DEPARTMENT OF THE ARMY
U.S. ARMY CORPS OF ENGINEERS, NORTHWESTERN DIVISION
PO BOX 2870
PORTLAND, OR 97208-2870

CENWD-PDW (1110-2-240b) 31 October 2022

MEMORANDUM FOR: Kevin Shaffer, Chief, CENWS-EN-HH-WM

SUBJECT: Approval of the Water Control Manual Update for Grand Coulee Dam

1. Reference: USACE, ER-1110-2-8156, Preparation of Water Control Manuals

2. Recommendation: Thank you for your efforts in working with the Bureau of Reclamation in the updating of the water control manual for the Bureau of Reclamation's Grand Coulee Dam Project. The updated manual is approved.

3. Point of Contact: If you have any additional questions regarding this matter, please contact Kasi Whorley, CENWD-PDW Hydrologic Engineering Team Lead, at [redacted]

Juliet H. Ammann
for STEVEN B. BARTON, P.E.
Chief, Columbia Basin Water
Management Division

CF:
CECW-CE (Smith)
CENWD-PDW-R (Ammann, Marshall)
CENWD-PDW-H (Proctor, Whorley)
CENWD-RBT (Otero)

GRAND COULEE DAM
COLUMBIA RIVER, WASHINGTON

WATER CONTROL MANUAL

US Army Corps
of Engineers
Seattle District

October 2022

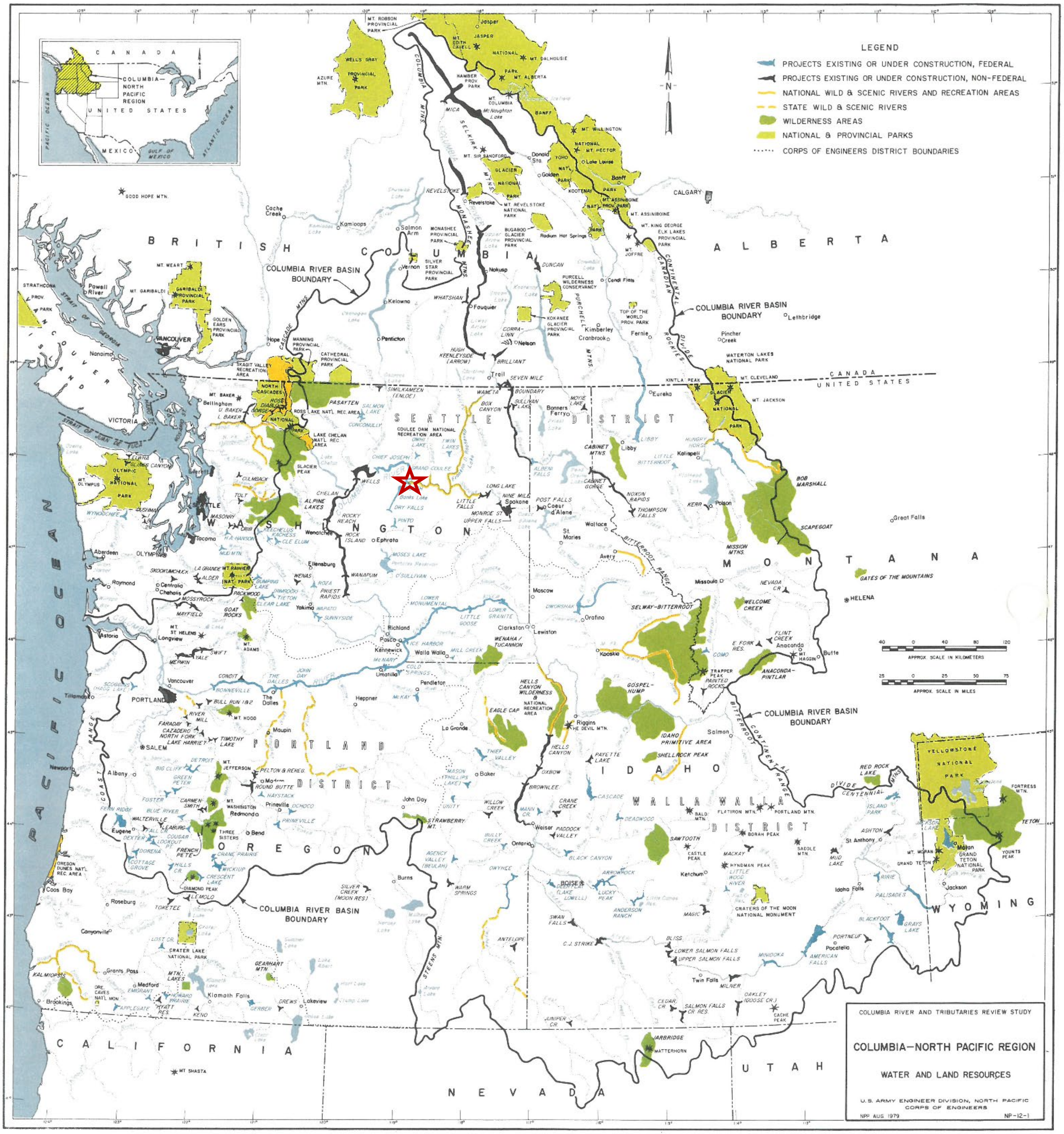
WATER CONTROL MANUAL

GRAND COULEE DAM
COLUMBIA RIVER, WASHINGTON

U.S. ARMY CORPS OF ENGINEERS, SEATTLE DISTRICT
Seattle, Washington

October 2022

AERIAL VIEW OF GRAND COULEE DAM ON THE COLUMBIA RIVER, WASHINGTON



MAP - COLUMBIA – NORTH PACIFIC REGION. Grand Coulee Dam indicated by red star. Detailed map of Lake Roosevelt above Grand Coulee Dam is provided in Plate 2-1.

NOTICE TO USERS OF THIS MANUAL

Regulations specify that this water control manual be published in loose-leaf form and only those portions requiring changes will be revised and distributed. This copy should be preserved in good condition so that inserts can be made to keep the manual current.

REVISIONS TO THIS MANUAL

As a continuing program, portions of this manual may occasionally be revised and updated. Pertinent information will be revised when changes become evident; likewise, changes in the plan of operation or in the project development will be reported. Whenever revisions are made, new pages containing the revised material will be issued to holders of the manual.

WATER MANAGEMENT ASSISTANCE PERSONNEL

In the event that unusual conditions arise during duty or non-duty hours, contact can be made by telephone using the following numbers:

Bureau of Reclamation, Boise, Idaho Office		**Telephone No.:**
Water Management Operations Team 24-hour number		
	Cell	[redacted]
Joel Fenolio, Supervisory Civil Engineer, Water Management		
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Coleman Smith, Project Power Manager	Office	[redacted]
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	Office Cell	[redacted]
