US Army Corps
of Engineers®
Walla Walla District

FINAL

Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

APPENDIX F
Hydrology/Hydraulics and Sedimentation

February 2002

FEASIBILITY STUDY DOCUMENTATION

	Document Title
Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement	
Appendix A (bound with B)	Anadromous Fish Modeling
Appendix B (bound with A)	Resident Fish
Appendix C	Water Quality
Appendix D	Natural River Drawdown Engineering
Appendix E	Existing Systems and Major System Improvements Engineering
Appendix F (bound with G, H)	Hydrology/Hydraulics and Sedimentation
Appendix G (bound with F, H)	Hydroregulations
Appendix H (bound with F, G)	Fluvial Geomorphology
Appendix I	Economics
Appendix J	Plan Formulation
Appendix K	Real Estate
Appendix L (bound with M)	Lower Snake River Mitigation History and Status
Appendix M (bound with L)	Fish and Wildlife Coordination Act Report
Appendix N (bound with O, P)	Cultural Resources
Appendix O (bound with N, P)	Public Outreach Program
Appendix P (bound with N, O)	Air Quality
Appendix Q (bound with R, T)	Tribal Consultation and Coordination
Appendix R (bound with Q, T)	Historical Perspectives
Appendix S*	Snake River Maps
Appendix T (bound with R, Q)	Clean Water Act, Section 404(b)(1) Evaluation
Appendix U	Response to Public Comments

*Appendix S, Lower Snake River Maps, is bound separately (out of order) to accommodate a special 11 x 17 format.

The documents listed above, as well as supporting technical reports and other study information, are available on our website at http://www.nww.usace.army.mil/lsr. Copies of these documents are also available for public review at various city, county, and regional libraries.

STUDY OVERVIEW

Purpose and Need

Between 1991 and 1997, due to declines in abundance, the National Marine Fisheries Service (NMFS) made the following listings of Snake River salmon or steelhead under the Endangered Species Act (ESA) as amended:

- sockeye salmon (listed as endangered in 1991)
- spring/summer chinook salmon (listed as threatened in 1992)
- fall chinook salmon (listed as threatened in 1992)
- steelhead (listed as threatened in 1997).

In 1995, NMFS issued a Biological Opinion on operations of the Federal Columbia River Power System (FCRPS). Additional opinions were issued in 1998 and 2000. The Biological Opinions established measures to halt and reverse the declines of ESA-listed species. This created the need to evaluate the feasibility, design, and engineering work for these measures.

The Corps implemented a study (after NMFS' Biological Opinion in 1995) of alternatives associated with lower Snake River dams and reservoirs. This study was named the Lower Snake River Juvenile Salmon Migration Feasibility Study (Feasibility Study). The specific purpose and need of the Feasibility Study is to evaluate and screen structural alternatives that may increase survival of juvenile anadromous fish through the Lower Snake River Project (which includes the four lowermost dams operated by the Corps on the Snake River—Ice Harbor, Lower Monumental, Little Goose, and Lower Granite Dams) and assist in their recovery.

Development of Alternatives

The Corps' response to the 1995 Biological Opinion and, ultimately, this Feasibility Study, evolved from a System Configuration Study (SCS) initiated in 1991. The SCS was undertaken to evaluate the technical, environmental, and economic effects of potential modifications to the configuration of Federal dams and reservoirs on the Snake and Columbia Rivers to improve survival rates for anadromous salmonids.

The SCS was conducted in two phases. Phase I was completed in June 1995. This phase was a reconnaissance-level assessment of multiple concepts including drawdown, upstream collection, additional reservoir storage, migratory canal, and other alternatives for improving conditions for anadromous salmonid migration.

The Corps completed a Phase II interim report on the Feasibility Study in December 1996. The report evaluated the feasibility of drawdown to natural river levels, spillway crest, and other improvements to existing fish passage facilities.

Based in part on a screening of actions conducted for the Phase I report and the Phase II interim report, the study now focuses on four courses of action:

- Existing Conditions
- Maximum Transport of Juvenile Salmon

- Major System Improvements
- Dam Breaching.

The results of these evaluations are presented in the combined Feasibility Report (FR) and Environmental Impact Statement (EIS). The FR/EIS provides the support for recommendations that will be made regarding decisions on future actions on the Lower Snake River Project for passage of juvenile salmonids. This appendix is a part of the FR/EIS.

Geographic Scope

The geographic area covered by the FR/EIS generally encompasses the 140-mile long lower Snake River reach between Lewiston, Idaho and the Tri-Cities in Washington. The study area does slightly vary by resource area in the FR/EIS because the affected resources have widely varying spatial characteristics throughout the lower Snake River system. For example, socioeconomic effects of a permanent drawdown could be felt throughout the whole Columbia River Basin region with the most effects taking place in the counties of southwest Washington. In contrast, effects on vegetation along the reservoirs would be confined to much smaller areas.

Identification of Alternatives

Since 1995, numerous alternatives have been identified and evaluated. Over time, the alternatives have been assigned numbers and letters that serve as unique identifiers. However, different study groups have sometimes used slightly different numbering or lettering schemes and this has led to some confusion when viewing all the work products prepared during this long period. The primary alternatives that are carried forward in the FR/EIS currently involve the following four major courses of action:

Alternative Name	PATH[1/] Number	Corps Number	FR/EIS Number
Existing Conditions	A-1	A-1	1
Maximum Transport of Juvenile Salmon	A-2	A-2a	2
Major System Improvements	A-2’	A-2d	3
Dam Breaching	A-3	A-3a	4

[1/] Plan for Analyzing and Testing Hypotheses

Summary of Alternatives

The **Existing Conditions Alternative** consists of continuing the fish passage facilities and project operations that were in place or under development at the time this Feasibility Study was initiated. The existing programs and plans underway would continue unless modified through future actions. Project operations include fish hatcheries and Habitat Management Units (HMUs) under the Lower Snake River Fish and Wildlife Compensation Plan (Comp Plan), recreation facilities, power generation, navigation, and irrigation. Adult and juvenile fish passage facilities would continue to operate.

The **Maximum Transport of Juvenile Salmon Alternative** would include all of the existing or planned structural and operational configurations from the Existing Conditions Alternative. However, this alternative assumes that the juvenile fishway systems would be operated to maximize fish transport from Lower Granite, Little Goose, and Lower Monumental and that voluntary spill would not be used to bypass fish through the spillways (except at Ice Harbor). To accommodate this maximization of transport, some measures would be taken to upgrade and improve fish handling facilities.

The **Major System Improvements Alternative** would provide additional improvements to what is considered under the Existing Conditions Alternative. These improvements would be focused on using surface bypass facilities such as surface bypass collectors (SBCs) and removable spillway weirs (RSWs) in conjunction with extended submerged bar screens (ESBSs) and a behavioral guidance structure (BGS). The intent of these facilities would be to provide more effective diversion of juvenile fish away from the turbines. Under this alternative, an adaptive migration strategy would allow flexibility for either in-river migration or collection and transport of juvenile fish downstream in barges and trucks.

The **Dam Breaching Alternative** has been referred to as the "Drawdown Alternative" in many of the study groups since late 1996 and the resulting FR/EIS reports. These two terms essentially refer to the same set of actions. Because the term drawdown can refer to many types of drawdown, the term dam breaching was created to describe the action behind the alternative. The Dam Breaching Alternative would involve significant structural modifications at the four lower Snake River dams, allowing the reservoirs to be drained and resulting in a free-flowing yet controlled river. Dam breaching would involve removing the earthen embankment sections of the four dams and then developing a channel around the powerhouses, spillways, and navigation locks. With dam breaching, the navigation locks would no longer be operational and navigation for large commercial vessels would be eliminated. Some recreation facilities would close while others would be modified and new facilities could be built in the future. The operation and maintenance of fish hatcheries and HMUs would also change, although the extent of change would probably be small and is not known at this time.

Authority

The four Corps dams of the lower Snake River were constructed and are operated and maintained under laws that may be grouped into three categories: 1) laws initially authorizing construction of the project, 2) laws specific to the project passed subsequent to construction, and 3) laws that generally apply to all Corps reservoirs.

REGIONAL BASE MAP

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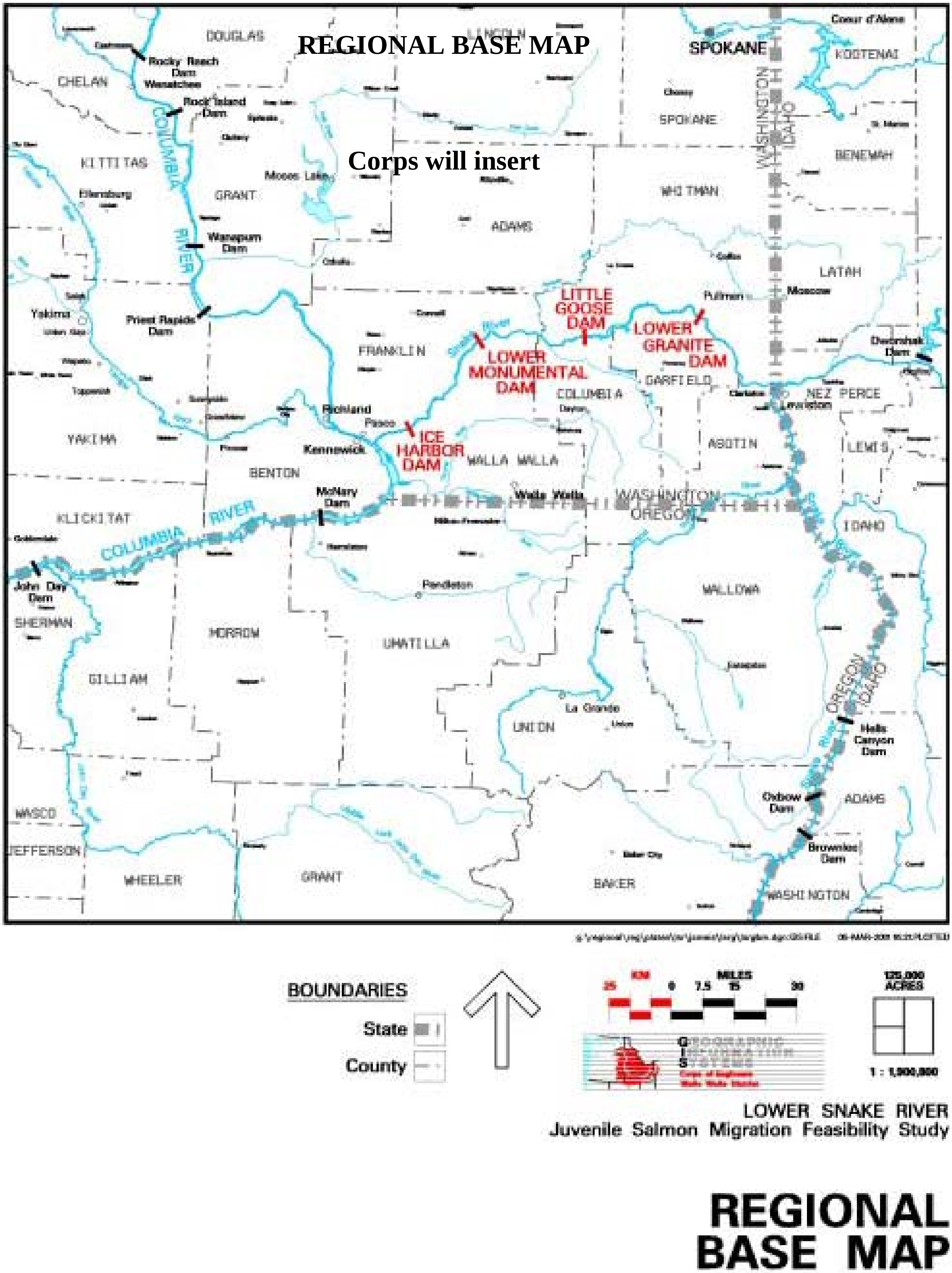

US Army Corps of Engineers®
Walla Walla District

Final
Lower Snake River Juvenile Salmon Migration Feasibility Report/ Environmental Impact Statement

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Appendix F
Hydrology/Hydraulics and Sedimentation

Produced by

U.S. Army Corps of Engineers
Walla Walla District

February 2002

FOREWORD

Appendix F was prepared by the U.S. Army Corps of Engineers (Corps), Walla Walla District. This appendix is one part of the overall effort of the Corps to prepare the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement (FR/EIS).

The Corps has reached out to regional stakeholders (Federal agencies, tribes, states, local governmental entities, organizations, and individuals) during the development of the FR/EIS and appendices. This effort resulted in many of these regional stakeholders providing input and comments, and even drafting work products or portions of these documents. This regional input provided the Corps with an insight and perspective not found in previous processes. A great deal of this information was subsequently included in the FR/EIS and appendices; therefore, not all of the opinions and/or findings herein may reflect the official policy or position of the Corps.

CONTENTS

CONTENTS

TABLES

PLATES

CHARTS

Executive Summary

Approximately 76.5 to 114.7 million cubic meters (100 to 150 million cubic yards) of sediment have been deposited upstream of the four lower Snake River dams since Ice Harbor Dam became operational in the early 1960s. Sediment totaling 0.76 million cubic meters (1 million cubic yards) will cover a section of land (2.59 square kilometers or 1 square mile) to a depth of approximately one-third meter (1 foot). Implementation of Alternative 1 (Existing System), Alternative 2 (Maximum Transport of Juvenile Salmon), or Alternative 3 (Major System Improvements) would have similar long-term results with respect to sedimentation, with Lower Granite Reservoirs continuing to trap the majority of inflowing sediments from the Snake and Clearwater rivers. However, if Alternative 4 (Dam Breaching) is implemented and the four lower Snake River dams are breached, approximately 50 percent (one-half) of the previously deposited materials will be eroded and transported by the Snake River within the first few years following dam breaching. The eroded materials will most likely be redeposited in Lake Wallula between the Snake River and Wallula Gap. Because the McNary Dam backwater pool extends upstream to Ice Harbor Dam, the very coarsest cobble materials could start depositing in the vicinity of Ice Harbor Dam. However, they could later be subject to resuspension and further transport downstream to Lake Wallula by floods that exceed the flows experienced at the time of their original deposition. The coarsest sediments would be deposited first, with the sediment deposits becoming progressively finer as they are transported farther downstream into Lake Wallula. Since these materials could previously be deposited behind the lower Snake River dams, and since flow velocities in Lake Wallula are generally lower than Snake River velocities, most of these sediments probably would be deposited in Lake Wallula rather than being transported downstream of McNary Dam. The remainder of the sediments previously deposited upstream of the lower Snake River dams and not eroded within the first few years of dam breaching would be subject to long-term erosion by wind and precipitation and could eventually also be transported downstream to Lake Wallula by the Snake River.

Between its confluence with the Snake River and Wallula Gap, the Columbia River covers an area approximately 16.1 kilometers (10 miles) long and 3,048 meters (10,000 feet) wide. Based on qualitative information, it appears quite likely that sediments larger than approximately 0.02 millimeter in diameter would deposit within this reach, while those smaller than 0.02 millimeter in diameter would likely pass downstream through the McNary Dam and likely continue to be transported as suspended sediment load downstream to the Columbia River estuary near the Pacific Ocean. The McNary Dam would likely capture all inflowing bed load materials.

The left (east) bank of the Columbia River, between its confluence with the Snake River downstream and its confluence with the Walla Walla River, appears to be susceptible to sediment deposition, based on qualitative analyses. Actual sedimentation patterns and depths are extremely difficult to predict in advance due to the numerous variable factors involved. Future proactive measures to protect water intakes from sedimentation effects might be required along this reach, although site-specific details are extremely difficult to predict in advance.

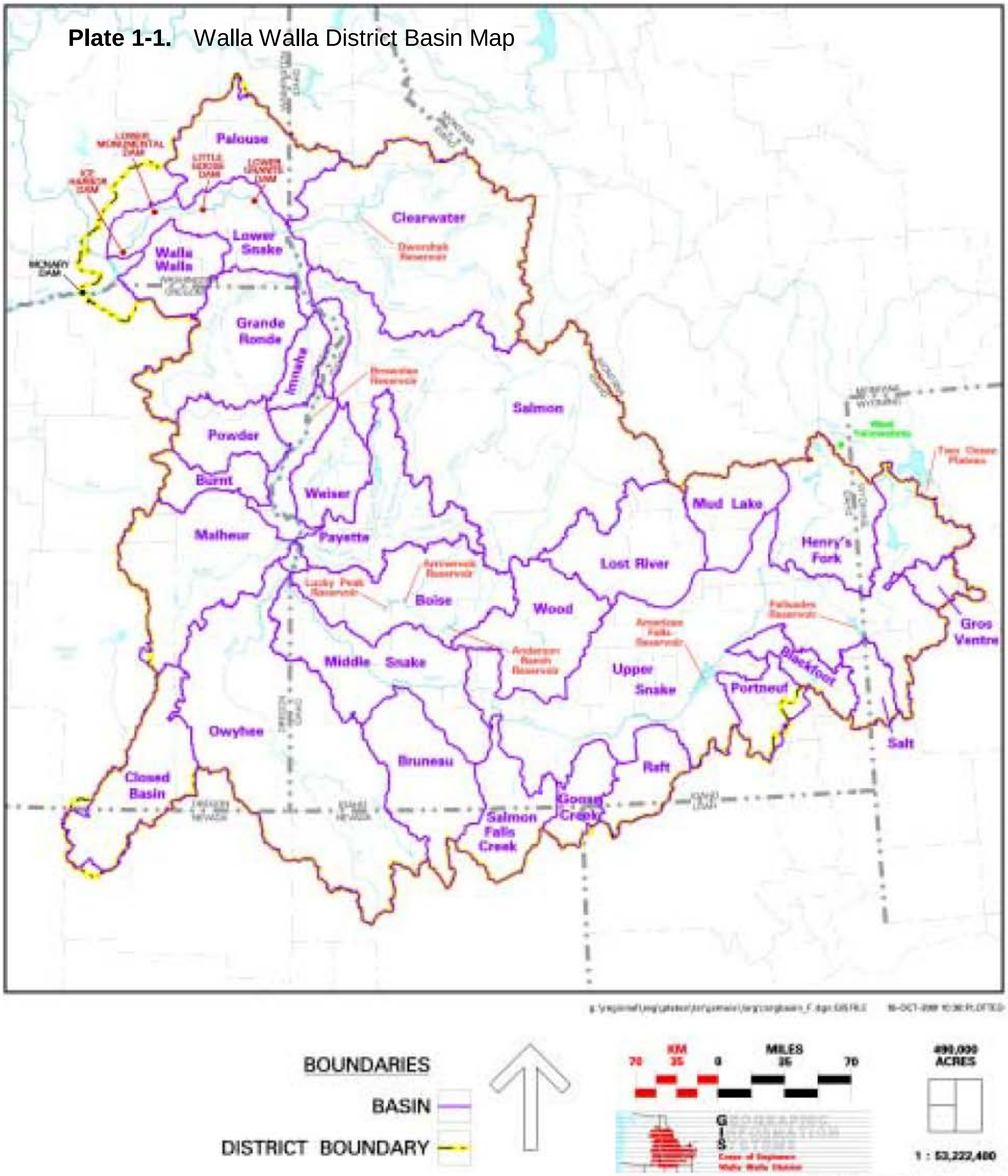
The lower Snake River downstream of Lewiston, Idaho, annually transports approximately 2.3 to 3.1 million cubic meters (3 to 4 million cubic yards) of new sediments that have been eroded from its drainage basin. If the four lower Snake River dams are breached, this material would be transported by the Snake River downstream to the Columbia River. Since the lower Snake River

dams would no longer be available to capture sediments inflowing annually, all but the finest suspended sediments carried by the Snake River would likely deposit within Lake Wallula. The very fine sediments that do not deposit in Lake Wallula would continue to be transported downstream of McNary Dam with their ultimate destination likely being the Columbia River estuary or the Pacific Ocean. If the four Lower Snake River dams are removed, the estimated cost for a sedimentation monitoring program designed to evaluate erosion and sediment transport during the first 10 years after dam breaching is estimated to be $2,158,680. Plates, tables, and charts presenting information related to lower Snake River facility storage curves, system flood control transfers, water travel times, and refill times are presented in this report.

1. Snake River Basin Description

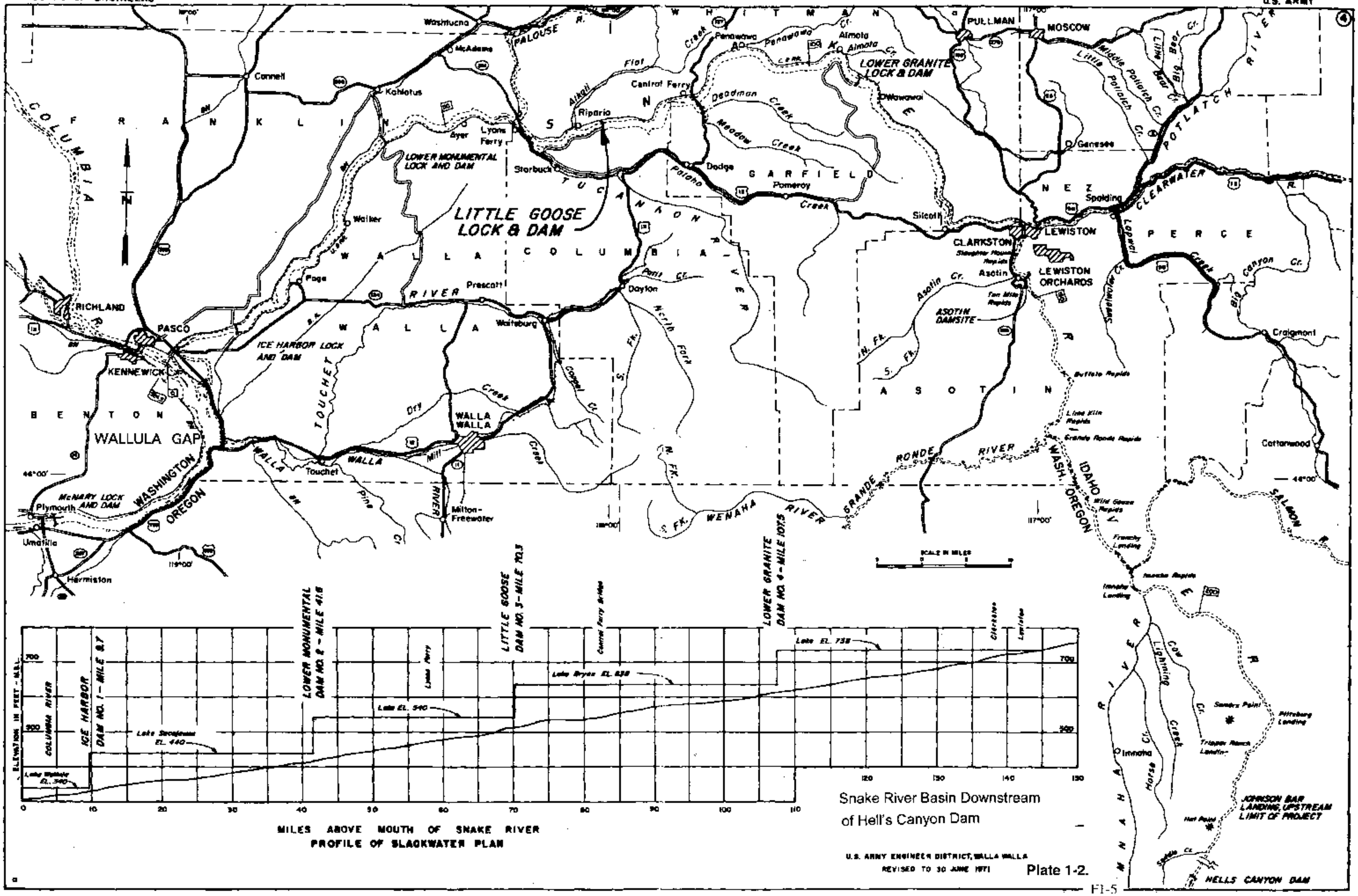
The Snake River Basin has a total drainage area of approximately 281,533 square kilometers (108,700 square miles) upstream of its confluence with the Columbia River near Pasco, Washington. Approximately 5 percent of the Snake River's total drainage area is located downstream of its confluence with the Clearwater River at Lewiston, Idaho, and this region is relatively arid compared to the Snake River's upstream drainage areas. Therefore, only a relatively small amount of runoff occurs along the lower Snake River downstream of the Clearwater River confluence. Runoff is contributed primarily from the Tucannon and Palouse Rivers, which both empty into the Snake River between Lower Monumental Dam and Little Goose Dam. Most of Idaho and lesser amounts of Oregon, Washington, Wyoming, Nevada, and Utah are within the Snake River Basin. The greatest overall dimensions of the basin are approximately 724 kilometers (450 miles) in both the north-south and east-west directions, measured as a straight line distance. Plate 1-1 is a map of the entire Snake River Basin and may be referenced for locations cited in this report. Plate 1-2 is a more detailed map of the lower Snake River Basin downstream of Hells Canyon Dam, and also illustrates portions of the Columbia River Basin upstream of McNary Dam. Table 1-1 is a listing of drainage areas at selected locations within the Snake River Basin as well as United States Geological Survey (USGS) gaging stations at selected sites within the basin downstream of Hells Canyon Dam.

Plate 1-1. Walla Walla District Basin Map



LOWER SNAKE RIVER
Juvenile Salmon Migration Feasibility Study

Plate 1–1.
WALLA WALLA DISTRICT BASIN MAP



Snake River Basin Downstream of Hell's Canyon Dam

U.S. ARMY ENGINEER DISTRICT, WALLA WALLA
REVISED TO 30 JUNE 1971

Plate 1-2.

Table 1-1. Snake River Basin Drainage Area and Stream Gage Summary

Location	USGS Station Number	Drainage Area (square kilometer/square mile)
Snake River at Hells Canyon Dam	13290450	189,847/73,300
Imnaha River at Imnaha, Oregon	13292000	1,611/622
Imnaha River at Snake River	none	1,813/700 (estimated)
Salmon River at Whitebird, Idaho	13317000	35,094/13,550
Salmon River at Snake River	none	36,519/14,100 (estimated)
Grande Ronde River at Troy, Oregon	13333000	8,482/3,275
Grande Ronde River at Snake River	none	10,541/4,070 (estimated)
Snake River near Anatone, Washington	13334300	240,766/92,960
Snake River at Clearwater River	none	242,165/93,500 (estimated)
North Fork Clearwater River at Dworshak Dam	none	6,320/2,440
Clearwater River at Spalding, Idaho	13342500	24,216/9,350
Clearwater River at Snake River	none	24,968/9,640 (estimated)
Snake River at Lower Granite Dam	none	267,288/103,200 (estimated)
Tucannon River near Starbuck, WA	13344500	1,116/431
Tucannon River at Snake River	none	1,424/550 (estimated)
Palouse River at Hooper, Washington	13351000	6,475/2,500
Palouse River at Snake River	none	6,734/2,600 (estimated)
Snake River at Columbia River	none	281,533/108,700 (estimated)
Columbia River below Priest Rapids Dam	12472800	248,640/96,000
Yakima River at Kiona, Washington	12510500	14,543/5,615
Yakima River at Columbia River	none	15,022/5,800 (estimated)
Columbia River at Snake River	none	266,770/103,000 (estimated)
Walla Walla River near Touchet, WA	14018500	4,292/1,657
Walla Walla River at Columbia River	none	4,662/1,800 (estimated)
Columbia River at McNary Dam	14019200	554,260/214,000

Notes:
1. USGS is acronym for United States Geological Survey
2. One square mile equals 2.590 square kilometers

2. Columbia River Basin Description

The Columbia River has a total drainage area of approximately 554,260 square kilometers (214,000 square miles) measured at McNary Dam, which is located at Columbia River kilometer 469.8 (river mile 292), and which is located approximately 51.5 river kilometers (32 river miles) downstream of the Columbia River's confluence with the Snake River. Plate 1-2 shows the location of McNary Dam. The Columbia River's drainage area upstream of the Snake River confluence is approximately 266,770 square kilometers (103,000 square miles). Thus at the confluence of the Snake and Columbia rivers, both rivers have approximately the same drainage area, with the Snake River drainage area being slightly larger than the Columbia River drainage area at this location.

