The enclosures from the U.S. Fish and Wildlife Service were received as presented. IPC made several attempts to obtain a better quality print/viewing copy from the USFWS but has not received one at the printing of the final license application.

Review of Idaho Power Company Documents Concerning Sediment-Related Impacts of the Hells Canyon Complex Dams on the Snake River in Hells Canyon

Peter R. Wilcock[2], John C. Schmidt[1], and Paul E. Grams[1,2]

[1]Department of Aquatic, Watershed, and Earth Resources
Utah State University
Logan, Utah 84322-5210

[2]Department of Geography and Environmental Engineering
The Johns Hopkins University
Baltimore, Maryland 21218

December 2002

1.0 Background and Structure of the Review

This report reviews documents prepared by the Idaho Power Company (IPC) in support of the application of IDACORP, Inc. for relicensing the T. E. Roach hydroelectric project, informally known as the Hells Canyon Complex (HCC). This project includes three dams located on the Snake River – Brownlee, Oxbow, and Hells Canyon -- that were completed between 1958 and 1967.

The application and supporting documents are approximately 25,000 pages in length, and a single paper copy of the application is reported to be contained in 33, three-inch thick binders (IDACORP, Inc. news release). Our charge was provided by Craig Kendall, hydrologist, Wallowa-Whitman National Forest, who provided us nine 'sediment transport review questions"(Appendix A) concerning the impacts of the HCC on the Snake River downstream from the HCC, especially within the Hells Canyon National Recreation Area (HCNRA). The area of concern includes the remaining riverine parts of the Snake River in Hells Canyon; other parts of the Snake River in Hells Canyon (as defined by Vallier, 1998) are inundated by Hells Canyon Reservoir and are not the subject of this review, except as pertains to computation of a system-wide sediment budget. Kendall requested that we focus our efforts on reviewing Parkinson et al. (2002). In support of this work, we also reviewed other supporting documents prepared by IPC, especially Miller et al. (2002). These documents were obtained electronically from the internet site http://www.collaborativeteam.org/usermain.asp. We also have reviewed previously published reports concerning the relationship between the HCC and downstream geomorphic resources (Grams, 1991; Schmidt et al., 1995; Collier et al.; 1996; Grams and Schmidt, 1999a, b).

In places, Parkinson et al. (2002) present lists of specific conclusions. Although our review addresses all these conclusions, we also provide point-by-point responses to some of these conclusions in Appendix B.

In our review, we examine key sediment-related resources. We define the essential sediment questions, the data collected and analyzed by IPC, and the conclusions that they reach concerning each topic. We comment on the merit of these conclusions and, where necessary, offer alternative interpretations of relevant data. We also describe future studies that can help resolve important uncertainties.

2.0 Introduction

Despite the length and complex detail of the IPC sediment and geomorphology studies, the basic issues are clear. The Snake River in Hells Canyon is a steep, high-energy river confined in a narrow gorge (Vallier, 1998; Miller et al., 2002). Sediment resources of primary interest are sand bars used as recreational campsites, fine-grained terraces that contain archaeological resources, and gravels of suitable size and location for spawning. The river has a large transport capacity relative to the rate at which sand and gravel are delivered to it. As a result, only a portion of the fine sediment delivered to the canyon is deposited and these deposits occur in locations, such as eddies behind debris fans at tributary mouths, that provide some protection from the flow. Studies in Grand Canyon, a canyon river system similar to Hells Canyon, show that the size and texture of eddy bars and channel-margin deposits are closely coupled to the sediment flux in the river (Rubin et al., 1998). These studies also show that the locations of these deposits are persistent but the sediments that comprise these deposits are transient and dynamic: their grain size and volume reflect the current water and sediment regime of the river. The deposits are maintained by a supply of sediment from upstream and, in the absence of such a supply, will be progressively eroded.

The three reservoirs comprising the HCC were completed between 1958 and 1967. The HCC produces a modest change in high flows within the Canyon and eliminates essentially all supply of sediment from the upstream Snake River watershed. The essential question is whether this mix—modest modification in high flows and elimination of upstream sediment supply—has produced a significant impact on sediment deposits in Hells Canyon. To address this question, two general issues must be addressed. First, what is the sediment supply to Hells Canyon and how has it changed following completion of the HCC? Central to this topic is the relative magnitude of upstream sediment supply (now eliminated by the HCC) and sediment supply from local tributaries below the HCC. Second, how have the sediment resources in Hells Canyon changed since completion of the HCC? An important concern here is distinguishing between natural variability of these dynamic sedimentary features and progressive change.

Once the sediment supply and sediment dynamics issues have been addressed, the remaining task is to connect the two, looking for plausible cause and effect. This is not an easy job. There is uncertainty in estimating sediment supply. Sandbar, terrace, and spawning gravel deposits exhibit spatial and temporal variability in their volume and composition. In the face of this uncertainty, estimates of reduced sediment supply must be compared to estimates of sediment loss from Hells Canyon.

We organize our report around these central issues: sediment sources, sandbar dynamics and terrace erosion, and spawning gravel dynamics.

3.0 Sediment Sources to Hell Canyon

The report acknowledges that the HCC traps sediment delivered by the Snake River to the HCC. Evaluating the impact of the HCC on sediment resources in Hells Canyon depends directly on the amount of upstream sediment supply that has been lost relative to the amount that is still supplied by local tributaries downstream from the HCC.

3.1 Upstream Sediment Supply

Sedimentation History in the Upper Snake River Basin: the "Sediment Slug"

IPC argues that accelerated erosion in the Snake River watershed upstream from the HCC occurred in the late 19th and early 20th centuries and the resulting sediment was subsequently transported downstream. IPC asserts that this "slug" of sediment, the product of unusually high erosion rates in the upstream watershed,, would have produced large bars in Hells Canyon, thereby biasing any interpretation that the HCC might have had an impact on Hells Canyon sediment resources. According to IPC, observations of decreased sand bar size are related to post-slug adjustment to "normal" conditions and are unrelated to the HCC. We agree that 19th century agricultural, forestry, and mining practices probably introducedlarge quantities of sediment into the watershed's streams. The issues relevant to the HCC, however, concern whether or not sufficient sediment was delivered to Hells Canyon in amounts that would have created unusually large sand or gravel bars, when this sediment arrived in Hells Canyon, and how long such deposits might have persisted in Hells Canyon. We disagree with IPC's findings on all of these accounts.

Studies conducted elsewhere in the United States suggest that IPC's assertions are probably wrong, are misleading, and cannot be evaluated without additional data. The primary issue is not whether there were high sediment yields in the mined lands, forests, or farm fields of Idaho, but whether or not these sediments ever reached Hells Canyon. Processes similar to those suggested by IPC were described by Gilbert (1917) for the movement of hydraulic-mining debris from the Sierra Nevada foothills into the Central Valley of California. Gilbert (1917) described the slow movement of a "wave" of mining debris that caused bed elevations of the Yuba and Sacramento Rivers to raise 3 to 5 m approximately 10 to 20 years after cessation of large-scale mining in the watersheds, and to return to their former elevation during the next 30 to 40 years. Estimates of the volume of hydraulic mining debris generated in the Sierra foothills are extraordinary, unprecedented in the American West, and likely to have been much larger than those generated in central Idaho. Even in California, however, James (1989, 1991, 1993) showed that sediment yield in other mined watersheds remained high in the late 20th century, and did not resemble the wave described by Gilbert (1917) for the Yuba River. Sustained sediment delivery has occurred elsewhere, because so much mining debris remains in small order valleys and on hillslopes. Thus, a slug may have moved from central Idaho, or sustained high levels of transport might continue to this day, such as at Mann Creek Reservoir on the upper Weiser River and Cascade Reservoir (Miller et al., 2002, Fig. 4.1).

However, it is more likely that much smaller amounts of sediment have actually reached the Snake River from headwater basins, because there are abundant locations where the products of accelerated erosion might be stored. For example, researchers have described the fate of the products of accelerated erosion in the Piedmont and Coastal Plain of the eastern United States (Trimble, 1974; Phillips, 1991) andthe American Midwest (Trimble, 1983, Beach, 1994). These studies show that large proportions of the products of accelerated hillslope erosion move slowly downstream because of temporary storage in small watersheds. Happ (1945) estimated that alluvial valleys in South Carolina are covered by about 1.2 m of upland sediment eroded in the late 1800s and early 1900s from hillslopes and farm fields. Rather than a slug of sediment producing large sand bars in Hells Canyon well into the 20th century, we find it more likely that 19th century sediment from upstream has been long sequestered in bars and floodplains, with smaller amounts moved through the Hells Canyon prior to completion of the HCC. Certainly the sequestration of sediment higher in the basin has been made much larger by the construction of reservoirs during the 20thcentury.

There are observations that can be made to estimatethe fate of the products of accelerated erosion. These include stratigraphic evidence of sedimentation in upland watersheds, historical data describing changes in stream-bed elevation through the river system,stratigraphic evidence in alluvial deposits along the Snake River, and historical accounts of the evidence of accelerated sediment transport. IPC presents little, if any, such evidence and the claims made are often internally inconsistent. For example, IPC asserts elsewhere that the streams draining central Idaho typically have deposited a large proportion of their loads in the Snake River Plain before reaching the Snake River. This observation makes it less likely that large quantities of sediment were delivered to Hells Canyon in the past. None of the reservoir sedimentation data reported by Miller at al. (2002, Fig. 4.1) suggest that sedimentation rates in Idaho batholith reservoirs were exceptionally high in the early part of the 20th century, although the rates reported for Mann Creek Reservoir on the upper Weiser River and Cascade Reservoir on the upper Payette are more than twice other estimates.

The interpretation that a sediment slug may have produced enlarged sand bars in the Hells Canyon depends not only on the delivery of large amounts of sediment, but on the persistence of this sediment within Hells Canyon for a long period of time. Sediment delivered in the early 20thcentury would have to remain within Hells Canyon for many decades in order to produce the enlarged bars that IPC argues existed in the 1950s. Such persistence is highly unlikely. Mean residence times for sediment in a narrow, high energy, canyon environment are likely measured in years, not many decades. Thus, it is unlikely that sediment delivered to Hells Canyon in the early 20thcentury (even more, in the 19th century) would remain in Hells Canyon in any significant amount by the 1950s.

We conclude that IPC's interpretation of the fate of any excess historical sediment is inconsistent with well-documented cases elsewhere and is unlikely. The amounts delivered to Hells Canyon, the timing of this sediment delivery, and the small residence time of sediment make its presence in the canyon in any substantial volume highly unlikely at the time that the HCC was constructed.

In addition to being unlikely, IPC's conclusions about a historical sediment slug are speculative and unsupported by necessary observation. No data are provided to evaluate their assertion, much less the argument that bars in Hells Canyon were unusually large at the time immediately prior to dam construction. The assertion that sand bar area in Hells Canyon has declined in response to reestablishment of pre-slug conditions and that reestablishment coincidentally occurred at the same time that the HCC was built is merely unsupported conjecture. Data are needed if one is to evaluate whether such a sediment slug ever existed, ever reached Hells Canyon, or ever passed downstream. The impact of the HCC on Hells Canyon sediment resources must be addressed by solid estimates of the sediment supply lost to the HCC, in comparison to the amount supplied by local tributaries below the HCC and the amount of sand lost by sand bars.

Quantifying the Magnitude ofSediment Yield from the Upper Snake River Basin

In an effort to demonstrate that the reduction in sediment supply to Hells Canyon is due to dams *other than* the HCC, Parkinson et al. (2002) estimate the amount of watershed area above the HCC that was blocked by dams before the HCC was constructed. The total drainage basin area upstream from the Snake River confluence with the Imnaha River is reported to be 74,238 mi^2, of which 60,200 mi^2 are upstream from dams constructed prior to construction of

Brownlee Dam in 1958 (Miller et al., 2002). Of the remaining 13,638 mi^2 basin above Hells Canyon Dam, 96% was blocked by the HCC: 9000 mi^2 is upstream from Weiser, ID and 4,100 mi^2 drains into the Snake between Weiser, ID, and Hells Canyon Dam (data from Miller et al., 2002). Only 538 mi^2 drains directly to Hells Canyon downstream from the HCC.