Powerhouse Operators – Grand Coulee Dispatch Supervisors		
	Office	[redacted]
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Reservoir Control Center (CENWS-RCC)*	Information	[redacted]
Travis Ball, Chief, Hydrology & Hydraulics Branch		
	Office Cell	[redacted]
Kevin Shaffer, Chief, Water Management Section		
	Office Cell	[redacted]
Leon Basdekas, Senior Water Manager, Upper Columbia Basin		
	Cell	[redacted]

*CENWS-RCC is located in the Water Management Section

Seattle District Operations Division		
Amy Reese, Chief	Office	[redacted]

United States Army Corps of Engineers, Northwestern Division		**Telephone No.:**
Reservoir Control Center, Portland, OR, (CENWD-PDW-R)		
Information		[redacted]
Julie Ammann, Chief	Office	[redacted]
Aaron Marshall, Lead, Regulation Unit	Office Cell	[redacted]

TABLE OF CONTENTS

TABLES

PLATES

EXHIBITS

Number

CHARTS

Number

FIGURES

Number

ACRONYMS AND ABBREVIATIONS

AA	Action Agencies
AF	Acre-feet
BiOp	Biological Opinion
BPA	Bonneville Power Administration
CBT	Columbia Basin Telecommunications Network
CENWD	Northwestern Division, U.S. Army Corps of Engineers
CENWD-PDW	Water Management, Corps, Northwestern Division
CENWD-PDW-H	Hydrologic Engineering and Power Branch, Corps, Northwestern Division
CENWD-PDW-R	Reservoir Regulation, Northwestern Division
CENWP	Portland District, U.S. Army Corps of Engineers
CENWS	Seattle District, U.S. Army Corps of Engineers
CENWW	Walla Walla District, U.S. Army Corps of Engineers
cfs	Cubic Feet per Second
CHPS	Community Hydrologic Prediction System
COOP	Continuity of Operations
Corps	U.S. Army Corps of Engineers
CROHMS	Columbia River Operational Hydromet Management
CTCR	Confederated Tribes of the Colville Reservation
CWMS	Corps Water Management System
DA	Data Acquisition
DCP	Drought Contingency Plan
DD	Data Dissemination
DSPR	Dam Safety Priority Rating
EAP	Emergency Action Plan
El	Elevation
ESA	Endangered Species Act
ESP	Ensemble Streamflow Prediction
FCRPS	Federal Columbia River Power System
GDACS	General Data Acquisition and Control System
GOES	Geostationary Operational Environmental Satellite System
GCL	Grand Coulee Dam
hp	Horsepower
kVA	Kilovolt-ampere
kW	Kilowatt
LRISRP	Lake Roosevelt Incremental Storage Release Project
mod	motor operated disconnect
MW	Megawatt
NAVD	North American Vertical Datum
NEPA	National Environmental Policy Act
NFP	Normal Full Pool
NGVD	National Geodetic Vertical Datum
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPD	North Pacific Division (former usage)
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NWPCC	Northwest Power and Conservation Council
NWPP	Northwest Power Pool (former usage)