3. Snake River Stream Description

The Snake River is 1,734 kilometers (1,078 miles) long and is the largest tributary of the Columbia River. It originates high in the Yellowstone National Park area of western Wyoming and traverses the southern part of Idaho in a broad arc running from east to west. It then flows almost due north, forming part of the boundary between Idaho, Oregon, and Washington. Near Lewiston, Idaho, it turns abruptly to the west and joins the Columbia River near Pasco, Washington. Total fall of the Snake River from its source near Two Ocean Plateau, Wyoming, to its confluence with the Columbia River is approximately 2,896 meters (9,500 feet), with an average slope of approximately 1.7 meters per kilometer (8.8 feet per mile) over its entire length. Between Lewiston and Pasco, the lower Snake River falls approximately 122 meters (400 feet) vertically in a distance of approximately 225 kilometers (140 miles), with an average slope of approximately 0.54 meters per kilometer (3 feet per mile) along this reach.

4. Existing Snake River Basin Water Resources Projects

The numerous artificial reservoirs and partially controlled lakes in the Snake River Basin have a substantial effect on the flow characteristics of the lower Snake River. Total usable storage in these upstream lakes and reservoirs is approximately 1,184,185 hectare-meters (9,600,000 acre-feet). Dworshak Reservoir has the greatest usable storage capacity with approximately 246,705 hectare-meters (2,000,000 acre-feet). It is followed with respect to usable capacity by American Falls Reservoir with approximately 209,699 hectare-meters (1,700,000 acre-feet), Palisades Reservoir with approximately 148,270 hectare-meters (1,202,000 acre-feet), Brownlee Reservoir with approximately 120,886 hectare-meters (980,000 acre-feet), and the Boise River Reservoir system with approximately 120,145 hectare-meters (974,000 acre-feet) combined storage within the Lucky Peak, Arrowrock, and Anderson Ranch Reservoirs.

5. Snake River Basin Geography and Geology

Several complex systems of mountain ranges, with intervening valleys and plains, lie within the Snake River Basin. Much of the southern part of the basin is included within the Columbia Plateau Province, a semiarid expanse formed by successive flows of basaltic lava. To the north of this plateau is a rugged area of mountain ridges and troughs, with deeply incised stream channels. This mountainous area is included within the Northern Rocky Mountain Province. Overall extremes of elevation are 4,196 meters (13,766 feet) above National Geodetic Vertical Datum 1929 (NGVD29) at Grand Teton Mountain in Wyoming to approximately 91.4 meters (300 feet) above NGVD29 at the Snake River's confluence with the Columbia River. The basin mean elevation is approximately 1,585 meters (5,200 feet) above NGVD29. Fenneman (1931) as well as other geography and geology texts should be consulted for a more in-depth discussion of the Snake River Basin's geography and geology.

The Snake River flows across a major physiographic region of the Pacific Northwest known as the Snake River Plateau and along the southern portion of the Columbia Plateau. The Snake River Plateau extends from southwestern Oregon across southern Idaho and includes parts of Nevada and Utah. The Columbia Plateau extends south from the upper curve of the Columbia River to the Blue Mountains, west to the Cascades, and east above the Snake River, just east of the Washington-Idaho state line. These two regions are comprised mainly of lava flows covered with soil. In areas where the Snake River has cut canyons, the dark basalt rock is a primary surface feature. Many of the soils of the Snake River Plateau are light and highly erodible with low rainfall limiting the ability of vegetative cover to reestablish once removed. This results in heavy sediment loads in the river, especially during the spring runoff season.

6. Snake River Basin Climate

Generally, the climate of the Snake River Basin is transitional between the maritime regimen west of the Cascade Mountain Range and the continental type climate of the northern Great Plains. Both maritime and continental air masses affect the basin, but since it is located in the zone of prevailing westerly flow, the maritime air masses predominate. The Rocky Mountains, located to the north and east, provide some protection against outbreaks of cold arctic air from Canada, but such incursions do occur occasionally in the winter season, particularly over the eastern part of the Snake River Basin. Because of the irregular topography and large differences in elevation and exposure, there are pronounced differences of local climates within the basin.

7. Snake River Basin Air Temperatures

Air temperatures within the Snake River Basin are controlled by elevation and distance from the Pacific Ocean, as well as by individual air masses and the season of the year. An important aspect of basin temperature to the regulation of water resources projects lies in the effect of temperature and solar radiation on snowmelt. The shape, timing, and peak discharge of the spring snowmelt runoff of the lower Snake River are determined to a considerable degree by the sequence of spring season basin temperatures. In addition, temperatures in the region have a pronounced effect on electric power demand and therefore on generation at hydroelectric projects that serve the area.

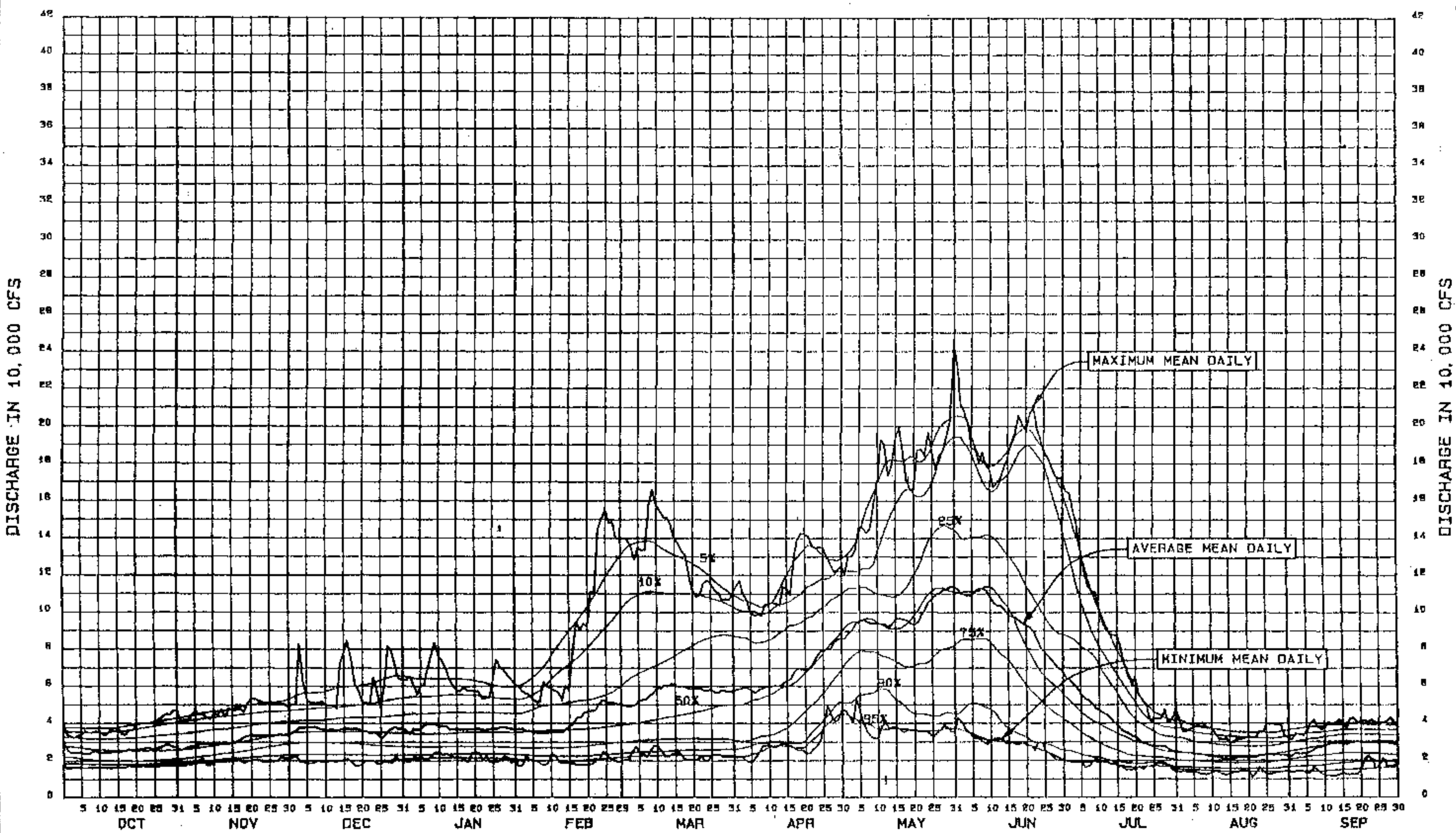
Normal summer maximum temperatures for most climatological stations are between 26.7 and 32.2 degrees Celsius (C) (80 and 90 degrees Fahrenheit [F]), and normal winter minimums are between -17.8 and -6.7 degrees C (0 and 20 degrees F). Extreme recorded temperatures are -54.4 degrees C (-66 degrees F) at West Yellowstone, Montana, which is located immediately outside the upper Snake River Basin boundary, and 47.8 degrees C (118 degrees F) at Ice Harbor Dam, Washington, and at Orofino, Idaho. Average frost-free periods in agricultural areas vary with location from about 50 to 200 days, and some small high elevation areas experience frost in every month of the year.

8. Snake River Basin Precipitation

The normal annual precipitation over the Snake River Basin ranges from less than 203 millimeters (8 inches) in the vicinity of Ice Harbor Dam and in portions of the plains of southern Idaho to an estimated maximum of 1,778 millimeters (70 inches) in the Bitterroot Mountains. The normal annual precipitation averaged over the entire basin is estimated to be approximately 508 millimeters (20 inches). Much of the winter precipitation is in the form of snow, a factor of great hydrologic importance. Snow course data are used for forecasting runoff volumes from major basins within the Snake River Basin.

9. Snake River Discharge Characteristics

Plate 9-1 presents the Snake River Summary Hydrographs for inflows into Lower Granite Lake. Plate 9-2 presents the Annual Peak Discharge Frequency Curves for the Snake River at Lower Granite Dam. Inflows into the Snake River between the Clearwater River and the Columbia River are minor when compared to the total Snake River discharge at Lower Granite Lake. Therefore, these summary hydrographs and peak discharge frequency curves may also be considered to be representative of the entire lower Snake River between the Clearwater and Columbia rivers.



NOTES:

1. SUMMARY HYDROGRAPHS PLOTTED FROM CORPS OF ENGINEERS MEAN DAILY INFLOW DATA FOR LOWER GRANITE DAM.
2. PERIOD OF RECORD IS OCT. 1975 THROUGH SEP. 1991
3. DRAINAGE AREA IS 103500 SQUARE MILES.
4. EXCEEDENCE LINES REPRESENT THE PERCENTAGE OF TIME THE FLOW IS EQUALLED OR EXCEEDED ON THAT PARTICULAR DAY.

SNAKE RIVER, WA

LOWER GRANITE INFLOW

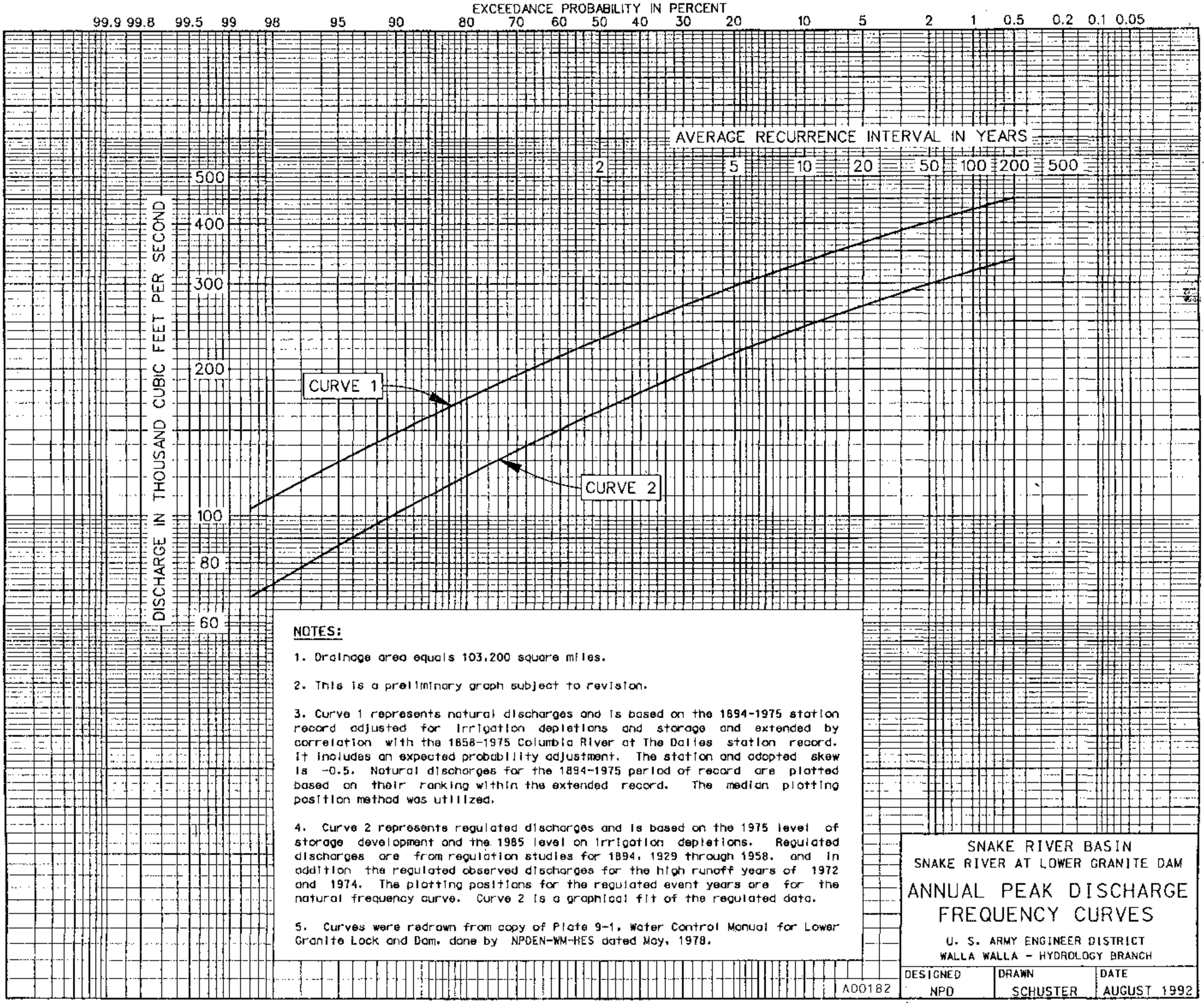
SUMMARY HYDROGRAPHS

U.S. ARMY ENGINEER DISTRICT

WALLA WALLA - HYDROLOGY BRANCH

MAXSON AUGUST 1992

Plate 9-1.



NOTES:

1. Drainage area equals 103,200 square miles.

2. This is a preliminary graph subject to revision.

3. Curve 1 represents natural discharges and is based on the 1894-1975 station record adjusted for irrigation depletions and storage and extended by correlation with the 1858-1975 Columbia River at The Dalles station record. It includes an expected probability adjustment. The station and adopted skew is -0.5. Natural discharges for the 1894-1975 period of record are plotted based on their ranking within the extended record. The median plotting position method was utilized.

4. Curve 2 represents regulated discharges and is based on the 1975 level of storage development and the 1985 level on irrigation depletions. Regulated discharges are from regulation studies for 1894, 1929 through 1958, and in addition the regulated observed discharges for the high runoff years of 1972 and 1974. The plotting positions for the regulated event years are for the natural frequency curve. Curve 2 is a graphical fit of the regulated data.

5. Curves were redrawn from copy of Plate 9-1, Water Control Manual for Lower Granite Lock and Dam, done by NPDEN-WM-HES dated May, 1978.

SNAKE RIVER BASIN
SNAKE RIVER AT LOWER GRANITE DAM

ANNUAL PEAK DISCHARGE FREQUENCY CURVES

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
NPD	SCHUSTER	AUGUST 1992

Plate 9-2.

10. Discussion of Low, Average, and High Flow Years (1994, 1995, 1997, Respectively)

Three flow years experienced during the 1990s may be assumed to generally represent a low flow year, an average flow year, and a high flow year. The year 1994 generally represents a lower than average flow year, 1995 generally represents an average flow year, and 1997 generally represents a higher than average flow year. The following runoff information was obtained from USGS water supply papers (WSP) for the respective time periods. The Clearwater River stream flow information was gathered at the USGS Clearwater River at Spalding gage (USGS number 13342500), and the Snake River stream flow information was gathered at the USGS Snake River near Anatone gage (USGS number 13334300). All USGS discharges are given as mean daily values and are not instantaneous discharges. The average mean daily flow for the Clearwater River at Spalding from March 1 through December 31 is 448 cubic meters (m^3/second) (15,820 cubic feet per second [cfs]), based on 1972 to 1998 data that reflected regulation by Dworshak Reservoir. The maximum unregulated discharge for the Clearwater River is 5,013 m^3/second (177,000 cfs), which occurred on May 29, 1948. The minimum unregulated discharge for the Clearwater River is 14 m^3/second (500 cfs), which occurred on January 9, 1937, and on December 1, 1952. The maximum regulated discharge for the Clearwater River is 3,710 m^3/second (131,000 cfs), which occurred on June 16, 1974. The minimum regulated discharge for the Clearwater River is 38 m^3/second (1,350 cfs), which occurred on October 31, 1971. The average mean daily flow for the Snake River for the period of March 1 through December 31 is 1,044 m^3/second (36,860 cfs) based on 1958 to 1998 data. The maximum period of record discharge for the Snake River at Anatone is 5,522 m^3/second (195,000 cfs), which occurred on June 18, 1974. The minimum Snake River discharge is 170 m^3/second (6,010 cfs), which occurred on September 2, 1958. Thus it can be seen that the annual maximum and annual minimum discharge on both the Snake and Clearwater rivers is generally experienced during the fish passage period from March 1 through December 31.

10.1 Low Flow Year Description (1994)

From March 1 through December 31, 1994, the total runoff volume for the Clearwater River was approximately 829,853 hectare-meters (6,724,900 acre-feet). This equates to an average discharge of approximately 314 m^3/second (11,080 cfs) over this 306-day period, which is 134 m^3/second (4,740 cfs) lower than the long-term average for this period. The peak discharge for the Clearwater River during this period was 1,150 m^3/second (40,600 cfs) on May 16. The minimum discharge for the Clearwater River during this period was 66 m^3/second (2,330 cfs) on September 29.

During this same period in 1994, the total runoff volume for the Snake River was approximately 1,575,423 hectare-meters (12,766,800 acre-feet). This equates to an average discharge of approximately 596 m^3/second (21,030 cfs) over this 306-day period, which is 448 m^3/second (15,830 cfs) lower than the long-term average for this period. The peak discharge for the Snake River during this period was 1,821 m^3/second (64,300 cfs) on May 11. The minimum discharge for the Snake River during this period was 274 m^3/second (9,660 cfs) on August 9.

10.2 Average Flow Year Description (1995)

From March 1 through December 31, 1995, the total runoff volume for the Clearwater River was approximately 1,400,763 hectare-meters (11,351,400 acre-feet). This equates to an average discharge of approximately 530 m^3/second (18,700 cfs) over this 306-day period, which is 82 m^3/second (2,880 cfs) greater than the long-term average for this period. The peak discharge for the Clearwater River during this period was 2,104 m^3/second (74,300 cfs) on December 1. The minimum discharge for the Clearwater River during this period was 122 m^3/second (4,300 cfs) on November 5. The fact that both the minimum and maximum mean daily flows for 1995 occurred within one month of each other illustrates the potential short-term variability of discharge within this basin.

This occurrence appears to be related to climatic circumstances, because the Clearwater River at the Spalding gage site rose in mean daily discharge from 586 m^3/second (20,700 cfs) on November 22 to a peak of 2,104 m^3/second (74,300 cfs) on December 1, then dropped to 453 m^3/second (16,000 cfs) on December 10. Concurrently, the South Fork of the Clearwater River at the Stites, Idaho, gage site (USGS number 13338500) was noted to rise in mean daily discharge from 16 m^3/second (559 cfs) on November 22 to a peak of 114 m^3/second (4,040 cfs) on December 1. The gage then dropped to 35 m^3/second (1,250 cfs) on December 10. Also concurrently, the Clearwater River at the Orofino, Idaho, gage site (USGS number 13340000) rose in mean daily discharge from 269 m^3/second (9,490 cfs) on November 22 to a peak of 2,073 m^3/second (73,200 cfs) on December 1. It then dropped to 394 m^3/second (13,900 cfs) on December 10. The North Fork of the Clearwater River's inflow to Dworshak Reservoir was measured at the Canyon Ranger Station, Idaho, gage site (USGS number 13340600). It rose in mean daily discharge from 126 m^3/second (4,460 cfs) on November 22 to a peak of 969 m^3/second (34,200 cfs) on December 1, then dropped to 189 m^3/second (6,680 cfs) on December 10.

During this same period, the total runoff volume for the Snake River was approximately 3,103,757 hectare-meters (25,152,000 acre-feet). This equates to an average discharge over this 306 day period of approximately 1,173 m^3/second (41,420 cfs), which is 129 m^3/second (4,560 cfs) greater than the long-term average for this period. The peak discharge for the Snake River during this period was 3,342 m^3/second (118,000 cfs) on June 5. The minimum discharge for the Snake River during this period was 422 m^3/second (14,900 cfs) on November 5. This serves to illustrate that maximum and minimum discharges on both the Snake and Clearwater rivers may, but not necessarily always, fall during the same time frame, since during 1995 the Snake River peak discharge occurred in early June and the Clearwater River peak discharge occurred in early December.

10.3 High Flow Year Description (1997)

From March 1 through December 31, 1997, the total runoff volume for the Clearwater River was approximately 1,886,107 hectare-meters (15,284,500 acre-feet). This equates to an average discharge of approximately 713 m^3/second (25,180 cfs) over this 306-day period, which is 265 m^3/second (9,360 cfs) greater than the long-term average for this period. The peak discharge for the Clearwater River during this period was 2,305 m^3/second (81,400 cfs) on May 17. The minimum discharge for the Clearwater during this period was 98 m^3/second (3,460 cfs) on September 10.

During this same period, the total runoff volume for the Snake River was approximately 4,230,152 hectare-meters (34,280,000 acre-feet). This equates to an average discharge of approximately 1,600 m^3/second (56,480 cfs) over this 306 day period, which is 556 m^3/second (19,620 cfs) greater than the long-term average for this period. The peak discharge for the Snake River during this period was 4,305 m^3/second (152,000 cfs) on May 11. The minimum discharge for the Snake River during this period was 487 m^3/second (17,200 cfs) on December 6.

11. Early Snake and Columbia River Basin Explorations That Describe Pre-Project Basin Conditions

Among the earliest scientific explorations in eastern Washington for which results have been published were those of Lieutenant Thomas W. Symons, who explored the Columbia River from the Colville Valley downstream to Ainsworth, located near the mouth of the Snake River. His exploration was made in the fall of 1881. His work is documented in "Report of an Examination of the Upper Columbia River and the Territory in its Vicinity," Forty Seventh Congress, 1st Session, Document No. 186, dated 1882 (Symons, 1882). Lieutenant Symons states on page 2 that his investigations were made "to determine its navigability and the advisability of putting steamships on it." His work also describes lands and explorations that were previously made and documented by Governor I.I. Stevens in his Pacific Railroad reports. In addition, Lieutenant Symons includes observations in his report made by Captain George B. McClellan in 1853 that were in turn documented by Governor Stevens in his railroad reports. Lieutenant Symons describes (p. 50) the Ainsworth area at the mouth of the Snake River as "a bleak, dreary waste in which for many miles around sage brush and sand predominate. Ainsworth is one of the most uncomfortable, abominable places in America to live in. You scan the horizon in vain for a tree or anything resembling one. The heat through the summer is excessive and high winds prevail and blow the sands about and into everything. By the glare of the sun and the flying sands one's eyes are in a continual state of winking, blinking, and torment."

Professor Israel C. Russell accomplished the most extensive and important early investigations of the Columbia Plains. The publications "Geologic Reconnaissance in Central Washington," USGS Bulletin No. 108 (1893) (USGS, 1893); "Reconnaissance in Southeastern Washington," USGS Water Supply and Irrigation Paper No. 4, (1897) (USGS, 1897) and "Geology and Water Resources of Nez Perce County, Idaho, Parts I and II," USGS Water Supply and Irrigation Papers No. 53 and No. 54 (USGS, 1901a; USGS, 1901b) document his investigations. These three expeditions were all conducted "for the purpose of ascertaining how far the geological structure of the arid portions of central Washington and Idaho favored the hope of obtaining artesian water for irrigation." Plate 11-1 is a picture of the Snake River canyon upstream of Lewiston, Idaho, taken by Professor Russell. Plate 11-2 is a picture of the Yakima River canyon south of Ellensburg, also taken by Professor Russell.

In the fall of 1902, Frank C. Calkins made an examination of the water resources of a portion of east-central Washington. The area he investigated extended from Ritzville west to Yakima, and from Pasco north to Ephrata. He described the climate at that time as being "arid" and a large portion of the district investigated was "without surface streams available for the uses of mankind" (USGS, 1905, p. 11). He also stated that "surface wells capable of supplying perennially even modest requirements of domestic use can be sunk only in places where conditions are locally favorable" (USGS, 1905, p. 11).

