Responses to FERC Additional Information Request S-1

Sediment Transport

Final Report
Part 1

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LIST OF APPENDICES

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SCHEDULE A: ADDITIONAL INFORMATION REQUEST S-1 SEDIMENT TRANSPORT

Time Required: 9 months

In section E.3 of your license application and in Technical Appendices E.1-1 and E.1-2, you provide information on the effects of the project on sediment transport and erosional processes in the Hells Canyon reach of the Snake River. However, several aspects of your analysis have not been verified based on field-conducted measurements, including the volumes of sediment that have been retained in the lower two reservoirs and your estimates of flows that mobilize sand and gravels. Furthermore, your studies do not evaluate the effects of sandbar toe erosion, and your sandbar slope stability analysis did not consider a range of flows that is representative of proposed operations. Therefore, please provide the following information, which we will use to evaluate the effects of the Project on sediment transport and to evaluate what types of measures might be implemented to protect and enhance sensitive beach and terrace areas.

(a) Using existing data, perform an analysis to confirm the volume of sediments trapped behind Oxbow and Hells Canyon. Use available pre-impoundment and post-impoundment bathymetric data to determine the volume of sediment trapped behind each dam. Compute the ratio of sediment volumes calculated based on this volumetric approach to the volumes previously calculated using tributary transport equations. Determine the average of this ratio for all three dams, including Brownlee, Oxbow, and Hells Canyon dams. This average ratio should then be used to validate and/or adjust the sediment transport calculation results for the Snake River below Hells Canyon dam. If sediment grain size data are available, please report the distribution of sand, gravel, and larger particles for the sediments trapped behind Oxbow and Hells Canyon dams.

(b) Your sandbar stability analyses have not taken into account toe erosion as a possible mechanism for sandbar deformation. Please perform an area inundation analysis for Pine Bar (RM 227.5), Salt Creek Bar (RM 222.4), Fish Trap Bar (RM 216.4), and China Bar (RM 192.3) for flows between 5,000 cfs and 30,000 cfs in increments of 5,000 cfs (e.g., 5,000 cfs, 10,000 cfs, 15,000 cfs … 30,000 cfs). Provide maps of each site showing the areas that would be inundated at each of the flow increments modeled. These plots will illustrate the minimum flows at which inundation and possible toe erosion may occur for each of these heavily used recreational sites.

(c) The minimum flows capable of mobilizing sand (1mm) downstream from Hells Canyon dam have not been clearly established from previous modeling studies and analyses. Using the existing MIKE 11 and MIKE 21 models, perform additional modeling for each site identified in Part 2, above, using a range of flows between 5,000 cfs and 30,000 cfs in increments of 5,000 cfs. Determine the minimum flow (in increments of 5,000 cfs) at which sand is mobilized at each of the sites. For flows equal to or exceeding the identified threshold for mobilization, provide plots delineating the areas in which sand is mobilized.

(d) Where sand is determined to be mobile in Part 3 above, determine whether an armor layer lies beneath the finer sediments and whether these sites are aggrading or incising. If an armor layer exists and these mobile sites represent locations where active bedload was deposited on top of the armor layer, calculate the volume of these active bedload deposits. These calculations will provide critical information for refining the sediment budget and understanding the relative importance of tributary sediment inputs and active bedload transport on spawning gravels and sandbars.

(e) Modeling estimates of sand and gravel mobilization have not been verified. Additionally, it has not been clearly established whether or not an active bedload component is present above the channel armor layer. In order to provide validation for modeling and transport calculations and to address the possibility of an active bedload component, please conduct field measurements of sand and gravel mobilization in representative regions where mobility was indicated in Part 3 above. Use Helly-Smith bedload sampling or other techniques to monitor sand and gravel bedload at the flow thresholds for sand and gravel mobility as predicted in Part 3 above.

(f) The sandbar slope stability analysis performed for the final license application did not consider a range of flows representative of proposed operations. Please repeat the sandbar slope stability analysis using a reduction in flow from 20,000 cfs to 10,000 cfs over a 2-hour period. This additional analysis will help to resolve concerns about sandbar stability.

(g) Supporting materials for the spatial and temporal analysis of sandbar distribution have not been included in the license application. Please provide the aerial photographs and sandbar mapping utilized for the sandbar analyses. This information will allow for a more complete review of the analysis and interpretations regarding geomorphic alteration within the river downstream of Hells Canyon dam

1. INTRODUCTION

Much of the data included in this response is closely related to and an extension of the information contained in the FLA and its associated technical reports. Therefore, we have included references to these documents where appropriate to show the linkage and remind the reader of the location of additional information. In general, the additional information is an extension of what is included in the FLA, and the findings are generally consistent with those discussed in the FLA.

2. RESPONSES

2.1. Response to (a)—Reservoir Sediment Volume

(a) Using existing data, perform an analysis to confirm the volume of sediments trapped behind Oxbow and Hells Canyon. Use available pre-impoundment and post-impoundment bathymetric data to determine the volume of sediment trapped behind each dam. Compute the ratio of sediment volumes calculated based on this volumetric approach to the volumes previously calculated using tributary transport equations. Determine the average of this ratio for all three dams, including Brownlee, Oxbow, and Hells Canyon dams. This average ratio should then be used to validate and/or adjust the sediment transport calculation results for the Snake River below Hells Canyon dam. If sediment grain size data are available, please report the distribution of sand, gravel, and larger particles for the sediments trapped behind Oxbow and Hells Canyon dams.

In using trapped volumes of sediment in the reservoirs to validate or modify the quantities of sediments supplied by the tributaries to the Snake River in Hells Canyon, the differences in the character of the tributaries should be kept in mind. Brownlee Reservoir traps sediment from a large area with a tremendous variation in slope, elevation, topography, geology, lithology, vegetation, and land use compared to the tributaries to the Snake River below Hells Canyon Dam (HCD). The characteristics of tributaries discharging into Hells Canyon Reservoir are much more similar to the tributaries to the

Snake River below HCD. Tributaries to Oxbow Reservoir appear to be more similar to tributaries to Brownlee Reservoir than tributaries to the Snake River below HCD.

The most straightforward way to estimate the volume of sediments trapped in the Oxbow and Hells Canyon reservoirs would be to simply take the difference between the pre-impoundment volume and the current volume, and the result would be the volume of sediments trapped over the intervening years. However, there are significant limitations on the existing data set for estimating the volume of sediments trapped in the HCC using this method. While pre-impoundment data are adequate for estimates of reservoir volume needed for operations (particularly since the primary area of interest for operations is the higher elevations that cover reservoir fluctuations), the data are not adequate for detailed comparison with current bathymetry for purposes of estimating sediment deposition. This is in part due to the relatively small amount of sediment deposited in Oxbow and Hells Canyon Reservoirs. The assumptions necessary to make a valid comparison and the associated potential errors tend to overwhelm the difference, which gives little confidence in estimates of sediment trapped. There are other methods to estimate the volume of sediments trapped in the HCC particularly since the primary interest is sediments from local tributaries, but all of these methods are hampered by limited and incomplete data and questions regarding data quality.

Given the problems with available data, IPC applied a variety of methods to various data sets to determine estimates of reservoir sedimentation from tributary sources. The methods that IPC used to estimate sediment trapped in the HCC reservoirs were:

1. Direct volume comparison using pre-impoundment topographic maps and post-impoundment bathymetry collected using either single beam or multi-beam echo sounders.

2. Transport calculations using tributary characteristics to estimate an average annual volume of sediments transported into the HCC.

3. Aerial photogrammetry at tributary mouths using pre-impoundment photographs and the same post impoundment bathymetry as mentioned in (1).

4. Geophysical investigations at tributary mouths and along transects in the reservoirs to estimate the thickness of sediment deposited since impoundment.

The data used and results of these methods are discussed in the following sections of this AIR and Table A-1 presents a summary of the data used.

2.1.1. Direct Volume Comparison

Existing Data

Bathymetry

Very limited data are available to estimate the volume of sediments trapped behind Brownlee, Oxbow, and Hells Canyon Dams. The two primary problems with the existing historic bathymetric data sets are that pre-impoundment mapping data are only available as 20’ contour maps and these maps do not include any bathymetry below the water surface in the original river channel itself including island areas in the river. Recent bathymetric data were not available in time to incorporate them into the final license application for Oxbow or Hells Canyon reservoirs. At the time of receipt of the AIR’s, bathymetric data for Oxbow Reservoir were not available. As of October 2004, we have fairly recent bathymetric data for all three reservoirs forming the HCC.

IPC contracted with a consultant (Gene Ralston) during 1996 through 1998 to collect bathymetric data using a single beam echo sounder in Brownlee Reservoir. These data were collected in transects across the reservoir with a longitudinal spacing of approximately 200’. Available data were compared with the pre-impoundment data to get sediment volumes presented in the license application filed in July 2003.

IPC contracted with a team of consultants (Terry Sullivan and Gene Ralston) to collect multi-beam bathymetric data in Hells Canyon Reservoir in December of 2002. These data were not available in time to incorporate into the analysis presented in the license application filed in July 2003. The upper reach of Hells Canyon Reservoir, especially in the bypass section between Oxbow Dam and Oxbow power plant discharge is very shallow and rocky. This reach is largely riverine and would be deep enough for effective multi-beam surveying only during a rare circumstance of Hells Canyon Reservoir being very full and high discharge (greatly in excess of Oxbow power plant capacity) from Oxbow Reservoir. Therefore, the consultant was able to collect only limited data upstream of the power plant area.

IPC contracted with a consultant (David Evans and Associates) to collect multi-beam bathymetric data in Oxbow Reservoir during July of 2004. The data were available October 2004. This reservoir has shallow reaches, particularly in the upper three miles or so, which limited the coverage in this area. However the contractor was able to map the reservoir to the base of Brownlee Dam.

Sediment Characteristics

As of the receipt of the AIR’s for the HCC, no data had been collected in Oxbow or Hells Canyon reservoirs to characterize sediment deposits. In the FLA are characteristics of the bed materials from select tributaries to Brownlee, Oxbow, and Hells Canyon reservoirs. These bed material samples were collected from the streambeds above the reservoir normal high pool elevation and should represent characteristics of sediment deposited in the reservoirs from the tributaries.

In order to expand the data set coverage and more completely address FERC's request, sediment samples in Oxbow and Hells Canyon reservoirs were collected in September 2004 and sent to an engineering laboratory for PSD analysis. Figures A-1 and A-2 show the locations of these samples in Oxbow and Hells Canyon reservoirs respectively. Tables A-2 and A-3 summarize the characteristics of the sediment samples collected in Oxbow and Hells Canyon reservoirs respectively. Appendix A is a Technical Memorandum prepared by CH2M HILL regarding the sampling methods and analysis.

Analysis

Bathymetric data for Brownlee Reservoir (collected using single-beam echo sounder) were used in the FLA to estimate sediment volumes and develop sediment characteristics of the deposited sediments. The sediment volumes for Brownlee Reservoir presented in the FLA are for the total volume including the mainstem, tributaries, and hill slope supplies. Therefore, in this AIR we focused on Oxbow and Hells Canyon reservoirs.

An initial effort to simply use the recent bathymetric data collected using a multi-beam echo sounder in Oxbow and Hells Canyon reservoirs to create a surface and subtract the surface created using the pre-impoundment topographic maps did not yield reasonable results. Direct comparison of these two data sets indicated that the current reservoir volume is greater than the pre-impoundment reservoir volume. The primary reasons for this discrepancy include:

- The river channel volume below the water surface is not included in the pre-impoundment topographic data set.
- Pre-impoundment topographic data are available only as 20' contour maps, so the accuracy of the elevation data is +/–10 feet, which may exceed the actual thickness of some of the deposits.
- There is a road with culverts along one side of both Oxbow and Hells Canyon reservoirs thus interrupting sediment supplies to the reservoirs.

Part of the difficulty in comparing pre-impoundment and post-impoundment volumes is that the pre-impoundment mapping was developed with land survey methods to the edge of the river (at an unknown discharge), does not extend below the original water surface, and does not include islands. This means that when the volume is estimated based on this pre-impoundment mapping, only the volume above the lowest contour can be included. To correct for this missing volume, the volume of the original river channel (below the water surface at the time of the map) and also the volume between the lowest contour and the water surface were estimated and added to the original volume.

To estimate the original channel volume for Hells Canyon Reservoir, we assumed that the channel cross sectional area for the length of the reservoir would be similar to the channel cross sectional area in the river below Hells Canyon Dam. We used results from the hydraulic model developed for the Snake River below Hells Canyon Dam (Parkinson 2003b) at 20,000 cfs to get a water surface elevation. The cross sectional area was determined at two locations below the dam. One location was at the flow measurement gage about ¾ mile below the dam near RM246.9 and the second location was at Johnson Bar (RM229.8) where stage is monitored for operation of Hells Canyon Dam. We increased this water surface elevation by 10’ (1/2 the contour interval) to account for the volume between the lowest contour line and the water surface and used the resulting cross sectional area. The average cross sectional area at these two locations was applied to the length of the Hells Canyon Reservoir to estimate a channel volume missing from the pre-impoundment maps. Power generation at Hells Canyon Dam began in 1967 and the multi-beam bathymetric data were collected in 2002, so the total estimate of sediment trapped in Hells Canyon Reservoir was divided by 35 years to arrive at the mean annual total sedimentation.

To estimate the channel volume for Oxbow Reservoir, a similar approach was used. The cross sectional area just downstream of Brownlee Dam was used with a flow of 20,000 cfs and Oxbow Reservoir drawn down to minimum pool. The water surface elevation in this case was also increased by 10’ to account for the volume between the river water surface elevation and the lowest contour. Oxbow Dam was completed in 1961 and the multi-beam bathymetric data were collected in 2004, so the total estimate of sediment was divided by 43 years to arrive at the mean annual total sedimentation.

Another significant problem that arises in using the approach of comparing reservoir volumes from pre-impoundment and current bathymetry to estimate the tributary supplies is that both Oxbow and Hells Canyon reservoirs have a paved road along the entire length of one side of the reservoir (along Oxbow Reservoir the road is on the Oregon side and along Hells Canyon Reservoir the road is on the Idaho side). Where these roads cross drainages, culverts interrupt the transport of sediment to the reservoir (except perhaps if a culvert fails). The roads are maintained by occasionally removing hill slope material that has collected in the borrow pit areas and sediment in the tributary mouths upstream of the culverts, but no records are kept of these volumes. While some sediment (particularly the smaller sizes) undoubtedly passes through the culverts, in effect the sediment supply from the tributaries and hill slopes on the roadside of the reservoirs is restricted. This in effect reduces the quantity of sediment reaching the reservoir by some unknown factor. This reduction further exacerbates the issues of uncertainty in the pre-impoundment data and emphasizes the need to pursue other methods.

Results

The results of these bathymetric comparisons are shown in Table A-4. When compared to the transport calculations (presented in the FLA and summarized again in Section 2.1.2), results vary widely from a low for Oxbow Reservoir where transport calculations (limited to a 100-year event or less) show no sediment supply to the reservoir, to a high in Hells Canyon Reservoir where transport calculations are 30 times greater than the volume in the reservoir estimated based on bathymetric data. The comparison in Brownlee Reservoir is complicated by the fact that Brownlee Reservoir traps sediment from the mainstem Snake River and two large tributaries (included in the estimates in the FLA) in addition to the smaller tributaries where the transport calculation methodology is applicable.

As discussed in Section 2.1.2, the transport calculations include only sediment sizes ranging from the lower end of sand size (0.063mm) and larger while the volume difference calculations include all sediment sizes including clays and silts. This is particularly problematic in Brownlee Reservoir where approximately 86% of sediments trapped are smaller than sand size (0.063mm) as presented in the FLA.

Given that the pre-impoundment bathymetric data involved uncertainties that are on the same order of magnitude or greater than the difference that we were trying to estimate, we decided to utilize other methods and data to validate tributary supply estimates from transport calculations. Although the AIR requested that we use existing information and additional analyses were not specifically requested, we felt that validating the supplies from tributary sources is important and warranted additional data collection and analyses.

2.1.2. Transport Calculations in the Tributaries

Technical Report E.1-1 (Parkinson 2003a) in the final license application for the Hells Canyon Complex includes a complete description of the transport calculations used to estimate sediment supplies from local tributaries. These calculations were based on channel surveys of the tributaries near their mouths, bed material samples collected near their mouths, and hydrology of each tributary based on a U.S. Geological Survey (USGS) methodology. Transport calculations were performed for selected tributaries that met or came close to meeting the criteria developed by the USGS as part of their hydrologic methodology (for example basin area, slope, etc). An average of the yield from calculated tributaries was then applied to other tributary watersheds and slopes directly into the Snake River to get total sediment transport for the reach.

The transport calculations included only sand size and larger sediments. Silt and clay sizes are not estimated by the transport calculations. Given the importance of sands and gravels to features below Hells Canyon Dam such as sandbars and gravel spawning beds, this limitation is not considered to be significant. However, it does mean that this issue must be considered when comparing these values with other estimates of sediment supply such as deposition volumes measured in reservoirs. As discussed in the Technical Report E.1-1 (Parkinson 2003a), the values resulting from the transport calculations assume that sediment supplies are not limited and the tabulated results were not adjusted for sediment supply limitations. Therefore, they represent an estimate near the upper bound of the range of sediment supplies from the tributaries; in E.1-1 we noted that a reasonable reduction of these values would be one order of magnitude (a factor of ten).

Calculations based on this methodology are not appropriate and were not performed for the mainstem Snake River or for the Burnt River or Powder River (large regulated tributaries to Brownlee Reservoir). However, transport values for the mainstem Snake River were estimated based on other data and transport values for the Burnt and Powder Rivers were estimated using the average of the transport calculations and applying this yield to the areas in the Burnt and Powder River drainage basins below the lowest dams in the systems. These calculations are discussed in detail in the FLA. The transport calculation methodology is appropriate for tributaries discharging to Oxbow and Hells Canyon reservoirs including Wildhorse River and Pine Creek.

Results

Results for this section can be found in Technical Report E.1-1 (Parkinson 2003a) and are not summarized separately in this response to AIR S-1. Results are included in the final summary table (Table A-7).

2.1.3. Aerial Photogrammetry at Tributary Mouths

Existing Data

IPC has located miscellaneous historic pre and post-impoundment aerial photography taken for various purposes such as road construction, power line construction, and dam construction. The dates on these photographs range from the mid 1950’s through the late 1960’s. Some of these photographic series have enough overlap for photogrammatic mapping and some do not. Although a limited number of these photographs appear to have targets in them, records of the locations of these targets are not available. In addition, the targets tend to not be in the areas of interest for tributary mapping. Also, camera calibration reports for these photographs are not available and these reports are necessary for photogrammatic mapping. IPC was able to locate pre-impoundment photographs in the areas of Dennett Creek (tributary to Brownlee Reservoir) and McGraw Creek and Steamboat Creek (tributaries to Hells Canyon Reservoir) that had the 60% overlap required for photogrammatic mapping.

Based on previous work, Nelson and Associates was able to determine adequate control for the aerial photographs at Dennett Creek. No control was available for the photographs of McGraw Creek and Steamboat Creek so IPC contracted with JUB Engineers to establish control and Valley Air Photos to take aerial photographs of the mouths of these two tributaries. Nelson and Associates was then able to use the recent photographs and control to establish control for the pre-impoundment photographs and develop topographic data for the tributary mouths. This topographic data can be compared to recent bathymetry data to estimate the volume of sediments from that tributary.

Analysis

Direct Photogrammatic Differences

This method of estimating sediment from tributary sources is to develop topography from pre-impoundment aerial photographs at selected tributary mouths and compare that to recent bathymetric data collected at those same locations. This allowed us to avoid the issue of pre-impoundment data having large contour intervals (20’) and no pre-impoundment bathymetric data collected in the original river channel. The recently developed pre-impoundment topography in the tributary areas was developed with a contour interval of 5 feet (accuracy +/–2.5 feet).

As discussed in the Existing Data section, we were able to locate suitable photography (pre-impoundment, 60% overlap, reasonable scale, and good quality) at 3 tributary mouths, Dennett Creek (Figure A-3) in Brownlee Reservoir, and McGraw Creek (Figure A-4) and Steamboat Creek (Figure A-5) in Hells Canyon Reservoir. Sediment supply was estimated for Dennett and McGraw Creek using transport calculations (in the FLA) allowing direct comparison of the methods.

