.20		4143.30
Apr 16-30	1325	4142.20		4143.30
May 1-15	1175	4141.90		4143.30
May 16-31	1175	4141.60		4143.30
JUN 1-15	1025	4141.05		4143.30
JUN 16-30	1025	4140.50		4143.30
JUL 1-15	805	4140.10		4143.30
JUL 16-31	805	4139.30		4143.30
Aug	942	4138.10		4143.30
Sep	1000	4137.50	4138.00	4143.05

Table 3. Iron Gate Base Flow and UKL Elevation Criteria.

November - February	Beginning of Month (End of Previous Month) UKL Storage Volume
March 1	(End of February UKL Storage) +(March 1st April-September 50% UKL Inflow Forecast) – (End-of-September Carryover Storage Target)
March 16	(March 15 UKL Storage) + (March 1st April-September 50% UKL Inflow Forecast) – (End-of-September Carryover Storage Target)
April 1	(End of March UKL Storage) + (April 1st April-September 50% UKL Inflow Forecast) – (End-of-September Carryover Storage Target)
April 16	(April 15 UKL Storage) + (April 1st April-September 50% UKL Inflow Forecast) –(End-of-September Carryover Storage Target)
May 1 – Sept	Use the index value computed for the previous April 16th

Table 3. Planning model definitions of Water Supply Index.

Klamath Project demands for irrigation and refuge water users are based on precipitation indices that define annual demand and its monthly distribution. A1 deliveries include diversion from UKL to the A Canal and diversion from Lake Ewauna to the Lost River Diversion Channel. A2 deliveries include diversions from the Klamath River to irrigation uses through the North and Ady Canals. Refuge deliveries as modeled are the Ady Canal deliveries to the Lower Klamath Lake National Wildlife Refuge. Tule Lake National Wildlife Refuge, D-pump operations, and distribution of Lost River water is not explicitly represented in the model. Annual demands are based on precipitation conditions are shown in Table 5.

The BO operation includes criteria for minimum elevations in UKL per the FWS 2008 BO. Criteria used by the KPSIM are shown in Table 2.

UKL can be run with existing capacity or with existing capacity plus expanded storage capacity that includes Agency Lake, Barnes Ranch, Tulana Farms, and Goose Bay areas. Evaporation and changes to consumptive use for these new storage areas are represented specifically in the model.

Flood control rules are adjusted from the original Pacific Power and Light levels to reflect the same amount of available storage space given the modified storage capacity. Flood control targets are shown in Table 2.

November		December		January		February	
Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation
0	0	0	0	0	0	0	0
104	0	132	0	176	0	246	0
117	0	143	2.46	210	7.07	273	0
124	0	175	2.46	222	10.45	293	0
133	0	187	2.46	254	10.45	312	0
147	0	195	2.46	275	10.45	314	0
150	0	210	2.46	286	10.45	328	0
152	0	216	2.46	312	10.45	349	1.28
160	0	269	2.46	323	11.01	373	32.21
180	0	277	5.23	326	32.34	377	65.15
190	0	289	9.22	333	38.18	383	70.92
213	0	302	29.08	340	54.6	398	79.31
238	0	307	35.48	348	68.37	416	100.24
260	0	315	50.36	351	87.25	430	122.46
265	7.97	320	74.46	377	89.03	488	129.51
270	17.26	335	101.33	404	92.05	508	140.06
290	31.6	345	106.8	421	109.32	522	147.73
320	44.03	356	111.78	454	145.6	550	161.61
379	66.35	362	124.2	488	166.32	555	165.78
416	69.02	463	130.66	545	175.85	556	176.33

Table 4A. Augmentation Flow Volumes in TAF as a function of WSI and timestep.

March 1-15		March 16-31		April 1-15		April 16-30	
Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation	Water Supply Index	Flow Augmentation
0	0	0	0	0	0	0	0
432	0	453	0	480	0	489	0
502	4.02	546	4.28	517	5.21	528	5.21
552	5.21	564	5.55	607	5.21	625	5.21
599	12.14	641	12.95	632	5.21	642	5.21
645	23.06	676	24.6	699	5.21	720	5.21
649	31.98	691	34.12	729	5.21	734	5.21
677	40.28	725	42.97	740	7.85	772	7.85
721	48.05	761	51.25	779	37.64	789	37.64
757	55.79	799	59.5	798	41.59	825	41.59
783	56.59	808	60.36	824	50.73	862	50.73
812	65.19	818	69.53	860	57.12	881	57.12
861	71.7	861	76.48	909	64.26	900	64.26
914	74.14	918	79.08	943	70.81	937	70.81
952	79.29	958	84.58	952	77.5	978	77.5
981	80.78	1004	86.16	986	81.52	1036	81.52
1053	85.83	1061	91.56	1043	86.43	1067	86.43
1075	89.55	1087	95.52	1142	92.23	1145	92.23
1115	91.64	1115	97.75	1177	96.99	1174	96.99
1199	94.76	1196	101.08	1243	103.09	1235	103.09

Table 4B. Augmentation Flow Volumes in TAF as a function of WSI and timestep.

Water Supply Index	May 1-15	May 16-31	June 1-15	June 16-30	July 1-15	July 16-31	August	September
	Flow Augmentation	Flow Augmentation	Flow Augmentation	Flow Augmentation	Flow Augmentation	Flow Augmentation	Flow Augmentation	Flow Augmentation
0	0	0	0	0	0	0	0	0
489	0	0	0	0	0	0	0	0
528	1.34	1.43	1.64	1.64	1.04	1.11	0.45	0
625	7.14	7.62	4.02	4.02	2.98	3.17	0.92	0
642	12.73	13.58	8.78	8.78	4.17	4.44	1.8	0.36
720	14.67	15.65	12.79	12.79	6.28	6.7	3.08	0.77
734	18.68	19.93	14.07	14.07	6.66	7.11	4.16	1.43
772	20.86	22.25	14.73	14.73	6.84	7.3	4.62	1.79
789	25.41	27.1	16.19	16.19	7.29	7.78	5.05	2.44
825	27.97	29.83	16.93	16.93	7.47	7.97	5.29	2.86
862	43.65	46.56	18.27	18.27	7.88	8.41	5.72	3.57
881	48.79	52.05	19.16	19.16	8.09	8.63	5.91	3.93
900	53.11	56.65	19.55	19.55	8.24	8.79	6.09	4.22
937	57.72	61.57	20.05	20.05	8.78	9.36	6.64	5.06
978	60.99	65.06	21.36	21.36	9.31	9.93	6.83	5.3
1036	65.9	70.29	50.64	50.64	9.88	10.54	7.14	5.77
1067	68.58	73.15	54.3	54.3	10.32	11.01	7.63	8.03
1145	72.6	77.43	58.02	58.02	12.44	13.27	9.29	9.64
1174	75.42	80.45	60.4	60.4	16.81	17.93	11.32	14.64
1235	79.44	84.73	64.26	64.26	18.6	19.83	12.61	16.72

Table 4C. Augmentation Flow Volumes in TAF as a function of WSI and timestep.

Feb-Mar Precipitation Index (in)	**A1 Demand Apr-Mar (TAF)**	**Refuge Demand Apr-Mar (TAF)**	**Oct-Jan Precipitation Index (in)**	**A2 Demand Apr-Mar (TAF)**
0.00 - 1.999	340	30	0.00 - 3.99	105
2.00 - 2.749	310	25	4.00 - 6.99	95
2.75 - 3.299	300	20	7.00 - 9.99	90
>= 3.30	275	15	>= 10.00	80

Table 5. Project demand as a function of precipitation.

KPSIM KBRA Operations

The Klamath Basin Restoration Agreement among stakeholders in the Klamath River basin with the objective of restoring and sustaining fisheries while establishing reliable water and power supplies. The KBRA includes specific hydrologic criteria that were implemented using a version of the Klamath Project Simulation Model (KPSIM). This documentation describes the operating criteria and implementation in the KBRA version of the Klamath Project Simulation Model (KPSIM).

Input data and operating rules for KBRA operation of the KPSIM are described below. Priorities for water use are:

- Deliver Project Irrigation allocation and meet National Wildlife Refuge demands
- Balance Iron Gate Flow and UKL elevation conditions – set targets and balance any shortage or surplus
- If Iron Gate Flow or UKL elevation would fall short of an environmental baseline under the above operation, first reduce Refuge delivery to no more than 24,000 acre-feet (24 TAF) April-October and then decrease Irrigation deliveries.

The specific operating criteria are:

Net Inflow to UKL is augmented by 30,000 acre-feet (30 TAF) per year distributed between March and October.

March through October Project demand from UKL and Klamath River is computed as a function of inflow forecast using following criteria:

> 330 TAF when March 1 inflow forecast is <= 287 TAF
> 385 TAF when forecast is > 569 TAF
> Linear interpolation between 330 TAF and 385 TAF for forecasts between 287 TAF and 569 TAF

November through February project demand is based on historic delivery.

March through October refuge demand from UKL and Klamath River is computed as a function of inflow forecast using the following criteria:

> 48 TAF when Mar 1 inflow forecast is <= 287 TAF
> 60 TAF when forecast is > 569 TAF
> Linear interpolation between forecasts of 287 TAF and 567 TAF.

November through February refuge demand is based on historic delivery. Demand for diversions from the Klamath River are reduced by estimated D Plant pumping.

Target flows at Iron Gate are selected based on cumulative winter or summer inflows to UKL through the previous time step, using the Inflow Exceedence Index (IEI). Values are interpolated between exceedence levels. The targets used in the model are shown in Table 6.

UKL level targets are selected based on cumulative winter or summer inflows to UKL through the previous time step, using the Inflow Exceedence Index (IEI). Values are interpolated between exceedence levels. The targets used in the model are shown in Table 7.

Probability	100%	98%	97%	90%	70%	50%	30%	10%	0%
Oct	970	970	1000	1000	1100	1300	1300	1300	1300
Nov	1000	1000	1000	1000	1100	1300	1300	1300	1300
Dec	1000	1000	1000	1000	1100	1300	1300	1300	1300
Jan	1000	1000	1000	1000	1100	2024	2223	2421	2421
Feb	1000	1000	1000	1000	1100	2353	2592	2831	2831
Mar 1-15	1100	1175	1398	1398	2085	2721	2988	3224	3224
Mar 16-31	1200	1250	1446	1446	2149	2932	3220	3458	3458
Apr 1-15	1250	1325	1494	1494	2212	3030	3335	3620	3620
Apr 16-30	1250	1325	1542	1542	2276	3015	3334	3710	3710
May 1-15	1100	1175	1240	1240	2090	2739	3306	3728	3728
May 16-31	1100	1175	1182	1182	1936	2559	3063	3675	3675
Jun 1-15	1000	1022	1109	1109	1746	2315	2782	3147	3147
Jun 16-30	1000	1022	1022	1022	1522	2008	2463	2781	2781
Jul 1-15	700	700	840	840	1070	1330	1830	2140	2140
Jul 16-31	700	700	840	840	1070	1330	1830	2140	2140
Aug	880	880	1110	1110	1260	1305	1430	1545	1545
Sep	970	970	1110	1110	1260	1305	1430	1545	1545

Table 6. **KBRA Iron Gate Flow Targets (cfs).**

Probability	100%	98%	97%	90%	70%	25%	0%	Flood
Oct	4137.80	4137.80	4138.85	4138.90	4139.20	4139.95	4140.20	4141.80
Nov	4138.80	4138.80	4139.61	4139.74	4140.02	4140.65	4141.00	4141.70
Dec	4139.80	4139.80	4140.21	4140.33	4140.59	4141.15	4141.50	4141.90
Jan	4140.80	4140.80	4140.91	4141.01	4141.23	4141.73	4142.00	4142.30
Feb	4141.60	4141.60	4141.61	4141.69	4141.87	4142.28	4142.50	4142.70
Mar 1-15	4141.70	4141.70	4142.20	4142.44	4142.52	4142.70	4142.80	4142.90
Mar 16-31	4141.80	4141.80	4142.40	4142.72	4142.76	4142.85	4142.90	4143.00
Apr 1-15	4141.30	4141.50	4142.80	4142.82	4142.86	4142.95	4143.00	4143.00
Apr 16-30	4141.20	4141.50	4142.90	4142.92	4142.96	4143.05	4143.10	4143.10
May 1-15	4141.00	4141.30	4143.00	4143.02	4143.06	4143.15	4143.20	4143.20
May 16-31	4140.70	4141.10	4141.60	4142.40	4142.70	4143.10	4143.10	4143.20
Jun 1-15	4140.40	4140.60	4141.20	4142.00	4142.40	4142.85	4142.85	4143.30
Jun 16-30	4139.80	4140.10	4140.80	4141.55	4142.10	4142.60	4142.60	4143.30
Jul 1-15	4139.60	4139.60	4140.32	4141.02	4141.57	4142.02	4142.02	4143.30
Jul 16-31	4139.10	4139.10	4139.80	4140.40	4141.00	4141.40	4141.40	4143.30
Aug	4138.10	4138.10	4139.14	4139.65	4139.80	4140.84	4140.84	4143.30
Sep	4137.50	4137.50	4138.50	4139.00	4139.05	4139.60	4140.30	4143.30

Table 7. KBRA UKL Target and Flood Control Elevations (feet).

During shortage years, irrigation and refuge supplies are redistributed to reflect KBRA language. KPSIM does adjustments on an annual basis as a post process. Monthly adjustments are done as a post process in a workbook. The KBRA process intends to develop a drought plan in which shortage criteria and minimum flows in the river are explicitly defined. However, at the time this document was complete, no such drought plan was available. The following assumptions were made in place of the drought plan:

1. Incorporation of a minimum flow of 100 cfs at Link River to provide adequate passage through the fish ladder and stream channel.

2. Incorporation of a minimum flow at Keno Dam of 300 cfs to provide adequate fish passage.

3. Minor adjustment of KBRA flow targets for use in the hydrology model for the time steps from July 1 through the end of September to improve flow conditions for adult migration and reduce the potential for fish die off. The changes that were implemented include reducing the target from 921 to 840 cfs for July 1 to 15, increasing the target from 806 to 840 cfs for July 16 to 31, increasing the target from 895 to 1110 cfs in August, and increasing the targets from 1010 to 1110 cfs in September.

4. Incorporation of minimum Ecological Base Flow levels during the periods from March 1 through June 30 and during the months of August and September. The EBF volumes would be represented by the Hardy Phase II 95% exceedence flow levels.

5. Minor adjustment to the flow targets for the month of March for water years represented by the 70% Exceedence. These adjustments include reductions in the targets from 2358 to 2085 cfs (March 1-15) and from 2343 to 2149 cfs (March 16-31). The change is consistent with rate of change for wetter water years.

6. Incorporation of minimum base flows of 800 cfs during the months of October through February. The minimum of 800 cfs is considered to be necessary to prevent adverse impacts to salmonids during the winter months.

7. Redistribution of irrigation and refuge supplies during shortage years to reflect KBRA language. KPSIM does adjustments on annual basis as a post process. Monthly adjustments are done as a post process in a workbook by the data manager which runs both models.

8. Minor adjustments were made to UKL elevation criteria in association with shortage adjustments.

UKL can be run with existing capacity or with existing capacity plus expanded storage capacity that includes Agency Lake, Barnes Ranch, Tulana Farms, Goose Bay, and Wood River areas. Evaporation and changes to consumptive use for these new storage areas are represented specifically in the model.

Flood control rules are adapted from the original Pacific Power and Light levels to reflect the same amount of available storage space given the modified storage capacity. Flood control targets are shown in Table 7.

KDRM Operations Criteria

The primary function of the KDRM is routing of flows from Keno Reservoir to the Klamath at Klamath gage. When the dams are removed, this is the KDRM's only function. When the dams exist, the KDRM also performs the following:

1. Compute power production
2. Sets target elevations for the reservoirs
3. Attempt to prevent spilling of reservoirs
4. Meet instream or target flow requirements
5. Create pulse flows when sufficient water exists

Target elevation is always set to the normal maximum elevation of the reservoir unless hydrologic conditions warrant a change. If the reservoir is spilling or a large event is occurring, the target elevation is set to the normal minimum elevations. If a spill is anticipated, additional releases are made in an attempt to prevent spilling. Table 8 lists the reservoir allocations.

Boyle Reservoir has a minimum release (bypass) requirement of 100 cfs. Total release is computed as a function of the inflow, previous storage, and target elevation and distributed to minimum release, power plant diversion, and additional spill. Power diversion is limited by power plant capacity. If power diversion and outlet works capacity limit the release, targeted release is constrained to available capacity.

Copco 1 has a minimum release (bypass) requirement of 5 cfs. Total release is computed as a function of the inflow, previous storage, and target elevation and distributed to minimum release, power plant release, and additional spill. Power plant release is limited by power plant capacity which is a function of rated capacity, head and tailwater. RiverWare iterates power computation to account for change in tailwater with change in release. If power plant release capacity and outlet works capacity limit the release, targeted release is constrained to available capacity. Copco 2 has no storage and total release is set to inflow. Power plant release is limited by power plant capacity which is a function of rated capacity, head and tailwater.

Iron Gate minimum release (bypass) requirement is determined by the upstream operating criteria and model. Total release is computed as a function of the inflow, previous storage, and target elevation and distributed to minimum release, power plant release, and additional spill. Power plant release is limited by power plant capacity which is a function of rated capacity, head and tailwater. If power plant release capacity and outlet works capacity limit the release, targeted release is constrained to available capacity. In addition, because Iron Gate's spillway is unregulated, the model releases water that has to be spilled. In those instances, total release could be higher than targeted release.

Boyle Capacity Allocations			
Pool	Elevation	Volume	Increment
Dead	3753.00	0.7	0.0
Inactive	3781.50	720.0	719.3
Normal Minimum	3788.00	1500.0	780.0
Normal Maximum	3793.00	2610.5	1110.5
Active	3793.50	2715.0	104.5

Copco Capacity Allocations			
Pool	Elevation	Volume	Increment
Dead	2588.50	29760.0	0.0
Inactive	2593.50	33895.7	4135.7
Normal Minimum	2601.00	40660.0	6764.3
Normal Maximum	2606.00	45390.0	4730.0
Active	2607.50	46867.0	1477.0

Iron Gate Capacity Allocations			
Pool	Elevation	Volume	Increment
Dead	2184.75	407.0	0.0
Inactive	2324.00	20000.0	19593.0
Normal Minimum	2324.00	55004.0	35004.0
Normal Maximum	2328.00	58794.0	3790.0
Active	2328.00	58794.0	0.0

Table 8. KDRM Reservoir Allocations.

In addition to the reservoir specific minimum releases, Boyle and Copco 1 attempt to meet any anticipated shortfall of minimum release at Iron Gate. If the anticipated unregulated flow at Iron Gate is less than the target flow, Boyle and Copco have to pass inflows up to release capacity. Note that this requirement was necessary in part because the upstream and downstream models are not coupled and have different timesteps. See the temporal disaggregation section below for additional detail.

Streamflow routing uses a variable time lag method that is a function of flow. Historic hourly flows were monitored in fall of 2009 and winter of 2010 to estimate lag times. Lag times in the reservoir reaches were approximated. Streamflow routing is an imperfect science but it is believed that the KDRM routes flows sufficiently well for the study analyzes.

The KDRM also estimates the distribution of power production by on-peak and off-peak. All Sunday releases are off-peak. Copco 1, Copco 2, and Iron Gate compute the other days as 0.6666 percent of the energy as on-peak. Boyle estimates the peak power volume and computes the on-peak energy as a function of peak power volume and total power volume.

The KDRM creates pulse flows (flushing flows) when sufficient water exists. The objective is to obtain a 4,500 cfs flow for three days every other year at Iron Gate to create habitat and reduce the disease vector. Sufficient water exists to creating a flushing release if the volume is greater than the volume of a specified hydrograph with ramping criteria that also meets the low flow requirements for the remainder of the month. Typically, the model was able to produce these hydrographs during medium years. Low flow years have insufficient volume to produce pulse flows and high flow years produce flows above the intended target regardless.

KDRM Temporal and Spatial Disaggregations

Monthly data are provided to the KDRM for a given hydrologic scenario for the same nodes that were used to develop natural flows. The KDRM requires daily data and a finer spatial resolution than the historic data nodes. The KDRM disaggregates monthly data temporally and daily data spatially to provide data at the desired spatial resolution.

Disaggregations of monthly to daily data are based on historic daily to monthly relations. Disaggregation fractions are computed using the filled historic daily data and equivalent monthly data. In addition to the disaggregation fractions, the KDRM needs rankings of the historic data by season. The rankings are computed in a workbook as a pre-process. Before a model run, synthetic monthly flows from the hydrologic traces are imported into the KDRM. At the beginning of each month, the disaggregation rules compute the seasonal volume, find the closest match to historic seasonal volume, and use the disaggregation fractions from the matched season to compute the daily flows for the month. Seasonal matching was used in lieu of monthly matching to reduce unnatural transitions between disaggregation periods.

The KDRM Keno daily flows are treated differently because those flows are regulated and because of the overlap with the KPSIM model. Both operating scenarios of the KPSIM attempt to meet target flows at Iron Gate. Because Iron Gate is downstream of the beginning of the KDRM, Keno daily flow is computed as daily Iron Gate flow without the reservoirs less Keno to Iron Gate daily gain. The target flow is subtracted from the total KPSIM flow at Iron Gate and only the excess water is disaggregated. The daily flow at Iron Gate is the sum of the disaggregated excess water and the target flow. If the KPSIM flow for the month is less than the IFR, the average daily flow is used.

Gains between Keno and Iron Gate use the pattern of disaggregated Keno flow. This was done to enable the KDRM to better meet Iron Gate IFR’s. In actual operations, additional water is released from UKL to meet Iron Gate IFR’s. However, this is not possible with the KDRM because it does not model UKL. Using Keno’s daily pattern is a virtual emulation of supplemental releases of UKL.

The temporally disaggregated data downstream of Iron Gate Dam are spatially disaggregated to a number of tributaries. The spatial distribution factors were estimated as a function of the drainage area at the tributary and the drainage area of the next downstream gage. This approach produces similarly shaped hydrographs for all the tributaries between gages but maintains mass balance with respect to the total daily gain of the reach.

KDR Model Adjustments

Both the BO and KBRA operations of the KPSIM use historic forecasts to inform decisions. Furthermore, the KBRA uses UKL inflow exceedence data and has other historic dependencies in the computation of Project and Refuge water demand. Because the KDR is using synthetic hydrologies, both versions of the KPSIM were modified to accommodate these hydrologies. Detailed documentation of these modifications is available elsewhere. The following paragraphs are an overview of the modifications.

Forecast generation for both KPSIM operations are based on an index to 1977 through 2009 historic forecasts. It was observed that historic forecasts can be classified as dry or wet. The dry/wet threshold for historic inflows is 400 TAF. 400 TAF was used for BO forecast generation. The threshold for the KBRA operation was set at 430 TAF to account for the additional UKL inflow used by the KBRA. If a dry year, the latest index of the dry forecasts is used and the dry index is incremented. If a wet year, the latest index of the wet forecasts is used and the wet index is incremented.

Winter and summer inflow exceedences for the KBRA are computed as a pre-process for every hydrology. The pre-process is included in the functionality of the data and model manager (documentation available).

Under the terms of the KBRA, annual agricultural allocation is defined based on the March 50% forecast for April-September UKL Inflows. The same imperfect forecasts used for reservoir operations are used for allocation. An index of the historic relation between full use (385 TAF) and less use was used. In addition, distribution patterns as a function of the April through September forecasted UKL inflow were developed. A random number was used as the exceedence level to determine winter A2 deliveries. Refuge demands are adjusted for summer D Plant pumping which is estimated as a function of April through September UKL forecasted inflow.

Another adjustment made for dams out operations was to add an estimate of the net gain of evaporation and riparian evapotranspiration. It was necessary to use the estimated net gain because insufficient data existed to compute evaporation for the natural flow computations. In addition, although reservoir evaporation will be removed, riparian evapotranspiration will increase. Therefore, the net gain to the river is the reduction in evaporation minus the increase in evapotranspiration. The estimated annual gains by reservoir are shown in Table 9. The KPSIM uses a monthly distribution of the gains which is disaggregated to an average daily value in the KDRM.

Reservoir	Evaporation and Riparian ET Reduction Volume (acre-feet/year)	Evaporation and Riparian ET Reduction Volume (cfs)
JC Boyle	158	0.219
Copco 1	2990	4.129
Iron Gate	2980	4.117
Total	6153	8.499

Table 9. Estimated annual net gain in evaporation and riparian evapotranspiration.

17.6. Forecasts For Synthetic Flows and Dynamic Agricultural Demand

Klamath Dam Removal Study
Forecast Generation and Demand Representation in Upstream Operation Models
David King and Nancy Parker
02/24/2011

Introduction

Models of operations under current and assumed future conditions are being used to study the potential effects of Klamath Dam Removal (KDR) on flows and associated effects in the Klamath River. These models will be run under both current hydrological conditions and conditions indicating potential future climate change. Several hydrologies were developed as discussed below. All selected hydrologies are processed through a monthly upstream WRIMS model (KPSIM) and a daily downstream RiverWare model (KDR Model – KDRM). The KPSIM is operated with a current conditions operation and a proposed future operation. The No Action alternative, also known as current conditions or Dams In, uses the Biological Opinion's (BO's) under which the Klamath Project now operates and requires use of data for forecasted inflows. The other alternative, known as future conditions or Dams Out, uses the most recent criteria for the Klamath Basin Restoration Agreement (KBRA), which also uses inflow forecast data and implements project demands in a specific sequence tied to historical hydrology. Adaptations to data handling in both scenarios were necessary to accommodate the robust input hydrology that has been developed for the KDR Study.

Historic data from water years 1977 through 2009 were used to develop three synthetic types of hydrology for dams-in and dams-out planning scenarios. The types of synthetic hydrology are:

1. Indexed sequential – A hydrograph created by repetition of historic hydrology.
2. Stochastic – Hydrographs created using statistical software reflecting statistics from historical hydrology.
3. Climate change – Hydrographs created using a watershed model forced with weather conditions consistent with several climate change scenarios.

Documentation of the development of the three hydrologies is available elsewhere.

Previous studies using the KPSIM used a combination of historic forecasts or perfect knowledge of the forecasts. The BO operation uses forecasts to inform flow requirements and delivery cuts. KBRA uses forecasts to assess water supply and define refuge and project agricultural demands. Historical forecasts were not compatible with the synthetic KDR hydrology traces. Therefore, dynamic methods were developed to compute forecasts from the synthetic hydrologies and to apply those to the BO and KBRA operations. The following sections document these methods.

The BO operation uses the March and April 50% forecasts to inform operations criteria. The KBRA model uses the March 50% forecast as one factor to inform seasonal delivery targets, and then defines monthly demands using data keyed to the historical period of record. Methods were needed to define forecast values from synthetic inflows for both scenarios, and to define demands for the KBRA scenario.

This document will describe the methodologies for addressing each of these information needs for KPSIM operations.

Synthetic Forecast Generation

Hydrologic forecasts provide reservoir and river system operators a reasonable estimate of expected inflow into Upper Klamath Lake (UKL). Previous KPSIM operations used actual historic forecasts to emulate data available to operators. The KDR modeling effort required computation of forecasts relative to the synthetic hydrologic inputs that were consistent with historic forecasts in terms of forecasting skill. The quality of historical forecasts can be demonstrated by plotting the forecasts against actual inflows and fitting a linear trend line to the points. The key question is what period of historical data set to use as the basis for the variability that characterizes these relationships. The full available period of record is water years 1961-2009. However, because water year 1977-2009 data are being used as the basis for KDR hydrologies and because it is believed that forecasting skill has improved, the data was analyzed for three periods as shown on Figure 1 for the historic Natural Resources Conservation Service (NRCS) March 50% forecasts.

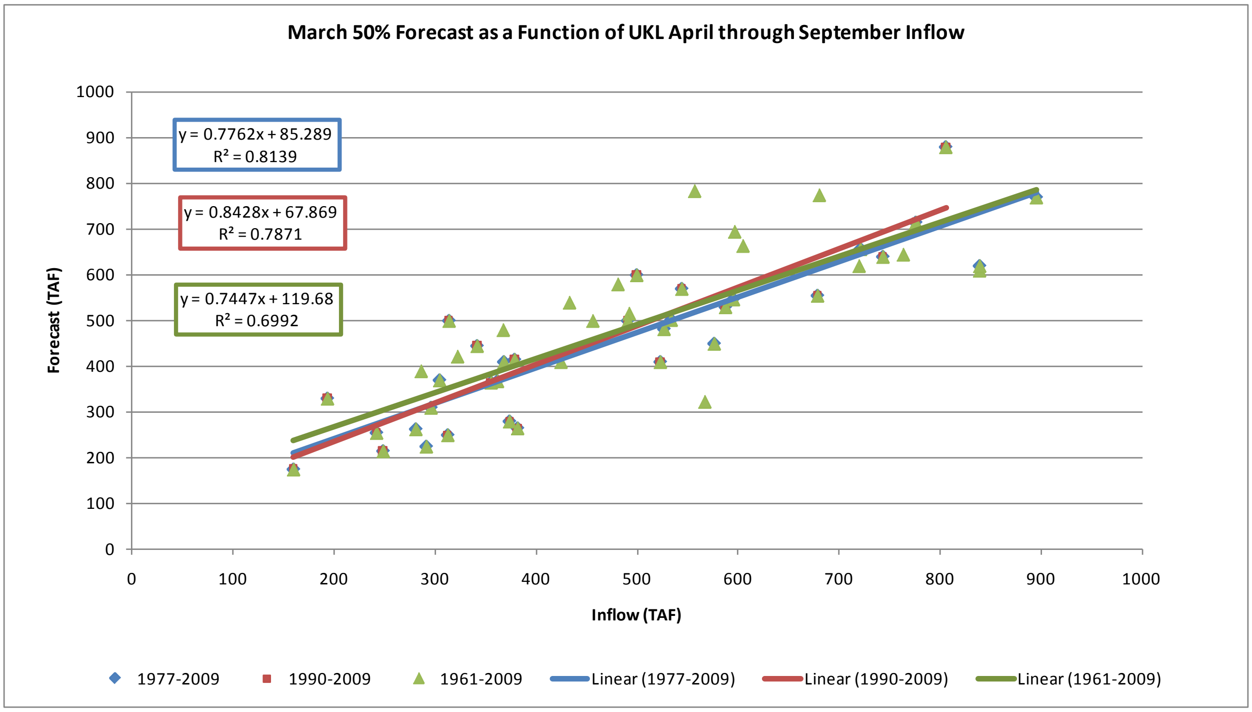


Figure 1. April through September Forecasts vs Actual Upper Klamath Lake Inflows.

The 1977-2009 data uniformly shows improved inflow/forecast relationships over those for 1961-2009 for all three forecasts, with all of the r-squared values improving significantly. Similar improvement however can not be seen by moving to the more recent 20-year period. For most cases, the r-squared values for the regression relationships are slightly worse for the 20-year period than for the 33-year period. Based on these observations, it was decided that methodology for developing forecasts from inflow values would be built upon data from the 1977-2009 period of record.

The regression equations seen on Figure 1 could be used to approximate forecast values from inflows, but if the resulting errors to actual historical errors are compared, they would have a much smaller range with fewer extreme values. It was desired to capture the nature of actual errors that have occurred and apply this knowledge to the derivation of synthetic forecast values from synthetic hydrologies. An examination of forecast errors was made with the goal of identifying if patterns exist in the errors that track with the actual inflows. If positive errors are defined as inflows greater than the forecast and negative errors as inflows that fall short of the forecast, a vague trend can be seen that shows more negative errors in drier years and more and larger positive errors in wetter years as shown on Figure 2. However, no apparent statistically significant characterization of this trend exists.

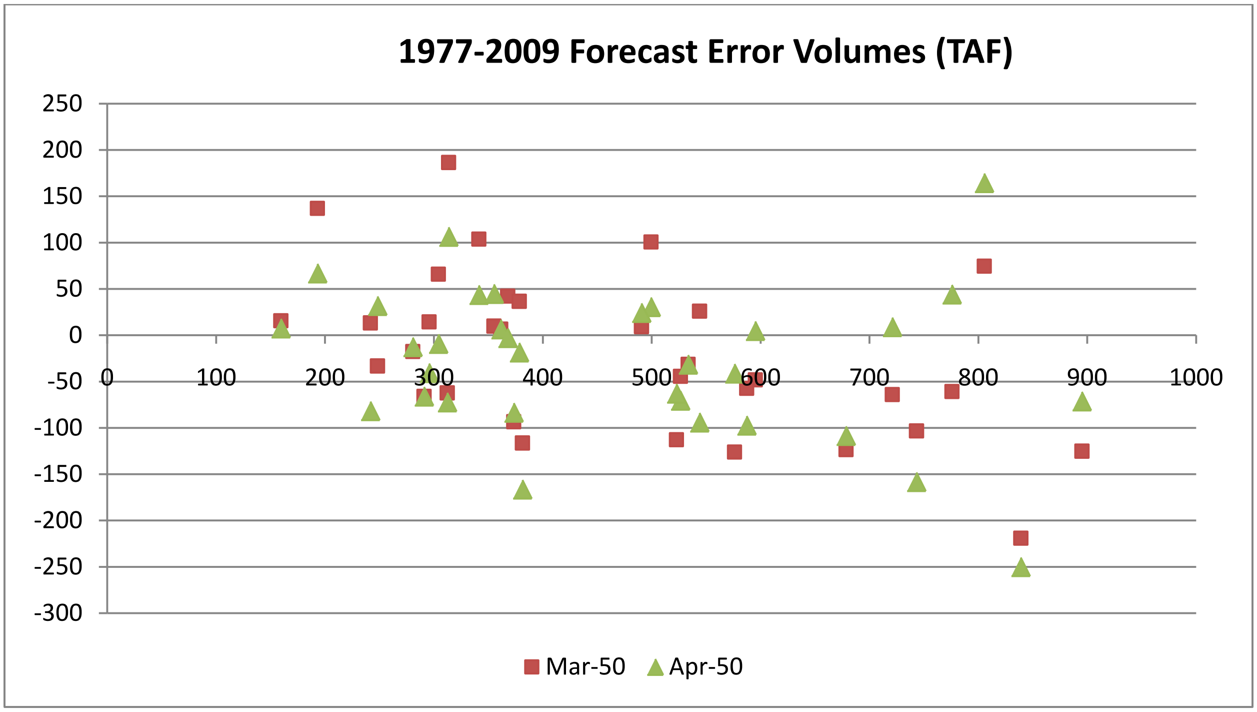


Figure 2. Forecast Error Relative to Actual April through September UKL Inflow.

It is clear that the forecast errors in wetter years have a larger range and have a greater chance of being positive (underestimating inflow) than in drier years. For the 33-year period hydrologic record, dividing the years into categories with April through September inflows above or below 400 thousand acre-feet (TAF) yielded two sets of 17 and 16 years respectively. The differences in forecast error volume in the two groups can be seen in Table 1. The drier year group has lower average errors which is a function of having both under forecasting and over forecasting cases. The range of errors is lower in the drier group for every type of forecast.

	Mar-50	**Apr-50**
Dry Average	14	-14
Dry Maximum	187	107
Dry Minimum	-116	-166
Wet Average	-57	-44
Wet Maximum	101	165
Wet Minimum	-219	-250

Table 1. Summary of historic forecast error volumes above and below 400 TAF.

Each set of years was ranked in chronological order so that the associated forecast errors for each year group represent the range of potential errors that would be encountered for years that were hydrologically similar. These forecast error volumes were put into an indexed table. At the beginning of any model run, indices to both the drier and wetter error tables are set to one. As the model run proceeds, each year is assessed to determine whether the total April through September inflow is above or below 400 TAF. The forecast error volume is selected from either the wetter table or the drier table, and an increment is made to the appropriate index. The forecast error is applied to the actual inflow to derive the forecast value and the model uses this value as the basis for forecast-dependent operations. KBRA operations include an additional 30 TAF per year of inflow to UKL. The indexing process was adjusted for the increased inflows by using a 430 TAF as the dry/wet threshold for KBRA operations.

Test results using this approach show forecasts error volumes and percents that are consist with historic as shown on Figure 3. This approach was used in KPSIM to include forecast error in reservoir operation decisions using all hydrologies.

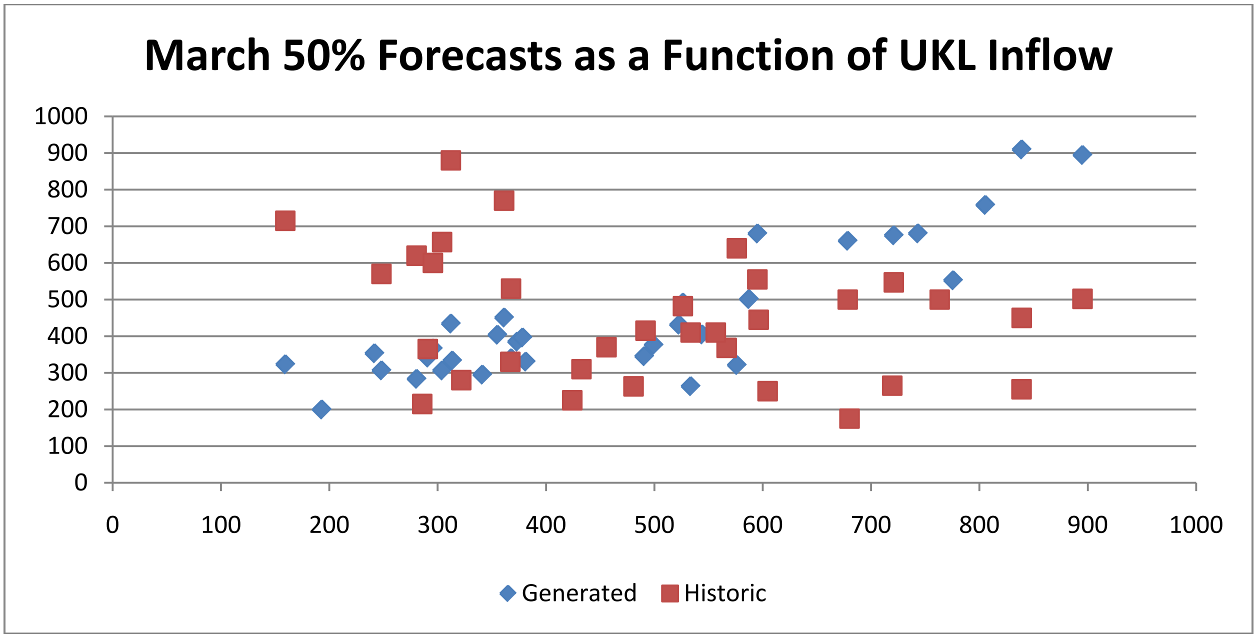


Figure 3. Generated to Historic Forecast Comparison.

Annual KBRA Agriculture Allocation

Under the terms of the Klamath Basin Restoration Agreement, an annual allocation of March-October water supply to agricultural purposes is defined based on the March 1st 50% forecast for April-September UKL Inflows as shown on Figure 4. For forecasts of 287 TAF or less, the allocation is 330 TAF. For forecasts of 567 TAF or greater, the allocation is 385 TAF. And for forecasts between 287 and 567 TAF, the allocation is interpolated between 330 and 365 TAF.

To support KBRA modeling done for the dam removal study, a time series of input demand data (target deliveries) was pre-processed based on the historical sequence of hydrology as detailed in the following steps. The annual allocation is determined from the historical inflow forecast and the allocation is distributed over the March-October period by following the observed historical delivery pattern for that year. If actual historical delivery is smaller than the computed distributed allocation for a particular

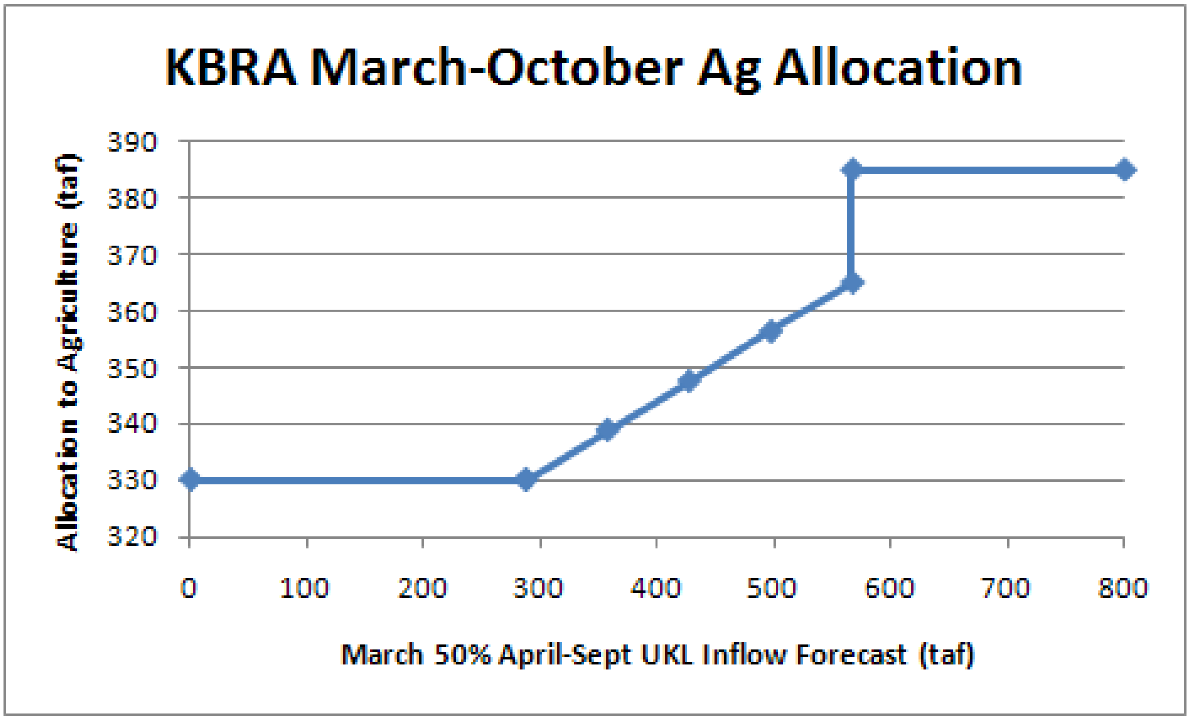


Figure 4. KBRA Agriculture Allocation.

timestep, the smaller value is used as the demand value by the model. This approach is intended to reflect observed historical project operations in which wetter year total March-October diversions often did not reach 385 TAF.

Because model runs for the KDR study do not use the historical sequence of hydrology, a new, dynamic approach was developed to accommodate the intent of this implementation. An examination of project agriculture deliveries from 1981-2009, not including 2001-2005 (when operations were impacted by the shutoff and water bank program), shows that all years in which allocations would have been 365 TAF or lower had water deliveries higher than the allocation, indicating that the allocation would be fully utilized under a KBRA scenario. There were ten years when the allocation would have been 385 TAF based on the March 1st inflow forecast. Of these ten years, water delivery in three years was very close to 385 TAF and seven years had deliveries lower than 385. Insufficient supply ranged from 46 to 81 TAF.

To avoid using perfect foresight in the modeling, lacking correlations between unused allocation and forecast or inflow, and without an agent-based model upon which to predicate potential farm management decisions under the KBRA, a method was developed that uses an indexed table of allocation reductions, similar to the method previously described for forecast errors. The goal was to maintain the same ratio of number of years with full use of a 385 TAF allocation to number of years with reduced use. The set of years where historical forecasts would have resulted in allocations of 385 TAF were put in year order, and the associated sequence of presumed allocation reductions (3 zeros and 7 values between 46 and 81) became the indexed values by which successive allocations of 385 in any model run would be reduced.

Allocation Distribution

The next aspect of the KBRA KPSIM implementation that needed to be modified for the KDR was the assumption that March through October demands, based on the allocation, would follow historical delivery distribution patterns. Since the input hydrology for KDR model runs are not guaranteed to follow the same historical sequence, a more general approach was developed to determine allocation distribution over the March through October delivery season. Again examining the 1981-2009 period (without 2001-2005), average distributions were computed for three categories based on April through September UKL inflow - 1.) < 500 TAF; 2.) 500-700 TAF; 3.) >700 TAF. This approach is believed to be compatible with the intentions of the original KBRA model in that is preserves some sense of distribution variance with general water supply conditions. Separate relationships were derived for Area A1 and Area A2 demands as shown on Figure 5.

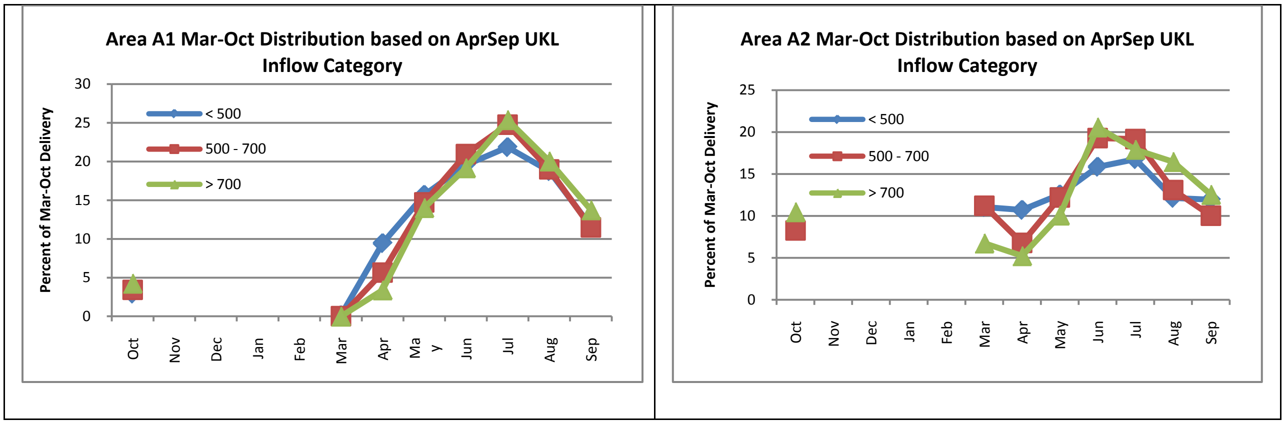


Figure 5. March through October Distributions of KBRA Agriculture Allocation.

Fall and Winter Area A2 Demands

Another aspect of KBRA KPSIM demands that had to be modified was the Area A2 demand in November through February. Historical deliveries to North and Ady canals in this fall and winter are difficult to characterize. No solid correlation can be found between precipitation or inflow data and diversions on either monthly or seasonal basis. It can be noted that in recent years (1995-2009), diversions have not shown the higher values that were seen in some earlier years. Total November-February diversions to the Ady and North Canals have varied between 20.2 and 43.5 TAF. If historic diversions are ranked as shown on Figure 6, a reasonably linear distribution is observable. It was suggested that a random number between zero and one be used in the equation shown in the plot to generate a seasonal demand which could be distributed on the average historical monthly pattern of Nov-.23, Dec-.26, Jan-.33, Feb-.18, based on 1995-2009 data.

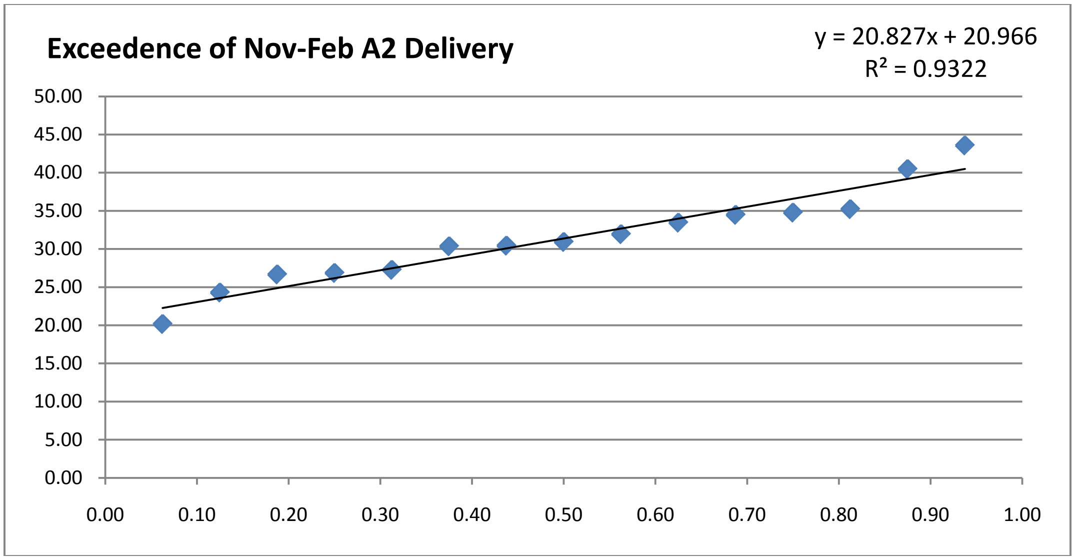


Figure 6. Ranked Fall and Winter Area A2 Historical Deliveries.

Refuge Demands

Refuge demands for the KBRA scenario were developed by the Fish and Wildlife Service (FWS). These are based on management assumptions and a set of historic input data elements, including repeating monthly values for overall demand and return flow operations and input time series data for UKL inflow and Tule Lake precipitation. For the KBRA scenario, the constant total annual refuge demand is 95.392 TAF, distributed by a 17-timestep pattern. Several additional considerations can affect the final demand for surface water delivery from the Klamath River which is discussed below.

April through October refuge demand may be reduced as a function of the March 1 forecast of April through September inflow to UKL. For forecasts of 263 TAF or less, demand is reduced by 20%. For forecasts over 580 TAF, no reduction occurs. For forecasts between 263 and 580 TAF, the reduction is linearly interpolated to be a value between 0% and 20% based on the value of the forecast.

D Plant pumping of water from Tule Lake to the Lower Klamath Lake area can also reduce the amount of water needed from the Klamath River, and there is specific logic for both winter and summer D Plant pumping. Winter is Nov-Mar, and it is assumed that D Plant pumping will be the total volume of the precipitation on the Tule Lake Sump area that happens in that period, distributed evenly through the 5 months. In order to apply this method to alternative hydrologies, it is necessary to define precipitation on the Tule Lake Sump. The Tule Lake area assumed for this study is 13,000 acres. Total winter Tule Lake precipitation for the historical record was computed by dividing the FWS values for the annual volumes by 13,000 TAF. Figure 7 shows a regression relationship between historical Klamath Falls precipitation for the November-March period and the derived Tule Lake Sump precipitation values. With an r-squared of .876, it was determined that a reasonable estimate of Tule Lake Sump precipitation could be defined as a function of model inputs for UKL precipitation.

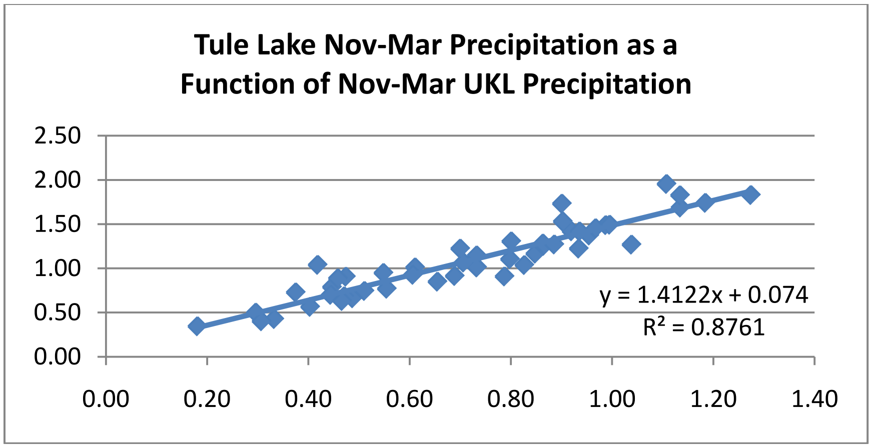


Figure 7. Tule Lake Precipitation to UKL Precipitation Relation.

Summer is April through October. The total volume of D Plant pumping in this period is a number between 0 and 20 TAF, distributed evenly by the exceedence value of the April through September UKL inflow. To adhere to this approach would require pre-processing all of the refuge demands. To use a dynamic approach, it is necessary to derive total pumping as a function of the inflow or inflow forecast. Plotting the FWS values for April through October D Plant Pumping against April through September UKL Inflow yields a linear relationship with an r-squared of .978, as shown on Figure 8. This approach to defining total April through October D Plant pumping can be used dynamically in the model. The monthly distribution of this total follows a constant pattern.