Canyon of Snake River, Looking North, Approximately 20 miles
South of Lewiston, Idaho

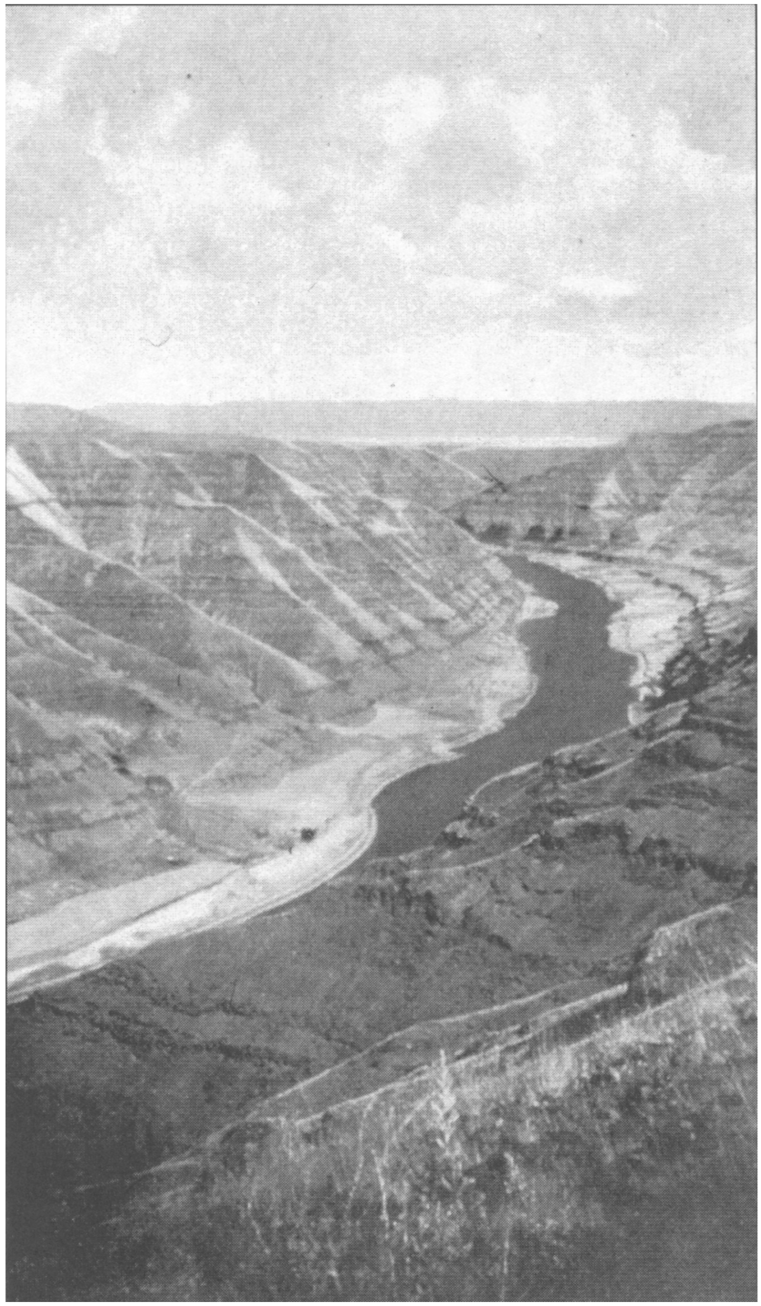


Photo Source: Plate XIII of U.S. Geological Survey Professional Paper 27, by Waldemar Lindgren, 1904, Photo by I.C. Russell.

Plate 11-1. Snake River Upstream of Lewiston, Idaho

Yakima River Canyon, Looking Northwest

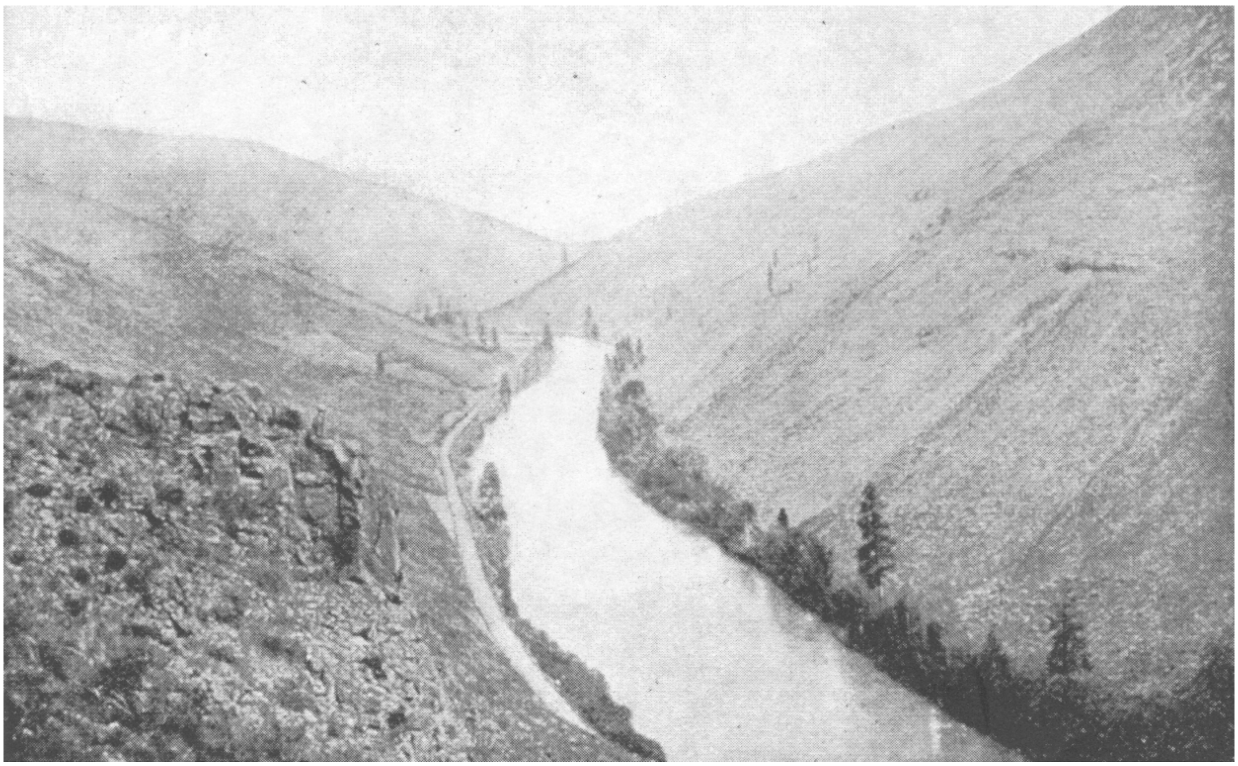


Photo Source: Plate VII of U.S. Geological Survey Bulletin 108, Photo by I.C. Russell.

Plate 11-2. Yakima River Canyon South of Ellensburg, Washington

In 1909, the USGS and the State Board of Health of Washington began a "cooperative study of the quality of the surface waters of the State of Washington, including their seasonal variation in composition and in physical characteristics, and the pollution to which they are subject" (USGS, 1914). Prior to this time, no systematic study of the quality of the surface waters of Washington had been made, although miscellaneous analyses of water from a few lakes and rivers had been published in periodicals or in special reports to municipalities. Analyses of serial samples of water from the Salmon and Palouse rivers were made by the U.S. Reclamation Service in 1905 (USGS, 1914). Samples of water were collected from the Snake River at the Northern Pacific Railway bridge near Burbank, Washington, from March 13, 1910, through January 31, 1911. The quality of the water was subject to considerable variation according to discharge. In Water Supply Paper 339 (USGS, 1914), pages 73-74, it is noted that "the water of the Snake River at Burbank is usually turbid and should be clarified before being used for drinking or manufacturing."

12. Pre-Project Water Temperatures

Prior to the construction of the four lower Snake River facilities, only sporadic water temperature information was gathered on the lower Snake River. Periodic water temperature data was collected on the Snake River near Clarkston, downstream of the Clearwater River at Clarkston, upstream of the Clearwater River confluence, and near Anatone. During Water Years 1952-1956, daily water temperatures were recorded on both the Snake River near Clarkston, at a location downstream of the Snake-Clearwater confluence during Water Years 1952-1955 and at a location near Central Ferry for Water Year 1956, and on the Columbia River at Maryhill Ferry near Rufus, Oregon. This information is recorded in USGS 1957, 1958, 1959a, 1959b, and 1960. In Water Year 1969, four temperature values were published for the Snake River upstream of the Clearwater and ranged from 4 degrees C (39.2 degrees F) on February 24, 1969; to 22 degrees C (71.6 degrees F) on August 10, 1969 (USGS, 1969). From October 1970 through September 1972, eleven temperature values were published, ranging from 1.8 degrees C (35.2 degrees F) on January 13, 1972; to 21.0 degrees C (69.8 degrees F) on August 31, 1971 (USGS, 1972). During Water Years 1958 through 1976, daily water temperatures were recorded for the Columbia River at the Dalles (USGS Station Number 14105700) and were obtained electronically from the Portland office of the USGS. Table 12-1 summarizes the Columbia River water temperature information gathered from Water Years 1958 through 1976, as well as that data gathered on the Snake and Columbia Rivers for Water Years 1952-1956. USGS, 1964a; USGS, 1968; and USGS, 1996, also present water temperature information gathered on the Snake and Columbia rivers and may be consulted for a more in-depth presentation and discussion of water temperatures, under both pre-project and post-project conditions.

Table 12-1. Snake and Columbia River Water Temperatures

Temperature	Snake River		Columbia River		Columbia River	
Range (Deg F)	# of Obs	% of Total	# of Obs	% of Total	# of Obs	% of Total
	(YRS 1952-1956)		(YRS 1952-1956)		(YRS 1958-1976)	
32.00 – 35.00	76	4.16	40	2.19	27	0.50
35.01 – 40.00	331	18.12	194	10.62	452	8.35
40.01 – 45.00	234	12.81	295	16.15	1144	21.13
45.01 – 50.00	240	13.13	244	13.35	841	15.53
50.01 – 55.00	247	13.52	257	14.07	571	10.54
55.01 – 60.00	245	13.41	273	14.94	748	13.81
60.01 – 65.00	150	8.21	260	14.23	846	15.62
65.01 – 70.00	204	11.16	205	11.22	698	12.89
70.01 – 75.00	83	4.54	49	2.68	68	1.26
75.01 – 80.00	17	0.93	10	0.55	18	0.33
80.01 – 85.00	0	0.00	0	0.00	2	0.04
85.01 – 90.00	0	0.00	0	0.00	0	0.00
Totals:	**1827**	**100.00**	**1827**	**100.00**	**5415**	**100.00**

Notes:

1. Source of Snake and Columbia river temperature data for Water Year 1952 was United States Geological Survey (USGS) Water Supply Paper (WSP) 1253. For Water Year 1953 data source was USGS WSP 1293. For Water Year 1954 data source was USGS WSP 1353. For Water Year 1955 data source was USGS WSP 1403. For Water Year 1956 data source was WSP 1453. Data used were for USGS gaging station names “Snake River near Clarkston, Washington;” and “Columbia River at Mary Hill Ferry near Rufus, Oregon.”
2. Source of Columbia River temperature data for Water Years 1958-1976 was digital data provided by USGS Water Resources Division office in Portland, Oregon. Data used were for USGS gaging station named “Columbia River at The Dalles, Oregon;” USGS Station Number 14105700.
3. All missing pieces of data in the original data sets were developed through linear interpolation between known data points contained in the respective data sets.
4. To convert temperatures from degrees Fahrenheit to degrees Celsius, use this formula: Deg C = (Deg F – 32.0) x (5.0/9.0)

13. Pre-Project Natural Water Surface Level Fluctuations

Prior to the construction of the four lower Snake River facilities, water levels in the lower Snake River were uncontrolled and free to fluctuate as the river's discharge varied throughout the year. At the Riparia gaging site, located approximately at Snake River kilometer 107.8 (river mile 67), the difference between the highest and lowest known river stages is approximately 7.6 meters (25 feet), measured vertically. For the Snake River gaging site near Clarkston, this water surface elevation difference is greater than 9.1 meters (30 feet), measured vertically. Professor Israel Russell stated in 1897 that "when the snow is melting on the mountains of Idaho and Wyoming the Snake River rises from 6.1 to 9.1 meters (20 to 30 feet) above its summer stage, and becomes a wild, rushing flood of muddy water" (USGS, 1897, p. 20). Plate 13-1, a picture taken by Professor Russell, shows an irrigation water wheel on the Salmon River. By noting the height of gravel and cobble deposits on the river's banks, one can see from this picture the magnitude of the annual water level fluctuation on the Salmon River. Similar activity of differing magnitude can be expected on the lower Snake River. Thus the riparian zone in the vicinity of the Snake River subject to annual erosion effects due to natural water level fluctuations is on the order of 7.6 to 9.1 meters (25 to 30 feet), measured vertically. Depending on ground surface slopes at any given location, this may translate into much greater distances when measured along the ground surface at the location of interest.

Since 1897, reservoir projects (flood control and/or irrigation) constructed on the river system above the four Lower Snake River Projects have significantly reduced flood peaks on the Snake River. The following tabulation summarizes flow peak data that were shown on the frequency curves (data period 1894 to 1975) on page F9-3.

Percent Chance Flood	Unregulated m3/second (cfs)	Regulated m3/second (cfs)
50	6,542 (231,000)	4,616 (163,000)
10	9,458 (334,000)	6,910 (244,000)
2	11,412 (403,000)	8,496 (300,000)
1	12,064 (426,000)	9,034 (319,000)

The HEC-2 computer program was used to evaluate general water surface profile differences between the unregulated and regulated flood peaks on the lower Snake River if the Lower Snake River Projects were to be breached. For the 50 percent chance peak, there is an approximate water surface profile reduction difference of 1.52 meters (5 feet) between the 231,000 cfs unregulated peak and the 163,000 cfs regulated peak. For the 1 percent chance peak, there is an approximate water surface profile reduction difference of 2.44 meters (8 feet) between the 426,000 cfs unregulated peak and the 319,000 cfs regulated peak.

Irrigation Water Wheel, Salmon River

Photo Source: Plate V of U.S. Geological Survey Water Paper 4, Photo by I.C. Russell.

Plate 13-1. Irrigation Water Wheel on Salmon River

14. Generalized Description of Snake River Fish Passage

The adult anadromous fish passage period on the Snake River extends from approximately March 1 through December 31, and the juvenile anadromous fish passage period extends from approximately March 25 through December 15. Potential flow conditions expected during these fish passage periods may be obtained from Plate 9-1, which shows Snake River Summary Hydrographs for the inflow to Lower Granite Reservoir. As can be seen from Plate 9-1, both the annual peak discharge and the annual minimum discharge generally occur during the fish passage period, although exceptions may occur within any given year. Since inflows between Lower Granite and the Columbia River's confluence with the Snake River are relatively minor as compared to the Snake River's total discharge, the Summary Hydrographs shown on Plate 9-1 may also be assumed to apply for the entire Snake River reach downstream of its confluence with the Clearwater River at Lewiston, Idaho.

15. Effects of Turbidity on Fish

Turbidity and fine sediments have long been recognized as affecting aquatic life, with much research activity on a world-wide scale having been devoted to answering questions related to these effects. Both positive and negative effects have been noted, such as reduced predation due to turbidity and decreased fish production due to fine sediment deposition in salmon spawning and rearing areas. Numerous papers have been published on the relationship of turbidity, sediment, and aquatic life; a short, non-inclusive list of references with a brief discussion of each is given here for further study as desired.

"The Direct Effect of Turbidity on Fishes," by I. Eugene Wallen, in The Bulletin of Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma; Arts and Sciences Studies, Biological Series Number 2, Volume 48, January 1951. This publication describes a test of 380 fish within 16 species to determine the direct effect of montmorillonite clay turbidity on them. These tests indicated that observational behavioral reactions that appeared as a turbidity effect did not develop until concentrations of turbidity neared 20,000 parts per million (ppm). In one species, reactions did not appear until turbidities reached 100,000 ppm. It was also noted that most individuals of all species endured exposures to more than 100,000 ppm of turbidity for a week or longer, but the same fish died at turbidities of 175,000 to 225,000 ppm.

"Turbidity Reduces Predation on Migrating Juvenile Pacific Salmon," by Robert S. Gregory and Colin D. Levings, in Transactions of the American Fisheries Society 127:275-285, 1998. These two authors field-tested the hypothesis that predation by piscivorous fish is reduced in turbid as compared with clear water. Work was done on the Harrison River in Canada (turbidity normally less than 1 nephelometric turbidity unit) and the naturally turbid Fraser River in Canada (turbidity normally ranges from 27 to 108 nephelometric turbidity units).

"The Influence of Turbidity on Juvenile Marine Fishes in Estuaries, Field Studies at Lake St. Lucia on the Southeastern Coast of Africa," by D.P. Cyrus and S.J.M. Blaber, in Journal of Experimental Marine Biology, Volume 109, pages 53-70, 1987, Elsevier Science Publishers. This publication documents a 3.5-year long study, conducted during the early 1980s in Africa, to investigate the relationships between water turbidity and estuarine fish distribution.

"Summer and Winter Habitat Selection by Juvenile Chinook Salmon in a Highly Sedimented Idaho Stream," by T.W. Hillman and J.S. Griffith, in Transactions of the American Fisheries Society 116:185-195, 1987. These two authors assessed the Red River in Idaho, a stream heavily embedded with fine sediment. Their work was accomplished during 1985-1986.

"Recovery of Game Fish Populations Impacted by the May 18, 1980, Eruption of Mount Saint Helens," by Bruce A. Crawford, Fishery Management Report 85-98, Washington Department of Game, May 1986. This report addresses the effect of the eruption on the gamefish fisheries in the lakes in the Mount Saint Helens National Volcanic Monument and the adjacent lakes located within Cowlitz, Lewis, and Skamania counties. The data and observations were collected from May 1980 to May 1986.

"Effects of Mount Saint Helens Eruption on Salmon Populations and Habitat in the Toutle River," by Douglas J. Martin, Lawrence J. Wasserman, Robert P. Jones, and Ernest O. Salo, a Technical Completion Report for the U.S. Department of the Interior, Bureau of Reclamation, October 26, 1984, FRI-UW-8412. This report states that "high concentrations of suspended sediment caused many adult spawners to avoid the Toutle River in 1980 and 1981, and instead return to the Upper Cowlitz River and Kalama River. Adult salmon and steelhead that returned to the Toutle River were observed spawning in most tributaries formerly utilized before the eruption. Adult salmon spawned in unstable volcanic substrates with average concentrations of fine particles (less than 0.850 mm in diameter) ranging from 11.2 percent to 36.0 percent in 1981 and from 11.2 percent to 33.5 percent in 1982." The report also states that "sediment problems and channel instability on the debris avalanche are expected to diminish in 30 to 35 years" and that "smolt survival for the future is optimistic if suspended sediment levels are lower than 5,000 milligrams per liter (mg/l) during the spring outmigration period."

"Habitat Utilization by Juvenile Pacific Salmon if the Glacial Taku River, Southeast Alaska," by Michael L. Murphy, Jonathan Heifetz, John F. Thedinga, Scott W. Johnson, and K.V. Koski, in Canadian Journal of Fish and Aquatic Science, Volume 46, 1989. This study was conducted to determine patterns of habitat use by juvenile salmon in summer in the lower Taku River, a river which is turbid with glacial silt most of the year. The river flow is low (less than 100 m^3/second [3,531 cfs]) in winter and high (greater than 700 m^3/second [24,717 cfs]) during snowmelt in June. Turbidities were noted to range from 0 to 600 Jackson Turbidity Units.

"Effects of Chronic Turbidity on Density and Growth of Steelheads and Coho Salmon," by John W. Sigler, T.C. Bjornn, and Fred H Everest, in Transactions of the American Fisheries Society 113:142-150, 1984. This report states that "yearling and older salmonids can survive high concentrations of suspended sediment for considerable periods, and acute lethal effects generally occur only if concentrations exceed 20,000 mg/l, but little is known about the effects of turbidity on newly emerged young."

"Effects of Suspended Sediments on Aquatic Ecosystems," by C.P. Newcombe and D.D. MacDonald, in North American Journal of Fisheries Management 11:72-82, 1991. In the preparation of this report, more than 70 papers on the effects of inorganic suspended sediments on freshwater and marine fish and other organisms were reviewed to compile a database on such effects. This report states that "despite considerable research, there is little agreement on environmental effects of suspended sediment as a function of concentration and duration of exposure." The report also states that "regression analysis indicates that concentration alone is a relatively poor indicator of suspended sediment effects but the product of sediment concentration (in mg/l) and duration of exposure (in hours) is a better indicator of effects."

"Channel Suspended Sediment and Fisheries: A Synthesis for Quantitative Assessment of Risk and Impact," by Charles P. Newcombe and Jorger O.T. Jensen, in North American Journal of Fisheries Management 16:693-719, 1996. This report presents the results of a meta-analysis of 80 published reports on fish responses to suspended sediment in streams and gives six empirical equations that relate biological response to duration of exposure and suspended sediment concentration. The six equations address various taxonomic groups of lotic, lentic, and estuarine fishes, life stages of species within those groups, and particle sizes of suspended sediments.

All of the above references also include numerous other references within them, which should provide a comprehensive background of turbidity and sediment effects on fisheries.

16. Snake River Basin Sedimentation

The four lower Snake River facilities, as well as other dam and reservoir projects within the Snake River Basin, impound the majority of sediments transported into them by tributary streams. The major storage projects located immediately upstream of Lower Granite Dam are Dworshak Dam on the North Fork of the Clearwater River and Hells Canyon Dam on the main stem of the Snake River. At present, the Lower Granite facility impounds the majority of sediments that are contributed to the Snake River and Clearwater River from upstream portions of the Snake River Basin, which are not tributary to either the Dworshak or Hells Canyon facilities. This includes sediment inflows from the Lochsa River, the South Fork of the Clearwater River, and the Potlatch River, which are tributaries to the Clearwater River, and the Imnaha River, the Salmon River, and the Grande Ronde River, which are tributaries to the Snake River downstream of Hells Canyon Dam. Two major tributaries to the Snake River that enter the Snake River between Lower Granite Dam and the confluence of the Snake River with the Columbia River are the Tucannon River and the Palouse River, which are both tributaries to the Lower Monumental reservoir.

At present on the Columbia River, Priest Rapids Dam, which is the next upstream dam from the Snake-Columbia River confluence, as well as other upstream storage projects, impounds the majority of the sediments presently being transported. In addition to the Snake River, the Yakima River and the Walla Walla River are the two major tributaries to the McNary Dam reservoir (Lake Wallula).

Professor Russell presents an outline sketch of the geological history of Southeastern Washington on pages 88-92 of USGS, 1897. He discusses “reasons for believing that the canyon of the Snake River was excavated to its present depth before the time in the earth’s history known as the Glacial Epoch.” He states that “a great gravel terrace in the canyon of the Snake River and similar terraces in the canyons of the Columbia and Spokane Rivers show that after they were worn to their present depth they were filled to a height of 91.4 to 121.9 meters (300 to 400 feet).” He also states that “this filling is attributed to the overloading of the streams with debris furnished by glaciers and by swollen mountain streams. The cause of this change was climatic.” These observations illustrate the types and magnitudes of sedimentation activity potentially previously experienced along the Snake River over Geologic Time and provide a frame of reference for comparison to potential sedimentation effects that may occur if the lower Snake dams are breached.

17. Snake River Basin Soil Characteristics

Soil characteristics within the Snake River Basin vary considerably by geographic location, making it extremely difficult to apply site-specific information basin wide. For this reason, several of the Snake River's subbasins having published information available will be briefly discussed. Paul E. Packer states in his paper "Status of Research on Watershed Protection Requirements for Granitic Mountain Soils in Southwestern Idaho" (Renard et al., 1997), that "the mountain lands that constitute the upper drainage basins of the Boise, Payette, and Salmon Rivers in south-central Idaho have long presented a difficult watershed management problem." The soil in these basins is generally highly erodible, loose granitic soil, which is highly vulnerable to displacement by raindrop impact and to erosion by overland flow, particularly during high intensity rainstorms. F.G. Renner (1936), in his report "Conditions Influencing Erosion on the Boise Watershed," noted the following relationships:

- Erosion was found to vary directly with the degree to which the plant cover had been depleted and the soil surface disturbed.
- Erosion was found to vary directly with the steepness of slope, increasing up to about 35 percent gradient. On steeper slopes, other factors interfered with the evaluation of this relationship.

It is expected that these relationships may also apply to the Salmon River watershed.

In direct contrast to the coarse granitic soils of the Salmon, Payette, and Boise River basins, much of the central Palouse region in Idaho and Washington is covered chiefly by thick loess deposits that are highly erodible. Loess is a fine-grained windblown deposit of late Pliocene, Pleistocene, and Holocene age and is the most important source of sediment in the Palouse River Basin. One factor responsible for the mechanical shaping of the loess hills, besides normal surface runoff and wind action, is the buildup of large banks of snow on the north and east faces of the hills. As these snowbanks melt, excess runoff causes deeper erosion of the soil on the north and east slopes. This is especially true in the Colfax-Pullman-Moscow area. In the easternmost part of the Palouse River Basin, local relief is high, the loess cover is thin, and precipitation is relatively heavy. In the westernmost part of the Palouse River Basin are scablands that lack an integrated drainage system and have little local relief. Lakes are numerous and signify the lack of integrated drainage. Interchannel areas in the scabland are locally characterized by remnant mantles of loess.

Sediment transport in the Palouse River Basin is highly dependent on climatic activity. During a four year study period extending from July 1961 through June 1965, 81 percent of the total 4 year suspended sediment load occurred during the storm periods of February 3 through 9 of 1963, December 22 through 27 of 1964, and January 27 through February 4 of 1965. USGS (1970) documents the results of these studies. The single storm of February 3 through 9 of 1963 accounted for approximately 50 percent of the total suspended load. This study determined that the average annual sediment discharge of the Palouse River at its mouth was approximately 1,433,376,000 kilograms (1,580,000 tons) per year and that the average annual sediment yield was approximately 168,129 kilograms per square kilometer (480 tons per square mile). However, the sediment yield ranged from 1,751 kilograms per square kilometer (5 tons per square mile) in the western part of the Palouse River Basin to 735,568 kilograms per square kilometer (2,100 tons per square mile) in the central part of the basin having the loess hills. Sediment yield in the eastern part of the basin ranged from 161,124 kilograms per square kilometer (460 tons per square mile) to more than 350,270 kilograms per square kilometer (1,000 tons per square mile).

The Tucannon River Basin is similar to the Palouse River Basin in that the headwater areas are rugged volcanic highlands and the downstream portions are characterized by extensive loess deposits. Its sedimentation activity should somewhat qualitatively resemble that of the Palouse River Basin.

18. Prior Snake River Basin Sedimentation Studies

Verle C. Kaiser has conducted long-term studies starting in the mid-1930's of the annual erosion rates on standards plots throughout Whitman County, Washington; and his observations are among the very few sustained and systematic records of erosional processes in the general region. He concluded that:

1. Sediment delivery to the active channels is small relative to the amount of detached soil, with the difference deposited at the base of slopes and in swales.
2. Soil loss and sediment delivery are not in simple relation to rainfall or runoff but depend to a great degree on antecedent ground temperature and moisture conditions as well as on effective rainfall intensity.

His data also suggest that erosion rates may range through cycles of 10 to 15 years, which complicates the definition of "average" or "normal" rates of soil loss and sediment yields. His work is documented in Kaiser (1967) and the above descriptions of his studies were from USDA (1982, page 13).

McCool and Papendick (1975) also discuss the variability of sediment yields in Palouse-type watersheds. They noted that daily, seasonal, or annual variability in yields is very large in the small-grained dryland regions of the Pacific Northwest. Individual runoff events can account for more than half of the annual sediment yield. Sediment transport during a given year or a single large storm can be as large as the total of four or five other years. They recommended that intensive sampling during storms should be the basis of any field program. They concluded that "sampling programs based on weekly samples, even at stations with excellent streamflow records, can give extremely misleading results and sampling programs of only one or two years duration can also give extremely misleading results." McCool has also found that the distribution of frozen ground is a dominant factor in soil loss during individual storms (USDA, 1982).

From 1972 through 1979, the USGS gathered both suspended load and bedload information on the Snake and Clearwater rivers in response to recognized needs for this inflowing sediment information. The results of this data gathering effort are documented by USGS (1980).

Suspended sediment and bedload transport was monitored within the Tucannon River drainage basin from October 1979 through September 1980. Other than the studies accomplished on the Snake and Clearwater Rivers from 1972 through 1979, no bedload transport monitoring had been attempted in southeastern Washington prior to the Tucannon River monitoring. USDA (1982) documents the Tucannon River studies and should be consulted for more in-depth information on them.