The two primary complications of using these photographs for accurate mapping are: 1) There are no camera calibration reports available for the camera used to take these photographs and 2) There are no targets and associated coordinate data (to establish horizontal and vertical control) available for the photographs. Nelson and Associates addressed the lack of a camera calibration report by locating other photography taken with what they believe is the same camera that does have control associated with it and using that photography to essentially back calculate camera calibration parameters. We addressed the lack of control in the photographs by establishing and targeting control near the tributaries with pre-impoundment photographs and re-flying those areas. Then points identified in both the old and the new photography can be used to transfer control to the old photographs. Dennett Creek already had targeted photographs from a more recent flight so it did not need to be re-flown. McGraw Creek and Steamboat Creek were targeted (targets placed on the road across from the creek mouth) and flown in

November 2004. Topographic information for the tributary mouths were developed by Nelson and Associates from the photographs and made available for analysis in January 2005.

Surfaces for each tributary mouth were created based on both the old aerial photography and the recent bathymetry. A boundary was drawn around the tributary fan area. The area generally followed a triangular shape with one vertex at the point where the tributary enters the reservoir at full pool and the opposite line near the edge of the pre-impoundment water surface. Upstream and downstream limits of the area were drawn based on a general fan shape and geomorphic judgment. Note that the deposition in the fan area likely does not include all of the silt and clay and perhaps even some of the smaller sand sizes from the tributary because these smaller sizes have likely been transported downstream from the fan complexes into the reservoir. But the deposition likely does include most if not all of the coarser material. Therefore, comparing this to the transport calculations should be reasonable.

Geomorphic Interpretation

The photogrammatic analysis is based on using recent bathymetry as the upper bounding surface to calculate volumes of sediment. While this recent bathymetry is good data, it does not fully cover a strip of area along the reservoirs edge for a couple reasons. First, it is not always possible to collect the bathymetry under full pool conditions. Brownlee Reservoir (a storage reservoir) is not always full and Oxbow and Hells Canyon reservoirs are used for re-regulation and load following. Second, it is not possible to use bathymetric equipment right up to the shoreline. All bathymetric equipment has some minimum depth at which it can be operated and the equipment must be submerged below the water surface to function. Also, in the HCC reservoirs, there are rock hazards along most of the shoreline and to protect the equipment it is not possible to run even to the minimum depth that the equipment would still function. In good conditions, data can be collected to within 1 meter of the surface. Where water hazards exist or if the character and slope of the shoreline are unfavorable, this distance increases. Also, if the reservoir were below full pool during the survey or part of the survey, that distance would increase.

Another factor is that some portion of the post-impoundment sediment load is deposited above the full pool line because of changes in flow characteristics of the stream (change in base level) as it enters the reservoir. This deposition can be clearly seen by visual observation of gravel deposits that extend up the tributaries well above full pool elevation.

Therefore, there are areas/volumes at the tributary confluences that are not accounted for in the photogrammatic analysis. In order to try to include these areas in its evaluation, IPC contracted with CH2M HILL to study the tributary mouths with good photography and mapping. CH2M HILL used the available data and professional judgment to delineate pre and post-impoundment sediment fans both above and below the water surface. Appendix B is the technical memorandum prepared by CH2M HILL.

Results

Figures A-3 through A-5 show the tributary fans and boundaries selected. A volume of material was estimated by using GIS to determine the difference between the two surfaces. This method assumes that material transported by the tributary will tend to remain in the fan shaped area and not be transported into the reservoir very far. For larger sizes of sediments such as sands and gravels, this is probably a conservative but reasonable assumption. Given that the transport calculations only include sands and larger sizes, the results should represent similar material sizes. Table A-5 shows the results of the photogrammetry and geomorphic interpretation.

2.1.4. Geophysical Investigation

IPC contracted with Golder and Associates Inc. (GAI) to collect geophysical data in the HCC reservoirs and at four sandbars in the Snake River in Hells Canyon in October of 2004. The sandbar portion of this investigation is discussed later in this response to AIR S-1 (d). The geophysical data obtained in the HCC reservoirs consisted of seismic reflection and subbottom profiler data collected with low frequency and high frequency acoustic systems. The two systems, having different acoustic characteristics, provided maximum resolution (SBP, 5 kHz) and good subsurface penetration (seismic reflection 700 Hz to 2 KHz) which is important for mapping the thickness of fine-grained and medium to coarse-grained sediment. These data were primarily collected on eleven tributaries identified in the FLA as potentially important contributors of sediment to the HCC and not blocked by road culverts. Geophysical data were also collected along track lines where sediment samples were collected in Hells Canyon Reservoir and Oxbow Reservoir during September of 2004.

Analysis

Geophysical methods were generally not able to distinguish the interface between pre-impoundment (topography existing at the time of the construction of the HCC) and post-impoundment sediments. One reason for this is that post-impoundment sediments, in many locations were very coarse-grained and the equipment used for the geophysics investigation could not penetrate them. Also, some post-impoundment fans are likely placed directly on top of pre-impoundment fans. Since the material is derived from the same source, the acoustic signal is unable to distinguish between the two. GAI were able to calculate some sediment volumes where tributaries enter the reservoirs and in the original river channel. The volumes identified tend to be located where relatively fine-grained sediments would accumulate (lower in the fans and in the original river channel). The sediments identified in the original river channel are identified as sand or fine-grained based on the sediment characterization discussed previously in this section. Other volumes are judged to be fine-grained material based on their location and GAI's experience with the interpretation of acoustic data. The volumes estimated based on this methodology help define the lower limits of the range of sediment supplied by the tributaries to the HCC.

Results

Table A-6 shows the results of the investigation using geophysical methods for HCC tributary sediment supplies. The geophysics investigation was able to identify sediment volumes at more tributaries than the other methods because it is dependant on fewer existing data sources (such as pre-impoundment data sets) than the other methods. This data also likely represents the lower end of the range of sediment volumes because it primarily represents smaller sizes such as fine grain sands, silts and clays and does not include larger sediment sizes such as gravels and cobbles.

Overall Conclusions

Table A-7 shows a summary of the results of all of the investigations discussed in this section. The table shows the results of the various investigations and all of the numbers are converted to common units based on the assumption of the bulk density of sediments deposited in the reservoir being 100 lbs/ft^3. At the bottom of the table, all of the various estimates are compared to the transport calculations. As discussed in the FLA, the transport calculations produce values near the upper end of a range of sediment supply estimates. All of the other methods presented here are on the lower end of the range of tributary sediment supply.

The comparison of tributary transport calculations to overall HCC sedimentation from bathymetry yields a ratio of 16.9:1, or transport calculations estimating 16.9 times more sediment supply than the bathymetric estimate. This is consistent with the FLA where we suggested that transport calculations could overestimate tributary supplies by approximately an order of magnitude. Transport calculations for Brownlee Reservoir are a bit problematic because transport in the mainstem Snake River was estimated using measured sediment samples collected by the USGS as discussed in the FLA (Parkinson 2003a). Also, sediment yield from a large percentage of the area draining to Brownlee Reservoir (for example the Burnt and Powder River drainage basins below the lowest dam in the drainage) was estimated using the unit area yield from the relatively small number of tributaries for which calculations were actually performed. Table A-7 shows ratios based on the various methods and drainage basins ranging from 1.7:1 through 350:1.

In analyzing these data and calculations, the following points should be kept in mind:

- As discussed in the FLA, transport calculations are high, therefore it is expected that the ratio would be greater than one (i.e. direct measurements are lower than the estimates based on transport calculations).

- Direct bathymetric measurement and comparison would seem the most direct method of measurement but is hampered by problems with pre-impoundment data including limited resolution, no information within the original river channel, roads, etc.

- Geophysics is another direct measurement that didn't work well in the reservoirs. This is likely because much of the post-impoundment sedimentation from the tributaries is too similar to the pre-impoundment deposition and it is difficult to identify the interface between the two.

- Photogrammetry is probably the most appropriate to compare to the transport calculations because it is focused in the areas where the larger sizes from the tributaries are deposited and (where information is available), the pre-impoundment information has good resolution. However, photogrammetry is also limited by the lack of pre-impoundment information and can only be used in certain locations where early photographs exist. Also, photogrammetry does not include the smaller sizes that are likely transported away from the immediate tributary fan area.

- Topographic interpretation is probably not as accurate as photogrammetry, but is probably better than the total reservoir volumes or the geophysics approaches. Plus it can be applied in more locations than photogrammetry. Topographic interpretation only identifies fairly thick deposits and therefore the estimates based on this method are also likely on the low side.

- With any of these methods, because the period of impoundment is on the order of 40 years, the long-term geologic supply of sediments from the tributaries will be underestimated as compared to the transport calculations that rely on a large range of possible flows up to the 100-year event.

The direct bathymetric comparison for the HCC resulted in a ratio of 16.9:1. The average ratio of the photogrammetric analysis that can be compared to transport calculations is 12:1, and the average ratio of the topographic interpretation approach is 21:1. For reasons discussed above, the geophysics results aren't appropriate for direct comparison with the transport calculations. Given that sediment transport estimates are often discussed in orders of magnitude, and all of these ratios are much closer to one order of magnitude (10:1) than two orders of magnitude (100:1), the tributary supply reduction discussed in the FLA of an order of magnitude (10:1) is reasonable.

2.2. Response to (b)—Sandbar Inundation Mapping

(b) Your sandbar stability analyses have not taken into account toe erosion as a possible mechanism for sandbar deformation. Please perform an area inundation analysis for Pine Bar (RM 227.5), Salt Creek Bar (RM 222.4), Fish Trap Bar (RM 216.4), and China Bar (RM 192.3) for flows between 5,000 cfs and 30,000 cfs in increments of 5,000 cfs (e.g., 5,000 cfs, 10,000 cfs, 15,000 cfs … 30,000 cfs). Provide maps of each site showing the areas that would be inundated at each of the flow increments modeled. These plots will illustrate the minimum flows at which inundation and possible toe erosion may occur for each of these heavily used recreational sites.

IPC used its existing MIKE 11 HD model (Parkinson 2003b) to provide boundary conditions to a MIKE 21C 2-D hydraulic model (Parkinson 2003b and AIR S-1(c)) at each of the listed sandbars. The results from the MIKE 21C models were used to plot inundation maps for the requested flows over an aerial photograph of each of the sandbars taken September 17, 2004.

Substrate Maps

The next step in developing the inundation maps required development of substrate maps that delineated the area of sand at each sandbar. For two of the sandbars (Pine Bar and Fish Trap Bar), we used substrate maps developed for aquatics studies and research related to the relicensing effort to define the boundaries of the sand areas. Substrate maps were not available for Salt Creek Bar and China Bar so technicians used the same methods and equipment to map substrate at these two bars for this AIR. The classification of substrate in these investigations is based on a visual determination using a referenced measuring rule or Mylar grid and a modified Brusven scale (Groves and Chandler 1999) where the sand-pebble classification includes sizes smaller than 6mm. While this technically includes sizes larger than sand (and the required 1.0 mm size), in practical terms areas falling into this class are dominated by sand (not pebble) sizes. IPC recently (November 2004) collected additional information on substrate of the dry portions of the sandbars and this information was used to verify and update the substrate maps. The sand areas delineated are also used in the sandbar mobilization work discussed in S-1(c).

Results

The inundation maps for the requested flows are shown in Figures B-1 through B-6 for Pine Bar (RM227.5), B-7 through B-12 for Salt Creek Bar (RM222.4), B-13 through B-18 for Fish Trap Bar (RM216.4), and B-19 through B-24 for China Bar (RM192.3).

2.3. Response to (c)—Mobilization of 1mm Sand

(c) The minimum flows capable of mobilizing sand (1mm) downstream from Hells Canyon dam have not been clearly established from previous modeling studies and analyses. Using the existing MIKE 11 and MIKE 21 models, perform additional modeling for each site identified in Part 2, above, using a range of flows between 5,000 cfs and 30,000 cfs in increments of 5,000 cfs. Determine the minimum flow (in increments of 5,000 cfs) at which sand is mobilized at each of the sites. For flows equal to or exceeding the identified threshold for mobilization, provide plots delineating the areas in which sand is mobilized.

IPC analyzed four (4) sandbars below Hells Canyon Dam using MIKE 21C to establish the minimum flow that mobilizes 1.0 mm sand particles at each sandbar and determine the spatial extent of sand mobilization at each sandbar for each requested discharge. The four sandbars analyzed were Pine Bar at RM227.5, Salt Creek at RM222.4, Fish Trap at RM216.4, and China Bar at RM192.3. The flows used for these analyses ranged from 5,000 cfs to 30,000 cfs in 5,000 cfs increments for a total six flows. The results are presented on maps (in addition to tables) that display the sand polygons at each bar and the area where 1.0mm sand is stable or mobile for each flow. The mobilization maps are shown in Figures C-1 through C-6 for Pine Bar (RM227.5), C-7 through C-12 for Salt Creek Bar (RM222.4), C-13 through C-18 for Fish Trap Bar (RM216.4), and C-19 through C-24 for China Bar (RM192.3). The general procedures used to determine mobility and develop the maps are explained below.

Incipient Motion Calculations

Incipient motion is discussed and defined in the FLA and, as noted in the FLA, various researchers have presented many methods for determining conditions of incipient motion. Methods for defining incipient motion have been based on either visual observation or theoretical calculations and range from motion of any sediment particle through motion of a certain percentage of surface particles to general motion of the bed. For the purposes of responding to this AIR, incipient motion of sand was determined to be the point when the calculated applied shear stress equaled or exceeded the calculated critical shear stress for a 1.0 mm-sized particle. To complete this calculation, IPC used its existing MIKE 11 HD model (Parkinson 2003b) to provide boundary conditions to MIKE 21C 2-D hydraulic models (Parkinson 2003b and AIR S-1(c)) at each of the listed sandbars. The MIKE 21C 2-D hydraulic models for Pine Bar and Fish Trap Bar were already developed for studies completed for the FLA, but new MIKE 21C models were developed for Salt Creek Bar and China Bar in order to respond to this AIR. We developed these new 2-D models for this analysis so that depth and velocity information would be spatially represented across the sandbars rather than using channel average information that would have resulted from using MIKE 11 (a 1-D model).

The results from the MIKE 21C models (which are a curvilinear grid) were imported into a 2m x 2m grid within GIS for analyses and mapping. These results were used to calculate the applied shear stress (τ_0) and critical shear stress (τ_c) for 1.0 mm sand in each grid cell to determine if this size particle in the cell is mobile or stable. The general procedure and equations used for computing the applied and critical shear stress are as follows:

Applied shear stress values for each cell were calculated using the following equation (Einstien 1950):

$$\tau_0 = \rho_w \left(\frac{u_z}{5.75\log(\frac{12.27z}{3d_{84}})} \right)^2 \qquad (1)$$

Where:

τ_0 is the applied shear stress in N/m^2

ρ_w is the density of water in kg/m^3,

u_z is the resultant velocity of the cell in m/s,

z is the water depth in meters,

and d_{84} is the particle size where 84% of the particles by weight are smaller than the given value.

As part of work included in the FLA, IPC collected sediment samples at Pine Bar and Fish Trap Bar in November 2002 and analyzed them for particle size distribution. The d_{84} from this sampling was used for Pine Bar and Fish Trap Bar. Obtaining the necessary permits and approvals from the USFS to collect these samples took about 18 months. Therefore, we did not attempt to collect additional samples from Salt Creek Bar and China Bar, but used d_{84} values from Fish Trap Bar as a surrogate.

Critical shear stress was calculated using the following equation:

$$\tau_c = \theta_c \left(\rho_s - \rho_w \right) g d_p \qquad (2)$$

Where:

τ_c is the critical shear stress in N/m^2,

ρ_s is the density of sediment in kg/m^3,

ρ_w is the density of water in kg/m^3,

g is the acceleration due to gravity m/s^2,

d_p is the particle size being evaluated for incipient motion (1.0 mm per the AIR),

and θ_c is the critical dimensionless shear stress parameter or Shields parameter.

The critical dimensionless shear stress (Shields parameter) is often taken from the Shields diagram. The critical dimensionless shear stress is a function of the boundary Reynolds number, which varies with hydraulic conditions. In many river situations, it is often assumed that the flow is fully developed and turbulent (at the boundary), in which case the critical dimensionless shear stress is constant. However, we recognized that at the four sandbars being analyzed, it is possible that at lower discharges some locations may not be fully turbulent. In these cases, the Shields parameter could be less than the value for turbulent conditions (in which case a particle could be mobilized with less applied shear). Therefore, we opted to use an analytical expression of Shields diagram rather than a fixed value so the Shields parameter could vary spatially with hydraulic conditions. The critical dimensionless shear stress (Shields parameter) was determined using a the following equations developed by Rao (Rao 1989):

$$\theta\left(\mathrm{Re}_s\right) = 0.5e^{-0.5}\left(C + \frac{0.444}{\mathrm{Re}_s}\right)\varphi\left(\mathrm{Re}_s\right) \quad (3)$$

$$\phi\left(\mathrm{Re}_s\right) = 10^{\frac{e^{\frac{-1}{2.46}\frac{1}{2.46}\ln\left(\frac{\mathrm{Re}_s}{6.5}\right)^2}}{-2}} \quad (4)$$

Where:

$\theta(\mathrm{Re}_s)$ is the critical dimensionless shear stress parameter,

and Re_s is the shear velocity Reynolds number.

In Rao's original equation, C equaled 0.1349, which yielded a critical shear stress of 0.041 for hydraulically rough conditions. A value of C equal to 0.197 yields a critical shear stress of 0.06, which is what the Shields diagram typically shows for uniform sediments such as a sand bed (Rouse, 1939). This is discussed further in the FLA (Parkinson 2003a). In order to be consistent with the analysis presented in the FLA, we used a C of 0.155, which yields a critical shear stress of 0.047. Using a critical shear stress of 0.047 shows mobility at a lower applied shear stress than a value of 0.06. The applied shear stress is not reduced to account for bed forms or side slope of the channel. This is not an inherent problem, but when combined with a critical shear stress of 0.047, this adds another level of conservatism in estimating mobility. Partitioning of shear stress is discussed in some detail in Appendix 4 of Secondary Consultation of the FLA.

The Reynolds number and shear velocity are discussed in the FLA and were calculated for each cell by:

$$\mathrm{Re}_s = \frac{u_{st} d_{50}}{\upsilon} \tag{5}$$

and

$$u_{st} = \sqrt{\frac{\tau_0}{\rho_w}} \tag{6}$$

Where:

u_{st} is the shear velocity,

d_{50} is the particle size for which 50 percent of the particles are smaller by weight,

ν is the kinematic viscosity in m^2/sec,

τ_o is the applied shear stress in N/m^2 from equation(1),

and ρ_w is the density of water in kg/m^3.

This analysis resulted in a prediction of stable and mobile areas for each requested discharge at each of the four bars. It should be noted that while the calculations were carried out for the entire 2-D model domain, the results indicating mobility of 1.0 mm sands are only valid where the substrate is sand. These areas are shown in Figures C-1 through C-24.

Minimum Flow that Mobilizes Sand

The final step required identifying the flow where incipient motion of 1.0 mm sand begins at each of the listed sandbars. This was determined by comparing the area of sand mobilized to the total sand area inundated for each requested discharge. When this ratio exceeded 1%, the bar was determined to be mobile. The mobile sand area and the total inundated sand area for each sandbar and flow is provided in Table C-1. In IPC's opinion, using a threshold of 1% is conservative, especially considering that total shear stress was applied to determine incipient motion and wasn't reduced for bed forms or side slopes.

The modeling results indicate that China Bar is essentially always mobile, while Pine Bar and Fish Trap Bar begin to mobilize at 10,000 cfs, and Salt Creek bar doesn't mobilize until approximately 30,000 cfs. Interestingly, sandbar surveys by IPC and Grams and Schmidt (Grams and Schmidt 1999) have indicated that China Bar has been fairly stable, while the other bars have experienced more change over time. This may be an indication that discharges that significantly mobilizes sand on the bars (such as the high flows of 1997 and 1998) are important to their persistence.

2.4. Response to (d)—Sandbar Volume where Sand is Mobilized

> (d) Where sand is determined to be mobile in Part 3 above, determine whether an armor layer lies beneath the finer sediments and whether these sites are aggrading or incising. If an armor layer exists and these mobile sites represent locations where active bedload was deposited on top of the armor layer, calculate the volume of these active bedload deposits. These calculations will provide critical information for refining the sediment budget and understanding the relative importance of tributary sediment inputs and active bedload transport on spawning gravels and sandbars.

Sandbar Volume

In general, the Snake River in Hells Canyon (as presented and discussed in the Technical Report E.1-1) was formed by flows much larger than present day flows. These pre-historic flows established a stable, armored channel bed in the context of recent flow records, over which smaller size sediments are stored and transported. It is likely that many of the sand features associated with the river, including the four bars in question, are deposits on top of this armor layer. Calculating the volume of these deposits required estimating the thickness of the sand deposit for both the on-shore and offshore portions of the bars.