The report assigns sediment yield values to the different parts of the Snake River Basin in order to estimate the amount of the total basin sediment yield that is trapped in Brownlee reservoir relative to other reservoirs upstream. IPC concludes that "Brownlee Reservoir has only trapped 8% of the total volume of sediment accumulated within the basin upstream from the HCC" (Miller et al., 2002, p. 4-23). We find this estimate to be a serious underestimate, due to a persistent bias in the calculations designed to overestimate the sedimentation in upstream reservoirs and thus minimize the proportional sedimentation in the HCC. As an illustration of this bias, the sediment yield value to reservoirs upstream from the Owyhee Riveris estimated to be 0.15 af/mi^2/yr (330 tons/mi^2/yr) for Swan Falls and American Falls Reservoirs. This estimate is inconsistent with Miller at al. (2002, p. 4-7)'s own estimate of 0.0018-0.028 af/mi^2/yr (3.9-61 tons/mi^2/yr) developed from USGS (1994, 1995) transport data for the same part of the watershed. Thus, IPC argues that there is high sediment yield, or low sediment yield, in this part of the basin, depending on how it suits their argument. In fact, the comparison on which Miller et al. (2002)'s 8% estimate is computed comparesthe total estimated reservoir sedimentation in the 20th century with sedimentation in Brownlee Reservoir since 1958. IPC repeats this 8% estimate throughout its summary documents in an effort to discount the role of the HCC in blocking sediment transport of the Snake River, and this estimate is a deception.

The total amount of sediment IPC (Miller et al. 2002) estimates to be stored in Brownlee Reservoir (1,550 acre-feet/year or 2.78 million tons/year) can reasonably be derived from the9000 mi^2 upstream from Brownlee that were not blocked by reservoirs at the time of HCC construction. The sediment yield for this basin would be 0.172 af/mi^2/yr (373 tons/mi^2/yr), which is similar to the estimated average sedimentation rates for reservoirs draining western Idaho and eastern Oregon, as reported by Miller at al. (2002) (Table 1). Similar rates of sedimentation are reported by Miller et al. (2002) for deposition into Unity Reservoir on the Burnt River and into Oxbow Reservoir derived from the Wildhorse River.

IPC makes no comprehensive estimate of reservoir sedimentation into the entire HCC, making it difficult to evaluate the total sediment-trapping impact of the HCC on the downstream environment. The reservoir sedimentation data for Oxbow and Hells Canyon Reservoirs are poor to non-existent, and IPC reports that sediment yield increases downstream. Assuming the same yield as for the 9000 mi^2 basin upstream from Brownlee – 0.172 af/mi^2/yr (373 tons/mi^2/yr) -- one reasonably estimates that total storage in the HCC averages about 2250 af/yr (4.9 million tons/yr).

These sediment yield estimates are vastly different from those that Miller et al. (2002) report for tributaries draining directly into Hells Canyon (discussed below). The reported average sediment yield for the downstream tributaries is 28,100 tons/mi^2/yr, a value roughly 100 times greater than estimated for upstream sediment supply. In general, IPC asserts that little sediment was delivered to Hells Canyon from the 13,100 mi^2 basin previously unaffected by dams, no sediment was delivered from the 60,200 mi^2 basin affected by dams, and that virtually all of the sediment in Hells Canyon was, and is today, supplied by the 538 mi^2 basin directly tributary to the river downstream from Hells Canyon Dam. This argument is simply not credible.

We find that the upper basin sediment yield estimates provided by IPC are internally inconsistent, and that a more reasonable interpretation of these estimates indicates that the HCC has trapped a large volume of sediment in proportion to the flux that formerly entered Hells Canyon from upstream. Analysis of the data provided by IPC is greatly hindered by the fact that Miller et al. (2002) change the units in the reported data, and these changes make it very hard to evaluate consistency in the data. A simple table of all reported values would facilitate analysis by critical readers.

Uncertainty associated with estimates of basin sediment yield can easily serve to obscure a more fundamental point. Evaluation of the impact of the HCC on downstream sediment resources depends quite simply on the sediment supply interrupted by the HCC and its magnitude relative to remaining sediment supply below the HCC. The upstream supply of import is that delivered to Brownlee reservoir, the upstream of the 3 HCC reservoirs. There are two independent sources of information for making these estimates: sediment gaging records at the Snake River at Weiser gage and sedimentation measurements in Brownlee reservoir. Estimates of sediment yield from higher in the Snake River basin are not only enormously uncertain, but also less relevant to the problem at hand.

USGS Gage: Snake River at Weiser

Parkinson et al. (2002) discuss the fact that the USGS has collected suspended sediment samples at the Snake River at Weiser gage beginning in 1977, but do not make much use of these data except to mention that 20% of the measured sediment load is sand-sized. These data can be used to provide an independent estimate of the Snake R. sediment supply to the HCC that can be compared to the estimate of Miller et al. (2002, table 4.5).

Between November 14, 1977, and September 10, 1999, the USGS measured suspended sediment concentrations 91 times. Of these samples, 60 have grain size information reported, and 53 of those samples report sand (coarser than 0.062 mm) in transport. The proportion of sand in the transport averages 19% and shows no significant trend with discharge (Figure 1). This proportion is similar to the estimates of the proportion of sand entering the Snake from the Boise and Payette Rivers, as reported by Miller at al. (2002, p. 4-12).

The measured sediment discharge at Weiser can be regressed on the water discharge to provide a rating curve for estimating sediment supply to the HCC. The rating curves for total suspended sediment discharge (sand + silt + clay) and sand discharge are given in Figure 2 for the 60 samples with reported grain size information. The rating curve for sand is somewhat steeper than that for the total suspended sediment, a commonly observed phenomenon. The rating curves can be multiplied by the reported daily mean discharge at Weiser to provide an estimate of upstream sediment supply to the HCC. For the water years 1911-2000, the average annual suspended discharge is 949,000 tons, including 208,000 tons in the sand size range. For the post-dam era (water years 1959-2000), the average annual suspended discharge is 978,000 tons, including 214,000 tons in the sand size range. In each case, sand makes up 22% of the total annual suspended sediment discharge. This estimate is similar to that calculated by multiplying Miller et al.'s average daily load estimate by 365 (2002, Table 4.5), which yields an estimate of 1,100,000 tons.

There are two reasons why the annual sediment transport rate at the Weiser gage may underestimate the actual sediment delivery to Brownlee Reservoir. First, daily average values were used in calculating the sediment load, which will underestimate the sediment discharge when discharge varies over the day. For a river the size of the Snake, these within-day variations are probably small, however. Second, we are interested in the transport of the coarser sediment, which will tend to be found in higher concentrations closer to the river bed. This material can be undersampled and, therefore, underrepresented in the sediment rating curve and calculation of sediment yield.

River cross-section stability

Parkinson et al. (2002, figure 69) report channel cross sections for the Snake River gage at Weiser. They conclude that the cross-section history indicates that the Snake River is not an active, mobile river. Inspection of Figure 69 reveals deposition of a bar 2 to 4 ft thick and more than 400 ft across during some periods of measurement. It is hard to reconcile bar migration of this magnitude with an inactive channel. Further, the report mistakenly associates stability in cross section with small transport rates. Consider a large concrete pipe: its cross section remains perfectly stable, but it is capable of carrying sediment at small rates or enormous rates, depending on the rate at which water and sediment are supplied to it. A river section, particularly if its bed is composed of coarse sediments, can perform the same way. It is incorrect to associate a stable cross-section with minimal transport rates. The essential question concerns the estimated flux of fine sediment, including sand, entering Brownlee Reservoir from upstream and the estimated disruption of this flux caused by the HCC. These estimates are better made from measurements of the flux and not of the cross-section within which it occurs.

Reservoir sedimentation

IPC's estimate of upstream sand supply relies primarily on records of sedimentation in Brownlee Reservoir. Although reports of resurveys of the reservoirs are not explicitly discussed, we deduce from Appendix B of Technical Report E.1-1 (Brownlee Reservoir Aquatic Sediment Study – Physical and Mineralogical Analysis, by CH2MHill) and discussion in Parkinson et al. (2002) that the only bathymetric information available are pre-construction topographic maps with a 20 ft contour interval and a reservoir survey in 1997. This information is insufficient to develop an estimate of upstream sediment supply or its average sizes with the resolution necessary to answer questions about the impact of the HCC on sediment resources in the Hells Canyon. It is also striking that no data are presented concerning the bathymetry of Oxbow or Hells Canyon Reservoirs. It is thus impossible to develop an overall number of the total sediment trapped in the HCC, although we provide an estimate, described above.

CH2MHill (Appendix B) conducted a sampling program of river and reservoir sediments between 1998 and 2000. Sampling consisted of 3 deep cores, 18 grab samples along the river and in the mouths of six tributaries, and shallow sediment cores collected approximately every 5 river miles through Brownlee Reservoir. Although these samples provide a useful picture of the materials being delivered to and trapped in the reservoir, we find that they do not provide an adequate sampling scheme to describe the supply of the coarser sediment (sand and gravel) that is of primary interest regarding sediment resources in the Hells Canyon. The depositional environment in the upper Brownlee reservoir is complex, particularly due to the 100 ft variation in pool level over time (corresponding to a more than 20 mile shift in the upstream extent of the pool). Deposits of sand and spawning gravels within the reservoir are likely to be localized and a reliable estimate of their volume would require identifying, mapping, measuring, and sampling all major sand and gravel deposits. A sample every 5 mi simply does not provide the resolution needed to determine, even roughly, the amount of sand and gravel trapped in the reservoir.

There is certainly clear evidence of sand deposition in the reservoir. For example, the shallow sample at RM315 consists of 63% sand. This sample is 1 of only 2 located within what appears to be the primary delta deposit, located in the vicinity of lower pool elevations. It is likely that sediment deposited at higher pool levels would be reworked and deposited in this vicinity.

We conclude that the IPC estimate of 4% sediments coarser than silt is likely a large underestimate of the sand and coarser sediment volume in the HCC. A more reasonable estimate is that 22% of the total sediment stored in Brownlee Reservoir is sand, based on measurements at Weiser.

3.2 Tributary sediment supply

Method

Sediment supply from tributaries downstream from the HCC was calculated for 17 tributaries accounting for 55% of the 538 mi^2 area. Transport rates were estimated with the Schoklitsch equation using as input samples of bed material, a surveyed cross section, and a surveyed channel slope. A sediment-rating curve (sediment transport rate as a function of discharge) was developed using the calculated transport rates and a flow resistance equation for steep mountain streams. Annual sediment yield was estimated using the calculated sediment rating curve and an estimated flow duration curve for each stream. The flow duration curve was developed from USGS regional curves for the 20%, 50%, and 80% exceedance flows. These three flows were then fitted by a “log curve” to determine discharges at 5% exceedance intervals.

Uncertainty

There is enormous uncertainty associated with these estimates of tributary sediment supply. The primary sources of uncertainty are:

(1) *Transport relation.* Calculations of sediment transport rates from a formula (any formula) might optimistically be claimed to be accurate within a factor of two or three. In cases with limited input (as is the case here), that uncertainty could easily be an order of magnitude. That is, an actual transport rate of, for example, 100 g per meter per second could very well be

calculated as a transport rate of 10 g per meter per second or 1000 g per meter per second.

(2) *20/50/80 exceedance curve*: the stated standard error for estimating the 20%, 50%, and 80% flow exceedance at each site is –46 to 85%.

(3) *5% increments on the flow exceedance curves*: the actual exceedance values used in the sediment yield calculations are based on a log fit to the 3 estimated points at 20%, 50%, and 80%. Because the transport relation is nonlinear, most calculated transport actually occurs at the highest flows (in this case those associated with 15%, 10%, and 5% exceedance), which are estimated by *extrapolating* from the fitted line. Flow duration curves tend to be strongly nonlinear at the largest flows (e.g. exceedances smaller than 10%) and are unlikely to be fitted adequately by any simple trend. As a result, most of the calculated transport rates are produced by flows that are estimated using an inaccurate extrapolation from three data points that are themselves an estimate with large uncertainty.

None of the elements of the tributary sediment supply estimate alone would necessarily produce unacceptable uncertainty for a very approximate analysis. The Schoklitsch formula is a recognized, if rarely used, transport formula. The USGS regional curves provide some basis for estimating flow magnitude in ungaged streams. Extending a 3-pt flow duration curve to a 20-pt flow duration curve with a "log curve" gives a coarse estimate of larger flows, although more accurate approaches can be found. It is in combination that the uncertainties associated with each element produce an estimated sediment supply with so much uncertainty as to have no practical use.