The Corps developed an HEC-6 model of Lower Granite Reservoir as a tool to assist in reviewing the adequacy of the Lower Granite facility as related to sedimentation effects on navigation and flood control. The results of this study were documented by the Corps (1984). Further refinement of this initial work continued and in December 1992 another draft preliminary report was published which documented studies done as of that date (Corps, December 1992). The Corps also performed sedimentation studies in McNary Reservoir as part of the Tri-Cities levee studies. Results of these studies are documented by the Corps (May 1992a).

19. Present Lower Snake River and McNary Reservoir Sedimentation Studies

In support of the Lower Snake River Juvenile Salmon Migration Feasibility Study, sedimentation studies were conducted to evaluate the effects of breaching the four lower Snake River dams on sedimentation activity on the lower Snake River and the Columbia River between the Snake River confluence and McNary Dam. In downstream order, these dams are Lower Granite Dam, Little Goose Dam, Lower Monumental Dam, and Ice Harbor Dam. For these studies, the existing HEC-6 model for Lower Granite Reservoir was extended utilizing existing geometric information for the lower Snake River and the Columbia River between the Snake River confluence and McNary Dam. Recent channel sounding information taken downstream of Ice Harbor Dam was also incorporated into the model.

In addition, fluvial geomorphology studies were conducted on the lower Snake River. These investigations of channel morphology are presented in Appendix H, Fluvial Geomorphology. The objectives of these studies were to describe the physical characteristics and habitats of the pre-dam river, quantify the geomorphic features that describe salmon production areas, and to evaluate changes in the flow regime under near-dam breaching.

Most of the sediment that has accumulated within the lower Snake River reservoirs is located in Lower Granite because it has been the most upstream reservoir since 1975. From data collected, Ice Harbor has accumulated about 25 million cubic yards (MCYD) of sediment, Lower Monumental has about 4 MCYD, Little Goose has about 18 MCYD, and Lower Granite has about 84 MCYD. A sediment transport monitoring program was established for Lower Granite Reservoir in 1972, three years prior to Lower Granite Project's completion and pool raise in 1975, to quantify the inflowing sediment loads. This included both the suspended load and the bed load. USGS gathered data from 1972 through 1979 and has published this information in their report dated 1980 and titled "Sediment Transport in the Snake and Clearwater Rivers in the Vicinity of Lewiston, Idaho." This report should be consulted for further information regarding this inflowing sediment data collection program. In addition, the Walla Walla District Corps established a system of 71 sedimentation ranges, which is described in their Lower Granite Project Design Memorandum 39, dated 15 May 1975, entitled "Lake Sedimentation Ranges." Forty-four (44) ranges were initially established on the Snake River, 24 ranges initially established on the Clearwater River, and three established on Asotin Creek. This report (with revisions) should be consulted for further information regarding this sedimentation range program established in lower Granite Reservoir. Lower Granite's sedimentation ranges have been routinely surveyed several times since their initial survey in 1974, with follow-up surveys being done in 1976, 1977, 1979, 1982, 1983, 1984, 1985, 1986, 1987 (limited survey), 1989, 1992 (February, May, and July before and after 1992 Lower Granite Drawdown Test), 1995, 1996 (limited survey of only four ranges near Snake and Clearwater confluence), 1997, and 2000. In February 1984, the Walla Walla District Corps published an Interim Report entitled "Sedimentation Study- Interim Report- Lower Granite Project, Snake River, Washington and Idaho," which presents information regarding early sedimentation modeling studies conducted for the Lower Granite Project. In 1992, the Walla Walla District published a report entitled "Lower Granite Sedimentation Study, Preliminary Evaluation and Progress Report" as a follow-up to the 1984 study and report.

Until recently, minimal efforts had been accomplished on the other three Lower Snake River Projects with respect to sedimentation studies. In 1998, the first sedimentation ranges were established in Lake Sacajawea, with 37 ranges being designated between Snake River RMs 9.97 and 41.18. In 1999, 33 sedimentation ranges were established in Lake West between Snake River RMs 41.83 and 70.03. This augmented the sedimentation ranges established in 1969 in the vicinity of the Palouse River's confluence with the Snake River. This also augmented the sediment ranges established in 1976 in the vicinity of the Tucannon River's confluence and Alkali Creek's confluences with the Snake River. In 1998, 34 sedimentation ranges were established in Lake Bryan between Snake River RMs 70.70 and 104.26. This augmented sedimentation ranges previously established in the vicinity of Deadman Creek, Meadow Creek, and Schultz Bar. Some sedimentation ranges have been established and periodically monitored within McNary Reservoir, with 21 being established on the Columbia River between Columbia River RMs 293.40 and 343.94; and eleven being established on the Snake River between Snake River RMs 0.85 and 8.72. In addition, sedimentation ranges have been established on the Lower Walla Walla River and Lower Yakima River immediately upstream of their confluences with the Columbia River.

Numerous samples of sediment have been taken within Lower Granite Lake and analyzed by recognized soils laboratories, such as the Corps laboratory in Troutdale, Oregon and the Battelle Marine Research Laboratory located in Sequim, Washington. In 1985, the Battelle Marine Research Laboratory analyzed core samples taken in the vicinity of the Port of Clarkston located on the Snake River's left bank immediately downstream of the Snake and Clearwater River's confluence. In 1988, 1989, 1990, 1991, and 1993, the Corps Troutdale laboratory performed soils analyses on samples gathered within the Lower Granite Lake. These sample analyses have supported generalized conclusions with respect to sediment gradations noted within other river/reservoir systems. The noted mean sediment sizes generally decrease (become smaller) as one progresses further downstream within the reservoir. This change in sediment grain size is primarily due to the generally reducing flow velocities noted as one proceeds downstream within Lower Granite Lake, which is influenced by the increasing flow depths. As the flow velocities become smaller, the ability of the river to keep sediment in suspension decreases with the larger sediment sizes settling out first in the upstream end of the reservoir and progressively smaller grain sizes settling out further downstream in the reservoir. At its upstream end within Lower Granite Lake, near Snake River RM 142, a maximum flow depth of 20 feet represents an example of the changing flow section. In the vicinity of Silcott Island near Snake River RM 130, a representative maximum flow depth is 60 feet, and in the vicinity of Lower Granite Dam near Snake River RM 108 a representative maximum flow depth is 100 feet. Thus, the Snake River is approximately five times as deep near Lower Granite Dam as it is in the vicinity of the cities of Lewiston and Clarkston. It has been generally noted that the predominant grain sizes noted in samples taken upstream of Silcott Island have been sand-sized particles and the predominant grain sizes noted downstream of Silcott Island have been silt sized particles. However, predominant grain sizes have been noted to be highly variable and not easily categorized with respect to location. They have also been noted to vary with differing flow regimes. Generalizations about the characteristics of sediment must be made with great caution with necessary qualifications being clearly stated.

Section 2.5 of the Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement Appendix C, Water Quality discusses sediment quality studies accomplished on the lower Snake River since 1997 and should be consulted for further information regarding these studies.

Very limited sedimentation modeling was accomplished on the lower Snake River from the vicinity of its confluence with Asotin Creek downstream to its confluence with the Columbia River; and on the Columbia River between its confluence with the Snake River downstream to McNary Dam. A basic data set to model these reaches with the Corps HEC-6 Sediment Model was developed and the resulting model was utilized to make very generalized sedimentation studies along these reaches. It was generally noted during these modeling studies that the lower Snake River had the capability to erode and transport sediments along the entire reach upstream of Ice Harbor Dam. It was also noted that sediment deposition would occur downstream of Ice Harbor Dam, assuming that McNary Dam continued to operate at its normal pool elevation of 340 feet above mean sea level. Modeling of the 1992 Lower Granite Drawdown sedimentation activity was also accomplished utilizing the HEC-6 model with mixed success. The HEC-6 model tried utilizing the sediment range and sediment transport data gathered in the field during the 1992 Lower Granite Drawdown. HEC-6 has known limitations with respect to the modeling of the re-suspension and transport of silts and clays and this was noted during these modeling efforts. Because HEC-6 is a one-dimensional model, its predictions are averages made laterally across any given cross section along any given study reach of interest. No definitive conclusions were made as the result of these 1992 Lower Granite Drawdown modeling efforts, although much valuable insight was gained with respect to utilization of the HEC-6 model. During these modeling efforts, the program's author was able to make some adjustments to the computer code.

Rates of sedimentation activity are highly variable and dependent upon many geophysical factors that cannot be accurately predicted in advance of their occurrence. This makes future prediction of sedimentation activity highly speculative and subject to qualification. Examination of previous studies can provide insights with respect to this variability. For example, in 1969 USGS prepared the Water Supply Paper 1868 entitled "Sediment Transport by Streams in the Walla Walla River Basin, Washington and Oregon, July 1962-June 1965." They found during this time that "two runoff events resulting from rain and snowmelt on partially frozen ground produced 76 percent of the suspended sediment discharged from the basin during the (three year) study period" (page 2). USGS also found that "although the average annual runoff for the period 1962 to 1965 was only slightly less than that of 1951 to 1953, the sediment discharge was more than 50 percent greater" (page 26). This was due to more severe erosion occurring during the 1962 to 1965 period as a result of the floods of December 1964 and January to February 1965. USGS also reported that "the total duration of selected storm events composed only about 9 percent of the entire period of study. However, the combined runoff for selected storm events was about 38 percent of the total and the sediment transported was about 94 percent of the total" (page 23). In another report entitled "Sediment Transport by Streams in the Palouse River Basin, Washington and Idaho, July 1961 to June 1965," (Water Supply Paper 1899-C dated 1970) the USGS states that "the years during which precipitation is heavy are not necessarily those during which the sediment discharge is high. For example, the sediment load transported past Hooper in 1962-1963 was higher than that in 1964-1965, even though more precipitation occurred during the latter period" (page C34). USGS also states on page C34 that "less sediment was transported in the Palouse River at Hooper during the December 1964 storm than during the storm of February 1963 partly because (1) the soil mantle was frozen to great depths, and it was readily thawed by the warm temperatures, allowing water to percolate into the subsoil; (2) a lighter snowpack existed; (3) an inflow of cool air closely followed the initial rainfall and caused the runoff rate to decrease in some places; and (4) little rain fell on bare soil after the snowpack had been removed." These brief discussions illustrate the complexity of the runoff processes associated with sediment transport and the extreme difficulties in predicting soil erosion and sediment transport.

20. Sedimentation Due to Lower Snake River Dam Breaching

If the four lower Snake River dams are breached, Lake Wallula, which is impounded by McNary Dam, will collect the majority of the sediments presently held behind the lower Snake River dams. Lake Wallula will also collect the majority of the annual sediment load naturally carried by the lower Snake River. Studies, data analysis, and professional judgements outlined in Section 19 were used to develop the sediment erosion, transport, and deposition information presented in this section. Under present conditions, Lower Granite Dam is capturing an average inflowing sediment load of approximately 2.3 to 3.1 million cubic meters (3 to 4 million cubic yards) per year that the lower Snake River is carrying due to various basin runoff processes. Tables 20-1 through 20-3 show the gradations of the inflowing bed load, suspended load, and total load, respectively. These tables are all based on sediment information contained in USGS (1980). Breaching of the four lower Snake River dams would allow this annual sediment load to be carried downstream to Lake Wallula, where the majority of the inflowing sediment would likely be deposited. The very finest silts and clays likely would be carried downstream through Lake Wallula with their ultimate destination being the Lower Columbia River estuary or the Pacific Ocean. Since the completion of Ice Harbor in 1962, approximately 76.5 to 114.7 million cubic meters (100 to 150 million cubic yards) of material has been deposited behind the four lower Snake River dams, with the approximate distribution shown in Table 20-4. A section of land, which is equivalent to 2.59 square kilometers (1 square mile), would be covered to a depth of one-third meter (1 foot) by 0.76 million cubic meters (1 million cubic yards) of sediment. Plates 20-1 through 20-5 show qualitative predictions of areas in Lake Wallula that are likely to experience notable sediment deposition, although it is emphasized that the entire reservoir downstream of the confluence of the Columbia and Snake rivers is susceptible to experiencing sedimentation effects. Interpretation of aerial photographs taken on April 14, 1983, of Lake Wallula sedimentation range information and of HEC-6 sedimentation model results was combined with professional judgment in the development of Plates 20-1 through 20-5. On the date of the aerial photographs, the mean daily discharge on the Columbia River at Priest Rapids Dam was 4,843 m3/second (171,000 cfs) and on the Snake River was approximately 2,124 m3/second (75,000 cfs) based on records taken at the Spalding and Anatone gaging stations. Due to the various uncertainties inherent in sedimentation processes, actual sedimentation experienced may or may not follow these predicted patterns.

The areas of deposition shown on Plates 20-1 through 20-5 assume that sediments released into Lake Wallula due to the breaching of all four lower Snake River dams have had sufficient opportunity to be transported down the Snake River and to be redistributed within Lake Wallula. This process will occur over a period of several years after the breaching of all four dams. The depositional areas shown on Plates 20-1 through 20-5 will probably experience the most notable deposition of sediments, which will probably be on the order of a meter or a few feet in depth. However, it is emphasized that the entire Lake Wallula area downstream of the Snake River's confluence with the Columbia River is susceptible to sedimentation activity and potentially could experience sediment deposition on the order of one-third meter (1 foot) outside of the delineated areas. It is also emphasized that sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during the development of Plates 20-1 through 20-5 and, therefore, actual sedimentation experienced after dam breaching may differ from these generalized maps.

Table 20-1. Snake and Clearwater Rivers Suspended Load Summary - Sediment Inflow into Lower Granite Lake: Particle Size Distribution and Percentage of Total Sample by Weight

Grain Size Range (millimeters)	Snake River Inflow (Percent)	Clearwater River Inflow (Percent)	Composite Inflow (Percent)
1.0-2.0	0.03	0.01	0.02
0.5-1.0	0.66	1.59	0.97
0.25-0.5	10.07	14.82	11.65
0.125-0.25	19.72	14.14	17.88
0.0625-0.125	17.20	10.07	14.83
0.031-0.0625	7.78	5.33	6.96
0.016-0.031	9.57	9.87	9.67
0.008-0.016	8.86	11.34	9.68
0.004-0.008	7.94	6.79	7.56
0.002-0.004	4.69	5.46	4.94
<0.002	13.48	20.58	15.84
Percentage Sum	100.00	100.00	100.00

Data Source: United States Department of the Interior
United States Geological Survey (USGS) Boise, Idaho
Sediment Transport in the Snake and Clearwater Rivers In the Vicinity of Lewiston, Idaho
Michael L. Jones and Harold R. Seitz
Open File Report 80-690, August 1980

All percentages computed on a weight basis using suspended load data gathered by the USGS on the Snake River at Anatone, Washington (USGS Station Number 13334300) and on the Clearwater River at Spalding, Idaho (USGS Station Number 13342500) from 1972 through 1979, and published in the above referenced data source. These data represent grain size information for sediments actively being transported by the rivers as suspended sediment load.

Table 20-2. Snake and Clearwater Rivers Bed Load Summary – Sediment Inflow into Lower Granite Lake: Particle Size Distribution and Percentage of Total Sample by Weight

Grain Size Range (millimeters)	Snake River Inflow (Percent)	Clearwater River Inflow (Percent)	Composite Inflow (Percent)
90-128	3.57	4.44	3.83
64-90	12.36	7.11	10.82
45-64	9.63	10.79	9.97
32-45	9.40	3.96	7.79
22.6-32	8.67	3.49	7.14
16-22.6	5.76	1.77	4.58
11.3-16	3.93	1.17	3.11
8-11.3	1.54	0.91	1.35
5.7-8	0.86	0.74	0.82
4-5.7	0.65	0.52	0.61
2.8-4	0.74	0.53	0.68
2-2.8	0.77	0.41	0.66
1.4-2	1.02	0.46	0.85
1-1.4	1.40	0.91	1.26
0.71-1	3.36	5.29	3.93
0.50-0.71	10.40	20.97	13.53
0.35-0.50	12.59	17.85	14.15
0.25-0.35	9.67	13.86	10.92
0.18-0.25	2.85	3.98	3.18
0.12-0.18	0.52	0.59	0.54
0.09-0.12	0.15	0.10	0.13
0.06-0.09	0.08	0.06	0.07
<0.06	0.08	0.09	0.08
Percentage Sum	100.00	100.00	100.00

Data Source: United States Department of the Interior
United States Geological Survey (USGS) Boise, Idaho
Sediment Transport in the Snake and Clearwater Rivers In the Vicinity of Lewiston, Idaho
Michael L. Jones and Harold R. Seitz
Open File Report 80-690, August 1980

All percentages are computed on a weight basis using bed load data gathered by the USGS on the Snake River at Anatone, Washington (USGS Station Number 13334300) and on the Clearwater River at Spalding, Idaho (USGS Station Number 13342500) from 1972 through 1979, and published in the above referenced data source. These data represent grain size information for sediments actively being transported by the rivers as bed load.

Table 20-3. Snake and Clearwater Rivers Total Load Summary – Sediment Inflow into Lower Granite Lake: Particle Size Distribution and Percentage of Total Sample by Weight

Grain Size Range (millimeters)	Snake River Inflow (Percent)	Clearwater River Inflow (Percent)	Composite Inflow (Percent)
90-128	0.19	0.20	0.20
64-90	0.65	0.32	0.55
45-64	0.51	0.49	0.50
32-45	0.50	0.18	0.40
22.6-32	0.46	0.16	0.36
16-22.6	0.31	0.08	0.23
11.3-16	0.21	0.05	0.16
8-11.3	0.08	0.04	0.07
5.7-8	0.05	0.04	0.04
4-5.7	0.04	0.03	0.03
2.8-4	0.04	0.02	0.04
2-2.8	0.04	0.02	0.04
1.0-2	0.16	0.07	0.13
0.50-1.0	1.36	2.71	1.80
0.25-0.50	10.72	15.59	12.33
0.125-0.25	18.85	13.70	17.15
0.0625-0.125	16.30	9.62	14.09
0.031-0.0625	7.36	5.09	6.61
0.016-0.031	9.06	9.42	9.18
0.008-0.016	8.39	10.83	9.19
0.004-0.008	7.52	6.48	7.18
0.002-0.004	4.44	5.21	4.69
<0.002	12.76	19.65	15.03
Percentage Sum	100.00	100.00	100.00

Data Source: United States Department of the Interior
United States Geological Survey (USGS) Boise, Idaho
Sediment Transport in the Snake and Clearwater Rivers In the Vicinity of Lewiston, Idaho
Michael L. Jones and Harold R. Seitz
Open File Report 80-690, August 1980

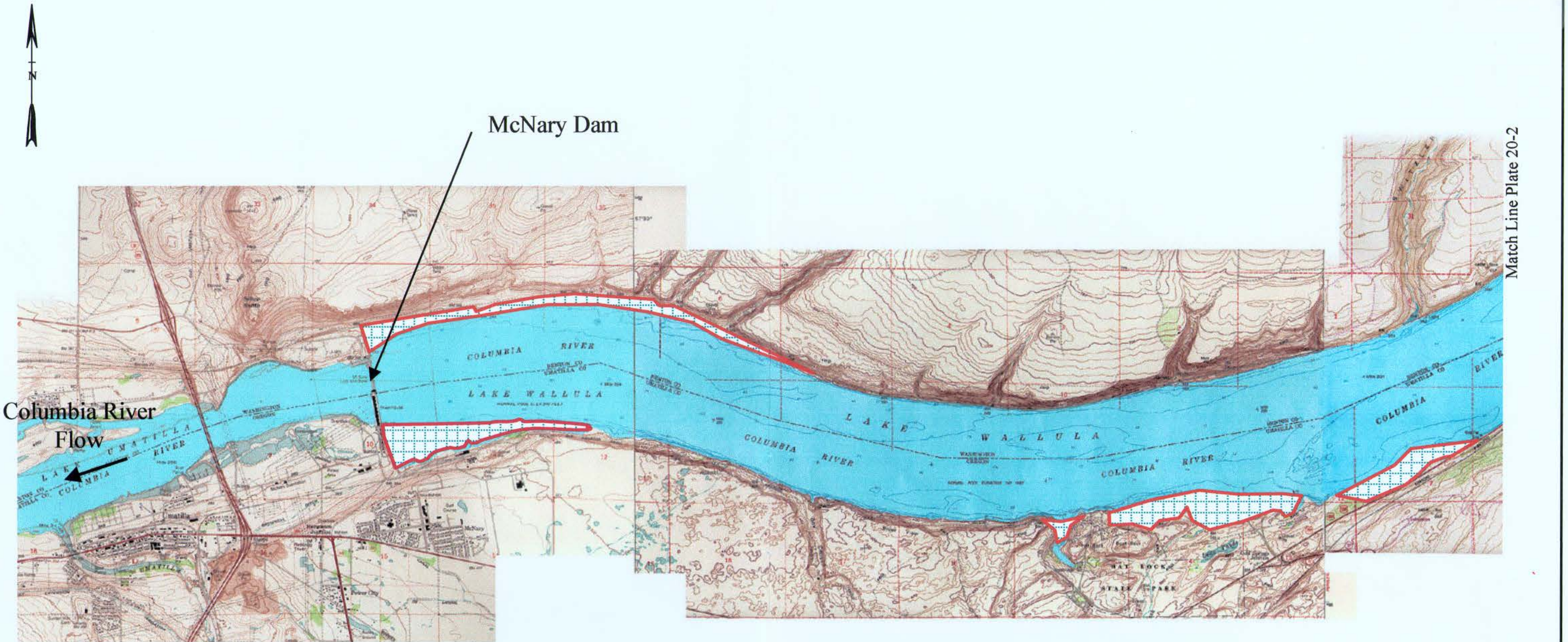
All percentages are computed on a weight basis using the sum of suspended and bed load data gathered by the USGS on the Snake River at Anatone, Washington (USGS Station Number 13334300) and on the Clearwater River at Spalding, Idaho (USGS Station Number 13342500) from 1972 through 1979, and published in the above referenced data source. This data represents grain size information for sediments actively being transported by the rivers as a combination of both bed load and suspended load.

Table 20-4. Distribution of Sediment Carried by the Lower Snake River and Deposited in McNary and Four Lower Snake River Reservoirs From 1953 through 1998

Facility	Date In Service	Dates Facility Impounded Sediment	Estimated Volume Sediment Impounded
McNary	1953	1953-1961 (9 years)	20.6-27.7 MCMTR (27-36 MCYD)
Ice Harbor	1962	1962-1968 (7 years)	16.1-21.4 MCMTR (21-28 MCYD)
Lower Monumental	1969	1969-1970 (1 year)	2.3-3.1 MCMTR (3-4 MCYD)
Little Goose	1970	1971-1975 (5 years)	11.5-15.3 MCMTR (15-20 MCYD)
Lower Granite	1975	1975-1998 (24 years)	55.1-73.4 MCMTR (72-96 MCYD)
Totals:	**(McNary and Lower Snake)**	**46 Years**	**105.5-140.7 MCMTR (138-184 MCYD)**
	(Lower Snake Facilities Only)	**37 Years**	**84.9-113.2 MCMTR (111-148 MCYD)**

Notes:

1. MCMTR is abbreviation for million cubic meters. MCYD is abbreviation for million cubic yards. Multiply by 0.7646 to convert from million cubic yards (MCYD) to million cubic meters (MCMTR).
2. Lower Snake River assumed to carry approximately 2.3 to 3.1 million cubic meters (three to four million cubic yards) of sediment per year, on the average. This amount is based on suspended sediment and bed load data collected from 1972 through 1979 on the Snake and Clearwater rivers upstream of Lower Granite Reservoir. The actual amount varies from year to year with climate and basin conditions, and can not be accurately predicted in advance.
3. Time in service dates and time projects collected sediment approximated to the nearest year.
4. Sediment contributions by Snake River basin watersheds downstream of the confluence of the Snake River and Clearwater River are not reflected in sediment volumes listed in this table.
5. Sediment contributions into McNary Reservoir (Lake Wallula) by the Yakima River, Columbia River, Walla Walla River, and other tributaries are not included in the above table. This table only includes sediments transported by the lower Snake River.



Potentially most notable areas of sediment deposition.

NOT TO SCALE

Notes:

1. Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2. Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

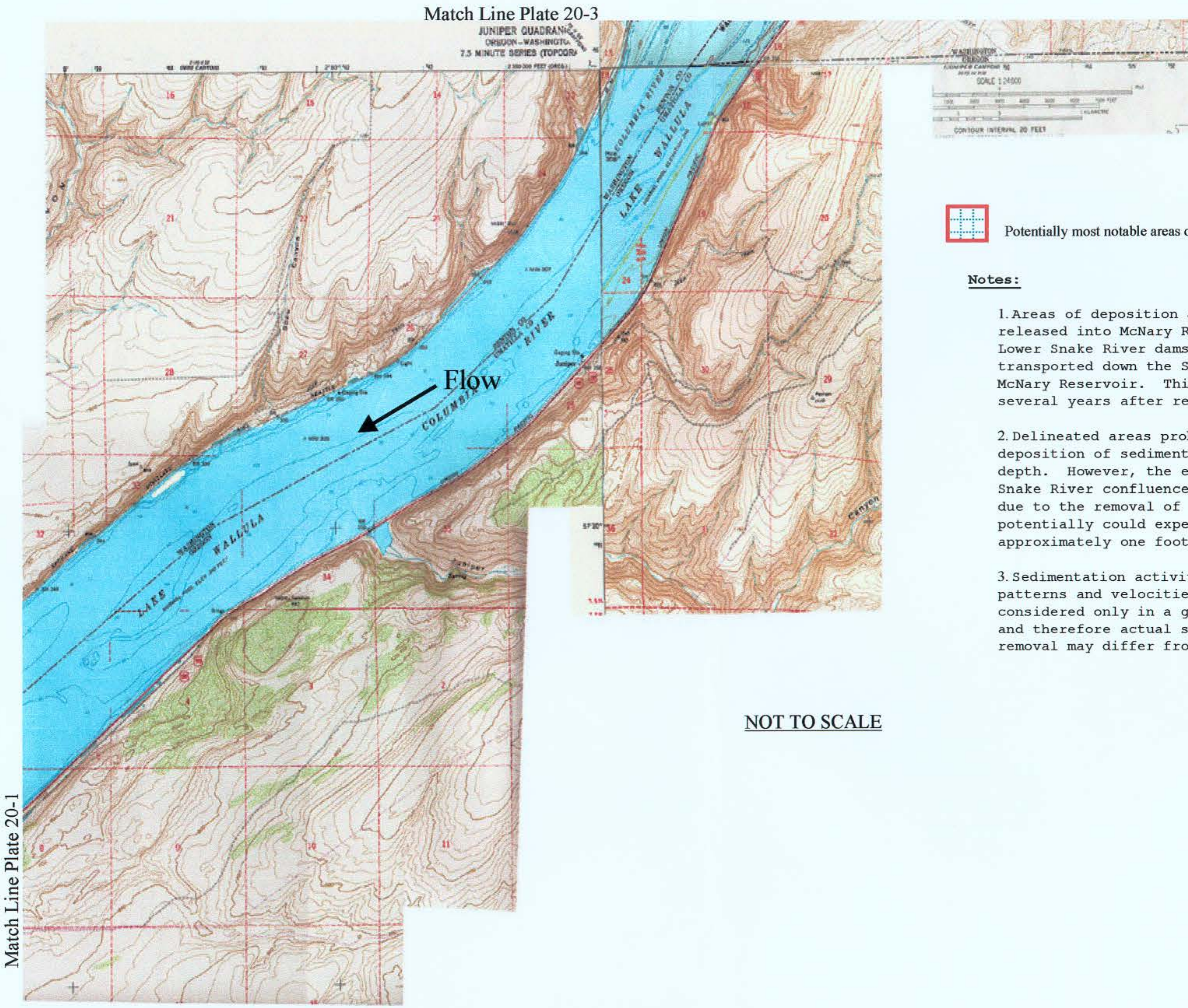
3. Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
McNary Dam and Lake Wallula

U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDE	C. KOCH	OCT 1998



Potentially most notable areas of sediment deposition.

