

## HOWARD HANSON DAM SEDIMENT MANAGEMENT PROJECT

**Karl Eriksen, Hydraulic Engineer, Seattle District, U.S. Army Corps of Engineers, Seattle, WA, [karl.w.eriksen@usace.army.mil](mailto:karl.w.eriksen@usace.army.mil) and Kent Easthouse, Physical Scientist, Seattle District, U.S. Army Corps of Engineers, Seattle, WA, [kent.b.easthouse@usace.army.mil](mailto:kent.b.easthouse@usace.army.mil)**

**Abstract** The Corps of Engineers Seattle District (Corps) initiated the Howard Hanson Dam (HHD) Sediment Management Project (SMP) in 2006 with the goal of using erosion to reduce the amount of sediment stored in the reservoir. The sediment deposition and resulting higher pool elevations interfere with the operation and maintenance of the regulating outlet structure and a new downstream fish passage facility. The stored sediments may have impacted the downstream ecosystem by reducing the amount of fine grained material in the aquatic and riparian environments, and interrupting the movement of spawning gravels. The SMP is currently in a testing phase to develop erosion and sediment transport information to be used for planning, permitting, and implementation. The Corps is proposing to implement SMP operations in three phases; 1) annually pass the incoming sediment load, 2) erode a portion of the sediment stored behind HHD and lower the winter operating pool to elevation 1055 ft, and 3) erode the remainder of the sediment deposits and have near run-of-river conditions.

Sediment began accumulating shortly after HHD was completed in 1962. The sediment accumulation has caused the minimum winter operating pool elevation to rise from 1038 ft to 1073 ft. The sediment deposits behind HHD are unusual in that they are primarily located near the dam, not in deltas where the major tributaries enter the reservoir. About 80 percent of the approximately 2 million cubic yards of sediment deposits are below elevation 1070 ft and within one mile of the outlet. The deposits are composed primarily of silt and sand, with some clay and limited gravel. The deposits range from a few feet deep on the overbank terraces, up to around 40 ft deep in parts of the old river channels.

The SMP testing phase is focused on test drawdowns of the HHD reservoir to generate controlled erosion of the reservoir deposits. The purpose of the drawdowns is to collect suspended sediment data to use in the calibration and verification of sediment transport models to be used to determine downstream impacts. Test drawdowns have been planned for each winter since 2006, but hydrologic conditions have only allowed for one actual test in WY 2008. During the WY 2008 drawdown, turbidity and suspended sediment sampling was conducted at three sites located one, four and 30 miles downstream of the dam. Near the dam, suspended sediment concentrations reached 3149 mg/L and turbidity peaked at 583 NTU. The downstream suspended sediment concentrations were in the 300 – 400 mg/L range. Bed material samples have been collected before and after each drawdown season to measure changes in bed material composition.

### INTRODUCTION

Howard Hansen Dam (HHD) is a Corps of Engineers multi-purpose project located on the Green River about 45 miles southeast of Seattle, Washington. The dam was completed in 1962 and provides flood control, water supply, and environmental enhancement. Sediment began accumulating in the reservoir shortly after the dam was completed and has caused the minimum winter operating pool to rise from 1038 ft to 1073 ft. The higher pool elevations have had little

effect on flood regulation, but do hamper operation and maintenance of the regulating outlet structure. If sediment continues to accumulate, it could interfere with the operation of a new fish passage facility, being built to help restore salmon runs to the upper Green River. The Seattle District has implemented the HHD sediment management project (SMP) to investigate methods and the potential impacts of discharging reservoir sediment into the Green River (USACE, 2005).

### **SEDIMENT MANAGEMENT GOALS**

The HHD SMP is a long term program to test and, if feasible, implement sediment flushing from the reservoir into the Green River. The initial phase involves test drawdowns of the reservoir during storm events to erode sediment deposits and measure the downstream impacts. The sedimentation and biological information gained in this phase will be used to plan actions to flush large volumes of sediment from the reservoir. Future HHD SMP activities that would discharge stored sediment would be implemented in a phased approach, where each phase would depend on the results of the preceding phase.

The goal of the first phase of sediment flushing would be to annually discharge sediment volumes roughly equivalent to the incoming sediment loads. This "pass through" of sediment would require carefully regulating reservoir discharges and pool elevations to maintain flowing water conditions within the reservoir for as long as possible during each storm. The flowing water would transport most of the inflowing fine sediment, and some of the sand, through the reservoir. It may be necessary to erode some deposits at the beginning or end of storms to make up for the deposition that will occur when the pool elevation rises around the peak of storm. The drawdown test results would be used to develop guidance for discharge/pool elevation operations to be followed in this phase.

