TECHNICAL REPORT

Klamath River Dam Removal Study:

Sediment Transport DREAM-1 Simulation

Prepared for
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1330 Broadway, 13th Floor
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(Contract No. 06-141)

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October 2008

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Acknowledgement

A pre-project sediment transport technical workshop was conducted at NMFS office in Santa Rosa, California, attended by Michael Bowen (California State Conservancy), Brian Cluer (NMFS), Yantao Cui (Stillwater Sciences), William Dietrich (UC Berkeley), Dennis Gathard (GEC), Gordon Grant (USDA Forest Service), Frank Ligon (Stillwater Sciences), Thomas Lisle (USDA Forest Service), Gary Parker (U Illinois Urbana), Timothy Randle (Bureau of Reclamation), Marcin Whitman (California Department of Fish and Game), and Laura Wildman (American Rivers, via conference line). The participants of the workshop provided many suggestions that proved to be valuable to this study. The peer review comments from Brian Cluer, Dennis Gathard, Blair Greimann and Thomas Lisle are incorporated into this technical report. Helps from Jon Hicks, who provided information with regard to Klamath River Basin hydrology, and Dennis Gathard, who provided information with regard to reservoir deposits and dam removal design, are gratefully appreciated. Finally, we thank Michael Bowen, California State Conservancy project manager, for his guidance and discussions over the course of the project and the careful review of the draft report.

Suggested citation:

Stillwater Sciences (2008) Klamath River dam removal study: sediment transport DREAM-1 simulation. *Technical Report*, Prepared for California Coastal Conservancy, 1330 Broadway, 13th Floor, Oakland, CA 94612, 73 pages, October.

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Sediment Transport DREAM-1 Simulation

Executive Summary

Introduction

Iron Gate, Copco 1, Copco 2, and J.C. Boyle dams, located on the Klamath River in Oregon and California downstream of Upper Klamath Lake, are under consideration for possible removal. Data collected to date indicate that 11.5 to 15.3 million m^3 (15 to 20 million cubic yards) of deposits are stored within the four reservoirs (Eilers and Gubala 2003; GEC 2006). Unlike the other mid- to large-sized dam removal projects in the U.S. (e.g., Marmot Dam on the Sandy River, Oregon; dams on the Elwha River, Washington; Matilija Dam on Ventura Creek, California; and San Clemente Dam on Carmel River, California), the deposits in the above four reservoirs on the Klamath River have a high water content (~ 80% by volume), and the majority of the sediment particles are fine-grained (i.e., in the silt and clay range), while the composition of the Klamath River channel bed downstream of these dams are cobble sized (e.g., Stillwater Sciences 2004; Cui et al. 2005; GEC 2006; Shannon and Wilson Inc. 2006). As a result, if the deposits are released downstream, high suspended sediment concentrations and their associated biological impacts due to the quick release of fine sediment will most likely be the major concern (GEC 2006), while concerns for downstream sediment deposition common to other dam removal projects will be minor, as demonstrated by the "worst-case-scenario" assumption analyses conducted in Stillwater Sciences (2004).

Previous studies (GEC 2006) have concluded that the best removal alternative is to remove J.C. Boyle and Copco 2 dams prior to the removal of Copco 2 and Iron Gate dams. J.C. Boyle Reservoir contains less than 4% of the total deposits in the four reservoirs combined, and Copco 2 Reservoir contains negligible deposits. Following the removal of J.C. Boyle and Copco 2 dams, a concurrent drawdown of Copco 1 and Iron Gate reservoirs will be commenced in late fall or early winter in preparation for the removal of the two dams. This concurrent drawdown removal alternative recognizes that Iron Gate Reservoir does not have adequate trapping efficiency to effectively trap the fine sediment released from the upstream reservoirs under a sequential removal alternative that removes the upstream dams before Iron Gate Dam removal (GEC 2006, Stillwater Sciences 2007), and thus, attempts to minimize the duration of high turbidity event as a way of reducing the potential impact to river biota due to dam removal. This technical report provides the modeling results for potential sediment release during this concurrent drawdown process and during dam removal. Through numerical explorations under many hydrological conditions and several possible engineering and management options under the concurrent drawdown alternative, we identify the preferred reservoir drawdown options (i.e., starting date, rate of drawdown, size of the bottom outlet to be constructed on Copco 1 Dam, and potential management measures) in reducing impact from high suspended sediment concentration (or total suspended solid, referred to as TSS hereafter) and provide results under the preferred drawdown options. Results provided in this report have provided the basis for the assessments of biological impacts associated with the removal of these four dams (Stillwater Sciences 2008).

Approach

Sediment transport simulations were conducted with DREAM-1, one of the two **D**am **R**emoval **E**xpress **A**ssessment **M**odels (Cui et al. 2006a,b). DREAM-1 is a peer reviewed sediment transport model; it has been examined extensively with both flume and field data (e.g., Cui et al. 2006a, 2006b, 2008b; Wooster 2003); and the model and its predecessor have been used successfully in dam removal evaluations and other important sediment transport related projects, including a preliminary study of potential sediment deposition downstream of Iron Gate Dam due to dam removal (Cui and Parker 1999; Stillwater Sciences 1999; Stillwater Sciences 2004). Taking advantage of the significantly reduced field data requirement compared to many other sediment transport models while not compromising the quality of the modeling, we conducted a large number of runs (70 documented runs and many undocumented runs), identifying the preferred engineering and management options and providing a comprehensive picture of the potential sediment transport dynamics following dam removal under different hydrologic conditions and the preferred engineering and management options.

Conclusions

Main conclusions of this study include:

- The Copco 1 outlet used for reservoir drawdown should be constructed to approximately 18.2 m^2 (~ 200 ft^2, with outlet dimensions of 14 x 14 ft, 13 x 15 ft, or 10 x 20 ft, or two 10 x 10 ft).
- Using Upper Klamath Lake to manage the flow into Copco 1 Reservoir during the drawdown period appears unlikely to achieve the objective of reducing the following spring's suspended sediment concentration.
- Increasing the limit on the rate of reservoir drawdown should generally facilitate the erosion of sediment during the winter period, which reduces the suspended sediment concentration in the following spring. However, the potential benefit of increasing the drawdown limitation beyond 1.8 m/day (6 ft/day) is minimal.
- Geotechnical engineers have expressed a preference for a slower drawdown at the beginning of the drawdown process (PanGEO 2008). Starting the drawdown on 6 November at a rate of 0.3 m/day (1 ft/day) results in a prediction that suspended sediment concentration at Iron Gate station will not exceed 1,000 ppm prior to 15 November for all runs except one. This corresponds to a probability of less than 5% that maximum increase in daily-averaged TSS prior to 15 November will exceed 1,000 ppm. The one run with the increased daily-averaged TSS at Iron Gate station exceeding 1,000 ppm prior to 15 November is less than 2,000 ppm.
- Under the preferred drawdown scenario that starts drawdown on 6 November at 0.3 m/day (1 ft/day) and increases to 1.8 m/day (6 ft/day) on 15 November, winter (15 November to 21 March) the increased daily-averaged TSS exceeds 10,000 ppm at Iron Gate station, 5,000 ppm at Seiad Valley station, and 3,000 ppm at Orleans station for all the runs. The simulated highest increase in daily-averaged TSS in winter for all the runs under this drawdown scenario exceeds 30,000 ppm at Iron Gate and Seiad Valley stations, and 10,000 at Orleans and Klamath stations.
- Under the preferred drawdown scenario, the increase in daily-averaged TSS in spring (after 21 March) is less than 2,000 ppm at Iron Gate station, less than 1,000 ppm at Seiad Valley station, and less than 500 ppm at Orleans and Klamath stations for all runs but one, which has a maximum increase in daily-averaged TSS less than 5,000 ppm at Iron Gate station, 3,000 ppm at Seiad Valley station, 2,000 ppm at Orleans station, and 1,000 ppm at Klamath station in spring.
- No discernable sediment deposition is predicted for any of the runs downstream of Iron Gate Dam, indicating minimal potential for deposition or increases in flooding risk associated with sediment deposition. In addition, elimination of the attenuation effects from the four reservoirs should not increase flooding risks because they presently have limited active storage and provide minimal flood attenuation for larger peak flood events.
- Coarse sediment (sand and coarser) released during reservoir drawdown and dam removal travels slower than fine sediment because of the attenuation of bedload transport.

- The amount of pool filling will be small, based on the minimal predicted reach-averaged sediment deposition downstream of the dam. Flume experiments indicate that pool topography will persist, and if pool infilling occurs, it will be short lived prior to returning to pre-sediment release topography.
- Fine sediment infiltration is expected to be limited to a shallow depth near the bed surface, which can be readily flushed during a high flow event after the fine sediment supply in the former reservoir area is exhausted. There are potential opportunities to use Upper Klamath Lake to stockpile water in advance for a flushing flow release to clean fine sediment deposit as soon as the dam structures are removed. A limited sampling of the bed material prior to reservoir drawdown and removal will provide more confidence with fine sediment infiltration predictions and will provide baseline information for a potential post-dam removal monitoring program.

Potential biological impacts from the sediment release are provided in a separate technical report (Stillwater Sciences 2008).

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Table of Contents

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1. Introduction

Four dams on the Klamath River are being considered for removal: Iron Gate, Copco 1 and 2, and J.C. Boyle dams, which are located in Oregon and California downstream of Upper Klamath Lake (Figure 1). Data collected to date indicate that 11.5 to 15.3 million m^3 (15 to 20 million cubic yards) of deposits are stored within the four reservoirs (Eilers and Gubala 2003; GEC 2006). Unlike the other mid- to large-sized dam removal projects in the U.S. (e.g., Marmot Dam on the Sandy River, Oregon; dams on the Elwha River, Washington; Matilija Dam on Ventura Creek, California; and San Clemente Dam on Carmel River, California), the deposits in the above four reservoirs on the Klamath River have a high water content (~ 80% by volume), and the majority of the sediment particles are fine-grained (i.e., in the silt and clay range), while the composition of the Klamath River channel bed downstream of these dams are cobble sized (e.g., Stillwater Sciences 2004; Cui et al. 2005; GEC 2006; Shannon and Wilson Inc. 2006). As a result, if the deposits are released downstream, high suspended sediment concentrations and their associated biological impacts due to the quick release of fine sediment will most likely be the major concern (GEC 2006), while concerns for downstream sediment deposition common to other dam removal projects will be minor, as demonstrated by the "worst-case-scenario" assumption analyses conducted in Stillwater Sciences (2004). Quantifying and evaluating the potential high sediment concentrations is a necessary step when considering the feasibility for removing these dams because dredging all the deposits in the reservoirs is unlikely going to be economically and technically feasible[1].

This technical report provides the modeling results for potential sediment release during the drawdown process in preparation for dam removal. Results provided in this report have provided the basis for the assessments of biological impacts associated with the removal of these four dams (Stillwater Sciences 2008).

2. Overview of Reservoir Deposits: A Summary of Previous Studies

The California State Coastal Conservancy commissioned a series of studies (e.g., GEC 2006; Shannon and Wilson Inc. 2006) in an effort to better understand the volume and composition of the reservoir

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[1] It was proposed by some that mechanical removal of the reservoir deposits would avoid downstream release of sediment and high TSS levels downstream of Iron Gate. However, previous analyses have found that mechanical removal of material is likely infeasible, and would probably contribute to high suspended sediment loads downstream of Iron Gate, thereby negating the desired result of mechanical removal of sediment (GEC 2006). Sediment dredging is costly, and may render the project financially infeasible. In addition to these barriers, dredging is probably technically infeasible because: a) drawing down the reservoirs to a level where sediments are available for dredging would likely trigger erosion and suspension of fine sediment, thereby increasing turbidity levels, causing adverse impacts downstream of Iron Gate Dam; b) due to the high water content in the reservoir deposits, temporarily disposing the dredged sediment onshore would require the construction of massive temporary levees to hold them in place; and c) the bottom outlet to be constructed on Copco 1 Dam and the existing tunnel near the bottom of Iron Gate Reservoir are not large enough to accommodate winter high flow, and it is economically infeasible to build the Copco 1 bottom outlet or to enlarge the Iron Gate tunnel to sizes large enough to do so. As a result, winter high flow events would re-inundate the dredged deposits. During the subsequent drawdown event, the breaching of the temporary levees would be almost certain, thereby releasing the dredged deposits back to the channel and resulting in high TSS downstream of Iron Gate; d) due to "c," above, ponds above the reservoir surface level would need to be constructed, and it appears there is not enough upland flat surface available for this purpose.

deposits in three of the four lowermost reservoirs on the Klamath River (Iron Gate, Copco 1, and J.C. Boyle). The fourth reservoir, Copco 2, was found to have negligible stored sediment (Eilers and Gubala 2003; GEC 2006). Here we summarize some of the findings reported in these studies (e.g., GEC 2006; Shannon and Wilson Inc. 2006) in a format that can be used directly for the sediment transport analysis in this technical report.

There are two sources for the data used in this summary: physical and chemical composition data obtained by Analytical Resources Inc. (ARI) reported in Appendix E in GEC (2006), and the water content and organic carbon content obtained by Shannon and Wilson Inc. (2006) (also reported in GEC 2006).

The ARI test results for Iron Gate, Copco 1, and J.C. Boyle reservoirs are summarized in Tables 1, 2, and 3, respectively. In these three tables, data in columns 2 and 3 were directly copied from ARI data sheets presented in Appendix E of GEC (2006), and columns 4 through 8 were calculated based on the assumptions that (1) the amount of material other than water, solids and organic carbon is small and can be neglected in deriving solid and organic carbon contents in the deposits; and (2) water, solids and dry organic carbon have densities of 1,000 kg/m^3, 2,650 kg/m^3 and 1,100 kg/m^3, respectively. Data calculations presented in columns 4 through 8 are straightforward and are not discussed.

Tables 1, 2 and 3 also summarize the mean, standard deviation, and maximum and minimum values of the test results. To help better comprehend the information presented in these tables, the summary results for mean values of solids, organic carbon and water contents in the deposits are also presented in two diagrams in Figure 2, one as mass fractions (Figure 2a) and the other as volumetric fractions (Figure 2b) for solids, organic carbon and water. The solid and organic carbon masses contained per unit volume of deposit are presented in Figures 3 and 4, respectively. The solid content of 640 kg/m^3 (40 lb/ft^3) used for suspended sediment analysis by GEC (2006) is also presented in Figure 3, which indicates a reasonable approximation.

In addition to the test results from ARI provided in Appendix E of GEC (2006), Shannon and Wilson Inc. (2006) also tested five samples, one each from Iron Gate and J.C. Boyle Reservoirs, and three from Copco 1 Reservoir. The Shannon and Wilson Inc. (2006) test results are presented in Table 4, where results in columns 2 and 3 are copied directly from Shannon and Wilson Inc. (2006). Note that the Shannon and Wilson Inc. (2006) results are presented in a different format than those reported from the ARI tests, and formulations for converting the results to those presented in columns 4 through 7 are not apparent. The derivations of equations for converting results from columns 2 and 3 to the rest of Table 4 are provided in Appendix A.

The Shannon and Wilson Inc. (2006) test results shown in columns 6 and 7 in Table 4 are also presented in Figures 3 and 4, in comparison with the ARI test results. Comparison in Figures 3 and 4 indicates that the results between ARI tests and Shannon and Wilson Inc. (2006) tests are consistent.

Using the mean value for total solid in deposit (column 7) and total organic carbon in deposit (column 8) provided in Tables 1 through 3, and based on the volume of deposit in reservoirs reported in GEC (2006), the amounts of solid particles and dry organic carbon in the reservoirs are summarized in Tables 5, according to which there are approximately 7.35 million metric tons of solid particles and 766 thousand metric tons of dry organic carbon in the estimated 15.6 million cubic meters of reservoir deposit. Note that the estimated total volume of deposits in the four reservoirs by Eilers and Gubala (2003) based on current and historical reservoir storage curves is 11.5 million cubic meters, which is 25% lower than the 15.6-million-cubic-meter estimate of GEC (2006). Using Eilers and Gubala's (2003) volumetric estimate, the amount of solid particles and dry organic carbon in the reservoir deposits would be approximately 5.52 million metric tons and 576 thousand metric tons, respectively.[2]

3. Overview of Project Removal Plan

The recommended project alternative in GEC (2006) calls for the removal of J.C. Boyle and Copco 2 dams prior to the removal of Copco 1 and Iron Gate dams. Following the removal of J.C. Boyle and Copco 2 dams, a concurrent drawdown of Copco 1 and Iron Gate reservoirs will be conducted in preparation for the removal of the two remaining dams so that impacts from releasing portions of the reservoir deposits will be concentrated for a minimal duration. This drawdown alternative is selected based on GEC's (2006) evaluation, subsequently confirmed by Stillwater Sciences (2007), that Iron Gate Reservoir will be unable to trap the majority of the sediment released from the upper reservoirs if a sequential removal alternative is chosen. Removing J.C. Boyle and Copco 2 dams prior to the removal of Copco 1 and Iron Gate dams also takes into consideration the sediment volumes found in various reservoirs. There is only a small amount of sediment contained upstream of J.C. Boyle Dam (Table 5) and negligible sediment is stored upstream of Copco 2 Dam.

Under the proposed drawdown scenario, an outlet will be constructed near the bottom of Copco 1 Dam with an operational gate installed at the downstream end of the outlet to control the discharge and regulate the rate of Copco 1 Reservoir drawdown. An existing tunnel at Iron Gate Dam will be modified for controlled drawdown of the Iron Gate Reservoir. The drawdown will start in late fall or early winter while there is the least potential impact to fisheries resources. A detailed project removal plan can be found in GEC (2006).

4. Overview of DREAM-1 and its Application to Klamath Dam Removal

DREAM-1 is one of the two **D**am **R**emoval **E**xpress **A**ssessment **M**odels developed for simulation of sediment transport following dam removal (Cui et al. 2006a, b). DREAM-1 was designed for simulations where the sediment deposit in the reservoir upstream of the dam under consideration for removal is composed primarily of non-cohesive fine sediment (i.e., sand and silt). It simulates the transport and deposition of fine sediment and is applicable to rivers with any combination of sand-bedded, gravel-bedded, and bedrock reaches downstream of the dam. Because DREAM-1 does not simulate the transport of gravel, it treats the gravel-beds downstream of the dam and the pre-dam historical gravel beds upstream of the dam as immobile — fine sediment either passes through or deposits onto the gravel-bedded surface and potentially transforms it into a sand-bedded reach if the sand deposit becomes sufficiently thick. For flow parameter calculations, the model applies a standard backwater equation (e.g., Chaudhry 1993) for low Froude number conditions (i.e., Froude numbers < 0.9, see Cui et al. 2006a for details) and applies a quasi-normal flow assumption (i.e., friction slope is identical to local bed slope; see Cui and Parker 2005) for high Froude number conditions. The model applies Brownlie's (1982) bed material equation for calculating sediment transport capacity and considers the transport of particles coarser than 0.0625 mm (i.e., sand and coarser) as one unit for mass conservation calculations, and considers the finer particles (i.e., particles finer than 0.0625 mm) as throughput load, which is assumed unable to redeposit onto the channel bed once it is released into the water column from the reservoir

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[2] The amount of sediment deposits are presented in mass instead of in volume in this report, because volumes of reservoir deposits are dependent on water contents, which vary significantly for different projects.

deposits through erosion process. Further, it is assumed that reservoir erosion is governed by the mobilization of coarse particles (i.e., particles coarser than 0.0625 mm), and at any cross section, eroding the reservoir deposit down to a given elevation by mobilizing sand and coarser particles will result in the release of all the fine sediment particles (i.e., particles finer than 0.0625 mm) above that elevation. This assumption is slightly different from that used in GEC (2006), where it was assumed that a lowering of the reservoir water surface by a given depth will result in the release of fine sediment of the same depth in the deposits. Our assumption will produce a slightly slower release of the fine sediment deposits than the assumption of GEC (2006), and as a result, higher suspended sediment concentration in the next spring and slightly lower suspended sediment concentration in the winter following reservoir drawdown.

The model requires the following input parameters: initial channel profile, initial thickness of fine sediment deposits in the reservoir and downstream reaches, channel cross sections simplified as rectangles with widths equal to the bankfull channel width, water discharge series, the rate and size of sediment supply, and the downstream base-level control (i.e., either downstream water surface elevation or fixed bed elevation). Model output includes the evolution of the thickness of fine sediment deposits within the reservoir and downstream reaches, coarse and fine sediment fluxes, and daily-averaged total suspended sediment concentration (TSS) along the river in response to the specified water discharge and sediment supply conditions. Note that simulated TSS values reported hereafter are daily-averaged values. In this particular case, because background TSS values are not known, we have assumed zero background TSS, and as a result, the simulated TSS represents an increase in daily-averaged total suspended sediment concentration. Details of the model descriptions, model sensitivity tests and model examinations can be found in Cui et al. (2006a, 2006b, 2008b) and Wooster (2003), and applications of predecessors of DREAM-1 can be found in Cui and Parker (1999) and Stillwater Sciences (1999).

The dam removal alternative evaluated with DREAM-1 for the Klamath River dams is a concurrent drawdown of Copco 1 and Iron Gate reservoirs. Because the deposit volume in J.C. Boyle Reservoir accounts for less than 4% of the total deposits in all the three reservoirs combined (Table 5), sediment release following the removal of J.C. Boyle Dam is neglected in the analysis presented in this report.

To simulate the concurrent drawdown of Copco 1 and Iron Gate reservoirs, we first simulated the drawdown of Copco 1 Reservoir to generate time-series of sand and fine-sediment fluxes and water discharge released from Copco 1 Reservoir during its drawdown, which are then used as the upstream end input for simulation of Iron Gate Reservoir drawdown. Simulation of the reservoir drawdown requires the model to incorporate the following parameters: a) discharge into the reservoir, b) reservoir storage capacity curve (Figure 5), c) discharge capacity curve (Figure 6), and d) limitations on drawdown rate (discussed later) so that their combination determines the reservoir pool level and the discharge released to downstream of the dam. The incorporation of the reservoir storage capacity curves and discharge capacity curves implements the principle of mass conservation for water (i.e., discharge through the dam is determined by the discharge capacity curve, and the flow into the reservoir less the flow out of the reservoir is equal to the change in water volume stored in the reservoir and subsequent change in pool level according to the reservoir storage capacity curve, subject to limitations on drawdown rate). These calculations represent a relatively straightforward water budget analysis and thus are not presented in detail in this report.

Other than modifications to include reservoir storage capacity and discharge capacity curves, the preferred alterative runs (Runs 44 through 52 and 54 through 58) also incorporated the roughness and partial aerial coverage corrections for sand transport over a gravel-bedded channel as detailed in Cui et al. (2008b). These corrections have minimal effect on predicted suspended sediment transport (and thus, the TSS), but provide a more accurate simulation for the transport of bedload (sand and coarser) in the reaches downstream of Iron Gate Dam when sand deposits on the channel bed as a result of reservoir drawdown and dam removal is too thin to completely cover the gravel bed (i.e., thickness of sand deposit

→ 0). The implementation of the roughness and partial aerial coverage corrections requires an estimate of surface median size downstream of Iron Gate Dam, which is provided in Figure 7. The surface median size between 0 and 145 km downstream of Iron Gate Dam was a relatively accurate estimate based on field data provided in PacifiCorp (2002), but the surface median size downstream of 145 km was intentionally under estimated because no surface grain size data are available. An under estimate of surface median size for roughness and partial aerial coverage corrections allows us to provide some improvements over the predicted bedload flux, but at the same time, ensures that we do not "over correct" the prediction (see the formulations in Cui et al. 2008b). If additional surface median grain size data becomes available in the future, we propose to rerun DREAM-1 in case the predicted bedload flux is needed for additional analyses, which would take minimal effort to implement.

The longitudinal profile downstream of Iron Gate Dam used as input for simulations is based on the Ayres Associates (1999) topographic survey in 1951 (Figure 8a). Reach-averaged slope derived from the longitudinal profile (Figure 8b) indicates a consistent, relatively steep slope (~0.0025) for the first 240 km of channel downstream from Iron Gate Dam. Bankfull channel width downstream of Iron Gate Dam used as input for simulations was digitized from a set of 1998, 1:7,500 scale aerial photographs and interpolated at the computational nodes (Figure 8c).

The sediment deposit thicknesses within Copco 1 and Iron Gate reservoirs used for simulations are based on cross sections in Shannon and Wilson (2006) (Figure 9). Based on sediment deposit data presented in Tables 1 and 2 and Figure 2, it is assumed that 15.9% and 19.9% (by volume) of the deposits in Copco 1 and Iron Gate reservoirs, respectively, are sediment particles (see Section 2 for details). The grain size distributions of the sediment in the reservoir deposits are taken as the average of all the samples in Shannon and Wilson (2006) (Figure 10). To simulate the erosion of the reservoir deposits, it is assumed that the drawdown will result in a trapezoidal channel with a bottom width of 61m (200 ft) and a bank slope of 1:10 (V:H) in both reservoirs. This low bank slope allows more deposits to be eroded for downstream transport than a bank slope typically observed in the field (e.g., Cui and Wilcox 2008), and thus, implicitly includes some of the erosion processes (e.g., slumping of the deposits) associated with the high water content of the deposits. Sensitivity tests were conducted to examine differences in volumes eroded from the deposits by varying the bottom width and bank slope of the trapezoidal channel; results from the sensitivity tests are presented later in this report.

5. Considerations for the Date of Reservoir Drawdown

The modeling presented in this report examines the suspended sediment concentration following drawdown of Copco 1 and Iron Gate reservoirs under the concurrent drawdown scenario outlined in GEC (2006) and described briefly in Section 3. Under this concurrent drawdown scenario, both Copco 1 and Iron Gate reservoirs start to lower their pool levels on the same date in the late fall or early winter, with a primary objective to flush as much fine sediment as possible out of the reservoirs within the shortest possible duration to minimize the magnitude and duration of potential high turbidity events in the following spring. Modeling results provided by GEC (2006, 2007) indicate that a TSS concentration as high as 10,000 ppm or greater will be associated with the reservoir drawdown, which could result in mortalities to multiple fish species depending on the timing of these high concentrations.

