BAKER RIVER PROJECT RELICENSE

Aquatic Resources Working Group

May 8, 2003

8:30 a.m. – 3:00 p.m.
WA Department of Ecology
Room 1B/1C
3190 160th Ave. SE, Bellevue, WA

AGENDA

1. Review Agenda, Minutes, Schedule	8:30 – 8:45
2. Settlement Process- Status of 2nd Draft PMEs-Prep for May 14 Cross-Resource Workshop	8:45 – 10:00
Break	10:00 – 10:15
3. Fish Passage Technical Work Group Report	10:15 – 10:30
4. Report from Instream Flow Technical Working Group (A09a)	10:30 – 11:30
5. Review Study Plans/Requests: updates on A01a/b (A26b)	11:30 – 12:00
Lunch (meeting snacks or bring your own)	12:00 – 12:30
6. Review Study Plans/Requests: updates on A9 (b,c,d), A14a, A16, A17, A20, A24, A25, A26a, A37, A38, A39, Others?	12:30 – 2:30
7. Action Items	2:30 - 2:35
8. Update from Solution Team Meeting	2:35 - 2:40
9. Additional Issues	2:40 - 2:50
10. Set Agenda for June 12th 2003 (USFS Building-Mt. Lake Terrace)	2:50 - 2:55
11. Evaluate Meeting	2:55 – 3:00

May 8, 2003

Driving Directions to Dept. of Ecology Office (Bellevue):

1) **Eastbound on I-90 from I-5 or I-405: Take exit 11A, Keep left, drive past the 150th Ave. SE exit and take the 156th Ave. SE exit.**
2) **Cross over the freeway and move one lane to the left to avoid the 'exit only' lane.**
3) **At the first light, turn right onto Eastgate Way. Follow Eastgate to 160th Ave. SE (3rd light) and turn left.**
4) **Once on 160th Ave. SE, turn into the third driveway on the right. Beige two story building. Parking in front of the building or one block on the opposite side of 160th Ave. SE.**

BAKER RIVER PROJECT RELICENSE

Aquatic Resources Working Group

May 8, 2003
8:30 a.m. - 3:00 p.m.
Department of Ecology, Bellevue - Eastgate

MEETING NOTES

Aquatics Working Group Mission: *"To identify issues and develop solutions and recommendations addressing fish and aquatic resource interests related to the Baker River Project and its operations, leading to a settlement agreement."*

Fish Team Leader: Arnie Aspelund, 425-462-3442, arnie.aspelund@pse.com

PRESENT: Arnie Aspelund, Nick Verretto, Cary Feldmann (PSE), Arn Thoreen (Skagit Fisheries Enhancement Group), Mike Ramey, Phil Hilgert and Sue Madsen (R2), Bill Reinard (Wildcat Steelhead Club), Steve Fransen (NMFS), Stan Walsh (Skagit Systems Cooperative), Greta Movassaghi, Scott Lentz, by phone (USFS), Rod Sakrison and Bob Wright (DOE), Marc Daily (Meridian Environmental), Gary Sprague (WDFW), Gene Stagner (USFWS), Ruth Mathews (The Nature Conservancy), Terry Key (Lotek Wireless), Lyn Wiltse, facilitator and Mary Jean Bullock (PDSA Consulting, Inc.).

The next CROSS RESOURCE WORKSHOP MEETING will be MAY 14, 8:00 – 5:00 at the EMBASSY SUITES in LYNNWOOD. Stay tuned for details. Presenter: Steve Fransen

FUTURE WORKING GROUP DATES AND LOCATIONS (2nd Thursday of each month): June 12, July 10 (WA Ecology, Bellevue - Eastgate), August 14, September 11 (TBD), October 9, November 13, December 11, 2003 from 8:30-3:00 at USFS Office in Mountlake Terrace.

May 8, 2003 Agenda
8:30 – 3:00 p.m. at WA Dept. of Ecology, Bellevue – Eastgate

1. Review Agenda, Minutes, Schedule
2. Settlement Process – Status of 2nd draft proposed actions after April 1, 2 Retreat
   - Prep for May 14 Cross-Resource Workshop
3. Fish Passage Technical Working Group Report
4. Instream Flows Technical Working Group Report (A9)
5. Studies
   - A01a, b, and A26 (b) – Reservoir Tributary Surveys
   - A9 (a, b, c, d) - Skagit River Flow & Habitat Assessment
   - A14a - Reservoir Shoreline Erosion
   - A16 - Lower Baker Alluvial Fan Assessment
   - A17 – Tributaries Surveys Upstream of Barriers
   - A20 – Large Woody Debris Management
   - A24 - Hydrologic & Geomorphic Analysis
   - A25 – Inventory of Unnatural Predation Opportunity
   - A26 (a) - Reservoir Production Potential
   - A37 – Evaluation of Aquatic/Riparian Habitats (Without Project Alternative)
   - A38 - Bull Trout Population Assessment
   - A39 – Native Non-Salmonid
6. Action Items
7. Update from Solution Team Meeting
8. Additional Issues?
9. Set agenda for June 12, 2003 meeting @ USFS Building in Mountlake Terrace
10. Evaluate meeting

INTRODUCTIONS
We were pleased to welcome observer Terry Key (of Lotek Wireless) and Mike Ramey (R2 Resource Consultants)!

NEW ACTION ITEMS
- Nick: Send out electronic versions of the May 7, Downstream Fish Passage Alternative Status Summary by May 9th.
- ALL: Send in comments on A16 Study Plan by May 22.
- ALL: Let Phil know of any other important data sources that R2 should include in A09c or A09d.
- Arnie: Ensure that the Technical Scenarios Teamlet minutes, etc. are posted on the website.

SETTLEMENT PROCESS
The Second Draft PMEs were sent out May 7th. These will be discussed during the morning of the May 14th workshop. The afternoon of the workshop will be devoted to apparent cross-resource conflicts. There is no official comment period for these as the process to continually

refine this is on going. Steve Fransen will be our presenter of these at the workshop. Thanks Steve!

PDEA

The partial preliminary PDEA is freshly out for review. It has been sent to Solution Team members already and Arnie will make sure that folks from this Working Group also receive a copy by May 9th. Everyone should submit their comments through their Solution Team representative. Comments on this partial PDEA and the draft license application are due by June 2.

FISH PASSAGE TECHNICAL WORKING GROUP REPORT

The group met April 28th. For now, they are pursuing a modification of the gulper option. Jim Stowe is doing some additional research on a floating screen tower option used at Pelton Round Butte.

They will discuss the potential cost and design of the modified gulper alternative at the next meeting on May 19. Once they agree, PSE has committed to begin designing the preferred option immediately. Other downstream passage options are tabled at this point. Agency prescription authority is reserved.

In the meantime, the Baker Agency Group met on May 6 and came up with a list of performance and standards to ensure fish passage success. A key standard is fish passage overall through the system. Steve distributed a memo outlining what they came up with. For survival rates, they would like to see:

1) At least 98% fish passage survival through collection facilities (upstream and downstream)
2) At least 95% for smolts that migrate to the dam fore bay.
3) At least 80% reservoir passage survival

Multiplying these three points together gives at least a 75% level for over all fish survival. Since perfect fish passage is not likely achievable, they are also calling for a supplementation program to secure full reservoir seeding for sockeye and coho since they have historically high survival rate in the Baker System.

They are also suggesting a Chinook and steelhead program. (The Skagit *River* System may already be "maxed" out on the number of hatchery steelhead that can be released *under current management directives based on hatchery/wildstock interaction concerns* and we remember Dick's concern with these. It was noted that philosophical differences exist around use of hatchery fish among Working Group members.)

This memo also asks for immediate PME implementation by PSE.

It also calls for the Floating Surface Collector to be initiated with a 1,000 cfs flow, assuming it's technically feasible. Otherwise, the initial collector may be sized at 500 cfs.

There would be a penalty associated with non-performance (paid into the HERC fund).

Monitoring, maintenance and reporting are expected for all PMEs and are not intended to be limited to Section 18 prescriptions.

Next steps: We will need to identify what criteria measurement methods would be used. We will also come up with a schedule for implementation.

INTERIM PROTECTION PLAN (IPP)
PSE submitted the draft Chinook Biographical Assessment in May, 2002 to FERC. FERC passed it to NMFS in August. NMFS asked for additional data. FERC said "No – Go with what you've got."

PSE submitted a bull trout BA to FERC on December, 2002. FERC sent it to USFWS in mid-January. USFWS wrote back asking for additional data.

There will be an Interim IPP meeting on July 18 to review action items and see if it is possible to get an extension.

INSTREAM FLOWS TECHNICAL WORKING GROUP REPORT (A9)
The Technical Working Group met May 2. After the participants have reviewed the notes, they will be provided for broader distribution. They will meet again June 3 somewhere in the Seattle Area. See below for details.

GENERAL NOTE RE: DATA DISCREPANCY!
Due to changes in vertical datum, calculations using GIS datums may need to be changed. A memo on this will be forthcoming.

R-2 STUDIES REPORT PROTOCOL
Phil announced that draft versions are being sent out for review for the first time will have a color title page and no comment section appended at the front or back.

Subsequent versions of the report (no document change) will show comments at the front of the document. The document footer will not be changed and the version date will remain the same as that distributed for preliminary review.

Subsequent versions of the report (with document changes) will show comments appended to the back of the document. The document footer will be changed and the version updated to distinguish the document from previous versions.

Final draft documents and comments (with or without document changes) will be denoted by "Final Draft". Any comments will be appended to the back of the document and a response provided for each. The document footer will be changed and the version updated to distinguish the document from previous versions.

STUDY REQUEST SUBMITTALS/STUDY PLAN DEVELOPMENT

Study #	Title	Notes/Next Steps

A01a Reservoir Tributary Habitat Surveys	Ron Campbell of R2 has reviewed Emily's report. He and Phil will be meeting in the next few days with Emily to finalize this report for distribution.
A01b Reservoir Tributary Biological Surveys	See A26b
A01 Reservoir Tributary Delta Surveys	See report for 101.A. ACTIVE
A02 LB River Habitat Mapping	Sue walked us through a PowerPoint presentation of the results of this report. The report will be out for review by the July 10 meeting.
A03 Reservoir Fish Population Characteristics	Not discussed. No action yet. PSE will review existing information for the PDEA.
A04 LB/Skagit River Flow, Gaging	Not discussed. Last meeting Phil reported that they downloaded pressure sensors last and are still in the process of collecting data. Links to A9. ACTIVE
A05 Water Quality Sampling	Nothing new to report.
A06 UB Passage Design Baffle Modification	Complete.
A07 Lower Baker Forebay Bathymetry	Complete.
A08 UB Passage System Evaluation	Complete.
A09A Skagit River Flow and Habitat Assessment	Phil reported that by their next meeting on June 3, the stage discharge relationship for all 24 transects will be determined. They will re-do 2002 spawning data using the 24 transect stage discharge relationships. They will also be looking at spawning vs. incubation and emergence flows for the unregulated Baker River at Concrete (daily flows). We will be looking at various ways to define spawning periods, using Stan's E03 as a starting point. Using the 10 highest days during the spawning period (average daily), they will identify the frequency, timing duration of instances where, under unregulated conditions, the spawning flow wouldn't be met (less than 1/3). This should help us identify what we want to run, through HYDROPS when the habitat models are available, we can use them to fine tune the data we get from HYDROPS. They will be using results from A9c and A9d to come up with a proposed periodicity for various life stages of species. They will also be identifying non-species- specific evaluation criteria (in the context of periodicity as per the previous sentence). In terms of prioritizing analyses to be done, they want to look at hourly information first (stranding, trapping, spawning, and incubation analysis).

	They will be working with Brad Caldwell to identify various assumptions used in the lower Skagit River Instream Flow Study (for consistency). Finally, they will be overlaying lower Skagit River HSI curves with those of the Middle Skagit River data.
A09B Salmonid Redd Selection and Maintenance in the Middle Skagit in Response to River Fluctuation from Hydropower Peaking	Phil reported that this draft report is complete. He is reviewing it and will send it out for our review by April 28. Prepared by Adam Weybright.
A09C Distribution, Timing and Depth of Salmonid Redds	Comments were due April 21. All were asked to identify any additional data sources that R2 has not included in the references in this report.
A09D Distribution, Timing of Salmonid Fry	All were asked to let Phil know of any other references ASAP. This report will be out by June 2.
A10 Baker River Delta Habitat Assessment-Char	Complete. Note: USFWS is concerned with impacts to char and indirectly to bald eagles through chum and also to cutthroat.
A11 Nutrient Addition	Tie to A26.
A12 Instream Flows for Bio-diversity	Split between R-A21 & R-A09.
A13A Water Quality Impacts of Human Uses of the Reservoir and Adjacent Shorelines.	Not discussed. Removed from list of studies this group will address, reported by Brady in September. Greta reported the USFS will pursue this in the recreation working group.
A13B Water Quality Impacts on Aquatic Habitat	Removed from list of studies we will address. Tabled for now. Awaiting results of A14a.
A14A Reservoir Shoreline Erosion	Comments on report were due April 30th. Issues with the vertical datum will push this period back 1 month. Greta will meet with a representative from National Park Service on May 12 and will be sending in comments on this report shortly thereafter. Arnie will be the contact on this across all resource area Working Groups.
A15 UB Delta Scour	Sue is in the process of writing this report. Stay tuned….
A16 Lower Baker River Alluvial Fan Assessment	The draft study plan was distributed. Sue explained that R2 sees a strong tie of this study to PMEs. On January 17th the Lower Baker Technical Group met and identified five alternatives for PMEs and recommend that, as Phase 1, R2 would do a preliminary feasibility analysis of each of these five alternatives (listed on page 5 of the Study Plan). Note: They will continue to button up with the USACE and the Skagit Fisheries Enhancement Group as these affect their plans for the Little

	Baker Side Channel Restoration Project. Phase 2 would give a conceptual level design (+50%-30%). After receiving comments on this (due by May 22) the Technical Working Group will get together again and identify the alternatives to move forward to Phase 2. They will get the approval from this group before initiating Phase 2. A technical memo will be the deliverable from Phase 1. This memo will contain one to two pages of analysis for each alternative. The Phase 1 analysis will include technical feasibility, potential consequences, potential benefits, any "flags" that may indicate a reason for some of the alternatives not to move on to Phase 2.
A17 Tributaries Surveys Upstream of Barriers	This is on hold due to changes/inconsistencies in vertical datum data calculations.
A18 Baker River Survey Upstream of 1 km.	Merged into A01a and A01b. ACTIVE.
A19 Review Limnological Information	This study has been combined with A26.
A20 Large Woody Debris Management	The deadline for comments on this report was April 21. The final draft report will be out as by our June meeting.
A21 Skagit Wild & Scenic River Values	This is being addressed by A9 and A24.
A22 Baker Lake Trout Impacts Evaluation	No longer necessary due to change in management direction in favor of cancellation of non-native trout stocking in the reservoirs. Removed from list of studies we will consider.
A23 Baker River Wild & Scenic River Values	This is being addressed through A15.
A24 Hydrologic and Geomorphic Analysis	Comments on Part 1 (hydrology portion) were due April 30. This period was extended to the end of day June 9. The final report will be out by our July 10 meeting. Part 2 (Geomorphic Analysis) is out for review. Three figures (mostly photos) are missing from Section 4 of this report. Sue will get those out to folks electronically and bring hard (color) copies to our next meeting. Comments due by July 15.
A25 Unnatural Predation	Study is ongoing. The catch data have not yet been summarized. We will discuss this at our June meeting
A26A Reservoir Limnology-Production Potential	Nick reported that he received the draft report from Asit in late April. He did not distribute it as he had planned for our review prior to this meeting, because he (Nick) had some serious concerns with

	the validity of some of Asit's analysis methods and interpretations. Nick has met with him to discuss his concerns and has also asked him to re-format the report so it will be better understood and more useable for our analyses. Nick will receive this revised report by May 22. He will send it out at that time for our review. He will invite Asit to attend our July 10 meeting to discuss the report with this group. In the meantime, Nick will get Asit some additional scale information.
A26B Tributary Production Potential	See A1 above.
A27 Middle Skagit Incubation Flows	Addressed in A9.
A28 Fish Passage-Reservoir Management	Now addressed in Fish Passage Studies A30 to A34. ACTIVE
A29 Estimate Sockeye Production from Different Incubation Sources	This year, we have sockeye emerging out of Beach 3 and 4. For now, we have agreed to collect and preserve 100 samples. We can determine what to do with them latter on (otolith analysis).
R-A30 Near-Field Smolt Behavior	Completed. Coordinated through Fish Passage Tech. Group.
R-A31 Fish Passage-Far Field Smolt Migration	Completed. Coordinated through Fish Passage Tech. Group.
R-A32 Fish Passage-Kelt Radio telemetry	Completed. Coordinated through Fish Passage Tech. Group.
R-A33 Fish Passage-PIT Tag Migration	Completed. Coordinated through Fish Passage Tech. Group.
R-A34 Fish Passage-Downstream Run-Timing Correlation	Completed. Coordinated through Fish Passage Tech. Group.
R-A35 Fish Passage-Upstream Run-Timing	Completed. Coordinated through Fish Passage Tech. Group.
R-A36 Native & Wild Inland Fish Population Assessments	WDFW is collecting native trout fish samples. We are participating in this sampling in our other surveys, taking tissue samples in support of this study. Mark will send out the revised Study Request on A36: Native & Wild Inland Fish Population Assessments for discussion at a future meeting.
R-A37 Without Project Alternative (evaluation of Aquatic & Riparian Habitat)	This Study is ready to go once a decision on reference numbers has been made (datum issue).
R-A38 Bull Trout Population Assessment & Risk Analysis	This report was distributed. There are tasks in this Study that need to get started in the near future, so comments need to be in as soon as possible. Phil will be coordinating a Technical Working Group on this (Gene, Scott). At the latest bring your comments with you to our July 10th meeting.

R-39 Native Non Salmonid	Ruth passed her initial Study Request on to Scott. He will help flesh this out and send it to Phil to review by the end of May. We may handle this in a similar manner as A17.

REPORT ON OLD ACTION ITEMS

- Scott: Emailed a copy of Habitat Restoration/Conservation PME to Arnie to distribute to Working Group members by April 18.
- Cary: Put together conference call to discuss new language for second draft proposed actions (April 21 from 3:00 to 5:00).
- Cary: Sent out electronic version of a red-line draft of the 2nd draft proposed actions on April 1.
- Arnie: Emailed out Greta's erosion control PME.
- ALL: Sent Arnie your comments on 2nd draft actions by April 17.
- ALL: Planned to phone in for the April 21 conference call!
- Sue: Sent Arnie sediment proposed actions to distribute.
- ALL: Reviewed A24 Part 1 report and got comments to Sue by end of April.
- All: Reviewed Study Report for A9c. Be ready to discuss at our May 8 meeting.
- Stan (Gary): Set up a meeting of BAG (Baker Agency Group) to address goals for fish passage (May 6).
- All: Sent Stan your ideas on goals for fish passage by April 15.
- Sue: Put together draft study plan for alluvial fan (A16) and draft PME language by May 1.

ACTION ITEM CARRIED OVER FROM APRIL 1 AND 2 RETREAT

- Paul: Get folks results from the 11 runs. Need to verify input data, along with corresponding explanation.
- Note: Others related to the HYDROPS Model were transferred to the Technical Scenarios Teamlet (TST).

UPDATE FROM SOLUTION TEAM MEETING

The main topics at the April Solution Team meeting were flood control (it was agreed that this is a responsibility of the USACE and that PSE is not in the business of, or in any position to assume risk for, providing flood control.

Also, we discussed the settlement process, in particular that the Louis Berger Group would prepare the license articles in addition to the draft PDEA. Rob Mohn outlines what would be included in the partial draft that came out last week. We also discussed the upcoming May 14 Cross Resource Workshop.

ADDITIONAL ISSUES?

There were none.

HANDOUTS

- Agenda for 5-08-03 meeting

- Updated Participant Contact List
- Final Minutes from 4-10-03 meeting
- Long-term Aquatics Schedule
- Updated Aquatics Study Request Index
- Updates Aquatics Study Index
- Proposed language for 3.4.1 Implement Fluvial Geomorphic Management (R2)
- Baker Agency Group (BAG) conference of 5/6/03 – Memorandum from Steve Fransen to the Baker Aquatics Work Group
- Fish Habitat Model of the Middle Skagit River
- Table – Summary of Middle Skagit River juvenile salmonid life history dynamics. (Study A-09d)
- Comments on Baker River Hydropower Project, Draft Study A-20 Large Woody Debris (USFS 3/27/2003)
- Cross Resource Working Group Meeting, May 14, 2003 Agenda
- Draft Memo – Downstream Fish Passage Alternatives Status Summary, Prepared for Fish Passage Technical Working Group; Prepared by Kate Welch, MWH, May 7, 2003
- Feasibility Assessment of Potential Protection, Mitigation and Enhancement Measures for Lower Baker Alluvial Fan Study Plan A-16
- Hydrology and Geomorphology of the Baker and Middle Skagit Rivers (Study A-24) R2 Resource Consultants
- Native Char Investigations Baker River Watershed Study Plan A-38 R2 Resource Consultants

PARKING LOT
- State agency presentations re: mandates (agency direction)
- Create a master list of possible studies across all working groups and share with all
- Access to the Baker River Project hourly operational model (Charles Howard)
- Participate in Lower Skagit Work Group for native char
- Create Overall "Study Plan" for Studies that will drive the Relicensing Process
- Address Trap & Haul – other species
- PSE agreed to take over the Little Park Creek smolt trapping effort this year. Implementation is underway.

EVALUATION OF MEETING
Well-Dones
- Thanks to DOE for hosting us this month and last!
- Sue's A2 and A16 presentation
- Abbreviated studies report for Solution Team
- Short Solution Team update
- Got out early
- Cary's analogy to watches

What Needs to Be Changed
- Traffic

- Cracker juggling “knee”ds attention

What’s Hot?

- Datum issue
- Fish passage
- Alluvial fan

Studies Update for Solution Team

- Lots! Comments are due.

Tentative June 12, 2003 Agenda
8:30 – 3:00 p.m. at USFS Building in Mountlake Terrace

1. Review Agenda, Minutes, Schedule
2. Settlement Process – Status of 2nd draft proposed actions (debrief of May 14th workshop)
3. Fish Passage Technical Working Group Report
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10. Evaluate meeting

Baker River Hydroelectric Project

(FERC No. 2150)

HYDROLOGY AND GEOMORPHOLOGY OF THE BAKER AND MIDDLE SKAGIT RIVERS

(STUDY A-24)

Part 2 of 2

PART 2: SEDIMENT TRANSPORT AND CHANNEL RESPONSE

DRAFT REPORT

Prepared by:

R2 Resource Consultants, Inc.

