# Supplemental Erosion Monitoring Plan for Box Canyon Hydroelectric Project FERC No. 2042

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# Box Canyon Hydroelectric Project
# FERC No. 2042
# Supplemental Erosion Monitoring Plan

## Table of Contents

## LIST OF FIGURES



## LIST OF TABLES

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**June 2007**

## Executive Summary

This Supplemental Erosion Monitoring Plan for the Box Canyon Hydroelectric Project has been prepared in response to FERC's order dated September 29, 2006. This supplement to that previously filed plan has been prepared in consultation with the Department of the Interior (DOI) and Kalispel Indian Tribe (Tribe). The entirety of the plan and this supplement were prepared in fulfillment of the requirements of the new operating license for the Box Canyon Project issued by FERC on July 11, 2005 (112 FERC 61,055) at: 1) License Article 408; 2) the Department of Interior's (DOI) Condition No. 3.E and F (License Appendix A); and USDA Forest Service Condition No. 8 (License Appendix B).

This plan also incorporates certain recommendations that were provided as a result of the Peer Review Process that was undertaken in accordance with USFS License Condition No. 8, which were accepted by the PUD No. 1 of Pend Oreille County (District), as documented in the Box Canyon Shoreline Erosion Monitoring Plan Peer Review Response Summary dated July 19, 2006. The summary document and the individual responses embedded within each of the three independent peer reviews (Gerstel 2006; Miller 2006; Riedel 2006) are also being submitted as documentation of this process and consultation (see Appendix A).

The District established and monitored 32 shoreline erosion monitoring sites. Sixteen of those sites have been monitored since the spring of 2000, with all remaining sites monitored since fall 2001. Two of those sites have been treated with erosion control and prevention measures.

In addition to the 32 sites monitored since at least 2001, the District has now established an additional seven (7) sites on Kalispel Indian Reservation (KIR) lands as required by the FERC Order Issuing New License for the Project, at Appendix A (DOI Section 4(e) conditions) Condition No.3E. The District has also now established an additional three (3) sites on National Forest System lands, as agreed to with the USDA Forest Service in full compliance with the FERC Order Issuing New License for the Project at Appendix B (USDA Forest Service Final 4(e) Terms and Conditions) Condition No. 8.

All sites currently being monitored are identified on updated Erosion Monitoring Site Maps dated May 2007 and included herein as Appendix B.

The basic procedure for documenting rates of erosion at each site relies on detailed electronic instrument surveys of the shoreline bank profile by professional land surveyors, the most accurate means available for documenting shoreline profiles and changes in those profiles through time. This procedure identifies the depth of erosion that may occur throughout the shoreline profile from top of bank to two to three feet below waterline at the time of each survey. It also measures rate and extent of bank recession of interest particularly at the top-of-bank point.

Surveys are conducted twice per year, once in the spring following peak runoff, and once in the fall prior to the onset of winter snow and ice that precludes accurate survey. Additional surveys will be conducted at a subsample of sites immediately prior to spring peak flows. These profiling procedures are supplemented with professional assessment to identify the form of erosion process and to identify likely causative factors that occur at each monitoring site. These assessment procedures can also be applied throughout the reservoir and at any particular location of interest to the agencies, landowners, or the District.

Article 408 of the new FERC License also requires the District to determine the degree to which project operations contribute to shoreline erosion. To address this requirement, the District will employ the shoreline erosion profiles developed at each of the monitoring sites in conjunction with river stage duration curves to identify the percent of time that the profiles are exposed to river waters for both the "with" and "without" project cases. This analysis, coupled with determination through monitoring and modeling of project-related wave energy, allows calculation of an index of "project share" of erosion at each site. This index of project share will also be adjusted for erosion that occurs during extreme spring floods. A final adjustment to project share is then made qualitatively through consideration by the District and affected agencies and landowners of subjective factors that cannot be calculated. These final adjustment factors include considerations such as predisposition to erosion of a site because of erosion that may have occurred there naturally and human and animal disturbance factors.

Geotechnical studies of KIR shorelines are also required by DOI Condition No. 3E, Appendix A of the Order Issuing New License. The District submitted the Geotechnical Engineering Study plan to FERC on September 1, 2006 and FERC approved the plan without modification on September 29, 2006. The District's plan and FERC's order are now included with this Supplemental Erosion Monitoring Plan as Appendices C and D, respectively.

## I. License Requirements for Shoreline Erosion Monitoring

The Box Canyon Project license was issued July 11, 2005, and Article 408 required that the District file a plan for Commission approval to monitor erosion throughout the project reservoir within six months of the date the new license was issued (by January 11, 2006). In compliance with this deadline, the District filed a draft plan dated December 15, 2005, with FERC on January 10, 2006. As required, the District prepared the December 15, 2005 plan in consultation with the Forest Service (USFS), DOI, Kalispel Indian Tribe (Tribe), and the Washington Department of Fish and Wildlife (WDFW). However, important comments were received from these agencies subsequent to the December 15, 2005 draft. A revised draft was prepared so as to incorporate these agency comments prior to submitting the draft to a peer review process that was required by USFS License Condition No. 8 (in License Appendix B). The District subsequently filed yet another revised draft plan with FERC on August 29, 2006, which incorporated those peer review process recommendations agreed to by the District in consultation with the Forest Service and that specifically addressed USFS section 4(e) condition No. 8 requirements for erosion monitoring of National Forest System shoreline lands.

A separate plan to control and prevent erosion must be filed subsequent to the monitoring plan described here. This Erosion Control, Prevention and Remediation Plan was originally due to be filed at FERC by August 29, 2007. However, on January 16, 2007, the District, with concurrence of the interested agencies, petitioned FERC for an extension of this date to July 11, 2010, based on the need to formulate the Erosion Control and Prevention Plan on the results developed from implementation of the shoreline erosion and geotechnical monitoring.

On March 6, 2007, FERC issued an order amending the Erosion Monitoring Plan. In this order, FERC found that the August 29, 2007 plan adequately incorporated the requirements under USFS section 4(e) condition No. 8, but that coordination to establish the seven new KIR erosion sites with the Kalispel Indian Tribe delayed the new site surveys from being done, and that none of the required seven new erosion monitoring sites on the KIR had been identified within the August 29, 2007 plan. FERC then ordered that the District file for Commission approval, a supplement to the Erosion Monitoring Plan for the KIR, as required under the U.S. Department of Interior section 4(e) Condition No. 3F.

This Supplemental Erosion Monitoring Plan specifically includes the Department of Interior 4(e) Condition No. 3E and F requirements, including establishment of the seven newly identified KIR sites.

Article 408 of the license states that the purpose of the monitoring is twofold:

1. Determine the location and rate of shoreline erosion at various points throughout the reservoir, and
2. Determine the degree to which project operations contribute to such erosion.

Article 408 further directs that the plan include:

- A minimum of 29 monitoring stations, including 9 sites included in Appendix E8-2 of the license application and description of results to date
- Listing and maps of 20 new monitoring stations, including site conditions and existing erosion rate category
- A reasonable number of stations on KIR and USFS lands
- A description of methodology and maintenance program for all monitoring stations
- A schedule for filing the annual monitoring reports with the Commission
- Documentation of consultation
- Copies of comments and recommendations on the completed plans
- Specific descriptions of how comments are accommodated by the plans
- Reasons licensee has not adopted a recommendation, if any, based on project-specific information
- A description of past monitoring results

Article 408 also directs that following approval by the Commission the plan shall also provide for monitoring:

- Twice yearly

- After floods with ≥ 20-year recurrence interval
- After drawdown rates in excess of three inches per hour

Article 408 also requires that annual monitoring reports be filed with the Commission after consultation with the USFS, DOI, WDFW, and KIR, and must include:

- Comparison of data from the semi-annual measures
- Assessments categorizing erosion rates into low, moderate, and high
- The processes causing the erosion at the various monitoring sites
- Whether and to what extent erosion can be attributed to project operations
- Identification of significant new or recurring erosion areas

Department of Interior also provides Erosion Monitoring Plan requirements at 4(e) Condition No. 3F. These requirements and how this Supplemental Erosion Monitoring Plan addresses them follow.

<u>Item F.1. – Establish a total of eight erosion monitoring stations on the KIR.</u>

As noted by the BIA in their comments dated March 26, 2007, eight erosion monitoring stations have been established on the KIR shorelines and this requirement has been met.

<u>F.2. – Conduct biannual monitoring</u>.

As noted by the BIA in their comments dated March 26, 2007, the Plan calls for <u>biannual monitoring,</u> and this requirement is being met.

<u>F.3. – Update erosion occurrence maps.</u>

During 2007, the District will re-examine the erosion rate classifications for each site and will subsequently develop updated Shoreline Erosion Hazard and Occurrence maps, once the new data required by this Plan are assembled. These new maps may be developed as early as 2008, or may need to wait until 2010, depending upon when meaningful rate of erosion data will have been developed for the 10 new Forest Service and KIR shoreline sites. See sections II and VII where this requirement is reiterated within the context of the various new sources of information to be collected per the Plan.

<u>F.4. – Monitor areas that are currently actively eroding at low, moderate, and high rates as described in FLA</u>.

<u>Monitoring of areas actively eroding at low, moderate, and high rates</u> is fundamental to the monitoring strategy upon which this plan was developed. Average rates of erosion for each of these classes provide representative rates of erosion for all shoreline areas mapped per Appendix E8-1 of the FLA. However, particularly because of the amendments to the August 29, 2006 plan incorporated as a result of the Forest Service peer review process, and with review and concurrence of the Technical Committee erosion Subcommittee, this Supplemental Erosion Monitoring Plan makes it clear that new and revised classifications, or even an entirely new

classification system, may be advisable based on the additional field work and data that must first be collected. This commitment is further explained in sections V and II of this Plan.

To further clarify that areas actively eroding at low, moderate and high rates are being monitored, the District proposes to provide interim revised shoreline erosion and hazard occurrence maps wherein all monitoring locations are identified and provided as an additional feature of the map.

F.5. – Monitor areas for which the erosion *hazard* is moderate or high per the FLA. Again, this is not specifically identified in the plan and is not linked to the FLA.

Moderate and high erosion hazard areas generally correspond with areas that are currently actively eroding at moderate and high rates as mapped per Appendix E8-1 of the FLA. Areas of high and moderate hazard and moderate to high rates of erosion are currently being monitored. Correlation of hazard and occurrence typically occurs because of the predominance of the escarpments (i.e., the steep streambanks) formed from unconsolidated alluvium that form most of the project shoreline; these areas are hazardous and they do indeed erode. To clarify that high and moderate hazard areas are being monitored, the District proposes to provide interim revised shoreline erosion occurrence maps wherein all monitoring locations are identified and provided as an additional feature of the map.

Erosion F.6 – Identify the effects of the Project…. on wave action, undercutting, bank toppling, slumping, ground water piping, and rilling and dry ravel erosion processes.

The Plan provides several pages of text describing detailed field and modeling procedures for determining the relative importance of potential erosion processes, including all of the erosion processes mentioned by the BIA. The Plan then also describes in detail how the relative importance of various causal mechanisms of observed erosion processes will be evaluated. In particular, see tables MP-1 and MP-2 at Pages 22 and 23 of this document, which provide systematic procedures for these evaluations. Causation of process and existence of the process should not be confused, and the Plan carefully separates the two. For instance, undercutting, bank toppling, rilling, and dry ravel are erosion processes, whereas wave action and ground water piping are causal mechanisms.

The Plan clearly states in the second paragraph of Section V (Determining the Processes Causing Erosion) that it may be impossible to quantify the amount of erosion that any one process contributes to total bank erosion because the contributing processes are interdependent. That is, these processes generally occur simultaneously at a given location, and are often caused by a combination of causal mechanisms also often occurring simultaneously and interactively. Nevertheless, the Plan does provide elaborate and detailed procedures for determining project share of erosion at a specific location, and in so doing, in effect has provided an integrated procedure for evaluating project effects on both processes and causation.

F.7- Identify project effects on riparian habitat loss.

As noted by the BIA in its March 26, 2007 comments, the Plan addresses this requirement. See first paragraph following item F.8.

F.8. – Identify remedial measures.

This Supplemental Erosion Monitoring Plan does not address remedial measures. Development of remedial measures will be an element of the Erosion Control and Prevention Plan. As noted by the BIA in its March 26, 2007 comments, the parties issued a request to FERC that this Erosion Control and Prevention Plan be submitted in 2010 and that, "This plan is to include remedial measures." The BIA also correctly noted that the District has agreed to implement measures in the interim. At this time, the District continues to work with the parties to determine specifically how this will occur.

The text of this paragraph following this sentence is as it appeared in previous versions of this Plan, and although it repeats information previously discussed in items F.1 through F.8 above and elsewhere, continues to provide useful context and is the source for item F.7. Within one year of license issuance, the DOI requires that a total of eight sites be monitored on KIR lands, and that the annual monitoring reports identify effects of project operations, including effects of drawdown and wave action on undercutting, bank toppling, slumping, ground water piping, rilling, and raveling, and that the District identify the effects of project operations on riparian habitat loss caused by inundation, bank toppling, and slumping. Moreover, the DOI requires that the Shoreline Erosion Monitoring Plan "Identify remedial measures." This latter requirement appears to conflict with the Article 408 requirement for an Erosion Control and Prevention Plan that is not due until two years after issuance of the license. Given that remedial measures, at least in the context of a Shoreline Erosion Control and Prevention Plan, logically follow development and implementation of the measures called for in this Shoreline Erosion Monitoring Plan, and the data that will be collected and analyzed as a result, the District and the involved agencies have agreed to petition FERC to defer the identification of remedial measures and to include them in the Erosion Control and Prevention Plan, and to defer filing of that plan with the Commission. Nevertheless, Section IX of this document describes the information to be collected via this Shoreline Erosion Monitoring Plan that will assist with development of the Shoreline Erosion Control and Prevention Plan.

The DOI per Appendix A of the Order Issuing New License pursuant to the Section 4(e) Implementation and Monitoring Plan also requires that the District develop certain geotechnical studies at the eight KIR monitoring sites. The plan for these geotechnical studies was developed in collaboration with the DOI, Tribe, the WDFW, and USFS as required by Section 4(e) Implementation and Monitoring Plan and was submitted to FERC as a separate document in August 2006, and was approved by FERC on September 29, 2006.

The DOI further requires that the District update the Erosion Occurrence Maps located at Figure 8.1 in Appendix E8-1 of the District's Final License Application (FLA) (PUD 2000) within 3 years after license issuance, at intervals not greater than 5 years thereafter, and within 1 year after a flood event with a recurrence interval of 20 years or greater.

The USFS Final 4(e) Terms and Conditions require that monitoring of National Forest shorelines document erosion processes and site conditions, including shoreline site stratigraphy, composition, slope, reservoir width and setting, elevation, water surface elevation, and flow. The USFS also requires that additional monitoring sites be established on National Forest lands. The District received a letter from the Colville National Forest Supervisor dated December 12, 2005, documenting agreement to the existing ten monitoring sites located on National Forest Lands, and requesting that three sites be added. The District and the Forest Service collaboratively located these three additional sites on March 31, 2006, and they were first surveyed for location, elevation, and shoreline profile in fall 2006.

Together with the 32 sites monitored since 2001, the three new Forest Service and seven new KIR monitoring sites brings the total number of sites monitored by the District to 42.

At a meeting at the District offices on November 9, 2005, representatives of the Tribe, USFS, WDFW, DOI, and the District universally agreed that developing a single Shoreline Erosion Monitoring Plan that incorporates each of the License Article 408 and section 4(e) requirements would be beneficial. The following plan has been developed accordingly. It is based largely on the Shoreline Erosion Monitoring Plan provided in Appendix E8-2 of the FLA (PUD 2000) that is supplemented and modified so as to incorporate the additional requirements of the new license noted above, comments received from the agencies through March 21, 2006, additional recommendations developed as a result of the Forest Service/PUD peer review process completed in July 2006, and BIA comments dated March 26, 2007 on the August 2006 Erosion Monitoring Plan.

## II. Introduction and Site Selection Procedures

Although Article 408 did not require initiation of monitoring sites until after issuance of a new license by FERC, in fact the District had proactively set up these sites by 2002, and has been performing monitoring to refine methodology, identify the most effective procedures, and to get some experience running this program.

In accordance with the Settlement Agreement and FERC license amendment issued February 26, 1999, and the new Project license issued July 11, 2005, by 2005, the District had already established 32 project shoreline monitoring sites. Thirty of these sites have not been treated with erosion control measures; two of them have. Consistent with the previous Shoreline Erosion Monitoring Plan submitted in the FLA at Appendix E8-2, the District determined site locations, monitoring methods, and monitoring intervals, conducted the necessary surveys, and processed all data to provide annual monitoring reports. The Box Canyon Technical Committee (originally developed pursuant to the 1999 Settlement Agreement) reviewed these locations and methods before these surveys were initiated.

As noted in the FLA Exhibit E8.0, and in the annual erosion monitoring reports prepared for the District by Western Watershed Analysts (WWA), beginning with the report filed in 2002, the majority of shoreline erosion observed in the project area is characterized by bank undercutting and bank slope steepening, sometimes accompanied by bank toppling and relatively small, in most cases, slump/earthflows, of the steep terrace escarpments that border much of the project shorelines. To a lesser degree, gully and rill erosion and dry ravel erosion of surfaces exposed through these processes also occurs. Frost heave may also occur at many sites, acting interactively with other erosion processes. Factors that potentially affect erosion rate of project shorelines include soil texture and cohesiveness, rock content, stratigraphy, height of terrace escarpments bordering the river, reservoir water levels and reservoir water levels relative to "natural" levels (that vary by river mile relative to project endpoints), wave action, river velocities, and disturbances caused by man and animals.

As noted in Exhibit E8.0 of the FLA, direct consideration of the many factors controlling erosion processes affecting project shorelines in a formal sampling strategy would require an infeasible number of study locations. However, to implement a monitoring network representative of a variety of erosion circumstances, they were addressed with an indirect strategy based on relative erosion hazard.

WWA classified all project shorelines into four erosion rate classes (high, medium, low, and not active) based on observable geomorphic characteristics. These characteristics included vegetative density, exposure of root systems, rilling, raveling, evidence of slumping or shallow planar failure forms of mass wasting, bank overhang and undercutting, shoreline steepness, terracing and/or beach development associated with wave action, exposure of root systems, evidence of tree toppling from terraces at the edges of shoreline escarpments, and disturbance caused by man and animals. Because most locations evidencing obvious erosion were associated with terrace escarpments that form project shorelines and that are impacted by Pend Oreille River waters for at least some portion of time, bank height of shoreline surfaces was also mapped, and grouped into three classes (<12', 12' to 24', > 24').

Using these procedures, at least two, and most times three sites falling within each combination of bank height and erosion rate class were located where landowner permission for monitoring could be secured. Sites within each of these rate and bank height classes were further selected to insure dispersion of sites throughout the length of the project.

The District believes that its shoreline classification system, along with purposeful geographic distribution of sites throughout the length of the Project, provides a useful monitoring strategy. While average rate of shoreline erosion could be calculated merely as an arithmetic average from these sites without stratification provided by the classification, the District continues to believe that more meaningful values are developed based on the relative rate classes of high, medium, low and not active. Nevertheless, these classifications were made some years ago without quantitative data. Moreover, the data collected to date do not indicate that depth of erosion or rate of bank recession varies with bank height. Therefore, the District has concluded that it is no longer useful to report rate of erosion data by bank height class in future monitoring reports.

Now that 32 monitoring sites have been monitored for 4 to 6 years, the District proposes as part of this monitoring plan to reclassify each monitoring site by relative rate class in view of the actual rate of erosion measured, as has been suggested in the comments of some of the interested agencies. The District is also prepared to examine the utility of classification based on the site characteristics evaluations, including: shoreline stratigraphy and landform, Erosion Process

Evaluation Indices, and Causative Factor Evaluation information to be collected as part of this plan. The Shoreline Erosion Hazard and Occurrence maps will then be updated in view of this new information. It may be possible to provide a useful reclassification following 2007 field data collection. However, given that shoreline erosion data at the 10 new sites will only have begun to be collected and that it requires at least a few years of annual data to develop a meaningful annual rate of erosion, useful reclassification may not prove possible until 2010. Classification per these systems throughout the reservoir's shorelines is expected to be useful for understanding erosion process and generally effective erosion control procedures. However, it is important to recognize that rates of erosion may have little or no bearing on assignation of "project share" of erosion control responsibility. In fact, the technical procedures for determining project share, described at Section VII of this plan, are not dependent upon rate of erosion.

For this current Shoreline Erosion Monitoring Plan, the District proposes to continue monitoring at each of the 32 sites established to date plus the additional 10 sites recently established for a total of 42 sites.

## III. Objectives

The following objectives have been developed consistent with direction per license section 408 and the requirements of the 4(e) Conditions from the DOI and USFS:

1. Determine the rate of shoreline erosion at monitored locations throughout the reservoir.
2. Determine the relative importance of operative erosion processes at each monitored location; determine when they occur seasonally and through longer intervals of time in association with annual hydrologic variability.
3. Determine the relative rate of erosion for all project shoreline locations through extrapolation of results from monitored locations based on similarity of location, geomorphic, and hydrologic circumstances.
4. Determine the degree to which project operations contribute to such erosion.

## IV. Monitoring Procedures

An excellent and comprehensive review of the various techniques available for measuring reservoir bank erosion and the potential erosion processes at work is provided by the U.S. Army Corps of Engineers (Gatto 1988).

While Gatto (1988) notes that procedures appropriate for a given project depend on shoreline circumstances and project objectives, he shows that electronic distance measurement procedures provide some of the most accurate procedures available for documenting bank profile and crest recession through time, particularly where banks are high or composed of sediment that is easily disturbed - circumstances common to the eroding shoreline locations of Box Canyon Reservoir. Accordingly, total station electronic survey procedures have been employed by WWA and the District at all sites measured since 2000. Consistent with direction provided by the license's DOI Section 4(e) requirements at Condition 3.F, which requires the plan to incorporate the Licensee's FLA Appendix E8-2 Shoreline Erosion Monitoring Plan (PUD 2000), these same survey procedures, supplemented with additional measures and documentation as described below, will continue to be employed at all existing and future monitoring sites.

The total station electronic survey techniques employed for this monitoring plan are capable of relocating survey points with horizontal accuracy of within 0.10 feet. Vertical accuracy at these survey points can then be measured to within 0.01-foot accuracy. However, while the instruments are capable of this accuracy, actual accuracy becomes limited by the surveyor's ability to precisely relocate the survey level rod at exactly the same point, and to do this so that it rests in precisely the same manner on the soil surface. Because the rod must be placed on shoreline bank locations that often are quite steep, and on soil materials that are often loose and subject to movement, the practical limits of vertical accuracy are closer to 0.05 feet. Similarly, horizontal bank recession will be reported to the nearest 0.05 feet. Consistent with this level of accuracy and best presentation of useful information, shoreline profile and erosion data will be reported to two decimal places (i.e., to the nearest one one-hundredth foot). These measurements provide the best estimate of the location and rate of erosion at monitored sites that can be developed.

Using these total station electronic survey procedures, three transects perpendicular to the shoreline are surveyed at each site. Each monitoring site is permanently established by placing two deep-seated steel pins nearly flush with the ground surface. These are also located above the area of active bank erosion and far enough removed from the current top-of-bank point so that horizontal distance of bank recession can be documented through time. Site reference locations and MSL elevations have also now been established through standard survey procedures to known benchmarks.

Monitoring site transects are relocated and elevations resurveyed from the top-of-bank pins during each time of measurement. The number of survey points and their vertical and horizontal spacing varies to best capture important profile features. Normally, each survey point is relocated and resurveyed during each set of measurements. However, shoreline profile shape may change as erosion proceeds, and it is occasionally advantageous, as suggested in agency comments, to relocate, eliminate, or add survey points to capture important profile features, breaks in slope, and progression of important erosion features.

For the 32 monitoring sites monitored since 2001, 9 to 20 points have been surveyed at each transect, depending on the bank height, shoreline horizontal extent from waterline (and below) to top of bank, and shoreline profile complexity. A similar number of survey points are being established at each of the 10 new sites. These surveyed profiles generally extend from 2 to 3 feet below the waterline at time of survey (the practical limit of a person wearing chest waders)[1] to several feet beyond the shoreline crest defined by pronounced decrease in slope, generally on a terrace. As part of this plan, the District will examine all monitoring sites during 2006 and in the

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[1] Forest Service Final (e) Terms and Conditions Condition No. 8 – Erosion Monitoring Plan requires that "Transects shall extend to the location of the lowest water elevation during the past 10 years" while also providing accuracy "in the order of magnitude of 1 inch." Our plan's total station survey procedures provide this level of accuracy, but it can only be provided below the water line to the wadeable depth present at the time of measurement. Measurement beyond wadeable depth using survey procedures is far less accurate; essentially requiring entirely different remote sensing forms of measurement that are inherently inaccurate. Moreover, our measurements to date reveal little or no erosion occurring below low water levels at nearly all sites.

future on a continuing basis to see if additional survey points are needed to more accurately define all transect profiles. However, irrespective of whether every detail of a transect profile is recorded during a given survey, bank erosion and recession that occurs over time will be apparent in the data and indicative when these data are compared to each other through time.

Survey data will be recorded in a database and bank profiles graphed at each transect location. Digital photographs will also be taken at each site each time it is surveyed and will be displayed along with the transect(s) bank profile represented. Because of the file sizes involved, these photographs, profiles, and the supporting Excel data will likely be provided as appendices to the annual monitoring reports. Water stage at time of each survey and stage at 10,000 cfs (the flow at Box Canyon exceeded approximately 93% of the time) will also be recorded and displayed on each shoreline profile.

During 2007, the District's consulting geologist will record representative bank stratigraphy at each monitoring site in the form of geologic cross sections. Additionally, the District also will identify important areas and occurrences of erosion on each bank profile as it occurs. As recommended by the peer reviews, the District expects that these additional forms of information will help the District more accurately and systematically identify relative rate and forms of erosion occurring throughout the reservoir's shorelines at sites that are not directly monitored through the District's detailed bank profiling procedures. Mean depth of erosion, and mean rate of bank recession, at the monitoring sites will also be provided as distributions. These distributions in relation to the additional monitoring information noted above and in comparison to rates of erosion documented for other reservoir shorelines as suggested in the peer review by Riedel (2006) will help identify which sites are truly eroding at low, moderate or high rates, or that are not currently active / not eroding. Documentation of rates of bank recession coupled with digital photography will provide information needed for identifying riparian habitat loss caused by bank toppling, slumping, and other forms of erosion.

The precise rate and form of erosion that occurs within even a small area of shoreline length (e.g., 100 feet) is often highly variable. For instance, at some point in time a small section of escarpment only a few feet wide may topple, whereas the remainder of the adjacent shoreline area with similar characteristics experiences no such toppling, at least at this same point in time. In view of this variability and to better represent the general condition of a monitored site, three surveyed transects located approximately 20 feet apart are established at each site. Variability in erosion rate is illustrated by the three bank profiles measured at site 23 that we include as an example in Section VII of this report. Site 23; transect 1, evidences only minor erosion in relation to transects 2 and 3. Transect 2 appears to have experienced bank sloughing, toppling, or slumping. At transect 3, a deposit that likely developed as a result of bank sloughing and toppling that would have occurred prior to our first survey was subsequently eroded away.

Spacing of approximately 20 feet for site transects was selected to better represent the general nature and rate of erosion process characteristic of a site by grouping the transects close enough to one another such that they characterize a single area, rather than spacing them so far apart that they fall into some other "area" with substantially different characteristics, thereby becoming separate and distinct "sites." Twenty-foot spacing also allows survey from a single (in most cases) instrument location that provides accuracy, time, and cost advantages. Using three transects at a site is akin to inventorying multiple plots within a given forest stand so as to characterize conditions within that stand more accurately than would be provided by a single plot (or by a single transect). The District retains all data for each transect individually for each monitoring site and for each measurement in electronic format. This data will be provided in electronic form as an appendix to the annual monitoring reports (the data is far too voluminous to be conveniently transmitted via hard copy). While data and profiles will be developed and available for review for each transect within these appendices, within the monitoring report results for the three transects at a monitored site will generally be presented as the average (i.e., the mean) depth of erosion occurring at that site.

Deposition of sediment occurs at least periodically within portions of transects at some monitoring sites. Earlier comments by the agencies indicated they felt that inclusion of these positive values (i.e., deposition) might distort the information and cause important erosion at other portions of the profile to be overlooked. The District carefully considered these comments, but as a result of the peer review and recommendations, the District and the agencies have agreed to continue to include positive values when computing net erosion. Nevertheless, the District also will identify important areas and occurrences of erosion on each bank profile as it occurs so that they are not obscured or inadvertently "lost" through the net depth of erosion calculation.

Standard procedures for this monitoring program are to survey all sites twice each year; once in the spring and once in the fall. The spring surveys are timed to follow spring runoff when water surface elevations have dropped to relatively low levels corresponding to approximately 20,000 cfs or less, to allow surveys to proceed to relatively low elevations for each site. The fall surveys are timed to occur before water levels rise substantially above summer low levels and prior to severe winter weather. Experience with these procedures since 2002 demonstrates that timing of these surveys to follow normal spring peak flows, and in the fall prior to winter snow and ice, provides the best practicable means for isolating peak flow effects. Peak flows have been documented to be associated with major erosion sequences, and virtually all Pend Oreille River annual peak flows, other than minor events substantially smaller than the mean annual flood,[2] occur in the spring from late April through June (Table 1). The hydrograph representing flows at gage #12396500 below Box Canyon Dam recorded from July 2001 through September 2004, illustrates the timing of past erosion monitoring surveys in relation to Pend Oreille River flows (see Figures 1 and 2).

[2] Based on 52 years of record for USGS gage 12396500, the mean annual flood of the Pend Oreille River below Box Canyon Dam is 82,800 cfs.

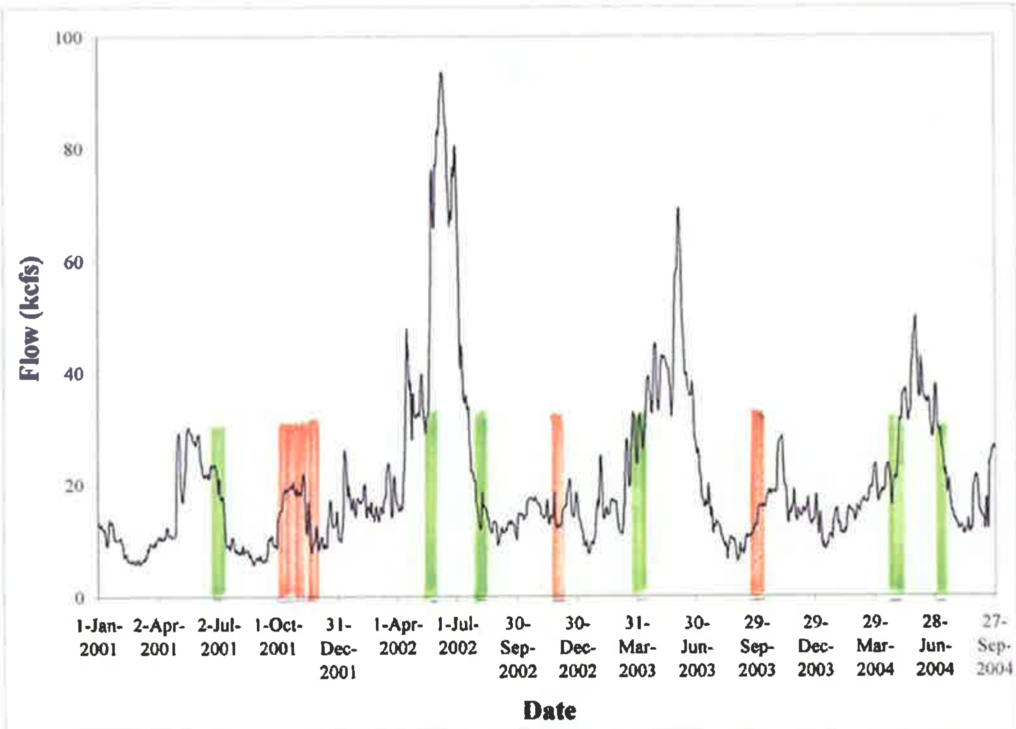


**Figure 1. Flow at Gage 12396500 Below Box Canyon Dam**

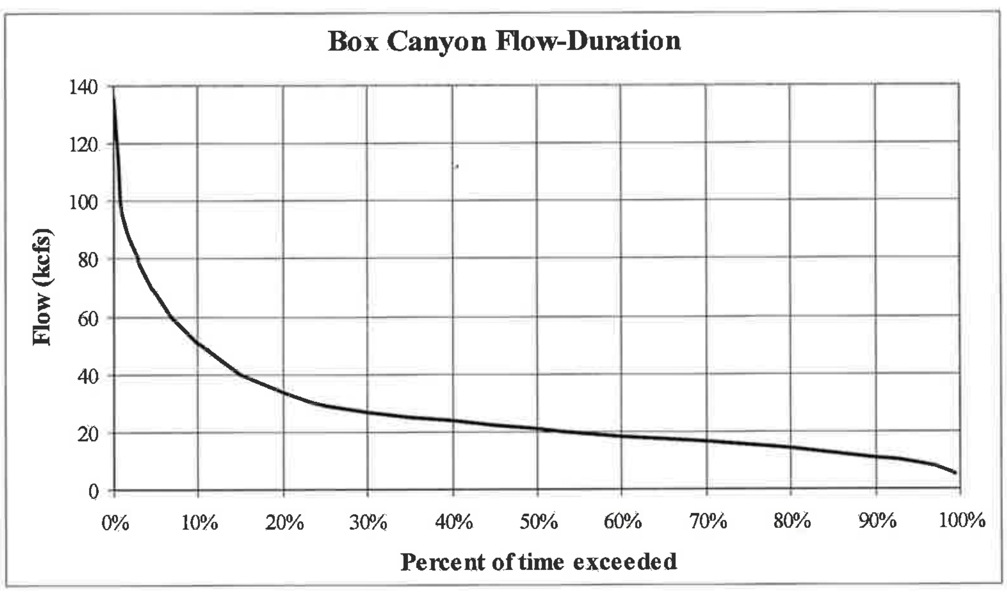


**Figure 2. Box Canyon Flow Duration Curve**

In addition to the spring and fall measurements at each monitoring site, pre-flood surveys will be made at four sites located in the Cusick Flats area (as suggested by the Tribe) and at four additional sites, two near Newport (near the upstream limits of the Project) and near Ione (near the downstream limits of the Project) in order to help isolate the erosion strictly associated with spring flows, which is important for determining Project share of erosion described in Section VII. These sites will be located in collaboration with the Tribe, USFS, and other interested agencies. The District expects to select actively eroding areas as evidenced by the District's monitoring data and/or areas of particular concern to the agencies for these spring pre-flood measurements.