IPC initially felt the most direct approach to determining the thickness (and ultimately volume) of the sand deposits would be to collect core samples down to the armor layer (similar to the sampling conducted at Pine Bar and Fish Trap Bar that is presented in the FLA). However, based on IPC's previous experience in conducting this type of work at two of these bars, the amount of time required to obtain approvals (approximately 18 months) to conduct the work exceeded the time allowed for the response to this AIR. Furthermore, core sampling would have been difficult to conduct in the offshore areas, and cores in the onshore areas would have resulted in a limited number of data points. Therefore, IPC elected to investigate the use of non-intrusive geophysical techniques that could provide more complete spatial coverage in both the on and offshore environments, be essentially non-invasive, and be conducted within the timeframe of the AIR.

IPC contracted with Golder and Associates Inc. (GAI) to use geophysical techniques to determine the depth and volume of sand at the four sandbars. The techniques included electronic resistance imaging (ERI) and ground penetrating radar (GPR) on the sandbars and sub-bottom profiling and seismic reflection profiling offshore. The depths of sand in conjunction with topographic data supplied by IPC were used to estimate the volume of sand at each sandbar. The results of the geophysical survey suggest that the sandbars are underlain by a sedimentary unit that consists of coarse-grained materials (limited sub-surface penetration). GAI interpreted the change in sub-surface penetration, or transparency, as indicative of less mobile material below that depth.

With the river in its current form and under current hydrology, the sandbars in these locations are not necessarily isolated patches of sand underlain by an armor layer and separated from adjacent terraces. Rather, terraces that have a component of sand material bound the sandbars in these areas and these terraces appear to extend to (or nearly to) the canyon walls. These terraces are not inundated by any flows recorded or observed during present day history, but do appear to supply sand to the bars below. Therefore, sandbar volumes were estimated by focusing the survey to areas of the bar that are inundated by historic flows, and less effort was placed on gathering geophysics data for the terrace.

The geophysical methods were unable to provide an exact classification of the material that underlies the sandbars. It was not possible to determine if it is an armor layer from pre-historic flows, bedrock, or coarse-grained material that could not be penetrated by the geophysical techniques used. Core samples would need to be extracted from each bar for analysis to verify or classify the nature of this underlying material. As noted above, the time required to get approval for this type of sampling has been much longer than the time allowed for the response to this AIR. And, since the goal is to determine the volume of material above an armor layer, an exact classification does not appear to be necessary.

It should also be noted that the sand areas and volumes delineated using geophysical methods do not completely match the sand polygons discussed in AIR S-1 (b). This results primarily from the sampling methods. The substrate polygons were determined using visual assessment of the surface, whereas the geophysical methods identified sand where the thickness was sufficient to be resolved with the instruments. While differences between the two methods occur both on-shore and offshore, they are more prominent in the offshore area.

Maps of each bar showing the sand isopachs are included as Figures D-1 through D-4. The sand volume estimates for each bar are presented in Table D-1.

Sandbar Aggradation or Degradation

In developing the FLA, IPC gathered and interpreted several series of aerial photographs and presented this information. As part of this response, IPC also interpreted an additional set of aerial photographs taken (by IPC) in 2003 and supplemented the information presented in the FLA, which is presented in AIR S-1 (g). This addresses the total number of visible sandbars in the river between HCD and the Salmon River. It does not address the change in sandbar volumes.

In developing the FLA, IPC also spent considerable time in an attempt to geo-reference some of the older photos showing the larger bars so that changes in size over time could be quantified. Our GIS expert ultimately decided that we could not defensively achieve the accuracy required to do this using the old photographs. Therefore, the only quantifiable information available (that we are aware of) regarding the changes in shape and size of individual sandbars over time is information presented in reports by Grams and Schmidt (Grams and Schmidt 1999) and a series of surveys that IPC has conducted at four individual sandbars (presented and discussed in AIR S-1 (g)). As discussed in the response to AIR S-1 (g), IPC surveyed the four sandbars in 2003 and 2004 and this information is used to extend the information presented in the FLA.

Based on the sandbar counts, it is clear that between the mid-1950's and mid-1970's there was a significant decline in the number and size of sandbars in Hells Canyon. From the mid-1970's to the present time, there appear to be some periods of rebuilding sandbars and also continued reduction in sandbar quantity. It is not entirely clear whether the number of sandbars have reached a new equilibrium with some increases and decreases depending on hydrologic (and associated supply) conditions (as suggested in the FLA), or if the numbers of bars are still approaching an equilibrium and until it is reached, the trend will continue to be toward loss of sandbars in the Canyon. It should also be noted that while the counts provide an indication of the number of bars that are present through time in Hells Canyon, it is not possible to definitively tie any changes in numbers back to specific events such as activities in the upstream watershed or construction of the HCC. As discussed in the FLA, the earliest usable photo record does not represent pre-development conditions for the watershed or a state of equilibrium. In fact, it follows significant upstream watershed activities that were independent of the construction of the HCC.

In the AIR, FERC implied that comparing the amount of sand in the four sandbars to the quantity of material supplied by the upstream tributary sources might lend some insight to the importance of these supplies to sandbar persistence. The mass of sand found in each of the bars is compared to the upstream annual supply of sands in Table D-2. The supplies used in this comparison are one order of magnitude less than the supplies determined using transport calculations as presented in the FLA. We recognize that the volume of sand at a bar is not likely to be entirely lost and replaced each year, and that the tributary supply estimates are annual averages of events that are episodic rather than regularly occurring. Therefore, it might be more appropriate to multiply the annual ratios by the number of years representing a hydrologic or planning cycle.

Sandbar transect surveys conducted by IPC between 1997 to 2004 indicate that in general the river side of the sand bars are retreating towards the riverbank terraces. In some cases, this is more apparent for portions of the bars that get a lot of recreation use. It is important to note that following high flows in 1998, the elevation of the tops of the bars increased. Basically, this information shows that sandbars can experience aggradation during flood events (1997 to 1998), and erosion during low flow periods (2000 to 2004). However, the 1997 data is from the fall and we don't have data prior to the significant flood that occurred the spring of 1997. While this information continues to demonstrate that the size and shape of the bars are dynamic in nature, the data don't cover a full range of hydrologic conditions, which makes it difficult to draw definitive quantitative conclusions regarding aggradation or degradation.

Results from the sand mobility modeling (AIR S-1 (c)) show that 1.0 mm sands are mobile at all flows at China Bar, while flows approaching 30,000 cfs are required to mobilize sand at Salt Creek. Based on transect surveys, China Bar has been fairly stable relative to other bars that have been monitored over time. While intuition may lead one to believe that high levels of mobility could be correlated to degradation, the mobility modeling results indicate that this isn't the case. These results suggest that mobility may be an important component of sustaining sandbars.

Results of geotechnical slope stability analysis are discussed in the FLA and in AIR S-1 (f). The analysis in the FLA analyzed instantaneous recession from flood flows and extreme load following operations (16,000 cfs), and the information in AIR S-1 (f) evaluates load following for a 10,000 cfs recession. These analyses indicate that in general the sandbars do not become unstable and experience geotechnical failure or degradation under these conditions.

Sediment provenance analysis presented in the FLA indicates that sediments in the bars are comprised of both local and upstream sources. Between 50% and 85% of the sediments originate from the Idaho Batholith, which is drained primarily by the Boise, Payette, and Salmon Rivers. The Boise and Payette would have historically contributed the batholith sediments found in the four sandbars. Dams were constructed in these watersheds in the early part of the 20th century, cutting off the batholith supply of sediments. The provenance information provides evidence that the sandbars were historically dependent on upstream supplies of sediment that were cutoff prior to construction of the HCC. There is recent evidence that these watersheds still produce sands above their impoundments. Figure D-5 is a photograph from January 15, 2005 of a power canal in Horseshoe Bend, ID, that diverts water from the Payette River above Black Canyon Reservoir to a hydro plant on the Payette upstream of Black Canyon. The power canal is drained on a regular basis to allow the sand to be removed.

In summary, based on the available aerial photographs, our topographic sandbar surveys, and the mobility modeling results, the data suggest the following:

- Based on aerial photography, there has been a decrease in the number and size of bars since the timeframe of the early aerial photographic records. Although the photographic record indicates the greatest decrease in sandbar numbers immediately following completion of HCD, the change in numbers following this initial decrease has been much less. This initial decrease is indication that construction of the HCC likely decreased the number of bars in the system, as the system existed at that time. However, as discussed in the FLA, the timeframe of first sets of photos coincide with the construction of the HCC, and don't establish a trend prior to its construction. As a result, while the photo record shows a decrease in numbers of sandbars through time, the anthropogenic disturbances upstream (and the effects on sediment supplies) and the timing of the construction of the HCC make it very speculative to attribute the changes in sandbar numbers to only the HCC, ignoring the effects of upstream development. In IPC's opinion, it would be very difficult (if not impossible) to definitively demonstrate that without the HCC, the number of bars in Hells Canyon now (2005) would be the same as they were in the 1960's. In fact, it is very unlikely that the early photo record represent an equilibrium condition because of the other upstream developments in the Snake watershed, and the fact that 87% of it was already cut off from supplying sediment to the Hells Canyon reach at the time the HCC was constructed.

- Based on the topographic surveys the bars show signs of rebuilding following flood events (1997–1998) and degradation during periods of extended low flows lacking flood events (2000–2004). This is consistent with the number of bars observed in aerial photographs following wet and dry periods.

- The mobility modeling indicates that mobility alone of sand doesn't appear to be closely correlated with degradation of sandbars. The modeling results indicate that mobility may be important to sustain sandbars, which is consistent with the topographic surveys where there was aggradation following a flood event.

- Slope stability modeling of the sandbars for conditions of instantaneous draw down resulting from flood recession and two different load following scenario's indicated that in general the sandbars do not become unstable and experience geotechnical failure or degradation under these conditions.

- The volume of sand measured in the four sandbars is relatively small compared to the adjusted quantity of sand estimated to be available from tributary supplies below HCD and above each sandbar.

2.5. Response to (e)—Monitoring Bed Load

(e) Modeling estimates of sand and gravel mobilization have not been verified. Additionally, it has not been clearly established whether or not an active bedload component is present above the channel armor layer. In order to provide validation for modeling and transport calculations and to address the possibility of an active bedload component, please conduct field measurements of sand and gravel mobilization in representative regions where mobility was indicated in Part 3 above. Use Helly-Smith bedload sampling or other techniques to monitor sand and gravel bedload at the flow thresholds for sand and gravel mobility as predicted in Part 3 above.

Bedload sampling has been conducted using a Helley-Smith sampler at the four sandbars. Specific verification of sand mobility at these sites had not been conducted previously.

Sandbars

Field measurements for bed mobilization were conducted at four sandbars: Pine Bar at RM227.5, Salt Creek at RM222.4, Fish Trap at RM216.4, and China Bar at RM192.3. In order to collect valid samples at these sandbars for flows requested by FERC, the HCC needed to be operated to provide steady flows at the individual sandbars for the duration of the sampling. We estimated that it would take approximately 4 hours to collect adequate data at each bar for each flow. In order to schedule when the flows needed to be released from the dam, we used the MIKE 11 HD model to estimate travel time between the dam and each of the bars. The farther downstream from the dam, the more "flattened out" or "attenuated" a change in flow tends to become. Therefore, we decided to allow a variation in flow at each of the bars of plus or minus 5% during sampling. For example, sampling for 20,000 cfs at a bar could start when flow was estimated to be between 19,000 cfs and 21,000 cfs. This required that steady flows for the lower bars (especially China Bar) be run longer than four hours to compensate for the attenuation of the flow change.

In order to reduce the amount of time that flows had to be held steady, IPC decided to equip and run two separate crews to perform the monitoring. Also, in the initial monitoring period with two of the lower flows, it was possible to monitor two flows on the same day due in part to easier sampling and longer daylight hours. However, with higher flows increasing the complexity of sampling it was only possible to monitor one sandbar at one flow per day per crew.

Equipment

The two Helley Smith samplers used in this effort were similar but not identical. One was borrowed from the University of Idaho and one was purchased from Rickly Hydrological Company (BL-84). The sampler purchased from Rickly Hydrological Company is a 65 lb. (29.5 kg) cable-suspended bedload sampler with 3" x 3" (76 mm x 76 mm) opening and 1.4 expansion ratio. A tailfin arrangement provides flow direction orientation and sliding collar allows adjustment of balance point based on streamflow conditions. The collar was set so that the sampler entered the water tail first to aid in rapid orientation with the streamlines of flow. This suspension attitude also ensures that the sampler orifice will lift up immediately when the unit is raised from the bed to eliminate loss of sample. This sampler uses a style #3 nylon mesh sampler bag. The sampler borrowed from the University of Idaho has the same characteristics such as throat size, expansion ratio, tail fins, and mounting point, with a slightly different weight due to different construction materials and slightly different size of frame.

In order to use the Helley Smith sampler to collect bed load material, the sampler must be kept in place and held stationary for a sufficient amount of time (enough time to collect a valid quantity of sediment if there is movement). Given the relatively low velocities and the variability in velocities (both magnitude and direction) and the potential for a boat hull to change hydraulic characteristics in the area sampled, we decided that it was not practical to deploy the sampler from a jet boat. Therefore, we equipped two catarafts as work platforms from which the sampler could be deployed. The catarafts were equipped with stations for two people, one to lower and raise the Helley Smith sampler and one to locate and hold the cataraft in position. The Helley Smith sampler was deployed near the middle of the cataraft through an opening in the floor plates. At Pine Bar, we were able to run a rope from the rock out in the channel to locations on the sandbar to hold the cataraft in place for the portion of the bar between the rock and the sandbar. At the other three sandbars we used a combination of anchors out in the current and ropes to shore to locate and hold the cataraft in place.

Given that most of the areas where we needed to deploy the sampler did not have a level bed, we were concerned that the sampler would not provide valid data due to: 1) digging into the sand, thus scooping up sand; 2) coming to rest at an orientation not parallel to the current; 3) coming to rest with part of the sampler hung up on a large rock. Therefore, we mounted an underwater camera lens above the mouth of the Helley Smith samplers oriented so that we could see the sampler mouth and visually determine if there was mobility during the sample period and confirm the Helley Smith orientation relative to the flow and bed surface. The underwater lens also allowed us (in most locations) to verify the substrate type at the sampled location. A monitor was located on the cataraft so that one of the crew could visually monitor the status of the sampler. During the initial sampling, one crew had only a monitor and therefore no ability to record images from the underwater lens other than written notes. Otherwise, a video camera was used as a monitor and video clips of the deployment were generally collected.

A handheld GPS (GEO XT) was used to determine cataraft location relative to sand substrate, where to locate the sample point, and to record the actual location of the sample point. Accuracy of post-processed locations is sub-meter.

Samples were contained in sealable plastic freezer bags with sample information recorded both in a field book and on the plastic bag.

Sample Collection Procedures

Each monitoring crew consisted of 4 people. Two people were on the cataraft and deployed and retrieved the sampler, operated the equipment and took notes. Two other people stayed on shore to handle ropes and provide other assistance as necessary. Taking into account the relatively low velocities over much of the sand bar areas, we decided to operate on the assumption that if an area was mobile, we might need to leave the sampler in place for up to 15 minutes to collect a meaningful sample. In general, the Helley Smith sampler was deployed by hand using a rope from the cataraft and the underwater lens was monitored to ensure that the nose of the sampler did not dig into the sand and thus collect a false sample. If the sampler appeared to be oriented incorrectly based on debris in the water floating through the field of view, the sampler was picked up to try to correct the orientation. Once the sampler was down, the substrate, time, and point number for the GPS location, whether or not movement could be visually determined, and any other pertinent information were noted.

The initial deployment was typically 5 minutes unless it was visually clear that the bed was mobile. If it was visually clear that the bed was mobile the sampler was left deployed for 15 minutes. Also, based on previous sampling and judgment, if it was determined that there was high potential for movement, the initial deployment was left for 15 minutes unless it was visually clear that there was no movement. After the 5-minute deployment, the sample was retrieved and the mesh bag checked for signs of sand. If a significant quantity sand was judged to be in the bag (generally determined by whether there was more than a few grains stuck to the mesh and enough to collect) it was collected in a freezer bag and the sampler was re-deployed for 15-minutes. If only organic material was collected in the bag or if the bag was empty, it was washed clean and noted as not mobile. At collection, no effort was made to separate sand from organics such as leaves, twigs, and pine cones. Notes were made indicating whether or not a sample was collected at this location.

Video clips were taken for most of the deployments. Times from the video were recorded to allow correlation between video clips and sample locations. Video was not recorded for the full sample duration in most instances.

Sample locations were determined by overlaying the area of sand and stability/mobility (as indicated by the model) and installing this map on the GEO XT’s. With GPS showing the current location on this map, we were able to locate the cataraft to sample places with sand and in both the predicted stable and mobile areas.

Sample Analysis

Samples collected were taken to a local engineering laboratory (TerraCon, Boise, ID) for analysis. All samples were oven dried and weighed to get a dry weight. Samples with enough mass to satisfy or nearly satisfy ASTM requirements (500grams) were sieved to develop PSD data. Samples that had organic material in them (most of the samples) were burned to get a dry weight of sediment.

Results

In the field we generally bagged anything that the sampler collected as long as there was any sand that could be retrieved from the sampler mesh bag. This resulted in many samples consisting of very small amounts of material and even smaller amounts of sand after the organic material was burned off. Therefore, some of the points where a sample was collected were subsequently determined to be non-mobile because the amount (or lack thereof) of sand actually recovered was so small.

We also reviewed the videotape of the sampling and used this to re-evaluate mobility at the sample points. In some cases, it was visually apparent that sand sizes were mobile but no sample was collected due to sampler orientation relative to flow lines or uneven substrate surface. Conversely, if no mobility was observed but if the sampler was seen to "scoop" a sample during deployment or retrieval and only a small amount of sediment was contained in the sample; this point would be determined to be stable. Figures E-1 through E-24 show the locations where the sampler was deployed at each sandbar and each flow and Table E-1 shows the results of samples (including PSD) that were collected at these locations. Note that some of the PSD's are based on small sample weights and should be used with caution. The Figures present three (3) types of results for the sampling effort, 1) Locations where no sand movement was indicated from the video or Helley-Smith samples, 2) Locations where sand movement was indicated either by sampling or movement noted in the video, and 3) Locations where movement of 1.0 mm sand was verified with PSD's obtained from the Helley-Smith samples. At the locations where "sand movement was indicated" steady movement was usually not observed, only occasional sand movement was observed due to what appeared to be velocity bursts. We presented these locations as "sand movement indicated" even if no sample was collected or a very small sample was collected. A summary of each sandbar is presented below:

- The sampling results for Pine Bar follow the model results well, except for the 15,000 cfs flow, where the field effort indicates less movement than what the modeling results indicate. At 30,000 cfs some mobility was indicated by the model in the side channel, which was verified by the sampling results.

- At Salt Creek Bar, the field results followed the modeling results well for flows of 10,000 cfs, 15,000 cfs and 20,000 cfs. At 25,000 cfs and 30,000 cfs some visual movement was noted in areas predicted to be stable by the model. All of the samples except one collected at Salt Creek Bar were less than 10% of the size required to perform a PSD analysis.

- At Fish Trap Bar for discharges of 10,000 cfs, 15,000 cfs and 20,000 cfs, the field results conform to the modeling results well, with the field results indicating a more stable bed at 15,000 cfs and 20,000 cfs. For 25,000 cfs at Fish Trap Bar, the field results indicate more mobility on the upstream end of the bar than the modeling results, but the d_{50} of these samples range from 0.44 mm to 0.72 mm. At 30,000 cfs, the sampling results are reasonably consistent with the model results.

- For China Bar, the field effort indicates a more stable bed than the modeling results for flows of 10,000 cfs and 15,000 cfs. At 20,000 cfs, 25,000 cfs and 30,000 cfs, there are a few sample points where the field samples do not match the modeling. Most of these are close to transition zones between mobile and stable areas.

There are several issues that should be kept in mind when using the data from this sampling effort:

First—Given the generally low and variable velocities over most of the sampled area, it was difficult to properly orient the Helley Smith sampler. In some cases, the proper orientation was clear, based on visual indications from the underwater lens and twisting the deploying rope could rotate the sampler or simply raising the sampler slightly and letting it rotate by itself and dropping it when the “correct” orientation was achieved. In other cases, the visual indication was not clear either due to changes in the current with time or low visibility due to the depth of the sampler and/or turbidity in the water.

