Estimated Mercury Concentrations and Turbidity Resulting from Removal of Condit Dam

Objective

The objective of this analysis is to investigate a range of potential fine-grained sediment release scenarios from Northwestern Lake following the proposed removal of Condit dam to determine the potential near-term impacts on suspended sediment concentrations, turbidity, and mercury concentrations in the White Salmon and Columbia Rivers. This analysis builds on previous analyses developed in the Sediment Behavior Analysis Report (G&G Associates, May 2004) and Condit Dam Removal Study, Sediment Erosion Analysis Northwestern Lake, (Gathard, March 1998) and incorporates information on impounded sediment mercury concentrations developed from recent sediment quality investigation work conducted at Northwestern Lake by Kleinfelder.

The 2004 Sediment Behavior Analysis Report investigated total suspended solids and turbidity impacts occurring in three different time periods: near-term in which the initial reservoir flush and river erosion were evaluated; mid-term, in which exposed sediment surface erosion processes were analyzed; and long-term, in which erosion from flood plain development was analyzed. This investigation only addresses near-term erosion processes to estimate the number of days that specific water quality guidelines for turbidity and mercury may be exceeded. The 2004 Sediment Behavior Analysis Report provided estimates of general near-, mid- and long-term ranges of total suspended solids and turbidity levels over specific time periods that could be expected following removal of Condit dam. The 2004 Sediment Behavior Analysis Report did not consider mercury concentrations.

Results of analysis of mid-term processes showed low levels of turbidity in the Columbia River. Results of analysis of long-term flood formation processes showed only a few events in 30 years that might cause elevated levels of turbidity in the Columbia River in excess of water quality criteria.

Background

Condit dam was completed in 1913 and impounds a reservoir, Northwestern Lake, which has a surface area of approximately 92 acres. Since its construction, Condit dam has trapped sediment from the White Salmon River in Northwestern Lake. Condit dam is proposed to be removed by first breaching the dam at its base and allowing much of the sediment and all of the water impounded in Northwestern Lake to be released. The initial surge of water and sediment from the breach in the bottom of the dam will increase total suspended solids (TSS) and turbidity in the White Salmon River and in the Columbia River. A large pool at the mouth of the White Salmon River, the Underwood In-Lieu Fishing Access Site (In-Lieu Site), will capture a portion of the sediments, mostly sand and some silt-sized particles, before they enter the Columbia River.

Immediately after the breach of Condit dam, accumulated sediment within the reservoir will start to erode with the escaping water. The depth and location of sediment immediately upstream of the dam face are illustrated in Figure 1. For most of the length of the reservoir the original river channel was located in a narrow rock channel with very steep side slopes. It is expected that the sediment in the first mile upstream of the dam, which is composed primarily of silt and clay sized particles, will be eroded to form nearly vertical cut slopes within the first week after the breach. The steep cut slopes will fail and flatten in the following weeks. During this period initial TSS levels will be very high and will decrease with time.

TSS concentrations downstream of the dam will drop significantly due to dilution as the White Salmon River and Columbia River waters mix. Average water velocities in the Columbia River upstream of Bonneville dam are significantly slower than those in the White Salmon River upstream of the Underwood In-Lieu Site. The lower velocities will allow most of the particles silt sized and larger to settle in the Columbia River before reaching the Bonneville dam. However, some of the clay-sized particles, the fraction of the sediment smaller than 0.004 millimeters (mm) in diameter, will stay in suspension and not settle in the Bonneville Pool. Approximately two-thirds of those particles passing the Bonneville dam will remain in suspension to the mouth of the Columbia River.

As determined in the Sediment Behavior Analysis Report, approximately 876,000 cubic yards (cy) of the trapped sediment in Northwestern Lake is made up of silt and clay particles smaller than 0.0625 mm in diameter. When eroded, these particles will be suspended in the water column.