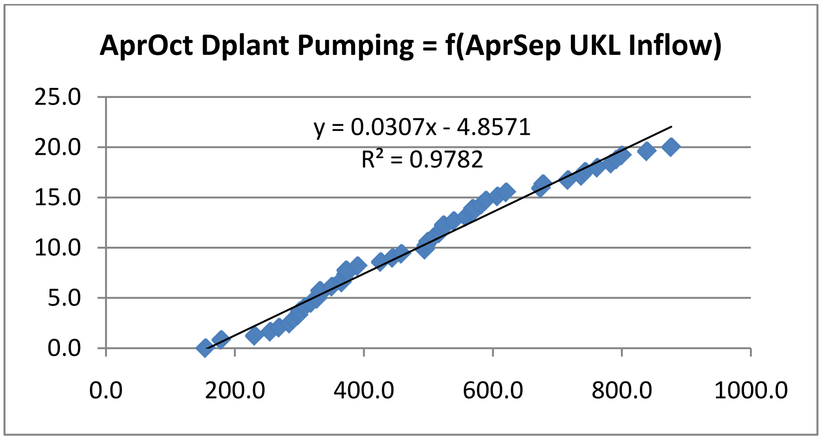


Figure 8. Determination of Summer D Plant Pumping.

Given data inputs developed as described above, actual demands for surface diversions of Klamath River water to the Refuge are determined as follows. Winter demand is calculated in November through March as the timestep distributed annual demand, potentially reduced by the amount of water coming from the D Plant. Summer demand is calculated in April through October, also as the timestep distributed annual demand, but potentially reduced by both the percentage reduction factor discussed above and the D Plant contribution.

Klamath Straits Drain (KSD) flows from the Refuge to the Klamath River were also determined by the FWS analysis. They are a repeating annual time series totaling 21.107 TAF. In April through October, the KSD return is subject to the same level of reduction that is applied to the refuge demand. Also, in any time step when D Plant pumping provides more water than the refuge demand needs, over-supply is added to the KSD return.

All repeating time-series inputs have been retained in lookup tables as model input, and the regression relationships described above were coded in the KDR versions of the KBRA KPSIM model to create a fully dynamic representation of the agricultural and refuge demands. The effects of modifications to the KBRA version of the KPSIM for KDR operations are shown on Figure 9 and in Table 2.

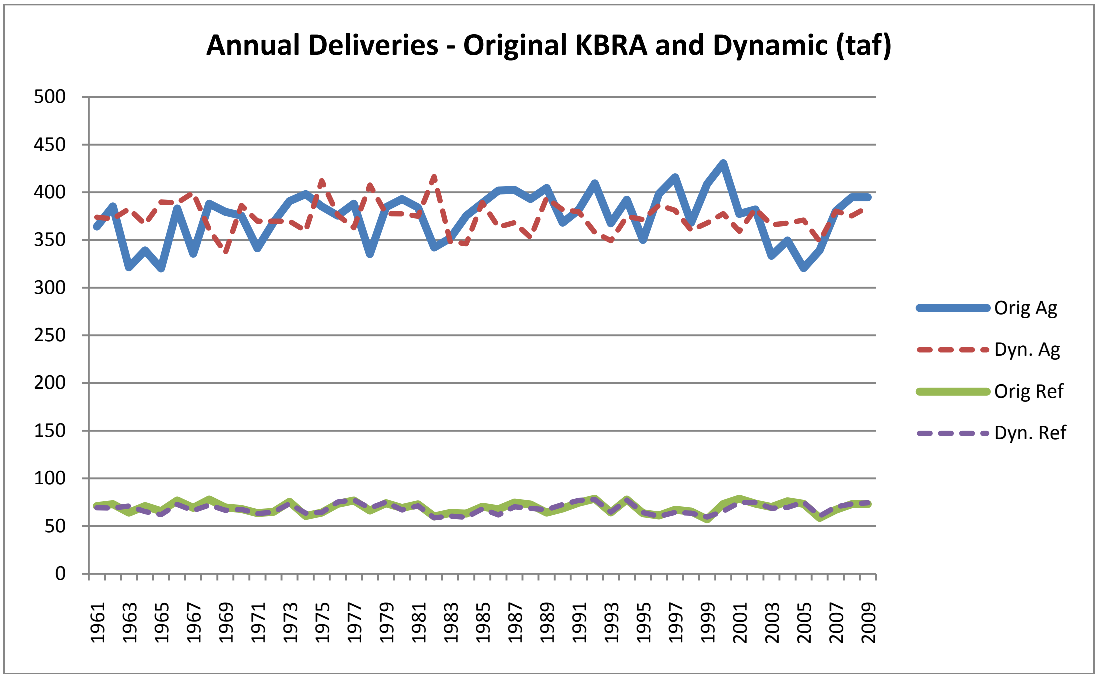
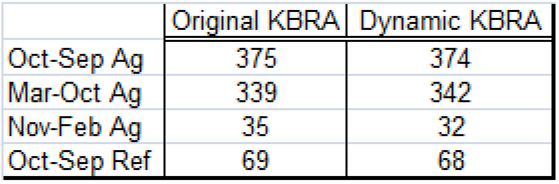


Figure 9. Comparison of Original and Dynamic KBRA Demand Implementations.



	Original KBRA	Dynamic KBRA
Oct-Sep Ag	375	374
Mar-Oct Ag	339	342
Nov-Feb Ag	35	32
Oct-Sep Ref	69	68

Table 2. Comparison of Original and Dynamic KBRA Delivery Totals in TAF.

18. Appendix F. Exceedance Flows for No Action and Dam Removal Alternatives Based Upon Index Sequential Hydrology

Table 18-1. Exceedance Flows for Dam Removal Alternative.

Keno – Dam Removal												
Month	**0.01**	**0.05**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**0.95**	**0.99**
1	8713	5376	3295	2152	1859	1711	1537	1060	650	568	475	362	283
2	8486	5240	4361	2946	2336	1991	1606	1154	694	517	428	377	284
3	8572	6538	5375	3896	2931	2521	2214	2030	1879	1446	939	782	718
4	7174	5719	4919	3659	2996	2546	2181	1891	1660	1418	1005	870	756
5	4605	3541	3017	2507	2233	1956	1745	1510	1298	1005	811	681	497
6	2448	2366	2264	2072	1900	1717	1372	1238	1035	860	731	658	571
7	1825	1660	1549	1338	1095	965	763	673	576	466	412	363	274
8	1187	1042	927	865	805	772	740	707	665	621	566	537	479
9	1214	1161	1094	976	908	873	838	801	747	689	612	571	539
10	1053	998	928	876	823	779	738	697	661	626	533	448	284
11	3299	1195	1040	870	794	740	690	651	613	547	448	410	362
12	6599	3386	1915	1227	927	846	766	691	635	578	448	410	284
Iron Gate – Dam Removal													
Month	**0.01**	**0.05**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**0.95**	**0.99**
1	11284	6837	4317	2762	2387	2213	1994	1642	1215	1052	981	946	856
2	10465	6739	5594	3720	3061	2635	2242	1847	1197	1036	948	886	823
3	11036	8133	6509	4765	3778	3214	2949	2698	2448	2007	1479	1264	1102
4	8920	7197	6043	4652	3829	3360	2952	2535	2281	2012	1385	1306	1242
5	5813	4569	3962	3362	2915	2534	2315	2120	1832	1487	1209	1138	1082
6	3234	3046	2826	2602	2394	2209	1857	1649	1461	1273	1049	989	940
7	2174	2068	1968	1764	1475	1291	1153	1040	967	895	824	772	716
8	1604	1464	1370	1251	1194	1153	1112	1070	1023	976	928	867	818
9	1606	1536	1448	1364	1303	1243	1196	1153	1111	1068	998	963	935
10	1407	1382	1350	1286	1223	1177	1130	1083	1033	981	930	834	731
11	3799	1408	1371	1297	1225	1177	1129	1081	1017	947	839	773	716
12	9726	5026	2979	1630	1382	1324	1266	1184	1060	1005	951	878	730

Seiad – Dam Removal

Month	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
1	24683	17276	11811	6796	4982	4262	3553	2950	2543	2105	1807	1648	1451
2	18876	13603	9972	8053	6503	5392	4477	3946	3153	2412	1778	1566	1375
3	19398	14669	12042	8977	7094	5968	5284	4675	4084	3523	2462	2162	1743
4	14692	11460	10095	8269	7091	6035	5122	4647	4196	3392	2556	2127	1714
5	12020	9768	8636	7173	5799	5016	4528	4148	3841	3174	2199	1909	1652
6	8956	7176	5992	4830	4108	3586	3161	2843	2422	2042	1598	1353	1134
7	4298	3455	3034	2522	2060	1755	1562	1386	1260	1135	993	898	761
8	2332	1854	1746	1503	1382	1336	1291	1246	1186	1116	1024	951	841
9	2094	1840	1757	1609	1533	1457	1387	1324	1261	1186	1096	1031	949
10	3195	1961	1821	1692	1595	1535	1475	1414	1330	1245	1126	1056	951
11	7641	4494	3130	2436	2158	1874	1752	1635	1473	1349	1249	1167	1082
12	18664	11002	7635	4796	3491	2652	2311	2106	1939	1739	1520	1414	1169

Orleans – Dam Removal

Month	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
1	71076	40971	30339	20425	15335	11909	9566	7579	6342	5316	4358	3035	2217
2	51278	34715	26214	19522	16577	14385	12105	10075	8511	6913	4930	3959	2119
3	46223	32295	26516	20340	16838	14456	12688	11138	9805	8256	6327	5088	3233
4	28716	23982	21681	18349	15291	13606	12215	10798	9328	7891	6305	4715	3577
5	25073	21218	19209	16673	14254	11848	10206	9206	8134	6623	4799	3997	3276
6	20282	15104	12626	9710	8300	7169	6181	5360	4620	3767	2808	2283	1778
7	8296	6077	5156	4111	3509	3039	2701	2440	2206	1938	1601	1384	1216
8	3648	2835	2671	2395	2203	2073	1968	1863	1745	1626	1400	1261	1110
9	3353	2512	2389	2218	2091	1994	1898	1805	1714	1623	1416	1263	1109
10	8215	3554	3050	2618	2367	2182	2058	1949	1833	1697	1493	1291	1105
11	26304	15507	10672	6675	4885	3898	3269	2739	2393	2174	1979	1884	1478
12	53820	33047	23740	14446	10853	8509	7018	5878	4859	3894	2946	2516	2044

Klamath – Dam Removal

Month	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
1	144969	90661	70144	49767	37517	28858	23875	19034	14383	10811	8112	6589	3617
2	107147	78958	62557	43383	35619	31167	27183	23935	20744	16996	12053	9097	3628
3	101402	75480	59282	44009	36213	30950	26764	23933	20754	18088	14993	11582	7654
4	68772	51697	44196	35846	30030	25562	21981	19624	17589	15516	12580	9858	6106
5	44819	36956	33791	29796	26256	20369	17728	15903	13936	11706	9866	8578	5915
6	38074	25636	20425	16238	13943	12127	10467	9083	7762	6492	5296	4532	3437
7	14685	9949	8538	6913	5813	5094	4550	4117	3748	3325	2938	2609	1881
8	6714	4938	4399	3898	3602	3378	3170	2977	2788	2607	2374	2175	1688
9	6036	4830	4120	3663	3415	3181	2965	2780	2638	2497	2290	2178	1941
10	17879	7453	5818	4724	4160	3789	3522	3266	2992	2723	2457	2258	1948
11	72926	41734	24489	14314	10488	7995	6464	5383	4611	3922	3360	3068	2694
12	124313	74833	54421	34345	26321	20895	17079	13818	11052	8828	6240	5063	3260

UKL Elevations - Dam Removal

Month	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
1	4142.3	4142.2	4142.2	4142.0	4141.9	4141.7	4141.4	4141.1	4141.0	4140.7	4140.4	4140.2	4139.5
2	4142.7	4142.7	4142.6	4142.5	4142.4	4142.3	4142.1	4141.8	4141.7	4141.4	4141.1	4140.9	4140.6
3	4143.0	4143.0	4142.9	4142.9	4142.8	4142.8	4142.7	4142.6	4142.4	4142.2	4141.9	4141.6	4141.3
4	4143.2	4143.1	4143.1	4143.1	4143.0	4143.0	4143.0	4142.8	4142.7	4142.6	4142.2	4141.9	4141.7
5	4143.2	4143.2	4143.2	4143.1	4143.1	4143.0	4142.9	4142.7	4142.5	4142.3	4142.0	4141.7	4141.3
6	4143.2	4143.1	4143.0	4142.8	4142.6	4142.4	4142.2	4142.0	4141.9	4141.7	4141.4	4141.1	4140.5
7	4142.7	4142.3	4142.0	4141.7	4141.5	4141.3	4141.1	4141.0	4140.8	4140.6	4140.3	4140.1	4139.4
8	4141.6	4141.1	4140.8	4140.6	4140.4	4140.2	4140.1	4140.0	4139.8	4139.6	4139.4	4139.2	4138.5
9	4140.8	4140.4	4140.1	4139.8	4139.6	4139.5	4139.4	4139.3	4139.1	4139.0	4138.8	4138.5	4137.7
10	4140.9	4140.3	4140.0	4139.6	4139.5	4139.4	4139.2	4139.1	4139.0	4138.9	4138.7	4138.2	4137.5
11	4141.6	4141.2	4140.7	4140.3	4140.1	4139.9	4139.7	4139.5	4139.4	4139.2	4139.0	4138.7	4137.8
12	4141.9	4141.8	4141.7	4141.4	4141.0	4140.8	4140.6	4140.4	4140.1	4139.9	4139.7	4139.4	4138.5

Table 18-2. Exceedance Flows for No Action Alternative.

Keno – No Action													
Month	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
1	7304	3746	3167	2222	1980	1727	1273	966	859	757	649	586	430
2	8128	4846	4014	3248	2903	2418	2113	1025	906	826	602	563	532
3	9752	6252	4895	3760	3138	2793	2374	2087	1544	1163	856	765	691
4	7381	5419	4638	3460	2960	2508	1928	1138	1023	950	816	723	549
5	5091	3252	3074	2757	2513	2282	1961	1370	1235	1037	868	784	432
6	2808	2682	2524	2243	1377	1243	1167	1099	1026	947	757	688	626
7	1146	995	902	800	770	740	711	676	641	601	543	497	432
8	913	851	801	771	741	711	687	666	645	624	585	551	376
9	1032	922	891	829	780	739	700	680	659	639	619	592	497
10	1187	1065	1054	1033	1011	990	968	947	922	874	827	783	571
11	2126	2045	1943	1602	1260	1036	988	941	896	852	808	721	571
12	4764	3209	2987	2403	2105	1475	1019	928	878	828	742	672	497
Iron Gate – No Action													
Month	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
1	9401	4926	4027	3035	2663	2428	1940	1409	1348	1287	1222	1145	1083
2	10826	6138	5224	4058	3572	3148	2645	1626	1405	1342	1279	1247	1150
3	11185	7494	5866	4807	3971	3500	3125	2702	2098	1663	1449	1342	1250
4	9243	6758	5684	4409	3792	3250	2598	1737	1566	1478	1370	1283	1158
5	6126	4494	4098	3579	3150	2891	2543	1970	1751	1529	1316	1222	1098
6	3603	3209	3071	2769	1864	1720	1596	1514	1431	1310	1183	1124	1076
7	2477	1401	1321	1210	1168	1126	1084	1038	991	943	879	843	814
8	1224	1204	1179	1129	1080	1051	1029	1007	985	963	941	930	837
9	1390	1306	1221	1172	1123	1073	1046	1021	997	972	948	936	871
10	1574	1410	1399	1379	1358	1337	1316	1295	1274	1254	1233	1175	1089
11	2650	2395	2273	1850	1629	1402	1373	1344	1315	1286	1257	1242	1230
12	6876	3711	3498	3068	2537	1947	1589	1392	1351	1310	1269	1248	1232

Seiad – No Action

Month	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
1	23176	16706	10462	6915	5245	4504	3853	3089	2653	2325	1954	1775	1654
2	18690	12460	9866	8150	6901	5659	4870	4135	3444	2849	2202	1885	1581
3	20530	13590	11207	9071	7312	6249	5505	4891	4068	3108	2585	2291	1816
4	15125	11243	9808	8119	6993	5876	4940	4006	3454	2882	2455	2190	1752
5	11801	9784	8561	7196	6038	5200	4637	4168	3698	3036	2377	2003	1705
6	9429	7499	6152	4873	3971	3362	2926	2616	2326	2047	1714	1468	1251
7	4286	2804	2430	1971	1679	1541	1435	1360	1294	1228	1107	1032	949
8	1903	1593	1522	1400	1344	1288	1232	1189	1147	1105	1053	990	941
9	1818	1604	1552	1448	1374	1317	1260	1210	1171	1131	1092	1072	964
10	3195	2015	1855	1801	1747	1692	1638	1588	1540	1492	1444	1420	1263
11	6548	4603	3726	2936	2556	2352	2195	1995	1833	1753	1673	1633	1467
12	14990	9842	7596	5562	4264	3690	3078	2607	2309	2084	1881	1754	1650

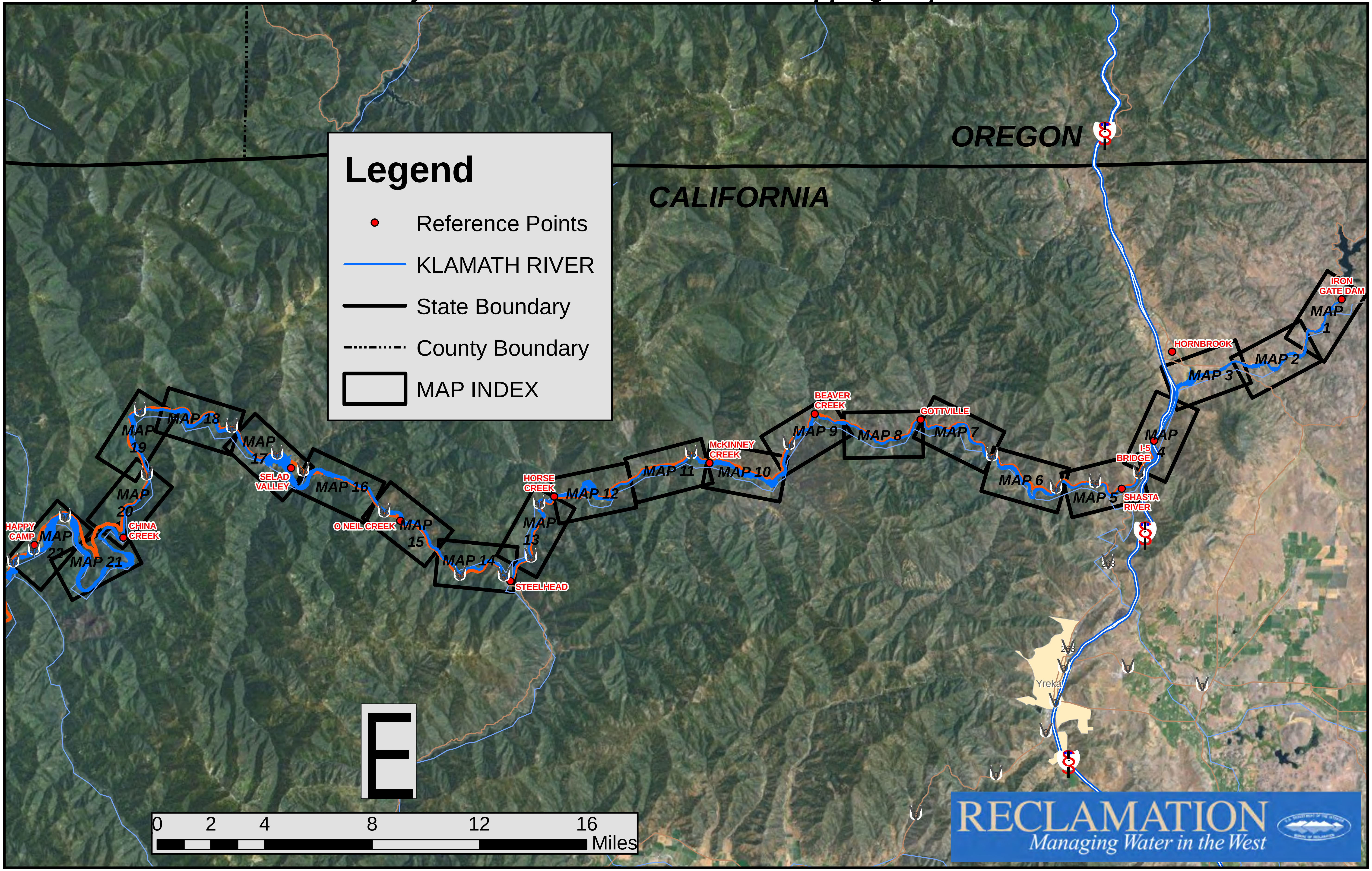
Orleans – No Action

Month	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
1	70051	40008	29698	20166	15315	12149	9788	8021	6751	5588	4503	3266	2311
2	51458	33602	26096	19624	16846	14682	12537	10627	8918	7175	5387	4402	2368
3	46589	32076	25607	20575	16948	14685	12847	11246	9902	8219	6320	5149	3322
4	28688	23710	21460	18019	15357	13608	12131	10499	8902	7308	5977	4670	3565
5	24973	21078	19235	16811	14230	11889	10401	9285	8117	6720	4860	4169	3363
6	21235	15718	12662	9610	8229	7075	6024	5230	4525	3737	2917	2405	1819
7	8140	5534	4623	3654	3165	2808	2569	2369	2197	1991	1718	1531	1313
8	3133	2611	2416	2246	2099	1986	1873	1794	1716	1639	1432	1306	1152
9	3111	2415	2166	2041	1930	1836	1764	1693	1620	1512	1396	1273	1118
10	8353	3678	3174	2728	2466	2345	2224	2113	2018	1922	1760	1632	1442
11	26499	15931	10916	7132	5361	4371	3718	3220	2819	2542	2298	2182	1843
12	56365	31178	23391	14856	11435	9289	7771	6487	5458	4487	3356	2925	2549

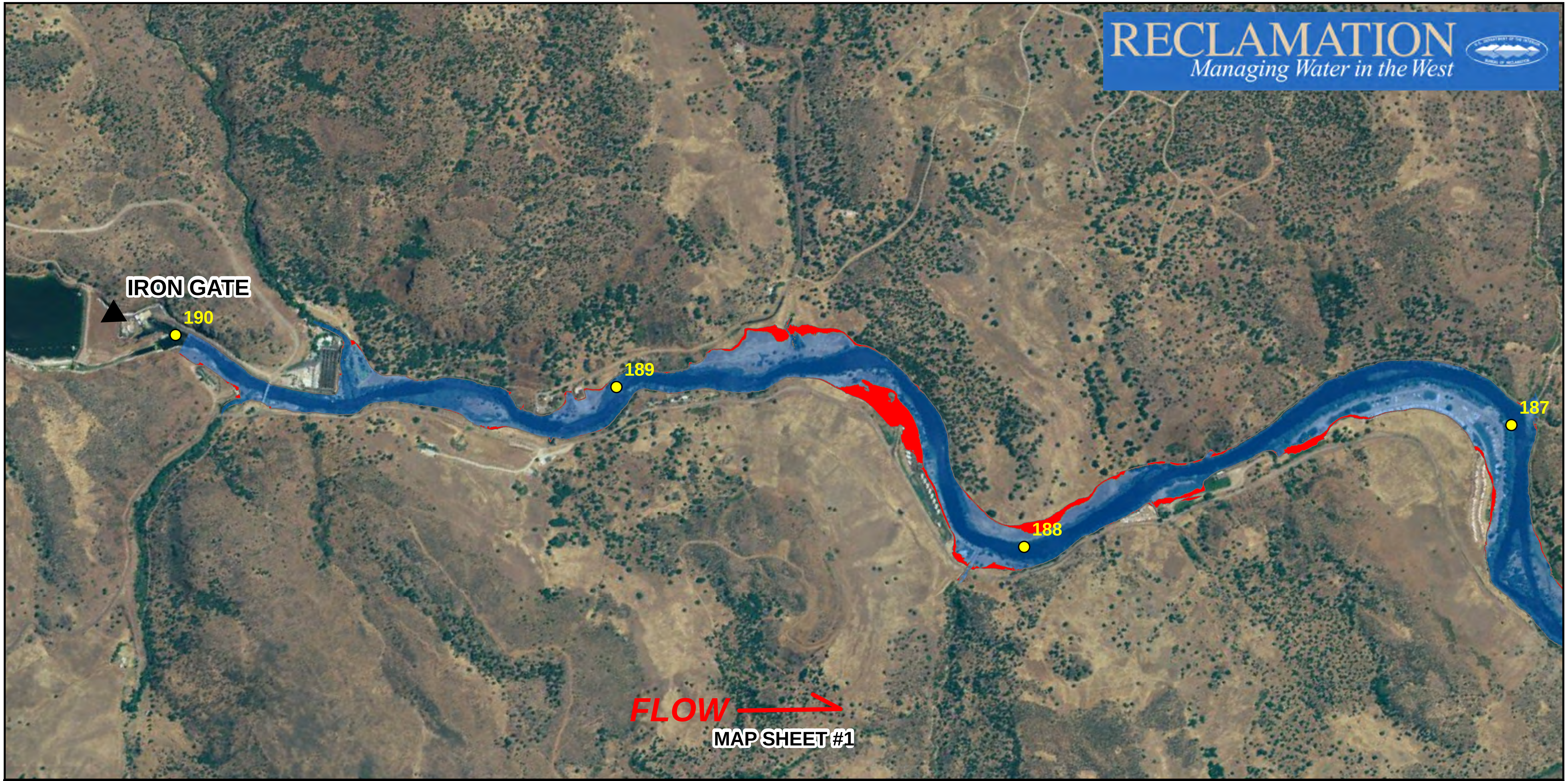
Klamath – No Action												
Month	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
1	140898	89268	69023	49722	37711	28968	23923	19477	14680	11328	8310	6630	3749
2	105374	78331	61893	43738	36032	31361	27432	24307	21028	17412	12336	9360	3906
3	101402	74833	58516	43959	36463	30906	26712	24002	20927	18172	14938	11489	7654
4	69495	51098	43721	35405	29921	25296	21943	19475	17096	15105	12070	9911	6153
5	45026	36564	33656	29845	26240	20315	17623	15937	13960	11818	10132	8744	6022
6	38576	25832	20592	16215	13826	11992	10303	8932	7645	6439	5383	4676	3505
7	14352	9788	8080	6492	5521	4857	4395	4037	3704	3387	3018	2767	1949
8	6338	4802	4263	3755	3511	3268	3098	2929	2766	2611	2425	2175	1691
9	5685	4480	3915	3528	3255	3034	2823	2688	2552	2404	2235	2151	1922
10	17879	7552	6048	4865	4283	3943	3655	3431	3201	2950	2660	2500	2170
11	71733	41734	24951	14768	11064	8383	6872	5765	5000	4348	3755	3414	2937
12	124313	74632	53785	34976	26520	21348	17504	14584	11781	9234	6829	5633	3819
UKL – No Action													
Month	0.01	0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95	0.99
1	4143.4	4143.1	4142.6	4142.0	4141.6	4141.2	4140.9	4140.7	4140.5	4139.9	4139.3	4138.8	4138.5
2	4143.4	4143.4	4143.3	4142.7	4142.2	4141.8	4141.6	4141.3	4141.1	4140.7	4140.0	4139.4	4139.0
3	4143.4	4143.4	4143.3	4143.3	4142.9	4142.3	4142.1	4141.9	4141.7	4141.4	4140.8	4140.1	4139.3
4	4143.4	4143.4	4143.3	4143.3	4143.2	4142.8	4142.5	4142.4	4142.3	4142.0	4141.5	4140.5	4139.5
5	4143.4	4143.4	4143.3	4143.2	4143.0	4142.7	4142.5	4142.3	4142.2	4142.0	4141.6	4141.0	4139.3
6	4143.3	4143.1	4142.9	4142.6	4142.4	4142.1	4141.9	4141.7	4141.4	4141.1	4140.8	4140.6	4138.8
7	4142.7	4142.3	4142.1	4141.7	4141.4	4141.1	4140.8	4140.5	4140.3	4140.0	4139.7	4139.5	4138.5
8	4141.9	4141.6	4141.2	4140.7	4140.3	4140.0	4139.7	4139.4	4139.2	4139.0	4138.7	4138.5	4138.1
9	4141.5	4141.1	4140.8	4139.9	4139.7	4139.4	4139.0	4138.6	4138.4	4138.3	4138.1	4138.0	4137.7
10	4141.7	4141.3	4141.0	4139.9	4139.7	4139.5	4139.0	4138.6	4138.3	4138.0	4137.9	4137.8	4137.5
11	4142.6	4141.9	4141.3	4140.4	4140.2	4139.9	4139.6	4139.1	4138.8	4138.4	4138.0	4137.9	4137.6
12	4143.3	4142.3	4141.9	4141.1	4140.7	4140.5	4140.3	4140.1	4139.6	4139.1	4138.5	4138.2	4137.9

19. Appendix G. Mapping of 100-year Flood Plain under No Action and Dam Removal Alternatives

Secretary's Determination on Klamath River Dam Removal and Basin Restoration
100-year Flood Draft Innundation Mapping Map Index



RECLAMATION
Managing Water in the West



Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood Inundation Mapping

● USGS RIVER MILE

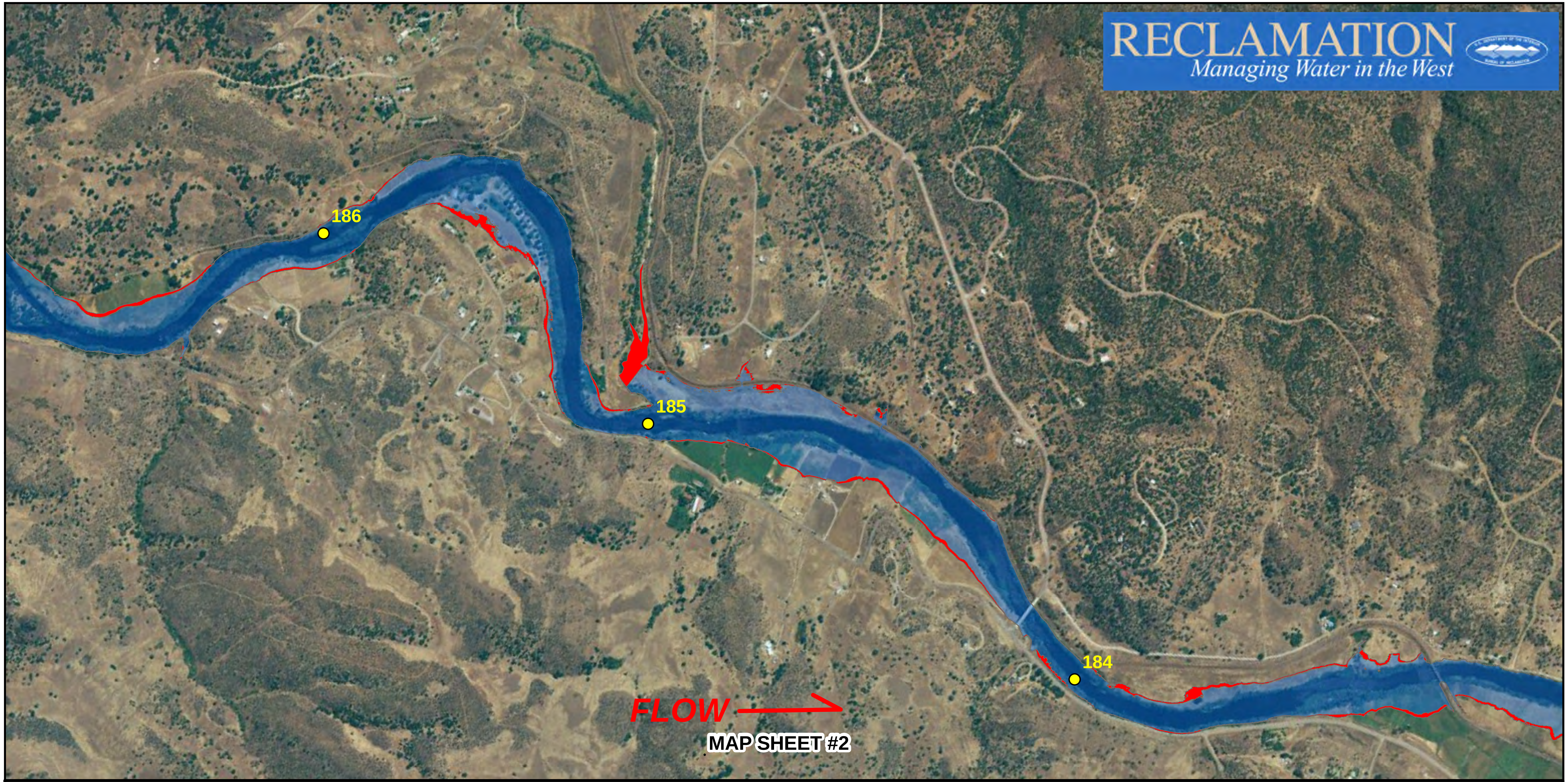
🟥 FUTURE DAM REMOVAL

▨ FUTURE NO ACTION

N

0 0.1250.25 0.5 0.75 1 Miles

Sedimentation and River Hydraulics Group
Technical Service Center
Denver, CO
04/14/2011



Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood
Inundation Mapping

- ● USGS RIVER MILE
- 🟥 FUTURE DAM REMOVAL
- 🟦 FUTURE NO ACTION

N

0 0.1250.25 0.5 0.75 1 Miles

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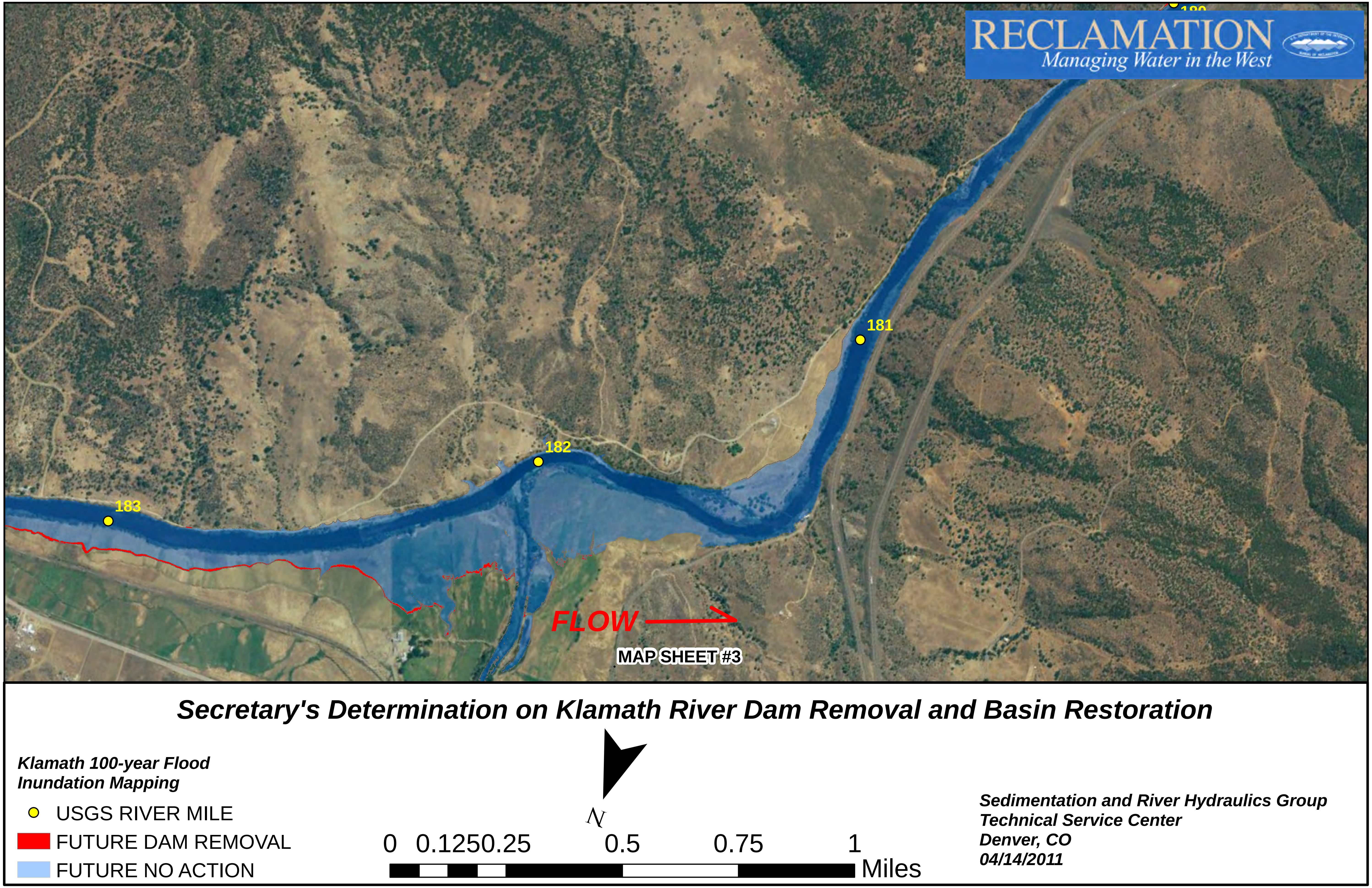

Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood Inundation Mapping

● USGS RIVER MILE
🟥 FUTURE DAM REMOVAL
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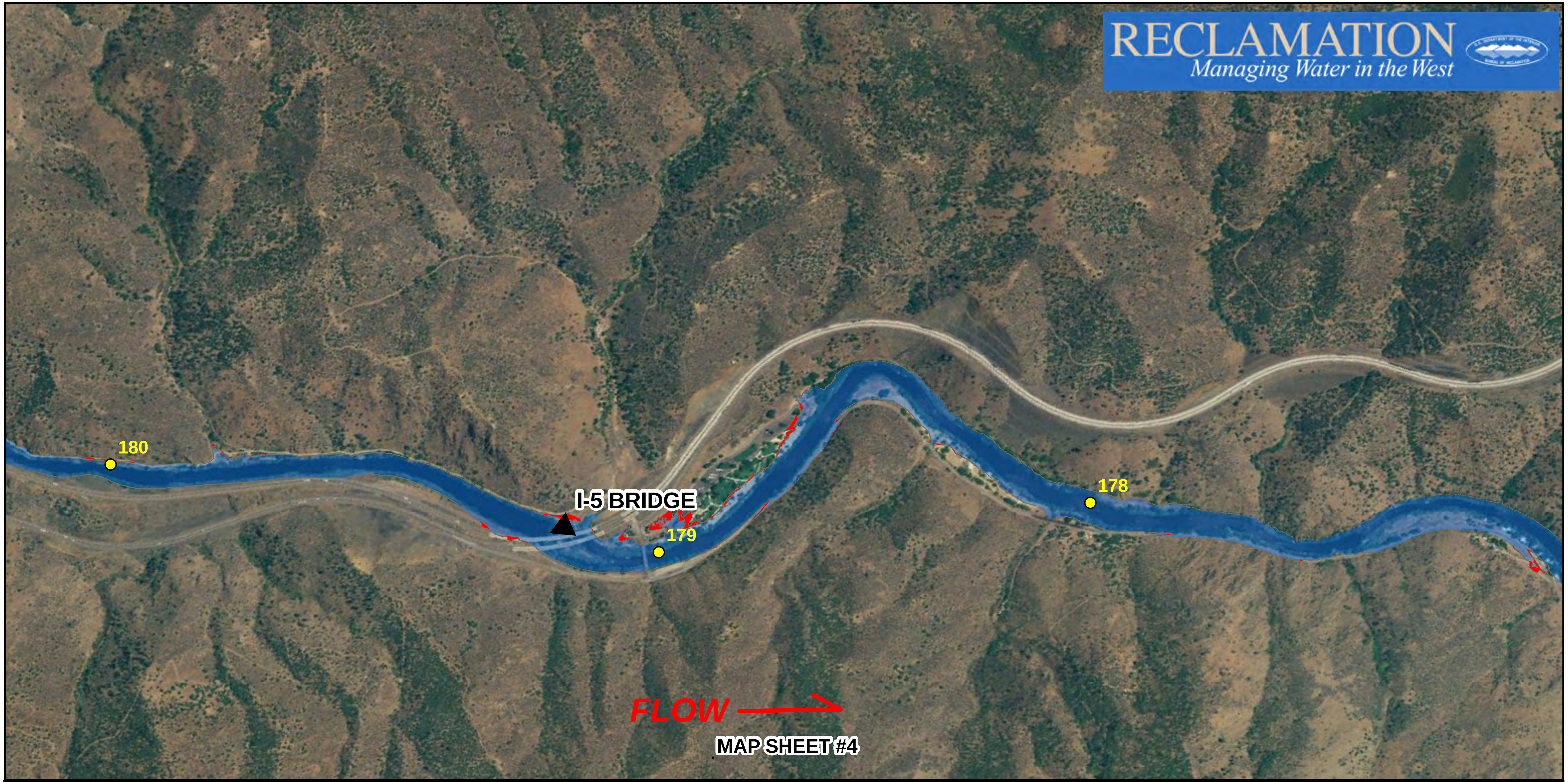

Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood
Inundation Mapping

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- 🟦 FUTURE NO ACTION

N

0 0.1250.25 0.5 0.75 1
Miles

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Secretary's Determination on Klamath River Dam Removal and Basin Restoration

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Secretary's Determination on Klamath River Dam Removal and Basin Restoration

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Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood Inundation Mapping

● USGS RIVER MILE
🟥 FUTURE DAM REMOVAL
🟦 FUTURE NO ACTION

N

0 0.125 0.25 0.5 0.75 1
Miles

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Klamath 100-year Flood
Inundation Mapping

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🟥 FUTURE DAM REMOVAL
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N

0 0.1250.25 0.5 0.75 1 Miles

Sedimentation and River Hydraulics Group
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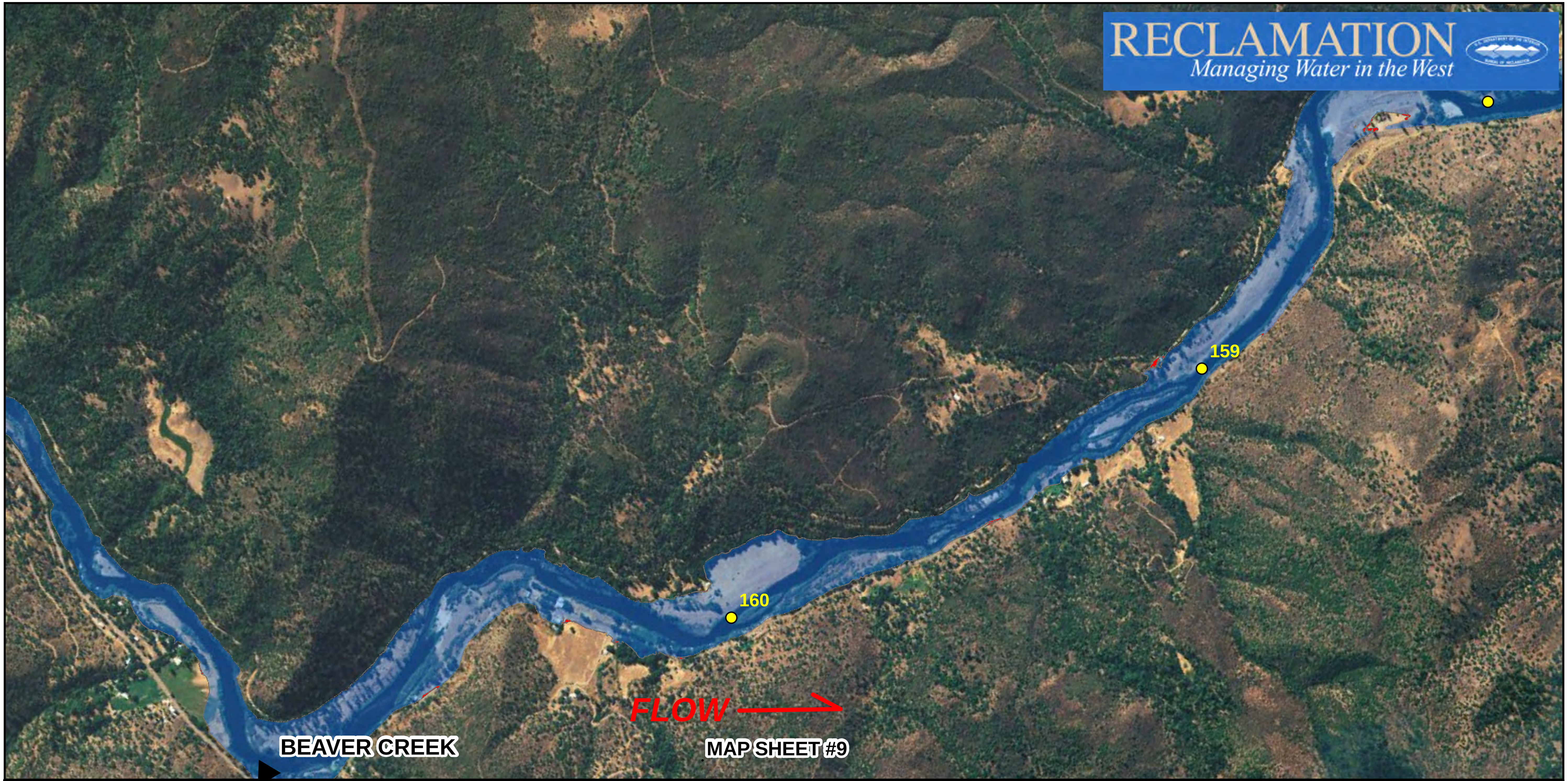

Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood Inundation Mapping

- ○ USGS RIVER MILE
- 🟥 FUTURE DAM REMOVAL
- ▨ FUTURE NO ACTION

N

0 0.125 0.25 0.5 0.75 1 Miles

Sedimentation and River Hydraulics Group
Technical Service Center
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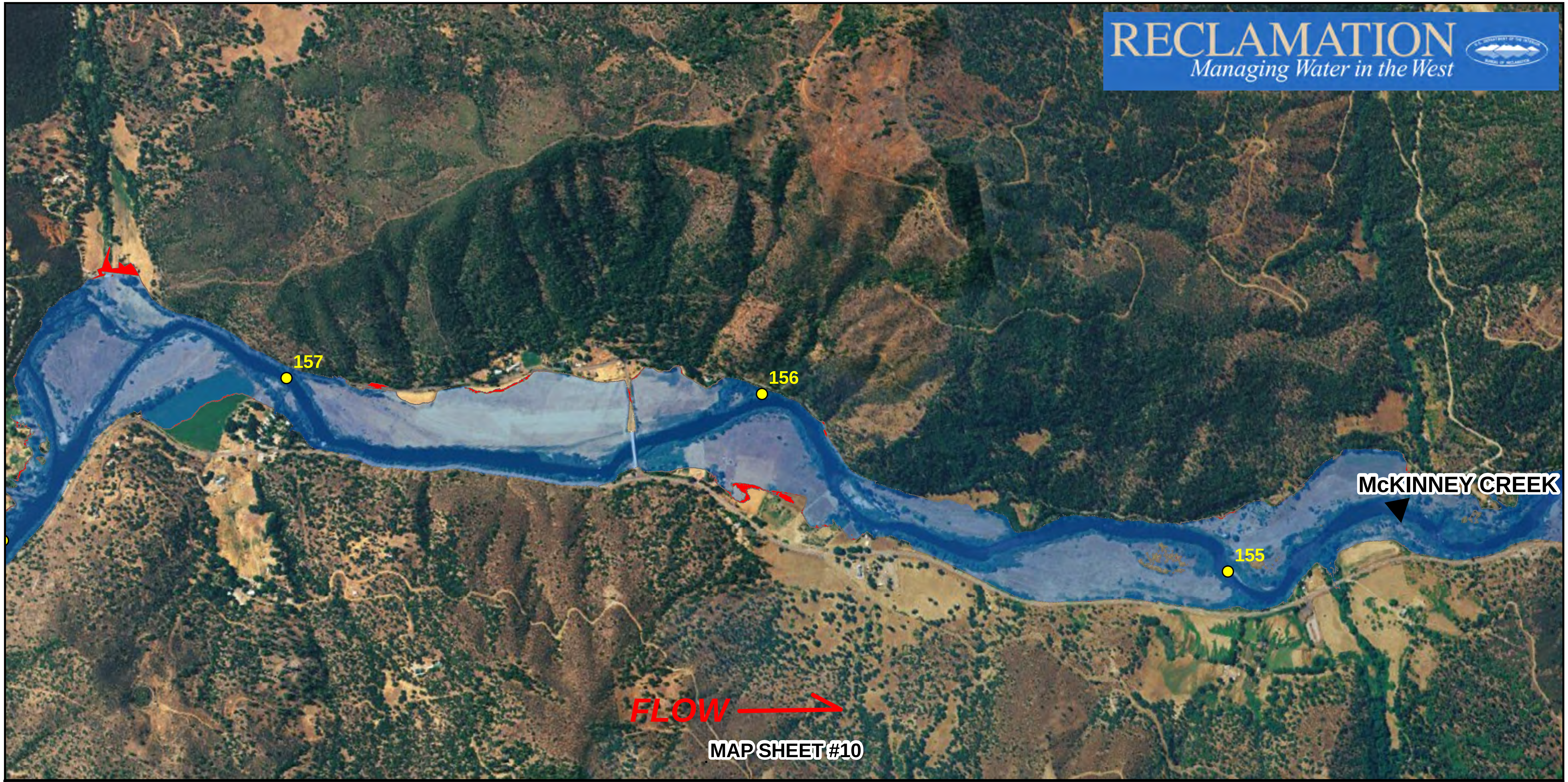
04/14/2011



Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood
Inundation Mapping

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N

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Miles

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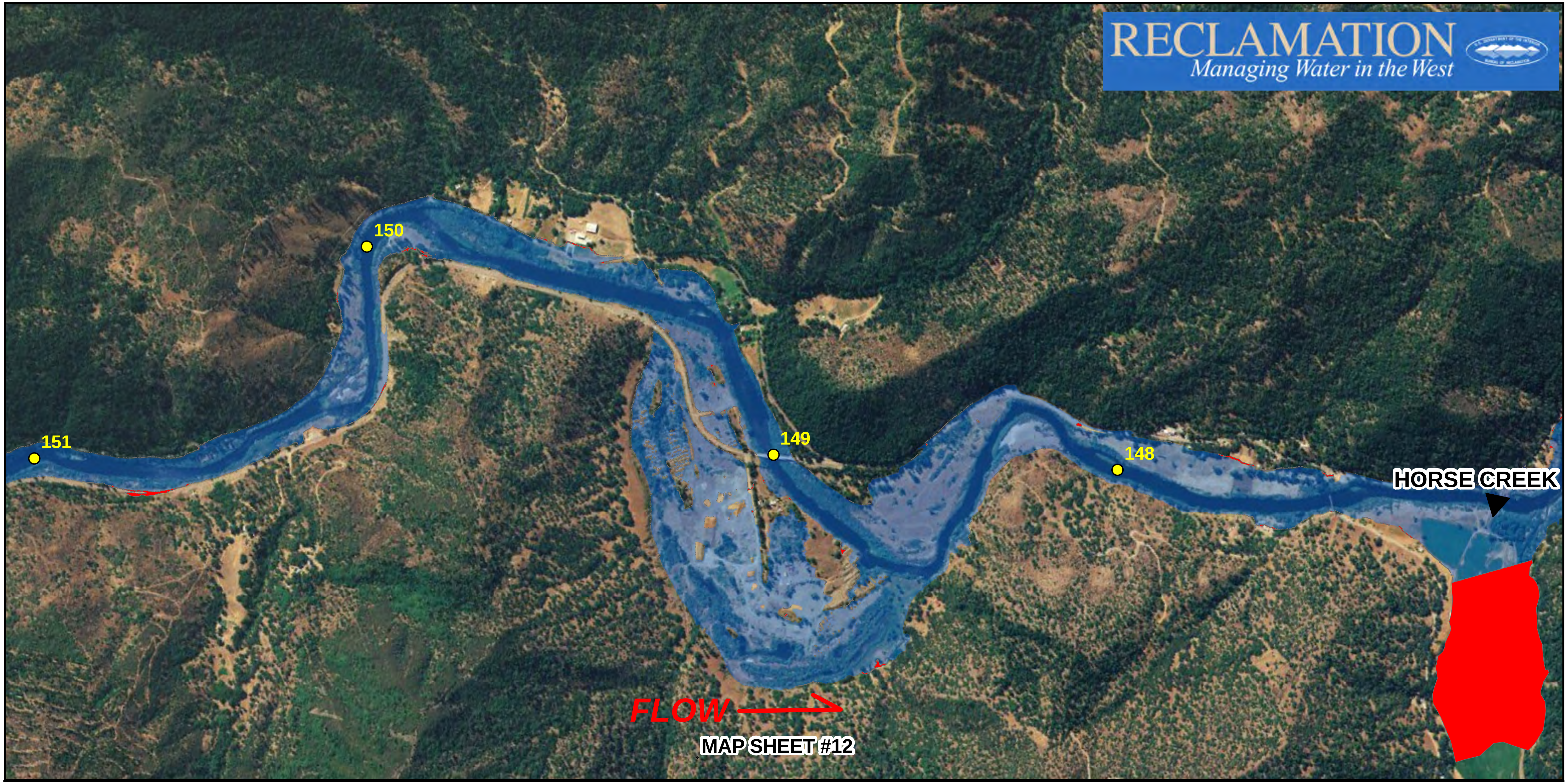

Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood Inundation Mapping

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Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood
Inundation Mapping

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N

0 0.125 0.25 0.5 0.75 1
Miles

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Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood Inundation Mapping

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Miles

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Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood
Inundation Mapping

- ● USGS RIVER MILE
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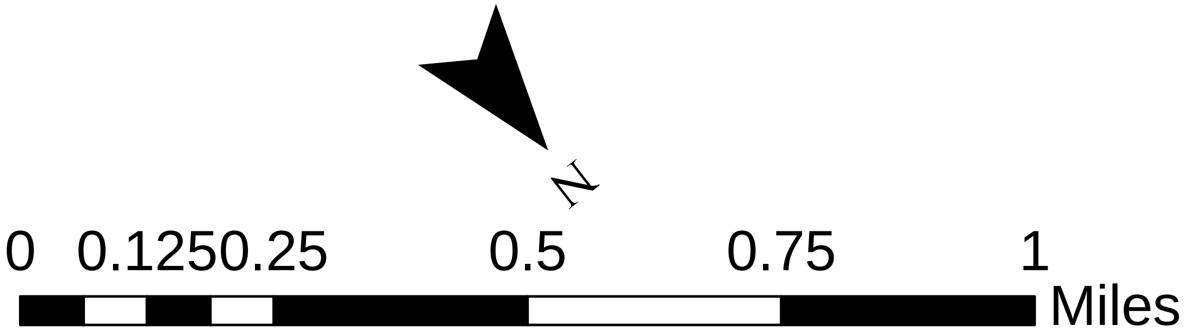
- 🟦 FUTURE NO ACTION



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Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood
Inundation Mapping

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🟥 FUTURE DAM REMOVAL

🟦 FUTURE NO ACTION

N

0 0.125 0.25 0.5 0.75 1 Miles

Sedimentation and River Hydraulics Group
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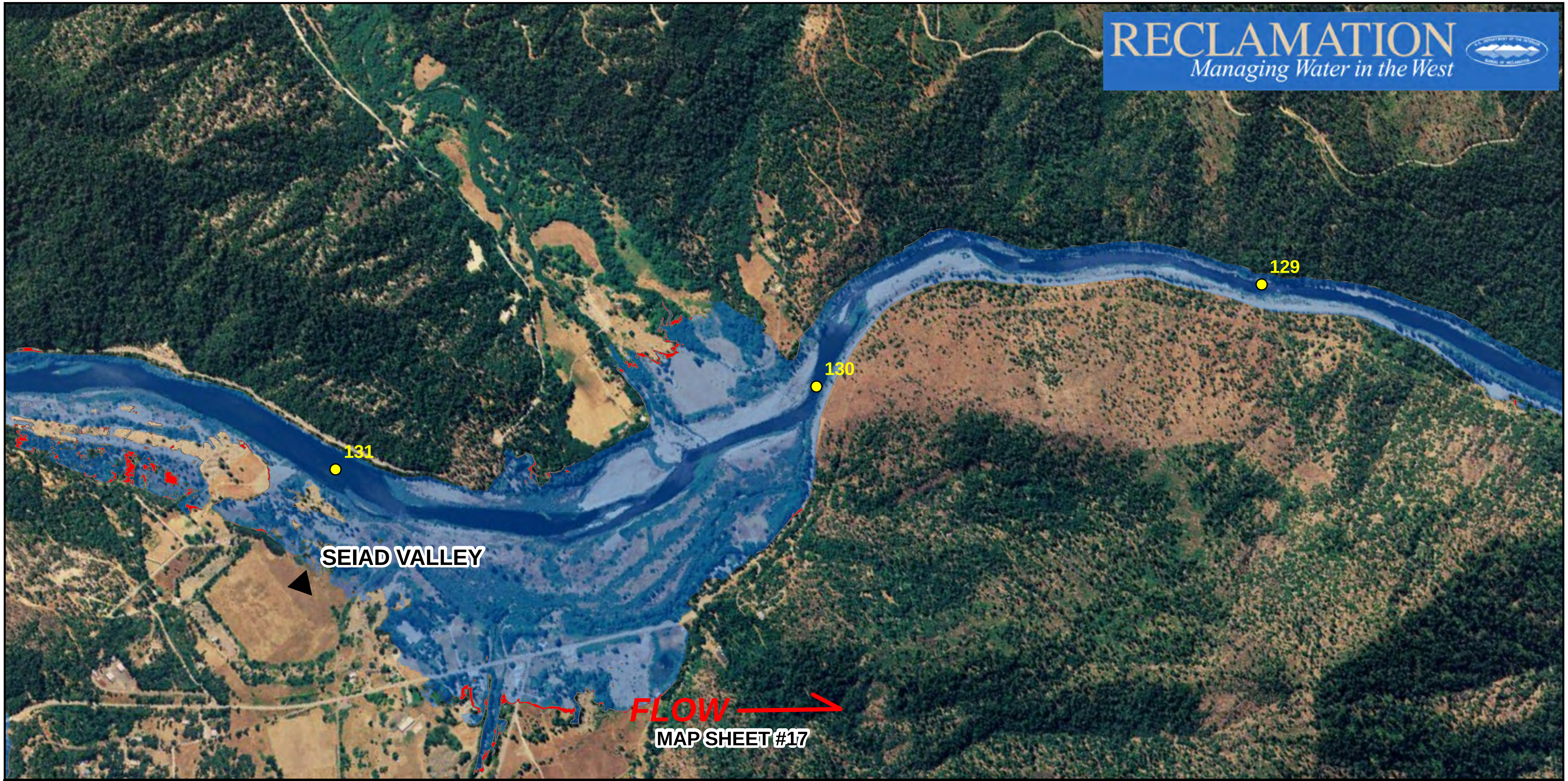

Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood Inundation Mapping

- ● USGS RIVER MILE
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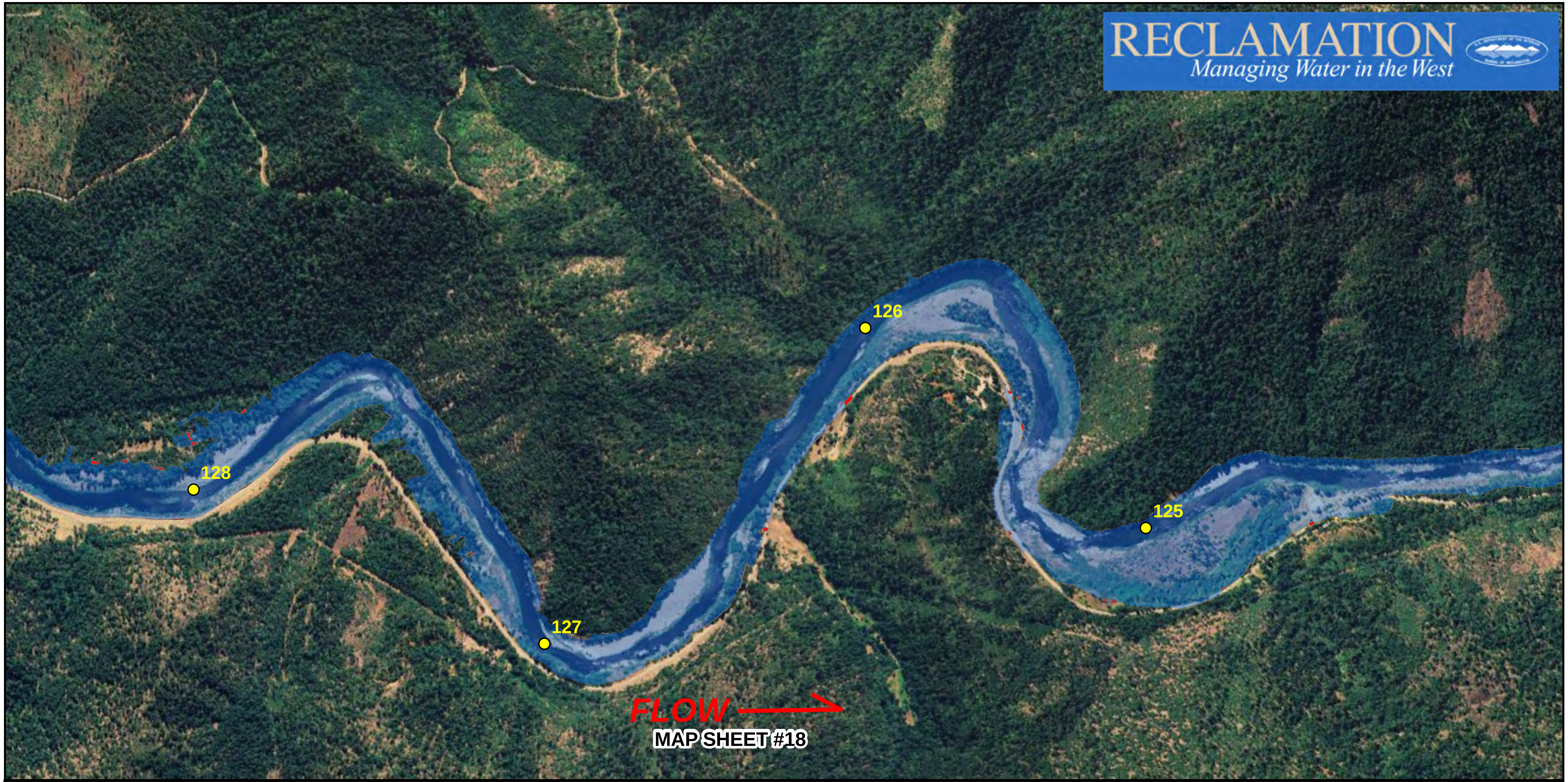

Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood
Inundation Mapping

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Klamath 100-year Flood Inundation Mapping

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🟦 FUTURE NO ACTION

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0 0.125 0.25 0.5 0.75 1 Miles

Sedimentation and River Hydraulics Group
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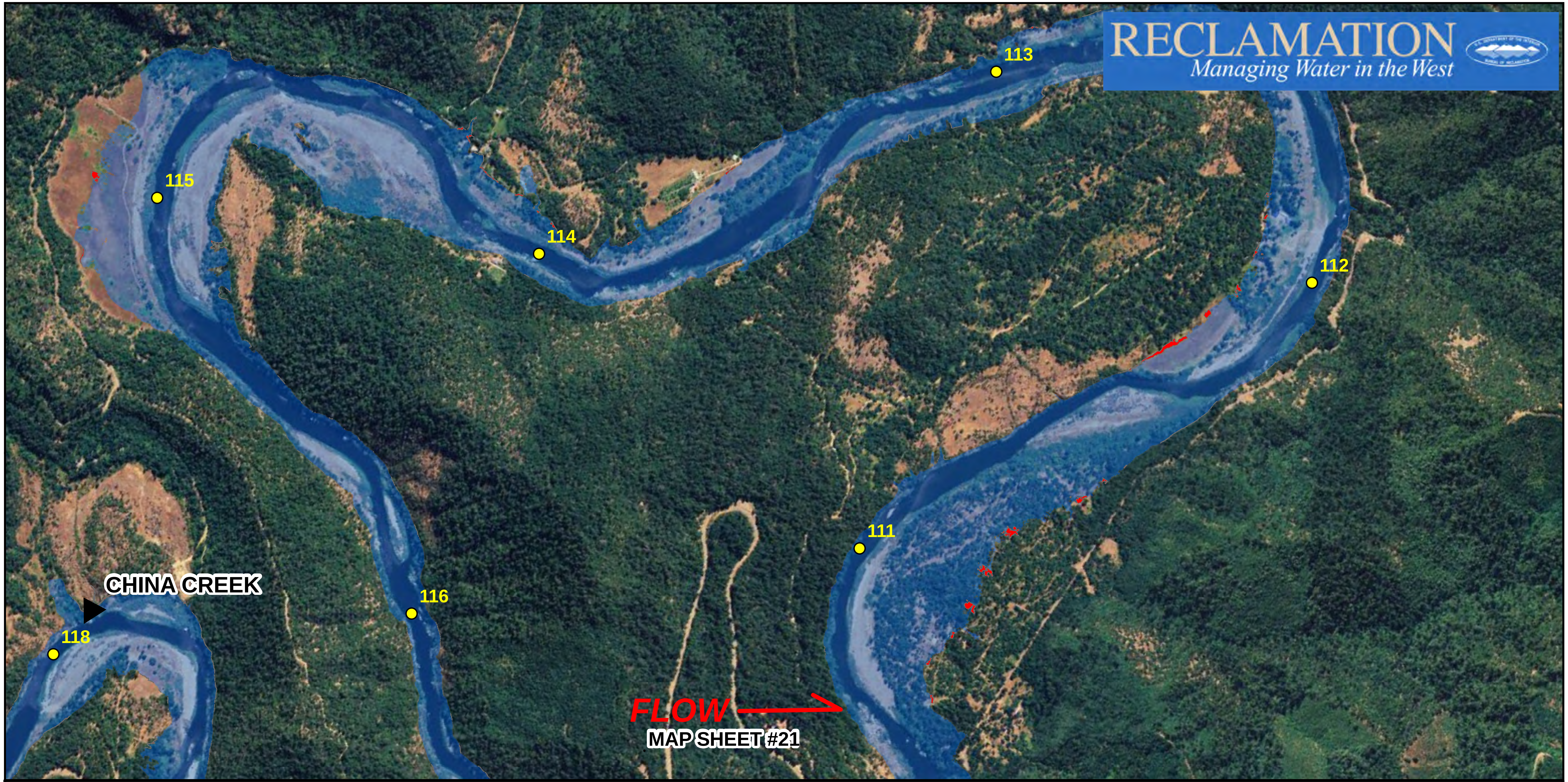

Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood Inundation Mapping

- ● USGS RIVER MILE
- 🟥 FUTURE DAM REMOVAL
- 🟦 FUTURE NO ACTION

N

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Sedimentation and River Hydraulics Group
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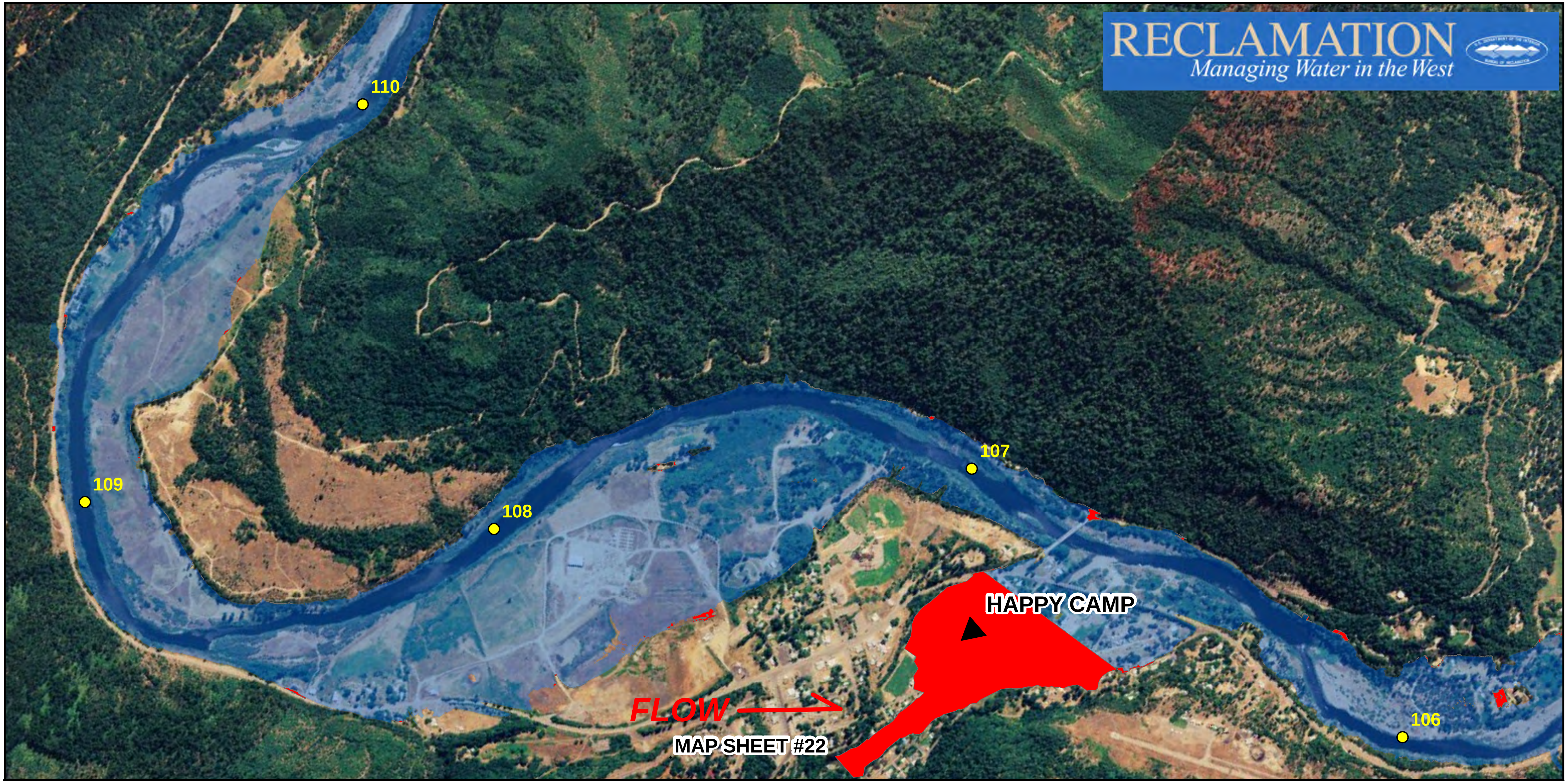

Secretary's Determination on Klamath River Dam Removal and Basin Restoration

Klamath 100-year Flood Inundation Mapping

- ● USGS RIVER MILE
- 🟥 FUTURE DAM REMOVAL
- 🟦 FUTURE NO ACTION

N

0 0.1250.25 0.5 0.75 1 Miles

Sedimentation and River Hydraulics Group
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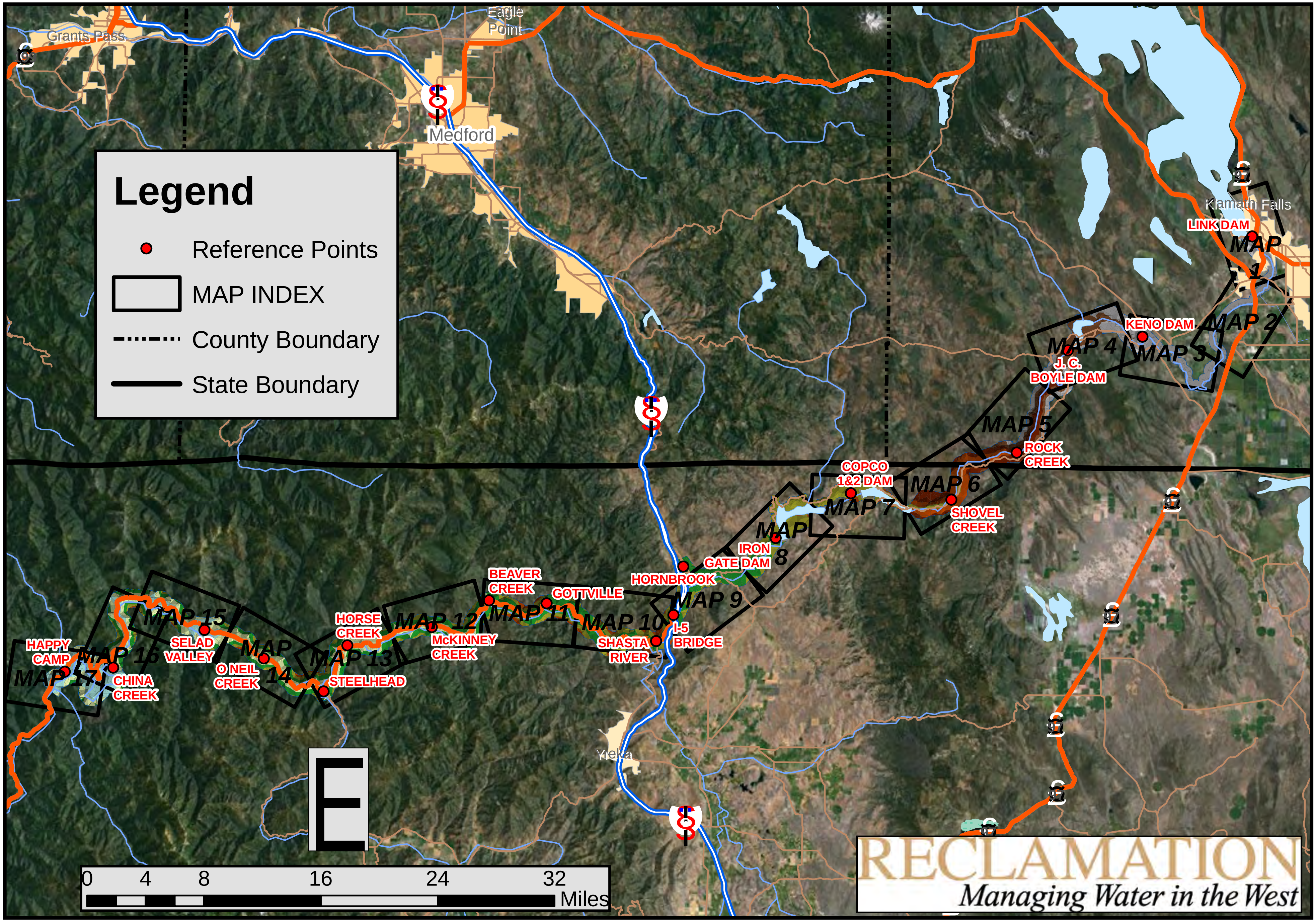
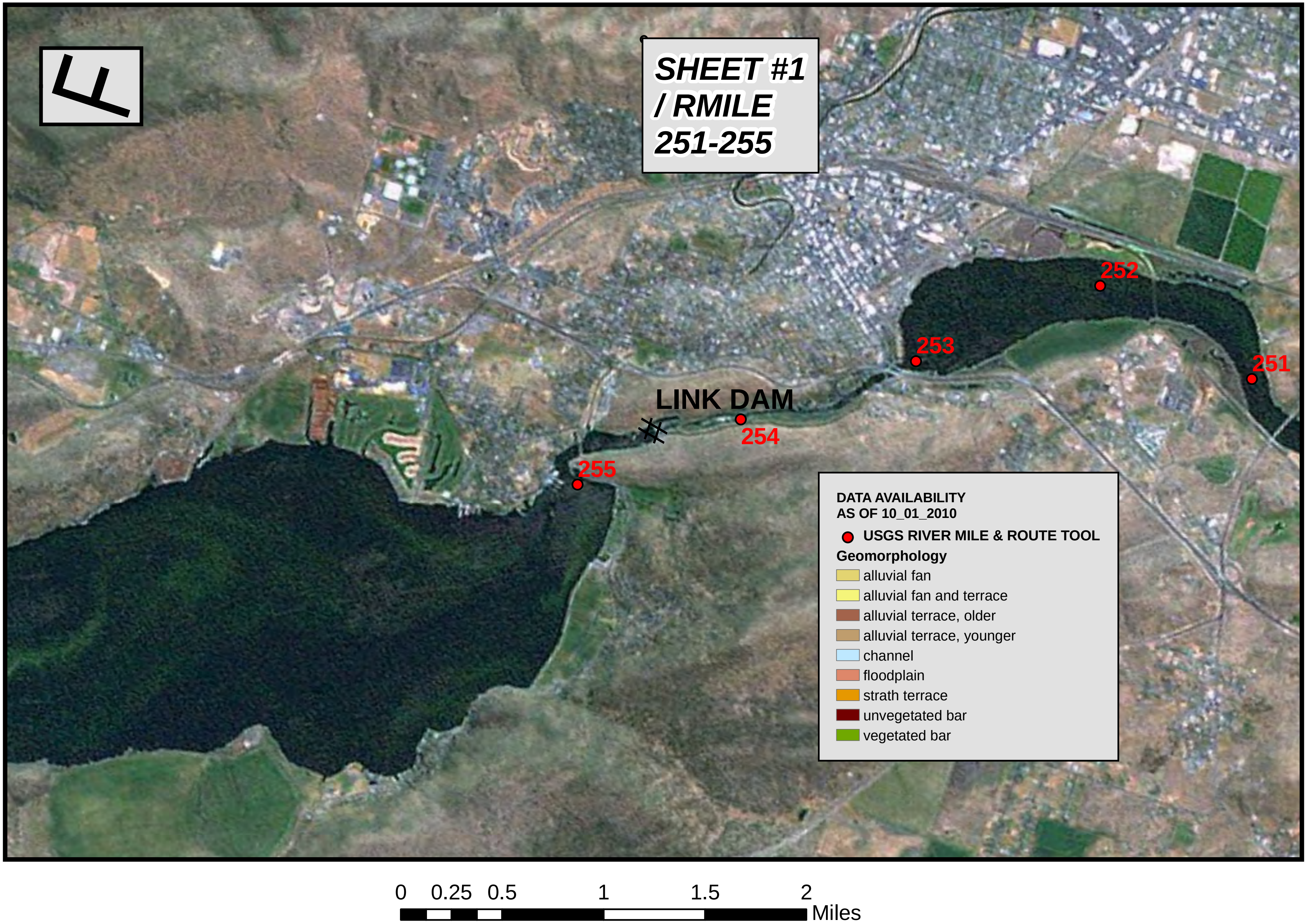
20. Appendix H. Geomorphic Mapping

KLAMATH RIVER DAMS GEO-SPATIAL DATA MAP INDEX



KLAMATH RIVER DAMS GEO-SPATIAL DATA MAP BOOK



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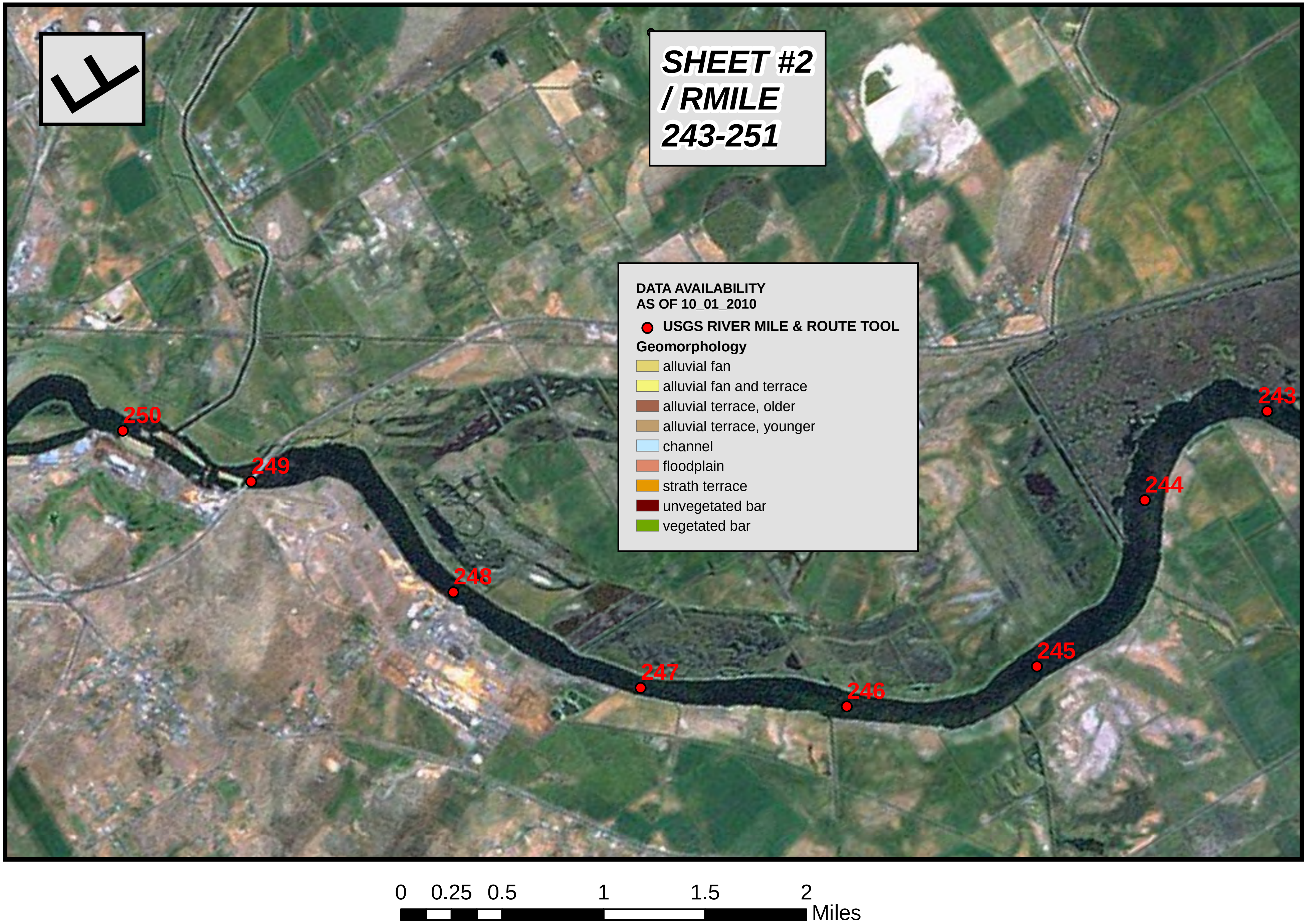

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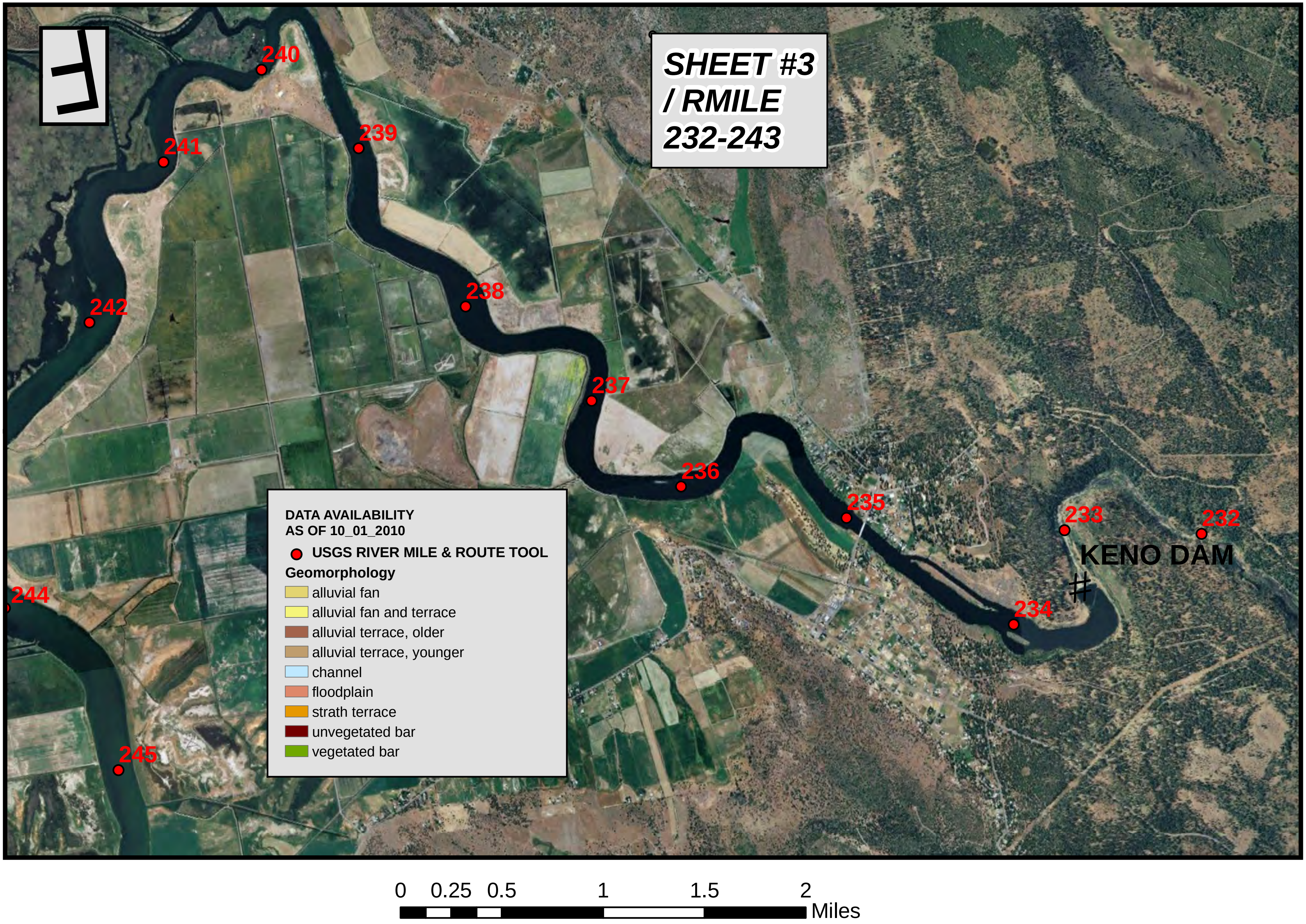

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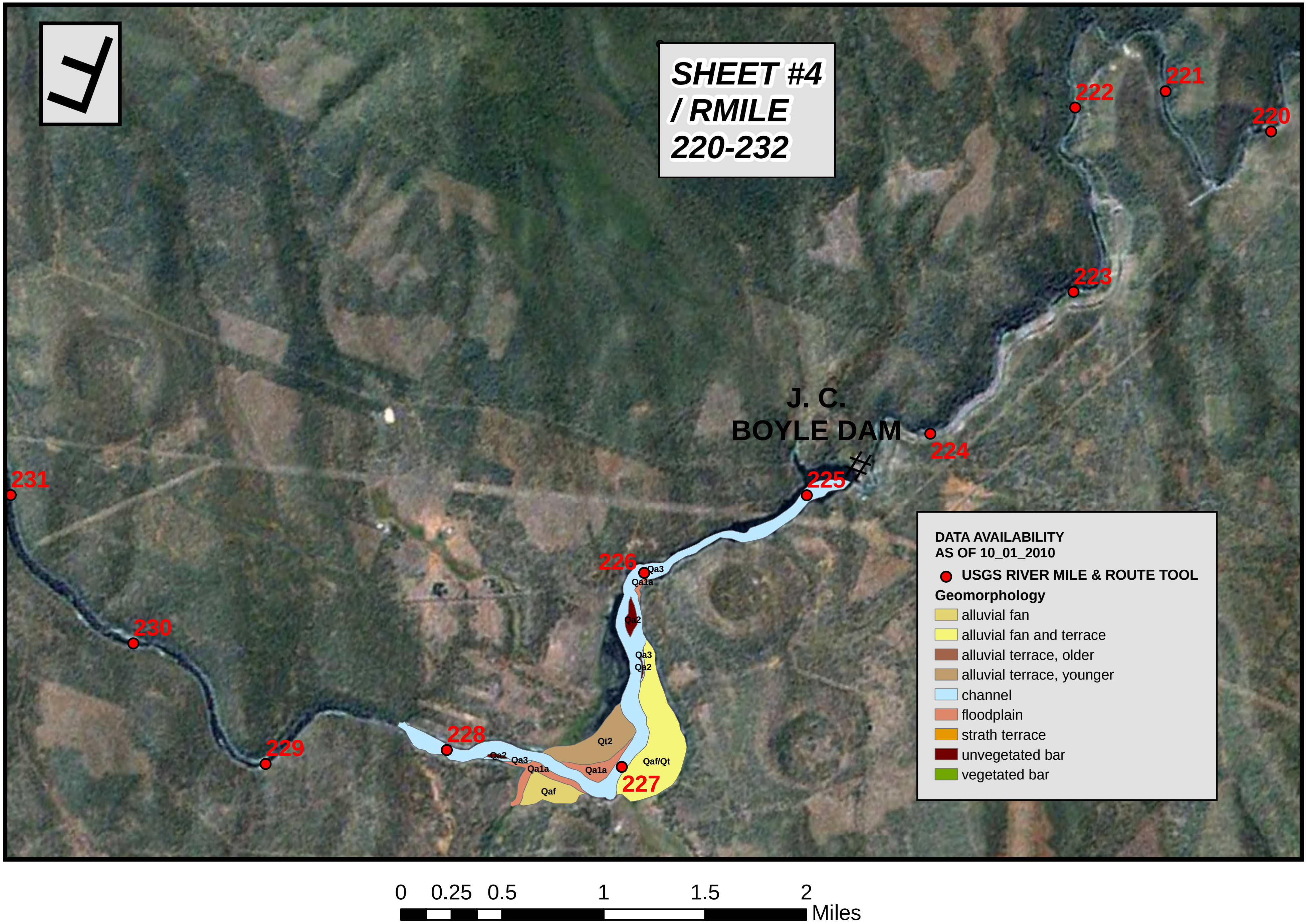

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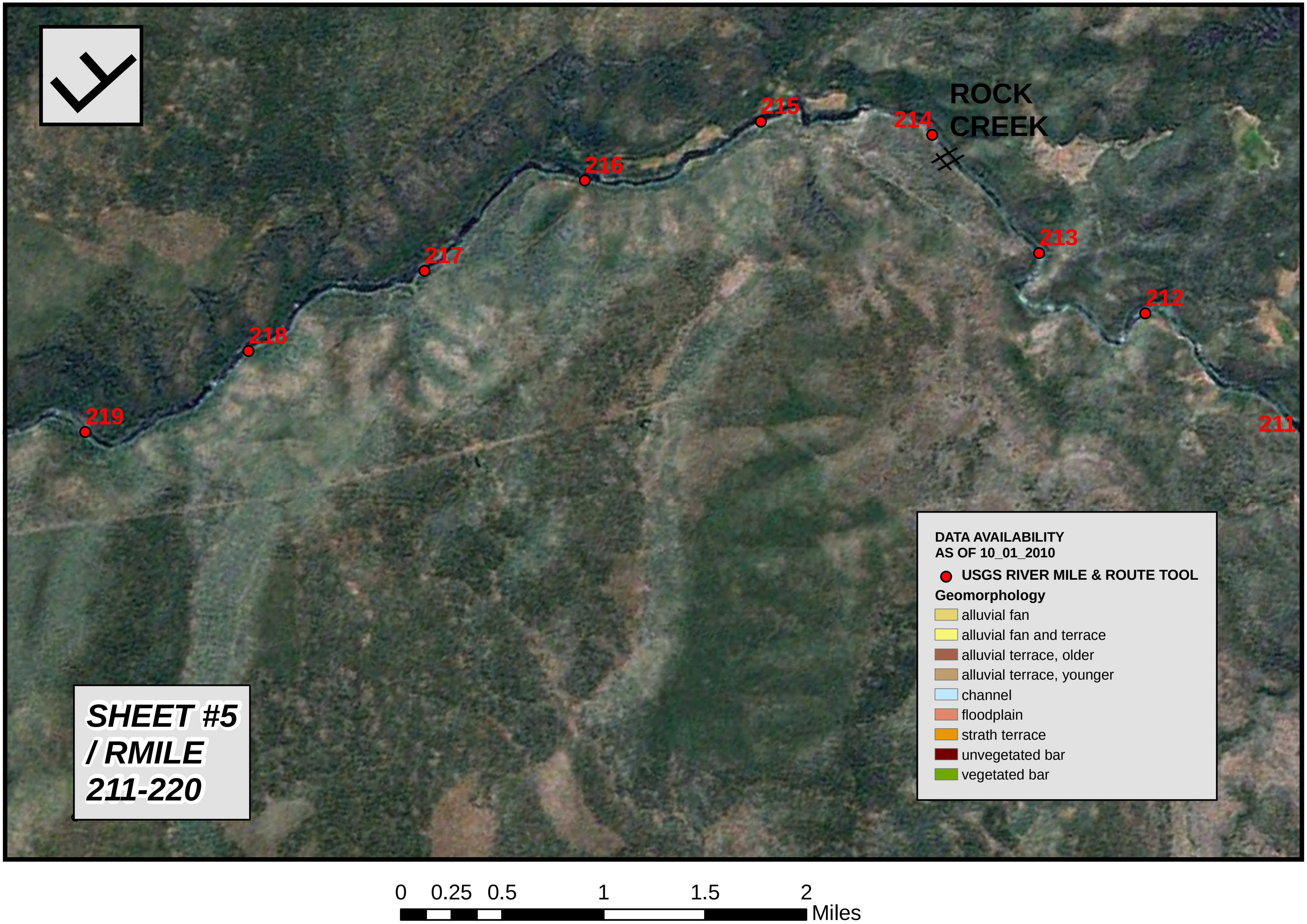

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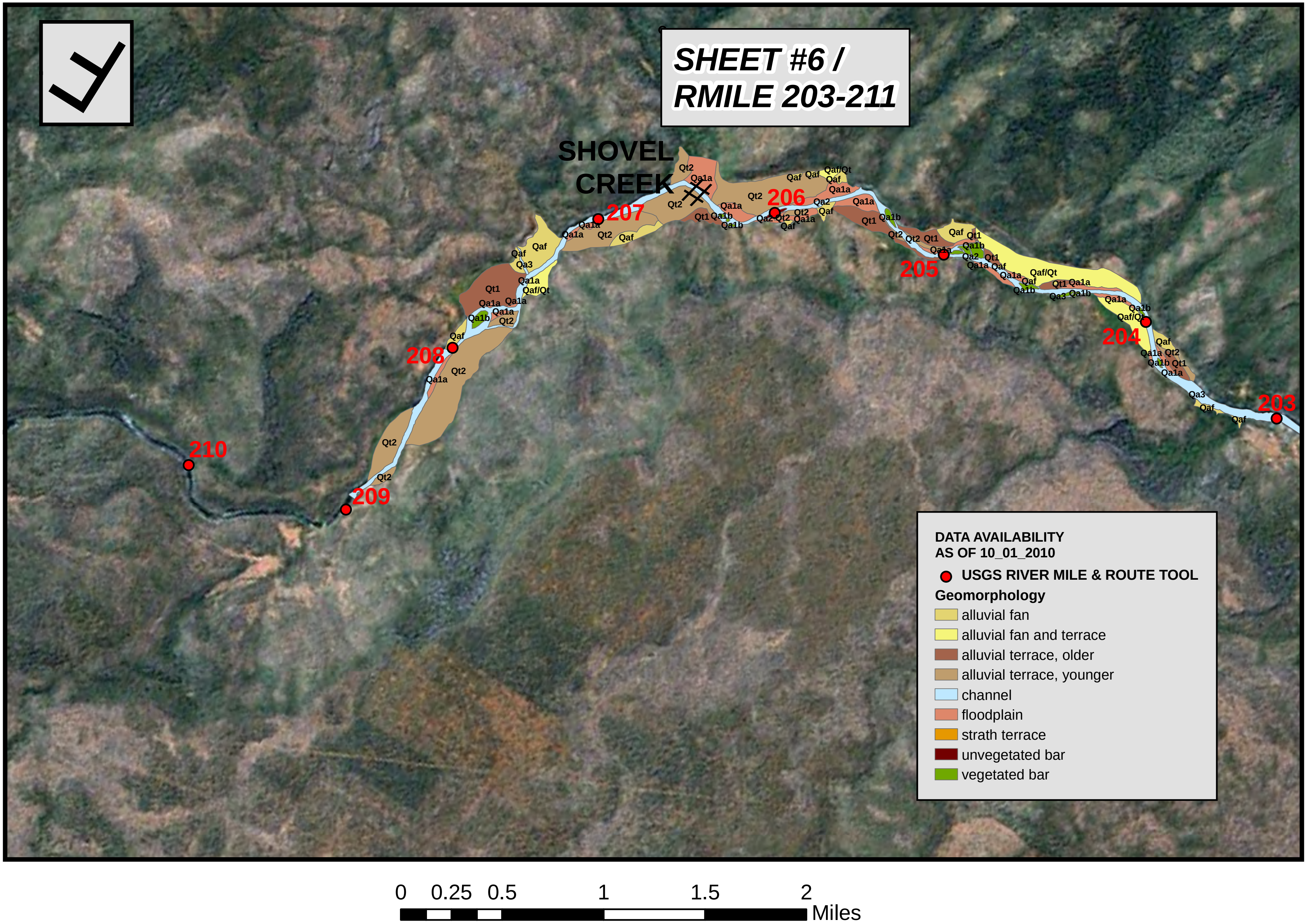

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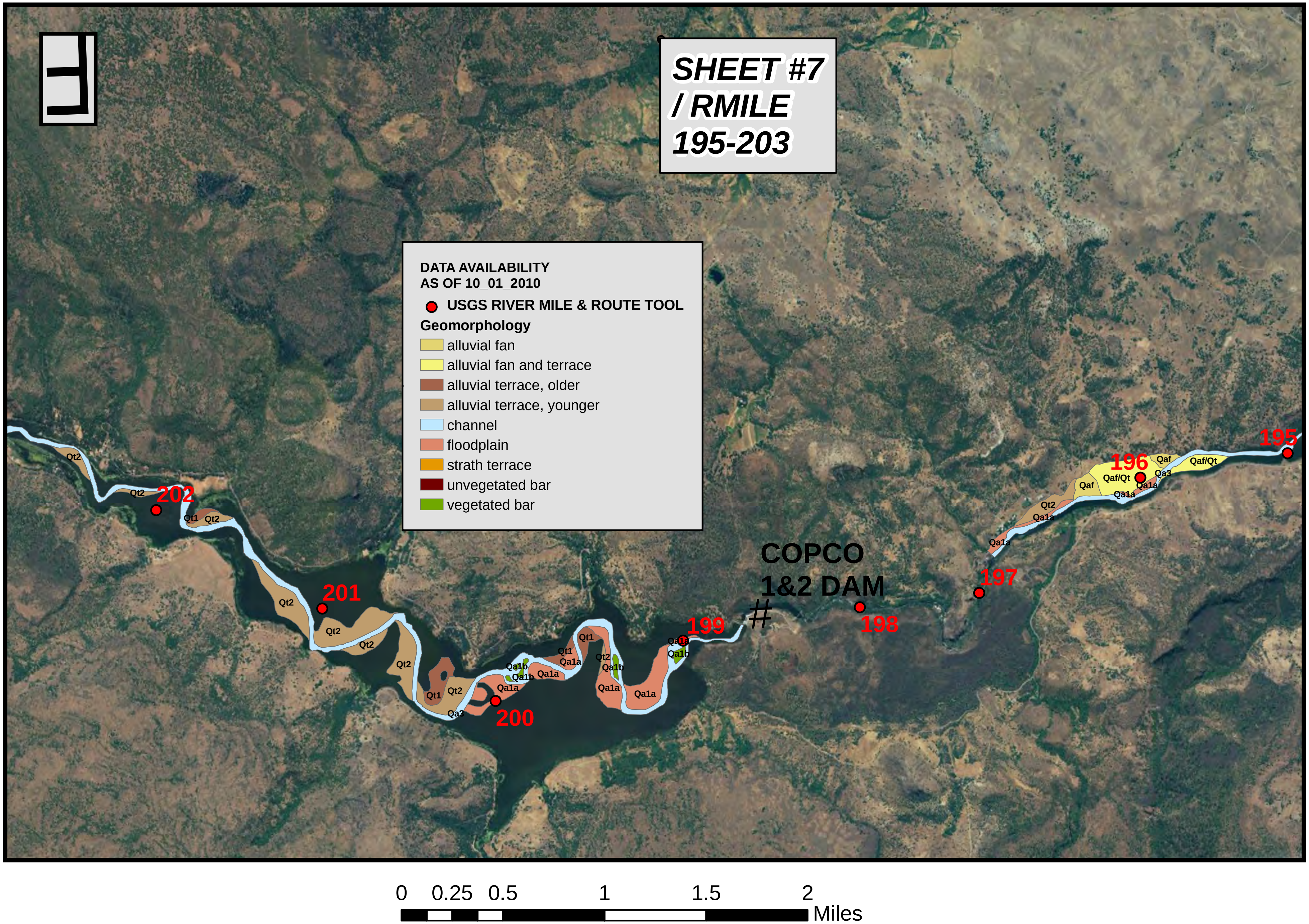

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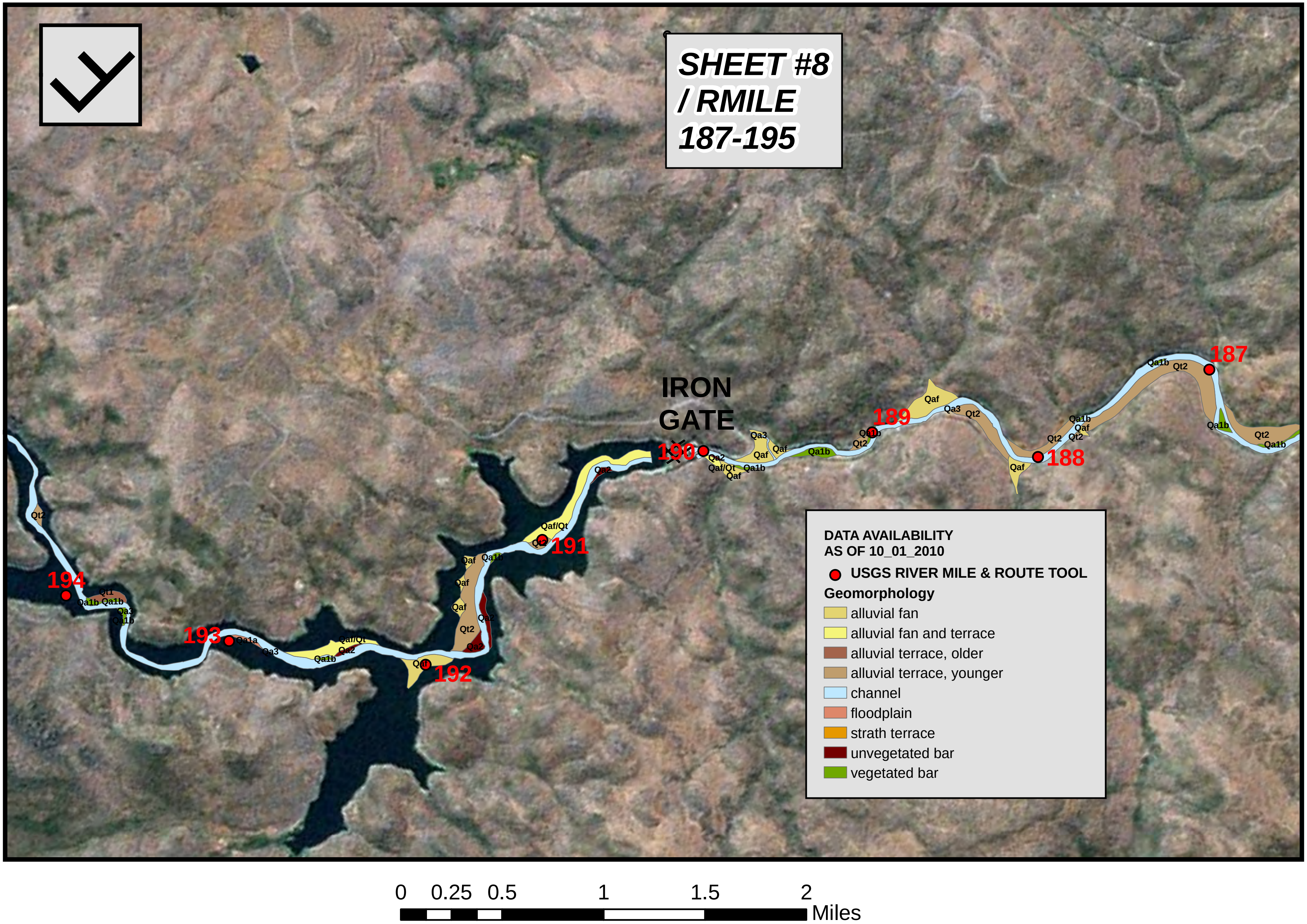