Second—In some locations because of shifting or strong currents it was difficult to hold an exact location with the cataraft. In these cases, the position of the cataraft while collecting GPS data could be slightly different than the position of the deployed sampler (but within one or two meters). Also, in these cases, if the sampler needed to be deployed a second time to collect a 15-minute sample, the cataraft could shift position slightly between the first and second deployment thus deploying the sampler in a slightly different location than the initial deployment. However, this shift was usually within a few meters of the original position.

Third—Every effort was made to field verify the modeling results by evenly distributing the samples over the sandbar area. However, due to strong and varying current directions, in a few instances the cataraft could not always be placed precisely where desired. Therefore, the sample points are distributed as uniformly over the area to be sampled as crew safety allowed.

Fourth—the data collected in this effort show only mobility at the monitored points, they do not yield any information on the rate of sand loss from (or deposition to) these areas nor whether mobile sand is simply deposited in another area on the sand bar or if it is transported downstream.

Fifth—The field effort provided results that show where sand particles were stable or show some indication of mobility. During the field effort, a portion of the sand mobilized appeared to redeposit at other locations on the bar. This was observed at fish trap bar during the two highest flows, 25,000 and

30,000 cfs. One item the field crews visually noted during the testing was the amount of sand mobilized and entrained due to boat wakes. This sand was not limited to particles below the water line, but included particles well above the water line that were entrained in the wave washing off of the bar. Based on these field observations, we have developed the opinion that boat wakes have an effect on the sandbars below Hells Canyon Dam. This mechanism cannot be ignored when evaluating causes of erosion in the Hells Canyon reach.

Evidence of Active Bed Load

Given the lack of high flows in recent years, there has been limited opportunity to monitor movement of an active bed load. However, IPC has observed on many occasions anecdotal evidence that verifies there is an active bed load component in the Snake River in Hells Canyon. For example, in 1998 IPC installed pressure transducers in the Snake River in Hells Canyon to collect data for calibrating a hydraulic model. The transducers generally consisted of a transducer head mounted in a weight with a ½” conduit from the transducer head back to the bank above the high water mark to a data logger. The transducer was generally 50 to 150 feet out from shore during normal water flows. The transducers were deployed from a boat by laying the cable along the riverbed starting from shore and working out to the limit of the cable. Between the low water mark and the data collector box, the exposed cable was covered with loose rock to reduce the likelihood of vandalism but the underwater portion of the cable was not buried during installation. Several of these transducers were removed in January 2002. Divers were used to retrieve the transducers and in several cases, found that the cable and transducer were covered by up to two feet of sediment and they had to follow the cable out from shore pulling it up as they went to locate the transducer head.

During investigations looking for snails and mollusks in the fall of 2004, IPC divers visually searched several areas in the Snake River below HCD. These divers noted that in many locations even when the bank above the waterline consisted of large rocks and boulders with little or no sand or fine materials, the riverbed and banks below water contained significant pockets of sand in between the larger substrate types.

IPC installed 15 scour chains in spawning beds in the Snake River below HCD in December 2003, following the majority of Fall Chinook spawning activity. Substrate at these areas is in the range of 1” to 6” diameter. In October 2004 IPC relocated 12 of these scour chains for monitoring and noted that several had been partially buried. Some of this disturbance could have been a result of salmon spawning activity moving the substrate but nonetheless it indicates that there is potential movement of surface material in the canyon. The peak flow between installation and monitoring of the scour chains was 30,800 cfs.

Other evidence of an active bed load component includes the sediments supplied by tributary blowouts (sediment rich, mass wasting event that changes the tributary fan topography). Subsequent to a "blowout" of Granite Creek (RM 239.6) in May of 2003, boat drivers and others familiar with the river pointed out several sand and gravel features along the bank of the river below Granite Creek that had obviously changed shape, size, and surface color. Because we did not have detailed topographic information prior to the event, we were unable to quantify these changes but this clearly demonstrates sediment supply and movement through the Hells Canyon Reach of the Snake River.

While Granite Creek is one of the larger drainages between the HCD and the Salmon River and might be expected to deliver significant quantities of sediment to the Snake River, Two Corral Creek (RM 222.3) is a relatively small tributary in the canyon. It is small enough that it did not make the cut when we selected drainages to survey and sample for sediment transport during preparation for the FLA. Two Corral Creek is an ephemeral drainage that normally does not have surface flow into the Snake River during the summer. However, in late June, 2004 Two Corral Creek had a "blowout" event and transported substantial amounts of material into the Snake River, extended the fan into the Snake River approximately 18 feet over a width of about 300 feet, and cut a channel in the drainage that was approximately 60 feet wide and 4 feet deep. This channel was in the tributary canyon several hundred feet above the confluence of Two Corral Creek and the Snake River. Figure E-25 shows aerial photographs of the Two Corral Creek fan the previous year and about 3 months after the "blowout". We surveyed a cross section and slope the day following this "blowout" event and collected a bed material sample from the fan area. Calculations based on these data using the bed material particle size distribution (PSD) to estimate a flow resistance value showed that the peak flow during this event was about 6,600 cfs. This estimated flow value is a fairly coarse estimate for several reasons, but consistent with USGS methods to estimate peak discharges of ungaged events. First, Two Corral Creek was significantly deformed by this flood so the channel cross section that we surveyed after the fact is almost certainly not the same as the cross section that was present at the time of peak discharge. The channel probably underwent a cycle of erosion and then subsequent re-deposition as the flood peak receded. Second, we estimated roughness based on a bulk material sample collected on the fan below the cross section. While this sample should be fairly representative of the bed material, the roughness estimated based on this sample does not include shape factor losses and larger boulders, trees, and other vegetation that can have a significant effect on effective roughness during a flood event as the flow goes around them or transports them during the event.

Several IPC employees and Dr. James Milligan/University of Idaho and Dr. Jim Liou/University of Idaho happened to be at Kirby Creek Lodge the evening that Two Corral Creek blew out. During the same storm event, Muir Creek (RM 218.9) also experienced a blowout event. Muir Creek is a small creek across from Kirby Creek. Muir Creek is also an ephemeral stream and flows are rarely seen at the confluence with the Snake River. During a very short period (on the order of an hour or so) Muir Creek flowed at such a high rate that the noise attracted our attention at Kirby Creek Lodge several hundred feet downstream and across the river. We collected a grab sample of the water coming out of Muir Creek and also in the Snake River below a couple of rapids that would have mixed the flows to some degree. The next day we collected a grab sample from the Snake River well above the creeks that had blown out. The background suspended sediment in the Snake River was 7 mg/L which is consistent with previous suspended sediment samples collected for background levels. The suspended sediment in Muir Creek where it entered the Snake River was 93,700 mg/L. The suspended sediment in the Snake River below Muir Creek was 333 mg/L. We were unable to estimate the peak flow in Muir Creek. It should be noted that the day following the Muir Creek event it was very difficult to tell that it had flooded, and it is possible that the frequency of these events is higher than records or observations indicate. While again this does not quantify the sediment load from the tributaries it is further anecdotal evidence that tributaries can contribute significant quantities of sediment to the river in episodic events.

While these observations do not quantify bed load sediment, they make it clear that there is movement of sediment in the mainstem of the Snake River in Hells Canyon and the mass movements in the tributaries episodically deliver large quantities of sediment to the system. This is consistent with the FLA where we conclude that local tributaries do supply sediment and that there is transport of sediments over a pre-historic armor layer.

2.6. Response to (f)—Sandbar Slope Stability Analysis

(f) The sandbar slope stability analysis performed for the final license application did not consider a range of flows representative of proposed operations. Please repeat the sandbar slope stability analysis using a reduction in flow from 20,000 cfs to 10,000 cfs over a 2-hour period. This additional analysis will help to resolve concerns about sandbar stability.

This section is an update of a technical memorandum prepared by CH2M HILL and presented the FLA. The updated technical memorandum is included in Appendix C of this AIR.

Background

The original analysis for the load following scenario considered an 11-hour drawdown for Pine Bar, Fish Trap Bar, and Tin Shed. Use of the modified infinite slope fundamentally relies on a factor of safety (FS) associated with the equilibrium seepage slope (ESS) that assumes the slope is fully saturated and infinitely long. These assumptions are conservative (that is, the likelihood of slope failure is overestimated) due to the following factors:

- Relying on a fully saturated and infinitely long slope neglects other components of the potential failure surface that are above the saturated zone.
- Complete saturation assumes no change in the phreatic surface, independent of time. This instantaneous drawdown creates the maximum difference in pore pressure on the seepage face. Even though the AIR requests a two-hour drawdown, we used an instantaneous drawndown because there was not a defensible means of estimating the shape of the phreatic surface over a two-hour period.

In addition, other conservative factors were incorporated into the analysis. Examples include:

- The final choice of critical slopes was based on a combination of steepness of the existing sandbar slopes and occurrence of maximum drawdown for the two load following scenarios.
- The angle of internal friction was assumed to be 26 degrees (the minimum value obtained from laboratory direct shear tests) to compensate for uncertainties in soil properties.

A comparison of the results of the original analysis (based on load following from 26,000 cfs to 10,000 cfs) to the analysis contained herein is presented in the discussion section.

Methods

The sandbar slope stability analysis has been revised to address FERC's request. Discharge records indicate that the maximum recorded drawdown occurred on March 6, 1995, when the maximum drawdown head ranged between 1.6 m (Fish Trap) to 1.13 m (Tin Shed) over a period of about 11 to 12 hours. For the three sites, the discharge associated with these observed heads was 26,000 cfs (736 m^3/s) at high water level to 10,000 cfs (283 m^3/s) at low water level.

Other lower load swings were also examined, and these were found to cause fluctuations in river water level between the range of elevations indicated, but at a lesser drawdown head. During summer months, the flow fluctuations from the dam are typically limited to 10,000 cfs (283 m^3/s), but this load swing could occur more frequently than the 16,000 cfs (453 m^3/s) load swing.

Analyses of all the three sites for the 10,000 cfs load swing, specifically due to reduction in flow from 20,000 cfs (566 m^3/s) to 10,000 cfs (283 m^3/s) are, thus, included in the revised analysis. This flow reduction would result to lowering of the water level elevations in the three sites as follows:

- Fish Trap Site: Elev. 348 m to Elev. 346.86 m for a maximum drawdown head of 1.14 m (3.7 feet)

- Pine Bar Site: Elev. 376.39 m to Elev. 375.48 m for a maximum drawdown head of 0.91 m (3.0 feet)
- Tin Shed Site: Elev. 346.57 m to Elev. 345.83 m for a maximum drawdown head of 0.74 m (2.4 feet)

The time analysis was not incorporated because use of a fully saturated surface provides the most conservative estimate of potential slope failure and there wasn't a reliable means of estimating the slope of the phreatic surface.

Identical to the original analysis, stability analyses were conducted using slope cross-sections or transects generated from surveys of the site. To minimize the number of cases to be analyzed, the transect slopes generated for each site were examined, and the sites with the most critical slopes were initially selected for analysis. The Fish Trap site was selected for complete analysis using the two load following scenarios while the Pine Bar site was judged to be the more critical for the flood recession scenario. The flood recession analysis conducted for the Fish Trap site was primarily carried out to back up the flood recession analyses for the Pine Bar site. All three sites were analyzed for the 10,000 cfs (283 m^3/s) load swing, which represents the more frequent load following scenario.

The stability evaluations were carried out using a combination of three methods, namely: (a) modified infinite slope analysis, (b) traditional infinite slope analysis, and (c) limit equilibrium procedure. The modified infinite slope is a graphical method that is based on the fundamental equation for evaluating the FS of a saturated, infinite slope with seepage parallel to the face. This method was used on this project to determine the extent of slope materials that would be affected by fluctuations of the water level. Traditional infinite slope equation was used to estimate the FS of the slope analyzed by the modified infinite slope method. On some selected slopes, these FS estimates were verified by limit equilibrium procedure using the computer program PCSTABL. The complete methodology is described in Appendix C.

Results

16,000 cfs Flow Fluctuation

The minimum and maximum ESS at the Fish Trap site, defined by the slope angle α, was found to range between 10 and 14 degrees, depending on the values of unit weight and angle of internal friction of the soil in the slope. The existing slope (β) at this site varies between 5.7 and 13.3 degrees.

Slopes flatter than the ESS are designated as "unlikely" to fail by seepage-induced instability. Slopes steeper than the ESS are designated as "likely" to fail by seepage-induced instability resulting from the specified drawdown in the river water level. Using these criteria, it appears that most of the existing slopes for the Fish Trap site (transects 1 through 9) could be regarded as "unlikely" to fail by instability due to the 16,000 cfs flow fluctuation caused by operation of the Hells Canyon Dam. For the case of transects 10 and 11, where the existing slopes are steeper than the ESS, slope materials inside the potential failure constitute transient sediments that would accumulate and disperse in a cyclic pattern following conditions of rapid drawdown due to the load following operation in the dam.

Similar to the modified infinite slope analysis, results of FS modeling calculations suggest that, except for the slopes in transects 10 and 11, most of the existing sandbar slopes at the Fish Trap site are "not likely" to fail by the sudden lowering of the river water level as a result of the Hells Canyon Dam operation. The average FS estimated for these slopes range between 1.1 and 1.8 (see Table F-1). (As a reminder, in limit equilibrium analysis, the FS is defined as the factor by which the strength of the soil exceeds the strength needed to maintain stability. Thus, a FS of greater than 1 indicates that the slope is stable.)

10,000 cfs Flow Fluctuation

All three sites show similar results of analyses using the 10,000 cfs flow fluctuation in river water level. At the Fish Trap site the existing slope (β) of the sandbar for this site within the limits of the drawdown elevation varies between 5.7 and 12.7 degrees. Except for transects 10 and 11, the calculated average FS appear to vary between 1.0 and 1.8. These results appear to be very similar to that of the 16,000 cfs flow fluctuation.

At the Pine Bar site the existing slope (β) of the sandbar at this site varies between 5.1 and 14 degrees. Except for transect 1, 3, 4, 5, and 6, the calculated average FS varies between 1.0 and 2.3. At some slope segments along transects 1, 3, 4, 5, and 6 the FS is less than 1.0. At these transects, the volume of the sandbar that is considered to be in the transient state is very small due to the smaller magnitude of drawdown (that is, 1 meter [3 feet]) and the fact that the existing slope within the limits of the drawdown is close to the ESS value.

At the Tin Shed site the existing slope (β) of the sandbar at this site varies between 2.3 and 9.9 degrees. Since the existing slope is less than the minimum ESS value of 10 degrees, it is expected that the average FS at this site is at least 1.0 (range of FS is 1.0 to 4.5).

Summary

Because of the methodology and conservative nature of the original analysis, the revised analysis reaches the same overall conclusions. In summary, the combination of traditional and modified infinite slope analyses indicates that slope failure of the Fish Trap, Pine Bar, and Tin Shed sites due to the load following operation (for both 16,000 cfs and 10,000 cfs flow fluctuations) is not expected.

Some portions of the sandbar at the Fish Trap site exceed the slope necessary to maintain stability. However, field observations indicate that the slopes at this portion of the bar may comprise gravel and cobble materials that appear to possess higher strength (particularly due to interlocking) than represented by the shear strength assumed in the analyses (that is, $\phi = 26$ degrees, which is for a loose silty sand).

FS from the traditional infinite slope and limit equilibrium analyses vary depending on whether the minimum, maximum, or average soil properties are used but are typically greater than 1.0 for all transects for even the minimum properties. In design cases where it is necessary to consider potential loss of life or loss of property, a FS of greater than 1.5 is usually required. For a less critical case, a FS of 1.3 would often be acceptable. If the average soil properties determined from laboratory testing are used in conjunction with the fact that the soils comprising the sandbars contain a heterogeneous mix of fine to coarse sand with some interlocking gravel and cobbles, the estimated FS for the majority of the sandbar slopes are expected to be 1.3 or greater.

2.7. Response to (g)—Supporting Materials for Sandbar Distribution Analysis

(g) Supporting materials for the spatial and temporal analysis of sandbar distribution have not been included in the license application. Please provide the aerial photographs and sandbar mapping utilized for the sandbar analyses. This information will allow for a more complete review of the analysis and interpretations regarding geomorphic alteration within the river downstream of Hells Canyon dam.

A sandbar count analysis was conducted using aerial photos as described in Technical Report Appendix E. 1-1 Section 9.9.2. For this analysis, photos from various years (1955, 1964, 1973, 1977, 1982, 1997) were obtained from the USDA APFO, USACE and IPC. These photos were used in conjunction with a river mile map (comprised of digital ortho-photos overlain with river mile locations) to identify sandbars on both sides of the Snake River from Hells Canyon Dam (RM 247.6) downstream to the Salmon River Confluence (RM 188.28). To provide FERC with the supporting material for this spatial and temporal analysis, these photos have been burned onto five DVDs, of which two copies are submitted with this AIR. The contents of these DVDs are summarized in Appendix D. The photos have been compressed to allow them to fit onto a manageable number of DVDs. Many of the photos were scanned as TIF files that were approximately 96 MB. The majority of these files have been converted to JPEG files, which reduced their size down to approximately 15 MB. Even though the files have been reduced in size, they still maintain a high enough resolution to enable the user to zoom to the same extent that was used during the original sandbar count analysis.

The actual sandbar counts have been included as Tables G-1 through G-9. They include the year of the photos, the approximate flow, sandbar number, location (side of river and approximate river mile), photo number and comments associated with the sandbar. In the comments section, the name of the sandbar was identified when possible to give a better location of where the sandbar occurred. Also, an “O” was placed in the comments section to denote the occurrence of a sandbar away from the river’s edge. These types of sandbars were identified because the aerial photos were taken at various flows, and many times sandbars seen next to the river in one set of photos might be identified away from the river’s edge in another photo because of a lower water level.

Also provided are the river mile maps (Figures G-1 through G-32), which are 1:24,000 scale USGS Digital Orthophoto Quadrangles (DOQ’s) that have markers every tenth of a river mile from HCD downstream to the mouth of the Salmon River. Digital Orthophoto Quadrangles were used because they are a uniform-scale image, and can be used as a map that allows for the overlay of other map information within GIS (i.e., river miles, distance measurements, etc.). Having a uniform-scale image in conjunction with river miles marked on them allowed us to consistently identify the location of sandbars found in the aerial photos.

Adjusted Sandbar Counts

A set of aerial photos covering the HC reach of the Snake River in 2003 was acquired shortly after the FLA was submitted. The aerial flight was to be conducted during a steady-state flow of 8500 cfs; however, inclement weather conditions were moving into the area forcing the flight to be pushed forward. Because of this, the flow varies in segments of the river from 8,500 cfs to approximately 10,000 cfs. The flows during the period of the aerial flight were routed using the MIKE11 model, and a reach weighted average discharge was estimated for five-mile segments from HCD to the Salmon River. The reach weighted average discharge used to determine the adjusted sandbar count for this aerial flight was 9,230 cfs. A sandbar count was then conducted on the 2003 photos (based on the 9,230 cfs flow), and the results have been included in this section of AIR S-1 (the 2003 photographs are included on the submitted DVD’s).

In the FLA, a factor of three bars per 1,000 cfs was used to adjust the sandbar count for discharge differences between each year of aerial photos. Figure 14 in Appendix E.1-1 of the FLA contained this information, and while adding 2003 data to this figure, it was noted that the adjusted sandbar count value for 1977 was written down incorrectly. The adjusted sandbar value was reported as 144 sandbars; it should have been reported as 155 sandbars, which is consistent with the adjustment factor of three bars per 1,000 cfs. Figure G-33 in this AIR is similar to Figure 14 in E.1-1 except the value for 1977 has been corrected and information for 2003 has been added.

The 2003 data was also added to the five-mile increment adjustment methodology that was described in the FLA. Since the flows for the 2003 aerial photos were lower than 12,000 cfs, the count was adjusted down to normalize it to a 12,000 cfs flow. As described in the FLA, these segments were then broken up into three main sections of the river: Hells Canyon Dam to Pine Bar (HCD-PB), Pine Bar to Pittsburg Landing (PB-PL) and Pittsburg Landing to the Salmon River confluence (PL-SR). The original figure in the FLA was modified to include the 2003 data, and is included in this document as Figure G-34.