Accumulated Sediment Volume

Bathymetry work conducted in 1996 indicated that approximately 2.4 million cubic yards of sediment were retained in the reservoir based on a comparison with topographic information available from 1912. The Sediment Behavior Analysis Report (G&G Associates, 2004) analyzed the effects of the sediment release based on an estimated sediment volume in Northwestern Lake of 2.4 million cubic yards. This volume was computed based on average cross sectional areas taken at 500-foot intervals along the length of the reservoir. Cross sections were used as the best means of determining the river location, volume of eroded sediment, and bank erosion after the dam breach. The method, however, is not the most accurate method of determining total sediment volume in the reservoir because of the relatively large distance between cross sections. New bathymetric information was collected in 2006 by Finley Engineering Company and the total sediment volume within Northwestern Lake was calculated to be 2.3 million cubic yards (Finley, 2006). A more accurate and precise approach to determine sediment volume, vertical integration between elevation contours, was used to develop that volume estimate.

In 2006, following 93 years of project operations, the average annual sediment accumulation within Northwestern Lake was 24,700 cubic yards. Using this sedimentation rate, Northwestern Lake should again contain 2.4 million cubic yards of sediment in the year 2011. Thus, the analysis contained within the Sediment Behavior Analysis Report is still relevant and can be viewed as conservative since the sediment volume used in the report's analysis is greater than that currently within the reservoir.