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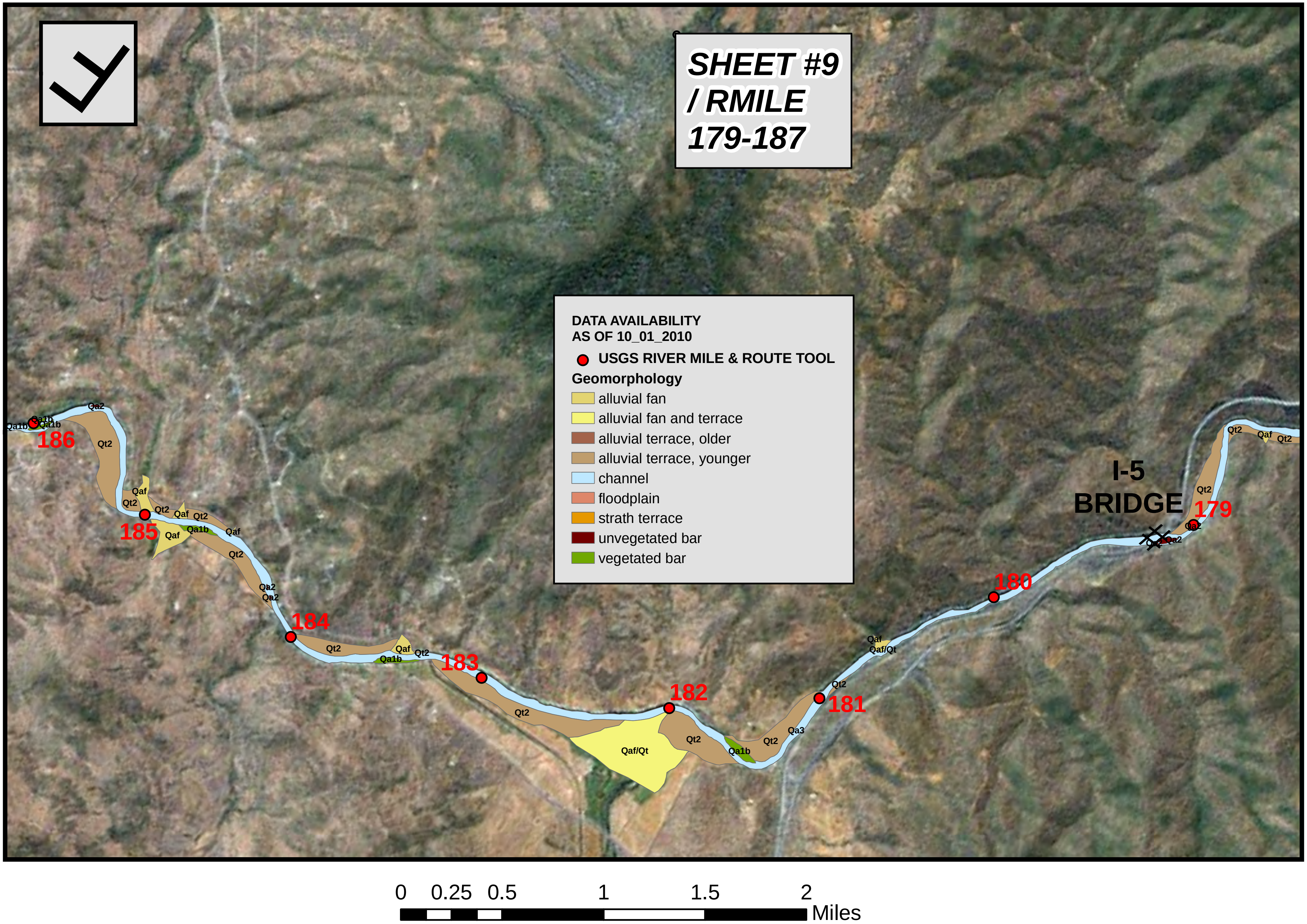

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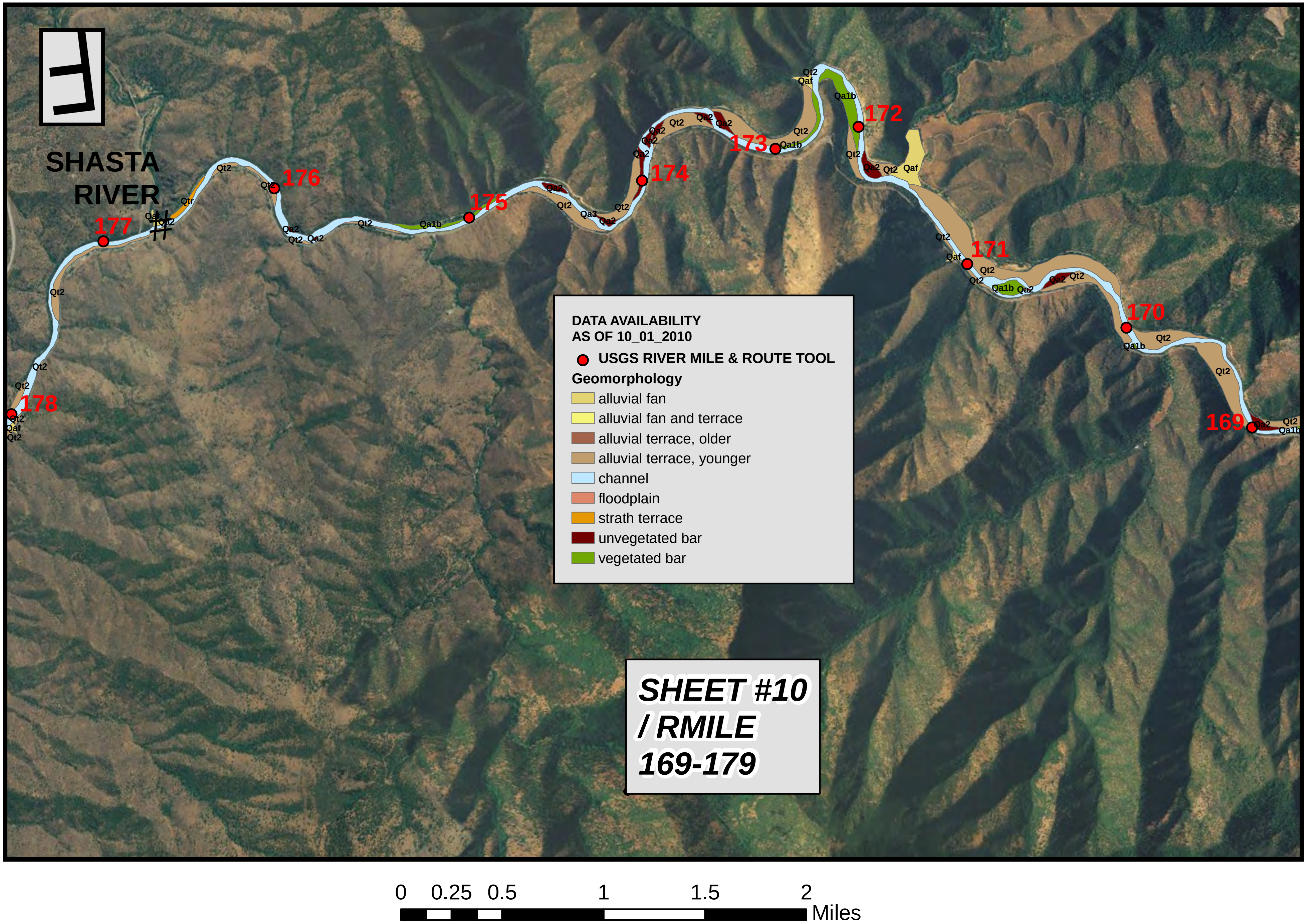
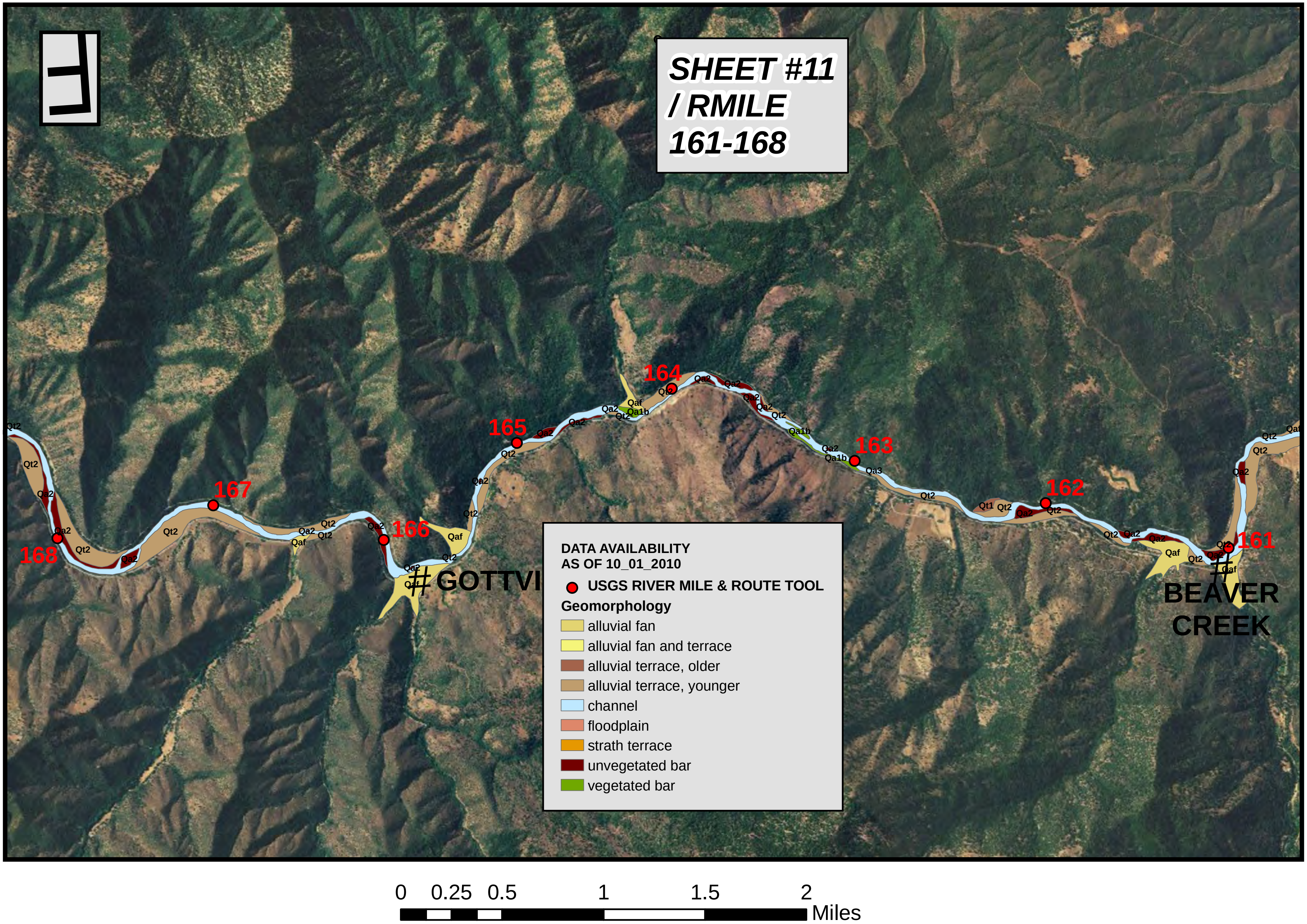


SHEET #10 / RMILE 169-179

KLAMATH RIVER DAMS GEO-SPATIAL DATA MAP BOOK



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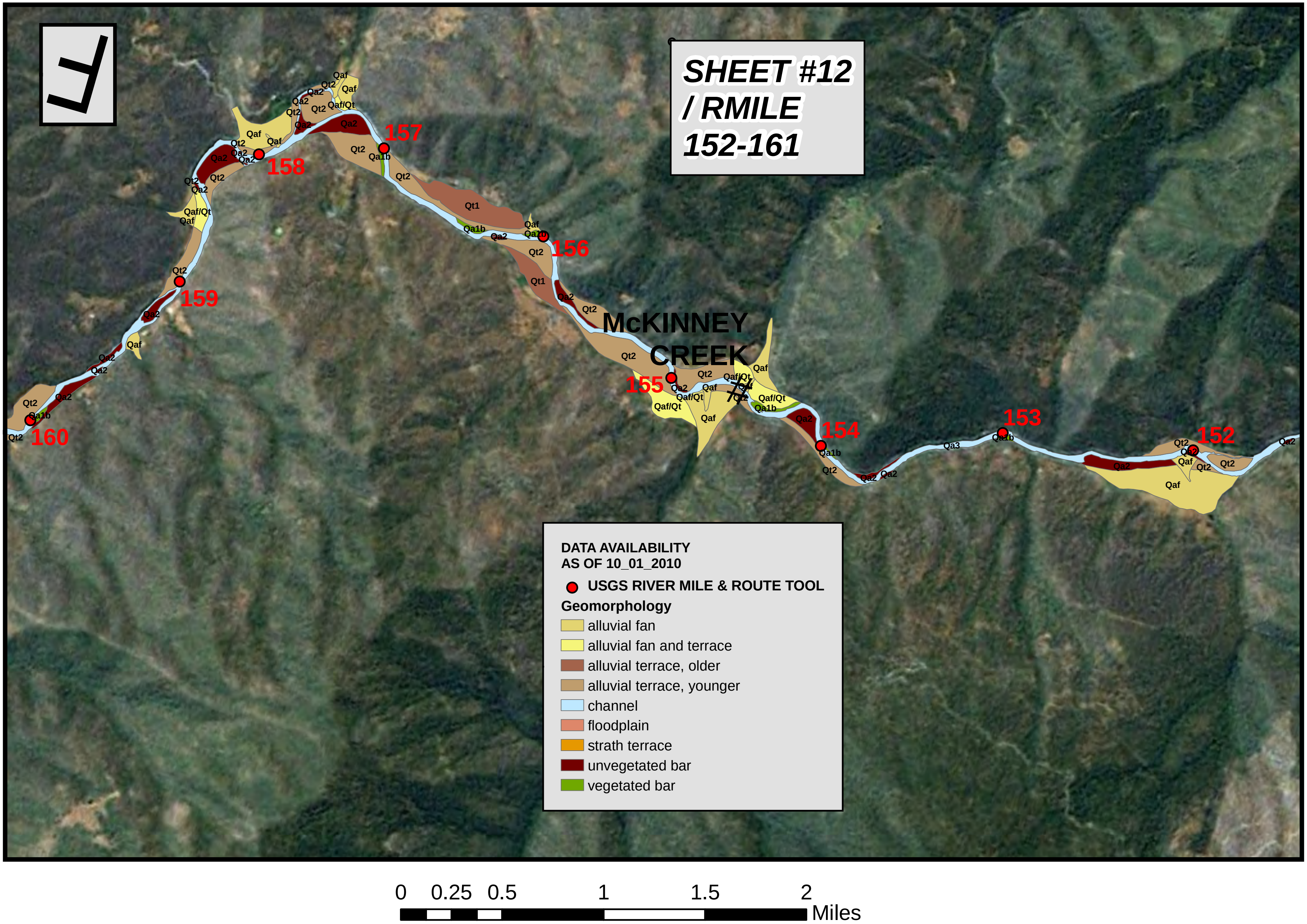

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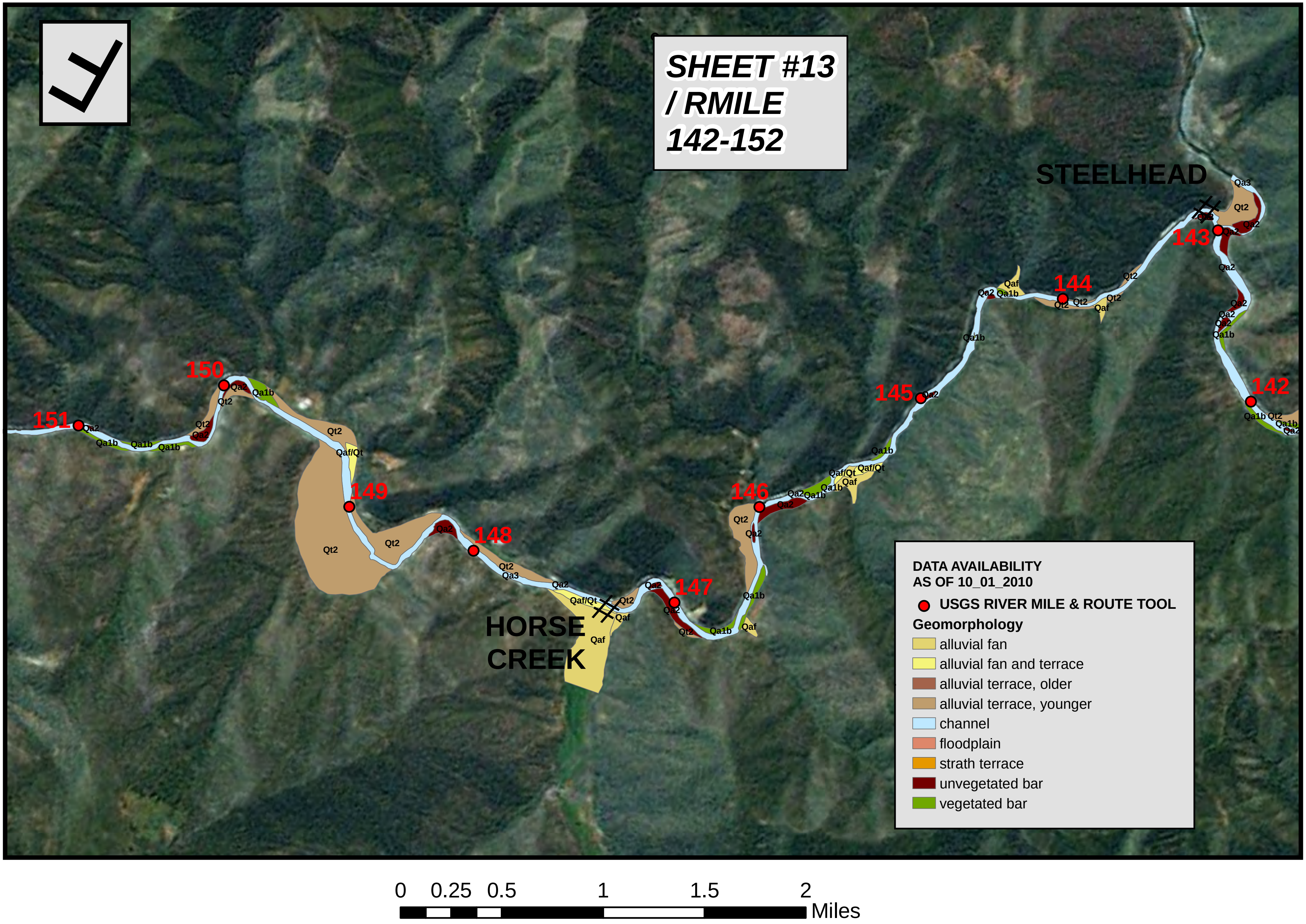
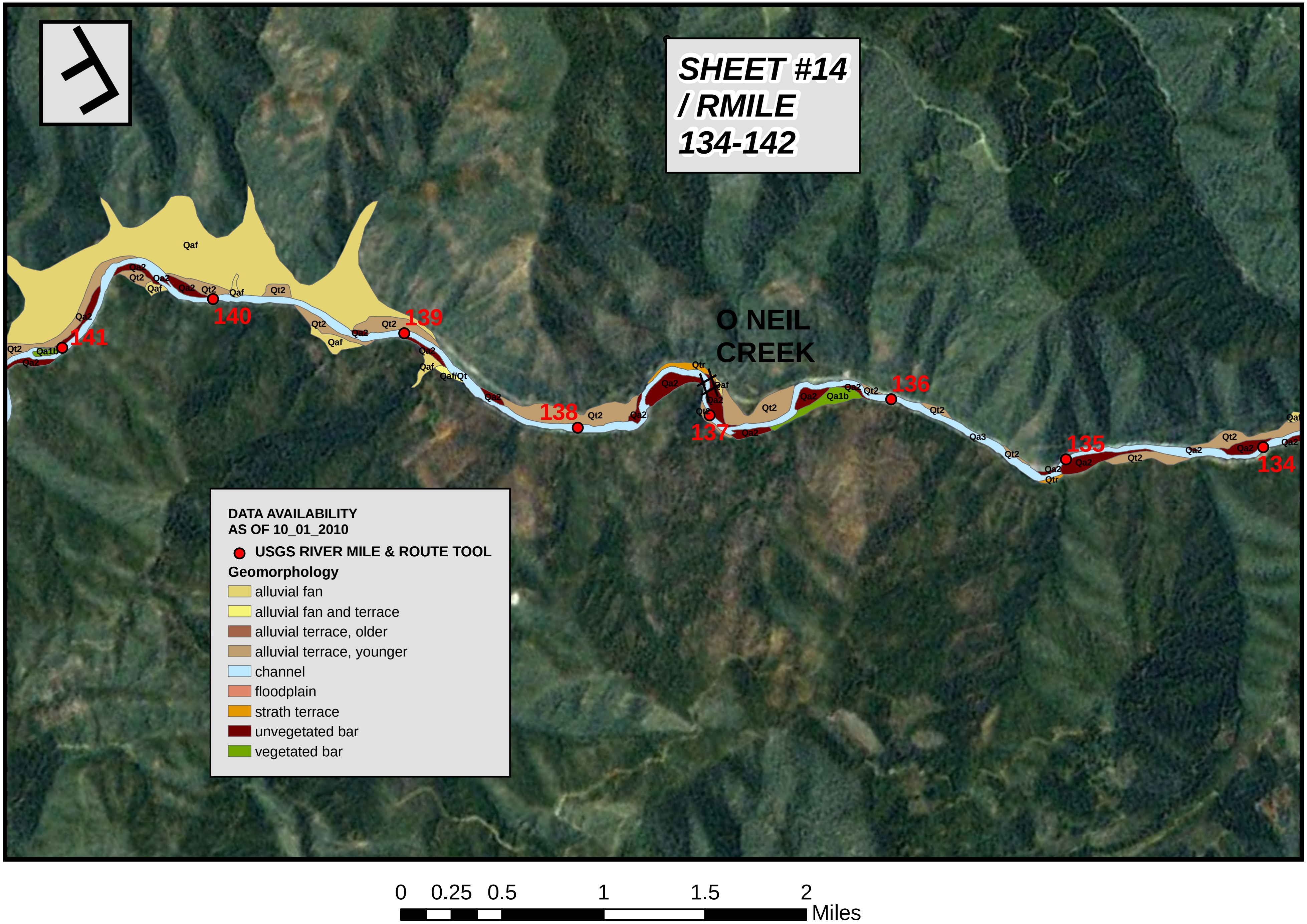
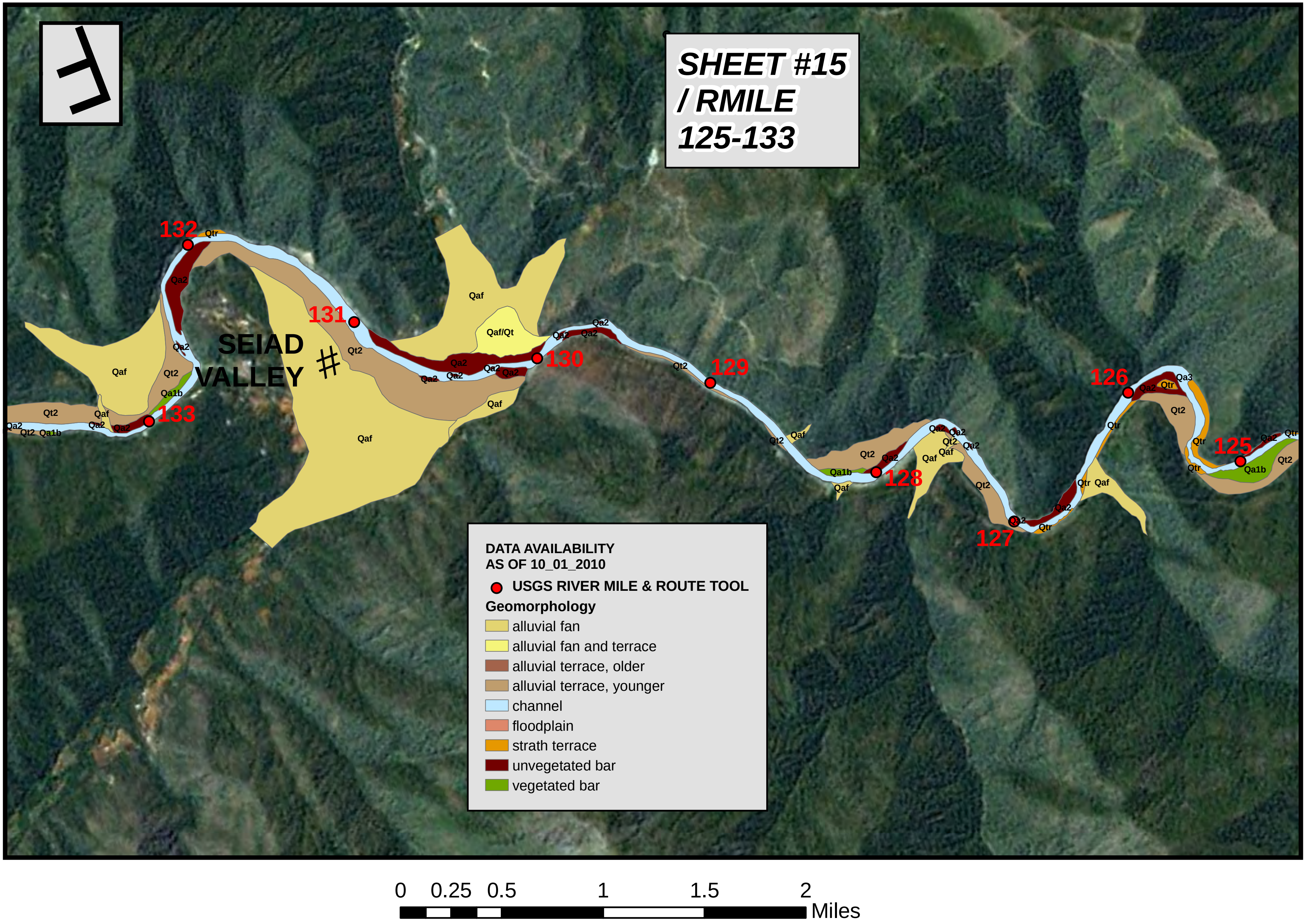


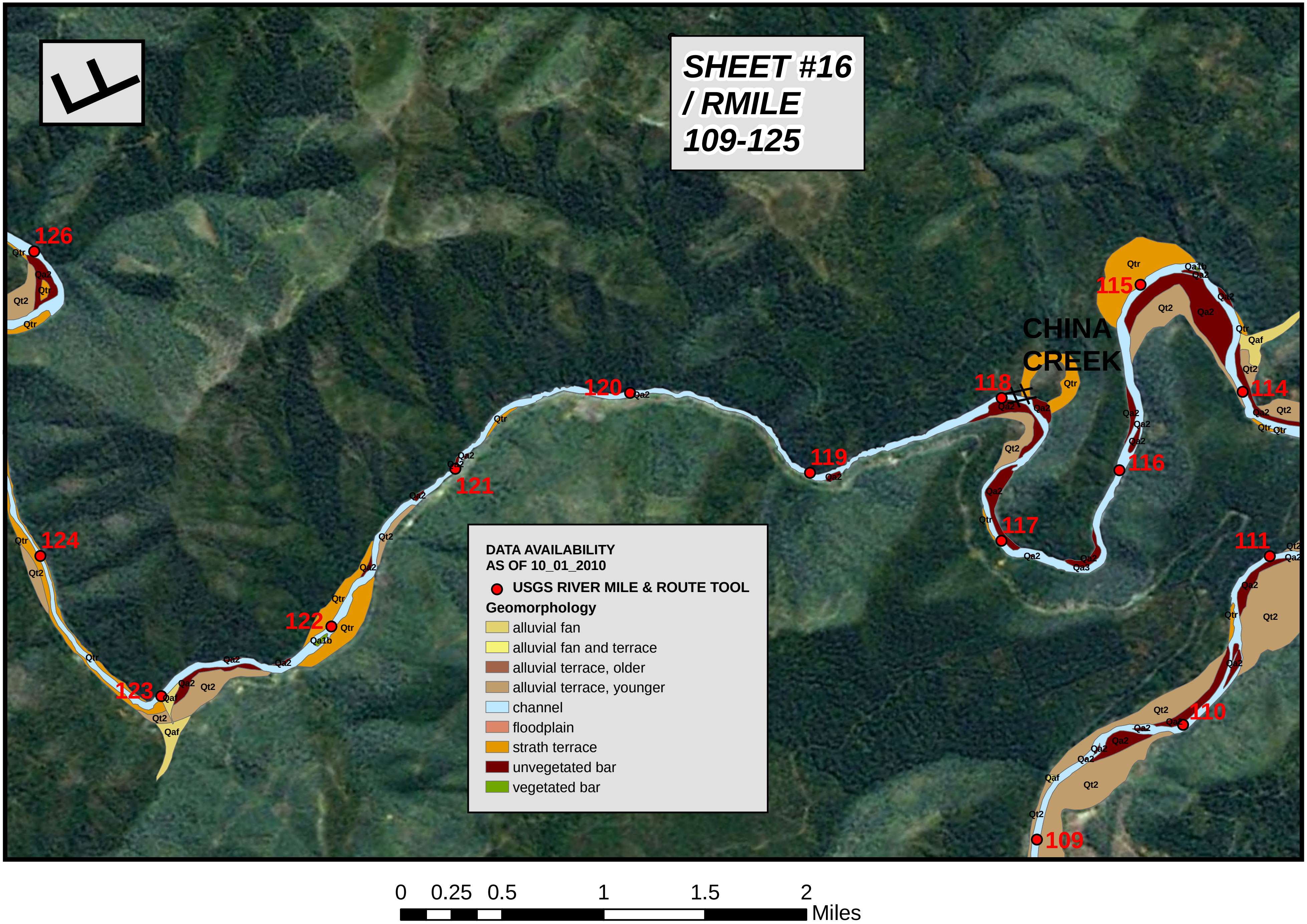
KLAMATH RIVER DAMS GEO-SPATIAL DATA MAP BOOK



KLAMATH RIVER DAMS GEO-SPATIAL DATA MAP BOOK



KLAMATH RIVER DAMS GEO-SPATIAL DATA MAP BOOK



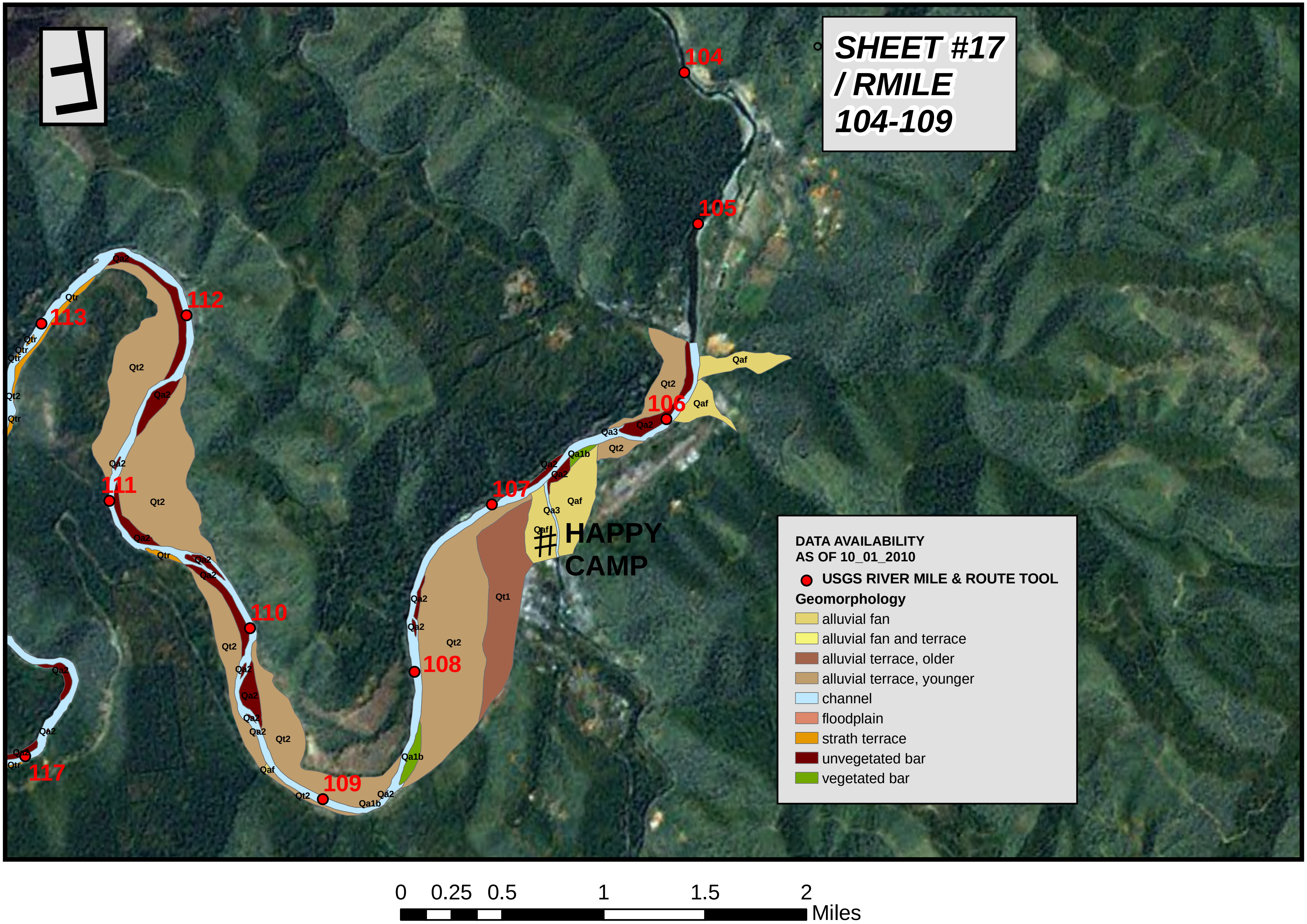
DATA AVAILABILITY
AS OF 10_01_2010

● USGS RIVER MILE & ROUTE TOOL

Geomorphology

- ▨ alluvial fan
- ▨ alluvial fan and terrace
- ▨ alluvial terrace, older
- ▨ alluvial terrace, younger
- ▨ channel
- ▨ floodplain
- ▨ strath terrace
- ▨ unvegetated bar
- 🟩 vegetated bar

KLAMATH RIVER DAMS GEO-SPATIAL DATA MAP BOOK



21. Appendix I. Drill Logs of Groundwater Wells near PacifiCorp Reservoirs

21.1. Drill Logs near J.C. Boyle Reservoir

Table 21-1. Summary of well logs for wells within 2.5 miles of J.C. Boyle Reservoir. List of abbreviations used in table are at end of chapter.

Log_Number	**54713**	**54714**	**54615**	**13668**	**51633**
GS Elev	3797	3805	3781.6	3810	3827
Nearest Res.	JC Boyle	JC Boyle	JC Boyle	JC Boyle	JC Boyle
Dist. To Res (ft)	29.5	62.3	65.6	183.7	203.4
Res Elev. (ft)	3787.0	3787.0	3787.0	3787.0	3787.0
Res. Bed. UPST (ft)	3780.0	3780.0	3780.0	3780.0	3780.0
Res. Bed. DNST (ft)	3720.0	3720.0	3720.0	3720.0	3720.0
Top_Perf	84.4	49.1	125.2	22.0	126.0
Top_P_Elev	3712.6	3755.9	3656.4	3788.0	3701.0
Bottom_Perf	84.4	79.1	125.2	180.0	315.0
Bot_P_Elev	3712.6	3725.9	3656.4	3630.0	3512.0
Depth	84.4	79.1	125.2	180.0	315.0
Well Bottom Elev.	3712.6	3725.9	3656.4	3630.0	3512.0
1st Water				155.0	126.0
1st Water Elev				3655.0	3701.0
W.B. Zone				155.0	126.0
W.B. Zone Elev				3655.0	3701.0
GPM				15.0	55.0
Static_Water	20.3			120.0	126.0
Static_wtr_Elev	3776.8			3690.0	3701.0
Unit Top (ft bgs)	0	0	0	0	0
Unit Bot (ft bgs)	20.7	22.7	5.2	1	5
Unit Material	tuff, bedded	tuff, bedded	alluvium	soil, brn	clay, brn w/ rock, broken
Unit Top	20.7	22.7	5.2	1	5
Unit Bot	44.39	49.1	33.7	22	19
Unit Material	sediments, mixed	sediments, mixed	SDST w/ CGLT - tuff	clay, brn	basalt, gray, hard
Unit Top	44.39	49.1	33.7	22	19
Unit Bot	51.31	58.2	38.2	34	24
Unit Material	basalt, sheared	basalt, sheared	silt, diatomaceous	lava, blk	basalt, broken w/ ash, brn
Unit Top	51.31	58.2	38.2	34	24

Log_Number	54713	54714	54615	13668	51633
Unit Bot	69.4	64.1	41.4	102	31
Unit Material	basalt, breccia	basalt, breccia	SDST - tuff	lava, brn	basalt, gray & brn, broken
Unit Top	69.4	64.1	41.4	102	31
Unit Bot	84.4	79.1	43.2	133	50
Unit Material	basalt	basalt	silt, diatomaceous	lava, red	basalt, gray, hard
Unit Top			43.2	133	50
Unit Bot			73.7	155	54
Unit Material			sand, silty w/ silt - fluvial volcaniclastics	lava, blk	ash, brn w/ basalt
Unit Top			73.7	155	54
Unit Bot			75.5	180	75
Unit Material			basalt flow top	CGLT, lava, brn	basalt, gray, hard
Unit Top			75.5		75
Unit Bot			85.2		92
Unit Material			basalt A		ash, brn w/ basalt
Unit Top			85.2		92
Unit Bot			96.5		101
Unit Material			basalt X		basalt, gray, hard
Unit Top					101
Unit Bot					118
Unit Material					ash, brn w/ basalt
Unit Top					118
Unit Bot					125
Unit Material					basalt, gray, hard
Unit Top					125
Unit Bot					127
Unit Material					basalt, gray, fract'd w/ water
Unit Top					127
Unit Bot					148
Unit Material					basalt, brn & gray, broken w/

Log_Number	54713	54714	54615	13668	51633
					water
Unit Top					148
Unit Bot					152
Unit Material					ash, brn w/ basalt w/ water
Unit Top					152
Unit Bot					167
Unit Material					basalt, gray, hard
Unit Top					167
Unit Bot					192
Unit Material					basalt, fract'd, broken w/ water
Unit Top					192
Unit Bot					206
Unit Material					basalt, gray, hard w/ water
Unit Top					206
Unit Bot					209
Unit Material					ash, fract'd, soft
Unit Top					209
Unit Bot					231
Unit Material					basalt, gray, hard w/ water
Unit Top					231
Unit Bot					234
Unit Material					basalt, broken w/ water
Unit Top					234
Unit Bot					270
Unit Material					basalt, gray, hard w/ water
Unit Top					270
Unit Bot					273
Unit Material					basalt, gray, fract'd w/ water
Unit Top					273

Log_Number	**54713**	**54714**	**54615**	**13668**	**51633**
Unit Bot					291
Unit Material					basalt, gray, hard
Unit Top					291
Unit Bot					308
Unit Material					basalt, broken w/ ash w/ water
Unit Top					308
Unit Bot					315
Unit Material					basalt, gray, caving

Log_Number	**54618**	**14002**	**13628**	**10514**	**10059**
GS Elev	3833.3	3876	3885	3876	3908
Nearest Res.	JC Boyle	JC Boyle	JC Boyle	JC Boyle	JC Boyle
Dist. To Res (ft)	278.9	2706.8	2884.0	4721.4	5518.6
Res Elev. (ft)	3787.0	3787.0	3787.0	3787.0	3787.0
Res. Bed. UPST (ft)	3780.0	3780.0	3780.0	3780.0	3780.0
Res. Bed. DNST (ft)	3720.0	3720.0	3720.0	3720.0	3720.0
Top_Perf	125.5	98.0	201.0	275.0	30.0
Top_P_Elev	3707.8	3778.0	3684.0	3601.0	3878.0
Bottom_Perf	125.5	238.0	241.0	315.0	281.0
Bot_P_Elev	3707.8	3638.0	3644.0	3561.0	3627.0
Depth	125.5	238.0	281.0	324.0	281.0
Well Bottom Elev.	3707.8	3638.0	3604.0	3552.0	3627.0
1st Water		181.0	210.0	242.0	77.0
1st Water Elev		3695.0	3675.0	3634.0	3831.0
W.B. Zone		181.0	210.0	230.0	203.0
W.B. Zone Elev		3695.0	3675.0	3646.0	3705.0
GPM		25.0	30.0	40.0	12.0
Static_Water		178.0	204.0	189.0	222.0
Static_wtr_Elev		3698.0	3681.0	3687.0	3686.0
Unit Top (ft bgs)	0	0	0	0	0
Unit Bot (ft bgs)	10.7	4	5	5	1
Unit Material	alluvium, gravelly	clay, brn, gravelly	topsoil w/ boulders	soil	topsoil
Unit Top	10.7	4	5	5	1
Unit Bot	16.7	19	25	13	13
Unit Material	silt, diatomaceous	clay, brn	lava, brn w/ clay	clay, brn	clay, brn
Unit Top	16.7	19	25	13	13
Unit Bot	50.5	47	59	75	16
Unit Material	SDST w/ CGLT - tuff	clay, gray, sandy	rock, blk	clay, blue	gravel, cemented
Unit Top	50.5	47	59	75	17
Unit Bot	54.5	56	71	122	35
Unit Material	silt, diatomaceous	clay, blk, sandy	cinders, brn	clay, brn	clay, brn
Unit Top	54.5	56	71	122	35
Unit Bot	56.7	71	210	132	77
Unit Material	SDST - tuff	clay, gray, gravelly	lava, blk	rock	clay, blue
Unit Top	56.7	71	210	132	77

Log_Number	**54618**	**14002**	**13628**	**10514**	**10059**
Unit Bot	70.5	87	226	230	101
Unit Material	sand, silty w/ silt - fluvial volcaniclastics	clay, gray, sandy	cinders, red	rock, gray w/ clay, brn	clay, blue w/ streaks of blk sand
Unit Top	70.5	87	226	230	101
Unit Bot	75	92	261	281	118
Unit Material	basalt flow top	clay, gray	lava, blk	rock, gray, broken	clay, blue
Unit Top	75	92	261	281	118
Unit Bot	85.5	108	277	305	134
Unit Material	basalt W	SDST, brn	cinders, red	rock, brn	SDST, gray
Unit Top	85.5	108	277	305	134
Unit Bot	100.7	134	282	324	155
Unit Material	basalt X	lava, brn, broken	lava, blk	rock, gray, broken	clay, blue w/ streaks of fine blk sand
Unit Top		134			155
Unit Bot		154			184
Unit Material		volcanics, red & brn			clay, blue
Unit Top		154			184
Unit Bot		238			203
Unit Material		volcanics, gray, hard w/ water			SDST, brn & clay
Unit Top					203
Unit Bot					212
Unit Material					lava, brn w/ clay
Unit Top					212
Unit Bot					215
Unit Material					rock, blk
Unit Top					215
Unit Bot					223
Unit Material					lava, brn w/ clay
Unit Top					223
Unit Bot					238
Unit Material					rock, gray w/ clay

Log_Number	**54618**	**14002**	**13628**	**10514**	**10059**
Unit Top					238
Unit Bot					257
Unit Material					rock, gray
Unit Top					257
Unit Bot					280
Unit Material					lava, brn, bubbly
Unit Top					280
Unit Bot					281
Unit Material					rock, gray

21.2. Drill Logs near Copco Reservoir

Table 21-2. Summary of well logs for wells within 2.5 miles of Copco Reservoir. List of abbreviations used in table are in Table 3-15 at end of chapter.

Log_Number	**70943**	**555722**	**406066**	**512954**	**555712**
GS Elev	2623.5	2624.8	2686.4	2613.4	2642.7
Nearest Res.	Copco	Copco	Copco	Copco	Copco
Dist. To Res (ft)	39.4	55.8	85.3	98.4	154.2
Res Elev. (ft)	2602.0	2602.0	2602.0	2602.0	2602.0
Res. Bed. UPST (ft)	2598.0	2598.0	2598.0	2598.0	2598.0
Res. Bed. DNST (ft)	2493.0	2493.0	2493.0	2493.0	2493.0
Top_Perf (ft bgs)	70.0	23.0	49.0	75.0	100.0
Top_P_Elev	2553.5	2601.8	2637.4	2538.4	2542.7
Bottom_Perf (ft bgs)	84.0	184.0	300.0	225.0	120.0
Bot_P_Elev	2539.5	2440.8	2386.4	2388.4	2522.7
Depth	90.0	184.0	300.0	384.0	220.0
Well Bottom Elev.	2533.5	2440.8	2386.4	2229.4	2422.7
1st Water	32.0		*180.0		
1st Water Elev	2591.5		*2506.4		
W.B. Zone			*180.0		
W.B. Zone Elev			*2506.4		
GPM		13.0	0.1	2.0	15.0
Static_Water (ft bgs)	15.0	40.0		50.0	80.0
Static_wtr_Elev	2608.5	2584.8		2563.4	2562.7
Unit Top (ft bgs)	0	0	0	0	0
Unit Bot (ft bgs)	32	10	21	18	40
Unit Material	clay w/ boulders	clay, tan	clay, blk	SH, gray	clay, brn
Unit Top	32	10	21	18	40
Unit Bot	33	184	25	97	75
Unit Material	gravel w/ water	rock, blue-grn w/ qtz stringers	clay, yellow	SH, brn	clay, tan
Unit Top	33		25	97	75
Unit Bot	60		44	130	220
Unit Material	clay w/ boulders		sand & gravel w/ clay, brn	rock, reddish-tan	rock, blk & grn w/ qtz stringers
Unit Top	60		44	130	
Unit Bot	75		180	225	
Unit Material	clay, blk		SDST, gray	rock, lt tan w/ minor rock, gray w/ rock, red,	

Log_Number	**70943**	**555722**	**406066**	**512954**	**555712**
				hard	
Unit Top	75		180	225	
Unit Bot	90		181	338	
Unit Material	rock		SDST, gray, broken w/ water	rock, white	
Unit Top			181	338	
Unit Bot			300	384	
Unit Material			SDST, gray	rock, reddish-tan	

Log_Number	113378	93347	406065	713255	1075453
GS Elev	2637.3	2655.4	2657.6	2624.9	2690.4
Nearest Res.	Copco	Copco	Copco	Copco	Copco
Dist. To Res (ft)	160.8	183.7	196.9	196.9	239.5
Res Elev. (ft)	2602.0	2602.0	2602.0	2602.0	2602.0
Res. Bed. UPST (ft)	2598.0	2598.0	2598.0	2598.0	2598.0
Res. Bed. DNST (ft)	2493.0	2493.0	2493.0	2493.0	2493.0
Top_Perf (ft bgs)	16.0	15.0	200.0	104.0	50.0
Top_P_Elev	2621.3	2640.4	2457.6	2520.9	2640.4
Bottom_Perf (ft bgs)	75.0	110.0	200.0	124.0	200.0
Bot_P_Elev	2562.3	2545.4	2457.6	2500.9	2490.4
Depth	75.0	110.0	200.0	124.0	200.0
Well Bottom Elev.	2562.3	2545.4	2457.6	2500.9	2490.4
1st Water	49.0		150.0		80.0
1st Water Elev	2588.3		2507.6		2610.4
W.B. Zone	49.0		150.0		80.0
W.B. Zone Elev	2588.3		2507.6		2610.4
GPM	25.0	20.0	0.8	30.0	17.0
Static_Water (ft bgs)	40.0	15.0	60.0	60.0	35.0
Static_wtr_Elev	2597.3	2640.4	2597.6	2564.9	2655.4
Unit Top (ft bgs)	0	0	0	0	0
Unit Bot (ft bgs)	20	15	18	22	6
Unit Material	adobe w/ boulders	clay, brn	clay, blk	adobe, brn	clay, blk
Unit Top	20	15	18	22	6
Unit Bot	49	30	21	75	25
Unit Material	soil w/ rock	soil, diatomacious earth	clay, white	adobe, gray	clay, yellow
Unit Top	49	30	21	75	25
Unit Bot	60	45	32	95	45
Unit Material	boulders, sm w/ water	clay, brn	ash, red	gravel, gray-blk, cobbly	CLST, white
Unit Top		45	32	95	45
Unit Bot		110	47	104	47
Unit Material		rock, brn	CLST, blue, caving	SH, brn	sand & gravel
Unit Top			47	104	47
Unit Bot			98	124	80

Log_Number	113378	93347	406065	713255	1075453
Unit Material			CLST, blue	SH, grn, hard w/ rock, blk	basalt, blk
Unit Top			98		80
Unit Bot			99		82
Unit Material			CLST, blue, broken		SDST, blue, w/ qtz w/ water
Unit Top			99		82
Unit Bot			150		95
Unit Material			clay, blue		SDST, blue
Unit Top			150		95
Unit Bot			151		140
Unit Material			CLST, blue, broken		basalt, blk
Unit Top			151		140
Unit Bot			200		142
Unit Material			clay, blue		SDST, blue, fract'd w/ water
Unit Top					142
Unit Bot					180
Unit Material					basalt, blk
Unit Top					180
Unit Bot					182
Unit Material					SDST, blue, fract'd w/ water
Unit Top					182
Unit Bot					200
Unit Material					SDST, blue

Log_Number	**750784**	**406993**	**126312**	**1075456**	**781717**
GS Elev	2676.3	2657.6	2636.1	2657.6	2700.1
Nearest Res.	Copco	Copco	Copco	Copco	Copco
Dist. To Res (ft)	242.8	259.2	272.3	420.0	429.8
Res Elev. (ft)	2602.0	2602.0	2602.0	2602.0	2602.0
Res. Bed. UPST (ft)	2598.0	2598.0	2598.0	2598.0	2598.0
Res. Bed. DNST (ft)	2493.0	2493.0	2493.0	2493.0	2493.0
Top_Perf (ft bgs)	460.0	152.0	63.0	50.0	40.0
Top_P_Elev	2216.3	2505.6	2573.1	2607.6	2660.1
Bottom_Perf (ft bgs)	500.0	172.0	83.0	425.0	512.0
Bot_P_Elev	2176.3	2485.6	2553.1	2232.6	2188.1
Depth	510.0	172.0	83.0	425.0	512.0
Well Bottom Elev.	2166.3	2485.6	2553.1	2232.6	2188.1
1st Water				125.0	118.0
1st Water Elev				2532.6	2582.1
W.B. Zone				125.0	118.0
W.B. Zone Elev				2532.6	2582.1
GPM	40.0	10.0	10.0	15.0	100.0
Static_Water (ft bgs)	60.0	150.0	40.0	50.0	261.0
Static_wtr_Elev	2616.3	2507.6	2596.1	2607.6	2439.1
Unit Top (ft bgs)	0	0	0	0	0
Unit Bot (ft bgs)	384	150	6	6	1
Unit Material	No Log	rock, tan	clay, brn	clay, blk	soil, blk
Unit Top	384	150	6	6	1
Unit Bot	390	172	35	20	15
Unit Material	rock, brn, fract'd	granite, broken, decomp'd	clay, lt brn, sticky	clay, yellow	SDST, brn
Unit Top	390		35	20	15
Unit Bot	500		65	35	30
Unit Material	rock, gray, decomp'd		clay, blue, sticky	CLST, white	CLST, yellow
Unit Top	500		65	35	30
Unit Bot	510		70	95	58
Unit Material	rock, gray, hard, fract'd		sand, blue, cemented	basalt, blk	SPTN, blue
Unit Top			70	95	58
Unit Bot			80	125	60
Unit Material			rock, brn, decomp'd	SDST, blue w/ qtz	SDST, brn
Unit Top			80	125	60

Log_Number	750784	406993	126312	1075456	781717
Unit Bot			83	127	118
Unit Material			rock, brn, hard w/rock, blk	SDST, blue, fract'd w/ water	basalt, blue, hard
Unit Top				127	118
Unit Bot				345	119
Unit Material				basalt, blk	basalt, brn, fract'd w/ water
Unit Top				345	119
Unit Bot				347	120
Unit Material				QTZ, fract'd w/ water	basalt, brn
Unit Top				347	120
Unit Bot				408	135
Unit Material				basalt, blk	basalt, blue
Unit Top				408	135
Unit Bot				410	140
Unit Material				basalt, blk, fract'd w/ qtz w/ water	basalt, brn, fract'd w/ water
Unit Top				410	140
Unit Bot				425	348
Unit Material				basalt, blk	lava, blk, hard
Unit Top					348
Unit Bot					350
Unit Material					lava, blk w/ water
Unit Top					350
Unit Bot					376
Unit Material					ash, red
Unit Top					376
Unit Bot					378
Unit Material					lava, red w/ qtz w/ water
Unit Top					378
Unit Bot					400
Unit Material					lava, blk, hard
Unit Top					400
Unit Bot					440

Log_Number	**750784**	**406993**	**126312**	**1075456**	**781717**
Unit Material					SPTN, grn
Unit Top					440
Unit Bot					510
Unit Material					basalt, blk
Unit Top					510
Unit Bot					512
Unit Material					basalt, blk, q/ qtz w/ water

Log_Number	**1089469**	**824871**	**50076**	**784332**	**784331**
GS Elev	2727.8	2775.5	2667.5	2672.6	2688.0
Nearest Res.	Copco	Copco	Copco	Copco	Copco
Dist. To Res (ft)	547.9	1148.4	1335.4	2004.7	2142.5
Res Elev. (ft)	2602.0	2602.0	2602.0	2602.0	2602.0
Res. Bed. UPST (ft)	2598.0	2598.0	2598.0	2598.0	2598.0
Res. Bed. DNST (ft)	2493.0	2493.0	2493.0	2493.0	2493.0
Top_Perf (ft bgs)	28.0	140.0	44.0	130.0	95.0
Top_P_Elev	2699.8	2635.5	2623.5	2542.6	2593.0
Bottom_Perf (ft bgs)	350.0	204.0	60.0	150.0	110.0
Bot_P_Elev	2377.8	2571.5	2607.5	2522.6	2578.0
Depth	350.0	250.0	60.0	150.0	110.0
Well Bottom Elev.	2377.8	2525.5	2607.5	2522.6	2578.0
1st Water	250.0	140.0	52.0	146.0	22.0
1st Water Elev	2477.8	2635.5	2615.5	2526.6	2666.0
W.B. Zone	250.0		52.0	146.0	
W.B. Zone Elev	2477.8		2615.5	2526.6	
GPM	10.0	42.0	12.0	25.0	25.0
Static_Water (ft bgs)	90.0	45.0	32.0	13.0	10.0
Static_wtr_Elev	2637.8	2730.5	2635.5	2659.6	2678.0
Unit Top (ft bgs)	0	0	0	0	0
Unit Bot (ft bgs)	25	9	5	70	22
Unit Material	rock, brn, broken	clay, blk	clay, sticky	clay, brn w/ rock	topsoil w/ boulders
Unit Top	25	9	5	70	22
Unit Bot	250	16	15	75	40
Unit Material	rock, gray, hard	clay, brn w/ cobbles	clay, brn & red	boulders, blue & gray	clay, blk w/ water
Unit Top	250	16	15	75	40
Unit Bot	251	26	17.5	146	63
Unit Material	rock, gray, fract'd w/ water	basalt	clay, brn & red, hard	clay, brn w/ rock	clay, brn w/ rock, sm
Unit Top	251	26	17.5	146	63
Unit Bot	310	35	40	150	74
Unit Material	rock, gray, hard	gravel & cobbles	clay, white & gray	rock, broken w/ water	cinders, blk & brn & red
Unit Top	310	35	40		74
Unit Bot	312	70	53		77
Unit Material	rock, gray, hard, fract'd	SH, brn w/ gravel	mud, blue w/ water		rock, brn broken

Log_Number	**1089469**	**824871**	**50076**	**784332**	**784331**
Unit Top	312	70	53		77
Unit Bot	350	95	60		102
Unit Material	rock, gray, hard	SH, brn w/ qtz	rock		rock, brn, hard
Unit Top		95			102
Unit Bot		135			110
Unit Material		rock, blue-gray w/ qtz			clay, blue
Unit Top		135			
Unit Bot		150			
Unit Material		SH w/ rock, blue-gray w/ qtz			
Unit Top		150			
Unit Bot		163			
Unit Material		SH, purple			
Unit Top		163			
Unit Bot		171			
Unit Material		rock, blue-gray			
Unit Top		171			
Unit Bot		260			
Unit Material		SH, gray & blk			

Log_Number	**783919**	**1075033**
GS Elev	2866.8	2995.9
Nearest Res.	Copco	Copco
Dist. To Res (ft)	5325.1	6276.6
Res Elev. (ft)	2602.0	2602.0
Res. Bed. UPST (ft)	2598.0	2598.0
Res. Bed. DNST (ft)	2493.0	2493.0
Top_Perf (ft bgs)	140.0	31.0
Top_P_Elev	2726.8	2964.9
Bottom_Perf (ft bgs)	180.0	128.0
Bot_P_Elev	2686.8	2867.9
Depth	184.0	128.0
Well Bottom Elev.	2682.8	2867.9
1st Water		50.0
1st Water Elev		2945.9
W.B. Zone		50.0
W.B. Zone Elev		2945.9
GPM	30.0	8.0
Static_Water (ft bgs)	20.0	18.0
Static_wtr_Elev	2846.8	2977.9
Unit Top (ft bgs)	0	0
Unit Bot (ft bgs)	10	3
Unit Material	adobe	clay, blk
Unit Top	10	3
Unit Bot	18	12
Unit Material	rock, grn, harder	clay, brn
Unit Top	18	12
Unit Bot	45	32
Unit Material	SH, brn	boulders w/ sand & gravel
Unit Top	45	32
Unit Bot	80	42
Unit Material	rock, grn, harder	clay, blue
Unit Top	80	42
Unit Bot	85	50
Unit Material	rock, blk w/ red color	rock, blue
Unit Top	85	50

Log_Number	783919	1075033
Unit Bot	90	52
Unit Material	rock, lt grn	rock, brn w/ water
Unit Top	90	52
Unit Bot	110	85
Unit Material	rock, blk & red, interbedded	rock, blue
Unit Top	110	85
Unit Bot	180	87
Unit Material	rock, lt grn	rock, blue, fract'd w/ water
Unit Top	180	87
Unit Bot	182	128
Unit Material	rock, brn, soft	rock, blue
Unit Top	182	
Unit Bot	184	
Unit Material	rock, grn, hard	

21.3. Drill Logs near Iron Gate Reservoir

Table 21-3. Summary of well logs for wells within 2.5 miles of Iron Gate Reservoir. List of abbreviations used in table are in Table 3-15 at end of chapter.