15250 NE 95th Street

Redmond, Washington 98052-2518

May 8, 2003

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LIST OF TABLES

ACRONYMS AND ABREVIATIONS

ARWG	Aquatic Resources Working Group
cfs	cubic feet per second
GIS	Geographic Information System
GLO	General Land Office
GPS	Global Positioning System
IHA	Indicators of Hydrologic Alteration
LWD	Large woody debris
MBSNF	Mount Baker Snoqualmie National Forest
msl	Mean Sea Level
PSE	Puget Sound Energy
R2	R2 Resource Consultants
RM	river mile
RVA	Range of Variability Analysis
SSC	Skagit System Cooperative
SCL	Seattle City Light
USACE	U.S. Army Corps of Engineers
USFS	United States Forest Service
USGS	United States Geological Survey
WY	Water Year

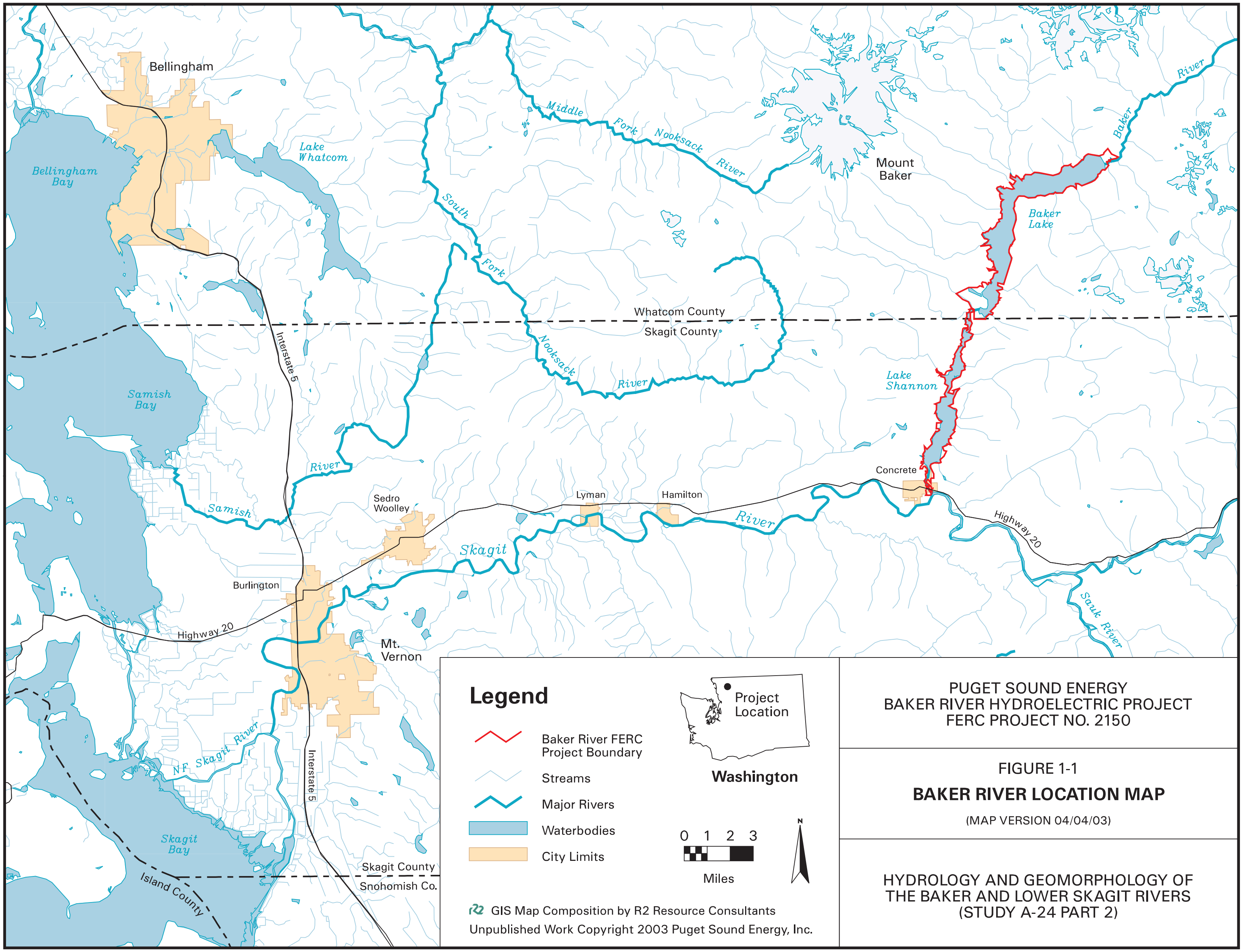
1. INTRODUCTION

The Baker River Hydroelectric Project is owned and operated by Puget Sound Energy, Inc. (PSE). The Baker River Project (FERC No. 2150; hereafter referred to as the Baker Project) consists of the Lower Baker Development (completed in 1925) and the Upper Baker Development (completed in 1959). The Baker Project is located in Skagit County, Washington, about 70 miles north of the city of Seattle, and 50 miles south of the Canadian border (Figure 1-1). The Project was licensed for 50 years, effective May 1, 1956, by the Federal Power Commission, now known as the Federal Energy Regulatory Commission (FERC). The Project's current license expires on May 1, 2006, and PSE has filed its notice of intent to seek relicense of the Project.

As a prerequisite to filing a new license, the applicant must consult with federal, state and local agencies, affected Indian Tribes, non-governmental agencies and the general public. The FERC allows an applicant for a new license to engage in a "traditional" or "alternative" pre-filing process. In March 2000, PSE began efforts to engage all potentially interested parties, including resource agencies and tribes, in a collaborative approach to relicensing. Under the Alternative Licensing Procedures (ALP) established by FERC in 1997, the licensee consults with the agencies, tribes and other interested parties from the outset of the process and seeks to obtain agreement on licensing issues to be addressed in the new license. Participants cooperatively examine environmental issues and design scientific studies as needed. As part of this process, PSE established five primary working groups focusing on the following resource areas: aquatic resources; terrestrial/wildlife; recreation/aesthetics; cultural/historical; and economics and operation. The purpose of these working groups is to identify issues and review available information, select studies that need to be completed, and make recommendations about the resource area.

The goal of the Aquatic Resources Working Group (ARWG) is identify issues and develop solutions and recommendations addressing fish and aquatic resource interests related to the Baker Project and its operations, leading to a settlement agreement. The ARWG has requested a series of studies to be undertaken in support of the relicensing process, and has numbered those studies consecutively. One of the issues identified is the ongoing effect of Baker Project operations on the hydrology and geomorphology of the Baker and middle Skagit rivers. Flow regulation can affect geomorphic processes including the hydrologic and sediment transport regime of a river, causing changes in channel morphology that alter habitat conditions, riparian communities and aquatic ecology. Study A-24 describes project effects on the hydrologic regime, sediment transport and the responsiveness of channels downstream of the Project Area to changing inputs of water, wood and sediment.

Study A24 is presented in two parts to facilitate the review processes. Part 1 describes differences in the hydrologic regime of the Baker and Skagit Rivers under regulated and unregulated conditions. This report represents Part 2 of Study A24. Part 2 describes the results of analyses that focused on Sediment Transport and Channel Response. The draft study results are presented in two documents to allow a more efficient review of the material.



PUGET SOUND ENERGY
BAKER RIVER HYDROELECTRIC PROJECT
FERC PROJECT NO. 2150

FIGURE 1-1
BAKER RIVER LOCATION MAP
(MAP VERSION 04/04/03)

HYDROLOGY AND GEOMORPHOLOGY OF THE BAKER AND LOWER SKAGIT RIVERS (STUDY A-24 PART 2)

1.1 GEOLOGIC AND CLIMATIC SETTING

The hydrologic regime of the Baker and Skagit rivers is strongly influenced by climate and geology. The Baker River basin is located on the western flank of the North Cascades Physiographic province in western Washington, extending from the glaciated peaks of Mount Baker and Mount Shuksan through a deeply entrenched valley carved by glaciers. The Baker River is the second largest tributary to the Skagit River system, contributing flows from a basin area of approximately 297 square miles. Streamflows in the Baker River are driven by runoff from fall rain events, spring snowmelt and, in the case of the larger tributaries in the northwestern portion of the Baker River basin, by glacial melt. Although average monthly flows are typically highest from May through July, peak flows generally occur during the late fall and winter in response to heavy precipitation.

The bedrock geology of the Baker River basin is complex. The western two-thirds of the basin is underlain by slates, limestones, phyllites and metavolcanic rocks of the Chilliwack Group dating from the late Paleozoic era. Superimposed on this older material are the much younger volcanic rocks originating from the Mount Baker volcano. The eastern third of the basin consists of greenschists and phyllites of the Shuksan Metamorphic Suite, dating from the mid-Cretaceous. These geologic formations represent episodes of mountain building over millions of years through uplift, folding and volcanism.

The landforms of the basin have been sculpted by repeated glaciation and fluvial erosion. Alpine glaciation produced sharp peaks and ridges as well as cutting deep valleys. Continental glaciation rounded many of the landforms at lower elevations and scoured the pre-existing drainages. A large lobe of the cordilleran ice sheet push up the Skagit River valley, creating an ice dam behind which large lakes were formed, trapping alluvium carried by sediment-laden streams. One of these glacial lakes occupied the Baker River valley. As the ice retreated from the Skagit Valley, the lake drained and the Baker River rapidly carved a canyon through the glacial outwash and lacustrine sediments. The lower Baker River, now inundated by Lake Shannon, downcut through this material. In areas where the sediments were shallow and lay over bedrock, downcutting of the river formed deep, narrow bedrock controlled canyons. In areas where the sediments were thick the river was able to migrate laterally as it downcut, forming a wider valley bordered by steep bluffs composed of glacial outwash and lacustrine sediments.

During the same period, alpine glaciers originating from the higher peaks were also retreating, delivering large amounts of sediment to the upper Baker River valley. Baker Lake appears to have been formed where glacial outwash from the Swift and Park creek valleys coalesced and spread up valley pushing the Baker River to the southeast and raising the elevation of the valley bottom relative to the area immediately upstream (Kevin Scott, USGS, pers. comm 2003). Sediment from the portion of the basin east of Swift Creek slowly filled Baker Lake, forming a very wide flat delta feature (Figure 1-2).

After the glaciers had largely retreated, a series of volcanic events sent a sequence of mudflows, pyroclastic flows and lava flows down the tributary streams draining the southern flank of Mount Baker. Numerous flows events have been identified, including a series of large events that occurred as recently

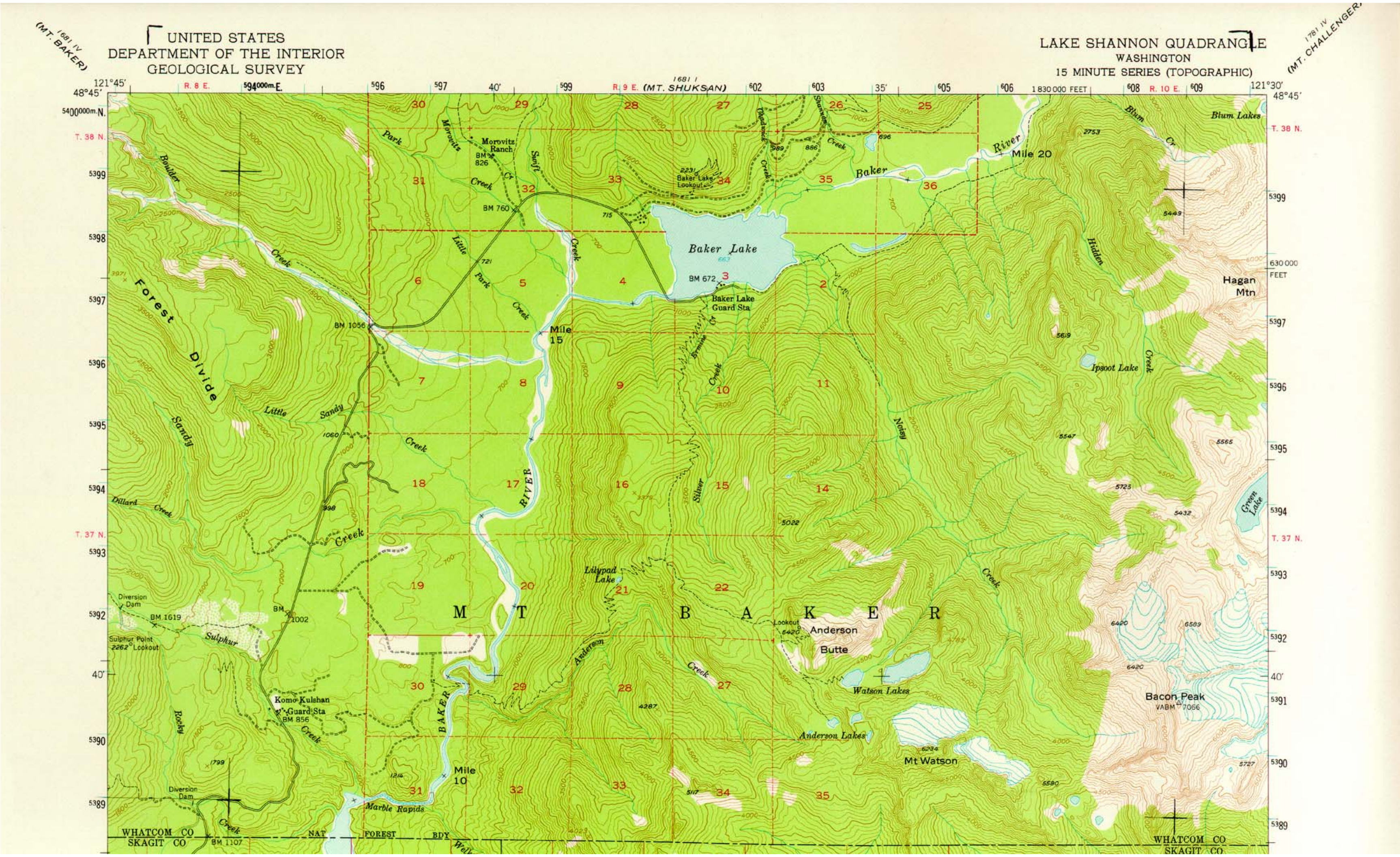


Figure 1-2. Topographic map of the Baker River valley upstream of Lake Shannon prior to construction of the Upper Baker Development (USGS 1952).

as the mid-19th century (Kevin Scott, USGS, pers. comm. 2003). In 1843, a pyroclastic flow event traveled down the Boulder Creek valley, depositing sediment across a broad fan that extended up valley as far as Swift Creek. Early vegetation maps suggest that hot gases associated with this flow event burned trees down the Boulder Creek valley and across the fan (Plummer et al., 1898). At around the same time a volcanic event from Mount Baker is reported to have resulted killed fish in the Skagit River (Harris, 1980). A subsequent mudflow down Morovitz Creek apparently blocked the Baker River near the outlet of natural Baker Lake (Kevin Scott, USGS, pers. comm. 2003). Carbon dating indicates that this event occurred in 1856; hydrologic records document an extremely large flood event that year that may have resulted from the Baker River breaching the temporary blockage. The 1856 mudflow is also believed to have raised the water level in natural Baker Lake by around 12 feet; accounts of early settlers describe a band of submerged trees around the lake that had been killed by a sudden change in water level (Whatcom Museum of History and Art, 1999).

1.2 PROJECT OVERVIEW

The Baker Project consists of the Upper Baker and Lower Baker Developments. The Lower Baker Development consists of the Lower Baker Dam, a powerhouse, reservoir and associated facilities. Lower Baker Dam is located on the Baker River approximately 1.2-miles mile north of the confluence of the Baker and Skagit rivers. The dam is a 285-foot high concrete gravity arch structure constructed in 1925. The top of Lower Baker Dam is at elevation 446.87 feet, and water is released through the turbine intake (elevation 350 feet) or through the dam spillway (spillway crest elevation 424.8 feet) (Figure 1-3). The dam has 23 spill gates, each of which is 14 feet high and 9.5 feet wide.

Lake Shannon, the reservoir formed by Lower Baker Dam, is approximately seven miles long and covers an area of about 2,218 acres at normal full pool (elevation 438.6 feet). Approximately 159,465 acre-feet of water are stored in Lake Shannon at full pool, including about 122,565 acre-feet of active storage above the minimum generating pool. Under normal operating conditions, Lake Shannon is held at full pool during the summer months. Minimum reservoir elevations are typically attained from November through March or early April. Lake Shannon can be operated in coordination with Baker Lake to provide flood control protection, but there is no formal agreement governing Lake Shannon operations for storage of winter storm runoff.

The Upper Baker Development consists of the Upper Baker Dam, a powerhouse, reservoir and associated facilities. Upper Baker Dam is a concrete gravity dam constructed in 1959. The top of Upper Baker Dam is at elevation 732 feet and water is released through the turbine intakes (elevation 654 feet) or through the three 30-foot high by 25-foot wide tainter spill gates (spillway crest elevation 694 feet) (Figure 1-4).

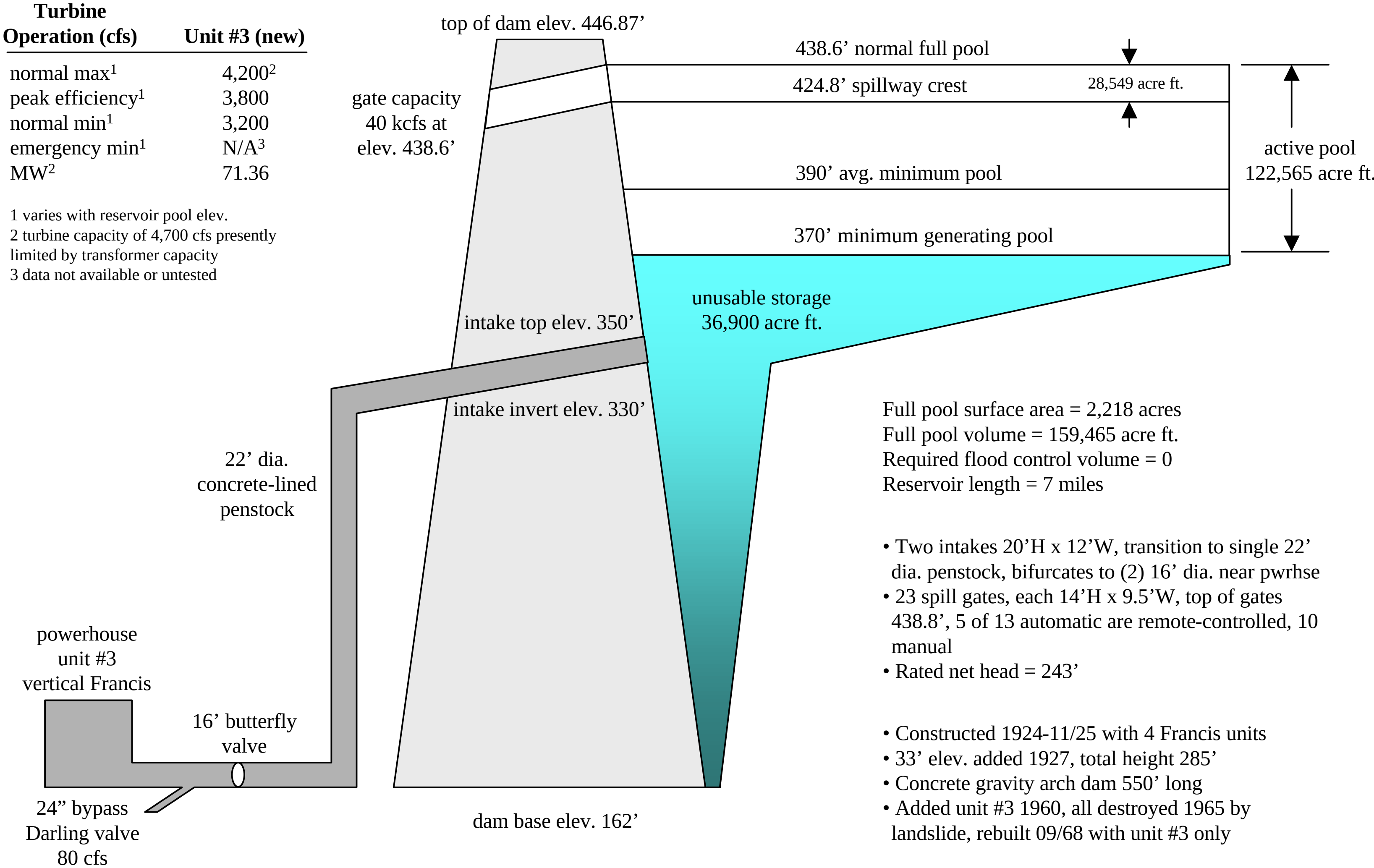
Baker Lake, the reservoir formed by Upper Baker Dam, is approximately nine miles long and covers an area of about 4,985 acres at normal full pool (elevation 724.0 feet). Roughly 285,472 acre-feet of water are stored in Baker Lake at full pool, of which approximately 184,796 acre-feet is active storage above the minimum generating pool. Under normal operating conditions, Baker Lake is held near full pool

Lower Baker Dam

Section View - Not to Scale

Turbine Operation (cfs)	Unit #3 (new)
normal max[1]	4,200[2]
peak efficiency[1]	3,800
normal min[1]	3,200
emergency min[1]	N/A[3]
MW[2]	71.36

1 varies with reservoir pool elev.
2 turbine capacity of 4,700 cfs presently limited by transformer capacity
3 data not available or untested



Full pool surface area = 2,218 acres
Full pool volume = 159,465 acre ft.
Required flood control volume = 0
Reservoir length = 7 miles

- Two intakes 20’H x 12’W, transition to single 22’ dia. penstock, bifurcates to (2) 16’ dia. near pwrhse
- 23 spill gates, each 14’H x 9.5’W, top of gates 438.8’, 5 of 13 automatic are remote-controlled, 10 manual
- Rated net head = 243’

- Constructed 1924-11/25 with 4 Francis units
- 33’ elev. added 1927, total height 285’
- Concrete gravity arch dam 550’ long
- Added unit #3 1960, all destroyed 1965 by landslide, rebuilt 09/68 with unit #3 only

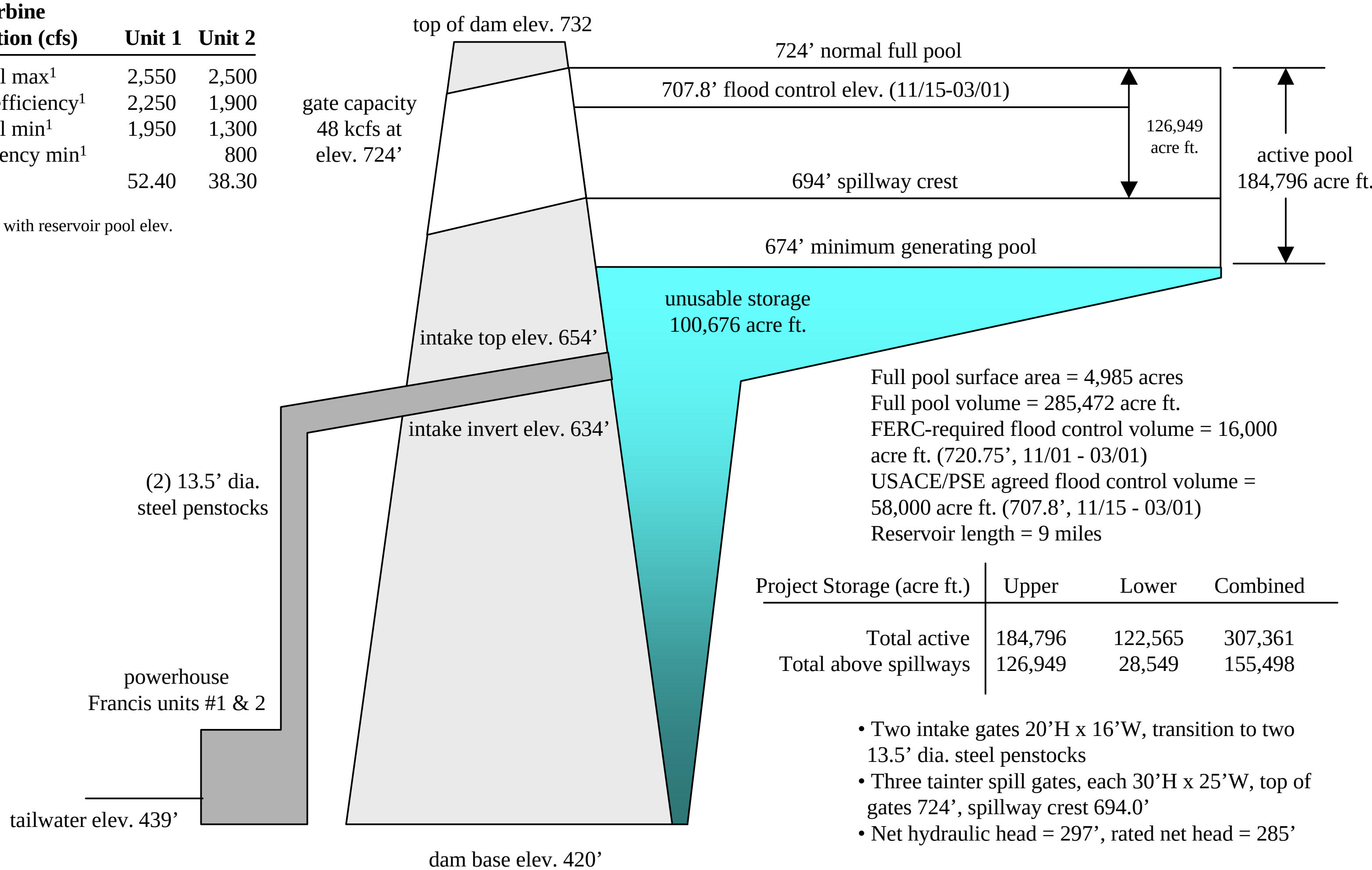
Figure 1-3. Schematic of Lower Baker Development.

Upper Baker Dam

Section View - Not to Scale

Turbine Operation (cfs)	Unit 1	Unit 2
normal max[1]	2,550	2,500
peak efficiency[1]	2,250	1,900
normal min[1]	1,950	1,300
emergency min[1]		800
MW	52.40	38.30

1 varies with reservoir pool elev.



Full pool surface area = 4,985 acres
Full pool volume = 285,472 acre ft.
FERC-required flood control volume = 16,000 acre ft. (720.75', 11/01 - 03/01)
USACE/PSE agreed flood control volume = 58,000 acre ft. (707.8', 11/15 - 03/01)
Reservoir length = 9 miles

Project Storage (acre ft.)	Upper	Lower	Combined
Total active	184,796	122,565	307,361
Total above spillways	126,949	28,549	155,498

- Two intake gates 20'H x 16'W, transition to two 13.5' dia. steel penstocks
- Three tainter spill gates, each 30'H x 25'W, top of gates 724', spillway crest 694.0'
- Net hydraulic head = 297', rated net head = 285'

- Constructed 06/56 - 10/59 with 2 Francis units
- Concrete gravity dam 1200' long, 312' high
- 12' roadway at elev. 732'

Figure 1-4. Schematic of Upper Baker Development

during the summer months. Minimum reservoir elevations are typically attained from November through March or early April. PSE's license obligates PSE to operate the Upper Baker Development to provide the U.S. Army Corps of Engineers (USACE) with 16,000 acre-feet of flood control storage between November 1 and March 1. In addition, PSE is obligated to provide up to 84,000 acre-feet of flood control storage if requested by the USACE (for a total of up to 100,000 acre-feet of flood control storage). Under the current agreement between PSE and the USACE, PSE must maintain Baker Lake elevations at or below 720.25 feet by November 1 to provide 16,000 acre-feet of flood control storage at the Upper Baker Development, and to elevation 707.8 feet or lower under normal operating conditions from November 15 to March 1 (to provide a total of 74,000 acre-feet of flood control storage at the Upper Baker Development).