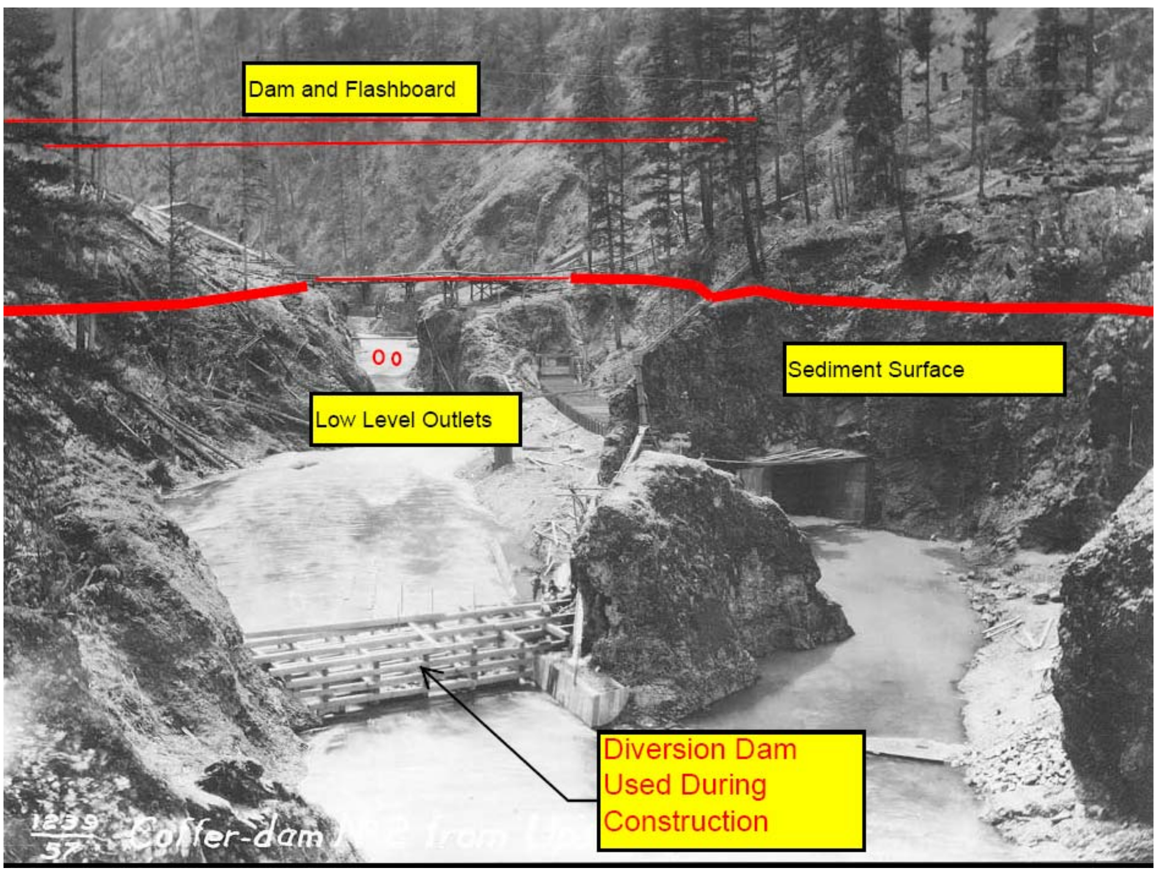

Figure 1: Looking downstream at dam location during construction

Sediment Sampling

Sediment sampling and analysis of Northwestern Lake sediments has shown low concentrations of mercury at various locations in sediment impounded behind Condit dam (Kleinfelder, March 2007). The results of subsequent sampling confirmed the presence of low levels of mercury in reservoir sediments and in background sediment samples collected in the nearby region and at the Underwood In Lieu site at the mouth of the White Salmon River (Kleinfelder, 2007b). The Washington Department of Ecology (WDOE) has requested that PacifiCorp determine the expected mercury concentration in river water downstream of Condit dam after the proposed dam breach.

The following analysis is based on the mercury sediment concentrations reported by Kleinfelder in March 2007 and November 2007. These sampling efforts determined that the lower reservoir dredged material management unit consists primarily of fine-grained sediment and that the average mercury concentration in those sediments is 0.617 milligrams per kilogram (mg/kg). Thus, for the purposes of this analysis it has been assumed that all suspended sediments have a mercury concentration of 0.617 mg/kg. Information about sediment grain size and the distribution of sediment within the reservoir (Northwestern Lake) was developed in earlier reports (Gathard, 1998 and G&G Associates, 2004).

Analysis Conducted

Uncertainty regarding the volume and timing of fine-grained sediment erosion exists due to unknown conditions in the sediments, such as the presence of woody debris, and the behavior of the sediments during the erosion process immediately following the breach of the dam. Three different scenarios were investigated as a means to bracket the possible erosion possibilities and evaluate their water quality impacts. Analyses of the water quality impacts resulting from the release of fine-grained sediments following the proposed dam breach were conducted for three water quality parameters in a spreadsheet model that uses a mass balance approach to determine the volume of sediment eroded into the river and the resulting water quality impacts of that release. The three water quality parameters investigated include total suspended solids (TSS) concentration, turbidity, and total mercury concentration. Previous analyses in the Sediment Behavior Analysis Report (G&G Associates, May 2004) evaluated the downstream effects of dam removal on TSS and turbidity but did not consider water quality impacts related to mercury in the sediments.

Previous analyses were conducted to evaluate TSS and turbidity effects by analyzing the fastest and slowest expected release of the sediments from the reservoir. It was assumed in these analyses that the fastest evacuation of the reservoir would release a greater volume of sediment and a slower evacuation of the reservoir would release a smaller volume of sediment. A faster evacuation results in higher initial TSS and turbidity levels but for a shorter duration than would occur with a slower evacuation.

The previous analyses in 2004 conservatively included clay, silt, sand, and gravel erosion in the TSS levels immediately downstream of Condit dam. In the scenarios developed in this report, discussed in more detail below, only particles smaller than 0.125 mm were considered in the TSS and mercury analyses. Larger particles suspended in the reservoir reach will settle in the wider reaches of the White Salmon River downstream of the dam or immediately downstream of the mouth of the White Salmon River in the Columbia River. All of the material sand size and larger will settle within 5 miles of the mouth of the White Salmon River in the Bonneville Pool, as shown in Figures 2 and 3 below.