Notes:

1. Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2. Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

3. Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

NOT TO SCALE

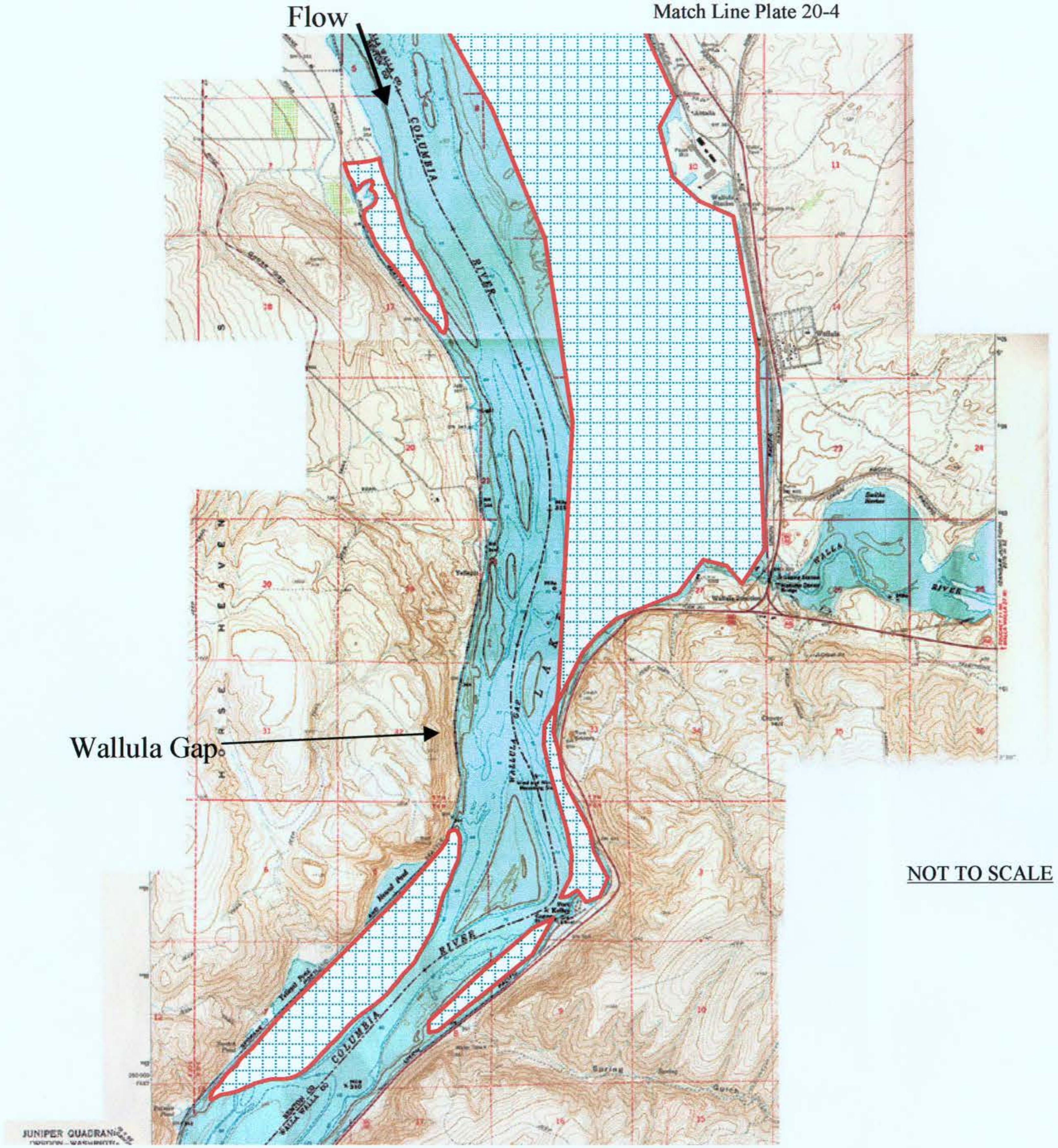
COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
Upper Lake Wallula

U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDE	C. KOCH	OCT 1998

Match Line Plate 20-4



Match Line Plate 20-2

NOT TO SCALE

Potentially most notable areas of sediment deposition.

Notes:

1. Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2. Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

3. Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

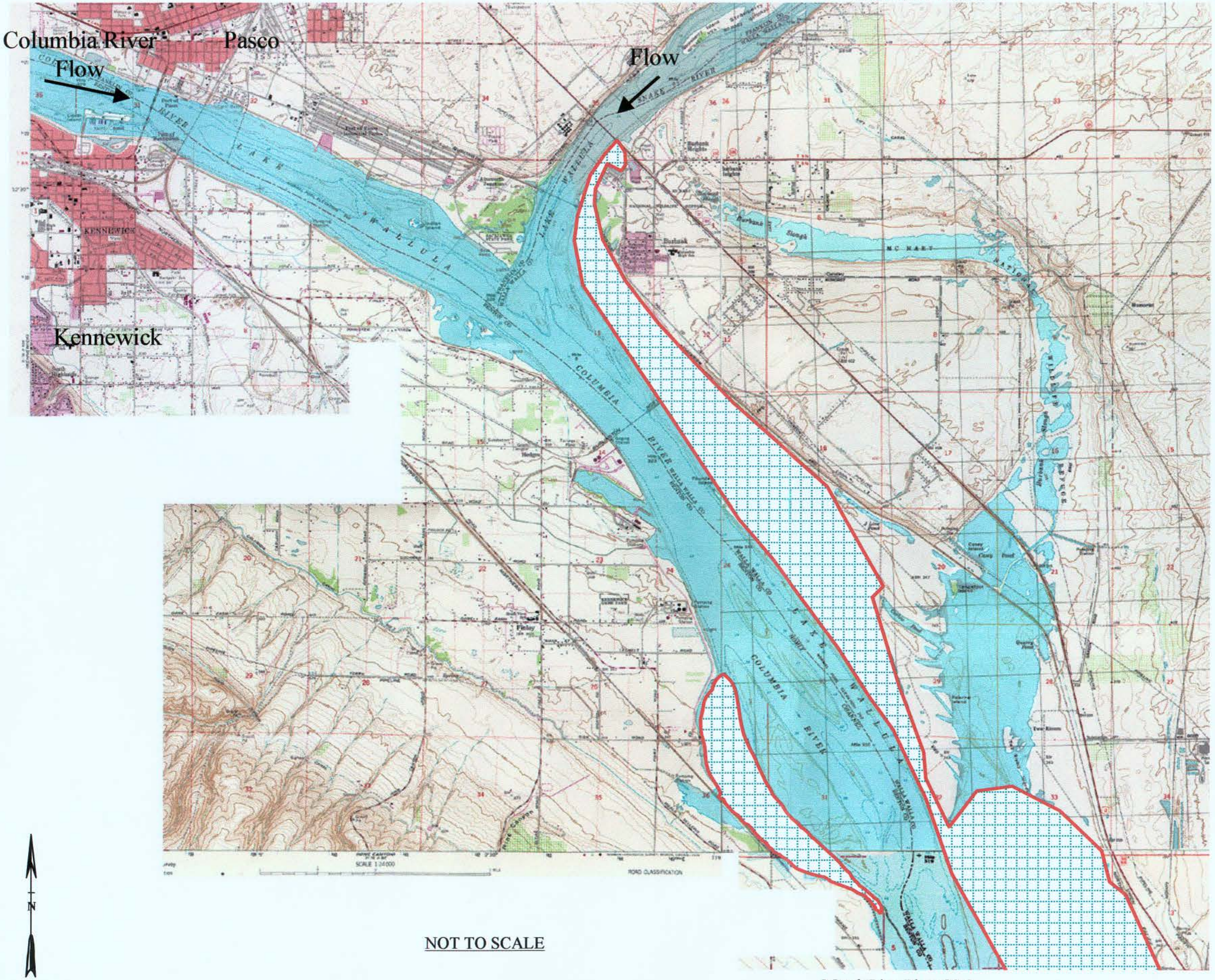
COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
Wallula Gap

U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDE	C. KOCH	OCT 1998

Match Line Plate 20-5



Potentially most notable areas of sediment deposition.

Notes:

1. Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2. Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

3. Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

Match Line Plate 20-3

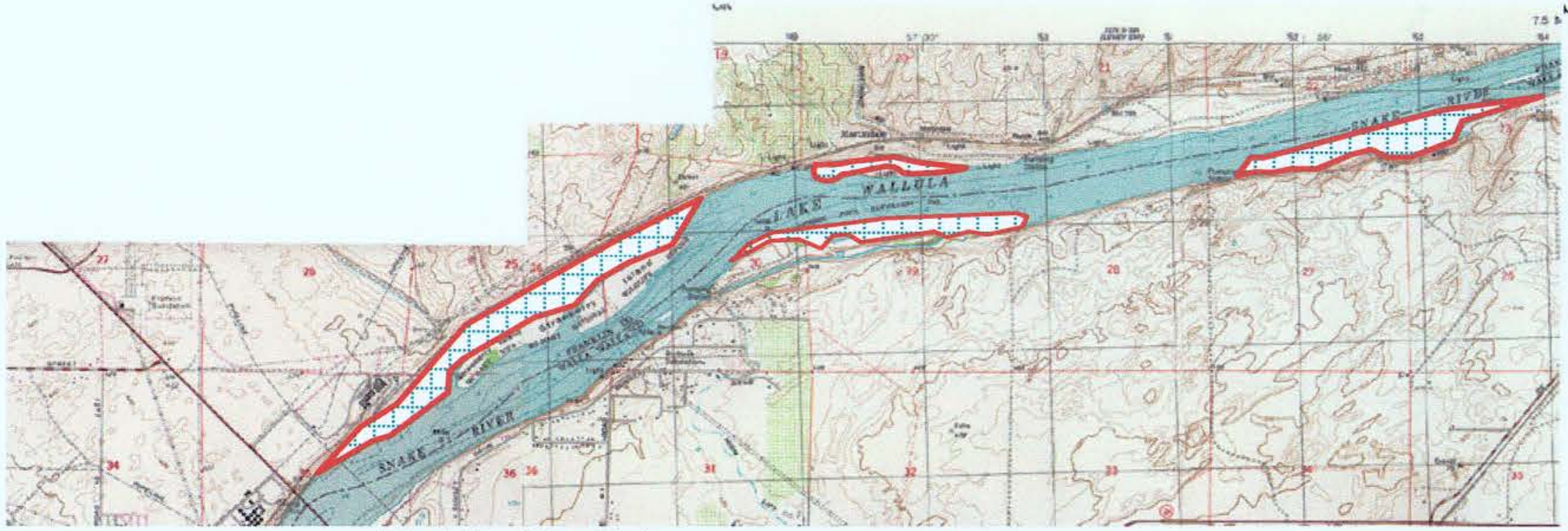
COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
Columbia-Snake River Confluence

U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDE	C. KOCH	OCT 1998

Snake River
Flow



Match Line Plate 20-4

NOT TO SCALE

Potentially most notable areas of sediment deposition.

Notes:

1. Areas of deposition are delineated assuming that sediments released into McNary Reservoir due to the removal of all four Lower Snake River dams have had sufficient opportunity to be transported down the Snake River and redistributed within McNary Reservoir. This process will occur over a period of several years after removal of all four dams.

2. Delineated areas probably will experience the most notable deposition of sediments, probably on the order of a few feet of depth. However, the entire McNary Reservoir downstream of the Snake River confluence is susceptible to sedimentation activity due to the removal of the four Lower Snake River dams, and potentially could experience deposition on the order of approximately one foot outside of the delineated areas.

3. Sedimentation activity is highly dependent on localized flow patterns and velocities. These localized effects were considered only in a generalized sense during map preparation and therefore actual sedimentation experienced after dam removal may differ from these generalized maps.

COLUMBIA RIVER BASIN
COLUMBIA RIVER

McNARY RESERVOIR
POTENTIAL SEDIMENTATION DUE TO LOWER SNAKE RIVER DAM REMOVAL
Immediately Upstream
of the Columbia-Snake River Confluence
U.S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
SPANGRUDE	C. KOCH	OCT 1998

If the four lower Snake River dams are breached, approximately 50 percent (one half) of the previously deposited materials will be eroded and transported by the Snake River within the first few years following dam breaching. The eroded materials will most likely be re-deposited in Lake Wallula between the Snake River and Wallula Gap. Since McNary Dam's backwater pool extends up to Ice Harbor Dam, the very coarsest cobble materials could start depositing in the vicinity of Ice Harbor Dam, although they could later be subject to re-suspension and further transport downstream to Lake Wallula by floods, which exceed the flows experienced at the time of their original deposition. The coarsest sediments would be deposited first, with the sediment deposits becoming progressively finer as they are transported further downstream into Lake Wallula. Since these materials were once able to be previously deposited behind the lower Snake River dams and since the flow velocities in Lake Wallula are generally lower than the Snake River's velocities, it is very likely that most of these sediments will also be deposited in Lake Wallula rather than being transported downstream of McNary Dam. The remainder of the sediments previously deposited upstream of the lower Snake River dams and not eroded within the first few years of dam breaching would be subject to long-term erosion by wind and precipitation and could eventually also be transported downstream by the Snake River to Lake Wallula.

The lower Snake River downstream of Lewiston, Idaho, annually transports approximately 2.3 to 3.1 million cubic meters (3 to 4 million cubic yards) of new sediments that have been eroded from its drainage basin. If the four lower Snake River dams are breached, this material would be transported by the Snake River downstream to the Columbia River. Since the lower Snake facilities would no longer be available to capture sediments inflowing annually, all but the finest suspended sediments carried by the Snake River would likely deposit within Lake Wallula. The very fine sediments that do not deposit in Lake Wallula would continue to be transported downstream of McNary Dam, with their ultimate destination likely being the Columbia River estuary or the Pacific Ocean.

The sediment presently impounded by the four lower Snake River dams that would accumulate within Lake Wallula (50 to 75 millions cubic yards of material) within a few years after lower Snake River dam breaching and continue at an average rate of 2.3 to 3.1 million cubic meters (3 to 4 million cubic yards) per year due to the Snake River's annual sediment load would eventually expect to impact the water surface profile of Lake Wallula. Freeboard for the Tri-Cities levees could then be potentially impacted at some point in the future. The degree of potential impact and that date in the future cannot be predicted with any reasonable accuracy; but it would be correctly influenced by where the sediment accumulates and whether any dredging would be done to alleviate the problem.

Both this appendix and Appendix H, Fluvial Geomorphology (Section 4.5) discuss sediment transport. A 5 year time is referenced by both the time period that it would take to erode and transport the Lower Granite sediment. Appendix H (Figure 4-18) indicates that most of the sediment would be removed in 2 years or less. That rate will be dependent upon flow rates, climatic condition, and the manner in which the lower Snake River dams would be breached. This appendix has focused more on the time that it will take to transport the lower Snake River sediment into McNary Reservoir and that is the reason that this appendix indicates a little longer overall time period for transport and deposition.

There are many uncertainties associated with the erosion and resuspension, the transport, and then the deposition of the Lower Granite and remaining lower Snake River sediment accumulations into

McNary Reservoir. The order and timing for breaching of the lower Snake River dams along with the magnitude of upstream flows entering the lower Snake River during breaching will determine the actual timing of the sediment transport and both are unknown at this time. Whether the sediment is transported into McNary Reservoir in 2 years or 5 years is not expected to influence the decision on how to sequence the dam breaching. Performing additional studies or data analysis for the sediment transport before the dam breaching are not expected to significantly improve transport and deposition estimates. The current plan is to monitor sediment transport during breaching (if breaching occurred) and then dredge or correct problems as they arise. Section 26 outlines the monitoring plan and expected costs.

21. Discussion of Dam Breaching Effects on Fish Passage After Dam Breaching

Dr. Barton Evermann, a former ichthyologist with the United States Fish Commission, described some of the Snake River's characteristics in his paper entitled "A Preliminary Report Upon Salmon Investigations in Idaho in 1894." On pages 257 to 259, he describes the Snake River between Twin Falls and Lower Salmon Falls. In this report, he states that "salmon can not possibly ascend the Snake River farther than the foot of Shoshone Falls; and it was also believed that certain falls below Shoshone Falls (Auger Falls, Upper Salmon Falls, and Lower Salmon Falls) interfere seriously with the ascent of salmon." Lower Salmon Falls is near Snake River, kilometer 922 (river mile 573), Upper Salmon Falls is near Snake River kilometer 937 (river mile 582), Auger Falls is near Snake River kilometer 977 (river mile 607), Shoshone Falls is near Snake River kilometer 990 (river mile 615), and Twin Falls is near Snake River kilometer 993 (river mile 617). Between Lower Salmon Falls and Upper Salmon Falls, the Snake River drops approximately 33.5 meters (110 feet) in 14.5 kilometers (9 miles), for an average slope of 2.3 meters per kilometer (12 feet per mile). Between Upper Salmon Falls and Auger Falls, the Snake River drops approximately 42.7 meters (140 feet) in 40.2 kilometers (25 miles) for an average slope of 1.1 meters per kilometer (5.6 feet per mile). Between Auger Falls and Shoshone Falls, the Snake River drops approximately 61 meters (200 feet) in 12.9 kilometers (8 miles) for an average slope of 4.7 meters per kilometer (25 feet per mile). The average slope for the Snake River between the Clearwater confluence and Shoshone Falls is approximately 1.0 meter/kilometer (5.3 feet per mile). These slopes are all greater than the Snake River's average slope computed between its confluences with the Clearwater and Columbia rivers. Since salmon were once able to swim through the lower Snake River before construction of the four lower Snake River dams, it may be assumed that breaching of the dams and the re-emergence of rapids and falls will have no impact on their ability to again swim through this reach of the river.

22. McNary Reservoir (Lake Wallula) Sedimentation Generalized Description

The distance from the Snake and Columbia Rivers' confluence downstream to McNary Dam is approximately 53.1 kilometers (33 miles) as measured along the Columbia River's centerline. The distance between their confluence and Wallula Gap is approximately 16.1 kilometers (10 miles). The Columbia River's width along this 16.1-kilometer (10-mile) reach is approximately 3,048 meters (10,000 feet). Assuming an average width of 3,048 meters (10,000 feet) and an average effective depth for water conveyance of 9.1 meters (30 feet) results in an approximate average flow area of 27,870 square meters (300,000 square feet). Because the average annual discharge of the Columbia River at McNary Dam is approximately 5,664 m^3/second (200,000 cfs), the average flow velocity for this discharge along this reach is on the order of 0.3 meter (1 foot) per second. Based on Figure 2.46, found on page 102 of American Society of Civil Engineers (ASCE) Manual 54, Sedimentation Engineering, the sediment sizes potentially able to be transported through this reach of McNary Reservoir might likely be those having a mean diameter less than 1.0 millimeter. Assuming an average water velocity of 0.3 meter (1 foot) per second as previously computed, the approximate time required to travel the 16.1-kilometer (10-mile) distance from the confluence downstream to Wallula Gap is 14.6 hours (52,800 seconds). Assuming an average distance of vertical particle fall of 15.2 meters (50 feet) over a time period of 52,800 seconds results in an average fall velocity of approximately 0.029 centimeter per second. Using Figure 2.2, found on page 25 of ASCE Manual 54, a particle approximately 0.02 millimeter in diameter will fall at approximately 0.029 centimeters per second in water at 12 degrees C (54 degrees F). Therefore it is quite likely that particles greater than 0.02 millimeter in diameter could potentially settle out in McNary Reservoir upstream of Wallula Gap and those smaller than 0.02 millimeter could likely be carried downstream and pass through McNary. This is because the Columbia River narrows drastically to a width of approximately 1,524 meters (5,000 feet) downstream of Wallula Gap, which translates to increased water flow velocities and increased sediment transport capabilities downstream of Wallula Gap. The diameter of 0.02 millimeter is approximately that of the finest particles contained in the medium silts size class. Therefore, it is quite likely that materials in the fine and very fine silts size classes, in all clay size classes, as well as colloidal materials transported past Wallula Gap will also subsequently pass through McNary as the Columbia River's suspended sediment load. The fact that McNary Dam's spillway crests are approximately 15.2 meters (50 feet) above the Columbia River's streambed make it highly unlikely that bedload materials will pass through McNary Project.

This generalized description of potential sedimentation activity within Lake Wallula is valid for either the condition of the four lower Snake River dams being in place or for any combination of lower Snake River dam breaching. Lake Wallula has the capacity to trap all but the finest sediments, as previously described, and it is extremely unlikely that any of the Columbia River's bedload will pass through McNary Dam due to the vertical distance from the Columbia River's streambed up to McNary Dam's spillway crest. Therefore it is highly unlikely that the breaching of the lower Snake River dams will cause appreciable sediment deposition downstream of McNary Dam, since it appears that McNary has the ability to capture all but the finest suspended sediments. It is extremely unlikely that these suspended sediments will deposit upstream of the Columbia River estuary.

23. Sedimentation Downstream of McNary

Since only particles finer than the medium silts size class will likely pass through McNary, the sources of coarser materials downstream of McNary Dam as well as additional fine materials must be local runoff and streams that enter the Columbia River downstream of McNary Dam. Some examples of such tributaries are the Umatilla River, the John Day River, the Deschutes River, the Hood River, and the Willamette River. The Umatilla River enters the Columbia River along its left bank approximately 3.2 kilometers (2 miles) downstream of McNary Dam. Its suspended and bed loads can potentially cause sedimentation problems in the vicinity of this confluence because of reduced flow velocities downstream of the confluence. The Umatilla River's drainage area is approximately 5,931 square kilometers (2,290 square miles), its average discharge is 13.3 m^3/second (469 cfs), and its maximum discharge is approximately 560.7 m^3/second (19,800 cfs). The John Day River's drainage area is approximately 19,684 square kilometers (7,600 square miles), its average discharge is 59.0 m^3/second (2,085 cfs), and its maximum discharge is approximately 1,212.1 m^3/second (42,800 cfs). The Deschutes River's drainage area is approximately 27,195 square kilometers (10,500 square miles), its average discharge is approximately 164.4 m^3/second (5,805 cfs), and its maximum discharge is approximately 1,990.9 m^3/second (70,300 cfs). The Hood River's drainage area is approximately 722.6 square kilometers (279 square miles), its average discharge is 28.7 m^3/second (1,015 cfs), and its maximum discharge is 659.9 m^3/second (23,300 cfs). The Willamette River's drainage area is approximately 28,749 square kilometers (11,100 square miles), its average discharge is 888.4 m^3/second (31,370 cfs), and its maximum discharge noted prior to flooding in 1996 is 8,014.6 m^3/second (283,000 cfs).

24. Water Supply Intakes in McNary Pool

Based on qualitative inspection of aerial photographs, topographic mapping, and available sediment range surveys, the left (east) bank of the Columbia River from the point of its confluence with the Snake River downstream to its confluence with the Walla Walla River near Wallula Gap appears to be very susceptible to sediment deposition. Actual deposition depths and patterns likely to be experienced are difficult to predict in advance, due to the complex nature of sedimentation activity and its dependence on localized flow patterns. To avoid problems due to potential sediment deposition, water intakes should be located as far above the streambed as practical and should be located in areas having noticeable flow velocities high enough to discourage the deposition of sediment. Locating water intakes in quiescent areas is not advisable, due to the potential for higher rates of sediment deposition.

25. Time Required to Reach a New Equilibrium After Dam Breaching

Due to many variables, primarily related to climate, it is difficult to predict the time needed for landscape recovery after dam breaching. However, generalized qualitative predictions can be realistically made using information available both within the study area and from published literature. In January 1973, the Lewiston Hydroelectric Project, located on the Clearwater River approximately 8.05 kilometers (5 miles) east of Lewiston, Idaho, was removed as part of the Lower Granite Lock and Dam construction process. Sediment range surveys were made upstream of this relatively small project in 1971 (before dam breaching) and in 1975 and 1982 (after dam breaching). These surveys indicate that most of the erosion occurred between dam breaching in 1973 and the first survey in 1975. Some relatively minor erosion occurred between the 1975 and 1982 surveys. This information suggests that a significant portion of the channel sediment erosion will have occurred within about 2 to 5 years after dam breaching. Erosion of sediments not subject to annual riverine erosive action, but subject to only weather erosion such as that from precipitation and wind action, could take many years to accomplish and is extremely hard to assess because of the uncertainties in weather prediction.

The Executive Summary of the Department of Interior, Bureau of Reclamation, report entitled "Sediment Analysis and Modeling of the River Erosion Alternative," written as part of the Elwha River Ecosystem and Fisheries Restoration Project in October 1996, gives this information concerning sedimentation activity in relation to the breaching of the Elwha and Glines Canyon dams: "model results predicted that 15 to 35 percent of the coarse sediment (sand, gravel, and cobbles) and about half (50 percent) of the fine sediment (silt and clay sized particles) would be eroded from the two reservoirs. The remaining sediment would be left behind along the reservoir margins as a series of terraces. Fine sediment concentrations released from the reservoirs would be high during periods of dam breaching, typically 200 to 1000 ppm but occasionally as high as 30,000 to 50,000 ppm. Release concentrations would be relatively low (less than 200 ppm) during periods of high lake inflow when dam breaching activities and lake drawdown would stop. After the dams are breached, fine sediment concentrations would be low and near natural conditions during periods of low flow. Concentrations would be high during progressively higher floodflows as erosion channels widen in the reservoir areas. Within two to five years, concentrations would return to natural levels."

During the 1992 Lower Granite Drawdown Test, suspended sediment concentrations of 3,000 to 9,000 mg/l were measured. Modeling done using HEC-6 produced similar concentrations. Therefore, if the lower Snake River dams were breached, the 3,000 to 9,000 mg/l concentrations would be expected to occur. It is possible for higher concentrations to be found for short time periods as was cited in the 1996 BOR Elwha Report. However, the Elwha dam is a storage project as compared to run-of-the-river projects, so the Elwha dam concentration predictions may not be applicable.

26. Sedimentation Monitoring Before and After Dam Breaching

The following monitoring requirements are foreseen to adequately evaluate erosion and sediment transport if the four lower Snake River dams are breached:

Surveys **Total Cost $1,507,500**

Sediment range resurveys would be required to document the extent and progression of bed and bank erosion during and after the pool drawdown. An initial survey would be required to establish baseline conditions before the start of the drawdown. The initial survey would involve resurveying existing ranges in locations that are subject to frequent change and the establishment of ranges in locations where none presently exist. Immediately following the drawdown of one or more reservoirs, the ranges in the affected pool and the reach extending downstream to the next dam would need to be surveyed. Periodic resurveys would be required until the channel approached a stable condition.

A. Initial survey

1. Establish 32 new ranges in Lower Monumental pool at $1,000 each	$32,000
2. Establish 3 new ranges in McNary Pool	3,000
3. Complete bankline surveys on Little Goose, Ice Harbor 75 ranges at $500 each	37,500
Total	$72,500

B. Post drawdown survey assuming all four pools at once

Resurvey 205 ranges at $1,000 each	$205,000

C. Annual resurvey to be performed each year after the runoff season for 5 years, with a final survey at the end of 10 years. Each survey would extend overbank to range monument.