NWRFC	Northwest River Forecast Center
PNCA	Pacific Northwest Coordination Agreement
PUD	Public Utility District
RCC	Reservoir Control Center
RFC	River Forecast Center
RM	River Mile
RWCDS	Regional Water Control Data System
SFTP	Secure File Transfer Protocol
SNOTEL	Snow Telemetry
SOP	Standard Operating Procedure
SSARR	Streamflow Synthesis & Reservoir Routing
TDG	Total Dissolved Gas
TMT	Technical Management Team
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WCDS	Water Control Data System
WCM	Water Control Manual
WDFW	Washington Department of Fish and Wildlife
WPP	Western Power Pool
WSF	Water Supply Forecast
WSRFS	National Weather Service River Forecast System

PERTINENT DATA

LOCATION OF DAMSITE

County, State.......... Grant County, Washington
River.......... Columbia River
Distance above Mouth of Columbia River .... 596.9 RM
Distance above Chief Joseph Dam.......... 51.0 RM

HYDROLOGIC DATA

Drainage Area .... 74,700 mi^2
Average Annual Discharge (1942-2020; 78 years).......... 108,600 cfs
Minimum Daily Discharge (05/14/2001)[1]/, regulated .... 20,600 cfs
Maximum Recorded Discharge (06/12/1948).......... 638,000 cfs
Maximum Regulated Peak Discharge (06/27/1967) .... 418,000 cfs

HYDRAULIC DATA

Minimum Normal Pool Elevation .... El 1,208 ft
Average Annual Minimum Pool Elevation.......... El 1,241 ft
Normal Full Pool Elevation .... El 1,290 ft
Maximum Normal Flood Control Pool. .... El 1,290 ft
Minimum Recorded Reservoir Elevation (1973)[1] .... El 1,156.7 ft
Maximum Recorded Reservoir Elevation (1943,1945,1976).......... El 1,290.4 ft
Minimum Flow at Grand Coulee .... *no minimum*
Maximum Tailwater Hourly Drawdown Limits at Grand Coulee.......... *See Section 7.02*
Maximum Spillway Discharge at El 1,290 ft. .... 935,000 cfs
Maximum Outlet Works Discharge[2] at El 1,290 ft .... 191,920 cfs
Maximum Combined Hydraulic Capacity of Left Powerhouse, Right Powerhouse, and Nathaniel Washington Power Plant at El 1,290 ft .... 280,000 cfs

RESERVOIR STORAGE

POOL NAME	ELEVATION	GROSS STORAGE[3] ACRE FEET
Minimum Operating Pool	El 1,208 ft	4,365,786
Normal Full Pool (NFP)	El 1,290 ft	9,715,346
Top of Inactive Storage Pool	El 1,208 ft	4,365,786

[1] Minimum discharges and forebay elevations listed above are the lowest since the initial filling of the reservoir. Lower discharges and elevations during the initial reservoir filling are not reported because they are unrepresentative of the project's present operation.

[2] Outlet works are not intended for use if flow over the spillway gates is greater than 2 feet.

[3] Reference Table 2-1 in the table section of this manual for storage contents. No embankment storage is included in this data.

All elevations in this manual are referenced to National Geodetic Vertical Datum (NGVD) of 1929 unless noted otherwise

POOL STORAGE CONTENTS

POOL NAME	ELEVATION RANGE ft	STORAGE AF
Gross Storage	El 865 to El 1,321.8	12,516,080
Active Joint Use Storage	El 1,208 to El 1,290	5,349,560
Inactive Storage	El 1,026 to El 1,208	4,055,742
Dead Storage	El 865 to El 1,026	310,044

LAKE SURFACE AREA AND LENGTH

Surface area:
- at El 1,290 ft .... 81,991 acres
- at El 1,208 ft .... 47,758 acres
- at El 1,026 ft .... 6,728 acres

Reservoir Length .... 187 mi

DAM

Type .... Concrete Gravity
Height .... 550 ft
Upstream Radius .... 652.13 ft
Top of Dam Elevation[4] .... 1,311.08 ft
Crest Length .... 5,223 ft
Width At Top of Dam .... 41.42 ft
Maximum Base Width .... 500 ft