In 3 of the 17 tributaries (including Wolf Creek, one of the largest), IPC calculates zero sediment supply. They offer this result as evidence that their calculation approach is conservative. This logic is weak and could be just as easily be used to argue that their sediment yield estimates for other watersheds are unreasonably large in the face of zero transport calculated for other watersheds. In fact, the only conclusion that can be drawn from the enormous range in sediment supply estimates (0 to 160,000 tons/mi^2/yr) is that the uncertainty associated with the estimates is enormous.

Bias

The report claims that the transport estimates are conservative, based on choices made in developing the calculation procedure. Although the factors cited (e.g. no transport until 85% of the sizes are moving; use of daily mean flow estimates rather than instantaneous flows) do reduce the calculated transport rate, another factor is likely more important and suggests that the calculated sediment supply is actually far too large.

The primary source of an overestimating bias is the use of the calculated transport capacity to estimate actual sediment yield. This means that IPC assumes that the tributary streams would be able to transport sediment at the calculated rates at all flows. This is unlikely. In a large flood (which would account for most of the transported sediment) in these steep tributaries, it is likely that much of the readily transported sediment would be rapidly mobilized and evacuated, leading to a rapid decrease in transport rates, or *supply-limited* transport. The authors observed loose sediment available for transport in some of these stream channels and suggest that this indicates that transport would not be supply limited. This is insufficient evidence. A conclusion that the transport could occur at full capacity at all flows would require documentation of the availability of transportable sediment *in quantities approximating those estimated to be transported.* In Granite Creek (which is calculated to supply more than half of the total tributary sediment supply), this would be more than 5 million tons of sediment *each year* (or 160,000 tons/mi^2/yr). No evidence is given that such quantities of sediment are available for transport, and we find this number to be improbably large.

Parkinson at al. (2002) report that the watershed area draining directly to the Hells Canyon below the HCC is 548 mi^2. Their estimate of sediment supply from this area is 16.6 million tons per year. This value is more than 16 times the annual sediment load measured on the mainstem Snake R at Weiser. The magnitude of the IPC estimate of local tributary yield is implausible relative to the volume of transport in the mainstem.

As reported by Miller at al. (2002), the watershed area draining directly into the HCC is 4,100 mi^2. The average sediment supply calculated for tributaries below the HCC is 28,100 tons/mi^2/yr. This value is two to three orders of magnitude larger than most of the estimates reported for any place upstream from Hells Canyon (Table 1), and well over one order of magnitude larger than the largest of those estimates. Although the landscape typically includes areas of high and low sediment yield, it would be unusual that the sediment yields would be so large downstream from the HCC yet so much less upstream. If a sediment yield of 28,100 tons/mi^2/yr were applied to the 4100 mi^2 drainage directly entering the HCC, then sediment delivery to the HCC reservoirs would be 53,000 acre-feet *each year*, a value almost as large as the 62,000 acre-feet reported by IPC over a 40-year period. More remarkably, this rate of sediment supply would have *entirely filled* all available storage in all three HCC reservoirs by about 1990. The IPC estimate of local tributary sediment yield is simply implausible.

3.3 Mineralogical and grain size analyses of sediment sources

Samples of river sediment in Hells Canyon were compared with river samples above the HCC and with samples taken from local tributaries to Hells Canyon. The mineralogy and grain size of the samples were compared to evaluate whether sediment in Hells Canyon is derived primarily from local tributaries or from the Snake River above the HCC. IPC concludes that the Hells Canyon samples are different from those upstream, indicating that the sediment source is the tributaries below HCC. In both the mineralogical and grain size comparisons, we find there is little basis to support these conclusions in the data presented and that the assumptions and sampling underlying the comparisons would not, in any event, allow such a comparison to be made.

In order to determine whether the HCC has altered the sediment supply to Hells Canyon, it is necessary to demonstrate that the sediments sampled within Hells Canyon are of pre-dam origin. If upstream sediments could be shown to differ significantly from pre-dam deposits in Hells Canyon, a case could be made that the sediment source has always been local and, therefore, that the HCC has had little impact on the sediment supply. If, on the other hand, one is comparing upstream sediments to post-dam deposits in Hells Canyon, one is merely documenting that the sediments *currently found in Hells Canyon* are derived from local sources, which may not be surprising given that the samples were collected in a highly dynamic environment more than 40 years after the upper basin was isolated from Hells Canyon.

Therefore, it is incumbent on those following this logic, i.e. IPC, to unambiguously demonstrate that they have sampled pre-dam deposits in Hells Canyon. Almost no description is given of the procedure used to select sample locations in either the sediment transport report or in Appendix F of Miller et al. (2002), which presents the mineralogical analysis. However, given the description of the sampling methods (most samples in Hells Canyon appear to have been collected by shovel during low water conditions) and the grain size of the samples, it seems reasonable to infer that the samples were collected from channel-margin deposits and bars that are actively transported during high flows. River discharge in the Hells Canyon in the 1990s included the largest flows on record; we find it likely that the sediment sampled was mobile during these flows and earlier post-dam high flows. Certainly, no attempt is made to suggest that these samples are pre-dam, and we find it unlikely that they would be. Notwithstanding this essential methodological flaw, the data presented do not indicate a dominant local source, as the report concludes. We demonstrate this below.

Mineralogy

For the coarse material mineralogy (Figure 1, top panel of Appendix F of the Geomorphology Report), the data indicate that a lithological trend exists in which a simpler, two-part lithology upstream of the HCC becomes more varied below the HCC. Given the height and steep slope of the canyon, one would expect local lithologies to appear in the river bed sediments within the canyon. However, this observation does not lead unambiguously to the conclusion that upstream rocks are not present in the riverbed sediments. More striking is the mineralogical information for the fine (< 4 mm) sediments. The mineralogy of both upstream and downstream samples is classified as almost entirely quartz/plagioclase and mafics. The upstream and downstream samples are largely indistinguishable, with the exception of the appearance of small amounts of metamorphic rock (1-10%) in the Hells Canyon samples. The mineralogical report (Appendix F) concludes that "the relative lack of K-feldspar in the downstream samples strongly suggests that finer bed sediments are derived from local sources, rather than bedrock sources up-river of the complex". Based on the lower panel of Figure 1 of Appendix F, this conclusion appears entirely unwarranted: the upstream samples also have no K-feldspar. The upstream and downstream samples are largely indistinguishable and, if anything, suggest a consistent sediment source rather than the local source claimed by IPC. Even if the Hells Canyon samples were demonstrably pre-dam and, therefore, suitable for an appropriate comparison, the data presented simply do not indicate a difference between upstream and downstream samples.

Grain size

Figures 72 and 73 of Parkinson et al. (2002) compare grain-size distributions for samples above the HCC, within Hells Canyon, and in local Hells Canyon tributaries. The report concludes, "the results … corroborate the conclusion that sediments in the Snake River below the HCC are from local sources". We find no basis for this conclusion. First, the spread in the data, and the overlap among the different curves, cannot be used to draw any clear conclusions. Second (and more significant), it is well known that the local hydraulic environment exerts a stronger control on the composition of deposited sediment than does the overall supply to a river reach. This is why studies looking for longitudinal variations in sediment grain size must rigorously sample from comparable local environments along the entire river (e.g. all samples collected from riffles, or from the upstream side of bars, etc.). No such local control on sample location is reported. In fact, it is safe to conclude that the local hydraulic environment of the Hells Canyon tributaries is certainly different from depositional environments along the mainstem. Even if the reported size distributions were truly different, the absence of sample location control makes any comparison based on grain size meaningless.

3.4 Summary on Sediment Supply

IPC asserts that there was an anthropogenically-derived "slug" of sediment that moved from central and southern Idaho into Hells Canyon during the first half of the 20th Century that was derived from accelerated hillslope and valley erosion caused by mining, agriculture, urbanization, grazing, and post-wildfire erosion (Miller et al., 2002, Chapter 2). This sediment entered Hells Canyon before the HCC was completed and observations of decreases in sand bar size are related to the natural reestablishment of smaller bars due to the evacuation of this "slug.

We agree that historical erosion and sedimentation in the upstream watershed may have been large in the 19th and early 20th century. Our interpretation of the fate of any increased erosion is quite different from IPC's, however. Much of this sediment was probably deposited close to its source, much higher in the watershed. No evidence is provided that a substantial amount of fine sediment actually ever reached Hells Canyon. More importantly, no evidence is provided to demonstrate that sand bar size in Hells Canyon was unusually large in the mid 20th century and was related to arrival of this slug that may never have reached Hells Canyon. Any increased sediment load that reached Hells Canyon would have passed through the steep, high energy canyon quickly. The amount of sand that can be stored in Hells Canyon is limited, determined by the location and size of protected areas capable of storing sand. Studies in other debris fan-dominated canyons with abundant eddy deposits, e.g. Grand Canyon, show that bar size is sensitively adjusted to the sediment flux and bars decrease in size if the sediment flux greatly decreases. If a slug ever did reach Hells Canyon, eddy bars would have begun to diminish in size soon after the slug had moved downstream, and thus shrinkage of bars would have begun prior to construction of the HCC.

The IPC has not *demonstrated* their sediment slug hypothesis in any way, whether regarding evidence of increased sediment loads in the basin's rivers or evidence of larger sand bars in Hells Canyon. We find their interpretation implausible and inconsistent with documented cases elsewhere; it is clearly undemonstrated.

IPC makes a detailed effort to demonstrate that much of the sediment supply from the upper Snake River Basin was isolated from the Hells Canyon before the HCC was ever constructed. We find that their values of sediment yield are inconsistent with reasonable values found in the literature.Further, IPC takes both sides of the argument: that sediment supplies to Hells Canyon were sufficiently large to produce enlarged sand bars in Hells Canyon all the way up to the time of construction of the HCC and, at the same time, that sediment supplies to the Hells Canyon were sufficiently reduced by the time that the HCC was constructed that the HCC itself had little effect on an already much diminished sediment supply. In the end, this duplicity must be bypassed by solid information on the sediment supply to Hells Canyon.

Evaluation of the impact of the HCC on downstream sediment resources depends on the sediment supply interrupted by the HCC and its magnitude relative to remaining sediment supply below the HCC. The relevant upstream supply is that delivered to Brownlee Reservoir, the upstream of the 3 HCC reservoirs, as well as to Oxbow and Hells Canyon Reservoirs. There are two independent sources of information for making these estimates: sediment gaging records at the Snake River at Weiser gage and sedimentation measurements in Brownlee Reservoir.

A preliminary estimate of the upstream sand supply can be based on the Snake River at Weiser gage. The upstream supply of sand (>0.062 mm) for the Snake River at Weiser is about 215,000 tons per year, based on the 1959-2000 discharge record and the sand rating curve at the gage. This is likely an underestimate, because coarser sizes in transport travel close to the river bed and are proportionally missed by the sampling device.

The reservoir information presented by IPC is insufficient to develop a reliable estimate of sand supply at a resolution useful for identifying HCC impacts on downstream sediment resources. Parkinson et al. (2002) state that total sedimentation between pre-dam conditions and 1997 is 62,000 acre-feet and that 4% of this material is sand. Using an approximate bulk density of 100 lbs/ft^3, this represents approximately 135,000 tons per year of sand deposition over the 40-year time span. This value is 37% smaller than the value of 215,000 tons per year based on measurements at the Weiser gage. Using a more reliable estimate of the composition of sediment delivered to Brownlee of 22% sand (as indicated by the Weiser gage), the sand deposition in Brownlee Reservoir would be 745,000 tons per year, a value more than three times the Weiser sediment load estimate.

Because the sediment supply estimated for the Wesier gage is likely too small due to the missing sediment load near the bed and because the actual volume of sediment stored in Brownlee Reservoir is poorly known, we suspect that the annual sand supply sequestered by the HCC is likely to fall in the range 250,000 to 750,000 tons per year. This estimate is for sediment supply from the Snake River to Brownlee Reservoir and does not include the additional sediment supply from the 4,100 mi^2 watershed draining directly into the HCC.

If a reliable estimate of upstream sand supply is needed, the best course of action would be to comprehensively map, survey and sample sand deposits in Brownlee Reservoir.

A less accurate alternative would be to add bed load sampling to the suspended sediment sampling at the Weiser USGS gage and increase the frequency of both samples.

The method used to estimate sediment supply from tributaries below the HCC has such enormous uncertainty as to render the calculations useless for any practical purpose. This uncertainty notwithstanding, a key assumption in the calculation (sediment supply calculated as full transport capacity) makes it likely that the calculated sediment supply is significantly overestimated.