Resurvey 205 ranges 6 times at $205,000 each	$1,230,000

Sediment Transport **Total Cost $258,780**

Suspended and bedload measurements would be made at the Anatone and Spalding USGS gage sites, downstream of each of the four Snake River dams, and downstream of McNary. The purpose of this effort would be to document the increase in bed load and suspended sediment resulting from the erosion of sediment deposits behind the four Snake River facilities. Sediment transport would be measured downstream of the pool to be lowered and below each downstream facility immediately prior to the beginning of the drawdown. This will establish a baseline condition for the drawdown period. Sediment transport would then be measured once each day during the drawdown process and for 30 days following complete evacuation of the pool. During the following spring runoff period, sediment transport measurements would be made at 15-day intervals from 15 April through 30 July downstream of each of the five facilities and at the Anatone and Spalding gage sites. During the next 4 years and again after 10 years, suspended and bedload measurements would be measured near the peak of the runoff period. These latter measurements would be made at three locations: 1) the Anatone gage site, 2) the Spalding gage site, and 3) just downstream of Ice Harbor Dam.

Estimated Costs:

A.	Pre-drawdown sediment transport measurements	
	Measurements at 7 locations on same day	
	Assume two boat crews 3 days each at 1500/day:	$9,000
	(Probably a bit high, since one crew may work out of Tri-Cities USGS office)	
	Lab at 90/sample (bed load and suspended)	630
B.	Drawdown sediment transport measurements	
	Assume two boat crews 60 days each:	$180,000
	Lab at 90/sample	37,800
C.	Annual sediment transport measurements	
	Assume two boat crews, total of 4 days each measurement	
	Five events at $6000 each	$30,000
	Lab at 90/sample	1,350

Sediment Gradation **Total Cost $80,000**

Sediment sampling before and after the drawdown would provide a means of determining how the various sizes were moving downstream, how fast the river was cleaning sediment from the original channel bed, and how the substrate was changing in Lake Wallula as a result of the drawdown. If all of the dams were to be breached simultaneously, it is likely that the transport capacity of the flow will be exceeded for a time. Under these conditions the upper reaches of the river would erode down to the original cobble layer first. Progressively, more of the river would be swept clean in a downstream direction as the sediment is swept along by the current.

The effort could be as simple as following the upstream edge of the sediment downstream by a single boat crew operating continuously on the river, keeping records on the approximate location of the upstream edge of the sediment layer as it washed downstream, or it could involve sediment sampling which would include the depositional area in Lake Wallula.

Aerial Photography **Total Cost $62,400**

Fly river before drawdown, immediately after drawdown, once each year for 5 years and again at 10 years after drawdown. Cost per flight is about $7,800.

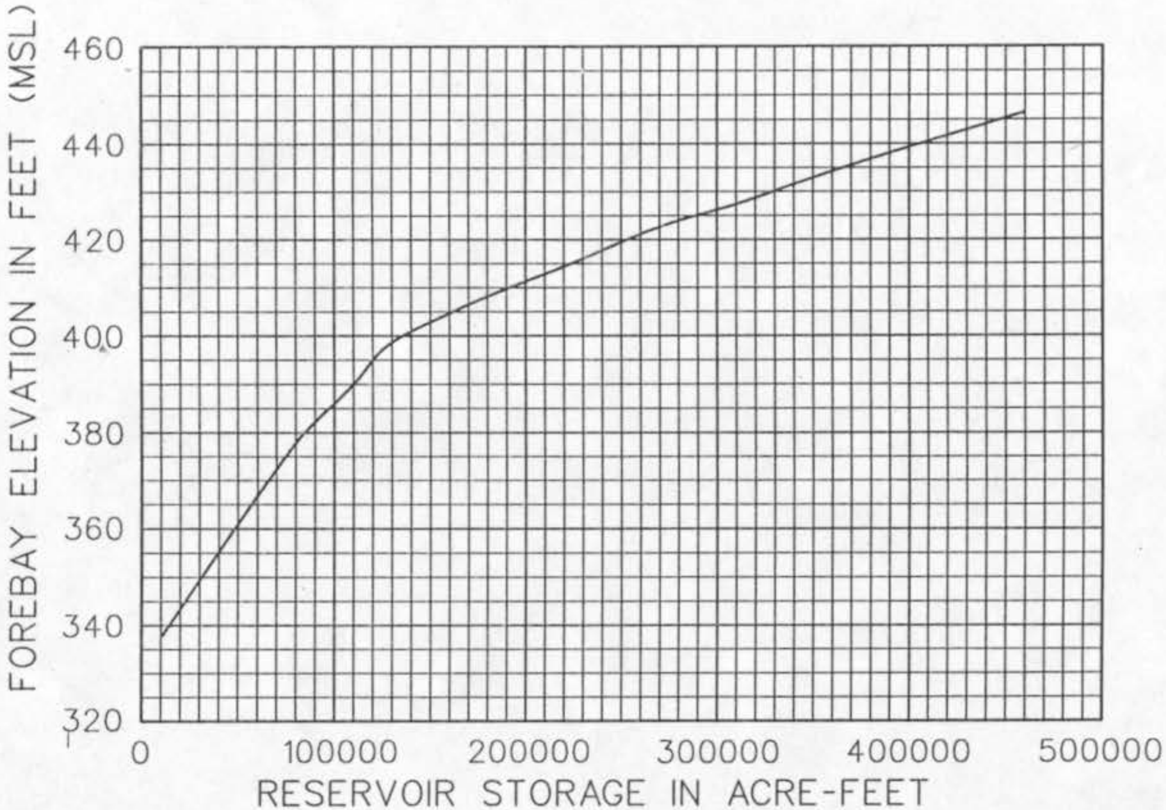
Data Analysis and Reporting **Total Cost $250,000**

Analyze the collected data and write one or more reports explaining the results of the monitoring.

SEDIMENT MONITORING ESTIMATED TOTAL COST: $2,158,680

27. Lower Snake River Project Storage Curves

Charts 27-1 through 27-4 present relations between project forebay elevations and reservoir storages for Ice Harbor, Lower Monumental, Little Goose, and Lower Granite facilities. These charts are all based on a lower Snake River discharge of 1,416 m^3/second (50,000 cfs), the approximate mean daily discharge of the lower Snake River.



NOTES:

1. RESERVOIR CAPACITY IS A FUNCTION OF BOTH POOL ELEVATION AND DISCHARGE. THIS CURVE IS BASED ON A DISCHARGE OF 50,000 CUBIC FEET PER SECOND.
2. ELEVATION STORAGE VALUES WERE COMPUTED USING U. S. ARMY CORPS OF ENGINEERS SOUNDINGS (DATED JUNE 10, 1935) AND 10-FOOT CONTOUR INTERVAL MAPS (BASED ON 1956 AERIAL PHOTOGRAPHY.)

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR RESERVOIR

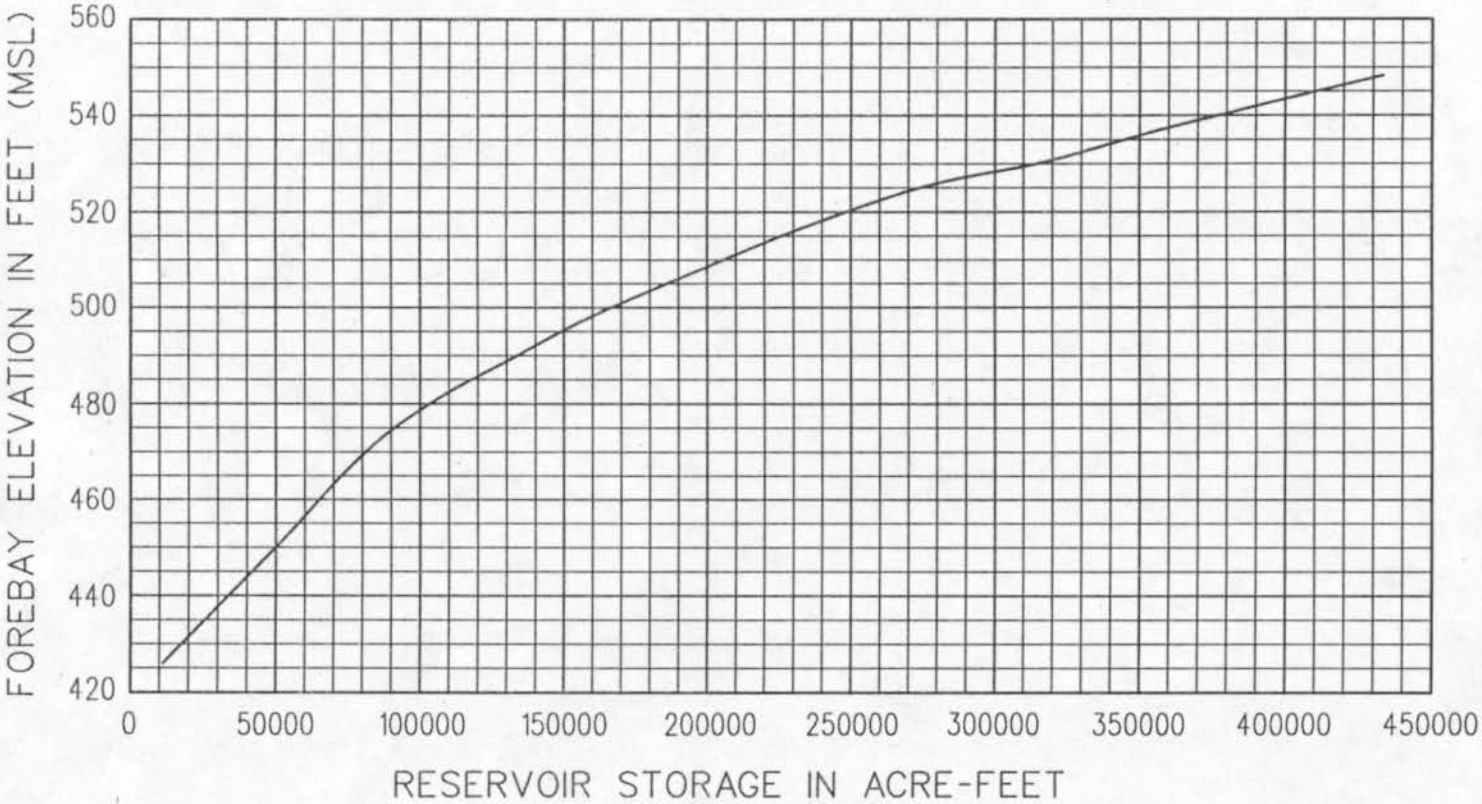
FOREBAY ELEVATION VERSUS RESERVOIR STORAGE

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	15 OCT 1992

A00197

Chart 27-1.



NOTES:

1. RESERVOIR CAPACITY IS A FUNCTION OF BOTH POOL ELEVATION AND DISCHARGE. THIS CURVE IS BASED ON A DISCHARGE OF 50,000 CUBIC FEET PER SECOND.
2. ELEVATION STORAGE VALUES WERE COMPUTED USING U. S. ARMY CORPS OF ENGINEERS SOUNDINGS (DATED JUNE 10, 1935) AND 10-FOOT CONTOUR INTERVAL MAPS (BASED ON 1956 AERIAL PHOTOGRAPHY.)

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
LOWER MONUMENTAL RESERVOIR

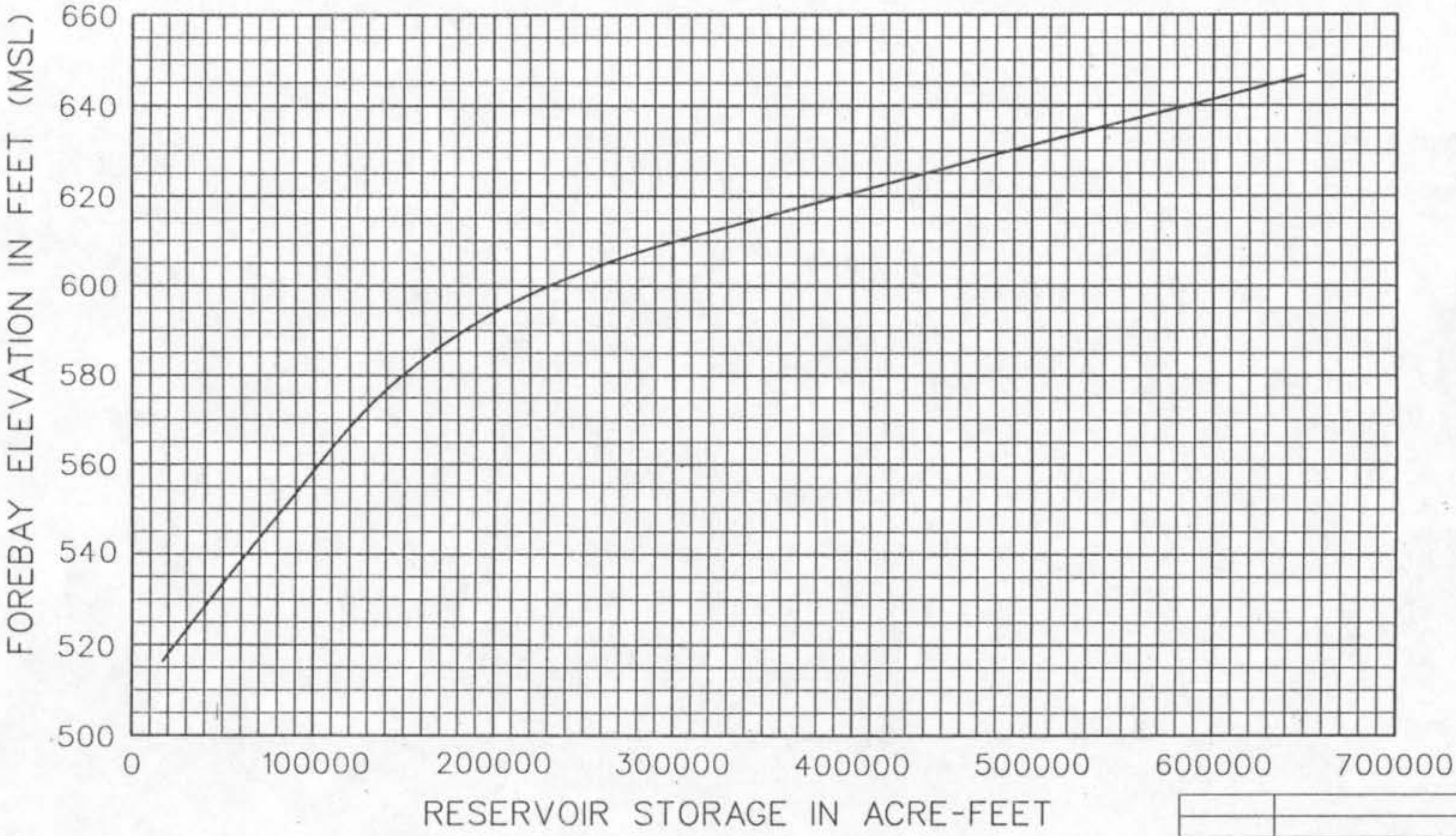
FOREBAY ELEVATION
VERSUS
RESERVOIR STORAGE

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	14 OCT 1992

A00195

Chart 27-2.



NOTES:

1. RESERVOIR CAPACITY IS A FUNCTION OF BOTH POOL ELEVATION AND DISCHARGE. THIS CURVE IS BASED ON A DISCHARGE OF 50,000 CUBIC FEET PER SECOND.
2. ELEVATION STORAGE VALUES WERE COMPUTED USING U. S. ARMY CORPS OF ENGINEERS SOUNDINGS (DATED JUNE 10, 1935) AND 10-FOOT CONTOUR INTERVAL MAPS (BASED ON 1956 AERIAL PHOTOGRAPHY.)

DATE	REVISION	BY

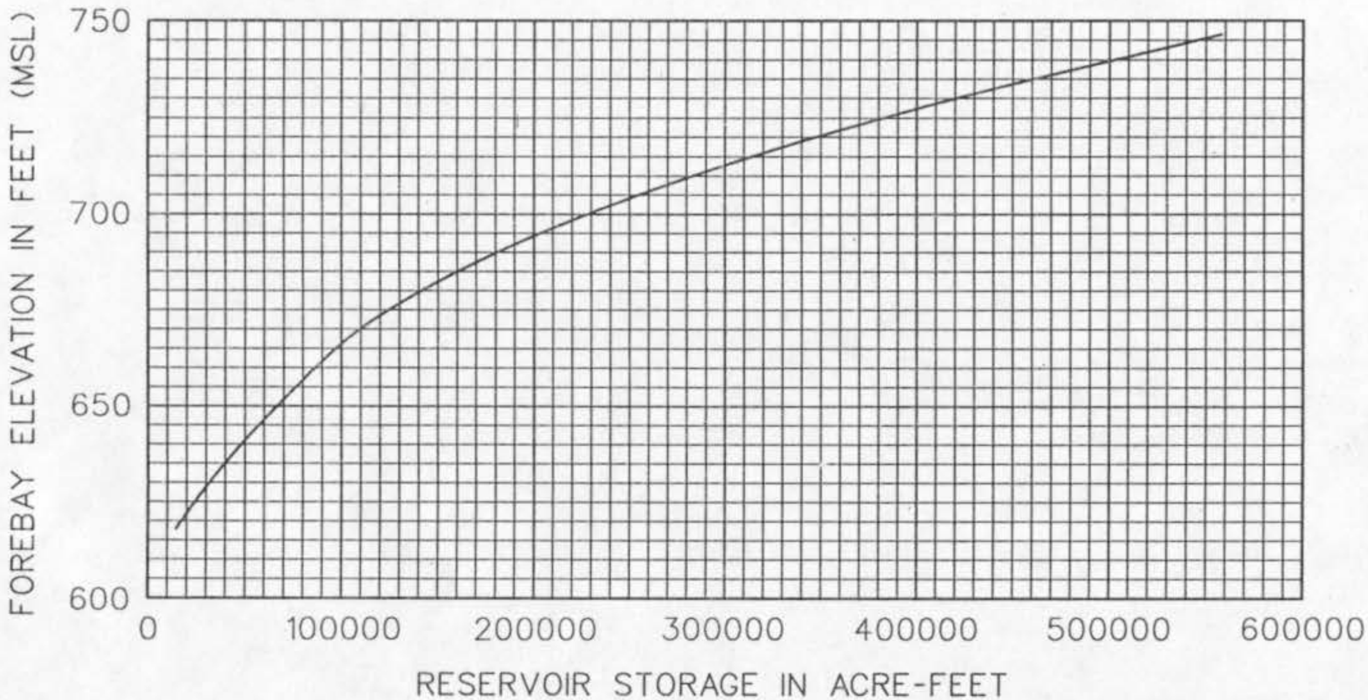
SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
LITTLE GOOSE RESERVOIR

FOREBAY ELEVATION VERSUS RESERVOIR STORAGE

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

	DESIGNED	DRAWN	DATE
A00196	MAXSON	SCHUSTER	15 OCT 1992

Chart 27-3.



NOTES:

1. RESERVOIR CAPACITY IS A FUNCTION OF BOTH POOL ELEVATION AND DISCHARGE. THIS CURVE IS BASED ON A DISCHARGE OF 50,000 CUBIC FEET PER SECOND.
2. ELEVATION STORAGE VALUES WERE COMPUTED USING U. S. ARMY CORPS OF ENGINEERS SOUNDINGS (DATED JUNE 10, 1935) AND 10-FOOT CONTOUR INTERVAL MAPS (BASED ON 1956 AERIAL PHOTOGRAPHY.)

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
LOWER GRANITE RESERVOIR

FOREBAY ELEVATION
VERSUS
RESERVOIR STORAGE

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

A00194

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	14 OCT 1992

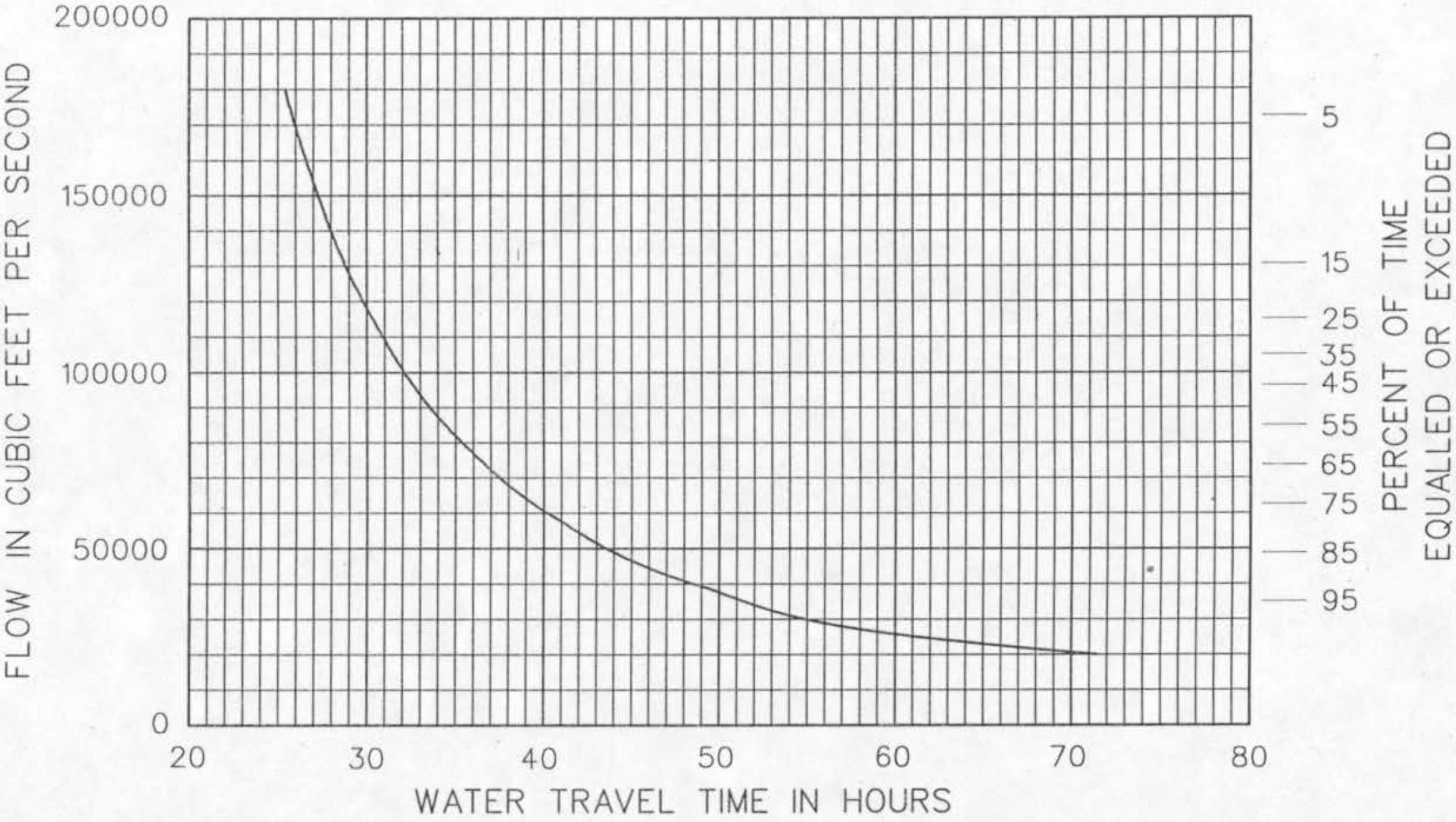
Chart 27-4.

28. Flood Control Transfers

The four lower Snake River facilities are not presently operated to provide any flood control and therefore, dam breaching would not modify the existing flood control capabilities within the Snake River system. However, breaching would eliminate any potential to use their reservoir space for system flood control purposes, since no means would be available to pond the water and use this under controlled conditions. Since the four lower Snake River facilities are all classified as run-of-river projects, their available storage is minimal when compared to projects designed to provide some degree of flood control. Based on Charts 27-1 through 27-4, the total gross storage space available in the four lower Snake River facilities is approximately 222,120 hectare-meters (1,800,000 acre-feet). Of this storage space, approximately 154,250 hectare-meters (1,250,000 acre-feet) occurs between the project spillway crests and the normal pool elevations.

29. Lower Snake River Water Travel Times

Charts 29-1 through 29-6 present lower Snake River water travel times between the Clearwater River and the Columbia River for several lower Snake River facility pool conditions, ranging from natural free flow to normal full pool. Reservoir drawdown will create reaches of free-flowing river between each dam and the next downstream pool, with greater lengths of free-flowing reaches being created by greater amounts of drawdown. The average water velocity through each reservoir will increase. However, it is important to note that each alternative except the dam breaching option maintains a large pool, and that water velocities are not substantially changed through the pools. The increase in the average velocity of the reservoir is most affected by the substantial increase in the free-flowing reach. The drawdown alternatives result in a substantial decrease in average water travel time, based on mathematical modeling using the Corps HEC-2 model (Water Surface Profiles). This was confirmed by measurements taken during the 1992 drawdown test. The dam breaching option results in the greatest decrease in water travel time, essentially returning the river in this reach to almost a near-natural state. The average water travel time ranges from 8 to 18 percent of what it would be at normal pool elevation for flows from 708 m^3/second to 4,531 m^3/second (25,000 cfs to 160,000 cfs).



NOTES:

1. TRAVEL TIMES ON THIS CURVE WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES," (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES; 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN COLUMBIA-SNAKE RIVER CONFLUENCE TO LOWER GRANITE DAM.

2. THIS ALTERNATIVE IS FOR ACHIEVING NEAR FREE FLOW CONDITIONS.

3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

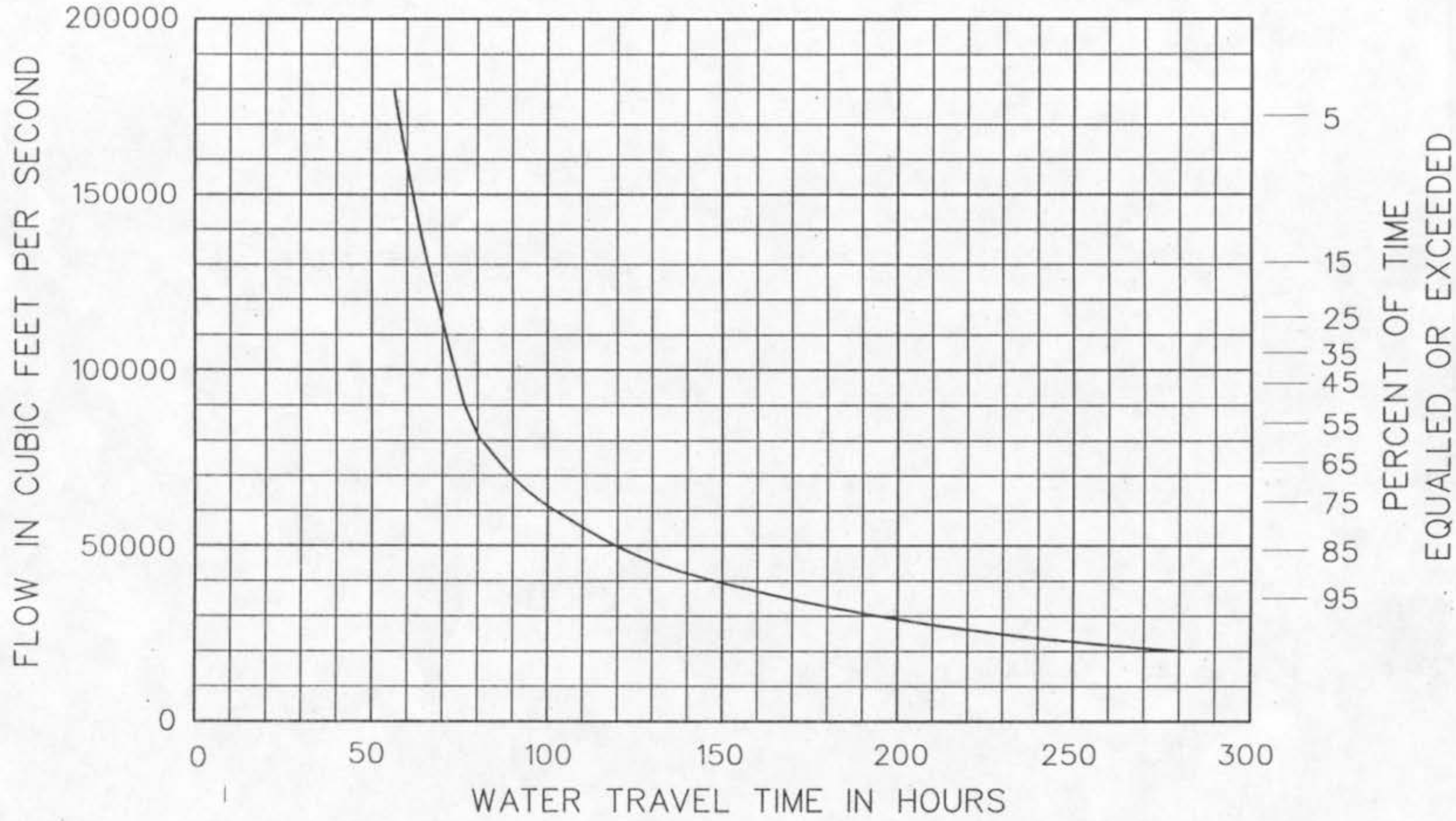
WATER TRAVEL TIME NEAR FREE FLOW

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	21 AUG 1992

A00183

Chart 29-1.