1.3 STUDY APPROACH

The overall geomorphic evaluation includes three primary components: 1) an assessment of changes in the hydrologic regime of the Baker and Skagit rivers conducted using a modified version of the Indicators of Hydrologic Alteration (IHA) methodology described by Richter et al. (1996); 2) development of subbasin-scale sediment budget (inputs/storage/output) and an estimate of the bedload transport capacity of the Baker River under continued project operations and without the influence of the project; and 3) an evaluation of the responsiveness of the Lower Baker and Skagit river channels downstream of the Project to changes in the flow regime, sediment yield and LWD inputs that would occur under ongoing project operations and without the influence of the Baker Project. This report describes the results of Part 2 of Study A24: the sediment transport and channel response analysis.

The results of this study provide a quantitative estimate of the amount of sediment that will be intercepted by the Baker Project under ongoing operations. This information is used to estimate how much sediment the Baker River would contribute to the middle Skagit River under unregulated conditions, but does not necessarily answer the question of how much of the sediment that would be supplied by the Baker River should be replaced to maintain or restore the natural sediment balance in the Skagit River. In a landscape level assessment of basin-wide geomorphic processes, including sediment transport, Beamer et al. (2000) concluded that sediment supply from most of the lands draining to Baker Lake and Lake Shannon was comparable to what would be expected under unmanaged conditions. However, almost 50 percent of the Sauk River basin, and numerous tributary streams downstream of the Baker River, such as Finney Creek, are currently delivering higher than average levels of sediment to the Skagit River (Beamer et al., 2000). In addition, the volume of sediment intercepted by Seattle City Light's Skagit Project (FERC No. 253; hereafter referred to as the Skagit Project) and the effect of that reduction in sediment supply on the Skagit River is unknown. The current strategy of the Skagit Watershed Council focuses on reducing sediment inputs to the Skagit River (Beamer et al., 2000). Restoration or mitigation for sediment transport associated with the Baker Project relicensing will need to be developed in coordination with other programs currently underway in the Skagit basin.

The evaluation of channel responsiveness and reach-scale channel morphology in the Baker and Skagit Rivers provide basic information needed to interpret effects of proposed changes in Baker Project operations or PM&Es on aquatic habitat in the Baker and middle Skagit rivers. Historic channel morphologic conditions serve as the basis for determining how and why various segments of the river look and function as they do today and how they would look or function over the upcoming license period without the Baker Project's influence. An understanding of the current and potential natural channel morphology in the various reaches of the Baker and middle Skagit rivers may be used as a guide to the development and application of potential mitigation or enhancement measures.

The evaluation of channel responsiveness also addresses the functional role large woody debris plays in various portions of the Baker and Skagit rivers based on channel type, and describes the anticipated channel response to wood inputs under the existing channel configuration. However, this study does not include a detailed wood budget for the Baker River system. Wood budgets are explicitly addressed by a separate study (A-20) and are thus beyond the scope of this effort.

2. METHODS

Data collection for Part 2 of Study A24 consisted of three major activities: 1) compilation and review of existing literature, maps and aerial photographs; 2) spatial analysis of Geographic Information System (GIS) data collected for companion studies; and 3) field data collection. Existing literature was obtained from Puget archives, the Mount Baker-Snoqualmie National Forest, Skagit System Cooperative and searches of the University of Washington and Western Washington University library collections.

The following sections describe specific data collection and data analysis methods utilized to accomplish the overall project objectives and to address specific issues of concern identified by stakeholders. Methods used to predict sediment yield to the Project Reservoirs and from the Baker River to the middle Skagit River are presented in Section 2.1. Section 2.2 describes the approach used to evaluate channel responsiveness to the changes in sediment yield described in this report and to the changes in flow regime described in Part 1. The results of the sediment yield analysis are presented in Chapter 3. Chapter 4 provides a discussion of general channel responsiveness and describes the likely effects of changes in hydrology and sediment transport identified in Chapter 3 of this report and in Part 1 of this study (R2, 2002) on river channels downstream of the Baker Project Area.

2.1 SEDIMENT TRANSPORT

Sediment originates on hillslopes and is delivered to stream channels via erosion or mass wasting. Sediment that is delivered to a stream and transported downstream out of the basin is hereafter referred to as the sediment yield. Hydroelectric developments can alter the sediment yield and transport regime in a number of ways. Dams form permanent impoundments that interrupt the downstream movement of sediment as transported material settles in the deep, low velocity reservoirs. Trapping of sediment within the impoundment reduced the sediment yield to downstream reaches and may result in sediment starvation accompanied by bed armoring and incision depending on the channel type. Conversely, if downstream sediment inputs are high and diversion of flow to produce power substantially reduces the magnitude of flood flows, undesirable amounts of sediment may accumulate within the channel.

Within the Project Area, alluvial sediment is delivered to the reservoirs by the Baker River at the upstream end and from numerous tributaries along the length of the reservoirs. The Baker River upstream of Baker Lake is unregulated. The Baker River downstream of Upper Baker Dam is almost completely inundated by Lake Shannon at high pool levels. The reservoirs also receive some input of colluvial sediment from steep, unstable portions of the adjacent hillsides. The magnitude of colluvial inputs is not considered here, but may be large. Mass wasting along reservoir margins is discussed in Study A14 (AESI, 2003). The Baker Project reservoirs have sufficient storage capacity to trap the larger incoming sediments. Of particular ecological concern is the effect of the reduction in gravel delivered to downstream reaches.

As a first step towards addressing these concerns, sediment yield estimates were developed for the Baker River and tributaries that deliver sediment to the reservoirs. The total sediment yield was broken into two components: suspended load and bedload. Bedload represents the coarsest potion of the total sediment load. Bedload is intermittently transported by a river during high flow events. When bedload is mobilized it typically rolls or bounces along the channel bottom. In steep channels where the ability of the river to move sediment (transport capacity) exceeds the sediment supply, the bed is typically composed of bedrock or boulders that are mobilized only by extreme high flow events. Bedload moving through such channels is typically stored in patches associated with stable obstructions. In contrast, the sediment supply generally exceeds the transport capacity in low gradient, unconfined alluvial channels, and bedload accumulates within the valley bottom, forming a floodplain. The bed material of alluvial channels is typically representative of the size and composition of bedload moving through the system. Bedload typically constitutes 10 to 20 percent of the total load, and may represent as much as 17 to 23 percent of the total load for mountainous basins (Gregory and Walling, 1973).

The suspended load consists of sediment particles that are fine enough to travel in suspension within the water column. Coarse material carried as suspended load during high flows may settle out in low velocity areas or along channel margins or it may be deposited on the floodplain. Finer sediments are rapidly transported downstream to the Skagit River and ultimately to Puget Sound.

The analysis of sediment transport through the Baker Project Area consisted of two major steps. First, the amount of sediment delivered to the Baker Project Reservoirs was estimated. The sediment yield of tributaries to the Baker River was estimated using three separate approaches: modeling of bedload inputs from selected tributaries based on field surveys; modeling of suspended load inputs from similar nearby basins using long-term water quality monitoring data; and application of regional bedload input rates. Next, simplified sediment budgets were developed to describe the routing and storage of sediment through the Baker Project area under current conditions and without the influence of the project.

2.1.1 Sediment Yield

The Baker River and large tributaries draining to Baker Lake from the west, including Swift Creek, Park Creek, Sandy Creek and Boulder Creek, are fed by glaciers located on the southeast flank of Mount Baker. Mount Baker is an active volcano, and local geologic evidence suggests that some or all of these tributaries have historically experienced extreme mudflow events (lahars) as a result of volcanic activity. As a result, the long-term sediment yield from these streams is expected to be high, as evidenced by the pronounced alluvial fans that have formed where they enter the Baker River valley. Tributaries draining to Baker Lake from the east, and most of the tributaries draining to Lake Shannon are fed primarily by precipitation and a seasonal snowpack that develops at higher elevations; non-glacial mountain streams such as these typically have lower sediment inputs than glacial streams. The long-term sediment yield of non-glacial tributaries is expected to be lower than that of tributaries fed by glaciers.

Three approaches were used to estimate the amount of sediment transported into and through the Baker Project area from tributary areas. Method 1 focused on estimating the bedload yield for tributaries to the Baker River. First, the bedload yield of selected tributary streams was calculated by developing a bedload rating curve and linking it to a flow duration curve. The bedload rating curve was developed using field data from tributary streams in the Baker River watershed. A detailed description of field data collection and modeling methods is provided in Appendix A.

Method 2 focused on estimating the annual suspended sediment yield using long-term water quality monitoring data from a similar nearby unregulated river. The Washington Department of Ecology has collected suspended sediment data from the Nooksack River located to the north of the Skagit River basin since 1979. Suspended sediment and flow duration data for the Nooksack River at Deming gage was used to develop a suspended sediment rating curve and to estimate the annual suspended sediment yield.

For both Methods 1 and 2, bedload was assumed to represent a fixed proportion of the suspended sediment load. The relationship between bedload and suspended load was used to back calculate the total annual sediment yield. Analysis results from Methods 1 and 2 were compared to published regional estimates of bedload yield. Comparison of data developed through these two independent approaches was used to check the validity of the estimated bedload yield for the Baker River.

Development of sediment yield estimates using the methods applied for this analysis requires making several fundamental initial assumptions.

1) Sediment production rates differ between streams with glacial and non-glacial source areas but within a given type of source area are equal throughout the area. This assumption simplifies most of the important factors governing sediment production and transport. In reality, variations in geology, soils, precipitation regime, topography, vegetation and land-use all affect the type of sediment delivered to the channel and the magnitude, frequency and duration of sediment transport.

2) Land use in the basin would not change sufficiently over the analysis period to alter sediment production rates. This assumption may be reasonably accurate for portions of the basin located within North Cascades National Park, but is not true for lands managed by the USFS, WDNR and private landowners. Land use and management on federal lands has changed over time, most notably in the past 10 years through implementation of the Northwest Forest Plan. Forest practice regulations on state and private lands have also changed recently and currently include measures specifically designed to reduce management-related sediment delivery to streams. However, conducting an inventory of the specific effects of these changes and predicting how they will influence sediment yield in the future is beyond the scope of this effort.

3) Direct sediment inputs to the reservoirs from mass wasting and shoreline erosion are negligible relative to fluvial inputs from tributary streams. This assumption may be true for Baker Lake; however, large, active mass wasting sites are common adjacent to Lake Shannon. Sediment inputs from shoreline erosion and mass-wasting are being evaluated in a separate study. The results of those efforts are summarized in the discussion section and compared to the results of this study to facilitate an evaluation of the validity of this assumption.

4) All data used for this analysis are accurate and representative. It was assumed that all data used for these analyses that were obtained from other sources (e.g., topographic surveys, flow duration curves) are accurate. Discussions of specific shortcomings and the effect they would have on sediment yield estimates generated for this study are presented in conjunction with the analysis results. It is further assumed that regional values used for these analyses (e.g., sediment bulk density, regional sediment yield estimates) are representative of the Baker River Watershed.

2.1.2 Sediment Routing Through the Project Area

Some of the sediment delivered to the Project Area from the Baker River and tributary streams deposits in Baker Lake and Lake Shannon and the rest of the sediment is passed downstream to the Skagit River. Without the influence of the reservoirs, some of the sediment from the Baker River and its tributaries would be stored in natural Baker Lake and within the Baker River valley and the rest would be transported downstream to the Skagit River.

An analysis of the sediment trapping efficiency was conducted for both natural Baker Lake and the reservoirs. The total quantity of sediment supplied to each reservoir, lake or mainstem reach was estimated as described above. The amount of sediment trapped in the lake or reservoir or delivered to downstream reaches was accounted for based on the sediment trapping efficiency of each reservoir and the transport capacity of the river. The trap efficiencies of natural Baker Lake and each reservoir were determined using the modified Brune Curve Method (Linsley et al., 1982). Hydraulic characteristics of each reservoir pool were evaluated to determine trap efficiencies for sediment size fractions ranging from very fine clay to small cobbles using a method that the U.S. Bureau of Reclamation recommends for turbulent flow (Borland, 1971; Chen, 1975; and Raudkivi, 1993). A detailed description of the specific models and assumptions utilized to evaluate the reservoir trapping efficiency and develop the sediment budgets is provided in Appendix A.

Sediment budgets were developed for two conditions: regulated conditions assuming ongoing project operation and unregulated conditions without the influence of the project. The sediment budget accounts for tributary sediment yields to each reservoir, deposition of sediment within the reservoir, and the outgoing sediment that is delivered to downstream reaches.

Historical patterns of sediment deposition within Baker Lake and Lake Shannon were evaluated qualitatively to identify where sediment is accumulating within the reservoirs. Sediment deposition within Baker Lake was analyzed by comparing topographic maps from 1959 and 1999. Sediment deposition in Lake Shannon was assessed by comparing a sequence of historical aerial photographs.

2.1.3 Sediment Storage

Another approach typically used to evaluate the sediment yield in managed river basins is an assessment of deposition within reservoirs over time. Bathymetry data and storage capacity curves currently available for the Baker Project are not accurate enough to allow a direct calculation of the volume and depth of sediment that has accumulated in the reservoir over time. However, depositional patterns were evaluated qualitatively to identify sites where sediment is currently being stored.

Sediment storage within the Baker River valley without the influence of the Project was evaluated by comparing the sediment transport capacity for alluvial portions of the mainstem Baker River with the total sediment yield of tributary areas. If average annual sediment yield is higher than the sediment transport capacity of the Baker River, then bedload would be expected to accumulate within the valley as gravel bars in the channel or overbank deposits on the floodplain. Conversely, if the bedload transport capacity is higher than the sediment yield, then the Baker River would be expected to export more sediment than is delivered by tributary areas and long-term channel incision would be expected to occur.

2.1.4 Baker River Sediment Contributions to the Skagit River

The contribution of sediment originating from the Baker River to the sediment supply of the middle Skagit River was assessed using regional sediment yield values and data on suspended sediment loads at the Skagit River near Mount Vernon gage located downstream of the confluence with the Baker River. On a regional basis, the total sediment yield of the Skagit River per unit area was assumed to be the same the sediment yield per unit area from the Baker River basin downstream of natural Baker Lake. Baker River contributions to the overall sediment yield are therefore equivalent to the ratio of the effective contributing area of the Baker River basin to the total drainage area of the Skagit River basin at the confluence with the Baker River.

The total sediment load of the Skagit River was also estimated using measured data on the annual suspended sediment load at the Skagit River at Mount Vernon gage site. Calculations were completed using the same approach as described for Method 3 in Section 2.1.1. Suspended sediment contributions from the Baker River were estimated based on the sediment budgets developed as described in Section 2.1.2. Suspended sediment contributions from the Skagit River basin upstream of the Skagit Project were assumed to be the same per unit drainage area as for the Baker River. The total sediment load of tributary areas downstream of the Baker and Skagit Projects was estimated by subtracting contributions from the Baker and Skagit Rivers from the total sediment load, then assuming that bedload contributions from unregulated tributary areas were equivalent to 15 percent of the suspended sediment load.

2.2 CHANNEL RESPONSE POTENTIAL

Channel morphology is a useful tool for classifying streams and rivers because it: 1) dictates habitat conditions used by the various life-history stages of salmonid species (Beechie and Sibley, 1997); 2) directly influences the productive capacity of each habitat type (Vannote et al., 1980; Naiman et al., 1992; Paustian et al., 1992); and 3) varies in terms of sensitivity and response to changes in inputs of water, sediment and wood from natural or anthropogenic disturbances (Paustian et al., 1992; Montgomery and Buffington, 1993; Rosgen, 1997).

Hypotheses regarding the most likely effect of Baker Project operations on channel conditions may be made by evaluating the channel type and response potential of affected reaches. The nature of Project effects will vary depending on the channel type, and on the inherent rate of sediment delivery and the hydrologic regime (Table 2-1). Potential responses range from relatively minor textural adjustments of the substrate (i.e., fining or coarsening) to large-scale changes in bedform and channel type.

Channel segments with consistent geomorphic characteristics and response potential were delineated based on landform, stream gradient, channel confinement, and channel planform. Channel segments were classified using a modified version of the system developed by the USFS Region 10 (Paustian et al., 1992). The USFS system is based on identification of "fluvial process groups" that describe the interrelationship between watershed processes such as the flow regime, fluvial erosion and mass wasting, and large woody debris (LWD) recruitment and the role of wood in habitat formation. Channel gradient and confinement were measured from USGS 1:24,000 scale maps. Landforms were identified using a combination of topographic maps, geology maps and aerial photo analysis.

Table 2-1. Conceptual model of the channel response below dams to changes in the flow regime and sediment yield relative to conditions without the influence of the project (after Grant 2000).

	Low Frequency of Bed-Mobilizing Flows	High Frequency of Bed-Mobilizing Flows
High Sediment Supply Below Dam	Aggradation at tributary confluence's Textural shifts throughout channel Island and bar formation	Weakly developed armor layer Textural shifts at tributary confluence's
Low Sediment Supply Below Dam	Minor textural adjustment Imbrication/increased embeddedness	Well developed armor layer Degradation Bar and island erosion

3. SEDIMENT TRANSPORT

Sediment inputs to the Baker Project were estimated using three separate approaches in order to evaluate the range of conditions that might be expected to occur over the upcoming license period. A simplified sediment budget approach was used to estimate the amount of sediment moving into and through the Baker Project Area under current conditions and without the influence of the Project. The results of the assessment of the likely sediment yields from tributary areas are presented in Section 3.1. The estimates of average annual sediment yield, combined with stream and reservoir characteristics are used to develop simplified sediment budgets that describe the routing of sediment through the Baker Project area. This analysis is described in Section 3.2. A qualitative description of the distribution of sediments accumulating within reservoirs is provided in Section 3.3. In Section 3.4, the contribution of sediment originating from the Baker River basin to the sediment supply of the middle Skagit River is described semi-quantitatively based on the estimated current and without project contributions from the Baker River and a review of existing literature describing sediment yields in the Skagit River.

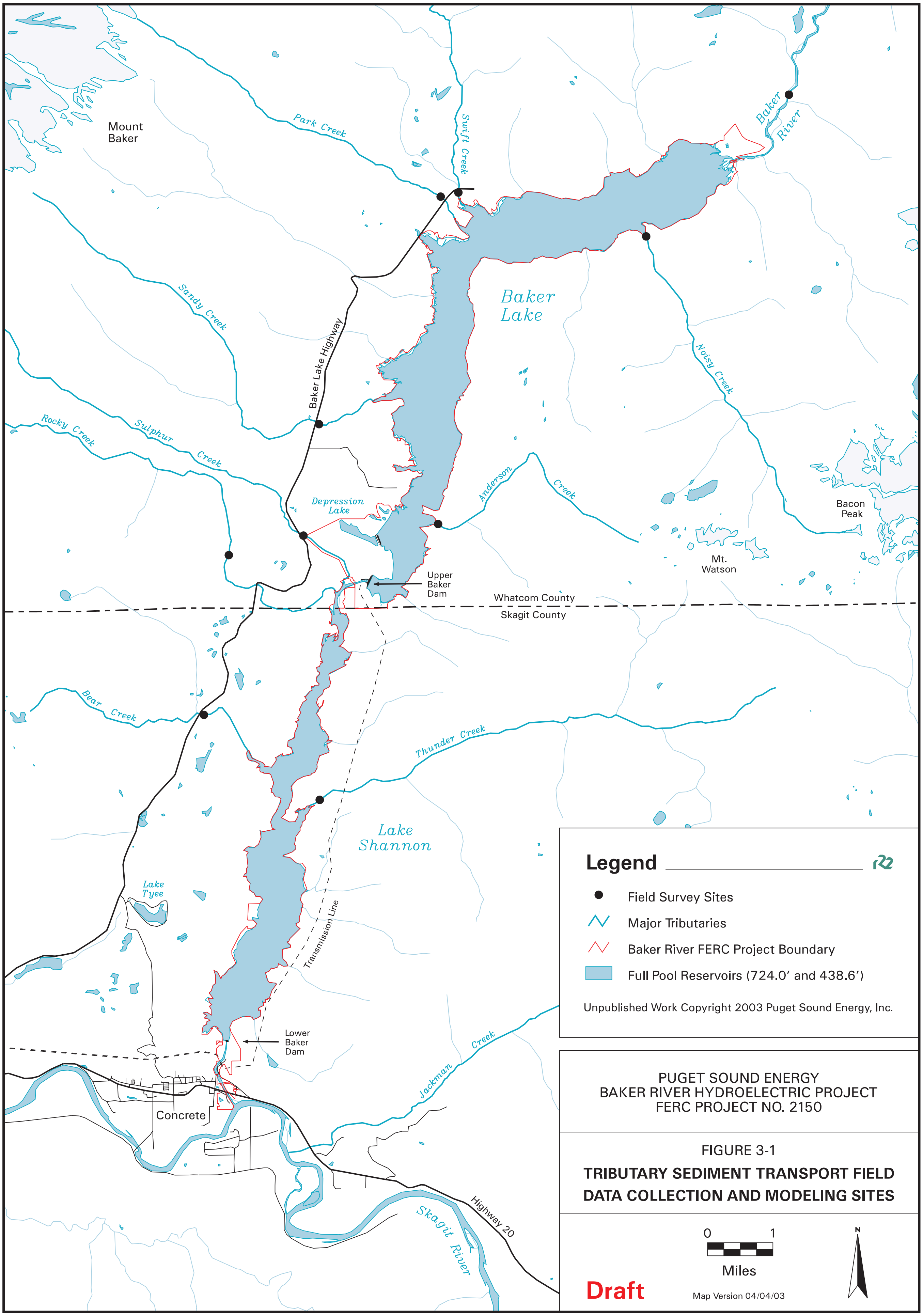
3.1 SEDIMENT YIELD

Tributary sediment yields were assessed using three methods. Method 1 consisted of collecting data from alluvial sections of major tributary streams and modeling annual bedload transport. Method 2 consisted of estimating the annual suspended sediment yield based on data from a nearby undammed glacial river and using that information to back calculate bedload yield per unit area. Method 3 consisted of a literature review to identify regional estimates of bedload yield to provide information on the likely range of bedload contributions for streams within the Baker River basin.

3.1.1 Method 1 – Bedload Modeling

Bedload inputs were modeled for the upper Baker River and for eight major tributary streams where flow duration data were available (Figure 3-1). The estimated annual bedload yield rate per unit drainage area from those tributaries was used to estimate the average sediment yield from the entire area draining to the Baker Project Area. Modeling results indicate that the estimated annual bed material load contributed by the surveyed tributaries ranges from 98 to over 7,500 tons per year. Individual values are highly dependent on site conditions, in particular the existing bed substrate at the survey site. Since these data represent a single point in time and space for each tributary, the values generated from field data were averaged to better reflect the likely range of conditions throughout the basin over the long-term.

Tributary basins were classified as glacial on non-glacial based on the percent glacial cover reported in Williams (1987) or by measurement of areas mapped as glacier or permanent snowfield on digital 1:24,000 scale topographic maps dating from 1989. On a per unit area basis, glacially-fed tributaries contribute an average of approximately 134 tons of bedload per square mile per year. Assuming that



Mount Baker
Park Creek
Swift Creek
Baker River
Baker Lake
Sandy Creek
Baker Lake Highway
Rocky Creek
Sulphur Creek
Depression Lake
Anderson Creek
Noisy Creek
Bacon Peak
Mt. Watson
Upper Baker Dam
Whatcom County
Skagit County
Bear Creek
Thunder Creek
Lake Shannon
Lake Tyee
Transmission Line
Lower Baker Dam
Concrete
Jackman Creek
Skagit River
Highway 20
Legend
Field Survey Sites
Major Tributaries
Baker River FERC Project Boundary
Full Pool Reservoirs (724.0′ and 438.6′)
Unpublished Work Copyright 2003 Puget Sound Energy, Inc.
PUGET SOUND ENERGY
BAKER RIVER HYDROELECTRIC PROJECT
FERC PROJECT NO. 2150
FIGURE 3-1
TRIBUTARY SEDIMENT TRANSPORT FIELD DATA COLLECTION AND MODELING SITES
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bedload amounts to approximately 15 percent of the suspended sediment load (equivalent to approximately 13 percent of the total sediment load), this translates to an average total sediment yield of 1,028 tons of sediment per square mile per year from tributaries with glaciers in their source area. In contrast, estimated average annual bedload contributions from non-glacial tributaries are approximately 14 tons of bedload per square mile per year. Assuming that bedload amounts to approximately 15 percent of the total sediment load, this translates to an average of yield of 108 tons of sediment per square mile per year from tributaries with no glaciers in their source area.