Consultation with fisheries biologists who are familiar with the Klamath River fisheries indicates that there are fewest fish species in different life stages in the Klamath River during the winter, and thus it is preferable to start the drawdown in early December or later. However, due to limitations of the tunnel in Iron Gate Dam to be used for reservoir drawdown, starting the drawdown later than November 15 will pose the risk of the reservoirs refilling during early winter high flow events before the reservoirs can be emptied during drawdown. This would result in the portions of the sediment deposit remaining stored behind the dams to be released the following spring, causing the undesirable scenario of a high-turbidity event during the spring. As a result, it was determined to start the drawdown either on or before 15 November, and if the drawdown starts before 15 November, it must satisfy the condition that the probability for suspended sediment concentration exceeding 2,000 ppm prior to 15 November is low. In addition to turbidity concerns, the selection of the starting date for reservoir drawdown also takes into account geotechnical concerns for dam safety (discussed in more detail later in this report).

6. Selection of Representative Hydrologic Years for Modeling Purposes

Daily discharge records at the USGS Klamath River below Iron Gate Dam gaging station (#11516530, Iron Gate station hereafter) are available for the period of 1 October 1960 to 20 May 2007 and were used for selection of representative hydrologic years as input to the DREAM-1 model. If a drawdown begins on 15 November, the reservoirs can be emptied within approximately 15 to 50 days at a drawdown rate of 0.9 to 3.0 m/day (3 to 10 ft/day). Thus, we determined that the critical period would be between 15 November and 31 December. Figure 11(a) presents the runoff between 15 November and 31 December for the recorded period based on the daily discharge records at Iron Gate station. Of interest in Figure 11(a) is that there is an apparent decrease in runoff for the period of 15 November through 31 December in the mid-1980s. The average runoff for 15 November through 31 December decreased by approximately 48%, from 353.8 million m^3 for 1961–1984 to 184.5 m^3 for 1985–2006. Figure 11(b) also shows an approximately 21% decrease in average annual runoff between the two periods. Further analysis and discussions with staff from USBR Klamath Regional Office confirmed that the Klamath Basin started a dry cycle in the 1980s, and there were no significant changes in the management of Upper Klamath Lake (Jon Hicks, per. comm.., Oct. 2008)[3].

To simulate the sediment transport dynamics during reservoir drawdown in preparation for dam removal, we selected the representative hydrologic years mostly from the post-1984 period (Figure 12). Only two wet years were selected from the pre-1984 period: year 1983 represents the wettest year in record, and year 1970 represents another wet year based on runoff for the period of 15 November through 31 December (Figure 12b). The other selected representative years for model simulations include 1998, 1996, 1985, 2005, 1986, 1999, 1997, 2003, 2002, 1994, 1992 and 1991 (Table 6). We selected a large number of wet years instead of only a few, because the risk of having a high turbidity event in the next spring is not entirely dependent on the runoff, as the timing of the high flow event also plays an important role. In general, an earlier high flow event following reservoir drawdown will result in the refilling of the reservoirs before the majority of the deposits can be flushed out. As a result, more sediment will be released in the next spring when the reservoirs can be drawn down again as the winter high flows recede, producing high suspended sediment concentrations. Table 6 illustrates that the selected representative years provide a good representation of a wide range of flow conditions for both the entire period of record and for the post-1984 period. For the post-1984 period, for example, year 1998 represents the wettest year, year 2003 represents an average year, and year 1991 represents the driest year. For the entire recorded period, years 1983, 2005 and 1991 represent the wettest, the average, and the driest years, respectively. The daily discharge record at Iron Gate station for some of the selected years is presented in Figure 13.

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[3] Although changes to the Biological Opinion in the 1990s resulted in changes to PacifiCorp's project operations, such changes cannot account for the observed decrease in runoff shown in Figure 11, because none of the PacifiCorp's reservoirs has a large enough operational storage to significantly alter the runoff in the river.

In DREAM-1 simulations presented in this report, the daily discharge record at the Iron Gate station is applied to the reach upstream of Copco 1 Dam. This discharge record is then routed through Copco 1 Reservoir, providing a discharge record at the Copco 1 Dam outlet, which is then used for the reach between Copco 1 and Iron Gate dams during the simulations. Similarly, the adjusted discharge released from Iron Gate outlet is applied to the reach between Iron Gate Dam and the Shasta River confluence, and discharge records at the Seiad Valley (USGS #11520500) and Orleans (USGS #11523000) stations are also adjusted accordingly to account for the flood routing from Copco 1 and Iron Gate reservoirs before they are applied to the reaches between Shasta River and Scott River confluences and between Scott and Trinity River confluences, respectively.

7. Numerical Experiments on Drawdown Alternatives

Numerous documented and undocumented numerical experiments were conducted to examine different combinations of drawdown rate, drawdown starting date and Copco 1 Dam outlet size. A summary of the seventy (70) documented runs (including sensitivity test runs) is provided in Table 7, and the detailed results are provided in an Excel file attached to Appendix B in a CD. Results for additional runs in the future may be added to the Excel file without further report documentation, if they become available. Here we present results from a few runs to demonstrate the selection of a preferred drawdown alternative. Simulations for the preferred alternative are presented in Section 8, and sensitivity test runs are presented in Section 9.

Numerical experiments were first conducted by assuming that a 9.3 m^2 (100 ft^2, or 10×10 ft) outlet would be constructed near the bottom of Copco 1 with an invert elevation of 757.7 m (2,486 ft). Simulations that limit the drawdown rate to 0.9, 1.8 and 2.7 m/day (3, 6 and 9 ft/day) indicate that increasing the drawdown limit from 0.9 m/day (3 ft/day) to 1.8 m/day (6 ft/day) resulted in decreased TSS in the next spring for some of the simulated hydrologic conditions, while further increasing the drawdown limit to 2.7 m/day (9 ft/day) provided minimal additional improvement in TSS reductions for the following spring, for all the hydrologic conditions simulated. This is demonstrated by comparing the results for Runs 7, 8 and 9 that assumed 0.9, 1.8 and 2.7 m/day (3, 6 and 9 ft/day) drawdown limitations, respectively (Figure 14). A similar comparison between the 1.8 and 2.7 m/day drawdown limitation is also observed for the case where the Copco 1 outlet is sized at 18.2 m^2 (14 by 14 ft) (see the comparison between Runs 47 and 53 in the attachment to Appendix B).

Because of the persistent high TSS for the following spring for a few runs, we experimented with a few options that might potentially reduce the spring TSS, including:

- Starting drawdown on 15 July at a rate of 0.08 m/day (0.25 ft/day), then increase to a higher rate (0.9 m/day, or 3 ft/day for the cases tested) on 15 November (Runs 26, 27 and 28);
- Restricting the drawdown rate to 0.08 m/day (0.25 ft/day) in the next spring when the pool level approaches the previous lowest level (Run 29);
- Managing discharge from Upper Klamath Lake or an upstream reservoir to maintain discharge into Copco 1 Reservoir at a specified value during drawdown, and to delay the winter high flow into Copco 1 Reservoir (Runs 32, 33, 34 and 35);
- Increasing the size of the bottom outlet to be constructed on Copco 1 Dam to 18.2 m^2 (Run 30 and thereafter).

Numerical experiments with the early slow drawdown indicate that the 15 July drawdown at a rate of 0.08 m/day (0.25 ft/day) before a faster drawdown on 15 November provides minimal or no benefit in reducing spring TSS and causes high TSS before 15 November, as demonstrated in Figure 15. As a result, the 15 July drawdown alternative is not recommended.

Numerical experiments with restricting the drawdown rate to 0.08 m/day (0.25 ft/day) in the next spring when the pool level approaches the previous lowest level indicate that it may reduce the magnitude of the spring TSS level, but at the expense of an increased duration as demonstrated in Figure 16. This option is not recommended because the option of a larger Copco 1 outlet appears to provide more benefit and is discussed below.

Four runs (Runs 32, 33, 34 and 35, see detail in Appendix B) were conducted to examine the potential for using Upper Klamath Lake or an upstream reservoir to manage the inflow to Copco 1 Reservoir in order to reduce downstream TSS the following spring. Here we discuss the results for Run 32, where discharge for calendar year 1998 (post-1984 wettest year) into Copco 1 Reservoir is managed with Upper Klamath Lake to approximately 50 m^3/s (1,750 cfs) for 30 days before releasing the extra water stored in Upper Klamath Lake downstream. The natural and managed inflow to Copco 1 is shown in Figure 17(a) and the resulting extra storage in Upper Klamath Lake, which has a surface area of 24,906 hectares, is shown in Figure 17(b). Results of Run 32 are provided in Figure 18(a), along with results from Run 30 in Figure 18(b), which is identical to Run 32 except that discharge into Copco 1 Reservoir follows the natural hydrograph. Comparing results in Figures 18(a) and 18(b) indicates that managing the flow using Upper Klamath Lake in Run 32 resulted in increased spring TSS magnitude. Other runs experimenting with flow management using Upper Klamath Lake (Runs 33, 34, 35, see Table 7 for modeling parameters) also produced minimal or no benefit in reducing the spring TSS. Although there are potentially other flow management scenarios for Upper Klamath Lake that may result in reduced TSS in the spring following reservoir drawdown, the runs conducted to date demonstrate that it will be difficult to manipulate the inflow into Copco 1 with upstream reservoirs in a beneficial manner. Further complicating managed flow scenarios, the implemented flow management scenario would have to be carried out without the benefit of knowing future flow conditions, unlike a modeling exercise. Thus, we do not recommend using Upper Klamath Lake to manage the flow conditions during the period of Copco 1 and Iron Gate drawdown.

In contrast to the discouraging results of the other simulated alternatives, numerical experiments that increased the Copco 1 outlet to 18.2 m^2 (196 ft^2, or 14 by 14 ft) indicate that the increased Copco 1 flow capacity provides a significantly reduced spring TSS values for wet years. For example, comparing Runs 2 and 30 (Figure 19) demonstrates that spring TSS for a 9.3 m^2 (100 ft^2) outlet can be more than 10,000 ppm while the 18.2 m^2 (196 ft^2) outlet reduced the spring TSS to below 1,000 ppm.

Based on the results discussed in this section, we recommend constructing the Copco 1 outlet to approximately 18.2 m^2 (or approximately 200 ft^2, e.g., one outlet sized at 14 by 14 ft, 13 by 15 ft, or 10 by 20 ft, or two 10 by 10 ft outlets, depending on cost and feasibility), and to limit the drawdown rate to 1.8 m/day (6 ft/day). The preferred drawdown alternative also incorporates the concerns of geotechnical engineers, who wish to start the drawdown at 0.3 m/day (1 ft/day) for a few days before increasing to a higher rate (PanGEO 2008). The preferred drawdown alternative and modeling results for selected representative hydrologic years are presented in Section 8 below.

8. Modeling Results for Preferred Drawdown Alternative

The preferred drawdown alternative starts the drawdown process on 6 November at a rate of 0.3 m/day (1 ft/day) and increases to 1.8 m/day (6 ft/day) on 15 November. Starting the 0.3 m/day (1 ft/day) drawdown earlier than 6 November results in higher than 2,000 ppm suspended sediment concentration prior to 15 November (see Run 42 in Appendix B). Fourteen runs (Runs 44 through 52, and 54 through

58) were conducted for the preferred drawdown alternative using the hydrologic conditions starting 6 November of 1998, 1996, 1985, 2005, 1986, 1999, 1997, 2003, 1994, 1991, 1992, 2002, 1970, and 1983, respectively (Table 7), which represents a wide range of hydrologic conditions (Table 6 and Figure 12). Of the 14 runs for the preferred drawdown alternative, only 9 are presented below. Results for Runs 54, 55 and 56, which used discharge records from 1991, 1992 and 2002, respectively, are very similar to that of Run 52 (year 1994 discharge) and thus, are not reported here. Similarly, results for Runs 57 and 58, which used discharge records from 1970 and 1983, respectively, are very similar to that of Run 44 (year 1998 discharge) and are not reported here. All the runs not reported here can be found in the CD attached to Appendix B for more detailed examination. In all of these runs, the Copco 1 outlet is assumed to be 18.2 m^2 (e.g., 14 by 14 ft). Simulated suspended sediment concentrations downstream of Copco 1 Dam and at the Iron Gate, Seiad Valley, and Orleans gaging stations, and sediment fluxes at the Iron Gate and Orleans stations, are presented in Figures 20 through 29. Simulated numbers of days with suspended sediment concentrations exceeding specified values at Iron Gate, Seiad Valley and Orleans stations are presented in Tables 8, 9, and 10, respectively. In addition to Iron Gate, Seiad Valley and Orleans gaging stations, suspended sediment concentration at Klamath gaging station (USGS #11530500) is calculated for runs 44 through 52 based on simulated suspended sediment concentration at Orleans gaging station and discharge records at both Orleans and Klamath gaging stations, whenever discharge records are available. The calculated number of days with suspended sediment concentrations exceeding specified values at Klamath gaging station is provided in Table 11. The calculated suspended sediment concentrations at Klamath gaging station are used in the ecological analysis in Stillwater Sciences (2008).

Simulated suspended sediment concentrations for three periods are discussed below:

Fall (from the date of intial drawdown to 15 November): Simulated maximum TSS for the period prior to 15 November is generally less than 1,000 ppm at the Iron Gate station except for Run 46 (starting drawdown on 6 November 1985) with a one-day TSS that exceeds 1,000 ppm but is less than 2,000 ppm. This corresponds to a probability of less than 5% that 1,000 ppm will be exceeded. At the Seiad Valley and Orleans stations, simulated TSS values for all the runs are less than 1,000 ppm. At the Klamath station, calculated TSS values for the eight runs with available discharge are less than 500 ppm (TSS at the Klamath station for the ninth run, Run 45, cannot be calculated because discharge records are not available).

Winter (15 November to 21 March): Simulated TSS for the winter period is high for all model runs. At the Iron Gate station, maximum TSS exceeds 10,000 ppm for all the runs and exceeds 30,000 ppm in some runs. At the Seiad Valley station, maximum TSS exceeds 10,000 ppm for eight of the nine runs and can be as high as 30,000 ppm. At the Orleans station, five of the nine runs have maximum TSS that exceed 10,000 ppm but are less than 20,000 ppm. At the Klamath station, one run has a maximum TSS that exceeds 10,000 ppm. The magnitude of winter suspended sediment concentration is comparable to that provided in GEC (2006, 2007).

Spring (after 21 March): Simulated maximum TSS for the following spring is generally less than 2,000 ppm at the Iron Gate station, less than 1,000 ppm at the Seiad Valley station, and less than 500 ppm at the Orleans and Klamath stations except for one run (Run 47 that starts drawdown on 6 November 2005). For Run 47, the simulated maximum TSS is between 3,000 and 5,000 ppm at the Iron Gate station, between 2,000 and 3,000 ppm at the Seiad Valley station, and between 1,000 and 2,000 ppm at the Orleans station.

Simulated sediment fluxes at Iron Gate and Orleans stations shown in Figures 20 through 28 indicate that the fine sediment (silt and finer) moves downstream faster than coarse sediment (sand and coarser), evidenced by a much greater delay in coarse sediment flux at all stations.

Results for sediment deposition thickness downstream of the dams are not presented because none of the runs produced discernable sediment deposition downstream of Iron Gate Dam. A more detailed discussion with regard to downstream sediment deposition and the resulting flooding risks is presented below in Section 9.4.

Analyses of the potential biological impacts associated with the simulated TSS for Runs 44 through 52 are provided in Stillwater Sciences (2008).

9. Discussion

Many simplifications are implemented in the numerical simulations presented in this report, as is the case with any large-scale sediment transport modeling. Here we discuss the potential consequences and uncertainties resulting from some of these simplifications.

9.1 Dimension of the eroded channels in the reservoirs

Simulation results provided in this report assumed that the flow will reoccupy the pre-dam historical river valley based on the observation that the topographic low in the reservoir area is still visible (Stillwater Sciences 2004; Cui et al. 2005b). It is further assumed that the flow will cut through the deposit in the river valley to form a trapezoidal channel with a 61-m (200-ft) bottom width and a 1:10 (V:H) bank slope following that of GEC (2006). Under this assumption, there will be 2.2 million metric tons of sediment (1.78 million metric tons silt and finer, and 0.43 million metric tons of sand and coarser) released to the Klamath River downstream of Iron Gate Dam. This represents approximately 30% of the 7.35 million metric tons of sediment particles deposited in all the reservoirs (Table 5).

The actual average channel geometry formed following reservoir drawdown and dam removal will likely have a similar or smaller area than the assumed channel. The observed channel width near Iron Gate Dam downstream of the reservoirs is generally less than 50 m (Figure 8c), which is narrower than the assumed bottom width of the trapezoidal channel. Accounting for a 1:10 bank slope for the assumed channel, the bankfull width of the eroded channel in the numerical model should be significantly wider than the observed bankfull width near Iron Gate Dam. Assuming a 3-m bankfull depth, for example, the assumed channel would have a bankfull width of approximately 120 m, which is approximately 2.5 times of the measured bankfull width in the vicinity of Iron Gate Dam (Figure 8). As a result, these simulations most likely represent a larger volume of sediment erosion than will actually occur during reservoir drawdown and dam removal.

Here we provide results from sensitivity test runs that vary the assumed bottom channel width and bank slope in order to investigate the potential effects of releasing more or less sediment. As a potential best-case-scenario, we assumed a 46-m (150-ft) bottom width and a 1:3 bank slope. Despite our assessment that the numerical runs may over-estimate the amount of sediment release, we also conducted sensitivity test runs that assumed a much wider channel (91 m, or 300 ft, at the bottom, with a 1:10 bank slope) as a worst-case scenario. The worst-case scenario could represent a case where there are unknown and significant errors in the assessment of the thickness of reservoir deposits or a case where excessive mass wasting of the reservoir deposit occurs along the margins of the newly formed channel. The sensitivity runs are Runs 45B, 45W, 51B, 51W, 52B, and 52W, in which "B" is short for "best" (i.e., the narrow channel-width runs), and "W" is short for "worst" (the wider channel-width runs). The sensitivity runs used the same hydrologic conditions as the matching numbered preferred alternative run (e.g., Runs 45B and 45W used the same hydrograph as Run 45). The sensitivity runs tested a wet year with approximately a 10% post-1984 exceedance probability (1996 hydrograph used in Runs 45B/W), an average year with approximately 50% post-1984 exceedance probability (2003 hydrograph used in Runs 51B/W), and a dry year with approximately 90% post-1984 exceedance probability (1994 hydrograph used in Runs 52B/W). As before, exceedance probabilities are based on Klamath River runoff between 15 November and 31 December at Iron Gate station.

As expected, the best-case scenario runs reduced, and the worst-case scenario runs increased, the magnitude of suspended sediment concentration compared to the normal runs. The best-case scenario runs resulted in approximately 1.30 million metric tons of sediment release (1.05 million metric tons of silt and finer, and 0.25 million metric tons of sand and coarser) to the downstream reach, or approximately 18% of the estimated sediment stored in all the reservoirs (Table 12). The worst-case scenario runs resulted in approximately 2.92 million metric tons of sediment release (2.35 million metric tons of silt and finer, and 0.57 million metric tons of sand and coarser) to the downstream reach, or approximately 40% of the estimated sediment stored in all the reservoirs (Table 12). Compared to the runs that assumed 61-m (200-ft) bottom width and 1:10 bank slope (the normal runs hereafter), the best-case scenarios runs resulted in 41% less sediment release and the worst-case scenario runs resulted in 32% more sediment release (Table 12). Comparisons of simulated TSS between the sensitivity runs and the normal runs are provided in Table 13 and in Figures 29, 30 and 31. Results indicate that the general patterns of suspended sediment concentration are similar between the normal and sensitivity test runs. The potential impacts to fisheries resources due to the uncertainties represented in the sensitivity runs are considered in the biological assessment in Stillwater Sciences (2008).

9.2 Potential contributions of sediment deposits stored in tributaries

Simulation results presented in this report do not include sediment deposited at tributary confluences that drain into the reservoir areas. Potential consequences of neglecting tributary sediment deposits are addressed by analyzing the sediment deposit in Jenny Creek (the largest tributary entering the reservoir areas). Based on a sediment deposit profile provided in GEC (2006), sediment deposition in Jenny Creek is approximately 3 m thick on average and extends approximately 1 km upstream from Iron Gate Reservoir into Jenny Creek. Assuming the deposit is 10 m wide (based on visual inspection during field reconnaissance), the deposit volume in Jenny Creek is approximately 30,000 m^3, or less than 0.2% of the estimated 16 million m^3 of deposits in all the reservoirs (Table 5). Other tributaries contain significantly less deposit volume than Jenny Creek, as demonstrated in a longitudinal profile of Camp Creek in GEC (2006). Thus, we conclude that including the sediment deposits at tributary confluences in the modeling would not result in significant differences in the simulated suspended sediment concentration during reservoir drawdown and dam removal.

9.3 Surface erosion in the reservoir area following dam removal

Surface erosion in the former reservoir area is another potential factor that may contribute to long-term high suspended sediment concentrations in the Klamath River following dam removal. Although the DREAM model can not simulate this surface erosion, we discuss the physical processes of surface erosion during and following dam removal and provide a qualitative evaluation to address concerns related to surface erosion.

During the initial reservoir drawdown period in late November, surface erosion is expected to occur once the pool level approaches the level of the deposits on the terraces. This will likely be the most significant period of surface erosion from the reservoir deposits; however, the added sediment from surface erosion should be insignificant compared to the erosion from the main channel area, which will be high during the initial drawdown. In addition, the assumed 1:10 (V:H) low bank slope should also accounted for at least part of the sediment eroded from the surface. Following the drawdown of the reservoirs in late November, the reservoirs may re-fill during winter high flow events (e.g., Figures 20, 21, 22, 23, 26, 27, and 28) and one or more additional drawdown events could occur in the following spring, depending on the specific hydrologic conditions. Additional surface erosion would be expected during these subsequent drawdown periods, if they occur. However, because the majority of the unconsolidated sediment that can be eroded easily through surface-erosion processes would be eroded during the winter drawdown period, less surface erosion is expected in the spring than during the winter drawdown period.

Following the completion of the drawdown in the next spring, flow will not be able to access the terraces because, following the complete removal of the dams, the river will be confined in the narrow historical river valley, which has banks composed of pre-dam alluvial deposits that cannot be eroded easily by the flow. As a result, potential long-term surface erosion will only result directly from rainfall impact, which should alleviate over time and eventually become negligible following the emergence of vegetation in the former reservoir area. Even under the worst-case scenario of a minimal restoration effort that only includes broadcasting appropriate seeds to enhance the growth of vegetation in the former reservoir area, at least some herbaceous vegetation cover (grasses and forbs) should establish within one year following dam removal (i.e., after an initial winter-spring rainy season following seeding that promotes germination and seedling establishment) to begin to minimize surface erosion. Subsequently, we do not expect high suspended sediment events to occur due to surface erosion after approximately one year following the complete removal of the dams. Increases in suspended sediment concentration in the Klamath River due to surface erosion as a result of rain-fall impact during and within one year following the complete removal of the dams are expected to be small due to the dilution effect from the large discharge in the Klamath River relative to surface flow discharge within the former reservoir area during a rainfall event. Restoration measures can also be implemented to reduce the risk of increases to suspended sediment concentrations from surface erosion during this period, which are currently being evaluated in a different project funded by the California State Coastal Conservancy.

9.4 Downstream sediment deposition and flooding risks as a result of sediment deposition

As stated earlier in Section 8, no discernable change in bed elevation due to sediment deposition in the Klamath River downstream of Iron Gate Dam is produced during reservoir drawdown in any of the numerical runs, because the 0.25–0.57 tons of sand and coarser particles will be spread out thinly in the more than 300-km-long reach of the Klamath River downstream of Iron Gate Dam or transported out of the river to the ocean. Due to the inherent uncertainties of sediment transport numerical modeling, we cannot definitely conclude that no sediment deposition downstream of Iron Gate during and after dam removal will occur; however, it is reasonable to conclude that the thickness of sediment deposition downstream of Klamath River, if any, will be minimal. This is consistent with our first assessment (Stillwater Sciences 2004) based on several worst-case assumptions that greatly increase the likelihood of sediment deposition downstream of Iron Gate Dam following dam removal. The conclusion that there will be minimal deposition is also consistent with data that show there is only a small fraction of coarse sediment (sand and coarser) in the deposits (Figure 10). For example, normal run simulations predicted that only about 0.43 million metric tons of sand and coarser material will be released to the reach downstream of Iron Gate Dam. Given the large discharge and consistent steep slope (~ 0.0025, see Figure 8b) of the Klamath River, the lack of discernable sediment deposition downstream of Iron Gate Dam in model simulations is not surprising.

This assessment concludes that additional flooding risk associated with potential sediment deposition downstream of Iron Gate Dam is minimal due to the lack of deposition. The dam removal plan itself (GEC 2006) also asserts minimal additional flooding risk associated with sediment deposition during and following dam removal. As discussed earlier, the recommended reservoir drawdown starts in early November, allowing for the majority of sediment to be released downstream during the drawdown period while Copco 1 and Iron Gate dams are still functional. Once a winter high flow occurs, the two reservoirs will refill, causing downstream sediment release to cease because of the decreased shear stress in the reservoir area associated with increasing reservoir depth. This period of reservoir backfilling with no sediment release should allow for any sediment deposited downstream of Iron Gate Dam to quickly transport downstream and minimize the thickness of any dissipating sediment pulse that forms (e.g., Lisle et al. 2001; Cui et al. 2003a,b; Cui and Parker 2005; Cui et al. 2005a). As a result, the thickness of sediment deposit, if any, will be greatly reduced at the time when the two reservoirs are completely full and the Klamath River downstream of Iron Gate Dam begins to receive the high peak flood.

Another flood-related concern is whether dam removal will result in an increase in peak flows due to the elimination of storage capacity from the reservoirs and subsequent potential peak flow attenuation. However, J.C. Boyle, Copco 1 and 2, and Iron Gate reservoirs do not provide flood-control benefits due to the limited active storage. For example, the total retention time for J.C. Boyle, Copco 1 and Iron Gate reservoirs with inflows of 283 m^3/s (10,000 cfs, approximately a 3-yr recurrence interval flow event), is only 0.1, 0.3, and 0.2 days, respectively[4], and the fourth reservoir, Copco 2 Reservoir, does not have any active storage for flood retention. The minimal total retention time from the four reservoirs for even a modest flood event (i.e., a 3-year flow at 283 m^3/s) indicates that they provide minimal flood retention for flood events with higher peaks that cause concern for downstream flooding. Thus, their removal should not result in increased flooding risks associated with the elimination of active reservoir storage.