SPILLWAY SEGMENT

Type .... Overflow, Drum Gate Controlled
Location .... Center of Main Dam
Number of Drum Gates 11
Crest elevation[5] .... El 1,260 ft
Length .... 1,650 ft
Control .... 28 ft high x 135 ft wide Drum Gate
Maximum Rise of Drum Gates .... 28 ft
Maximum Discharge at El 1,290 ft. .... 935,000 cfs

OUTLET WORKS

Number 40
Type (each) .... 8.5 ft dia. steel lined outlet conduits with trash racks
Control (each) .... Tandem Ring-Seal Gates
Intake Center Line Elevation .... El 1,036.67 ft & El 1,136.67 ft
Invert Elevation of lower tier outlet tubes .... El 1,032.5 ft
Invert Elevation of upper tier outlet tubes .... El 1,132.5 ft
Max. Discharge at El 1,290 ft .... 191,920 cfs

[4] Top of parapet wall elevation is 1,314.58 ft
[5] Lowest elevation at which drum gates can be used is 1265.5 feet (with flashboards)

HYDROELECTRIC FACILITIES

LEFT POWERHOUSE

Location..Downstream toe of Dam, West Side of the Spillway
Maximum Output (9 units at NFP plus 3 station service units)...1,155 MW

RIGHT POWERHOUSE

Location..Downstream toe of Dam, East Side of the Spillway
Maximum Output (9 units at NFP)...1,125 MW

NATHANIEL WASHINGTON POWER PLANT

Location..Downstream Face of the Forebay, East Side of the River
Maximum Output (6 units at NFP)...4,215 MW

JOHN W. KEYS III PUMP-GENERATING PLANT

Location...............................West Side of the Reservoir, Immediately Upstream of the Left Abutment
Maximum Output (6 units at NFP)...314 MW

PENSTOCKS

Number (Left Powerhouse, Right Powerhouse, Washington Plant, Keys Plant)...................30 (9, 9, 6, 6)
Intake Center Line Elevation for Left and Right Powerhouses ....El 1,041 ft
Maximum Diameter for Left and Right Powerhouses...18 ft
Length for Left and Right Powerhouses .... 322 ft
Intake Center Line Elevation for Washington Power Plant ....El 1,140 ft
Maximum Diameter for Washington Power Plant..40 ft
Length for Washington Power Plant.. 170.75 ft
Penstock Angle with Horizontal for Washington Power Plant... 45 degrees

VERTICAL DATUM CONVERSION

Unless noted otherwise, elevations in this Water Control Manual are given in the vertical datum NGVD29. The following table lists the conversion factor used to convert elevations from NGVD29 to NAVD88 at selected locations. To convert from NGVD29 to NAVD88, add the conversion factor to the elevation. Conversion factors were calculated using the VERTCON grid in ArcGIS from the National Geodetic Survey of the National Oceanic and Atmospheric Administration (NOAA).

	Conversion Factor
Location	**Feet**
Grand Coulee Dam, Top of Dam	3.93
Lake Roosevelt at Keller Ferry Dock (North)	4.16
Lake Roosevelt at Lincoln	3.92
Lake Roosevelt at Inchelium Ferry Dock	3.97
Lake Roosevelt at Colville River	4.09
Columbia River at International Boundary	4.04

SECTION 1. INTRODUCTION

<u>1.01 Authorization for Manual.</u> This manual is prepared in accordance with applicable policies, regulations, and laws regarding the preparation of Water Control Manuals including where applicable direction pursuant to Section 7 of the Flood Control Act of 1944 (33 U.S.C 709). Specific U.S. Army Corps of Engineer Regulations and Manuals used to prepare the manual include the following:

- **ER 1110-2-240, Water Control Management, paragraph 2-4.c.(3)**, dated 30 May 2016, which assigns to District Engineers the responsibility for development of plans and manuals for operation of reservoirs.
- **EM 1110-2-3600, Management of Water Control Systems**, dated 10 October 2017, which provides technical guidance on management and operation of water control systems and general guidance on content of Water Control Manuals (WCM).
- **ER 1110-2-8156, Preparation of Water Control Manuals**, dated 30 September 2018, which provides specifications on WCM content and format.
- **NWDR 1110-2-6, Deviation Requests for Approved Water Control Manuals**, dated 1 May 2015, provides guidelines concerning deviations from approved WCMs and delegates deviation authority to the chief, Columbia Basin Water Management Division (CENWD-PDW).
- **ER 1110-2-8160, Policies for Referencing Project Elevation Grades to Nationwide Vertical Datums,** establishes U.S. Army Corps of Engineers policies for referencing project elevation grades to nationwide vertical datums established by the U.S. Department of Commerce and is a requirement in ER 1110-2-8156.