**Table 1. Maximum Annual Peak Flows, Pend Oreille River Below Box Canyon #12396500**

| Water Year | Date | Gage Height (feet) | Streamflow (cfs) |
|---|---|---|---|
| 1948 | Jun. 1948 | 38.00 | 167,000 |
| 1953 | Jun. 17, 1953 | 25.68 | 95,100 |
| 1954 | May 29, 1954 | 27.36 | 103,000 |
| 1955 | Jun. 20, 1955 | 22.98 | 80,900 |
| 1956 | Jun. 06, 1956 | 31.74 | 125,700 |
| 1957 | May 26, 1957 | 25.84 | 97,100 |
| 1958 | May 29, 1958 | 25.85 | 97,100 |
| 1959 | Jun. 26, 1959 | 26.25 | 99,200 |
| 1960 | May 22, 1960 | 20.20 | 69,200 |
| 1961 | Jun. 09, 1961 | 29.14 | 114,600 |
| 1962 | Jun. 07, 1962 | 22.86 | 82,800 |
| 1963 | Jul. 04, 1963 | 17.37 | 57,100 |
| 1964 | Jun. 18, 1964 | 30.30 | 119,900 |
| 1965 | Jun. 06, 1965 | 23.84 | 88,200 |
| 1966 | May 12, 1966 | 16.88 | 56,900 |
| 1967 | Jun. 10, 1967 | 28.34 | 110,000 |
| 1968 | Jun. 07, 1968 | 21.47 | 65,500 |
| 1969 | May 21, 1969 | 24.15 | 76,100 |
| 1970 | Jun. 06, 1970 | 26.14 | 103,000 |
| 1971 | May 14, 1971 | 27.00 | 114,000 |
| 1972 | Jun. 13, 1972 | 34.54 | 136,000 |
| 1973 | Jun. 02, 1973 | 13.82 | 27,500 |
| 1974 | Jun. 26, 1974 | 34.31 | 133,000 |
| 1975 | Jun. 28, 1975 | | 103,000 |
| 1976 | May 22, 1976 | | 88,400 |
| 1977 | Oct. 07, 1976 | | 29,000 |
| 1978 | Jun. 02, 1978 | | 67,600 |
| 1979 | May 29, 1979 | 24.78 | 87,100 |
| 1980 | May 30, 1980 | 26.99 | 98,300 |
| 1981 | May 26, 1981 | | 106,000 |
| 1982 | Jun. 25, 1982 | | 105,000 |
| 1983 | May 31, 1983 | 23.53 | 84,000 |
| 1984 | Jun. 25, 1984 | 22.34 | 73,100 |
| 1985 | Jun. 13, 1985 | | 62,300 |
| 1986 | Jun. 04, 1986 | | 79,200 |
| 1987 | May 08, 1987 | | 44,300 |
| 1988 | May 19, 1988 | 17.48 | 58,000 |
| 1989 | May 17, 1989 | 20.67 | 63,600 |
| 1990 | Jun. 14, 1990 | 24.48 | 83,700 |
| 1991 | May 28, 1991 | 26.44 | 104,000 |
| 1992 | Nov. 07, 1991 | 10.98 | 32,400 |
| 1993 | May 24, 1993 | 1997.97 | 56,800 |
| 1994 | Apr. 26, 1994 | 1994.42 | 33,600 |
| 1995 | Jun. 12, 1995 | 2002.39 | 77,100 |
| 1996 | Jun. 15, 1996 | 2008.34 | 100,000 |
| 1997 | Jun. 07, 1997 | 2015.44 | 134,000 |
| 1998 | Jun. 03, 1998 | 2003.57 | 84,600 |
| 1999 | Jun. 22, 1999 | 2004.48 | 82,700 |
| 2000 | May 24, 2000 | | 54,000 |
| 2001 | May 03, 2001 | | 32,100 |
| 2002 | Jun. 10, 2002 | 2007.47 | 100,000 |
| 2003 | Jun. 05, 2003 | 2003.11 | 80,500 |
| 2004 | Jun. 01, 2004 | 1996.59 | 51,300 |

Per Article 408 of the new license, the semi-annual surveys will be supplemented with additional monitoring following floods with recurrence interval of 20 years or greater as measured at the USGS gage # 12396500 below Box Canyon Dam[3] and following drawdown rates in excess of three inches per hour. This additional monitoring will be conducted as soon as water levels have receded to levels allowing observation and meaningful evaluation of shoreline profiles. Examination of flood hydrographs recorded at gage # 12396500 indicates that this should be possible within 7 to 10 days following these flood events when flows have receded to approximately 40,000 cfs or less. However, the form of this additional monitoring will not be to conduct bank profile surveys, because: 1) FERC requires the District to identify new or recurring erosion areas, and this cannot be done via bank profile survey, since not all points of the 160 miles of shoreline are surveyed; 2) surveyed profile monitoring will follow all spring flood events irrespective of their magnitude, however, survey of the approximately 42 sites required by full implementation of this plan will require, as a practical matter, a period of two to four weeks to complete, and cannot immediately follow peak flows or rapid drawdown events, particularly if shorelines remain fully or partially submerged during relatively high flows during recession on the falling limb of the hydrograph; 3) identification of the form and causative factors associated with erosion that may have occurred requires professional assessment in the field relatively soon following these events - a form of monitoring that cannot be provided through profile survey.

Instead of the usual transect surveys, which are not feasible immediately following floods or rapid drawdown, conditions at each monitoring site will be field reviewed and documented to describe evidence of bank toppling, sloughing, slumping, pronounced wave or waterline-related erosion, piping, or any other form of observable mass erosion, along with any evidence of causation. In addition, the entire project shoreline will also be similarly surveyed so as to identify any new or recurring erosion areas consistent with Article 408. Processes causing erosion at each of the monitoring sites, and throughout the reservoir, will also be carefully documented during these annual reviews using procedures described in Section VI of this plan. Moreover, this additional monitoring will also be conducted annually, irrespective of the occurrence of unusual events.

The bank profile surveys allow calculation of depth of erosion at each transect. The sum of annual depth of erosion multiplied by the average width (width being the length of the shoreline profile from top to bottom elevation) and the total length of shoreline within each erosion rate class yields an estimate of total annual eroded volume for the Project's shorelines. This estimate has been included in the annual monitoring reports prepared since 2002. Results through fall 2005 for each of the 30 untreated monitoring sites are provided in this report in Appendix A. All subsequent annual reports will also be submitted to the Commission by March 31 of the year following survey.

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[3] DOI Condition 3.F.1 demands that this monitoring be conducted "within 7 days after an emergency event or operating condition beyond the control of the licensee, or within 7 days after a flood event with a recurrence interval of 20 years or greater (as measured at USGS gage number 12395500, Pend Oreille River at Newport, Washington). However, the Newport gage is not telemetered and does not provide real-time data as does the Box Canyon gage that we will rely upon. Additionally, and as noted further in this plan, while measurement will routinely follow flood events, measurement within 7 days of major peak flows may be impossible due to high water levels and shoreline inundation.

While past annual monitoring reports have provided an estimate of total project shoreline erosion, providing such an estimate is no longer an objective, and these estimates will no longer be calculated. Instead, consistent with monitoring objective #1, the rate of shoreline erosion will be reported for each monitoring site. Average eroded depth at each site will be reported for each monitoring interval and in total since inception of the monitoring program. Bank profiles that document conditions at the time first measured will be plotted with the most recent profile in each report. Water level at the time of measurement will be documented on the bank profiles at each location, along with the water level at 10,000 cfs as suggested by the agencies. To standardize all results, depth of erosion and horizontal recession at top-of-bank will be expressed as rate per year values.

Figure 3 shows the shoreline profile for transect 2 at site 23, located on the left bank at RM 87 just downstream from Newport, is provided below as an example of how the survey data are plotted so that the initial and most recently processed survey data can be compared. A representative photograph of the site is also provided. As suggested by the agencies, future plots will also indicate water level at 10,000 cfs and will identify the location and form of erosion where it occurs on the profiles.

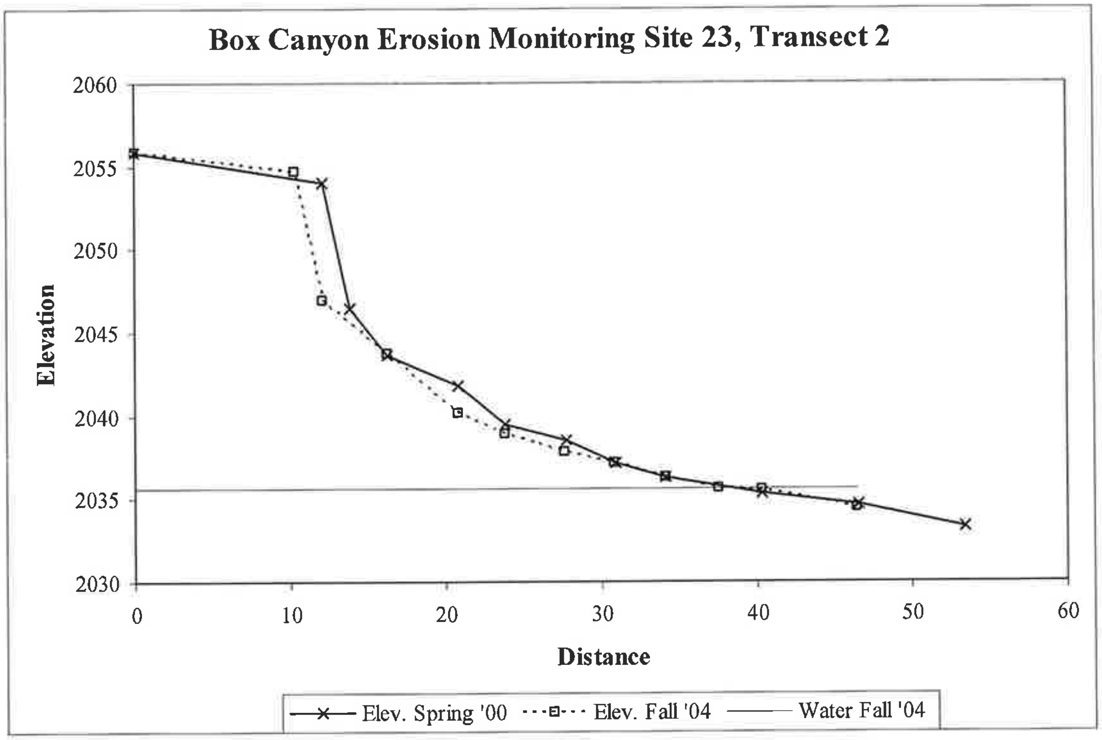



**Figure 3 - Example data plot and site photograph**

Additional documentation of conditions at each monitoring site will also be provided to supplement the surveyed bank profile data. Pend Oreille County Soil Survey soil series name and number (e.g., Kaniksu 60) will be recorded, along with a general description of the soil (e.g., sandy loam over gravelly sand) and the local landform (e.g., outwash terrace escarpment). Using the surveyed profiles, bank stratigraphy will also be thoroughly documented through field delineation of each distinct material layer from the top of the shoreline to the water line at the time of survey in the form of geologic cross sections. Each layer will also be described by texture, color, and Unified Soil Classification System field identification procedures (Wu 1970, pages 24 – 25). Geology of the project's shoreline and areas behind the shoreline will be mapped through field verification of existing geologic maps available for the area. Shoreline and back shore area landforms will also be mapped using the system, or some adaptation of this system, suggested in the peer review by Riedel (2006).

| Landform Type | Characteristics | Soil type |
|---|---|---|
| Valley Wall | Bedrock Canyon with colluvial soils Zone 1* | Mobate, Rasio |
| Glacial Valley Wall | Glacial till and drift on valley walls in Zones 1 and 2. | Newbill, Inkler |
| Floodplain | Cusick basin channel and gravel bars Zones 3 and 4 | Blueside and Kegel |
| Terrace <12 ft | Lacustrine terrace Zone 2 | Anglen and Cusick |
| Terrace > 24 ft. | Outwash and lacustrine, Zones 1 and 2 | Bonner and Kegel |
| Levee and other human | Variable, Zone 3 | n/a |

(* See following figure for Riedel's descriptions of zones 1, 2, 3 and 4.)

Strata of remaining shorelines (i.e., the areas not monitored through surveyed profiles) will be inferred based on site geology, landform and strata at the monitored sites. Also potentially useful for understanding erosion process and form throughout the reservoir are general diagrams of the form suggested by Reidel (2006) in his peer review. The District will explore the utility of such diagrams as it pursues collection of geologic, landform and other information.

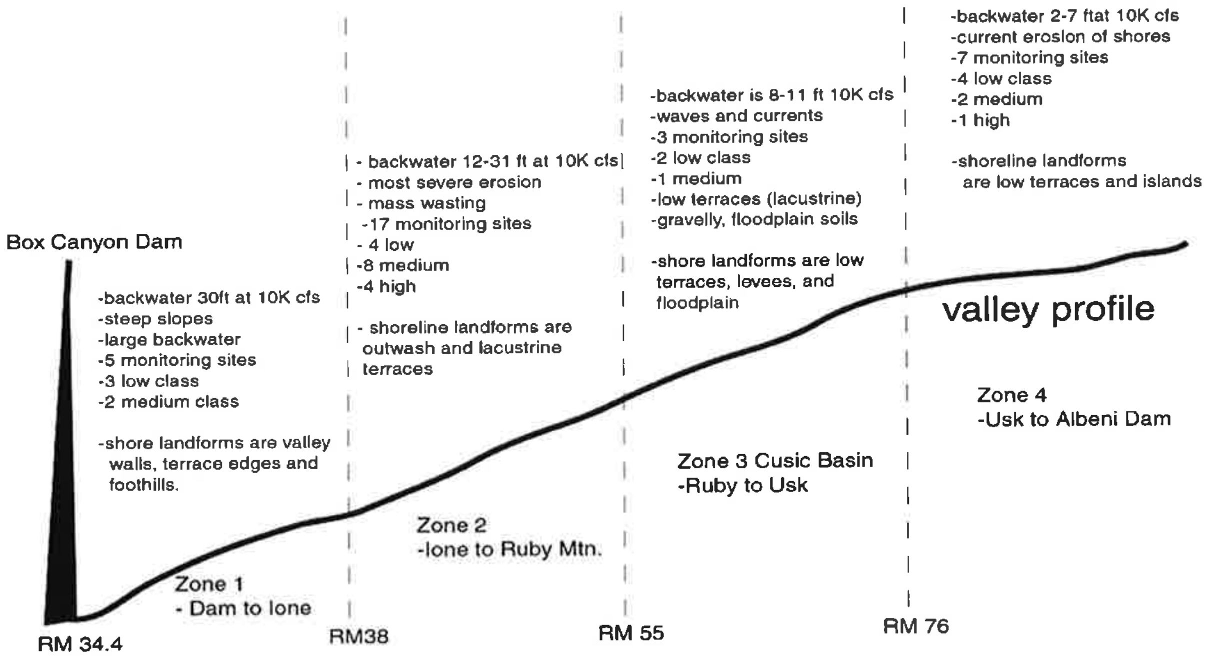



**Figure 4. Erosion zones along a longitudinal profile at Box Canyon Hydroelectric Project (from Reidel 2006).**

## V. Determining the Processes Causing Erosion

License Article 408 requires assessment of the processes causing erosion at the monitoring sites. This can be accomplished through systematic documentation of the various processes potentially affecting each site. This documentation is best accomplished through professional evaluation via a qualitative rating system. Such rating systems are widely used in natural resource circumstances - two examples are the Pfankuch (Rosgen 1996) stream stability evaluation system and the BLM's Properly Functioning System approach for assessing stream habitat quality.

The District believes that systematic application of qualitative evaluation procedures is a sound procedure for determining the relative importance of erosion processes at a given site. Nevertheless, the District does not want to encourage unrealistic expectations. As the U.S. Army Corps of Engineers has reported (Gatto and Doe 1983; Lawson 1985; Gatto 1988), it may be impossible to quantify the amount of erosion that any one process contributes to total bank erosion because there are many contributing processes, all of which are interdependent.

The District has developed rating systems using tables MP-1 and MP-2 for evaluating the relative importance of each erosion process that may be present at a shoreline location and for evaluating the causative factors that may be affecting it. This system will be implemented at each surveyed monitoring site and then applied to the remainder of the shoreline by rating each individual unit of High, Moderate, Low, and Not Active erosion as mapped on the District's Shoreline Erosion maps. The system should be considered as a prototype that requires field testing and adjustment during 2007. Assuming that these techniques provide useful documentation of the erosion processes at work, they would be employed at each monitoring site in a systematic and repeatable manner during future years for the life of the monitoring program. The sequence of tasks to accomplish this work will be:

I. At each surveyed monitoring site:
1. Complete tables MP-1 and MP-2, including notation of landforms and land uses
2. Adjust prototype table MP-1 rating scales as needed to best fit rates of erosion documented by the surveyed profiles
3. Develop geologic cross sections

II. For remaining shoreline erosion rate mapping units
1. Verify mapping unit boundaries and adjust as necessary
2. Complete tables MP-1 and MP-2, including notation of landforms and land uses
3. Adjust H, M, L, and N erosion rate calls as indicated by Table MP-1 rating results

This form of qualitative evaluation and mapping is consistent with similar erosion severity evaluations discussed within the literature. While these systems have provided useful information in many previous studies, boundaries between mapping units often gradually grade into one another, and there often is no distinct geographical point that forms an abrupt boundary between an area that is not eroding or that may be eroding at some higher relative rate. This is somewhat analogous to the mapping boundaries between soil mapping units where true "boundaries" often do not exist between units because one soil type's characteristics blend into the next. This is a form of uncertainty that is inherent with these forms of mapping. Moreover, as suggested by peer review (Gerstel 2006), boundaries may shift through time, and important shifts will be recorded as they are observed through periodic assessments. Nevertheless, it is the District's consulting geologist's opinion that the various evaluation procedures and mapping procedures likely will provide correct estimates of relative rates of erosion rate for well over 90% of all mapping units once these procedures have been fully implemented in 2007 and the maps revised as needed.

**Table MP-1: Erosion Process and Erosion Rate Evaluation Index**

| Indicator (I) or Process | Relative Level of Activity and Rate of Erosion Indicators | | | | Comments |
|---|---|---|---|---|---|
| | **High** | **Moderate** | **Low** | **Not Active** | |
| Mass Wasting | Rotational or shallow planar failures of shore and backshore areas common and/or large **H** | Occasional or small failures involving both shore and backshore areas **M** | Little evidence of rotational or planar failure **L** | No evidence of rotational or planar failure **N** | **RATE MASS WASTING SEPARATELY** |
| (I) Shoreline Steepness | > 100% slope **5** | 50 to 100% slope **3** | 20 to 50% slope **1** | < 20% slope **0** | |
| (I) Vegetative density or surface protection by stones (cover) | Less than 10% coverage of shoreline surfaces exposed to reservoir waters **5** | 20 to 50% coverage **3** | 50 to 90% coverage **1** | >90% coverage **0** | |
| (I) Terracing by waves or current | Pronounced and/or multiple wave or current-formed steps or terraces common **5** | No more than 1 distinct step or terrace **3** | Single step < 1 foot high step or terrace **2** | No evidence of wave or current formed steps or terraces **0** | |
| Undercutting | Bank cutting nearly continuous; undercut depth commonly greater than 1 foot **5** | Significant bank cutting, but mostly <1 foot deep **3** | Some intermittent bank undercutting, mostly <1 foot deep **2** | No evidence of undercutting **0** | |
| Toppling | Abundant and recent toppled banks and/or vegetation are obvious **5** | Occasional toppling. Recent toppling not common; most banks and vegetation remains stable **3** | Toppling is rare; nearly all banks and vegetation remains stable **2** | No evidence of toppling **0** | |
| Rilling | Numerous long and/or deep rills, many >2" deep **4** | Rills common, but mostly <1" deep **3** | Some rills evident, but intermittent and shallow **2** | No evidence of rilling **0** | |
| Raveling (Also a key indicator of frost heave) | Fresh colluvium accumulates to depths in excess of 2 feet at slope base. Generally loose, coarse-textured soil **4** | Fresh colluvium accumulates to depths in excess of 1 foot at slope base. Generally fine to medium textured firm soil **3** | Little evidence of colluvium due to ravel. Generally fine to medium textured firm soil **2** | No evidence of ravel **0** | |
| **Total Score** | **< 3: Not Active** | **3 – 12: Low** | **13-21: Moderate** | **> 21: High** | |

## Table MP-2: Causative Factor Evaluation

| **Date**<br>**Observers** | **Location Description** | **Shoreline Landform and Soils**<br>(e.g., outwash terrace; GP gravelly sand) | **Backshore Landform & Land Uses** |
|---|---|---|---|
| **Site Number** | | | |

| **Causative Factor** | **Relative Level of Activity** | | | | **Comments** |
|---|---|---|---|---|---|
| | **High** | **Moderate** | **Low** | **Not Apparent** | |
| Wave Erosion | Pronounced and/or multiple distinct wave- form steps common | No more than 1 distinct wave-form steps apparent | Single wave-form step < 1 foot high | No evidence of wave form steps | |
| Current Erosion | Distinct unidirectional current eroded terrace > 1 ft. horizontally and/or vertically | Distinct but small current-eroded terrace 0.5 to 1 ft. | Barely discernable current-eroded terrace <0.5 | Eroded terraces not apparent | |
| Piping and/or Groundwater | Numerous distinct pipes greater than ½ inch in diameter and/or extensive saturation of banks; active groundwater drainage if observed following drawdown | Some distinct pipes greater than ½ inch in diameter and/or areas of saturated banks; at least some groundwater drainage if observed following drawdown | Few, distinct pipes. Limited seepage following drawdown. Little evidence of groundwater or drainage | No evidence of Piping or saturation associated with groundwater or drainage | Seepage following spring high flows not associated with project operations may occur and should be noted |
| Trampling | Occurrence of human and/or animal traffic develops ruts in mineral soil | Moderate level of human and/or animal foot traffic; all duff removed and mineral soils exposed | Some evidence of human and/or animal foot traffic; damage to living vegetation, but mineral soil not exposed | No evidence of trampling | |
| Anthropogenic Disturbance | Shoreline evidences severe anthropogenic soil disturbance; little or no vegetation remains | Shoreline evidences moderate anthropogenic soil and vegetative disturbance | Limited evidence of anthropogenic soil or vegetative disturbance. | No evidence of anthropogenic soil or vegetative disturbance. | Disturbance does not include installation of erosion control and prevention measures |

Current velocity has often been reported as an agent of erosion for rivers (Klingeman et al. 1993; Reidel 1990; Klingeman et al. 1990) and because of the run-of-river nature of Box Canyon Reservoir, it was recommended by one of the draft plan peer reviews that it be more formally considered. Accordingly, current velocity will be measured in 2007 at all surveyed sites experiencing erosion rated as high or moderate and examined with tractive force analysis to see if shoreline materials at these sites may be eroded by current. Measurements will be made at representative low, moderate and high flows. Qualitative observations will also be made during wave monitoring to see how sediments entrained by wave action are transported at and potentially away from wave-monitored sites. Evaluation of velocity effects is also included as a causative factor to be evaluated via Table MP-2.

Groundwater is also cited as a contributor to erosion of shorelines particularly where seepage forces occur due to subsurface drainage of areas landward of steep shorelines, during saturated conditions at high reservoir levels, and following drawdown (Gatto and Doe 1983; Gatto 1988; Lawson 1985; Riedel 1990; Saint-Laurent et al. 2001). Groundwater presence and likely contribution to erosion and/or mass wasting will be observed and noted at all surveyed sites and all shorelines evaluated via tables MP-1 and MP-2.

Mass wasting in the form of deep-seated slumps or shallow-planar (debris avalanche) failures has been found to be the dominant form of erosion for some reservoirs (Reidel 1990, for Ross Lake; Gatto and Doe 1988, for Dworshak Reservoir). These forms of erosion also occur at least occasionally along Box Canyon shorelines. Accordingly, and consistent with peer review recommendations, the District's consulting geologist will conduct a mass wasting inventory of the reservoir's shorelines. The form, location, size (i.e., approximate depth, width (parallel with shore), and length (perpendicular to shore), slope, surrounding landforms, and apparent contributing factors will be recorded for each landslide. Landslides will be re-inventoried at no less than every 5 years (i.e., 2012). Landslides that move rapidly in response to floods or other triggering events may be re-inventoried annually as needed to document important episodic movement.

Waves are often cited as the dominant process of shoreline erosion of many reservoir shorelines (Riedel 1990; Saint-Laurent et al. 2001), although Lawson (1985 at page 18) notes that these claims are often made without substantiation. Nevertheless, because of the potential importance of waves, the District will use a combination of field measurements and modeling procedures to estimate the increase in wave energy expended on Box Canyon Reservoir shorelines and that may be attributable to existence of the reservoir. The procedures employed will be:

- Establish six (6) monitoring sites, three (3) on each side of the reservoir, distributed along the reservoir's length adjacent to sites exhibiting observable erosion, to represent various channel orientations and bank configurations.
- At each monitoring location, instrumentation will be assembled to continuously monitor wind speed and direction for a period of one year, encompassing both the summer recreational season and times of little or no watercraft traffic during the winter and other periods.
- Twice during the period of wind speed monitoring, field visits will be conducted to measure wave height, period, and direction at each monitoring site. At least one of these

field visits will be scheduled to ensure that relatively heavy (i.e., summer weekend) watercraft traffic occurs during measurement sessions and we will attempt to time measurements such that "storm" waves can be evaluated during particularly windy circumstances. Average wave heights (crest to trough) will be measured with a wave board using the procedures of Klingeman et al. (1993, page 14) far enough away from the water's edge to prevent influence of waves breaking near shore. Average wave periods (time between successive crests) will be measured with a stopwatch. Wave direction will be measured using a compass. During these field measurement procedures, presence of watercraft will be noted, and separate measurements of watercraft wake waves will be made in the same manner in order to estimate the influence of watercraft traffic on wave energy. Careful records of field measurement times and locations will be kept in order to correlate measurement times with wind speed records. Bank configuration will also be characterized in terms of average bank slope below the waterline, in order to estimate the effect of wave breaking near the water's edge.

- Fetch lengths at each monitoring site will be calculated based on channel width, channel orientation, and prevailing wind/wave direction(s) at the time of the field measurements using the methods of Smith (1991). Using relationships employed by Saint-Laurent et al. (2001) and Smith (1991), wave height and period, and resulting wave energy, will be calculated. Field measurements will be used to calibrate/verify these calculations. Wind peak intensity and duration data at existing nearby long-term stations will also be examined. Assuming reasonable correlation of field data with long-term station data (e.g., $r^2 > 0.80$), the one year of field data can be extended to simulate a much longer period of record and range of data that will include "large wind events." This approach obviates the need for a longer (and expensive) original data collection effort of more than one year where irrespective of the number of years data are collected, "one or more large wind events" can continue to be missed. The result will be an estimate of the average wave power per unit length of shoreline at each monitoring location. This power can also be adjusted for wave breaking based on bank slope beneath the water surface.
- To estimate wave energy as if the reservoir did not exist, fetch lengths can be recalculated assuming channel widths that would exist without the reservoir. These lengths can be obtained through evaluation of river shoreline maps that have been developed by the District for the range of natural river flows so that natural (and with-project) fetch can be evaluated seasonally. Wave energy with these new fetch lengths will be calculated and compared to those with the project to estimate the percentage of wave energy due to the existence of the project. Although the specific relationship between wave energy and bank erosion is unknown (and highly dependent on bank character, materials, etc.), we can assume that bank erosion due to waves in a given location is proportional to wave energy.
- Using these results, wave power can then be simulated for any other location of the project based on critical wind direction for waves impacting that location, with and without project fetch for that location, and for watercraft traffic. Error and uncertainty of these measures and calculations will be discussed within discussion of the results.

The result of this analysis will be an estimate of the change in wind-related wave erosion in today's reservoir compared to the "without project" case, and as described above, can be used to examine wave phenomena at specific locations.

The share of "watercraft wave action" of the total "wave action" impacts will also be estimated and evaluated. Watercraft use data gathered during recreation surveys will be evaluated and compared to estimated watercraft use "without" the project. It may also be possible to form estimates of increased watercraft use through comparison of pre- and with project local census and/or shoreline residence numbers. Additional details for determining "with" and "without" project watercraft traffic remain to be developed by the District's recreation specialist and consulting geologist. Watercraft use on similar rivers in the region that do not have impoundments may also be valuable for determining whether an increase in watercraft traffic on the Pend Oreille River can be attributed to the existence of the project. These procedures will be evaluated in 2007 so that they can be included in the wave energy evaluations and as project share of erosion is considered.

## VI. Determining the Degree to Which Project Operations Contribute to Erosion

Article 408(a) of the license states that the purpose of the Shoreline Erosion Monitoring Plan is twofold: 1) Determine the location and rate of shoreline erosion at various points throughout the reservoir, and 2) Determine the degree to which project operations contribute to such erosion. Furthermore, Article 408(b) requires the District to file a separate Erosion Control and Prevention Plan within two years of issuance of the license, and that this plan is to be based in part on the District's monitoring efforts. Addressing this Article 408 requirement, this section of the District's Shoreline Erosion Monitoring Plan provides a systematic, reproducible, and quantitative approach for determining project share at any and all District erosion monitoring locations, and at any project shoreline location, monitored or not. The procedure is intended for consistent general application (i.e., anywhere), but it is not intended to provide a "general" one-size-fits-all value.

Determining "project share" at any given location of the project shoreline is complex and difficult. This is particularly true for Box Canyon Reservoir because erosion occurs on essentially the same shoreline landforms, locations, and elevations as it did prior to the project, a circumstance unique within the literature that the District has reviewed to date. In addition, as acknowledged within the District's response to the peer review provided by Riedel at #R11, these procedures should be considered experimental; while the District will continue to review erosion monitoring plans and discussions of project share for other FERC projects and reservoirs, to date the District has found no other projects, studies or other accounts that discuss determination of project share based on erosion monitoring data. The District will continue to review this literature, and as suggested by the peer review, cite these accounts within discussion of project monitoring results.

Despite these difficulties, having a system for data collection designed to provide specific information necessary for an analysis that determines "project share" is essential if the monitoring plan is to fulfill the FERC purposes for the plan. The measurements and additional investigations described in this monitoring plan are designed to help determine project share at specific sites. While this plan has been prepared to include a systematic procedure for using monitoring data to help determine project share, with most of the procedure intended to be highly quantitative and precisely defined, it also allows as suggested in the comments of some agencies, for consideration of intangibles that might be associated with factors unique to a given site or that are not anticipated at this time.

There are certain principles affecting erosion phenomena along the project's shorelines that help shape a reasoned approach to determining project share:

1. Water levels in Box Canyon Reservoir are unaffected by Box Canyon Dam at flows above 90,000 to 102,000 cfs. All shoreline surfaces currently subject to water and erosion at water levels affected by the project, with exception of shorelines within Box Canyon (extending for 0.6 miles above the dam), would also be subject to erosion for at least some period of time at naturally high water levels not affected by the project.

2. Some eroding shoreline surfaces at elevations above those reached by project-affected flows (i.e., approximately 102,000 cfs at the entrance to Box Canyon decreasing to 90,000 cfs at RM 55 near Ruby Ferry) are predisposed to erosion because of erosion that occurs pervasively at low to moderate flows at elevations affected by the project.

3. Erosion occurs at an accelerated rate during floods, although the majority of total erosion may occur at lower flows.

Based on these principles, and on the data that will develop as a direct result of the District's monitoring program, the following approach has been developed for determining project share.

Using flow duration and stage duration data submitted in the FLA, stage duration relationships can be determined for two conditions: stage as affected by the project,[4] and natural stage not affected by the project. These stage relationships can be developed for any location along the project's shoreline. Using the first-measured profile at each of our monitoring sites for convention, the stage relationships can be used to determine the percent of time that the eroding area of shoreline of concern is subject to inundation and river-associated erosion. This key area will be determined individually at each monitoring site. The difference in the "with" and "without project" percent of time values provides an index to the percent "project share" of exposure (%PSE) for this surface. The calculation is:

% Project Share of Exposure =

(% time exposed "with" - % time exposed "without") / % time exposed "with"

This calculation provides an index to project share for area subject to erosion below 90,000 to 102,000 cfs (depending on location upstream of Box Canyon Dam), with flood recurrence intervals of approximately 3 and 4 years, respectively.

The Project Share of Exposure Equation does not account for erosion that may have occurred at today's water levels associated with erosion occurring prior to the project at lower water levels on these same shoreline slopes. This "pre-project predisposition" problem is greatest downstream of Ruby Ferry where very high terrace escarpments often border the river, and

[4] The stage duration relationship "with" the project at Cusick was submitted with the FLA.

where the project has increased water levels at normal flows by relatively large amounts. Unfortunately, we know of no data-based means for addressing this problem, and suggest that it is best considered on a site-specific basis as particular locations are addressed.

The Project Share of Exposure calculation also does not address principle 2.

Principle 2 can best be addressed by onsite evaluation. First, if the upslope area (the area never affected by backwater from Box Canyon Dam) is not evidencing erosion based on both on-site observation and the surveyed monitoring data, the exercise ends. If it is evidencing erosion, the slope falls within one of three basic conditions:

- The upslope area is **not** predisposed to erosion due to erosion downslope; in this case the project share of the upslope erosion is zero.
- The upslope area **is** predisposed to erosion due to erosion downslope; in this case the project share of the upslope erosion is equal to the project share downslope.
- The upslope area is partially predisposed (or is indeterminant) to erosion due to erosion downslope. In this case we cannot know the true "project share"; we assign by convention one half of the downslope project share (i.e., a value lying half way between zero and the downslope share).

The approaches discussed above address principles 1 and 2, but do not address the further complication posed by principle 3 - erosion occurs at an accelerated rate during floods. During floods, the project does not affect water levels, because all the gates are removed at Box Canyon Dam and the river flows freely. To account for erosion during floods, total average annual erosion can be adjusted by the amount of erosion that occurs during floods. This adjusted amount of erosion can then be applied to the project share of exposure to arrive at an index to the project share of erosion.

Following the occurrence of two peak flows in excess of 90,000 cfs for a week or more, this flow being chosen somewhat arbitrarily to establish a meaningful value to account for erosion that occurs during reasonably extreme peaks, an index to Project Share can be calculated as:

Project Share Index = (total erosion – extreme peak erosion) x project share of exposure

With the quantity of erosion associated with extreme peak flows determined as:

Total erosion occurring between fall and spring measurements, extreme peak years, minus
Total erosion occurring between fall and spring measurements, normal years.

Using this approach, project share of erosion is indexed for erosion that occurs during flows up to approximately the 3-year flood (90,000 cfs).

Another complicating situation arises at some locations wherein shoreline erosion is caused or exacerbated by landowner destruction of shoreline vegetation, or through trampling by man or animals. In these cases, further adjustment to project share is warranted. No general approach for this adjustment can be suggested at this time based on quantitative data; factors affecting these circumstances likely will demand site-specific determinations and agreement of the parties involved.

A similar approach can be used to determine project share at sites other than at the surveyed monitoring sites. Project Share of Exposure and Project Share Index can be calculated for any location. However, in the absence of surveyed profile data for these locations, location of eroding surfaces would need to be based on site-specific professional assessment. The District expects to conduct these assessments collaboratively with affected landowners and agencies.

As an illustration of the proposed method of determining the estimate of project share of erosion, we have developed an example calculation using site 23, located near RM 87, left bank, just downstream from Newport. Site elevations above mean sea level were established through survey in spring 2006. However, for this example we continue to use the estimated elevation above mean sea level for calculations as they appeared in the April 3, 2006 version of this plan that was peer reviewed. True elevations will be used for all sites as actual monitoring results are reported.

We start with defining the range of elevations of concern, i.e., the range of elevation on the shoreline where active erosion is occurring or is likely to occur. Referring to the bank profiles for site 23 below, it appears that the entire profile is of concern, and the full range of profile elevation from approximately 2,034' to 2,054' elevation applies. Referring to the stage-duration relationship we derived for this location's river mile, we determine that the "with project" elevation 2,034' is inundated about 57% of the time, whereas "without the project" elevation 2,034' would have been inundated only about 28% of the time. The calculation for Project Share of Exposure (PSE) is then:

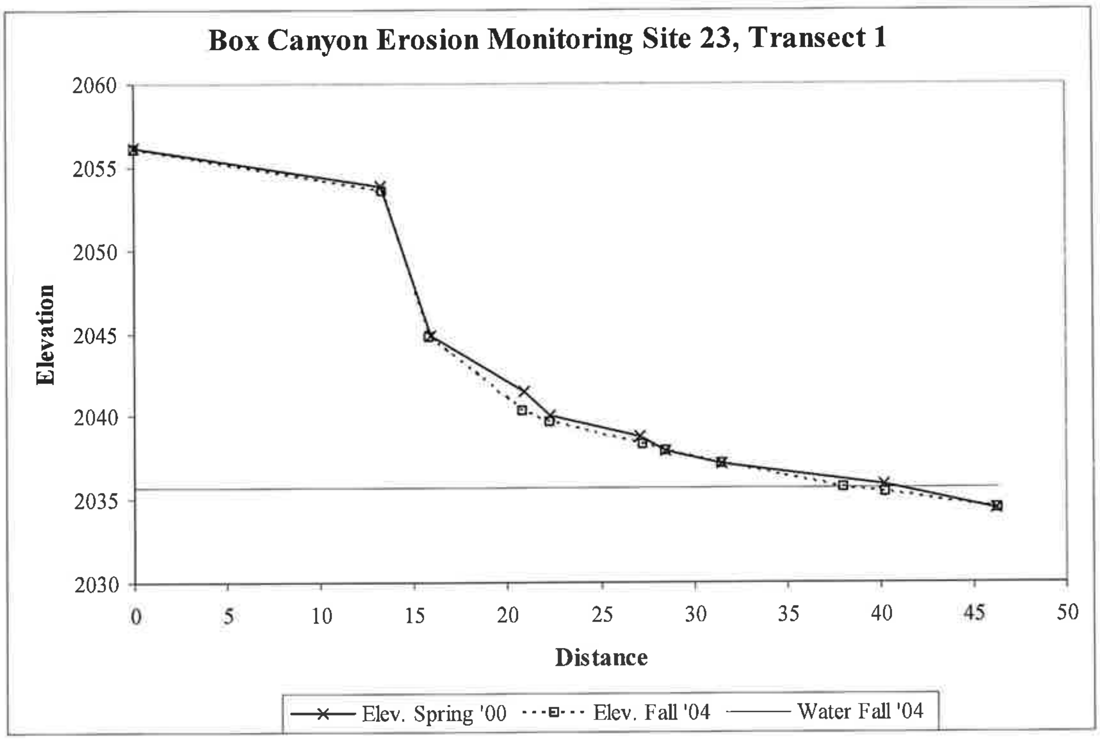
PSE = (% time exposed "with" - % time exposed "without") / % time exposed "with"
= (57% - 28%) / 57%
= 51%

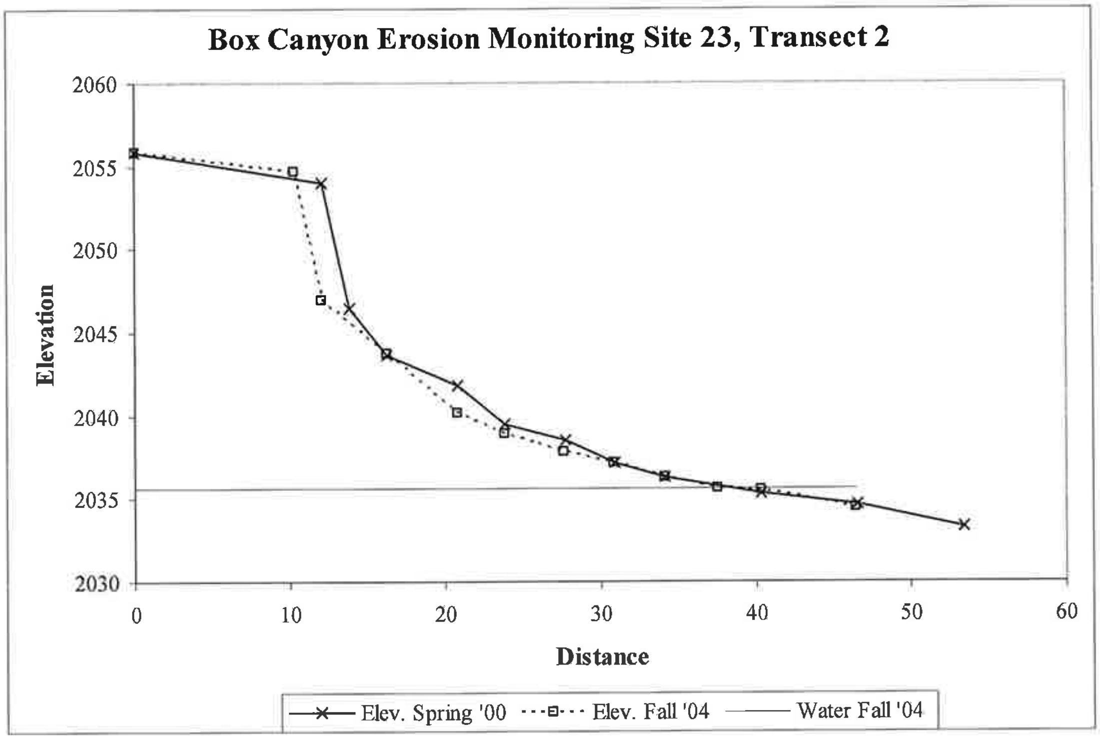
Through professional assessment, the upper part of the shoreline profile at site 23 is determined to be predisposed to erosion because of erosion at stages affected by the project, therefore, the PSE remains 51% for the entire shoreline profile.