The goal of the second phase would be the controlled erosion of a portion of the sediment deposits. This would require lowering the pool to a point where currents within the reservoir are great enough to erode deposited sediments. The discharges and pool elevations best suited for the controlled erosion would be defined during the pass through phase of the SMP. This phase would remove enough sediment to lower the winter pool to around 1055 ft, to make operation and maintenance of the dam and outlet works easier and safer.

The goal of the final phase would be to remove the remainder of the sediment stored behind HHD, lowering the winter pool to elevation 1038 ft, and allowing near run-of-river operation of HHD. The time frame for implementing this goal will depend on the results of second phase.

In addition to improving reservoir operations, increased sediment discharges could benefit the Green River. The lack of suspended sediment might be a factor in reduced downstream habitat complexity. The fine grained sediment discharges from the reservoir could provide material for the aquatic and riparian environments along the river. However, there are concerns that fine sediments may deposit in potential salmon spawning gravels and degrade that habitat. Biological monitoring will be conducted downstream of HHD during drawdowns to investigate potential benefits and/or impacts.

## BACKGROUND

During the winter, HHD is operated to provide flood control and municipal water supply. A low pool elevation is maintained to provide storage for storm runoff. However, the minimum pool elevation is restricted by the need to minimize turbidity in the water released for municipal supply. To avoid erosion of sediment deposits, and the resulting turbidity, the low pool elevation is set slightly higher than the surface of the sediment deposits near the outlet. The minimum winter pool elevation was originally 1038 ft, but it has gradually risen to around 1075 ft because of the accumulated sediment deposits.

The low winter pool at HHD has created an unusual sediment deposition pattern. Sand and fine sediments are deposited throughout the reservoir when the pool rises for flood storage. Then as the pool is evacuated after a storm, those sediments are washed down into the low pool and re-deposited closer to the outlet. About 80 percent of the approximately 1,650 ac-ft (2.7 million cubic yards (mcy)) of sediment deposits are stored below elevation 1070 ft and within one mile of the outlet. The remainder of the deposits, mostly slower moving gravels, are in small deltas and the channels downstream of where the major tributaries enter the reservoir. The sediment deposits have not significantly reduced HHD flood regulation capabilities; the 1,650 ac-ft of sediment deposits are less than 2 percent of the approximately 105,000 ac-ft of flood storage in the reservoir.

Figure 1 shows 1961, 1979, and 2003 reservoir bottom profiles along the original river alignment. The sediment surface rose rapidly between 1961 and 1979 as the deposits filled the narrow river channel. The rate of rise slowed after 1979 as sediment began depositing on overbank terraces. The sediment surface has a very steep slope near the outlet, rising from 1040 ft to 1056 ft in 150 ft and reaching elevation 1060 ft about 1,000 ft upstream of the outlet. The channel then flattens out and remains near elevation 1060 ft for the next 2500 ft, upstream to the confluence of the channels from the North Fork and Main Stem Green River. Upstream of the confluence, the channel gradient increases and the deposits intersect the original channel about 8,000 ft upstream of the outlet.

The deposits range from a few feet deep on the overbank terraces, up to nearly 40 ft deep in parts of the original river channel. The 1979 and 2003 cross-section plots in Figure 2 show the reservoir deposition pattern 2,000 ft upstream of the outlet. Sediment cores collected in 2006 found the deposits located within 8,000 ft of the outlet are composed primarily of sand and silt, with small amounts of clay and gravel (USACE, 2006).