IPC reports on core samples collected in Brownlee Reservoir showing that the size of sediment in the Brownlee delta are finer than the sizes of existing sands in Hells Canyon sand bars. Thus, IPC argues that sediments trapped in the HCC have no relevance to the sand bar resources of Hells Canyon. IPC's comparison of Hells Canyon sediment samples with samples above the HCC has no useful meaning for the arguments they make. Such a comparison could only be useful if the Hells Canyon samples were demonstrably pre-dam. They do not make this demonstration and, we suspect, the Hells Canyon samples used by IPC are composed of post-dam sediments. Thus, it is no surprise that these sediments would differ from upstream sediments. Even without this fundamental flaw in their logic, IPC tries to make a case when even cursory inspection of the mineralogy and grain size of the samples reveals no significant difference between samples within Hells Canyon and those from upstream.

The IPC License application states:

> Grams and Schmidt did not consider that 87% of the watershed upstream of the HCC was already behind dams (or sediment traps) by the time that Brownlee Dam was completed. Therefore, the majority of their assumed sediment supply was already unavailable. They also lacked information on sediments actually trapped in Brownlee Reservoir. Such information would have shown that only minor amounts of sand have been trapped. These sands are of the fine and very fine sizes and include almost no coarser sand sizes. In contrast, sandbars downstream have the full range of sand sizes, from very fine to very coarse sizes. Therefore, the applicant's analysis and findings invalidate several of the key assumptions on which Grams and Schmidt relied when they concluded that the HCC was the sole cause of sandbar degradation in Hells Canyon.

This statement is unfortunately misleading. The essential conclusions of Grams and Schmidt were that sand bars in Hells Canyon decreased in number and area following construction of the HCC. This is a simple, empirical observation that depends on no assumptions about sediment supply to the Hells Canyon. Parkinson et al. (2002) ignore this obviously problematic finding, although Miller et al. (2002) acknowledge it. Neither report

presents any evidence disputing the findings of Grams (1991) or Grams and Schmidt (1999).The proportion of the watershed above HCC that was already behind dams at the closure of Brownlee Reservoir is, essentially, beside the point. Judgments about whether the amount of sediment trapped in Brownlee Reservoir is "minor" requires a context: the interrupted sediment supply must be compared with the remaining supply below the dams and the amount lost from Hells Canyon. Although an estimate of sediment delivery to HCC can be made, there is no reliable estimate of the magnitude of sediment delivery from tributaries below HCC. It can be shown (discussed below) that the quantity of sediment trapped by the HCC is a large multiple of the amount of sediment eroded from Hells Canyon sand bars, indicating that sediment trapping by the HCC remains the likely explanation for Hells Canyon sand bar loss over the past half century. Finally, IPC's use of today's sand bar composition to estimate the eliminated sand supply involves a simple logical fallacy: today's sand bars may not (and probably do not) have the composition of pre-dam sand bars.

4.0 Sand Bar Dynamics

The relationship between the studies of Miller et al. (2002) and Parkinson et al. (2002) is not explicitly discussed by IPC, and this limits critical analysis of the integrated view held by IPC regarding the fate of sand bars in Hells Canyon. In their identification of issues and concerns, Parkinson et al. (2002) recognize the importance of sand bars as a resource to river recreationists and note that there is widespread perception that the sand bars have eroded as a consequence of the operations of the HCC (E.1-1, p. 13). Their treatment of the subject is terseand includes no discussion of the relevant literature, although they describe quantitative measurements for limited time periods and for limited reaches of the Snake River. They also describe measurements of sand bar change in the late 1990s. Miller at al. (2001) discuss the previous studies of Grams (1991) and Grams and Schmidt (1999a, b) as well as referring to the results of Parkinson et al. (2002).Thus, we assume that the report of Miller et al. (2002) reflects the integrated opinions of IPC on this subject. Below, we evaluate the quantitative studies described by Parkinsonet al. (2002) and the analysis of Miller at al. (2002).

4.1 Parkinson et al. (2002)'sAnalysis of Sand Bars from Aerial Photographs

Parkinson et al. (2002) conducted a study of sand bars using historical aerial photographs. They used three methods: (1) repeat measurements of bar area from rectified aerial photographs, (2) measurements of bar position relative to stable reference points, also from rectified aerial photographs, and (3) a count of sand bar occurrence from aerial photographs. Because they do not present any results from the second method, only methods one and three are discussed below.

For the repeat measurements of bar area they selected 10 sand bars and measured the area of those bars in photographs from 1946, 1948, 1949, 1955, 1961, 1964, and 1968, although they did not measure every bar in each of those years. In their analysis, they measured area of exposed sand on digitized and rectified aerial photographs. Table 1 lists their 10 sites, which we have cross-referenced to the sand bars included in the study conducted by Grams (1991). Four of these are sites where Grams (1991) showed small or no significant change between 1964 and 1990, three are sites where Grams (1991) showed more than 50% of the bar eroded, and one is a bar that eroded completely. Two of the sites could not be reliably cross-referenced. Because Grams (1991) showed that the number of bars decreased by about 75% between 1955 and 1990, the sites chosen by IPC are biased towards sand bars that have changed the least. Pine Bar, Salt Creek Bar, Fish Trap Bar, and China Bar are among the largest and most stable bars in Hells Canyon. While these may be appropriate monitoring sites, they are not representative of the overall condition of sand bars in Hells Canyon.

In their analysis of bar area, IPC adjusted the measured areas to account for discharge differences between photographs. However, they do not report what the discharges were for each of the photographs or give the exact date of the photographs. They adjusted bar area by assuming a sand bar slope and then calculating the horizontal position of the edge of water given a vertical change in water surface elevation. They assume the slope is the submerged angle of repose of sand, which is 28 degrees. They cite no other application of this assumption and provide no evidence to support the assumption. Because the sand is deposited in moving water and is almost continually affected by either streamflow or wind, there is no basis for assuming that the bars are at the angle of repose. A brief examination of the field data IPC collected at Salt Creek Bar, Fish Trap Bar, and China Bar shows that the bars are not nearly that steep. According to those data (Figures 29, 30, 31, 32, 34, 35, and 36) bar slopes are typically between about 5 and 10 degrees, but may be higher or lower. This range and variability of bar slopes would likely preclude the application of any area adjustment that uniformly applied a constant correction to all bars. Finally, they do not report the unadjusted bar areas, so it is impossible to know how severely the discharge adjustment affects the results.

IPC also mapped sand bars using 1946 and 1955 aerial photographs along 12.5 river miles beginning at river mile 42 mi downstream from Hells Canyon Dam. IPC provides no reasoning or justification for their study reach selection. They conclude that in this reach, the number of sand bars was similar in 1946 and 1955, which argues against their conclusion that Hells Canyon sand bars at this time were shrinking due to the passage of a "sediment slug" from the upper Snake River basin.

4.2 Parkinson et al. (2002)'s Sand Bar and Terrace Particle Size.

IPC presents grain-size distribution data for the active portion of four sand bars and the high terraces adjacent to two of those bars. They do not calculate median particle sizes, but the graphs show it to range from about 0.2 to 0.6 mm. The size of the sand in the terrace is smaller at both locations where those samples were collected. The terrace sand is about 0.1 mm smaller at Fish Trap Bar and about 0.5 mm smaller at China Bar. Thus, IPC's conclusion that "*the material in the adjacent cutbanks is from the same source as the material in the current sandbars*" is not supported by the data they present. Conversely, IPC's limited data suggest that the material in terraces may be significantly smaller than the material comprising the active sand deposits. Thus the material comprising pre-dam deposits may have been significantly finer than the contemporary post-dam deposits. The coarse sand that comprises today's sand bars in Hells Canyon is likely related to the absence of finer sediments. In Grand Canyon, sand bar [illegible] closely [illegible] the grain sizes of the suspended load. Thus, the coarsening of Hells Canyon deposits [illegible] from terraces to bars is most likely a reflection of the trapping of very fine sand [illegible] in the HCC. Thus, while IPC's statement that sand bars in Hells Canyon are coarser than the sediment trapped in Brownlee Reservoir (p. 79) may be correct, it is incorrect to interpret this to mean that trapping of sediment in upstream reservoirs has had no effect on sand bars in Hells Canyon.

4.3 Sand Bar Monitoring Data

IPC presents sand bar monitoring data for three sites also surveyed by Grams (1991) and Grams and Schmidt (1999b). The IPC data span the period from 1997 to 2000 while the Grams and Schmidt (1999) data span the period from 1990 to 1998. IPC also report data for one additional site surveyed by Grams and Schmidt only in 1998. IPC does not discuss the earlier data and does not attempt to compare their surveys with previous measurements. Grams and Schmidt (1999b) showed that there were areas of aggradation and degradation of sand at each of these sites but that net degradation occurred at each site and the area of cobble armor increased at each site. Both the IPC data and the Grams and Schmidt (1999b) are too limited to make general conclusions regarding large-scale trends in sand bar storage in Hells Canyon. A sample of three or four bars for 80 miles of river is not sufficient. It is only possible to conclude that there is significant reworking of the sand each year and for the three sites surveyed by Grams and Schmidt in 1990 and 1998, there appears to be a trend of gradual net degradation of the sand bar surfaces. The IPC report states that "the banks remained stable" between 1997 and 2000. The Grams and Schmidt (1999b) data, however, show that the cutbanks into the high terraces have eroded significantly between 1990 and 1998.

4.4 Summary on Sand Bar Dynamics

A clear record of the change in sand bar number and area can be developedfrom the results of Grams (1991), Grams and Schmidt (1999b), and Miller et al. (2002). Sand bar size varied abouta relatively large average condition until the late 1960s. After that time, sand bars quickly declined in size and the rate of sand bar loss was more rapid near Hells Canyon Dam than further downstream. The rate of change in bar area is much less today than in the first decade after completion of the HCC. This is strong evidence, free of any assumptions, that sediment trapping in the HCC is responsible for the sand bar loss. The results of Miller et al. (2002) and Parkinson et al. (2002) do not substantially challenge or modify this story.The remaining issue to provide quantitative evidence linking (or refuting) a cause-and-affect relation between HCC and sand bar loss in Hells Canyon. IPC's arguments here hinge on the sediment budget issue analyzed in section 3 of this evaluation. We find little credible data to support IPC's contention that the sand bars were unusually large just prior to completion of the HCC and that the decrease in bar area is unrelated to the existence of the dams.

IPC's License application states:

> Another key assumption on which Grams and Schmidt's conclusions depend is that the Snake River and specifically the sandbars in the Hells Canyon reach were in a state of dynamic equilibrium from 1955 to 1964. They did not consider anthropogenic disturbances in the watershed above the HCC. However, these disturbances initially increased the sediment supply to the Snake River, after which over 500 dams with over 10 million acre-feet of storage were built. Therefore, assuming that the Hells Canyon reach was at a

> state of dynamic equilibrium following approximately 100 years of upstream activity and development is not appropriate, and making this assumption leads to the erroneous conclusion that the HCC is responsible for all changes to sandbars in the Hells Canyon reach."

We separate evaluation of IPC's arguments between analysis of their critique of the results of Grams and Schmidt's studies and critique of the possible reasons for the historical changes described by Grams and Schmidt.

We can not find any place in either Parkinson et al. (2002) or Miller et al. (2002) where the historical evidence of decrease in sand bar area or volume determined by Grams (1991) or Grams and Schmidt (1999b) is questioned. These earlier studies are adequately summarized by Miller et al. (2002, p. 5-30), and the results are not questioned. Grams (1991) and Grams and Schmidt (1999b) showed that the number and area of river edge sand bars along the Snake River decreased greatly soon after completion of the HCC, and the magnitude of these changes decreases downstream. Grams (1991) showed that sand bars decreased in area and number by approximately 75% between 1964 and 1990. Most of this decrease occurred between 1964 and 1973. Grams hypothesized that most of the erosion occurred during high dam releases in 1965, 1970, and 1971, although he did not have the temporal resolution in sand bar measurements needed to prove this assertion. It is possible that much of the erosion documented by Grams (1991) occurred after 1968 and was missed entirely by the IPC analysis.

Rather than reevaluate the full historical and spatial record developed by Grams (1991) and Grams and Schmidt (1999b), IPC conducted studies of limited spatial and temporal scope that yield ambiguous results largely unrelated to the findings of the previous studies. The conclusions reached by IPC in their license application are not supported by their own reports, and the IPC arguments are based on assumptions and assertions about the sources and quantities of sand in transport and not on the historical data measured by Grams (1991) and Grams and Schmidt (1999b).