9.5 Potential temporary loss of pool habitat

As is with any one-dimensional numerical sediment transport modeling, a DREAM-1 simulation result represents a reach-averaged result of channel aggradation and degradation and is not capable of providing detailed aggradation/degradation data at a morphologic unit scale (e.g., pool-riffle) (Cui et al. 2008b). Because the release of sediment includes some sand and coarser grained sediment, it is reasonable to assume that there will be some temporary filling of pool habitat following reservoir drawdown and during dam removal. The potential filling of the pool habitat, however, can be expected to be rather small due to the prediction that there will be no discernable sediment deposition downstream of Iron Gate Dam during the entire dam removal process. In addition, our flume experiments for fine and coarse sediment pulse evolution over a coarse bed with forced pool-riffle morphology indicate that during temporary filling pools still maintain pool topography (i.e., a diversity of shallow and deep portions persists and pools do not become simple planar features). Pools are typically the first morphologic unit to evacuate sediment as a sediment pulse disperses from a given location, and in fine sediment pulse experiments pools quickly returned to a depth equal or greater than the configuration pre-sediment pulse arrival (Wooster et al., manuscript in preparation titled "Channel response to fine and coarse sediment pulses at varying spatial scales in a flume with forced pool-riffle morphology").

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[4] PacifiCorp relicencing documents, available at http://www.pacificorp.com/File/File16142.pdf, http://www.pacificorp.com/File/File16143.pdf, and http://www.pacificorp.com/File/File16144.pdf, accessed in June 2008.

9.6 Potential fine sediment infiltration into spawning gravel

A primary fisheries concern for releasing a large amount of fine sediment over a gravel-bedded river, as with the case of Klamath River dam removal project, is that fine sediment may infiltrate the gravel bed, reducing the quality of spawning habitat and resulting in mortality of salmonid eggs and alevins (hatchlings) (e.g., Cooper 1965; Koski 1966; Greig et al. 2005a, 2005b, 2007; Sear et al. 2005, Wooster et al. 2008). The recent flume experiments of Wooster et al. (2008) and theoretical analysis of Cui et al. (2008a) indicate that the amount of fine sediment deposition will decrease exponentially with depth. As a result, significant fine sediment infiltration occurs only to a shallow depth near the surface. Using an analytic approach and geometric analogies, Wooster et al. (2008) demonstrated that, if any infiltration of silt or finer sediment is to occur, it can only infiltrate to a depth of a few sand diameters under most circumstances. Due to the limited depth of infiltration, it is expected that any fine sediment infiltrated into the gravel bed during the Klamath River dam removal process will be short-termed and can be flushed out during a high flow event (typically a bankfull flow) after the fine sediment supply in the reservoirs is exhausted.

One potential management option to accelerate the flushing of the fine sediment that infiltrates to a shallow depth of the bed material and deposits on the bed surface is to use Upper Klamath Lake to stockpile water in advance and to release a bankfull or higher flow as soon as the dam structures are removed, provided that such a high flow event will not result in negative biological consequences. Feasibility and detailed planning of such a management option is out of the scope of this study. A limited number of bed material samples should also provide more information as to whether the current bed is already saturated with sand, which will improve confidence in potential fine sediment infiltration predictions and would provide baseline information for post-dam removal monitoring.

10. Conclusion

Results of DREAM-1 simulations under various drawdown alternatives for the concurrent drawdown scenario of Copco 1 and Iron Gate reservoirs indicate the following:

- The Copco 1 outlet used for reservoir drawdown should be constructed to approximately 18.2 m^2 (~ 200 ft^2, with outlet dimensions of 14 x 14 ft, 13 x 15 ft, or 10 x 20 ft, or two 10 x 10 ft).
- Using Upper Klamath Lake to manage the flow into Copco 1 Reservoir during the drawdown period appears unlikely to achieve the objective of reducing the following spring's suspended sediment concentration.
- Increasing the limit on the rate of reservoir drawdown should generally facilitate the erosion of sediment during the winter period, which reduces the suspended sediment concentration in the following spring. However, the potential benefit of increasing the drawdown limitation beyond 1.8 m/day (6 ft/day) is minimal.
- Geotechnical engineers have expressed a preference for a slower drawdown at the beginning of the drawdown process (PanGEO 2008). Starting the drawdown on 6 November at a rate of 0.3 m/day (1 ft/day) results in a prediction that suspended sediment concentration at Iron Gate station will not exceed 1,000 ppm prior to 15 November for all runs except one. This corresponds to a probability of less than 5% that maximum increase in daily-averaged TSS prior to 15 November will exceed 1,000 ppm. The one run with the increased daily-averaged TSS at Iron Gate station exceeding 1,000 ppm prior to 15 November is less than 2,000 ppm.
- Under the preferred drawdown scenario that starts drawdown on 6 November at 0.3 m/day (1 ft/day) and increases to 1.8 m/day (6 ft/day) on 15 November, winter (15 November to 21 March)

the increased daily-averaged TSS exceeds 10,000 ppm at Iron Gate station, 5,000 ppm at Seiad Valley station, and 3,000 ppm at Orleans station for all the runs. The simulated highest increase in daily-averaged TSS in winter for all the runs under this drawdown scenario exceeds 30,000 ppm at Iron Gate and Seiad Valley stations, and 10,000 at Orleans and Klamath stations.

- Under the preferred drawdown scenario, the increase in daily-averaged TSS in spring (after 21 March) is less than 2,000 ppm at Iron Gate station, less than 1,000 ppm at Seiad Valley station, and less than 500 ppm at Orleans and Klamath stations for all runs but one, which has a maximum increase in daily-averaged TSS less than 5,000 ppm at Iron Gate station, 3,000 ppm at Seiad Valley station, 2,000 ppm at Orleans station, and 1,000 ppm at Klamath station in spring.
- No discernable sediment deposition is predicted for any of the runs downstream of Iron Gate Dam, indicating minimal potential for deposition or increases in flooding risk associated with sediment deposition. In addition, elimination of the attenuation effects from the four reservoirs should not increase flooding risks because they presently have limited active storage and provide minimal flood attenuation for larger peak flood events.
- Coarse sediment (sand and coarser) released during reservoir drawdown and dam removal travels slower than fine sediment because of the attenuation of bedload transport.
- The amount of pool filling will be small, based on the minimal predicted reach-averaged sediment deposition downstream of the dam. Flume experiments indicate that pool topography will persist, and if pool infilling occurs, it will be short lived prior to returning to pre-sediment release topography.
- Fine sediment infiltration is expected to be limited to a shallow depth near the bed surface, which can be readily flushed during a high flow event after the fine sediment supply in the former reservoir area is exhausted. There are potential opportunities to use Upper Klamath Lake to stockpile water in advance for a flushing flow release to clean fine sediment deposit as soon as the dam structures are removed. A limited sampling of the bed material prior to reservoir drawdown and removal will provide more confidence with fine sediment infiltration predictions and will provide baseline information for a potential post-dam removal monitoring program.

Potential biological impacts from the sediment release are provided in a separate technical remport (Stillwater Sciences 2008).

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TABLES

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Table 1. ARI test results for Iron Gate Reservoir samples. Data in columns 2 and 3 are duplicated from Appendix E of GEC (2006).

Sample	Preserved Total Solid by Mass[a] (%)	Total Organic Carbon by Mass[a] (%)	Water Content by Mass[b] (%)	Total Solid as % of Bulk Volume of the Deposit[c]	Total Organic Carbon as % of Bulk Volume of the Deposit[c]	Total Solid in Deposit[c] (kg/m³)	Total Organic Carbon in Deposit[c] (kg/m³)
IG-1, S-1[d]	63.10	2.24	34.66	39.35	3.37	1042.84	37.02
IG-1, S-1	33.20	2.24	64.56	15.83	2.57	419.59	28.31
IG1, S-1 (replicate)[e]	33.20	2.25	64.55	15.83	2.59	419.60	28.44
IG1, S-1 (replicate)[e]	33.90	2.12	63.98	16.25	2.45	430.75	26.94
IG2, S-1	28.80	2.11	69.09	13.27	2.34	351.75	25.77
IG2, S-1	28.80	2.11	69.09	13.27	2.34	351.75	25.77
IG2, S-1 (replicate)[e]	29.00	2.71	68.29	13.40	3.02	354.97	33.17
IG2, S-1 (replicate)[e]	29.30	2.60	68.10	13.56	2.90	359.42	31.89
IG3, S-1	26.40	4.42	69.18	11.98	4.83	317.46	53.15
IG4, S-1	26.20	3.76	70.04	11.86	4.10	314.36	45.11
IG5, S-1	73.60	1.64	24.76	51.41	2.76	1362.35	30.36
IG5, S-1	73.60	1.64	24.76	51.41	2.76	1362.35	30.36
IG5, S-1 (replicate)	72.80	1.54	25.66	50.38	2.57	1335.00	28.24
IG5, S-1 (replicate)[e]	72.40	1.77	25.83	49.89	2.94	1322.14	32.32
IG6, S-1	27.70	3.03	69.27	12.67	3.34	335.85	36.74
IG7, S-1	23.60	3.45	72.95	10.48	3.69	277.67	40.59
IG8, S-1	24.60	3.53	71.87	11.00	3.80	291.60	41.84
IG-9, S-1	33.20	1.44	65.36	15.82	1.65	419.21	18.18
Mean	36.34	2.67	60.99	19.91	3.11	527.63	34.20
Standard Deviation	18.67	1.01	18.08	15.67	0.93	415.14	10.23
Maximum	73.60	4.42	72.95	51.41	4.83	1362.35	53.15
Minimum	23.60	1.44	24.76	10.48	1.65	277.67	18.18

a. ARI test data termed as “preserved total solids” and “total organic carbon”;
b. Calculated by assuming that the majority of the sample mass is composed of solids, organic carbon and water, representing minimum water contents due to potential water loss during the handling of the samples (Agnes Tirao and Dennis Gathard, personal communication, 2 November 2007);
c. Calculated based on the assumed density for water, solids, and dry organic carbon of 1,000 kg/m³, 2,650 kg/m³, and 1,100 kg/m³, respectively;
d. Excluded in calculating mean, standard deviation, and maximum and minimum values because of its discrepancy with the other three test for the same sample;
e. Excluded in calculating mean, standard deviation, and maximum and minimum values because they are replicate samples.

Table 2. ARI test results for Copco 1 Reservoir samples. Data in columns 2 and 3 are duplicated from Appendix E of GEC (2006).

Sample	Preserved Total Solid by Mass[a] (%)	Total Organic Carbon by Mass[a] (%)	Water Content by Mass[b] (%)	Total Solid as % of Bulk Volume of the Deposit[c]	Total Organic Carbon as % of Bulk Volume of the Deposit[c]	Total Solid in Deposit[c] (kg/m^3)	Total Organic Carbon in Deposit[c] (kg/m^3)
C-1, S-1	80.30	0.39	19.31	60.64	0.71	1607.08	7.79
C-10, S-1	24.00	3.67	72.33	10.69	3.94	283.28	43.32
C-11, S1	34.70	2.48	62.82	16.75	2.88	443.91	31.73
C-12, S-2C/3C	35.00	16.20	48.80	17.21	19.19	456.12	211.12
C-12, S-2C/3C	23.40	8.33	68.27	10.43	8.94	276.36	98.38
C-12, S-2C/3C (replicate)[d]	23.40	6.60	70.00	10.41	7.07	275.85	77.80
C-12, S-2C/3C (replicate)[d]	23.40	6.94	69.66	10.41	7.44	275.95	81.84
C-2, S-1	23.10	4.48	72.42	10.23	4.78	271.10	52.58
C-3, S-1	24.20	3.44	72.36	10.79	3.70	285.99	40.65
C-4, S-1	20.00	3.92	76.08	8.66	4.09	229.38	44.96
C-5, S-1	24.00	3.68	72.32	10.69	3.95	283.28	43.44
C-6, S-1	23.40	8.33	68.27	10.43	8.94	276.36	98.38
C-7, S-1	50.00	1.56	48.44	27.45	2.06	727.53	22.70
C-8, S-1	21.10	5.03	73.87	9.22	5.29	244.20	58.21
C9, S-1	22.50	4.06	73.44	9.92	4.31	262.78	47.42
C-9, S-1	22.50	4.06	73.44	9.92	4.31	262.78	47.42
C-9, S-1 (replicate)[d]	22.50	3.24	74.26	9.91	3.44	262.56	37.81
C-9, S-1 (replicate)[d]	22.60	2.64	74.76	9.95	2.80	263.75	30.81
Mean	30.59	4.97	64.44	15.93	5.51	422.15	60.58
Standard Deviation	16.42	3.88	15.70	13.81	4.53	365.95	49.79
Maximum	80.30	16.20	76.08	60.64	19.19	1607.08	211.12
Minimum	20.00	0.39	19.31	8.66	0.71	229.38	7.79

a. ARI test data termed as “preserved total solids” and “total organic carbon”;

b. Calculated by assuming the majority of the sample mass is composed of solids, organic carbon and water, representing minimum water contents due to potential water loss during the handling of the samples (Agnes Tirao and Dennis Gathard, personal communication, 2 November 2007);

c. Calculated based on the assumed density for water, solids, and dry organic carbon of 1,000 kg/m^3, 2,650 kg/m^3, and 1,100 kg/m^3, respectively;

d. Excluded in calculating mean, standard deviation, and maximum and minimum values because they are replicate samples.

Table 3. ARI test results for J.C. Boyle Reservoir samples. Data in columns 2 and 3 are duplicated from Appendix E of GEC (2006).

Sample	Preserved Total Solid by Mass[a] (%)	Total Organic Carbon by Mass[a] (%)	Water Content by Mass[b] (%)	Total Solid as % of Bulk Volume of the Deposit[c]	Total Organic Carbon as % of Bulk Volume of the Deposit[c]	Total Solid in Deposit[c] (kg/m^3)	Total Organic Carbon in Deposit[c] (kg/m^3)
J-1, S-1	16.00	7.46	76.54	6.76	7.59	179.05	83.48
J-1, S-1	16.00	7.46	76.54	6.76	7.59	179.05	83.48
J-1, S-1 (replicate)[d]	16.10	6.36	77.54	6.80	6.47	180.09	71.14
J-1, S-1 (replicate)[d]	16.10	6.21	77.69	6.79	6.31	180.07	69.45
J-3, S-1	74.20	1.24	24.56	52.15	2.10	1382.08	23.10
J-4, S-1	29.40	4.67	65.93	13.65	5.22	361.76	57.46
J-5, S-1	40.20	4.56	55.24	20.35	5.56	539.20	61.16
Mean	35.16	5.08	59.76	19.93	5.61	528.23	61.74
Standard Deviation	24.07	2.57	21.57	18.87	2.25	500.19	24.79
Maximum	74.20	7.46	76.54	52.15	7.59	1382.08	83.48
Minimum	16.00	1.24	24.56	6.76	2.10	179.05	23.10

a. ARI test data termed as “preserved total solids” and “total organic carbon”;

b. Calculated by assuming the majority of the sample mass is composed of solids, organic carbon and water, representing minimum water contents due to potential water loss during the handling of the samples (Agnes Tirao and Dennis Gathard, personal communication, 2 November 2007);

c. Calculated based on the assumed density for water, solids, and dry organic carbon of 1,000 kg/m^3, 2,650 kg/m^3, and 1,100 kg/m^3, respectively;

d. Excluded in calculating mean, standard deviation, and maximum and minimum values because they are replicate samples.

Table 4. Shannon and Wilson Inc. (2006) test results for reservoir deposit samples. Data in columns 2 and 3 are reported in Shannon and Wilson Inc. (2006) and GEC (2006).

Sample[a]	Amount of Organic Carbon as % of Solid and Dry Organic Carbon Mass[b]	Water Content as % of Solid and Dry Organic Carbon Mass[c]	Total Solid as % of Bulk Volume of the Deposit[d]	Total Organic Carbon as % of Bulk Volume of the Deposit[d]	Total Solid in Deposit[d] (kg/m^3)	Total Organic Carbon in Deposit[d] (kg/m^3)
J-1, S-5	12.50	304.10	9.48	3.26	251.22	35.86
IG9, S-2	7.70	107.40	23.34	4.69	618.51	51.59
C-6, S-5	12.70	330.30	8.79	3.08	232.94	33.88
C-2, S-4	15.50	228.30	11.63	5.14	308.20	56.54
C-4, S-6	10.30	238.40	10.36	2.87	274.54	31.57

a. J denotes J.C. Boyle Reservoir, IG denotes Iron Gate Reservoir, and C denotes Copco 1 Reservoir;

b. Reported in Shannon and Wilson Inc. (2006) and GEC (2006), termed as "organic content";

c. Reported in Shannon and Wilson Inc. (2006) and GEC (2006), termed as " water content";

d. Calculated based on the assumed density for water, solids, and dry organic carbon of 1,000 kg/m^3, 2,650 kg/m^3, and 1,100 kg/m^3, respectively.

Table 5. Summary of reservoir deposits by content.

Reservoir	Volume of Deposit (m^3)[a]	Solid in Deposit (Metric tons)[b]	Carbon in Deposit (Metric tons)[c]
Iron Gate	6,790,000	3,583,000	232,000
Copco 1	8,318,000	3,511,000	504,000
J.C. Boyle	486,000	257,000	30,000
Total	15,594,000	7,351,000	766,000

a. Based on Tables 13 through 15 in GEC (2006), approximated to the nearest thousand cubic meters;

b. Based on volume in column 2 and mean total solid content presented in Tables 1 through 3;

c. Based on volume in column 2 and mean organic carbon content presented in Tables 1 through 3.

Table 6. Selected representative years for sediment transport simulation.

Representative Year [a]	Exceedance Probability [b]	
	Post-1984	The Entire Record
1983	n/a	0.021
1970	n/a	0.083
1998	0.0435	0.292
1996	0.0870	0.354
1985	0.1304	0.375
2005	0.1739	0.500
1986	0.2174	0.521
1999	0.2609	0.563
1997	0.3043	0.604
2003	0.4783	0.688
2002	0.8261	0.917
1994	0.8696	0.938
1992	0.9130	0.958
1991	0.9565	0.979

a. Calendar year;
b. Based on Klamath River runoff at Iron Gate Station for the period between 15 November and 31 December.

Table 7. Summary of DREAM-1 runs investigating the drawdown of Copco 1 and Iron Gate Reservoirs. Results of the runs are provided in an Excel file in a CD attached to Appendix B.

Run #	Drawdown Starting Date	Calendar Year	Limitations on Drawdown	Copco 1 Outlet Dimension (ft)	Roughness and Partial Sand Coverage Corrections	Other Notes
1	15-Nov.	1998	3 ft/day	10X10	No	
2	15-Nov.	1998	6 ft/day			
3	15-Nov.	1998	9 ft/day			
4	15-Nov.	1996	3 ft/day			
5	15-Nov.	1996	6 ft/day			
6	15-Nov.	1996	9 ft/day			
7	15-Nov.	1985	3 ft/day			
8	15-Nov.	1985	6 ft/day			
8B						150-ft channel, 1:3 bank slope
8W						300-ft channel, 1:10 bank slope
9	15-Nov.	1985	9 ft/day			
10	15-Nov.	2005	3 ft/day			
11	15-Nov.	2005	6 ft/day			
12	15-Nov.	2005	9 ft/day			
13	15-Nov.	1986	3 ft/day			
14	15-Nov.	1986	6 ft/day			
15	15-Nov.	1986	9 ft/day			
16	15-Nov.	1999	3 ft/day			
17	15-Nov.	1999	6 ft/day			
18	15-Nov.	1999	9 ft/day			
19	15-Nov.	1997	3 ft/day			
20	15-Nov.	1997	6 ft/day			
21	15-Nov.	1997	9 ft/day			
22	15-Nov.	2003	3 ft/day			
23	15-Nov.	2003	6 ft/day			
23B						150-ft channel, 1:3 bank slope
23W						300-ft channel, 1:10 bank slope
24	15-Nov.	1994	3 ft/day			
25	15-Nov.	1994	6 ft/day			
25B						150-ft channel, 1:3 bank slope
25W						300-ft channel, 1:10 bank slope
26	15-Jul.	1998	0.25 ft/day before 15-Nov., 3 ft/day starting 15-Nov.			
27	15-Jul.	1996				
28	15-Jul.	1985				
29	15-Nov.	1998	6 ft/day			Restricting drawdown rate to 0.25 ft/day in the spring if pool level approaches previous low.

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Table 7 (continue)

Run #	Drawdown Starting Date	Calendar Year	Limitations on Drawdown	Copco 1 Outlet Dimension (ft)	Roughness and Partial Sand Coverage Corrections	Other Notes
30	15-Nov.	1998	6 ft/day	14X14	No	
31	15-Nov.	1996				
32	15-Nov.	1998				Using Upper Klamath Lake for flow regulation, trial No. 1
33	15-Nov.	1996				
34	15-Nov.	1998				Using Upper Klamath Lake for flow regulation, trial No. 2
35	15-Nov.	1996				
36	15-Nov.	1985				
37	15-Nov.	2005				
38	15-Nov.	1986				
39	15-Nov.	1999				
40	15-Nov.	1997				
41	15-Nov.	2003				
42	15-Nov.	1994				
43	1-Nov.	1998	1 ft/day before 15-Nov., 6 ft/day starting 15-Nov.	14X14	Yes	
44	6-Nov.	1998				
45	6-Nov.	1996				
45B						150-ft channel, 1:3 bank slope
45W						300-ft channel, 1:10 bank slope
46	6-Nov.	1985				
47	6-Nov.	2005				
48	6-Nov.	1986				
49	6-Nov.	1999				
50	6-Nov.	1997				
51	6-Nov.	2003				
51B						150-ft channel, 1:3 bank slope
51W						300-ft channel, 1:10 bank slope
52	6-Nov.	1994				
52B						150-ft channel, 1:3 bank slope
52W						300-ft channel, 1:10 bank slope
53	6-Nov.	2005	1 ft/day before 15-Nov., 9 ft/day starting 15-Nov.	14X14	Yes	
54	6-Nov.	1991	1 ft/day before 15-Nov., 6 ft/day starting 15-Nov.	14X14	Yes	
55	6-Nov.	1992				
56	6-Nov.	2002				
57	6-Nov.	1970				
58	6-Nov.	1983				

Note: 1. *1 ft = 0.3048 m;*
2. *Channel dimension within the reservoirs are assumed to be 200 ft wide with a bank slope of 1:10 (V:H), unless noted otherwise.*

Table 8. Simulation results for the number of days with suspended sediment concentration exceeding specified values at the Iron Gate station.

Period	Calendar Year to Start Drawdown	1998 [a] (Run 44) (Post-1984 wettest year)	1996 (Run 45) (Post-1984 2nd wettest year)	1985 (Run 46) (Post-1984 3rd wettest year)	2005 (Run 47) (Post-1984 4th wettest year)	1986 (Run 48) (Post-1984 5th wettest year)	1999 (Run 49) (Post-1984 6th wettest year)	1997 (Run 50) (Post-1984 7th wettest year)	2003 (Run 51) (Post-1984 average year, 50% exceedance probability)	1994 [b] (Run 52) (Post-1984 dry year, 90% exceedance probability)
Before 15-Nov.	> 100 ppm	3	2	4	2	3	4	3	2	1
	> 500 ppm	2	1	2	1	1	2	2	1	0
	> 1,000 ppm	0	0	1	0	0	1	0	0	0
	> 2,000 ppm	0	0	0	0	0	0	0	0	0
15-Nov. to 21-Mar.	> 100 ppm	65	49	63	44	64	53	55	65	88
	> 500 ppm	36	33	51	33	46	46	46	53	68
	> 1,000 ppm	29	30	39	26	40	39	41	51	56
	> 2,000 ppm	23	22	22	25	32	34	35	48	42
	> 3,000 ppm	18	19	17	22	26	27	29	34	33
	> 5,000 ppm	9	14	12	17	17	19	18	23	23
	> 10,000 ppm	3	6	3	8	4	5	5	7	13
	> 20,000 ppm	0	1	0	1	0	1	1	1	6
	> 30,000 ppm	0	0	0	1	0	0	0	1	1
	> 40,000 ppm	0	0	0	0	0	0	0	0	0
After 21-Mar.	> 100 ppm	67	64	10	61	10	13	21	0	0
	> 500 ppm	3	9	7	16	3	2	2	0	0
	> 1,000 ppm	0	2	2	6	1	1	0	0	0
	> 2,000 ppm	0	0	0	2	0	0	0	0	0
	> 3,000 ppm	0	0	0	2	0	0	0	0	0
	> 5,000 ppm	0	0	0	0	0	0	0	0	0

a. Results for Runs 57 and 58, which used the discharge records from 1970 (a wet year) and 1983 (the wettest year in the entire period of record), respectively, produced similar results;

b. Results for Runs 54, 55 and 56, which used discharge data for three other dry years, produced similar results.

Table 9. **Simulation results for the number of days with suspended sediment concentration exceeding specified values at the Seiad Valley station.**

Period	Calendar Year to Start Drawdown	1998 [a] (Run 44) (Post-1984 wettest year)	1996 (Run 45) (Post-1984 2nd wettest year)	1985 (Run 46) (Post-1984 3rd wettest year)	2005 (Run 47) (Post-1984 4th wettest year)	1986 (Run 48) (Post-1984 5th wettest year)	1999 (Run 49) (Post-1984 6th wettest year)	1997 (Run 50) (Post-1984 7th wettest year)	2003 (Run 51) (Post-1984 average year, 50% exceedance probability)	1994 [b] (Run 52) (Post-1984 dry year, 90% exceedance probability)
Before 15-Nov.	> 100 ppm	3	2	3	2	3	3	3	2	1
	> 500 ppm	1	0	1	0	1	1	1	0	0
	> 1,000 ppm	0	0	0	0	0	0	0	0	0
15-Nov. to 21-Mar.	> 100 ppm	52	47	61	42	57	51	53	63	80
	> 500 ppm	31	28	48	27	44	41	44	51	53
	> 1,000 ppm	26	22	31	22	35	37	37	48	43
	> 2,000 ppm	17	17	22	21	30	32	32	34	26
	> 3,000 ppm	9	12	16	16	24	23	23	20	20
	> 5,000 ppm	7	6	10	10	12	18	16	11	16
	> 10,000 ppm	0	3	3	4	3	4	3	5	9
	> 20,000 ppm	0	0	0	1	0	0	0	1	2
	> 30,000 ppm	0	0	0	0	0	0	0	1	0
	> 40,000 ppm	0	0	0	0	0	0	0	0	0
After 21-Mar.	> 100 ppm	39	51	9	45	6	13	13	0	0
	> 500 ppm	1	1	2	10	1	1	0	0	0
	> 1,000 ppm	0	0	0	4	0	0	0	0	0
	> 2,000 ppm	0	0	0	1	0	0	0	0	0
	> 3,000 ppm	0	0	0	0	0	0	0	0	0

a. Results for Runs 57 and 58, which used the discharge records from 1970 (a wet year) and 1983 (the wettest year in the entire period of record), respectively, produced similar results;

b. Results for Runs 54, 55 and 56, which used discharge data for three other dry years, produced similar results.