This number must then be adjusted for any increases due to increased wave energy, due to both increased fetch lengths and/or increased watercraft traffic. We do not yet have data for these factors, but this information will be gathered as part of the wave study described earlier in this monitoring plan. However, suppose for the purposes of illustration that increased fetch lengths in the reservoir are found to increase wave energy at site 23 by 10% at stages where shorelines actively erode, that recreational watercraft traffic increases wave energy on the shoreline by an average of 30%, and that the District and the interested agencies and landowners have determined that one half of this increased traffic and wave energy is attributable to the project (i.e., an increase in watercraft wave energy of 15% due to the project). These two values are additive, for an overall increase in erosion due to wave action of 25%. PSE adjusted for increased wave energy attributable to the project is then calculated as:

51% x (1 + 0.25) = 64%

Finally, the average erosion depth at all three transects at site 23 is 0.37 feet for the period from spring 2000 to fall 2004. Multiplying this erosion depth by 64% yields 0.24 feet for our estimate of project-related erosion for the 3-1/2 year monitoring period. Maximum flow during this period reached 100,000 cfs, but exceeded 90,000 cfs for only about 4 days. Therefore, no further adjustment to account for erosion during extreme flood flows is made at this time.




Box Canyon Erosion Monitoring Site 23, Transect 2
Elevation
2060
2055
2050
2045
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10
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40
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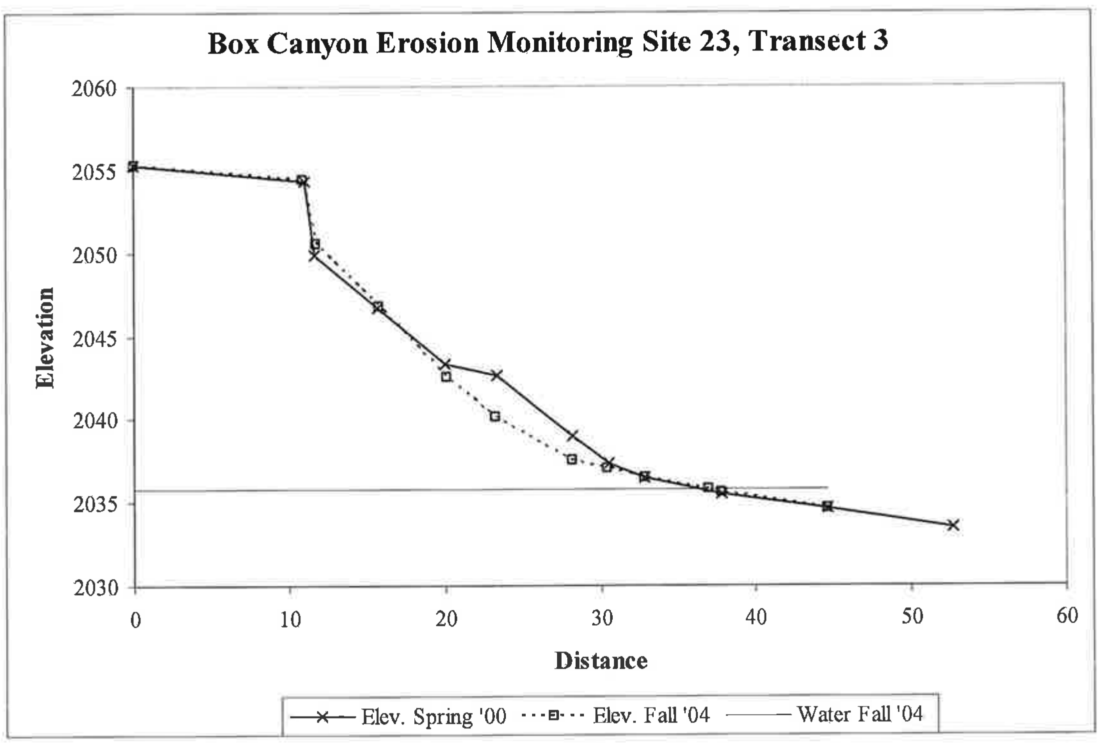
60
Distance
Elev. Spring '00
Elev. Fall '04
Water Fall '04


Box Canyon Erosion Monitoring Site 23, Transect 3
Elevation
2060
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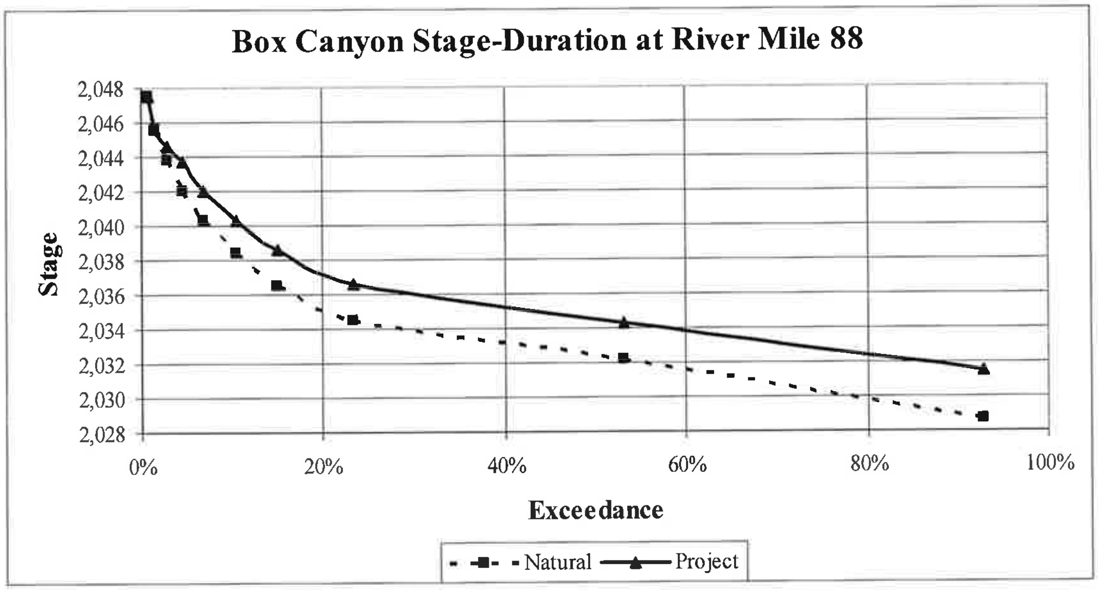
Elev. Fall '04
Water Fall '04




To develop a final estimate of project share of erosion at locations of interest, exposure time, flood impact, without-project predisposition to erosion, human disturbance factors, animal disturbance factors, and wave action analysis will be combined. Because many of these factors cannot be quantified, this final determination of project share must be based on professional judgment and agreement of the parties involved. It is assumed that areas like USFS campgrounds and Kalispel Reservation shorelines, for example, will be of interest for this determination. The District will develop the required data and analyses and then work with the affected landowner and concerned agencies to reach consensus on the final "project share" at a site. Although preliminary project share can be determined based on a few years of data, final determination of project share that includes adjustment for erosion that occurs during extreme peak flows may require several years of data that includes periods of extreme flows.

## VII. Results to Date

Appendix E of this report provides summary data for the 30 untreated sites monitored through fall 2005, with some sites surveyed as early as spring 2000. The highest peak flow recorded, 100,000 cfs with a recurrence interval of approximately 4 years, occurred on June 10, 2002. All other peaks recorded for the period are less than the mean annual flood, and flows in general were relatively low. Rates of erosion experienced during the period may also have been relatively low.

These data demonstrate that there is high variability in the depth of erosion observed. This variability occurs in the data for individual transects, between transects at a given monitoring site, and between sites within erosion rate classes. Taken together with the fact that most interval measures yield erosion values of less than 0.1 foot, we believe that data for individual intervals should only be used cautiously, and that longer intervals of time are required to reflect more accurate rates of true erosion. Figure E-1 in Appendix E shows average depth of erosion that has been observed since inception of measurements at each site by erosion rate class. We note that average depth of erosion at a site or group of sites can obscure more significant erosion that occurs at a particular site or critical portion of its shoreline profile. For future reports, cumulative erosion from earliest date of measurement will continue to be computed and displayed in tables and as bank profile data. We will also display statistics for each site. Where we compare site results, we will standardize results by reporting average annual values.

The data also demonstrate that at least some erosion appears to be occurring at some sites classified as "not active." These data also indicate that the rate class call at some sites may need to be revised. Given that we now have a reasonable body of data to guide this exercise, we expect to reexamine all rate class calls at our monitoring sites during the summer of 2007.

Consistent with recommendations from the District/USFS peer review of this monitoring plan, rates of shoreline erosion developed for Box Canyon will also be compared to rates reported by the literature and in the general form suggested in the peer review provided by Reidel.

**Rates of erosion reported from other large hydroelectric projects in Washington State.**

| Reservoir | Vertical erosion | Bank recession rate (feet/year) |
|---|---|---|
| Ross Lake – estimated# | 2.8 -9.2 ft | 1.0- 5.2 |
| Ross lake – observed* | n/a | 0.8-4.2 |
| Lake Chelan | 2-4 ft | 0-4.0 |
| Rufus Woods | n/a | 0-7.9 |
| Pend Oreille | n/a | 0-5.0 |

#one-time estimate based on tree-root exposure
*bank recession on Ross Lake monitored since 1994.

## VIII. Information Useful for Developing the Erosion Control and Prevention Plan

The District had planned to establish all erosion monitoring sites required by this plan prior to the spring 2006 peak flows. However, delays in receiving permission to monitor at the new sites to be located on KIR lands prevented these surveys. However, now that the peer review process has been completed, the three new sites to be located on Forest Service lands were established and included in the fall 2006 measurements. Currently, FERC requires filing of an Erosion Control and Prevention Plan by August 29, 2007. Information regarding rate and form of erosion gathered from the 32 existing monitoring sites will be most useful for this purpose. Information gathered from the three new Forest Service sites and seven new KIR monitoring sites will provide less than 1 year of monitoring and are unlikely to be useful for this purpose. However, it should again be noted that the District expects, with concurrence of the affected agencies, to petition FERC to extend this deadline to July 2010. Information gathered at all 42 sites is expected to be useful by this point in time.

The District will develop shoreline profiles at each of the 32 sites monitored since 2001, and will be able to calculate the project share of exposure at each of these sites. By July 2010, the District will also have acquired data that will allow calculation of the project share of exposure at each of the 10 new Forest Service and KIR monitoring sites.

Developing a preliminary estimate for project share of erosion also requires consideration of wind and watercraft wave effects. Now that the peer review process is complete, the District expects to conduct the necessary wave measurements by December 31, 2007. The wave studies also require that the District monitor wind for a full year. The District plans to install the required anemometers by July 1, 2007 to collect the year's data and to complete the subsequent modeling of wave energy required by December 31, 2009. These data would then be available to help formulate the Erosion Control and Prevention Plan.

During the summer of 2007, and now that this monitoring plan has been modified to include peer review process recommendations, the District expects to complete documentation of shoreline site stratigraphy, composition, slope, reservoir width and setting, elevation, water surface elevation, and the evaluation of erosion process and causation at each monitoring site in 2007.

Based on all of the foregoing, the District during 2007 will also re-examine the erosion rate classifications for each site and subsequently develop updated Shoreline Erosion Hazard and Occurrence maps once these new data are assembled. These new maps may be developed as early as 2008, or may need to wait until 2010 when meaningful rate of erosion data will have been developed for the 10 new Forest Service and KIR shoreline monitoring sites. Assuming that some changes will occur, the District will recompute all rate class metrics. These metrics may remain useful for applying the results from the monitored sites throughout the project shoreline.

The District originally expected to locate and install necessary groundwater wells for the geotechnical studies required by the DOI for KIR shorelines during the summer of 2006. However, completion of the peer review process and coordination with the Tribe delayed installation to February 2007. These six wells are now installed, and groundwater elevations are being logged at hourly intervals. Useful information from these studies at least in part requires drawdown events, and perhaps even "rapid" drawdown events. These drawdown events will most likely occur in association with spring peak flows. As a result, the geotechnical studies are highly unlikely to yield useful data in time to be considered for the Erosion Control and Prevention Plan currently due by August 29, 2007.

In summary, the shoreline erosion monitoring program will yield several sources of information useful for development of the Erosion Control and Prevention Plan that currently must be submitted to FERC by August 29, 2007. At least 32 monitoring sites will have been established. Shoreline profiles will have been surveyed at these sites, and Project share of exposure will have been calculated at each site from the "with" and "without" project stage duration relationships. Erosion process and causation will have been evaluated at each monitored site and will have been evaluated more generally throughout the reservoir. Wind studies and geotechnical studies will have been initiated, but will not provide useful results by August 29, 2007. If FERC defers the due date for the Erosion Control and Prevention Plan as the District has requested, then these studies, plus data from the 10 new Forest Service and KIR monitoring sites will also provide useful data for that plan.

## IX. Adaptive Management

In its classic context, monitoring is employed in an adaptive management approach to help ensure that data will be properly collected, analyzed, and used to adjust land management measures as needed to reach desired and defined conservation goals. Typically, monitoring is conducted relative to precisely defined expectations (e.g., temperatures will remain below x°C), sometimes referred to as "triggers." If a trigger is reached, then a management response is required. This management response may be predefined, or it may be established through some predefined process for developing it.

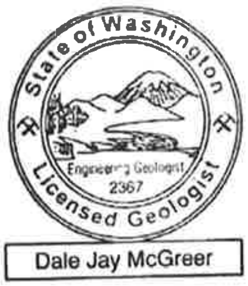
Incorporation of adaptive management into the District's monitoring plan is somewhat different than the classic context described above, in that it is the monitoring itself that is to be modified through time, not management of the Box Canyon Project as dictated by the operating license. In this modified context, the District will continually review its field, analysis, and reporting procedures collaboratively with the interested agencies (those represented in the Erosion Subcommittee of the Technical Committee) and adjust its procedures as warranted. The District expects that most such review and potential adjustment will occur during preparation of the annual erosion monitoring reports and review of those reports by the Erosion Subcommittee.

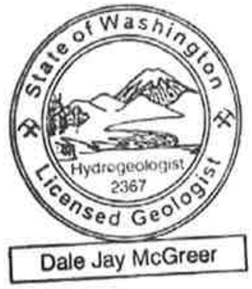
Particularly as a result of recommendations accepted from the peer review process completed in July, 2006, the District agreed to review certain monitoring data, results, and potential procedures as elements of its adaptive management approach to monitoring. These include:

- Use of remote sensing systems such as airborne LIDAR (laser technology), airborne SAR (synthetic aperture radar) systems, and satellite-based SAR systems relying on radar interferometry to estimate rate and location of shoreline erosion and bank recession. Accuracy, precision, complexity, and cost will be examined.
- Recognizing that certain information may necessarily rely on qualitative ratings, once it has collected the required geologic, landform, stratigraphic, and other site characteristics data required by this Plan, the District will review its monitoring information to see if regression or Bayesian statistical methods might be useful for extrapolation of results from monitored sites to other areas of the project shorelines.
- Examine the feasibility of identifying the relative time frame that erosion processes have been acting upon sites.

Supplemental Box Canyon Shoreline Erosion Monitoring Report Prepared June 14, 2007.

Dale J. McGreer, PG



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# APPENDIX A

# PEER REVIEW SUMMARY DOCUMENT AND INDIVIDUAL RESPONSES

# Box Canyon Shoreline Erosion Monitoring Plan
# Peer Review Response Summary

**July 19, 2006**

Dale J. McGreer, P.G.
Western Watershed Analysts

for

Pend Oreille Public Utility District

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Introduction.

Peer reviews of the District's Shoreline Erosion Monitoring Plan that address specific answers to a discreet list of Peer Review Questions developed collaboratively by the District and the Forest Service were solicited and received from three peer reviewers: Wendy Gerstel; John Riedel, and Stanley Miller. The District developed detailed responses to each actionable peer review recommendation together with the original text of those reviews. This Response Summary attempts to synthesize the collective review comments and the District's responses for each Peer Review Question. We apologize in advance for any omission of important comments or mischaracterization of reviewer comments or conclusions that may have inadvertently occurred in our attempt to paraphrase and provide a succinct summary. The exact wording of each reviewer's comments and the District's responses can be found within the individual District's Response to Reviewer's Comments documents.

(1) Does the Erosion Monitoring Plan provide adequate methodology and scientific rigor to determine the location and rate of shoreline erosion that is occurring at various points throughout the reservoir?

Each of the reviews concludes that the basic procedure for monitoring that relies on surveyed shoreline profiles is a sound procedure for documenting erosion at monitored sites and that 42 sites is adequate. For instance Miller reports, "The survey methods being used at the monitoring sites are state-of-the-art in regard to ground survey technology and are appropriate for collecting this type of data." However, several suggestions for improvement were made, particularly regarding extrapolation from monitored (surveyed) sites to other areas.

One reviewer suggested less emphasis on depth of erosion from profiles, recommending less costly bank recession measurements, while another reviewer suggested a more detailed statistical approach for evaluating depth of erosion data developed from profiles.

***1. <u>Response</u>: Bank recession is measured at each monitoring site and will be provided in monitoring reports. Feasibility of adding recession-only sites at important locations will be evaluated. Considerable information would be lost if profiles were not surveyed, plotted, and depth of erosion discussed; profiling will be continued. The District agrees that providing the statistical distribution of mean depth of erosion developed from our sample of 42 sites adds value, but does not agree that distributions of eroded depth values for survey points along transects at individual sites is appropriate because these values are serially correlated and are not independent from one another.***

Reviewers each commented that the proposed methods are not comprehensive because they do not consider all potential processes affecting bank recession.

***2. <u>Response</u>: The plan and its procedures will be amended such that each of these potential processes is considered. However, the technical literature makes it abundantly clear that it is essentially impossible to quantitatively isolate each erosion process; the District measures total erosion at each site and qualitatively evaluates the relative importance of each process, but it does not and cannot measure them separately. This applies to all processes: wave-related erosion, velocity-related erosion, freeze/thaw processes, overland flow processes, groundwater-related processes, etc.***

Two of the reviewers emphasized that uncertainty in estimation of project share of erosion should be clearly discussed, and error associated with the estimation procedure should be determined.

***3. <u>Response</u>: The plan can be modified to more explicitly discuss uncertainty, and we may be able to provide "best estimate" values for accuracy of some factors. A discussion of error however, as a statistical term, cannot be provided because several of the factors used in estimation of project share are not developed as quantitative samples with associated error estimates (i.e., variance, standard deviation). For instance, what is the error in the pre or post-project backwater curve at a given river mile and flow? At best, we may be able to estimate the accuracy of these curves, but we have no measure of error.***

All reviewers emphasized a need to map the geology and landforms for the entire shoreline, and to develop soil strata information to allow for more accurate extrapolation of erosion rates from monitored to non-monitored sites.

***4. <u>Response</u>: The plan will be amended to include a requirement for geologic and landform mapping of the projects shorelines. Shoreline strata will be described at the monitoring sites in the form of geologic cross sections as suggested by Gerstel and will be inferred for the remainder of the shoreline based on landform and geology.***

Reviewers variously noted that methods presented for estimating project share of wave erosion are a good start, but that more sites or duration of monitoring should be added. One reviewer recommended developing an automated data collection system that could be left at sites for several days at a time.

*5. Response: The wind and wave monitoring part of the plan was not intended to be exhaustive. The purpose for the monitoring is to collect wind-caused and boat-caused wave calibration data for modeling to estimate the relative increase in wave energy due to increased fetch and increased boat traffic attributable to the project. Once such a model is calibrated, increased fetch and increased boat traffic can be estimated and the model applied to any location along the project's shorelines. The peer reviewers do not identify how much monitoring would be "enough"; they only argue that more is better. But no amount of monitoring leads to a data-based estimate of wave-caused erosion; it only yields an estimate of wave erosive energy useful as project share is considered. We apply this estimate within a procedure that helps determine project share at any specific location of interest. The District believes that the wind monitoring part of the erosion monitoring plan provides a reasonable approach for collecting data adequate for this purpose. However, the District will examine adequacy of the data following an initial data collection and modeling effort as an element of the monitoring plans adaptive management approach.*

(2) Does the Erosion Monitoring Plan contain the methodology and scientific rigor to determine the degree to which project operations contribute to erosion (i.e. project share)?

a. At specific sites?

One peer reviewer concludes that while the monitoring plan presents a partially quantified, objective approach, he notes several reasons why it will be exceedingly difficult to fully address this question, that previous methodologies that address project share have not been cited, that the procedure is experimental, that the procedure should be considered a minimum, first-order estimate, and error or uncertainty for project share of erosion should be assessed. A second reviewer observes that the plan provides a rational means to estimate the project share of erosion at the sampling sites when the required technical information is available, including future data on wave energy. The third reviewer concludes that project share of determined erosion rates appears to be distinguishable from background rates based on the described use of flow duration curves.

*6. Response: The District appreciates reviewer's conclusions that the procedure provides an objective and rational approach, while also acknowledging that determining project share is exceedingly difficult. Determining project share for locations along Box Canyon's shorelines is particularly difficult because erosion occurs on essentially the same shoreline landforms, locations, and elevations as it did prior to the project, a circumstance unique within the literature reviewed to date. We agree that the approach is experimental (i.e., it has not been previously applied), but do not agree that it is a "minimum, first-order estimate". To the contrary, while we continue to review erosion plans and discussions from other projects, to date we have found no other projects, studies or other accounts that discuss determination of project share based on erosion monitoring data.*

b. Generally throughout the reservoir?

One reviewer observes that the plan does not address the issue of estimating project share generally throughout the reservoir and provides inadequate information or descriptions of any methods to tackle this general assessment. A second reviewer observes that calculations and assessment are likely to have a lower degree of certainty in areas to which data have been extrapolated, particularly if upland conditions and geology are not adequately assessed.

***7. Response:* The District acknowledges that the method does not address project share "generally throughout the reservoir". Because environmental circumstances, causation, and rate of erosion vary widely depending on specific location along the reservoir's shorelines, the District has never believed that a "general" project share value is applicable. For this reason, the monitoring procedures were never intended as a means of determining a "general" value. The intent is to consistently apply the procedures "at sites other than at the surveyed monitoring sites". The procedure is intended for consistent general application (i.e., anywhere), but it is not intended to provide a "general" one-size-fits-all value.**

c. Are there other characteristics that should be included in the monitoring that would help make these determinations?

The peer reviewers made several suggestions. These include: estimating the quantity of surface erosion at the monitoring sites via the WEPP or RUSLE models and subtracting this quantity from the amount measured via surveyed profiles; additional wave monitoring (see previous response); measurement of other factors including vegetation, freeze/thaw processes, currents, and groundwater piping; mapping of shoreline and back-shore area landforms, geology and stratigraphy (see previous response).

***8. Response.* The reviewers tend to infer that each of the processes contributing to erosion can be isolated and quantified. We repeat our previous response to this notion: The technical literature makes it abundantly clear that it is essentially impossible to quantitatively isolate each erosion process; the District measures total erosion at each site and any point on the profiles and qualitatively evaluate the relative importance of each process, but it does not and cannot measure them separately. This applies to all processes: wave-related erosion, velocity-related erosion, freeze/thaw processes, overland flow processes, groundwater-related processes, etc.**

3) Does the erosion monitoring plan contain the methodology and scientific rigor to identify the location, extent, and types of project-caused and project-exacerbated erosion processes on National Forest System lands?

The one review that directly addresses the question states, "The Plan provides a prudent and reasonable erosion monitoring strategy for FS lands through the field survey sites and the proposed wave-energy monitoring and analysis. The project share computations discussed in 2a. and 2b. above can be applied at each monitoring site located on FS lands and provide a scientific framework for making interpolations of these effects to non-sampled sites, provided those non-sampled sites do have available background information (such as slope height and steepness, soil type, vegetation cover, flow and stage duration)." Two reviews conclude that there are or appear to be an adequate number of monitoring sites (8) on USFS land. Two of the reviews suggest that increased frequency of measurements would help isolate mechanisms and event-driven erosion.

***9. <u>Response</u>: Increased frequency of measurements designed to isolate mechanisms and event-driven erosion would in practice be very difficult to accomplish. For instance, monitoring after storm events would be very difficult to implement on a practical basis, essentially requiring a trained observer plus a survey crew to interrupt other schedules in order to respond to unpredictable events to make detailed observations. Additionally, isolation of storm effects requires both pre and post storm surveying that would require knowing when these events would occur – a difficult proposition. Moreover, based on data taken to date, it does not appear that increased frequency would isolate measurable erosion, because erosion rates are so low.***

The utility of the shoreline erosion rate classes and the methodology for determining these classes is addressed in two of the reviews. One reviewer notes that the classification system is useful as long as it allows for reproducible extrapolation to sites not being monitored, suggesting elsewhere in her comments that geologic cross-sections and geomorphic classification would better allow these determinations. The second reviewer notes that the use of erosion rate classes can prove to be quite useful in this type of study, especially if it provides an input component to GIS applications, regression analysis, or other statistical estimation tools. However, to be reliable, this class designation protocol must be clearly documented and must be applied consistently and uniformly. He further notes that the methodology for determining these classes has not been explained in detail within the Plan, and that a written field guide or worksheet needs to be generated that can serve as a standard protocol for rating a site according to erosion-rate class.

***<u>10. Response: T</u>he plan will be modified to require geology, landform and stratigraphy mapping and will develop an erosion rate/severity rating form to allow more systematic classification of project shorelines into rate classes.***

4) <u>Will the plan methodology and frequency of sampling be capable of identifying significant new or recurring erosion areas along the reservoir?</u>

One reviewer observes that biannual surveys combined with surveys following large discharge events are adequate, particularly if the causative factors table is improved and mass wasting sites are mapped. Further, the biannual and larger event driven monitoring schedule is sufficient to meet the goals of the plan. A second reviewer notes that the procedures will readily identify significant erosion activity occurring at any of the 42 monitoring sites, but will have only limited effectiveness in pointing out new or recurring erosion areas generally across the whole study area. He further observes that exhaustive annual reconnaissance surveys to inventory the entire shoreline likely are impractical, but there may be known "trouble" sites that could be photographed and quickly assessed for bank recession.

***11. Response.*** ***The plan requires annual surveys to identify new or recurring erosion areas, and the District sees no alternative to this approach. We don't see that it's possible to anticipate where new erosion might occur. By definition, "trouble" sites would be places that are readily identifiable and therefore not new. We will also examine the practicability of adding bank recession measurement sites to supplement the surveyed profile monitoring sites.***

5) Can the reviewer suggest alternative methods that might be easier, less costly, more effective, and yet be able to meet the objectives of the plan?

One reviewer suggests measuring bank recession rather than measuring (depth-oriented) profiles. However, the other reviewers actually suggest additional detail and information relevant to the profiling approach. Two reviewers also suggest looking into the feasibility of remote sampling as a means of estimating rates of erosion.

***12. Response.*** ***The plan provides the data for bank recession measures at each of the monitoring sites and the District will examine the feasibility of adding additional bank recession sites. The District will also look into the feasibility of remote sampling as a means of estimating rates of erosion.***

BOX CANYON HYDROPOWER PROJECT

Peer Review Report Of

"Box Canyon Project Shoreline Erosion Monitoring Plan"

July 10, 2006

Prepared For:

Pend Oreille Public Utilities District
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***Including Pend Oreille Public Utility District response comments dated July 19, 2006.***

1.0 Introduction

This review is being submitted in fulfillment of the professional services contract signed May 9, 2006, with the Pend Oreille County Public Utilities District (PUD). The review comments are based on the following; 1.) initial reading of the "Box Canyon Project Shoreline Erosion Monitoring Plan" (revised draft for peer review, dated April 3, 2006), and the Box Canyon 2006 Shoreline Erosion Monitoring Report, 2.) field review lead by Dale McGreer and conducted on May 11, 2006, 3.) subsequent thorough rereading of the "Box Canyon Project Shoreline Erosion Monitoring Plan", and 4.) review of relevant regional geologic references (see reference list). Additional valuable references are included in the monitoring plan reference list (McGreer, 2006), and so are not referenced in this peer review report.

2.0 Executive Summary

The author of the "Box Canyon Project Shoreline Erosion Monitoring Plan" (McGreer, 2006), clearly recognizes the complexity of the task at hand - addressing and capturing the differences between 'natural' and 'project-caused" erosion of the banks of the Pend Oreille River, and the Box Canyon Hydropower Project. The plan is a well-organized, thoughtful treatment of the many necessary components for a monitoring plan. However, reviewers are asked to, and can always find comments to make. So, the following is a summary of general questions or concerns arising from the requested review of the monitoring plan. More detailed comments are found in the body of this report.

- Survey site profiles should include geologic data (not just USCS descriptions) and be represented as geologic cross-sections.

- Evaluation of erosion conditions and causes would benefit from discussion, and possibly measurement of upland processes and their associated effects. Expected changes, such as increased density in development and nfrastructure, should be factored into the analysis.

- Site classification should include geomorphic/landform categories. These will reflect the underlying geologic units and contribute to successful extrapolation of results to shoreline reaches not being currently being monitored.

- To overcome the challenges of high-flow-stage surveying, consider trying to occupy sub-aqueous profile points from a boat. This method would permit data collection to reflect high flow conditions and important analysis of seasonal variation in profiles, both positive and negative.

- Data analysis would benefit from sediment volume transport estimates and bank retreat rates. This would pertinently expand the current focus of monitoring which is primarily on reporting depth of erosion along each surveyed profile.

Sections 1.0 through 4.0 of this report follow the format for peer review reporting recommended by the client (Pend Oreille PUD). Section 5.0 includes additional specific comments on the monitoring plan, and copies of previous email communication addressing some of the same issues. I hope you will find the review comments helpful.

3.0 Subject of review

Review comments presented in this report focus on the geologic, geomorphic, and engineering geology aspects of the erosion monitoring plan for the Box Canyon Hydropower Project. Because of the expertise of the other two reviews in statistical analysis and jurisdictional permitting issues, this review does not address those aspects of the plan.

4.0 Peer Review Criteria/Findings

4.1 Does the Erosion Monitoring Plan provide adequate methodology and scientific rigor to determine the location and rate of shoreline erosion that is occurring at various points throughout the reservoir?

The monitoring plan does a thorough job of selecting and monitoring current locations of shoreline erosion; however, it does not explain how surveying and monitoring site selection will deal with shifting areas of erosion. This may require initiating surveys at new locations, or discontinuing surveys if currently-monitored areas stabilize within the monitoring period.

***G1. We appreciate the reviewer's observation that the plan does a thorough job of selecting and monitoring current areas of erosion. Locations of eroding areas may indeed shift; these areas will be identified during the annual review of the project shorelines and during the process of locating new areas of erosion. It may also be possible during these reviews to identify areas that no longer appear to be eroding or that are eroding less severely, or more severely than initially mapped. The maps can be adjusted to***

***reflect these shifts, and these areas can be highlighted so that they are apparent.***

***G2. We do not currently plan to initiate new surveyed monitoring sites or to abandon existing sites. However, this can be considered as we develop 5-year reports where we may recommend addition or deletion of sites.***

a. Are there other characteristics that should be included in the monitoring that would help meet this objective?

Geologic and geomorphic descriptions of the uplands adjacent to the river/reservoir should be included in site descriptions, and in the site classification system. This would allow for extrapolation of erosion rate classes to areas currently not being monitored, as well as defensible arguments for relocation of profiles to areas of similar geologic/geomorphic characteristics, if necessary.

***G3. We will produce a geomorphic/landform map for the reservoir shorelines and adjacent uplands. We make this same commitment in our response R9.***

b. Are the technical methods used to acquire data most appropriate and up-to-date? Are there other better-suited methods available?

Methods are appropriate, especially considering common fiscal constraints. A recommendation would be to extend sub-aqueous measurements into deeper water, possibly by positioning from an anchored boat. Additionally, investigate the feasibility of using LiDAR or other high-precision hand-held survey instrumentation.

***G4. We acknowledge that methods are appropriate.***

***G5. We tried using boats to get deeper in the water, but maintaining position of the boat and of the survey rod proved impossible to do with adequate accuracy. Also, review of results to date reveals that little erosion is occurring along the shorelines below low pool elevations at least at wadeable depths. Given the difficulty and imprecision of measures from boats, and that not much erosion is occurring below low pool, we think little value would be added by sub-aqueous measures to greater depth. We also note that Reidel in his review suggests shifting emphasis on profiling (i.e., depth measures) to measures of bank recession, further suggesting there is little value in additional sub-aqueous measurements.***

***G6. We will explore using Lidar as an adaptive management approach to the plan. Accuracy, precision, complexity, and cost will be examined.***

***G7. We are not aware of what other survey instrumentation the reviewer might be referring to. In a follow-up email, we asked for clarification. The reviewer could suggest nothing specific, but we will at least enquire with our surveyor's to see what might be available.***

c. Can the data collected at monitoring site locations be extrapolated to help determine rate of erosion at other locations?

I think this can be done with reasonable accuracy as long as the sediments affected, slope gradients, and upland processes can be compared and contrasted. (See Sec. 5.0).

***G8. We acknowledge that this may be possible and will implement this approach. We will be systematically rating the severity and causation of erosion processes and the rate of erosion with the field evaluation forms. We can also consider similarity of sites with respect to character of shoreline profile, landform, and sediments affected.***

d. Does the Plan provide an adequate procedure for doing so?

Regarding extrapolation of data, and as stated above, the plan could use some additional discussion of the geology, geomorphology, and upland processes (current and predicted future).

***G9. We will be gathering this information; see previous comments G3 and G8.***

4.2 Does the Erosion Monitoring Plan contain the methodology and scientific rigor to determine the degree to which project operations contribute to erosion (i.e., project share) identified in 1 above.

a. At specific sites?

"Project share" of determined erosion rates appears to be distinguishable from background rates based on the described use of flow duration curves.

***G10. We acknowledge.***

b. Generally throughout the reservoir?

Calculations and assessment are likely to have a lower degree of certainty in areas to which data have been extrapolated, particularly if upland conditions and geology are not adequately assessed.