Log_Number	**311084**	**14918**	**78652**	**4355**	**334387**
GS Elev	2712.9	2329.4	2409.0	2467.7	2508.8
Nearest Res.	Iron Gate	Iron Gate	Iron Gate	Iron Gate	Iron Gate
Dist. To Res (ft)	544.6	554.5	620.1	712.0	866.2
Res Elev. (ft)	2328.0	2328.0	2328.0	2328.0	2328.0
Res. Bed. UPST (ft)	2320.0	2320.0	2320.0	2320.0	2320.0
Res. Bed. DNST (ft)	2165.0	2165.0	2165.0	2165.0	2165.0
Top_Perf (ft bgs)	52.0	40.0	80.0	20.0	25.0
Top_P_Elev	2660.9	2289.4	2329.0	2447.7	2483.8
Bottom_Perf (ft bgs)	270.0	160.0	140.0	70.0	420.0
Bot_P_Elev	2442.9	2169.4	2269.0	2397.7	2088.8
Depth	270.0	160.0	140.0	100.0	420.0
Well Bottom Elev.	2442.9	2169.4	2269.0	2367.7	2088.8
1st Water	*168.0	20.0	25.0	30.0	
1st Water Elev	2544.9	2309.4	2384.0	2437.7	
W.B. Zone	*250.0	20.0	25.0	50.0	
W.B. Zone Elev	2462.9	2309.4	2384.0	2417.7	
GPM	25.0	40.0	6.0	10.0	0.1
Static_Water (ft bgs)		-5.0	*25.0	50.0	290.0
Static_wtr_Elev		2334.4	*2384.0	2417.7	2218.8
Unit Top (ft bgs)	0	0	0	0	0
Unit Bot (ft bgs)	32	20	20	2	350
Unit Material	rock-dirt	clay, brn, rocky	clay, brn w/ rock	hardpan	N/R
Unit Top	32	20	20	2	350
Unit Bot	106	40	40	30	395
Unit Material	clay, gray w/ rock, brn	rock, brn, soft w/ water	rock, brn, soft	adobe, gray	CLST, blue
Unit Top	106	40	40	30	395
Unit Bot	168	100	50	70	420
Unit Material	clay, gray w/ rock, brn	rock, grn, hard	rock, gray	gravel, volcanic	lava ash, red
Unit Top	168	100	50	70	
Unit Bot	209	140	60	100	
Unit Material	rock, brn-gray	rock, gray	rock, brn	gravel, volcanic w/ clay	
Unit Top	209	140	60		
Unit Bot	229	160	70		

Log_Number	**311084**	**14918**	**78652**	**4355**	**334387**
Unit Material	rock, brn	rock, grn	rock, gray		
Unit Top	229		70		
Unit Bot	270		140		
Unit Material	rock, brnsh-gray w/water		rock, brn		

Log_Number	**184187**	**311078**	**333890**	**99852**	**1087529**
GS Elev	2712.9	2465.9	2371.7	2712.9	2712.8
Nearest Res.	Iron Gate	Iron Gate	Iron Gate	Iron Gate	Iron Gate
Dist. To Res (ft)	987.6	1095.9	1683.2	1735.6	2073.6
Res Elev. (ft)	2328.0	2328.0	2328.0	2328.0	2328.0
Res. Bed. UPST (ft)	2320.0	2320.0	2320.0	2320.0	2320.0
Res. Bed. DNST (ft)	2165.0	2165.0	2165.0	2165.0	2165.0
Top_Perf (ft bgs)	271.0	22.0	23.0	20.0	100.0
Top_P_Elev	2441.9	2443.9	2348.7	2692.9	2612.8
Bottom_Perf (ft bgs)	291.0	246.0	271.0	500.0	200.0
Bot_P_Elev	2421.9	2219.9	2100.7	2212.9	2512.8
Depth	291.0	246.0	271.0	500.0	200.0
Well Bottom Elev.	2421.9	2219.9	2100.7	2212.9	2512.8
1st Water	50.0		46.0	191.0	180.0
1st Water Elev	2662.9		2325.7	2521.9	2532.8
W.B. Zone	280.0		210.0		
W.B. Zone Elev	2432.9		2161.7		
GPM	15.0	12.0	12.0	5.0	25.0
Static_Water (ft bgs)				150.0	
Static_wtr_Elev				2562.9	
Unit Top (ft bgs)	0	0	0	0	0
Unit Bot (ft bgs)	45	25	23	1	160
Unit Material	topsoil, clays into lava, lt gray	clay, adobe	clay, red	soil, brn	clay, adobe
Unit Top	45	25	23	1	160
Unit Bot	281	46	46	12	200
Unit Material	lava, lt gray w/ clay, gray & blue	clay, lt brn, sticky	clay, gray	clay, brn	rock, brn
Unit Top	291	46	46	12	
Unit Bot	291	87	148	26	
Unit Material	lava, lt gray	rock w/ clay, gray	clay, redish-brn w/ water	CLST, brn	
Unit Top		87	148	26	
Unit Bot		128	210	160	
Unit Material		clay, reddish-gray	gravel, brn w/ water	SDST, blue	
Unit Top		128	210	160	

Log_Number	**184187**	**311078**	**333890**	**99852**	**1087529**
Unit Bot		246	271	195	
Unit Material		clay, grayish-brn	rock, gray to brnsh-gray w/ water	CLST, red	
Unit Top				195	
Unit Bot				250	
Unit Material				SDST, blue	
Unit Top				250	
Unit Bot				268	
Unit Material				CLST, red	
Unit Top				268	
Unit Bot				290	
Unit Material				SDST, blue	
Unit Top				290	
Unit Bot				291	
Unit Material				SDST, blue, broken	
Unit Top				291	
Unit Bot				312	
Unit Material				CLST, red	
Unit Top				312	
Unit Bot				367	
Unit Material				SDST, grn	
Unit Top				367	
Unit Bot				382	
Unit Material				CLST, red	
Unit Top				382	
Unit Bot				383	
Unit Material				SDST, blue, broken	
Unit Top				383	
Unit Bot				448	
Unit Material				CLST, blue	

Log_Number	**781723**	**369526**	**414209**	**99834**	**1075044**
GS Elev	2171.0	2571.2	2624.8	2323.7	2815.2
Nearest Res.	Iron Gate	Iron Gate	Iron Gate	Iron Gate	Iron Gate
Dist. To Res (ft)	3025.1	3376.1	3507.4	3776.4	5049.5
Res Elev. (ft)	2328.0	2328.0	2328.0	2328.0	2328.0
Res. Bed. UPST (ft)	2320.0	2320.0	2320.0	2320.0	2320.0
Res. Bed. DNST (ft)	2165.0	2165.0	2165.0	2165.0	2165.0
Top_Perf (ft bgs)	35.0	25.0		20.0	52.0
Top_P_Elev	2136.0	2546.2		2303.7	2763.2
Bottom_Perf (ft bgs)	90.0	200.0		200.0	260.0
Bot_P_Elev	2081.0	2371.2		2123.7	2555.2
Depth	90.0	200.0		200.0	268.0
Well Bottom Elev.	2081.0	2371.2	2624.8	2123.7	2547.2
1st Water	62.0	105.0		25.0	185.0
1st Water Elev	2109.0	2466.2		2298.7	2630.2
W.B. Zone	35.0	*105.0		156.0	185.0
W.B. Zone Elev	2136.0	*2466.2		2167.7	2630.2
GPM	75.0	20.0		25.0	30.0
Static_Water (ft bgs)	30.0	30.0		10.0	30.0
Static_wtr_Elev	2141.0	2541.2		2313.7	2785.2
Unit Top (ft bgs)	0	0		0	0
Unit Bot (ft bgs)	3	2		1	2
Unit Material	clay, blk	clay, blk	No Log	soil, brn	clay, blk w/ cobbles
Unit Top	3	2		1	2
Unit Bot	18	12		16	18
Unit Material	clay, brn	clay, brn		clay, brn	clay, brn
Unit Top	18	12		16	18
Unit Bot	24	35		37	28
Unit Material	sand & boulders	CLST, red		basalt, brn, broken w/ water	ash,red
Unit Top	24	35		37	28
Unit Bot	30	105		100	45
Unit Material	SDST, brn	CLST, blue		basalt, blue	rock, brn, soft
Unit Top	30	105		100	45
Unit Bot	62	108		112	120
Unit Material	SPTN, blue	CLST, red, broken w/ water		CLST, purple	rock, blue, hard

Log_Number	**781723**	**369526**	**414209**	**99834**	**1075044**
Unit Top	62	108		112	120
Unit Bot	63	170		156	185
Unit Material	SPTN, blue w/ qtz w/ water	CLST, red		basalt, blue	rock, blue
Unit Top	63	170		156	185
Unit Bot	90	175		157	186
Unit Material	SPTN, blue	CLST, blue, broken w/ water		basalt, blue, broken w/ water	rock, blue, fract'd w/w water
Unit Top		175		157	186
Unit Bot		200		180	240
Unit Material		SDST, blue		basalt, blue	rock, blue, hard
Unit Top				180	240
Unit Bot				182	242
Unit Material				basalt, blue, broken w/ water	rock, blue, fract'd w/w water
Unit Top				182	242
Unit Bot				200	268
Unit Material				basalt, blue	rock, blue, hard

Log_Number	**781725**	**781726**	**1075458**	**1087565**	**134222**
GS Elev	2696.6	2460.8	2672.5	2696.1	2481.5
Nearest Res.	Iron Gate	Iron Gate	Iron Gate	Iron Gate	Iron Gate
Dist. To Res (ft)	5262.7	5331.6	5479.3	6942.6	7585.7
Res Elev. (ft)	2328.0	2328.0	2328.0	2328.0	2328.0
Res. Bed. UPST (ft)	2320.0	2320.0	2320.0	2320.0	2320.0
Res. Bed. DNST (ft)	2165.0	2165.0	2165.0	2165.0	2165.0
Top_Perf (ft bgs)	54.0	55.0	40.0	140.0	120.0
Top_P_Elev	2642.6	2405.8	2632.5	2556.1	2361.5
Bottom_Perf (ft bgs)	265.0	530.0	125.0	300.0	160.0
Bot_P_Elev	2431.6	1930.8	2547.5	2396.1	2321.5
Depth	275.0	625.0	125.0	300.0	160.0
Well Bottom Elev.	2421.6	1835.8	2547.5	2396.1	2321.5
1st Water	120.0	180.0	65.0	120.0	100.0
1st Water Elev	2576.6	2280.8	2607.5	2576.1	2381.5
W.B. Zone	120.0	180.0	65.0	140.0	100.0
W.B. Zone Elev	2576.6	2280.8	2607.5	2556.1	2381.5
GPM	7.0	12.0	100.0	20.0	20.0
Static_Water (ft bgs)	52.0	130.0	35.0	120.0	50.0
Static_wtr_Elev	2644.6	2330.8	2637.5	2576.1	2431.5
Unit Top (ft bgs)	0	0	0	0	0
Unit Bot (ft bgs)	4	1	9	4	10
Unit Material	clay, blk	clay, blk	clay, blk	topsoil	clay, brn
Unit Top	4	1	9	4	10
Unit Bot	20	30	38	20	40
Unit Material	clay, brn	clay, brn	SDST, brn	clay	rock, brn, soft
Unit Top	20	30	38	20	40
Unit Bot	46	120	55	120	140
Unit Material	CLST, red	SDST, blue, hard	basalt, blue, hard	SH, gray	rock, gray
Unit Top	46	120	55	120	140
Unit Bot	85	150	60	260	160
Unit Material	SPTN, blue, hard	CLST, blue	CLST, purple	SH, dk gray	rock, gray,hard
Unit Top	85	150	60	260	
Unit Bot	120	180	65	300	
Unit Material	ash, red	SDST, blue	basalt, blue	SH, gray, fract'd	
Unit Top	120	180	65		
Unit Bot	121	182	78		

Log_Number	**781725**	**781726**	**1075458**	**1087565**	**134222**
Unit Material	SPTN, blue w/ qtz w/ water	SDST, blue, fract'd w/ water	basalt, blue, fract'd w/ qtz w/ water		
Unit Top	121	182	78		
Unit Bot	160	360	107		
Unit Material	SPTN, blue, hard	SDST,blue	basalt, blue, hard		
Unit Top	160	360	107		
Unit Bot	220	361	110		
Unit Material	ash, red	SDST, blue, fract'd w/ water	basalt, blue, fract'd w/ water		
Unit Top	220	361	110		
Unit Bot	235	410	118		
Unit Material	SPTN,blue, hard	SDST, blue	basalt, blue, hard		
Unit Top	235	410	118		
Unit Bot	236	430	125		
Unit Material	SPTN, blue, fract'd w/ water	basalt, blue	CLST, purple		
Unit Top	236	430			
Unit Bot	275	431			
Unit Material	SPTN,blue, hard	basalt, blue, fract'd w/ water			
Unit Top		431			
Unit Bot		530			
Unit Material		basalt, blue			
Unit Top		530			
Unit Bot		625			
Unit Material		ash, red, caving			

Log_Number	**134223**	**134224**	**14912**	**14911**	**958105**
GS Elev	2481.5	2481.5	2389.6	2389.6	2767.5
Nearest Res.	Iron Gate	Iron Gate	Iron Gate	Iron Gate	Iron Gate
Dist. To Res (ft)	8199.2	8271.4	8904.6	9649.4	10499.2
Res Elev. (ft)	2328.0	2328.0	2328.0	2328.0	2328.0
Res. Bed. UPST (ft)	2320.0	2320.0	2320.0	2320.0	2320.0
Res. Bed. DNST (ft)	2165.0	2165.0	2165.0	2165.0	2165.0
Top_Perf (ft bgs)	20.0	80.0	40.0	100.0	30.0
Top_P_Elev	2461.5	2401.5	2349.6	2289.6	2737.5
Bottom_Perf (ft bgs)	530.0	120.0	60.0	120.0	247.0
Bot_P_Elev	1951.5	2361.5	2329.6	2269.6	2520.5
Depth	530.0	120.0	60.0	120.0	250.0
Well Bottom Elev.	1951.5	2361.5	2329.6	2269.6	2517.5
1st Water		80.0	25.0	60.0	140.0
1st Water Elev		2401.5	2364.6	2329.6	2627.5
W.B. Zone		80.0	25.0	60.0	140.0
W.B. Zone Elev		2401.5	2364.6	2329.6	2627.5
GPM	1.0	15.0	50.0	50.0	
Static_Water (ft bgs)	60.0	30.0	10.0	28.0	-5.0
Static_wtr_Elev	2421.5	2451.5	2379.6	2361.6	2772.5
Unit Top (ft bgs)	0	0	0	0	0
Unit Bot (ft bgs)	10	5	20	20	2
Unit Material	clay, brn	clay, brn	clay, brn w/ gravel	clay, brn w/ rock	soil, brn
Unit Top	10	5	20	20	2
Unit Bot	40	20	60	40	17
Unit Material	rock, brn, soft	rock, red, soft	rock, blk w/ water	rock, lt gray	boulders
Unit Top	40	20		40	17
Unit Bot	95	40		80	18
Unit Material	clay, red, hard	rock, brn, soft		rock, gray w/ water	clay, brn
Unit Top	95	40		80	18
Unit Bot	120	120		120	27
Unit Material	rock, blk	rock, brn w/ water		rock, blk	rock, blue, broken
Unit Top	120				27
Unit Bot	530				140
Unit Material	rock, dk brn				rock, gray, hard
Unit Top					140
Unit Bot					141

Log_Number	**134223**	**134224**	**14912**	**14911**	**958105**
Unit Material					rock, gray, fract'd w/ water
Unit Top					141
Unit Bot					180
Unit Material					rock, gray, hard
Unit Top					180
Unit Bot					200
Unit Material					rock, red, hard
Unit Top					200
Unit Bot					210
Unit Material					rock, gray, hard
Unit Top					210
Unit Bot					211
Unit Material					rock, gray, fract'd w/ water
Unit Top					211
Unit Bot					250
Unit Material					rock, gray, hard

22. Appendix J. Reference Sediment Motion

The reference condition that is most commonly used is where the non-dimensional transport rate, W^*, is equal to 0.002 (Parker, 1990).

$$W^* = \frac{(s-1)gq_s}{\rho_s\left(\tau_g/\rho\right)^{1.5}} = 0.002 \qquad (1)$$

where s = relative specific density, g = acceleration of gravity, q_s = sediment transport rate, ρ_s = sediment density, τ_g = grain shear stress, ρ = water density. The transport rate, q_s, is primarily dependent upon the Shield's number, θ:

$$\theta = \frac{\tau_g}{\gamma(s-1)D_{50}} \qquad (1)$$

where θ = dimensionless Shield's number; τ_g = grain shear stress; γ = specific weight of water; s = relative specific density of sediment; and D_{50} = mean sediment size. The Shields number that gives W^* = 0.002 is termed the reference Shield's stress (θ_r). It can be described as the condition when many particles are moving and there is a small, but measureable, sediment transport rate. In our analysis, it corresponds to a Shields number of 0.0386.

The total shear stress can be separated into grain shear stress and form drag. Grain shear stress is commonly understood to be responsible for bedload transport and the shear stress due to form drag is commonly ignored. The channel grain shear stress τ_g is calculated as

$$\tau_g = \gamma R' S \qquad (2)$$

where R' = channel hydraulic radius due to grain shear stress; and S = friction slope. The total shear stress is partitioned into that due to form drag and that due to grain roughness. Manning's equation is valid for the channel hydraulic radius due to grain shear stress:

$$U = \frac{C_m}{n_g} R'^{\frac{2}{3}} S_f^{\frac{1}{2}} \qquad (3)$$

where C_m = 1.0 for SI units, and 1.486 for English units, or $C_m = (g/9.81)^{\frac{1}{3}}$, and R' is the hydraulic radius due to grain shear stress . Dividing this equation by the Manning's equation gives:

$$\frac{R'}{R} = \left(\frac{n_g}{n}\right)^{1.5} \qquad (4)$$

where R is the total hydraulic radius and n is the total Manning's roughness coefficient. The Manning's roughness coefficient for the bed grains, n_g, can be computed from the roughness height. First, the logarithmic velocity distribution is integrated over the depth to yield (López and Barragán, 2008):

$$\frac{U}{u_*'} = \frac{1}{\kappa}\ln\frac{R'}{k_s} + 6.25 \tag{5}$$

where κ is the von Karman constant (0.4), u_* is the shear velocity, and the log-law constant has assumed to be 6. Eq (5) can be approximately fit by the power law relation:

$$\frac{U}{u_*'} = 8.1\left(\frac{R'}{k_s}\right)^{\frac{1}{6}} \tag{6}$$

where k_s is a representative roughness height. Parker (1991) also used Eq (6) to approximate the roughness coefficient in gravel bed streams. The fit is best for R/k_s values between 5 and 200, which is the value most natural rivers will fall into. The error associated in predicting Manning's n values with this approximation is less than 3%.

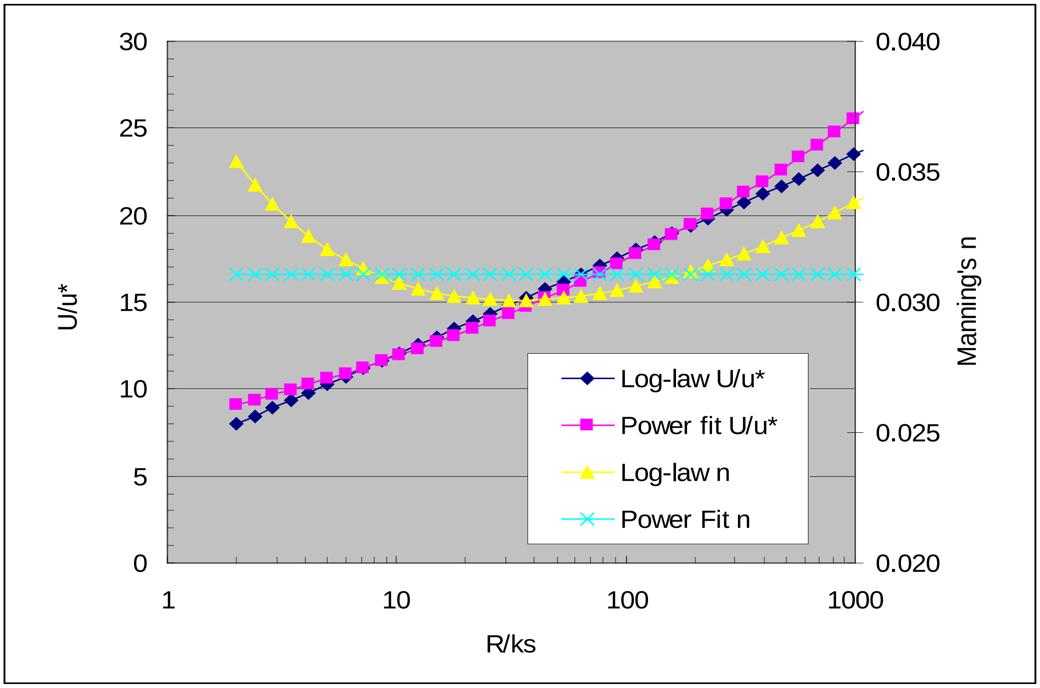


Figure 22-1. Comparison between Eq. 5 and 6. Also shown on the figure is the comparison between assuming k_s = 240 mm.

The Manning's roughness coefficient due to grain shear, n_g, can then be computed from the roughness height using the following dimensionally consistent formula:

$$n_g = 0.058\left(k_s / g\right)^{\frac{1}{6}} \tag{7}$$

Several different relations in alluvial rivers have been proposed for k_s ranging from 0.95 D_{50} (Federal Highway Administration, 1975) to 3 D_{90} (van Rijn, 1982). A more recent publication, López and Barragán (2008), suggests that $2.4D_{90}$, $2.8D_{84}$, and $6.1D_{50}$ all give equivalent predictions of Manning’s Roughness coefficient for river beds with gravel size or larger sediment, with a nonsinuous alignment and a flow path free of vegetation or obstacles. In their publication, they use the log law approximation (5) to compute Manning’s n, but as shown above, the error associated with using the power fit approximation (6) is less than 3 %.

23. Appendix K. Other Drawdown Scenarios Analyzed

Other drawdown scenarios are analyzed in this appendix.

Table 23-1. Scenarios analyzed for Reservoir Drawdown.

Scenario Number	Description
1	• Reopen old river diversion tunnel at Copco 1 and use this to drain reservoir beginning Nov 15, 2019 • Copco 1 is limited to 3 ft/day of drawdown. • Begin drawdown of J.C. Boyle and Iron Gate beginning Nov 15, 2019
2	• Do not use low level outlet at Copco 1, instead notch from top beginning Nov 15, 2019. • Notching of Copco 1 is at a rate of 6ft /wk. The notching will be two 20 ft wide sections, in alternating 12 ft high sections. • Begin drawdown of J.C. Boyle and Iron Gate beginning Nov 15, 2019 using low level outlets
3	• Do not use low level outlet at Copco 1, instead notch from top beginning Jan 1, 2019. • Notching of Copco 1 is at a rate of 6ft /wk. The notching will be two 20 ft wide sections, in alternating 12 ft high sections.
4	• Use low level outlet at Copco 1 and notch from top beginning Nov 15, 2019. • Notching of Copco 1 is at a rate of 6ft /wk. The notching will be two 20 ft wide sections, in alternating 12 ft high sections.
5	• Use low level outlet at Copco 1 and notch from top beginning Jan 1, 2019. • Notching of Copco 1 is at a rate of 6ft /wk. The notching will be two 20 ft wide sections, in alternating 12 ft high sections. • Begin drawdown of J.C. Boyle and Iron Gate beginning Jan 1, 2020
6	• Use low level outlet at Copco 1 and notch from top beginning Nov 15, 2019. • Limit drawdown rate at Copco I to 1 ft/d for upper 50 ft of reservoir, 3 ft/d below that • Notching of Copco 1 is at a rate of 6ft /wk. The notching will be two 20 ft wide sections, in alternating 12 ft high sections. • Begin removal of J.C. Boyle beginning Feb 15, 2020
7	• Use low level outlet at Copco 1 and notch from top beginning Jan 1, 2020 • Limit drawdown rate at Copco 1 to 1 ft/d for upper 50 ft of reservoir, 3 ft/d below that • Notching of Copco 1 is at a rate of 6ft /wk. The notching will be two 20 ft wide sections, in alternating 12 ft high sections. • Begin removal of J.C. Boyle beginning Jan 1, 2020

The following are common to all scenarios:

- Existing Low Level Outlet Capacities at Iron Gate and J.C. Boyle will be used.
- Iron Gate drawdown is begun at same time as Copco Reservoir
- Iron Gate drawdown rates are limited to 10 ft/day of drawdown
- Deconstruction of J.C. Boyle and Iron Gate embankments will not begin until after May 1.

23.1. Scenario 1

This scenario assumes drawdown begins Nov 15, 2019 and only the low level outlets are used to drain J.C. Boyle, Copco 1, and Iron Gate reservoirs.

The results of the hydrologic reservoir routing are shown in Figure 23-5 to Figure 23-2. The reservoir elevations in the 3 larger reservoirs are shown for 3 years: a dry year (2001), and median year (1976), and a wet year (1984). These were defined as years that had a 10%, 50%, and 90% exceedance in terms of flow volume between March and June. The daily exceedance values for reservoir elevations are also shown in the figures.

Because the flows commonly exceed the low level outlet capacity in the winter and spring, the reservoirs refill to some extent depending upon whether it is a dry, median, or wet year. In the dry year, J.C. Boyle does not refill more than a few feet; Copco 1 refills to about 2520 ft, and Iron Gate refills to about 2200 ft. In the median year, J.C. Boyle refills to about 3760 ft, Copco 1 to about 2575 ft, and Iron Gate to about 2225 ft. In a wet year, all three reservoirs overtop their spillway, or come very close to overtopping their spillway.

Because of its Iron Gate is an earthen dam, it cannot be overtopped at any time during the deconstruction. There has not been any event that would exceed the elevation 2240 feet at Iron Gate after May 1 based upon the hydrologic simulations using the period of record 1961 – 2008. After June 15, the Iron Gate reservoir can be maintained at an elevation of below 2190. Iron Gate Dam must not create any significant reservoir pool after Dec 1 to eliminate the possibility of a flood wave being created by a partially removed earthen dam.

The results of the sediment transport analysis for the years 2001, 1976, and 1984 are shown in Figure 23-7, Figure 23-8, and Figure 23-9, respectively. The concentrations are given below Iron Gate dam. There are significant dilution effects as tributaries enter downstream and this will be discussed later.

During a dry year, high concentrations may persist all the way well into the spring. The high concentrations are of shorter duration during a median year, but there are spikes of high concentration as the reservoir refills and empties.

During a wet year, there are spikes of concentration during period where the reservoir is draining, but there are also period where the reservoir is filling and the concentrations decreases to low. When the reservoirs finally drain completely in June and July, the concentrations remain high until August.

The amount of sediment eroded from each of the reservoirs under a dry, median, and wet year is shown in Figure 23-11. If dam removal occurs during a wet year, up to 56 % of the reservoir sediment would be eroded, whereas, about 38% of the sediment would be eroded if removal were to occur during a dry year. The remaining sediment is expected to stabilize upon the terraces. The erosion resistance of the dried sediment increased by more than 10 times based upon the erosion tests in Appendix D. Report on Erodibility Characteristics of Reservoir Sediment by Agricultural Research Service.

The sediment left on the terraces will also consolidate significantly. It is expected the thickness of the sediment left behind will decrease by about 40%. The volume will decrease by a larger amount and there will be significant cracking of the sediment. The cracking will allow preferential flow paths to form within the sediment and the overland flow during rain storms will create rills in the sediment. Stabilization of sediment is a primary reason why aggressive re-vegetation of the reservoir is necessary. Once grasses and other native species colonize the reservoir sediment, erosion will be significantly reduced.

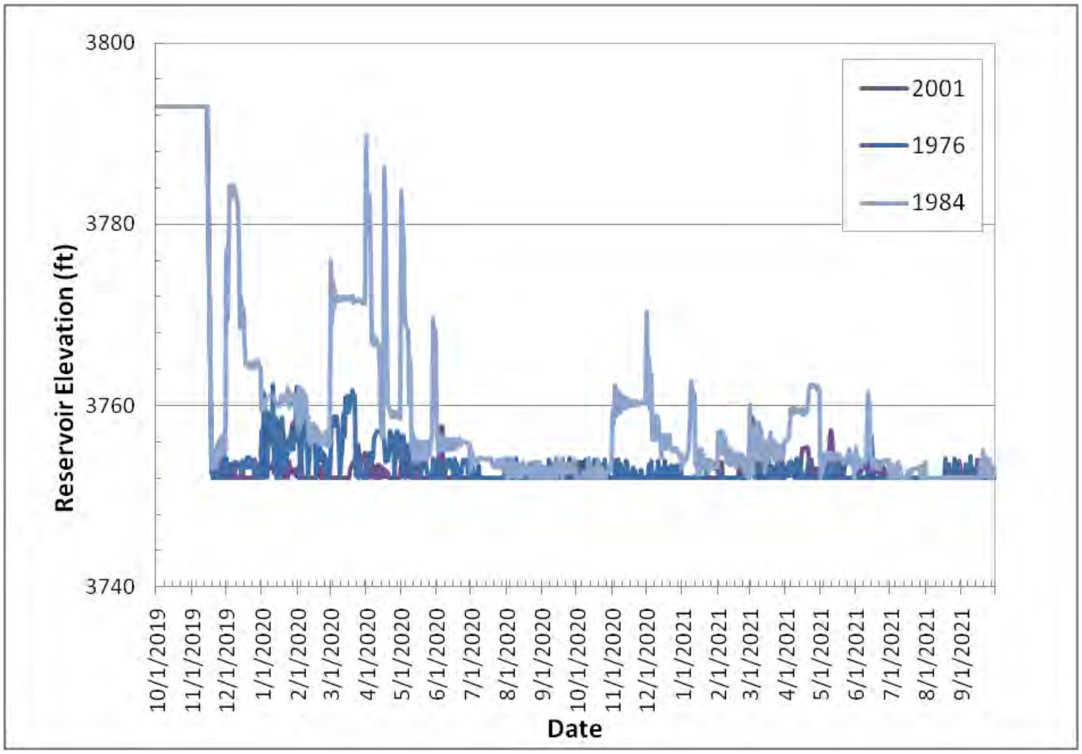


Figure 23-1.JC Boyle elevation for typical dry (2001), median (1976), and wet(1984) years for Scenario 1.

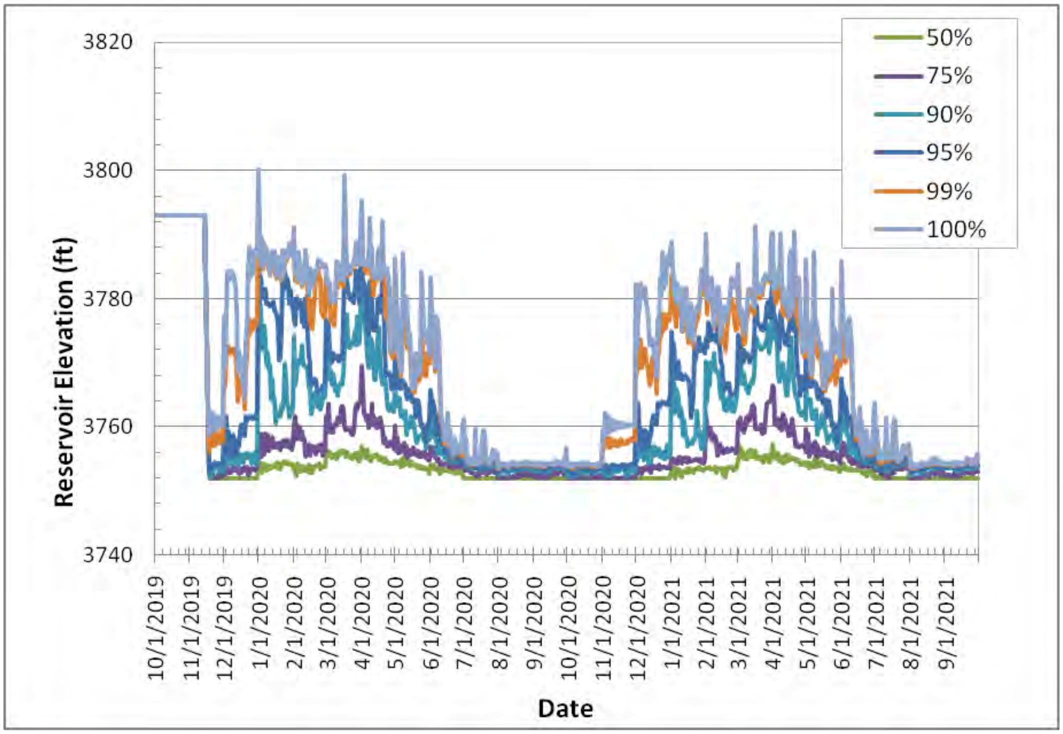


Figure 23-2. J.C. Boyle Non-Exceedance Elevations for all years from 1961 to 2008 for Scenario 1.

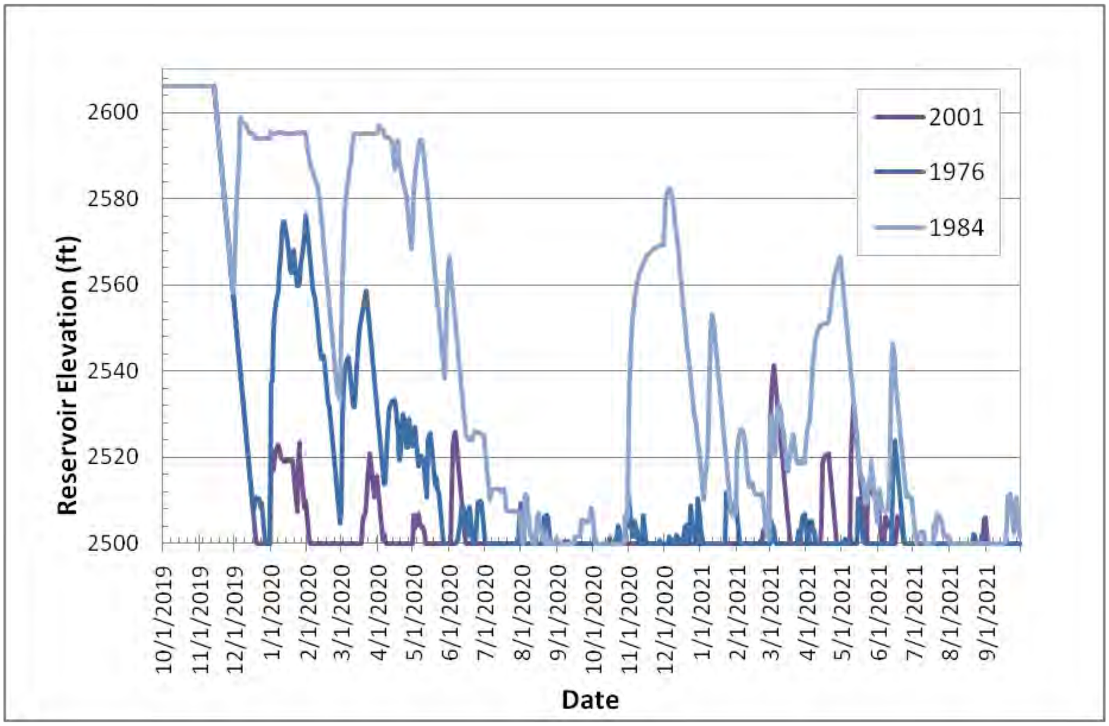


Figure 23-3. Copco 1 elevation for typical Dry (2001), Median (1976), and Wet (1984) years for Scenario 1.

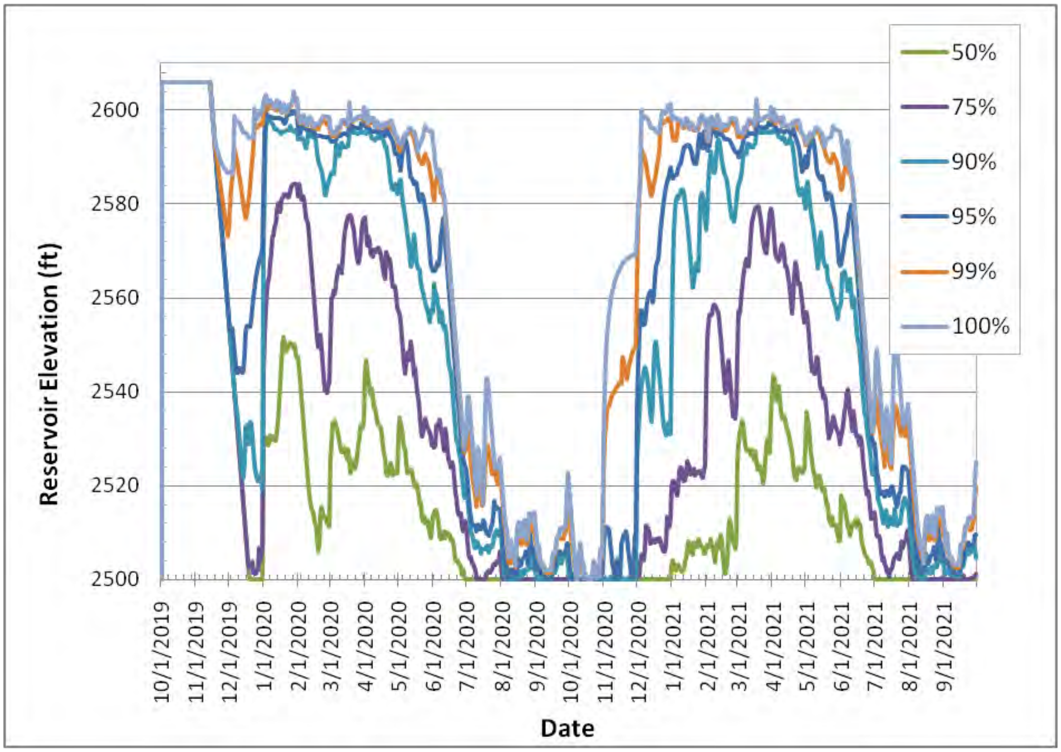


Figure 23-4. Copco 1 non-exceedance elevations for all years from 1961 to 2008 for Scenario 1.

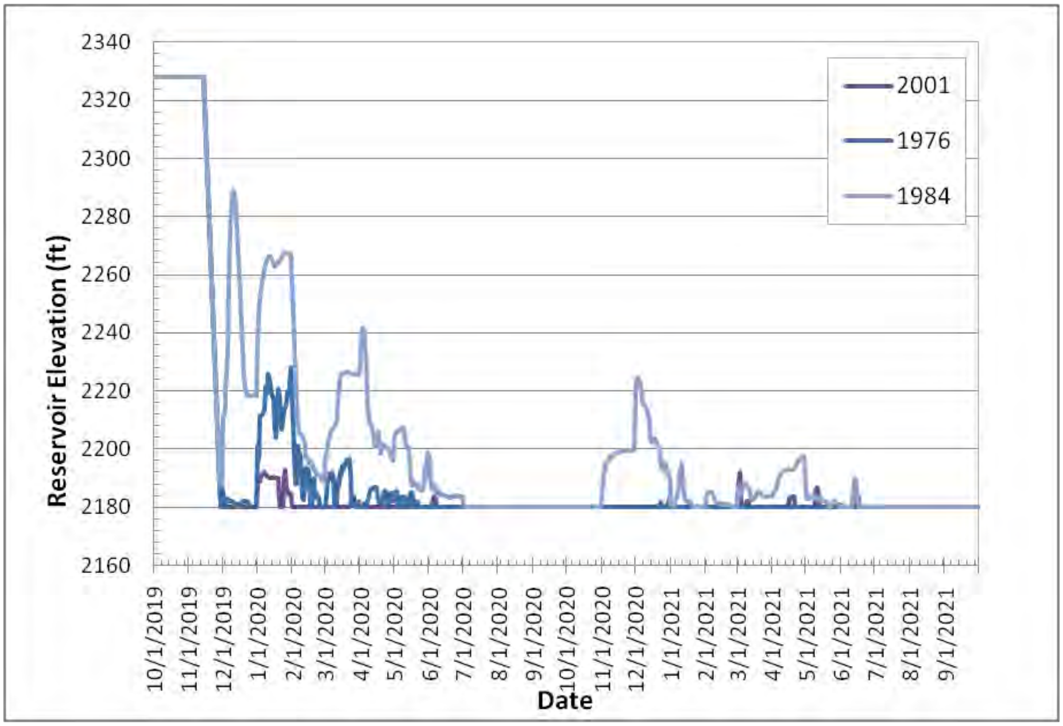


Figure 23-5. Iron Gate elevation for typical Dry (2001), Median (1976), and Wet (1984) years for Scenario 1.

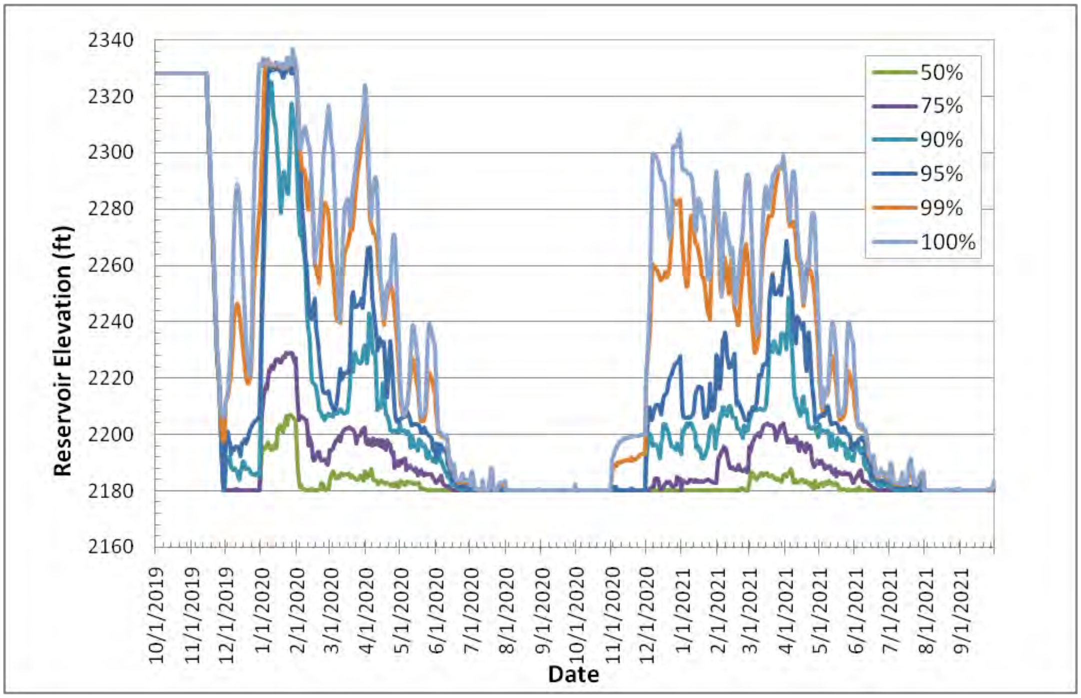


Figure 23-6. Iron Gate Non-Exceedance Elevations for all years from 1961 to 2008 for Scenario 1.

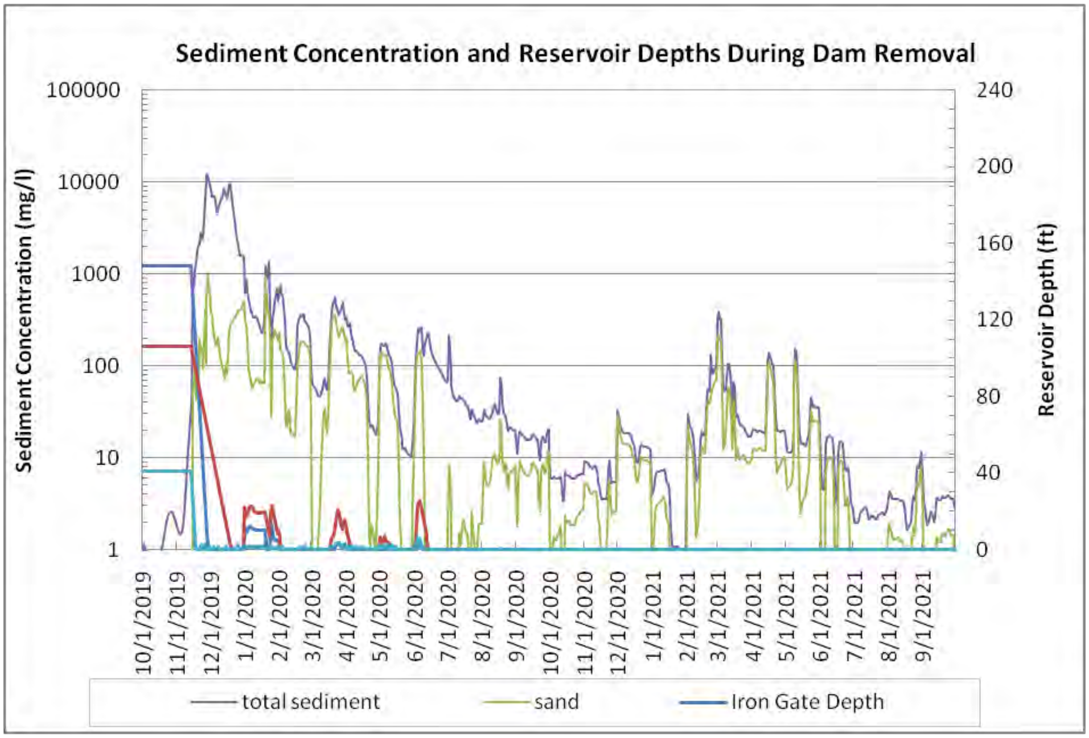


Figure 23-7. Simulated reservoir depths and sediment concentration below Iron Gate for WY 2001 (Dry year) for Scenario 1.