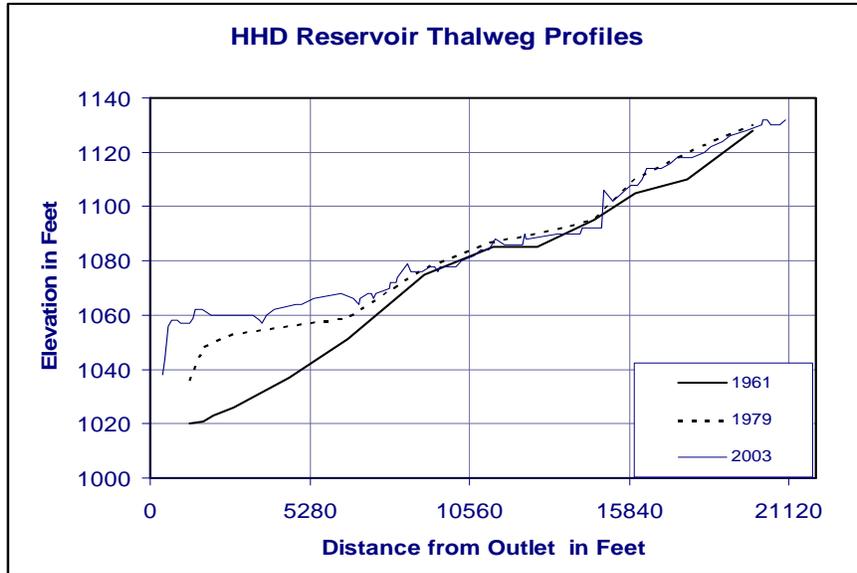


Figure 1 HHD reservoir bottom profiles measured along the original channel alignment upstream from the outlet structure located at 0 ft on the profile.

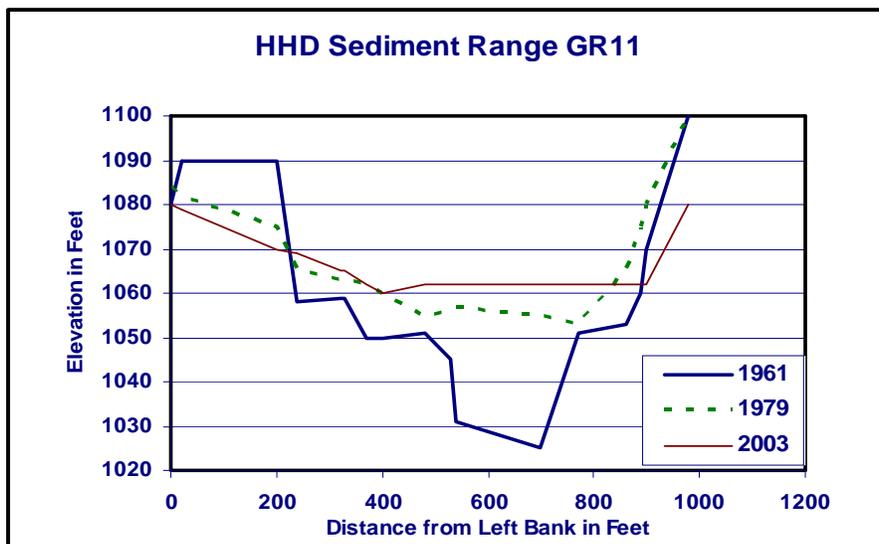


Figure 2 HHD reservoir sediment range located 2,000 feet upstream of the outlet.

### TEST DRAWDOWNS

To investigate sedimentation processes in the HHD reservoir and downstream in the Green River, Seattle District plans to conduct a series of test drawdowns. Each drawdown will involve carefully lowering the pool to the 1070-1065 ft range to generate controlled erosion of the reservoir sediment deposits. The focus of the investigation within the reservoir is the relationship between pool elevation and outflow discharge, as it relates to sediment erosion and transport. Downstream of HHD, monitoring is performed to investigated are turbidity,

suspended sediment transport and sediment deposition in downstream spawning gravels. The suspended sediment data collected will be used in the calibration and verification of sediment transport models of the reservoir and Green River. The erosion and sedimentation results from the testing phase will be used in planning, permitting, and implementation of the SMP.

Test drawdowns have been planned for each winter since 2006, but hydrologic conditions have only allowed for one actual test in WY 2008. Drawdowns can only be conducted at the beginning or end of a storm hydrographs that occur between 1 November and 1 February. To conduct a drawdown at the beginning of a storm hydrograph, the discharge must be above 500 cfs and forecast to reach at least 2,500 cfs within 24 hours. On the falling limb of the hydrograph, a drawdown can be conducted as long as the discharge remains above 1,500 cfs. These restrictions are intended to protect downstream water quality and fisheries resources, and are specified in the Washington Department of Ecology (WDOE) water quality permit (WDOE, 2009). WDOE (2009) has also set limits on downstream turbidity. The drawdown must be temporarily reversed if turbidity exceeds 500 NTU for 2 hours; the drawdown must cease if turbidity exceeds 500 NTU for 4 hours or reaches 600 NTU.

The ideal drawdown experiment would occur when HHD discharges are relatively steady and preferably below 3,000 cfs and above 1,500 cfs. The falling limb of the hydrograph generally presents the best opportunity for conducting a drawdown. The hydrograph recession can last for several days, providing adequate time and more stable discharges for a drawdown experiment.