5.0 Erosion of Terraces in Hells Canyon

IPC asserts that there is little erosion of terrace deposits in Hells Canyon and where erosion occurs, it is unrelated to HCC operations because the flood hydrology of the Snake River has not been changed by the HCC. Miller et al. (2002) summarize the findings of Grams and Schmdit (2002a) concerning erosion at Tin Shed, but they state that flows did not overtop the terraces and thus could not have eroded terrace cutbanks. Grams and Schmidt (1999a, b) demonstrated that terrace cutbanks have retreated in many locations in the late 1990s, and that cutbank erosion has been associated with high flows that reach the lower half of many cutbanks. Although no measurements were made during the high flows of the late 1990's, Grams and Schmidt (1999b) argued that these high flows must have caused cutbank erosion because they were the only significant geomorphic force operative on these areas. IPC points out that recreational foot traffic and wind might cause such erosion.

[illegible] [illegible] that IPC's argument that HCC flows are unrelated to terrace erosion is unsupported. [illegible] [illegible] failed to support this contention, and the other processes [illegible] [illegible] [illegible] [illegible] high flows did reach the base of many cutbanks in 1997. [illegible] Grams and Schmidt (1999b) and the most reasonable interpretation of thecause of these measured bank retreat are those high flows.

6.0 Gravel mobility, with emphasis on spawning gravels

Parkinson et al. (2002) estimated the mobility of the river bed in Hells Canyon using estimates of bed surface grain size and calculations of shear stress derived from stage and energy slope calculations from a hydraulic model. In addition to calculations along 566 cross sections above the Salmon River confluence, calculations were made at 17 spawning gravel sites.

Grain size information for the main channel sites was collected from "photo sieving" of underwater video taken at approximately 600 locations along the river bed. Because the video was not taken at each of the cross sections used to calculate bed mobility, judgment had to be used when selecting the grain size sample used in the calculations, introducing an important source of error. Sediment grain size at spawning gravel sites was collected using the same or similar photo analysis approach (Groves and Chandler, 2201).

Bed shear stress was calculated for the main channel sites using the standard depth-slope product. In this, the section average shear stress is calculated as the product of the specific weight of water, the flow hydraulic radius, and the flow energy slope. This provides a measure of the total shear stress (force per area) acting on the cross section, but not the stress acting on particular locations within the section. Shear stress for the spawning gravel sites was calculated by substituting local flow depth over the spawning gravels for the hydraulic radius.

Incipient motion of the bed material was evaluated using a dimensionless shear stress of 0.047. Because the dimensionless shear stress is calculated using the bed surface size distribution, (rather than the subsurface), a value of 0.047 may be expected to indicate small to moderate transport rates because a surface-based dimensionless stress for incipient motion is likely to be in the vicinity of 0.03 to 0.035 (e.g. Parker, 1990; Wilcock et al., 1996).

Calculations of sediment incipient motion based on bed grain size observations and shear stress calculations are highly uncertain. Grain size will vary within the spawning gravel deposit and the flow field over the spawning gravels will not be a simple 1d field for which the depth/slope product is appropriate. A section averaged dimensionless shear stress of 0.047 may be expected to be associated with moderate, even intense transport, at some locations throughout the section or at locations within the spawning gravels.

6.1 Stability, mobility, and the health of spawning gravels.

The [illegible] report uses the term bed stability to indicate the presence or absence of sediment transport. In the report, a "stable" bed indicates an "immobile" bed and the intent of the report appears to be to document the general immobility of the river bed and of the spawning gravels. We find this to be a curious approach, inasmuch as immobile gravels below dams can be considered to be less suitable for spawning than are gravels that are mobilized with some frequency. Periodic mobilization of spawning gravels is thought to help maintain a state of looseness that facilitates redd construction and is often a specific objective of reservoir releases intended to provide beneficial "flushing flows" (e.g. Reiser et al., 1989; Biosystems Analysis Inc, 1992; Kondolf and Wilcock, 1996). The conclusion drawn by IPC that the bed and the spawning gravels are generally "stable" is a conclusion that the bed is generally immobile.

putting the spawning gravels in a condition colloquially referred to as "fossilized". Fortunately, we think that the mobility of the spawning gravels is likely larger (at least locally) than indicated in the report, based on the use of a section-averaged shear stress (or flow depth over spawning gravels) and a relatively large threshold dimensionless shear stress of 0.047.

An interesting factor is the New Years 1997 flood. If spawning success within Hells Canyon (above Salmon River) improved following that flood, or the area of successful spawning increased, this would suggest that the resupply of gravel from local tributaries during that event may have played a role in improving spawning gravels.

6.2 Summary on Gravel Mobility

The methods used by IPC to evaluate bed mobility are approximate. The conclusion that the bed is generally immobile is correct for large stretches of river composed of very large cobbles and boulders. However, we suspect that smaller gravels suitable for spawning are likely mobile under post-dam conditions and further study is needed to confirm this mobility. Reliable conclusions concerning gravel mobility require direct field observations and cannot be based on hydraulic models and calculated values of dimensionless shear stress.

7.0 Sand supply compared to sand bar erosion

Although no reliable estimate of sediment supply from tributaries below HCC is currently available, an initial estimate of the upstream sand supply that has been eliminated by the HCC can be usefully compared to the volume of sand bar erosion within Hells Canyon. Based on the sediment supply estimated for the Wesier gage and the actual volume of sediment stored in Brownlee Reservoir, we estimate that the annual sand supply sequestered by the HCC is likely to fall in the range 250,000 to 750,000 tons per year. This estimate is for sediment supply from the Snake River at Brownlee Reservoir and does not include the additional sediment supply from the 4,100 mi^2 watershed draining directly into the HCC.

An estimate of sand lost to sandbars in Hells Canyon can be based on the measured decrease in sandbar area of 139,355 m^2 between 1964 and 1990 for the Hells Canyon Dam to Salmon River reach (Grams 1991, Grams and Schmidt 1999b). It is difficult to estimate the thickness of eroded sand in bars, although the average eroded thickness is unlikely to be less than 1m or greater than 3m. So, a minimum estimate of sand lost from sand bars is approximately 140,000 m^2 and a maximum estimate is 420,000 m^2 plus another 45,000 m^2 lost in eroded areas below the water level for the photographs analyzed. Using a bulk density of 1765 kg/m^3, this range of estimated erosion represents approximately 10,500 to 35,000 tons per year of sand lost to the sand bars.

The rate of sand bar erosion represents at most one-seventh of the rate at which sand is supplied to Brownlee Reservoir and is likely a much smaller fraction of the sequestered upstream supply. The reduction in sand concentration in Hells Canyon due to the removal of upstream sand supply could easily be associated with sand bar erosion of this relative magnitude. In the absence of a reliable estimate of sand supply from local tributaries, a cause-effect relation between sand trapping in Brownlee reservoir and sand bar erosion in hells Canyon remains a likely scenario with important supporting evidence.

8.0 Conclusions

Following construction of the HCC, the sand bars in Hells Canyon began to erode. The number and area of sand bars decreased most rapidly in the decade immediately following dam closure and sediment loss was greatest near the dam and progressed downstream. The evidence for sand bar loss, which is quite clear and is described in the studies of Grams (1991) and Grams and Schmidt (1999a,b), is acknowledged by IPC (Miller et al., 2002, p. 5-23 to 5-24, 5-30), not challenged on technical merit, but is generally ignored in the voluminous IPC reports. We find the evidence for large scale sand bar erosion beginning at the time of completion of the HCC to be the appropriate starting point for the related investigation of the causes of this loss.

The coincidence of sand bar loss with the timing and location of the HCC indicates a strong causal relation. This connection was pointed out by Grams (1991) and Grams and Schmidt (1999 a,b), although their study included no sediment budget that would quantitatively link HCC operations with the sand bar loss. Nevertheless, the explanation of the causes of the documented decreases in sand bar area are consistent with studies on other debris-fan dominated canyons [illegible] downstream from large dams.Sand is stored in sheltered areas along the channel margins [illegible]. These deposits are dynamic, and sand is exchanged with the river flow each time the bars are inundated. When sand concentration in the main flow is large, more sand enters depositional areas than is eroded from it and the sand bars grow in number, area, and volume. When concentrations in the main flow are small, more sand is eroded from the deposits than is deposited, and the sand bars diminish in size. Thus, the volume of sand in storage is sensitive to the concentration of sand in transport and, therefore, to the supply of sand to the river. When the upstream supply of sand is eliminated by trapping in reservoirs, sand concentrations in the river decrease and sand bar erosion exceeds deposition, leading to the loss of sand bars. It is this simple connection between eliminated sand supply, reduced sand transport, and eroded sand bars that is the most likely explanation of the clear empirical evidence of decreasing sand bar area in Hells Canyon.

Quantification of this relationship between the HCC and downstream sand bar loss requires precise and accurate development of a sediment budget for the grain sizes of relevance to the Hells Canyon system. IPC is to be congratulated in their recognition of the need to develop such a budget, but the budget that they indirectly develop is both incomplete and misleading.

A reasonable estimate of the eliminated upstream sediment supply can be [illegible] measured reservoir sedimentation and river gaging, although more certainty in [illegible] be useful. [illegible] estimates of the quantity and sizes of sediment trapped by the HCC are not consistent [illegible] record of sediment flux of the Snake River at Weiser, and it is very likely that IPC's [illegible] of the sizes of sediment in Brownlee are in error due to a limited sampling program. IPC offers no estimate of the total sedimentintercepted by Oxbow or Hells Canyon reservoirs, even though their estimates of local sediment yield from drainages tributary to those reservoirs would suggest that the amount of sediment stored there is large.

The sediment supplied to the Snake River below the HCC (the only remaining sediment supply to the Hells Canyon) remains entirely undemonstrated. The extensively documented estimates provided by IPC are developed using an inappropriate methodology based on naïve assumptions, leading to estimates that are demonstrably inaccurate in terms of both their magnitude and variability. Quantification of the impact of HCC on sediment loss in Hells Canyon requires a credible estimate of the sediment supply from local tributaries below Hells Canyon Dam.

In the absence of a reliable estimate of the sediment supplied from local tributaries, it is not possible to estimate the proportional reduction in sediment supply caused by the HCC. It is possible, however, to compare the volume of eliminated upstream sediment supply to the volume of sand lost from the Hells Canyon. IPC did not present such a comparison. We find that the rate of sand loss in Hells Canyon is no more than one tenth of the rate at which sand had been supplied from upstream, but is now eliminated by the HCC. This ratio indicates that the sand bars in Hells Canyon represent a small proportion of the previous sand transport through Hells Canyon, an observation that is consistent with, and supports, the conclusion that the HCC is largely responsible for sediment losses in Hells Canyon. This conclusion rests not only on the available empirical evidence linking a reduction in upstream supply (in time, space and magnitude) with the observed sediment loss in Hells Canyon, but is also consistent with our understanding of sediment dynamics in canyon rivers.

Rather than address the evidence demonstrating a cause-and-effect connection between the HCC and sand loss in Hells Canyon, IPC chooses to introduce a variety of arguments with the goal of diverting attention from the main issues, or of undermining the dam impact conclusion without addressing the primary evidence. In the latter category is IPC's estimate of local tributary supply. The intent here was clearly to develop a case that sediment supply from below the HCC is so enormous that any interference in the mainstem sediment supply (including its complete elimination) would have negligible effect on sand resources in Hells Canyon. Even without considering the implausibility of this effort and the weaknesses in the methodology, the results produced by IPC, on their own, demonstrate in their variability and absurdly [illegible] that the sediment supply estimates are of no practical value.

A similar effort to undermine the dam-impact story without addressing the primary evidence is the claim that comparisons of sediment samples from the Hells Canyon with sediment samples upstream of the HCC indicate that sediment in Hells Canyon has a local source that is unaffected by the HCC. The data presented simply do not demonstrate the difference suggested by IPC. More critically, the comparison is based on fundamental conceptual flaw: in order to demonstrate that the Hells Canyon samples indicate a local supply unaffected by the dam, it is necessary to compare samples capable of demonstrating this point. The argument IPC wishes to make is that sediment in Hells Canyon *has always* had a local source, such that construction of the HCC would have a negligible influence on sediment supply to the Hells Canyon. This requires that the Hells Canyon samples must be clearly of pre-dam origin. IPC made no attempt to make such a demonstration and, based on the location of sampling and the flood record of the past decade, it is most likely that the Hells Canyon samples are post-dam. The upstream-downstream comparison of samples is simply not valid.