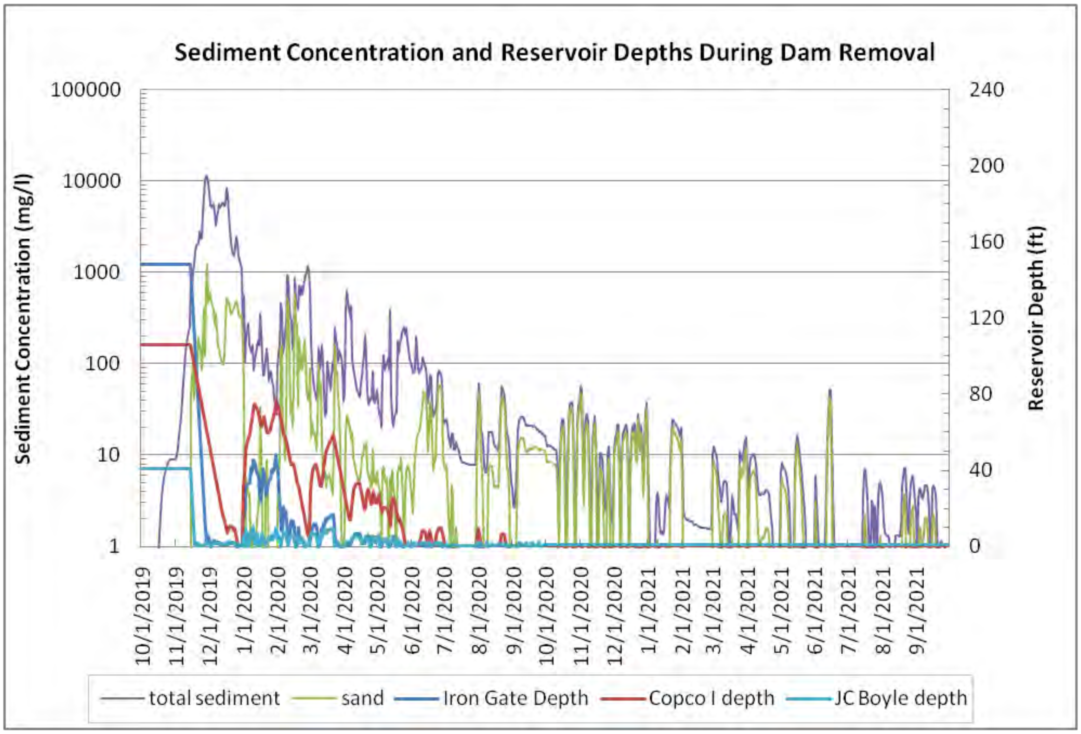


Figure 23-8. Simulated reservoir depths and sediment concentration below Iron Gate for WY 1976 (median year) for Scenario 1.

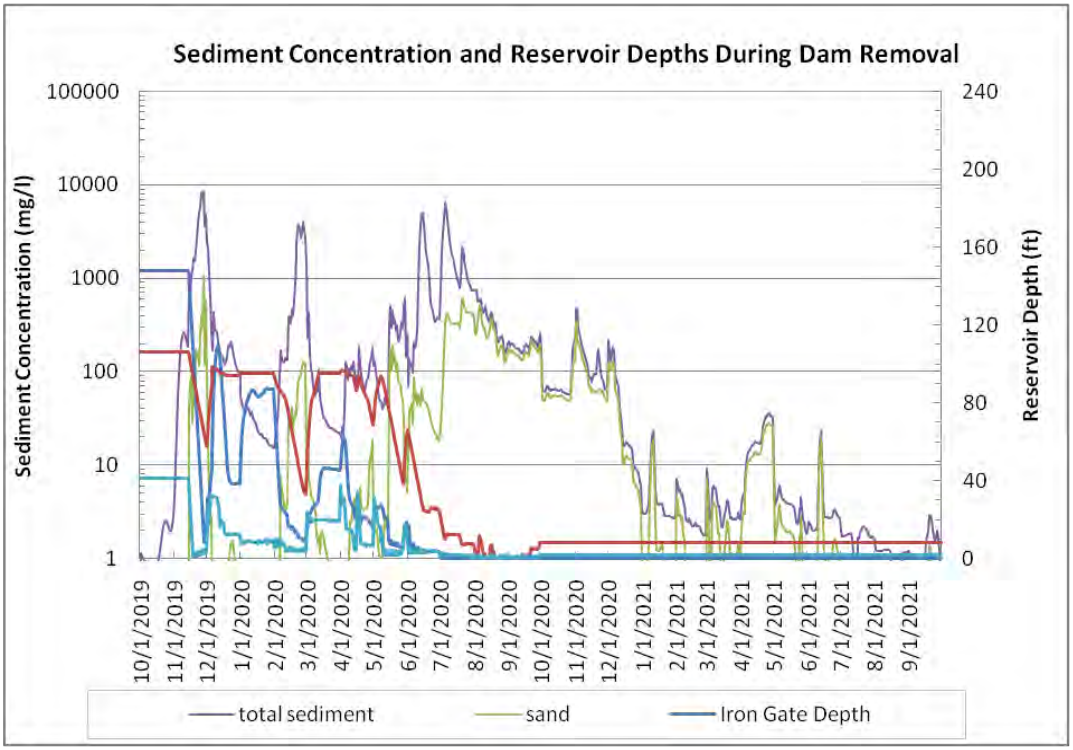


Figure 23-9. Simulated reservoir depths and sediment concentration below Iron Gate for WY 1984 (wet year) for Scenario 1.

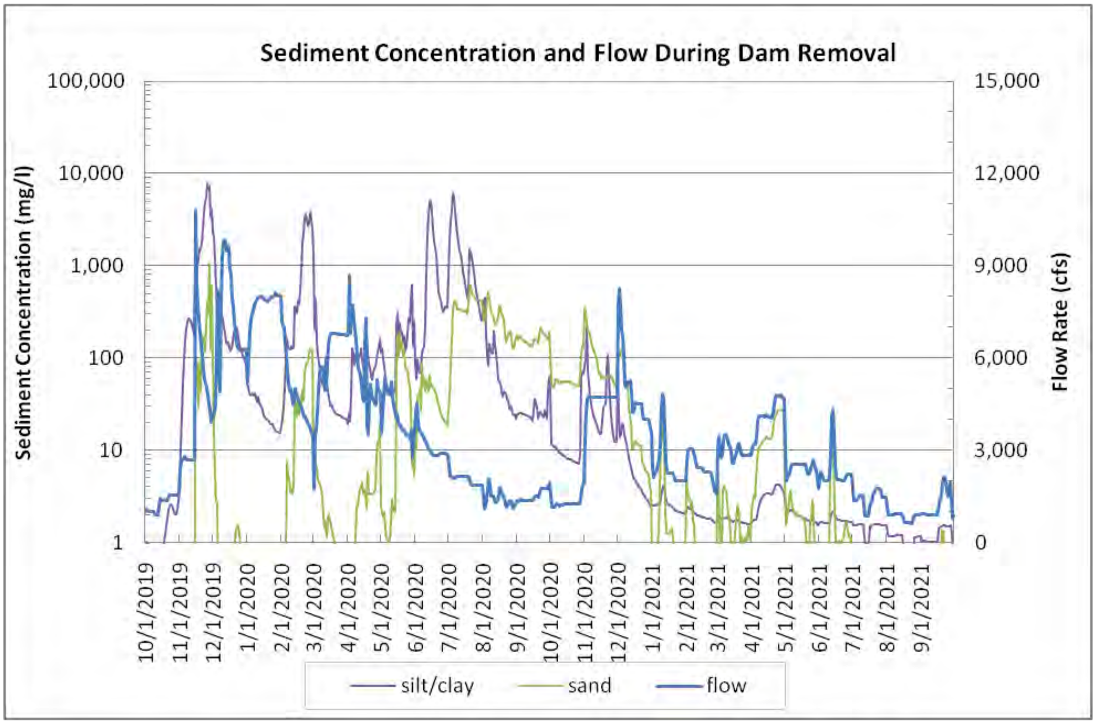


Figure 23-10. Simulated flows and sediment concentration below Iron Gate for WY 1984 (wet year) for Scenario 1.

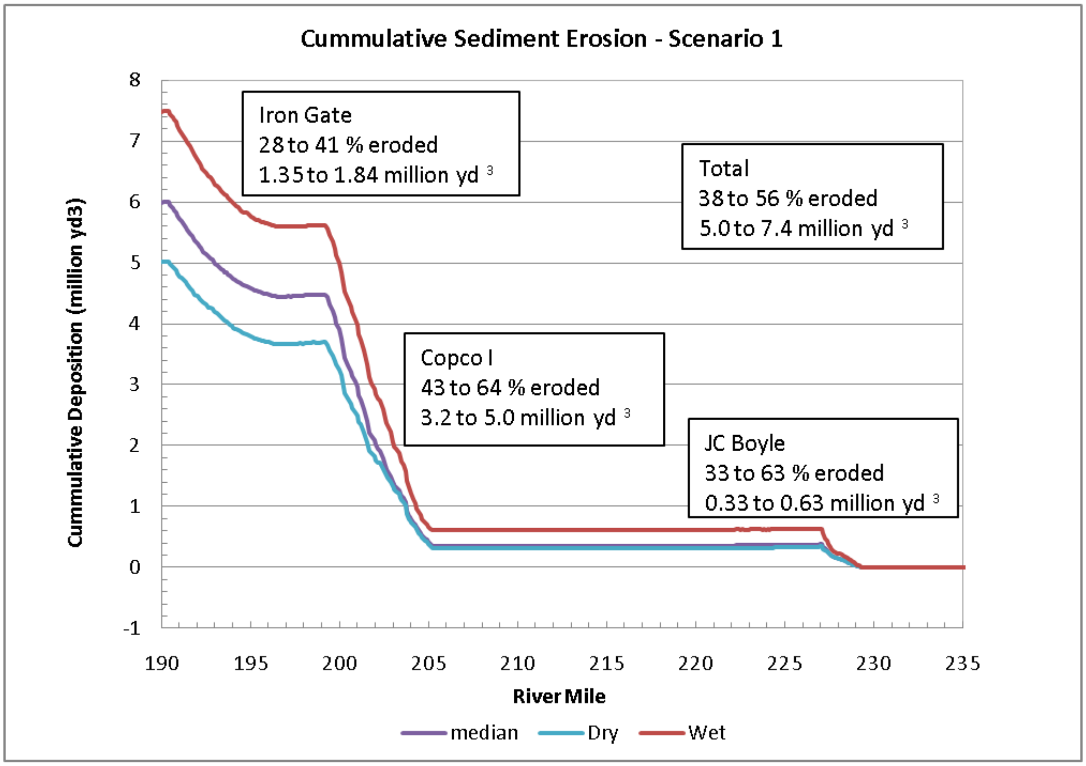


Figure 23-11. Volume of sediment erosion for Scenario 1 for the dry, median, and wet year types for Scenario 1.

23.2. Scenario 2

Scenario 2 assumes that the drawdown begins Nov 15, 2019, but that instead of using the low level outlet at Copco 1, Copco 1 Dam is notched from the top. The concrete of the dam is removed at a rate of 6 ft/week. Therefore is takes over 3 months to remove Copco 1 Dam and then the reservoir cannot refill after this time. The reservoir elevations at Copco and Iron Gate reservoirs for the dry, median and wet water years are shown in Figure 23-12 and Figure 23-13. The non-exceedance reservoir elevations for Iron Gate are shown in Figure 23-14.

The reservoir elevation at Copco I is essentially controlled by the notching. Iron Gate reservoir show slightly more refilling because the Copco 1 is now storing less water and allows higher flows to reach Iron Gate.

The peak concentrations for Scenario 2 are slightly lower than for Scenario 1 because the reservoir elevation at Copco I decreases slower under Scenario 2 than 1 and therefore sediment is eroded at a slower rate.

Because Copco 1 does not refill during the spring runoff, the concentrations after April are significantly lower for Scenario 2 than Scenario 1.

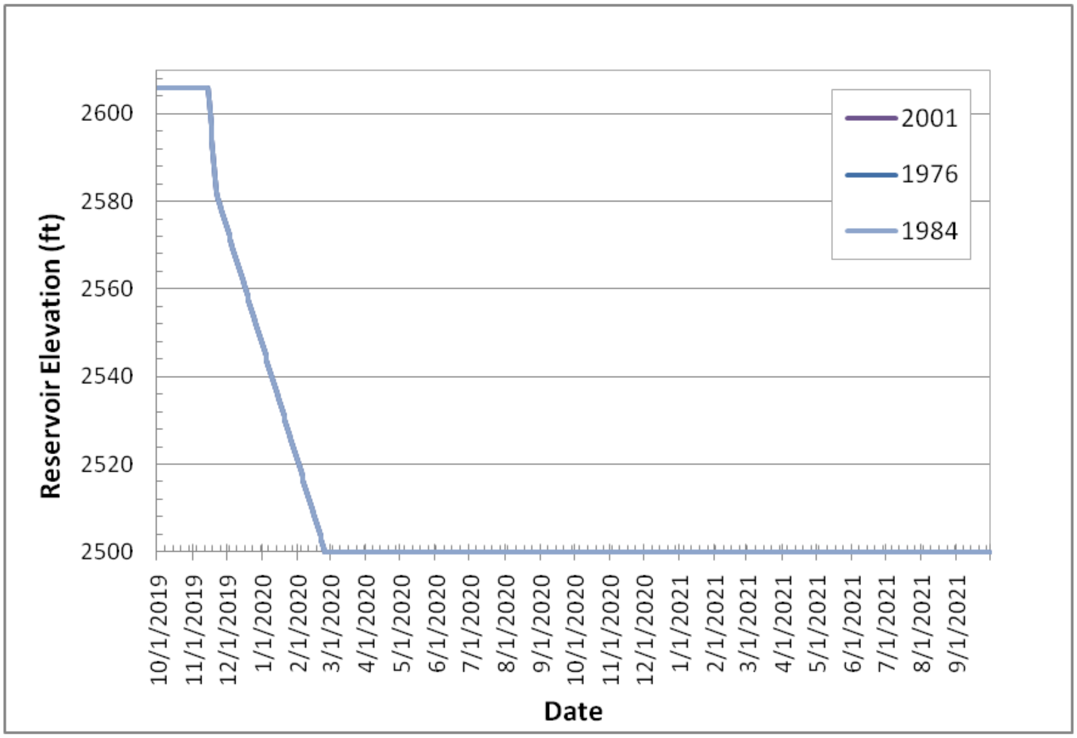


Figure 23-12. Copco 1 elevation for Typical Dry (2001), Median (1976), and Wet (1984) years for Scenario 2.

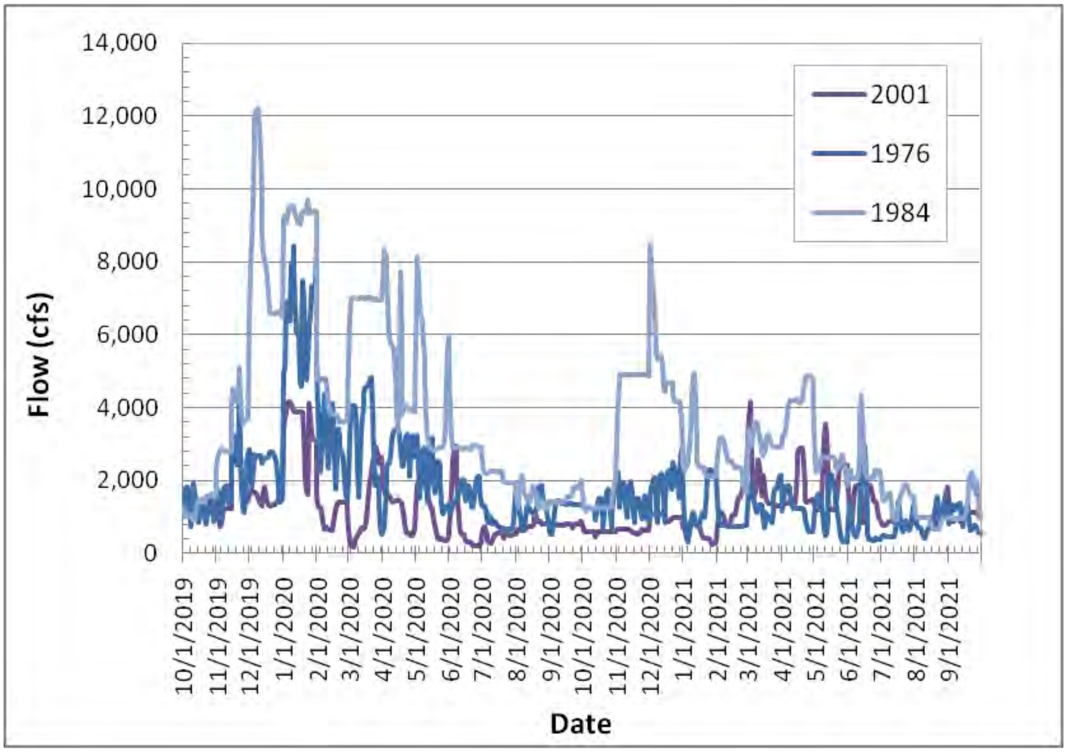


Figure 23-13. Iron Gate elevation for typical Dry (2001), Median (1976), and Wet Years for Scenario 2.

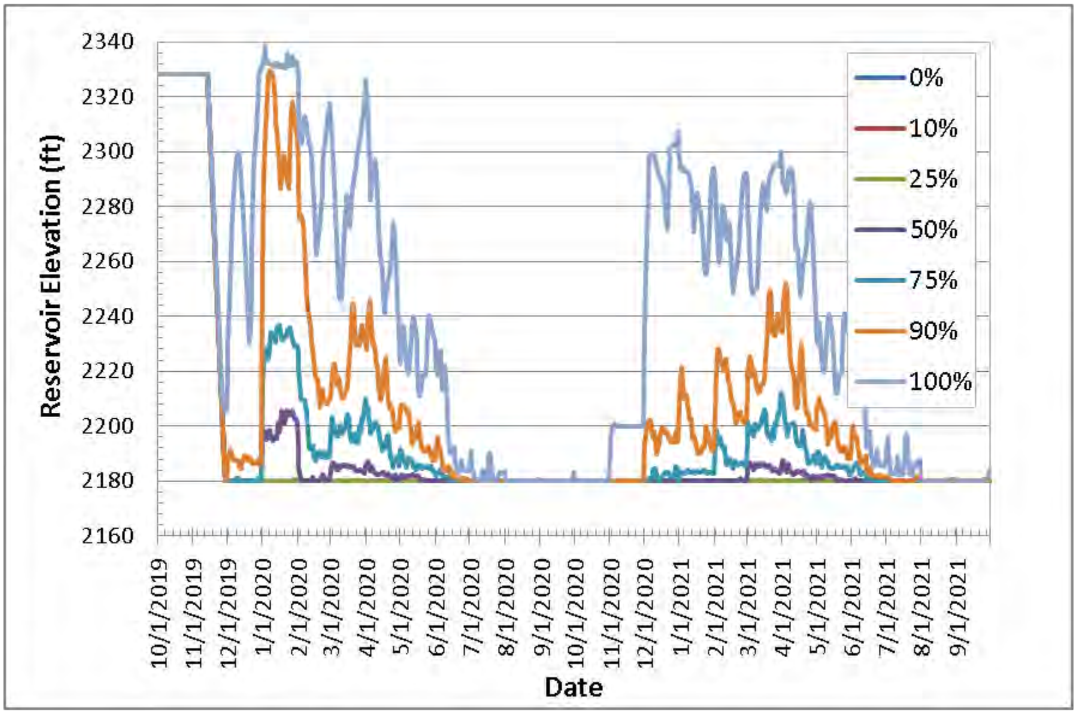


Figure 23-14. Iron Gate Non-Exceedance Elevations for all years from 1961 to 2008 for Scenario 2.

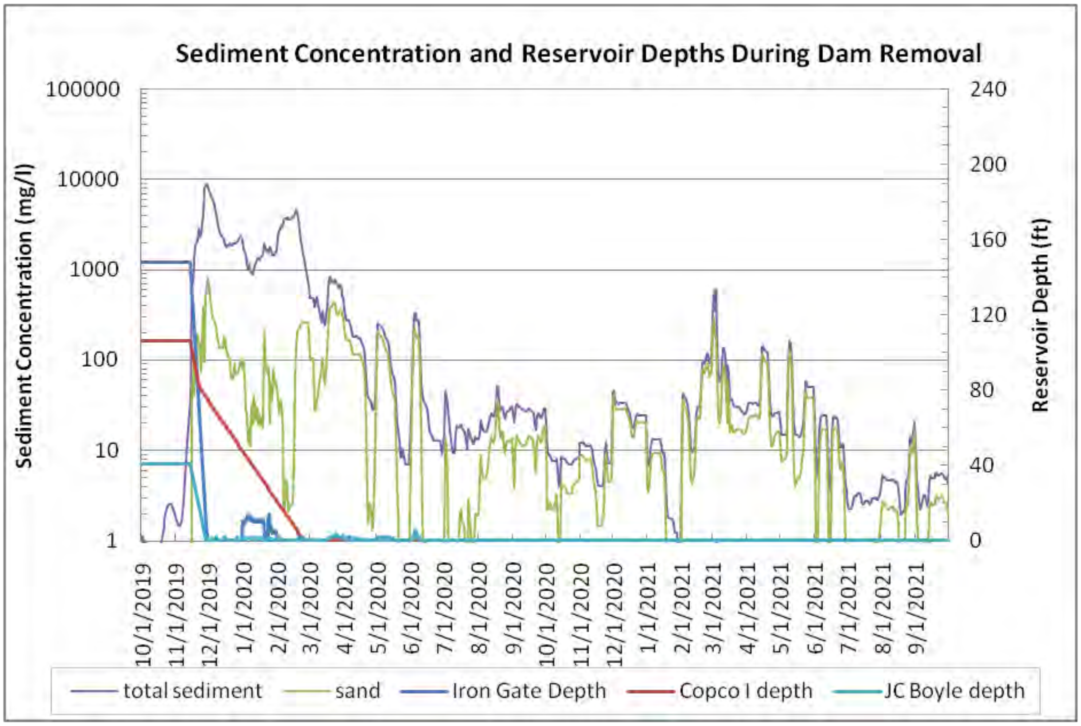


Figure 23-15. Simulated reservoir depths and sediment concentration below Iron Gate for WY 2001 (Dry year) for Scenario 2.

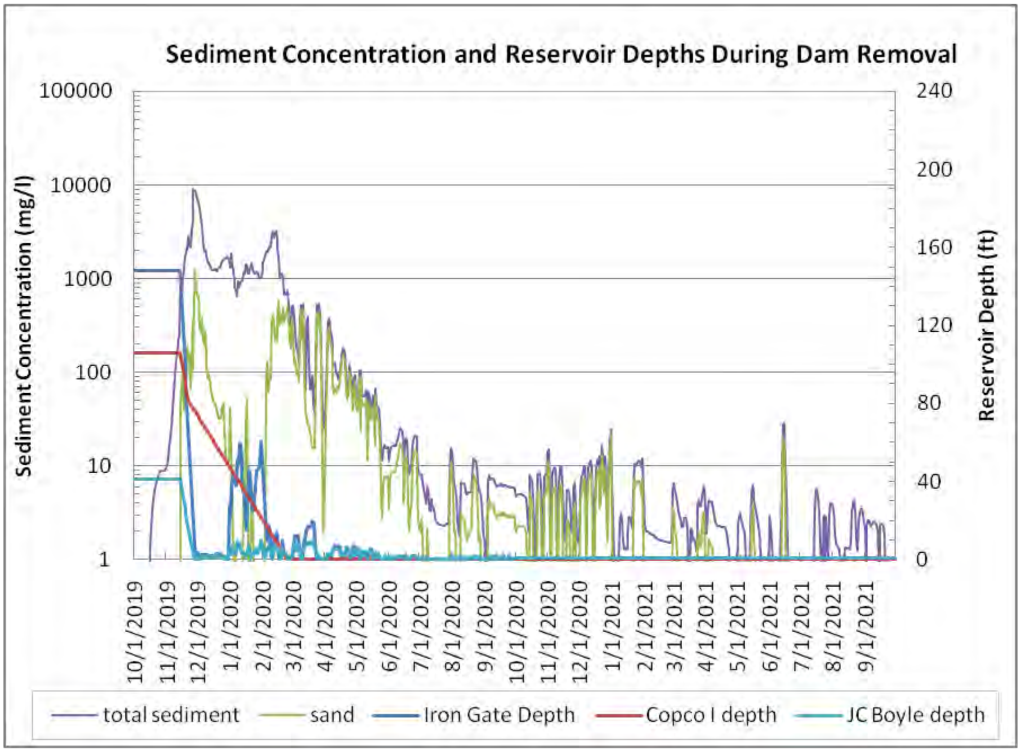


Figure 23-16. Simulated reservoir depths and sediment concentration below Iron Gate for WY 1976 (median year) for Scenario 2.

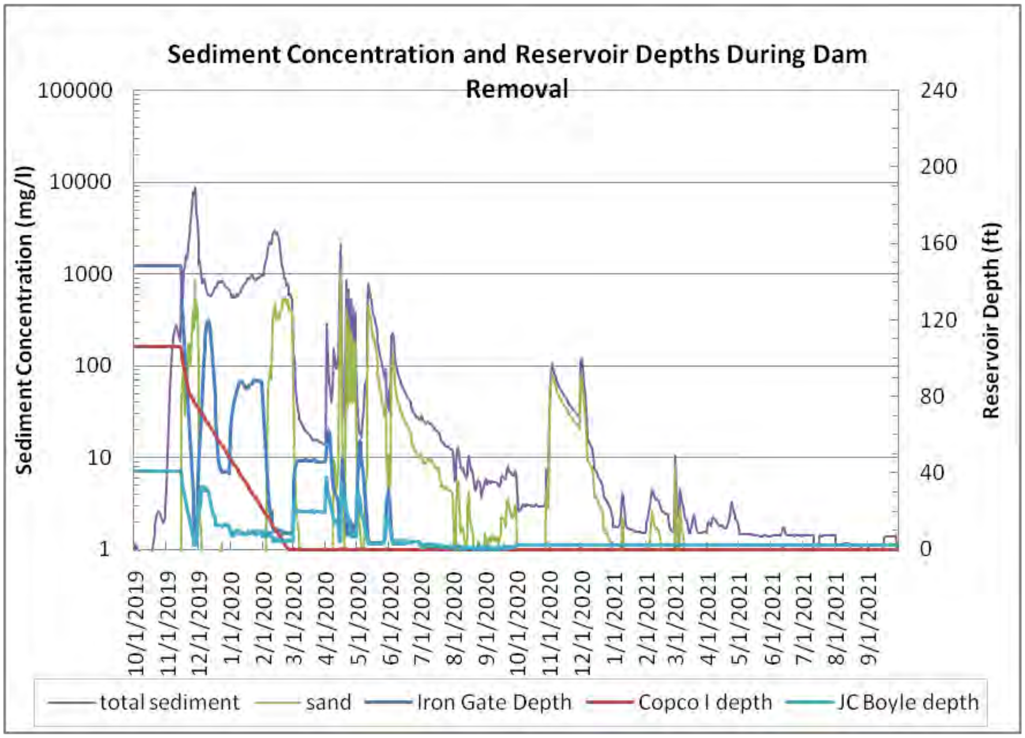


Figure 23-17. Simulated reservoir depths and sediment concentration below Iron Gate for WY 1984 (Wet year) for Scenario 2.

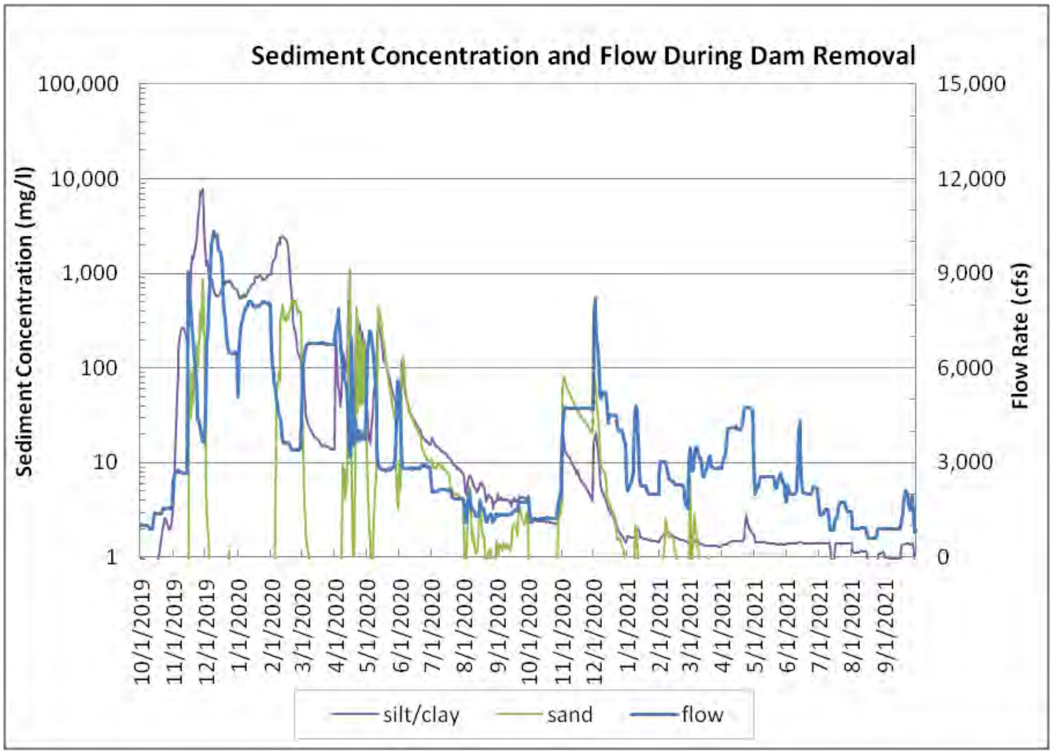


Figure 23-18. Simulated flows and sediment concentration below Iron Gate for WY 1984 (Wet year) for Scenario 2.

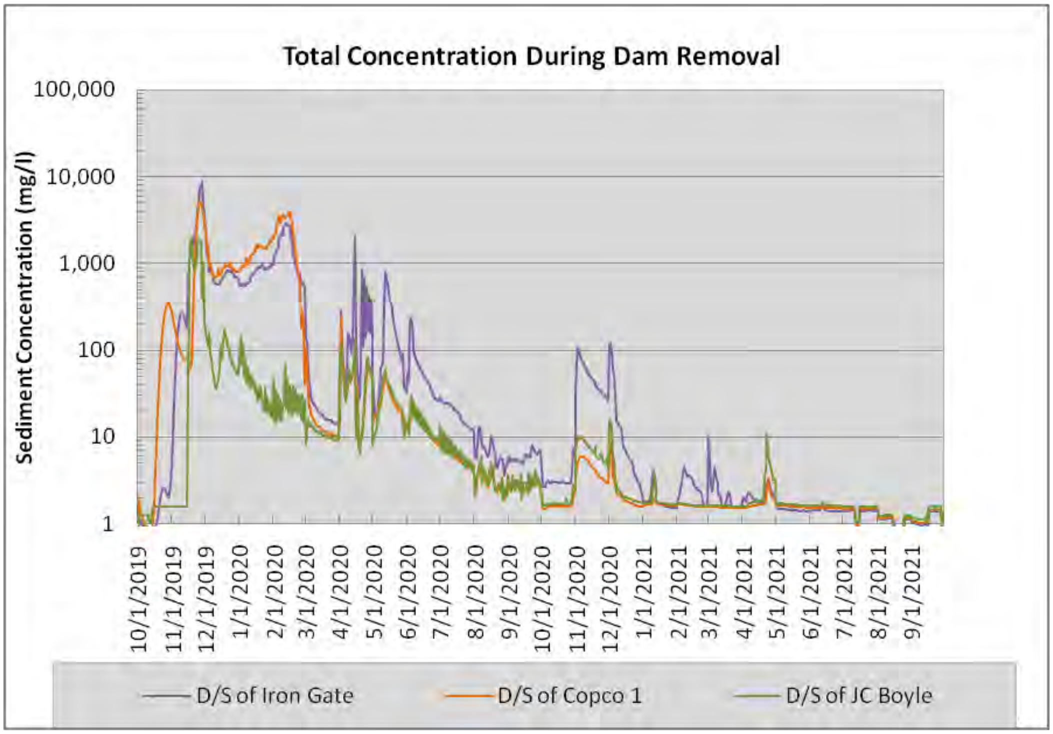


Figure 23-19. Simulated sediment concentrations below J.C. Boyle, Copco 1, and Iron Gate for WY 1984 (Wet year) for Scenario 2.

23.3. Scenario 3

Scenario 3 assumes that drawdown commences Jan 1, 2020. The low level outlet is used to drain J.C. Boyle and Iron Gate reservoirs, and Copco 1 is removed as in Scenario 2, being notched from the top. The low level outlet at Copco 1 is not used.

Copco 1 is not drawdown until the beginning of April and therefore the sediment concentrations remains high until then. Copco 1 does not refill after that date and concentrations quickly decrease after drawdown.

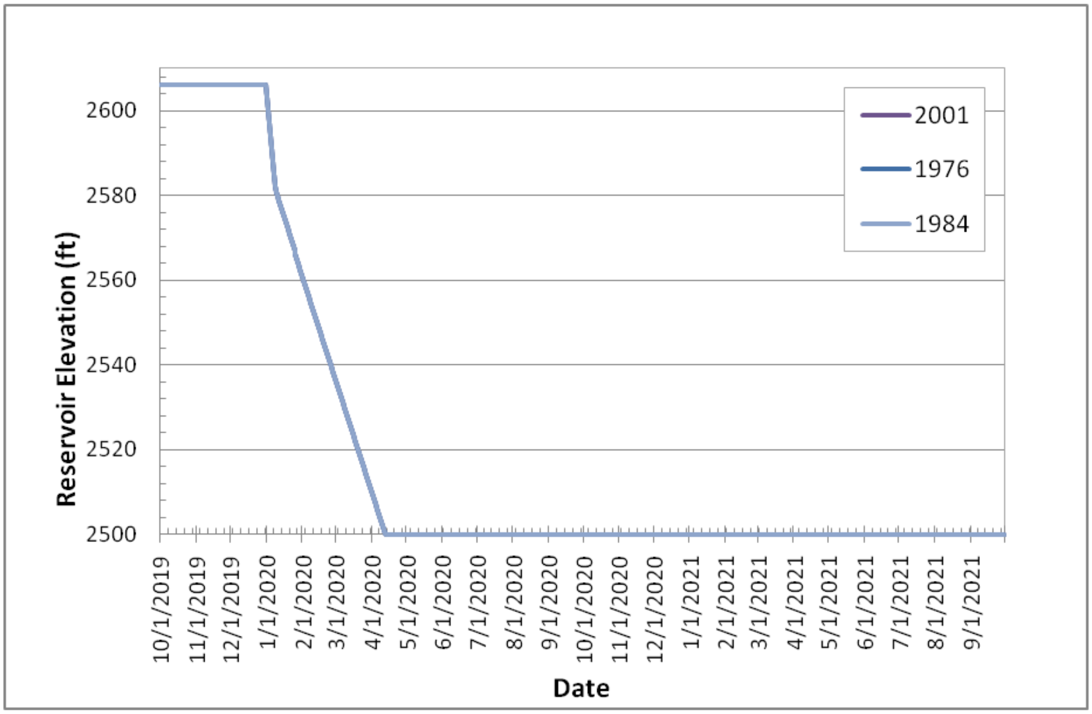


Figure 23-20. Copco 1 elevation for typical Dry (2001), Median (1976), and Wet Years for Scenario 3.

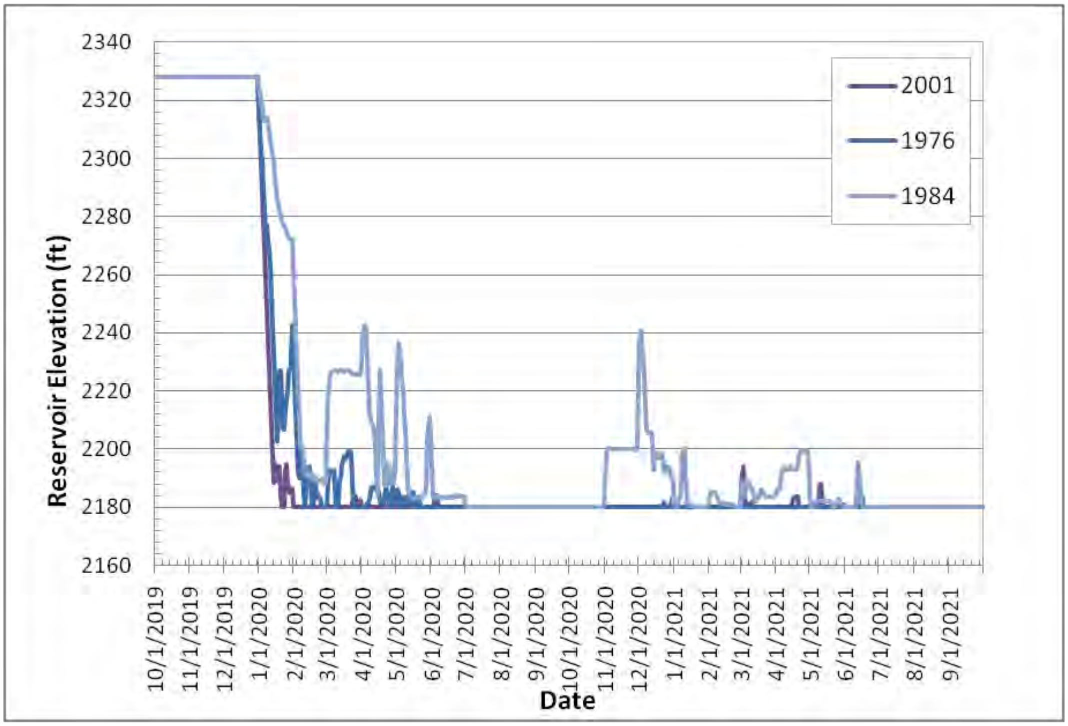


Figure 23-21. Iron Gate elevation for typical Dry (2001), Median (1976), and Wet (1984) years Scenario 3.

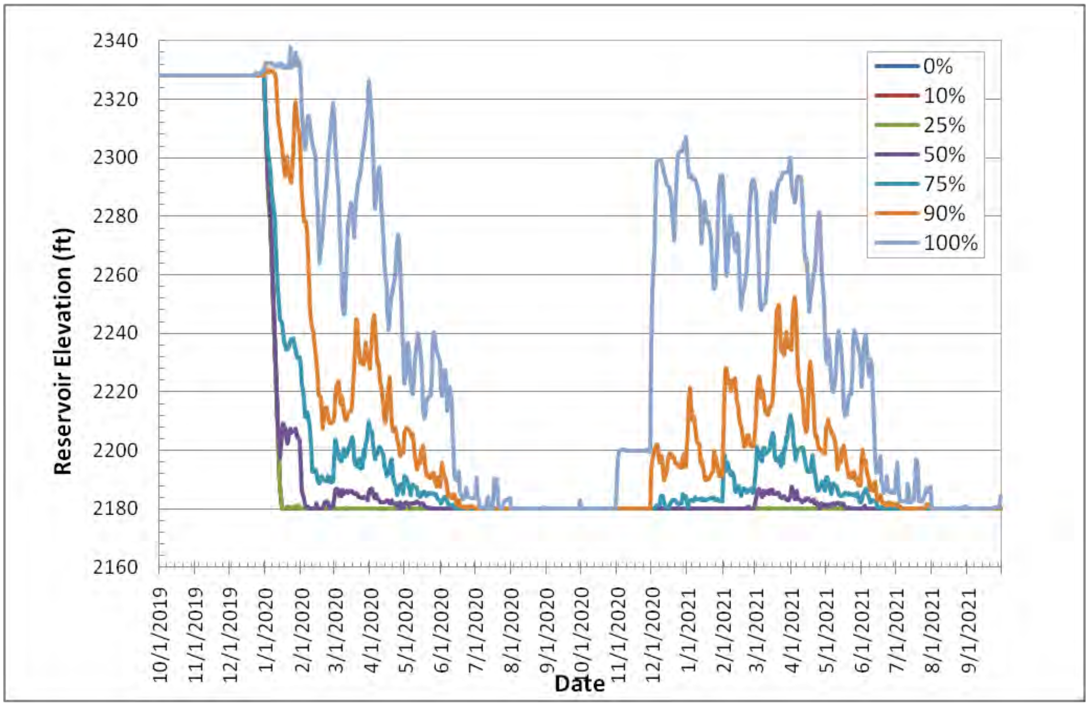


Figure 23-22. Iron Gate Non-Exceedance Elevations for all years from 1961 to 2008 Scenario 3.

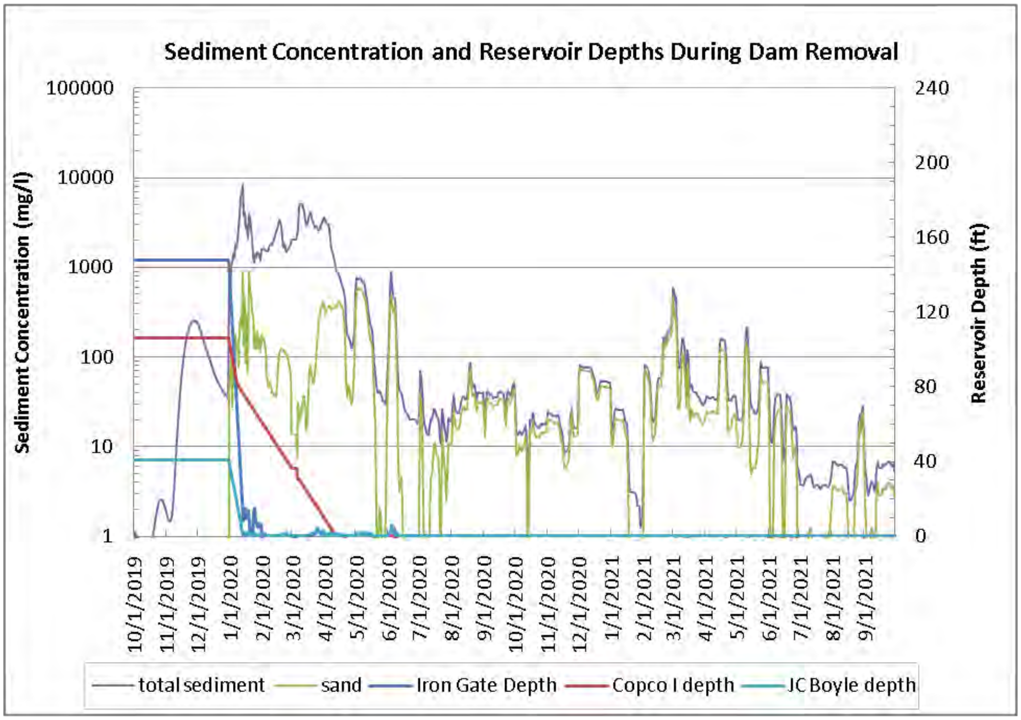


Figure 23-23. Simulated reservoir depths and sediment concentration below Iron Gate for WY 2001 (Dry year) Scenario 3.

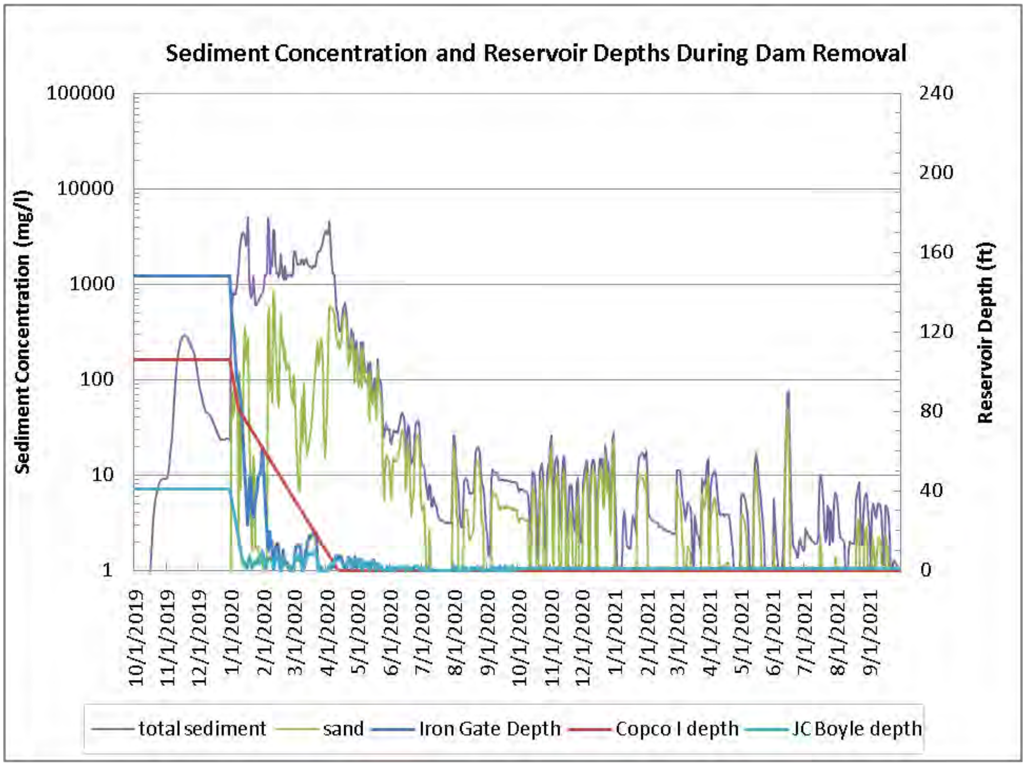


Figure 23-24. Simulated reservoir depths and sediment concentration below Iron Gate for WY 1976 (median year) Scenario 3.

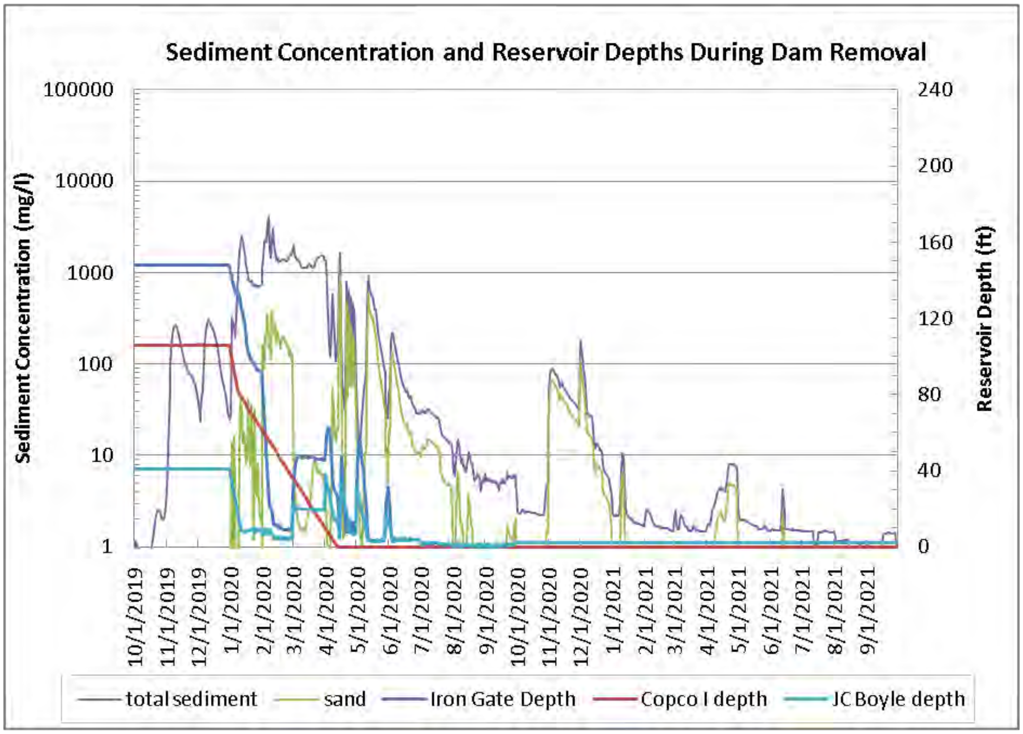


Figure 23-25. Simulated reservoir depths and sediment concentration below Iron Gate for WY 1984 (wet year) Scenario 3.

23.4. Scenario 4

Scenario 4 assumes that the low level outlet of Copco 1 is used to empty the reservoir and in addition Copco 1 is notched from the top at a rate of 6ft/wk. Therefore, the dam is removed to the existing stream bed by the end of February. The results for the reservoir routing are shown in Figure 23-26, Figure 23-27, and Figure 23-28. The results for J.C. Boyle are essentially the same for all Scenarios.

Copco 1 does not refill because the dam is removed by March 1. This eliminates the large spikes in concentration that occurred under Scenario 1 when the reservoir refills and then empties. The results for the sediment concentrations are given in Figure 23-29, Figure 23-30, and Figure 23-31 for the dry, median, and wet years.

There are still smaller spikes in concentration due to the refilling of Iron Gate in the wet year, but the concentration is below 1,000 mg/l downstream of Iron Gate after March 1 for all water year types.

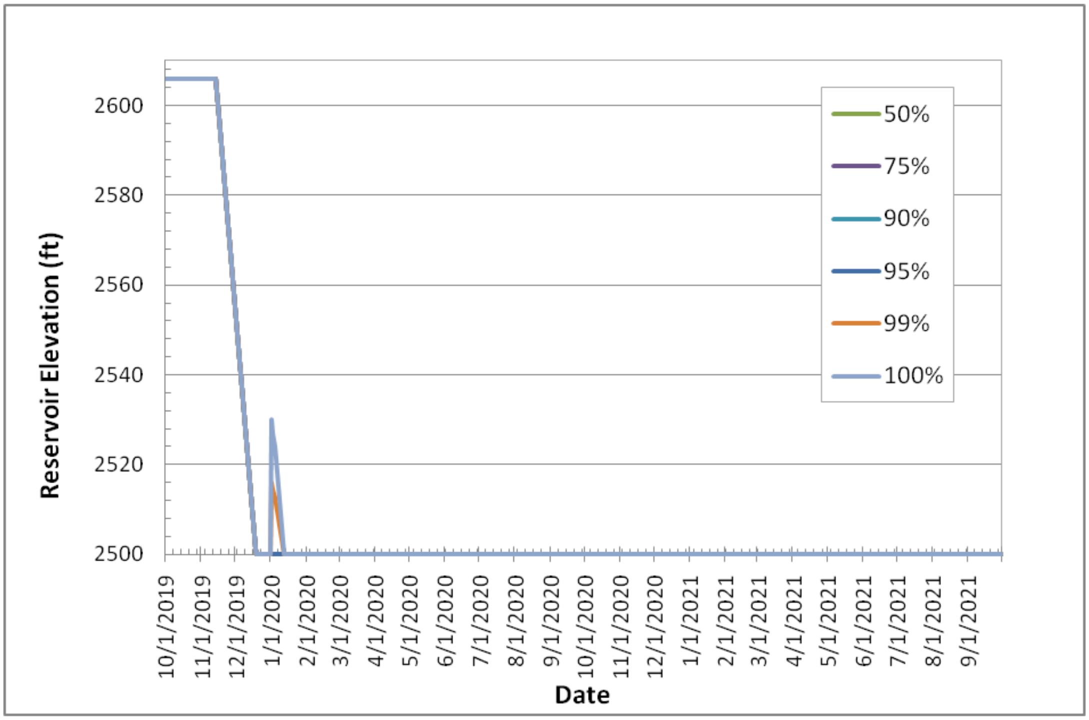


Figure 23-26. Copco 1 Non-Exceedance Elevations for all years from 1961 to 2008 for Scenario 4.

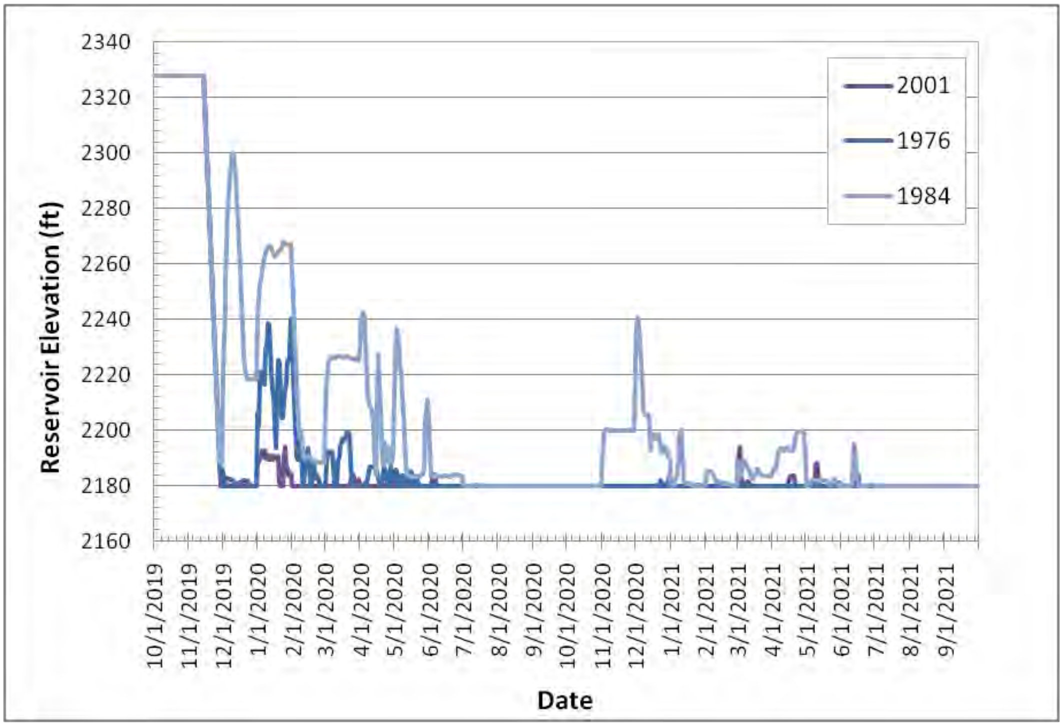


Figure 23-27. Iron Gate reservoir elevations for typical Dry (2001), Median (1976), and Wet (1984) years for Scenario 4.