1.02 Purpose and Scope. This manual presents the reservoir regulation plan for Grand Coulee Dam (GCL) which is owned and operated by the Bureau of Reclamation. This manual shall be used as a reference document for higher authority and as a guidance manual for Corps and Reclamation staff involved in project activities. Detailed information describing project features, data collection facilities, forecasting procedures, reservoir regulation plans, and the effects of regulation are provided in this manual.

1.03 Related Manuals and Reports.

- "The Columbia River Basin Master Water Control Manual," prepared by the Corps' Northwestern Division (NWD), dated December 1984.
- "Columbia River System Operations – Final Environmental Impact Statement", dated July 2020. Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers.
- "Columbia River System Operations – Environmental Impact Statement Record of Decision", dated September 2020. Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers.
- "Grand Coulee Dam Water Control Manual", dated April 1985. U.S. Army Corps of Engineers, Seattle District. This manual supersedes the 1985 WCM.
- "Columbia River Basin Water Management Plan," Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers, developed annually.
- Columbia River Treaty Flood Control Operating Plan, U.S. Army Corps of Engineers, Northwestern Division, North Pacific Region, For the United States Entity, May 2003.
- Supplemental Consultation on Remand for Operation of the Federal Columbia River Power System, 11 Bureau of Reclamation Projects in the Columbia Basin and ESA

Section 10(a)(I)(A) Permit for Juvenile Fish Transportation Program," National Marine Fisheries Service, 20 May 2010. (2010 Supplemental BiOp)

- "Endangered Species Act - Section 7 Consultation Biological Opinion U.S. Fish and Wildlife Service Reference: 01EWFW00-2017-F-1650, Columbia River System Operations and Maintenance of 14 Federal Dams and Reservoirs," United States Fish and Wildlife Service, 24 July 2020.
- "Endangered Species Act Section 7(a)(2) Biological Opinion, and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for the Continued Operation and Maintenance of the Columbia River System," National Marine Fisheries Service, 24 July 2020.
- "Water Reliability in the West – 2021 SECURE Water Act Report", dated January 2021. Reclamation (Bureau of Reclamation). Prepared for United States Congress. Denver, CO: Bureau of Reclamation, Policy and Administration.
- "Grand Coulee, Lake Roosevelt – Water Quality Report", CRSO EIS Supporting Document, dated July 2020. U.S. Army Corps of Engineers – Northwestern Division, Bureau of Reclamation – Pacific Northwest Region.
- "Grand Coulee, Lake Roosevelt – Sediment Quality Report", CRSO EIS Supporting Document, dated August 2020. U.S. Army Corps of Engineers – Northwestern Division, Bureau of Reclamation – Pacific Northwest Region.
- "Record of Decision for Upper Columbia Alternative Flood Control and Fish Operations – Final Environmental Impact Statement", dated August 2009. Reclamation (Bureau of Reclamation).

- "Report on the Columbia Basin Project on the Columbia River," dated May 10, 1945. U.S. Department of the Interior.
- "The Columbia Basin Project", dated 1998. Simonds, Joe. Reclamation (Bureau of Reclamation History Program).
- "1941 Order of Approval in the Matter of the Application of the Government of the United States for Approval of the Construction and Operation of the Grand Coulee Dam and Reservoir," International Joint Commission, 15 December 1941.
- Design memoranda, operating manuals and other reports of interest concerning the project are available in the Reclamation offices in Boise, Idaho and Denver, Colorado.

1.04 Project Owner. GCL is owned by the U.S. Bureau of Reclamation (Reclamation).

1.05 Operating Agency. GCL is a multiple-purpose water resource project that is operated by the U.S. Bureau of Reclamation (Reclamation). The facility is staffed by Reclamation personnel.

1.06 Regulating Agency. Section 7 of the Flood Control Act of 1944 directs the Secretary of the Army to prescribe regulations for the use of storage allocated for flood control (flood risk management in today's terminology). The responsibility for prescribing such regulations governing the use of storage allocated for flood risk management at GCL is delegated to the Corps' Northwestern Division (NWD). The NWD coordinates and cooperates with many other agencies and groups to accomplish effective flood control regulation. Flood risk management regulation for GCL is implemented by the Division Reservoir Control Center (CENWD-PDW-R) in conjunction with Reclamation's water management staff in the Boise, Idaho office. Details of this coordination are discussed in the Master Water Control Manual and in this water control manual. Other than flood risk management, regulation for all other purposes at GCL is the responsibility of Reclamation.