NOTES:

1. TRAVEL TIMES ON THIS CURVE WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES," (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES: 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN COLUMBIA-SNAKE RIVER CONFLUENCE TO LOWER GRANITE DAM.

2. WATER SURFACE ELEVATIONS ARE TO REMAIN AT THE EXISTING SPILLWAY CRESTS WHICH ARE 391, 483, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE AND LOWER GRANITE, RESPECTIVELY.

3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

A00184

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

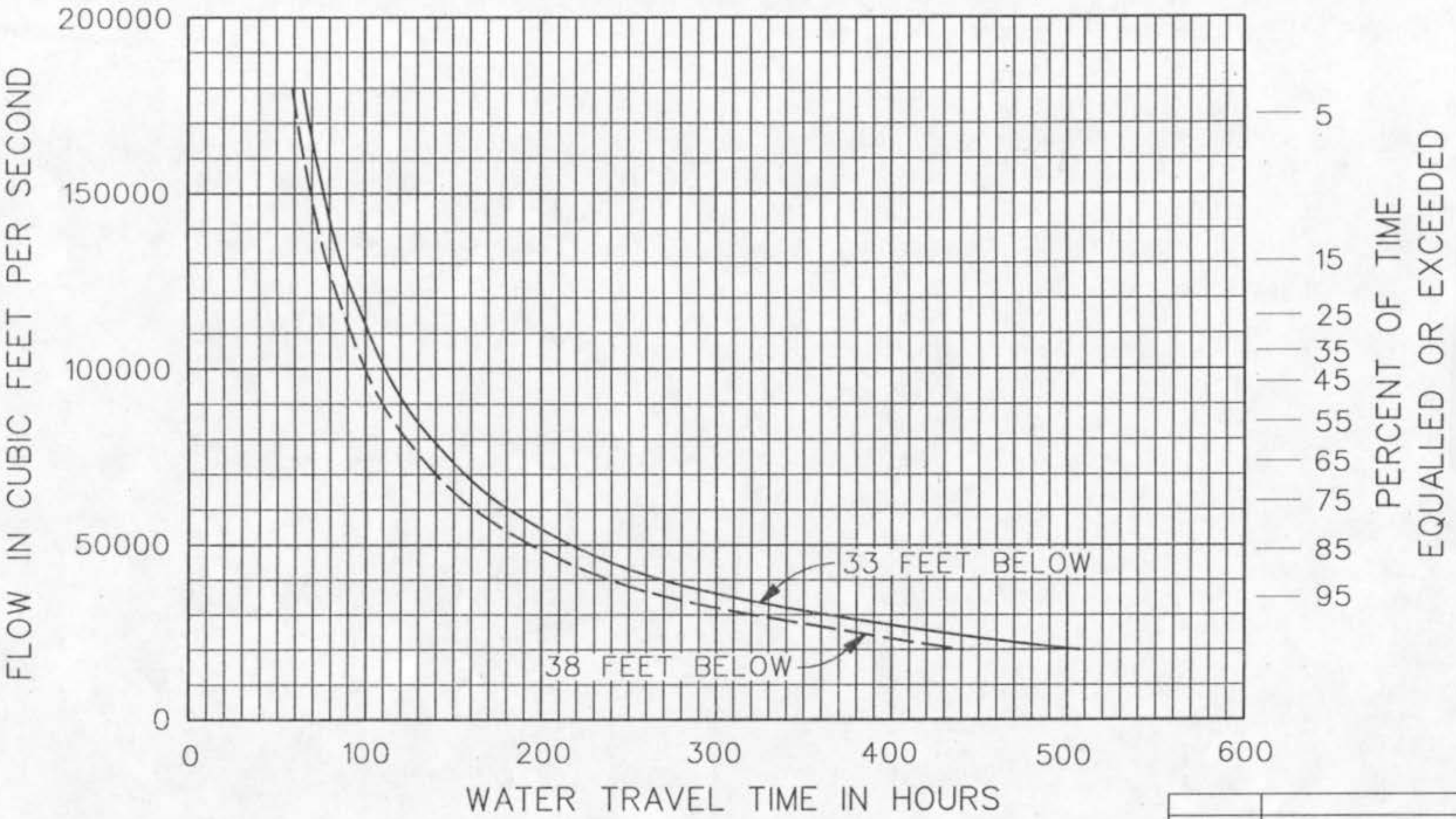
WATER TRAVEL TIME

SPILLWAY CREST

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	21 AUG 1992

Chart 29-2.



NOTES:

1. THESE CURVES WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES," (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES: 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN THE COLUMBIA-SNAKE RIVER CONFLUENCE AND LOWER GRANITE DAM.

2. THIS ALTERNATIVE DRAWS DOWN LOWER MONUMENTAL, LITTLE GOOSE AND LOWER GRANITE RESERVOIRS 33 (38) FEET TO ELEVATIONS 507 (502), 605 (600), AND 705 (700) FEET MSL, RESPECTIVELY, AND ICE HARBOR RESERVOIR 25 FEET TO ELEVATION 415 FEET MSL.

3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

A00185

DATE	REVISION	BY

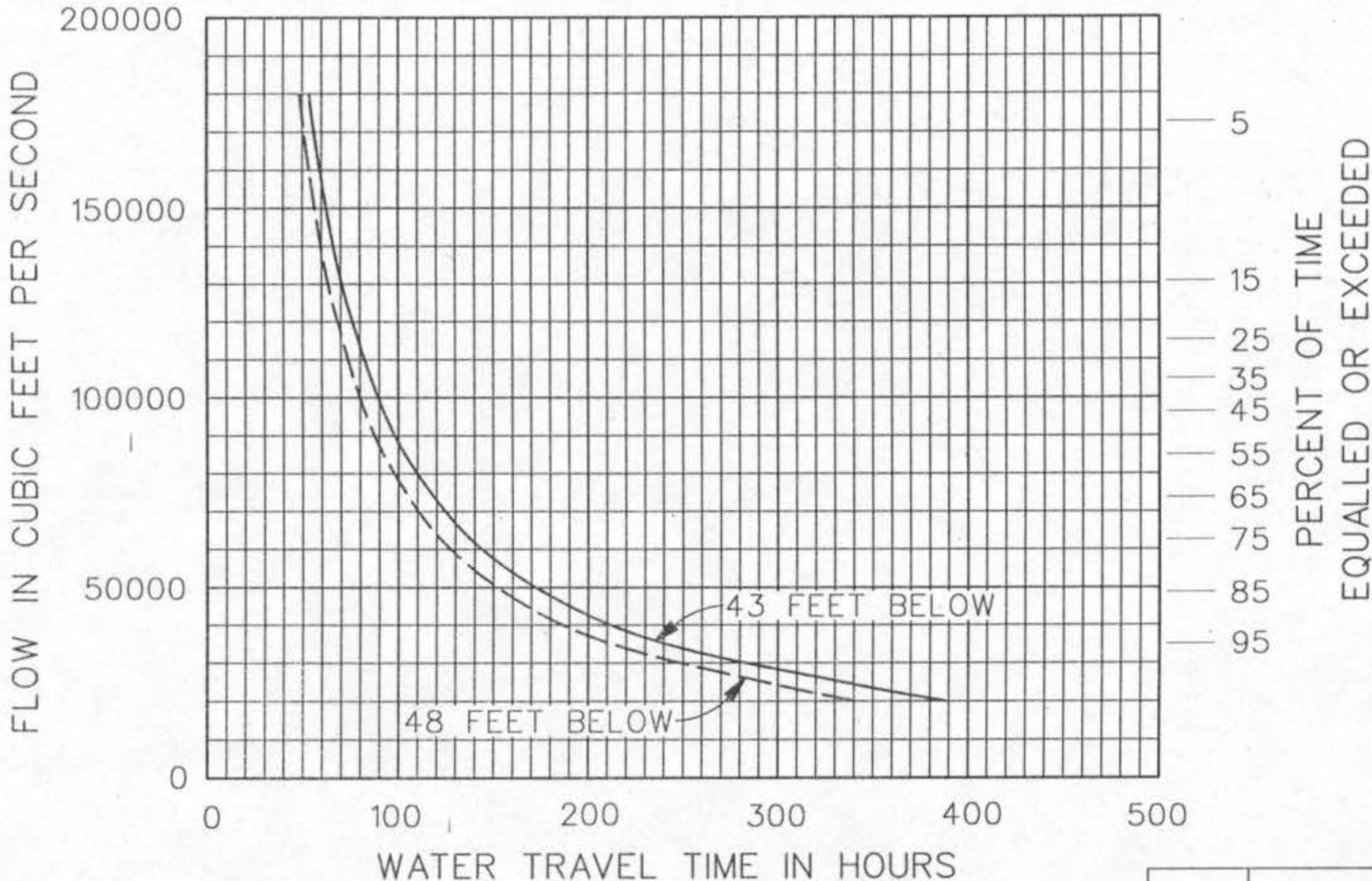
SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

WATER TRAVEL TIME 33 & 38 FEET BELOW NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	21 AUG 1992

Chart 29-3.



NOTES:

1. THESE CURVES WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES," (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES: 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN THE COLUMBIA-SNAKE RIVER CONFLUENCE AND LOWER GRANITE DAM.

2. THIS ALTERNATIVE DRAWS DOWN LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS 43 (48) FEET TO ELEVATIONS 497 (492), 595 (590), AND 695 (690) FEET MSL, RESPECTIVELY, AND ICE HARBOR RESERVOIR 35 FEET TO ELEVATION 405 FEET MSL.

3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

A00186

DATE	REVISION	BY

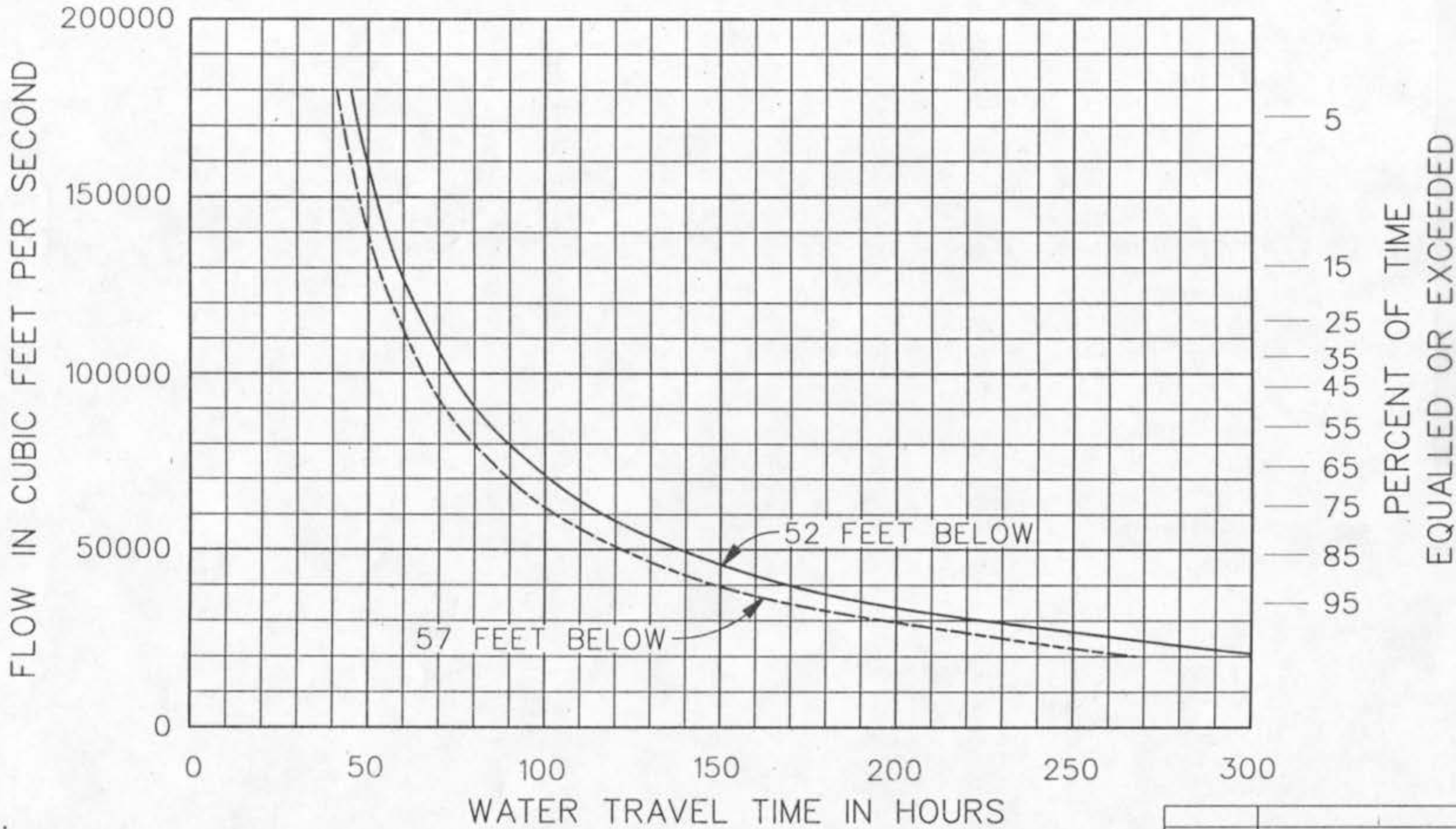
SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

WATER TRAVEL TIME 43 & 48 FEET BELOW NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	25 AUG 1992

Chart 29-4.



NOTES:

1. THESE CURVES WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES," (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES: 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN THE COLUMBIA-SNAKE RIVER CONFLUENCE AND LOWER GRANITE DAM.

2. THIS ALTERNATIVE DRAWS DOWN LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS 52 (57) FEET TO ELEVATIONS 488 (483), 586 (581), AND 686 (681) FEET MSL, RESPECTIVELY, AND ICE HARBOR RESERVOIR 43 FEET TO ELEVATION 397 FEET MSL.

3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

A00187

DATE	REVISION	BY

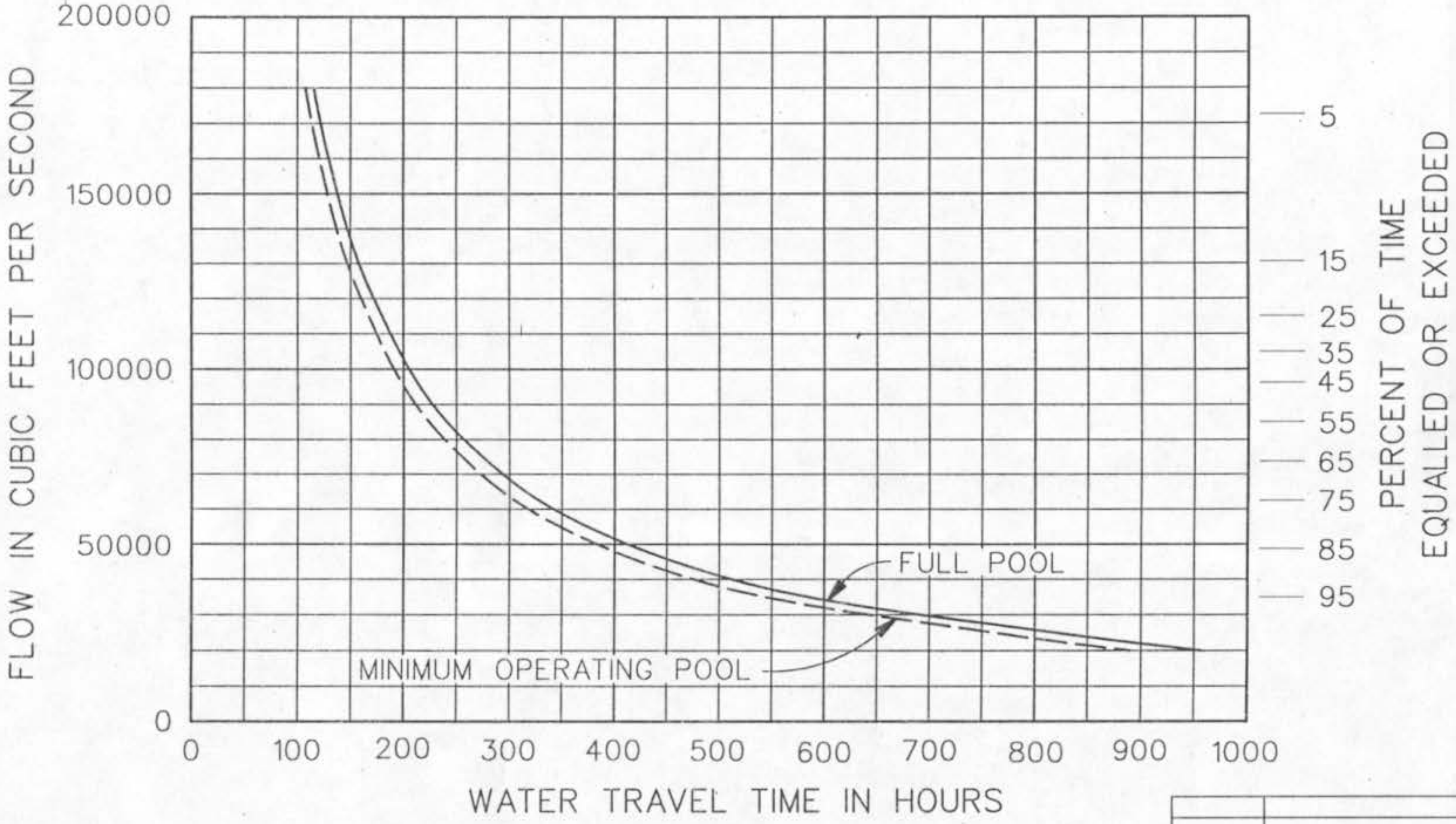
SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

WATER TRAVEL TIME 52 & 57 FEET BELOW NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	21 AUG 1992

Chart 29-5.



NOTES:

1. THESE CURVES WERE COMPUTED USING THE HYDROLOGIC ENGINEERING CENTER PROGRAM "WATER SURFACE PROFILES," (HEC-2). CROSS SECTIONS USED IN THE MODEL WERE DEVELOPED FROM TWO SOURCES: 1) SEDIMENT RANGE DATA FROM RIVER MILE 107.4 (LOWER GRANITE DAM) TO THE SNAKE-CLEARWATER RIVER CONFLUENCE AND 2) 1934 SOUNDING DATA AND TOPOGRAPHIC MAPPING FOR THE REACH BETWEEN THE COLUMBIA-SNAKE RIVER CONFLUENCE AND LOWER GRANITE DAM.

2. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 15 APRIL TO 15 JUNE FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
SNAKE RIVER FROM COLUMBIA RIVER CONFLUENCE TO CLEARWATER RIVER CONFLUENCE

WATER TRAVEL TIME
FULL POOL / MINIMUM
POOL ELEVATIONS

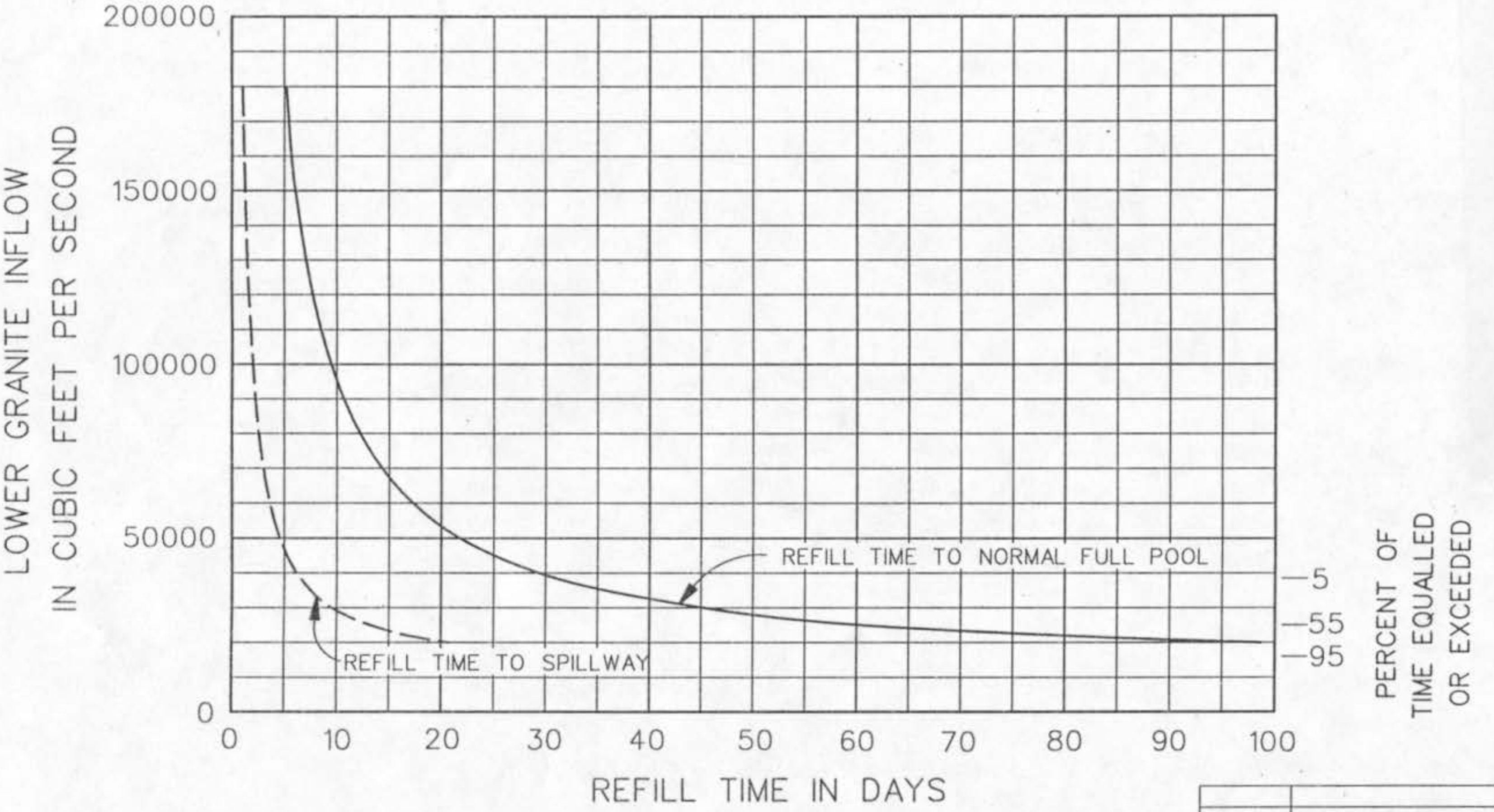
U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

A00188	DESIGNED	DRAWN	DATE
	MAXSON	SCHUSTER	8 OCT 1992

Chart 29-6.

30. Lower Snake River Refill Times

Charts 30-1 through 30-5 present reservoir refill times required to refill the four lower Snake River reservoirs for conditions ranging from near natural freeflow conditions up to drawdown to the project spillway crest elevations.



NOTES:

1. THIS CURVE DEPICTS THE TIME TO REFILL THE FOUR LOWER SNAKE RIVER PROJECTS FROM EXISTING SPILLWAY CRESTS OF 391, 438, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE, RESPECTIVELY, TO NORMAL FULL POOL. THE ORDER OF REFILL IS NOT CONSIDERED.
2. A MINIMUM PROJECT RELEASE OF 11,000 CUBIC FEET PER SECOND IS CONSIDERED IN THE REFILL TIMES.
3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 1 SEPTEMBER THROUGH 31 OCTOBER FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS

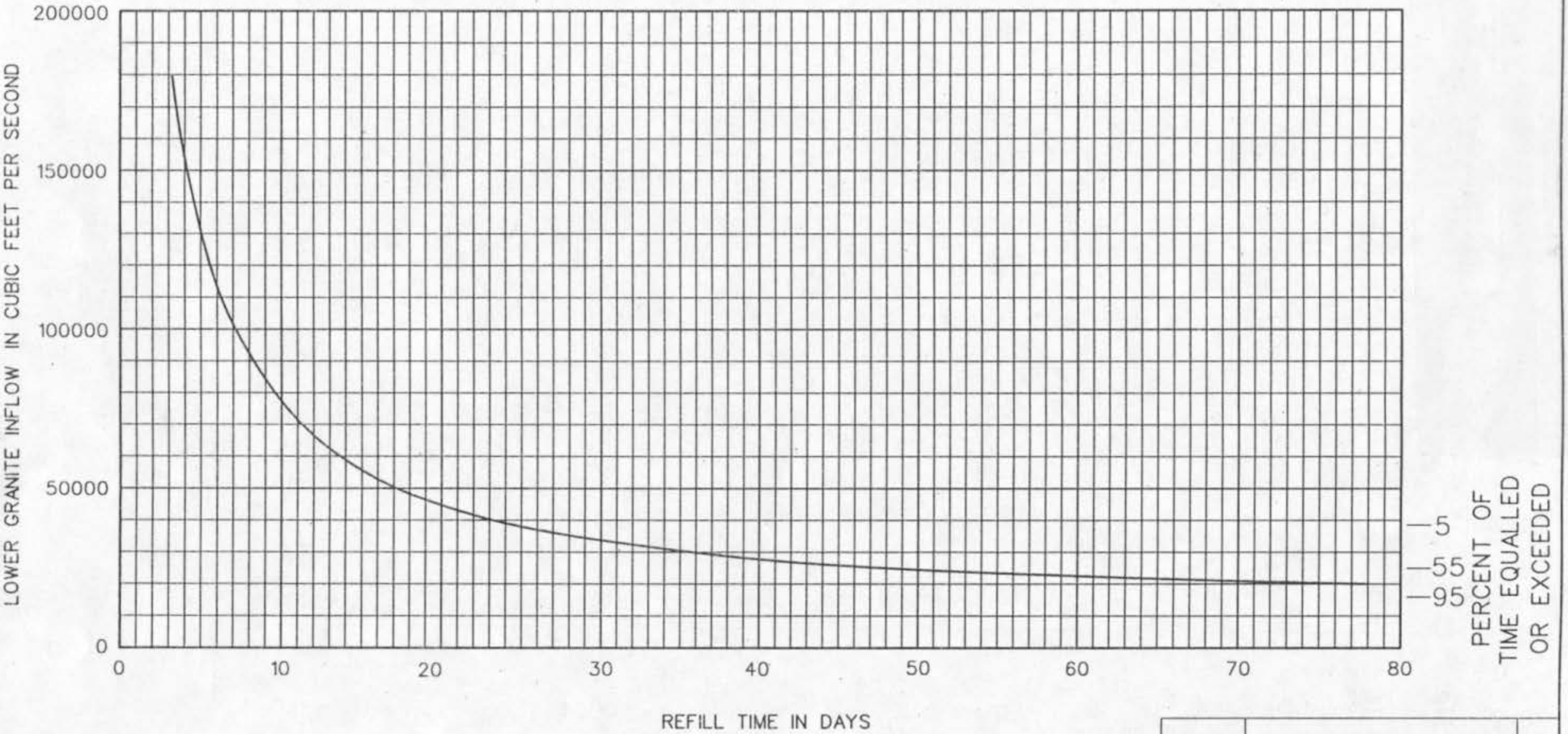
REFILL TIME FROM NEAR NATURAL CONDITION TO NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	13 OCT 1992

A00193

Chart 30-1.