Table 10. Simulation results for the number of days with suspended sediment concentration exceeding specified values at the Orleans station.

Period	Calendar Year to Start Drawdown	1998 [a] (Run 44) (Post-1984 wettest year)	1996 (Run 45) (Post-1984 2nd wettest year)	1985 (Run 46) (Post-1984 3rd wettest year)	2005 (Run 47) (Post-1984 4th wettest year)	1986 (Run 48) (Post-1984 5th wettest year)	1999 (Run 49) (Post-1984 6th wettest year)	1997 (Run 50) (Post-1984 7th wettest year)	2003 (Run 51) (Post-1984 average year, 50% exceedance probability)	1994 [b] (Run 52) (Post-1984 dry year, 90% exceedance probability)
Before 15-Nov.	> 100 ppm	3	2	3	1	3	3	3	2	0
	> 500 ppm	1	0	1	0	1	1	1	0	0
	> 1,000 ppm	0	0	0	0	0	0	0	0	0
15-Nov. to 21-Mar.	> 100 ppm	42	34	59	36	46	50	48	51	60
	> 500 ppm	20	19	33	21	38	37	36	37	33
	> 1,000 ppm	12	14	23s	19	32	31	26	26	23
	> 2,000 ppm	7	10	15	13	23	22	16	18	19
	> 3,000 ppm	3	7	9	11	14	9	7	13	15
	> 5,000 ppm	0	4	7	7	6	5	5	9	10
	> 10,000 ppm	0	0	3	0	1	1	0	3	2
	> 20,000 ppm	0	0	0	0	0	0	0	0	0
After 21-Mar.	> 100 ppm	28	9	8	30	2	8	2	0	0
	> 500 ppm	0	0	0	4	0	0	0	0	0
	> 1,000 ppm	0	0	0	2	0	0	0	0	0
	> 2,000 ppm	0	0	0	0	0	0	0	0	0

a. Results for Runs 57 and 58, which used the discharge records from 1970 (a wet year) and 1983 (the wettest year in the entire period of record), respectively, produced similar results;

b. Results for Runs 54, 55 and 56, which used discharge data for three other dry years, produced similar results.

Table 11. Calculated number of days with suspended sediment concentration exceeding specified values at the Klamath station, based on simulated results at the Orleans station and the discharge records at both Orleans and Klamath stations.

Period	Calendar Year to Start Drawdown	1998 [b] (Run 44)	1996 (Run 45)	1985 (Run 46)	2005 (Run 47)	1986 (Run 48)	1999 (Run 49)	1997 (Run 50)	2003 (Run 51)	1994 [c] (Run 52)
		(Post-1984 wettest year)	(Post-1984 2nd wettest year)	(Post-1984 3rd wettest year)	(Post-1984 4th wettest year)	(Post-1984 5th wettest year)	(Post-1984 6th wettest year)	(Post-1984 7th wettest year)	(Post-1984 average year, 50% exceedance probability)	(Post-1984 dry year, 90% exceedance probability)
Before 15-Nov.	> 100 ppm	2	N/A[a]	2	1	2	2	1	2	0
	> 500 ppm	0		0	0	0	0	0	0	0
15-Nov. to 21-Mar.	> 100 ppm	32		50	27	45	47	39	47	35
	> 500 ppm	11		21	20	32	31	26	21	20
	> 1,000 ppm	5		14	13	26	21	14	17	15
	> 2,000 ppm	3		8	10	11	8	6	13	10
	> 3,000 ppm	1		6	6	4	4	4	9	5
	> 5,000 ppm	0		3	1	1	1	0	6	0
	> 10,000 ppm	0		1	0	0	0	0	0	0
	> 20,000 ppm	0		0	0	0	0	0	0	0
After 21-Mar.	> 100 ppm	3		6	19	1	2	1	0	0
	> 500 ppm	0		0	1	0	0	0	0	0
	> 1,000 ppm	0		0	0	0	0	0	0	0

a. Discharge record at the Klamath gaging station is not available.

b. Results for Runs 57 and 58, which used the discharge records from 1970 (a wet year) and 1983 (the wettest year in the entire period of record), respectively, produced similar results;

c. Results for Runs 54, 55 and 56, which used discharge data for three other dry years, produced similar results.

Table 12. Mass of sediment erosion from the model runs (in million metric tons)

	Normal Runs	Best-case-scenario runs	Worst-case-scenario runs
Sand and coarser	0.43	0.25	0.57
Silt and finer	1.78	1.05	2.35
Total	2.21	1.30	2.92
Fraction of total reservoir deposits[a]	30%	18%	40%
Change relative to normal runs		-41%	+32%

a. The sediment deposit in all the reservoirs is estimated at approximately 7.35 million metric tons, see Table 5.

Table 13. Simulation results for sensitivity tests for channel dimension within the reservoirs, showing the number of days with suspended sediment concentration exceeding specified values at the Iron Gate station.[a]

Period	TSS (ppm)	Start drawdown on 15 Nov. 1996 (a wet year with approximately 10% exceedance probability[b])			Start drawdown on 15 Nov. 2003 (the average year with approximately 50% exceedance probability[b])			Start drawdown on 15 Nov. 1994 (a dry year with approximately 90% exceedance probability[b])		
		Run 45	Run 45B	Run 45W	Run 51	Run 51B	Run 51W	Run 52	Run 52B	Run 52W
Before 15-Nov.	> 100	2	2	2	2	2	2	1	1	1
	> 500	1	0	1	1	0	1	0	0	0
	> 1,000	0	0	0	0	0	0	0	0	0
15-Nov. to 21-Mar.	> 100	49	44	55	65	62	63	88	60	80
	> 500	33	30	45	53	41	59	68	43	71
	> 1,000	30	25	36	51	40	53	56	35	62
	> 2,000	22	19	27	48	33	47	42	31	58
	> 3,000	19	13	21	34	24	42	33	25	52
	> 5,000	14	6	16	23	12	29	23	21	33
	> 10,000	6	4	9	7	2	15	13	10	19
	> 20,000	1	0	2	1	0	2	6	2	6
	> 30,000	0	0	1	1	0	1	1	0	4
	> 40,000	0	0	1	0	0	1	0	0	1
	> 50,000	0	0	0	0	0	0	0	0	0
After 21-Mar.	> 100	64	54	72	0	0	23	0	0	0
	> 500	9	0	28	0	0	0	0	0	0
	> 1,000	2	0	4	0	0	0	0	0	0
	> 2,000	0	0	0	0	0	0	0	0	0

a. See Table 7 for detailed descriptions for the runs;
b. Based on Klamath River runoff at Iron Gate station between 15 November and 31 December for the post-1984 period.

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FIGURES

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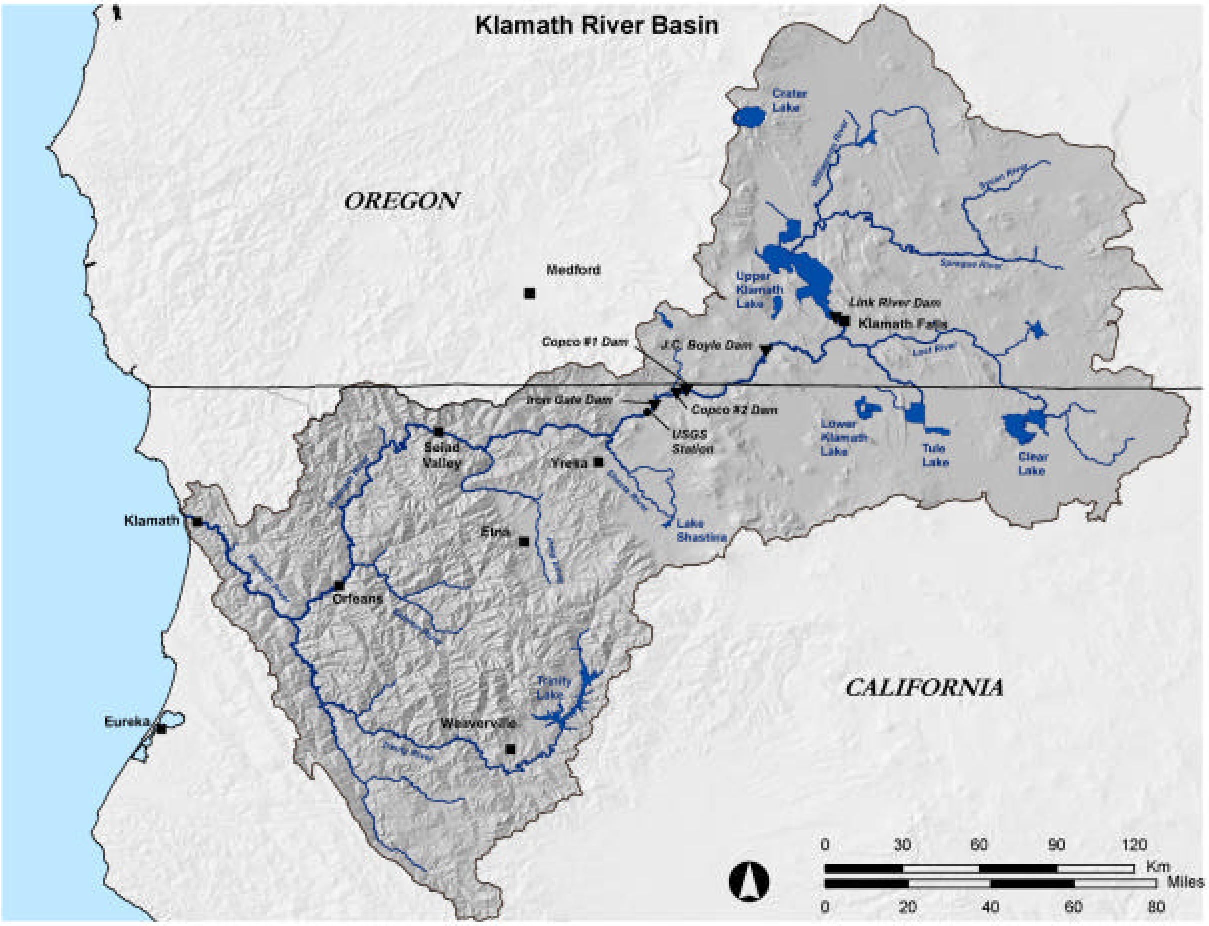
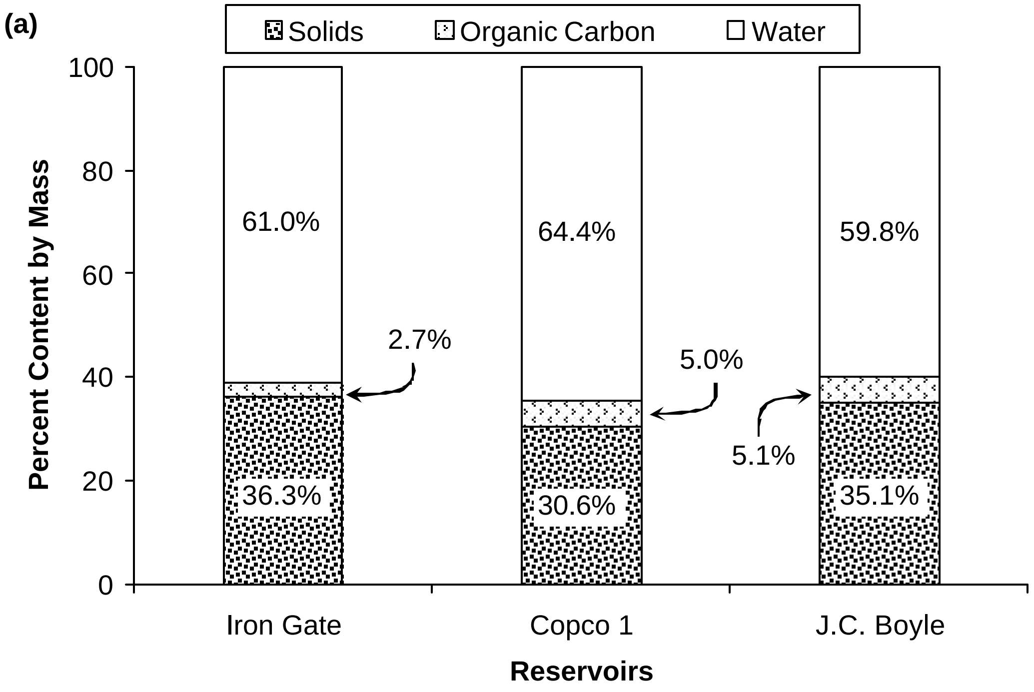


Figure 1. Klamath River watershed, showing the location of J.C. Boyle, Copco 1, Copco 2, and Iron Gate dams.



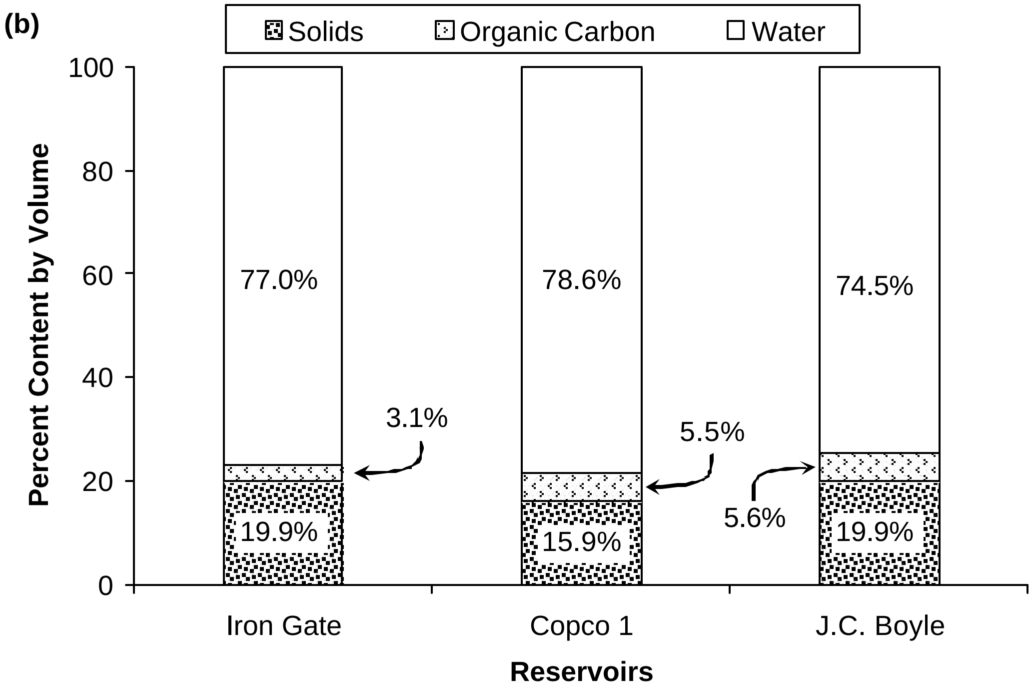


Figure 2. Primary composition of the deposits in Iron Gate, Copco 1, and J.C. Boyle reservoirs, based on the mean value of the ARI test data: (a) by mass; and (b) by volume.

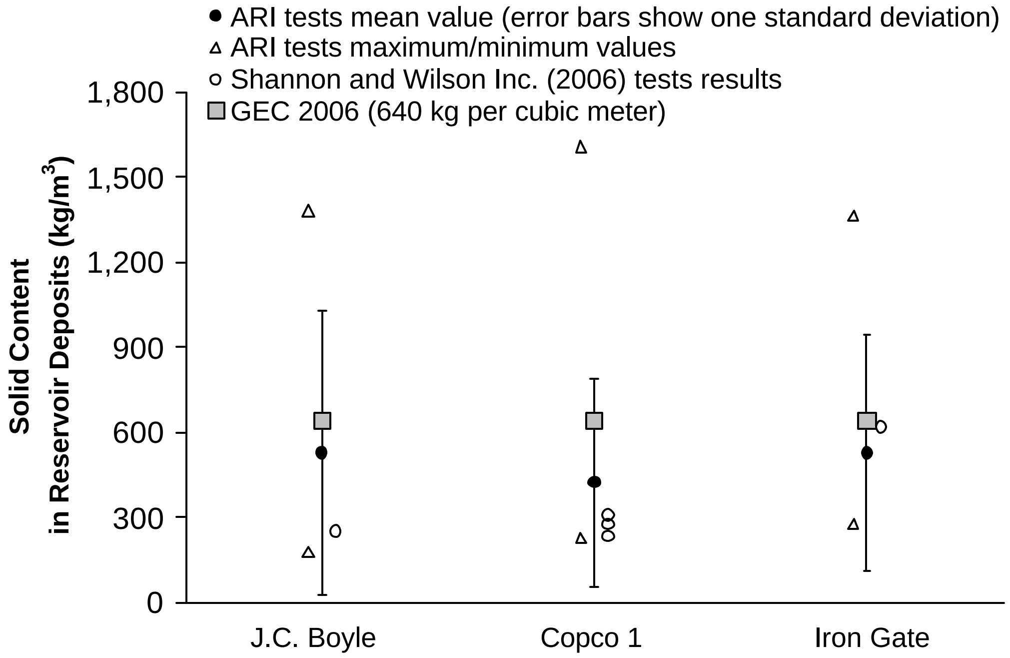


Figure 3. **Solid content in reservoir deposits based on ARI tests (GEC 2006) and Shannon and Wilson Inc. (2006) tests.**

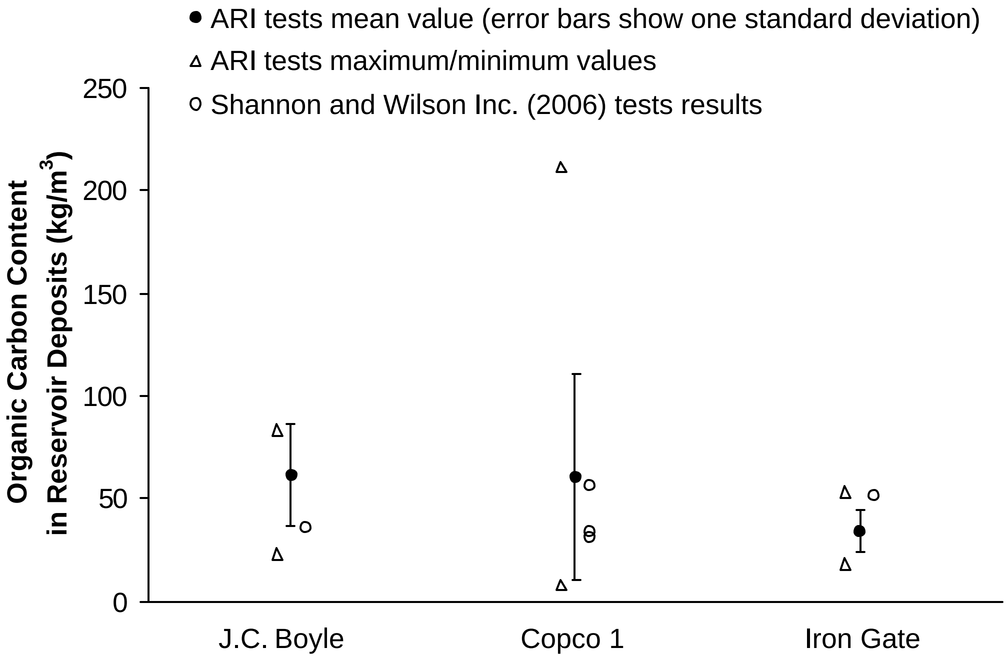


Figure 4. **Organic carbon content in reservoir deposits based on ARI tests (GEC 2006) and Shannon and Wilson Inc. (2006) tests.**

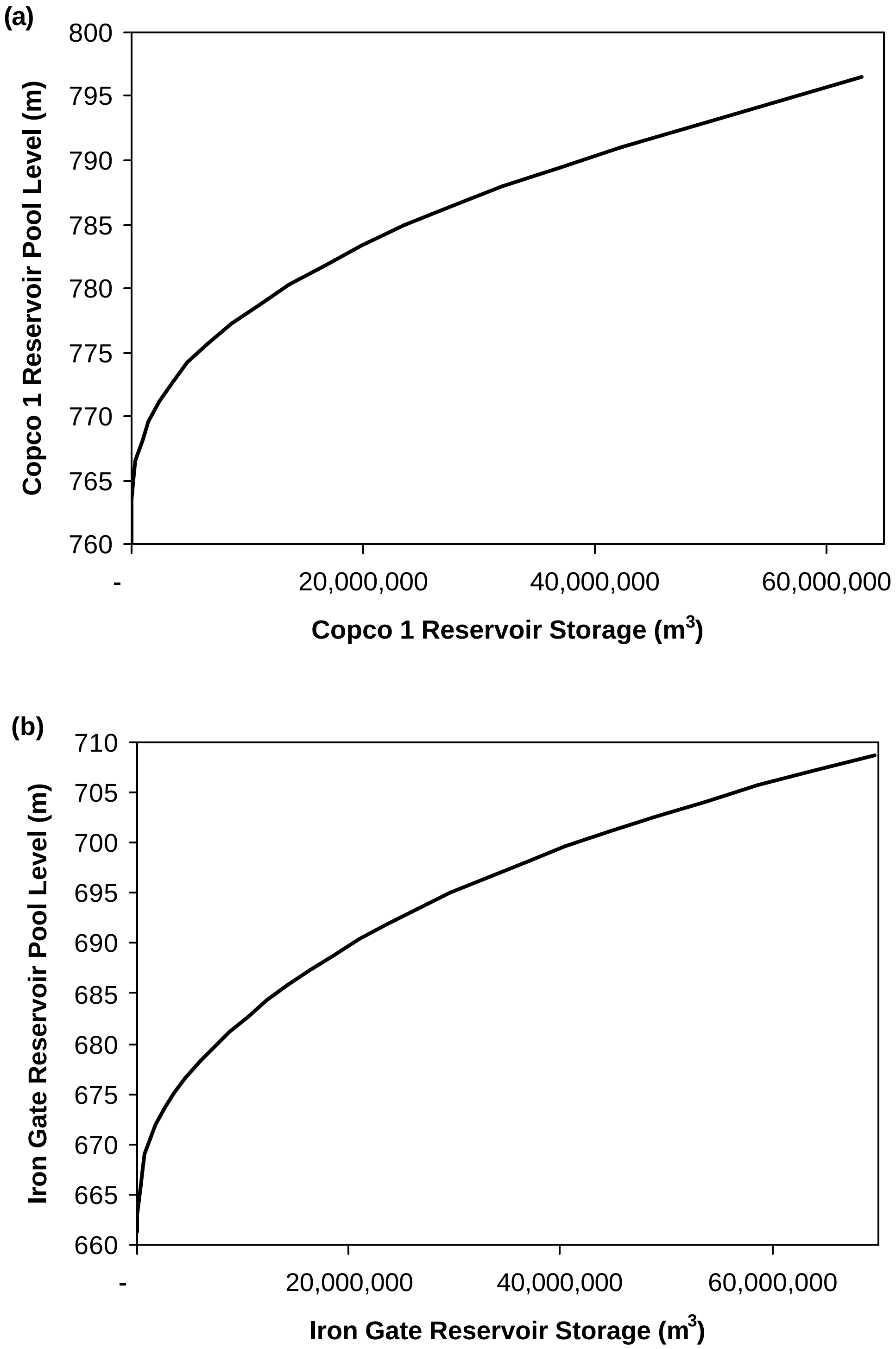


Figure 5. Reservoir storage capacity curves for: a) Copco 1 Reservoir and b) Iron Gate Reservoir, based on data in GEC (2006).

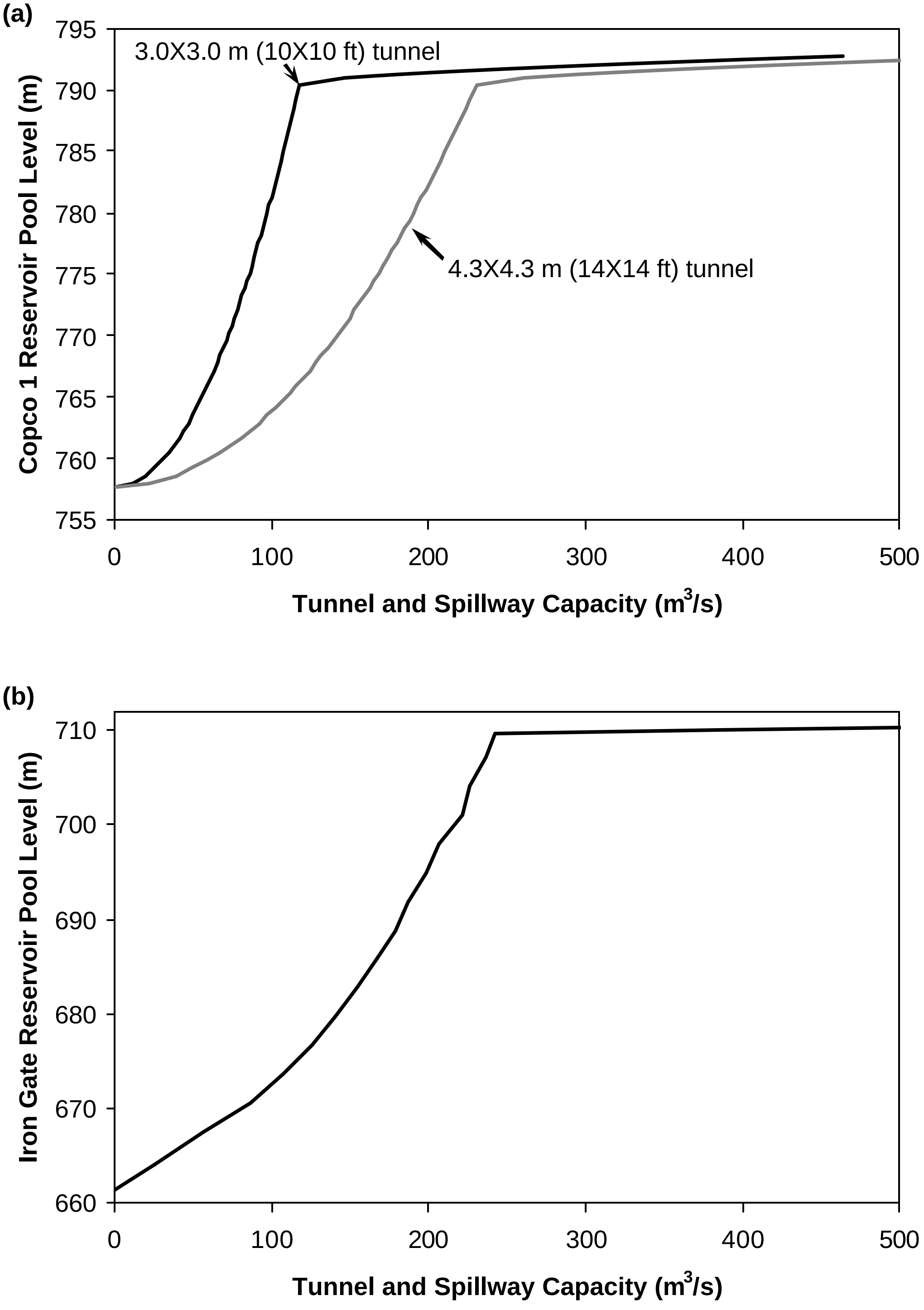


Figure 6. Discharge capacity curves for: a) Bottom outlet to be constructed on Copco 1 Dam, and b) existing tunnel on Iron Gate Dam, based on information in GEC (2006).