***G11. We acknowledge, and as stated in previous comments G9 we will assess upland conditions and geology.***

c. Are there other characteristics that should be included in the monitoring that would help make these determinations?

(See comments Sections 4.1 and 5.0.)

***G12. No response required.***

With regards to Forest Service License Condition No. 8:

4.3 Does the Erosion Monitoring Plan contain the methodology and scientific rigor to identify the location, extent, and types of Project-caused and Project-exacerbated erosion processes on National Forest System lands?

a. Are there other characteristics that should be included in the monitoring that would help identify project related erosion?

Methods to identify location, extent, and types of "project-caused" erosion are well-defined, but obviously require certain assumptions regarding dam-related flow increases vs. local storm or run-off related effects. Increased monitoring frequency would improve the accuracy of such determinations, and the ability to isolate the different natural vs. project-related effects. Measurements might be taken following significant storm events, controlled reservoir level changes, or to address seasonal use effects like heavy weekend boat traffic with tighter time bracketing. Documenting the increasing bulkhead construction and noting any associated effects on sediment transport should be included in the monitoring.

***G13. We appreciate the reviewer's observation that Methods to identify location, extent, and types of "project-caused" erosion are well-defined. The effects of dam-related flow increases (actually, the dam predominantly affects stage rather than flow) vs. local storm or run-off related effects are inherent within the project share procedures as effect of increased stage and associated predisposition to erosion processes is evaluated.***

***Based on data taken to date, it does not appear that increased frequency would isolate measurable erosion, because erosion rates are so low. Monitoring after storm events would be very difficult to implement on a practical basis, essentially requiring a trained observer to interrupt other schedules in order to respond to unpredictable events and make detailed observations. Moreover, actual measurement to quantitatively isolate storm effects requires both pre and post storm surveying that would require knowing when these events would occur – a practical impossibility, particularly when we consider mustering survey crews whose schedules are also busy. Monitoring after controlled reservoir level changes could yield useful information, but it may be difficult to accomplish, particularly because the PUD has no control over inflow from Albeni Falls Dam. Weekend monitoring could be useful for understanding wave effects during heavy periods of boat use on the reservoir, and we will incorporate this into the plan.***

***G14. It may be possible to track bulkhead construction. However, measurement of sediment transport goes well beyond the scope of shoreline erosion monitoring, and we do not see that it would yield useful information.***

b. Will the data gathered under the plan be sufficient to determine whether, and to what extent, erosion can be attributed to project operation?

With little Forest Service land directly adjacent to the project, it is reasonable to conclude that data will be sufficient to evaluate project effects on those land parcels that are adjacent. It is also worth noting that activities on Forest Service lands upslope of, even if not directly adjacent to the project may contribute to sediment transport and deposition effects on it.

**G15. We agree it is reasonable to conclude that data will be sufficient to evaluate project effects on those land parcels that are adjacent.**

***G16. We acknowledge that*** **activities on Forest Service (and other) lands upslope of** ***the project may affect erosion processes and rates and will amend field forms so that these activities are noted.***

c. Is the overall plan suitable for determining the extent erosion can be attributed to project operations?

Both yes and no, for the reasons already stated in other sections above.

***G17. See previous responses.***

d. Is the use of shoreline erosion rate classes useful? Is the methodology for determining these classes appropriate to meet the overall goal of the plan? Can you suggest a more useful system?

The classification system is useful as long as it allows for reproducible extrapolation to sites not being monitored. The classification system also needs to be able to accommodate and record changes in the spatial and temporal distribution of class boundaries. I do have some concerns that site conditions may force classification changes more frequently than expected, particularly for the "no activity" class. To better account for this, please see recommendations under section 4.1a and 5.0.

***G18. The reviewer acknowledges that the classification system is useful and suggests elsewhere in her comments using upland conditions, geology, landforms and soils information to allow better extrapolation to sites not being monitored. See earlier responses where we have agreed to assemble this information.***

***G19. Regarding changes in classifications or boundaries, see previous comments G1 and G2.***

e. Are the data analysis methods employed suitable to meet the goals of the plan? Are there other methods better suited for analysis of this data?

[This review does not address statistical quantitative data analysis.]

With regard to the Plan in general:

4.4 Will the plan methodology and frequency of sampling be capable of identifying significant new or recurring erosion areas along the reservoir?

[See comments in Section 5.0.]

4.5 Can the reviewer suggest alternative methods that might be easier, less costly, more effective and yet be able to meet the objectives of the plan?

[See comments in Section 5.0.]

5.0 Specific review comments and recommendations (generally sequential with organization of monitoring plan report):

1. It seems likely that freeze-thaw would play a role in the Pend Oreille River valley environment, reducing soil strength and making soils more susceptible to erosion (Gatto, 1995). If this is so, the proposed monitoring schedule is not set up to identify and isolate these effects (or those of ice flow break-up and movement), thus skewing either favorably or unfavorably the contribution of the project to erosion.

***G20. Regarding freeze-thaw, we do not dispute that it may make project shoreline soils more susceptible to erosion. However, there is no way to isolate freeze-thaw; in fact it is difficult to determine how much any one process contributes to erosion by itself. Gatto(1983) even states "it may be impossible to quantify the amount of erosion that any one process contributes to total bank erosion because there are many contributing processes, all of which are interdependent." Also see comment R2.***

2. It is not clear how "a limited number of sampling sites" will be selected for surveying immediately prior to spring run-off.

***G21. We will amend the plan to specify how we will select these sites. Our preliminary view is to select actively eroding sites from those located along***

***Forest Service and KIR lands, the latter having originally made this suggestion.***

3. If the objective of monitoring "after drawdown rates in excess of three inches per hour" is to determine the effects of drawdown, then monitoring should be done at the maximum allowable drawdown, and not "in excess of" that. Wouldn't the project already be in violation of its operating license otherwise? Drawdown data seems important to explain how the 3" per hour threshold was determined. For consistent drawdown measurement, recording the rate below the dam makes most sense. I would expect that changes in drawdown rates at specific gages would be different for different flow stages. If the drawdown rate were to be referenced to the Cusick gage, instead of at the dam, then it would seem important to know what the different rate changes were along the length of the reservoir. If necessary, or agreed, the maximum allowable rate of drawdown could then be adjusted accordingly.

***G22. We could monitor at 3"/hour rather than >3"/hour, if that ever occurs. As the plan states, monitoring following rapid drawdown would be by professional review of shoreline conditions; monitoring via survey has to wait until flows and river stage decreases to where shorelines can be accessed.***

4. It would seem important to investigate the effects of drawdown on bank soil strength properties. The groundwater monitoring wells along the KIR reach will be a good opportunity to study this and should be located accordingly.

***G23. We acknowledge, and this will be incorporated in the geotechnical monitoring plan for KIR lands.***

5. On page 3, it is unclear how KIR sites will be evaluated for "project effects" on riparian habitat loss. As written, one would first need to identify the contribution of habitat loss from each process listed (toppling, inundation, slumping, etc.), THEN distinguish between "normal" and "project operation" cause for each process. Is that really possible to deliver?

I do think the KIR sites have the potential to be the most informative because of their detailed analysis, and the PUD might consider expanding that level of study to some other representative project sites.

***G24. We agree that the plan requires clarification. Because erosion processes are interactive and erosion rates associated with each erosion process cannot be isolated with certainty, it is not possible to isolate habitat loss associated with each process.***

***G25. As required by the terms of the new license, the PUD plans to conduct geotechnical monitoring only at KIR sites. The PUD has no current plans to conduct geotechnical monitoring at other sites. However, based on the utility of results developed for the KIR sites, the PUD we may consider expanding these efforts to other areas of the reservoir in the future.***

6. When listing the effects on erosion include groundwater, with more specifics on "disturbance caused by man and animal", and on geology and stratigraphy, as mentioned elsewhere in this report.

***G26. We agree to note the presence of groundwater effects and to include more detail regarding the nature of disturbance, geology, and stratigraphy as we identify causes of erosion at specific sites.***

7. Regarding erosion rate classification, consider assigning relative time frames for each, particularly "not active" status. For example, one might define it as, "not active in the past X years".

***G27. The existing rate classification applies to the current time frame. To be able to say what the history is at a specific location is uncertain and not easily accomplished. However, we can examine the feasibility of this idea as mapping and monitoring progress through time,* particularly for the "not active" category*.***

8. If there is a site-selection bias towards locations showing erosion, and sites were not selected randomly, then the plan should state that clearly. These conditions are transient, and rationale could easily cause confusion or be lost. Establish how H,M,L, and Not-Active bank erosion classes were established prior to data collection and analysis. (Page 5 states that 2-3 sites are selected within each combination category of bank height and erosion rate class.)

***G28. There was no bias in site selection, and the plan states how the sites were selected in each class. However, site selection was also not random, because we located monitoring sites where we were able to obtain landowner permission. The plan specifies the (subjective) criteria used for classification, and the plan states that these classifications will be reviewed and amended over time. The forms that the plan now incorporates for qualitatively yet systematically evaluating process severity and cause are expected to be useful for reevaluating rate classes. We also agree to develop a new rating table to evaluate locations for rate of erosion based on the factors that are described on page 5 of the plan.***

9. Under "Objectives", it would be useful, and probably more appropriate, to have shoreline location descriptions include upland geomorphic conditions, which strongly control "hydrologic circumstances". This would be especially useful in extrapolating results to other similar landforms and stratigraphy. During our field tour there was mention that spring ponding of water occurs on river-adjacent terraces. This likely affects hydrologic conditions of the channel banks.

***G29. Objective 3 (p. 6 of plan) states that relative rate of shoreline erosion will be based on extrapolation of results from monitored locations based on similarity of location, geomorphic, and hydrologic circumstances. We agree to modify the objective to include both shoreline and upland circumstances. Also see previous responses G3, G8 and G16.***

10. On page 8 there is discussion of the variability occurring in any particular shoreline reach and that for this reason, some sites consist of 3 measured transects, subsequently averaged to report a single depth of erosion. I recommend preserving and presenting these data separately (not averaging) in order to address and document the issue of variability in erosion. This information will be critical in erosion control management planning.

***G30. All sites include 3 transects (although in a few isolated cases data may have been lost or otherwise unusable at specific transects). The annual monitoring reports do report individual transect data (p. 13-14 of plan).***

11. I agree with the need to preserve and report positive value data to capture deposition, not only erosion. This provides a more realistic picture of what processes might be occurring between surveys. I therefore recommend against "treating positive values (accretion) as zero values" (email from McGreer to Reidel, June 25, 2006).

***G31. Our procedure to date has been to report both positive and negative values, and to report the net amount of erosion that has occurred at each monitoring site and for each transect at each site. This reviewer has recommended not changing this procedure, and we agree. We also will amend the procedure to more clearly display the quantity of bank recession at top of bank. We will also continue to develop the profile plots that we believe provide the best way to illustrate conditions and what has occurred at a particular transect.***

12. Again, I recommend constructing geologic cross sections for each profile. Soil descriptions of survey profiles are necessary, but are not as informative at depth as descriptions of the geology. Using only the USCS would provide less information relevant to susceptibility of sediments to erosion or potential stabilization effects.

***G32. We agree to develop a representative cross-section for each monitoring site.***

13. Regarding wave effects: Having only six wave monitoring sites seems a bit under-representative of 30+ miles (times 2) of shoreline. It might be useful to include some individual storm wave measurements, then develop average storm duration and intensity factors for an estimate of wave effects. Wave data analysis should include both flow stage data and seasonal recreational activities data. Is this included in the fetch calculations? Probably best noted separately. The duration of any particular water level stage would seemingly have a significant affect on wave erosion contribution to bank changes, or eventual stabilization.

***G33. The wind and wave monitoring part of the plan was not intended to be exhaustive, but simply as a means of collecting wind-caused and boat-caused wave calibration data for modeling to estimate the relative increase in wave energy due to increased fetch and increased boat traffic. Once such a model is calibrated, increased fetch and increased boat traffic can be estimated and the model applied to any location along the project's shorelines. The peer review does not identify how much monitoring would be "enough"; it only suggests that 6 is not enough (i.e., more is better). But no amount of monitoring leads to a data-based estimate of wave-caused erosion; it only yields an estimate of wind erosive energy, and the increase in this energy attributable to the project. We apply this estimate within a procedure that helps determine project share at any specific location of interest. Nevertheless, we agree that it might be useful to include some individual storm wave measurements and agree to try to do so. Storm-generated waves and duration data are inherent within the modeling based on wind (and therefore wave) duration/intensity data. These data can be examined in relation to river stage by examining wind velocity duration with river stage duration, and with watercraft use, by season or by month.***

14. Is there any pre-project watercraft use data available? In comparing water craft use on Box Canyon Res. to that on rivers without impoundment, and considering changes over time, make sure to also look at increases in residential density over time (past and predicted) (Public Utilities District No. 1 of Pend Oreille County, 2000). In this context, it might even be more important to evaluate seasonal use than "project share", as well as relate it to sensitive flow stages and bank exposures.

***G34. We do not know yet if there is any pre-project watercraft data.***

***G35. We will work with the PUD and its consultants regarding other data on watercraft and/or residential density collected as a result of relicensing. We can develop stage-duration data specific to the boating season, watercraft use, and in relation to sensitive flow stages and bank exposures.***

15. Because of the ~10% variability in flows assumed responsible for "project share", consider looking at the more conservative upper threshold of 102K cfs, rather than 90K cfs for considering project share. There isn't clear argument given for using the less conservative 90K cfs threshold.

***G36. We believe the reviewer misunderstood the circumstances affecting river stage in relation to the 90 to 102K flows. The affect of the dam varies with the distance upstream from the dam; nearer the dam, the project does not affect river levels above 102k cfs, but further upstream, the project does not affect river levels above 90k cfs. We will examine the monitoring plan to see if we can more clearly explain this.***

16. I suggest incorporating some analysis/discussion of the effects of bulkheads and other bank hardening structures on sediment erosion and transport (not only human and animal disturbance to vegetation). Bulkhead construction should be expected to increase with residential development, and will likely need to become a part of planning and management discussions in the future. Data regarding effects will be invaluable. This effort could be included with the recommended discussion and analysis of other upland land use effects such as roads, culverts, etc. (Public Utilities District No. 1 of Pend Oreille County, 2000).

***G37. We can discuss effects of bulkheads and other bank hardening structures on erosion processes and rates. Discussion of sediment transport goes beyond the scope of the District's shoreline erosion monitoring efforts.***

17. Include in the overall analyses a prediction of the effects on erosion of infrastructure expansion and residential development. This information could be developed with the "Beneficial Use" maps and other GIS layers found in the licensing application data (Public Utilities District No. 1 of Pend Oreille County, 2000).

***G38. Although we are not sure that this would be particular helpful, the District could include discussion of infrastructure expansion and residential development on erosion processes and rates within monitoring reports.***

6.0 Previous email communication

6.1 (Copied from email communication on 6/30/06 from Gerstel to McGreer, regarding geologic cross sections)

For the geology, my thought was that you could incorporate a representation of the stratigraphy into your survey profiles. I would base it as much as possible on the field observations, capturing geologic contacts along the profile with a survey point. Some profiles may only encounter one geologic unit, thereby needing no additional points on the profile. Others, such as where we looked at silt over gravels with you, would have more contact identifying points along the profile. Hopefully, since your sites are selected based on occurring erosion, there should be decent exposures of the geology. If it is not exposed, taking the information from Waggoner (1990 and references within), and Joseph (1990 and references within) would probably be the best way to go. I also think it's useful to bring a coring device along on your site visits, especially since much of what you'd encounter is silt and easily cored. If you get to refusal, you know a little more.

I think the USCS can still be used compatibly with the geologic units, as most of them are probably unconsolidated. But without using the geologic nomenclature per existing mapping, the USCS description alone generally implies the sediments are residual and not depositional. Key is to clearly state whether your units are engineering geologic, or geologic. However, I'd argue that for the purposes of extrapolating from monitored reaches to un-monitored, the geology/geomorphology classifications would serve you better.

What I did for coastal bluff mapping was use the graphing tools in EXCEL to plot up the survey profile data [we had LiDAR data for slope profiles] (preserving individual points rather than blending to a line graph), then add in points for geologic contacts (identifying them along the profile and distinguishing between the two by using different symbols - in our case points sometimes coincided). I then imported graphs/plots into Power Point to project contacts into the slope and fill with appropriate patterns. It was time consuming, but worked pretty well. Feedback I got at poster presentation I gave at a GSA shortly after was that no one had devised a better way to do that yet.

***G39. See previous comment G3.***

6.2 (Copied from email communication on 5/22/06 from Gerstel to McGreer regarding measuring wave energy)

As far as he [Hugh Shipman] knows, most of the work on wave monitoring in Puget Sound was done in Rich Passage to investigate the ferry wave issue under litigation. He thinks it's Pacific International doing the work under private contract, so the data is probably still proprietary.

We also talked about the complexities of analyzing the data, differences in analysis error depending on the depth of water in which the instrument is set up, and changes in recording sensitivity depending on high vs. low tides (in their case). Hugh suggested the time consuming data analysis and instrument maintenance would probably warrant contracting with someone who already does this work and has the instrumentation.

I also asked if Hugh knew anyone who'd done anything with seismologic data or instrumentation to get at wave frequency and intensity. He thought there were some folks in CA who'd tried to get at the wave data recorded on seismographs, but that it likely reflected large, "percussive" outer beach signals, and such equipment might not pick up smaller lake waves. I would guess the wave data they were analyzing was incidental to the real record they were going for of seismicity, and that they hadn't set out to measure wave noise but to try to pull it out of the other data.

One other person who might be able to help with this is Dave Finlayson. He's working on a post doc at USGS after completing his PhD at UW on Puget Sound coastal geomorphology. I glanced at his website

http://david.p.finlayson.googlepages.com/home

where he talks about looking at storm waves, fetch, wave energy. He pparently did some "hindcasting" of wave energy by applying a model that "computes random, short-crested wind-generated waves in coastal regions, including lakes and estuarine waters (Holthuijsen, Booij et al. 2003)". Maybe he can speak to aspects of the model that would be useful to your project, or other models that might apply better.

***G40 Reviewer is referencing information regarding wave monitoring and modeling procedures. The District appreciates receipt of these sources of information and will continue to review applicable procedures as it plans and conducts wave studies.***

7.0 References

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McGreer, D.J., 2006; Box Canyon Project Shoreline Erosion Monitoring Plan - Revised Draft for Peer Review, April 2, 2006, prepared for Pend Oreille Public Utilities District, 46 p.

Public Utilities District No. 1 of Pend Oreille County, 2000; Box Canyon Hydroelectric Project, Application for New License, Federal Energy Regulatory Commission No. 2042, Compact Disc, January, 2000.

Waggoner, S.Z., 1990; Geologic Map of the Chewelah 1:100,000 Quadrangle, Washington-Idaho, Washington Division of Geology and Earth Resources, Open File Report 90-14, 63 p., 1 Plate.

# *Technical Peer Review Report*

*for*

*Box Canyon Shoreline Erosion Monitoring Plan*

*Prepared for*

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*June 29, 2006*

**Including Pend Oreille Public Utility District response comments dated July 19, 2006.**

***Technical Peer Review Report for 2006 Box Canyon Shoreline Erosion Monitoring Plan***

*Introduction*

*As part of its Federal Energy Regulatory Commission (FERC) renewal license application for the Box Canyon Dam, the Public Utility District No. 1 of Pend Oreille County was required to submit a shoreline erosion monitoring plan for the Pend Oreille River above the dam. Western Watershed Analysts (WWA), a consulting firm in Clarkston, WA, was contracted to develop the monitoring plan, to establish background field information, and to implement the first stages of the plan. Field work began in 1999, and survey data of ground-surface profiles at 16 shoreline sampling sites were first collected in spring 2000. An additional 16 sites subsequently were surveyed in fall 2001 to make a total of 32 sites. Three transects (located approximately 20 ft apart) were surveyed at each sampling site in the late spring and in the fall of each year.*

*The sampling sites were classified according to bank height (low, less than 12 ft; moderate, from 12 to 24 ft; and high, greater than 24 ft) and to erosion-rate class (nil, slow, moderate, high). Results from the semi-annual surveys were summarized in a WWA report to the Pend Oreille County PUD, entitled "Box Canyon 2006 Shoreline Erosion Monitoring Report", dated February 13, 2006. In a more comprehensive follow-up report ("Box Canyon Project Shoreline Erosion Monitoring Plan: Revised Draft for Peer Review", dated April 3, 2006), WWA recommended the establishment of 10 additional shoreline monitoring sites, three on USDA-FS lands and seven on tribal lands of the Kalispel Indian Reservation. Also, WWA outlined a plan to evaluate wave related erosion, to identify the processes causing shoreline erosion, and to quantify the degree to which project operations (flow regulation at the dam) contribute to shoreline erosion upstream from the dam.*

*On May 11, 2006, three independent technical reviewers visited the project area and were given a site tour (by boat) hosted by the PUD and Dale McGreer of WWA. A wrap-up meeting was held that afternoon in the District offices in Newport, WA, wherein District representatives (Mark Cauchy and Eileen Dugger) and Nancy Glines of the USDA-FS provided clarification in regards to the technical review scope and scheduling. Reviewers' comments would be due at the District office by July 1, 2006. The District would then expect to address and incorporate recommendations from the peer review process into a revised Shoreline Erosion Monitoring Plan due to FERC by August 29, 2006.*

*The discussion that follows is intended to focus on the scientific and technological aspects of the Box Canyon shoreline erosion monitoring work and is based only on technical data and reports made available to this reviewer as of May 15, 2006. Potential impacts or conditions related to economic, political, or social factors have not been considered at this time.*

*Executive Summary*

In July of 2005, the Federal Energy Regulatory Commission (FERC) issued the Pend Oreille County PUD a new License to Operate the Box Canyon Hydropower Project. Two license conditions (Article 408 and USDA-FS Condition No. 8) required monitoring of the shoreline erosion on the Pend Oreille River for approximately 60 miles above the dam. Condition No. 8 submitted by the Forest Service also required peer review of this monitoring plan.

The three technical peer reviewers selected by and agreed upon by the PUD and by the Forest Service were Wendy Gerstel, Jon Riedel, and myself. We spent a day at the project site (May 11, 2006), which included meetings with PUD, Forest Service, and WWA personnel, as well as a boat tour to visit several of the erosion monitoring sites and to provide some familiarity with shoreline conditions along the reservoir. Documents and reference media provided to the reviewers included the Box Canyon 2006 Shoreline Erosion Monitoring Report (dated February 13, 2006), the Box Canyon Project Shoreline Erosion Monitoring Plan: Revised Draft for Peer Review" (dated April 3, 2006), and a CD containing the PUD's licensing application.

One of the primary review criteria focuses on the adequacy of the Erosion Monitoring Plan to provide sufficient methods and scientific rigor to allow reasonably accurate estimation of shoreline erosion rates throughout the reservoir area. The Plan concentrates on electronic/laser based ground surveys of sampling transects along the exposed shoreline at 42 monitoring sites. The implementation of semi-annual surveys will provide sufficient ground elevation data to describe the soil loss at each monitoring site. Instead of using the mean elevation change along a transect to describe the erosion, I recommend that statistical descriptors (minimum, maximum, median, percentile values) be used to describe and compare soil loss among the monitoring sites. Although such measurements will provide solid information on soil loss at the monitoring sites, their usefulness in extrapolating the information to non-sampled sites along the shoreline has not been clearly described in the Plan. Any proposed subjective, qualitative procedure for making such extrapolations should be supplemented and/or confirmed by an objective procedure based on such things as environmental factors, erosion-causative factors, and statistical inference models (e.g., regression, hypothesis testing, conditional probability analysis).

Another key review criterion emphasizes the capability of the Plan to evaluate the degree to which the hydropower project operations contribute to shoreline erosion. This is known as the "project share" of the observed erosion. Again, at the monitoring sites the Plan lays out a well-conceived method to estimate the project share exposure, leading to a rational evaluation of the project share index. However, the method to extrapolate these results to non-sampled sites along the shoreline is not described in detail within the Plan and appears to rely heavily on subjective methods. The use of an erosion rate classification system may be helpful in this task, but such a classification scheme needs to be carefully documented and consistently applied.

Other recommendations are presented in this review and address issues such as the building of a GIS model of the project area (if appropriate reference data sets are already available), investigation of the feasibility of using satellite-based SAR (synthetic aperture radar) methods to develop maps of differential ground elevations at different times), the identification and recon monitoring of 20 to 30 supplemental monitoring sites located at representative or critical areas along the shoreline, and a greater use of basic statistical methods to describe the ground elevation measurements and help make extrapolations to non-sampled sites.

*Summary of Site Visit and Project being Reviewed*

*Our site visit of May 11, 2006, included a boat tour from Cusick (approximate River Mile 70) to Ione (River Mile 37.5) with shoreline stops at the following erosion monitoring sites:*

1. *Site 18 (River Mile 59.2; USDA-FS);*
2. *Site 16 (River Mile 56.5; USDA-FS);*
3. *Site 35 (River Mile 44.7; USDA-FS).*

*Each of the three transects at all the sites was clearly marked with orange wooden stakes, as shown by the example in Figure 1. Some of the transects were located in areas with low to medium vegetation cover, others were located in relatively bare areas. Due to increasing spring runoff, reservoir water levels were high enough that the lower portions of the transects were submerged. Bank exposures at the sites were on the order of 20 to 25 ft high and showed some evidence of minor surface erosion, slumping (Figure 2), and overall bank recession (Figure 3).*

*At least five other monitoring sites were viewed at a distance as the boat continued downstream, and Dale McGreer pointed them out and identified them according to erosion rate class (N, L, M, H). Upon request, Dale provided a summary sheet with brief soil descriptions at the monitoring sites, which indicated that the most common soils were silts, and poorly graded sands and gravels. Sites 16 and 18 contain primarily silt and are classified as M (medium) erosion rate. Site 35 has poorly graded gravel with silt and is classified as M erosion rate.*

*Figure 1. One of the shoreline erosion sampling transects at Site 18.*

*Figure 2. Evidence of over-steepening and block slumping near Site 35.*

*Figure 3. Evidence of bank recession near Site 35.*

*Primary objectives for the Box Canyon shoreline erosion monitoring plan are presented in the Draft Report, dated April 3, 2006:*

1. *Determine the rate of shoreline erosion at monitored locations throughout the reservoir;*
2. *Determine the relative importance of operative erosion processes at each monitored location and when they occur seasonally and through longer intervals of time in association with annual hydrologic variability;*
3. *Determine the relative rate of erosion for all project shoreline locations through extrapolation of results from monitored locations based on similarity of location, geomorphic, and hydrologic circumstances;*
4. *Determine the degree to which project operations contribute to such erosion.*

*The District currently is monitoring 32 shoreline sites, with each site consisting of three transects spaced approximately 20 ft apart. Transects are surveyed in the late spring and in the fall using electronic surveying equipment that targets handheld prism staffs placed along the slope-run of each transect. Elevation data are recorded and then used to generate semi-annual profiles (cross-sections) for each transect. Averaged annual changes in elevations for the three transects at a given site then provide an estimate of annual soil loss at the site. For example, in comparing the Spring 2000 profiles to the Spring 2001 profiles, annual average soil loss ranged from 0.14 ft down to less than zero (i.e., slight aggrading or deposition).*

*For future monitoring work, the District proposes to continue monitoring these 32 sites, and will establish seven new sites on Kalispel Indian Reservation shorelines (as required by DOI) and three new sites on USDA-FS shorelines. Thus, the long-term monitoring program intended to meet Objective 1 will consist of 42 sites being surveyed semi-annually and at times of specific flow conditions mandated by Article 408 of the FERC License, which are: 1) after any flood event with a recurrence interval of 20 years or greater, and 2) after drawdown rates in excess of 3 in./hr. as measured at Box Canyon Dam. Furthermore, the DOI requires that the District update the Erosion Occurrence Maps submitted in the Final License Application within three years after license issuance, at intervals not greater than five years thereafter, and within one year after any flood event with a recurrence interval of 20 years or greater.*

*In regard to Objective 2, the District proposes to use a qualitative rating system to evaluate erosion processes and causative factors. A prototype rating system is scheduled for initial field testing, implementation, and adjustment in 2006. Subsequently, the rating system would be applied systematically to each of the 42 monitoring sites to track the impacts of erosion processes and causative factors in a consistent, rational manner. Special quantitative field measurements at six new monitoring sites will focus on wave energy expended along the shoreline due to the presence of reservoir backwater. The study will investigate naturally generated waves due to wind and fetch, as well as waves due to watercraft wakes during the summer recreational season. The goal is to be able to quantify the amount of wind-related wave erosion and watercraft-related wave erosion due to the presence of the reservoir, and distinguish them from wave erosion effects that would have occurred without the Box Canyon Dam project being in place.*

*Though not directly stated in the Draft Report, it appears the District plans to use the rating systems for erosion processes and causative factors to extend/extrapolate a rational, qualitative assessment of erosion prediction to all project shoreline locations in order to meet Objective 3. This extrapolation process has not been well described or documented in the literature available for current review.*

*To meet Objective 4, the District is proposing a "tiered" scheme (tied to principles that affect erosion phenomenon along the shorelines) to distinguish erosion amounts that can be specifically attributed to project operation. The highest tier represents river flows that exceed 90,000 cfs, whereby water levels in the reservoir are not affected by the presence of Box Canyon Dam due to the natural flow restriction in the river valley that occurs at Box Canyon. In other words, at such high flow events, the water levels upstream from the Canyon are the same, whether the dam is present or not. For the second tier (flows below 90,000 cfs) flow duration and stage duration data can be used to develop stage duration relationships for two conditions: natural stage not affected by the project, and stage as affected by the project. Such stage relationships can be generated for any location along the project's shoreline, and then using a shoreline profile the stage relationships can provide the percent of time the eroding area of shoreline is impacted by inundation and river-associated erosion (this is used in the PSE calculation; see below).*

*By combining the two conditions (tiers), a value of Project Share Index can be computed at any shoreline location where a surveyed profile and erosion estimates are available:*

$$\text{Project Share Index} = (\text{Total Erosion} - \text{Extreme Peak Erosion}) \times PSE$$

*where:*

$$PSE = \text{Project Share of Exposure } (\%)$$

$$= \frac{(\%\text{ Time Exposed with Proj.} - \%\text{ Time Exposed without Proj.})}{\%\text{ Time Exposed with Proj.}}$$

*Total Erosion = total cumulative erosion at given site for a given time period*

*Extreme Peak Erosion = (total erosion based on fall-spring data in extreme peak years) – (total erosion based on fall-spring data in normal years)*

*Thus, project share of erosion is indexed for erosion that occurs during years with peak flows up to 90,000 cfs, while the erosion that occurs in extreme peak flow years (>90,000 cfs) is not attributed or allocated to project share.*

*Peer Review Criteria and Findings*

*The following discussion is itemized according to the requested review criteria, and my responses are presented in the same sequence as the criteria originally set forth in the Peer Review Description document, dated March 24, 2006.*

*1. Does the Erosion Monitoring Plan provide adequate methodology and scientific rigor to determine the location and rate of shoreline erosion that is occurring at various points throughout the reservoir?*

The spatial distribution of the current 32 shoreline monitoring sites appears to be adequate and provides representative locations, with the exception of the zone between RM 65 and 70, which coincides with Kalispel Indian Reservation lands. This spatial gap in sampling should be remedied by the planned addition of seven new sites on tribal lands, as requested by DOI.

***M1. We acknowledge that the spatial distribution and proposed number of sites is adequate.***

The frequency of sampling seems appropriate (i.e., field surveys of the transects at each monitoring site) set at twice per year, and after large floods (recurrence interval of 20 years or greater), and after periods of large drawdown rates at the dam (exceeding 3 in./hr.). Although ground surveys with state-of-the-art electronic/laser equipment are time consuming, they provide the only direct means to observe and monitor soil loss and bank recession over the long-term. Unless permanent, deep-seated markers (monuments) are installed along each sampling transect, the accuracy of the profile surveys is limited to the nearest 0.05 - 0.10 ft at best in the horizontal and vertical directions due to ground-surface irregularities and the inability for the surveying technician to exactly re-locate measurement points along the transects. Thus, the reporting of survey results with accuracy to the nearest 0.001 ft (as seen in the WWA Erosion Monitoring Report, dated February 13, 2006) is not reasonable and leads to an unwarranted level of confidence in the measured values.

***M2. We acknowledge that the proposed frequency and equipment are appropriate.***

***M3. In the future we will report erosion depths to two decimal places consistent with measurement accuracy on the order of 0.05 ft. We could report the data only to the nearest 0.1 feet, but we believe this would result in a loss of useful information.***

I am not sure that the actual "location and rate of shoreline erosion" can be "determined" by these widely spaced sampling sites along the shoreline. At the sampling sites, investigators certainly can measure ground-surface elevation changes along the specific transects and develop an overall estimate of erosion amounts and rates at the site. The only "determinations" that can be made are the ground elevation changes observed at specific locations that can be repeatedly sampled (see discussion immediately below in part a.). Thus, the survey data allow for reasonably accurate <u>estimates</u> of the erosion experienced at each of the sampling sites, not a conclusive "determination" of the erosion that has occurred across the approximate 60 ft by 35 ft area of shoreline covered by the sampling site and its three transects. Real "determination" of the erosion amount would require impractical, extensive investigation and analysis, such as collecting all soil material eroded from the site or generating finely gridded contour maps of the site's ground surface which then could be quantitatively compared over time.

***M4. We acknowledge that our measurements are estimates. We will make this clear within the monitoring plan and annual reports. However, "determine", not "estimate" is the term found within the FERC requirements for the new operating license.***

Furthermore, the notion of "determining the locations of shoreline erosion" actually implies that the erosion estimates obtained at each of the 42 sampling sites can be compared against each other and ranked in descending order, so that the shoreline sampling locations with the highest erosion rates can be distinguished readily from those with much lower erosion rates. The proposed monitoring plan certainly is capable of achieving this end.

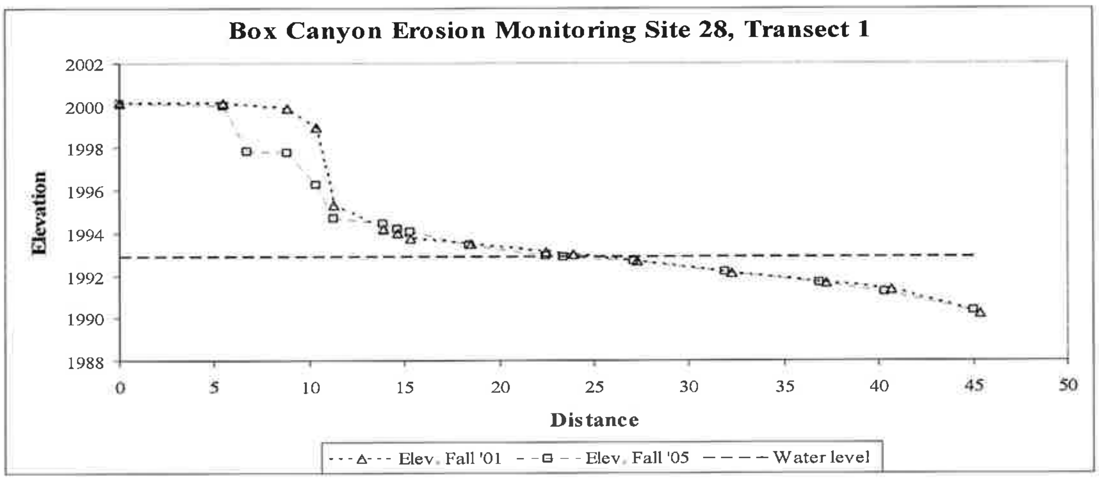
*a. Are there other characteristics that should be included in the monitoring that would help meet this objective?*

Every effort should be made by the survey team to repeat the horizontal (x, y) position of measurement points along each transect. Such re-positioning in subsequent surveys allows consistent repeatability at the same locations on the ground surface; a horizontal accuracy of 0.10-0.20 ft should not be that difficult to obtain. For example, along a given transect there may be 15 locations that can be repeatedly surveyed, and the actual elevation changes of those 15 locations can be tracked with time. Rather than report an average erosion value for that transect (or for a site, which is a composite of three transects), the individual 15 values can be presented as a statistical distribution with summary descriptors such as minimum value, maximum value, mean, and median. The same can be done for all three transects combined at the site.