Sediment yield predicted from field data appeared to be only weakly related to the extent of the basin covered by glaciers. This is consistent with research from elsewhere in the Pacific Northwest (Des Loges and Gilbert, 1998). Recent studies suggest that lithology, sediment storage within the basin, and the type of glaciers present and recent glacial history all have a strong influence on sediment yield (Harbor and Warburton, 1998; Bogen, 1997).

3.1.2 Method 2 – Suspended Load Modeling

The Nooksack River is located directly north and west of the Baker River (Figure 3-2). Like the Baker River, the Nooksack River originates from the snowfields and glaciers on Mount Baker and Mount Shuksan, draining an area of approximately 800 square miles. The Nooksack River flows north and west for about 90 miles before draining into Puget Sound near Bellingham, Washington. There are no large dams or storage reservoirs on the Nooksack River, and flows are largely unregulated, although the City of Bellingham diverts up to 100 cfs from the Middle Fork Nooksack River for municipal use (Wiggins et al., 1998). The Nooksack River has a similar geology, water source and climatic regime as the Baker River and is thus believed to represent a reasonable unregulated analog to the Baker River.

The sediment yield of the Nooksack River was estimated using data on suspended sediment collected at the Nooksack River at Deming gage. The Washington Department of Ecology has measured suspended load at the Nooksack River at Deming gage (Gage No. 12210500) under flow conditions ranging from around 500 cfs to over 70,000 cfs. There is a reasonably high degree of correlation between the suspended load measurements and the flow measurements at that gage (Figure 3-3). A relationship between flow and suspended load measurements was developed from the measured data and used to calculate suspended load from 66 years of daily flow measurements for that gage.

The average annual suspended load of the Nooksack River at Deming was determined to be approximately 226,000 tons over the 66-year period. Assuming the bed load is equivalent to 15 percent of the suspended load, then the bed load represents an additional 34,000 tons of sediment per year. The total drainage area of the Nooksack River at Deming gage is 584 square miles. The total sediment load would therefore be equivalent to 445 tons per square mile per year.

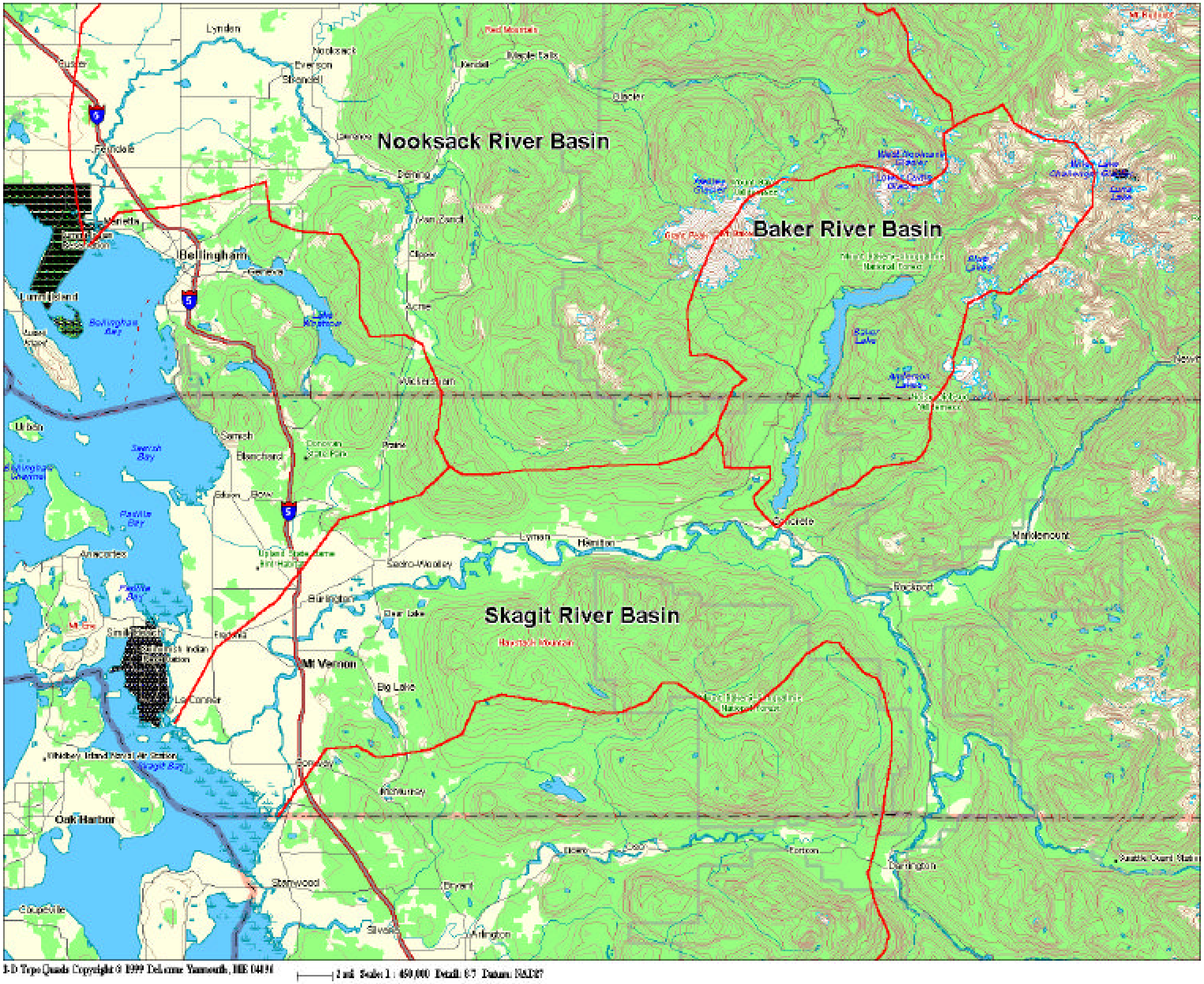


Figure 3-2. Topographic map depicting the relative locations of the Baker River, Skagit River and Nooksack River basins.

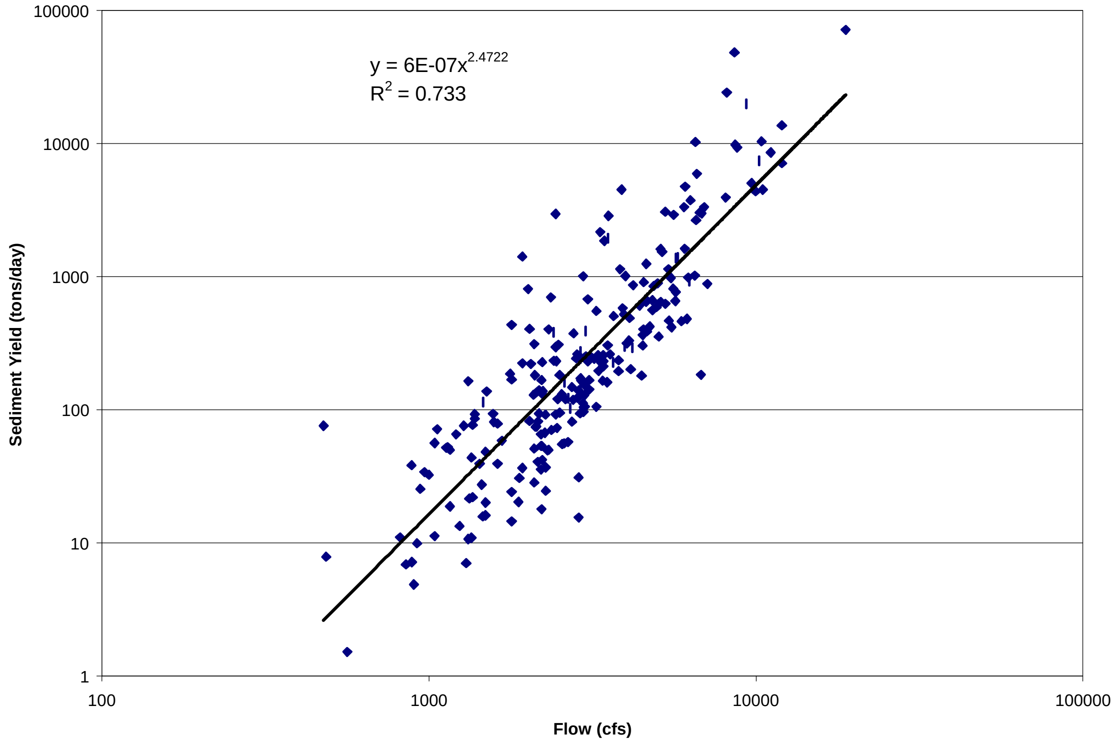


Figure 3-3. Suspended sediment rating curve for the unregulated Nooksack River at the Nooksack River at Deming gage (USGS Station # 12210500) site (Data from WDOE 2003).

3.1.3 Method 3 – Literature Review

Studies conducted elsewhere in the Pacific Northwest indicate that the sediment yield of rivers varies depending on whether the river system is fed by glaciers or rain and snowmelt. Rivers fed by non-glacial sources typically have sediment yields in the range of 30 to 300 tons per square mile per year (Table 3-1). In the case of the Green River, the annual estimated sediment yields varied dramatically between years, from 28 to 543 tons per square mile per year (Williams, 1968).

Rivers where the flow originated from glacial sources tend to have much higher sediment yields (Table 3-1). Des Loges and Gilbert (1998) plotted sediment yields ranging from about 57 to 1000 tons per square mile per year for glacial lakes in the British Columbia Coast range; however, five of the six sites identified had annual sediment yield rates of more than 300 tons per square mile per year. Evaluations of nearby glacial rivers in Washington, including the Elwha River, White River and Nisqually River report sediment yields on the order of 1,000 to 2,000 tons per square mile per year (Table 3-1).

Table 3-1. Literature values for sediment yields from glacially-fed rivers in the Pacific Northwest.

Author	Location	Source	Total Annual Sediment Yield
Hamilton, 1994	Bull Run, OR	non-glacial	30-50 tons/mi^2
Costa 1994	Typical forested basins	non-glacial	54 tons/mi^2
Williams 1968	Green River, WA	non-glacial	294 tons/mi^2
Desloges and Gilbert 1998	British Columbia	glacial	57-1,000 tons/mi^2
Department of Interior 1996	Elwha River, WA	glacial	893 tons/mi^2
Dunne 1986	White River, WA	glacial	1,300 tons/mi^2
Nelson 1974	Nisqually River, WA	glacial	2,500 tons/mi^2

Overall, the average estimated sediment yield from glacially-fed tributaries within the Baker Lake subbasin based on bedload modeling is within the range reported in the literature for nearby glaciated rivers. Modeled estimates of bedload yield are highly dependent on the particle size distribution and channel configuration at individual study sites, and strongly reflect the recent flow regime. Thus, the wide range of estimated bedload yield for the various tributaries is not unexpected. Similarly, except for Thunder Creek, estimated bedload yields from tributaries with no glaciers in their drainage areas are also consistent with values reported in the literature for forested mountain basins. The estimated sediment yield based on suspended sediment data from the Nooksack River is somewhat lower than would be expected for an undammed glacial river.

3.2 SEDIMENT ROUTING THROUGH THE PROJECT AREA

In order to assess the potential range in the amount of sediment routed into and through the Baker Project Area over the upcoming 40 year license period via fluvial transport, estimated sediment inputs from tributary areas were calculated using both the average sediment yield rate based on modeling of tributary bedload transport (i.e., 108 tons per square mile per year for areas with no glaciers and 1,028 tons per square mile per year for area with glaciers), and higher values consisted with sediment yield rates recorded at other regional rivers (i.e., 200 tons per square mile per year for non-glacial areas and 2000 tons per square mile per year for glacial-areas). The results are reported below for current conditions (i.e., with both Project Reservoirs in place) and for a theoretical scenario without the influence of the Baker Project (i.e., no reservoirs).

3.2.1 Sediment Routing Under Current Project Configuration

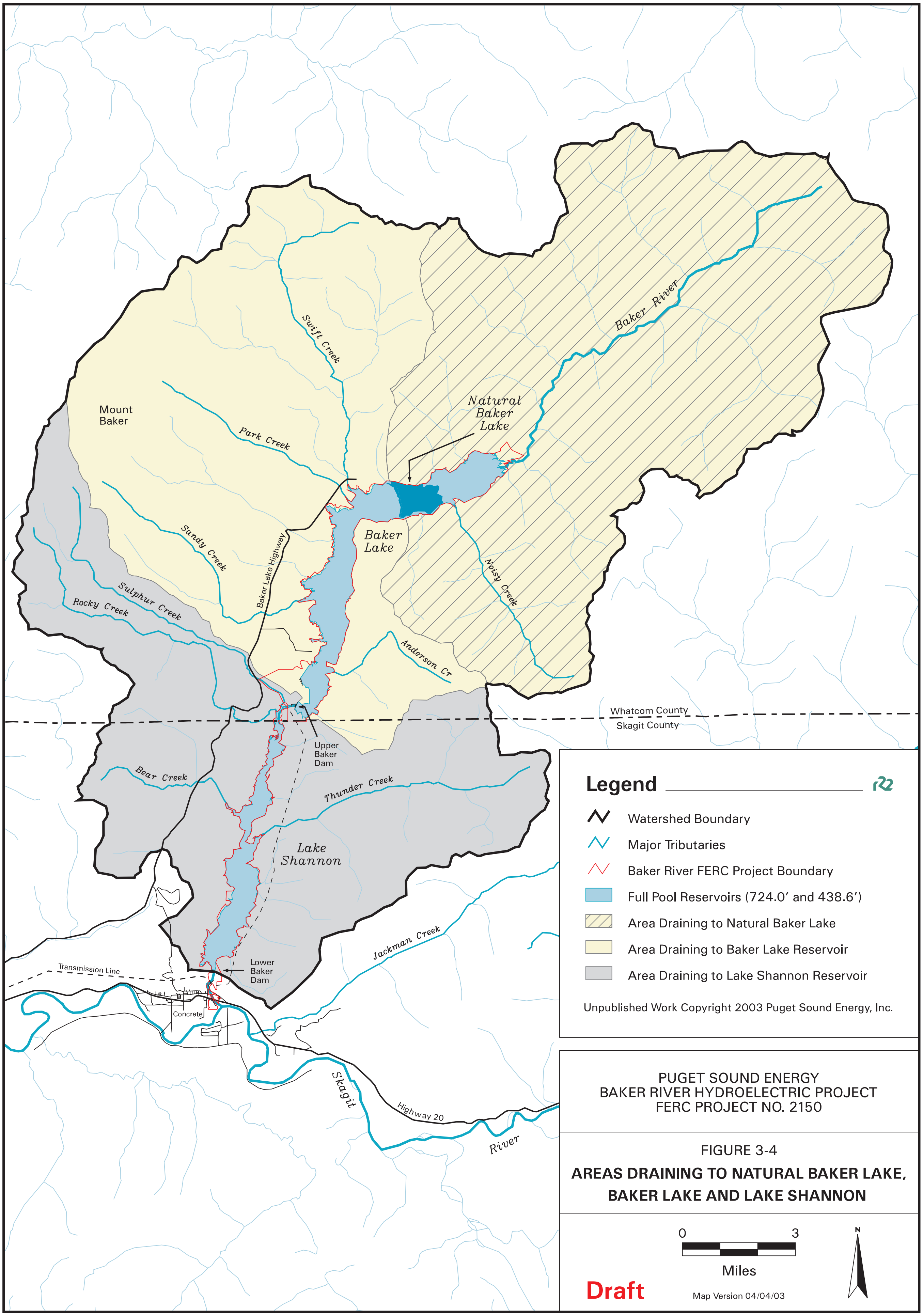
Baker Lake Sediment Budget

Baker Lake Reservoir is formed by the Upper Baker Development, where storage began in 1959. The existing reservoir is about 9 miles long and covers an area of about 4,800 acres at normal full pool (elevation 724.0 feet MSL). Baker Lake has a total storage capacity of about 285,000 acre feet at normal full pool. Baker Lake reservoir receives inflow from a 215 square mile drainage area (Figure 3-4). The primary sources of surface water runoff to Baker Lake include the Baker River, Shannon Creek, Noisy Creek, Swift Creek, Park Creek, Boulder Creek, Sandy Creek and Park Creek. Drainage areas of these sources, listed in Table 3-2, range from 5 square miles for Shannon Creek to approximately 89 square miles for the Baker River at the upstream end of Baker Lake. A number of smaller, unnamed tributaries also drain to Baker Lake.

The 215 square mile area draining to Baker Lake consists of 58 square miles that are fed solely by non-glacial sources (snowmelt and rainfall), and 157 square miles that are fed by both precipitation and glacial melt. The majority of glacially-fed tributaries are located upstream of Baker Lake, or along the west shore draining the flanks of Mount Baker. The total bedload yield to Baker Lake Reservoir is estimated to range from approximately 20,000 to 42,000 tons per year, depending on the yield rate applied (field versus literature based). Assuming that bedload represents 15 percent of suspended load, the total annual sediment yield would be approximately 157,000 to 325,000 tons per year (Table 3-3).

Table 3-2. Drainage areas of principal sources of surface water runoff to Baker Lake, Washington

Source	Drainage Area (mi^2)	Percent glaciated
Baker River	89	18.5
Shannon Creek	5	0
Swift Creek	37	3.1
Park Creek	11	16.3
Boulder Creek	11	23
Sandy Creek	11	3.4
Noisy Creek	14	4
Anderson Creek	6	0



PUGET SOUND ENERGY
BAKER RIVER HYDROELECTRIC PROJECT
FERC PROJECT NO. 2150

FIGURE 3-4

AREAS DRAINING TO NATURAL BAKER LAKE, BAKER LAKE AND LAKE SHANNON

Table 3-3. Sediment budget for Baker River upstream of the Upper Baker Dam near Concrete, Washington under on going operations.

		Ongoing Project Operations (tons/year)
Incoming from Baker River and tributaries	Total Load	157,000-325,000
	Suspended Load	137,000-283,000
	Bedload	20,000-42,000
Trapped in Baker Lake	Total Load	137,000-283,000
	Suspended Load	117,000-241,000
	Bedload	20,000-42,000
Outgoing to Lake Shannon subbasin	Total Load	20,000-42,000
	Suspended Load	20,000-42,000
	Bedload	0

Baker Lake traps sediment delivered from tributary streams. The hydraulic characteristics of existing Baker Lake were used to determine bulk sediment trap efficiencies. The average annual inflow to existing Baker Lake is about 1,901 cfs and the reservoir storage volume at full pool is about 285,000 acre-feet. From the Modified Brune Curve method, the trap efficiency of Baker Lake Reservoir at full pool ranges from 87 to 93 percent. Baker Lake is commonly drawn down for flood control during the fall and winter, when most of the flows capable of transporting sediment occur. The median pool elevation during this time period is approximately 698 feet msl; at this pool level the trap efficiency ranges from 79 to 89 percent. For this study, a trap efficiency of 87 percent is assumed for Baker Lake Reservoir. Based on this assumption, of the 157,000 to 325,000 total tons of sediment delivered to Baker Lake annually, 137,000 to 283,000 tons is trapped in the reservoir and 20,000 to 42,000 tons is passed downstream to Lake Shannon (Table 3-3). The sediment accumulating in Baker Lake includes all of the bedload delivered by tributary streams, and a portion of the suspended load. All of the approximately 20,000 to 42,000 tons of material delivered to Lake Shannon each year would consist of suspended load.

Hydraulic characteristics of existing Baker Lake were also used to determine grain size-specific sediment trap efficiencies. Results of these analyses are shown in Figure 3-5. Existing Baker Lake traps virtually all sediment larger than medium silt and passes most sediment smaller than medium clay. Some of the coarse clays and fine silts would be trapped and some would be passed, depending on the grain size and on the flow through the reservoir.

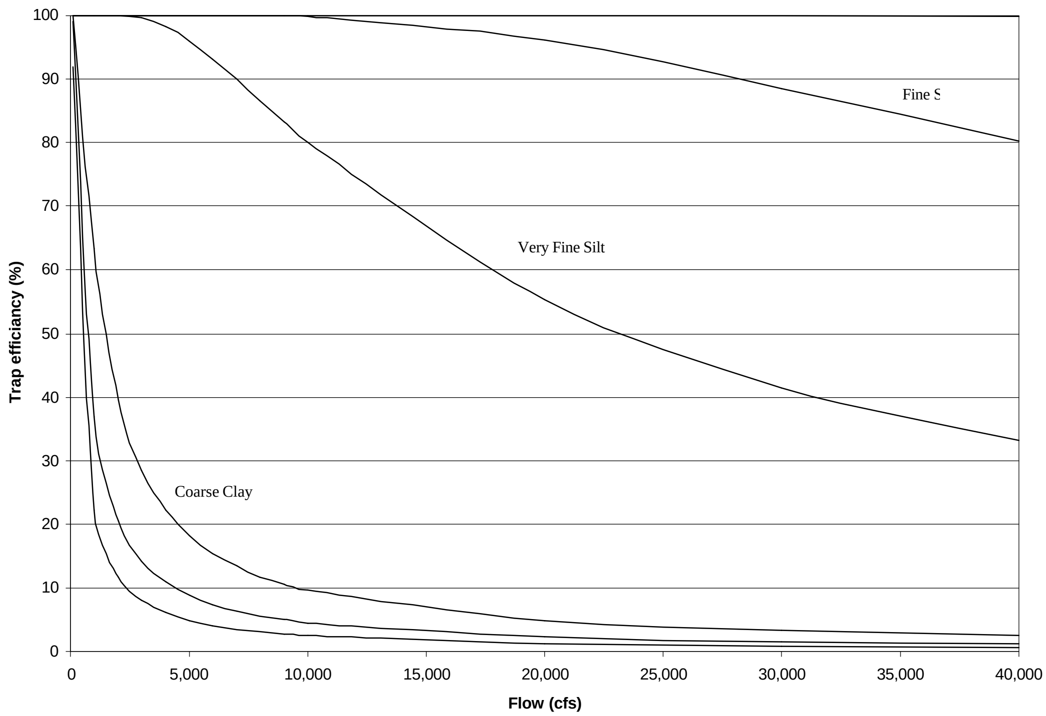


Figure 3-5. Grain-size specific sediment trapping efficiencies of Baker Lake Reservoir for flows ranging from zero to 40,000 cfs.

Lake Shannon Sediment Budget

Lake Shannon is the reservoir formed by the Lower Baker Development, where storage began in 1925. Lake Shannon is located directly downstream of Upper Baker Dam, with virtually no intervening riverine reach when the reservoir is at full pool. The existing reservoir is about 7 miles long and covers an area of about 2,190 acres at normal full pool (elevation 438.6 feet MSL). Lake Shannon has a total storage capacity of about 160,000 acre-feet at normal full pool.

Lake Shannon receives inflow from a 297 square mile drainage area, including areas draining to Baker Lake (Figure 3-4). The contributing area downstream of Upper Baker Dam is approximately 82 square miles. The primary sources of surface water runoff to Lake Shannon include the discharge from Upper Baker Dam, and Sulphur, Rocky, Bear and Thunder creeks. Drainage areas of the largest tributaries, listed in Table 3-4, range from 10 square miles for Bear Creek to approximately 22.4 square miles for the Thunder Creek. The contributing area downstream of Upper Baker Dam was subdivided into glacial and non-glacial source areas, as described for the Baker Lake subbasin.

Table 3-4. Drainage areas of principal sources of surface water runoff to Lake Shannon, Washington.

Source	Drainage Area (mi^2)	Percent glaciated
Sulphur/Rocky[1]	21	8
Bear Creek	10	0
Thunder Creek	22	0

[1] Sulphur and Rocky Creek are lumped and the entire area is considered to be influenced by glacial runoff. Both streams have headwaters in the Schrieber's Meadow area fed by Easton glacier; these channels reversed drainage due to glacial retreat and channel capture in the early 1960s (Nicholls, pers. comm. 2002).

Tributary sediment yields were estimated using average sediment yields per unit area derived from field surveys and literature review. The total sediment yield was calculated by multiplying the area with glacial and non-glacial sources by the appropriate average sediment yield rate per unit area (field versus literature based). The exception to this rule was Thunder Creek. Due to the current high estimated sediment yield and clear evidence of particularly large depositional features and suspended sediment inputs associated with this tributary, the field-based sediment yield estimate of 2,181 tons per square mile was applied to the Thunder Creek basin under both the field and literature-based sediment yield scenarios.

The bedload sediment yield to Lake Shannon is estimated to range from approximately 10,000 to 12,000 tons per year, depending on the yield rate applied (field versus literature based). Assuming that bedload represents 15 percent of suspended load, the total annual tributary sediment yield would be approximately 75,000 to 95,000 tons per year. An additional 20,000 to 42,000 tons of suspended sediment would be delivered from the Upper Baker River subbasin each year (Table 3-5).