NOTES:

1. THIS CURVE DEPICTS THE TIME TO REFILL THE FOUR LOWER SNAKE RIVER PROJECTS FROM EXISTING SPILLWAY CRESTS OF 391, 438, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE, RESPECTIVELY TO NORMAL FULL POOL. THE ORDER OF REFILL IS NOT CONSIDERED.
2. A MINIMUM PROJECT RELEASE OF 11,000 CUBIC FEET PER SECOND IS CONSIDERED IN THE REFILL TIMES.
3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 1 SEPTEMBER THROUGH 31 OCTOBER FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS

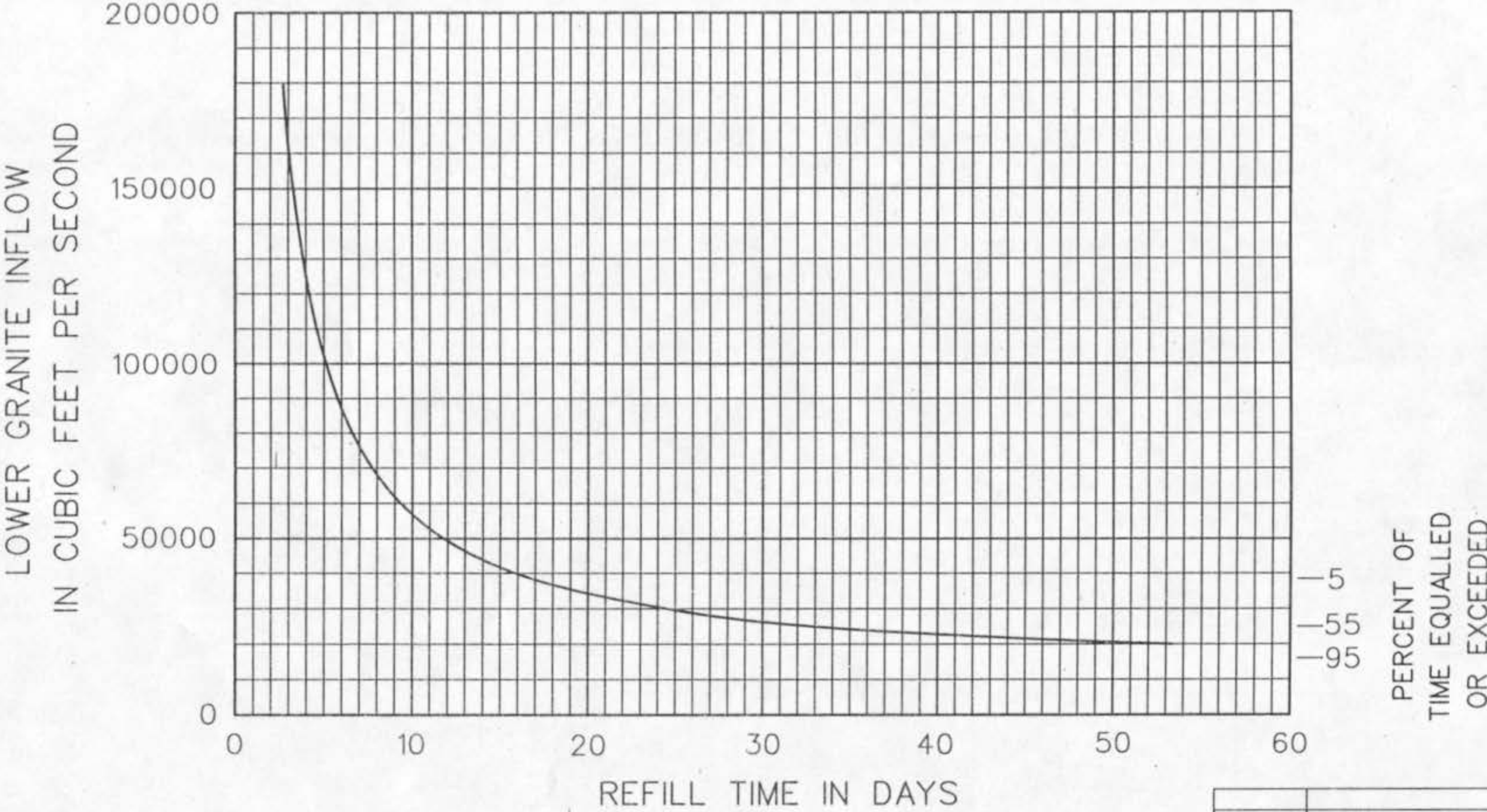
REFILL TIME FROM SPILLWAY CREST TO NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	9 OCT 1992

A00192

Chart 30-2.



NOTES:

1. THIS CURVE DEPICTS THE TIME TO REFILL THE FOUR LOWER SNAKE RIVER PROJECTS FROM EXISTING SPILLWAY CRESTS OF 391, 438, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE, RESPECTIVELY TO NORMAL FULL POOL. THE ORDER OF REFILL IS NOT CONSIDERED.
2. A MINIMUM PROJECT RELEASE OF 11,000 CUBIC FEET PER SECOND IS CONSIDERED IN THE REFILL TIMES.
3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 1 SEPTEMBER THROUGH 31 OCTOBER FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, & LOWER GRANITE RESERVOIRS

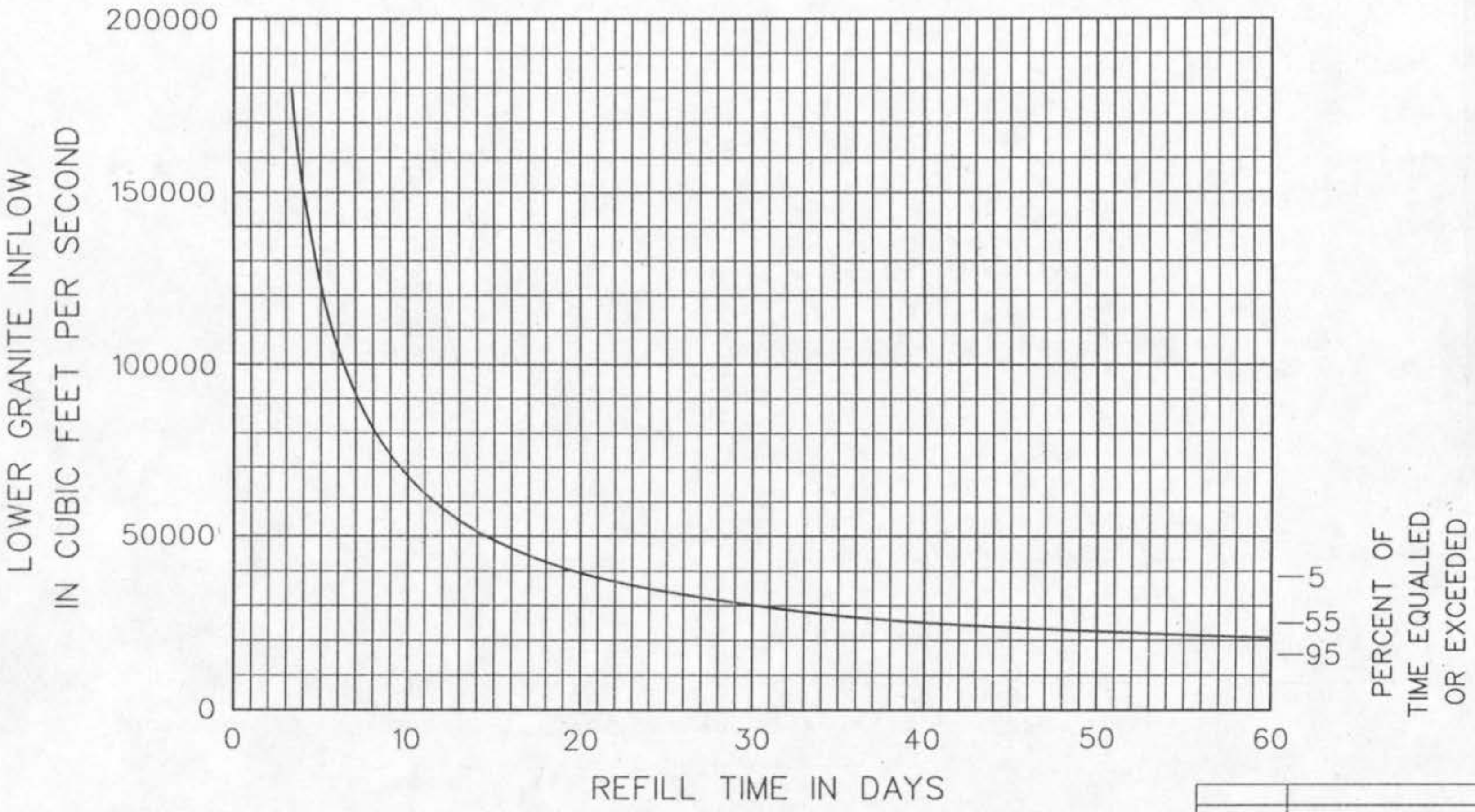
REFILL TIME FROM 33 FEET BELOW TO NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

A00189

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	9 OCT 1992

Chart 30-3.



NOTES:

1. THIS CURVE DEPICTS THE TIME TO REFILL THE FOUR LOWER SNAKE RIVER PROJECTS FROM EXISTING SPILLWAY CRESTS OF 391, 438, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE, RESPECTIVELY TO NORMAL FULL POOL. THE ORDER OF REFILL IS NOT CONSIDERED.
2. A MINIMUM PROJECT RELEASE OF 11,000 CUBIC FEET PER SECOND IS CONSIDERED IN THE REFILL TIMES.
3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 1 SEPTEMBER THROUGH 31 OCTOBER FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS

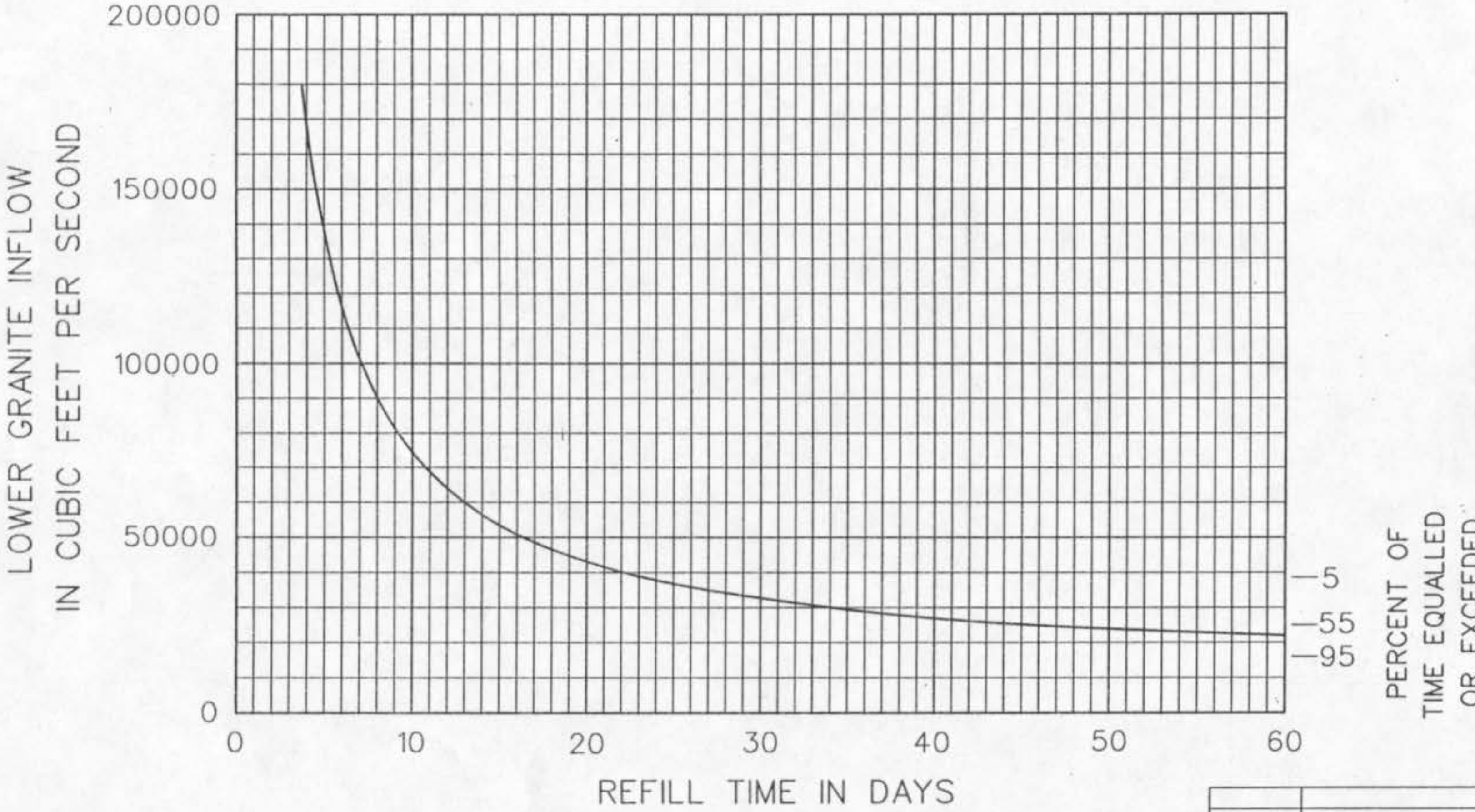
REFILL TIME FROM 43 FEET BELOW TO NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

A00190

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	9 OCT 1992

Chart 30-4.



NOTES:

1. THIS CURVE DEPICTS THE TIME TO REFILL THE FOUR LOWER SNAKE RIVER PROJECTS FROM EXISTING SPILLWAY CRESTS OF 391, 438, 581, AND 681 FEET MSL FOR ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE, RESPECTIVELY TO NORMAL FULL POOL. THE ORDER OF REFILL IS NOT CONSIDERED.
2. A MINIMUM PROJECT RELEASE OF 11,000 CUBIC FEET PER SECOND IS CONSIDERED IN THE REFILL TIMES.
3. DURATION PERCENTAGES WERE COMPUTED FOR LOWER GRANITE INFLOWS FOR 1 SEPTEMBER THROUGH 31 OCTOBER FOR THE PERIOD 1976 THROUGH 1992.

DATE	REVISION	BY

SNAKE RIVER BASIN
SYSTEM CONFIGURATION STUDY
ICE HARBOR, LOWER MONUMENTAL, LITTLE GOOSE, AND LOWER GRANITE RESERVOIRS

REFILL TIME FROM 52 FEET BELOW TO NORMAL FULL POOL ELEVATION

U. S. ARMY ENGINEER DISTRICT
WALLA WALLA - HYDROLOGY BRANCH

DESIGNED	DRAWN	DATE
MAXSON	SCHUSTER	9 OCT 1992

A00191

Chart 30-5.

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32. Glossary

Note: Unless otherwise noted, the sources of information utilized in this glossary are the glossaries contained in either the U.S. Army Corps of Engineers Engineer Manual entitled River Hydraulics, EM-1110-2-1416 (Headquarters, 15 October 1993) or the U.S. Army Corps of Engineers Scour and Deposition in Rivers and Reservoirs (HEC-6) User's Manual (Hydrologic Engineering Center, August 1993).

Aggradation: The geologic process by which stream beds, floodplains, and the bottoms of other water bodies are raised in elevation by the deposition of material eroded and transported from other areas. It is the opposite of degradation.

Alluvial: Pertains to alluvium deposited by a stream or flowing water.

Alluvial Deposit: Clay, silt, sand, gravel, or other sediment deposited by the action of running or receding water.

Alluvial Stream: A stream whose channel boundary is composed of appreciable quantities of the sediments transported by the flow, and which generally changes

Alluvium: A general term for all detrital deposits resulting directly or indirectly from the sediment transported by (modern) streams; thus including the sediments laid down in river beds, floodplains, lakes, fans, and estuaries.

Armoring: The process of progressive coarsening of the bed layer by removal of fine particles until it becomes resistant to scour. The coarse layer that remains on the surface is termed the "armor layer." Armoring is a temporary condition; higher flows may destroy an armor layer and it may reform as flows decrease. Or, simply, the formation of a resistant layer of relatively large particles resulting from removal of finer particles by erosion.

Backwater Curve: Longitudinal profile of the water surface in a stream where the water surface is raised above its normal level by a natural or artificial obstruction.

Bank Migration: Lateral or horizontal movement of the banks of a streamcourse.

Bed Forms: Irregularities found on the bottom (bed) of a stream that are related to flow characteristics. They are given names such as "dunes," "ripples," and "antidunes." They are related to the transport of sediment and interact with the flow because they change the roughness of the stream bed. An analog to stream bed forms are desert sand dunes (although the physical mechanisms for their creation and movement may be different.)

Bed Load: Material moving on or near the stream bed by rolling, sliding, and sometimes making brief excursions into the flow a few diameters above the bed, i.e., "jumping." The term "saltation" is sometimes used in the place of "jumping." Bed load is bed material that moves in continuous contact with the bed; contrast with "suspended load."

Bed Material: The sediment mixture of which the moving bed is composed. In alluvial streams, bed material particles are likely to be moved at any moment or during some future flow condition.

Bed Rock: A general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.

Boulder: A sediment particle having a diameter greater than 256 millimeters.

Boundary Roughness: The roughness of the bed and banks of a stream or river. The greater the roughness, the greater the frictional resistance to flows; and, hence, the greater the water surface elevation for any given discharge.

Calibration: Adjustment of a model's parameters such as roughness or dispersion coefficients so that it reproduces observed prototype data to acceptable accuracy.

Channel: A natural or artificial waterway which periodically or continuously contains moving water.

Clay: A sediment particle having a diameter between 0.00024 and 0.004 millimeters.

Cobble: A sediment particle having a diameter between 64 and 256 millimeters.

Cohesive Sediments: Sediments whose resistance to initial movement or erosion is affected mostly by cohesive bonds between particles.

Colloid: A sediment particle having a diameter less than 0.00024 millimeters.

Concentration of Sediment: The dry weight of sediment per unit volume of water-sediment mixture, i.e. milligrams per liter (mg/l) or parts per million (ppm).

Cross Section: Depicts the shape of the channel in which a stream flows. Measured by surveying the stream bed elevation across the stream on a line perpendicular to the flow. Necessary data for the computation of hydraulic and sediment transport information.

Cross-sectional Area: The cross-sectional area is the area of a cross section perpendicular to the direction of flow beneath the water surface.

Degradation: The geologic process by which stream beds, floodplains, and the bottoms of other water bodies are lowered in elevation by the removal of material from the boundary. It is the opposite of aggradation.

Deposition: The mechanical or chemical processes through which sediments accumulate in a (temporary) resting place. The raising of the stream bed by settlement of moving sediment that may be due to local changes in the flow, or during a single flood event.

Depth of Flow: The depth of flow is the vertical distance from the bed of a stream to the water surface.

Discharge: The discharge, usually abbreviated as "Q," is the volume of a fluid or solid passing a cross section of a stream per unit of time.

Drainage Basin: The area tributary to or draining into a lake, stream, or measuring site. See also Watershed.

Dunes: Bed forms with triangular profile that advance downstream due to net deposition of particles on the steep downstream slope. Dunes move downstream at velocities that are small relative to the streamflow velocity.

Erosion: The wearing away of the land surface by detachment and movement of soil and rock fragments through the action of moving water and other geological agents.

Floodplain: Normally dry land adjacent to a body of water such as a river, stream, lake, or ocean, which is susceptible to inundation by floodwaters.

Flow Duration Curve: A measure of the range and variability of a stream's flow. The flow duration curve represents the percent of time during which specified flow rates are exceeded at a given location. This is usually presented as a graph of flow rate (discharge) versus percent of time that flows are greater than, or equal to, that flow.

Fluvial: (1) pertaining to streams. (2) growing or living in streams or ponds. (3) produced by river action, as a fluvial plain.

Fluvial Sediment: Particles derived from rocks or biological materials which are transported by, suspended in, or deposited by streams.

Gaging Station: A selected cross section of a stream channel where one or more variables are measured continuously or periodically to record discharge or other parameters.

Geology: A science that deals with the physical history of the earth, especially as recorded in rocks and landforms.

Geomorphology: The study of landform development under processes associated with running water.

Gravel: A sediment particle having a diameter between 2 and 64 millimeters.

Hydraulic Depth: The hydraulic depth is the ratio of cross-sectional area to top width at any given elevation.

Hydraulic Radius: The hydraulic radius is the ratio of cross-sectional area to wetted perimeter at any given elevation.

Hydraulics: The study and computation of the characteristics, e.g. depth (water surface elevation), velocity, and slope of water flowing in a stream or river.

Hydrograph: A graph showing, for a given point on a stream or channel, the discharge, water surface elevation, stage, velocity, available power, or other property of water with respect to time.

Hydrology: The study of the properties, distribution, and circulation of water on the surface of the land, in the soil, and in the atmosphere.

Manning's *n* value: *n* is a coefficient of boundary roughness, *n* accounts for energy loss due to the friction between the bed and the water. In fluvial hydraulics (moveable boundary hydraulics), the Manning's *n* value usually includes the effects of other losses, such as grain roughness of the moveable bed, form roughness of the moveable bed, bank irregularities, vegetation, bend losses, and junction losses. Contraction and expansion losses are not included in Manning's *n*, and are typically accounted for separately.

Mathematical Model: A model that uses mathematical expressions (i.e., a set of equations, usually based upon fundamental physical principles) to represent a physical process.

Mean Velocity: The mean velocity is the discharge divided by the area of water at a cross section.

Model: A representation of a physical process or thing that can be used to predict the process's or thing's behavior or state.

Particle Size: A linear dimension, usually designated as "diameter," used to characterize the size of a particle. The dimension may be determined by any of several different techniques, including sedimentation sieving, micrometric measurement, or direct measurement.

Prototype: The full-sized structure, system, process, or phenomenon being modeled.

Qualitative: A relative assessment of a quantity or amount.

Quantitative: An absolute measurement of a quantity or amount.

Reach: (1) the length of a channel uniform with respect to discharge, depth, area, and slope; e.g., "typical channel reach" or "degrading reach," etc., (2) the length of a stream between two specified gaging stations, control points, or computational points.

Reservoir: An impounded body of water or controlled lake where water is collected and stored.

Ripple: Small triangular-shaped bed forms that are similar to dunes, but have much smaller heights and lengths.

Runoff: Flow that is discharged from an area by stream channels; sometimes subdivided into surface runoff, groundwater runoff, and seepage.

Sand: A sediment particle having a diameter between 0.0625 and 2 millimeters.

Scour: The enlargement of a cross section by the removal of boundary material through the action of the fluid in motion.

Sediment: (1) particles derived from rocks or biological materials that have been transported by a fluid. (2) solid material suspended in or settled from water. A collective term meaning an accumulation of soil, rock, and mineral particles transported or deposited by flowing water.

Sedimentation: Consists of five (5) fundamental processes: (1) weathering, (2) erosion, (3) transportation, (4) deposition, and (5) diagenesis, or consolidation into rock. Also refers to the gravitational settling of suspended particles that are heavier than water.

Sediment Yield: The total sediment outflow from a drainage basin in a specific period of time. It includes bed load as well as suspended load, and is usually expressed in terms of mass or volume per unit of time.

Shear Force: The shear force is the shear developed on the wetted area of the channel and it acts in the direction of flow. This force per unit wetted area is called the shear stress.

Shear Stress: Frictional force per unit of stream bed area exerted on the stream bed by the flowing water. An important factor in the movement of bed material.

Silt: A sediment particle having a diameter between 0.004 and 0.0.0625 millimeters.

Sorting: The dynamic process by which sediment particles having some particular characteristic (such as similarity of size, shape, or specific gravity) are naturally selected and separated from associated but dissimilar particles by the agents of transportation.

Stage: The stage is the vertical distance from any selected and defined datum to the water surface.

Stage-Discharge (Rating) Curve: Defines a relationship between discharge and water surface elevation at a given location.

Stream Discharge: The volume of flow passing a stream cross section in a unit of time.

Stream Gage: A device that measures and records flow characteristics such as water discharge and water surface elevation at a specific location on a stream. Sediment transport measurements are usually made at stream gate sites.

Suspended Bed Material Load: That portion of the suspended load that is composed of particle sizes found in the bed material.

Suspended Load: Includes both suspended bed material load and wash load. Sediment that moves in suspension is continuously supported in the water column by fluid turbulence.

Tail Water: The water surface elevation downstream from a structure, such as below a dam, weir, or drop structure.

Thalweg: The line following the lowest part of a valley, whether under water or not. Usually is the line following the deepest part, or middle, of the bed or channel of a river.

Top Width: The width of a stream section at the water surface, it varies with stage in most natural channels.

Total Sediment Load (Total Load): Includes bed load, suspended bed material load, and wash load. In general, total sediment load cannot be calculated or directly measured.

Transportation (Sediment): The complex processes of moving sediment particles from place to place. The principal transporting agents are flowing water and wind.

Turbidity: Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the sample. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, and plankton and other microscopic organisms. (this description approved by Standards Methods Committee, American Public Health Association, 1994)

Wash Load: That part of the suspended load that is finer than the bed material. Wash load is limited by supply rather than hydraulics. What grain sizes constitute wash load varies with flow and location in the stream. Sampling procedures that measure suspended load will include both wash load and suspended bed material load. Normally, that is of sediment particles smaller than 0.062 millimeters.

Water Column: An imaginary vertical column of water used as a control volume for computational purposes. Usually the size of a unit area and as deep as the depth of water at that location in the river.

Watershed: A topographically defined area drained by a river/stream or system of connecting rivers/streams such that all outflow is discharged through a single outlet. Also called a drainage area.

Wetted Perimeter: The length of wetted contact between a stream of flowing water and its containing channel, measured in a direction normal (perpendicular) to the flow.