### TEST DRAWDOWN TURBIDITY AND SEDIMENT SAMPLING

**Reservoir Drawdown Operations** For the 2008 water year, the USACE conducted one reservoir drawdown from December 4 to 6, 2007. Figure 3 shows the inflow, outflow, and forebay elevations measured during the drawdown. The drawdown began at 0900 hours on December 4, 2007 when forebay elevations were lowered below elevation 1070 feet and lasted until 0400 hours on December 6 when elevations rose above 1070 feet for a drawdown duration of about 43 hours. The maximum drawdown elevation reached was 1066.37 feet at 1100 hours on December 5, 2007. Inflows to and outflows from the reservoir during the drawdown ranged from about 2500 cfs to 4000 cfs.

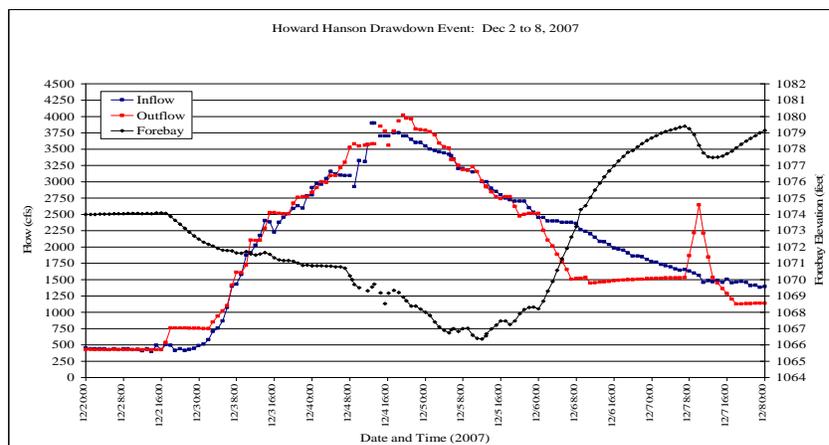


Figure 3 Inflow, outflow, and forebay pool elevation measured during the drawdown.

**Sampling Design and Data Collection Locations** Monitoring was conducted at four (4) stations located upstream and downstream of Howard Hanson Dam (see Figure 4) to determine the fate and transport of suspended sediments downstream of the project. The upstream station (HAQW) was located about 5.5 miles upstream from the dam, the first downstream station (HAHW) was located about 0.7 miles downstream of the dam, the second downstream station (GRAH) was located about 4 miles downstream of the dam, and the final downstream station (AUBW) was located about 32.5 miles downstream of the dam at an existing bridge crossing of the Green River. Water quality parameters analyzed during the drawdown included turbidity, total suspended solids, settleable solids, and particle size fractions.

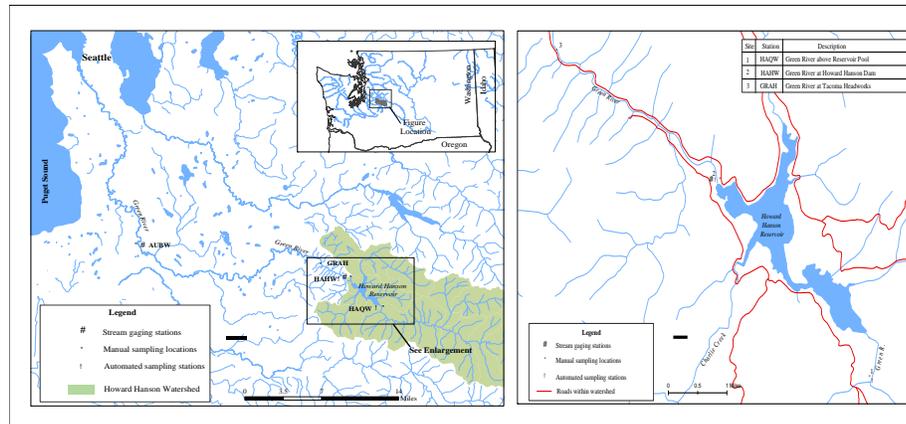


Figure 4 Location of Howard Hanson Dam reservoir drawdown water monitoring program in King County, Washington.

**Suspended Sediments and Turbidity Monitoring** Suspended sediments and turbidity monitoring consisted of collecting (1) manual and automated turbidity samples at stations HAQW, HAHW and GRAH, (2) cross sectional depth integrated manual suspended sediment samples at station AUBW, (3) automated point sample suspended sediment samples at station HAHW and (4) automated *in situ* suspended sediment concentrations and particle sizes at station HAHW. Cross sectional depth integrated sampling was planned at HAHW, but could not be conducted because of storm damage to the USGS cableway at this location.