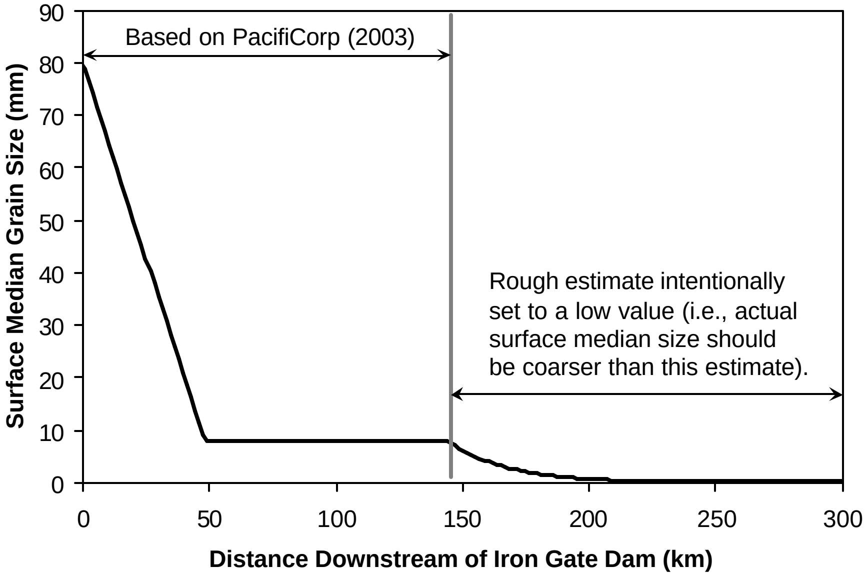


Figure 7. Estimated bed surface median grain size downstream of Iron Gate Dam. This estimate is used to implement the roughness and partial aerial coverage corrections for sand transport over a gravel-bedded channel for the final runs (see Cui et al. [2008b] for details of roughness and partial aerial coverage corrections). The roughness and partial aerial coverage corrections have minimal effect on predicted suspended sediment flux (and thus, TSS) but provide improved predictions for bedload (sand and coarser) downstream of Iron Gate Dam. Because no field data are available from roughly 145 km downstream of Iron Gate Dam to the mouth, we made a rough estimate that is intentionally set lower than the possible field values. As long as the surface grain size is not over estimated, the roughness and partial aerial coverage corrections should provide an improved prediction for bedload transport compared to if no corrections are implemented (Cui et al. 2008b).

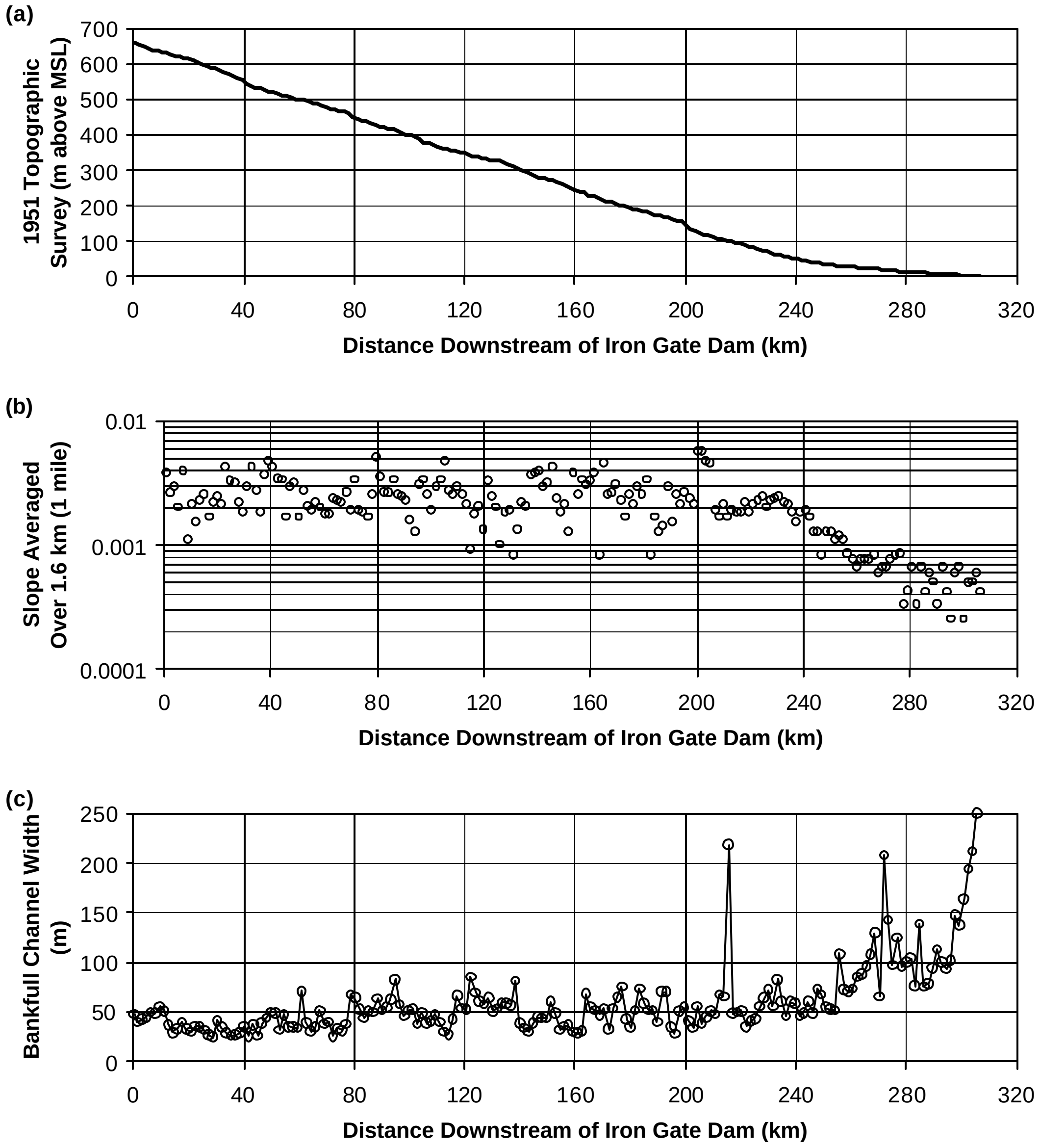


Figure 8. **(a). Longitudinal profile of the Klamath River downstream of Iron Gate Dam, based on 1951 topographic survey presented in Ayres Associates (1999). (b) Bed slope averaged over a 1.6 km (1 mile) distance. (c) Bankfull channel width along the Klamath River downstream of Iron Gate Dam. The widths were first digitized from 1:7,500 scale aerial photographs taken in 1998, and then interpolated over a 1.6-km (1-mile) spacing for dam removal simulations.**

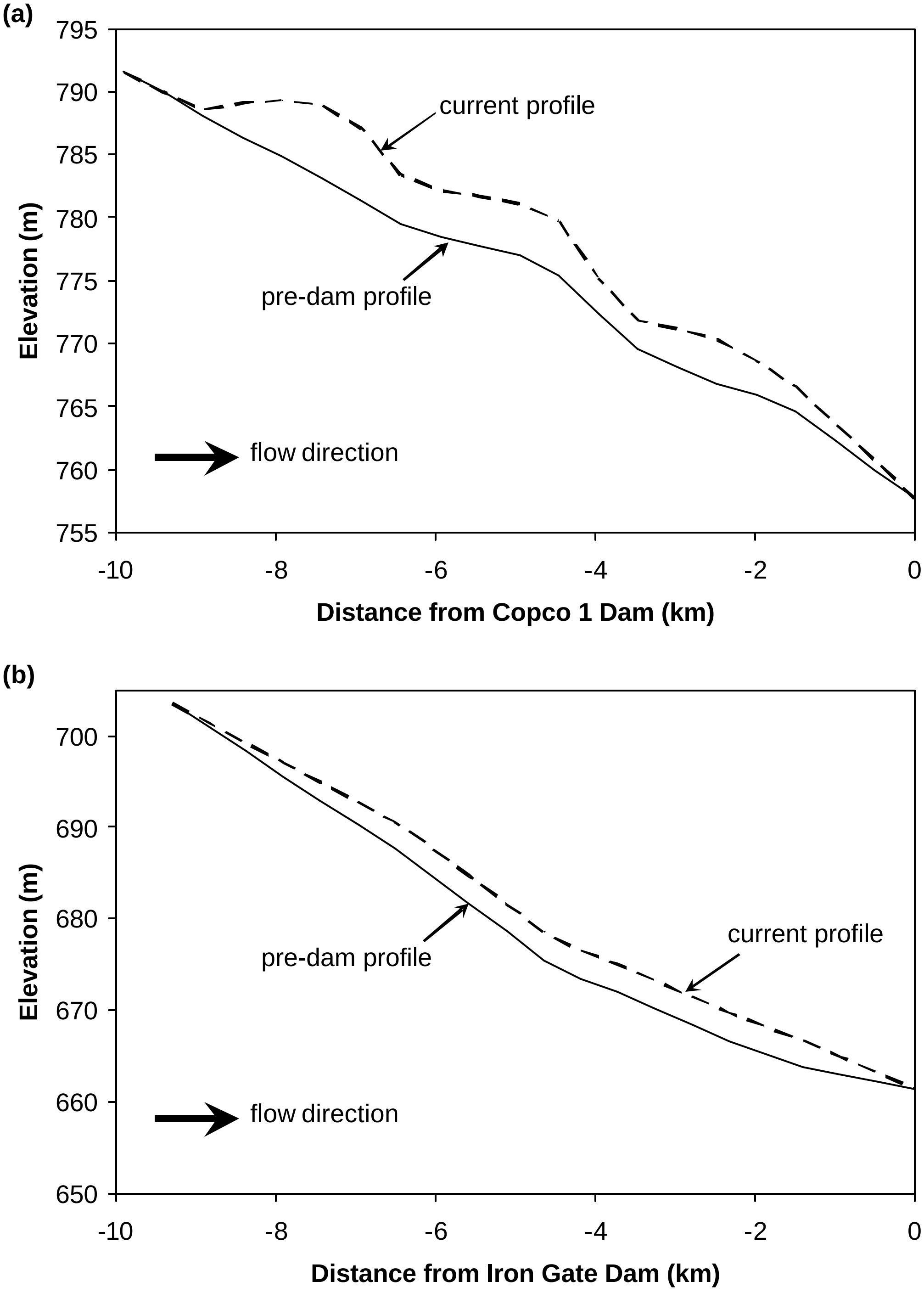


Figure 9. Thickness of reservoir deposits stored in: a). Copco 1 Reservoir, and b). Iron Gate Reservoir. Profiles are based on cross sections presented in Shannon and Wilson (2006), and negative values in x-axis indicate upstream of the dam.

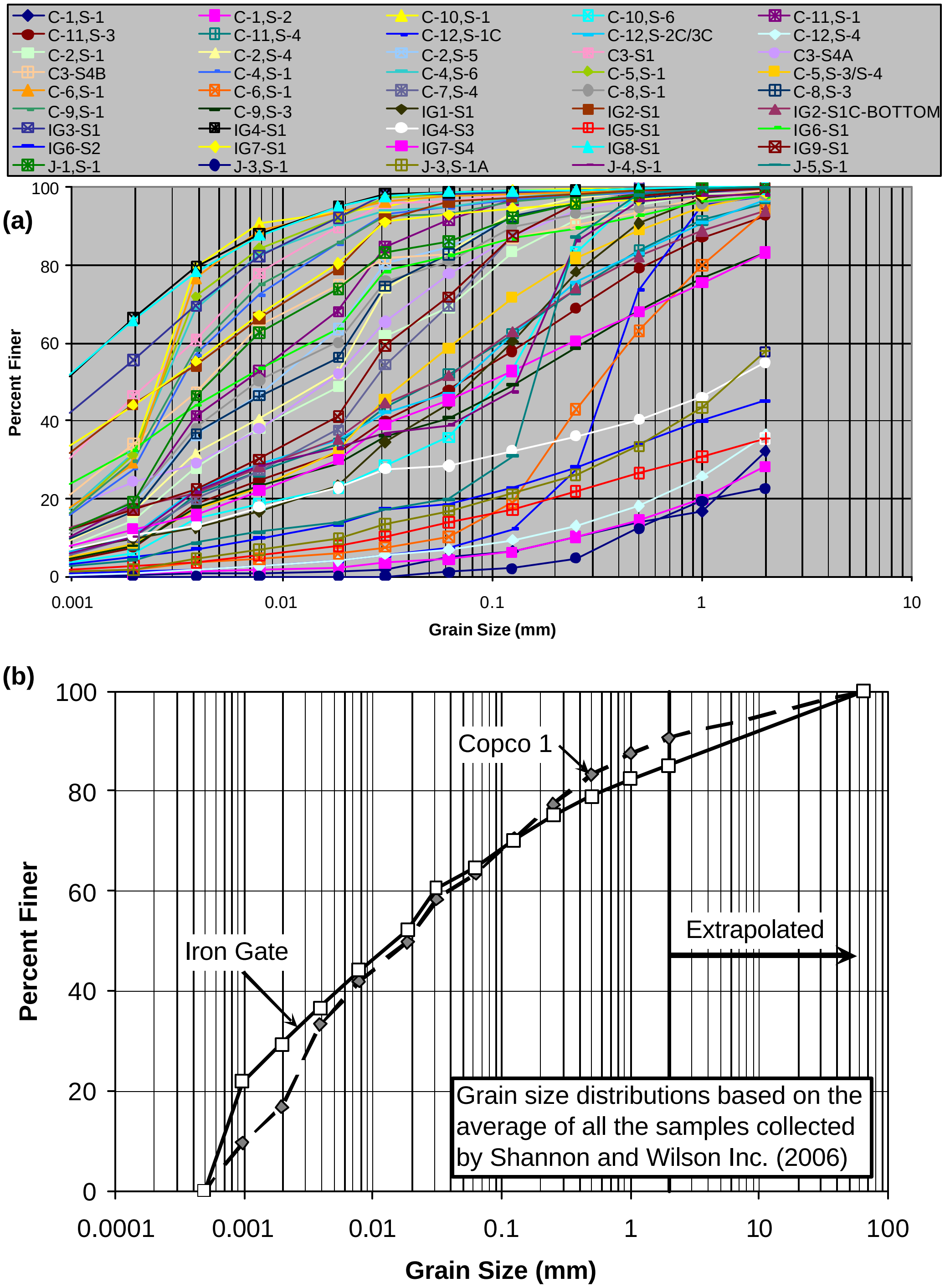


Figure 10. Grain size distributions of samples from reservoirs, based on data from Shannon and Wilson Inc. (2006). (a). All the sampling data, C denotes Copco 1 Reservoir, IG denotes Iron Gate Reservoir, and J denotes J.C. Boyle Reservoir; (b) Average grain size distributions for Copco 1 and Iron Gate deposits.

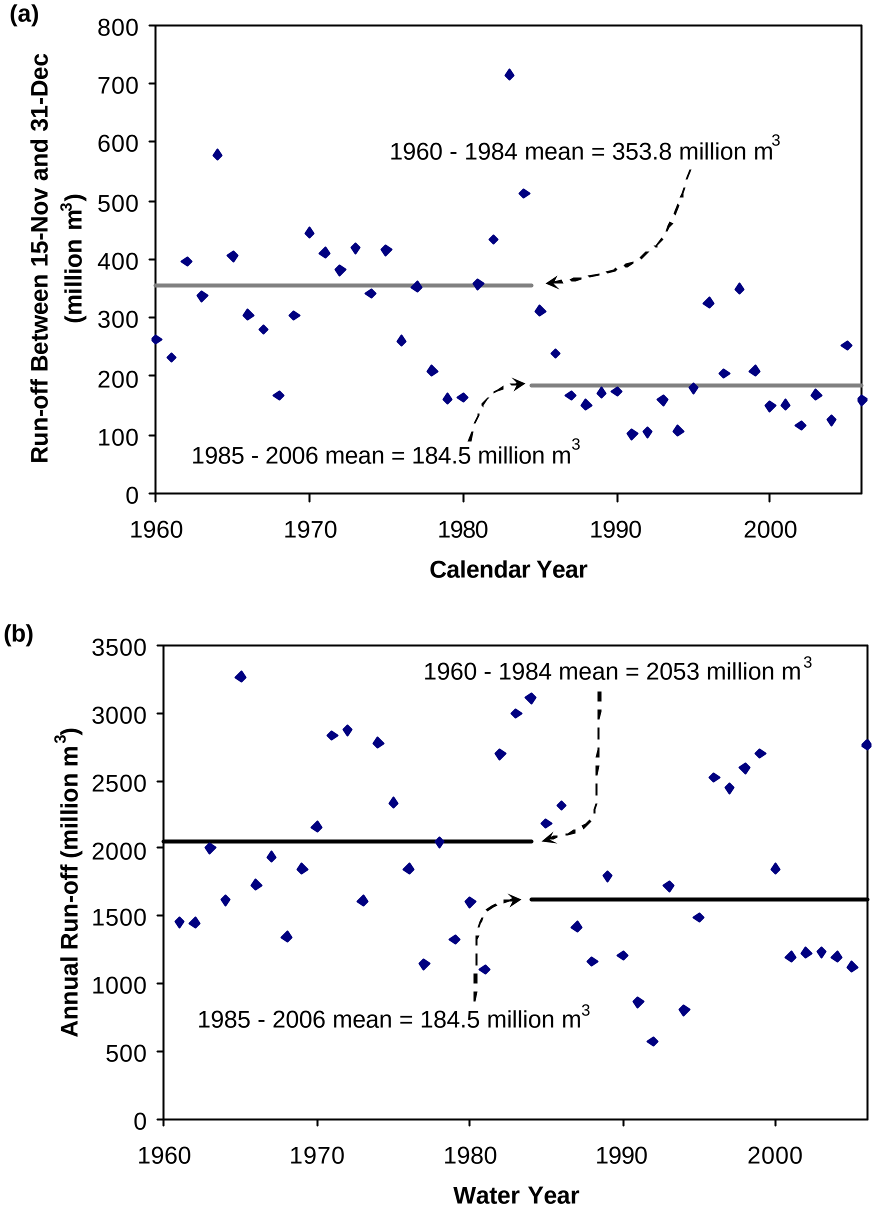


Figure 11. Calculated runoff for (a) period from 15 November to 31 December and (b) annual runoff based on daily discharge records at Klamath River below Iron Gate gage station (USGS #11516530).

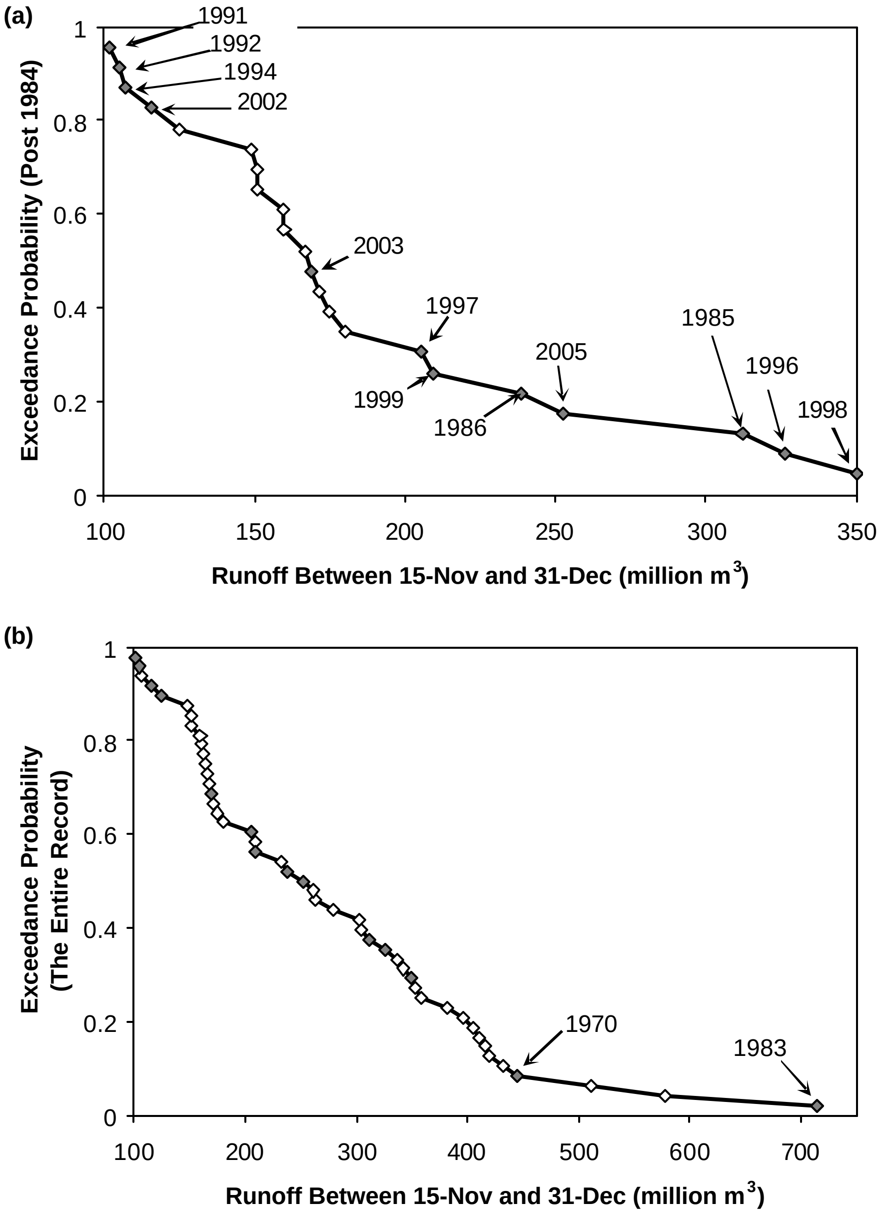


Figure 12. **Ranking of Klamath River runoff between 15 November and 31 December at Iron Gate Dam. (a). Post 1984 record; and (b). The entire record. The solid symbols are the years used in DREAM-1 simulations.**

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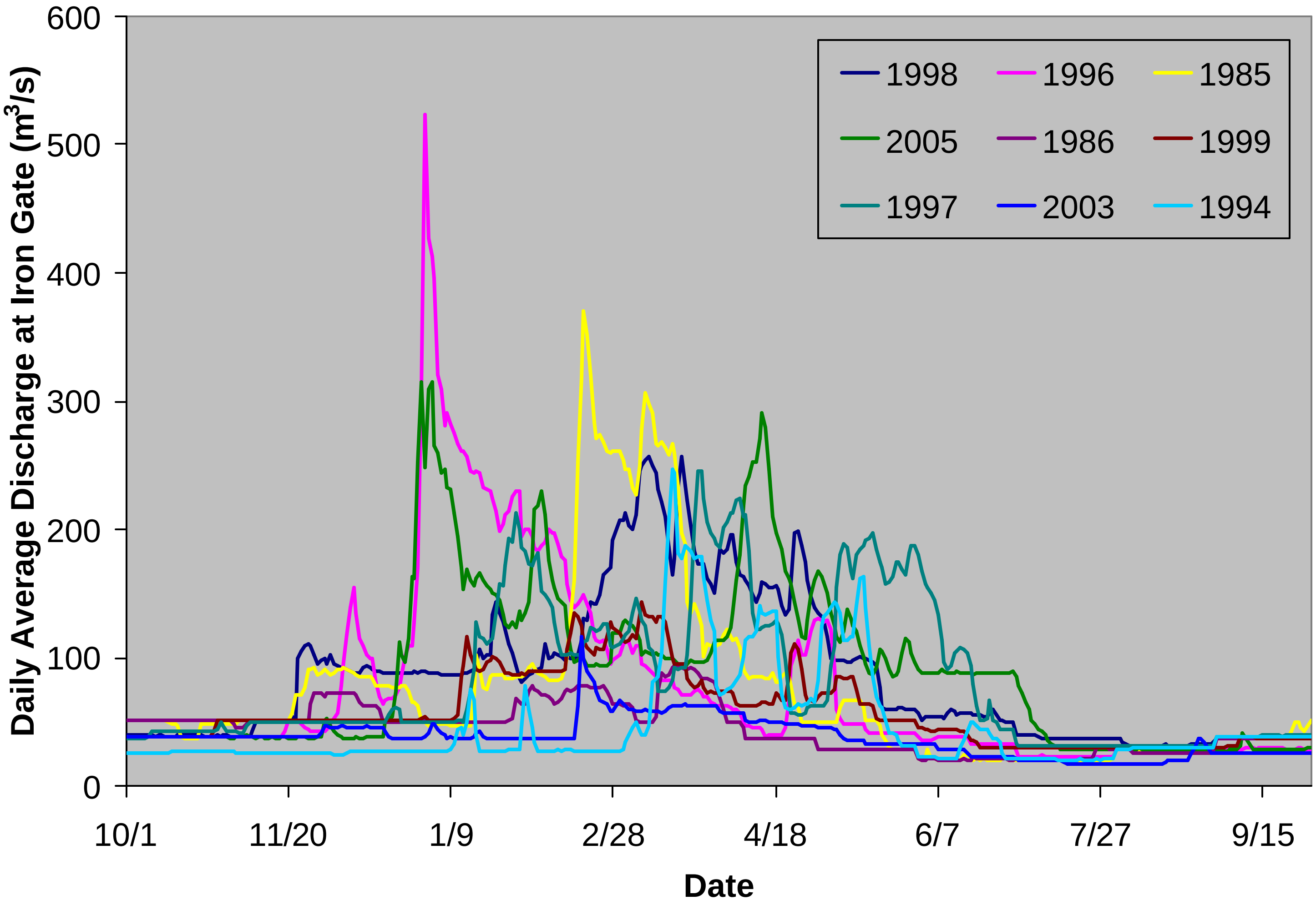

Figure 13. Daily discharge record for the selected years used in model simulations. Years indicate the calendar year for October, November, and December (i.e., they do not represent standard water years).