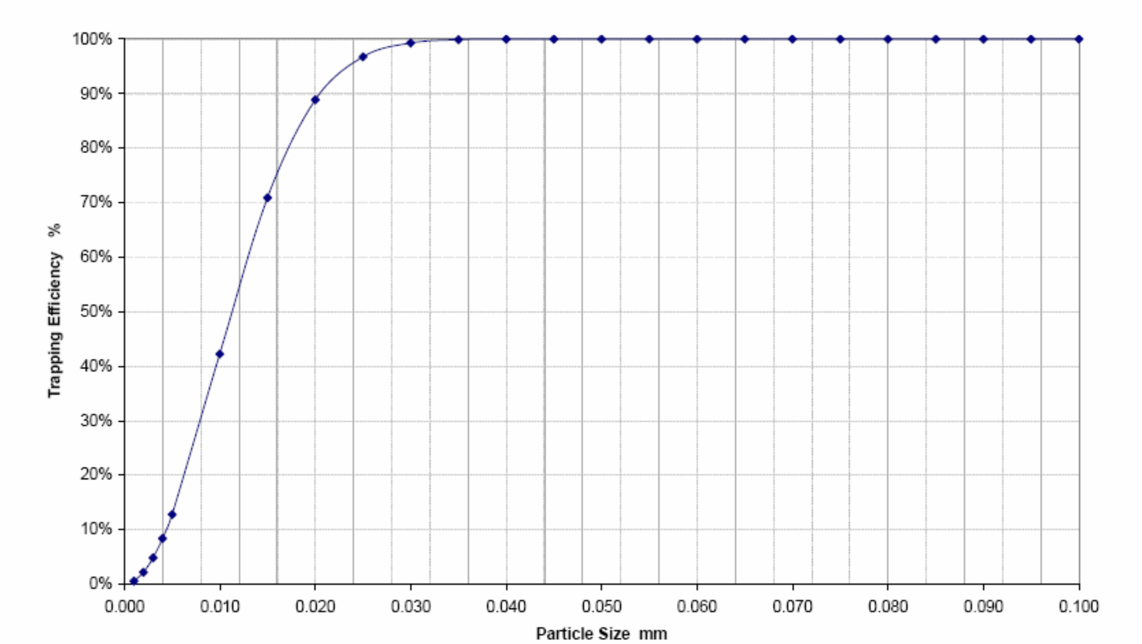

Figure 2: Trapping Efficiency in the Bonneville Pool

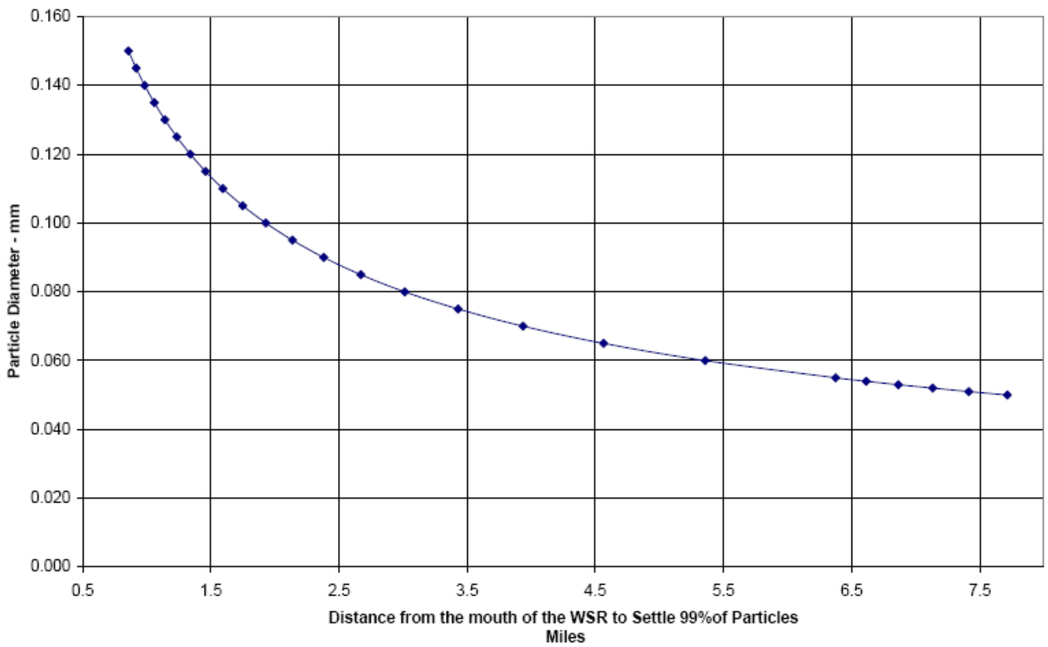

Figure 3: Settling Distance vs. Particle Size in the Bonneville Pool

Three scenarios have been analyzed using a spreadsheet model to evaluate water quality impacts based on differing assumptions regarding the erosion rate and the total volume of sediment eroded from the reservoir. The average mercury concentration found in samples of silt and clay in the lower dredged material management unit, 0.617 mg/kg, was used in the model as the concentration of mercury in all suspended silt and clay particles.