Manual grab samples were collected from as near to the center of the stream channel as possible and measurements performed using a Hach 2100P turbidimeter. Automated turbidity measurements were collected every hour using a Hydrolab MiniSonde 5 water quality probe, a Geomation 2380 data collection platform (DCP), a radio transmitter, and a power source. Probes were placed on an anchored pulley-ramp-track system that extended into the river to about the center of the channel approximately 1 foot off of the bottom of the river.

Cross sectional depth integrated suspended sediment sampling was performed at the AUBW station by two field technicians using the isokinetic, equal-discharge-increment (EDI) method (Edwards and Glysson 1999). Suspended sediment samples were collected with a Depth-Integrating Hand Line Type Model US DH-76 sampler from a bridge at station AUBW. Samples were transferred from the US DH-76 bottles into 1-gallon containers by gently swirling the sample while compositing to ensure that all particulates in the sampler bottle were transferred to

the laboratory bottle. Samples were shipped to the USGS Volcano Laboratory in Vancouver, WA for particle size analysis and suspended sediment concentrations.

Automated point sample suspended sediment monitoring was conducted at station HAHW using an ISCO-6712 automatic pump sampler equipped with 24 one-liter bottles. The ISCO-6712 pump sampler collected point samples at HAHW from a location near the center of the river about 1 foot off of the bottom. The pump sampler was programmed to collect hourly samples during the day and then every 3 hours during the night. Samples were transferred from the ISCO-6712 bottles into 1-gallon containers by gently swirling the sample while compositing to ensure that all particulates in the sampler bottle were transferred to the laboratory bottle. Samples were shipped to the USGS Volcano Laboratory in Vancouver, WA for particle size analysis and suspended sediment concentrations.

A Sequoia Scientific LISST-100X laser diffraction instrument (Laser In-Situ Scattering and Transmissometry) was deployed at Station HAHW at the same location as the ISCO-6712 pump sampler and was anchored near the center of the river channel about 1 foot off of the bottom of the river. The LISST-100X is designed to measure particle size distribution and volume concentration over 32 log spaced size classes from 2.5 to 500 microns. The LISST-100X used for this study had a 5 mm sampling path length to allow for a greater range in suspended sediment concentrations (about 3,000 mg/L upper limit using a 5 mm path length), and was programmed to average 120 measurements collected over 60 consecutive seconds at 10 minute intervals. All data recorded when the optical transmission of the laser was less than 20% but greater than 10% were deemed suspect, while data measured when the optical transmission was less than 10% were rejected (Pottsmith 2007).

## **RESULTS AND DISCUSSION**

**Turbidity Monitoring** During the December 4 – 6, 2007 drawdown, inflows to and outflows from Howard Hanson Dam increased as pool levels were drawdown (see Figure 3) resulting in an increase in downstream turbidity concentrations at station HAHW (Figure 5). Inflow turbidity (Station HAQW) changed little during the drawdown event and stayed below about 35 NTU during the entire event. Outflow turbidity values (Station HAHW) gradually increased from about 15 NTU to 150 NTU, as the pool was drawn down from about 1074 ft to 1071 ft, rapidly increased from about 150 to 400 NTU when the pool was drawn down from 1071 ft to 1069 ft, and decreased to less than 300 NTU when the pool was brought back up to near 1070 ft. Turbidities gradually increased as the pool was slowly drawn back down from about 1069.5 ft to about 1067 ft. When the pool was lowered below 1067 ft turbidity levels rapidly increased from about 300 NTU to over 500 NTU and quickly decreased below 500 NTU when the pool was raised above 1067 ft. Turbidity data suggests that movements of sediments during the drawdown were most pronounced at pool elevations less than 1067 ft.

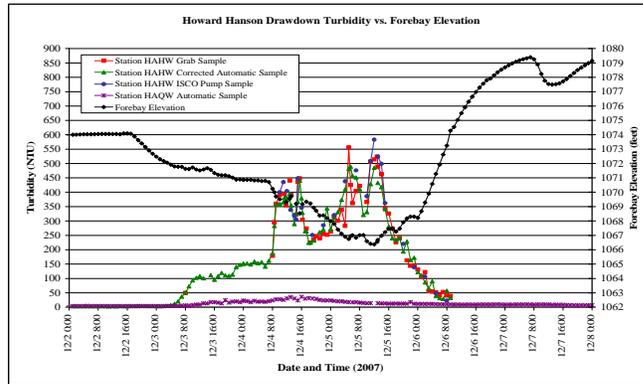


Figure 5 Howard Hanson Dam forebay elevation and flows compared to turbidity values measured during the drawdown.