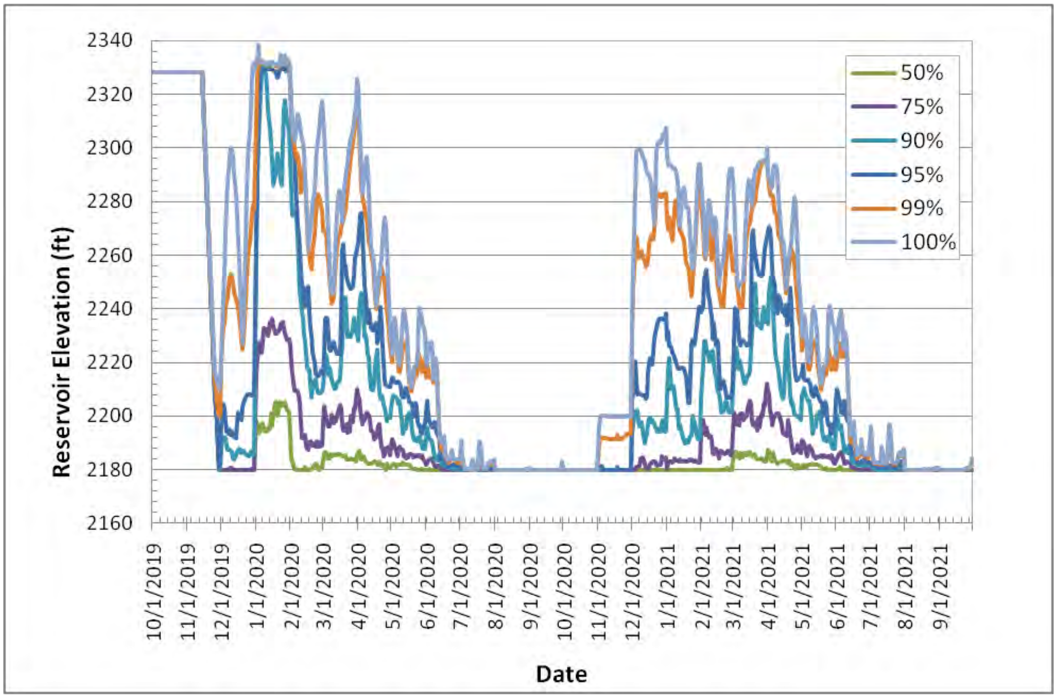


Figure 23-28. Iron Gate Non-Exceedance Elevations for all years from 1961 to 2008 for Scenario 4.

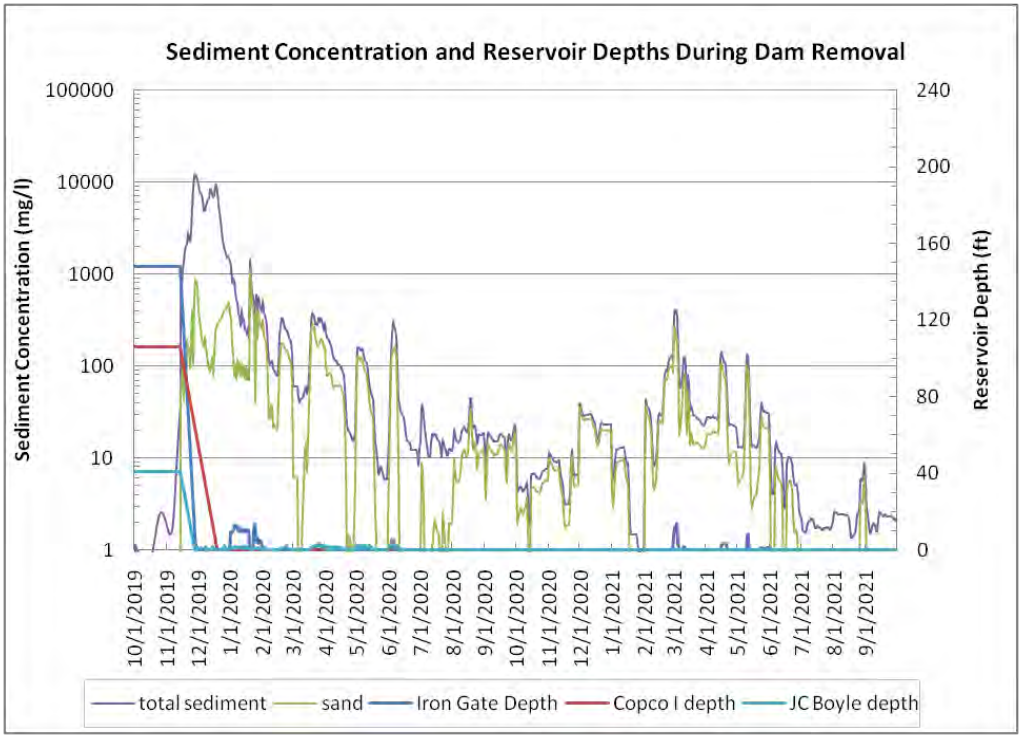


Figure 23-29. Simulated reservoir depths and sediment concentration below Iron Gate for WY 2001 (Dry year) for Scenario 4.

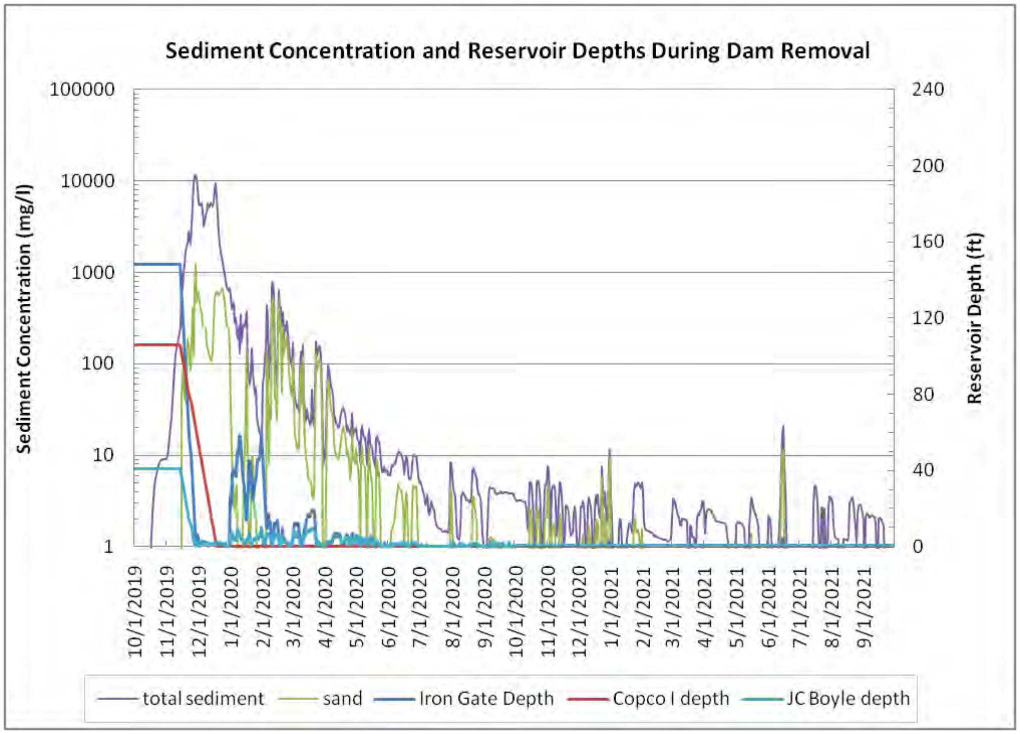


Figure 23-30. Simulated reservoir depths and sediment concentration below Iron Gate for WY 1976 (median year) for Scenario 4.

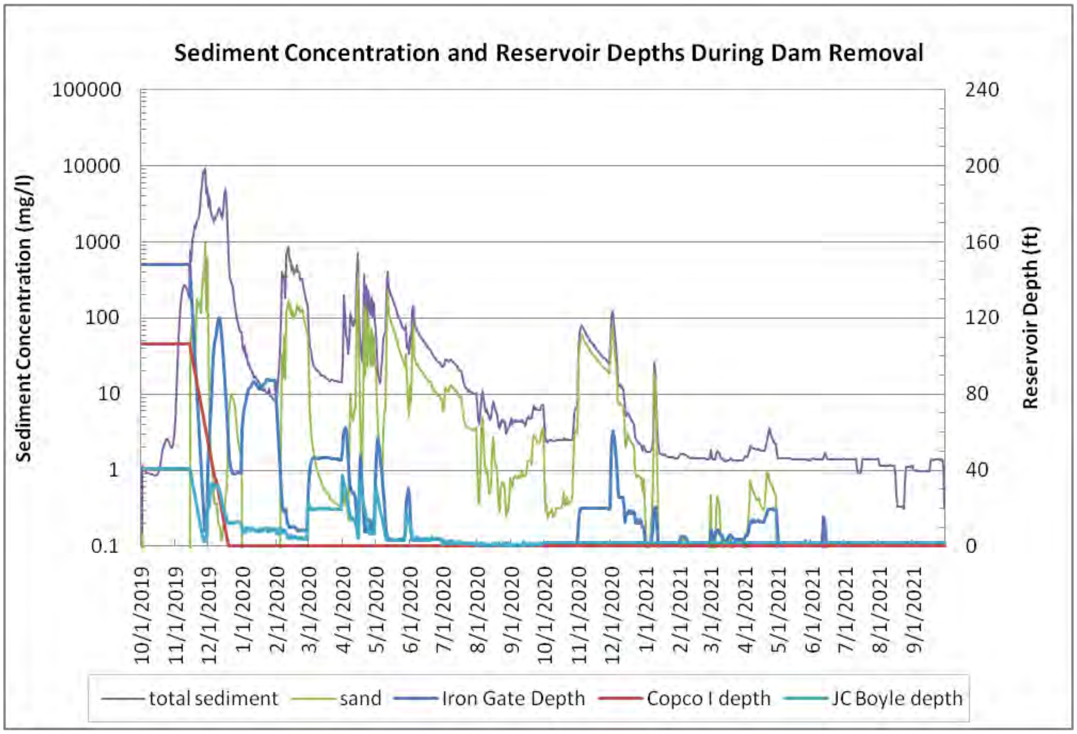


Figure 23-31. Simulated Reservoir Depths and Sediment Concentration below Iron Gate for WY 1984 (wet year) for Scenario 4.

23.5. Scenario 5

Scenario 5 assumes drawdown commences on Jan 1, 2020. The low level outlet of Copco 1 is used and in addition Copco 1 is notched from the top at a rate of 6ft/wk. Therefore, the dam is removed to the existing stream bed by mid April. The results for the reservoir routing are shown in Figure 23-26, Figure 23-27, and Figure 23-28.

Copco 1 drains more quickly for Scenario 5 than scenario 3 because the low-level outlet tunnel is used in addition to notching Copco 1 from the top. Because Copco 1 is drawdown faster in Scenario 5 than 3, the peak concentrations are higher and the concentrations are of shorter duration. The results for the sediment concentrations are given in Figure 23-29, Figure 23-30, and Figure 23-31 for the dry, median, and wet years.

There are still smaller spikes in concentration due to the refilling of Iron Gate in the wet year.

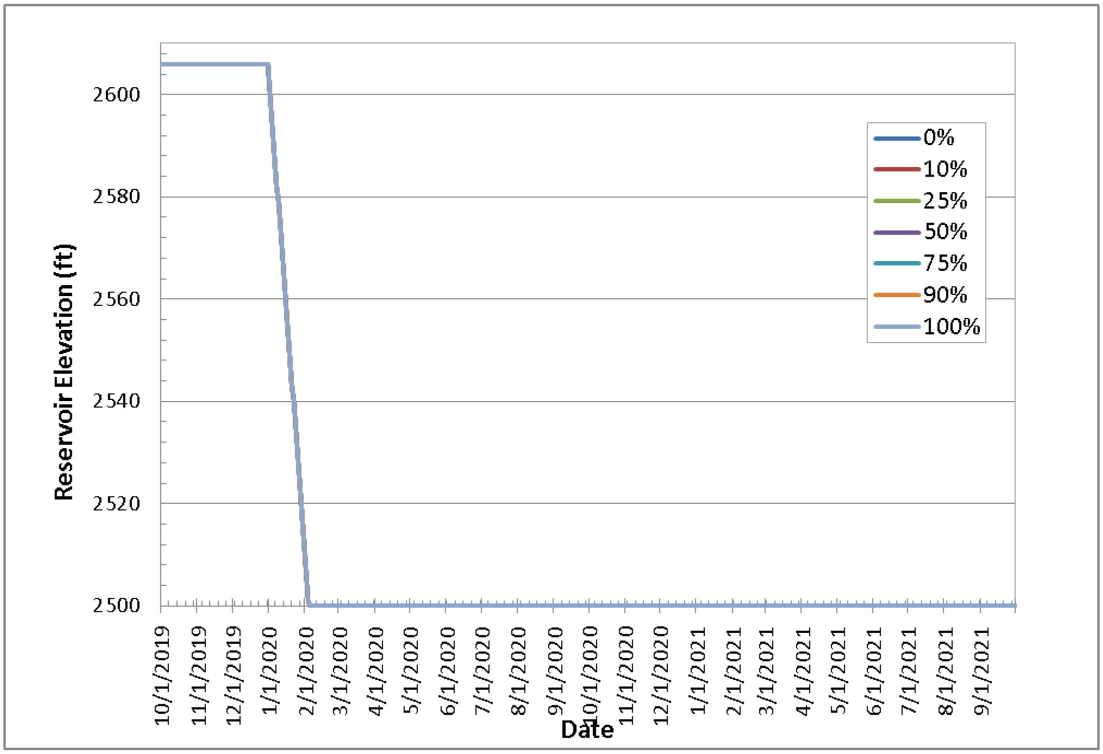


Figure 23-32. Copco 1 Non-Exceedance Elevations for all years from 1961 to 2008 for Scenario 5.

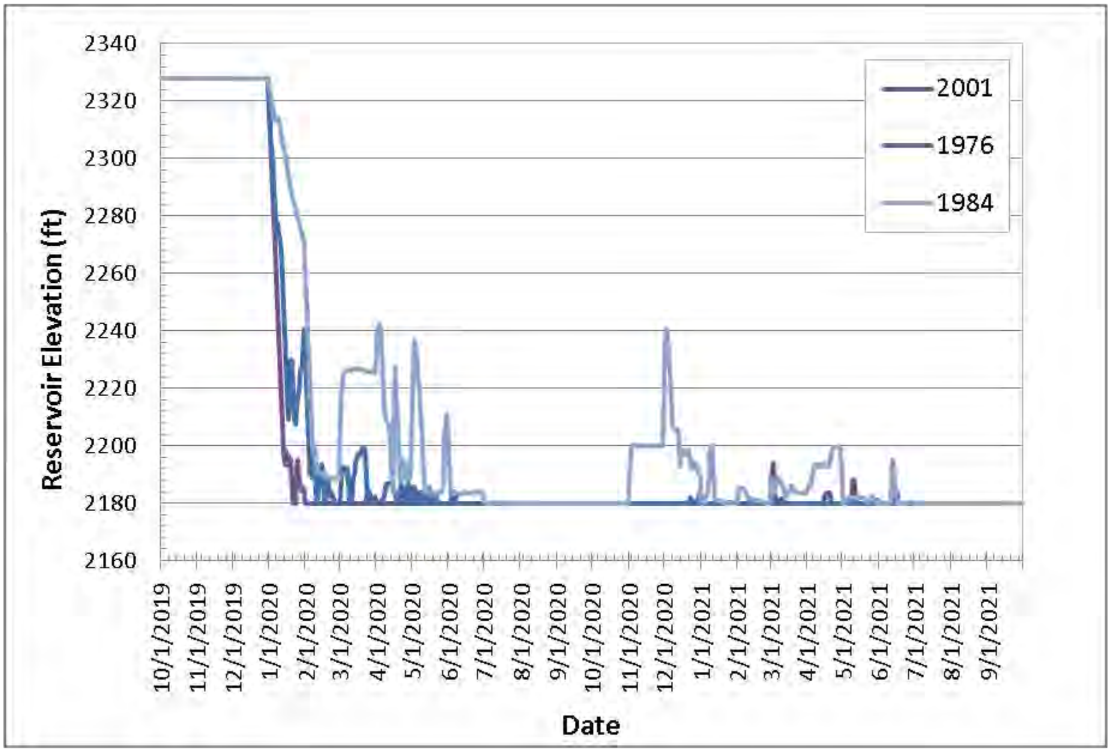


Figure 23-33. Iron Gate reservoir elevations for typical Dry (2001), Median (1976), and Wet (1984) years for Scenario 5.

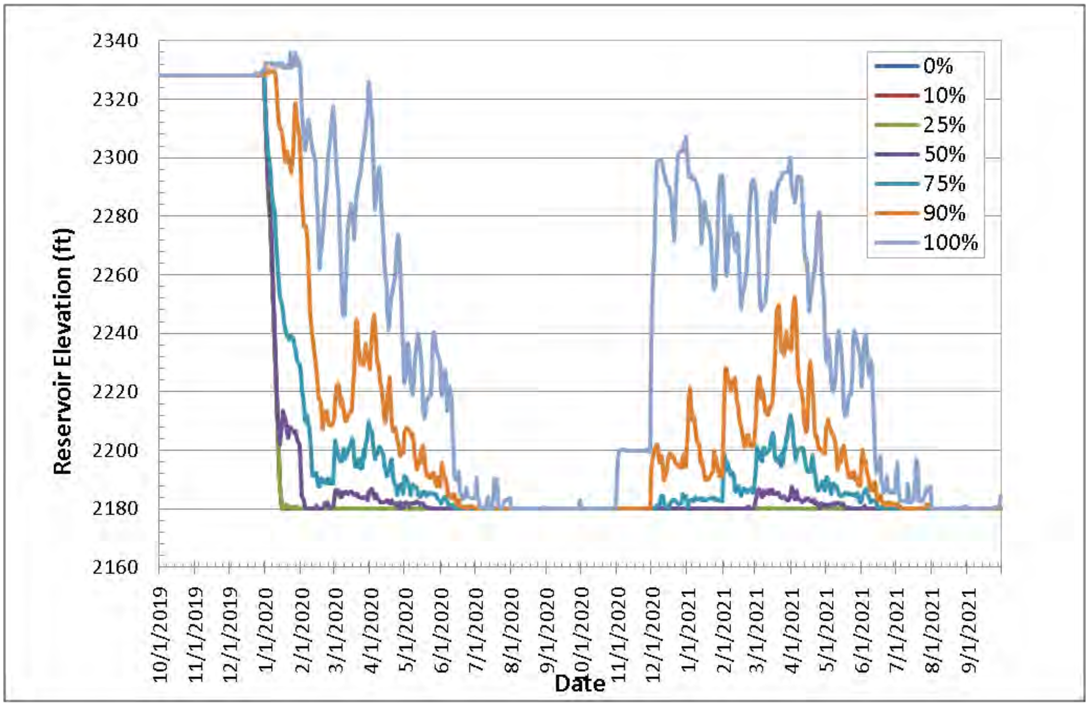


Figure 23-34. Iron Gate Non-Exceedance Elevations for all years from 1961 to 2008 for Scenario 5.

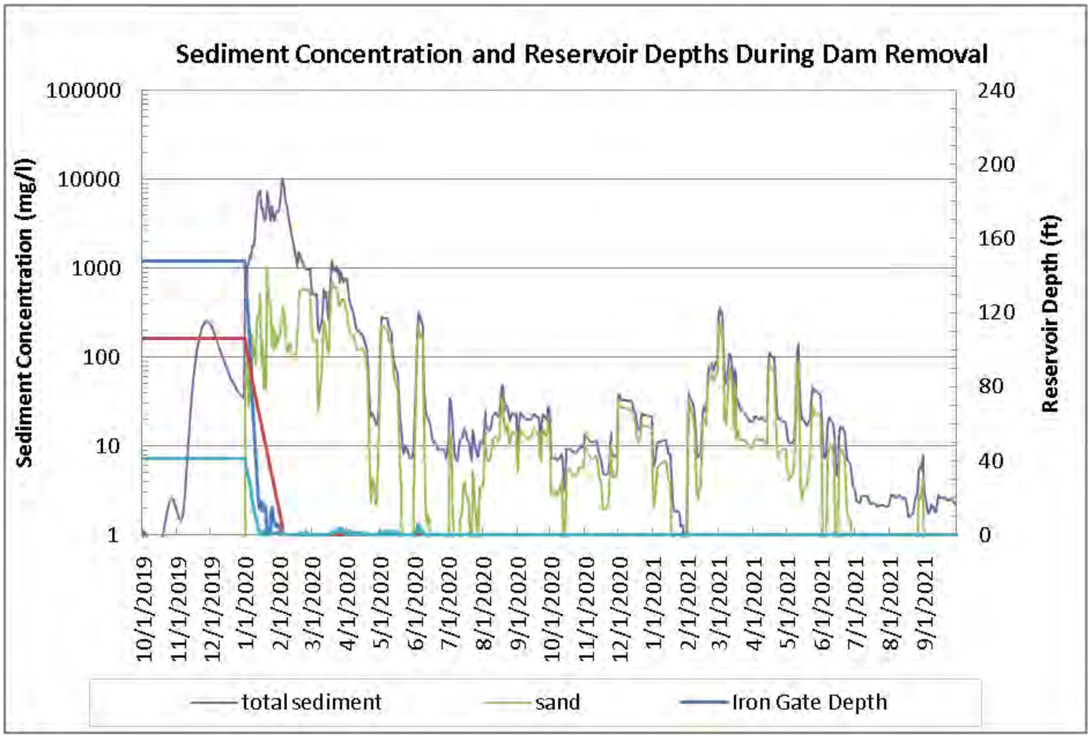


Figure 23-35. Simulated reservoir depths and sediment concentration below Iron Gate for WY 2001 (Dry year) for Scenario 5.

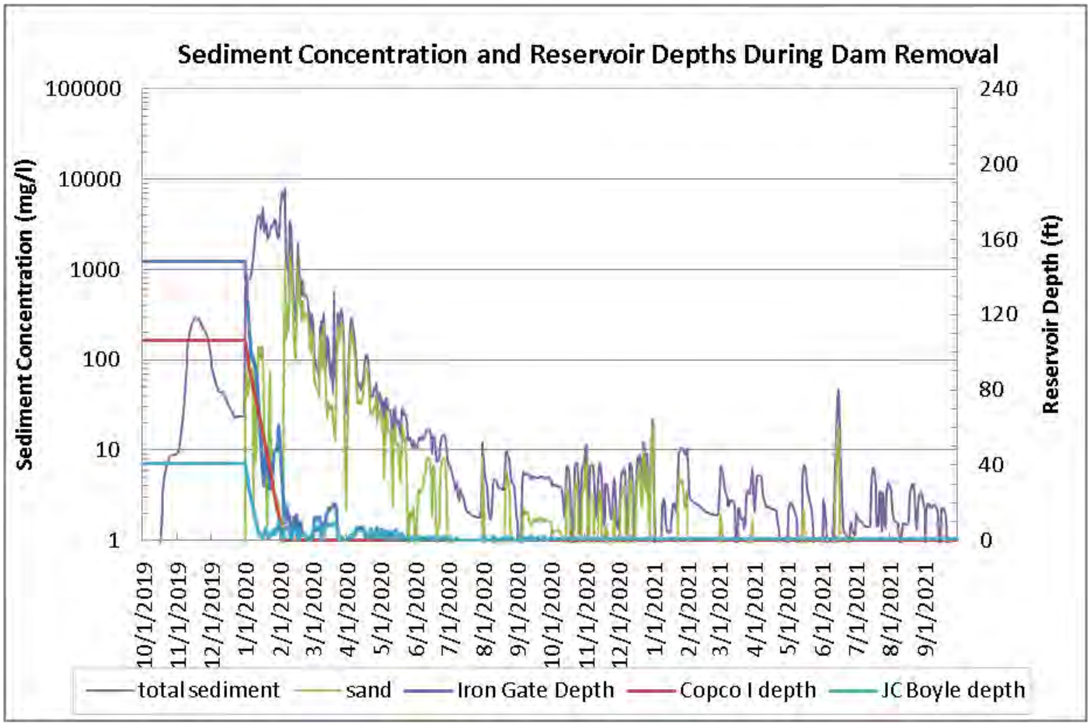


Figure 23-36. Simulated reservoir depths and sediment concentration below Iron Gate for WY 1976 (Median year) for Scenario 5.

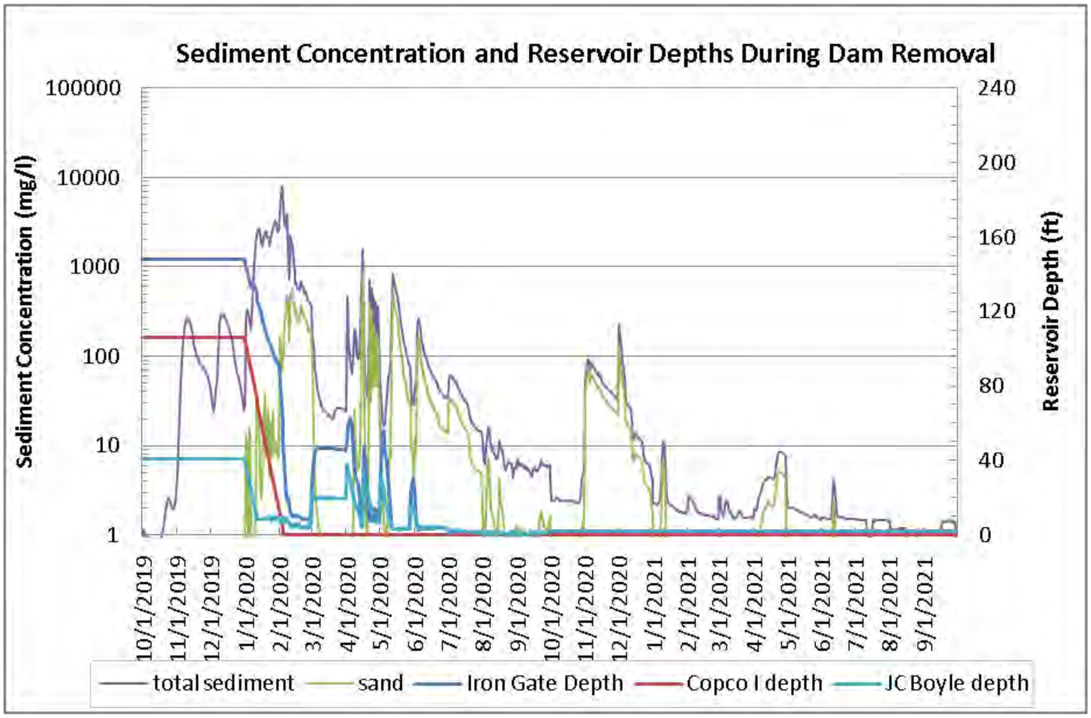


Figure 23-37. Simulated Reservoir Depths and Sediment Concentration below Iron Gate for WY 1984 (wet year) for Scenario 5.

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23.6. Scenario 6

Scenario 6 assumes drawdown commences on Nov 15, 2019. The low level outlet of Copco 1 is used and in addition Copco 1 is notched from the top at a rate of 6ft/wk. Therefore, the dam is removed to the existing stream bed by Mar 1, 2020. The drawdown rate is limited to 1 ft/day for the upper 50 feet of the reservoir and 3 ft/d below that. Drawdown at J.C. Boyle is assumed to begin Feb 15, 2020. The reservoir elevations for J.C. Boyle are shown in Figure 23-38.

The results for the sediment concentrations are given in Figure 23-39, Figure 23-40, and Figure 23-41, and for the dry, median, and wet years.

The results are similar to Scenario 2, but there is a small spike in concentration when J.C. Boyle is finally emptied in early March. The spike in concentration lasts only 1 day. In dry years, it can exceed 1,000 mg/l, but the high concentrations quickly recede.

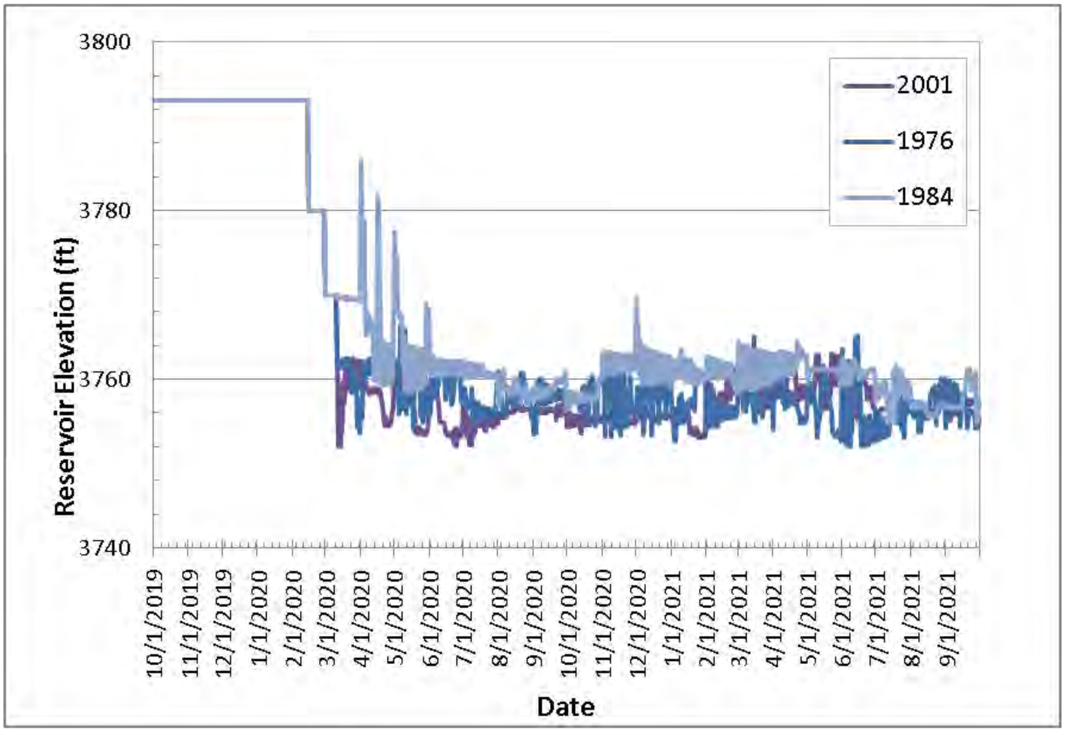

Figure 23-38. J.C. Boyle Elevations for dry, median, and wet year for Scenario 6.

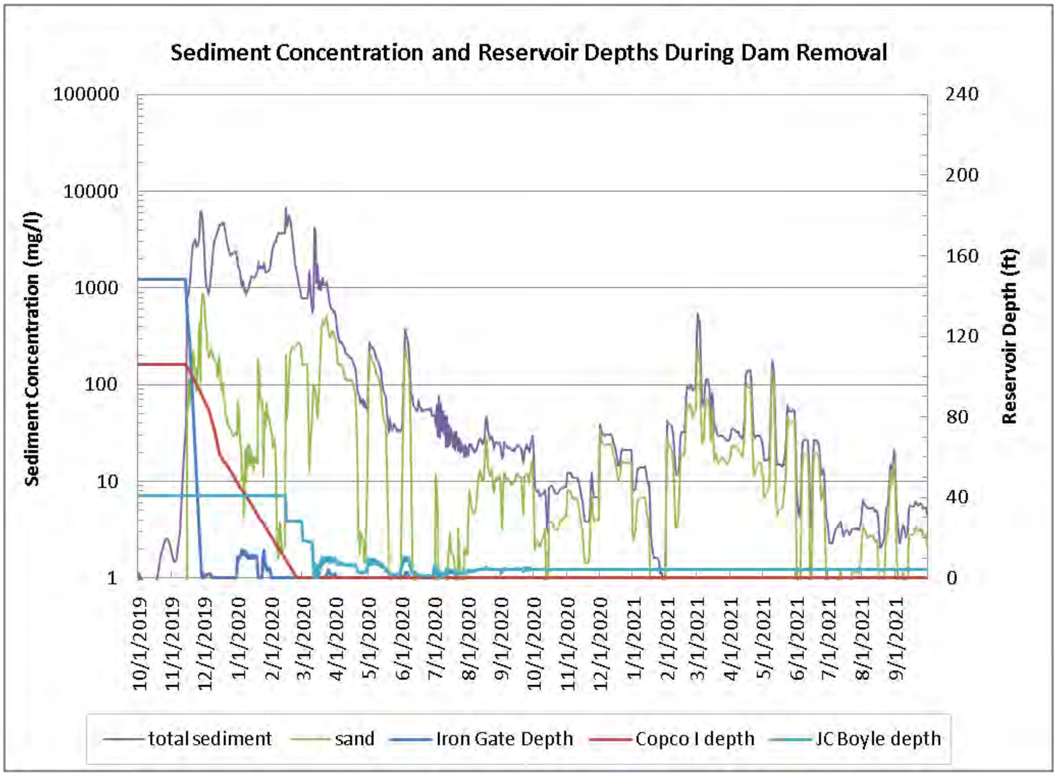

Figure 23-39. Simulated reservoir depths and sediment concentration below Iron Gate for WY 2001 (Dry year) for Scenario 6.

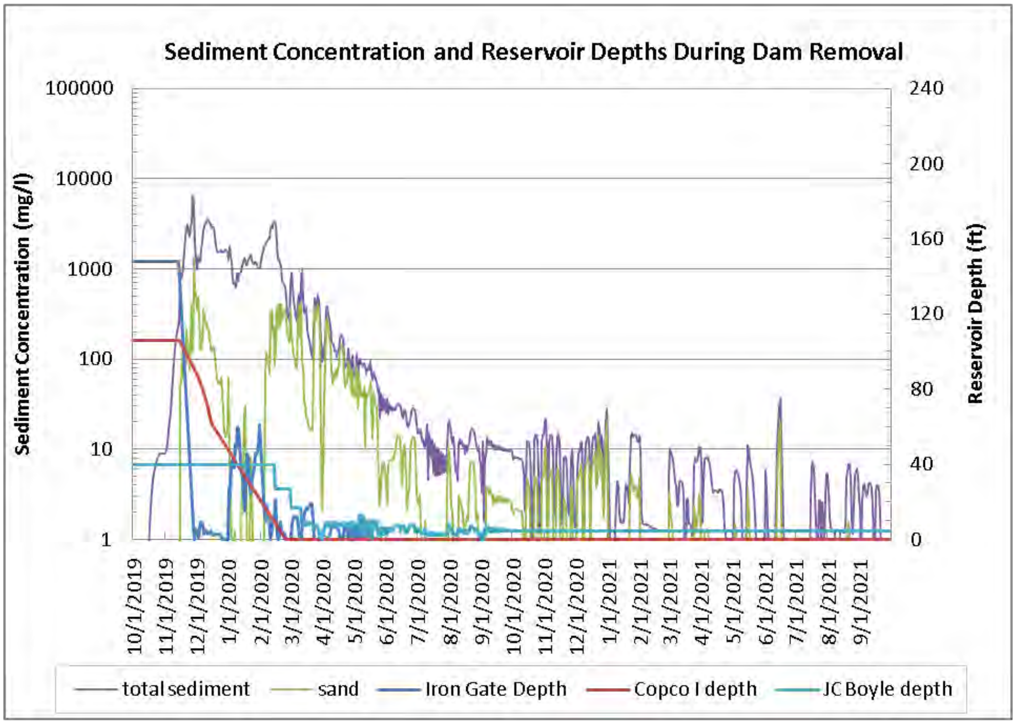

Figure 23-40. Simulated reservoir depths and sediment concentration below Iron Gate for WY 1976 (median year) for Scenario 6.

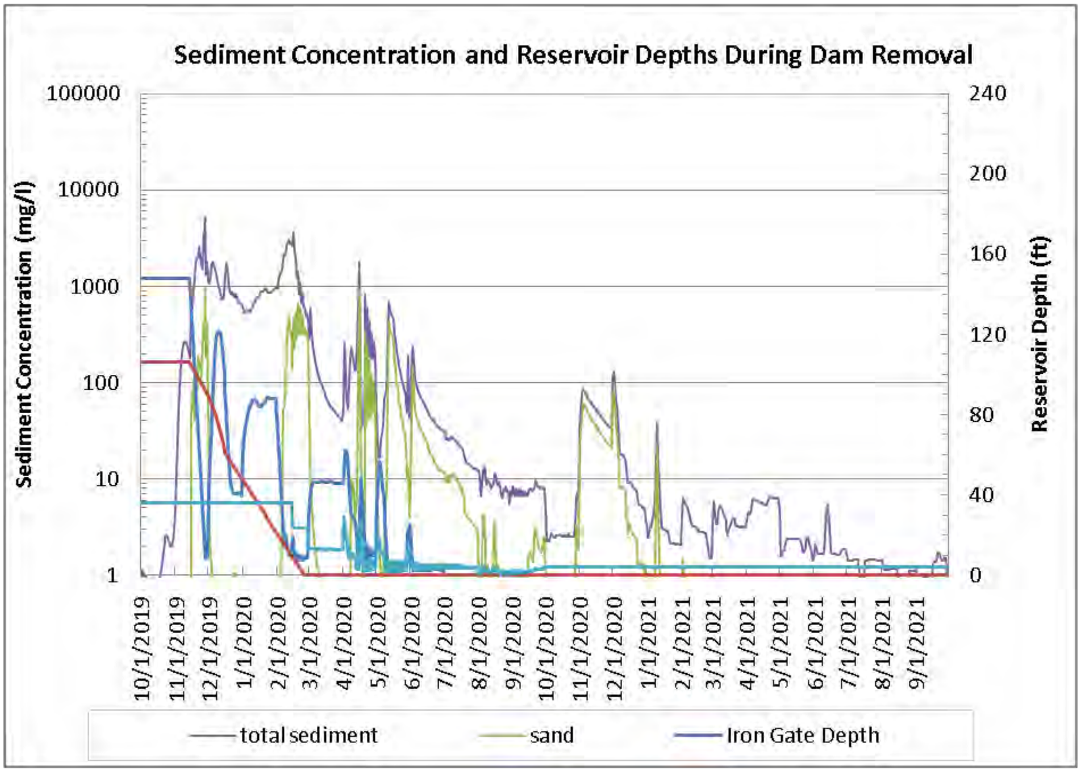

Figure 23-41. Simulated Reservoir Depths and Sediment Concentration below Iron Gate for WY 1984 (wet year) for Scenario 6.

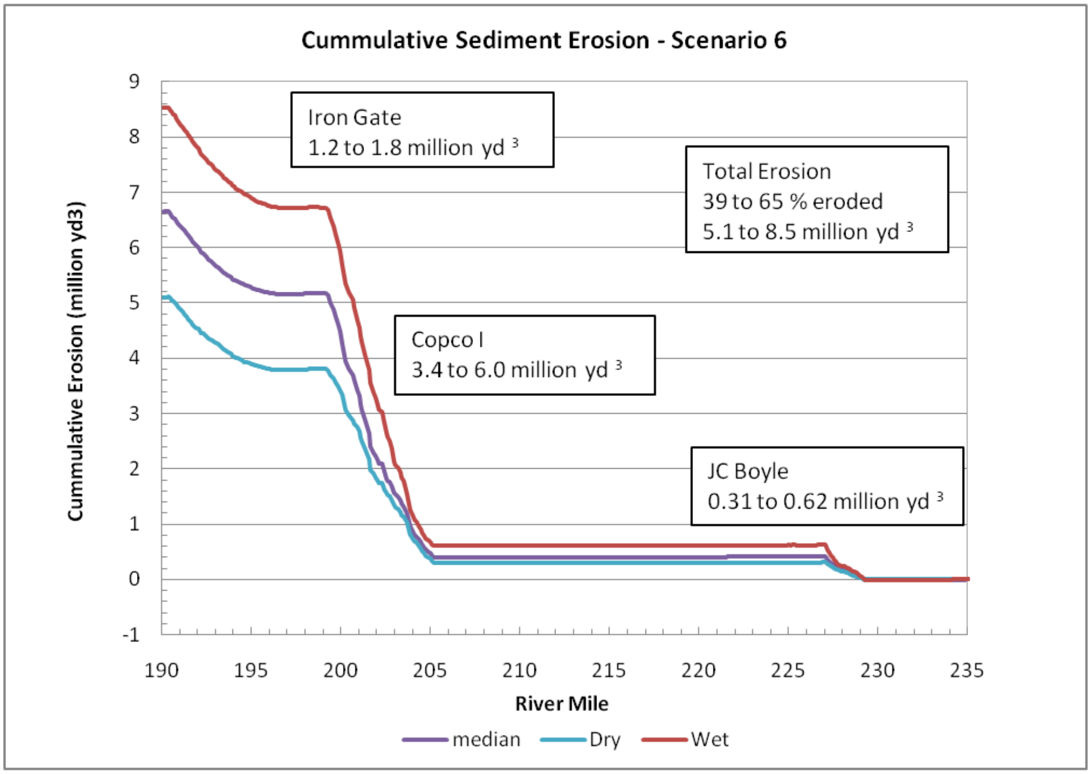

Figure 23-42. Cumulative sediment erosion for Scenario 6.

23.7. Scenario 7

Scenario 7 assumes drawdown for all three reservoirs commences on Jan 1, 2020. The low level outlet of Copco 1 is used and in addition Copco 1 is notched from the top at a rate of 6ft/wk. Therefore, the dam is removed to the existing stream bed by mid April 2020. The drawdown rate is limited to 1 ft/day for the upper 50 feet of the reservoir and 3 ft/d below that. Drawdown at J.C. Boyle is assumed to occur in a manner similar to Scenario 6, but begins Jan 1, 2020. The reservoir elevations for J.C. Boyle are shown in Figure 23-38.

Sediment Concentrations

The results for the sediment concentrations at Iron Gate are given in Figure 23-39, Figure 23-40, and Figure 23-41, and for the dry, median, and wet years. The results are similar to Scenario 3.

There are slightly elevated concentrations in November prior to the start of drawdown. There are fines in the upper portion of the reservoirs that are mobilized upon model start up and carried through the system. It doesn’t reflect reality, but is due to probably putting fine material too far upstream in the reservoir where velocities are still high enough to mobilize it.

A comparison between Scenario 7 and background concentrations for dry, median, and wet years at Seiad Valley, Orleans and Klamath stream gages is given in Figure 23-48, Figure 23-49, and Figure 23-50, respectively. The concentrations due to dam removal generally decrease in the downstream direction. The maximum concentrations at Iron Gate are approximately 8,000 mg/l under a dry water year, 6,000 mg/l under a median water year, and 4,000 mg/l under a wet water year. The maximum concentrations correspond to maximum drawdown rates or to the last portion of reservoir evacuation. It is expected that the maximum concentrations are under predicted because the model does not represent the variability that will existing during drawdown. For example, bank failure is assume to occur gradually during the drawdown process. In reality, a large bank failure may occur and suddenly add a large volume of sediment to the river. This high concentration will quickly dissipate but may cause a rapid spike in concentration. The concentrations in the plot are best interpreted as daily average concentrations that may vary significantly throughout the day.

The maximum concentrations at Seiad Valley decrease to approximately 2,000 to 3,000 mg/l under dry, median, and wet conditions. During the period Jan 1 to April 15, the concentrations are usually above 1,000 mg/l during the dry years, above about 700 mg/l for the median and wet years. The main difference between the dry, median, and wet is more on the duration of the higher concentrations. The concentrations under the dry water year are more often near the maximum concentration, whereas, under the wet water year, the concentrations are commonly just below 1,000 mg/l. The background concentrations at Seiad valley are expected to be less than 100 mg/l during months of Jan to Apr, but may spike to above 1,000 mg/l during wet water years as sediment is contributed from tributaries.

The maximum concentrations at Orleans are just above 1,000 mg/l for all water year types. Again, the main difference between dry, median, and wet is the duration that concentrations are near the maximum concentration. The background concentrations at Orleans will typically be around 100 mg/l, but will spike to around 1,000 during high flow events.

The maximum concentrations at Klamath are variable between water years. For the median and wet year, the maximum concentrations are due to high background concentrations pushing the concentrations to over 1,000 mg/l. The concentrations due to dam removal are expected to be around 700 to 800 mg/l at Klamath for the median and dry years and will occur near the end of Iron Gate drawdown in January and the end of Copco drawdown in April.

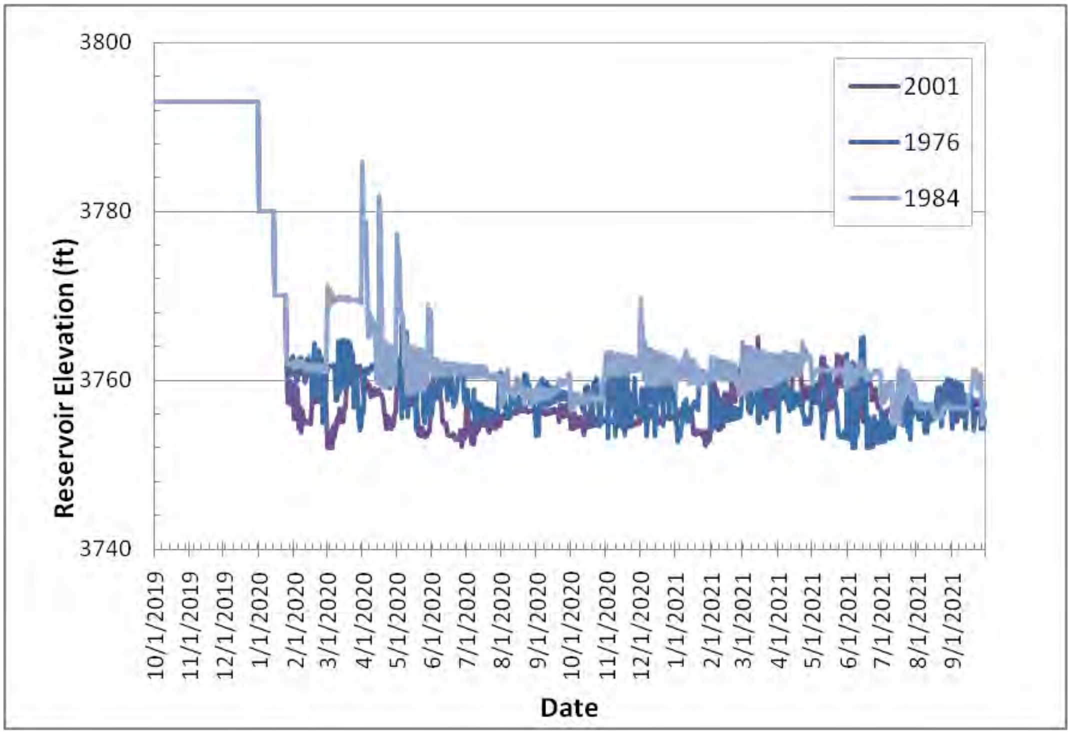

Figure 23-43. J.C. Boyle Elevations for dry, median, and wet year for Scenario 7.

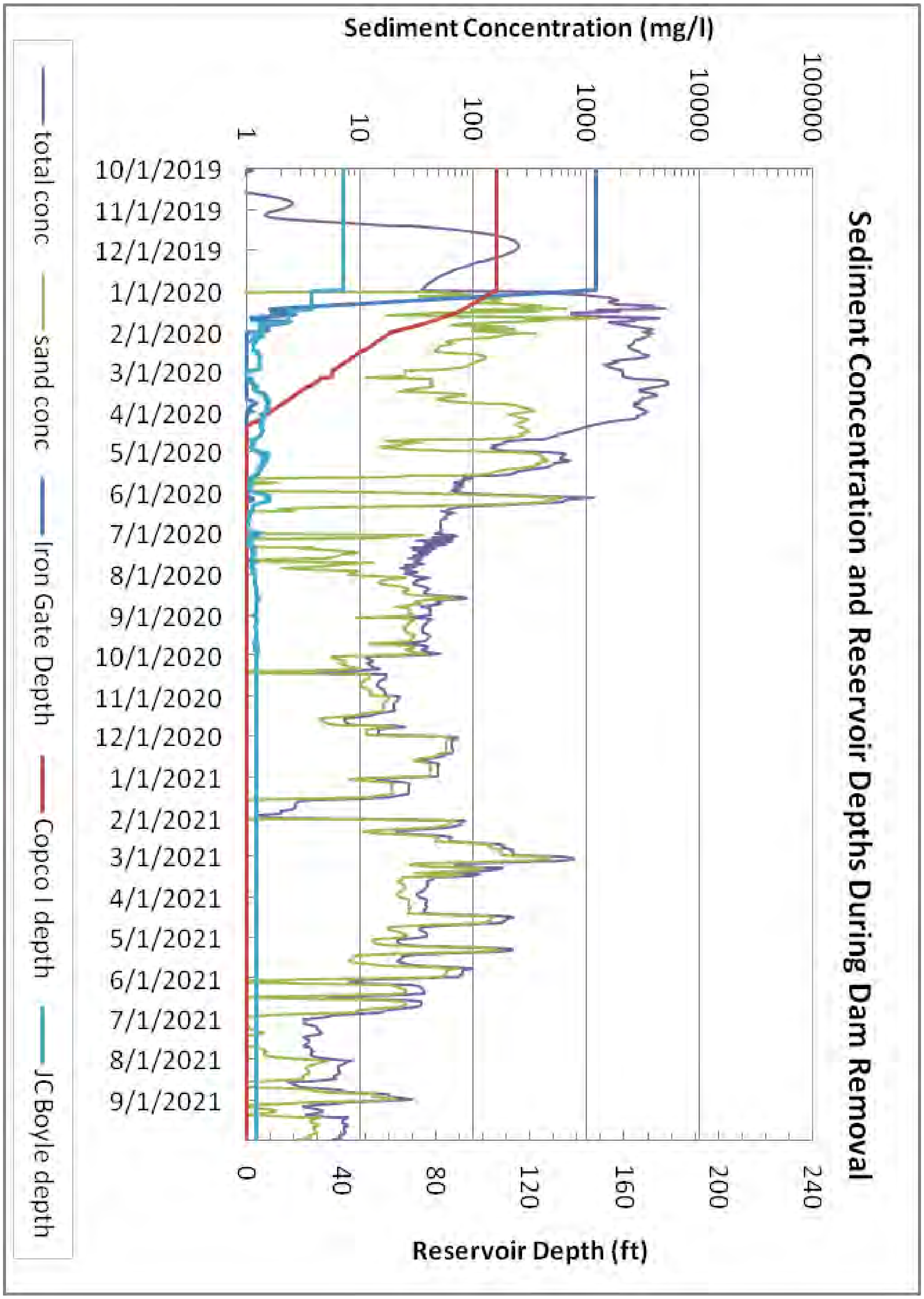

Figure 23-44. Simulated reservoir depths and sediment concentration below Iron Gate for WY 2001 (Dry year) for Scenario 7.