The hydraulic characteristics of Lake Shannon were used to determine bulk sediment trap efficiencies. The average annual inflow to Lake Shannon from the Upper Baker development and tributary streams is about 2,621 cfs and the reservoir storage volume is about 160,000 acre-feet. From the Modified Brune Curve method, the trap efficiency of Lake Shannon ranges from 72 to 84 percent. For this study, a trap efficiency of 78 percent is assumed for Lake Shannon. Based on this assumption, of the 95,000 to 137,000 total tons of sediment delivered to Lake Shannon annually, 74,000 to 107,000 tons would be trapped in the reservoir[1] and 21,000 to 30,000 tons would be passed downstream to the lower Baker River and ultimately to the Skagit River. Material transported past Lower Baker Dam would consist exclusively of suspended sediments.

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[1] This analysis assumes that all suspended sediment delivered to Lake Shannon has an equal chance of depositing in the reservoir. Suspended sediment transported past Upper Baker Dam is probably finer than suspended sediment delivered from tributary streams, and thus would be more likely to remain in suspension. Separation of inputs from the two sources based on the size classes delivered is beyond the scope of this analysis.

Table 3-5. Sediment budget for Baker River upstream of the Lower Baker Dam near Concrete, Washington.

		Ongoing Project Operations (tons/year)
Incoming from Baker Lake subbasin	Total Load	20,000-42,000
	Suspended Load	20,000-42,000
	Bedload	0
Incoming from Lake Shannon subbasin	Total Load	75,000-95,000
	Suspended Load	65,000-83,000
	Bedload	10,000-12,000
Trapped in Lake Shannon	Total Load	74,000-107,000
	Suspended Load	64,000-95,000
	Bedload	10,000-12,000
Outgoing to lower Baker and Skagit River	Total Load	21,000-30,000
	Suspended Load	21,000-30,000
	Bedload	0

Hydraulic characteristics of Lake Shannon were also used to determine grain size-specific sediment trap efficiencies. Results of these analyses are shown in Figure 3-6. Lake Shannon traps virtually all sediment larger than fine silt and passes most sediment smaller than coarse clay. Some of the coarse clays and medium silts would be trapped and some would be passed, depending on the grain size and on the flow through the reservoir.

Differences in the Lake Shannon storage capacity curves from 1929 to 1959 were used to check the estimated annual sediment deposition. This approach assumes that the reduction in storage capacity is entirely due to accumulation of sediment within the reservoir. The accuracy of the survey data used to develop the original and 1959 storage volume to depth relationships is a major limitation. For example an error of rate of plus or minus 5 percent and a reservoir storage volume of 160,000 acre feet results in an uncertainty of plus or minus 8,000 acre-feet (equivalent to between 150 and 250 years of estimated annual inputs). However, the comparison is useful for providing a "reality check" on sediment yield estimates generated for this analysis.

Based on the comparison of the storage capacity curves, approximately 4,111 acre-feet of sediment accumulated in Lake Shannon between completion of Lower Baker Dam in 1929 and completion of Upper Baker Dam in 1959. To convert this volume estimate into an estimate of the total tons of sediment an average sediment bulk density of 90 lb/ft^3 was assumed. This bulk density estimate was derived from sampling of glacial sediments in the White River system (R. Barnes, PSE, pers. comm., 2002.). This represents an average annual accumulation rate of 137 acre-feet (268,613 tons). Sediment accumulating in Lake Shannon over that period reflects the sediment yield from the entire 297 square mile drainage basin. In comparison, the annual accumulation in Lake Shannon without Upper Baker Dam in place estimated based on the sediment budget described above was 151,000 to 263,000 tons (60 to 105 acre-feet).

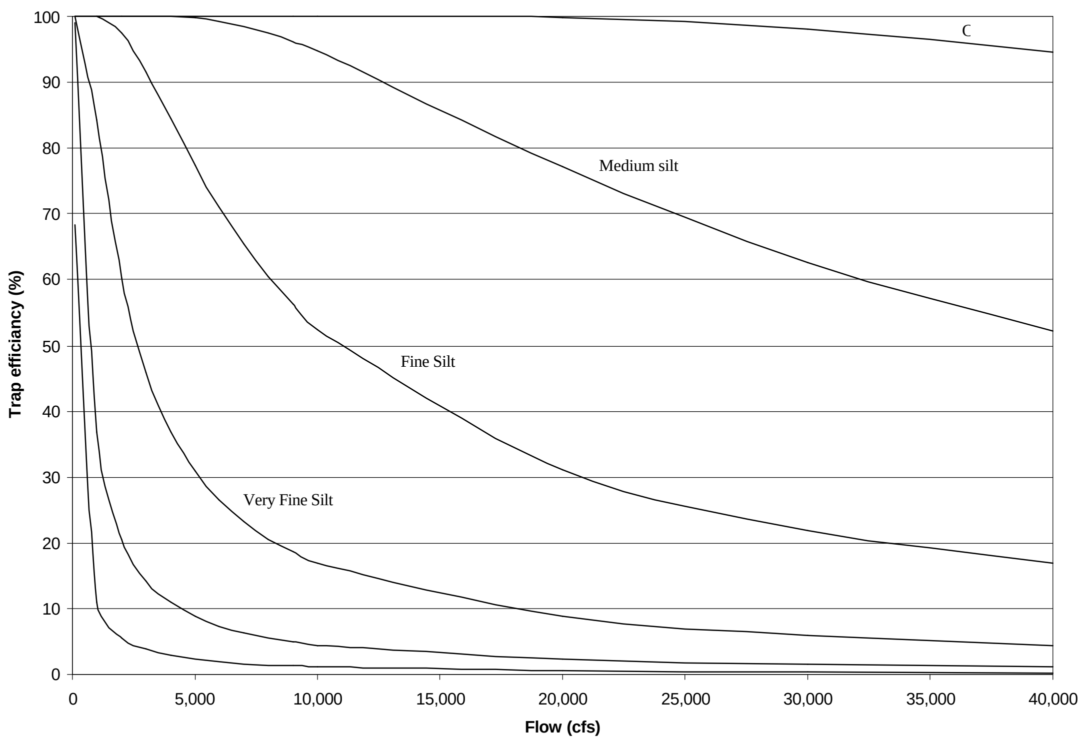

Figure 3-6. Grain-size specific sediment trapping efficiencies of Lake Shannon for flows ranging from zero to 40,000 cfs.

3.2.2 Sediment Routing Under Without Project Scenario

Prior to construction of Upper Baker Dam, a natural lake, also known as Baker Lake, existed at the upstream end of the Project Area (Figure 3-4). Natural Baker Lake was approximately 1.5 miles long and covered an area of 550 acres. The maximum depth was about 116 feet; depths appeared to be relatively consistent throughout the lake, averaging 100.5 feet (Smith and Anderson, 1921). Based on these measurements, the volume of natural Baker Lake is estimated to be approximately 55,275 acre-feet. For these analyses it is assumed that in the future without the influence of the Project, natural Baker Lake would have the same surface area and volume as measured in 1921.

Natural Baker Lake would serve as a sediment trap. The total area draining to natural Baker Lake is 118 square miles and consists of 103.5 square miles of glaciated area, and 13.5 miles of non-glaciated area.

The bedload yield to the Baker River upstream of the former outlet of Baker Lake is estimated to range from approximately 14,000 to 28,000 tons per year, depending on the yield rate applied (field versus literature based). Assuming that bedload represents 15 percent of suspended load, the total sediment yield would range from approximately 109,000 to 212,000 tons per year (Table 3-6).

Hydraulic characteristics of natural Baker Lake were used to determine bulk sediment trap efficiencies. The average annual inflow to natural Baker Lake would be about 1,043 cfs and the lake volume would be about 55,275 acre-feet. From the Modified Brune Curve method, the trap efficiency of natural Baker Lake ranges from 68 to 82 percent. For this study, a trap efficiency of 75 percent is assumed for natural Baker Lake. The average sediment yield to natural Baker Lake is estimated to be 109,000 to 212,000 tons, thus the average annual sediment accumulation would range from 82,000 to 159,000 tons. Of the total sediment yield delivered to natural Baker Lake each year, approximately 27,000 to 54,000 tons would be passed downstream to the Baker River. All incoming bedload would be trapped in natural Baker Lake. All of the material passed downstream to the Baker River would consist of suspended sediments

Hydraulic characteristics of natural Baker Lake were used to determine grain size-specific sediment trap efficiencies. Results of these analyses are shown in Figure 3-7. Natural Baker Lake would trap virtually all sediment larger than coarse silt delivered to the reservoir and would pass most clay-sized and smaller sediments. Some of the silt would be trapped and some would be passed, depending on the grain size and on the flow through the lake.

The area of the Baker Lake subbasin that drains to the Baker River between the outlet of natural Baker Lake and the upper Baker Dam site is approximately 97 square miles, consisting of 52.4 square miles of glaciated area and 43.7 miles of non-glaciated area. The bedload yield to the Baker River from tributaries entering from this area is estimated to range from approximately 6,000 to 15,000 tons per year, depending on the yield rate applied (field versus literature based). Assuming that bedload represents 15 percent of suspended load, the total sediment yield would be approximately 49,000 to 114,000 tons per year (Table 3-6).

Without the influence of the Baker Project, the total sediment load delivered by tributaries downstream of the former Baker Lake plus suspended sediments transported through natural Baker would eventually be delivered to the Skagit River.

In total, the amount of sediment delivered to the Baker River and available for transport downstream to the Skagit River without the influence of the Baker Project would range from 151,000 to 263,000 tons per year. The majority of this material would consist of suspended sediments (silt size and smaller). The estimated annual bedload yield would be 16,000 to 27,000 tons per year. Assuming this material is similar in composition to bed material in the Baker River upstream of the project area, the bedload would consist of 84 percent gravel (13,500 to 22,700 tons) and 16 percent cobble (2,500 to 4,300 tons). The remainder of the material would consist of sand or boulders.

Table 3-6. Sediment budget for Baker River without the influence of the Baker Project Development compared to the sediment budget for regulated conditions.

		Without Project Influence (tons/year)	Current Conditions (tons/year)
Incoming from Baker River and tributaries above natural Baker Lake	Total Load	109,000-212,000	109,000-212,000
	Suspended Load	95,000-185,000	95,000-185,000
	Bedload	14,000-28,000	14,000-28,000
Trapped in Natural Baker Lake	Total Load	82,000-159,000	NA
	Suspended Load	68,000-131,000	NA
	Bedload	14,000-28,000	NA
Outgoing from Natural Baker Lake	Total Load	27,000-54,000	NA
	Suspended Load	27,000-54,000	NA
	Bedload	0	NA
Incoming from tributaries downstream of Natural Baker Lake	Total Load	49,000-114,000	49,000-114,000
	Suspended Load	43,000-99,000	43,000-99,000
	Bedload	6,000-15,000	6,000-15,000
Trapped in Baker Lake Reservoir	Total Load	NA	137,000-283,000
	Suspended Load	NA	117,000-241,000
	Bedload	NA	20,000-42,000
Outgoing from Baker Lake Reservoir	Total Load	NA	20,000-42,000
	Suspended Load	NA	20,000-42,000
	Bedload	NA	0
Incoming from tributaries to Lake Shannon	Total Load	75,000-95,000	75,000-95,000
	Suspended Load	65,000-83,000	65,000-83,000
	Bedload	10,000-12,000	10,000-12,000
Trapped In Lake Shannon	Total Load	NA	74,000-107,000
	Suspended Load	NA	64,000-95,000
	Bedload	NA	10,000-12,000
Available for transport to Skagit River	Total Load	151,000-263,000	21,000-30,000
	Suspended Load	135,000-236,000	21,000-30,000
	Bedload	16,000-27,000	0

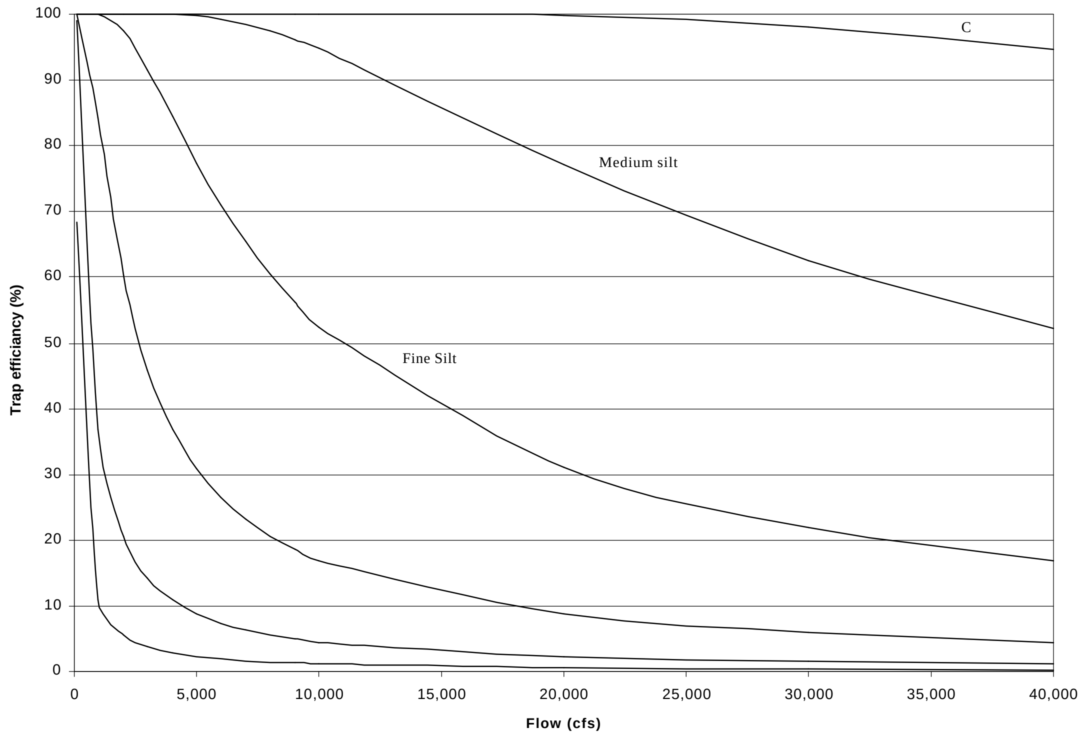

Figure 3-7. Grain-size specific sediment trapping efficiencies of natural Baker Lake for flows ranging from zero to 40,000 cfs.

3.3 SEDIMENT STORAGE

3.3.1 Sediment Storage Under Current Project Configuration

Sediment Storage in Baker Lake

Based on the annual sediment yield and reservoir trap efficiency estimated in Section 3.2.1, the amount of material delivered to Baker Lake Reservoir since the dam was constructed in 1959 ranges from 157,000 to 325,000 tons (3,400 to 7,100 acre feet). This is equivalent to a reduction in reservoir capacity of from around one to three percent. A similar reduction in reservoir capacity would be expected over the future 40-year license period, resulting in a cumulative reduction in reservoir storage capacity of two to six percent.

Existing topographic and bathymetry data provide little information on where sediment is currently stored within the reservoir. The accuracy of the survey data used to develop the original storage volume to depth relationships is a major limitation in using the historic and existing maps to quantify sediment storage in delta deposits. The historic topography consists of contour intervals with a spacing of 5-10 ft, and is not georeferenced. The 1999 topography layer consists of 5-foot contour intervals and is georeferenced, but only extends to elevation 685. Comparison of the maps indicates that the magnitude of errors is on the order of plus or minus 5 feet, even after correction of the 1959 datum to be consistent with the 1999 datum (AESI, 2003). Nevertheless, profile plots of delta landforms provide some valuable information on the location of deposition and approximate magnitude.

Bedload sediments drop out quickly when the transport capacity is reduced, therefore it is likely that much of the bedload has accumulated in deltas where the channels enter the reservoir. No data are currently available to quantitatively evaluate the thickness or extent of sediment deposits in Baker Lake. The largest delta landform is the feature that has formed where the Upper Baker River enters Baker Lake. This feature covers approximately 685 acres between elevation 685 feet and 724 feet.

Deposition on the Upper Baker Delta is cyclical, depending the changing reservoir pool elevation. When the reservoir pool is high, sediment deposits at the upstream end of the delta. As the reservoir pool is lowered seasonally, deposited sediments are remobilized and transported further into the lake. The reservoir is generally held at low pool during the fall and winter when most major sediment transport events occur, thus the majority of deposition is believed to have occurred at lower pool elevations (i.e., below 698 feet). Comparison of profiles constructed from the 1959 and 1999 topographic data suggests that the deposits within the drawdown zone are typically between 5 and 10 feet deep, within the potential range of error associated with the data sets (Figure 3-8). Assuming that all of the bedload and 60 percent of the suspended load is deposited in the delta (a proportion consistent with conditions described for the Elwha reservoirs [DOI 1996]), and that the deposited sediments were evenly distributed over the entire area, sediment delivered since development of Upper Baker Dam would range from 2 to 4.5 feet deep, a number that is reasonably consistent with observed changes in the delta profile.

Delta deposits are also present at the mouths of tributaries draining the east slopes of Mount Baker and entering Baker Lake from the west. These tributaries all originate from glaciers and would be expected to have naturally high sediment loads. Geologic investigations of the sediment deposits on the fan landforms reveal a complex mix of predominantly volcaniclastic and mudflow deposits mixed with fluvial deposits (Kevin Scott, USGS, pers. comm. 2003). Glacial outwash and mudflows originating from Mount Baker are believed to have been the primary processes responsible for building these fan landforms in Holocene times. For example, an individual mudflow down the Park Creek valley that occurred approximately 6,650 years ago is estimated to have delivered almost 20,265 acre-feet of sediment in the lower Park Creek and Baker River Valley (Scott et al., 2001). This sediment volume is equivalent to an estimated 1,800 to 3,600 years of fluvial transport under current climatic and flow conditions. Comparison of the 1999 and 1959 topographic maps suggest that deposition within Baker Lake since 1959 has extended these delta features (AESI, 2003). Comparison of profiles constructed from the 1959 and 1999 topographic data suggests that the deposits are typically between 5 and 15 feet deep (Figure 3-9).

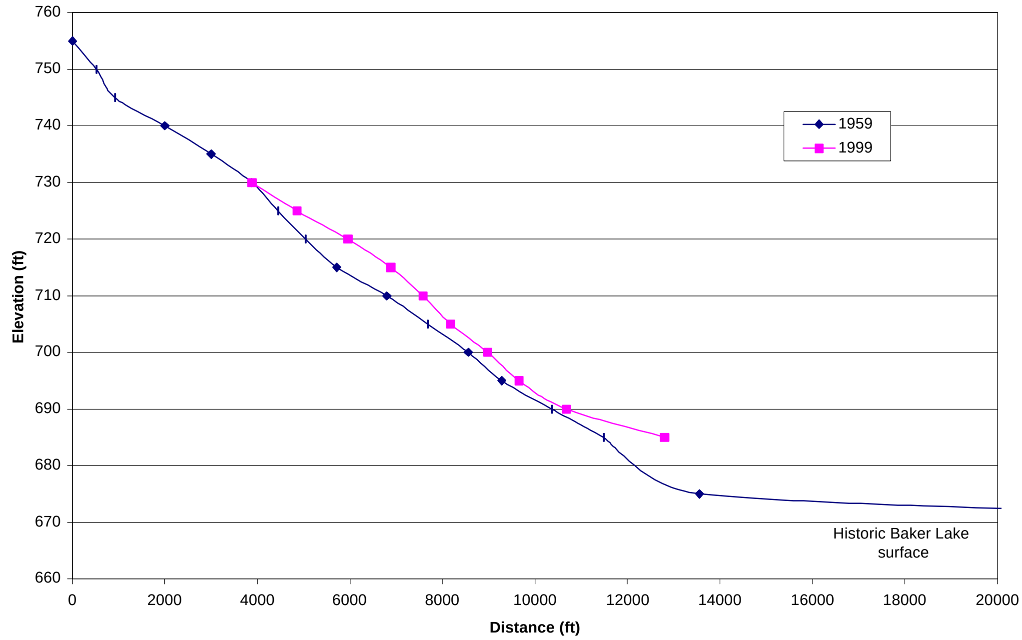

Figure 3-8. **Comparison of channel profiles from 1959 and 1999 across the delta that has formed at the upstream end of Baker Lake Reservoir.**

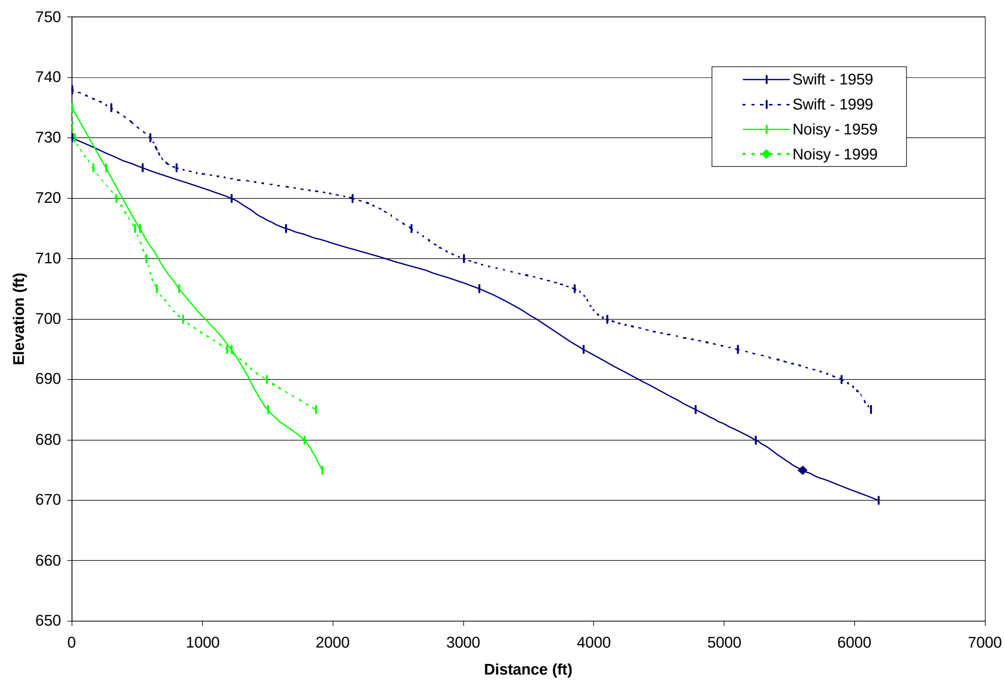

Figure 3-9. **Comparison of channel profiles from 1959 and 1999 for selected tributaries to Baker Lake.**

In contrast, no large alluvial fans were present at the mouths of tributaries draining to the Baker River from the east prior to construction of the Upper Baker Development (Figure 1-2). Delta deposits that have formed at the mouths of Noisy Creek and Anderson Creek since that time are small and appear to be fluvial in origin. Although these tributaries have sizable drainage areas and are sufficiently steep to transport most of the sediment delivered to them, only small existing deposits of sediment were noted at the mouths based on the comparison of topographic maps. The limited extent of these tributary delta deposits was confirmed during field surveys (Figure 3-10).

Finer suspended sediments that are transported past the deltas would be expected to settle out in topographic low areas at the bottom of the lake. The depression represented by the former Baker River channel consists of a 100 to 500 foot-wide channel with banks that were typically 4-8 feet high in unconfined areas (General Land Office [GLO] 1892). Assuming that fine sediments preferentially deposit within this topographically low area of the reservoir floor, suspended sediment delivery over the 43 years since storage behind Upper Baker Dam commenced would have filled the 8-mile long stretch of channel downstream of Baker Lake with approximately 3 to 8 feet of fine sediment.

Figure 3-10. Sediment deposit at the mouth of Noisy Creek, May 2001 at a reservoir pool elevation of approximately 705 feet msl.

Sediment Storage in Lake Shannon

Based on the annual sediment yield and reservoir trap efficiency estimated in Section 3.2.2, the amount of material delivered to Lake Shannon since Lower Baker Dam was constructed in 1925 ranges from 3,706 to 5,958 acre feet. This is equivalent to a reduction in reservoir capacity of from two to four percent. Over the future 40-year license period, an additional 1,512 to 2,182 acre feet of sediment would be expected to accumulate in Lake Shannon, resulting in a cumulative reduction in reservoir storage capacity of three to five percent since its construction in 1925.

A large delta deposit would have been expected to form at the upstream end of Lake Shannon prior to construction of the Upper Baker Development. The upstream end of Lake Shannon between elevation 390 and 435 feet (normal maximum pool elevation) consists of a narrow bedrock controlled canyon. Delta deposits would have been confined within this canyon, resulting in a relatively deep depositional feature as compared to the delta that has developed at the upstream end of Baker Lake. Comparison of the 1929 and 1959 storage capacity surveys suggest that most of the sediment delivered to Lake Shannon prior to construction of the Upper Baker Development accumulated between elevation 435 and 410 ft msl. This is consistent with the assumption that the majority of sediment delivered to a reservoir deposits on the delta. If all of the bedload, and 60 percent of the suspended load (numbers that are consistent with conditions described for the Elwha reservoirs) accumulated within the approximately 2-mile long, 500-foot wide canyon between elevation 390 and 435 feet MSL, the resulting deposit would have been about 5 to 15 feet deep.