**Suspended Sediment Monitoring** The LISST measurements of the silt/clay fraction compared well with the point samples collected by the ISCO sampler while the sand fraction comparisons were more variable (Figure 6). Gaps in the LISST data are due to the optical transmission dropping below the 10% to 20% range, likely the result of debris (e.g. a leaf or stick) on the optical lens as well as suspended sediment concentrations greater than the capability of the LISST to measure with a 5 mm path length. Both the LISST and ISCO point sampler measured an increase in silt/clay concentrations when the forebay pool initially dropped below 1070 feet, a decrease when the pool was slowly lowered from about 1069 ft to 1067 ft, and an increase when the pool was lowered below 1067 ft (Figure 6). Moreover, on December 5<sup>th</sup> between 0500 and 1400 the LISST accurately tracked the increases and decreases in the silt/clay fraction as the pool fluctuated above and below 1067 ft. The LISST silt/clay data correlates well with the ISCO point sample data during this time period.

The increase in sand when the pool dropped below 1070 ft. was measured by both the ISCO and the LISST. However, when the pool initially dropped below 1067 the increased sand measured by the ISCO was not tracked by the LISST. When the pool was dropped below 1067 a second time and reached the lowest elevation of 1066.37 ft, the LISST measured the rapid increase in sand fractions similar to the ISCO sampler before the LISST became inoperable due to low optical transmission values.

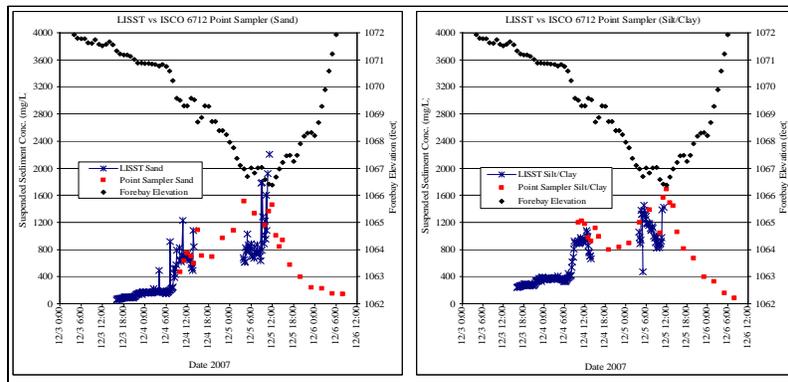


Figure 6 Comparison of LISST and ISCO 6712 point sampler sand and silt/clay concentrations measured during the drawdown.

**Sand and Silt/Clay Fractions** Analysis of silt/clay particle sizes measured by both the ISCO sampler and LISST showed the larger silt/clay particle sizes (i.e. 8  $\mu\text{m}$ , 16  $\mu\text{m}$  and 31  $\mu\text{m}$ ) to have the highest concentrations. The initial drawdown of the forebay pool below 1070 feet resulted in a rapid rise in all silt/clay fractions. Interestingly, all silt/clay fractions stabilized and began to decrease as the pool elevation was slowly drawn down from about 1069 feet to about 1067 feet. All Silt/clay particle size concentrations rapidly increased when the pool elevation fell below 1067 ft.

For suspended sediment in the sand size fraction, both the ISCO sampler and LISST data showed the finer sand particles (i.e. 63  $\mu\text{m}$  and 125  $\mu\text{m}$ ) to have the highest concentrations. The initial drawdown of the forebay pool below 1070 feet resulted in a rapid rise in the 63  $\mu\text{m}$  and 125  $\mu\text{m}$  size fractions with little to no increase in the larger particle sizes. Concentrations of the finest sand fraction (63  $\mu\text{m}$ ) stabilized as the pool elevation was slowly drawn down from about 1069 feet to about 1067 feet, while the larger sand fractions (125  $\mu\text{m}$ , 250  $\mu\text{m}$ , and 500  $\mu\text{m}$ ) increased in concentration. When the pool was drawn down below 1067 feet all sand fraction concentrations increased.