Analysis of sediment suspension rates was conducted in the Sediment Behavior Analysis Report (G&G Associates, May 2004). Sediment size fractions used to analyze the volume of sediment captured in the Bonneville Pool were based on size distribution results described in that report. HEC 6 sediment transport analysis was conducted in the Condit Dam Removal Study (Gathard, 1998) to determine the volume of silt- and clay-sized particles that could be trapped in the Underwood In-Lieu site pool.

The trapping efficiency and, therefore, the amount of silt and clay trapped at the Underwood In-Lieu site will depend on the elevation of the Columbia River at the mouth of the White Salmon River at the time of the breach. The average Columbia River surface elevation for the months of October through December was used to determine the volume of sediment trapped at the Underwood In-Lieu site. As reported in the Sediment Behavior Analysis Report and the Condit Dam Removal Study; 245,000 cubic yards of fine-grained sediment would most likely be trapped in the Underwood In-Lieu site at average water elevations for the period of October through December. That volume of trapped fine-grained sediment was used for analysis in this report.

Scenarios Investigated

Three scenarios were investigated in this analysis. The first scenario investigated, Scenario 1: 100 Percent Erosion, assumes that all of the 876,000 cubic yards of fine-grained sediment in the reservoir will be eroded over a period of approximately three months. For this scenario, the initial TSS levels are set at 50,000 parts per million (ppm) to simulate a relatively slow erosion process. Since a portion of the fine-grained sediment is mixed with coarser-grained sediment in the upper reservoir, eroding all the fine-grained sediment would require some coarser-grained sediment to erode before all the fine material could be exposed.

In the analysis, TSS concentrations decrease exponentially with time until all 876,000 cubic yards of fine-grained sediment is eroded from the reservoir. This scenario yields the most conservative (worst case) results in which high TSS levels persist for the longest time period while all fine-grained sediment is eroded. The results of this scenario are shown in Tables 3 and 4, along with the results of the other scenarios described below.

For comparison, a second scenario, Scenario 2: 75 Percent Erosion, was investigated using the same initial TSS concentration of 50,000 ppm declining exponentially but based on the assumption that only 75 percent of the fine-grained sediment in the reservoir is eroded into the river. Previous analysis of pre-dam river cross sections (Gathard, 1998) showed that much of the sediment is located above the river channel on high banks beyond the reach of high flow events and that this sediment may remain perched indefinitely above the river banks in a stable configuration following dam removal. Analysis from that previous work showed that no more than 75 percent of the fine-grained sediment would be likely to erode from the reservoir. Scenario 2 was developed to evaluate the water quality impacts resulting from the relatively slow release of a lower volume of fine-grained sediment. The conditions of Scenario 2 are more likely to occur than those contained in Scenario 1.

A third scenario, Scenario 3: High TSS Concentration, which assumes a higher initial TSS concentration immediately after the breach, was evaluated to provide an estimate of the water quality impacts under the set of conditions expected to be most likely following dam removal. When the dam is breached, most of the fine-grained sediment near the face of the dam will most likely erode with the free water in the reservoir as the water exiting the reservoir flows through the sediment at the bottom face of the dam. In this scenario, the initial TSS concentrations will be much higher than assumed in the first two scenarios. Based on the assumption that approximately 50% of the fine material would be eroded in the first day the initial TSS was calculated to be about 132,000 ppm. The "Initial TSS" tab in the spreadsheet provides the details used to calculate that TSS level.

A higher initial TSS concentration will remove more sediment at the start of the erosion process, leaving less material to be eroded in subsequent weeks. This will reduce the total amount of time required to erode the sediments. The TSS concentrations will decline more rapidly in this scenario because sediment in the path of the river will erode sooner when initial TSS concentrations are higher. This third scenario also assumed that only 75% of the total fine-grained sediment was eroded. This scenario is the most likely to occur of the three conditions analyzed because it is based on assumptions consistent with the physical conditions found in the reservoir. The first two scenarios illustrate possible but less likely results.