Since construction of Upper Baker Dam, delivery of sediment to the delta deposit at the upper end of Lake Shannon has been substantially reduced. Sediment from Rocky and Sulphur Creek still delivers directly to the former delta area, but these inputs would not have been sufficient to result in substantial additional accumulations. When the reservoir is drawn down, flows within the confined formed canyon area have sufficient power to rapidly transport deposited material downstream. As a result it is likely that much of the deltaic material previously deposited prior to construction of Upper Baker Dam has been remobilized and transported further downstream into Lake Shannon.

Aerial photographs of Lake Shannon, dating from 1940 to 2000, were reviewed to qualitatively identify areas of sediment deposition. Few large delta deposits associated with tributary streams were noted in Lake Shannon. The exception is Thunder Creek, where a large deposit of coarse sediment has deposited within the 300-foot wide valley just upstream of the reservoir. That feature appears to have grown substantially since the earliest available photo set. A series of very large mass wasting events reportedly occurred in Thunder Creek in the late 1940s (USFS, 2002). Other tributary streams in the Lake Shannon subbasin lacked pronounced deltas. Tributaries draining to Lake Shannon from the west traverse a flat valley prior to emptying into Lake Shannon. Bedload likely deposits in this valley and is slowly metered out to downstream reaches, thus delivery of sediment from west-side tributaries to Lake Shannon is less than would otherwise be expected.

Suspended sediment carried into Lake Shannon is expected to settle out in topographic low areas such as the former Baker River channel. The depression carved by the former Baker River consists of a 100 to 500 foot-wide channel with banks that were typically 4 to 8 feet high in unconfined areas (GLO 1892). Assuming that fine sediments preferentially deposit within this low area, suspended sediment delivery over the 77 years since storage behind Lower Baker Dam commenced would have filled the 10-mile long stretch of channel downstream of Upper Baker Dam with approximately 2 to 5 feet of fine sediment.

3.3.2 Sediment Storage Under the Without Project Scenario

Without the influence of the Baker Project, sediment delivered by the river and tributaries upstream of natural Baker Lake would deposit primarily within the lake. As noted in Section 3.3.1, natural Baker Lake had an estimated trap efficiency of 75 percent. Approximately 40 to 81 acre-feet of sediment per year would deposit in natural Baker lake, and approximately 13 to 27 acre-feet of suspended sediment per year would be passed downstream. Bedload and suspended sediment yield from tributaries entering the Baker River downstream of natural Baker Lake in the Baker Lake and Lake Shannon subbasins would be available for transport to the lower Baker River and eventually the Skagit River.

Some of the sediment delivered to the mainstem Baker River by tributary streams would likely be temporarily stored within the floodplain and channel of the Baker River. Historic maps and aerial photographs depict extensive gravel bars and floodplain landforms associated with these channel types suggesting that the sediment supply exceeded the sediment transport capacity. This study assumes that all suspended sediment delivered by tributary streams each year is transported downstream to the lower Baker and Skagit Rivers. This is an oversimplification, but estimation of the proportion of suspended sediment load stored within the bed or on the floodplain is beyond the scope of this assessment and would not materially change the estimate of bedload delivery under the without the influence of the project scenario.

There are no detailed surveys of the channel geometry and substrate in alluvial sections of the lower Baker River prior to construction of the Baker Project. Historic maps and survey data indicate that the channel width and gradient were similar to those measured for the Baker River upstream of Baker Lake. Hydraulic geometry data and the bedload rating curve the Baker River upstream of Baker Lake Reservoir were combined with the unregulated discharge rating curve for the Baker River at Concrete gage site to develop a rough estimate of the transport capacity of the lower river.

Based on this assessment, the annual bedload transport capacity for the alluvial portions of the lower Baker River is estimated to be approximately 12,424 tons per year. Estimated tributary bedload yields to the Baker River ranged from 16,000 to 27,000 tons per year. Since the estimated bedload yield exceeds the estimated transport capacity, some of the bedload delivered to the Baker River each year would likely be stored within the channel and floodplain. Assuming that the size distribution of bedload transported by the Baker River is similar to the bed surface particle size distribution, material delivered to the lower Baker River downstream of the Lower Baker Development would consist of 84 percent gravel (10,500 tons) and 16 percent cobble (2,000 tons). The remainder of the material would be sand or boulder sized material.

Downstream of the Lower Baker Development, the Baker River occupies a steep, narrow bedrock controlled canyon for approximately 0.6 miles, then enters the wide valley carved by the Skagit River. Where the Baker River crosses the Skagit River floodplain the channel is approximately 200 feet wide and is currently artificially straight and entrenched. The gradient is approximately 0.1 percent and the bed consists of an armor layer composed of large cobbles and boulders.

As described previously, the Baker Projects block the downstream transport of bedload. The model used for this analysis assumes an unlimited supply of material with the same particle size distribution as the bed material. Since there is virtually no bedload supplied to the lower Baker River from upstream except as a result of large episodic landslides, bedload transport modeling of the existing conditions likely overestimates both the flow required to initiate transport and the volume of material moved. Hydraulic conditions in the lower Baker River are further complicated by the backwater effect from the Skagit River during high flow. Detailed evaluation of the tractive force and flow required to initiate movement of the current armor layer is beyond the scope of this evaluation, but will be covered in Study A16 – Lower Baker Alluvial Fan. However, a comparison of estimated bedload transport with the existing channel configuration and flow regime versus bedload transport without the project assuming an unlimited supply of material the size of that measured in the upper Baker River is useful for determining the relative ability of this channel segment to transport sediment. Bedload transport modeling of the existing channel configuration and flow regime indicates that bedload transport does not occur until flows exceed about 8,000 cfs and thus would occur only when the Lower Baker Development is spilling.

Without the influence of the Baker Project, the flow regime and sediment supply to the lower Baker River was assumed to be the same as those synthesized for the mainstem Baker River upstream of the Lower Baker Development. However, the channel configuration of the lower Baker River was assumed to remain the same as for current conditions. As a result of the straight, entrenched nature of the existing channel, unregulated flows would continue to be contained within the channel, resulting in very efficient transport capacity. The estimated annual bedload transport capacity of the lower Baker River downstream of Lower Baker Dam without the influence of the Baker Project is 33,700 tons per year. The estimated transport capacity of the lower Baker River exceeds both the estimated sediment yield and the estimated transport capacity of upstream reaches. This suggests that if the dams were removed and uninterrupted sediment supply was restored, all of the bedload delivered to the lower Baker River would rapidly be routed downstream under the current channel configuration. In reality, due to the complex hydraulic conditions within the lower Baker River, some sediment would most likely accumulate within the channel, ultimately resulting in sufficient aggradation to alter channel conditions and restore its natural function as an alluvial fan. A theoretical discussion of expected channel response on the lower Baker alluvial fan to changes in water and sediment supply is presented in Chapter 5.0, and further hydraulic and sediment transport analyses will be conducted as part of Study A16 – Lower Baker Alluvial Fan.

3.4 BAKER RIVER SEDIMENT CONTRIBUTIONS TO THE SKAGIT RIVER

The Baker River Project affects delivery of sediment from the 297 square mile Baker River basin to the Skagit River. At the confluence with the Baker River, the Skagit River drains approximately 2,737 square miles, of which the Baker River basin represents approximately 11 percent. The Skagit River downstream of the Baker Project is a large alluvial river that rapidly moves bedload and suspended sediments to Puget Sound. The sediment yield of the Skagit River has been affected by a number of anthropogenic activities. The two hydroelectric Projects (Baker Project and Skagit Project) interrupt the transport of sediment from approximately 48 percent of the contributing area. These reductions in sediment yield may be partially or completely offset by increases in sediment yield resulting from land management activities. The majority of the Skagit basin is forested, and much of the forested area is managed for timber production. Recent studies within the Skagit basin suggest that forest management activities may significantly increase the amount of sediment delivered to stream channels (Paulsen, 1997). A recent screening level assessment of the Skagit basin found that sediment yields “not functioning” (i.e., substantially higher than they would be without land management) in over half of the subbasins in the Skagit River basin, and assigned a high priority to projects designed to reduce sediment yields (Beamer et al., 2000).

Current sediment yields in the Skagit River were assessed using regional sediment yield estimates and long-term data on suspended sediment collected at the Skagit River at Mount Vernon gage. The Washington Department of Ecology has measured suspended load at the Skagit River at Mount Vernon gage (Gage No. 12200500) under flow conditions ranging from around 6,000 cfs to 50,000 cfs. There is a fair degree of correlation between the suspended load measurements and the flow measurements at that gage (Figure 3-11). A relationship between flow and suspended load measurements was developed from the measured data and used to calculate suspended load from 61 years (1940 to 2001) of daily flow measurements for that gage.

The average annual suspended load of the Skagit River at Mount Vernon was determined to be approximately 385,000 tons per year over the 61-year period. This estimate likely underestimates the actual suspended sediment load because no samples from very large events (> 100,000 cfs) that are responsible for the majority of sediment transport are included in the data set. Our analyses suggest that with the Baker Project in place, the Baker River delivers approximately 20,000 to 29,000 tons of suspended sediment to the Skagit River each year, equivalent to approximately 67 to 98 tons per square mile per year. Assuming that the amount of suspended sediment passing the Skagit Project each year is similar (67 to 98 tons per square mile per year representing a total of 78,000 to 114,000 tons per year), the suspended sediment yield from the 1,637 square mile area draining to the Skagit River downstream of the two Projects would be approximately 242,000 to 287,000 tons per year. Assuming the bedload is equivalent to 15 percent of the suspended load, then bed load would represent an additional 36,000 to 43,000 tons per year. The total sediment load originating from the area downstream of the Baker and

Skagit Projects would therefore be equivalent to 170 to 202 tons per square mile per year. As noted previously, this estimate likely underestimates actual sediment yields. The true contribution from areas downstream of the Baker and Skagit Projects is most likely in the range of 400 to 600 tons per acre, a value consistent with the estimated sediment yield from the Nooksack basin (see Section 3.1.3) and other previously published estimates (USACE 1970). The majority of the area downstream of the Baker and Skagit projects is fed by glacial runoff from the Sauk and Cascade rivers.

The Baker River is the second largest tributary to the Skagit River and would be expected to contribute a substantial amount of sediment without the influence of the Project. The Baker River basin represents approximately 11 percent of the Skagit River drainage are at Concrete. However, as described in Section 3.2.3, sediment inputs from the upper Baker basin would largely be trapped in natural Baker Lake, reducing the effective contributing area of the Baker River to 179 miles (equivalent to 6.5 percent of the drainage area at the Skagit River near Concrete gage site). Assuming the sediment yield is proportional throughout the entire Skagit drainage, sediment contributions from the Baker River would therefore account for approximately 6.5 percent of the Skagit River sediment load.

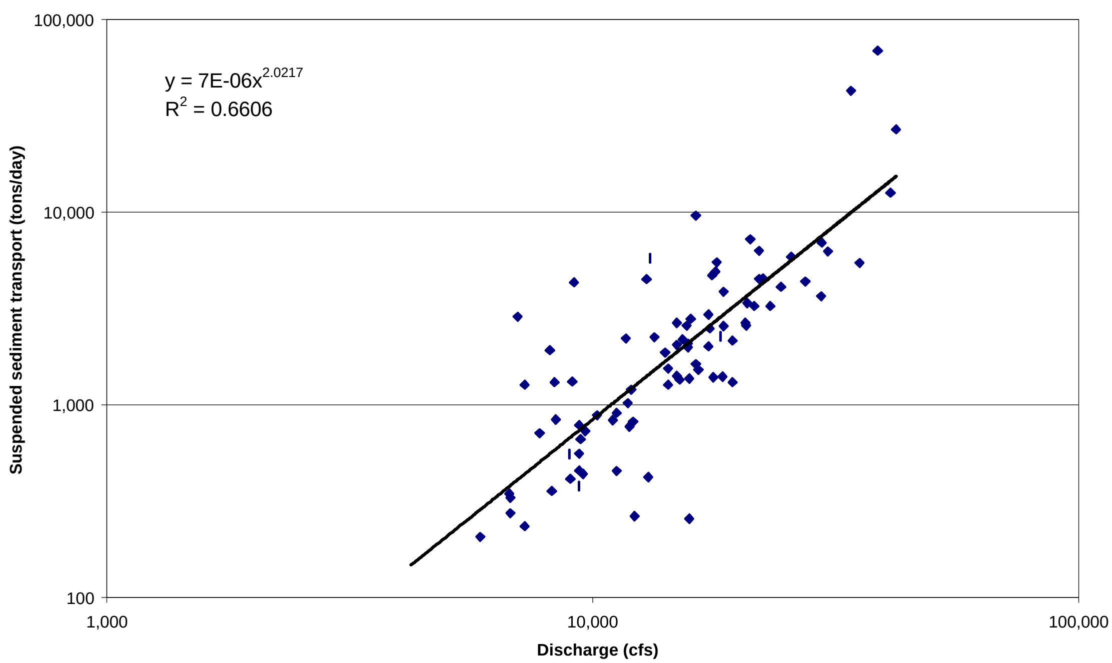

Figure 3-11. Suspended sediment rating curve for the regulated Skagit River at Mount Vernon gage (USGS Station # 12200500) site (Data from WDOE 2003).

4. CHANNEL RESPONSE

The hydraulic characteristics and sediment transport capacity of a river channel are largely functions of channel morphology. Response of river channels to changes in the sediment supply or flow regime is complex, and varies depending on channel morphology. Before predictions or conclusions can be made regarding the likely effects of changes in geomorphic inputs (i.e., water, sediment and wood), it is necessary to discriminate channels in a process-based framework. Channel types generally reflect relationships between sediment supply and transport capacity (Montgomery and Buffington, 1993). Bedrock controlled channels imply an excess of sediment transport capacity. Alluvial channels may be either supply-limited or transport-limited. Unconfined alluvial channels with significant floodplain storage indicate a long-term excess in sediment supply; however, if the flow regime or sediment inputs change, alluvial channels may incise through floodplain deposits, reducing the availability of sediment stored there and resulting in a net export.

Differences in landform characteristics, sediment transport and flow regime will result in differences in channel conditions within the various channel types. Channels confined by valley walls do not accumulate large amounts of sediment through development of floodplains. In narrow, confined river valleys, streamside landforms frequently consist of steep colluvial sideslopes or bedrock cliffs. In contrast, alluvial channels that occupy wide valley bottoms and have an excess of sediment supply build flat floodplain surfaces adjacent to the channel. Changes in climate, tectonic uplift, or anthropogenic activities may result in the abandonment of former floodplains and development of terrace complexes. Variations in channel morphology and associated landforms have profound implications regarding both their sensitivity to changes in the flow regime or sediment supply, as well as their suitability as habitat for flora and fauna.

Chapter 4 describes the channel characteristics in the Baker River and Skagit River downstream of the Baker Project and discusses the response potential to changes in flow, sediment and LWD inputs resulting from ongoing Baker Project operations given the existing channel morphology. Section 4.1 focuses on the lower Baker River, and Section 4.2 focuses on the middle Skagit River. Each section provides a brief overview of the current channel morphology and response potential, then describes the likely effects of changes in each of the primary geomorphic inputs considered here (i.e., water, sediment and wood)

4.1 BAKER RIVER

The lower Baker River downstream of the Lower Baker Development flows south for approximately 1.2 miles before joining the Skagit River. The lower Baker River channel consists of two distinct channel types: a canyon channel and a former alluvial fan channel (Figure 4-1). A summary of the typical channel morphologic characteristics of these channel types is provided in Table 4-1.

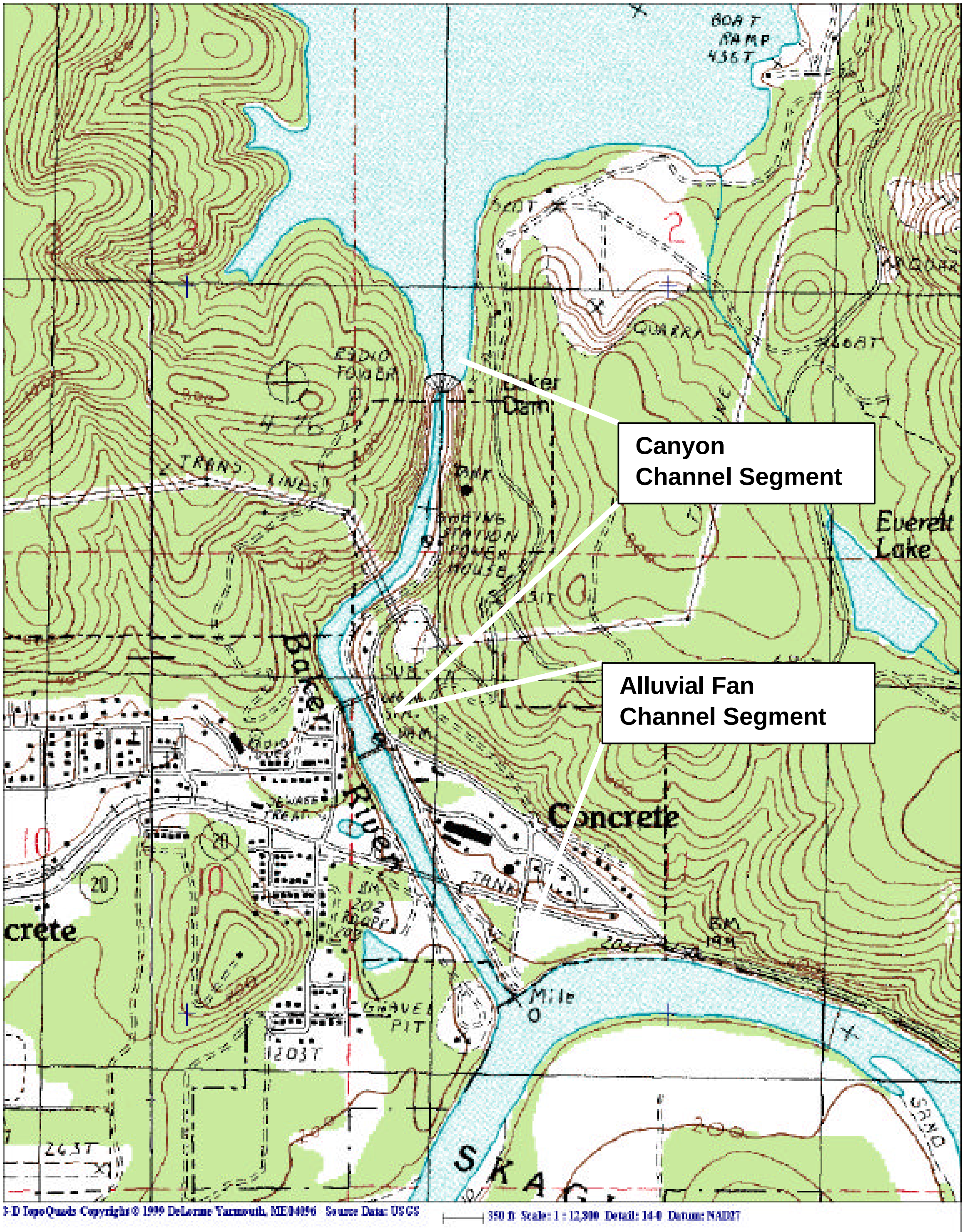

Figure 4-1. Channel response segments in the lower Baker River downstream of Puget Sound Energy's Lower Baker Development near Concrete, Washington.

Table 4-1. Channel type and physical characteristics associated with channel types delineated in the upper Baker subbasin.

Channel Type	Gradient (%)	Entrenchment[1]	Planform (sinuosity)	Dominant Substrate	Paustian Process Group
Alluvial floodplain	0-1%	>4	meandering (>1.2)	Cobble/ gravel	Glacial Outwash/ Floodplain
Alluvial fan	1-2%	>4	multiple thread (<1.2)	Mixed	Alluvial Fan
Canyon	2-4%	<2	single thread (1.0)	Boulder	Large Contained

[1] Entrenchment equals the ratio of valley width to channel width.

4.1.1 Lower Baker Canyon

From the Lower Baker Development (RM 1.2) to the weir and fish passage facilities located at RM 0.6, the river occupies a narrow bedrock controlled canyon (Figure 4-2). The gradient is approximately 2.5 percent, and the substrate consists of boulders and bedrock. The high channel confinement is further reduced by the presence of a road accessing the lower Baker Powerhouse at RM 0.9. Between RM 0.9 and the weir the channel is approximately 100-feet wide. The left bank consists of large rip rap.

Figure 4-2. Baker River canyon channel segment looking downstream from the base of Lower Baker Dam, September 30, 2000.

Canyon channels are deeply incised into structurally controlled valleys and do not have well-developed floodplains. High flows are generally contained within the active channel, and stream power is high, resulting in sporadic and discontinuous depositional features. Bed material is usually dominated by bedrock or boulders. Gravel and smaller material accumulates in patches in the lee of boulders or other stable obstructions, but typically is rapidly routed through this channel type. Stream banks consist of bedrock or boulders that are resistant to scour and thus are typically very stable. However, mass wasting of valley side slopes may represent an important source of wood and sediment. Individual pieces of large woody debris generally do not remain stable or form pools in canyon channels. Large pieces that become wedged across the channel or between large bed elements are subject to extreme hydraulic forces and rapidly break up into mobile fragments. Mobile pieces may accumulate temporarily along channel margins until they are mobilized by the next high flow. Although they tend to be less frequent and persist for shorter periods than in alluvial channel types, LWD jams can influence canyon channels (Paustian et al. 1992). Large accumulations of debris can trap gravel and cobble sized material that would otherwise be rapidly transported downstream. As a result of the high transport capacity and the absence of deformable bed and bank materials, canyon channels are generally not morphologically sensitive to changes in wood, water and sediment.

Hydrologic Regime

Baker Project Operations affect the hydrologic regime of the lower Baker River. Flows are bypassed around the upstream end of the lower Baker River canyon channel segment between Lower Baker Dam (RM 1.2) and the Powerhouse (RM 0.9) except during spill events. Flows within the bypassed reach typically consist of around 50 to 60 cfs of leakage through Lower Baker Dam. During spill events, water occupies the entire canyon floor. As a result there is a large difference in the wetted area between spill and non-spill conditions. However, spill events are rare, thus the wetted area of this reach remains consistent for most of the year.

Downstream of the Lower Baker Powerhouse, flows cycle between around 80 cfs when the Lower Baker Development is offline and around 4,100 cfs when the Lower Baker Development is generating. When the project is offline, flow conditions within the downstream portion of the canyon reach consists of a very low velocity area caused by backwater from the weir located at RM 0.6. When the Project is generating, flow velocities within this portion of the canyon channel segment are high. There is little difference in the channel width between high and low flows, thus the wetted channel area remains consistent. Baker Project operations reduce the magnitude of peak flows and increase the duration of flows of around 4,100 cfs (R2 2003). The rate of change as the Lower Baker Development goes on and offline is high, and stage changes of more than 3-feet in less than one hour are common in this reach.

Sediment Transport

Construction of lower Baker Dam cut off the supply of sediment to the canyon segment from upstream reaches. The reduced frequency of high flows reduced the sediment transport capacity. However, because of the limited existing sediments storage and high sediment transport capacity during spill events, mobile sediments that had been present in the channel were likely rapidly transported out of the canyon reach. The channel bed currently consists of an armor layer composed predominantly of large, immobile boulders and bedrock. Because the bed was armored with large, immobile materials even prior to development of the project, no substantial channel incision was documented, and no future incision would be expected to occur within the canyon channel.

Landslides occur frequently within the canyon segment of the lower Baker River. The canyon is formed in highly fragmented bedrock overlain by deep unconsolidated glacial deposits. A large landslide in 1917, prior to construction of Lower Baker Dam blocked the upstream migration of sockeye salmon through the lower Baker canyon. To remedy the situation, a narrow channel was blasted around the slide (HRA 2000). Another major landslide occurred within the lower Baker canyon in 1965 when a slope failure delivered over 300,000 tons (approximately 250,000 cubic yards) of sediment to the river and destroyed part of the lower Baker Powerhouse. More recently, a small slide occurred in 2002 following completion of habitat surveys. Several other small landslide tracks of variable ages may be observed in the field or on aerial photographs. Large landslides may temporarily block the river, but the high transport capacity should be sufficient to rapidly clear a flow path. The reduction in peak flows could prolong the period required for channel recovery after temporary landslide inputs in the future.

Large Woody Debris

The Baker River canyon channel segment likely historically served as an efficient conduit for large woody debris. Large pieces of LWD moving through the canyon during high flows would have been battered against the bedrock banks and large boulders on the bed. Material that became wedged across the channel or between large bed elements would have been subject to extreme hydraulic forces as well as battered by large bedload particle being transported through the canyon. All of these factors suggest that wood would not have persisted within the canyon segment.