**Total Suspended Sediment vs. Turbidity** Paired total suspended sediment concentrations and turbidity values measured from ISCO point samples collected at Station HAHW were assessed to estimate the relationship between turbidity and total suspended sediments during drawdown operations at Howard Hanson Dam (Figure 7). The relationship between total suspended sediment concentrations and turbidity values measured during the drawdown was good ( $r^2=0.9165$ ), with an excellent relationship between the clay/silt fractions and turbidity ( $r^2=0.985$ ) and a modest relationship between the sand fractions and turbidity ( $r^2=0.6771$ ). Because the majority of the Green River sediment loads are transported during a few large storms each year determining a relationship between suspended sediment and turbidity at Station HAHW is of value. Turbidity measurements are easier to obtain than suspended sediment data and the historical record for turbidity is substantially greater than for suspended sediment. Further paired data collected during other drawdowns needs to be evaluated before a relationship between turbidity and suspended sediments can be obtained.

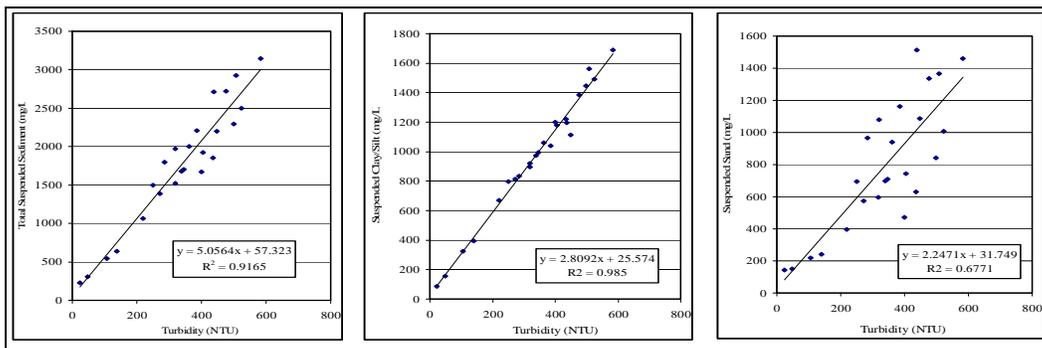


Figure 7 Relationship between suspended sediment concentrations and turbidity values measured during the drawdown.

**Particle Size Analysis** Grain size fractions for sediment collected by the ISCO point sampler during the drawdown are presented in Figure 8. In general, samples collected when forebay pool

elevations were near or above 1069 feet had the highest percentage of particles in the silt/clay size range. Samples with the highest percentage of particles in the sand size range tended to be collected when pool elevations were between 1068 and 1066 feet. Additionally, greater sand percentages were observed at a specific elevation when the reservoir was being drawn down and inflows were increasing compared to when the reservoir was being refilled and inflows were decreasing. Silt/clay in the 8  $\mu\text{m}$  to 31  $\mu\text{m}$  size range and sand in the 63  $\mu\text{m}$  to 250  $\mu\text{m}$  particle size range dominated all sample grain size fractions during the drawdown. Forebay pool elevation and inflow discharge were important for transporting different particle sizes down river. At the beginning of the drawdown, flows were increasing as the forebay pool was lowered which resulted in transporting the greatest amount of sand down river.

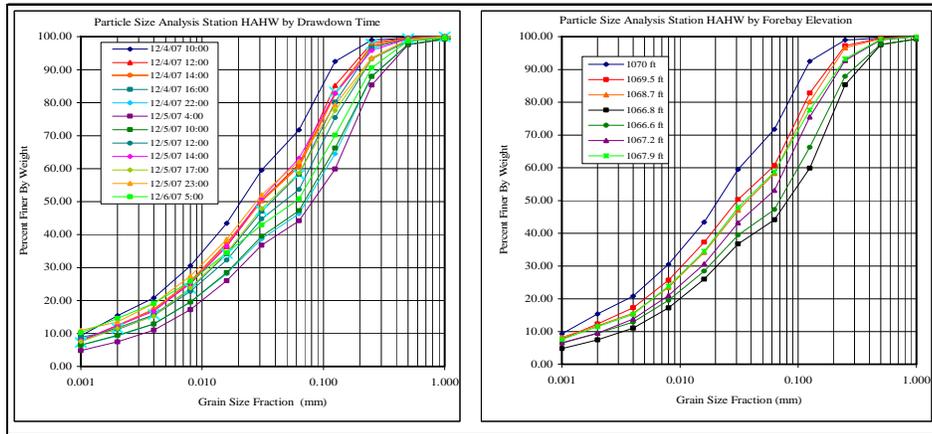


Figure 8 Grain size distributions of suspended sediment collected during the drawdown.