***M5. In theory such a statistical approach appears attractive. However, the implementation of such measurement methodology introduces certain practical problems. We currently survey transects by observing locations where the slope breaks (i.e., nick points) occur. While the x, y locations of survey points is repeatedly resurveyed with good precision, shape of eroding profiles may change, and we therefore change the specific locations of some survey points, add points, and drop points in order to most accurately reflect bank profile recession through time. At the very least, survey points will be added where top of bank points recede. As has previously been suggested by the Forest Service, we feel it is important to do add points, and to then drop unnecessary points to maintain the surveys as a manageable process, in order to most accurately represent bank profiles over the period of monitoring, and to most accurately identify where and to what extent erosion occurs along them.***

Thus, a more complete quantitative description of erosion amounts (and rates) is provided through the long-term monitoring plan. For example, using statistical distribution models of the elevation changes, investigators eventually may conclude that the 90-th percentile value (or some other percentile) serves as the best descriptor for comparing erosion rates among sampling sites. In addition, statistical analysis would provide enough information to conduct quantitative statistical tests to compare erosion rates at two different sites to evaluate whether the erosion estimates are significantly different from each other, or whether the two sites are actually indistinguishable (this is a type of statistical hypothesis testing using paired samples).

***M6. The monitoring plans objectives include determining the rate of erosion, the processes at work, extrapolation of rates from monitored sites to other areas of the shoreline, and determining project share. Determining whether one sites rate of erosion (i.e., depth of erosion) is statistically different from another's has not been an objective. Nevertheless, we do agree that providing the distribution of mean depths of erosion from our sample of 42 sites is appropriate and adds value. We do not agree that developing distributions based on the depths measured at individual points along a transects is a correct procedure. The depths measured at individual survey points are serially correlated; they are not independent, and cannot be represented as a distribution of independent values. This is well demonstrated by the profile for site 28, transect 1 where some form of mass erosion affected a series of point locations – a common occurrence.***




***Moreover, even if we were to consider the survey points along a transect as independent of one another (and we know they are not) we think it may be somewhat misleading to merely compare depth of erosion measured as a series of point measures; the same depth of erosion from a 2-foot high bank is certainly different from the identical depth of erosion from a 20-foot high bank. We also will be looking at and comparing rate of top of bank recession as suggested in Reidel's review, and we continue to believe that the profile plots themselves provide some of the best information, particularly when we identify areas and processes of erosion on these plots, as has also been suggested.***

*b. Are the technical methods used to acquire data most appropriate and up-to-date? Are there other better-suited methods available?*

The survey methods being used at the monitoring sites are state-of-the-art in regard to ground survey technology and are appropriate for collecting this type of data. One improvement that has been suggested previously is that of including one or more permanent, deep-seated monuments at each sampling transect. Such markers typically consist of a steel pipe or rod that is driven into the ground or imbedded into the ground to a depth below the locally recognized frost depth. Once the horizontal position of this marker has been established (using regional bench marks), it can serve as a local reference point to locate other sampling positions along transects and it also provides a known position to regularly monitor ground elevation (at its base) to precisely track changes in the ground surface. I acknowledge that such permanent markers may be aesthetically unacceptable or may be deemed a safety hazard to humans or animals and, thus, land owners may not consent to their installation.

***M7. We acknowledge that the survey methods are appropriate.***

***M8. We use at least two deep-seated reference markers at each site.***

Other technology that potentially could be used includes remote sensing systems, such as airborne LIDAR (laser technology), airborne SAR (synthetic aperture radar) systems, and satellite-based SAR systems relying on radar interferometry. This latter technology probably has the greatest potential (and is the most economically viable) for the Box Canyon project. Satellite SAR methods for monitoring ground movements have been around for nearly ten years (for example, see Ferreti et al., 2000), but the necessary software to rapidly process the radar data and provide high resolution (sub-centimeter ground-elevation changes on a 10-m wide ground pixel) has only flourished in the past few years (Atlantis Scientific, 2006). The method relies on comparing two SAR images (using interferometry technology) of the same ground location obtained at two different times. Subtle changes in the phase shift of the two data sets, or the interference patterns, are analyzed to produce a map of elevation deviations. Advertised applications of the technology include differential ground elevation (e.g., due to mining activity, volcanic activity, erosion, etc.) monitoring across sites many miles across (Vexcel, 2006). Additional information is provided in the Appendix, which describes the Atlantis EarthView® InSAR package for ground deviation mapping (note: Atlantis is a subsidiary of Vexcel Corp.).

Application of this SAR technology would require satellite images collected during low-water periods of July through October, so that a maximum amount of shoreline is exposed. It is my understanding that when SAR images are not available for a desired time at a given study area, then a satellite can be temporarily tasked specifically to scan an area at the desired time. If this satellite SAR technology can be applied to the Box Canyon project to provide meaningful ground deviation maps, the greatest advantage would be that a complete picture of the entire reservoir shoreline would be obtained. The maps also would display any ground subsidence or absidence that is occurring in the flood plain or terraces adjacent to the river channel.

***M9. We will explore using SAR as an adaptive management approach to the plan. Accuracy, precision, complexity, and cost will be examined.***

*c. Can the data collected at monitoring site locations be extrapolated to help determine rate of erosion at other locations? Does the Plan provide an adequate procedure for doing so?*

Again, I do not believe the use of the word "determine" is appropriate in this context. Ground-surface elevation data from the monitoring sites can be used to calculate reasonable estimates of the erosion rates at those sites. Extrapolation to unsampled locations along the shoreline will require knowledge of relevant environmental factors (e.g., soil type and texture, bank-slope steepness and aspect, river flow and stage duration, vegetation cover, wave action) along the shoreline. Regardless of whether a qualitative system or a mathematical system (such as multiple regression) is implemented here, the best we can hope for is reasonable <u>estimation</u> of the predicted erosion rates at unsampled sites.

***M10. We agree that these are estimates, that knowledge of relevant environmental factors is necessary and that these will be recorded, and that the best we can hope for is reasonable <u>estimation</u> of the predicted erosion rates at unsampled sites. Also see previous comment M4.***

The Revised Draft Report (dated April 3, 2006) indicates that this extrapolation will rely mostly on qualitative rating systems used for erosion processes and causative factors. However, the Plan does not provide adequate detail to explain how to implement this approach. Minimally, I would expect to see a causative-factor vs. environmental-factor matrix, so that investigators can identify any available sampling site that has a matrix similar to that obtained using conditions at the unsampled site of interest.

***M11. We agree to develop a new rating table that will evaluate locations for rate/severity of erosion based on the factors that are described on page 5 of the plan.***

Statistical, quantitative methods that have potential application to this problem include multiple regression (Davis, 1986, p. 470-478), where the dependent variable would be an erosion rate, or severity score, and the dependent variables would be relevant environmental factors; and a conditional-probability Bayesian method that has been applied to landslide hazard mapping (Miller et al., 2001) and to a spatial archaeological prediction model (Miller et al., 2005). The performance of any of these methods can be evaluated by blinding the predictive model to one or more known sampling sites and then making estimates at those sampling sites; if the errors (residuals) are small, then the model is performing well.

***M12. The District could agree to try regression or Bayesian analysis methods as an adaptive management approach after data has been collected on geomorphic factors, stratigraphy, and other site characteristics that we have agreed to assemble.***

*2. Does the Erosion Monitoring Plan contain the methodology and scientific rigor to determine the degree to which project operations contribute to erosion (i.e., project share) identified in 1 above.*

*a. At specific sites?*

The Plan presents a fairly detailed description of calculating the project share of exposure (expressed as a percentage) and then the subsequent value for the project share index at the shoreline sampling sites where erosion data and profile data have been collected. The use of a threshold flow of 90,000 cfs to separate out project effects from non-project effects seems to be appropriate. The proposed method, which is illustrated by a computational example at Site 23, provides a rational means to estimate the project share of erosion at the sampling sites when the required technical information is available, including future data on wave energy.

***M13. We acknowledge that 90k cfs (to 102k cfs, depending on distance from the dam) is appropriate, and the method is rational.***

*b. Generally throughout the reservoir?*

The "Revised Draft for Peer Review" (report dated April 3, 2006) states on page 22:

> *A similar approach can be used to determine project share at sites other than at the surveyed monitoring sites. Project Share of Exposure and Project Share Index can be calculated for any location. However, in the absence of surveyed profile data for these locations, location of eroding surfaces would need to be based on site-specific professional assessment. This assessment is expected to be conducted collaboratively by the District and affected landowners and agencies.*

This presents a qualitative approach to address specific other sites besides the established monitoring sites. It does not address the issue of estimating project share generally throughout the reservoir. The Plan does not include adequate information or descriptions of any methods to tackle this general assessment.

***M14. We acknowledge that the method does not address project share "generally throughout the reservoir". Because environmental circumstances, causation, and rate of erosion vary widely depending on specific location along the reservoir's shorelines, the District has never believed that a "general" project share value is applicable. For this reason, the monitoring procedures were never intended as a means of determining a "general" value. The intent is to consistently apply the procedures "at sites other than at the surveyed monitoring sites". The procedure is intended for consistent general application (i.e., anywhere), but it is not intended to provide a "general" one-size-fits-all value.***

One reasonable alternative to address this task would rely on the development of a GIS data base along the reservoir shoreline, where different layers in the database would consist of information required to compute the project share. Unfortunately, some of these layers would rely heavily on subjective, qualitative interpretations and, thus, may not meet accepted standards of unbiased, scientific rigor.

***M15. We agree such an approach would be too subjective. In addition, it does not lend itself to key considerations such as pre vs post-project backwater curves and how the river stages represented by them intersect shoreline profiles and stratigraphy. The District has no plans to pursue a GIS-based approach.***

*c. Are there other characteristics that should be included in the monitoring that would help make these determinations?*

One aspect of the shoreline erosion process that has not been addressed in the Plan is the natural hillside erosion that occurs in the 9-10 months when river flows are moderately low to low. Many of these exposed bank areas may be prone to natural sheet erosion from rainfall or snowmelt events, and this loss of soil has not been considered in the proposed erosion-rate calculations at the monitoring sites. One or more thunderstorms during July or August could account for soil loss at the monitoring sites that would otherwise be attributed to river activity; because the semi-annual survey schedule is set up for early spring (prior to peak runoff level) and then again in fall prior to snowfall, the soil loss from summer storms can not be specifically distinguished.

Furthermore, because annual peak flows above 90,000 cfs result in the same high-water lines upstream from the natural channel restriction at Box Canyon (regardless of whether the dam is in place), the general shoreline morphology and natural sheet erosion along the banks would be occurring regardless of project operations. In fact, due to backwater elevations during low-flow seasons, the toes of these banks are not exposed to the elements and actually reduce the annual amount of natural sheet erosion along the exposed shoreline. Unfortunately, this reduction may be more than outweighed by toe erosion caused by wave-energy effects due to increased fetch and watercraft activity.

To illustrate how natural sheet erosion can be estimated along the shoreline, the following example at Site 13 has been completed using RUSLE (Revised Universal Soil Loss Equation; Renard et al., 1994). This site consists of poorly graded sand and its profile is described by two slope segments, with the upper being 28 ftH : 25 ftV and the lower 10 ftH : 3 ftV. The average annual soil loss (ton/ac/yr) due to natural climate and runoff activity is given by:

$$A = R \cdot K \cdot (LS) \cdot C \cdot P$$

where: R = climate rainfall-intensity factor (= 10 for Spokane area);
K = soil erodability factor (= 0.36 for moderately compacted sandy loam);
LS = slope length and steepness factor (= 5.39 as computed by the RUSLE program for this slope configuration and soil texture);
C = soil cover factor (= 0.95 for mostly bare soil with sparse vegetation);
P = structural practices factor (= 1.0 for naturally smooth ground surface).

Thus, the estimated annual soil loss at Site 13 is 18.4 ton/ac/yr; if the monitoring site covers about 80 ft x 30 ft = 2400 $ft^2$, then the actual amount lost at the site is 18.4(2400 $ft^2$ / 43,560 $ft^2$) = 1.01 ton/year. However, this amount should be reduced by a percentage due to the time of year when high water is covering the shoreline (say, 20%, or 2½ months per year), giving a final estimate of 0.81 ton/yr at the site. Now, if the surveyed transects at Site 13 indicated an overall annual average vertical elevation loss of 0.07 ft (say, from spring 2000 to spring 2001), the measured soil loss at the site is 0.07 ft(2400 $ft^2$)(96 lb/ $ft^3$)(1/2000) = 8.06 ton/yr. Therefore, of the total measured soil loss at the site, about 10% can be attributed to natural sheet erosion of the bank slope and not to river flows. This percentage will vary from site to site based on local environmental conditions, but it does seems to represent a significant quantity that currently is not being factored into the erosion prediction and project share calculations. If the RUSLE method seems too generalized for such small-area sites, then the computer simulation model known as WEPP (1995) could be used instead in order to provide estimates of annual soil loss.

***M17. The District's consultants are highly familiar with application of the RUSLE and WEPP models. We could run RUSLE and/or WEPP to estimate the current rate of overland flow-related erosion and could compare that rate with total rates of erosion based on our surveyed transects. These predictions may help determine the relative importance of overland flow erosion, but we think the plan already includes such a procedure. RUSLE or WEPP predicted rates of erosion associated with overland flow cannot be compared to rates of erosion associated with other potentially important processes like freeze/thaw, dry ravel, waves, and groundwater processes because the amount of erosion attributable to these processes is not measured and likely cannot be because they are intermixed and interactive (Gatto and Doe 1983; Gatto 1988; Lawson 1985). Moreover, determining that current rates of overland flow erosion as predicted by RUSLE or WEPP is "natural" is another matter; we are still left with a question as to how much of measured or predicted erosion is project share.***

One critical component of the project share concept is the impact of wave energy along the shoreline. Although the Plan describes the establishment and use of six new monitoring sites to focus on wave measurements, two site visits during the year to measure wave heights, periods, watercraft wakes, etc., will not be adequate to provide representative data. Instead, a portable wave monitoring station should be developed, so that it can be installed for a week or so at each site to obtain local wave data for more than just a single day (and include a weekend timeframe to monitor increased recreation-related watercraft activity). The station should include a data acquisition system for an anemometer (for wind speed and direction) and a water-surface displacement meter (e.g., a displacement transducer or string-pot capable of recording the vertical deflections of a float sliding on a rod) to track wave activity. When such data are recorded in real time, the impact of watercraft wakes can be isolated from that of natural waves due to wind and fetch. Such monitoring would not have to be conducted long-term, but only for one or two seasons to obtain representative wave data at various locations around the reservoir.

***M18. The wind and wave monitoring part of the plan was not intended to be exhaustive. The purpose for the monitoring is to collect wind-caused and boat-caused wave calibration data for modeling to estimate the relative increase in wave energy due to increased fetch and increased boat traffic, some of which may be attributable to the project. Once such a model is calibrated, increased fetch and increased boat traffic can be estimated and the model applied to any location along the project's shorelines. The peer review does not identify how much monitoring would be "enough"; it only argues that more is better. But no amount of monitoring leads to a data-based estimate of wave-caused erosion; it only yields an estimate of wave erosive <u>energy</u> useful as project share is considered.***

***There also are practical considerations of leaving equipment exposed and unattended in public areas, there are issues associated with setting a wave recorder at a fixed point while water levels and wave energy change in relation to the shoreline, and there are issues associated with developing and successfully deploying untested and non-standard***

***equipment. We believe that the wind monitoring part of the erosion monitoring plan provides a reasonable approach for collecting adequate wave energy data. However, the adequacy of the data can best be determined following an initial data collection and modeling effort as an element of the monitoring plans adaptive management approach.***

3. *Does the Erosion Monitoring Plan contain the methodology and scientific rigor to identify the location, extent and types of Project -caused and Project -exacerbated erosion processes on National Forest System lands?*

It appears that combined Forest Service land segments comprise approximately 7-8 river miles of the total river-mile shoreline of 110 miles (i.e., 55 RM x 2, for right and left bank). This constitutes approximately 7% of the total shoreline length. Of the planned 42 monitoring sites, 13 will be located on Forest Service lands (31%). Thus, there seems to be a solid share of the monitoring sites assigned to FS lands. However, due to varying conditions along the shoreline, this does not necessarily guarantee that every location of project-related erosion will be identified and characterized.

The Plan provides a prudent and reasonable erosion monitoring strategy for FS lands through the field survey sites and the proposed wave-energy monitoring and analysis. The project share computations discussed in 2a. and 2b. above can be applied at each monitoring site located on FS lands and provide a scientific framework for making interpolations of these effects to non-sampled sites, provided those non-sampled sites do have available background information (such as slope height and steepness, soil type, vegetation cover, flow and stage duration).

***M19. We acknowledge that the plan is sufficient given collection of the background information noted.***

Additionally, it would be a good idea to maintain a photographic history and/or a record of bank recession measurements referenced to a specified natural landmark (e.g., tree or rock outcrop) at shoreline locations not covered by established monitoring sites. That way, accelerated erosion at a non-monitored site could be identified readily and not go unnoticed.

***M20. We agree that photo points are a good idea, but we have found that it is difficult to locate photo points from the water both in terms of an x, y location and fluctuating water levels. Nevertheless, the plan calls for digital photos of each monitoring site at time of each survey. In addition, it may be possible to document bank recession at additional sites through photo documentation of the distance from a reference tree or other landmark and top of bank as indicated with a survey rod. We will examine the utility and practicability of adding bank recession measurement sites and will incorporate this commitment within the monitoring plan.***

a. *Are there other characteristics that should be included in the monitoring that would help identify project related erosion?*

This has been addressed in the discussion/response to 2c. above.

b. *Will the data gathered under the plan be sufficient to determine whether, and to what extent, erosion can be attributed to project operation?*

Due to the presence of 13 monitoring sites on Forest Service lands, the proposed project share calculations can be applied with considerable confidence to these shoreline segments. Extrapolation to non-monitored sites will involve much more subjectivity, as discussed in the Draft Review Report (dated April 3, 2006) and in my response given in 2b. above. As stated earlier, the Report does not provide adequate information on the details of how such an extrapolation will be accomplished. I believe that basic environmental site characteristics must be obtained or evaluated at a shoreline location in order for a reasonable extrapolation to be applied there.

***M21. We agree that basic environmental site characteristics must be obtained or evaluated at a shoreline location in order for a reasonable extrapolation to be applied there. To this end, we will develop a shoreline geomorphic/landform map and record soil strata at the monitoring sites consistent with classifications and procedures suggested in the peer reviews provided by Gerstel and Riedel, and infer similar soil strata for other sites based on landform and geology.***

c. *Is the overall plan suitable for determining the extent erosion can be attributed to project operations?*

The Monitoring Plan lays out a solid strategy for estimating the project share of erosion at specific monitoring sites. The weak link (or the unknown link at this time) involves the extrapolation of the site-specific analysis to any general site along the shoreline. This qualitative approach is discussed briefly in the Plan, but sufficient detail is not provided for a thorough assessment of its merits.

***M22. See previous comment M14.***

The bigger issue actually may be that of estimating project share generally throughout the reservoir (see discussion 2b. above). The only means I see for accomplishing this task is to implement a comprehensive GIS database and analysis system for the reservoir area, one which is focused on DEM data (digital elevation model) for elevations and slopes, soil types, vegetation cover, landform classifications, and similar environmental characteristics.

***M23. See previous comments M14 and M15. Determining project share generally throughout the project is not an objective of the District's shoreline erosion monitoring plan. The intent is to consistently apply the procedures "at sites other than at the surveyed monitoring sites". The procedure is intended for consistent general application (i.e., anywhere), but it is not intended to provide a "general" one-size-fits-all value. Moreover, development of a GIS database approach would have to follow collection of geomorphic, soils, and other site descriptive information, development of regression or Bayesian predictive methods with adequate predictive power, and may need to be based on subjective***

***input. Given the time, cost, complexity, accuracy, and uncertainty of producing a useful product, the District does not plan to develop a GIS-based approach into its monitoring.***

d. *Is the use of shoreline erosion rate classes useful? Is the methodology for determining these classes appropriate to meet the overall goal of the plan? Can you suggest a more useful system?*

The use of erosion rate classes can prove to be quite useful in this type of study, especially if it provides an input component to GIS applications, regression analysis, or other statistical estimation tools. However, to be reliable, this class designation protocol must be clearly documented and must be applied consistently and uniformly.

The methodology for determining these classes has not been explained in detail within the Plan. The Erosion Monitoring Report (dated February 13, 2006) states: "Relative erosion rate class was estimated in the field based on observable characteristics of the shoreline soils, vegetation, evidence of slumping and sloughing, bank overhang and undercutting, shoreline steepness, and other geomorphic indicators of erosion rapidity." This general statement does not provide the details and mechanics needed for a trained investigator to go into the field and rate a stretch of shoreline. A written field guide or worksheet needs to be generated that can serve as a standard protocol for rating a site according to erosion-rate class.

***M24. See previous comment #M11 - we agree to develop a new rating table.***

e. *Are the data analysis methods employed suitable to meet the goals of the plan? Are there other methods better suited for analysis of this data?*

Implementation of statistical-based collection and interpretation of the transect surveying data, as well as statistical analysis and modeling of the data are the best ways to enhance the knowledge base for erosion estimates and extrapolations for this project. Examples of such methods are discussed previously in 1a. and 1c.

***M25. See previous comment M6.***

*With regards to the Plan in general:*

4. *Will the plan methodology and frequency of sampling be capable of identifying significant new or recurring erosion areas along the reservoir?*

Clearly, the Erosion Monitoring Plan will be able to readily identify significant erosion activity occurring at any of the 42 monitoring sites, but will have only limited effectiveness in pointing out new or recurring erosion areas generally across the whole study area. Exhaustive annual reconnaissance surveys to inventory the entire shoreline likely are impractical, but there may be known "trouble" sites that could be photographed and quickly assessed for bank recession (see final paragraph in response 3. above). These supplemental sites, perhaps numbering 20 to 30, would provide additional tracking of erosion effects along the shoreline and assist with the task of identifying new or recurring erosion areas along the reservoir.

***M26. We don't see that it's possible to anticipate where new erosion might occur. By definition, "trouble" sites would be places that are readily identifiable and therefore not new. Also, we are able to monitor erosion only at a finite number of locations considering time, cost, etc. We can examine possibilities for bank recession measurement sites, but we do not presuppose how many might be sufficient.***

As stated previously, the effects of sheet erosion on the banks during low-flow periods should be estimated and deducted from the erosion amounts measured at the monitoring sites. Such estimates may typically amount to about 10% of the average total annual soil loss experienced at a site. Summer thunderstorms could cause significant erosion and soil loss at exposed shoreline slopes, a soil loss that should not be attributed to river-flow or project-induced activity. In fact, it may be prudent to re-survey one or more transects before and after thunderstorm events to obtain a better understanding of this type of erosion activity.

***M27. We measure total erosion due to all factors, so we don't, and should not, deduct anything from our measurements.***

***M28. Based on data taken to date, it does not appear that increased frequency would isolate measurable erosion, because erosion rates are so low. Monitoring after storm events would be very difficult to implement on a practical basis, essentially requiring a trained observer to interrupt other schedules in order to respond to unpredictable events to make detailed observations. Moreover, actual measurement to quantitatively isolate storm effects requires both pre and post storm surveying that would require knowing when these events would occur – a practical impossibility.***

*5. Can the reviewer suggest alternative methods that might be easier, less costly, more effective and yet be able to meet the objectives of the plan?*

*I have not seen cost information related to the annual surveys of the shoreline transects, but based on my engineering experience I can make a rough estimate of such work, which would probably involve 12-14 days of field work and data reduction time to complete surveys at all 42 sites. This amounts to approximately $20,000 twice each year.*

*In recent discussions with a Vexcel representative, I was told that an initial satellite SAR analysis using two or three time steps (say, 2002 with 2004 and 2004 with 2006) would cost about $15,000 to $20,000 if the satellite imagery was available in archives, and about $30,000 if a satellite had to be specifically tasked to fly over and image the site at a specific time. Output would consist of color-contoured maps showing relative changes in ground elevation. Vexcel claims that elevation differences with sensitivity on the order of 2-3 mm (0.01 ft) often can be achieved. Assuming that a ground resolution of 10 m or better could be achieved, this option should at least be investigated to see if it would be useful for the Box Canyon Project. Ideally, a ground resolution of 2-3 m would be preferred, and it may be possible using airplane-based SAR platforms; however, increased costs would likely make this option prohibitive.*

**M29. Regarding use of SAR, see previous comment #M9. Horizontal resolution of 2-3m seems far too coarse compared to what we are trying to achieve. Nevertheless, we will explore the feasibility of applying such techniques as an adaptive management approach.**

*Regardless of how ground elevation data are obtained over time, statistical methods will provide the most objective and scientifically defensible means to extrapolate erosion data from monitoring sites to other locations along the shoreline. The initial development of a statistical protocol will require a financial investment, but its long-term application likely will save dollars due to less "hands-on" time needed by professionals in the case of a more subjective, qualitative approach.*

**M30. See previous comment M5, M6, M12, and M14.**

*Recommendations*

*Topic-specific recommendations for supplementing or enhancing the Shoreline Erosion Monitoring Plan have been presented in the previous section that covered review criteria and findings. Several of the key recommendations are summarized and reiterated below:*

*1. During field surveys along transects, the horizontal locations of sampling points should be repeated at subsequent survey times, so that ground-elevation changes can be tracked at those specific [x, y] map coordinates.*

**M31. See previous comments M5 and M6.**

*2. Statistical descriptors (minimum, maximum, median, percentiles) of the measured elevation changes at a monitoring site should be calculated and used to describe the erosion amounts (soil loss) in addition to the mean value.*

**M32. See previous comment M6.**

*3. Statistical methods, such as multiple regression and conditional-probability analysis, should be applied (where appropriate) to extrapolate erosion rates or project share from monitoring sites to other sites along the shoreline.*

**M33. See previous comment M12.**

*4. If supportable by available datasets and deemed economically viable, a GIS database should be established for the land surface and any relevant environmental characteristics for a swath approximately 200-300 ft wide along the shoreline. This GIS can be used in conjunction with statistical models to make predictions of erosion rates and to generate hazard maps covering the entire shoreline of the reservoir.*

**M34. See previous comment M15.**

*5. The application of satellite-based SAR (synthetic aperture radar) for mapping ground elevation deviations should be investigated for its potential beneficial use at the project site.*

**M35. See previous comment M9.**

*6. A study is warranted to investigate the natural hill-slope erosion (soil loss) of the banks during low-flow periods using available predictive models, such as RUSLE or WEPP. This erosion amount needs to be deducted from the overall erosion estimates obtained by ground surveys, so that it is not included in the erosion caused by stream flow and wave activity.*

**M36. See previous comments M17.**

*7. A set of supplementary recon sites (20-30) should be identified and monitored so that a chronology of photographic images and observed bank recession will be available to complement the survey sites and assist with identifying new or recurring erosion areas along the reservoir.*

**M37. See previous comments M207 and M26.**

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*Biographical Summary of Qualifications*

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*Current Title: Professor of Geological Engineering*
*Department of Civil Engineering, University of Idaho*

*Education*

*Ph.D. 1982 Geology (Engineering Geostatistics), University of Wyoming*
Dissertation: Statistical and Fourier Methods for Probabilistic Design of Rock Slopes
*M.S. 1979 Geological Engineering, University of Arizona*
*B.S. 1976 Geological Engineering, University of Arizona*

*Service at University of Idaho*

*1985 Assistant Professor of Geological Engineering; 1988 Associate Professor; 1995 Professor*

*Other Professional Experience*

*1985- Independent Consulting Engineer, Moscow, Idaho*
*1983-85 Assistant Professor, Geological Engineering Program, Washington State Univ.*
*1980-82 Part-time Lecturer, Department of Civil Engineering, University of Wyoming*
*1977-80 Project Engineer, Rock Mechanics Div., Pincock, Allen & Holt, Inc., Tucson, AZ*

*Professional Registration*

*Professional Engineer (PE): Idaho, Montana, Washington, Arizona*
*Certified Professional in Erosion and Sediment Control (CPESC)*

*Professional Activities/Memberships*

*Society for Mining, Metallurgy, and Exploration (SME)*
*Member, Closure/Reclamation/Remediation Committee of the Environmental Division*
*American Society of Civil Engineers (ASCE)*
*Member, Geotechnical Risk Assessment and Management Committee*
*International Erosion Control Association (IECA)*
*Member, Slope Technology Sub-Committee*

*Selected Recent Publications*

*Miller, S.M. and T.R. Howard, 1999, Repairing Landslides with Geotechnical and Erosion Control Tools;* Erosion Control, ***6: 6**, p. 43-50.*

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*Selected Recent Research Activity*

*1996-98 Erosion Control for Highway Construction and Maintenance;*
*Idaho Transportation Dept., $94,517.*

*1996-99 Landslide Evaluation and Assessment in North-Central Idaho;*
*Potlatch Corp., $49,400.*

1996-97 Relationships Among Roads, Buffer Strips, and Streams;
USDA-FS Intermountain Research Station, $10,472.

*1997-99 Sediment Control and Stream Water Quality in the Mica Creek Watershed;*
*US-EPA, $38,541.*

*1999-2003 Rockfall Classification and Mitigation;*
*Idaho Transportation Dept., $86,954.*

*2005-present Relating Indicator Soil Properties to Water Tension in Expansive Soils;*
*GeoTek, Inc., $26,400.*

*Appendix*

*Overview of the EarthView® InSAR software available from Atlantis Scientific, a subsidiary of Vexcel Corp.*

# Box Canyon Hydroelectric Project Technical Peer Review Report

**INCLUDING PEND OREILLE PUD RESPONSE COMMENTS**
**PREPARED JULY 19, 2006**

**Jon Riedel**

June 2006

## Executive Summary

Box Canyon Dam was completed in 1956 on the Pend Oreille River in northeastern Washington. The low height of the dam results in very little storage capacity, making Box Canyon a 'run of the river' type project with a 55 mile long reservoir. Primary influences of the project on the natural hydraulic and hydrologic regimens of the river and valley include:

- backwater effect that raises water surface elevation 30 ft at 10,000 cfs between the dam and Ruby Mtn.,
- slowed current velocity of 1-2 ft/sec through most of the reservoir;
- daily reservoir water levels fluctuations; and
- increased fetch and wave energy associated with higher water levels, particularly in Cusic Basin.

The effects of the project are best understood in terms of a longitudinal view of the valley from Box Canyon to Newport (Figure 1). Zone 1 extends from the dam to Ione within the canyon, where banks are colluvial or glacial, and bank slopes are steeper. Zone 2 extends from Ione to Ruby Mountain, shoreline erosion is most severe because shoreline geology includes complicated stratigraphy in thick unconsolidated deposits, steep banks, and clear evidence of mass wasting. Also within Zones 1 and 2, current velocity is higher and more variable at all flows and project effects on water surface elevation are more pronounced. Zone 3 extends from Ruby Mountain through Cusic Basin to Usk. Within this zone bank height is generally low, with many areas protected by levees. It is reasonable to suspect that shoreline erosion is least severe within this zone. Zone 4 extends from Usk to Newport and Albeni Dam. Within this zone backwater effects from Box Canyon Dam are minimal, and the Pend Oreille River meanders through islands. and where project effects on water level and shoreline erosion are relatively small compared to Zone 2.

I am impressed by the amount of time and resources the PUD has put into monitoring shoreline erosion. Strengths of the draft erosion monitoring plan include a good approach to measuring wave energy, which is likely the primary process of shoreline erosion. Other strengths of the plan are that it contains an adequate set (47+) of monitoring sites and a reasonable method for classification of the condition of all shorelines. The relationship between river discharge, stage, and project influence was also well investigated, if not well illustrated in the plan.

The scientific rigor of the plan could be improved by quantifying non-wave erosion, focusing on horizontal bank recession, mapping of the geology of the entire shoreline, conducting wave and boat wake monitoring for more than one year, and mapping and monitoring the location and extent of mass wasting. Mapping of landforms is an effective and efficient method for characterizing shoreline geology.

Determining 'project share' of total erosion will be difficult to measure and defend if only wave energy is quantified. Uncertainty in estimation of project share of erosion should be assessed, and error associated with the estimation procedure should be determined.
The 'convention' of assigning half of total bank erosion above a certain water level to the project seems arbitrary, and was not explained in the plan.

Major recommendations for improving the plan include:

-Focus erosion monitoring on bank recession at a large number of sites using simpler, less expensive methods such as measuring from stakes placed above the bluff face.

-Map the entire shoreline and back shore areas of the project by mapping landforms, which will allow for a more defensible projection of erosion rates from monitored to non-monitored sites. A list of potential landform mapping units is presented below.

-Expand monitoring of erosion processes from a focus on waves to include freeze-thaw, groundwater, and unidirectional current erosion. More intensive monitoring would occur at 6-10 sites around the reservoir, depending on the number of landforms and complexity of shoreline geology. Monitoring would be conducted for a minimum of two years at these sites to account for some variation in weather and river discharge.

-Provide more detailed inventory and monitoring of areas of slope instability. At minimum, each large mass failure of the shoreline should be accurately mapped and assessed annually.

**Introduction**

In May 2006 I was chosen to conduct a peer review of the Box Canyon Hydroelectric Project Erosion Monitoring Plan. This plan was prepared by the Pend Oreille Public Utility District (PUD) and partners. Peer-review and completion of the plan is part of a new operating license for the project issued in 2005. The basis for this peer review included a field trip to the project on May 11, 2006, a review of reservoir erosion literature, and professional experiences with erosion associated with several other large hydroelectric projects in Washington State.

**Summary of the Subject Reviewed**

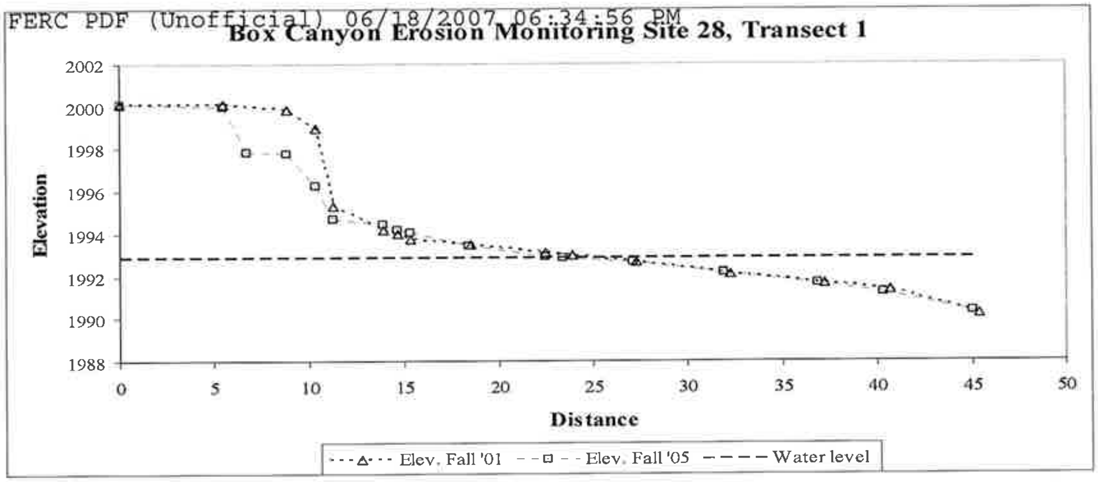
The subject reviewed was a plan for monitoring shoreline erosion associated with the Box Canyon Hydroelectric Project on the Pend Oreille River in northeastern Washington State. The plan was written to satisfy Article 408 (a) of the new operating license for this project, which states that the purpose of the Erosion Monitoring Plan is:

*To determine the location and rate of shoreline erosion that is occurring at various points throughout the reservoir and the degree to which project operations contribute to such erosion.*

The plan was also written to satisfy U.S. Forest Service condition #8 of the new license:

*The monitoring plan is to identify the location, extent, and types of Project-caused and Project-exacerbated erosion on National Forest system lands.*

**Peer Review Findings**




This section of the report includes analysis and discussion of the shoreline erosion plan via the specific peer review criteria established by the PUD.

(1) Does the Erosion Monitoring Plan provide adequate methodology and scientific rigor to determine the location and rate of shoreline erosion that is occurring at various points throughout the reservoir?

The scientific rigor of the Erosion Monitoring Plan could be improved in four areas:

- The plan emphasizes the vertical component of erosion along a profile, but not horizontal bank recession (Figure 2). These terms are not interchangeable, and in fact have very different meanings in the reservoir erosion literature (Lawson, 1985, Figure 6; Gatto and Doe, 1983). Lawson defines erosion as a 'mass concept' while noting that bank recession is a 'geometric concept'. Horizontal retreat of the bluff face is probably more relevant to ultimate development of an erosion control plan, and is the dimension of reservoir shoreline erosion most often monitored and discussed in the literature. Measurement of horizontal bank recession also is the net result of several erosion processes, regardless of elevation on profile (or transect). Reporting bank recession as the average of both positive and negative vertical changes obscures the importance of significant changes at any location along a given transect. It also minimizes the apparent rate of bank recession. For example, the 2006 monitoring report Attachment A lists site 28 as undergoing a 'slow' rate of bank erosion, yet the transect 1 clearly shows ~5 ft. of bank recession between 2000 and 2005.