Results

Figure G-33 shows the actual and the adjusted sandbar counts. The unadjusted number shows a reduction from 118 bars in 1997 to 102 bars in 2003, while the flow adjusted number shows a decline from 142 bars in 1997 to 94 bars in 2003. There are several possible explanations for this decrease in the number of sandbars in Hells Canyon. Some are discussed below. It is possible that even after the large drop in sandbar numbers in the early 1970's immediately after the closure of the HCC, there continues to be a downward trend in the number of sandbars in Hells Canyon and a new dynamic equilibrium as discussed in the FLA and AIR S-1 (d) has not yet been reached. Or, equilibrium has in general been reached, and the number of bars will continue to increase and decrease in response to sediment supply and hydrologic conditions. If this is the case, the 2003 series could be showing the low end of a range of dynamic equilibrium for sandbar numbers in the canyon. This would be consistent with an extended period of low flows—the same sort of decline is seen between 1977 and 1982, which was also a period of below normal stream flow. Also, recent aerial photographs are of a higher resolution, which results in better quality photographs compared to the images from earlier flights. The higher resolution makes it easier to distinguish the texture of features in the photographs. Therefore, areas that would have been interpreted as sand in earlier photos may now be interpreted as coarser materials because of better imagery. Also, technicians analyzing the 2003 photos were familiar with the river during that time period and that has an effect on the interpretation of possible sand features that was not available with the earlier photo series.

The flow adjustment (as described in the FLA) is based on three flights performed in 1973 within a period of a few days under varying flow conditions (5,000 cfs, 12,000 cfs, and 18,000 cfs). This was likely still within a period of substantial adjustment of sand features in Hells Canyon, and it is not known if the adjustments based on conditions during the 1973 time frame are still appropriate under conditions 30 years later. However, this is the best available information we have to compare photographs across varying flow conditions.

The 2003 sandbar count total of 102 sandbars was also added to the reach base methodology as described in the FLA, and incorporated into Figure G-34. The sandbars for 2003 were separated into five-mile increments, and adjustment factors from the FLA were utilized to calculate an adjusted sandbar totals for these increments. There is a decline in the overall number of bars and the number of bars in the PL-SR section of the river from 1997 to 2003. However, the number of bars in the PB-PL has remained stable, and the adjusted number for HCD-PB has actually increased by four sandbars. The increase in sandbars within the HCD-PB reach could be partially attributed to the Granite Creek blowout that occurred in late May of 2003 because sandbars were identified in that reach that were not apparent in prior years. See AIR S-1 (e) for a more complete discussion of the Granite Creek blowout.

Sandbar Transects

Background.

IPC conducted transect surveys on four sandbars (Pine Bar at RM 227.5, Salt Creek Bar at RM 222.4, Fish Trap Bar at RM 216.4, and China Bar at RM 192.3) on the Snake River in Hells Canyon to evaluate the changes in their topographical features. In the FLA, IPC presented the analysis of data collected from transect surveys conducted between 1998 and 2000. In addition to the information included in the FLA, there are limited amounts of survey data available for 1997, 1999 and 2002, which are included where the data are comparable. Since the submittal of the FLA in July 2003, IPC has collected additional survey data in 2003 and 2004. The transect data for the 2003 and 2004 surveys are based on transect lines established in 1998.

Hydrology

As presented in the FLA, Hells Canyon experienced the highest and second highest peak discharges as recorded by the Hells Canyon Gage (13290450) during years 1997 and 1998. From 2000 to present, the Snake River basin has experienced below normal flow conditions. A summary of hydrologic information for 2000 thru 2004 are presented in Table G-10. The Table includes the highest daily average, the instantaneous 15-minute Peak, and yearly average discharge for each year.

The tops of the active portion of the sandbars tend to be at an elevation corresponding to approximately 30,000 cfs. As Table G-10 indicates, this flow has only been exceeded in a couple of instances.

Pine Bar

In the FLA, IPC presented the results for Pine Bar for the following years: 1997, 1998, 1999 and 2000. Transects A (Figure G-35), B (Figure G-36), C (Figure G-37), and D (Figure G-38) were supplemented with the survey data collected during 2003 and 2004. The locations of these transects are shown in Figure G-39. Survey data from the 7 years demonstrate that Pine Bar experienced deposition in 1998, and is relatively stable with the exception Transects A and B, which are located in a high use area of the bar (recreation and river access). The 1998 survey was conducted in the fall, following the second highest peak flow of record.

There was some localized erosion and deposition on the upstream end of the bank and bar between 1998 and 2004. As seen in Transect B in 1998 (and verified in the field), there was not a well-defined channel between the bar and the bank on the upstream end. In 2000, survey data showed a defined channel, while the 2003 and 2004 survey data indicates that the channel continues to be reworked.

Salt Creek Bar

In the FLA, data was presented for Salt Creek Bar for the following years: 1997, 1998, and 2000. The transects at Salt Creek Bar are shown on Figure G-40 through G-43. The transect data show that most of the bar did not change noticeably between the 1998 and 2004 surveys. There were minor areas of erosion near the 12,000-cfs water surface elevation.

Fish Trap

In the FLA, the data was presented for Fish Trap Bar for the following years: 1997, 1998, 1999, and 2000. The transects at Fish Trap are shown in Figures G-44 through G-48. The survey data show that erosion occurred on the front of the bar below the 30,000 cfs elevation. The rest of the bar and bank did not appear to experience substantial changes between 2000 and 2004. In addition, the survey data from 2002, 2003, and 2004 indicate that the position of the cut-bank has not experienced any major changes since 1999.

China Bar

In the FLA, the data was presented for China Bar for the following years: 1997, 1998, and 2000. In the FLA, Transects A had a mis-labeled series. The data series labeled 1997 should have been labeled 1998 in Transect A, the other transects were labeled correctly. Transect data are shown in Figures G-49 through G-52. The figures show changes to the crest elevation that occurred between the 1997 and 2004 surveys. In the FLA we noted that comparing transects from 1997 to 2000 showed areas of both deposition and erosion, and that there wasn’t a clear trend one way or the other. Survey data from 2000 to 2004 show that the top elevation of China Bar has been consistent, but the river face of the bar is eroding toward the bank.

3. ACKNOWLEDGMENTS

We would like to extend thanks and appreciation to the many people that were instrumental in acquiring the necessary information and performing analysis associated with this AIR. This includes the field sampling crews that put in long strenuous days in Hells Canyon in all types of weather conditions.

Specifically the notable efforts of Steve Zanelli, Nathan Black, Toby Wilson, Mike Butler, and Brandal Glenn. We would also like to thank the IPC employees involved with orchestrating HCC operations for the special flow requirements required for the bed load sampling. Further, we'd like to acknowledge the contributions of CH2M Hill, David Evans and Associates, Golder and Associates, JUB Engineers, AeroGraphics, and Nelson and Associates for their extra efforts in helping us meet the needs and timeframes of the AIR.

4. LITERATURE CITED

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Table A-1. Data Used in Developing Estimates of Sediment Supply to HCC Reservoirs

Reservoir	Pre-Impoundment		Post-Impoundment		
	Aerial Photography	20' Contour Maps	Aerial Photography	Bathymetry	Geophysics
Brownlee	195x	Above and below normal high pool elevation	n/a	1996-98 Single-beam 200' transects	Dual Frequency Transects
Oxbow		Above and below normal high pool elevation	n/a	July 2004 Multibeam	Dual Frequency Transects
Hells Canyon	195x	Above and below normal high pool elevation	2004 for control of pre-impoundment photos	Dec. 2002 Multibeam	Dual Frequency Transects

Table A-2. Summary of Oxbow Reservoir Sediment Samples

Sample ID (RM[1])	River Mile	Water Depth (ft)	Material[2]	% Passing #200	D_{50} (mm)	Notes
OX 273	273	135	Organic gray to black sandy silt/clay	67.4	n/a	Spud = 6.9 ft., Organic reservoir sediment
OX 275.8 T	275.8	103	Black to dark gray silty sand	38.8	0.10	Spud = 1.1 ft., No odor
OX 275.8 R	275.7	64	Silty sand	25.0	0.11	No odor
OX 275.8 L	275.9	65	Sandy gravel with trace silt	10.6	3.03	
OX 276	276	112	Organic sandy silt/clay	55.7	n/a	
OX 279	279	72	Sandy gravel plus bivalve shells	---	---	3 attempts, 1st 2 empty
OX 279.5	279.5	95	Sand with gravel	2.3	0.39	Recovered sample on 2nd attempt
OX 282	282	62	Gravel/sand	---	---	3 attempts, no recovery except scrapings
OX 282.3	282.3	25	Rounded gravels and organic debris	---	---	3 attempts, poor recovery
OX 283 M	283	16	Gravel/sand	---	---	3 attempts, no recovery
OX 283 R	282.8	6	Gravel/sand	---	---	3 attempts, no recovery
OX 283 L	283.2	18	Gravel/sand	---	---	3 attempts, no recovery
OX 284	284	15	Cobbles/gravels substrate	---	---	3 attempts, no recovery

Notes
1) Sample ID is approximately equal to River Mile location
2) Samples with poor recovery not evaluated for PSD; estimated particle size by recovered materials, bottom characteristics and spud rod probing

Table A-3. Summary of Hells Canyon Reservoir Sediment Samples

Sample ID (RM[1])	River Mile	Water Depth (ft)	Material[2]	% Passing #200	D_{50} (mm)	Notes
HC 248.2	248.2	216	Brown to gray to black organic silt/clay with fine sand	87.1	n/a	Spud > 5.5 ft., gas bubbles in sample
HC 249.1A	249	83	Sandy gravel	6.3	25.0	Rocky - side slope deposition
HC 249.1B	249.05		Fine black silty sand	---	---	Poor recovery
HC 249.1C	249.1	189	Dark organic silt/clay	93.7	n/a	
HC 249.1D	249.15	193	Dark organic silt/clay with fine sand	83.8	n/a	Spud > 6.75 ft., organic
HC 249.1E	249.2		Gravelly	---	---	Rocky - side slope deposition
HC 251	251	183	Organic gray/brown silt/clay	92.2	n/a	Spud = 1.1 ft
HC 254	254	143	Organic gray/brown silt/clay with trace sand	89.5	n/a	Spud = 1.4 ft
HC 257	257	104	Dark gray/brown sandy silt	66.5	n/a	Spud = 1.4 ft., RM approximate - no gps point
HC 259.1 R	259	103	Silt/very fine sand	57.7	n/a	
HC 259.1 L	259.1	40	Very fine sand with trace silt	7.9	0.20	
HC 259.1 M	259.2	73	Very fine sand with trace silt	5.5	0.37	
HC 260	260	105	Very fine sand to silt	48.0	0.08	
HC 263	263	75	Silty sand	18.8	0.13	
HC 266	266	48	Sand with trace silt	8.6	0.28	
HC 269A	269	25	Sandy gravel	0.8	19.0	
HC 269B	269.1	25	Fine sand	2.8	0.62	
HC 270.8 L	270.7	8	Silty sand	26.9	0.14	Very slight odor
HC 270.8 M	270.8	8	Gravelly sand with trace silt	7.0	0.74	No odor
HC 270.8 R	270.9	20	Sandy gravel	4.0	12.77	No odor
HC 271.5	271.5	5	Boulder/cobble gravels	---	---	Could not reach sample location, No sample, boulder/cobble substrate

Notes
1) Sample ID is approximately equal to River Mile location
2) Samples with poor recovery not evaluated for PSD; estimated particle size by recovered materials, bottom characteristics and spud rod probing

Table A-4. Comparison of Reservoir Sedimentation Based on Full Pre-Impoundment Reservoir Bathymetry and Tributary Transport Calculations

Reservoir	Description	Volume	Mass[a]
		ac-ft	tons/year
Brownlee	1953	1,364,121	
1958 - 1998	Estimated Channel Volume	53,502	
	Estimated 1958 Volume	1,417,623	
	1998	1,355,578	
	Difference	62,046	2,783,799
	Difference (Sand or Larger)		387,000
	Transport Calculations		5,990,000
	Mainstem Snake River		279,000
	Ratio Calculations:Measured		**16.2:1**
Oxbow	1953 w/o channel included	50,720	
1961 - 2004	Estimated Channel Volume	13,076	
	Estimated 1961 Volume	63,796	
	2004	62,083	
	Difference	1,713	86,781
	Transport Calculations		0
			0.0:1
Hells Canyon	1953 w/o channel included	154,603	
1967 - 2002	Estimated Channel Volume	19,253	
	Estimated 1967 Volume	173,856	
	2002	171,571	
	Difference	2,285	142,188
	Transport Calculations		4,144,739
			29.1:1
HCC Total		Difference:	615,969
		Transport Calculations:	10,413,739
		Ratio:	**16.9:1**

Note that pre-impoundment information is not available in the year the dam was completed. This table assumes that significant storage would not start until the dam was completed.

Also note that transport calculations for Brownlee Reservoir do not include transport from the mainstem Snake River

[a]Mass for Brownlee is based on 82.4 lbs/ft^3 (see E.1-1 Sediment Transport, Supply, and Stability in the Hells Canyon Reach of the Snake River) and 100 lbs/ft^3 for Oxbow and Hells Canyon.

Table A-5. Summary of HCC Tributary Sediment Volume Calculations Based on Photogrammetry and Bathymetry

Tributary/ Reservoir	River Mile	Watershed Area	Photogrammetry		CH2M HILL Estimate	
			Fan Volume	Mass[1]	Fan Volume	Mass[1]
	mi	mi^2	ft^3	tons	ft^3	tons
Rock Creek/ Brownlee	320.1	45.5	n/a	n/a	8,828,345	441,417
Dennett Creek/ Brownlee	310.8	13.4	6,871,498	343,575	7,415,809	370,790
Sturgill Creek/ Brownlee	300.8	22.7	n/a	n/a	706,268	35,313
Brownlee Creek/ Brownlee	288.1	62.1	n/a	n/a	12,359,682	617,984
Salt Creek/ Oxbow	275.9	5.6	n/a	n/a	141,254	7,063
McGraw Creek/ Hells Canyon	259.2	12.3	2,442,266	122,113	3,796,188	189,809
Steamboat Creek/ Hells Canyon	248.1	4.68	n/a	n/a	1,412,535	70,627

[1]Assumes 100lbs/ft^3

Table A-6. Summary of HCC Tributary Sediment Volume Calculations Based on Geophysics Investigation

Tributary/ Reservoir	River Mile	Watershed Area	Geophysics	
			Fan Volume	Mass[1]
	mi	mi^2	ft^3	tons
Rock Creek/ Brownlee	320.1	45.5	660,113	33,006
Dennett Creek/ Brownlee	310.8	13.4	1,629,854	81,493
Sturgill Creek/ Brownlee	300.8	22.7	545,239	27,262
Brownlee Creek/ Brownlee	288.1	62.1	878,773	43,939
Summer Creek/ Oxbow	276.9	2.4	6,992	350
Salt Creek/ Oxbow	275.9	5.6	261,778	13,089
Pine Creek/ Hells Canyon	269.3	301	1,050,043	52,502
McGraw Creek/ Hells Canyon	259.2	12.3	54,912	2,746
Thirty Two Point Creek/ Hells Canyon	250.8	3.9	89,025	4,451
Steamboat Creek/ Hells Canyon	248.1	4.68	367,330	18,367

[1]Assumes 100lbs/ft^3

Table A-7. Summary of HCC Tributary Sediment Volume Calculations

		Tributary/Reservoir										
	Units	Rock Creek/ Brownlee	Dennett Creek/ Brownlee	Sturgill Creek/ Brownlee	Brownlee Creek/ Brownlee	Wildhorse River/ Oxbow	Summer Creek/ Oxbow	Salt Creek/ Oxbow	Pine Creek/ Hells Canyon	McGraw Creek/ Hells Canyon	Thirty Two Point Creek/ Hells Canyon	Steamboat Creek/ Hells Canyon
River Mile	n/a	320.1	310.8	300.8	288.1	283.1	276.9	275.9	269.3	259.2	250.8	248.1
Watershed Area	mi^2	45.5	13.4	22.7	62.1	177	2.4	5.6	301	12.3	3.9	4.68
Years Included	years	40	40	40	40	43	43	43	37	37	37	43
Transport Calculations												
Load 1957 - 1998 (40 years)	tons	0	5,640,000	2,872,000	1,032,000	0	n/a	0	0	1,040,000	n/a	n/a
Mean Annual Load	tons/year	0	141,000	71,800	25,800	0	n/a	0	0	26,000	n/a	n/a
Mean Annual Load	tons/year/ mi^2	0	10,522	3,163	415	0	n/a	0	0	2,114	n/a	n/a
Photogrammetry												
Fan Volume	ft^3	n/a	6,871,498	n/a	n/a	n/a	n/a	n/a	n/a	2,442,266	n/a	
Mass assuming $100 lbs/ft^3$	tons	n/a	343,575	n/a	n/a	n/a	n/a	n/a	n/a	122,113	n/a	0
Mean Annual Load	tons/year	n/a	8,589							3,300		0
Mean Annual Load	tons/year/ mi^2	n/a	641	n/a	n/a	n/a	n/a	n/a	n/a	268	n/a	0
CH2M HILL Estimate Based on Topography and Photo Interpretation												
Fan Volume	m^3	250,000	210,000	20,000	350,000	n/a	n/a	4,000	n/a	107,500	n/a	40,000
Fan Volume	ft^3	8,828,345	7,415,809	706,268	12,359,682	n/a	n/a	141,254	n/a	3,796,188	n/a	1,412,535
Mass assuming $100 lbs/ft^3$	tons	441,417	370,790	35,313	617,984	n/a	n/a	7,063	n/a	189,809	n/a	70,627
Mean Annual Load	tons/year	11,035	9,270	883	15,450	n/a	n/a	164		5,130		1,642
Mean Annual Load	tons/year/ mi^2	243	692	39	249	n/a	n/a	29	n/a	417	n/a	351
Geophysics												
Volume	m^3	18,693	46,154	15,440	24,885	0	198	7,413	29,735	1,555	2,521	10,402
Volume	ft^3	660,113	1,629,854	545,239	878,773	0	6,992	261,778	1,050,043	54,912	89,025	367,330
Mass assuming $100 lbs/ft^3$	tons	33,006	81,493	27,262	43,939	0	350	13,089	52,502	2,746	4,451	18,366
Mean Annual Load	tons/year	825	2,037	682	1,098	0	8	304	1,419	74	120	427
Mean Annual Load	tons/year/ mi^2	18	152	30	18	0	3	54	5	6	31	91
Ratios of Mean Annual Load compared with Transport Calculations (Transport Calculations/Alternate Method)												
Photogrammetry		n/a	16	n/a	n/a	n/a	n/a	n/a	n/a	8	n/a	n/a
Topography Interpretation		0	15	81	1.7	n/a	n/a	0	n/a	5.1	n/a	n/a
Geophysics		0	69	105	23	n/a	n/a	0	0	350	n/a	n/a

Table C-1. Mobile and Inundated Areas of Sandbars

Flow	Mobile Area	Inundated Area	Mobile Area as a Percent of Inundated Area
cfs	m^2	m^2	%
Pine Bar			
5000	0	9,595	0%
10000	51	10,854	0%
15000	1,053	12,123	9%
20000	309	12,625	2%
25000	855	13,131	7%
30000	1,276	13,391	10%
Salt Creek Bar			
5000	0	4,422	0%
10000	0	5,202	0%
15000	2	5,583	0%
20000	11	5,753	0%
25000	25	5,889	0%
30000	126	6,060	2%
Fish Trap Bar			
5000	0	1,180	0%
10000	15	1,685	1%
15000	213	2,203	10%
20000	449	3,244	14%
25000	731	4,036	18%
30000	1,132	4,509	25%
China Bar			
5000	386	765	50%
10000	670	988	68%
15000	761	1,184	64%
20000	755	1,479	51%
25000	850	1,698	50%
30000	928	1,903	49%

Table D-1. Sand Volume Estimate for Pine Bar, Salt Creek Bar, Fish Trap Bar and China Bar

Sand Bar	River Mile	Low End of Volume Range
	miles	m^3
Pine Bar	227.5	3,300 - 3,700
Salt Creek Bar	222.4	1,400
Fish Trap Bar	216.4	7,100 - 7,200
China Bar	192.3	2,100 - 2,200

Table D-2. Comparison of Sandbar Volume with Sand Supply

Description	Volume		Mass[1]	
Golders Estimate of Sandbar Volume				
Pine Bar (PB)	3,268	m^3	5,770	tons
Salt Creek Bar (SC)	1,381	m^3	2,438	tons
Fish Trap Bar (FT)	7,112	m^3	12,557	tons
China Bar (CB)	2,131	m^3	3,763	tons
Total	13,892	m^3	24,529	tons
Transport Calculations Sand Supply[2]				
HCD to Salmon - not incl Imnaha			148,285	tons/year
HCD to Pine Bar			94767	tons/year
Pine Bar to Tin Shed			11755	tons/year
Tin Shed to Salmon River			41763	tons/year
Sandbar mass by reach				
Mass PB			5,770	tons
Mass PB + SC			8,209	tons
Mass PB + SC + FT			20,766	tons
Mass PB + SC + FT + CB			24,529	tons
Compare Annual Supply to Bar Mass[3]				
PB			16.4	
PB + SC			11.5	
PB + SC + FT			5.1	
PB + SC + FT + CB			6.0	
[1]Mass based on 100 lbs/ft^3				
[2]All supplies reduced by one order of magnitude.				
[3]Ratio of Upstream Annual Supply to Mass of Sand in Bars				