<u>1.07 Vertical Datum.</u> Per the U.S. Army Corps of Engineers Engineering Regulations listed above, structures for inland flood risk management, navigation, and water control systems (to include levees, floodwalls, multipurpose hydropower projects, locks and dams, and non-tidal inland navigation systems) designed or constructed for flood protection or navigation clearance grades, hydraulic or hydrodynamic water surface profiles, river or pool stages, and stream gages in inland flood risk and water control systems shall be accurately referenced to the NSRS (e.g., NAVD88). For clarity in this document, vertical elevations listed in this manual are referenced to the original project vertical datum of NGVD 1929 unless noted otherwise. Datum conversion factors to the NAVD88 vertical datum are included in the Pertinent Data section.

SECTION 2. DESCRIPTION OF PROJECT

2.01 Location. Grand Coulee Dam (GCL) is in north central Washington on the Columbia River 596.9 river miles (RM) upstream of the mouth of the Columbia River. The dam is 51.4 RM upstream from Chief Joseph Dam (CHJ) at 545.5 RM. The project is approximately 229 miles east of Seattle, Washington, and approximately 87 miles west of Spokane, Washington. State Highway 155 crosses the Columbia River at the Grand Coulee Bridge just downstream of GCL. The center of the dam is located at a latitude/longitude of 47°57'20.7"N, 118°58'60"W. The project location and vicinity are shown on Plate 2-1.

2.02 Purpose. The GCL project is a major unit of the comprehensive water resource development of the Columbia River Basin. The project was initially authorized by Public Law 74-409, under the Rivers and Harbors Act of 1935. The project was originally authorized for "controlling floods, improving navigation, regulating the flow of streams of the United States, providing for storage and for the delivery of the stored waters thereof, for the reclamation of public lands and Indian reservations, and other beneficial uses, and for the generation of electric energy as a means of financially aiding and assisting such undertakings." The Columbia Basin Project Act was subsequently signed into law on March 10, 1943, "authorizing and re-authorizing" Grand Coulee under the Reclamation Project Act of 1939, based on the feasibility findings the Interior Secretary presented to Congress, and the Rivers and Harbors Act of 1935. In 1980, authorization for fish and wildlife conservation was provided under the Pacific Northwest Electric Power Planning and Conservation Act.

The International Columbia River Board of Control was established by Order of the International Joint Commission (IJC) dated 15 December 1941 to ensure the implementation of the provisions of that Order – which granted approval for the United States to construct and operate the Grand Coulee dam and reservoir (Franklin D. Roosevelt Lake) – and to continue to study the effect of the operation of the Grand Coulee dam and reservoir upon water levels at and above the international boundary. The 2-person Board keeps the IJC apprised of streamflow and water level data on both sides of the international boundary.

The combined electricity output of the GCL powerplant complex represents the largest hydroelectric plant in the United States. Hydroelectric power generated by the GCL project furnishes a large share of the power requirements in the Pacific Northwest, with a generating capacity of 6,809 MW. GCL operations are managed for both base load and peaking power. The average annual net generation of electricity for the GCL project is 21 billion kilowatt-hours. Electricity generated at the project is delivered to Bonneville Power Administration transmission lines for distribution.

The GCL project provides up to 5.349 million acre-feet (MAF) of reservoir space for flood risk management (the U.S. Army Corps of Engineers has transitioned from using the term "flood control" to "flood risk management" in accordance with *Memorandum for Commanders, Major Subordinate Commands, "USACE National Flood Risk Management Program Initial Guidance," 5 October 2009*).

As part of the Columbia Basin Project, GCL provides irrigation to over 720,000 acres of cropland. Banks Lake is the main irrigation holding reservoir for the project with an active storage capacity of 715,000 acre-feet. The 27-mile-long reservoir is supplied with water from Lake Roosevelt via twelve lift pumps, with six of the pumps capable of reversing flow direction and generating power when needed. The artificial reservoir is impounded by two dams, with North Dam at the northern end of the reservoir and Dry Falls Dam at the southern end. A series of canals, siphons, and tunnels at the southern end of Banks Lake transport the irrigation water to the greater Columbia Basin Project.

Recreation is provided through the PL 89-72 Federal Water Project Recreation Act of July 9, 1965 (see section 2.06 for description of public facilities). Franklin D. Roosevelt Lake stretches for 151 miles with about 600 miles of shoreline, with a portion of the lake area designated as a National Recreation Area and administered by the National Park Service (NPS). Portions of the lake area within the Colville Confederated Tribes Reservation and the Spokane Tribe Reservation are managed by the respective tribes through a management agreement with Reclamation, NPS, and Bureau of Indian Affairs.