***R1. We agree that bank recession deserves greater emphasis as we report our results, and the plan will be amended to incorporate this recommendation. We will report bank recession at each transect as measured at the top of bank in future annual reports. (Note: The Site 28 results demonstrate substantial rate of erosion whether expressed as a vertical depth, mass, or as horizontal recession (~4 feet in 4 years.) See figure for site 28, transect 1(view in print layout). (Note: Reidel (1990) identified 1143 erosion sites (all of them being mass wasted) for Ross Lake; bank recession rates were measured at 9 locations.)***

- The proposed methods are not comprehensive because they do not consider all potential processes affecting bank recession. The plan does not address the potentially important influence of currents, groundwater, and freeze-thaw processes on bank recession. On nearby Dworshak reservoir, groundwater-induced landslides are the primary shoreline erosion process, while on Pend Oreille reservoir in Idaho waves, freeze-thaw and groundwater processes were all found to contribute to bank recession (Gatto and Doe, 1983). The post-event driven monitoring of processes could be improved by use of relatively quantifiable terms in the causative factor evaluation. Specific examples are given below under 'Recommendations'.

***R2. Regarding currents, we will amend the plan to require that we measure velocities at a sampling of sites at various flow levels. These velocity measurements will be used to evaluate the likelihood and relative importance of velocity as an erosion agent. However, measurement of velocity cannot yield a quantitative estimate of the amount erosion that occurs due to velocity. It also cannot determine the proportion of total erosion attributable to velocity that occurs at a site. Quantifying the amount of erosion attributable to velocity, or for that matter any other agent of erosion, would require that it be isolated and measured separately, an impossibility along the project shorelines where several interrelated processes occur simultaneously. Gatto and Doe (1983) state, "It may be impossible to quantify the amount of erosion that any one process contributes to total bank erosion because there are many contributing processes, all of which are interdependent." Similar statements are found in Gatto (1988) and Lawson (1985). In fact, we have found virtually no studies that quantify the percentage of total erosion attributable to individual processes, although many studies qualitatively note the occurrence of various processes, and some studies qualitatively discuss what they believe to be the most important processes (Reidel 1990; Klingeman 1993).***

***R3. Regarding groundwater, we will make sure that the plan notes that it is a potential mechanism, we will observe its occurrence at our monitoring sites and elsewhere, and we may be able to evaluate its relative importance. Geotechnical studies to be conducted for KIR sites may help. However, we know of no way to quantify the proportion of erosion caused by groundwater. Also see comment R2.***

***R4. Freeze/thaw may occur within a soil mass, but shoreline soil then moves downslope via gravity as dry ravel or water-borne transport (i.e., raindrop splash, sheet wash, rilling, etc.), and these processes are interactive in both space and time with freeze/thaw. We have reviewed literature that mentions freeze/thaw as an important shoreline erosion process, but we have seen no studies that isolate and quantify its importance relative to other processes. Also see comment R2.***

- Monitoring of mass wasting of the shoreline should be systematic and include mapping of the size and distribution of these features. Mapping should continue well above the head scarp of identified features, even if beyond project boundaries. Conditions on the bank below the mass wasting should also be monitored.

***R5. We will modify the plan to include mass wasting inventory and to record their pertinent properties. We think modification of the procedures used by Reidel (1990 at page 36) may be practicable wherein he identified eroding areas of shoreline by visual means (i.e., he looked at the shoreline and judged it to be eroding or not), classified each of these areas into 1 of 3 "severity" classes based on failure size (Class I (>1,000 ft$^3$) versus Class II and III (<1,000 ft$^3$)) and bluff height (Class II (>3') versus Class III (<3')) and recorded key properties. It should also be noted that in Reidel (1990), all eroding areas identified were also mass-wasted areas, which is not the case for Box Canyon.***

- Uncertainty in estimation of project share of erosion should be clearly discussed, and error associated with the estimation procedure should be determined. This is particularly important if the monitoring plan remains focused on wind erosion.

***R6. We will modify the plan to more explicitly discuss uncertainty in more depth. Error however, as a statistical term cannot be developed because several of the factors used in estimation of project share are not developed as quantitative samples with associated error estimates (i.e., variance, standard deviation).***

- The monitoring plan could be improved by further reference to other monitoring methods and results on nearby reservoirs. In particular, the work of Lawson (1985), Gatto (1988), and others should form a conceptual basis for the Box Canyon monitoring plan.

***R7. We are familiar with several references to other monitoring methods and results on both nearby and distant reservoirs and rivers, and will build in references to these works wherever relevant.***

Given these shortcomings, the methods for determining the location of shoreline erosion have strengths and weaknesses. On the positive side, the 47 sites with three transects each included in the Monitoring Plan seems adequate. While a majority of these sites are in the lower reaches of the reservoir, they are located in a zone where reservoir operations have the largest impact on erosion rates due to backwater effects and shoreline geology.

***R8. We acknowledge that 42 sites is adequate.***

It is unclear to me whether or not the location of the sites is sufficiently stratified to account for variations in shoreline geology (Figure 1). Based on the field site review, the selection of sites seems adequate, but there remains a need to map the geology of the entire shoreline along the project to address this issue and several others. This mapping will allow for more accurate extrapolation of recession rates from monitored to non-monitored sites.

***R9. We will amend the plan to include a requirement for geomorphic/landform mapping. We will also record stratigraphy at each of the surveyed monitoring sites in the form of geologic cross sections as suggested in Gerstel's review at section 6.1. We agree that this mapping should*** **allow for more accurate extrapolation of recession rates from monitored to non-monitored sites.**

Methods presented for estimating project share of wave erosion are a good start, but duration of winds and monitoring for more than one year should be included as discussed below. I am concerned that only one year of data collection will miss one or more large wind events, however, a review of existing wind peak intensity and duration data should help clarify whether or not one year of data is enough.

***R10. We will review existing wind peak intensity and duration data at existing nearby long-term stations. Assuming reasonable correlation of field data with long-term station data (e.g., $r^2 > 0.80$), we can then extend the one year of field data to simulate a much longer period of record and range of data that will include "large wind events". This approach obviates the need for a longer (and expensive) original data collection effort of more than one year where irrespective of the number of years data are collected, "one or more large wind events" can continue to be missed.***

(2) Does the Erosion Monitoring Plan contain the methodology and scientific rigor to determine the degree to which project operations contribute to erosion (i.e. project share)?

While the monitoring plan presents a partially quantified, objective approach, I believe there are several reasons why it will be exceedingly difficult to fully address this question. First, no previous methodologies that successfully determine project share are cited, and the approach should be considered experimental. Second, shoreline erosion in the project is dynamic and complicated. While the influence of waves on erosion is correctly emphasized (Reid and others, 1988; Gatto and Doe, 1983), other factors including vegetation, freeze/thaw processes, currents, and groundwater piping are not measured. While the project clearly affects wave erosion processes through increased fetch and superimposing of water on slopes composed of unconsolidated sediments, the project also directly and indirectly influences other processes. For example:

-daily and seasonal fluctuations of water level control the location of shoreline erosion processes;
-frequently changing water levels can eliminate vegetation and accelerate erosion;
-increased humidity associated with the reservoir directly influences freeze/ thaw process; and
-the reservoir and recreational facilities create the potential for greater erosion from boat wakes.

***R11. We fully acknowledge that determining project share is exceedingly difficult. Determination of project share for locations along Box Canyon's shorelines is particularly difficult because erosion occurs on essentially the same***

***shoreline landforms, locations, and elevations as it did prior to the project, a circumstance unique within the literature we have reviewed to date.***

***The peer reviewer notes that no previous methodologies that successfully determine project share are cited, and the approach should be considered experimental. We agree. The new operating license for the project requires determination of shoreline erosion project share based on shoreline erosion monitoring. Moreover, and while we continue to review erosion plans and discussions from other projects, to date we have found no other projects, studies or other accounts that discuss determination of project share based on erosion monitoring data. We will continue to review this literature, and as the peer reviewer suggests, cite these accounts within the plan as we amend it.***

***We are measuring total erosion due to all factors at any given site, but we cannot separate erosion due to individual processes, because they all act together and are in fact interactive as noted in the literature (Gatto and Doe 1983; Gatto 1988; Lawson 1985). We will use process rating forms to determine the qualitative importance of the various processes at work at any given location. Also, we are not restricting project share to include only wind considerations; we will take into account water levels, which inherently considers the factors mentioned in the reviewer's comment.***

Third, the ability of the proposed methods to detect project share will vary within the reservoir. For example, where the project has greater influence on water level and slopes are steeper below Cusic Basin in zone 2, the Erosion Monitoring Plan may be able to distinguish project-share erosion at lower elevations on the bank. The seasonal nature of erosion also lends itself to determining project share in this area.

***R12. This may be correct, but no adjustment of the monitoring plan is called for.***

Fourth, it is unclear how the PUD determined the 'convention' for accepting that half of upslope erosion is caused by the project. While it is clear that river levels above 90,000 cfs are not controlled by the project, it is likely that undercutting at lower water levels could cause all of the erosion upslope (e.g. undercutting at a lower level triggers a mass movement that reaches far upslope).

***R13. The reviewer has misunderstood the convention; we do not assign half of upslope erosion to the project. As the plan explains at page 21, for the upslope part of an eroding shoreline profile never affected by backwater from Box Canyon Dam, but where that area may be partially predisposed to erosion due to erosion that occurs lower on the eroding profile (i.e., at elevations that are affected by Box Canyon backwater) one-half of the downslope project share is assigned to the upslope area. This convention is based on the rationale that because we do not know, and cannot know, the true (if there is such a thing) "project share", we assume a value half way between zero and the downslope share. We will amend the plan in an attempt to more clearly explain this.***

***The last sentence in the reviewer's comment is conjectural. Nevertheless, the reviewer may again misunderstand how project share is assigned to the upslope area. In the hypothetical case that the reviewer constructs where erosion of the upslope area has been determined to have been caused by erosion of the downslope area, the plan's procedure would assign the % project share of the downslope erosion also to the upslope area. This percentage would be 100% (i.e., "all") only if 100% of the downslope erosion was caused by the project.***

Considering all of these issues, quantification of project share should be considered a minimum, first-order estimate, and error or uncertainty for project share of erosion should be assessed.

***R14. Certainly it is true that the District's monitoring will only provide an estimate of project share, and we will incorporate discussion of uncertainty into both the plan and future reports. However, we are reluctant to accept that this is a "minimum, first-order estimate" given that the District's procedures for determining project share are far more detailed and founded on data than anything we have discovered to date within the literature. Also see previous comment R6 on error.***

3) Does the erosion monitoring plan contain the methodology and scientific rigor to identify the location, extent, and types of project-caused and project-exacerbated erosion processes on National Forest System lands?

There appears to be an adequate number of monitoring sites (8) located on USFS land.

***R15. We acknowledge that the number of sites on USFS land is adequate.***

Answers to Questions 1) and 2) apply here.

4) Will the plan methodology and frequency of sampling be capable of identifying significant new or recurring erosion areas along the reservoir?

Biannual surveys combined with surveys following large discharge events are adequate, particularly if the causative factors table is improved and mass wasting sites are mapped. Further, the biannual and larger event driven monitoring schedule is sufficient to meet the goals of the plan. Specific suggestions for improvement of the event/process table are given below in Recommendations.

***R16. We acknowledge that the strategy is adequate. We will make the suggested adjustments in the causative factors table and also will do the mass wasting mapping.***

Wave analysis and wave power approaches are generally adequate. However, the plan should consider monitoring for more than one year and also monitor duration of wave erosion by use of anemometers.

***R17. We acknowledge that the strategy is adequate. Also see previous comment R10 regarding duration of wave monitoring.***

5) Can the reviewer suggest alternative methods that might be easier, less costly, more effective, and yet be able to meet the objectives of the plan?

If the focus of the plan were shifted from vertical, along profile measurements of change, to horizontal bank recession (Figure 2), then less expensive monitoring techniques could be used at many of the 47 sites. These methods might include bank pins and measurement of retreat of the bluff face from a series of stakes placed well back of the eroding face.

***R18. We will report bank recession at top of bank from our survey data. Measuring only bluff retreat would yield much less information on rates and processes than do surveyed profiles. However, we can discuss this approach with the Forest Service and the Erosion Subcommittee.***

Since the entire shoreline is classified, the location and modern extent of erosion are well characterized. It may be more defensible, and less costly to relate shoreline erosion rate and severity to landform type, as discussed below.

***R19. Acknowledged.***

It would also be helpful to consider rates of erosion reported from other projects to help understand bank recession rates on Box Canyon in regional context. From data I have collected, the rates at Box Canyon are lower than Ross Lake and Lake Chelan, as well as other regional sites (Table 1).

***R20. We acknowledge that such information is available from other locations; we can include comparisons in annual monitoring reports.***

**Table 1. Rates of bank recession reported from other large hydroelectric projects in Washington State.**

| Reservoir | Vertical erosion# | Bank recession rate (feet/year)* |
|---|---|---|
| Ross Lake - estimated | 2.8 -9.2 ft | 1.0- 5.2 |
| Ross lake – observed** | n/a | 0.8-4.2 |
| Lake Chelan | 2-4 ft | 0-4.0 |
| Rufus Woods | n/a | 0-7.9 |
| Pend Oreille | n/a | 0-5.0 [correction: 0-1.0 DJM] |

#one-time estimate based on tree-root exposure
*see Figure 2 for horizontal bank recession geometry
**bank recession on Ross Lake monitored since 1994.

**Recommendations**

1) Clarify what is being measured in the plan and consider emphasizing bank recession instead of vertical changes on a transect (Figure 2). Understanding the net result of several processes and rate of bank recession will provide better guidance for prioritizing sites in an erosion control plan. If this approach is adopted, bank recession is less expensive to monitor than vertical erosion at 47 sites and more than 140 transects.

***R21. We will report bank recession. See previous comments R1 and R18. Also please note that the maximum rate of bank recession recorded at our monitoring sites is less than 1 foot/year. Maximum recession at any single transect is about 1.2 feet/year.***

2) Map the geology and stratigraphy of all shorelines and back-shore areas. It will be very difficult to meet Objective 3 without comprehensive classification. I understand that the PUD plans to collect this information in summer 2006. This will help with revision of rate classification at some sites (Pg. 21), and could be easily accomplished by referring to previously published geologic reports (e.g Carrara, 1996; Waitt and Thorson, 1983), the site classification, results of stratigraphic analyses by site, and the Pend Oreille County soil survey. Extrapolation of monitoring rates to non-monitored sites will be tenuous without this inventory.

***R22. We will map the geology and landforms of all shoreline and back-shore areas as suggested. Soil strata as geologic cross sections will be recorded at the monitoring sites. Strata of remaining shoreline will be inferred based on geology, landform and strata at the monitoring sites. Also see previous comment R9.***

On the Skagit Hydroelectric Project, shorelines were mapped as landforms. Landforms are large, easily recognized features of the landscape. Because each landform is created by discreet geologic processes, landform type accurately reflects shoreline geotechnical properties. An example of landform types that would be applicable to the Pend Oreille River are shown in Table 2. The Pend Oreille County soils survey listed soil types by three main sources of parent materials, which could loosely be called landforms. They included mountains and foothills, terraces and terrace escarpments, and floodplains and lake basins.

***R23. Such a classification system is likely useful, and we will implement this or a similar idea.***

**Table 2. Example of potential landform classification scheme for Box Canyon Project, with reservoir zone location (Figure 1) and Natural Resouces Conservation Service soil type.**

| Landform Type | Characteristics | Soil type |
|---|---|---|
| Valley Wall | Bedrock Canyon with colluvial soils Zone 1 | Mobate, Rasio |
| Glacial Valley Wall | Glacial till and drift on valley walls in Zones 1 and 2. | Newbill, Inkler |
| Floodplain | Cusic basin channel and gravel bars Zones 3 and 4 | Blueside and Kegel |
| Terrace <12 ft | Lacustrine terrace Zone 2 | Anglin and Cusic |

| | | |
|---|---|---|
| Terrace > 24 ft. | Outwash and lacustrine, Zones 1 and 2 | Bonner and Kie |
| Levee and other human | Variable, Zone 3 | n/a |

3) Consider more comprehensive and intensive monitoring of erosion processes, including currents, freeze/thaw, and other processes at a subset of sites. Based on my limited knowledge of the variability of the shoreline geology, I suggest 6-10 sites would be adequate. At each of these sites, for at least two years:

***R24. See previous comments R11.***

- Identify sites along the reservoir where bank geometry relative to the river channel predisposes them to higher rates of bank recession, such as the outside of meander bends, channel constrictions, and in the higher, more variable current velocity of zones 1 and 2 (i.e. downstream of Ruby Mountain). Measure current velocity at these and other sites to help understand the influence of the project on erosion associated with this process. Current velocity should also be monitored at various river/reservoir levels to assess vertical changes in bank material and erosion rates, which will help determine Project Share of erosion and links with mass wasting events.

***R25. We will amend the plan to incorporate these measurements of velocity. We agree these will help define which erosion processes are most important. They will also help define when erosion due to current may occur. We do not agree that they will help determine project share.***

- Include monitoring of sites in fine-grained (silt/clay) bank materials along north and east facing aspects that are prone to free/thaw processes. Develop methods such as use of bank pins and soil thermometers to quantify this process (Hooke, 1979; Gatto, 1988).

***R26. See previous comments R4 and R11.***

- Conduct wind and other process monitoring for more than one year to account for variations in weather, bank conditions, and runoff.

***R27. See previous comment R10.***

4) Add an objective on Page 6 of the Plan to record location of erosion on bank profile. Link the more qualitative post-large-event surveys with the biannual surveys. This could be easily accomplished by recording significant changes on bank profiles and maps.

***R28. We will record location and form of erosion on bank profiles. Post-large-event surveys and record of significant changes will occur as a matter of course in conducting surveys as part of executing the plan.***

5) Map and monitor the location of new sites and changes in mass movement activity. Locations of the sites and features should be linked to conditions and transects. Ultimately, they could be linked to erosion process, rate of bank recession, and vegetation manipulation by landowners.

***R29. See previous comments R5 and R16.***

6) Causative factor analysis. Specific ideas for improving this form include:

Trampling causative factor, use the following distinctions

a. high = development of ruts in mineral soil
b. moderate = all duff removed and mineral soils exposed
c. low = damage to living vegetation, but mineral soil exposed
d. not apparent = obvious

***R30. We will amend the plan to incorporate these trampling factors.***

Add a row for current erosion features:

a. high = distinct unidirectional current platform greater than 1 ft horizontally and/or vertically
b. moderate = distinct, but small current-eroded terrace 0.5 to 1 ft.
c. low = barely discernable current eroded terrace <0.5 ft.
d. not apparent

***R31. We will amend the plan to incorporate these velocity factors.***

7) Include figures in the Plan that explain some of the geometric relationships between the project, the river and the monitoring plan. Comprehending the complicated spatial distribution of erosion both along transects and longitudinally within the project was difficult. I developed two figures to help people not so familiar with the erosion monitoring plan understand processes. Figure 1 shows how the project affects water levels and erosion in four zones along the project from Newport to Albeni Dam. Figure 2 shows various geometric components of reservoir shoreline erosion. It would also be helpful to include examples of transect data and a summary table of erosion for the entire period of monitoring.

***R32. We agree that some diagrams or figures can be useful. Diagrams like reviewer's Figure 1 can be included within monitoring reports once the landform and stratigraphy mapping are complete.***

***R33. We will illustrate pertinent bank features upon the profiles provided in annual monitoring reports.***

***R34. Transect data and erosion tables for the period of record are included in annual reports.***

## References

Carrara, P. E, E.P. Kiver, and D.F. Stradling, 1996. The southern limit of Cordilleran ice in the Colville and Pend Oreille valleys of northeastern Washington during the late Wisconsin Glaciation. Canadian Journal of Earth Sciences 33, p. 769-778.

Chelan County Public Utility District Number 1, 2000, Inventory of shoreline erosion, Lake Chelan and bypass reach. FERC project 637.

Gatto, L.W. and W.W. Doe III, 1983, Historical Bank Recession at Selected sites along Corps of Engineers Reservoirs, U. S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory Special Report 83-30, 103 pp.

Gatto, L.W. 1988. Techniques for measuring reservoir bank erosion. U. S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory Special Report 88-3, 27p.

Hooke, J.M., 1979. An analysis of the process of river erosion. Journal of Hydrology, 42, p.39-62.

Lawson, D.E. 1985. Erosion of northern reservoir shores; An analysis and application of pertinent literature. U. S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory Monograph 85-1198p.

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Riedel, J.L., 1989. Conditions or reservoir and stream bank erosion associated with the Skagit Hydroelectric Project.

Waitt, R.B., Jr. and R.M. Thorson, 1983, The Cordilleran Ice Sheet in Washington, Idaho, and Montana. In Late-Quaternary Environments of the United States, Vol. 1, The Late Pleistocene, edited by S.C. Porter, p. 54-70. University of Minnesota Press, Minneapolis.

**Reviewer Biographical Summary**

Jon Riedel is a geologist with the National Park Service stationed at North Cascades National Park Service Complex in Washington. He is a licensed geologist with the State of Washington, holds Bachelor of Science and Master of Science degrees from the University of Wisconsin, and is completing a Ph.D. at Simon Fraser University in Vancouver, British Columbia. Jon has 18 years experience as a geologist in Washington, and extensive experience with erosion associated with hydroelectric projects. In 1998 he completed a review of existing conditions of reservoir and stream bank erosion associated with the Skagit Hydroelectric project, which led to development of a $1.345M erosion control plan. This plan included monitoring of shoreline erosion at five sites on Ross Lake. In the late 1990s Jon was also involved with the re-licensing of the Baker River and Lake Chelan hydroelectric projects. On Lake Chelan in central Washington, Jon participated as a member of the erosion workgroup, which completed an inventory of shoreline erosion sites and analysis of erosion processes along the 50-mile long reservoir. In 2005 he completed a $1.1M erosion control plan for NPS sites within Lake Chelan National Recreation Area at the north end of Lake Chelan.

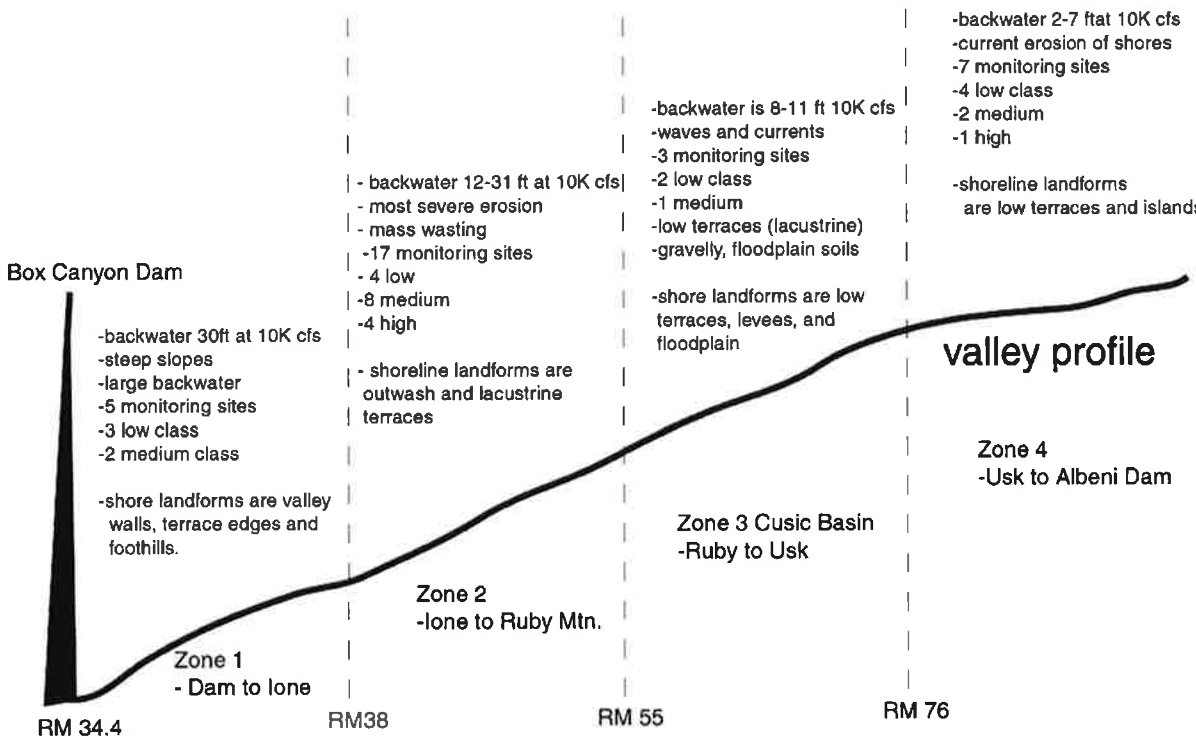



Figure 1. Erosion zones along a longitudinal profile at Box Canyon Hydroelectric Project.

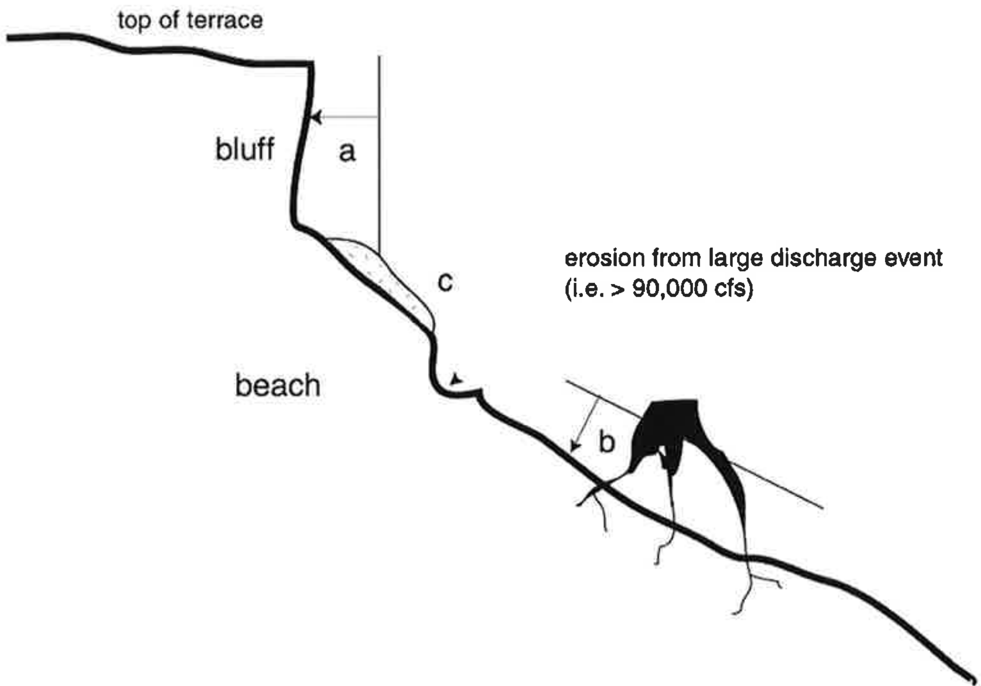
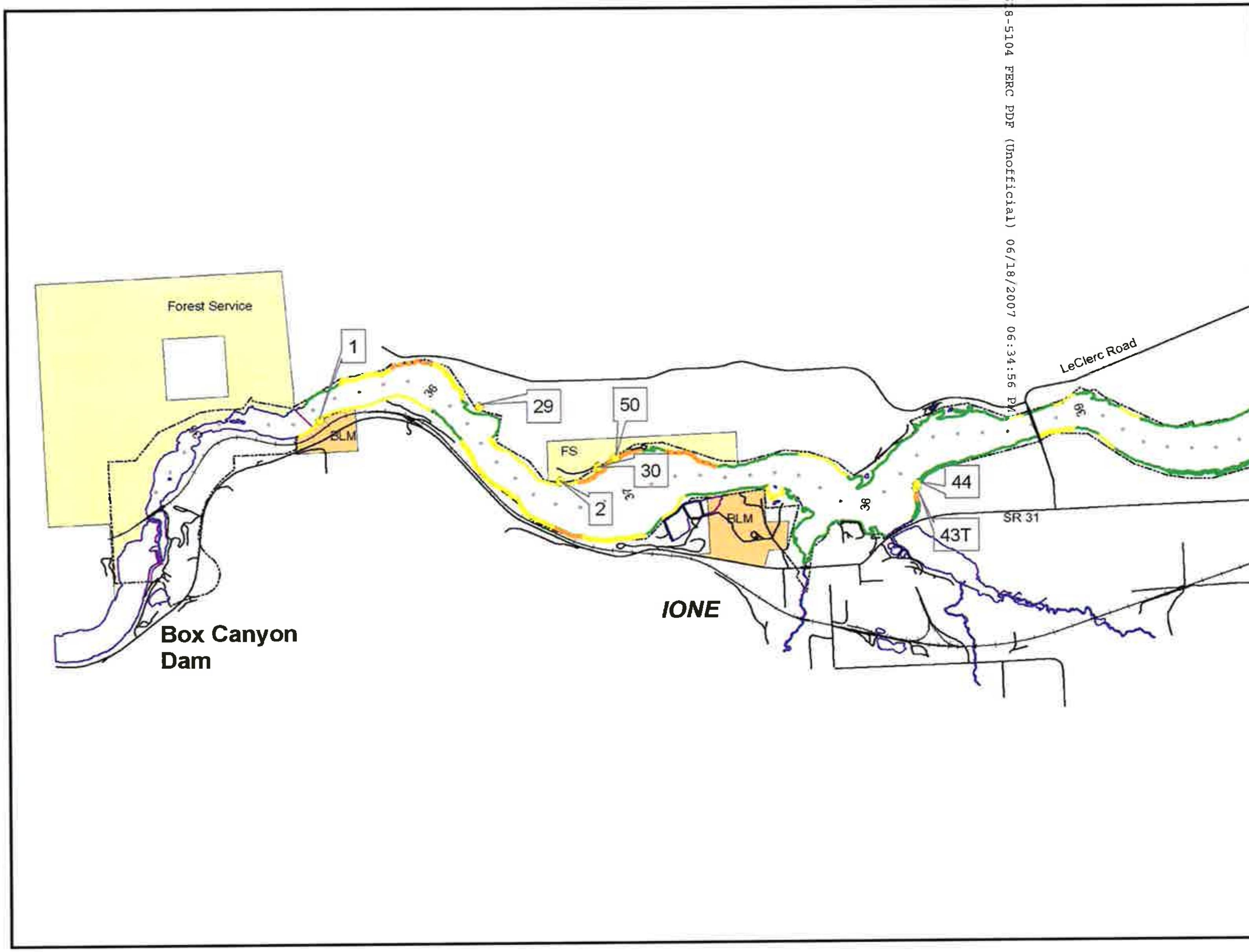


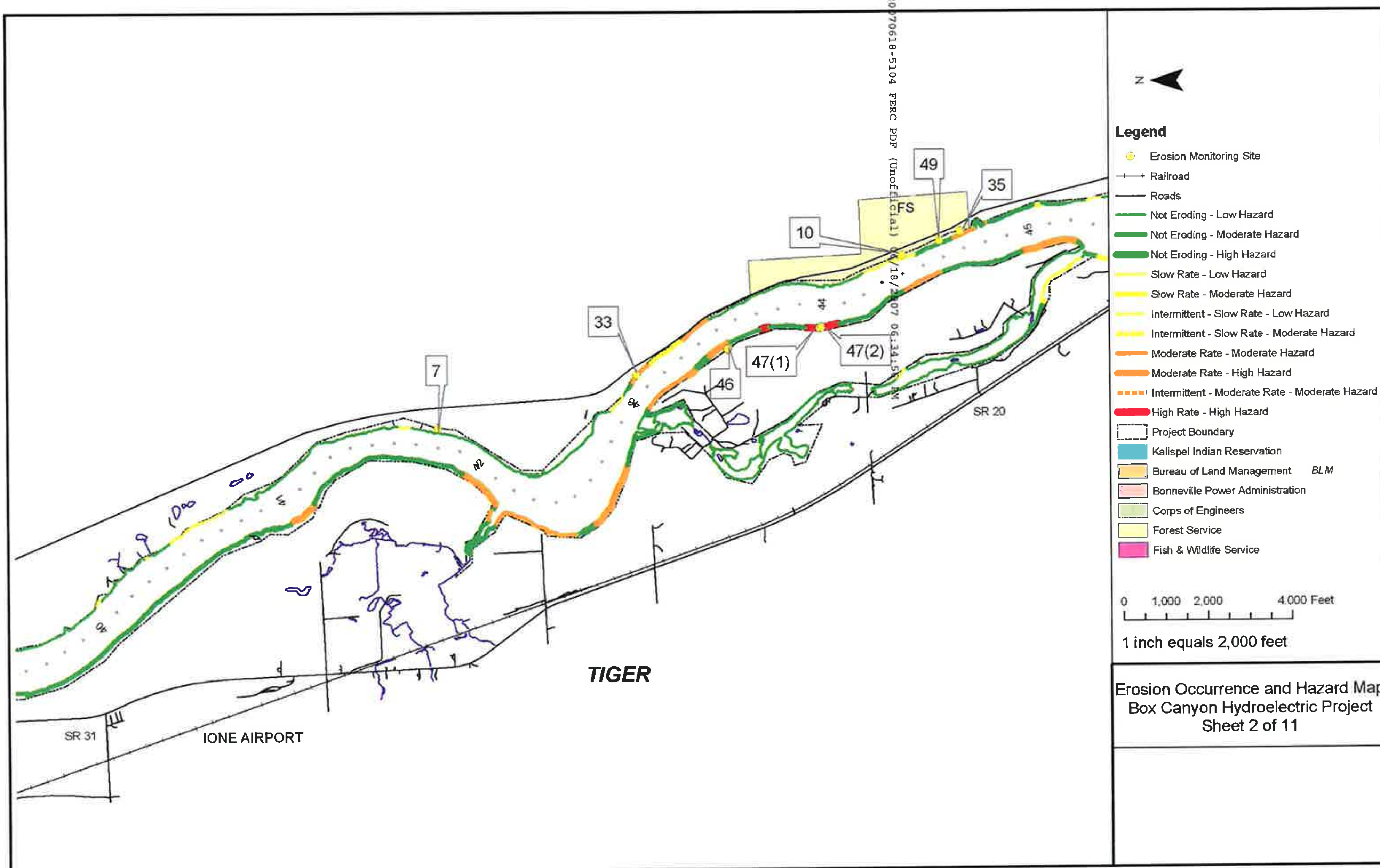

Figure 2. Reservoir shoreline erosion geometric concepts, modified from Lawson, 1986. Note (a) is bluff (bank) recession and (b) vertical erosion, and (c) temporary deposition.