For all three scenarios, the TSS concentration decreases exponentially with time after the breach of the dam with the exception of a spike in TSS levels associated with the removal of the diversion cofferdam used for original dam construction. The cofferdam is shown in Figure 1. TSS concentrations are modeled using an exponential equation that relates TSS to time after initial dam breach. The volume of fine-grained sediment released with each average daily flow was calculated for each daily time step and a running total was computed so that the total volume of sediment released in suspension equals the volume of fine-grained sediment released from the reservoir.

A previous report (Gathard, 1998) analyzed the spatial distribution and volume of sediment in particle size ranges in the reservoir based on two prior sediment sampling reports. This report found that there was approximately 876,000 cubic yards of material in the reservoir that would be classified as silt or clay, which have particle sizes smaller than 0.0624 mm in diameter. Particles with diameters from 0.0624 to approximately 0.125 mm may also be transported out of the reservoir as suspended sediment in the White Salmon River since water velocities in the river will be fast enough to suspend these larger particles. In the Columbia River, water velocities are, on average, much slower. It was assumed that the water velocity in the Columbia River would not suspend particles larger than 0.0624 mm in diameter.

All three scenarios estimate turbidity and total mercury concentrations at four locations: 1) immediately downstream of Condit dam, 2) in the Columbia River just downstream of the confluence with the White Salmon River after the White Salmon and Columbia Rivers are fully mixed in the Bonneville Pool, 3) in the Columbia River just downstream of Bonneville dam, and 4) in the Columbia River near Quincy, Oregon.

Previous work (Gathard, 1998) analyzed the volume of sediment that will be trapped in the Underwood In-Lieu Site at several Bonneville Pool water elevations. It was found that at the average Bonneville Pool elevation approximately 245,000 cubic yards of material finer than 0.0624 mm would be trapped in the Underwood In-Lieu Site. The TSS concentrations entering the Columbia River from the White Salmon River were reduced to account for the 245,000 cubic yards of fine-grained sediment trapped in the In-Lieu Site.

Flow on the Columbia River was taken from several sources to provide the best information possible at the particular sites where the analysis was conducted. For Columbia River flow just downstream of the White Salmon River, results were provided by the USGS at The Dalles, several miles upstream of the White Salmon River. Average daily flows were available for 125 years of records. These records were used to compute an average of average daily flows for each day for all years of record. The average flow for all 125 daily flow values was used as the daily flow in the Columbia River at the mouth of the White Salmon River. Flow at The Dalles slightly understates the flow at the mouth of the White Salmon River because it does not include flow from the White Salmon River, the Klickitat River, and Hood River.

The Corps of Engineers (Corps) monitors flow at Bonneville Dam. The averages of 25 years of daily flow data from the Corps were used to develop the daily flows at Bonneville Dam used for analysis just downstream of Bonneville dam.

USGS data were available for turbidity, TSS, and flow for the Columbia River at Warrendale and at Quincy, Oregon. These records were used to develop average daily flows for the Columbia River at Quincy, Oregon. The data were also used to develop background turbidity in the Columbia River at these two locations. The data at Warrendale were the nearest data set available for turbidity and TSS in the Columbia River at the confluence with the White Salmon River. These data were used to develop background values for turbidity near the confluence of the White Salmon River with the Columbia River. Turbidity data taken in the Columbia River at Quincy were used there.

The relationship between suspended sediment and turbidity in the Columbia River was developed in the G&G Report in 2004. The relationship developed in that report was used to calculate turbidity based on TSS concentrations.

Analysis of the data showed no significant correlation between flow and either TSS or turbidity. Turbidity varies significantly from year to year and from day to day for the time period under investigation. Therefore, the average of all available data from October through December was used as a background measurement for meeting WDOE water quality guidelines.

Results of analysis shown at Quincy, Oregon were developed from results in the Columbia River just below the Bonneville dam by dilution as a direct ratio of the flow at the two locations. No additional settling of fine-grained particles was included in the analysis. Some additional settling of fine-grained particles, roughly estimated to be about one-third of the total, in the river between Bonneville dam and the mouth of the Columbia River is anticipated. However, the physical conditions of the river are not well known so, to be conservative, this settling process was not included in the analysis.

Table 1 provides a summary of values assumed for these analyses.