**Downstream Sediment Analysis** Suspended sediment monitoring conducted about 32 miles downstream of Howard Hanson Dam near the city of Auburn (Station AUBW) provided valuable information on the fate and transport of suspended sediments downstream in the Green River during the drawdown event. Suspended sediment concentrations measured at AUBW were considerably lower than at HAHW (Figure 9). Additionally, suspended sediments at AUBW were dominated by the silt/clay fraction (70 to 90 percent), with little sand measured. These data were in contrast to station HAHW where the silt/clay fraction and sand fraction accounted for about 40 to 60 percent each depending on the elevation of the forebay and inflow volume.

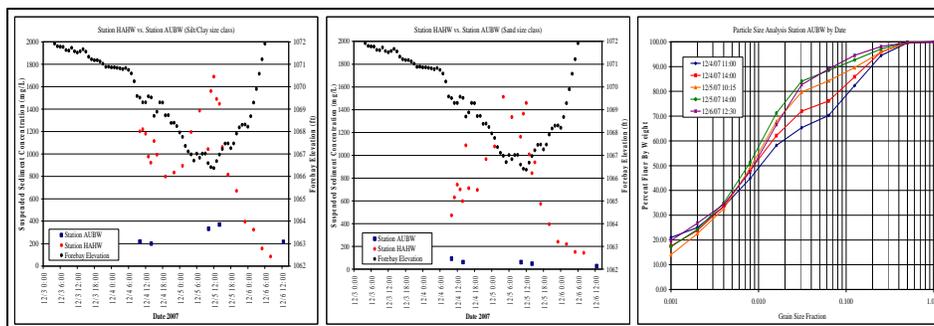


Figure 9 Downstream suspended sediment concentrations and particle sizes during the drawdown.

## CONCLUSIONS

Results from the 2007 drawdown experiment at Howard Hanson Dam indicate that substantial increases in sediment concentrations in the Green River are associated with drawing down the reservoir below the 1070 foot elevation. In-situ and automatic pump samplers deployed about 0.7 miles downstream of the dam at Station HAHW measured abrupt increases in suspended sediment when the pool was dropped below 1070 feet. These suspended sediment increases were largely dominated by the silt/clay fraction with lesser amounts of fine sand fractions. When the pool was lowered below the 1067 foot elevation a second increase in suspended sediments was measured, dominated by sand fractions in the 63  $\mu\text{m}$  to 125  $\mu\text{m}$  size range. When the pool was increased back above the 1067 foot elevation and the 1070 foot elevation, suspended sediment concentrations in the Green River quickly decreased to near background levels.

Monitoring data suggest that the lower the forebay pool, the greater the concentration of coarser sand to move down the river. The limited LISST data showed that during the drawdown, two critical forebay elevations existed. The first elevation was at 1070 feet. When the forebay was drawn below this elevation, silt/clay (2.72  $\mu\text{m}$  to 53.5  $\mu\text{m}$ ) and finer grained sands (63.1  $\mu\text{m}$  to 237  $\mu\text{m}$ ) began to be transported down the river. When the forebay was drawn below 1067 feet, coarser grained sands (280  $\mu\text{m}$  to 460  $\mu\text{m}$ ) began to be transported down the river. Suspended sediment data collected 32 miles downstream were dominated by silt/clay particle size fractions during the entire drawdown test.

A regression of turbidity values measured immediately downstream of the dam to suspended sediment concentrations indicated that a good relationship between the two parameters existed during the drawdown experiment. In particular, the silt/clay fraction was highly related to the turbidity values while the sand fraction was only moderately related to the turbidity values.

## REFERENCES

- Edwards, T.K. and G.D. Glysson. 1999. Field methods for measurements of fluvial sediments. United States Geological Survey Techniques of Water Resources Investigations, Book 3, Chapter C2.
- Pottsmith, C. 2007. Personal communication (Phone conversation with Kent Easthouse, US Army Corps of Engineers, Seattle District). Sequoia Scientific, Redmond, WA.
- USACE. 2001. Howard A. Hanson Dam water control manual. U.S. Army Corps of Engineers, Seattle District, April 2001.
- USACE. 2005. Howard Hanson Dam Reservoir Operations and Sediment Management Plan Water Year 2006: Downstream Surface and Subsurface Sediment Sampling Plan. Seattle District.
- USACE, 2006, Howard Hanson Dam Reservoir Sediment Sampling, 15-16 May 2006, Seattle District
- USACE. 2007. Howard Hanson Dam Reservoir Operations and Sediment Management Plan Water Year 2008: Water Quality Sampling and Analysis Plan. Seattle District.
- WDOE, 2009, Temporary Short-term Water Quality Modification, Order No. 7048, Northwest Regional Office, Bellevue, Washington, 28 July 2009.