2.03 Physical Components. The following are the major components of GCL:

- Reservoir
- Concrete gravity dam
- Powerplants
- Spillway
- Outlet works
- John W. Keys III Pump Generating Plant (pumps water into Banks Lake)
- Incidental facilities (visitor center, miscellaneous buildings, and facilities)

The locations of the major GCL components are displayed in Plate 2-2. Original dam sections and powerplant information are displayed in Plate 2-3. Details of the physical components are provided below:

a) Reservoir. Franklin D. Roosevelt Lake (Lake Roosevelt), the reservoir behind the dam, extends 151 miles northeast toward the Canadian border and up the Spokane River, a tributary of the Columbia, to within 37 miles of Spokane, Washington. The gross storage capacity of the reservoir is 9,715,346 acre-feet (AF) at El 1,290, with an active storage capacity of 5,349,560 AF between El 1,208 and El 1,290. The surface area of the full reservoir is 80,000 acres with approximately 600 miles of shoreline. The gross storage in Lake Roosevelt is provided in acre-feet (AF) in Table 2-1 and displayed on Chart 2-1. Refer to the Pertinent Data for additional reservoir data.

TABLE 2-1

LAKE ROOSEVELT GROSS STORAGE IN ACRE-FEET

Elevation (Feet)	Gross Storage (Acre-feet)	Elevation (Feet)	Gross Storage (Acre-feet)	Elevation (Feet)	Gross Storage (Acre-feet)
1,208	4,365,786	1,241	6,181,297	1,274	8,460,715
1,209	4,413,755	1,242	6,244,429	1,275	8,535,772
1,210	4,462,147	1,243	6,307,977	1,276	8,611,173
1,211	4,510,961	1,244	6,371,923	1,277	8,687,010
1,212	4,560,197	1,245	6,436,267	1,278	8,763,297
1,213	4,609,851	1,246	6,501,004	1,279	8,840,035
1,214	4,659,923	1,247	6,566,090	1,280	8,917,229
1,215	4,710,411	1,248	6,631,519	1,281	8,994,910
1,216	4,761,317	1,249	6,697,290	1,282	9,073,084
1,217	4,812,637	1,250	6,763,427	1,283	9,151,750
1,218	4,864,377	1,251	6,830,063	1,284	9,230,910
1,219	4,916,585	1,252	6,897,197	1,285	9,310,562
1,220	4,969,268	1,253	6,964,689	1,286	9,390,696
1,221	5,022,425	1,254	7,032,515	1,287	9,471,248
1,222	5,076,058	1,255	7,100,678	1,288	9,552,206
1,223	5,130,166	1,256	7,169,173	1,289	9,633,570
1,224	5,184,740	1,257	7,237,994	1,290	9,715,346
1,225	5,239,729	1,258	7,307,138		
1,226	5,295,128	1,259	7,376,605		
1,227	5,350,944	1,260	7,446,416		
1,228	5,407,181	1,261	7,516,695		
1,229	5,463,839	1,262	7,587,436		
1,230	5,520,927	1,263	7,658,490		
1,231	5,578,512	1,264	7,729,831		
1,232	5,636,599	1,265	7,801,459		
1,233	5,695,153	1,266	7,873,376		
1,234	5,754,167	1,267	7,945,582		
1,235	5,813,641	1,268	8,018,078		
1,236	5,873,586	1,269	8,090,863		
1,237	5,934,057	1,270	8,163,965		
1,238	5,995,063	1,271	8,237,538		
1,239	6,056,605	1,272	8,311,587		
1,240	6,118,683	1,273	8,385,987		

CHART 2-1
LAKE ROOSEVELT GROSS STORAGE

b) <u>Dam.</u> The Main Dam is a concrete gravity dam that is 550 feet high, 3,867 feet long, 500 feet wide at the base, and 41.42 feet wide at a crest height of El 1,311.08. The upstream face of the dam is vertical from the dam crest down to El 1,071.74, then curves upstream at a 652.13-foot radius to El 1,023.10, then slopes upstream (at a ratio of 1H:15V). The downstream face is vertical from the dam crest down to El 1,273 feet (except along the spillway overflow section), then slopes downstream (at a ratio of 8.8H:1V). The original dam was modified for the Washington Power Plant (also referred to as the Third Powerplant) by a Forebay Dam along the right abutment approximately parallel to the river and at an angle of 64 degrees to the axis of Grand Coulee Dam. The Forebay Dam is a concrete gravity dam that is 200 feet high, 1,270 feet long, approximately 60 feet wide at the crest, and has a crest of El 1,311.08. The upstream face of the Forebay Dam is vertical, and the downstream face is vertical from the dam crest of El 1,273 feet, then slopes downstream (at a ratio of 0.65H:1V). A 186-foot-long, variable height concrete gravity Wing Dam extends from the right end of the Forebay Dam to the right abutment. Forebay Dam information is displayed on Plate 2-4. The total length of the Main Dam, Forebay Dam, and Wing Dam is 5,223 feet.