[illegible] an diversionary argument made by IPC concerns the existence of the sediment "slug" from the upper Snake River Basin. IPC argues that the existence of such a slug must be considered when interpreting sand bar changes in Hells Canyon. The fate of sediment produced by accelerated erosion in the upper Snake River Basin in the 19th and early 20th centuries is largely unknown but, based on analogy with other cases with some documentation, it is likely that most of this sediment remains higher in the watershed. Sediment that worked its way into Hells Canyon would be transient, with a storage time in the high energy environment of the Canyon measured in a few years to a decade. IPC made no effort to demonstrate the existence of a sediment slug migrating through the Snake River Basin, although data are available with which the case could be made. The sediment slug concept promoted by IPC is, quite simply, undemonstrated and unlikely. More to the point, however, is that it is irrelevant. It is not necessary to construct a sediment budget for the entire Snake River Basin in order to evaluate the impact of the HCC on sediment resources in Hells Canyon. Rather, it is sufficient and much more relevant to directly connect the sand bar loss in Hells Canyon (which has been measured) with the reduction in upstream sediment supply due to reservoir sedimentation (which now has an approximate estimate) and the remaining sediment supply from tributaries below the HCC (which remains unkown).

We found the overall approach taken by IPC to be most discouraging. The available evidence on sand bar loss in Hells Canyon has been entirely omitted from the Parkinson et al. report. Our report analysis clearly shows the coincidence in space and time of sand bar loss with closure of the HCC complex. Although IPC purports to investigate this impact, they simply omitted from their analysis all air photographs taken after closure of the HCC. This is a curious approach if the goal is to honestly investigate the possible impacts of the HCC on the Hells Canyon sediment resources. The photographic analysis clearly demonstrates the sand bar loss following closure of the HCC. IPC does not directly challenge these results, but instead raises diversionary challenges to vaguely stated "assumptions" behind it. Rather than present an objective and open review based on the best available science, IPC uses arguments that divert attention away from the real issues, or that undermine compelling conclusions regarding the HCC without directly addressing the scientific evidence.

9.0 Recommendations for future studies

Informed decisions regarding reoperation of the HCC and other possible mitigation strategies require solid information on the altered sediment supply to Hells Canyon. The voluminous information provided by IPC does not meet these vital information needs. The uncertainty inherent in any attempt to rehabilitate a degraded river system requires that actions taken to rehabilitate sand bars and spawning gravels in Hells Canyon must be evaluated within an adaptive management context. Hence, a monitoring program must begin immediately in order to establish baseline information on sand bars, terraces, and spawning gravels and to begin determining their response to flow and sediment supply.

Sediment budget

A reliable understanding of the impact of the HCC on sediment supply and an acceptable plan for guiding reservoir operations to preserve the sediment resources in Hells Canyon requires an accurate understanding of sediment supply, storage, and discharge incorporated within the overall framework of a sediment mass balance. This work includes the following elements.

(1) Tributary sediment supply. At present, there is no reliable estimate of local tributary sediment supply. Both the magnitude and timing of tributary sediment supply are important. Reliable estimates of sediment supply require direct field observation; calculations based on transport formulas are not acceptable. An estimate of tributary sediment supply includes the following elements.

(a) Historical rates of sediment supply measured in all available reservoirs, including tributary deltas in Oxbow and Hells Canyon reservoirs and smaller reservoirs higher in local tributaries. To develop an adequate sample size, all available ponds and reservoirs in the region with geology, slope, and aspect similar to Hells Canyon should be [illegible]. Field surveys should include the volume and grain size of deposited sediment and the trap efficiency of the reservoir.

(b) The most important flaw in IPC's estimate of tributary sediment supply was the use of the calculated transport capacity to determine sediment yield, which assumes that monumental amounts of sediment were available for transport. Determination of actual sediment yield requires field work to determine the volume of sediment available for transport. This involves geomorphic mapping of colluvial and alluvial deposits, surveys to determine sediment volume and grain size, and an assessment of the erosion potential of these deposits. The number and selection of tributaries mapped should provide a representative sample of drainage area, geology, and aspect of the tributaries draining directly into Cells Canyon.

(c) There is evidence that sediment supplied from these watersheds is stored on a multi-year basis near the mouths of these tributaries. Field work is needed to evaluate the periodicity of sediment supply at the mouths of tributaries draining directly into Hells Canyon. Geomorphic mapping and annual monitoring of sediment deposits in the lower portions of the tributaries is needed to determine the storm conditions under which substantial tributary sediment is delivered to the mainstem Snake River and, from this information, the frequency, composition, and magnitude of this sediment supply

(2) Upstream sediment supply. Appropriate mitigation strategies require an [illegible] of the magnitude of the interrupted Snake River sediment supply relative to the [illegible] sediment supply below the HCC.

(a) A more detailed survey of all three HCC reservoirs is needed. Comparison of the new survey with the previous survey will provide a more accurate estimate of recent total sedimentation.

(b) A new, high-resolution topographic map of the pre-dam valley topography should be developed from historical aerial photographs. Comparison of modern surveys with a more accurate pre-dam topography will provide more a accurate estimate of the total sedimentation since construction of the HCC.

(c) Detailed mapping, surveying, and sampling of sand and gravel deposits in RM 310-340 in Brownlee Reservoir. This is the likely depositional location of the sediment delivered by the Snake River. Of particular importance is locating, mapping, surveying, and sampling of deposits of sand (and gravel). These deposits can be localized but uncommon, and an accurate estimate of their volume requires first that their location and extent be identified using a broader survey, followed by a systematic sampling within all areas of significant deposition. Reservoir drawdown may be useful for these surveys.

(2) Suspended sediment sampling should be reestablished at the Snake River Weiser gage. Sampling should be weekly, increasing to daily during periods of flow greater than a threshold producing large transport rates (e.g. 25,000 ft^3/s). Bed-load sampling should be initiated on the same schedule. Sediment sampling at Weiser provides a check on estimates of the volume of sediment deposited in the reservoir.

(3) Suspended and bed-load sediment sampling should be initiated at a section on the Snake River toward the downstream end of Hells Canyon, immediately above the Imnaha River confluence. Sampling should be weekly, increasing to daily during periods of flow in excess of 25,000 ft^3/s. Bed-load sampling should be initiated on the same schedule. Sampling at the downstream end of the Canyon provides information on the rate of sediment evacuation from Hells Canyon and is needed to balance the sediment budget.

(4)Sediment budget. Estimates of the local and upstream sediment supply {(1) and (2) above} and sediment discharge from Hells Canyon {(3) above} are combined with estimates of sediment lost from Hells Canyon sand bars and spawning gravels in a complete sediment budget. By developing reliable estimates of all inputs, storage, and outputs, accuracy of the estimates can be evaluated and the relative magnitude of different sediment sources can be reliably determined.

Sand Bars

Since IPC does not question the historical record of sand bar change in Hells Canyon, the focus on future studies should be to link the existing characteristics of sand bars to current dam operations. Regular measurements of scour and fill, grain size, and bar topography should be made at approximately 12 eddy bars in Hells Canyon representing a range of river locations. Surveys should be conducted before and immediately after high flows each Spring.

Such a monitoring program is essential in determining changes in one of the critical natural resources of Hells Canyon. The value of this monitoring program will increase in value with time and the effects of future floods can be linked with sediment transport during floods. A similar program in Grand Canyon is now one of the most important metrics of ecosystem health interpreted by river managers.

Bed Mobility

If spawning gravels in Hells Canyon are occasionally mobilized, then they are transported downstream at some rate, and their maintenance requires an upstream supply. Under post-dam conditions, this supply must come from the local tributaries. Entrainment estimates based on [illegible] models and specified values of the entrainment threshold simply cannot provide reliable estimates of spawning gravel behavior. The only real option for understanding spawning gravel entrainment and transport is to directly observe their motion in the field. This may be accomplished by marking grains within the spawning gravel area, or by placing marked or distinctive grains in the bed. By carefully surveying the locations of the marked grains, it is possible to return to the site after a high flow and deterusing a large number of tracer gravels or direct measurement of transport rates will be needed to assess the transport rate and resupply of the gravels.

Independence and Peer Review

All future work should be subject to rigorous, independent peer review. Review is needed not only for the completed work, but also for the study design prior to initiation of the work. Further, we find the presentation of facts and conclusions in the existing IPC reports to be so conspicuously biased toward a finding of no impact that we strongly recommend that future studies should not be conducted solely by IPC, or under their substantial direction. Rather, an externally reviewed study plan should be used to define specific projects that should be conducted by independent contractors, or by a fully collaborative agency/IPC team. The resulting work products, once independently reviewed, would then provide the information necessary for informed decisions about protecting the outstanding resource values in Hells Canyon.

The most enlightened management program would involve a federally administered adaptive management program in which all interest groups concerned about the Snake River in Hells Canyon would jointly administer a monitoring program. Findings of this program would be used to revise dam operations in ways that increase the potential of restricting future resource damage, and perhaps facilitate rehabilitation of the river ecosystem.

10.0 Considerations for future dam operations to protect the sediment resources of Hells Canyon

The primary sediment source for both sand bars and spawning gravels is now the tributaries below the HCC. As suggested in the IPC report, it is likely that these sediment inputs are very strongly episodic. Much of the time, the tributary streams transport little or no sediment and, when they do, much of this sediment may be temporarily stored in the tributary valley immediately above its confluence with the Snake River. Sediment delivery to the mainstem may occur predominantly during very large, rare floods, such as occurred in early January 1997. This suggests that sediment resources in Hells Canyon may experience "boom and bust" cycles in which long periods, possibly decades, of negligible sediment supply lead to progressive loss of sand bars and embeddedness of spawning gravel deposits, only to be briefly rejuvenated by significant sediment input from the local tributaries. If this is the case, protection of the canyon's sediment resources may be best achieved by responding effectively to the episodes of local sediment supply. For example, a large, short dam release immediately following a major tributary flood may allow a portion of the tributary-derived sand to be stored in high elevation beaches before it is evacuated from the canyon by normal dam operations. If spawning gravel transport is found to be substantial, then reservoir operation may need to be revised in an attempt to reduce peak flows in the river (e.g. by drawing down HCC and upstream reservoirs to the maximum extent possible prior to anticipated runoff events). Determination of the efficacy of such plans requires an understanding of the tributary sediment supply—its magnitude, timing, and location—and the dynamics of sand and gravel deposition within the mainstem. Any such predictions will have considerable uncertainty, such that an adaptive management approach will be needed in which the effects of management actions are predicted, evaluated, and revised

11.0 References

Biosystems Analysis Inc., 1992. *Lower Mokelumne River Management Plan*. San Francisco CA.

Collier, M., R.H. Webb, and J.C. Schmidt. 1996. Dams and rivers, a primer on the downstream effects of dams. U. S. Geololgical Survey Circular 1126, 94 p.

Grams, P. E., 1991. Degradation of alluvial sand bars along the Snake River below Hells Canyon Dam, Hells Canyon National Recreation Area, Idaho. Middlebury, VT. Middlebury College Department of Geology unpublished senior thesis. 98 p.

Grams, P. E. and J. C. Schmidt. 1999a. Sand bar erosion and deposition on the Snake River in Hells Canyon between 1990 and 1998. Final Report to the U. S. Forest Service. 26 p. plus figures.

Grams, P.E. and J.C. Schmidt. 1999b. Sand bar and terrace erosion between 1964 and 1996 at the Tin Shed and Camp Creek cultural resource sites on the Snake River in Hells Canyon. Final Report to the U. S. Forest Service. 20 p. plus figures.

Groves, [illegible] and J.A. Chandler. 2001. Physical habitat and water quality criteria for fall Chinook salmon associated with the Hells Canyon Complex, in P.A. Groves, ed., Evaluation of anadromous fish potential within the mainstem Snake River, downstream of the Hells Canyon Complex of reservoirs. Chapter 2. Technical Appendices for Hells Canyon Commplex Hydroelectric Project. Technical Report E.3.1-3. Idaho Power Co., Boise ID.

Miller, S., D. Glanzman, S. Doran, S. Parkinson, J. Buffington, and J. Milligan. 2002, Geomorphology of the Hells Canyon reach of the Snake River. Idaho Power Company Technical Report Appendix E.1-2, Hells Canyon Complex FERC No. 1971. 8 sections and 6 appendices.

Kondolf, G.M. and P.R. Wilcock. 1996. The flushing flow problem: defining and evaluating objectives. *Water Resources Research*. 32(8):2589-2599.

Parker, G., 1990. Surface-based bedload transport relation for gravel rivers. *J. Hydraulic Engineering*. 28(4), 417-436.