The bed and banks of the canyon are composed of bedrock or boulders that are resistant to scour. Large woody debris that does temporarily lodge within the canyon can play an important role in trapping sediment and providing cover. However, pools are generally formed by bedrock and are not sensitive to the presence or absence of large woody debris.

The presence of lower Baker Dam continues to interrupt the downstream transport of LWD. As noted above, LWD is probably never abundant in this channel segment, and has little influence on channel morphology. As a result, the canyon channel is not considered to be as responsive to LWD as alluvial channels located downstream.

4.1.2 Lower Baker Alluvial Fan

Downstream of RM 0.6 the lower Baker River enters the wide, low gradient Skagit River valley (Figure 4-1). Historically this segment of the lower Baker River consisted of an alluvial fan that formed where bedload sediments transported through the Baker River canyon were deposited on the floodplain of the Skagit River. Early maps and photos depict gravel bars and multiple distributary channels across the fan landform (Figure 4-3).

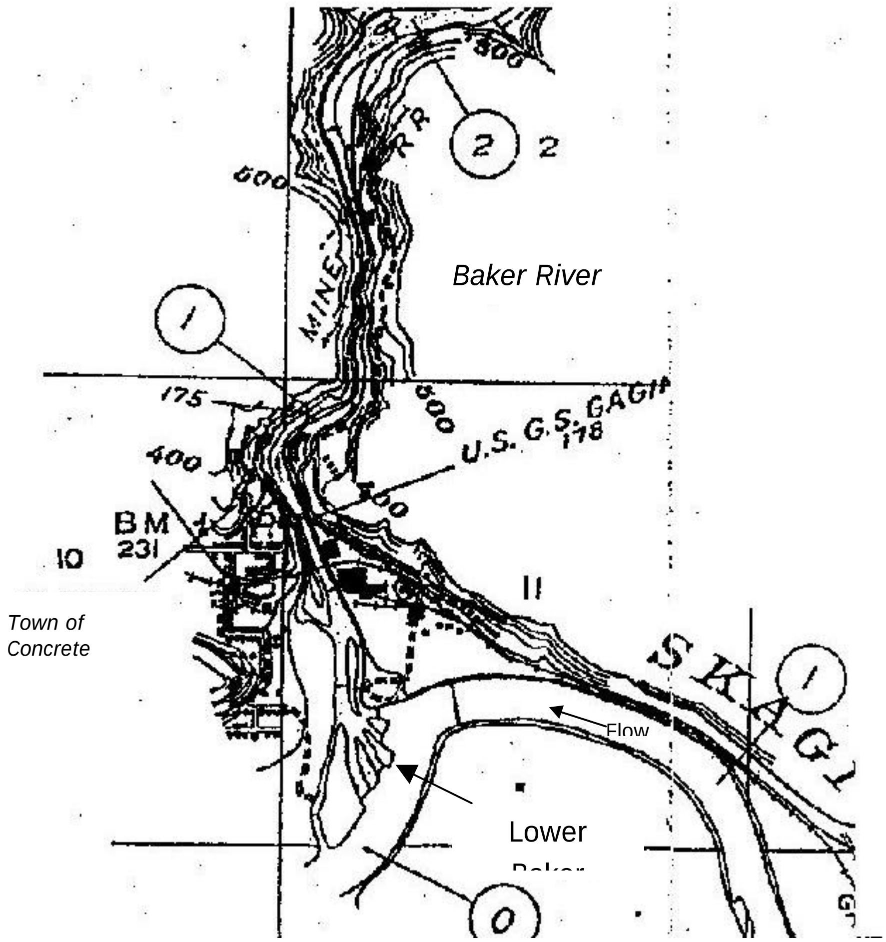

Figure 4-3. Configuration of the lower Baker River alluvial fan in 1913, prior to development of the Baker River Project (from Herron 1916)

Alluvial fans are depositional landforms in dynamic equilibrium that are constantly re-shaping themselves in order to most effectively transport the sediment delivered to them from upstream reaches (Fraser and Suttner, 1986). The primary geomorphic processes that creating and maintain alluvial fans aggradation, avulsion, and trenching. Aggradation occurs when steep, confined streams exit mountain valleys and enters wide valleys where stream flow can spread laterally, resulting in a dramatic reduction in transport capacity. Large bedload particles carried by the stream are dropped near the fan apex, while smaller particles are carried further downstream. The difference in sediment transport capacity results in a distinct fining of bed materials across the surface of the fan. Fan deposits are generally very porous, particularly at the upstream end, and flows may infiltrate through the deposit eventually re-emerging downstream. Avulsion occurs as sediment builds up within the fan distributary channel, ultimately forcing flow to overtop the banks and shift course into topographically lower areas. Trenching can occur either: a) as the result of an avulsion as the channel carves a new course; or b) if sediment inputs decrease, leaving a channel that is steeper than need to carry delivered sediments, resulting in a net export of material to downstream areas. Alluvial fan channels are highly sensitive to changes in the flow regime and supply of sediment and LWD.

Channel conditions in the lower Baker alluvial fan segment reflect the influence of historic and ongoing human activities. The town of Concrete was platted in the late 1800s, and two cement plants had been constructed on the lower Baker fan directly adjacent to the river by the early 1900s. These developed areas would have been vulnerable to floods, thus it is likely that some type of bank protection was implemented along the lower Baker River. The earliest known aerial photograph of the area (circa 1937) reveals a relatively straight channel, with a smaller distributary channel branching off to the west at almost a 90-degree angle. This distributary, now known as the Little Baker channel, did not appear on early maps. Anecdotal accounts suggest it may have been excavated to either route fish around a blockage formed by a landslide within the lower Baker canyon or to deliver cedar bolts to a nearby timber mill (HRA, 2000).

In 1957, habitat within the lower Baker River was further modified by dredging. No formal records of this activity exist; however, the dredging was reportedly conducted to ensure that the drop associated with PSE's newly constructed fish weir was sufficient to prevent adult salmonids from moving upstream at most flows (Barnes, 2002). The depth of the excavation is unknown, but presumed to be on the order of five or six feet.

The combined effect of the activities described above has been to severely constrain natural processes responsible for development and maintenance of the Baker River alluvial fan. The current straight, incised channel contains even the highest flows within its banks, and thus has a higher capacity to transport sediment than would be the case under natural conditions. At the same time, construction of the dams has reduced delivery of sediment and LWD to this channel segment. The reduction in sediment inputs has resulted in the development of a coarse armor layer that remains stable even at high flows.

Hydrologic Regime

Baker Project Operations affect the hydrologic regime of the lower Baker River and channel morphology in the lower Baker alluvial fan segment. Flows typically cycle between around 80 cfs when the Lower Baker Development is offline and around 4,100 cfs when the Lower Baker Development is generating at full capacity. When the project is offline, flow conditions within the alluvial fan channel segment consists of deep pool and short riffle immediately downstream of the weir, and a long, low velocity glide caused by backwater effects from Skagit River. When the Project is generating, flow velocities within the channelized alluvial fan reach are high. Hydraulic conditions throughout the alluvial fan segment are influenced by the combined effects of project operations and the backwater caused by the Skagit River, and are thus quite complex. There is little difference in the channel width between high and low flows, thus the wetted channel area remains consistent. Baker Project operations reduce the magnitude of peak flows and increase the duration of flows of around 4,100 cfs (R2, 2003). The rate of change as the Lower Baker Development goes on and offline is high, and stage changes of more than 3-feet in less than one hour are common in this reach (R2, 2003).

Sediment Transport

Construction of lower Baker Dam largely cut off the supply of sediment to the alluvial fan from upstream reaches. The combined effects of gravel mining on the fan and excavation of the channel following construction of the weir and fish trap at RM 0.6 further reduced the sediment supply. As a result of the high sediment transport capacity during power generation and spill events, mobile sediments that had been present in the channel were likely rapidly transported out of the alluvial fan reach even with the reduced frequency of peak flows and backwater effect of the Skagit River. The channel bed currently consists of an armor layer composed predominantly of large cobbles and boulders. Because the bed is now armored with large, immobile materials, no substantial future channel incision would be expected to occur within the alluvial fan segment.

Without the influence of the project, the lower Baker River could redevelop some of the characteristics of a natural alluvial fan channel. The channel bed would likely aggrade and become finer if sediment inputs increased, and small bars and islands would develop at the confluence with the Skagit River. Given the current incised channel it is possible that the channel would not aggrade sufficiently to re-initiate the lateral channel avulsions typical of alluvial fan landforms even if the sediment supply were increased.

Large Woody Debris

Similar alluvial fan channels elsewhere in the Skagit drainage contain large amounts of deposited or buried LWD (Thoreen, 2002). LWD that accumulates in the channel plays a role in initiating channel avulsions. Large woody debris that is buried during aggradational episodes and subsequently re-excavated during trenching forms pools and complex hydraulic features that serve as preferred habitats for many aquatic species. The current straight, entrenched channel of the lower Baker is less responsive to inputs of LWD than an undisturbed alluvial fan channel would be. Recruitment of LWD is negligible given the lack of lateral migration, absence of mature riparian forest adjacent to the stream and the interruption of wood transport from upstream reaches. Large woody debris that does enter the channel tends to be small and is rapidly transported downstream.

Without the influence of the Project, LWD would become more common in the lower Baker River as material transported from upstream could temporarily deposit there. Because the wood would have to pass through the steep, narrow canyon channel segment prior to reaching the fan, however, the majority of pieces transported from upstream would likely be fragments rather than large logs. Accumulation of large amounts of LWD and sediment in the lower Baker channel could substantially increase the tendency towards aggradation and would increase the likelihood that the channel would return to a state of frequent lateral channel avulsions across the fan landform.

Although some natural fan processes would be restored without the influence of the project, channel configuration and condition would continue to be affected by historic actions and ongoing management. For example, LWD delivered from upstream reaches would likely collect on the Highway 20 bridge piers, resulting in the potential for damage to the infrastructure and increased flooding concerns. Predicting the response of agencies responsible managing such impacts and the resultant affect on channel morphology is beyond the scope of this assessment.

4.2 SKAGIT RIVER

Outputs of water, sediment and LWD from the Baker River influence channel conditions in the Skagit River. However, activities undertaken by agencies or individuals external to operations of the Baker Project have also had a profound influence on channel conditions in the Skagit River and will continue to do so in the future. The intent of this section is to qualitatively describe the existing channel conditions and theoretical response potential in the Skagit River in order to provide a context for evaluating the ongoing effects of Baker Project operations and to qualitatively describe conditions that would develop without the influence of the Project. The following discussion of channel response is derived from previous studies of the Skagit River and studies of channel response in similar large rivers. A detailed analysis of historic changes in the Skagit River and the specific role of Baker Project operations is beyond the scope of this assessment.

The Skagit River downstream of the confluence with the Baker River is a very large alluvial river. The drainage area at the Concrete gage is 2,737 square miles, almost 10 times that of the Baker River. The bankfull channel width of single thread sections of the river averages 650 feet. Very large alluvial rivers are typically associated with a array of bars, secondary channels, side-channels, backwater sloughs and oxbow bow lakes that collectively represent a diversity of successional stages, thereby maintaining a diverse mosaic of habitat patches within the floodplain landform (Ward and Stanford, 1995).

Although the entire middle Skagit River is classified as an alluvial floodplain channel type the Skagit River may be subdivided into two reaches between the Baker River confluence (RM 56.5) and Sedro Woolley (RM 24.5), based on channel pattern and slope (Figure 4-4). From RM 56.5 to RM 36.6 the river is primarily a single thread channel with a gradient of approximately 0.1 percent. Off-channel habitats connected to the river are rare. Off-channel habitats isolated on the floodplain become more common in the vicinity of Hamilton (RM 40). Isolation of many of these habitats appears to be primarily related to construction of levees and agricultural development as most are separated from the river by roads and in some cases by entire towns. These features might be inundated by floods of the magnitude of the unregulated 100-year return interval event, but it is unlikely that even a flow of that magnitude would physically reconnect such features in the future without intervention.

From RM 36.6 to RM 24.5, the gradient of the Skagit River decreases to 0.05 percent and the channel becomes multi-threaded with frequent off-channel habitats. Like the section of river located just upstream, numerous remnant off-channel habitats that are currently disconnected from the Skagit River by roads and residences may be observed on aerial photos. However, this portion of the river also supports frequent off-channel habitats that remain directly connected to the river or that would become connected and possibly actively transport flow during large floods. Most of the off channel habitats currently connected with the Skagit River are highly “terrestrialized,” supporting dense stands of young to mid-seral stage vegetation.

4.2.1 Hydrologic Regime

As described in Chapter 3, operations of the Baker Project have altered the flow regime in the Skagit River. The most notable effects of the Baker Project are: 1) reductions in peak flows as a result of flood control operations during the fall and winter; 2) reduced flows during the springtime during project refill and 3) increased fall rate and frequency of large diurnal flow fluctuations.

Large alluvial floodplain channels typically respond to reduced peak flows by developing more homogenous riparian vegetation communities (in terms of both age and species diversity). The connectivity of off-channel habitats is reduced both by the lower frequency of flood events that inundate the floodplain and by the reduced rate of channel migration and rejuvenation of floodplain waterbodies. Even if the channels are not actively incising, the trend towards a single-thread channel may reduce the availability of spawning gravels as secondary channels where gravels often deposit become disconnected while the transport capacity of the single-thread mainstem increases. Flood control operations at the Baker Project have contributed to changes such as these that may be observed in the Skagit River.

Reduced flows during spring refill probably do not have a major effect on channel maintenance or sediment transport, but may affect the connectivity of off-channel habitats and groundwater levels within the floodplain. The combined affect of Baker and Skagit project operations has been to reduce the duration of flows between 25,000 to 35,000 cfs that formerly occurred quite commonly during the spring. This flow reductions would reduce the connectivity of floodplain and off-channel habitats that are wetted

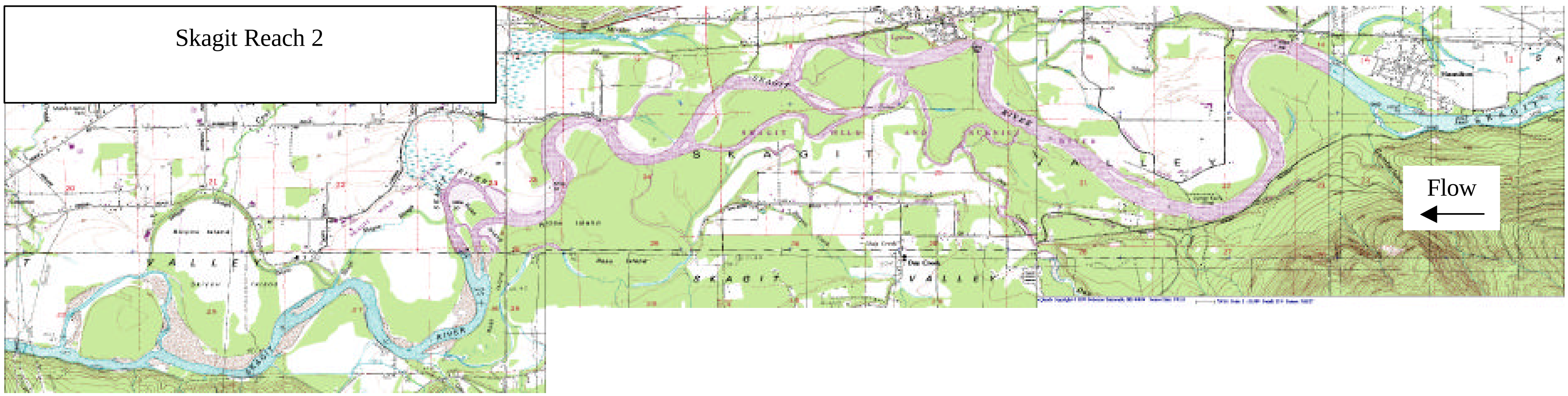

Figure 4-4. Topographic map of the middle Skagit River. The right side of the bottom map joins the left side of the top map. Note the braided channel and multiple off channel habitats in Reach 2.

at that flow range. More detailed information that may be used to assess the connectivity of off-channel habitats is currently being developed as part of Study A09 – Instream Flow. In combination with information on the effects of Baker Project operations presented in Part 1 of this report these data may be used to quantify specific effects of Baker Project operations and to identify potential mitigation and enhancement measures. An assessment of the influence of Baker Project operations on groundwater dynamics is beyond the scope of this assessment. However, the stage discharge relationship at various locations within mainstem Skagit River developed as part of study A09 may provide insight regarding the potential magnitude of changes in groundwater levels that could result from reduced flows during spring refill.

The increased frequency and fall rate of large daily flow fluctuations are expected to have minimal effects on geomorphic processes and channel conditions within the middle Skagit River. The stage change associated with typical Baker Project operations is small (approximately 6 inches) and the magnitude of flow changes under current conditions (3,000 to 4,000 cfs) is unlikely to substantially affect sediment transport. However, given the wide shallow nature of the Skagit River channel, particularly in Reach 2, the increased frequency of large daily flow fluctuations may affect both the amount of wetted habitat and the productivity of that portion of the channel subjected to daily flow fluctuations. The primary effects of the increased rise and fall rate of freshets are expected to be biological and will be further investigated as part of study A09.

4.2.2 Sediment Transport

Large alluvial channels like the Skagit River typically achieve a state of "dynamic equilibrium" over the long-term, under which the sediment transport capacity and sediment supply are approximately equal. Such channels tend to have deformable bed and banks comprised of material deposited by the river, and are thus very sensitive to changes in flow and sediment yield. Long-term increases in sediment yield or reductions in the sediment transport capacity result in aggradation, fining of the bed, increased channel width and potentially a shift from meandering to braided morphology. In contrast, long-term reductions in the sediment supply result in incision, bed coarsening, and disconnection of secondary channels and floodplains resulting in a transition to a simplified single thread morphology with few active bars or secondary channels.

As described in Chapter 3, development and continued operation of the Baker Project reduces the amount of sediment delivered to the Skagit River from the Baker River basin by approximately 6.5 percent as compared to the estimated natural background rates. The sediment supply to the middle Skagit River is also reduced by the Skagit Project, which (assuming sediment yield is proportional to drainage area) would contribute approximately 43 percent of the total sediment load passing the Skagit River near Concrete gage annually.

Flow regulation at the lower Baker Project development began in 1925, and, since the lower Baker Development is located just 1.2 miles upstream of the confluence with the Skagit River, would likely have begun to affect conditions in the Skagit River almost immediately. Reducing the sediment supply of the Skagit River by 6.5 percent would be expected to result in a coarsening of the bed material, but is unlikely to have been sufficient to have initiated wide-spread incision and bar and channel erosion. An evaluation of aerial photographs dating from 1942 revealed that the historic extent and configuration of bars and islands in the middle Skagit River downstream of the Baker River was very similar to that observed today, and there is no evidence that in-channel sediment deposits have substantially decreased. In fact, recent analyses by the USACE suggest that the Skagit River downstream of RM 24.5 has aggraded by approximately 1.5 feet since the mid-1960s (USACE, unpublished data).

Flow regulation and interruption of the downstream transport of sediment by the Skagit Project began at approximately the same time as the Baker Project (1929). The Skagit Project is located at RM 96.6, over 40 miles upstream of the Skagit River near Concrete gage. No existing information on the average bedload velocity in the Upper Skagit River was located, thus it is difficult to determine the rate at which downstream armoring as a result of the interruption in sediment supply at the Skagit Project would progress. Bedload velocities in other gravel bedded rivers have been documented to range from approximately one-half to one mile per year (Perkins, 1999). Assuming that the average bedload velocity in the Skagit River is similar to those rivers, the downstream progression of armoring resulting from the Skagit River Project would be projected to reach the Skagit River near Concrete gage between 1971 and 2013.

In contrast, flood control at both projects has reduced the sediment transport capacity of the middle Skagit River. In the absence of a large reduction in sediment supply, the reduced transport capacity would be expected to result in aggradation, particularly below the confluence with tributary streams that deliver large quantities of sediment. At present the relative effect of the reduced sediment supply versus the reduced transport capacity are unknown. A re-assessment of cross-sections and water surface elevations downstream of the Skagit River near Concrete gage site suggests that the reach has aggraded over the last several decades (USACE, unpublished data). Recent water surface elevations are higher than for similar historic flows at transects located upstream of the Skagit River near Sedro Woolley gage site, and surveys of transects located downstream of Sedro Woolley suggests that the lower Skagit River has aggraded by 1 to 2 feet since the 1970s.

The likely effects of Baker Project operations and the reduced sediment supply resulting from the Skagit Project on the sediment transport regime of the middle Skagit River are further confounded by the influence of land use. An assessment of changes in the sediment supply resulting from forest practices in the Skagit River basin suggests that forest harvest and road building may increase sediment supplied to tributary streams by 10 to 40 percent (Paulsen, 1997). A recent screening level assessment of the Skagit basin concluded that sediment yield was "not functioning" (i.e., substantially higher than it would be without land management) in over half of the subbasins in the Skagit River basin, and assigned a high priority to projects designed to reduce sediment yields (Beamer et al., 2000). Increased inputs from land-use activities may thus offset or mask the effects of reduced sediment supply resulting from Baker Project operations. As noted previously, aggradation has been documented in the Skagit River downstream of Sedro Woolley. In addition, the channel length between Sedro Woolley and Hamilton has decreased since the early 20th Century. Alluvial channels undergoing aggradation typically exhibit a reduction in channel length and increased channel slope, accompanied by braiding. In the case of the Skagit River it is unclear whether the reduced channel length results from aggradation in response to an increased sediment supply, reduced transport capacity or a simplification in the channel pattern as a result of levee construction and bank armoring.

Given that current efforts are focused on reducing the sediment yield of unregulated tributary streams, and that the effects of the reduced sediment supply resulting from construction of the Skagit Project may not have begun to affect conditions within the middle Skagit River, it is likely that sediment inputs to the middle Skagit will decrease in the future as compared to the current condition. The continued interruption of bedload by the Baker Project will contribute to this reduction. Reducing the sediment supply of the middle Skagit River could result in a coarsening of the channel bed. If the reduction in supply is greater than the reduction in transport capacity, it is possible that incision of the channel thalweg leading to abandonment of existing secondary channels and off-channel habitats could occur. Conversely, the reduced transport capacity associated with ongoing flood control could continue to offset these effects.

4.2.3 Large Woody Debris

Alluvial floodplain channels are typically highly responsive to large woody debris (Montgomery and Buffington, 1993; Paustian, 1992). Debris jams alter local current patterns and scour the bed and banks, in some cases hastening meander cutoffs or channel avulsions (Keller and Swanson, 1979). Deposition of sediment downstream of LWD jams may initiate formation of bars and islands (Abbe and Montgomery, 1996).

The primary functions of LWD in large rivers appear to be maintenance of off-channel areas, increasing the complexity of channel margins, and to a lesser extent formation of pools (Collins et al., 2002). Flow velocity in mainstem and large secondary channels are generally higher than preferred by young fish. For juvenile chinook and coho salmon, fish abundance along channel banks has a significant positive correlation with the amount of wood cover (Beamer and Henderson, 1998). Debris jams at side channel inlets also moderate flow velocities into and through those channels at high flows, improving habitat for smaller fish. Debris jams that build up in secondary channels or at the upstream end of bars and islands may ultimately block those channels and force flow onto the floodplain where it slowly infiltrates, replenishing shallow groundwater aquifers causing channel avulsions that result in the formation of new side and off-channel habitats. Woody debris may greatly enhance the habitat value of such pools, but is currently rarely the primary formative factor. A recent study on a reach of the lower Nisqually River that has been protected from development and is assumed to have retained the characteristics of pre-European indicated that individual pieces of LWD and jams formed 18 and 26 percent of all pools; multiple pieces that served to augment free-formed pools were noted in an additional 18 percent of the pools surveyed (Collins et al., 2002).

The Skagit River is a very large river with a wide channel (>500 feet) that is generally several times the length of even the tallest site potential trees. As a result, most individual pieces of LWD delivered to the Skagit River are easily transported during annual high flows. Historically, very large channel spanning raft jams developed in the Skagit River, particularly near the upstream end of the tidal influence zone between Mount Vernon and Sedro Woolley. Accounts of early settlers describe two vast accumulations of LWD starting in Mount Vernon and extending upstream for half a mile to a mile. The downstream-most jam was described as "so tightly packed that it could be crossed at almost any point in its entire extent and upon it had grown a veritable forest, in some cases trees of even two or three feet in diameter…" (Interstate Publishing Company, 1906). Another jam located about a mile upstream of the first was described as "to all appearances of comparatively recent formation" and increasing in size very rapidly, accumulating a quarter mile of debris at its upstream end within three years (Interstate Publishing Company, 1906). Following removal of the large raft jams in the late 1800s, the Army Corps of Engineers removed between 200 and 8,000 snags per year from the Skagit River between 1885 and 1910 (Collins et al., 2002).