Table 1: Sediment Parameters Used for Analysis

Item	Value Used	Units
Average Dry Weight of In-Situ Eroded Fine-grained sediment	70.9	pounds per cubic foot
Volume of Silt and Clay Contained in Northwestern Lake	876,000	cubic yards
Volume of Fine-grained sediment Trapped at Underwood In-Lieu Site	245,500	cubic yards

Water and Sediment Quality Guidelines

To assess the impacts of sediment release on water quality, estimated water quality concentrations were compared to Washington State and EPA water quality criteria and guidelines, as shown below in Table 2.

Table 2: Water Quality Criteria and Guidelines for Turbidity and Mercury

Turbidity	WDOE[1]; 5 NTU over background when the background is 50 NTU or less; or a 10% increase when the background is more than 50 NTUs	
Mercury	WDOE[2] acute criterion; single measurement cannot exceed	2.1 micrograms per liter (µg/L)
	WDOE[2] chronic criterion; 4-day average cannot exceed	0.012 µg/L
	EPA[3] acute guideline; single measurement cannot exceed	1.4 µg/L
	EPA[3] chronic guideline; 4-day average cannot exceed	0.077 µg/L

Sources:
[1] Washington Administrative Code Chapter 173-201A-200, Aquatic Life Turbidity Criteria in Fresh Water, Table 200 (1)(e), 2006.
[2] Washington Administrative Code Chapter 173-201A-240 Toxic Substances Table 240(3), 2006.
[3] United States Environmental Protection Agency Office of Water and Office of Science and Technology, 2004.

Findings

Turbidity levels were calculated over time at several locations downstream of Condit dam as discussed above. Results of the analysis for turbidity are presented below in Table 3, which shows the estimated number of days of exceedance of the WDOE turbidity criterion. Results of the analysis for mercury are shown below in Table 4, which shows the estimated number of days that mercury water quality criteria and guidelines may be exceeded based on the assumption that mercury background concentrations in the White Salmon and Columbia rivers are zero. The presence of background mercury concentrations would result in a greater number of predicted exceedances of water quality criteria and guidelines.

Results indicate that both turbidity and mercury concentrations will likely exceed water quality criteria and guidelines in the White Salmon River and in the Columbia River. Generally, Scenario 3 results in the least number of days of exceedance of WDOE criteria with the exception of mercury and turbidity downstream of Bonneville dam. Scenario 2 has fewer days of exceedance downstream of Bonneville dam. Values for turbidity, TSS concentration, and mercury concentration at Quincy are determined by the dilution associated with the increased flow in the Columbia River from Bonneville to Quincy. These values are calculated as the ratio of river flows at the two locations multiplied by the values for each downstream of Bonneville Pool.

Table 3: Exceedances of WDOE Turbidity Criterion

		Potential Days of Exceedance		
Criterion	Location	Scenario 1: 100% Erosion	Scenario 2: 75% Erosion	Scenario 3: High TSS Conc
WDOE Turbidity Criterion (5 NTU or 10% increase when background > 50 NTU)	In White Salmon River	114	88	44
	In Bonneville Pool	29	18	10
	Downstream of Bonneville Pool	0	0	2
	At Quincy, OR	0	0	1

Table 4: Exceedances of Mercury Water Quality Criteria and Guidelines

		Potential Days of Exceedance		
Criteria and Guidelines	Location	Scenario 1: 100% Erosion	Scenario 2: 75% Erosion	Scenario 3: High TSS Conc
WDOE Acute Mercury Criterion (2.1 µg/L)	In White Salmon River	40	33	20
	In Bonneville Pool	0	0	0
	Downstream of Bonneville Pool	0	0	0
	Quincy, Oregon	0	0	0
WDOE Chronic Mercury 4-Day Average Criterion (0.012 µg/L)	In White Salmon River	117	93	49
	In Bonneville Pool	39	22	17
	Downstream of Bonneville Pool	10	7	8
	Quincy, Oregon	6	4	7
EPA Chronic Mercury 4-Day Average Guideline (0.077 µg/L)	In White Salmon River	93	72	39
	In Bonneville Pool	0	0	5
	Downstream of Bonneville Pool	0	0	0
	Quincy, Oregon	0	0	0
EPA Acute Mercury Guideline (1.4 µg/L)	In White Salmon River	46	35	22
	In Bonneville Pool	0	0	0
	Downstream of Bonneville Pool	0	0	0
	Quincy, Oregon	0	0	0

The spreadsheet models present estimates of the total suspended solids concentrations expected in the White Salmon River following dam removal and the speed with which suspended sediment concentrations in the project area will drop over time. The turbidity and mercury concentrations associated with the suspended sediment concentrations are based on an assumption of complete mixing of suspended sediment within the receiving water bodies, either the White Salmon or Columbia Rivers.