Parkinson, S., K. Anderson, J. Conner, and J. Milligan. 2002. Sediment transport, supply, and stability in the Hells Canyon reach of the Snake River. Idaho Power Company Technical Report Appendix E.1-1. Hells Canyon Complex FERC No. 1971. 8 appendices.

Runge, [illegible] 2001. Hells Canyon MIKE 11 hydrodynamic model. Idaho Power Company Technical Report Appendix E.1-4, Chapter 5. Hells Canyon Complex FERC No. 1971. 51 p.

Reiser, [illegible] M.P. Ramey, and T.A. Wesche. 1989. Flushing flows, in *Alternatives in*

Regulated River Management. Chap. 4. edited by J.A. Gore and G.E. Petts. pp. 91-135, CRC Press. Boca Raton. FL.

Schmidt. J.C.. Grams. P.E. and Webb, R.H.. 1995. Comparison of the magnitude of erosion along two large regulated rivers. Water Resources Bulletin. 31(4): 617-631.

Schmidt. J. C. and D. M. Rubin. 1995, Regulated stream flow. fine-grained deposits, and effective discharge in canyons with abundant debris fans. in Natural and Anthropogenic influences in fluvial geomorphology edited by J. E. Costa. A. J. Miller. K. W. Potter, and P. R. Wilcock. 177-196.

Vallier. T. 1998. Islands and rapids: a geologic story of Hells Canyon. Confluence Press. Lewiston. Idaho.

Webb. R. H. J. C. Schmidt. G. R. Marzolf. and R. A. Valdez, eds., 1999. The controlled flood in Grand Canyon. American Geophysical Union Geophysical Monograph 110. 367 p.

Wilcock. P.R. G.F. Barta. C.C. Shea. G.M. Kondolf. W.V.G. Matthews. and J.C. Pitlick. 1996. Observations of flow and sediment transport on a large gravel-bed river. *Water Resources Research*. 32(9):2897-2909.

Figure 1. Percent sand in suspended sediment samples, USGS gage Snake River at Weiser ID.

Figure 2. Sediment rating curves, USGS gage Snake River at Weiser ID.

Table 1. Sites used in IPC aerial photograph analysis cross-referenced to sand bars identified by Grams (1991).

IPC study site by River mile	Match to Grams (1991) bar	1964 to 1990 change from Grams (1991)
229.8	Johnson Bar (R)	> 50% decrease
227.5	Pine Bar (R)	small decrease
222.4	Salt Creek Bar (L)	no significant change
216.4	Fish Trap Bar (L)	no significant change
208.3	Jones Creek (R)	> 50% decrease
204.3	(not identified)	--
201.1	channel margin (R)	> 50% decrease
196.8	(not identified)	--
193.8	reattachment bar (L)	entirely eroded
192.4	China Bar (L)	no significant change

Appendix A: Geomorphic Review Questions Provided by Craig Kendall

1. Is the effect of the HCC project on resources of concern adequately addressed? (i.e. are the effects of current and proposed ramping rates on beach erosion [illegible] and is the resulting conclusion accurate?).

2. There is concern that the reports focus on the "Big Picture" (i.e. the geologic factors which formed the Canyon) tends to minimize and obscure potential project-related effects such as beach erosion.

3. Is the method for determining influx of sediment into Brownlee adequate given that there is no analysis of bedload movement and no sediment budget was constructed above and below the project.

4. Are conclusions in the documents accurate for identifying sediment transport flows and the lack of bedload movement upstream from Brownlee Reservoir?

5. In general, are the equations and analysis used in the IPC documents valid?

6. IPC concludes that the project has no effect on beach erosion since the material trapped in the upstream end of Brownlee Reservoir is not from the same parent geology as that found in the beaches in the HCW&S River. This was based on a limited number of samples and did not include any sampling in sediment plumes near the tributaries to Hells Canyon Reservoir and Oxbow Reservoir which may [illegible] other material. Is the scope and scale of sediment sampling in Brownlee [illegible] and if not should the other reservoirs be evaluated as well?

7. Is the "slug of sediment" theory valid since there was no data to support it?

8. In their information presentations, IPC has discounted the Grams and Schmitt studies on beach erosion and concluded that based on their own three consecutive years of trend data the beaches in HCW&S River are stable. Is this valid?

9. What (if any) additional studies or analysis are needed to address USFS concerns (primarily beach erosion)?

Appendix B. Response to Specific IPC Conclusions

Specific conclusions are presented in list form in several places in Parkinson (2002). Although we address these points in our review, we also include point-by-point comments on these conclusions.

B1. Comments on Executive Summary Conclusions

In the Executive Summary (p. 2), Parkinson et al. (2002) present eight conclusions in a bulleted list.

- The storage capacity of the HCC is only about 10% of the average annual volume of the Snake River as given by calculated inflow to Brownlee reservoir. Therefore, the HCC has a relatively small effect on the hydrograph downstream of the complex.

Comment: Although the storage capacity of the HCC has a modest effect on downstream flow, it has changed flow through the Hells Canyon. Grams and Schmidt showed that . . .

- Changes in the river observed since the construction of the HCC (such as shrinking sand beaches) may be caused by human activity higher in the Snake River Basin since the mid-1800s and not by construction and operation of the HCC.

Comment: While sand supply from the entire watershed may have peaked and decreased over the past century, its connection with shrinking sand bars following completion of the HCC is tenuous, undemonstrated, and avoids the immediate issue of the quantity of trapped sediment relative to downstream supplies and sediment loss from Hells Canyon. We think it is likely that most of the fine sediment eroded from the watershed in the 19th and early 20th century either passed through the system in a matter of years or become sequestered in overbank and bar deposits, where it still remains. The sand bars in Hells Canyon are delicate and dynamic features, representing temporary and live storage of a portion of the sand delivered to the canyon. If a decrease in sand supply over the past century has contributed to shrinking the sand bars, it is curious to argue that completely eliminating the upstream sediment supply (due to storage in HCC) would be of little consequence. In any event, an unambiguous conclusion in this regard requires reliable quantification of the sources of sand to the canyon, which IPC has not provided.

- The transport competence of the Snake River upstream of the HCC is insufficient to mobilize and transport materials such as those found in the riverbed of the Hells Canyon reach. Therefore, no supply of bed materials would be available from sources upstream of the HCC under historical hydrological conditions.

Comment: A clear distinction needs to be made between sediments of different sizes. It is likely that this statement is correct regarding coarse gravel and cobble, but not for sand and fine gravel. Coarse cobble and boulders found in deeper parts of the Hells Canyon stream channel may be predominantly supplied from local tributaries. Sandbar caliber sediment *is* being delivered in significant quantities by the Snake river above the HCC. This sediment discharge has been measured by the USGS. The analysis conducted by IPC is not adequate to reliably judge the supply under modern conditions of fine to medium gravels used for spawning.

- Less than 4% of the sediment trapped in Brownlee Reservoir (the uppermost dam in the HCC and the first of the three constructed by IPC) is larger than fine sand. All of the features of interest downstream are largely made up of sediments larger than fine sand.

Comment: This argument diverts attention from the main point. It is not the *percentage* of coarse sediment delivered to Brownlee Reservoir that matters, buts its actual quantity and [illegible] compared to sediment sources below the HCC. We find that the estimate of the sand trapped in Brownlee Reservoir is unreliable and that further study is required to develop a reliable estimate. We also find that the proportion of sand delivered to Brownlee Reservoir is more likely approximately 22%, based on USGS measurements at Weiser. Drawing the grain size boundary at "larger than fine sand" may also be misleading. This choice is based on the assumption that the sediment features found in Hells Canyon *under present conditions* are representative of those found under predam conditions. The impact of the HCC on sediment resources in Hells Canyon must be referenced to predam conditions, not to conditions some 40 years later. The data presented by IPC suggests that the grain size of predam sand deposits may in fact be finer than observed under present conditions.

- The trapping of fine sediments in Brownlee Reservoir has not caused the downstream river to become more "sediment hungry" because the size and concentration of these sediments has no effect on transport capacity in the Hells Canyon reach of the Snake River.

Comment: This statement reflects a misunderstanding of the concept of transport capacity. Transport capacity is a measure of a river's ability to carry sediment and depends primarily on the channel geometry and flow rate. The presence or absence of an upstream sediment supply does not alter a river's capacity for transporting sediment. The term "sediment hungry" refers to a condition in which sediment is supplied to a reach at a rate that is smaller than the river's capacity to transport sediment. It is likely that the Snake River in Hells Canyon has always been "sediment hungry" with respect to sand and finer gravels, meaning that the river could carry additional sediment without a substantial change in its geometry and that the sediment stored in the Hells Canyon will be found in particular locations that provide some protection from the flow. There can be no doubt that the HCC has reduced the upstream sediment supply (it has essentially eliminated it) and that, therefore, the amount by which the transport capacity exceeds the sediment supply has increased. In that sense, the river is indeed "more sediment hungry". The appetite of the river is, however, not the most relevant concept for judging the impact of the HCC on sediment resources in Hells Canyon. Eliminating the upstream sand supply has reduced the sand transport rates and sand concentrations in the flow through Hells Canyon. Current research on sand deposits in canyon rivers indicates that a reduced sand concentration in the river flow is a direct cause of reduced sand bar size.

- Because the basic form and character of the river were established under vastly higher flow conditions, the bed and bank materials provide extremely limited opportunity for river movement.

Comment: Again, an important distinction must be made for sediments of different size and location. This statement is true, for example, for boulders found in deep parts of the river channel in Hells Canyon. It is demonstrably *not* true for sand bars, which have eroded considerably since closure of the HCC.

- Continuing supplies of sands, gravels, and cobbles from local sources below HCD have not been affected by the construction and operation of the HCC.

Comment:

- Human activities in and above the Hells Canyon area, such as mining and grazing, modified hill slope processes from the mid-1800's to the mid-1900s. These activities probably introduced an unusually large sediment supply to the river that decreased as the activities that introduced them also decreased. This "slug" of sediment may be working its way out of the Hells Canyon system.

Comment: An increase in watershed sediment supply may well have occurred in the 19th and early 20th centuries. We find it improbable that a sand "slug" would be gradually moving through the high-energy environment of the Hells Canyon. It is more likely that 19th century sediment from higher in the basin has been long sequestered in bars and floodplains and upper basin reservoirs or moved through the Hells Canyon long before the HCC was completed. The relative proportion remaining in the watershed, the locations of these deposits relative to existing dams, and the rate at which these deposits release sediment back in to the stream are largely unknown and any conclusions in the absence of this information are entirely speculative. The impact of the HCC on Hells Canyon sediment resources must be addressed by solid estimates of the sediment supply lost to the HCC, in comparison to the amount supplied by local tributaries below the HCC and the amount of sand lost by sand bars.

B2. Comments on Sediment Supply Conclusions

In Section 10.4, Parkinson et al. (2002) present six conclusions in a bulleted list on p. 83.

- There is no evidence that Brownlee Reservoir (the uppermost reservoir in the HCC) has trapped significant quantities of sediment in sizes that could affect any of the important resources. More than 96% of the material trapped in Brownlee Reservoir is smaller than fine sand and therefore smaller than the majority of the material found in the sandbars in Hells Canyon.

Comment: This statement is incorrect or misleading in three ways. First, there *is* clear evidence of an upstream supply of sediment of relevant sizes. The reservoir data reported by IPC provides evidence of this, although we find the data are inadequate to provide a reliable estimate. The USGS record of water and sediment discharge at Weiser provides clear evidence of the quantities of sand delivered to the HCC by the Snake River. Second, to cite the estimated delivery of sediment to Brownlee Reservoir as a percent is misleading. What is relevant is the *quantity* of sand that is trapped in the reservoir *in comparisonto* the quantity of sand that has been lost from the Hells Canyon sandbars. A rough estimate is that the annual rate of upstream sand supply (now trapped within the HCC) is *at leastten* times the rate at which sand is lost from the sandbars in Hells Canyon. This is significant. Finally, using the material found in Hells Canyon *today* as the basis for evaluating the impacts of the HCC on downstream sand resources avoids the probable adjustments in sandbar composition over the postdam period.

- The Snake River upstream of the HCC is incapable of transporting sediment of the size found in the riverbed in Hells Canyon under current hydrological conditions.