Table E-1. Hells Canyon Sandbar Movement Sediment Samples

Date	Sandbar	Flow	d_{16}	d_{50}	d_{84}	Total Dry Weight	Inorganic Weight
		cfs	mm	mm	mm	g	g
Pine Bar							
9/13/2004	Pine Bar	25,000	0.325	0.72	2.3	21	20.7
9/15/2004	Pine Bar	30,000	0.41	0.73	2.95	69.4	68
9/15/2004	Pine Bar	30,000	0.29	0.6	1.29	135.8	132.5
9/15/2004	Pine Bar	30,000	0.325	0.62	1.26	33.4	32.9
Salt Creek Bar							
9/8/2004	Salt Creek	15,000				0.61	0.1
9/13/2004	Salt Creek	25,000				18.97	12.4
9/13/2004	Salt Creek	25,000				17.73	17.73
9/13/2004	Salt Creek	25,000				13.9	13
9/13/2004	Salt Creek	25,000				11.15	10.5
9/13/2004	Salt Creek	25,000				6.29	6.29
9/13/2004	Salt Creek	25,000				12.42	11.9
9/13/2004	Salt Creek	25,000				3.93	2.2
9/13/2004	Salt Creek	25,000				84.43	47.5
9/13/2004	Salt Creek	25,000				14.49	13.8
9/15/2004	Salt Creek	30,000				6.68	6.3
9/15/2004	Salt Creek	30,000				87.2	82.6
9/15/2004	Salt Creek	30,000				21.23	0.5
Fish Trap Bar							
7/23/2004	Fish Trap	15,000				0.37	0.32
7/23/2004	Fish Trap	15,000				0.64	0.5
9/9/2003	Fish Trap	20,000				130.45	130.45
9/9/2004	Fish Trap	20,000				0.14	0
9/9/2004	Fish Trap	20,000				4.43	4.43
9/9/2004	Fish Trap	20,000				0.24	0
9/9/2004	Fish Trap	20,000				48.13	47.6
9/9/2004	Fish Trap	20,000				11.7	11.2
9/9/2004	Fish Trap	20,000				2.66	2.6
9/9/2004	Fish Trap	20,000				9.09	8.9
9/9/2004	Fish Trap	20,000				1.18	1.1
9/14/2004	Fish Trap	25,000				25.23	25.23
9/14/2004	Fish Trap	25,000				42.04	40.9
9/14/2004	Fish Trap	25,000	0.38	0.56	0.92	276.21	275
9/14/2004	Fish Trap	25,000	0.34	0.44	0.57	736.4	736.4
9/14/2004	Fish Trap	25,000				187.62	187.62
9/14/2004	Fish Trap	25,000				22.06	22.06
9/14/2004	Fish Trap	25,000				25.9	25.3
9/14/2004	Fish Trap	25,000				5.47	4.3
9/16/2004	Fish Trap	30,000				46.2	44.5
9/16/2004	Fish Trap	30,000	0.43	0.72	1.05	824.2	627.2
9/16/2004	Fish Trap	30,000	0.38	0.60	0.95	587.6	587.6
9/16/2004	Fish Trap	30,000	0.35	0.50	0.80	440.3	438.9
9/16/2004	Fish Trap	30,000	0.37	0.60	0.95	744.02	737.8
China Bar							
9/9/2004	China Bar	20,000				25.96	25.96
9/9/2004	China Bar	20,000				2.88	2.88
9/14/2004	China Bar	25,000	0.25	0.475	0.76	1617.6	1617.6
9/14/2004	China Bar	25,000	0.28	0.53	0.77	113.8	113.8
9/14/2004	China Bar	25,000	0.44	0.6	0.82	121.5	121.5
9/16/2004	China Bar	30,000				22	21.8
9/16/2004	China Bar	30,000	0.42	0.72	1.06	621.1	618.9
9/16/2004	China Bar	30,000				22.29	16.5
9/16/2004	China Bar	30,000	0.275	0.52	0.78	37.1	37.1

Table F-1. Estimated Factors of Safety at Fish Trap Site for Load Following Scenario (16,000 cfs Flow Fluctuation)

Infinite Slope Analysis with Seepage Parallel to the Face				
Transect Number	Existing Slope Angle, β	Factor of Safety, FS		
	(degrees)	Minimum FS	Maximum FS	Average FS
		(γ_{sat} = 93 pcf)	**(γ_{sat} = 107 pcf)**	
1	8	1.1	1.5	1.3
2	7.4	1.2	1.6	1.4
3	6	1.5	2	1.7
4	5.7	1.6	2.1	1.8
5	5.8	1.6	2	1.8
6	7	1.3	1.7	1.5
7	7.7	1.2	1.5	1.4
8	8.2	1.1	1.4	1.3
9	9.7	0.9	1.2	1.1
10	12.2	0.8	1	0.9
11	13.3	0.7	0.9	0.8

Notes:

Based on 1995 hydrograph data. The analysis was conducted for maximum drawdown from Elev. 348.55 m to Elev. 346.93 m due to load following.

Existing slope angles defined by β indicate a break in the slope within the range of drawdown elevations considered in the analyses.

Analysis assumed an angle of internal friction of 26 degrees for the soil within the sandbar.

Table G-1. Sandbar counts for the 1955 (11,000 cfs) aerial photos.

1955 (US Forest Service)									
Approx. Flow = 11,000 cfs									
		IDAHO (River Right)					OREGON (River Left)		
Sand Bar (#)	Side of River (Idaho)	Approximate River Mile	Photo Number	Comments	Sand Bar (#)	Side of River (Oregon)	Approximate River Mile	Photo Number	Comments
1	ID	245.8	6-23		1	OR	247.47	6-24	
2	ID	245.68	6-23	**0**	2	OR	247.01	6-24	
3	ID	245.52	6-23		3	OR	246.9	6-24	
4	ID	245.28	6-23		4	OR	246.79	6-24	
5	ID	244.65	2-111	**Brush Creek**	5	OR	246.03	6-24	
6	ID	244.52	2-111		6	OR	246.28	6-23	
7	ID	244.2	2-111		7	OR	246.1	6-23	
8	ID	244.04	2-112		8	OR	246.03	6-23	
9	ID	243.77	2-112		9	OR	245.3	6-23	
10	ID	243.75	2-112		10	OR	245.1	2-111	
11	ID	243.6	2-112		11	OR	244.44	2-111	
12	ID	243.36	2-112	**0**	12	OR	244.04	2-112	**0**
13	ID	243.27	2-112	**Moose Hole**	13	OR	243.38	2-112	
14	ID	243.05	2-112		14	OR	242.77	2-113	
15	ID	242.82	2-113		15	OR	242.62	2-113	0
16	ID	242.5	2-113	**0**	16	OR	242.2	2-113	**Battle Creek**
17	ID	239.94	2-115		17	OR	242.02	2-113	**Lower Battle Cr**
18	ID	238.76	2-115		18	OR	241.87	2-113	**Sand Dunes**
19	ID	238.6	2-116		19	OR	241.58	2-114	**0**
20	ID	238.43	2-105		20	OR	239.43	2-115	**0**
21	ID	237.59	2-105		21	OR	239.4	2-116	**0**
22	ID	237.1	2-105	**Dry Gulch**	22	OR	237.88	2-116	
23	ID	236.6	2-105		23	OR	237.85	2-105	
24	ID	236.33	2-105		24	OR	237.68	2-105	**Two Bars**
25	ID	236.04	2-104		25	OR	236.03	2-104	
26	ID	235.52	2-104		26	OR	235.7	2-104	
27	ID	235.07	2-104	0	27	OR	235.25	2-104	
28	ID	230.28	2-47		28	OR	235.07	2-104	0
29	ID	229.8	2-47	**Johnson Bar**	29	OR	234.98	2-104	
30	ID	229.04	2-47	**0**	30	OR	234.3	5-64	
31	ID	228.93	2-47	**Steep Creek**	31	OR	231.2	5-63	**0 Rush Creek**
32	ID	228.82	2-46		32	OR	229.62	2-47	
33	ID	227.58	2-46		33	OR	229.08	2-47	
34	ID	227.5	2-45	**Pine Bar**	34	OR	228.8	2-46	
35	ID	226.92	2-45		35	OR	228.68	2-47	
36	ID	226.17	2-45		36	OR	228.57	2-46	**Yreka Bar**
37	ID	225.82	2-45		37	OR	228.12	2-46	
38	ID	225.51	2-44		38	OR	227.87	2-46	
39	ID	225.49	2-44		39	OR	224.61	2-44	
40	ID	225	2-44		40	OR	224.43	2-44	**Myers Creek**
41	ID	224.5	2-44		41	OR	223.7	2-43	
42	ID	223.8	2-12		42	OR	223.5	2-43	
43	ID	222.06	2-12	**Gracie Bar**	43	OR	223.41	2-43	
44	ID	221.8	2-12		44	OR	222.93	2-12	**Hominy Bar**
45	ID	221.48	2-12	**Half Moon Bar**	45	OR	222.02	2-12	
46	ID	221.38	2-12		46	OR	222.4	2-12	**Salt Creek**
47	ID	221.13	2-12		47	OR	222.25	2-12	
48	ID	220.7	2-13		48	OR	222.14	2-12	**Two Corral Creek**
49	ID	219.57	2-13		49	OR	222	2-12	
50	ID	219.24	2-7		50	OR	221.67	2-12	
51	ID	218.8	2-7	**Kirby Creek**	51	OR	220.85	2-12	**Slaughter Gulch**
52	ID	218.2	2-7		52	OR	219.98	2-13	
53	ID	216.28	2-7		53	OR	219.93	2-13	
54	ID	210.84	2-19		54	OR	219.72	2-13	
55	ID	210.36	2-20		55	OR	218.6	2-7	
56	ID	209.25	2-20		56	OR	218.53	2-7	
57	ID	208.77	2-20		57	OR	218.13	2-6	
58	ID	208.38	2-33		58	OR	216.55	2-5	
59	ID	207.55	2-32		59	OR	216.45	2-5	**Fish Trap Bar**
60	ID	207.32	2-32		60	OR	216.34	2-5	
61	ID	206.82	2-32		61	OR	215.7	2-5	**Tin Shed Site**
62	ID	206.06	2-31		62	OR	215.35	2-4	
63	ID	205.7	2-31		63	OR	214.82	2-4	
64	ID	205.1	2-30		64	OR	212.58	2-4	
65	ID	204.84	2-30	**Ragtown Bar**	65	OR	211.58	2-19	
66	ID	204.4	2-30		66	OR	211.46	2-19	
67	ID	204.28	2-30		67	OR	211.16	2-19	0
68	ID	203.95	2-30		68	OR	210.76	2-19	
69	ID	203	5-43		69	OR	210.65	2-19	
70	ID	202.9	5-43		70	OR	210.58	2-19	
71	ID	202.47	5-43		71	OR	210.52	2-19	
72	ID	201.88	5-43		72	OR	210.46	2-19	
73	ID	201.63	5-43		73	OR	209.94	2-20	
74	ID	201.26	5-43		74	OR	209.85	2-20	
75	ID	201.18	5-43		75	OR	209.63	2-20	
76	ID	201.08	5-43		76	OR	208.25	2-33	
77	ID	200.9	5-43		77	OR	205.68	2-31	
78	ID	200.4	5-43		78	OR	205.5	2-31	
79	ID	199.27	2-79		79	OR	205.53	2-31	
80	ID	198.3	2-141		80	OR	205.3	2-31	
81	ID	197.2	2-142		81	OR	205.02	2-30	**0**
82	ID	195.56	2-142		82	OR	204.83	2-30	
83	ID	195.33	2-142	**Warm Springs**	83	OR	204.65	2-30	
84	ID	195.27	2-142		84	OR	204.47	2-30	
85	ID	194.96	2-149		85	OR	202.5	5-43	
86	ID	194.59	2-149		86	OR	201.93	5-43	
87	ID	194.2	2-149		87	OR	201.58	5-43	
88	ID	194.18	2-149		88	OR	200.8	5-43	
89	ID	194.15	2-149		89	OR	200.2	5-43	
90	ID	164.12	2-149		90	OR	199.35	2-79	
91	ID	194.08	2-149		91	OR	199.01	2-79	**Deep Creek (OR)**
92	ID	194.03	2-149		92	OR	198.91	2-79	
93	ID	193.65	2-149		93	OR	198.6	2-79	**Robinson Gulch**
94	ID	193.29	2-149		94	OR	198.28	2-141	
95	ID	192.41	1-158		95	OR	197.78	2-141	
96	ID	192.24	1-158		96	OR	196.75	2-142	
97	ID	190.73	1-158		97	OR	195.8	2-142	
98	ID	189.82	1-150		98	OR	195.6	2-142	
99	ID	189.8	1-150	**0**	99	OR	194.85	2-149	
100	ID	189.58	1-150		100	OR	194	2-149	
101	ID	189.14	1-150	**0**	101	OR	193.93	2-149	
102	ID	188.5	1-150		102	OR	193.7	2-149	
103	ID	188.28	1-150	**Salmon Confl.**	103	OR	192.43	1-158	
					104	OR	192.41	1-158	
					105	OR	192.35	1-158	**China Bar**
					106	OR	192.24	1-158	
					107	OR	192.2	1-158	
					108	OR	190.7	1-158	**Eureka Bar**
					109	OR	190.53	1-150	
					110	OR	190.38	1-150	
					111	OR	190.07	1-150	
					112	OR	189.68	1-150	
					113	OR	189.12	1-150	
					114	OR	188.64	1-150	
					115	OR	188.43	1-150	
					116	OR	188.3	1-150	

Table G-2. Sandbar counts for the 1964 (11,000) aerial photos.

1964 (US Forest Service)

Approx. Flow = 11,000 cfs

IDAHO (River Right)					OREGON (River Left)				
Sand Bar (#)	Side of River (Idaho)	Approximate River Mile	Photo Number	Comments	Sand Bar (#)	Side of River (Oregon)	Approximate River Mile	Photo Number	Comments
1	ID	245.8	18-17		1	OR	247.55	18-15	
2	ID	245.6	18-17		2	OR	247.45	18-15	
3	ID	245.3	18-17		3	OR	246.94	18-15	
4	ID	244.65	18-246		4	OR	246.9	18-17	
5	ID	244.6	18-246		5	OR	246.8	18-17	
6	ID	243.3	18-246		6	OR	245.8	18-17	
7	ID	243.1	18-249		7	OR	245.28	18-246	
8	ID	242.81	18-249		8	OR	245.1	18-246	
9	ID	242.5	18-249		9	OR	244.75	18-246	
10	ID	241.7	18-249	**0**	10	OR	244.04	18-246	
11	ID	239.94	18-241		11	OR	243.4	18-246	
12	ID	238.75	18-238		12	OR	242.8	18-249	
13	ID	238.65	18-238		13	OR	242.2	18-249	
14	ID	238.55	18-238		14	OR	241.9	18-249	
15	ID	237.1	18-145		15	OR	241.3	18-249	
16	ID	236.6	18-145		16	OR	241.05	18-241	
17	ID	236.4	18-145		17	OR	240.65	18-241	
18	ID	236	18-145		18	OR	236.3	18-145	
19	ID	235.5	18-145		19	OR	235.8	18-145	
20	ID	235.1	18-147		20	OR	235.25	18-145	
21	ID	234.02	18-147		21	OR	231.2	19-224	
22	ID	234.01	18-147		22	OR	230.95	19-224	
23	ID	234	18-147		23	OR	229.65	19-294	
24	ID	230.56	19-294	**0**	24	OR	229.2	19-294	
25	ID	230.54	19-294	**0**	25	OR	228.65	19-294	
26	ID	230.4	19-294	**0**	26	OR	228.55	19-294	
27	ID	230.25	19-294	**0**	27	OR	228.1	19-292	
28	ID	229.8	19-294	**Johnson Bar**	28	OR	228.05	19-292	**0**
29	ID	229.5	19-294	**0**	29	OR	227.98	19-292	
30	ID	229.1	19-294		30	OR	227.38	19-292	
31	ID	228.9	19-294		31	OR	227.35	19-292	
32	ID	228.8	19-294		32	OR	226.4	20-3	
33	ID	228.5	19-294		33	OR	226.25	20-3	
34	ID	228.4	19-294		34	OR	224.6	20-5	
35	ID	227.9	19-292		35	OR	224.45	20-5	
36	ID	227.7	19-292		36	OR	223.65	20-5	
37	ID	227.5	19-292	**Pine Bar**	37	OR	223.1	24-169	
38	ID	226.8	20-3		38	OR	223	24-169	
39	ID	226.2	20-3		39	OR	222.9	24-169	
40	ID	226	20-3		40	OR	222.4	24-169	**Salt Creek**
41	ID	224.3	20-5		41	OR	222.2	24-169	
42	ID	223.09	24-169		42	OR	221	24-169	
43	ID	222.1	24-169		43	OR	220.9	24-169	**0**
44	ID	222	24-169		44	OR	220.8	24-169	
45	ID	221.8	24-169		45	OR	220	24-163	
46	ID	221.5	24-169		46	OR	219.9	24-163	
47	ID	220.01	24-163		47	OR	219.7	24-163	
48	ID	219.92	24-163		48	OR	219.35	24-163	**0**
49	ID	219	24-163		49	OR	218.79	24-163	
50	ID	218.8	24-163	**Kirby Creek**	50	OR	218.6	24-163	
51	ID	218.2	24-163		51	OR	218.5	24-163	
52	ID	217.9	24-190		52	OR	218.1	24-190	
53	ID	217.4	24-190		53	OR	216.5	24-189	
54	ID	217.2	24-190	**0**	54	OR	216.4	24-189	**Fish Trap**
55	ID	216.95	24-190		55	OR	216.35	24-187	
56	ID	216.49	24-189		56	OR	215.75	24-187	
57	ID	216.3	24-189		57	OR	215.7	24-187	
58	ID	215.1	24-189		58	OR	215.35	24-187	
59	ID	214.8	24-187	**0**	59	OR	214.9	24-187	**0**
60	ID	213.91	24-156	**(middle)**	60	OR	214.81	24-187	
61	ID	213.5	24-156	**0**	61	OR	213.9	24-156	
62	ID	213.11	24-156	**0**	62	OR	213.2	24-156	
63	ID	212.5	24-156		63	OR	213.1	24-156	
64	ID	212.45	24-156		64	OR	212.6	24-156	
65	ID	212.25	24-156		65	OR	211.9	24-181	
66	ID	211.91	24-181		66	OR	211.85	24-181	**0**
67	ID	211.7	24-181		67	OR	211.8	24-181	**0**
68	ID	210.36	20-21		68	OR	211.6	24-181	
69	ID	210.35	20-21		69	OR	211.45	24-181	
70	ID	209.7	20-21		70	OR	211.38	24-181	
71	ID	209.2	20-21		71	OR	211.15	24-181	
72	ID	208.35	19-271		72	OR	210.8	20-21	
73	ID	207.9	19-271		73	OR	210.65	20-21	
74	ID	207.7	19-271		74	OR	210.6	20-21	
75	ID	207.6	19-271		75	OR	210.5	20-21	
76	ID	207.55	19-271		76	OR	210.45	20-21	
77	ID	207.3	19-271		77	OR	210.4	20-21	
78	ID	206.8	19-269		78	OR	209.95	20-21	
79	ID	206.4	19-269		79	OR	209.8	20-21	
80	ID	206.05	19-269		80	OR	209.3	20-21	**0**
81	ID	205.7	19-269		81	OR	208.25	19-271	
82	ID	205.56	19-267		82	OR	206.9	19-269	
83	ID	205.1	19-267		83	OR	205.9	19-269	
84	ID	204.85	19-267		84	OR	205.65	19-267	
85	ID	204.4	19-267		85	OR	205.55	19-267	
86	ID	204.3	19-267		86	OR	205.5	19-267	
87	ID	203.95	19-267		87	OR	205.3	19-267	
88	ID	203.5	18-186		88	OR	205	19-267	
89	ID	203	18-186		89	OR	204.84	19-267	
90	ID	202.9	18-186		90	OR	204.6	19-267	
91	ID	202.6	18-186		91	OR	204.5	19-267	
92	ID	202.4	18-186		92	OR	203.4	18-186	
93	ID	201.61	18-186		93	OR	203.2	18-186	
94	ID	201.6	18-186		94	OR	202.92	18-186	
95	ID	201.5	18-186		95	OR	202.5	18-186	
96	ID	201.2	18-186		96	OR	201.9	18-186	
97	ID	201.15	18-186		97	OR	200.75	19-15	
98	ID	201.05	18-186		98	OR	200.2	19-15	
99	ID	200.9	18-186		99	OR	199.46	19-15	
100	ID	200.4	19-15		100	OR	199.21	18-83	
101	ID	199.45	19-15		101	OR	199	18-83	**Deep Creek**
102	ID	199.25	19-15		102	OR	198.6	18-83	
103	ID	199.2	18-83		103	OR	198.3	18-83	
104	ID	199.16	18-83		104	OR	197.75	18-83	
105	ID	199.15	18-83		105	OR	196.75	31-247	**(14,000 cfs flow)**
106	ID	198.75	18-83		106	OR	194.95	31-247	**(14,000 cfs flow)**
107	ID	195.3	31-247	**(14,000 cfs flow)**	107	OR	194	19-21	
108	ID	195	31-247	**(14,000 cfs flow)**	108	OR	193.7	19-21	
109	ID	194.7	19-21		109	OR	192.8	19-178	
110	ID	194.2	19-21		110	OR	192.35	19-178	
111	ID	194.18	19-21		111	OR	192.25	19-178	
112	ID	194.13	19-21		112	OR	190.7	21-233	
113	ID	194.1	19-21		113	OR	190.25	21-233	
114	ID	194.05	19-21		114	OR	190.2	21-233	
115	ID	193.4	19-21		115	OR	189.7	21-233	
116	ID	193.2	19-21		116	OR	189.15	21-236	
117	ID	192.26	19-178		117	OR	188.65	21-236	
118	ID	190.69	21-233		118	OR	188.6	21-236	
119	ID	190	21-233		119	OR	188.45	21-236	
120	ID	189.2	21-236		120	OR	188.3	21-236	
121	ID	188.63	21-236						
122	ID	188.28	21-236	**Salmon Confl.**					

Table G-3. Sandbar counts for the 1973 (12,000 cfs) aerial photos.