# APPENDIX B

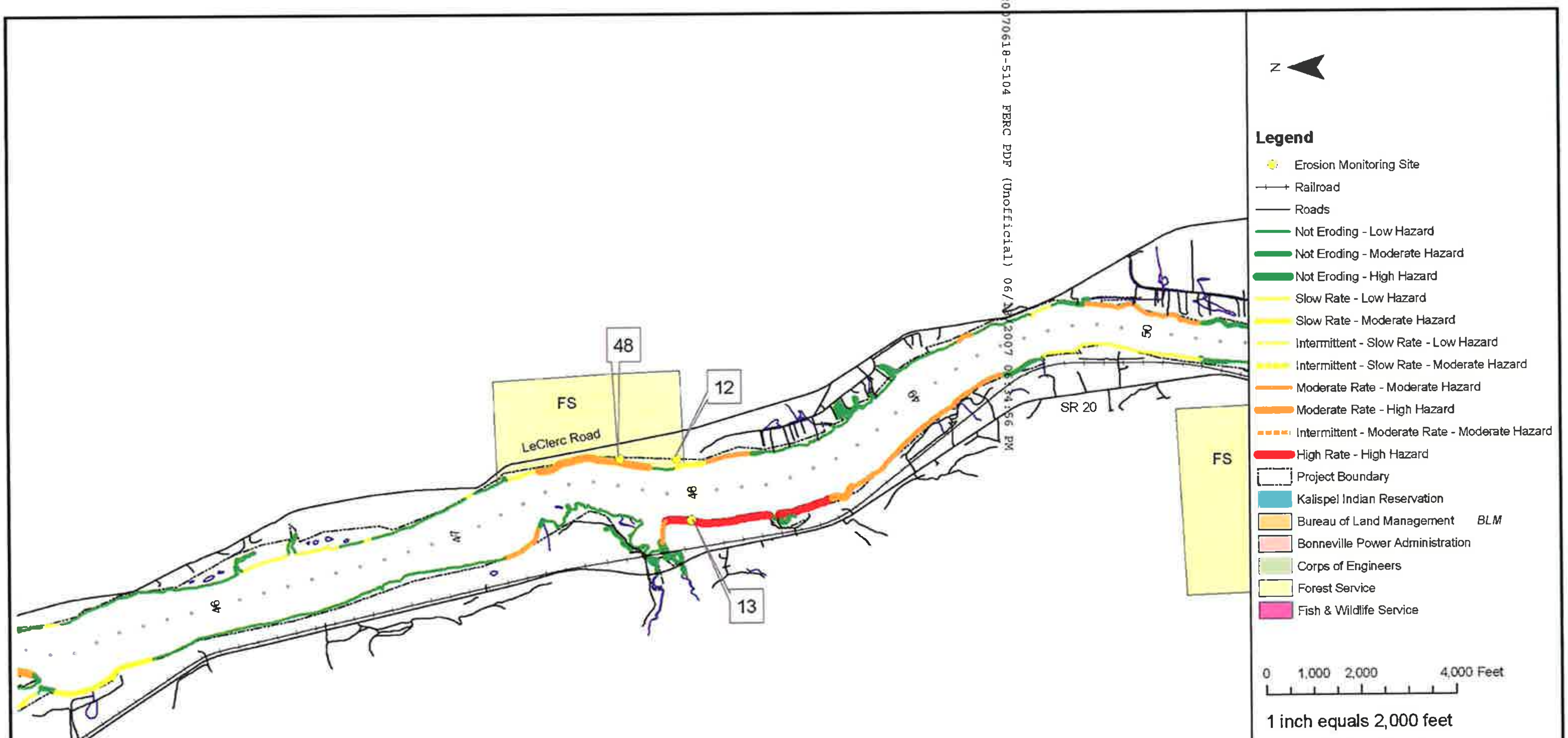
# UPDATED EROSION MONITORING SITE MAPS (MAY 2007)



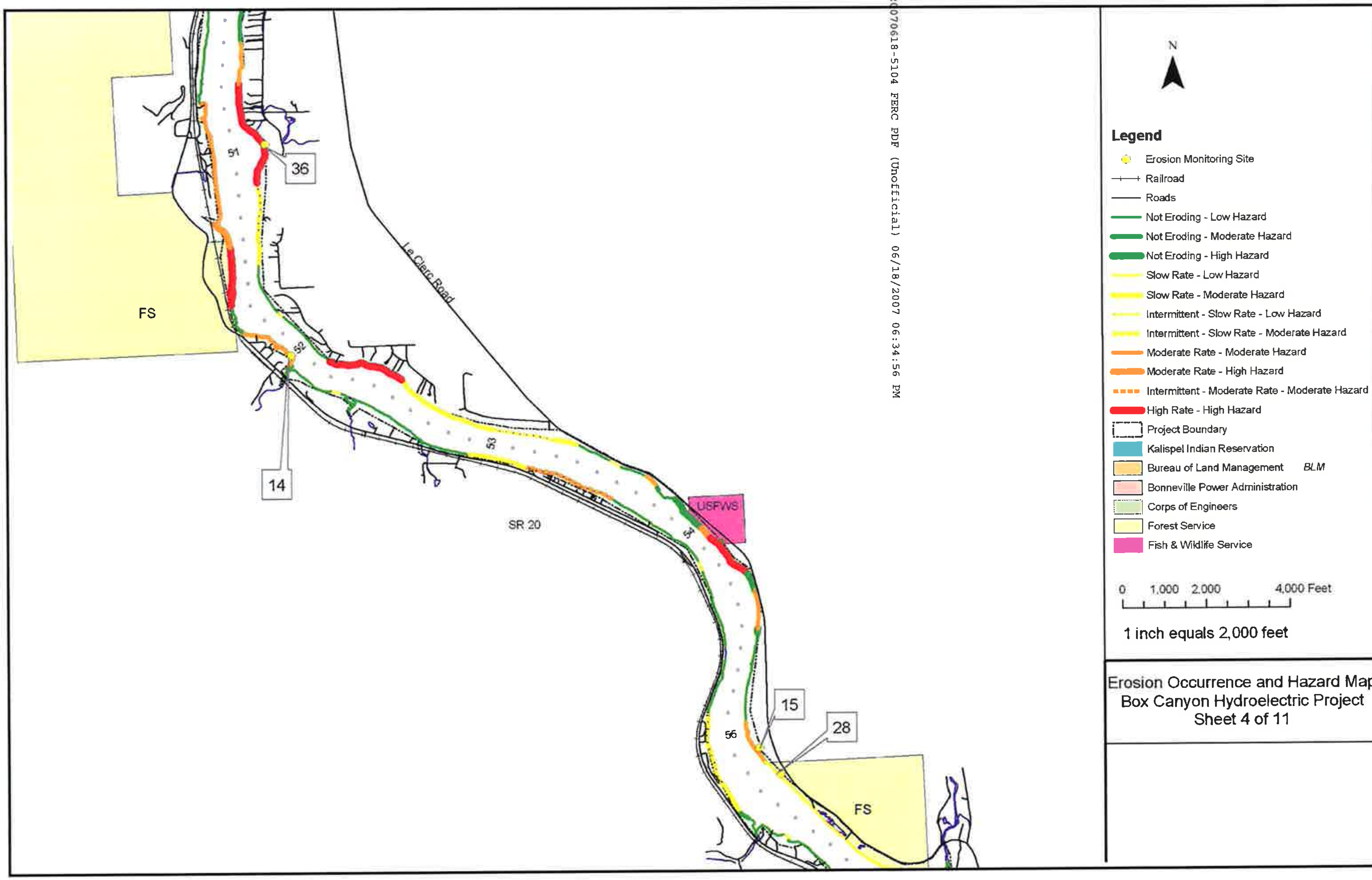

Erosion Occurrence and Hazard Map
Box Canyon Hydroelectric Project
Sheet 1 of 11




Erosion Occurrence and Hazard Map
Box Canyon Hydroelectric Project
Sheet 2 of 11




Erosion Occurrence and Hazard Map
Box Canyon Hydroelectric Project
Sheet 3 of 11


FS
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36
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14
Le Clerc Road
53
SR 20
USFWS
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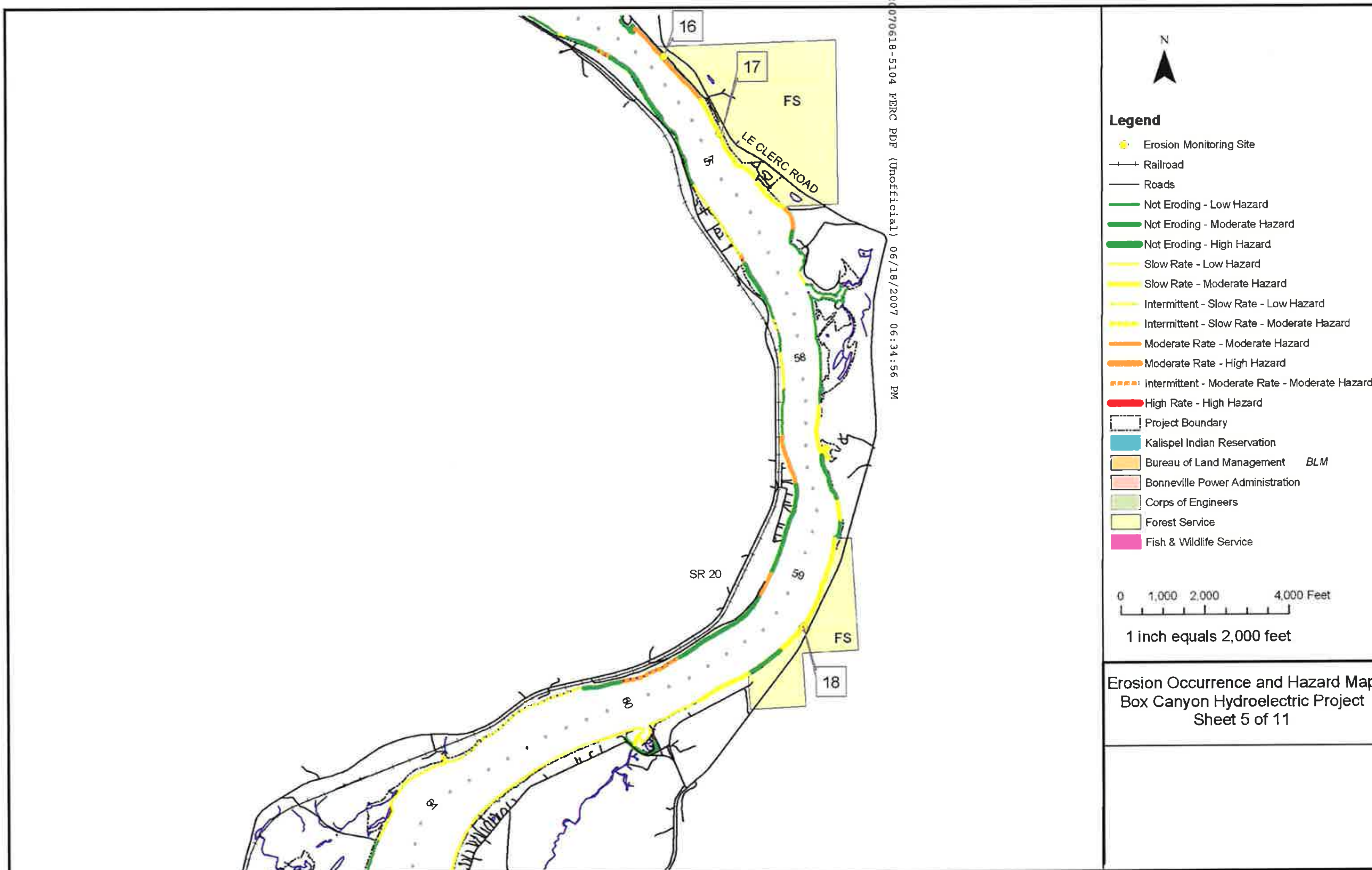
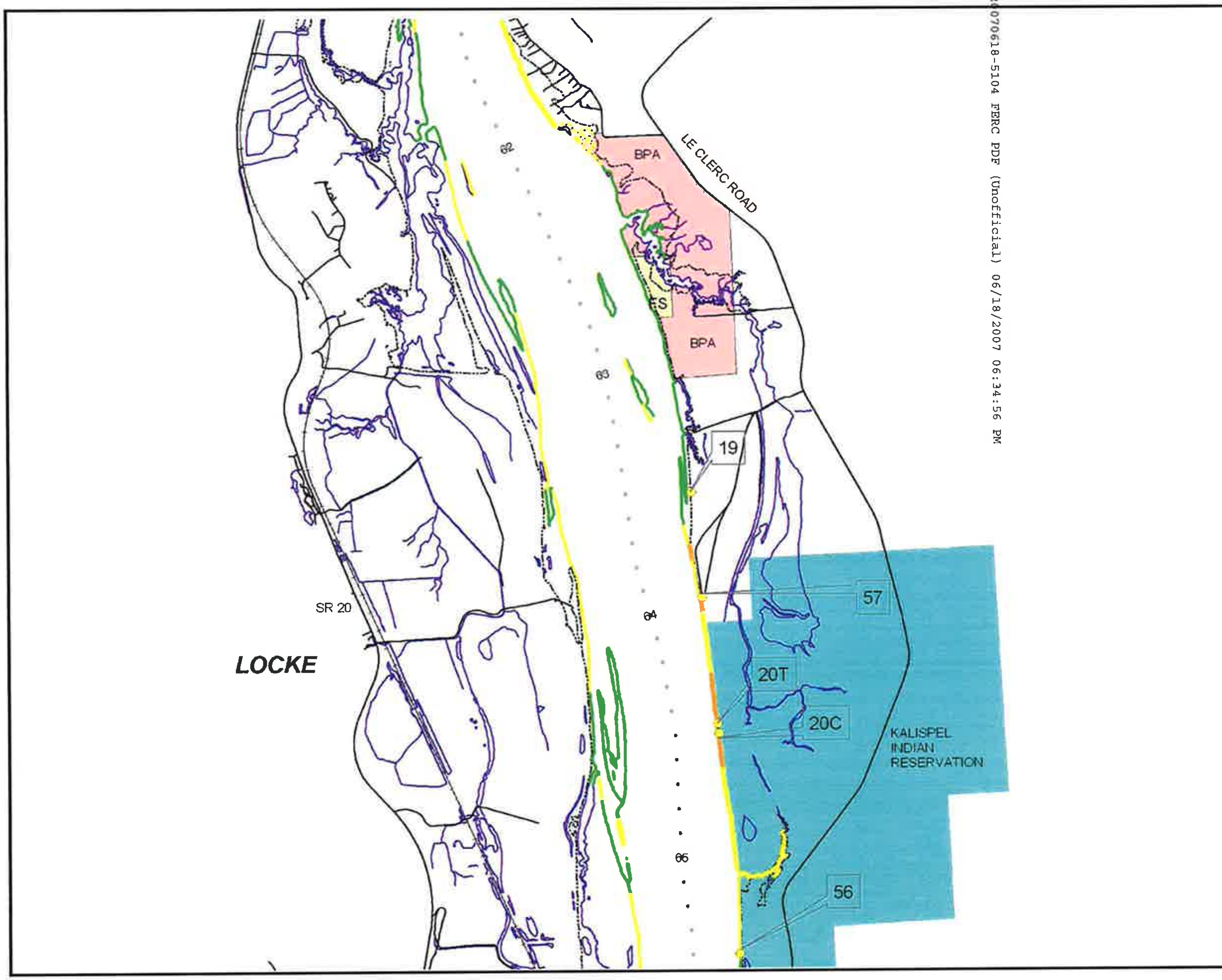
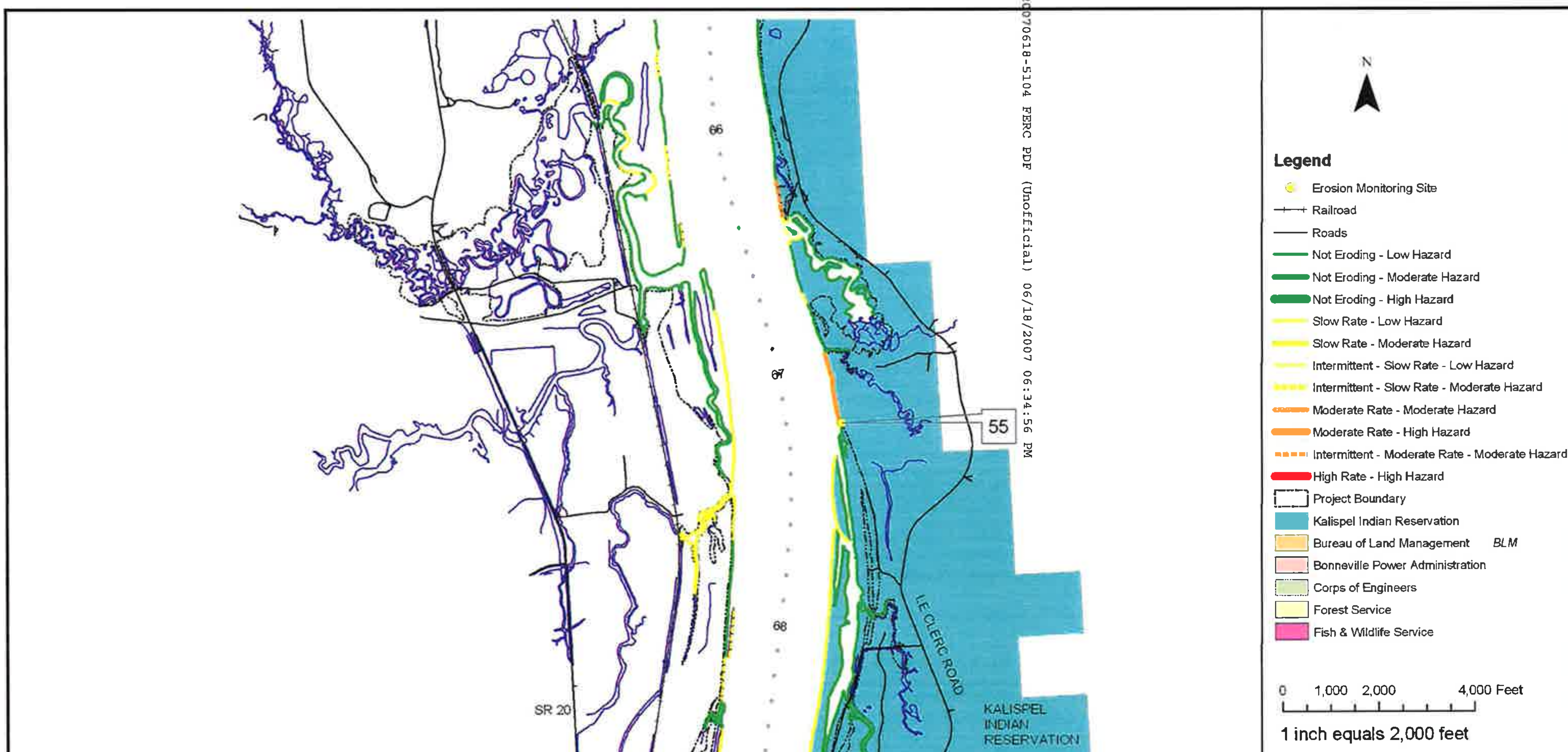
FS
N
Legend
Erosion Monitoring Site
Railroad
Roads
Not Eroding - Low Hazard
Not Eroding - Moderate Hazard
Not Eroding - High Hazard
Slow Rate - Low Hazard
Slow Rate - Moderate Hazard
Intermittent - Slow Rate - Low Hazard
Intermittent - Slow Rate - Moderate Hazard
Moderate Rate - Moderate Hazard
Moderate Rate - High Hazard
Intermittent - Moderate Rate - Moderate Hazard
High Rate - High Hazard
Project Boundary
Kalispel Indian Reservation
Bureau of Land Management BLM
Bonneville Power Administration
Corps of Engineers
Forest Service
Fish & Wildlife Service
0 1,000 2,000 4,000 Feet
1 inch equals 2,000 feet
Erosion Occurrence and Hazard Map
Box Canyon Hydroelectric Project
Sheet 4 of 11



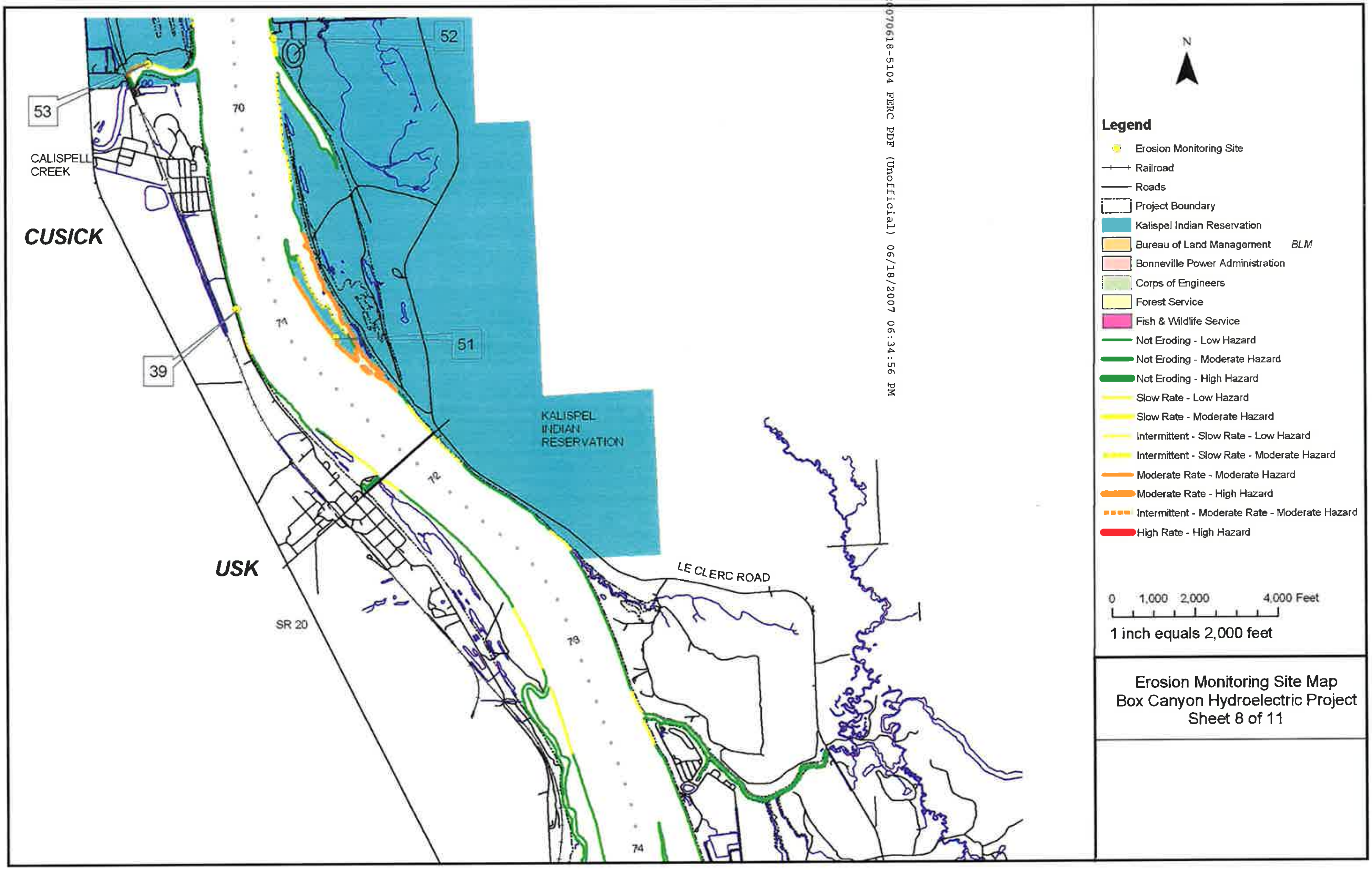

Erosion Occurrence and Hazard Map
Box Canyon Hydroelectric Project
Sheet 5 of 11



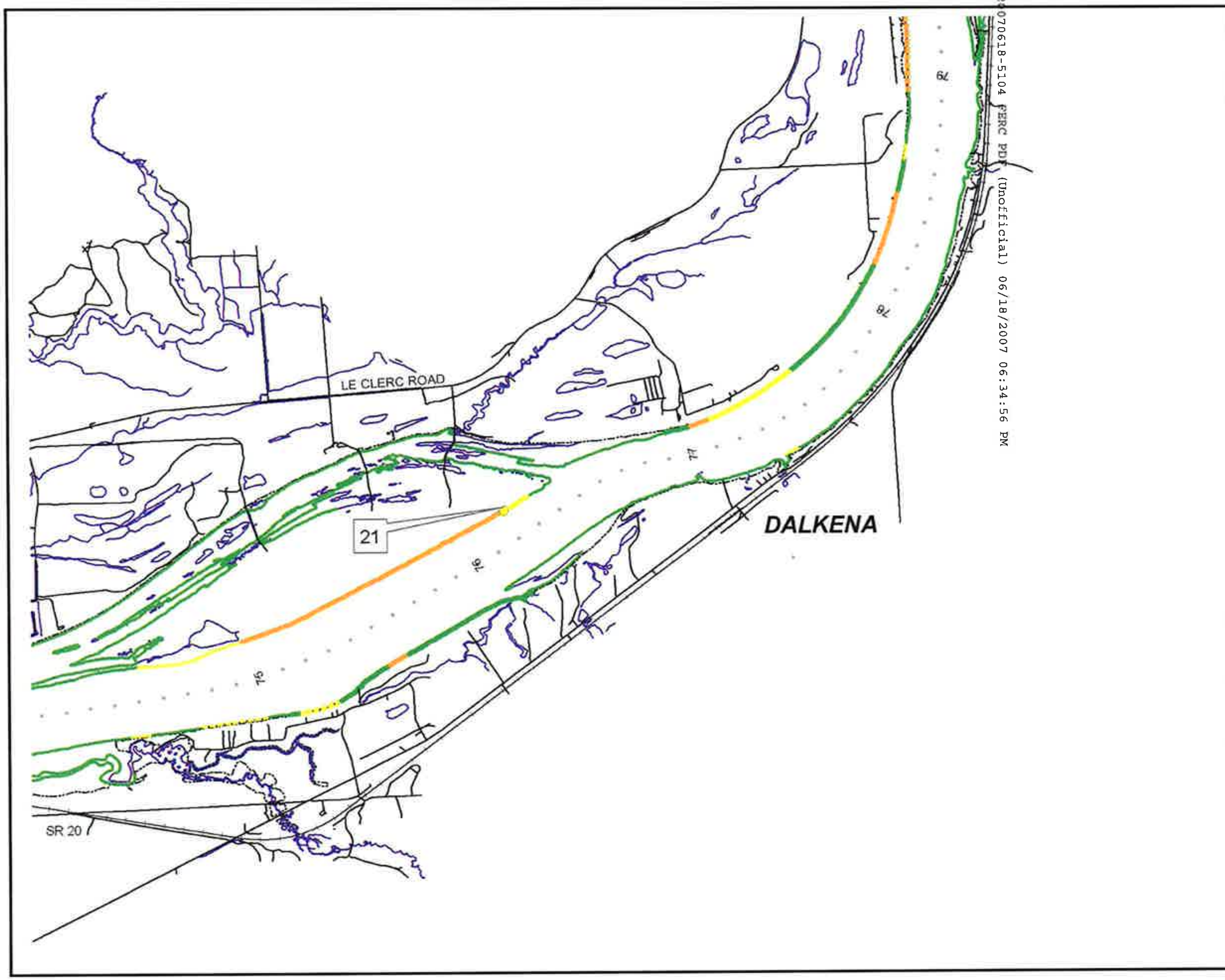

Erosion Occurrence and Hazard Map
Box Canyon Hydroelectric Project
Sheet 6 of 11



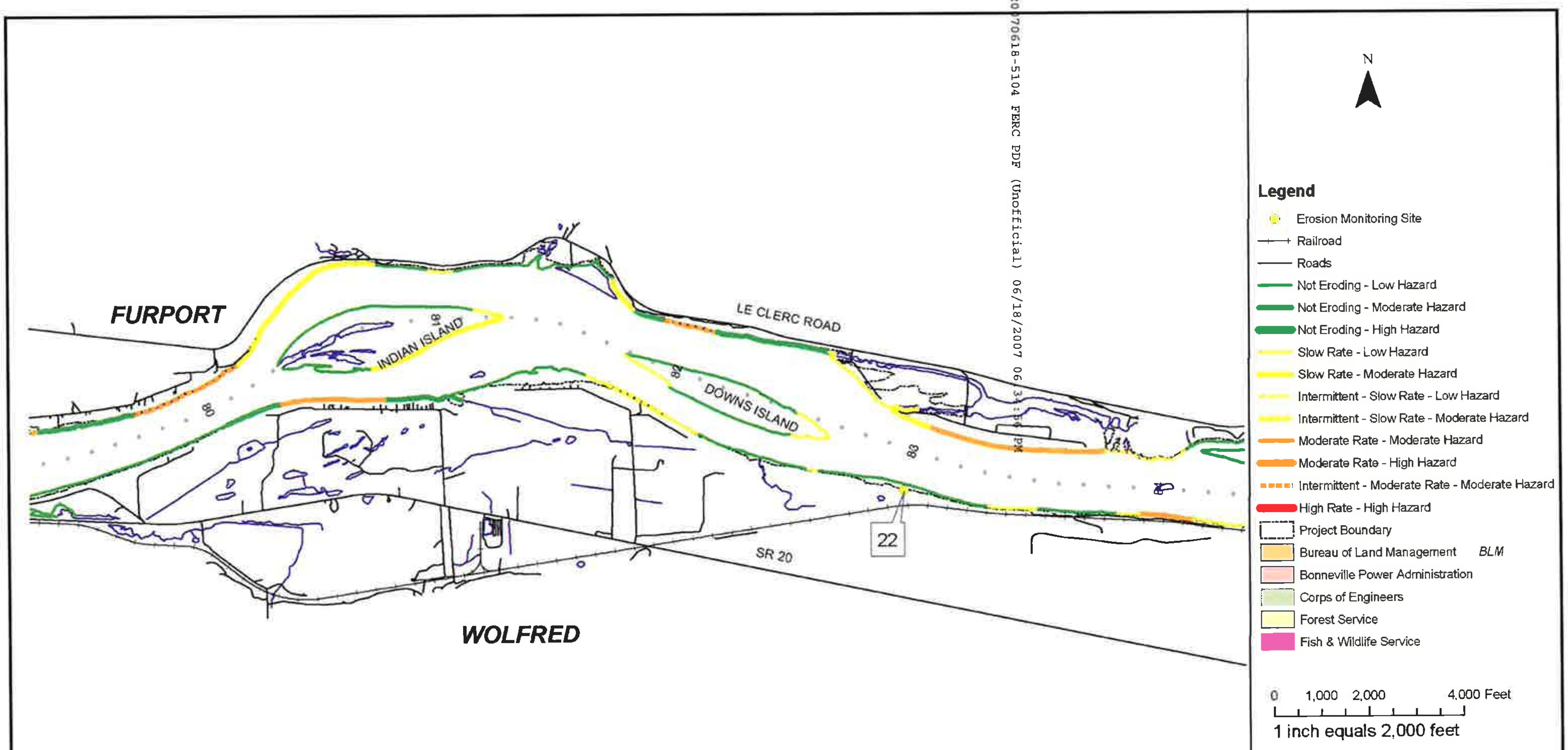

Erosion Occurrence and Hazard Map
Box Canyon Hydroelectric Project
Sheet 7 of 11



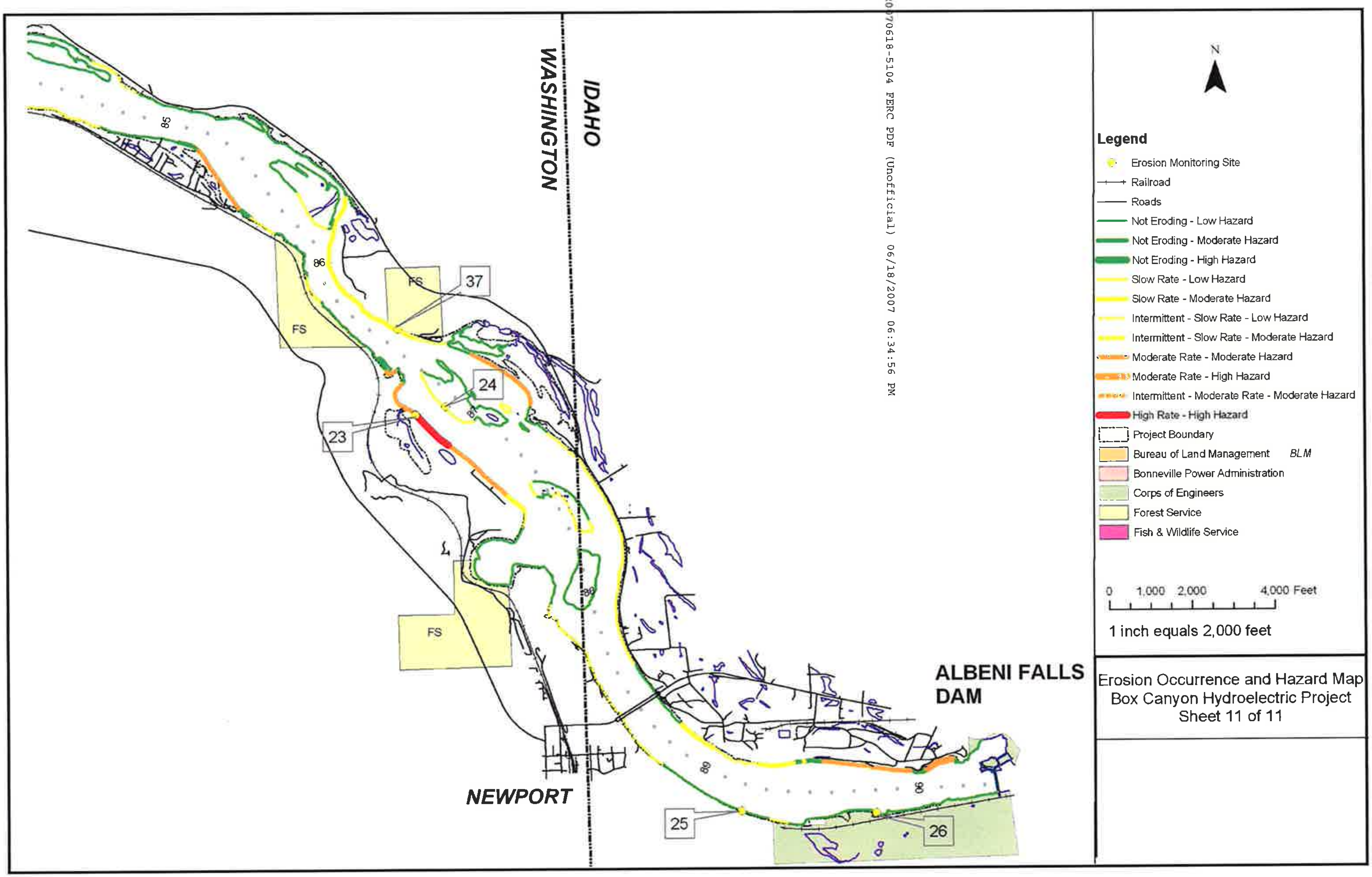

Erosion Monitoring Site Map
Box Canyon Hydroelectric Project
Sheet 8 of 11




Erosion Occurrence and Hazard Map
Box Canyon Hydroelectric Project
Sheet 9 of 11




Erosion Occurrence and Hazard Map
Box Canyon Hydroelectric Project
Sheet 10 of 11


IDAHO
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Legend
Erosion Monitoring Site
Railroad
Roads
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Intermittent - Moderate Rate - Moderate Hazard
High Rate - High Hazard
Project Boundary
Bureau of Land Management BLM
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Corps of Engineers
Forest Service
Fish & Wildlife Service
0 1,000 2,000 4,000 Feet
1 inch equals 2,000 feet
Erosion Occurrence and Hazard Map
Box Canyon Hydroelectric Project
Sheet 11 of 11

# APPENDIX C

# GEOTECHNICAL ENGINEERING STUDY

**Pend Oreille County Public Utility District**

Administrative Offices - P.O. Box 190 • Newport, WA 99156 • (509) 447-3137 • FAX (509) 447-5824
Box Canyon Hydro Project - P.O. Box 547 • Ione, WA 99139 • (509) 446-3137 • FAX (509) 447-6790

August 28, 2006

Ms. Magalie Roman Salas, Secretary
Federal Energy Regulatory Commission
Office of the Secretary
888 First St. NE, Room 1-A
Washington, D.C. 20426

SUBJECT: Box Canyon Hydroelectric Project, FERC No. 2042
Geotechnical Engineering Study

Dear Ms. Salas:

The Public Utility District No.1 of Pend Oreille County (District), licensee of the Box Canyon Hydroelectric Project (Project) files the attached Geotechnical Engineering Study to fulfill the requirements of the Department of Interior's (DOI) 4(e) Condition No. 3.E in Appendix A to the District's License Order for the Project (112 FERC 61,055).

DOI's Condition No. 3.E required the District to develop a plan for conducting geotechnical engineering studies on the Kalispel Indian Reservation. The District met with the Tribe representative on the reservation and identified location for study wells.

If you have any questions regarding this letter or the attached information, please contact me at (509) 447-9331.

Sincerely,

Mark Cauchy
Director of Environmental and Regulatory Affairs

cc: Attached service list

**SERVICE LIST**

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Garcia & Associates
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Bozeman, MT 59718

Mr. Jim Scheel
Pend Oreille County Public Utility District
P.O. Box 547
Ione, WA 99139

# Geotechnical Engineering Studies
# for
# Box Canyon Hydroelectric Project
# FERC No. 2042

**Submitted by**
**Public Utility District No. 1 of Pend Oreille County**
**Newport, Washington**

**Prepared by**

**Western Watershed Analysts**

**1339 Highland Avenue**
**Clarkston, WA 99403-2961**

**August 2006**

# Box Canyon Hydroelectric Project
# FERC No. 2042
# Geotechnical Engineering Studies

Western Watershed Analysts and/or its subcontractors (WWA) will coordinate work with the Kalispel Tribe (Tribe) to accomplish the geotechnical studies for the District called for in the Box Canyon Hydroelectric Project License[1]:

- Confer with the Tribe to coordinate potential locations for groundwater monitoring and bank stability modeling.
- Research available geologic studies, soil surveys, nearby well logs, etc. to obtain readily available geologic and/or soil conditions at each potential location.
- Coordinate with the Tribe to field locate three groundwater monitoring sites along the Tribe's shoreline. These three sites will be located adjacent to three of the eight shoreline erosion monitoring sites also to be established along the KIR shorelines.
- At each of the three groundwater monitoring sites, bore two groundwater monitoring wells at varying distances from the bank, using either truck-mounted or track-mounted drill rigs, depending on ease of access to the site. Feasibility of using hand-operated drilling equipment will also be explored if truck-mounted equipment is unacceptable to the Tribe.
- Collect core samples at each location for laboratory analysis of soil properties – depth from top of bank to low water level, using either Shelby tubes or split spoon samplers.
- Analyze soil parameters from core samples, including density, permeability, shear strength, and grain size distribution, from which can be derived the parameters necessary for modeling groundwater seepage and bank stability (hydraulic conductivity, friction angle, cohesion, erodibility). Soil parameter tests will be conducted on each separate layer of materials encountered in each sample at each location.
- Perform electronic cone penetration tests at each site to measure in situ cohesion of soils.
- Perform slug test or short-term pumping test at one monitoring well at each site to measure in situ permeability of soils.
- Install groundwater level monitors and data loggers in the wells drilled at each site. Data loggers can be programmed to record groundwater levels at essentially any desired frequency, e.g., daily for most periods of the year, or hourly during (known) periods of more rapid reservoir drawdown.