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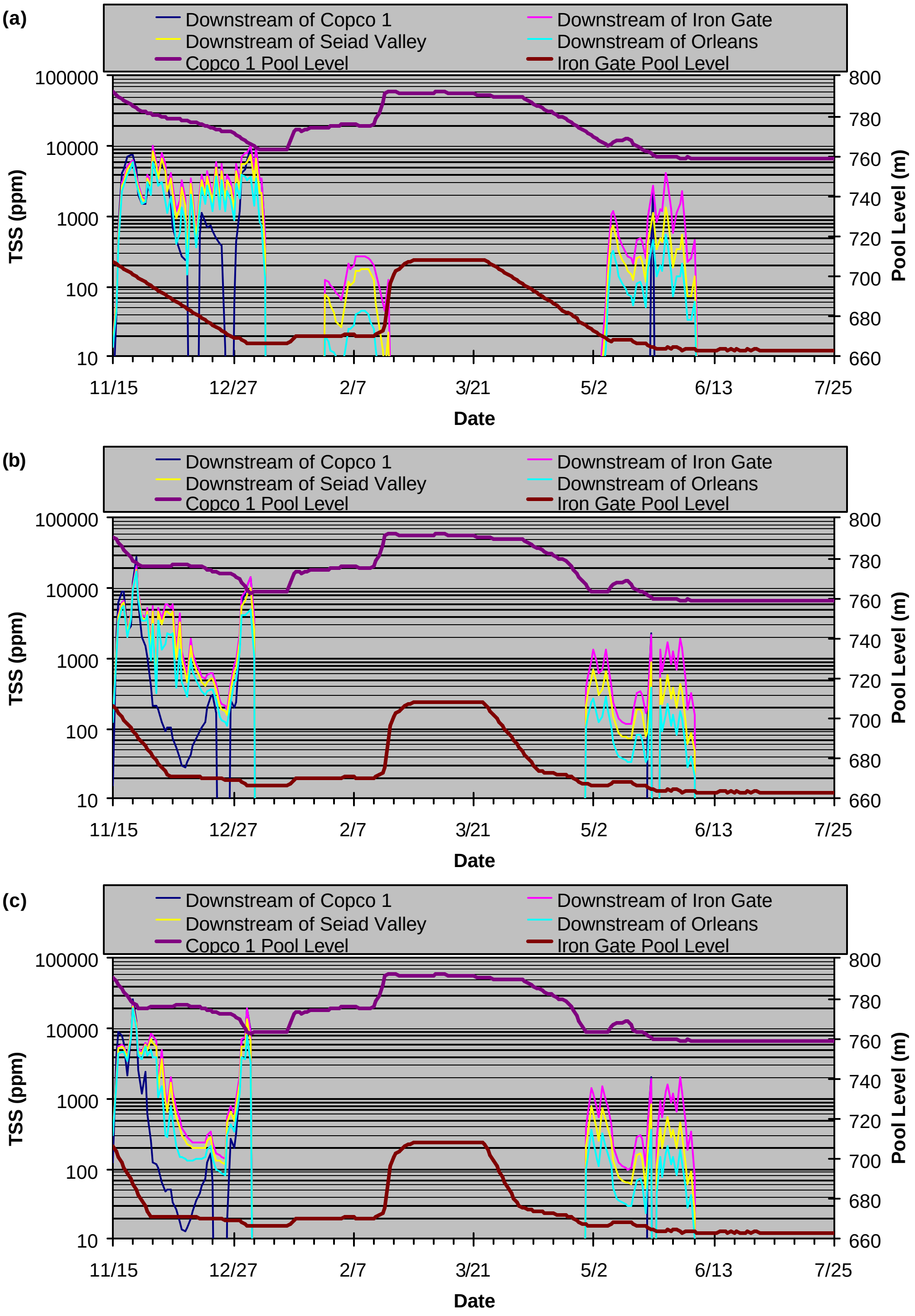

Figure 14. Simulation results for (a) Run 7, (b) Run 8, and (c) Run 9 with a 9.3 m^2 (100 ft^2) Copco 1 Dam outlet and 0.9, 1.8 and 2.7 m/day (3, 6 and 9 ft/day) drawdown limit, respectively, starting on 15 November. Discharge record used for simulation starts on 15 November 1985. Comparisons of the diagrams indicate the reduced TSS in the spring following initial drawdown to increase drawdown limit to 1.8 m/day (6 ft/day) and a lack of additional TSS reduction to further increase drawdown limit to 2.7 m/day (9 ft/day).

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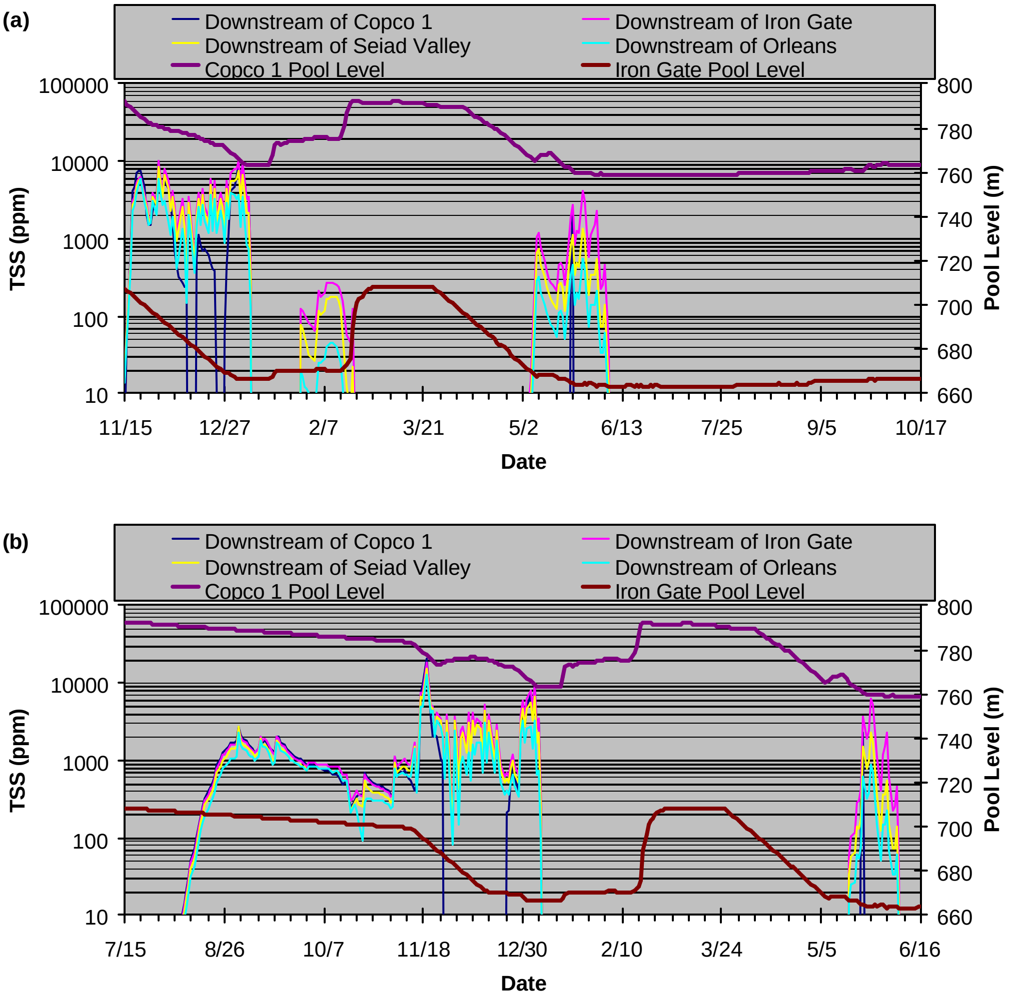

Figure 15. Simulation results for (a) Run 7 and (b) Run 28. In both runs Copco 1 bottom outlet is assumed to be 9.3 m^2 (100 ft^2). Run 7 starts drawdown on 15 November 1985 with a limitation of 0.9 m/day (3 ft/day) through the run. Run 28 starts drawdown on 15 July 1985 with a rate of 0.08 m/day (0.25 ft/day) that increases to 0.9 m/day (3 ft/day) on 15 November 1985. Comparison of the two runs indicates that there is no benefit to start the drawdown on 15 July at a lower rate because it does not reduce TSS in the spring following initial drawdown and causes higher TSS before 15 November.

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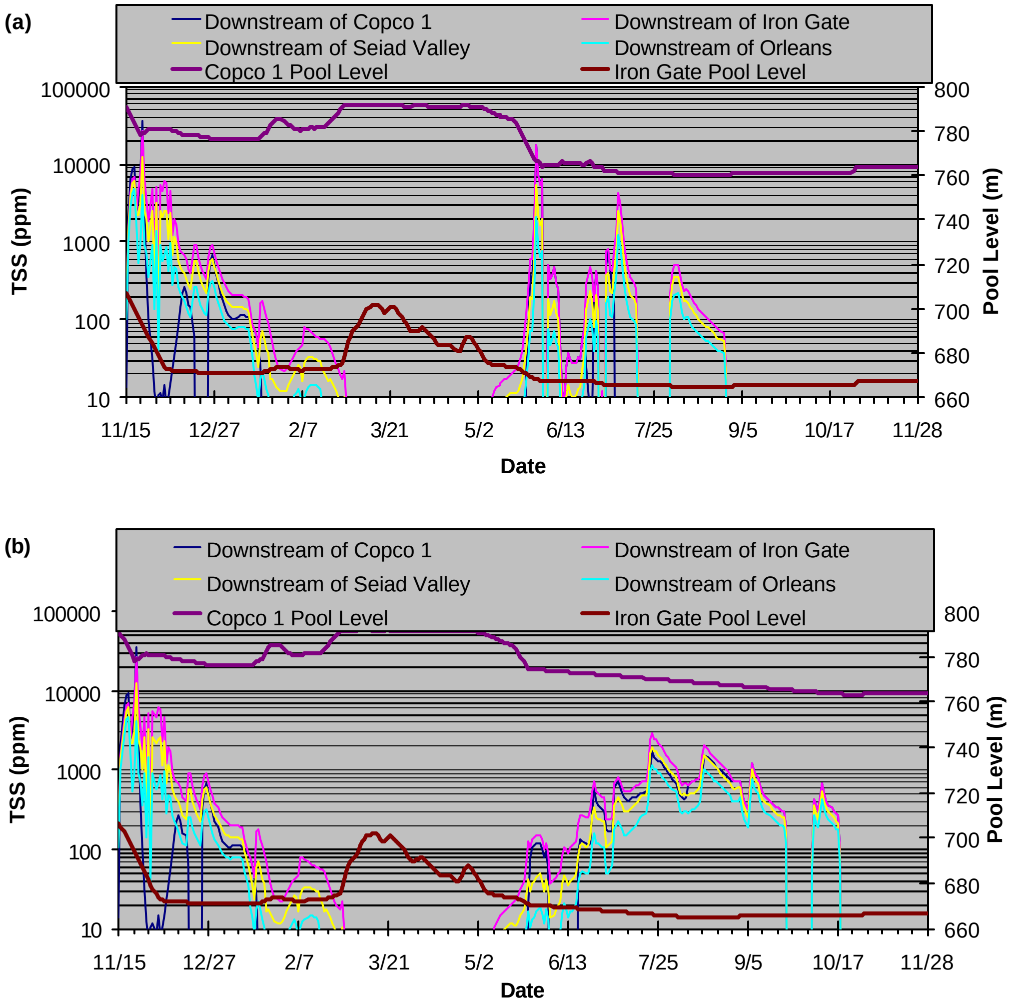

Figure 16. Simulation results for (a) Run 2 and (b) Run 29. In both runs Copco 1 bottom outlet is assumed to be 9.3 m^2 (100 ft^2), and drawdown starts on 15 November 1998 with a limitation of 1.8 m/day (6 ft/day). Run 29 also includes restricting the drawdown rate to 0.08 m/day (0.25 ft/day) in the following spring when pool level approaches the previous lowest level. Comparison of the two runs indicates that restricting the spring drawdown rate when pool level approaches the previous lowest level may reduce the magnitude of spring TSS but prolong its duration.

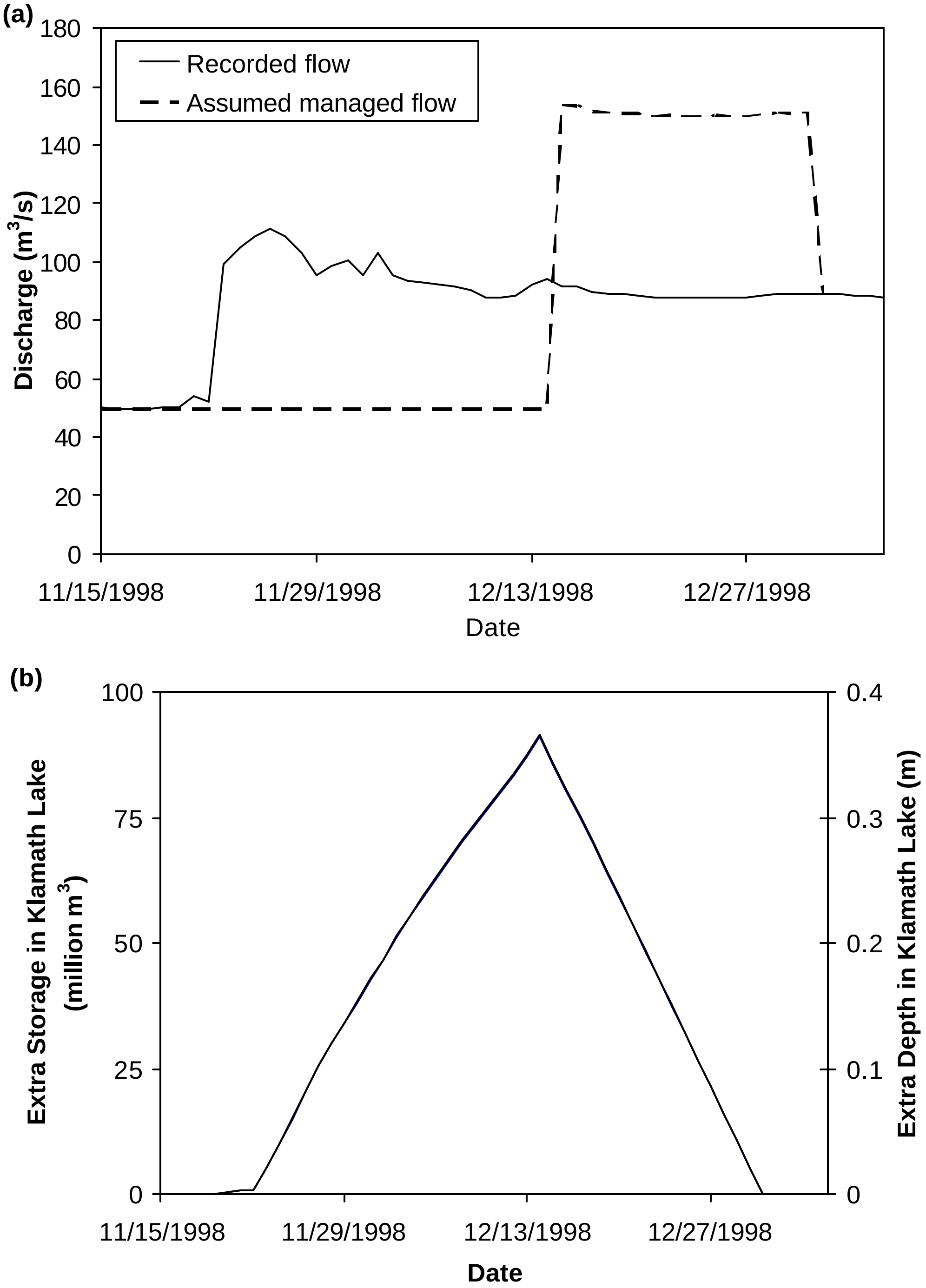

Figure 17. (a). Natural and hypothetical managed discharge into Copco 1 Reservoir; and (b) the resulting extra storage and depth in Upper Klamath Lake for Run 32 using the hypothetical managed discharge scenario.

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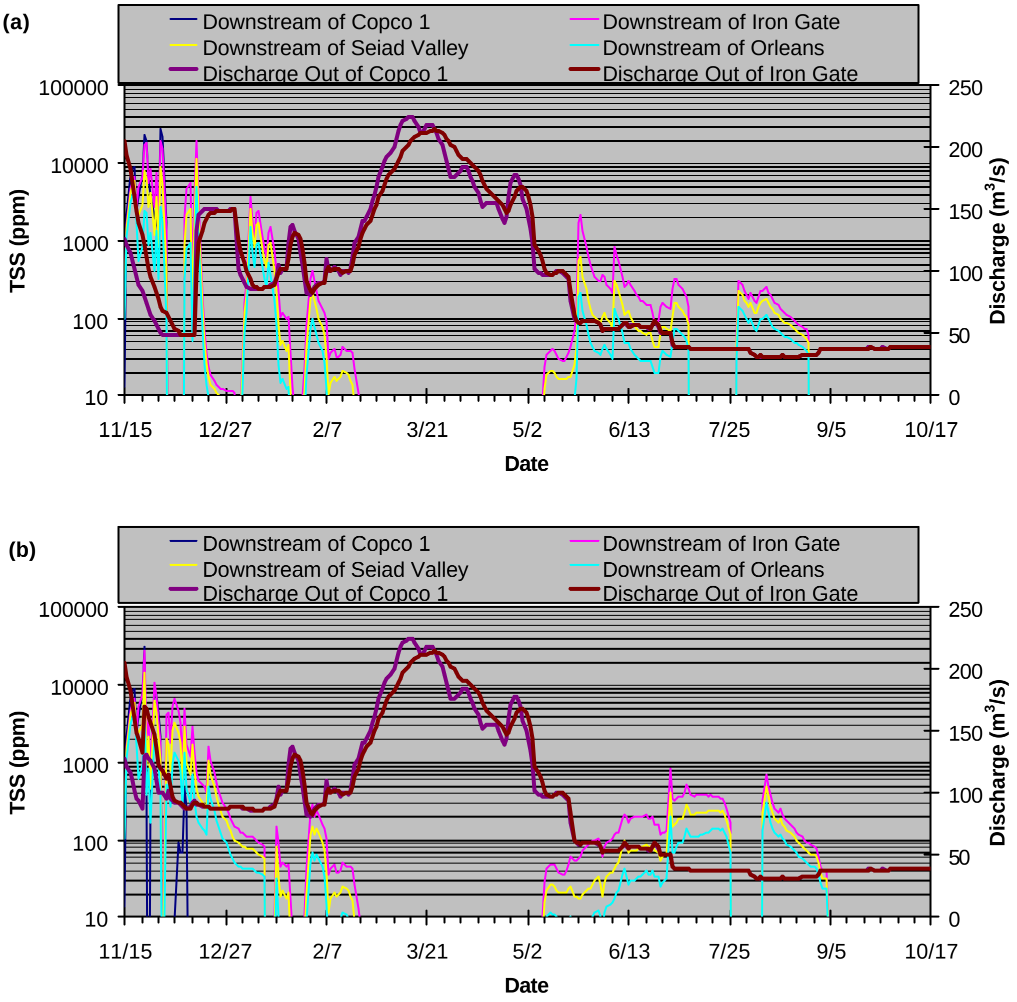

Figure 18. Simulated TSS and discharges out of Copco 1 and Iron Gate reservoirs for (a) Run 32 and (b) Run 30. In both cases reservoir drawdown is limited to less than 1.8 m/day (6 ft/day), and Copco 1 bottom outlet is assumed to be 18.2 m^2 (196 ft^2, or 14 by 14 ft). Run 32 applied a managed discharge into Copco 1 Reservoir as shown in Figure 17(a), and Run 30 applied an unmanaged discharge.

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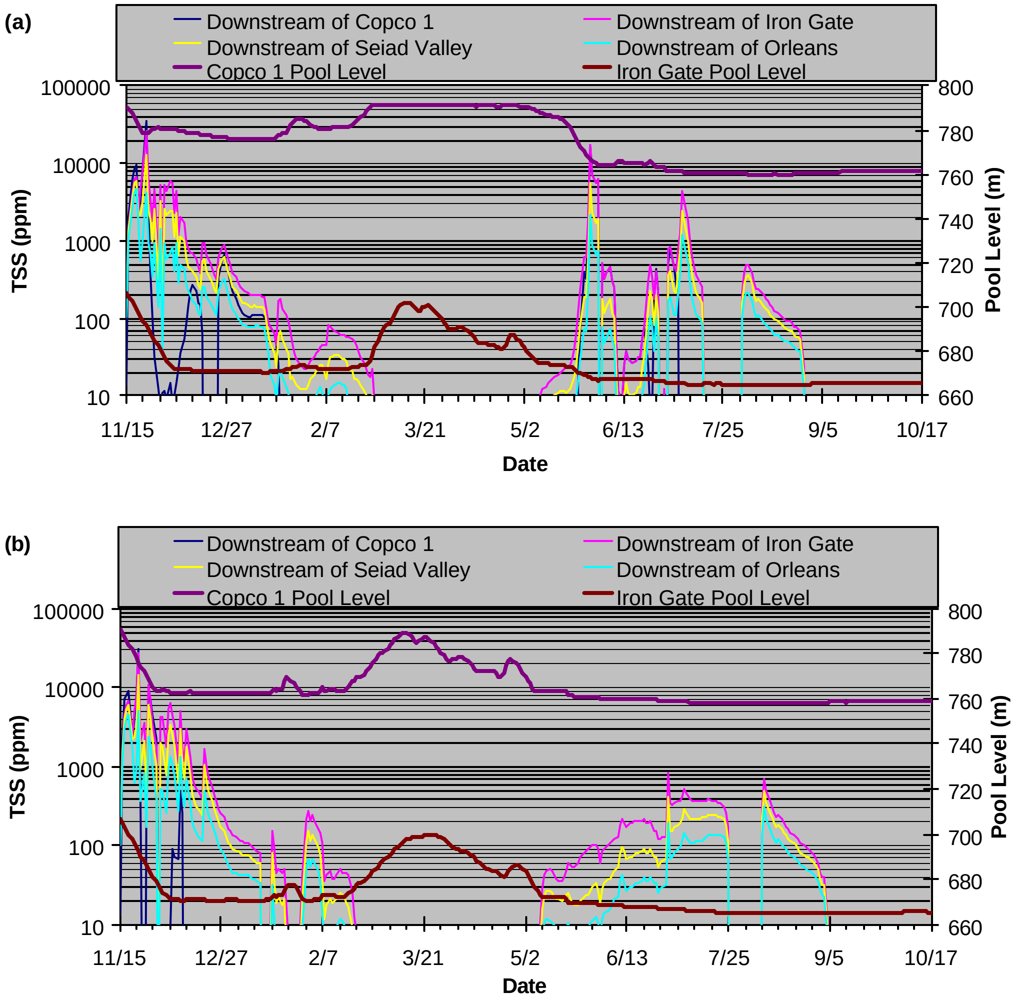

Figure 19. Simulated TSS and reservoir pool level for (a) Run 2 and (b) Run 30. In both cases reservoir drawdown is limited to less than 1.8 m/day (6 ft/day), and the drawdown starts on 15 November 1998. Run 2 assumed a 9.3 m^2 (100 ft^2, or 10 by 10 ft) Copco 1 outlet, while Run 30 assumed a 18.2 m^2 (196 ft^2, or 14 by 14 ft) Copco 1 outlet.

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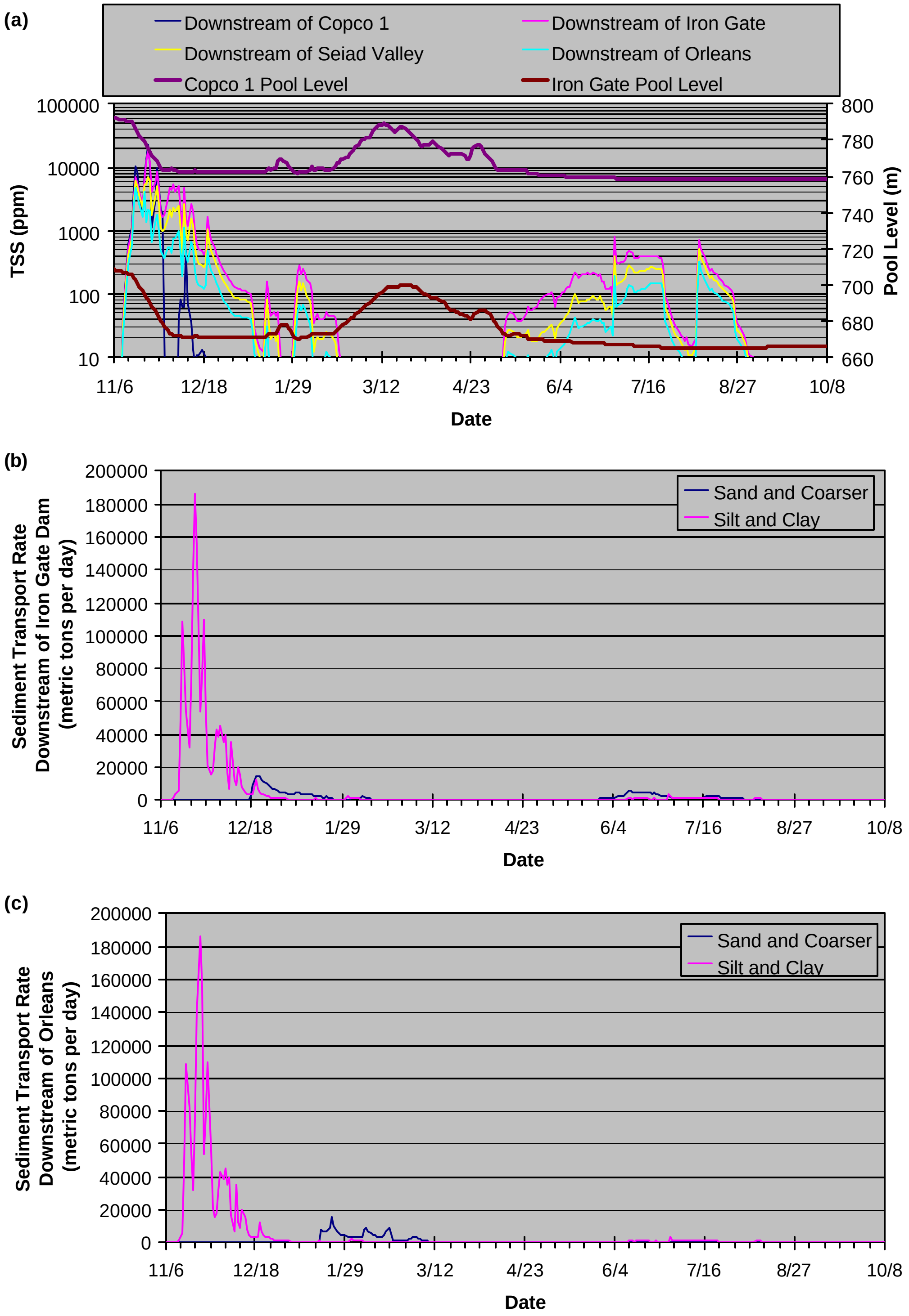

Figure 20. Simulated results for Run 44, which starts drawdown on 6 November 1998 (the wettest post-1984 year). (a). Suspended sediment concentration and reservoir pool level; (b) sediment flux downstream of Iron Gate Dam; and (c) sediment flux downstream of Orleans.