Although the historic LWD jams in the Skagit contained many logs greater than 8 feet in diameter (Interstate Publishing Company, 1906), much of the wood contained within the jam probably consisted of smaller pieces and fragments, similar to LWD jams and rafts documented in the Baker River for Study A20 (R2, 2003). Current wood abundance in two other large Puget Lowland Rivers (Snohomish and Stilliguamish) is estimated to be one to two orders of magnitude less than it was prior to European settlement (Collins et al., 2002). LWD jams presently observed in the middle Skagit typically consist primarily of deciduous trees of around 1 to 2 feet in diameter and included hundreds of fragments of smaller debris. Small to medium size jams currently occur at the mouths of most side channels. Wood is also accumulating at the upstream ends of bars and islands, the tops of many bars, and the outside of meander bends, typical locations for large alluvial rivers (Abbe and Montgomery, 1996). Existing LWD jams in the Skagit River are often associated with local scour that forms pools; however, most large pools are formed along the outside of meander bends, or in areas where secondary channels, tributaries or side channels converge with the mainstem. Large woody debris currently present in the Skagit River provides cover and velocity breaks along channel margins that may serve as refugia for fish during periods of high flow.

Woody debris originating in the Baker River basin and transported downstream was historically delivered to the Skagit River. Study A20 estimated that contributions of LWD from the Baker River without the Project in place would have represented approximately 7.1 percent of the total estimated LWD yield for the Skagit river basin at the confluence with the Baker River. Wood transported downstream through the Baker River would have passed through at least three bedrock canyons that were less than 100-feet wide (located between RM 0.6 and RM 1.9; RM 6.9 and 7.5 and RM 11 to 12.5), and thus would likely not have consisted of large intact trees. Smaller pieces of wood contributed by the Baker River would accumulate in debris rafts at side channel mouths and along channel margins, or would be incorporated into jams associated with large trees recruited directly from channel margins.

5. CONCLUSIONS

This Section briefly summarizes the results of Study A24 Part 1 and of the assessments of sediment transport and channel response presented in this document.

5.1 HYDROLOGY

The primary influences of Baker Project operations have been to reduce flood peaks, alter seasonal runoff patterns and increase the magnitude, frequency and hourly rate of change of daily flow fluctuations. Effects are more pronounced in the lower Baker River than in the Skagit River because of differences in channel size and morphology. The following sections summarize the major findings of Study A24 Part 1.

5.1.1 Baker River

Flow regulation by the Baker Project has not altered annual runoff volume, but does affect short duration annual flow components, seasonal flow patterns and daily and hourly flow fluctuations. The magnitude of annual peak flows is reduced, but the duration increases as floodwaters are captured in the reservoirs then slowly released. Annual low flows in the Baker River are reduced, because even when supplemented by leakage through the dam, existing minimum flows (80 cfs) are substantially lower than unregulated annual low flows (739 cfs).

The primary effect of Baker Project operations on seasonal flow components occur during the spring as a result of reservoir refill and in the fall and winter as a result of flood control operations. Average daily flows in May and June are 20 to 30 percent lower under regulated conditions as early snowmelt runoff is captured when the reservoir is refilled. Once the reservoir fills, average daily flows differ by less than 10 percent under regulated versus unregulated conditions. During the fall and winter, average daily flows are 15 to 20 percent higher than under regulated conditions because flood peaks are captured and released gradually. In addition, periods of very low flow lasting days or weeks commonly occur during winter cold spells under unregulated conditions. Flows resulting from hydropower operations are consistently higher during winter cold spells.

Daily and hourly flows in the lower Baker River are almost entirely governed by hydropower operations, except during periods of spill. The frequency of large daily changes in flow is higher, except during the late spring and early summer when large diurnal fluctuations associated with snowmelt are observed. Diurnal flow fluctuations resulting from snowmelt typically result in flow that peak late at night or early in the morning, and are lowest at midday or in the late afternoon. In contrast, the Baker Project generally ramps up in the early morning or evening, and is shut down late in the evening. The magnitude of daily flow fluctuations and rate of change that occur in the lower Baker River are substantially higher than those associated with natural daily flow fluctuations observed in nearby unregulated rivers.

5.1.2 Skagit River

The effects of Baker Project operations on the flow regime of the Skagit River are less pronounced than in the Baker River, although some important differences are observed. Annual runoff volumes and the mean annual discharge are similar under regulated and unregulated conditions. Annual and seasonal flow components are less affected by Baker Project operations than for the Baker River because inputs from other large, unregulated tributaries offset some of the differences. However, Baker Project operations in conjunction with hydropower operations at Seattle City Lights Skagit Project do result in additive effects. Peak flows are reduced, and Baker Project operations are estimated to be responsible for about 15 percent of the total reduction. Overall, flood control at both the Baker Project and Skagit projects reduces the magnitude of a 100-year return interval flow event from 293,000 cfs to about 220,000 cfs (USACE, 1998). Flows greater than 160,00 cfs (equivalent to a 10-year return interval event) still occur, but have a return interval of 40 years under regulated conditions. Low flows are less likely to occur during the winter, and are higher than for unregulated conditions.

The seasonal effects of flow regulation on the Skagit River are similar to those observed for the Baker River. Average daily flows are generally similar to unregulated conditions in the late summer, but the frequency and magnitude of daily flow fluctuations is higher. Average daily flows are higher in the late fall and winter. Baker Project operations account for about almost 40 percent of the increase in November, as the Project reservoirs are drawn down, and for about 15 percent of the increase in December through March. During the spring, flows in the Skagit River are currently lower than for unregulated conditions. Baker Project operations account for the majority of the difference in April, and from 20 to 25 percent of the difference in May and June. Hydropower operations capture freshets in the spring, reducing frequency of such events. Overall, monthly flows in the Skagit River under regulated conditions remain within the range of variability exhibited by unregulated flows.

The most notable change in the flow regime in the Skagit River resulting from Baker Project operations is the increased magnitude, frequency and rate of change of daily flow fluctuations. Daily and hourly flow fluctuations in the Skagit River reflect a mixture of flow regulation effects and natural variability. The rate of change for hourly flow fluctuations is substantially greater than for unregulated conditions, often greater than six inches per hour as compared to around one inch per hour under unregulated conditions. Both the Baker Project and Skagit Project generate daily flow fluctuations; however, the rate of change associated with events originating at the Skagit Project attenuates by the time those flows reach the Skagit River near Concrete gage. Daily stage changes resulting from Baker Project operations attenuate somewhat as a result of the much larger size of the Skagit River channel as compared to the Baker River channel. However, stage changes resulting from Baker Project operations have a greater rate of change than those originating at the Skagit Project. The rate of change resulting from natural freshets in the fall and winter may approach the rate of change resulting from Baker Project operations, but is typically lower.

In the spring, unregulated rivers in the Skagit basin experience regular daily flow fluctuations as a result of spring snowmelt. These diurnal fluctuations may have a magnitude similar to stage changes resulting from Baker Project Operations (i.e., 2,800 to 4,000 cfs). However, diurnal flow fluctuations resulting from snowmelt generally occur over a 12-hour period as compared to an approximately 4 hour period for flow fluctuations resulting from Baker Project operations. As a result, the rate of change resulting from Baker Project operations is substantially greater that for unregulated diurnal flow fluctuations.

5.2 SEDIMENT TRANSPORT

The Baker Project interrupts the downstream transport of sediment from the Baker River basin. Some suspended sediment is transported past the Lower Baker development, but all of the bedload carried by the mainstem Baker River and tributary streams accumulates within the reservoir. Interruption of sediment transport by the Baker Project has reduced the sediment yield of the Baker River and the amount of material contributed to the middle Skagit River. The following sections summarize the results of sediment transport analyses presented in Chapter 3.0.

5.2.1 Baker River

The mainstem Baker River receives sediment from tributary streams draining a 297 square mile watershed. Under regulated conditions, all of the bedload and a portion of the suspended load delivered to Baker Lake and Lake Shannon accumulate within the lakes. The reservoir trapping efficiency is a function of reservoir volume and inflows, and is thus greater for Baker Lake than for Lake Shannon. Approximately 15 percent of the suspended sediment delivered to Baker Lake is routed past Upper Baker Dam and delivered to Lake Shannon. Approximately 23 percent of the suspended sediment delivered to Lake Shannon is routed past Lower Baker Dam to the lower Baker and Skagit River. Suspended sediments transported past the dams consist of fine silt or smaller size material. No tributaries enter the Baker River downstream of Lower Baker Dam.

The Baker Project intercepts all of the bedload originating from the Baker River basin. Under unregulated conditions, the majority of sediment originating from tributaries, colluvial sources and bank erosion upstream of natural Baker Lake would deposit within the lake. All of the bedload, and approximately 25 percent of the suspended load would be retained within the lake. Tributary areas downstream of natural Baker lake supply an estimated from 16,000 to 27,000 tons of bedload to the Baker River each year. The annual bedload transport capacity for the alluvial portions of the lower Baker River is estimated to be approximately 12,500 tons per year. Since the estimated bedload yield exceeds the estimated transport capacity, some of the bedload delivered to the Baker River each year would likely be stored within the channel and floodplain. Material delivered to the lower Baker River downstream of the Lower Baker Development would consist of 84 percent gravel (10,000 tons) and 16 percent cobble (2,000 tons). The remainder of the bedload would be sand or boulder sized material. The suspended sediment yield under unregulated conditions would increase by a factor of about seven, from between 21,000 to 30,000 tons per year to between 135,000 to 236,000 tons per year.

5.2.2 Skagit River

Both the Baker River basin and upper Skagit River basin are characterized by mountainous terrain, extensive glaciers and ice fields and geologically recent volcanic activity. With the presence of natural Baker Lake, the effective area contributing bedload to the Baker River is 179 square miles. Assuming the sediment yield per unit area is the same for the Baker and Skagit Rivers, contributions from the Baker River represent approximately 6.5 percent of the sediment load carried by the unregulated Skagit River.

5.3 CHANNEL RESPONSE

Channel morphology is a function of landform, climate, sediment yield, hydrologic regime, LWD and position in the drainage network. The response of downstream channel segments to changes in those inputs resulting from the Baker Project is largely a function of channel type.

Reservoirs formed by the Baker Project have altered the downstream transport of water, sediment and wood. Changes in those geomorphic inputs are believed to have affected channel conditions in the lower Baker River and Skagit River downstream of the Project Area. A quantitative assessment of specific project effects is confounded by the influence of other land management activities including other hydroelectric projects, levees and flood control structures, timber harvest and road building and many others. However, the theoretical assessment of channel response potential described in Chapter 4 combined with the quantitative analysis of changes in hydrology and sediment transport described in Chapter 3 of this report and Part 1 of Study A24 provide information on the likely trajectory and magnitude of effects on the lower Baker and middle Skagit rivers. The following sections summarize the results described in Chapter 4

5.3.1 Baker River

The lower Baker River consists of approximately one-half mile of canyon channel that has a low response potential to changes in flow and sediment supply, and approximately one-half mile of alluvial fan channel that is highly responsive to changes in flow, sediment delivery and LWD. Baker Project operations have cut off the delivery of virtually all coarse sediment and LWD to these channel segments, substantially reduced the delivery of fine sediment, and reduced the magnitude of peak flows responsible for shaping the channel. The expected response to these altered inputs for the canyon channel would be a loss of gravel patches and potentially a coarsening of the substrate overall. Mobile sediments are believed to have been rapidly routed out of this channel segment since construction of Lower Baker Dam, and the bed is currently well-armored with a layer of boulders that are rarely mobilized even by high flows. Ongoing operations are not expected to result in further changes in channel morphology within this segment.

In contrast, alluvial fan channels are highly responsive to changes in water, sediment and LWD. Alluvial fans represent long-term sediment storage sites formed by the accumulation of bedload over time. Aggradation of alluvial fans reduces the ability of the channel to transmit peak flows, resulting in frequent avulsions as water attempts to find the most efficient path across the fan. The resulting landform features variable substrate distribution and a network of active and inactive distributary channels in varying states of succession that radiate outward from the fan apex.

Reducing the supply of bedload results in channel incision and a net export of stored sediments from the alluvial fan channel. The incised channel would contain high flows and more efficiently route water across the fan, reducing the frequency of channel avulsions and distributary channel formation and abandonment. Reducing the magnitude of peak flows and inputs of LWD further exacerbates these conditions. Existing conditions on the fan are similar to those that would be expected to result from Baker Project operations. Gravel mining, channel dredging, and development on the fan landform have also altered habitat and riparian conditions there, intensifying geomorphic effects that would be expected to result from Baker Project operations. The existing stable, simplified channel has evolved to configuration that rapidly routes water and sediment downstream, and would not be expected to change dramatically under ongoing operations.

5.3.2 Skagit River

The Skagit River downstream of the confluence with the Baker River is an alluvial floodplain channel that would be expected to be highly responsive to changes in the supply of water, sediment and wood. The Skagit River was divided into two reaches based on gradient and the complexity of the existing channel. The difference in channel complexity was apparent on the earliest existing set of aerial photographs dating from 1937, just over ten years after operations were initiated at the Lower Baker Development. The lack of visible secondary, side or off-channel habitats in the upstream reach on that photo set suggests that differences in channel pattern between the two reaches are not the direct result of Baker Project operations. However, Baker Project operations are likely to have affected channel conditions in the Skagit River, and those effects are likely to continue under ongoing operations.

Reductions in the amount of sediment contributed by the Baker River would be expected to result in a coarsening of the bed, but are likely not sufficiently large to initiate large scale incision of the Skagit River channel downstream of the confluence of the Baker River. The sediment yield of the Baker River represents a relatively small proportion (< 10 percent) of the overall Skagit River sediment load, and is believed to have been offset by the reduction in transport capacity resulting from flood control, and sediment inputs from tributaries downstream that have increased sediment yields as a result of forest harvest and road building. The rate at which degradation or channel armoring would progress downstream in the Skagit River in the absence of flow regulation can be approximated based on bedload velocities measured in similar rivers. Bedload velocities in several other large rivers in the Pacific Northwest range from approximately one-half mile to one mile per year (Perkins, 1999). Application of similar rates to the Skagit River suggests that the reduced sediment load resulting from Baker Project operations would have affected conditions downstream to Sedro Woolley by 1989. In contrast, reduced sediment inputs from the Skagit Project, which cut off sediment yield from a much larger proportion of the watershed, would not have begun to affect conditions downstream of the Baker confluence until 1970 at the earliest, and may not reach the Baker River confluence until 2013.

Effects resulting from the reduced sediment supply are confounded by the simultaneous reduction in peak flows. Bedload transport volumes are typically directly related to flow magnitude, with the largest flows transporting the greatest amount of sediment. Reduced flood flows would be expected to have reduced the bedload transport rate. An assessment of the relative influence of reduced sediment supply versus reduced peak flows on the Skagit River is beyond the scope of the present study. However, given the number of large tributaries that enter the Skagit River downstream of both projects, it is likely that the reduced transport capacity has offset some or all of the effects of the reduced sediment supply.

The reduction in peak flows resulting from the combined effects of Baker and Skagit River operations have reduced the frequency of very large flood events. The largest flood events (recurrence interval > 10 years) are believed to be most important for maintaining floodplain features and forming new side channels. The reduced frequency of these large floods is believed to have contributed to a reduction in the number and extent of off-channel habitats and may have altered groundwater recharge rates. The effects of reduced flood flows are compounded by the extensive network of levees and other flood control structures in the middle and lower Skagit River.

Baker Project operations also contribute to a reduction in the amount of LWD in the Skagit River in a several of ways. The Baker River would contribute LWD directly to the Skagit River in the absence of the Baker Project; however, this material would first have to be transported through the narrow, two-mile long canyon where the Lower Baker Development is currently located. The canyon is sinuous, approximately 100-feet wide and contains numerous very large bed elements, thus wood transported through the canyon would most likely become fragmented before it reached the Skagit River. The Baker Project has also affected LWD recruitment in the middle Skagit River by contributing to the reduction in peak flows that are largely responsible for bank erosion and direct recruitment of streamside trees with attached rootwads. Isolation of impacts resulting specifically from Baker Project operations is confounded by harvest of streamside forests and conversion of formerly forested areas to farmland. In addition, LWD was historically removed from the river to facilitate navigation, and continues to be removed to a lesser extent today to protect roads and bridges.

In summary, Baker Project operations have likely contributed to the overall reduction in channel complexity in the middle Skagit River by reducing flood magnitudes and LWD inputs. Changes in peak flows and the seasonal flow regime may affect the condition and connectivity of existing off-channel habitats, and may reduce groundwater recharge, thereby influencing riparian forest condition and succession. The reduced sediment supply could contribute to channel incision and bed armoring, but may be offset by the reduced transport capacity resulting from flood control operations as well as increased inputs from tributary channels downstream of the Project area.

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APPENDIX A

Tributary Bedload Modeling

APPENDIX A

TRIBUTARY SEDIMENT YIELDS

The total sediment supplied from the upper Baker River and tributaries is comprised of the sum of two components: bed material load and suspended load. Of these two components, the bed material load is particularly important because the coarser sediment in this portion has the potential to deposit and alter the channel morphology in alluvial stream systems. The bed material load of the mainstem and nine tributaries was determined by performing pebble count surveys, surveying channel cross-sections and slopes, and developing a sediment transport/flow rating curve that was applied to a flow duration curve to determine average annual bed material load quantities.

Tributary sediment yields in the Baker Watershed were estimated by calculating the bed material transport rate in various tributary streams using the Parker (1990a and 1990b) surface-based formulation. Estimated transport rates were then coupled with flow duration curves to calculate the average annual bedload transport for each tributary. The total sediment load was estimated by assuming that the calculated bedload yield represented 15 percent of the total sediment yield.

Field data were collected from eight tributaries to the Baker River. Tributaries selected for this study were chosen because they reflect a variety of water sources (glacial melt, precipitation and seasonal snowmelt) and land uses, had available information on annual flow duration, and had alluvial reaches located near the reservoir. In addition, field data was collected from the mainstem Baker River immediately upstream of Baker Lake and in the reach downstream of Lower Baker Dam.

A temporary benchmark was established at each survey site using a stable natural feature (e.g., boulder or stump). A representative cross-section was selected from each tributary. At each cross-section, a measuring tape was stretched across the stream and secured at both banks. Ground surface elevations were surveyed at measured horizontal distances across the transect using an automatic level and a level rod. The water surface elevations were surveyed near each bank. A water surface profile was surveyed within each creek extending up and downstream of the cross-section over a distance sufficient to establish a characteristic slope. Horizontal distances were surveyed using a tape measure or by performing stadia survey measurements.

Pebble counts were performed at each site to characterize the grain size distribution of the bed surface sediments. Pebble counts were performed by walking back and forth across the width of each channel or across an adjacent bar to cover an area defined by the channel width and a representative downstream length of the channel as recommended by Wolman (1954). Pebble samples were collected by reaching down and randomly selecting individual particles. The size of each selected particle was measured across the medial particle axis. A total of 100 particles were measured for each pebble count. The particle sizes from each pebble count survey were ranked from lowest to highest and a cumulative frequency analysis was performed to characterize the grain size distribution of the bed surface material.

The discharge and flow velocity in each tributary over a range of water stages was determined by applying Manning's formula. The bed material transport rate for each tributary was determined using the Parker (1990a and 1990b) surface-based formulation. To calculate the total bed load transport rate for a cross-section, an effective width was used. The effective width was estimated by subtracting two average flow depths from the water surface top width. Flow duration curves were obtained from studies performed for previous small hydropower FERC license applications on each tributary (HEDC, 1990; PSE, 1982a; PSE, 1982b; PSE, 1983a; PSE, 1983b; PSE, 1983c; PSE, 1984). A bedload transport rating curve was constructed using the field data and applied to the flow duration curve to determine the average annual bedload sediment yield.

The flow velocity in each tributary was determined by applying Manning's formula, to the creek in the following manner:

$$V_u = \frac{1.486}{n} R^{2/3}\sqrt{S}$$

where n is Manning's "n", R is the hydraulic radius of the channel, and S is the channel slope. Manning's "n" was estimated using the Limerinos (1970) formula, which is as follows:

$$n = \frac{0.0926\, R^{1/6}}{1.16 + 2.0 \log\left(\frac{R}{D_{84}}\right)}$$

where D_{84} is the particle size for which 84 percent of the sediment sample is finer. The pebble count survey of the bed surface layer was used to determine D_{84}.

The term RS is referred to herein as the nominal shear stress. This term accounts for the energy lost through a combination of friction and form drag. The friction component of this term is referred to herein as the effective shear stress. From the Meyer-Peter Muller (1948) formula, the effective shear stress is as follows:

$$t_{eff} = \left(\frac{0.0316\, D_{90}^{\ 1/6}}{n}\right)^{3/2} g \quad R\, S$$

The bed material transport rate for each tributary was determined over a range of flows using the Parker (1990a and 1990b) surface-based formulation. The bedload transport rate is not equal across the entire cross-section, thus an effective width rather than the total water surface width was used to calculate the bedload transport rate for each cross-section. The effective width was estimated by subtracting two average flow depths from the water surface width.

Flow duration data for the modeled tributaries was available from previous FERC License Applications. The flow duration curve for the upper Baker River was estimated using synthesized unregulated flow data for the Baker River at Concrete gage and assuming that runoff per unit area from the area draining to the upper Baker River was proportional to that of the entire basin.

SEDIMENT ROUTING THROUGH LAKES

The amount of sediment supplied to the lakes at the upstream end of the study reach was using the tributary sediment transport analysis and regional sediment yield data. Under the with Project scenario, sediment was routed through Baker Lake and Lake Shannon. Sediment routing through natural Baker Lake in the absence of the Project was also evaluated. The total quantities of sediment supplied, trapped, and passed were accounted for, based on the sediment trapping efficiencies of each reservoir.

The trap efficiencies of Baker Lake, natural Baker Lake and Lake Shannon were determined using the modified Brune Curve Method (Linsley et al., 1982), which is based on the following equation:

$$Y = 100\left(1 - \frac{1}{1 + a\,X}\right)^{n}$$

Where Y is the sediment trap efficiency in percent and X is the ratio of storage capacity to annual runoff volume. The best-fit trap efficiency is determined using 100 and 6.5 for “a” and “n”, respectively. The lower range of trap efficiency is determined using 65 and 2.0 and the upper range of trap efficiency is determined using 130 and 1.0 for “a” and “n”, respectively.

Hydraulic characteristics of each reservoir pool and natural Baker Lake were used to determine trap efficiencies for sediment size fractions ranging from very fine clay to small cobbles using a method that the U.S. Bureau of Reclamation recommends for turbulent flow (Borland, 1971; Chen, 1975; and Raudkivi, 1993). This method is based on the following equation:

$$E_i = 100\left[1 - \exp\left(\frac{-w_i A}{Q}\right)\right]$$

where E_i is the trap efficiency for a particular size fraction, w_i is the sediment particle fall velocity, A is the surface area of the pond, and Q is the flow through the pond. Particle fall velocity was obtained from the U.S. Inter-Agency Committee on Water Resources (1957) for particles ranging in size from very fine sand to fine gravel. The fall velocities for particles smaller than this size range were extrapolated in proportion to the square root of the particle size and the fall velocities for particles larger than this size range were extrapolated in proportion to the square of the particle size (Rubey, 1933).

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MEMORANDUM

Date: May 7, 2003

To: Baker Aquatics Work Group

From: Steve Fransen

Subject: Baker Agency Group (BAG) conference of 5/6/03

The BAG held a conference call among Gene Stagner (USFWS), Gary Sprague (WDFW), Stan Walsh (SSC), and me on May 6. The purpose of the conference was to discuss and, if possible, establish standards and performance criteria for the future fish passage facilities and operations of the Baker River hydro project. Part of the basis for the standards and criteria are the section 18 fish passage authority of USFWS and NMFS under the FPA. The remainder are intended to balance the fisheries program in a way that results in sustainability over the term of the license, at a minimum.

Performance and standards to satisfy our mutual interests are these:

1) Fish passage survival through fish collection facilities, upstream and downstream - 98%, or better.

2) Juvenile collection efficiency - 95%, or better, of the smolts that migrate to the dam forebay.

3) Reservoir passage and survival - 80% or better.

4) Fish survival overall, through 1, 2, & 3 above - 75% or better. The 98% and 95% values have administrative precedent in other NMFS fishway prescriptions. The 75% value for overall survival is not an administrative policy, but rather an estimate of the system survival necessary to result in self-sustaining anadromous fish populations capable of supporting a harvest management component.

5) A supplementation program to assure full reservoir seeding (the number value to be derived from the reservoir production potential study) for sockeye and coho, plus a chinook and steelhead program. The intent is to secure as much of the potential fish production from natural, as opposed to hatchery, production as is feasible.

6) No PSE delay, nor footdragging, in implementation of PMEs.

7) The Floating Surface Collector will be initiated with a 1,000 cfs flow, assuming it's technically feasible. Otherwise, the initial collector may be sized at 500 cfs.

8) Penalty for non-performance should be XXX additional to the HERC fund. A major problem with many licenses is the lack of adverse consequences to the Licensee for destroying public trust resources, so we added this to better protect the public.

9) Monitoring and maintenance are expected for all the fisheries PMEs, and are not intended to be limited to the section 18 fishways and their operations.