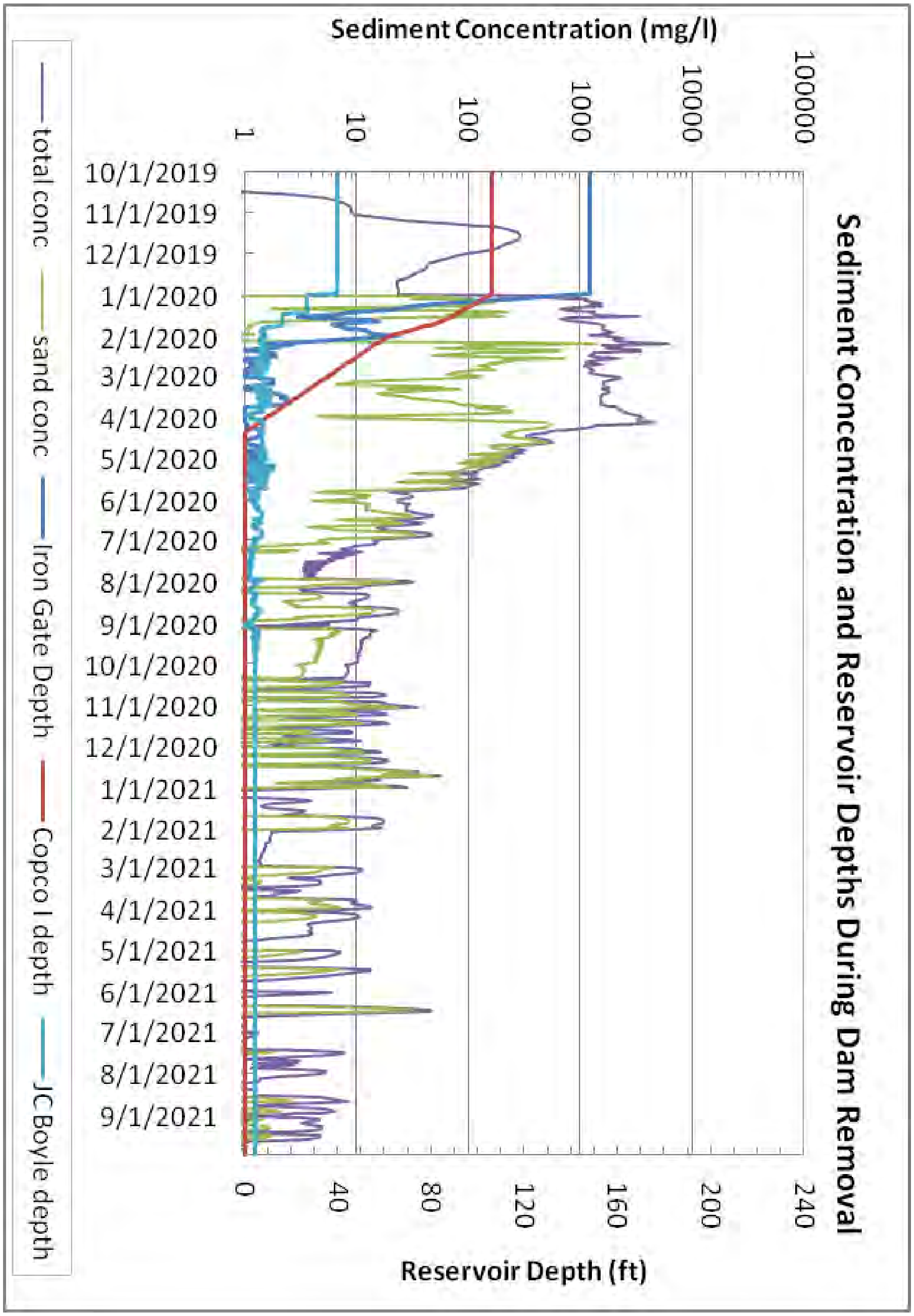

Figure 23-45. Simulated reservoir depths and sediment concentration below Iron Gate for WY 1976 (median year) for Scenario 7.

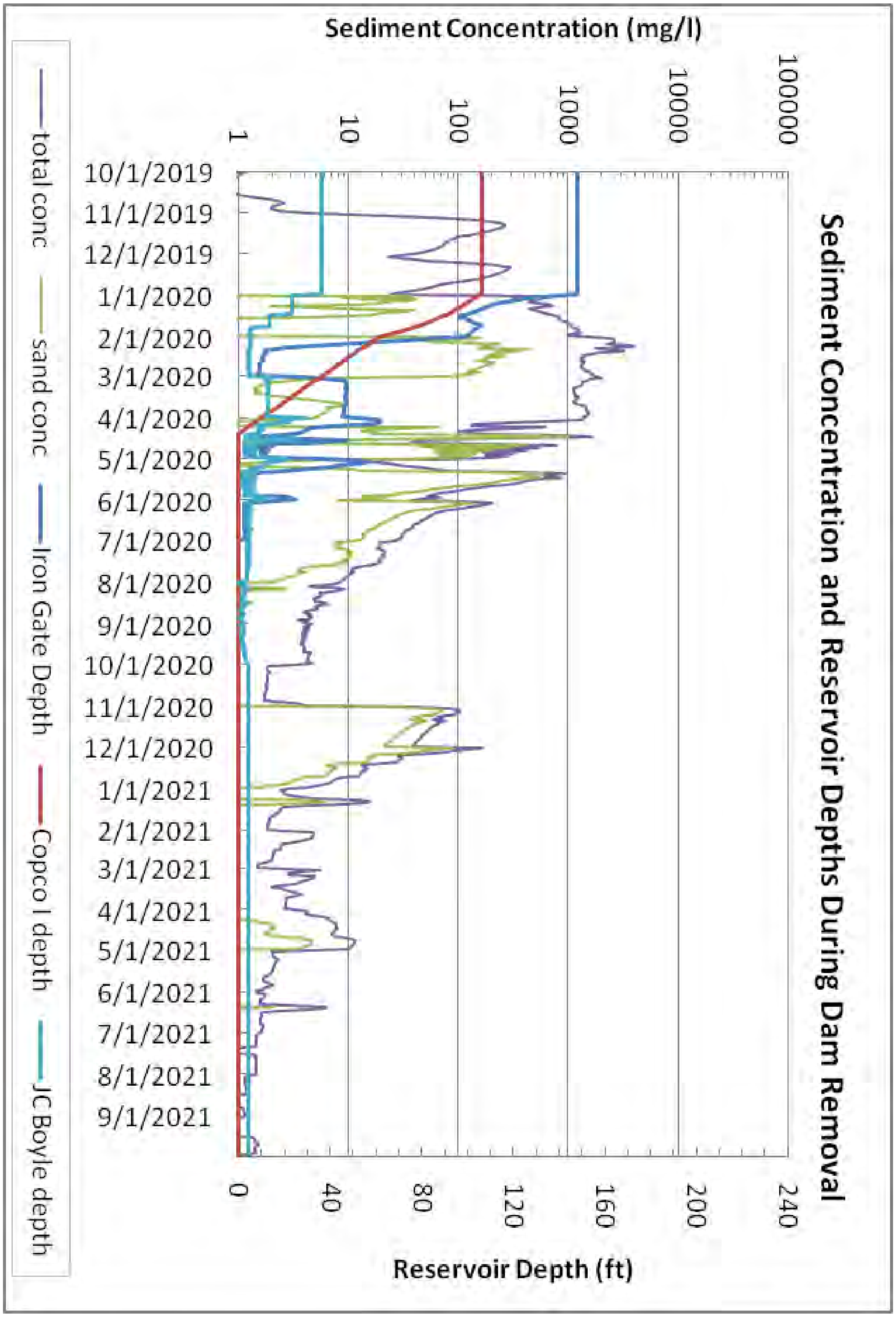

Figure 23-46. Simulated Reservoir Depths and Sediment Concentration below Iron Gate for WY 1984 (wet year) for Scenario 7.

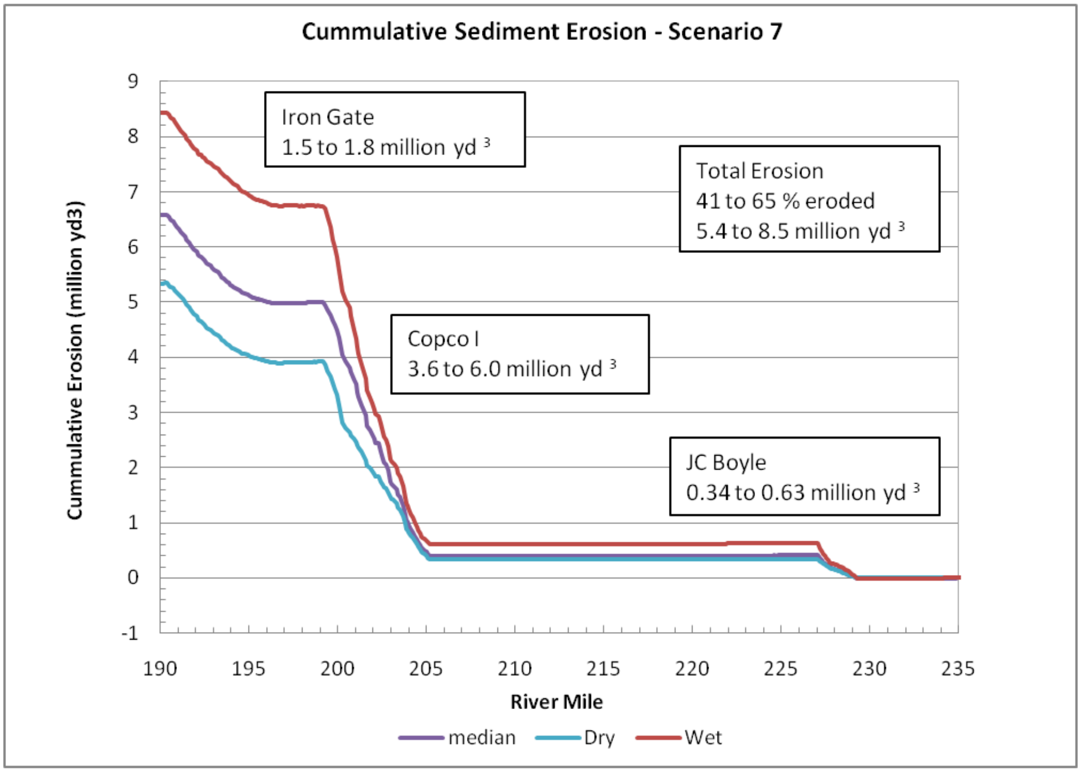

Figure 23-47. Volume of sediment erosion for Scenario 7.

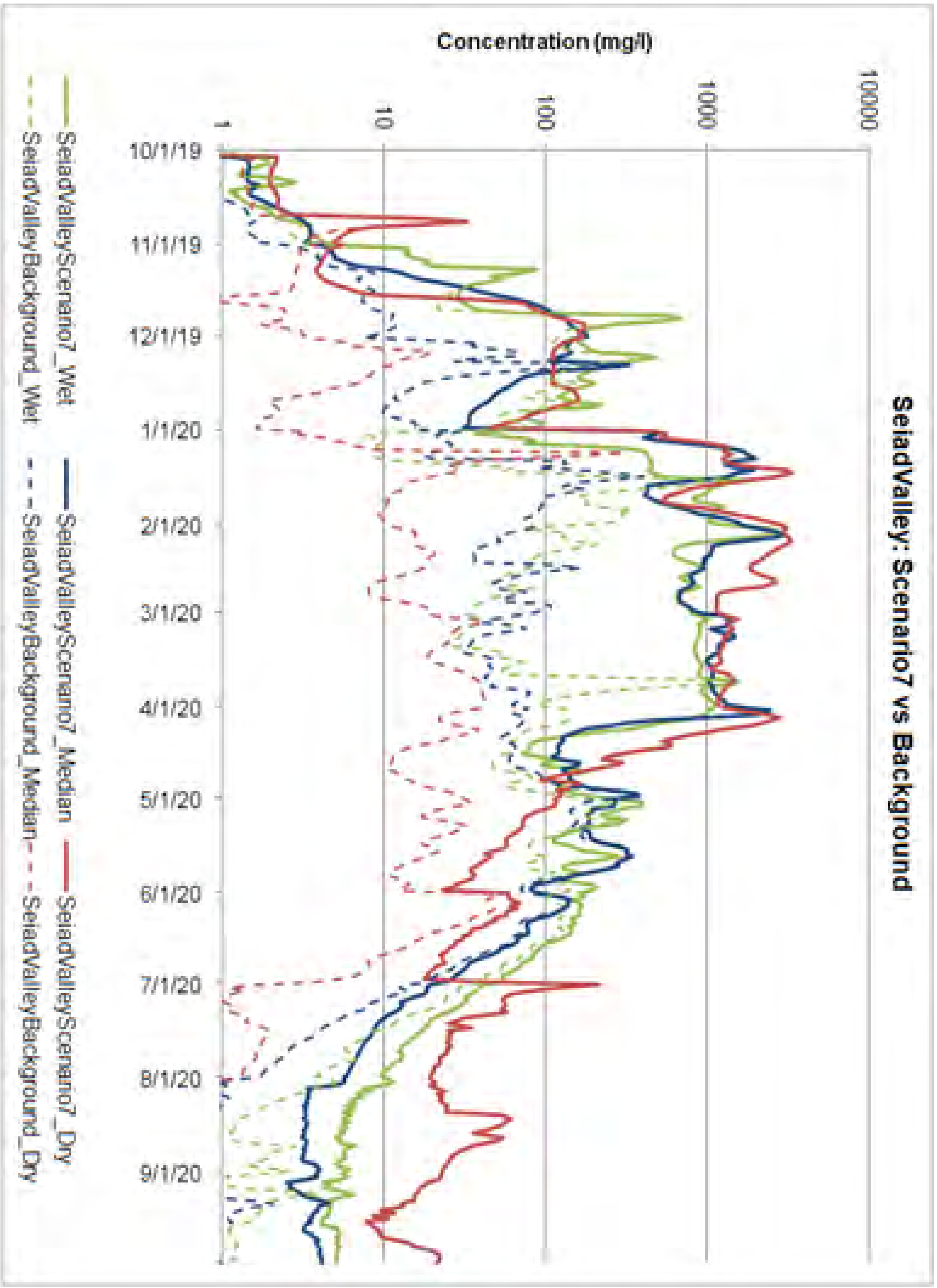

Figure 23-48. Sediment Concentrations at Seiad Valley for Scenario 7 and for Background conditions for dry, median and wet years.

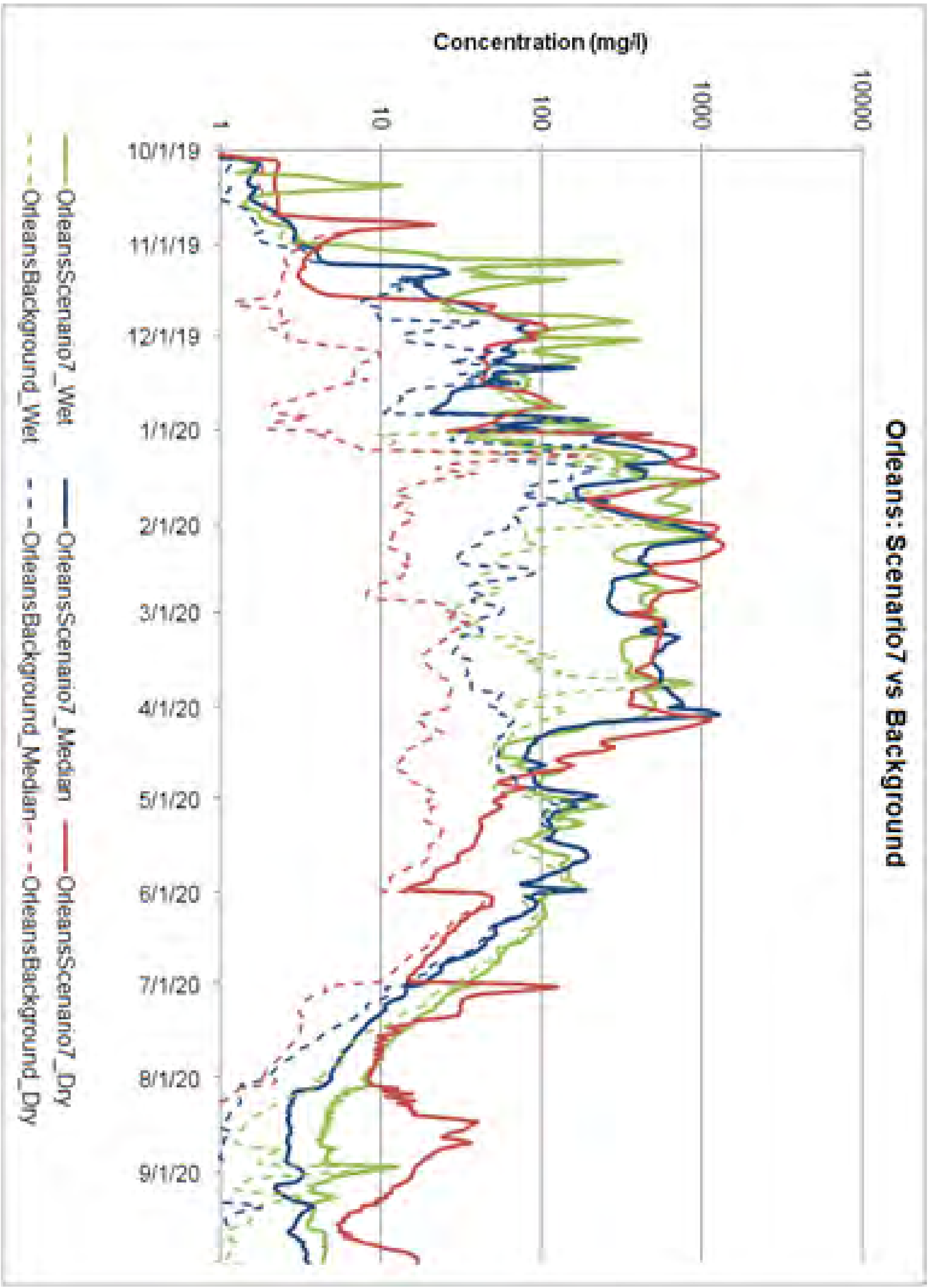

Figure 23-49. Sediment Concentrations at Orleans for Scenario 7 and for Background conditions for dry, median and wet years.

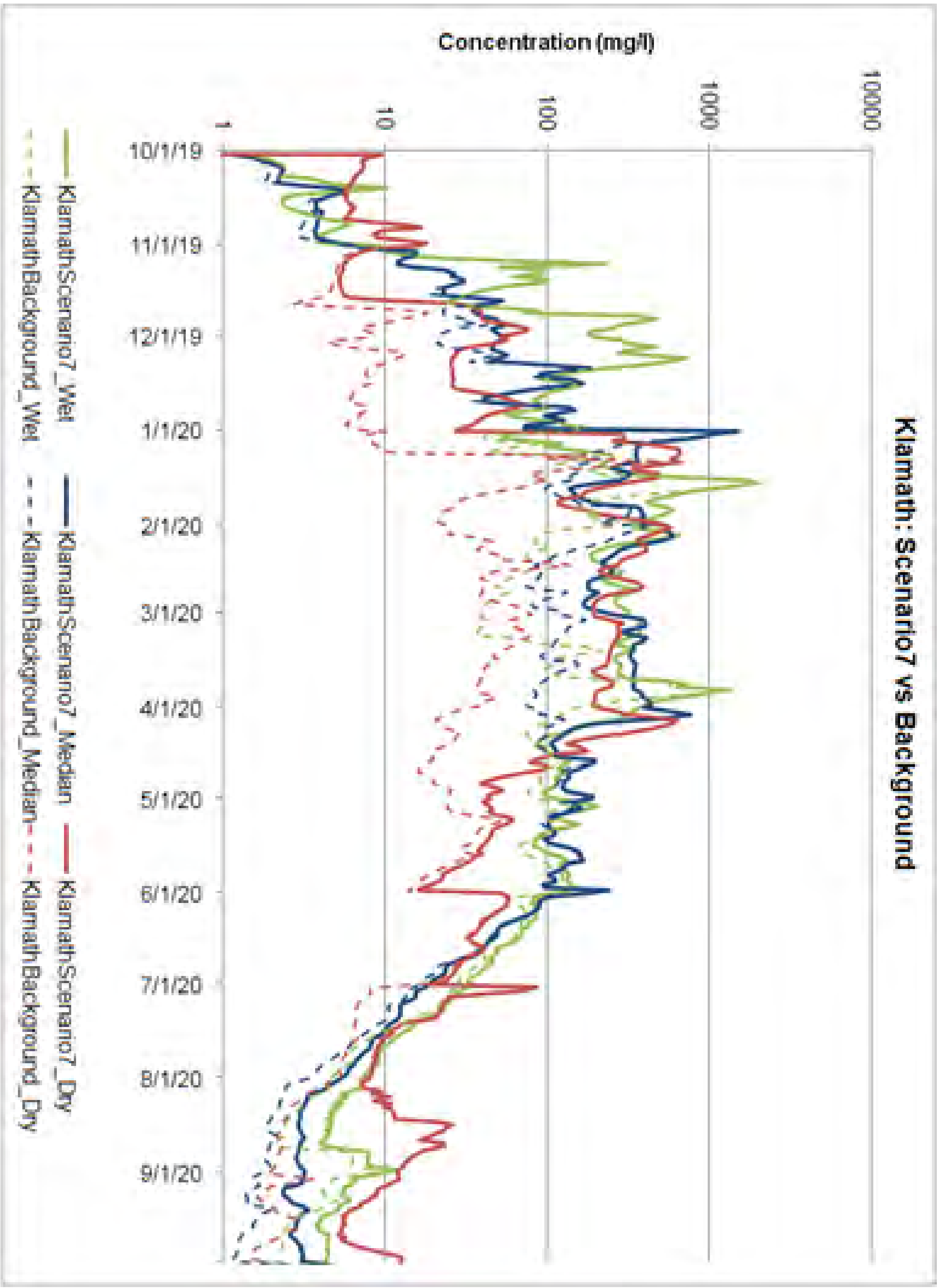

Figure 23-50. Sediment Concentrations at Klamath for Scenario 7 and for Background conditions for dry, median and wet years.

Figure 23-51. Sediment Concentrations at stream gage locations for Scenario 7 at 50% exceedance levels.

Figure 23-52. Sediment Concentrations at stream gage locations for background conditions at 50% exceedance levels.

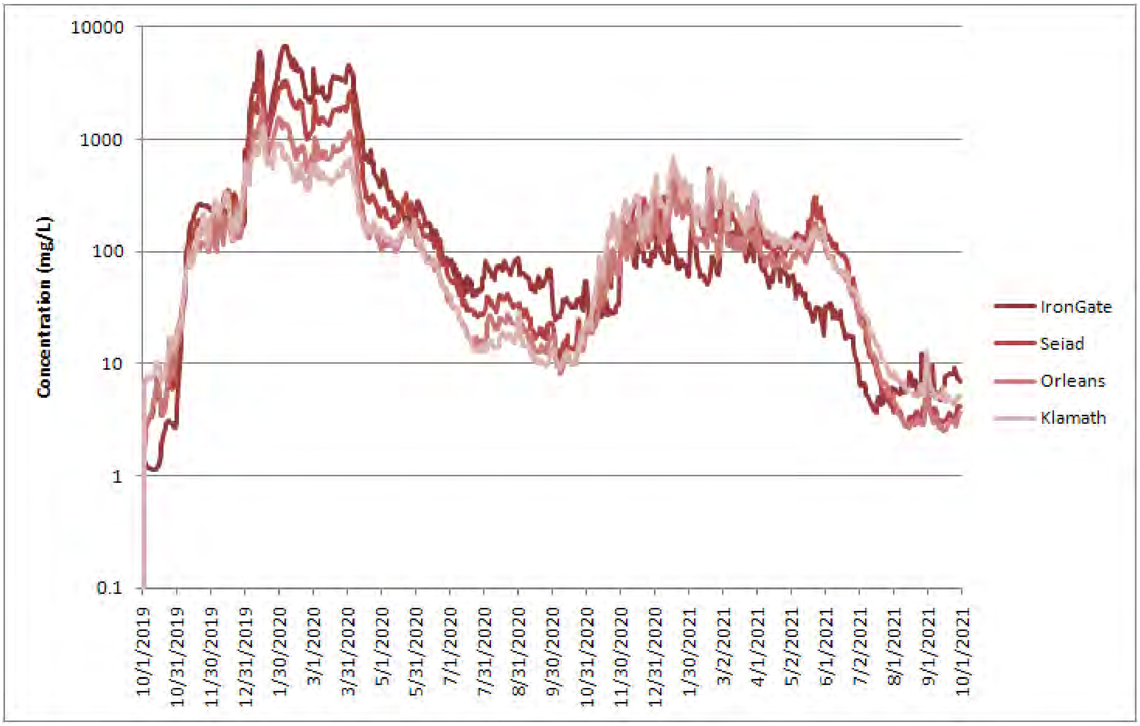

Figure 23-53. Sediment Concentrations at stream gage locations for Scenario 7 at 10% exceedance levels.

Figure 23-54. Sediment Concentrations at stream gage locations for background conditions at 10% exceedance levels.

23.8. 1D Model Sensitivity

One of the main model uncertainties was the sediment angle of repose.

Angle of Repose

The angle of repose is varied from 15 degrees to 5.7 degrees. The effect on the erosion volumes and concentration is significant. The angle of repose is likely the most important model parameter. When the angle of repose is decreased to 5.7 degrees (a slope of 10H:1V), significantly more sediment is eroded than when an angle of repose of 15 degrees is assumed. This is because a large portion of the reservoir slopes are steeper than 10%. Therefore, the sediment simply falls into the river channel with no applied shear stress.

The peak sediment concentrations are similar when an angle of repose of 5º is used, but the concentrations remain above 1,000 mg/l and 100 mg/l for a significantly longer period of time.

Geotechnical tests indicated that the angle of repose was above 25º, but Strauss (2010) indicated that this is likely an upper estimate and that the actual value could be significantly lower. Samples indicated the samples rapidly increase in shear strength when drained. As a simple test, the container in Figure 5-42 was tipped at a 4:1 slope a day after placement. The slope was maintained and the sediment did not show any significant movement. Therefore, as long as the sediment is freely drained, the sediment should maintain slopes of 4:1 or greater shortly after drawdown. The sediment will have very little strength when it is first saturated and an angle of repose of 5º is considered, but as the sediment drains, the angle of repose will quickly increase and it is not likely that the angle of repose remains at 5º for more than a few weeks.

It is possible that the sediment does slump toward the river channel for a period of time that is longer than predicted in the sediment model. The model assumes bank failure occurs instantaneously when in reality, the sediment may tend to act similar to a very viscous liquid for a period of time. The sediment may slowly slump into the river channel and be carried away. The duration of impacts shown in Figure 23-56 is not considered likely, but because of the large uncertainties in the project, such a scenario cannot be discounted. Water quality permits should consider potential extensions in the duration of impacts over those presented as best estimates.

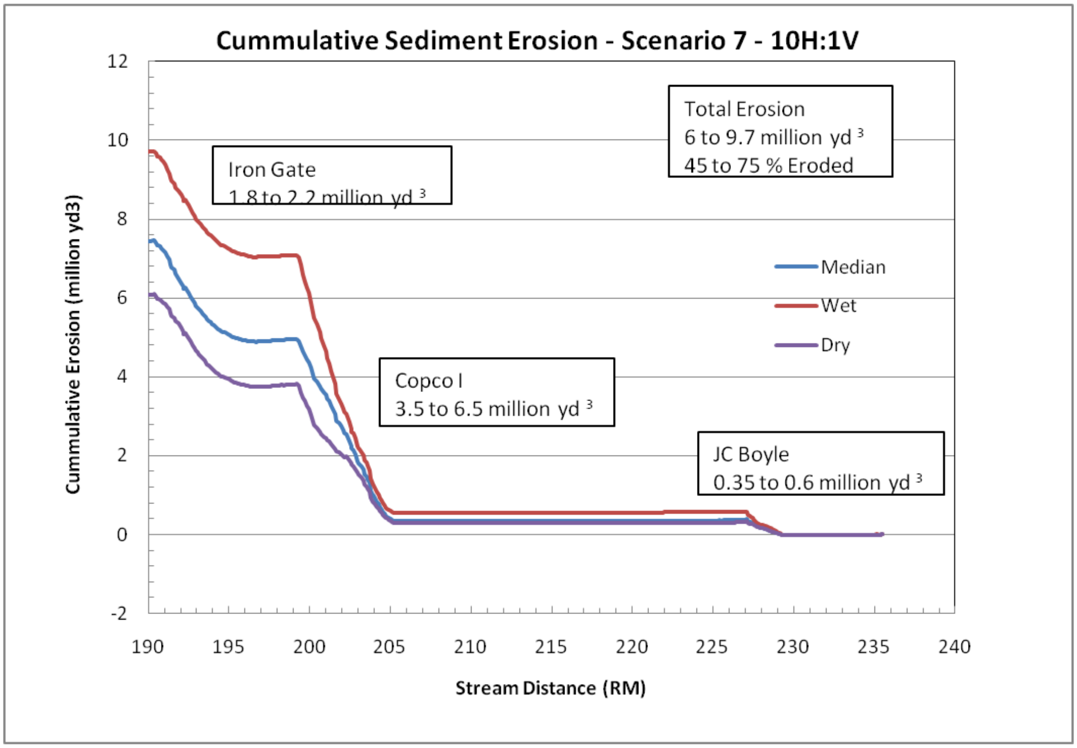

Figure 23-55. Sensitivity of Erosion Volumes to changes in Angle of Repose.

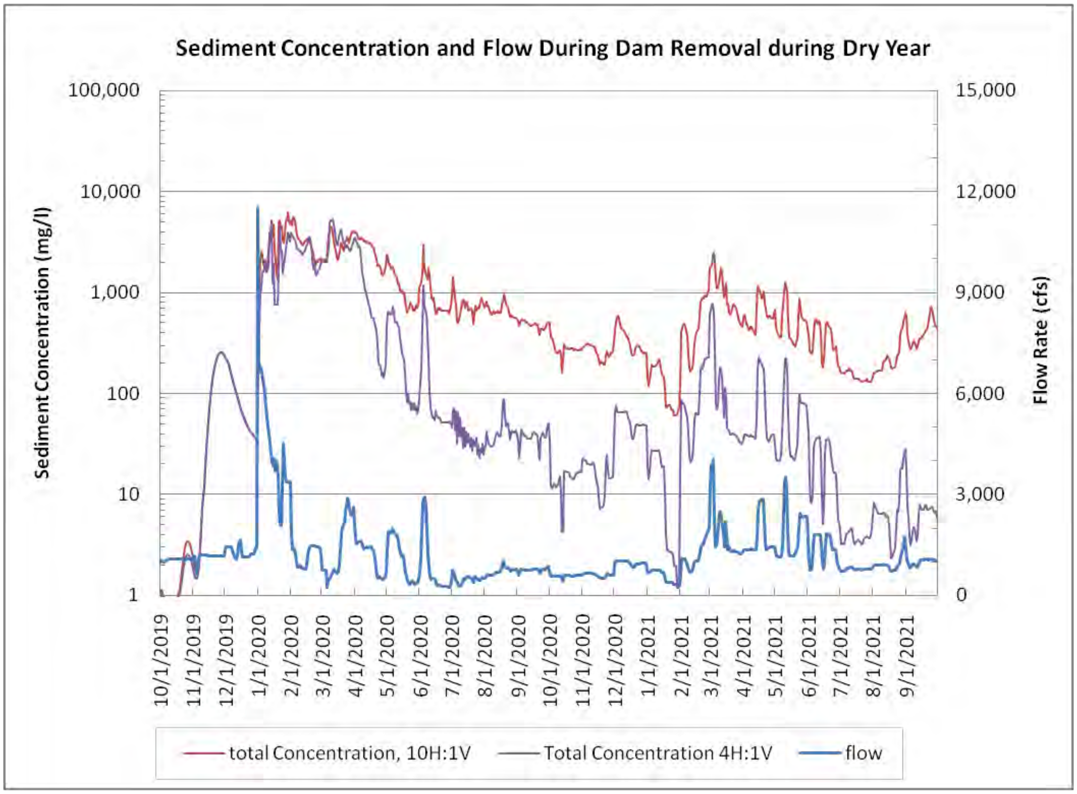

Figure 23-56. Sensitivity of model results to angle of repose of sediment.

23.9. Summary of Drawdown Model Results

The most important differences between the dam removal scenarios are the timing and magnitude of the sediment concentrations during the year of removal. There are expected to be no significant differences between the scenarios in terms of the long term impacts to sediment transport.

The sediment concentrations of all seven scenarios at the 5% exceedance level are shown in Figure 23-57. The 5% exceedance is computed on a daily basis and represents the concentration that is exceeded only 5 % of the time for a given day.

The magnitude of the sediment concentrations are greatest for the scenarios that have the higher drawdown rates at Copco 1 (Scenarios 1, 4, and 5). The peak concentrations are near or above 10,000 mg/l for several weeks. The magnitude of the concentrations that have smaller drawdown rates at Copco 1 peak at around 8,000 mg/l and this last only for a few days.

The durations of the concentrations above 1,000 mg/l are greatest for the scenarios that have lower drawdown rates at Copco 1 (2, 3, 6, and 7). The concentration remains above 1,000 mg/l for about 4 months.

The scenario that does not allow notching of Copco 1 (Scenario 1) shows high concentrations into June and July during wet years, whereas, all the other scenarios do not experience high concentrations past April.

If the drawdown of Copco 1 is not begun until Jan 1 and the drawdown rates are limited to 1ft/day or less, there will be high concentrations throughout March and into April.

The number of days above various concentration thresholds for given months are shown in Figure 23-58 to Figure 23-61. The exceedance levels in these charts refer to percent likelihood that concentrations will exceed the concentration threshold for a given number of days.

A comparison between just Scenario 6 and 7 is shown in Figure 23-62 and Figure 23-63, where the 5% and 50% exceedance concentrations for each day are shown. Scenario 6 has high concentrations at 50% exceedance levels between Nov 15 and March 1. Scenario 7 has high concentrations at a 50% exceedance level between Jan 1 and mid April.

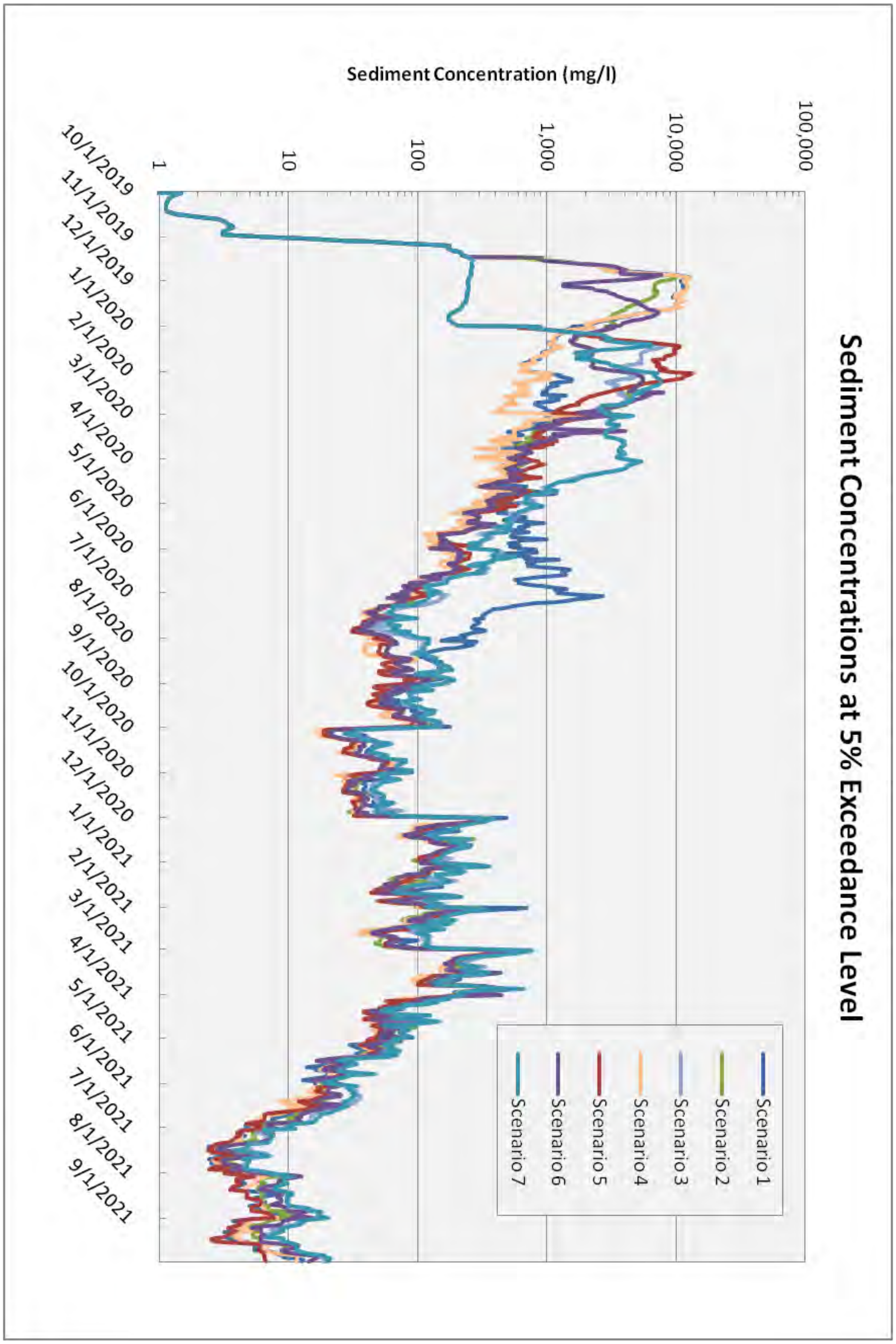

Figure 23-57. Sediment Concentration at 5% Exceedance Level for all Scenarios.

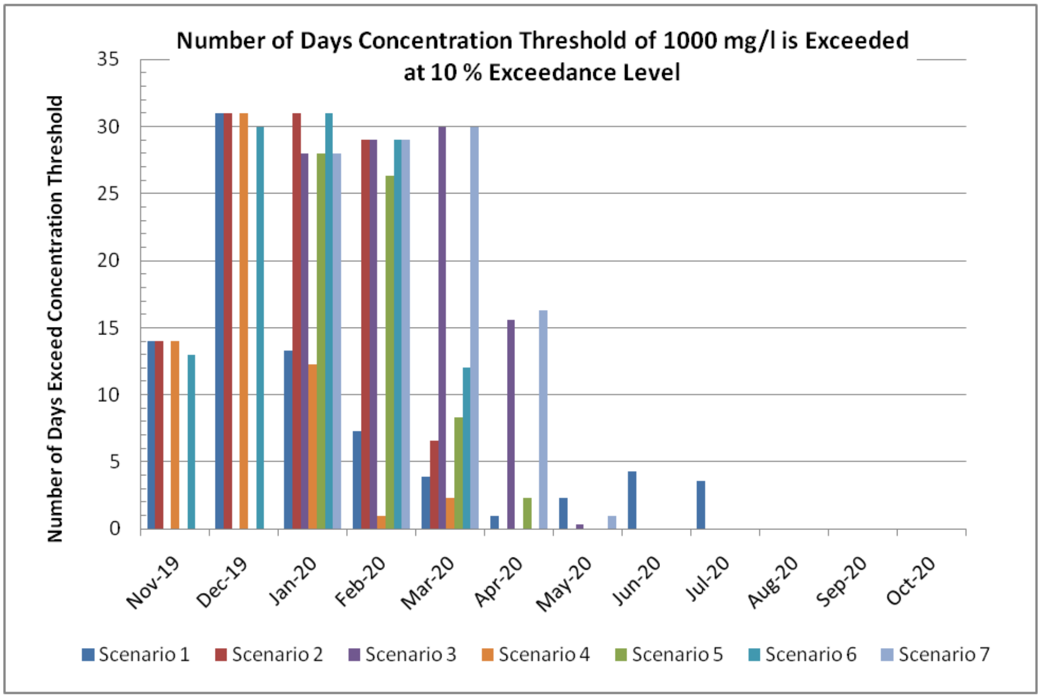

Figure 23-58. Number of Days Concentration Threshold of 1000 mg/l is Exceeded at a 10% Exceedance Level.

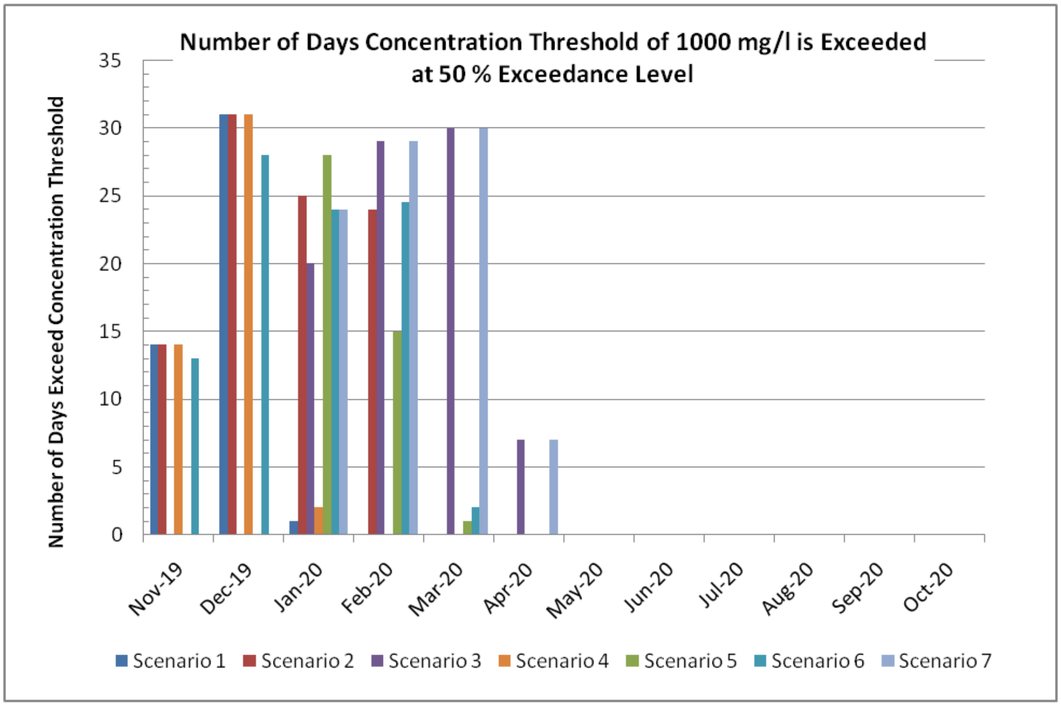

Figure 23-59. Number of Days Concentration Threshold of 1000 mg/l is Exceeded at a 50% Exceedance Level.

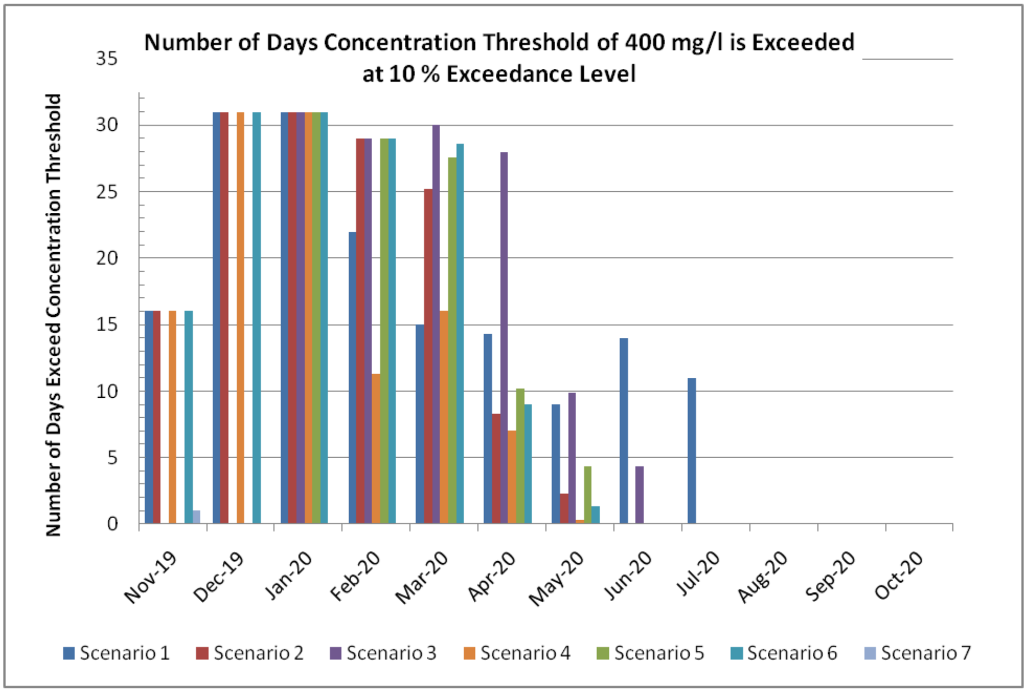

Figure 23-60. Number of Days Concentration Threshold of 400 mg/l is Exceeded at a 10% Exceedance Level.

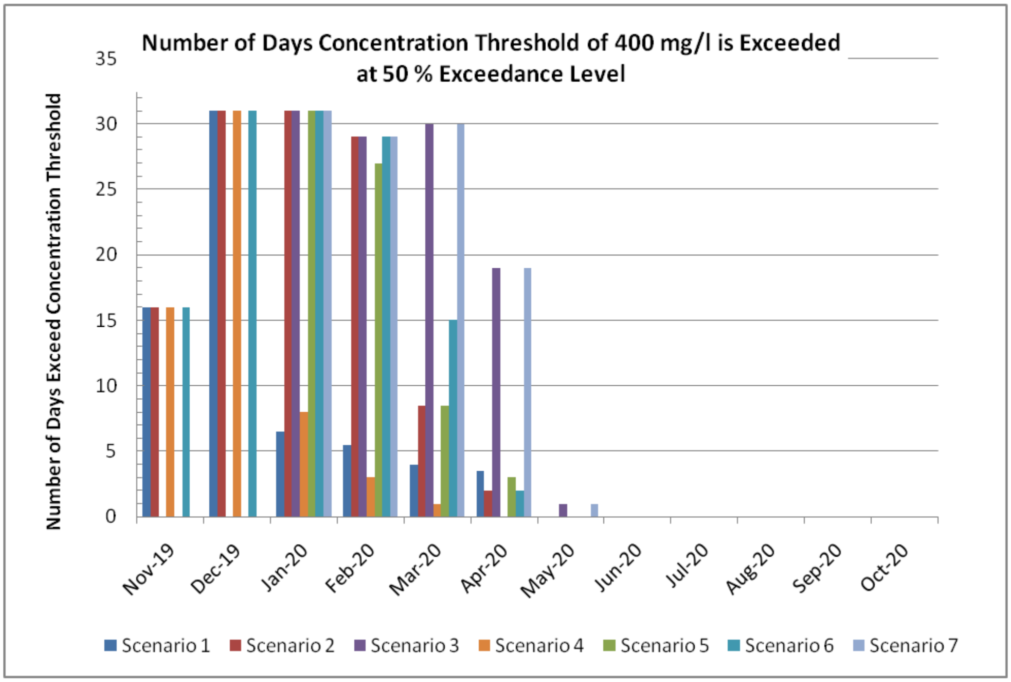

Figure 23-61. Number of Days Concentration Threshold of 400 mg/l is Exceeded at a 50% Exceedance Level.

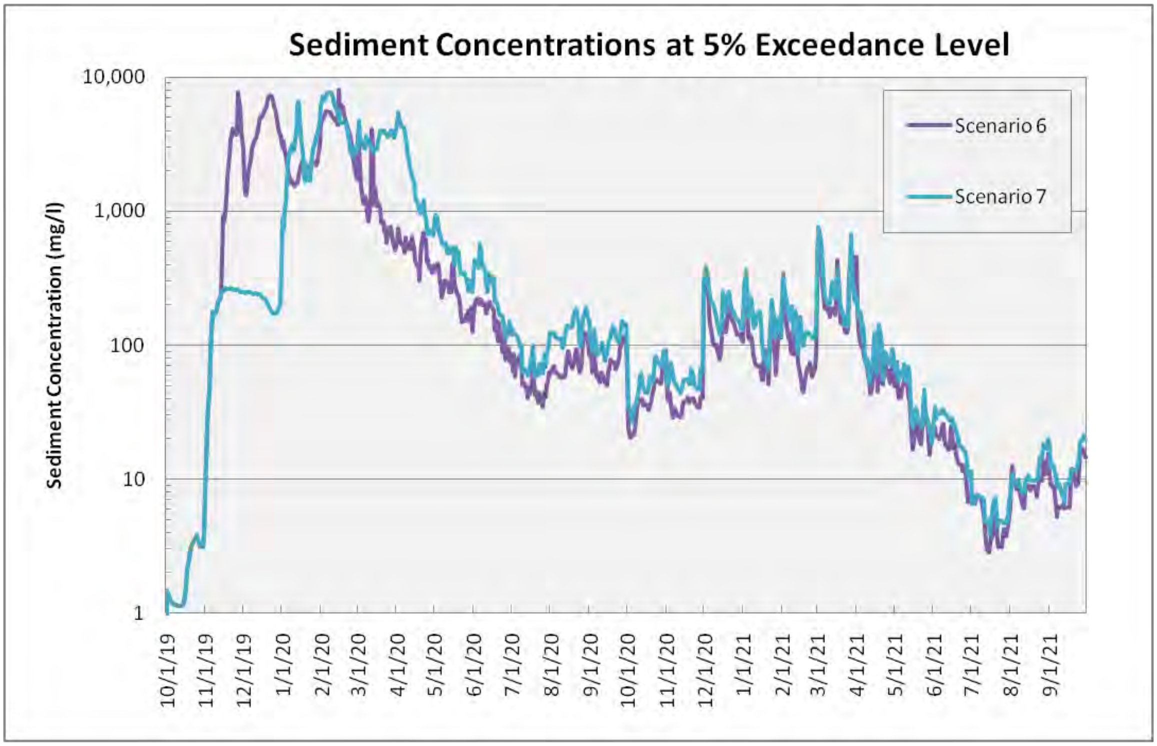

Figure 23-62. Comparison between Scenario 6 and 7 at 5% exceedance level.

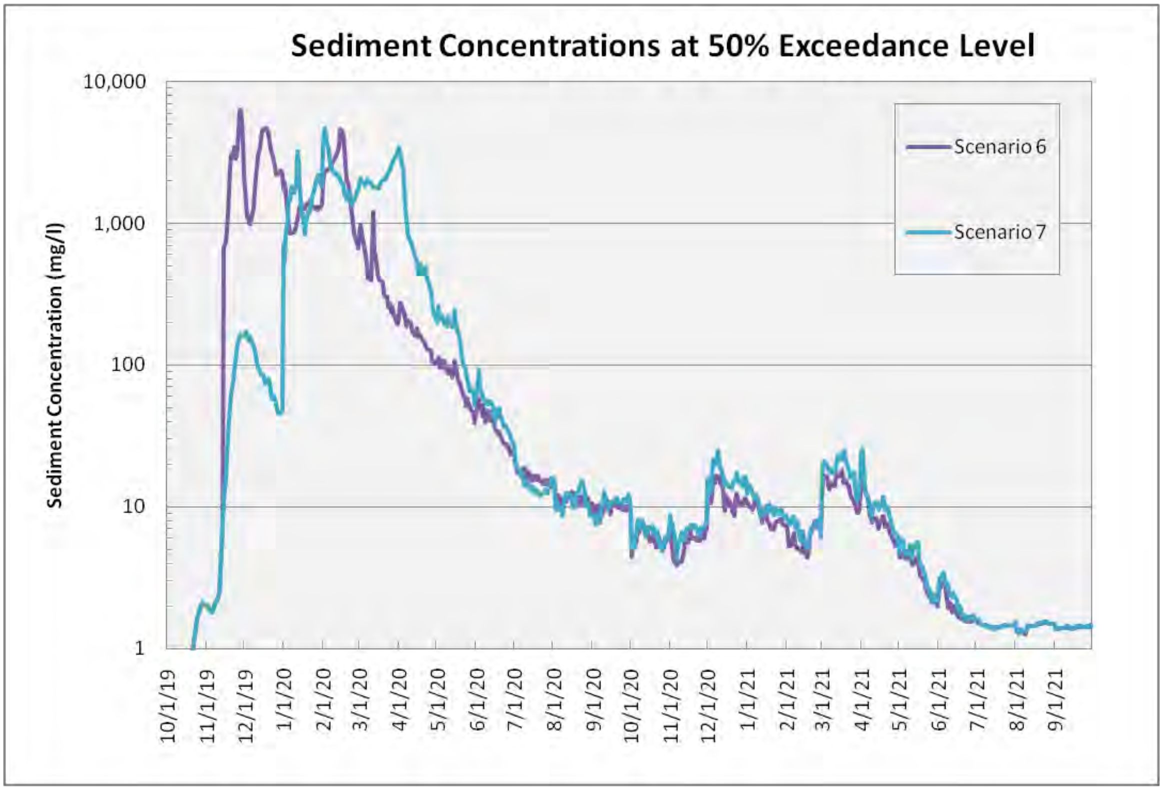

Figure 23-63. Comparison between Scenario 6 and 7 at 50% exceedance level.