The three scenarios presented are intended to provide a reasonable bracket of the expected number of days of potential water quality guideline exceedances at each location under the assumptions used for this analysis. These models assume a steady decline in sediment concentrations with time after dam breach. Actual conditions, however, may be different from those modeled due to conditions encountered in the reservoir. The timing of spikes in sediment concentrations may be associated with mass failure and erosion of the river banks. These events may occur at times other than those indicated in the model because bank failure may be affected by the concentration and location of buried logs or other debris perched above the newly formed river. It may be necessary to mechanically remove some of the woody material in order to release some sediment located above the river banks. This activity may occur at a later time, weeks or even months later, than shown in the spreadsheet model and thus the timing of these exceedances may vary though the number of days of exceedances would be unaffected.

Timing of water quality exceedances will also be slightly affected by the time required for sediment to be transported from Condit dam to the point of measurement. Sediment suspended in the water column may require more than 3 days to travel from the dam to Quincy, Oregon. Some longitudinal spreading of the sediment may occur but is not considered in these analyses. Longitudinal spreading should not be a significant mechanism in the short distance and limited width of the relatively high gradient White Salmon River. Within the Columbia River, longitudinal spreading will likely have more of an impact on observed water quality concentrations due to the size of the waterbody and the greater differences in river flow velocities across the width of the river. Longitudinal spreading will have the effect of reducing the magnitude of observed mercury concentrations, which could reduce exceedances of criteria, but could also lead to greater days of exceedances since elevated mercury levels may take longer to flush through the river than predicted in the spreadsheet model.

Thus, the estimates derived from the spreadsheet model should be viewed as average results that would likely be obtained from a range of samples collected in the river profile at the locations investigated. Water quality concentrations obtained from point sampling efforts following project removal may be higher or lower at any particular time than those estimated with this mass balance model due to incomplete mixing, the presence of preferential flow patterns, river bed geometry and flow patterns that will affect the location of sediment deposition, and other hydrodynamic factors not accounted for in the mass balance model used for this analysis. Also, the specific number of events that exceed water quality guidelines may vary slightly from those provided for a particular scenario shown in this document but should remain within the range provided in the tables above.

Discussion

Potential turbidity and mercury concentrations were evaluated for a period intended to cover the time range of construction activities associated with dam and sediment removal. The model yields a steady decline in the intensity of TSS concentrations leaving the dam site associated with a decline in the volume of sediment remaining in the reservoir. However, removal of unstable sediment may be required depending on conditions encountered after the reservoir is completely lowered and most of the sediment is eroded. This activity may cause the timing of the TSS levels and associated exceedances to vary from the conditions analyzed.

In addition, removal of the diversion cofferdam from original construction of the dam may occur anytime following the initial breach of the dam. For the purposes of this analysis cofferdam removal was assumed to occur near the beginning of February in the year after the initial breach. When that activity occurs, TSS and associated turbidity and mercury levels may increase. Erosion of the sediment behind and within the diversion cofferdam should happen within several days after the removal is complete. In the analyses, this activity is shown to occur in one day. Actual removal may require more time in which case turbidity and mercury levels would be lower. In general, no additional exceedances of water quality criteria or guidelines are anticipated after the diversion cofferdam removal; though large mass wasting events related to subsequent natural high flow events that erode remaining sediments have the potential to create exceedances of water quality criteria after near-term erosion of the sediment is complete.

Finally, the analysis presented in this report is highly dependent on the assumptions used to model sediment removal from the reservoir following dam breach. Differences in the assumed initial TSS concentrations in the river, river flows, and the rate of sediment erosion from the actual conditions observed following dam breach may have a large impact on the potential days of water quality exceedances predicted in this report. In addition, the presence of appreciable background mercury in the White Salmon and Columbia Rivers would also have a significant effect on the number of days of potential exceedances.

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