[1] 112 FERC 61,055 (2005), Appendix A, DOI 4(e) Condition 3.E.

- Retrieve data from monitoring wells monthly or quarterly, as needed.
- Employ Geo-Slope International's (GSI) SEEP/W or other similar model(s) to simulate the dissipation of excess pore pressure for reservoir drawdown at a rate of 3 inches per hour, at natural rates of drawdown that may exceed 3 inches per hour, and for any operating excursions where drawdown exceeds 3 inches per hour, at each of the eight sites.
- Employ the Agricultural Research Service (ARS) Bank Stability and Toe Erosion Model (BSM), or other similar model, to estimate the bank Factor of Safety (FOS) due to reservoir drawdown at a rate of 3 inches per hour at each of the eight sites; an FOS of 1.0 or less indicates instability, FOS of 1.0 to approximately 1.3 are considered conditionally stable, and FOS greater than approximately 1.3 are considered stable.
- Prepare a report summarizing the soil characteristics and modeling results at all eight sites.

# APPENDIX D

# SEPTEMBER 29, 2006 FERC ORDER APPROVING GEOTECHNICAL ENGINEERING STUDY

UNITED STATES OF AMERICA 116 FERC ¶ 62, 243
FEDERAL ENERGY REGULATORY COMMISSION

Public Utility District No. 1 of Pend Oreille County

Project No. 2042-084

ORDER APPROVING GEOTECHNICAL ENGINEERING STUDY PLAN, DEPARTMENT OF INTERIOR 4(e) CONDITION 3.E

(Issued September 29, 2006)

On August 29 and supplemented on September 21, 2006, Public Utility District No. 1 of Pend Oreille County (PUD), licensee, filed its Geotechnical Engineering Study Plan, pursuant to the Order Issuing New License issued July 11, 2005[5] and Department of the Interior 4(e) Condition 3.E in Appendix A for the Box Canyon Hydroelectric Project. The project is located on the Pend Oreille River in northeastern Washington and northwestern Idaho.

LICENSE REQUIREMENTS

As part of the Section 4(e) Implementation and Monitoring Plan (IMP) required by Condition No. 1, the Licensee is required to develop a plan for conducting geotechnical engineering studies on the Kalispel Indian Reservation (KIR), that should include:

*1. Accurate field surveys of the shoreline profile at 8 erosion monitoring transects located on the KIR. The eight transects shall include the one at river mile 64.5 identified in the Erosion Monitoring Plan the Licensee filed in response to the Commission's February 27, 2001, Additional Information Request (AIR), as well as 7 additional erosion monitoring transects located on the KIR and identified through consultation with the Secretary and the Tribe. The Licensee shall coordinate the locations of the erosion monitoring transects with data needs for other resources, such as cultural resources and fisheries resources, to maximize the value of the data collected.*

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5 112 FERC & 61,055 (2005)

*2. Monitoring of shoreline embankment ground water elevations with respect to a fixed elevation reference to determine changes in the phreatic surface in response to reservoir level fluctuations.*

*3. Incorporation of soil/site parameters (including, but not limited to, stratigraphy, friction angle, cohesion, graduation, unit weight, permeability, and ground water level) into a quantitative slope stability model to determine how the 3 inch-per-hour drawdown rate limit affects KIR shorelines. The model can be calibrated with field measurements acquired during erosion monitoring (described in Paragraph F) with updates included in the Annual Reports required by Condition No. 1.*

LICENSEE'S PLAN

PUD's plan includes: (1) Coordinate with the Tribe to identify potential locations for groundwater monitoring and bank stability modeling, (2) Obtain readily available geologic, soil conditions at each potential location, (3) Coordinate with the Tribe to field locate three groundwater monitoring sites along the Tribe's shoreline, (4) At each of the three groundwater monitoring sites, bore two groundwater monitoring wells at varying distances from the bank, (5) Collect core samples at each location for laboratory analysis of soil properties, and analyze soil parameters for modeling groundwater seepage and bank stability, (6) Perform electronic cone penetration tests at each site to measure in situ cohesion of soils, and slug test or short-term pumping test at one monitoring well at each site to measure in situ permeability of soils, (7) Install groundwater level monitors and data loggers in the wells drilled at each site to record groundwater levels, (8) Retrieve data from monitoring wells monthly or quarterly, as needed, (9) Employ Geo-Slope International's SEEP/W or other similar model(s) to simulate the dissipation of excess pore pressure for reservoir drawdown at a rate of 3 inches per hour, at natural rates of drawdown that may exceed 3 inches per hour, and for any operating excursions where drawdown exceeds 3 inches per hour, at each of the eight sites, (10) Employ the Agricultural Research Service Bank Stability and Toe Erosion Model, or other similar model, to estimate the bank Factor of Safety due to reservoir drawdown at a rate of 3 inches per hour at each of the eight sites, and (11) Prepare a report summarizing the soil characteristics and modeling results at all eight sites.

On March 30, 2006, representatives of PUD and the Kalispel Tribe visited the perspective sites along the Pend Oreille River to locate the wells for geotechnical studies. PUD provided a final copy of the Geotechnical Study Plan to the Department of the Interior on August 18, 2006 and to the Kalispel Tribe on August 21, 2006.

CONCLUSIONS

PUD coordinated with the Tribe to accomplish the Geotechnical Engineering Studies Plan. The plan was distributed to the Department of the Interior and the Kalispel

Tribe in August 2006. No comments were received by PUD. The plan satisfies the requirements of Department of the Interior 4(e) Condition 3.E for the Box Canyon Hydroelectric Project and is approved in this order.

The Director orders:

(A) The Geotechnical Engineering Studies Plan, filed August 29, 2006, pursuant to the Order Issuing New License and the Department of the Interior 4(e) Condition 3.E for the Box Canyon Hydroelectric Project is approved.

(B) This order constitutes final agency action. Requests for rehearing by the Commission may be filed within 30 days from the date of issuance of this order, pursuant to 18 CFR § 385.713.

Mohamad Fayyad
Engineering Team Lead
Division of Hydropower Administration
and Compliance

# APPENDIX E

# SURVEYED SHORELINE MONITORING DATA

## Table E-1. Monitoring Survey Results Spring 2000 to Spring 2001

| **EROSION RATE CLASS** | **BANK HEIGHT CLASS** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **< 12 ft. (Low)** | | | **12 - 24 ft. (Moderate)** | | | **> 24 ft. (High)** | | |
| **Not Active** | Site 7 | Site 19 | Site 25 | Site 12 | Site 22 | Site 39 | Site 29 | Site 44 | |
| Transect 1 | -0.048 | -0.194 | | -0.051 | -0.058 | -0.011 | | | |
| Transect 2 | -0.117 | -0.181 | | -0.035 | -0.035 | -0.031 | | | |
| Transect 3 | 0.003 | -0.140 | | -0.219 | -0.120 | 0.042 | | | |
| **Average (Not)** | **-0.113 ft.** | | | **-0.058 ft.** | | | **0.000 ft.** | | |
| **Slow** | Site 24 | Site 26 | Site 28 | Site 10 | Site 17 | Site 18 | Site 1 | Site 2 | Site 37 |
| Transect 1 | -0.022 | | | | -0.063 | -0.030 | | | -0.078 |
| Transect 2 | 0.017 | | | | -0.078 | 0.032 | | | -0.286 |
| Transect 3 | 0.041 | | | | -0.060 | -0.094 | | | -0.062 |
| **Average (Slow)** | **0.012 ft.** | | | **-0.049 ft.** | | | **-0.142 ft.** | | |
| **Moderate** | Site 15 | Site 20C | Site 33 | Site 16 | Site 21 | Site 35 | Site 14 | Site 30 | Site 46 |
| Transect 1 | -0.081 | -0.238 | -0.094 | -0.201 | -0.099 | | | | |
| Transect 2 | -0.059 | -0.115 | -0.113 | -0.163 | -0.032 | | | | |
| Transect 3 | -0.061 | -0.201 | -0.058 | -0.184 | -0.084 | | | | |
| **Average (Mod)** | **-0.113 ft.** | | | **-0.127 ft.** | | | **0.000 ft.** | | |
| **High** | Does not occur | | | Site 13 | Site 23 | | Site 36 | Site 47 | |
| Transect 1 | | | | 0.098 | | | -0.035 | | |
| Transect 2 | | | | -0.049 | | | -0.010 | | |
| Transect 3 | | | | -0.042 | | | 0.067 | | |
| **Average (High)** | | | | **0.002 ft.** | | | **0.007 ft.** | | |

## Table E-2. Monitoring Survey Results Spring 2001 to Fall 2001

| EROSION RATE CLASS | BANK HEIGHT CLASS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | < 12 ft. (Low) | | | 12 - 24 ft. (Moderate) | | | > 24 ft. (High) | | |
| **Not Active** | Site 7 | Site 19 | Site 25 | Site 12 | Site 22 | Site 39 | Site 29 | Site 44 | |
| Transect 1 | -0.007 | 0.085 | 0.032 | -0.080 | 0.073 | -0.124 | | 0.005 | |
| Transect 2 | -0.018 | 0.070 | 0.032 | -0.122 | 0.050 | -0.048 | | -0.108 | |
| Transect 3 | -0.083 | 0.073 | 0.024 | -0.105 | 0.073 | 0.033 | | -0.027 | |
| **Average (Not)** | **0.023 ft.** | | | **-0.028 ft.** | | | **-0.043 ft.** | | |
| **Slow** | Site 24 | Site 26 | Site 28 | Site 10 | Site 17 | Site 18 | Site 1 | Site 2 | Site 37 |
| Transect 1 | 0.059 | 0.014 | | | 0.019 | -0.082 | | | -0.052 |
| Transect 2 | 0.004 | -0.003 | | | 0.028 | -0.074 | | | 0.205 |
| Transect 3 | 0.041 | 0.034 | | | 0.021 | 0.009 | | | -0.016 |
| **Average (Slow)** | **0.025 ft.** | | | **-0.013 ft.** | | | **0.046 ft.** | | |
| **Moderate** | Site 15 | Site 20C | Site 33 | Site 16 | Site 21 | Site 35 | Site 14 | Site 30 | Site 46 |
| Transect 1 | 0.012 | 0.096 | -0.004 | 0.065 | 0.043 | | 0.378 | | 0.019 |
| Transect 2 | -0.012 | 0.094 | -0.010 | 0.024 | -0.036 | | 0.299 | | -0.075 |
| Transect 3 | -0.055 | 0.105 | 0.056 | 0.110 | 0.021 | | -1.618 | | -0.018 |
| **Average (Mod)** | **0.031 ft.** | | | **0.038 ft.** | | | **-0.169 ft.** | | |
| **High** | Does not occur | | | Site 13 | Site 23 | | Site 36 | Site 47 | |
| Transect 1 | | | | -0.164 | | | -0.061 | -0.116 | |
| Transect 2 | | | | -0.064 | | | -0.084 | -0.103 | |
| Transect 3 | | | | -0.070 | | | -0.172 | -0.190 | |
| **Average (High)** | | | | **-0.099 ft.** | | | **-0.121 ft.** | | |

## Table E-3. Monitoring Survey Results Fall 2001 to Spring 2002

| EROSION RATE CLASS | BANK HEIGHT CLASS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **< 12 ft. (Low)** | | | **12 - 24 ft. (Moderate)** | | | **> 24 ft. (High)** | | |
| **Not Active** | Site 7 | Site 19 | Site 25 | Site 12 | Site 22 | Site 39 | Site 29 | Site 44 | |
| Transect 1 | 0.000 | -0.060 | -0.050 | 0.039 | -0.108 | 0.042 | 0.018 | -0.019 | |
| Transect 2 | 0.000 | -0.048 | -0.053 | -0.073 | -0.235 | -0.256 | -0.034 | -0.036 | |
| Transect 3 | 0.000 | -0.027 | -0.074 | -0.010 | -0.131 | -0.242 | -0.058 | 0.090 | |
| **Average (Not)** | **-0.035 ft.** | | | **-0.108 ft.** | | | **-0.007 ft.** | | |
| **Slow** | Site 24 | Site 26 | Site 28 | Site 10 | Site 17 | Site 18 | Site 1 | Site 2 | Site 37 |
| Transect 1 | -0.033 | 0.066 | -0.292 | 0.000 | -0.099 | -0.076 | 0.000 | 0.000 | -0.010 |
| Transect 2 | 0.010 | -0.004 | -0.010 | 0.000 | -0.098 | 0.038 | 0.000 | 0.000 | -0.051 |
| Transect 3 | -0.035 | -0.042 | -0.064 | 0.000 | -0.107 | 0.040 | 0.000 | 0.000 | 0.015 |
| **Average (Slow)** | **-0.045 ft.** | | | **-0.034 ft.** | | | **-0.005 ft.** | | |
| **Moderate** | Site 15 | Site 20C | Site 33 | Site 16 | Site 21 | Site 35 | Site 14 | Site 30 | Site 46 |
| Transect 1 | -0.278 | -0.001 | 0.010 | -0.088 | -0.285 | 0.032 | 0.056 | -0.122 | 0.067 |
| Transect 2 | -0.240 | -0.052 | -0.062 | -0.128 | 0.005 | -0.097 | 0.102 | -0.085 | 0.000 |
| Transect 3 | -0.131 | -0.017 | 0.003 | -0.006 | -0.155 | 0.029 | 0.010 | -0.141 | -0.065 |
| **Average (Mod)** | **-0.085 ft.** | | | **-0.077 ft.** | | | **-0.020 ft.** | | |
| **High** | Does not occur | | | Site 13 | Site 23 | | Site 36 | Site 47 | |
| Transect 1 | | | | -0.111 | | | 0.047 | -0.011 | |
| Transect 2 | | | | -0.093 | -0.327 | | -0.057 | 0.016 | |
| Transect 3 | | | | -0.064 | | | 0.014 | 0.084 | |
| **Average (High)** | | | | **-0.149 ft.** | | | **0.016 ft.** | | |

**Table E-4. Monitoring Survey Results Spring 2002 to Fall 2002**

| EROSION RATE CLASS | BANK HEIGHT CLASS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | < 12 ft. (Low) | | | 12 - 24 ft. (Moderate) | | | > 24 ft. (High) | | |
| **Not Active** | Site 7 | Site 19 | Site 25 | Site 12 | Site 22 | Site 39 | Site 29 | Site 44 | |
| Transect 1 | -0.007 | 0.031 | -0.076 | 0.011 | -0.039 | -0.008 | -0.018 | -0.016 | |
| Transect 2 | -0.078 | 0.043 | -0.027 | 0.070 | -0.001 | -0.064 | -0.004 | -0.049 | |
| Transect 3 | 0.010 | 0.013 | -0.073 | 0.039 | 0.000 | 0.005 | -0.004 | -0.095 | |
| **Average (Not)** | **-0.018 ft.** | | | **0.001 ft.** | | | **-0.031 ft.** | | |
| **Slow** | Site 24 | Site 26 | Site 28 | Site 10 | Site 17 | Site 18 | Site 1 | Site 2 | Site 37 |
| Transect 1 | -0.071 | -0.076 | -0.036 | -0.036 | -0.054 | -0.027 | -0.149 | -0.102 | -0.062 |
| Transect 2 | -0.071 | -0.090 | -0.050 | -0.044 | -0.022 | 0.009 | -0.187 | -0.133 | -0.176 |
| Transect 3 | -0.114 | -0.041 | -0.050 | -0.045 | -0.001 | -0.062 | -0.147 | -0.254 | -0.099 |
| **Average (Slow)** | **-0.067 ft.** | | | **-0.031 ft.** | | | **-0.145 ft.** | | |
| **Moderate** | Site 15 | Site 20C | Site 33 | Site 16 | Site 21 | Site 35 | Site 14 | Site 30 | Site 46 |
| Transect 1 | 0.026 | 0.034 | -0.116 | 0.167 | 0.050 | -0.094 | -0.019 | 0.002 | -0.076 |
| Transect 2 | -0.007 | 0.012 | 0.026 | 0.003 | -0.042 | 0.019 | -0.089 | -0.286 | -0.177 |
| Transect 3 | 0.012 | 0.044 | -0.081 | 0.056 | 0.033 | -0.242 | 0.069 | -0.029 | -0.031 |
| **Average (Mod)** | **-0.006 ft.** | | | **-0.006 ft.** | | | **-0.071 ft.** | | |
| **High** | Does not occur | | | Site 13 | Site 23 | | Site 36 | Site 47 | |
| Transect 1 | | | | -0.220 | -0.202 | | -0.061 | -0.078 | |
| Transect 2 | | | | -0.084 | 0.020 | | -0.023 | -0.049 | |
| Transect 3 | | | | -0.063 | -0.103 | | 0.012 | -0.130 | |
| **Average (High)** | | | | **-0.109 ft.** | | | **-0.055 ft.** | | |

## Table E-5. Monitoring Survey Results Fall 2002 to Spring 2003

| EROSION RATE CLASS | BANK HEIGHT CLASS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | < 12 ft. (Low) | | | 12 - 24 ft. (Moderate) | | | > 24 ft. (High) | | |
| **Not Active** | Site 7 | Site 19 | Site 25 | Site 12 | Site 22 | Site 39 | Site 29 | Site 44 | |
| Transect 1 | 0.000 | -0.089 | -0.005 | -0.061 | -0.019 | -0.053 | -0.058 | -0.124 | |
| Transect 2 | 0.000 | -0.115 | 0.004 | -0.110 | -0.021 | 0.070 | -0.061 | 0.004 | |
| Transect 3 | 0.000 | -0.063 | 0.023 | -0.048 | -0.045 | -0.055 | -0.073 | 0.020 | |
| **Average (Not)** | **-0.027 ft.** | | | **-0.038 ft.** | | | **-0.049 ft.** | | |
| **Slow** | Site 24 | Site 26 | Site 28 | Site 10 | Site 17 | Site 18 | Site 1 | Site 2 | Site 37 |
| Transect 1 | 0.019 | -0.039 | -0.069 | 0.000 | -0.053 | -0.086 | -0.012 | 0.000 | -0.006 |
| Transect 2 | -0.010 | -0.033 | -0.050 | 0.000 | -0.080 | -0.092 | 0.045 | 0.000 | 0.055 |
| Transect 3 | 0.025 | -0.052 | -0.112 | 0.000 | -0.053 | -0.047 | 0.005 | 0.000 | 0.001 |
| **Average (Slow)** | **-0.036 ft.** | | | **-0.046 ft.** | | | **0.010 ft.** | | |
| **Moderate** | Site 15 | Site 20B | Site 33 | Site 16 | Site 21 | Site 35 | Site 14 | Site 30 | Site 46 |
| Transect 1 | -0.150 | -0.224 | -0.033 | -0.236 | -0.030 | 0.058 | 0.012 | -0.152 | -0.064 |
| Transect 2 | -0.022 | -0.126 | -0.007 | -0.230 | -0.151 | 0.026 | -0.050 | 0.268 | 0.083 |
| Transect 3 | -0.050 | -0.242 | 0.053 | -0.296 | -0.030 | -0.104 | -0.362 | 0.001 | -0.012 |
| **Average (Mod)** | **-0.089 ft.** | | | **-0.110 ft.** | | | **-0.031 ft.** | | |
| **High** | Does not occur | | | Site 13 | Site 23 | | Site 36 | Site 47 | |
| Transect 1 | | | | 0.155 | 0.073 | | -0.037 | -0.008 | |
| Transect 2 | | | | 0.017 | 0.095 | | -0.057 | -0.041 | |
| Transect 3 | | | | -0.029 | 0.433 | | -0.095 | 0.002 | |
| **Average (High)** | | | | **0.124 ft.** | | | **-0.039 ft.** | | |

**Table E-6. Monitoring Survey Results Spring 2003 to Fall 2003**

| EROSION RATE CLASS | BANK HEIGHT CLASS (HAZARD CLASS) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | < 12 ft. (Low) | | | 12 - 24 ft. (Moderate) | | | > 24 ft. (High) | | |
| **Not Active** | Site 7 | Site 19 | Site 25 | Site 12 | Site 22 | Site 39 | Site 29 | Site 44 | |
| Transect 1 | 0.004 | 0.086 | 0.064 | -0.060 | -0.119 | 0.069 | -0.005 | 0.072 | |
| Transect 2 | 0.057 | 0.074 | 0.031 | -0.032 | 0.056 | 0.307 | 0.034 | 0.006 | |
| Transect 3 | -0.013 | 0.079 | -0.017 | 0.011 | 0.033 | 0.330 | 0.018 | 0.014 | |
| **Average (Not)** | **0.041 ft.** | | | **0.066 ft.** | | | **0.023 ft.** | | |
| **Slow** | Site 24 | Site 26 | Site 28 | Site 10 | Site 17 | Site 18 | Site 1 | Site 2 | Site 37 |
| Transect 1 | 0.041 | 0.033 | 0.024 | -0.002 | 0.044 | 0.091 | 0.182 | 0.028 | 0.044 |
| Transect 2 | 0.043 | 0.074 | -0.004 | -0.033 | 0.042 | 0.060 | 0.051 | 0.053 | -0.035 |
| Transect 3 | 0.021 | 0.015 | 0.021 | -0.007 | 0.101 | 0.027 | 0.037 | 0.143 | 0.057 |
| **Average (Slow)** | **0.030 ft.** | | | **0.036 ft.** | | | **0.062 ft.** | | |
| **Moderate** | Site 15 | Site 20B | Site 33 | Site 16 | Site 21 | Site 35 | Site 14 | Site 30 | Site 46 |
| Transect 1 | 0.060 | 0.047 | 0.030 | 0.030 | 0.072 | -0.025 | -0.022 | 0.249 | -0.033 |
| Transect 2 | -0.031 | 0.087 | 0.054 | 0.320 | 0.073 | 0.026 | -0.003 | 0.115 | 0.027 |
| Transect 3 | -0.049 | 0.064 | 0.031 | 0.218 | -0.042 | -0.110 | 0.959 | 0.090 | 0.037 |
| **Average (Mod)** | **0.033 ft.** | | | **0.062 ft.** | | | **0.158 ft.** | | |
| **High** | Does not occur | | | Site 13 | Site 23 | | Site 36 | Site 47 | |
| Transect 1 | | | | -0.024 | -0.092 | | 0.029 | -0.039 | |
| Transect 2 | | | | -0.069 | 0.812 | | 0.091 | -0.033 | |
| Transect 3 | | | | -0.007 | -0.453 | | 0.065 | -0.108 | |
| **Average (High)** | | | | **0.028 ft.** | | | **0.001 ft.** | | |

**Table E-7. Monitoring Survey Results Fall 2003 to Spring 2004**

| EROSION RATE CLASS | BANK HEIGHT CLASS (HAZARD CLASS) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | < 12 ft. (Low) | | | 12 - 24 ft. (Moderate) | | | > 24 ft. (High) | | |
| **Not Active** | Site 7 | Site 19 | Site 25 | Site 12 | Site 22 | Site 39 | Site 29 | Site 44 | |
| Transect 1 | -0.053 | -0.092 | -0.042 | 0.045 | -0.047 | | -0.021 | -0.020 | |
| Transect 2 | -0.005 | -0.041 | -0.036 | 0.170 | -0.073 | -0.413 | -0.032 | -0.002 | |
| Transect 3 | -0.042 | -0.072 | 0.050 | 0.060 | -0.074 | | -0.033 | -0.014 | |
| **Average (Not)** | **-0.037 ft.** | | | **-0.047 ft.** | | | **-0.020 ft.** | | |
| **Slow** | Site 24 | Site 26 | Site 28 | Site 10 | Site 17 | Site 18 | Site 1 | Site 2 | Site 37 |
| Transect 1 | 0.028 | 0.017 | -0.175 | -0.040 | -0.034 | 0.026 | -0.043 | -0.035 | -0.016 |
| Transect 2 | 0.034 | 0.008 | -0.001 | 0.000 | -0.040 | -0.107 | -0.219 | 0.005 | -0.032 |
| Transect 3 | 0.069 | 0.052 | -0.068 | -0.008 | -0.034 | 0.031 | -0.028 | -0.011 | -0.023 |
| **Average (Slow)** | **-0.004 ft.** | | | **-0.023 ft.** | | | **-0.045 ft.** | | |
| **Moderate** | Site 15 | Site 20B | Site 33 | Site 16 | Site 21 | Site 35 | Site 14 | Site 30 | Site 46 |
| Transect 1 | -0.087 | -0.045 | -0.051 | -0.036 | -0.158 | 0.023 | 0.014 | -0.040 | 0.076 |
| Transect 2 | 0.059 | -0.084 | -0.103 | -0.242 | 0.023 | -0.066 | 0.033 | -0.029 | 0.140 |
| Transect 3 | -0.012 | -0.210 | -0.119 | -0.133 | -0.043 | 0.383 | -0.166 | 0.022 | -0.112 |
| **Average (Mod)** | **-0.072 ft.** | | | **-0.028 ft.** | | | **-0.007 ft.** | | |
| **High** | Does not occur | | | Site 13 | Site 23 | | Site 36 | Site 47 | |
| Transect 1 | | | | 0.137 | -0.094 | | 0.014 | 0.062 | |
| Transect 2 | | | | 0.186 | 0.009 | | -0.065 | 0.117 | |
| Transect 3 | | | | 0.028 | -0.049 | | 0.006 | 0.032 | |
| **Average (High)** | | | | **0.036 ft.** | | | **0.028 ft.** | | |

**Table E-8. Monitoring Survey Results Spring 2004 to Fall 2004**

| EROSION RATE CLASS | BANK HEIGHT CLASS (HAZARD CLASS) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | < 12 ft. (Low) | | | 12 - 24 ft. (Moderate) | | | > 24 ft. (High) | | |
| **Not Active** | Site 7 | Site 19 | Site 25 | Site 12 | Site 22 | Site 39 | Site 29 | Site 44 | |
| Transect 1 | 0.055 | 0.085 | -0.003 | 0.018 | -0.088 | | 0.070 | 0.093 | |
| Transect 2 | 0.030 | 0.033 | 0.009 | -0.070 | 0.009 | 0.433 | 0.045 | 0.038 | |
| Transect 3 | 0.010 | 0.070 | -0.029 | 0.011 | 0.059 | | 0.056 | 0.037 | |
| **Average (Not)** | **0.029 ft.** | | | **0.053 ft.** | | | **0.057 ft.** | | |
| **Slow** | Site 24 | Site 26 | Site 28 | Site 10 | Site 17 | Site 18 | Site 1 | Site 2 | Site 37 |
| Transect 1 | 0.046 | -0.044 | -0.032 | 0.040 | -0.021 | -0.020 | -0.110 | 0.002 | 0.015 |
| Transect 2 | 0.014 | -0.018 | -0.015 | 0.087 | 0.063 | 0.068 | 0.267 | 0.034 | -0.029 |
| Transect 3 | 0.018 | -0.037 | -0.017 | 0.052 | 0.058 | 0.014 | 0.075 | 0.043 | 0.014 |
| **Average (Slow)** | **-0.009 ft.** | | | **0.038 ft.** | | | **0.035 ft.** | | |
| **Moderate** | Site 15 | Site 20B | Site 33 | Site 16 | Site 21 | Site 35 | Site 14 | Site 30 | Site 46 |
| Transect 1 | 0.128 | 0.068 | 0.171 | 0.056 | 0.116 | 0.028 | -0.006 | 0.019 | 0.026 |
| Transect 2 | -0.099 | 0.049 | 0.012 | 0.165 | 0.021 | 0.012 | 0.140 | 0.029 | -0.124 |
| Transect 3 | 0.026 | 0.063 | -0.031 | 0.028 | 0.060 | 0.059 | 0.011 | 0.007 | 0.073 |
| **Average (Mod)** | **0.043 ft.** | | | **0.061 ft.** | | | **0.019 ft.** | | |
| **High** | Does not occur | | | Site 13 | Site 23 | | Site 36 | Site 47 | |
| Transect 1 | | | | -0.093 | -0.009 | | -0.018 | 0.019 | |
| Transect 2 | | | | -0.026 | -0.064 | | -0.090 | -0.144 | |
| Transect 3 | | | | -0.068 | -0.065 | | -0.037 | -0.025 | |
| **Average (High)** | | | | **-0.054 ft.** | | | **-0.049 ft.** | | |

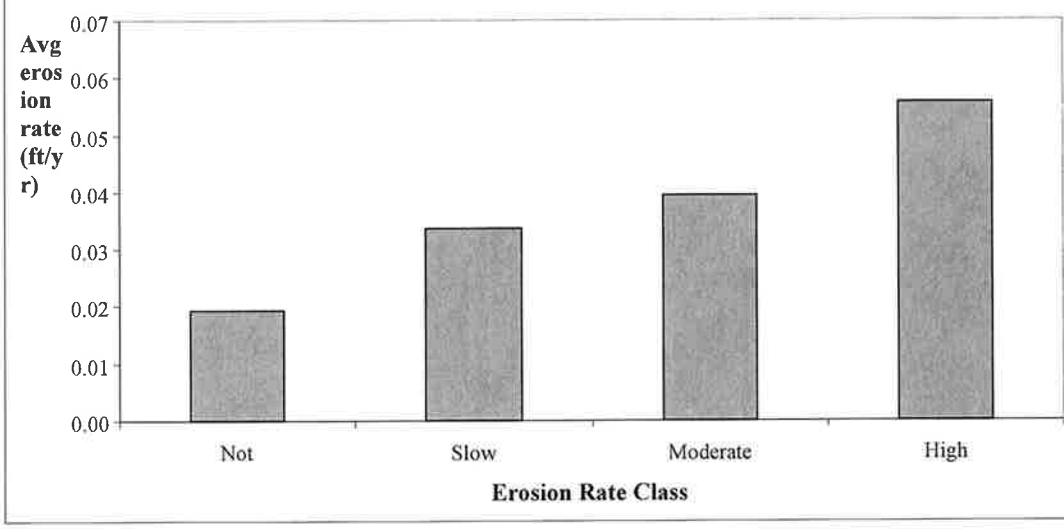
## Table E-9. Monitoring Survey Results Fall 2004 to Spring 2005

| EROSION RATE CLASS | BANK HEIGHT CLASS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | < 12 ft. (Low) | | | 12 - 24 ft. (Moderate) | | | > 24 ft. (High) | | |
| **Not** | Site 7 41.8R | Site 19 63.5R | Site 25 89.2L | Site 12 48.0R | Site 22 83.0L | Site 39 70.9L | Site 29 36.2R | Site 44 38.2L | |
| Transect 1 | -0.036 | -0.090 | -0.018 | -0.028 | 0.025 | | 0.134 | -0.048 | |
| Transect 2 | 0.004 | -0.064 | 0.023 | 0.028 | -0.090 | -0.137 | 0.126 | 0.063 | |
| Transect 3 | -0.007 | -0.083 | -0.039 | 0.018 | -0.086 | | 0.164 | -0.014 | |
| **Average (Not)** | **-0.034 ft.** | | | **-0.039 ft.** | | | **0.071 ft.** | | |
| **Slow** | Site 24 87.2I | Site 26 89.8L | Site 28 55.3R | Site 10 44.4R | Site 17 56.9R | Site 18 59.2R | Site 1 35.5L | Site 2 36.7R | Site 37 86.5R |
| Transect 1 | -0.062 | 0.023 | -0.051 | 0.262 | -0.066 | -0.078 | -0.045 | -0.026 | -0.020 |
| Transect 2 | -0.041 | 0.010 | -0.048 | 0.242 | -0.095 | -0.098 | -0.042 | -0.056 | -0.047 |
| Transect 3 | -0.056 | 0.036 | -0.030 | 0.247 | -0.031 | -0.154 | 0.021 | -0.052 | -0.055 |
| **Average (Slow)** | **-0.024 ft.** | | | **0.025 ft.** | | | **-0.036 ft.** | | |
| **Moderate** | Site 15 55.1R | Site 20C 64.5R | Site 33 43.1R | Site 16 56.5R | Site 21 76.2R | Site 35 44.7R | Site 14 52.0L | Site 30 36.9R | Site 46 43.5L |
| Transect 1 | -0.009 | -0.136 | -0.120 | -0.066 | -0.031 | -0.083 | -0.019 | -0.073 | -0.076 |
| Transect 2 | 0.004 | -0.231 | -0.022 | -0.070 | 0.004 | -0.158 | -0.049 | -0.061 | -0.088 |
| Transect 3 | -0.047 | -0.161 | -0.056 | -0.087 | -0.045 | -0.138 | 0.043 | -0.007 | -0.062 |
| **Average (Mod)** | **-0.086 ft.** | | | **-0.075 ft.** | | | **-0.044 ft.** | | |
| **High** | Does not occur | | | Site 13 48.0L | Site 23 86.8L | | Site 36 51.0R | Site 47 44.0L | |
| Transect 1 | | | | 0.553 | 0.162 | | -0.139 | -0.148 | |
| Transect 2 | | | | 0.556 | 0.333 | | -0.096 | -0.135 | |
| Transect 3 | | | | 0.611 | 0.083 | | -0.148 | -0.026 | |
| **Average (High)** | | | | **0.383 ft.** | | | **-0.115 ft.** | | |

**Table E-10. Monitoring Survey Results Spring 2005 to Fall 2005**

| EROSION RATE CLASS | BANK HEIGHT CLASS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | < 12 ft. (Low) | | | 12 - 24 ft. (Moderate) | | | > 24 ft. (High) | | |
| Not | Site 7 41.8R | Site 19 63.5R | Site 25 89.2L | Site 12 48.0R | Site 22 83.0L | Site 39 70.9L | Site 29 36.2R | Site 44 38.2L | |
| Transect 1 | 0.048 | 0.075 | 0.042 | 0.006 | 0.066 | | 0.003 | 0.084 | |
| Transect 2 | 0.003 | 0.101 | -0.026 | -0.016 | 0.077 | 0.156 | 0.011 | -0.049 | |
| Transect 3 | 0.031 | 0.109 | -0.031 | -0.076 | 0.034 | | 0.050 | 0.052 | |
| **Average (Not)** | **0.039 ft.** | | | **0.035 ft.** | | | **0.025 ft.** | | |
| **Slow** | Site 24 87.2I | Site 26 89.8L | Site 28 55.3R | Site 10 44.4R | Site 17 56.9R | Site 18 59.2R | Site 1 35.5L | Site 2 36.7R | Site 37 86.5R |
| Transect 1 | 0.051 | 0.010 | 0.094 | -0.141 | 0.090 | 0.070 | 0.036 | 0.056 | -0.120 |
| Transect 2 | 0.019 | -0.034 | 0.032 | -0.236 | 0.097 | 0.063 | 0.049 | 0.067 | -0.858 |
| Transect 3 | 0.014 | 0.025 | -0.352 | -0.179 | -0.091 | 0.086 | 0.006 | 0.025 | 0.027 |
| **Average (Slow)** | **-0.016 ft.** | | | **-0.027 ft.** | | | **-0.079 ft.** | | |
| **Moderate** | Site 15 55.1R | Site 20C 64.5R | Site 33 43.1R | Site 16 56.5R | Site 21 76.2R | Site 35 44.7R | Site 14 52.0L | Site 30 36.9R | Site 46 43.5L |
| Transect 1 | 0.107 | 0.090 | 0.086 | 0.060 | 0.003 | 0.020 | -0.009 | 0.061 | 0.089 |
| Transect 2 | 0.010 | 0.055 | 0.108 | 0.071 | 0.029 | 0.106 | -0.297 | 0.003 | 0.171 |
| Transect 3 | 0.002 | 0.036 | 0.077 | 0.106 | 0.005 | 0.101 | 0.022 | -0.012 | 0.076 |
| **Average (Mod)** | **0.063 ft.** | | | **0.056 ft.** | | | **0.012 ft.** | | |
| **High** | Does not occur | | | Site 13 48.0L | Site 23 86.8L | | Site 36 51.0R | Site 47 44.0L | |
| Transect 1 | | | | -0.048 | -0.114 | | 0.076 | 0.122 | |
| Transect 2 | | | | -0.070 | -0.166 | | 0.069 | 0.211 | |
| Transect 3 | | | | 0.010 | -0.289 | | 0.084 | -0.001 | |
| **Average (High)** | | | | **-0.113 ft.** | | | **0.094 ft.** | | |

**Figure E-1 - Shoreline Erosion Depth by Erosion Rate Class**



Submission Contents