1973 (Corp of Engineers -- Valley Air Photo)										
Approx. Flow = 12,000 cfs (March 23, 1973)										
IDAHO (River Right)						OREGON (River Left)				
Sand Bar (#)	Side of River (Idaho)	Approximate River Mile	Photo Number	Comments		Sand Bar (#)	Side of River (Oregon)	Approximate River Mile	Photo Number	Comments
1	ID	246	3-117			1	OR	245.8	3-117	
2	ID	245.5	3-117	**O**		2	OR	242.1	3-120	**O**
3	ID	245.3	3-118			3	OR	240.7	3-122	
4	ID	244.65	3-118			4	OR	228.65	3-131	**O**
5	ID	243.3	3-119			5	OR	228.09	3-132	
6	ID	241.7	3-121	**O**		6	OR	228.05	3-132	
7	ID	238.6	3-123			7	OR	227.9	3-133	
8	ID	236.6	3-125			8	OR	226.55	3-134	**O**
9	ID	235	3-126	**O**		9	OR	224.4	3-135	
10	ID	229.8	3-130	**Johnson Bar**		10	OR	222.4	3-139	**Salt Creek**
11	ID	229.5	3-130			11	OR	222.2	3-139	
12	ID	228.9	3-131			12	OR	220.9	3-140	
13	ID	227.5	3-133	**Pine Bar**		13	OR	220	3-141	
14	ID	226	3-134			14	OR	218.6	3-142	
15	ID	225	3-135			15	OR	216.4	3-145	**Fish Trap**
16	ID	222.05	3-139			16	OR	215.75	3-146	
17	ID	221.8	3-139			17	OR	215.7	3-146	
18	ID	221.5	3-140			18	OR	214.9	3-147	**O**
19	ID	221.15	3-140			19	OR	214.81	3-147	**O**
20	ID	218.8	3-142	**Kirby Creek**		20	OR	214.8	3-147	**O**
21	ID	218.2	3-142			21	OR	213.9	3-148	
22	ID	218.15	3-142			22	OR	212.6	3-149	
23	ID	217.9	3-142			23	OR	211.95	3-149	
24	ID	216.25	3-146			24	OR	211.85	3-149	
25	ID	211.05	3-150			25	OR	211.45	3-150	
26	ID	210.6	3-151	**O**		26	OR	211.15	3-150	**O**
27	ID	210.35	3-151			27	OR	210.6	3-151	
28	ID	208.8	3-153			28	OR	210.5	3-151	
29	ID	208.65	3-153			29	OR	210.49	3-151	
30	ID	208.58	3-153			30	OR	210.45	3-151	
31	ID	208.38	3-153			31	OR	210.19	3-151	
32	ID	208.37	3-153			32	OR	210	3-151	
33	ID	207.85	3-154			33	OR	209.75	3-151	
34	ID	207.54	3-154			34	OR	209.73	3-151	
35	ID	207.33	3-154			35	OR	209.7	3-151	
36	ID	206.84	3-155			36	OR	209.68	3-151	
37	ID	206.4	3-155			37	OR	209.65	3-151	
38	ID	206.04	3-155			38	OR	208.78	3-151	
39	ID	205.75	3-156			39	OR	208.21	3-153	**O**
40	ID	205.69	3-156			40	OR	208.09	3-154	**O**
41	ID	205.5	3-156			41	OR	207.6	3-154	
42	ID	205.45	3-156	**O**		42	OR	205.68	3-156	
43	ID	205.39	3-156	**O**		43	OR	205.59	3-156	
44	ID	205.35	3-156			44	OR	205.55	3-156	
45	ID	205.1	3-156			45	OR	205.5	3-156	
46	ID	204.9	3-158			46	OR	205.28	3-156	
47	ID	204.85	3-158			47	OR	205.05	3-156	
48	ID	204.77	3-158			48	OR	204.85	3-158	
49	ID	204.25	3-159			49	OR	204.55	3-159	
50	ID	203.95	3-159			50	OR	202.42	3-161	
51	ID	203.9	3-159	**O**		51	OR	201.9	3-161	
52	ID	202.85	3-160			52	OR	201.57	3-162	
53	ID	202.55	3-161			53	OR	200.4	3-163	**O**
54	ID	201.8	3-161	**O**		54	OR	200.18	3-163	
55	ID	201.58	3-162			55	OR	199	3-165	
56	ID	201.55	3-162			56	OR	198.56	3-165	**O**
57	ID	201.25	3-162			57	OR	198.25	3-168	
58	ID	201.15	3-162			58	OR	197.77	3-168	
59	ID	201.05	3-163			59	OR	194.9	3-170	
60	ID	200.35	3-163			60	OR	194.08	3-171	
61	ID	199.43	3-164	**O**		61	OR	194	3-171	**O**
62	ID	198.72	3-165	**O**		62	OR	193.8	3-1771	
63	ID	198.3	3-168			63	OR	192.48	3-173	
64	ID	196.05	3-170			64	OR	192.4	3-173	**China Bar**
65	ID	195.6	3-170			65	OR	192.26	3-173	
66	ID	195.4	3-170			66	OR	191.7	3-174	
67	ID	195	3-170			67	OR	191.2	3-174	
68	ID	194.6	3-171			68	OR	190.9	3-175	
69	ID	194.45	3-171			69	OR	190.1	3-175	
70	ID	194.15	3-171			70	OR	189.9	3-178	
71	ID	194.1	3-171			71	OR	189.2	3-178	
72	ID	193.25	3-173	**Divide Creek**		72	OR	188.6	3-178	
73	ID	193	3-173			73	OR	188.55	3-179	
74	ID	190.9	3-175			74	OR	188.5	3-179	
75	ID	190.5	3-178							
76	ID	188.65	3-178							

Table G-4. Sandbar counts for the 1973 (18,000 cfs) aerial photos.

1973 (Corp of Engineers -- Valley Air Photo)									
Approx. Flow = 18,000 cfs (March 22, 1973)									
IDAHO (River Right)					OREGON (River Left)				
Sand Bar (#)	Side of River (Idaho)	Approximate River Mile	Photo Number	Comments	Sand Bar (#)	Side of River (Oregon)	Approximate River Mile	Photo Number	Comments
1	ID	245.5	3-003	**O**	1	OR	245.8	3-003	
2	ID	245.3	3-003		2	OR	242.1	3-007	**O**
3	ID	244.65	3-003		3	OR	241.85	3-007	**O**
4	ID	243.3	3-005		4	OR	235.05	3-014	**O**
5	ID	242.83	3-005		5	OR	228.65	3-018	
6	ID	241.7	3-007	**O**	6	OR	228.55	3-018	
7	ID	241.5	3-007		7	OR	228.1	3-020	
8	ID	236.6	3-013		8	OR	228.08	3-020	
9	ID	235.1	3-014		9	OR	227.9	3-020	
10	ID	229.8	3-018	**Johnson Bar**	10	OR	226.55	3-021	**O**
11	ID	229.5	3-018		11	OR	224.4	3-022	
12	ID	228.9	3-018		12	OR	223.7	3-023	
13	ID	227.7	3-020	**O**	13	OR	223.4	3-023	
14	ID	227.5	3-020	**Pine Bar**	14	OR	223	3-023	**O**
15	ID	226.93	3-021		15	OR	222.8	3-023	
16	ID	226.15	3-021		16	OR	222.4	3-023	
17	ID	225.1	3-022		17	OR	222.15	3-024	
18	ID	223.1	3-023		18	OR	222	3-024	
19	ID	222.05	3-024		19	OR	220.8	3-024	
20	ID	221.88	3-024		20	OR	220	3-025	
21	ID	221.5	3-024		21	OR	218.6	3-026	
22	ID	218.8	3-025	**Kirby Creek**	22	OR	216.6	3-028	
23	ID	218.2	3-026		23	OR	216.55	3-028	
24	ID	218.15	3-026		24	OR	216.4	3-028	**Fish Trap**
25	ID	217.9	3-027		25	OR	215.75	3-031	**Tin Shed**
26	ID	217.2	3-027		26	OR	215.7	3-031	**Tin Shed**
27	ID	216.25	3-030		27	OR	215.58	3-031	**Tin Shed**
28	ID	212.45	3-033		28	OR	214.9	3-031	**O**
29	ID	211.05	3-035		29	OR	214.8	3-031	
30	ID	210.6	3-035	**O**	30	OR	213.9	3-032	
31	ID	210.4	3-035		31	OR	212.63	3-033	
32	ID	210.35	3-035		32	OR	212.6	3-033	
33	ID	208.35	3-036		33	OR	211.9	3-033	**O**
34	ID	207.55	3-037		34	OR	211.15	3-034	
35	ID	207.33	3-037		35	OR	210.6	3-035	
36	ID	206.81	3-038		36	OR	210.5	3-035	
37	ID	206.4	3-038	**High Range**	37	OR	210.45	3-035	
38	ID	205.75	3-039		38	OR	209.94	3-035	
39	ID	205.7	3-039		39	OR	209.75	3-035	**O**
40	ID	205.1	3-039		40	OR	209.73	3-035	
41	ID	204.85	3-041		41	OR	209.7	3-035	
42	ID	204.77	3-041		42	OR	209.65	3-035	
43	ID	204.25	3-042		43	OR	208.21	3-037	**O**
44	ID	204.02	3-042		44	OR	208.09	3-037	**O**
45	ID	203.95	3-042		45	OR	205.68	3-039	
46	ID	202.9	3-043		46	OR	205.55	3-039	
47	ID	202.55	3-043		47	OR	205.52	3-039	
48	ID	201.58	3-044		48	OR	205.5	3-039	
49	ID	201.25	3-044		49	OR	205.3	3-039	
50	ID	201.18	3-044		50	OR	204.85	3-041	
51	ID	200.9	3-045		51	OR	204.45	3-041	
52	ID	200.4	3-045		52	OR	202.48	3-043	
53	ID	199.43	3-045		53	OR	201.9	3-043	
54	ID	198.75	3-047		54	OR	201.6	3-044	
55	ID	198.3	3-047		55	OR	200.4	3-045	
56	ID	196	3-051		56	OR	200.2	3-046	
57	ID	195.33	3-052		57	OR	199	3-047	
58	ID	194.95	3-052		58	OR	198.6	3-047	
59	ID	194.55	3-052		59	OR	198.3	3-047	
60	ID	194.1	3-056		60	OR	197.78	3-048	
61	ID	193.2	3-056		61	OR	194.85	3-052	
					62	OR	194	3-056	
					63	OR	193.94	3-056	
					64	OR	193.7	3-056	
					65	OR	192.35	3-056	**China Bar**
					66	OR	190.74	3-058	
					67	OR	189.68	3-062	
					68	OR	189.1	3-062	
					69	OR	188.64	3-063	
					70	OR	188.43	3-063	
					71	OR	188.35	3-063	**O**

Table G-5. Sandbar counts for the 1973 (5,000 cfs) aerial photos.

1973 (Corp of Engineers -- Valley Air Photo)									
Approx. Flow = 5,000 cfs (March 25, 1973)									
IDAHO (River Right)					OREGON (River Left)				
Sand Bar (#)	Side of River (Idaho)	Approximate River Mile	Photo Number	Comments	Sand Bar (#)	Side of River (Oregon)	Approximate River Mile	Photo Number	Comments
1	ID	245.8	73-4110		1	OR	246.22	73-4110	
2	ID	245.3	73-4111	**O**	2	OR	246.1	73-4110	
3	ID	244.65	73-4111	**Brush Creek**	3	OR	246.03	73-4110	
4	ID	244.07	73-4112		4	OR	246.02	73-4110	
5	ID	243.29	73-4112	**Moose Hole**	5	OR	245.8	73-4110	
6	ID	242.88	73-4113		6	OR	241.8	73-4114	
7	ID	241.51	73-4114		7	OR	241.18	73-4114	**Sand Dunes**
8	ID	239.94	73-4115		8	OR	239.6	73-4116	
9	ID	238.45	73-4117		9	OR	236.09	73-4119	**Saddle Creek**
10	ID	237.8	73-4117		10	OR	235.26	73-4119	
11	ID	237.51	73-4117		11	OR	235.12	73-4119	
12	ID	237.08	73-4118	**Dry Gulch**	12	OR	235.18	73-4120	
13	ID	234.05	73-4120		13	OR	235.04	73-4119	**O Bernard Creek**
14	ID	229.8	73-4124	**Johnson Bar**	14	OR	234.99	73-4119	
15	ID	228.93	73-4124	**Steep Creek**	15	OR	231.8	73-4122	**Sluice Creek**
16	ID	228.89	73-4124		16	OR	228.67	73-4124	**O**
17	ID	227.68	73-4128		17	OR	228.57	73-4127	**O**
18	ID	227.57	73-4128		18	OR	228.08	73-4127	
19	ID	227.5	73-4128	**Pine Bar**	19	OR	227.33	73-4128	
20	ID	226.93	73-4128		20	OR	224.44	73-4131	
21	ID	226.19	73-4129		21	OR	224.28	73-4131	
22	ID	225.82	73-4129		22	OR	223.71	73-4131	
23	ID	225.12	73-4131	**O**	23	OR	223.69	73-4131	
24	ID	225	73-4130		24	OR	223.5	73-4132	
25	ID	224.52	73-4130		25	OR	223.46	73-4132	
26	ID	224.32	73-4131	**O**	26	OR	222.97	73-4132	
27	ID	223.08	73-4132		27	OR	222.4	73-4132	**Salt Creek**
28	ID	222.07	73-4132		28	OR	222.15	73-4132	**Two Corral**
29	ID	221.48	73-4133		29	OR	222	73-4132	
30	ID	221.38	73-4133		30	OR	220.85	73-4132	
31	ID	221.36	73-4133		31	OR	220.18	73-4134	
32	ID	221.17	73-4133		32	OR	219.99	73-4134	
33	ID	219.01	73-4135		33	OR	218.6	73-4135	
34	ID	218.8	73-4135	**Kirby Creek**	34	OR	216.66	73-4137	
35	ID	218.5	73-4136		35	OR	216.6	73-4137	
36	ID	218.18	73-4136		36	OR	216.45	73-4137	**Fish Trap Bar**
37	ID	218.17	73-4136	**O**	37	OR	215.95	73-4139	
38	ID	216.96	73-4137		38	OR	215.78	73-4139	
39	ID	216.27	73-4137		39	OR	215.74	73-4139	
40	ID	216.22	73-4137		40	OR	215.72	73-4139	**Tin Shed**
41	ID	214.9	73-4140		41	OR	215.6	73-4139	**Tin Shed**
42	ID	214.74	73-4140		42	OR	215.35	73-4139	
43	ID	210.85	73-4143		43	OR	214.85	73-4140	
44	ID	210.35	73-4143		44	OR	212.58	73-4141	
45	ID	209.88	73-4144		45	OR	211.91	73-4142	
46	ID	209.87	73-4144		46	OR	211.47	73-4143	
47	ID	208.75	73-4144		47	OR	211.15	73-4143	
48	ID	208.37	73-4145		48	OR	210.85	73-4143	
49	ID	207.9	73-4145		49	OR	210.68	73-4143	
50	ID	207.55	73-4146		50	OR	210.6	73-4143	
51	ID	207.32	73-4146		51	OR	210.47	73-4143	
52	ID	206.86	73-4147		52	OR	210.19	73-4144	
53	ID	206.82	73-4147		53	OR	209.95	73-4144	
54	ID	205.77	73-4147		54	OR	209.8	73-4144	
55	ID	205.7	73-4147		55	OR	209.72	73-4144	
56	ID	205.42	73-4147		56	OR	209.64	73-4144	
57	ID	205.1	73-4148		57	OR	209.53	73-4144	
58	ID	204.83	73-4148	**O**	58	OR	209.3	73-4144	**Tryon Creek**
59	ID	204.27	73-4149		59	OR	208.95	73-4144	
60	ID	203.95	73-4149		60	OR	208.25	73-4145	
61	ID	202.9	73-4151		61	OR	206.93	73-4147	
62	ID	202.58	73-4150		62	OR	205.9	73-4147	
63	ID	202.47	73-4151		63	OR	205.69	73-4147	
64	ID	201.88	73-4152		64	OR	205.53	73-4147	
65	ID	201.58	73-4152		65	OR	205.5	73-4147	
66	ID	201.09	73-4152		66	OR	205.32	73-4147	
67	ID	200.91	73-4152		67	OR	204.83	73-4148	
68	ID	200.05	73-4153		68	OR	204.62	73-4148	
69	ID	199.76	73-4154		69	OR	204.48	73-4149	
70	ID	199.3	73-4157		70	OR	204.14	73-4149	
71	ID	197.08	73-4157		71	OR	202.5	73-4151	
72	ID	195.33	73-4158	**Warm Springs**	72	OR	201.93	73-4151	
73	ID	194.96	73-4160		73	OR	201.61	73-4152	
74	ID	194.66	73-4160		74	OR	201.58	73-4152	
75	ID	194.59	73-4160		75	OR	200.92	73-4152	
76	ID	194.55	73-4160	**O**	76	OR	200.9	73-4152	
77	ID	194.08	73-4160	**Zig Zag**	77	OR	200.44	73-4153	
78	ID	194.05	73-4160	**Zig Zag**	78	OR	200.18	73-4153	
79	ID	193.29	73-4161		79	OR	199.47	73-4154	
80	ID	190.72	73-4164		80	OR	199.3	73-4154	
81	ID	190.01	73-4165		81	OR	199.15	73-4154	
82	ID	188.28	73-4166	**Salmon Confl.**	82	OR	199.01	73-4155	
					83	OR	198.6	73-4155	
					84	OR	198.3	73-4157	
					85	OR	196.75	73-4157	
					86	OR	195.58	73-4158	
					87	OR	194.85	73-4160	
					88	OR	194	73-4160	
					89	OR	193.92	73-4160	
					90	OR	193.7	73-4161	
					91	OR	192.35	73-4162	**China Bar**
					92	OR	192.24	73-4162	
					93	OR	192.2	73-4162	**O**
					94	OR	190.72	73-4164	
					95	OR	190.54	73-4164	
					96	OR	189.69	73-4166	
					97	OR	189.68	73-4166	
					98	OR	188.64	73-4166	
					99	OR	188.43	73-4166	

Table G-6. Sandbar counts for the 1977 (5,300 cfs) aerial photos.