Comment: A distinction must be made regarding the caliber of sediment in question. If the focus is the coarse cobble and boulders found in deeper parts of the Hells Canyon stream channel, it is likely that little would be supplied from upstream under current conditions. If the focus is sandbar caliber sediment, it is clear that Snake River above the HCC *is* delivering significant quantities of this sediment. This sediment discharge has been measured by the USGS. If the focus is on fine to medium spawning gravels, the analysis conducted by IPC is not adequate to reliably judge the supply under modern conditions.

- There are tributaries in Hells Canyon not affected by the HCC that supply sediment in the size range useful for maintaining the sandbars and gravelbed spawning sites in Hells Canyon.
- There is clear visual evidence that many of these tributaries have supplied sediment to the Snake River in Hells Canyon in recent years under current hydrologic conditions

Comment: We find that assumptions and methods used by IPC have led to a gross overestimate of the amount of this sediment supply. A reliable estimate of tributary sediment supply is not currently available. Further, the timing of tributary sediment delivery is an important and unresolved issue. Local tributaries below HCC do deliver sediment to the mainstem Snake River. This supply was probably significant during the winter 1997 floods. Evidence presented in the report suggests that these tributaries may contribute very little sediment to the mainstem Snake except during such large, rare storms. If significant tributary sediment supply occurs rarely (with a recurrence interval of many years or decades), the sediment resources in Hells Canyon may show short term benefit following major tributary floods, followed by decline under conditions of negligible sediment supply. We recommend that a sound estimate of the local sediment supply be made using sedimentation observations in smaller dams on tributaries and sedimentation within Hells Canyon reservoir. This information is needed to develop a working knowledge of the Hells Canyon sediment system, which can serve as a base for recommendations regarding operations of the HCC.

- Mineralogical composition of bed-material sediments suggests that these sediments are of local Hells Canyon origin. The lack of minerals characteristic of the upper regions of the Snake River Basin suggests that riverbed materials in the Hells Canyon reach were not transported from upper parts of the basin.

Comment: The data presented do *not* show distinctions between upstream and downstream. The "minerals characteristic of the upper regions of the Snake River Basin" are not evident in either upstream or downstream samples. Further, it is likely that the Hells Canyon sediments examined were *post-dam* deposits. If this is the case, a finding that they are of local origin has little significance because they were deposited after the upstream supply of sediment was cut off.

- There are data from the early 1900s (well before the HCC complex was built) through the present time indicating that the Snake River upstream of the HCC is highly stable, with limited movement of the bed material. More recent data from downstream of the HCC indicate similar findings.

Comment: Upstream of the HCC, the issue is the quantity of sediment supplied. The USGS observations at Weiser indicate the sediment discharge of sand. The IPC analysis is insufficient to document the transport of gravels suitable for spawning. A stable cross-section (in the sense that it does show substantial scour or aggradation) is not, of itself, an indication of small sediment transport rates. Downstream of the HCC, the stream channel is canyon bound and coarse bedded and clearly will not show large changes in its morphology. This, however, is not a particularly relevant point. The sediment resources of interest—sandbars and spawning gravels—are small, delicate, and typically found in protected areas of the channel. These resources are dynamic, meaning that the sediment is transported, and indicating that these features are sensitive to the availability of an upstream supply of sediment.

IPC's analysis of mean daily discharge data using the IHA software is of limited value because dam releases vary hourly in response to power production needs and these flow attributes were not evaluated. Accurate analysis of flow characteristics of the Snake River demands that flow duration characteristics, as well as others evaluated by the IHA software, be based on instantaneous discharge data.

5.2 Morphology

This short section characterizes the Snake River downstream from Hells Canyon as an F-1 type stream. Given the abundant physical measurements of Hells Canyon and the Snake River, no additional insight regarding the character of the river is gained by knowledge of this classification.

IPC refers to Hells Canyon as the river reach downstream from Hells Canyon Dam. Vallier (1998, p. 6-7) reviews nomenclature regarding the term Hells Canyon and points out that the physiographic feature is considered to have different lengths by different individuals. Vallier (1998) considers Hells Canyon to include the segment of the Snake River between the Oxbow and the mouth of the Grand Ronde" and he calls this "a liberal definition" based primarily on a common geologic history. He also states, "If I were to base my definition only on physiography, I would limit Hells Canyon to that segment of canyon between Kinney and Sheep Creeks". Kinney Creek is located approximately 10 miles upstream from Hells Canyon Dam and Sheep Creek is located about 18 miles downstream from the Dam, and Hells Canyon is approximately 28 miles long based on this criteria. Approximately 36% of this length has been inundated by the HCC.

The section notes that "the floodplain is extremely limited" and "interaction between the river and its bed and banks is largely limited to near-river areas that can be mobilized by the flow, such as bars, islands, terraces, and fans." This characterization is accurate, however, the important point about assessment of the effects of dam operations on the downstream river is not the proportion of the total bank that can be reworked and maintained by river flows, but the changes that have occurred in these reaches, regardless of their absolute length. It might be argued that the small proportion of the total river length that is comprised by sand bars or terraces makes those deposits more important from an ecological or recreational perspective.

5.2.1 Nearshore Characterization

IPC reports that 54% of the river banks are hillslopes. Bars increase in number in the downstream direction, and the average for the reach between Hells Canyon Dam and Asotin is 18 to 20 %. Debris fans average 18 % of the river banks and a reportedly "evenly spaced."

5.2.2. Channel Morphology

5.2.2.1. Valley Segment Morphology

IPC proposes that the study reach be divided into three segments based on differences in channel slope, which is 0.002 in the upper segment and 0.0007 in the lower segment.

Again, IPC emphasizes the narrow confinement of the Snake River in its canyon. While this confinement is a distinctive attribute of the study area, it merely serves to emphasize the importance of eddy bars, channel-margin deposits, terraces, and gravel bars in the riverine ecology and recreational uses of the canyon.

5.2.2.2. Reach-scale Morphology

5.2.2.2.1. Sinuosity and Confinement

IPC proposes a subdivision of the three valley segments into a series of 12 reaches, based on differences in sinuosity and confinement. It would have been helpful had IPC chosen to compare and contrast its classifications with those proposed by Vallier (1998), who proposed his own scheme for recognizing sections of the river with common attributes. It is not clear that IPCs classification is an improvement on previously published efforts, although certainly the river morphology data collected by IPC is superior to that available to Vallier (1998).

5.2.2.2.2. Reach Type

Miller at al. (2002, p. 5-9) find that the Snake River in the stidy area "shows the repeating sequence of pools and riffles" and that the spacing between pools typically has a value of between 5 and 10. Although observations like this are irrelevant to assessment of the environmental impacts of the HCC on downstream river resources, it is nevertheless an interesting observation of doubtful validity. Similar observations were made of the organization of the bed of the Colorado River in Grand Canyon by Leopold (1969), who argued that the Colorado River reflected self-formed attributes similar to alluvial rivers. IPC implies the same for the Snake River. In Grand Canyon, it is now recognized that the distribution of shallow and deep sections of the river are determined by the locations of tributary debris fans and the related distribution of pools, eddies, and gravel bars that comprise the widespread attributes of fan-eddy complexes (Schmidt and Rubin, 1995, Grams and Schmidt, 2000).

5.2.2.2.3. Channel Units

This section reviews findings from detailed mapping of channel units, similar to studies conducted on much smaller streams in the western U. S. This information is interesting to the geomorphologist who works in debris fan-dominated canyons but is of little relevance to assessment of the impact of the HCC on downstream river resources.

IPC reports that the frequency of debris fans in the upper and middle valley segments is approximately 3 fans/river km, which is a higher frequency than in most parts of the Colorado River in Grand Canyon (Schmidt et al., 1999). Thus, the role in debris fans and in fan-eddy complexes is more important here. IPC would have done well to have characterized the river using the fan-eddy classification scheme that is appropriate to a river of this organization, rather than apply a scheme of more relevance to small mountain streams.

5.2.2.2.4. Pools

This section characterizes pools and their residual depths. This information is interesting to the geomorphologist who works in debris fan-dominated canyons but is of little relevance to assessment of the impact of the HCC on downstream river resources.

5.2.2.3 Hydraulic Geometry

This information is interesting to the geomorphologist who works in debris fan-dominated canyons but is of little relevance to assessment of the impact of the HCC on downstream river resources.

5.3 Sediment Dynamics

5.3.1 Potential Sediment Sources

5.3.1.1 Local Tributaries

This paragraph reminds the reader that the local tributaries to the Snake River downstream from the HCC "is significant." Although we disagree with the IPC's estimates of the magnitude of sediment delivery from these tributaries, as described in our report, we agree with IPC's assessment of the importance of these tributaries to river management. Regardless of the magnitude of the sediment delivery, these tributaries are the only source of sediment to the Snake River upstream from the Imnaha River. Thus, it is essential to understand the magnitude and timing of these contributions if the "benefits" of this sediment can be maximized by operations of Hells Canyon Dam.

5.3.1.1.1 Short-term Quantitative Sediment Yield Estimates

This section summarizes the estimates of sediment delivery made by Parkinson et al. (2002). The cross-referencing between the Miller et al. (2002) and Parkinson et al. (2002) is poor here and limits the ability of the external reviewer to evaluate the estimates of IPC. In this case, IPC does not reference the source of the numbers reported and IPC assumes that the reviewer will find the computations elsewhere. Or perhaps IPC hopes that the external reviewer will not identify and evaluate the methods by which these estimates are made. Whatever the case, these estimates are made without discussion of the accuracy or precision of these numbers. Instead, IPC reports these numbers as if they were true when, infact, they are highly speculative and are clearly a gross overestimate of the amount of sediment entering Hells Canyon downstream from the dams.

IPC reports the following estimates of sediment yield downstream from the HCC:

	Drainage area, in square miles	Sediment yield, in tons/square mile/year	Sediment yield, in cubic yards/acre/year	Annual sediment delivery, in tons/year
Average sediment yield from 17 small tributaries to the Snake River	304	28,100	32.5	8.5
Other tributaries	191	28,100	32.5	5.4
Hillslopes directly sloping to Snake River	53	28,100	0	1.5

				15.4, of which 6.3 million tons/yr is gravel between 50-150 mm and 2.3 million tons/yr is sand

IPC is aware of the significance of these estimates, and states that "this estimate is about 5 times higher than the annual supply of sediment that has been retained by Brownlee Reservoir since 1958." Indeed, the large magnitude of these numbers demands that the estimates be based on more than uncalibrated engineering transport calculations.

IPC states that the combined sediment delivery from all tributaries to the Snake River is 15.1 million tons/year, however the product of 28,100 tons/square miles/year and 495 square miles (the total basin area of tributaries) is 13.9 million tons/year, which is 8% less than IPC's estimate.

5.3.1.1.2 Long-term Sediment Yield Considerations

Although the findings of Kirchner et al. (2001) are of interest to geomorphologists, they have little relevance here. Kirchner et al. (2002) comparedshort- and long-term sediment yield estimates, all of which were based on detailed field studies and sophisticated watershed modeling. These studies conducted in central Idaho did not utilize the uncalibrated formulae that result in the unrealistically high estimates made by IPC.

Observations of debris flow deposits and the locations within tributary drainages where these sediments are stored are of interest, and debris flows may be a major unquantified mechanism by which sediment is delivered to the Snake River. IPC would be well-served to undertake further studies to quantify this contribution.

<u>5.3.1.2 Hillslopes</u>

5.3.1.2.1 Short-term Quantitative Sediment Yield Estimates

IPC assumes the same sedimentyield rate to the Snake River as for the tributaries basins without any field based quantitative estimates to support this value.

5.3.1.2.2 Long-term Sediment Yield Considerations

It is helpful to be reminded that catastrophic geomorphic events can occur in Hells Canyon, and when they do, the USFS, ACoE, and IPC will undoubtedly be faced with the need to reconsider how the HCC dams release water downstream so as to achieve whatever management goals will be established at that time in response to a large natural catastrophe.

IPC provides geographic analyses of the distribution of slope steepness within the tributary basins, as well as the distribution of slopes with rock varnish (which is taken to indicate the absence of significant slope movement in the past 1000 yrs.). These data indicate that the hillslopes of Hells Canyon are likely to have high erosion rates. The point, however, is whether IPC's estimate of 28,100 tons/square mile/year is remotely realistic, and why such a rate only applies to that part of Hells Canyon downstream from Hells Canyon Dam and not to the areas of similar physiography and geology that flow directly into Hells Canyon Reservoir. The field

Grams and Schmidt (1991)'s conclusions.

In general, this work by IPC does not significantly add to the understanding of the system found by Grams and Schmidt (1999). No aspects of IPCs work contradicts the earlier findings.