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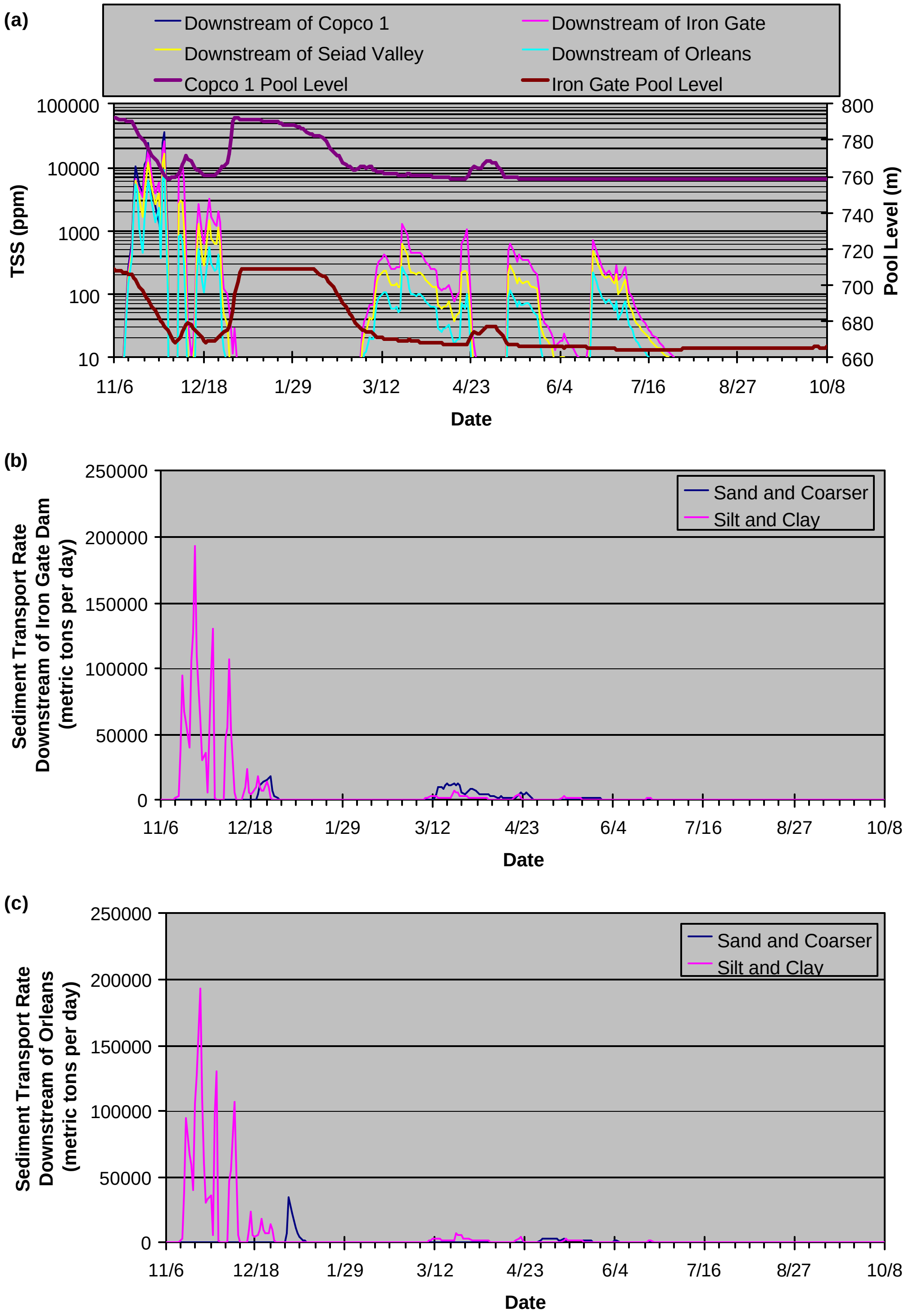

Figure 21. Simulated results for Run 45, which starts drawdown on 6 November 1996 (the 2nd wettest post-1984 year). (a). Suspended sediment concentration and reservoir pool level; (b) sediment flux downstream of Iron Gate Dam; and (c) sediment flux downstream of Orleans.

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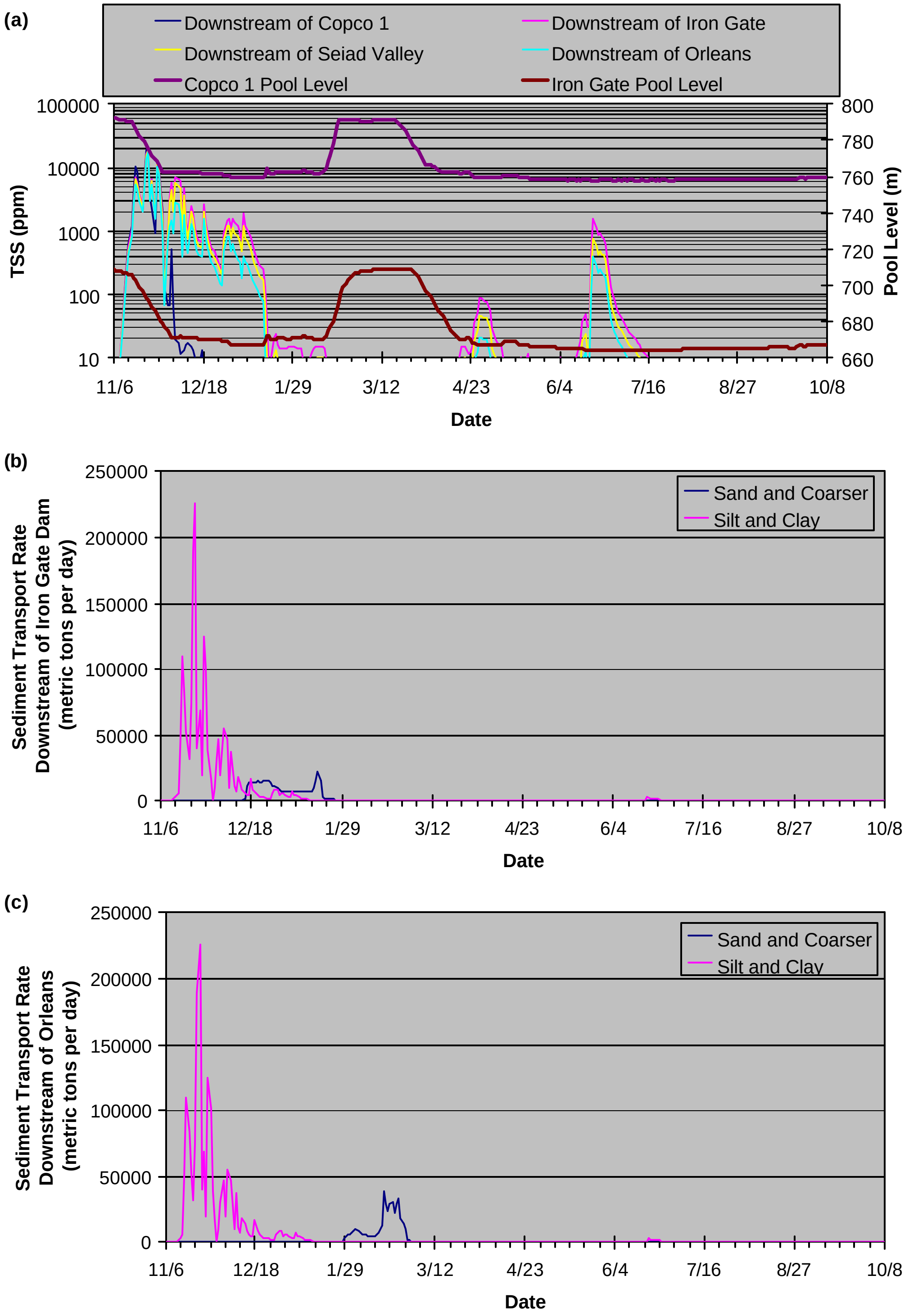

Figure 22. **Simulated results for Run 46, which starts drawdown on 6 November 1985 (the 3rd wettest post-1984 year). (a). Suspended sediment concentration and reservoir pool level; (b) sediment flux downstream of Iron Gate Dam; and (c) sediment flux downstream of Orleans.**

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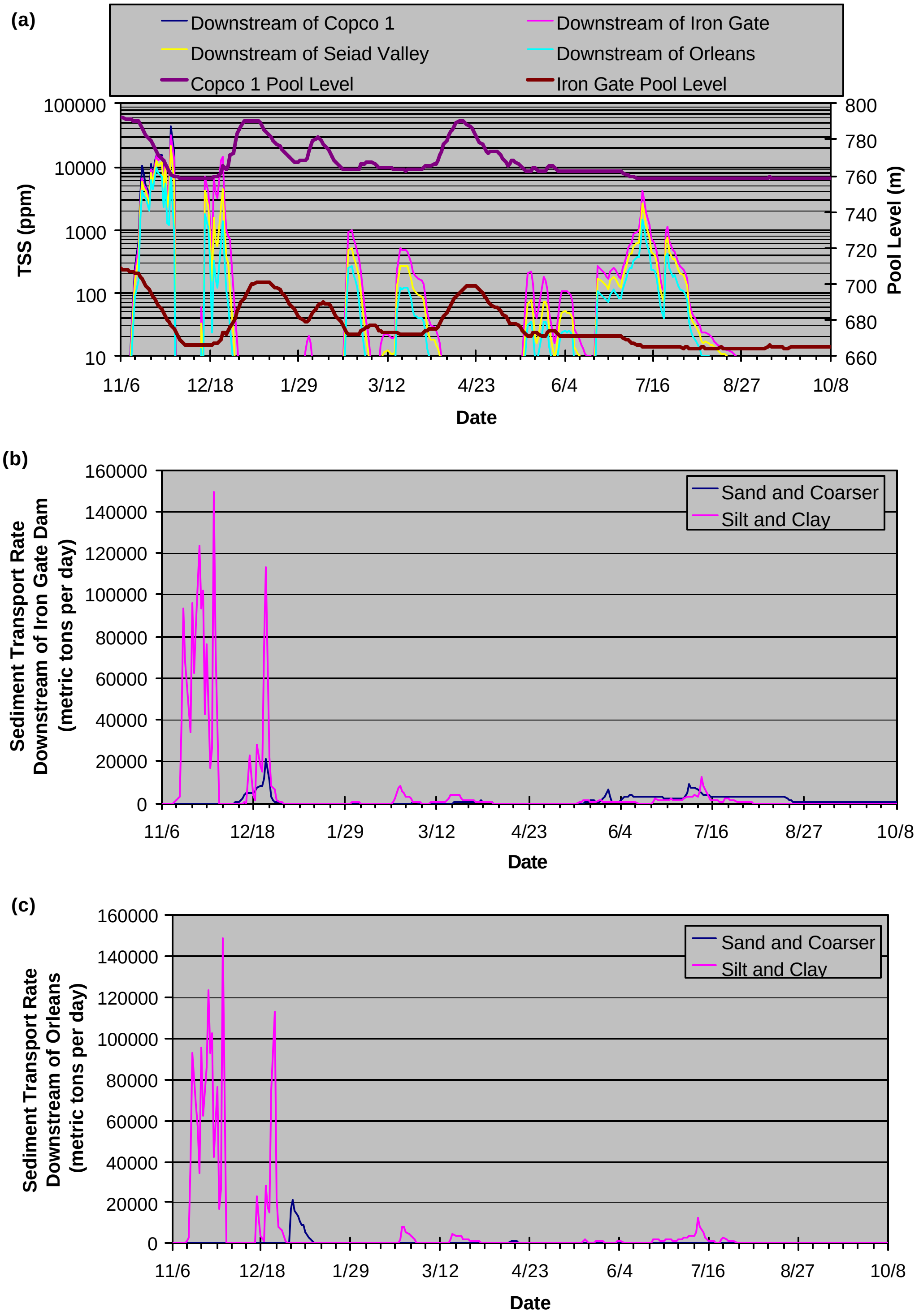

Figure 23. Simulated results for Run 47, which starts drawdown on 6 November 2005 (the 4th wettest post-1984 year). (a). Suspended sediment concentration and reservoir pool level; (b) sediment flux downstream of Iron Gate Dam; and (c) sediment flux downstream of Orleans.

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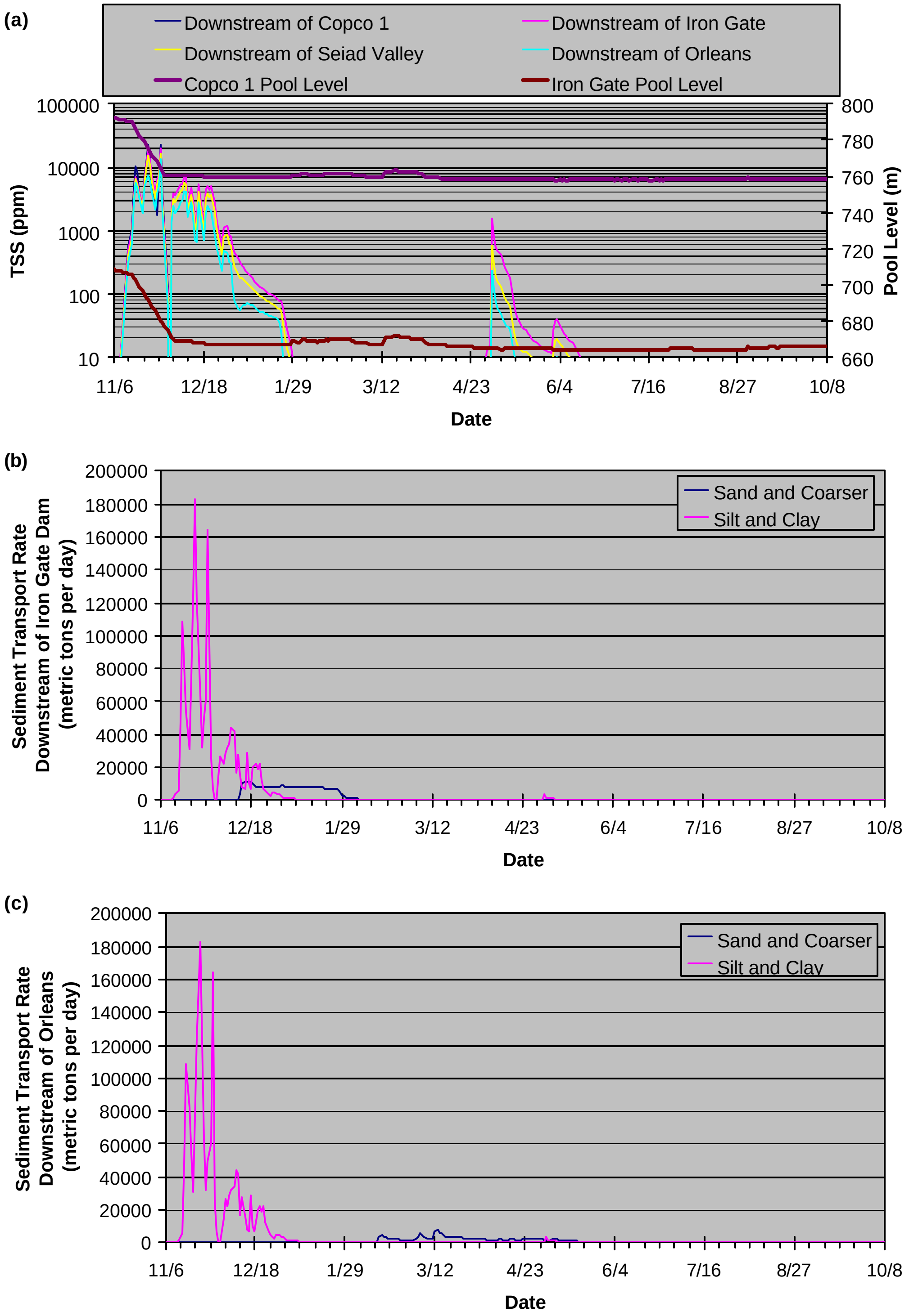

Figure 24. **Simulated results for Run 48, which starts drawdown on 6 November 1986 (the 5th wettest post-1984 year). (a). Suspended sediment concentration and reservoir pool level; (b) sediment flux downstream of Iron Gate Dam; and (c) sediment flux downstream of Orleans.**

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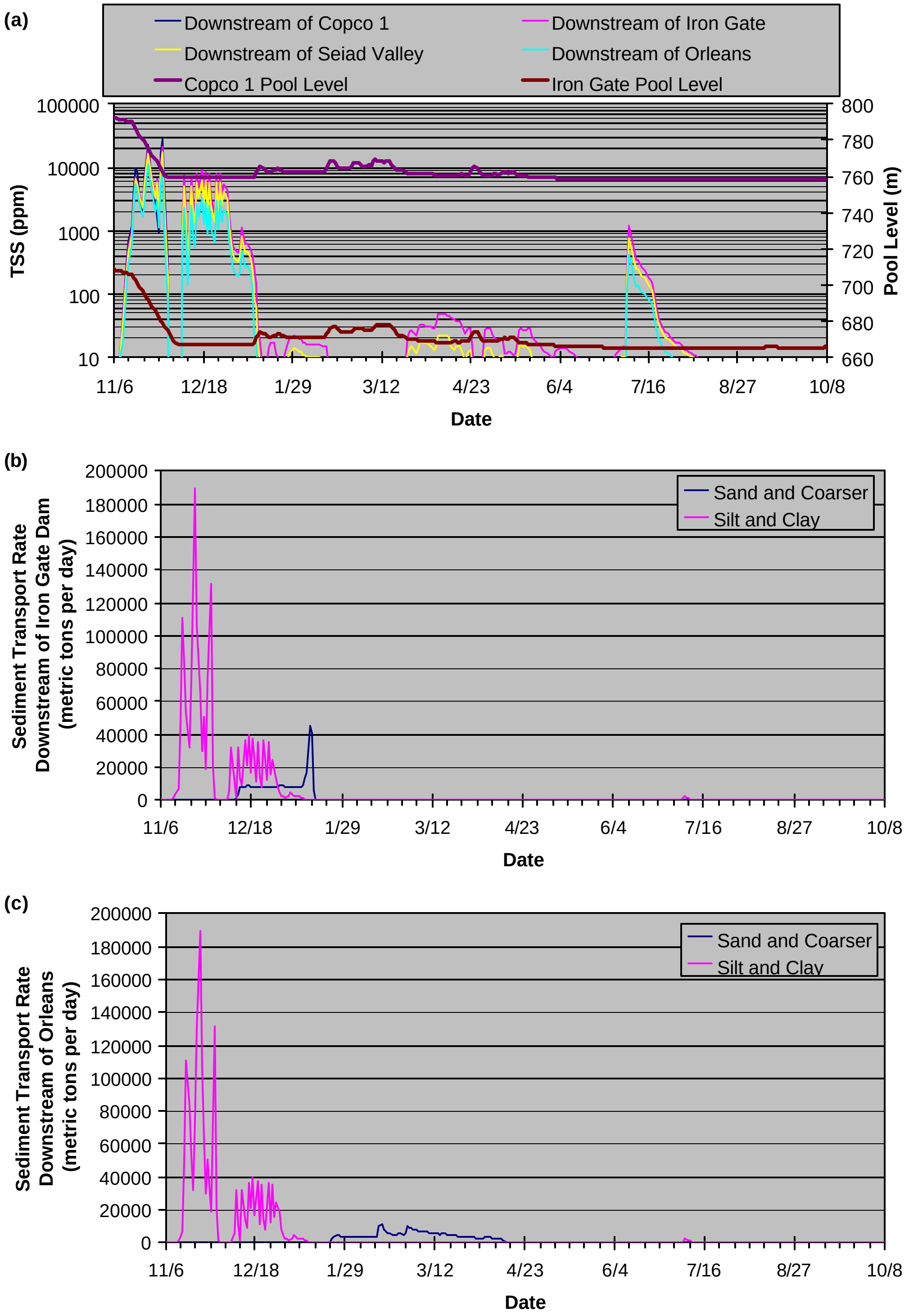

Figure 25. Simulated results for Run 49, which starts drawdown on 6 November 1999 (the 6th wettest post-1984 year). (a). Suspended sediment concentration and reservoir pool level; (b) sediment flux downstream of Iron Gate Dam; and (c) sediment flux downstream of Orleans.

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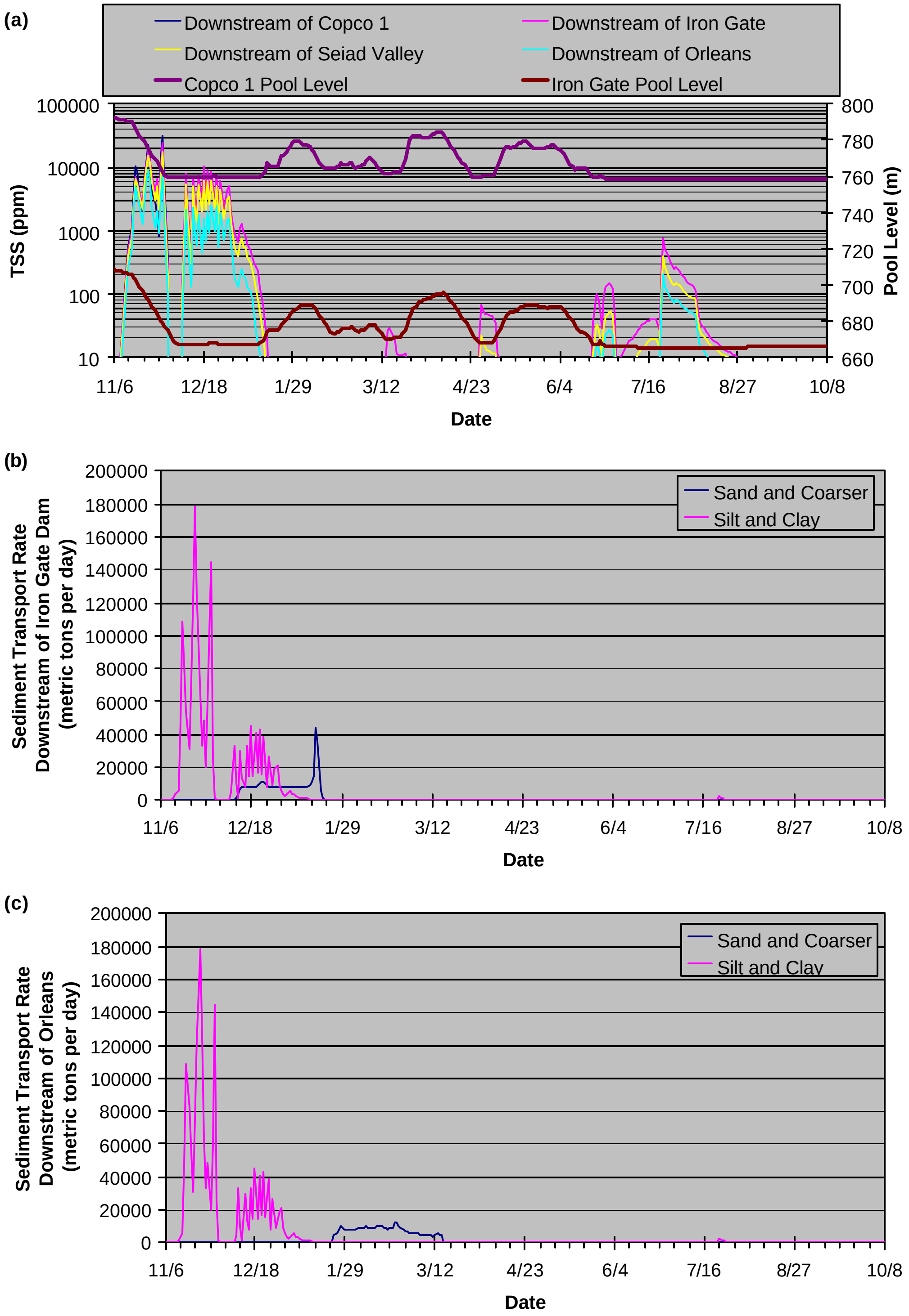

Figure 26. Simulated results for Run 50, which starts drawdown on 6 November 1997 (the 7th wettest post-1984 year). (a). Suspended sediment concentration and reservoir pool level; (b) sediment flux downstream of Iron Gate Dam; and (c) sediment flux downstream of Orleans.