1977 (Corp of Engineers -- Valley Air Photo)										
Approx. Flow = 5300 cfs										
IDAHO (River Right)						OREGON (River Left)				
Sand Bar (#)	Side of River (Idaho)	Approximate River Mile	Photo Number	Comments		Sand Bar (#)	Side of River (Oregon)	Approximate River Mile	Photo Number	Comments
1	ID	246	77-7-151			1	OR	246.09	77-7-151	
2	ID	245.5	77-7-151	**O**		2	OR	246	77-7-151	
3	ID	245.3	77-7-151			3	OR	245.8	77-7-151	
4	ID	244.65	77-7-149			4	OR	243.4	77-7-147	
5	ID	244.6	77-7-149			5	OR	242.1	77-7-145	**O**
6	ID	243.3	77-7-147			6	OR	241.9	77-7-145	**O**
7	ID	242.5	77-7-145			7	OR	240.65	77-7-143	
8	ID	241.7	77-7-145	**O**		8	OR	236.1	77-7-137	
9	ID	239.94	77-7-141			9	OR	235.38	77-7-135	**O**
10	ID	238.6	77-7-141			10	OR	235.34	77-7-135	**O**
11	ID	238.44	77-7-139			11	OR	235.25	77-7-135	
12	ID	236.6	77-7-139			12	OR	228.65	77-7-126	**O**
13	ID	235	77-7-135	**O**		13	OR	228.1	77-7-124	
14	ID	229.8	77-7-126	**Johnson Bar**		14	OR	226.55	77-7-123	**O**
15	ID	229.5	77-7-126	**O**		15	OR	224.4	77-7-119	
16	ID	228.9	77-7-126			16	OR	223.11	77-7-116	
17	ID	228.89	77-7-126			17	OR	223	77-7-116	
18	ID	227.5	77-7-123	**Pine Bar**		18	OR	222.9	77-7-116	
19	ID	226	77-7-121			19	OR	222.4	77-7-116	**Salt Creek Bar**
20	ID	225.1	77-7-121	**O**		20	OR	222.2	77-7-116	
21	ID	225	77-7-121			21	OR	222	77-7-116	
22	ID	224.3	77-7-119			22	OR	220.8	77-7-114	
23	ID	223	77-7-116			23	OR	220	77-7-114	
24	ID	222.05	77-7-116			24	OR	218.6	77-7-111	
25	ID	221.5	77-7-116			25	OR	216.4	77-7-109	**Fish Trap**
26	ID	221.4	77-7-116			26	OR	215.75	77-7-107	
27	ID	219	77-7-111			27	OR	215.7	77-7-107	
28	ID	218.8	77-7-111	**Kirby Creek**		28	OR	215.34	77-7-107	
29	ID	218.2	77-7-111			29	OR	214.9	77-7-107	**O**
30	ID	218.15	77-7-111			30	OR	214.81	77-7-107	**O**
31	ID	217.9	77-7-111			31	OR	214.8	77-7-107	**O**
32	ID	216.25	77-7-109			32	OR	212.6	77-7-103	
33	ID	212.55	77-7-103			33	OR	211.85	77-7-103	
34	ID	211.05	77-7-101			34	OR	211.8	77-7-103	
35	ID	211.02	77-7-101			35	OR	211.75	77-7-103	
36	ID	210.5	77-7-101	**O**		36	OR	211.35	77-7-103	
37	ID	210.45	77-7-101			37	OR	211.15	77-7-101	**O**
38	ID	210.35	77-7-101			38	OR	210.6	77-7-101	
39	ID	209.7	77-7-99			39	OR	210.5	77-7-101	
40	ID	208.8	77-7-99			40	OR	210.45	77-7-101	
41	ID	208.75	77-7-99			41	OR	210.4	77-7-101	**O**
42	ID	208.5	77-7-99			42	OR	210.19	77-7-101	
43	ID	208.38	77-7-98			43	OR	209.95	77-7-101	**O**
44	ID	208.37	77-7-96	**O**		44	OR	209.9	77-7-99	**O**
45	ID	207.9	77-7-96			45	OR	209.71	77-7-99	
46	ID	207.54	77-7-96			46	OR	209.7	77-7-99	
47	ID	207.33	77-7-96			47	OR	209.68	77-7-99	
48	ID	206.81	77-7-96			48	OR	209.65	77-7-99	
49	ID	206.4	77-7-96			49	OR	208.21	77-7-96	**O**
50	ID	205.69	77-7-94			50	OR	208.09	77-7-96	**O**
51	ID	205.48	77-7-94	**O**		51	OR	205.68	77-7-94	
52	ID	205.47	77-7-94	**O**		52	OR	205.5	77-7-94	
53	ID	205.39	77-7-92	**O**		53	OR	205.3	77-7-92	
54	ID	205.1	77-7-92			54	OR	204.85	77-7-92	
55	ID	204.9	77-7-92	**O**		55	OR	204.45	77-7-92	
56	ID	204.85	77-7-92			56	OR	203.4	77-7-90	
57	ID	204.8	77-7-92			57	OR	202.48	77-7-88	
58	ID	204.25	77-7-92			58	OR	201.9	77-7-88	
59	ID	204.02	77-7-90			59	OR	201.59	77-7-86	
60	ID	203.95	77-7-90			60	OR	200.4	77-7-86	**O**
61	ID	203.68	77-7-90	**O**		61	OR	200.18	77-7-86	
62	ID	203.48	77-7-90	**O**		62	OR	199	77-7-84	
63	ID	202.85	77-7-90			63	OR	198.6	77-7-82	
64	ID	202.55	77-7-88			64	OR	198.56	77-7-82	**O**
65	ID	201.8	77-7-88	**O**		65	OR	198.3	77-7-82	
66	ID	201.58	77-7-88			66	OR	196.75	77-7-80	
67	ID	201.25	77-7-86			67	OR	195.6	77-7-78	
68	ID	201.18	77-7-86			68	OR	194.85	77-7-78	
69	ID	201.05	77-7-86			69	OR	194.08	77-7-76	
70	ID	200.9	77-7-86			70	OR	194	77-7-76	**O**
71	ID	200.4	77-7-86			71	OR	193.68	77-7-76	
72	ID	199.43	77-7-84	**O**		72	OR	192.8	77-7-74	
73	ID	198.72	77-7-84	**O**		73	OR	192.35	77-7-74	**China Bar**
74	ID	198.3	77-7-82			74	OR	192.2	77-7-74	
75	ID	196.6	77-7-80	**O**		75	OR	192.18	77-7-74	
76	ID	196.05	77-7-80			76	OR	191.7	77-7-71	**O**
77	ID	195.6	77-7-78			77	OR	191.42	77-7-71	
78	ID	195.33	77-7-78			78	OR	190.74	77-7-71	
79	ID	194.95	77-7-78			79	OR	190.1	77-7-70	
80	ID	194.45	77-7-78			80	OR	189.7	77-7-68	
81	ID	194.35	77-7-76			81	OR	189.68	77-7-68	
82	ID	194.1	77-7-76			82	OR	188.63	77-7-68	
83	ID	193.4	77-7-76			83	OR	188.43	77-7-68	
84	ID	193.3	77-7-76			84	OR	188.3	77-7-68	
85	ID	193	77-7-76							
86	ID	192.42	77-7-74							
87	ID	192.28	77-7-74	**O**						
88	ID	189.15	77-7-68							
89	ID	189.14	77-7-68							
90	ID	188.4	77-7-68							
91	ID	188.28	77-7-68	**Salmon Confl.**						

Table G-7. Sandbar counts for the 1982 (14,100 cfs) aerial photos.

1982 (Corp of Engineers -- Valley Air Photo)										
Approx. Flow = 14,100 cfs										
IDAHO (River Right)						OREGON (River Left)				
Sand Bar (#)	Side of River (Idaho)	Approximate River Mile	Photo Number	Comments		Sand Bar (#)	Side of River (Oregon)	Approximate River Mile	Photo Number	Comments
1	ID	246.1	16-283			1	OR	245.8	16-283	
2	ID	245.5	16-283	**0**		2	OR	244	16-281	
3	ID	245.3	16-283			3	OR	242.1	16-279	
4	ID	244.65	16-283			4	OR	241.9	16-276	
5	ID	244.6	16-281			5	OR	240.65	16-276	
6	ID	243.3	16-280			6	OR	228.65	16-257	
7	ID	241.7	16-276	**0**		7	OR	226.55	16-255	**0**
8	ID	235.1	16-268	**0**		8	OR	224.4	16-252	**0**
9	ID	229.8	16-261	**Johnson Bar**		9	OR	223.7	16-250	
10	ID	229.5	16-261	**0**		10	OR	222.4	16-247	**Salt Creek**
11	ID	228.9	16-259			11	OR	222.1	16-247	
12	ID	227.7	16-257	**0**		12	OR	220.8	16-245	**0**
13	ID	227.5	16-257	**Pine Bar**		13	OR	220	16-244	
14	ID	226.15	16-255			14	OR	218.6	16-242	
15	ID	225.1	16-252			15	OR	216.4	16-240	**Fish Trap**
16	ID	223.1	16-247			16	OR	215.75	16-236	
17	ID	222.05	16-247	**0**		17	OR	215.7	16-236	
18	ID	221.88	16-245			18	OR	214.9	16-235	**0**
19	ID	221.5	16-245			19	OR	214.81	16-235	**0**
20	ID	221.4	16-245			20	OR	214.8	16-235	
21	ID	221.15	16-245			21	OR	213.9	16-233	
22	ID	218.8	16-242	**Kirby Creek**		22	OR	212.6	16-232	
23	ID	218.2	16-242			23	OR	211.9	16-230	
24	ID	218.15	16-242			24	OR	211.45	16-230	
25	ID	216.25	16-236			25	OR	211.15	16-230	
26	ID	212.45	16-232			26	OR	210.64	16-228	
27	ID	211.05	16-230			27	OR	210.6	16-228	
28	ID	210.35	16-228			28	OR	210.45	16-228	
29	ID	209.7	16-228			29	OR	210.19	16-228	
30	ID	209.2	16-225			30	OR	209.95	16-228	
31	ID	208.35	16-225			31	OR	209.72	16-228	
32	ID	207.9	16-223			32	OR	209.7	16-228	
33	ID	207.55	16-223			33	OR	209.69	16-228	
34	ID	207.33	16-233			34	OR	209.67	16-228	
35	ID	206.81	16-233			35	OR	209.64	16-228	
36	ID	206.4	16-221			36	OR	205.9	16-221	
37	ID	205.74	16-221			37	OR	205.68	16-221	
38	ID	205.1	16-218			38	OR	205.5	16-218	
39	ID	204.85	16-218			39	OR	205.3	16-218	
40	ID	204.25	16-218			40	OR	204.45	16-218	
41	ID	204.02	16-216			41	OR	202.48	16-214	
42	ID	203.95	16-216			42	OR	201.9	16-214	
43	ID	202.9	16-216			43	OR	200.4	16-209	**0**
44	ID	202.55	16-214			44	OR	199	16-207	
45	ID	201.58	16-214			45	OR	198.6	16-207	
46	ID	201.25	16-209			46	OR	198.3	16-207	
47	ID	201.18	16-209			47	OR	197.78	16-203	
48	ID	201.05	16-209			48	OR	194.85	16-199	
49	ID	200.9	16-209			49	OR	193.94	16-195	
50	ID	200.4	16-209			50	OR	193.68	16-195	
51	ID	199.43	16-207			51	OR	192.35	16-193	**China Bar**
52	ID	198.3	16-207			52	OR	192.2	16-193	
53	ID	195.55	16-200			53	OR	191.7	16-193	**0**
54	ID	195.33	16-200			54	OR	190.74	16-191	
55	ID	194.95	16-199			55	OR	189.68	16-189	
56	ID	194.1	16-199			56	OR	188.43	16-188	
57	ID	193.4	16-195							

Table G-8. Sandbar counts for the 1997 (21,000) aerial photos.

1997 (Idaho Power Company)										
Approx. Flow = 21,000 cfs										
IDAHO (River Right)						OREGON (River Left)				
Sand Bar (#)	Side of River (Idaho)	Approximate River Mile	Photo Number	Comments		Sand Bar (#)	Side of River (Oregon)	Approximate River Mile	Photo Number	Comments
1	ID	245.5	15-9	**0**		1	OR	245.8	15-9	
2	ID	245.3	16-2			2	OR	244.5	16-4	
3	ID	244.65	16-3			3	OR	244	17-2	
4	ID	244.6	16-4			4	OR	242.1	17-6	**0**
5	ID	241.7	17-7	**0**		5	OR	241.9	17-7	
6	ID	235.1	18-14			6	OR	240.65	18-2	
7	ID	229.8	21-5	**Johnson Bar**		7	OR	228.65	22-3	
8	ID	229.5	21-5	**0**		8	OR	228.55	22-3	
9	ID	228.9	22-3			9	OR	226.55	22-7	**0**
10	ID	227.7	22-5	**0**		10	OR	224.4	23-6	
11	ID	227.5	22-5	**Pine Bar**		11	OR	223.7	23-6	
12	ID	226.15	23-2			12	OR	223	23-6	
13	ID	225.1	23-4			13	OR	222.8	23-8	
14	ID	223.1	23-8	**0**		14	OR	222.4	23-8	**Salt Creek**
15	ID	222.05	23-8			15	OR	222.1	23-8	
16	ID	221.88	25-2			16	OR	220.8	26-2	
17	ID	221.5	25-2			17	OR	220	26-4	
18	ID	221.42	25-2			18	OR	218.6	27-3	
19	ID	221.18	25-4			19	OR	216.6	28-2	
20	ID	220.7	26-2			20	OR	216.55	28-2	
21	ID	218.8	26-4	**Kirby Creek**		21	OR	216.4	28-2	**Fish Trap**
22	ID	218.2	27-3			22	OR	215.75	28-4	
23	ID	218.15	27-3			23	OR	215.7	28-4	
24	ID	217.2	27-5	**0**		24	OR	215.6	28-4	
25	ID	216.25	28-2			25	OR	215.58	28-4	
26	ID	212.45	29-5	**0**		26	OR	214.9	28-4	**0**
27	ID	211.15	29-7			27	OR	214.81	28-4	
28	ID	210.6	29-7			28	OR	214.8	28-4	
29	ID	210.35	29-8			29	OR	213.9	28-6	
30	ID	209.2	30-1			30	OR	212.65	29-3	
31	ID	208.35	30-3			31	OR	212.59	29-3	
32	ID	207.9	30-6	**0**		32	OR	211.9	29-5	**0**
33	ID	207.55	30-6			33	OR	211.45	29-7	
34	ID	207.33	30-6			34	OR	210.5	29-7	
35	ID	206.81	30-6			35	OR	210.19	29-8	
36	ID	206.4	30-7			36	OR	209.95	29-9	
37	ID	205.75	31-2			37	OR	209.72	29-9	
38	ID	205.1	31-4			38	OR	209.7	29-9	
39	ID	204.85	31-4			39	OR	209.67	29-9	
40	ID	204.25	31-4			40	OR	209.64	29-9	
41	ID	204.02	32-2			41	OR	205.68	31-2	
42	ID	203.95	32-2			42	OR	205.5	31-2	
43	ID	202.9	32-4			43	OR	204.45	31-4	
44	ID	202.55	32-6			44	OR	202.48	32-6	
45	ID	201.58	33-2			45	OR	201.9	32-6	
46	ID	201.25	33-2			46	OR	200.4	33-5	
47	ID	201.18	33-2			47	OR	199	33-7	
48	ID	201.05	33-4			48	OR	198.6	33-7	
49	ID	200.9	33-4			49	OR	198.3	33-7	
50	ID	200.4	33-5			50	OR	197.78	34-3	
51	ID	199.43	33-5			51	OR	193.94	35-3	
52	ID	198.75	33-7			52	OR	193.68	36-1	
53	ID	198.3	33-7			53	OR	192.35	36-3	**China Bar**
54	ID	196	34-6			54	OR	192.2	36-3	
55	ID	195.33	34-8			55	OR	191.7	37-1	
56	ID	194.95	34-8			56	OR	190.74	37-1	
57	ID	194.1	35-3			57	OR	189.68	38-4	
58	ID	193.15	36-1			58	OR	189.1	38-4	
59	ID	188.28	38-4	**Salmon Confl.**		59	OR	188.43	38-4	

Table G-9. Sandbar counts for the 2003 aerial photos.

2003 (Idaho Power Company)										
Approx. Flow (RM 247.7 downstream to approx. RM 225)= 8500 cfs										
Approx. Flow (RM 225 downstream to approx. RM 220)= 9500 cfs										
Approx. Flow (RM 220 downstream to approx. RM 207)= 10,000cfs										
Approx. Flow (RM 207 downstream to approx. RM 188) = 9500 cfs										
IDAHO (River Right)						OREGON (River Left)				
Sand Bar (#)	Side of River (Idaho)	Approximate River Mile	Photo Number	Comments		Sand Bar (#)	Side of River (Oregon)	Approximate River Mile	Photo Number	Comments
1	ID	245.8	4			1	OR	246	4	
2	ID	245.3	4			2	OR	245.8	4	
3	ID	244.65	5	**Brush Creek**		3	OR	243.4	7	
4	ID	242.5	8	**0**		4	OR	241.88	9	
5	ID	238.6	15	**0**		5	OR	240.66	11	
6	ID	238.08	15			6	OR	236.1	19	
7	ID	236.64	17			7	OR	235.25	19	
8	ID	229.88	28			8	OR	231.22	25	**0**
9	ID	229.8	27	**Johnson Bar**		9	OR	230.98	25	
10	ID	228.93	28	**Steep Creek**		10	OR	228.7	29	
11	ID	227.68	31	**0**		11	OR	228.56	29	**Yreka Bar**
12	ID	227.5	31	**Pine Bar**		12	OR	228.1	29	**0**
13	ID	226.8	31	**0**		13	OR	228.08	29	
14	ID	226.14	33			14	OR	226.25	32	
15	ID	225.8	33			15	OR	224.45	35	
16	ID	225.1	34			16	OR	224.3	35	
17	ID	225	34			17	OR	222.95	36	
18	ID	224.5	35			18	OR	222.8	36	
19	ID	221.48	37			19	OR	222.4	37	**Salt Creek**
20	ID	221.41	37			20	OR	222.1	37	
21	ID	220.7	38	**0**		21	OR	220.85	38	
22	ID	219.01	41			22	OR	220	39	
23	ID	218.8	41	**Kirby Creek**		23	OR	218.6	41	
24	ID	218.18	43			24	OR	216.6	46	
25	ID	218.14	43			25	OR	216.4	46	**Fish Trap**
26	ID	216.27	46			26	OR	215.74	46	
27	ID	212.48	50			27	OR	215.7	46	
28	ID	210.35	52			28	OR	215.6	46	**Tin Shed**
29	ID	208.32	56			29	OR	214.85	46	
30	ID	207.92	56			30	OR	214.37	47	
31	ID	207.55	56			31	OR	214.3	47	
32	ID	207.33	56			32	OR	212.57	50	
33	ID	206.82	58			33	OR	211.45	52	
34	ID	206.42	58			34	OR	209.67	54	
35	ID	205.76	60			35	OR	205.5	60	
36	ID	205.1	60			36	OR	205.3	60	
37	ID	204.84	60	**0**		37	OR	204.4	61	
38	ID	204.28	63			38	OR	201.93	65	**0**
39	ID	203.95	63			39	OR	200.18	67	
40	ID	202.58	63			40	OR	199	69	**Deep Creek**
41	ID	201.58	65			41	OR	198.6	69	**0**
42	ID	201.25	65			42	OR	198.3	69	
43	ID	201.17	65			43	OR	195.61	74	
44	ID	201.08	65			44	OR	193.97	76	
45	ID	200.9	67			45	OR	193.7	76	
46	ID	200.4	67			46	OR	192.35	76	**China Bar**
47	ID	200.05	67			47	OR	192.24	76	
48	ID	198.3	69			48	OR	190.75	80	
49	ID	195.58	74			49	OR	188.43	82	
50	ID	195.33	74							
51	ID	194.95	74							
52	ID	194.08	74							
53	ID	188.28	82	**Salmon Confl.**						

Table G-10. Hells Canyon Gage Daily Average Peak, Peak—15 min, and Yearly Average Discharges for 2000 thru 2004

Year	2000	2001	2002	2003	2004
	04/19	01/17	03/31	05/31	06/03
Daily Average Peak (cfs)	32,400	21,300	27,500	41,900	25,400
	05/16	01/17	04/19	05/31	09/15
15-Min. Peak (cfs)	37,500	29,400	29,200	45,400	30,800
Yearly Mean (cfs)	20,194	13,577	15,574	12,961	16,146