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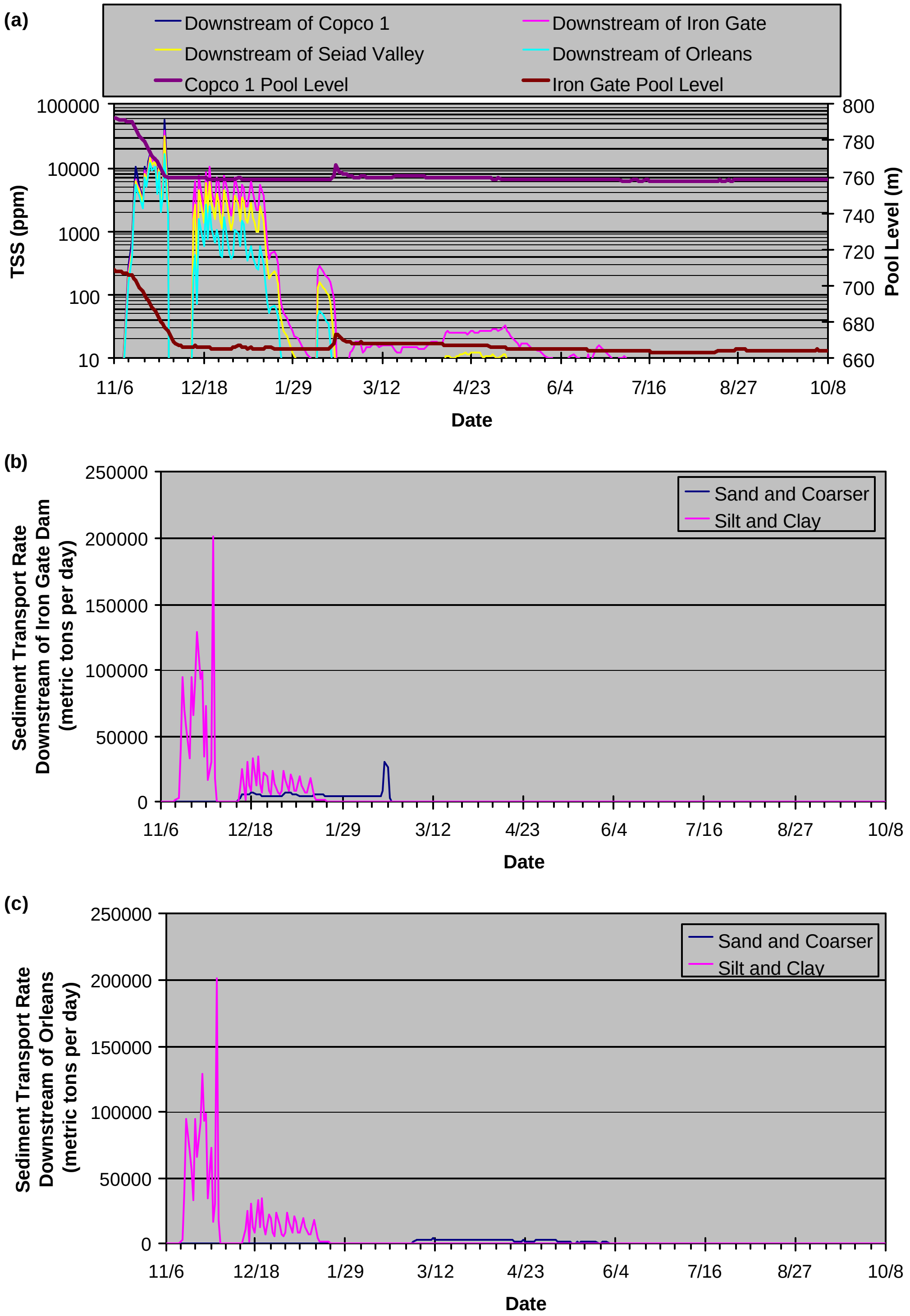

Figure 27. Simulated results for Run 51, which starts drawdown on 6 November 2003 (the average post-1984 year with a 50% exceedance probability). (a). Suspended sediment concentration and reservoir pool level; (b) sediment flux downstream of Iron Gate Dam; and (c) sediment flux downstream of Orleans.

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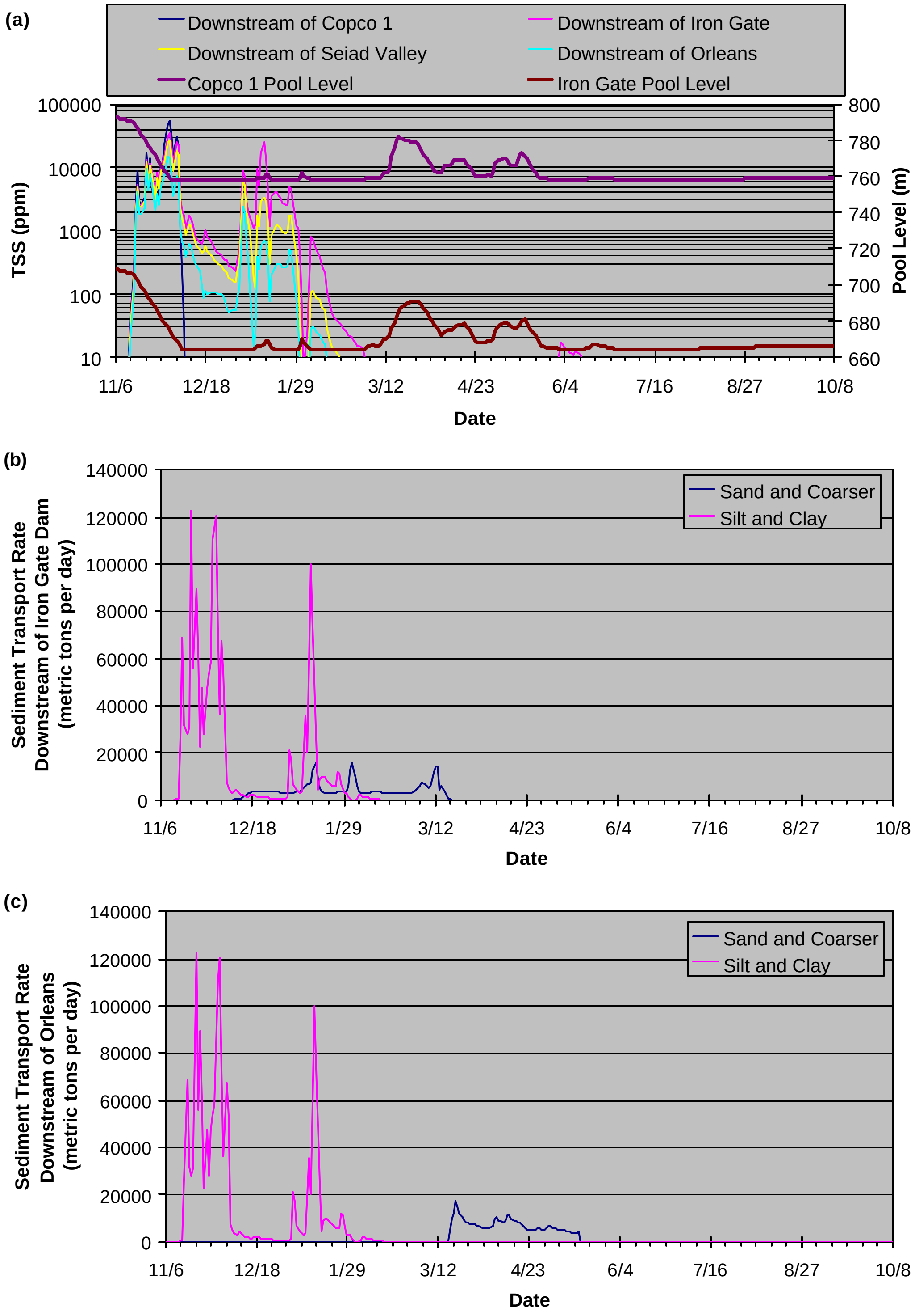

Figure 28. Simulated results for Run 52, which starts drawdown on 6 November 1994 (a dry post-1984 year with 90% exceedance probability). (a). Suspended sediment concentration and reservoir pool level; (b) sediment flux downstream of Iron Gate Dam; and (c) sediment flux downstream of Orleans.

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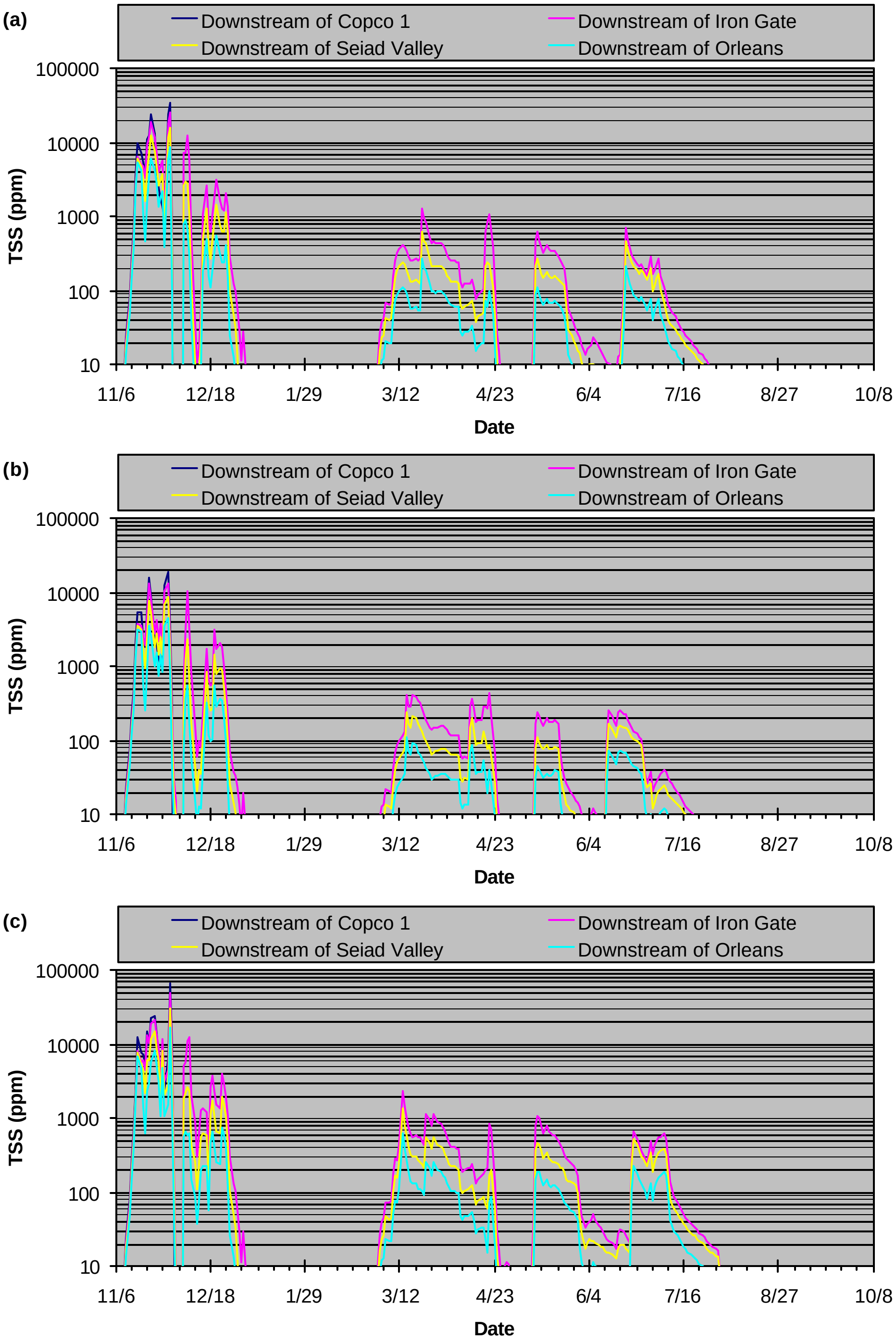

Figure 29. Comparison of simulated TSS for sensitivity test runs assuming different geometry for the channel formed in the former reservoir deposit for a typical wet year: (a) Run 45, assuming 61-m (200-ft) bottom width and 1:10 bank slope for the trapezoidal channel; (b) Run 45B, assuming 46-m (150-ft) bottom width and 1:3 bank slope for the trapezoidal channel; and (c) run 45W, assuming 91-m (300-ft) bottom width and 1:10 bank slope for the trapezoidal channel. All runs start drawdown on 6 November 1996, which has an exceedance probability of approximately 10% for Klamath River runoff at Iron Gate station for the period of 15-November and 31-December.

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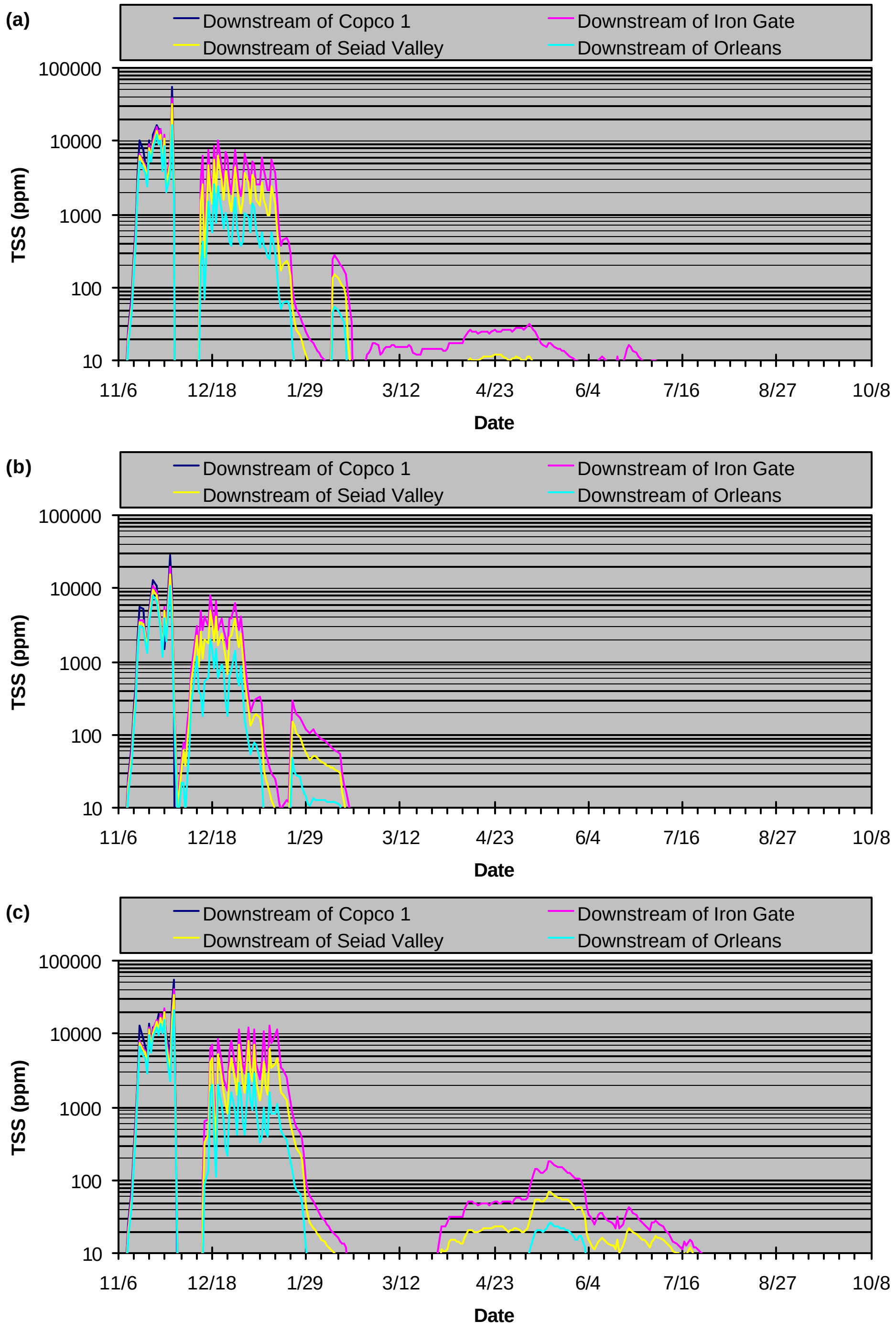

Figure 30. Comparison of simulated TSS for sensitivity test runs assuming different geometry for the channel formed in the former reservoir deposit for the average year: (a) Run 51, assuming 61-m (200-ft) bottom width and 1:10 bank slope for the trapezoidal channel; (b) Run 51B, assuming 46-m (150-ft) bottom width and 1:3 bank slope for the trapezoidal channel; and (c) run 51W, assuming 91-m (300-ft) bottom width and 1:10 bank slope for the trapezoidal channel. All runs start drawdown on 6 November 2003, which has an exceedance probability of approximately 50% for Klamath River runoff at Iron Gate station for the period of 15-November and 31-December.

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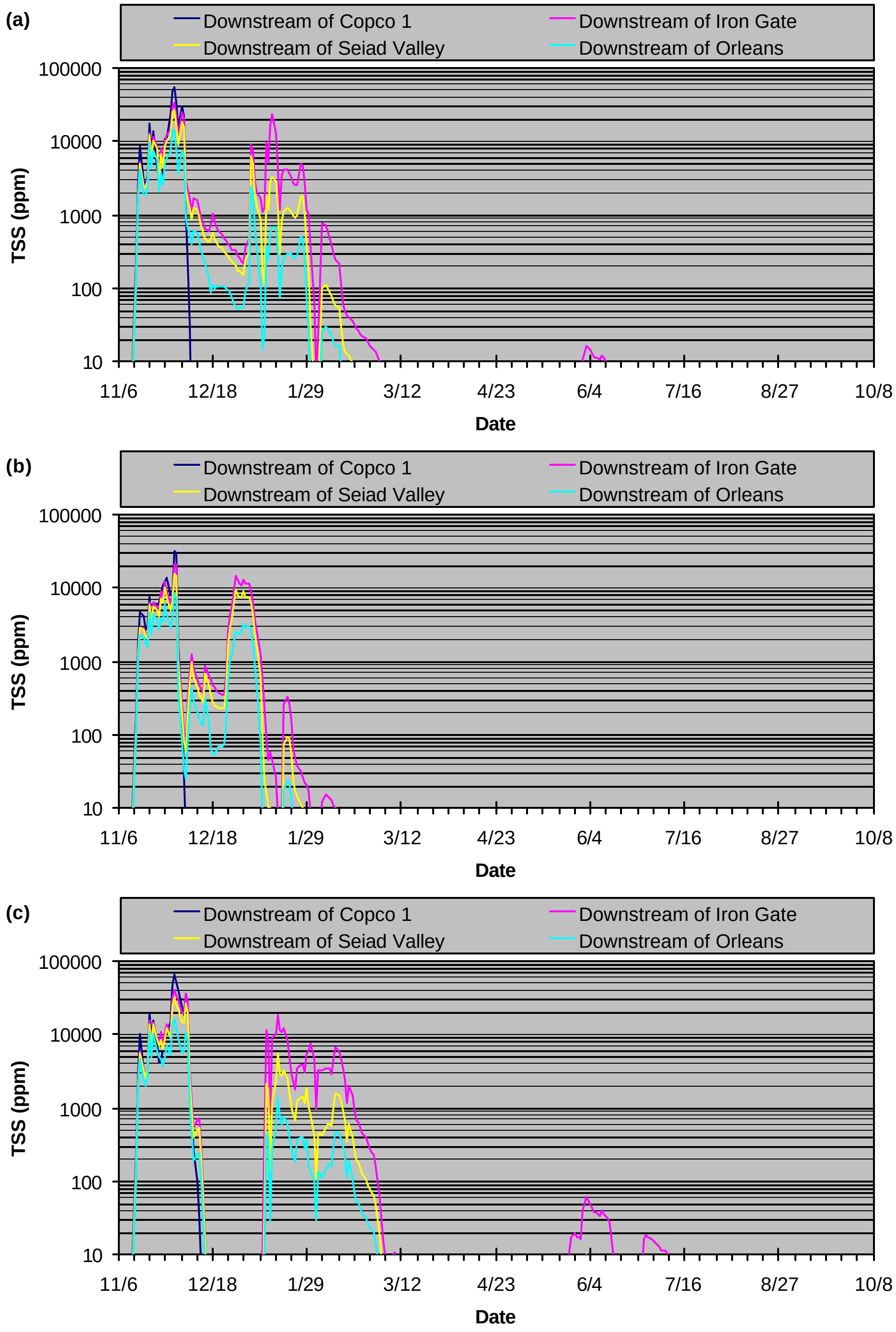

Figure 31. Comparison of simulated TSS for sensitivity test runs assuming different geometry for the channel formed in the former reservoir deposit for a typical dry year: (a) Run 52, assuming 61-m (200-ft) bottom width and 1:10 bank slope for the trapezoidal channel; (b) Run 52B, assuming 46-m (150-ft) bottom width and 1:3 bank slope for the trapezoidal channel; and (c) run 52W, assuming 91-m (300-ft) bottom width and 1:10 bank slope for the trapezoidal channel. All runs start drawdown on 6 November 1994, which has an exceedance probability of approximately 90% for Klamath River runoff at Iron Gate station for the period of 15-November and 31-December.

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APPENDICES

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Appendix A Derivation of equations to convert Shannon and Wilson Inc. (2006) data to ARI format

The water content given in column 3 of Table 4 is expressed as

$$\omega = \frac{M_w}{M_s + M_c} = \frac{V_w \rho_w}{V_s \rho_s + V_c \rho_c} \tag{1}$$

in which ω denotes water content defined as the water mass to the combined solids and organic carbon mass ratio; M_w denotes the mass of water in the sample; M_s denotes the mass of solids in the sample; M_c denotes the dry mass of organic carbon in the sample; V_w denotes the volume of water in the sample; ρ_w denotes the density of water; V_s denotes the volume of solids; ρ_s denotes the density of solids; V_c denotes the volume of organic carbon; and ρ_c denotes the density of dry organic carbon.

The organic carbon content given in column 2 of Table 2 is expressed as

$$c = \frac{M_c}{M_s + M_c} = \frac{V_c \rho_c}{V_s \rho_s + V_c \rho_c} \tag{2}$$

in which c denotes organic carbon content defined as dry organic carbon mass to the combined solids and dry organic carbon mass ratio.

By rearranging equations (1) and (2), respectively, we obtain the following equations:

$$V_w = \omega \frac{\rho_s}{\rho_w} V_s + \omega \frac{\rho_c}{\rho_w} V_c \tag{3}$$

$$V_c = \frac{c}{1-c} \frac{\rho_s}{\rho_c} V_s \tag{4}$$

Substituting equation (4) into equation (3) we obtain

$$V_w = \frac{\omega}{1-c} \frac{\rho_s}{\rho_w} V_s \tag{5}$$

Based on equations (4) and (5), we obtain the following two equations:

$$f_s = \frac{V_s}{V_s + V_c + V_w} = \frac{1}{1 + \frac{c}{1-c}\frac{\rho_s}{\rho_c} + \frac{\omega}{1-c}\frac{\rho_s}{\rho_w}} \tag{6}$$

$$f_c = \frac{V_c}{V_s + V_c + V_w} = \frac{\frac{c}{1-c}\frac{\rho_s}{\rho_c}}{1 + \frac{c}{1-c}\frac{\rho_s}{\rho_c} + \frac{\omega}{1-c}\frac{\rho_s}{\rho_w}} \tag{7}$$

in which f_s denotes the volumetric fraction of solids in the bulk sample (i.e., volume of solids as a fraction of the bulk volume of the sample, column 4 in Table 4); and f_c denotes the volumetric fraction of the organic carbon in the bulk sample (i.e., volume of dry organic carbon as a fraction of the bulk volume of the sample, column 5 in Table 4). The calculations from results shown in columns 4 and 5 to columns 6 and 7 in Table 4 are apparent and simple, and thus are not presented here. Assumptions in the calculation are given beneath Table 4.

Appendix B Results of all the documented runs

Results for a total of seventy (70) runs (plus any additional runs conducted later in support of the biological assessment) are provided in an Excel file in the attached CD[5]. A list of these seventy runs is given in Table 7 of this report and in the Excel file in the attached CD. Results are tabulated with each run occupying a separate worksheet, and the tab of the worksheet denoted with the run number. For example, tabulated results for Run 32 will be located in the worksheet “Run 32”. Results presented in the worksheets include: a) suspended sediment concentration at four locations (downstream of Copco 1 Dam, and at Iron Gate, Seiad Valley, and Orleans stations); b) pool levels in Copco 1 and Iron Gate reservoirs; c) water discharge at downstream of Copco 1 Dam and at Iron Gate, Seiad Valley and Orleans stations; d) coarse sediment (sand and coarser) transport rate at downstream of Copco 1 and at Iron Gate and Orleans stations; and e) fine sediment (silt and finer) transport rate at downstream of Copco 1 and at Iron Gate and Orleans stations. Note that discharge at Iron Gate, Seiad Valley and Orleans stations provided in the worksheets are different from the discharge records at these stations downloaded from USGS website because it also includes the release (during drawdown) and storage (when pool level rises) of Copco 1 and Iron Gate Reservoirs. Discharge entering Copco 1 is assumed to be identical to the recorded discharge at Iron Gate station, which is not provided in the worksheets but can be downloaded easily at the USGS website (gaging station #11516530).

Other than the tabulated results in the worksheets, additional results are presented in five charts with tabs “TSS (1)” , “ TSS (2)” , “ Qs ds Copco” , “Qs ds IG” , and “Qs ds Orleans”:

- Worksheet “TSS (1)” presents suspended sediment concentration values at four stations and the pool levels in Copco 1 and Iron Gate reservoirs;
- Worksheet “TSS (2) presents suspended sediment concentration values at four stations and discharge downstream of Copco 1 Dam and downstream of Iron Gate Dam;
- Worksheets “Qs ds Copco” presents sediment fluxes at downstream of Copco 1 Dam (i.e., sediment released from Copco 1 Dam);
- Worksheets “Qs ds IG) presents sediment fluxes at downstream of Iron Gate Dam (i.e., sediment released from Iron Gate Dam); and
- Worksheets “Qs ds Orleans” presents sediment fluxes downstream of Orleans station.

The results from the run that the charts depict can be readily changed. There is a label on each chart, indicating which run is shown on the chart. The run shown on all five charts can be changed to a different run by clicking the run number on any of the charts and providing a new run number at the data inquiry. In order for you to change the charts, you will need to set your Excel security level to “Medium”. This can be done by clicking “Tool” – “Options” – “Security” – “Macro Security” , and then set the security level to “Medium” and click “OK”. This needs to be done only once, and not at all if your Excel security level is already set to “Medium”. Each time when you open the Excel file in the CD, you need to click “Enable Macro” , which will allow you to make changes to the runs shown in the five charts.

The worksheets and charts in the Excel file are protected without password to prevent accidental modifications. It is encouraged that you copy the data and/or charts to a different file if you need to work with them. It is also advised that you save a backup copy in case you loss the working file.

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[5] The file is also available for downloading at https://files.stillwatersci.com/ with user name “KlamathRiver” and password “ DamRemoval” , both user name and password are case sensitive.