c) Spillway. GCL has a 1,650-foot-long spillway at the center of the Main Dam with a discharge capacity of 935,000 cfs at reservoir El 1,290. Flow is controlled by eleven 28- by 135-foot drum gates. Information on the drum gates is shown on Plate 2-5. The spillway has a concrete roller bucket energy dissipater (flip bucket) at the downstream base of the spillway. The maximum total discharge capacities with flashboards in place and without flashboards in place at various forebay elevations is provided in thousand-cubic feet per second (kcfs) in Table 2-2 and displayed in Chart 2-2. A spillway capacity report for Grand Coulee Dam was also completed by the Corps in May 2020 (see Exhibit 2-1).

d) Outlet Works. The outlet works for the dam consists of forty 102-inch-diameter steel-lined outlet conduits, located in two tiers at El 1,036.67 and El 1,136.67. Each outlet conduit is provided with tandem ring-seal gates for flow control. The outlet works discharge into the spillway. A third tier of outlet conduits, located at El 950, was used primarily for diversion during construction of the dam. These conduits have since been plugged with concrete. The spill capacities at various forebay elevations for the outlet works are included in Table 2-2 and displayed in Chart 2-2. The outlet works has a total spill capacity of 191,920 cfs at reservoir El 1,290. Information on the outlet works is provided on Plate 2-6 and Plate 2-7. Near the upstream (U/S) end of each outlet tube are installed two ring-seal gates, in tandem, with access to their gate mechanism and controls being through the dam inspection galleries at El 1,050

(Plate 2-6) and El 1,150 (Plate 2-7). On the U/S face of each block is a semicircular trash rack structure, 22.67 feet in radius and 250.07 feet high, which affords protection to the outlet tubes and ring-seal gates at both elevations in that block. Flow through each outlet tube is regulated by the downstream ring-seal gate. The upstream ring-seal gate is used as an emergency and maintenance gate. Up to three outlet conduits at one time can be dewatered for maintenance or inspection by installing a bulkhead gate in front of the conduit intake.

e) <u>Penstocks.</u> 18-foot diameter welded steel penstocks (Plate 2-8) convey water from the reservoir to the 161,805 horsepower main unit turbines in the Left Powerhouse and Right Powerhouse. From the intake at El 1,041, the Left Powerhouse and Right Powerhouse main unit penstocks (Plate 2-9) slope downhill for a length of about 322 feet, leveling off at El 938 before joining the turbine scroll cases. Forty-foot diameter welded steel penstocks convey water from the reservoir to the three 820,000-horsepower and three 1,053,900-horsepower turbines in the Washington Power Plant. From the intake at El 1,140, the Washington Power Plant unit penstocks move horizontally for 170.75 feet then slope downhill at a 45-degree angle, leveling off and reducing in diameter to 34.67 feet at El 946, before joining the turbine scroll cases.

TABLE 2-2
GRAND COULEE DAM SPILL CAPACITIES

Forebay Elevation (ft)	Outlet Works Discharge (kcfs)	Drum Gate Discharge, with Flashboards (kcfs)	Drum Gate Discharge, without Flashboards (kcfs)	Max Total Spill Capacity (kcfs)
1,208	149.8			149.86
1,210	151.6			151.6
1,215	154.4			154.4
1,220	157.1			157.1
1,225	159.9			159.9
1,230	162.7			162.7
1,235	165.4			165.4
1,240	167.8			167.8
1,245	170.4			170.4
1,250	173.0			173.0
1,255	175.3			175.3
1,260	177.7		0	177.7
1,265	180.3		55.0	180.3**
1,265.5	180.6	0	64.9	180.6**
1,267.5	181.5	20.8	104.5 (20.8*)	202.3**
1,270	182.7	46.8 (16.5*)	154.0 (16.5*)	199.2**
1,275	184.9	121.0 (16.5*)	302.5 (16.5*)	302.5
1,280	187.3	129.8 (16.5*)	478.5 (16.5*)	478.5
1,285	189.7	129.3 (16.5*)	693.0 (16.5*)	693.0
1,290	191.9	134.2 (22.0*)	935.0(22.0*)	935.0

*When outlet tubes are open directly below a drum gate, respective spill should not exceed 2’ in depth

**Max total spill capacity limited by max 2’ depth requirement for drum gates above open outlet tubes

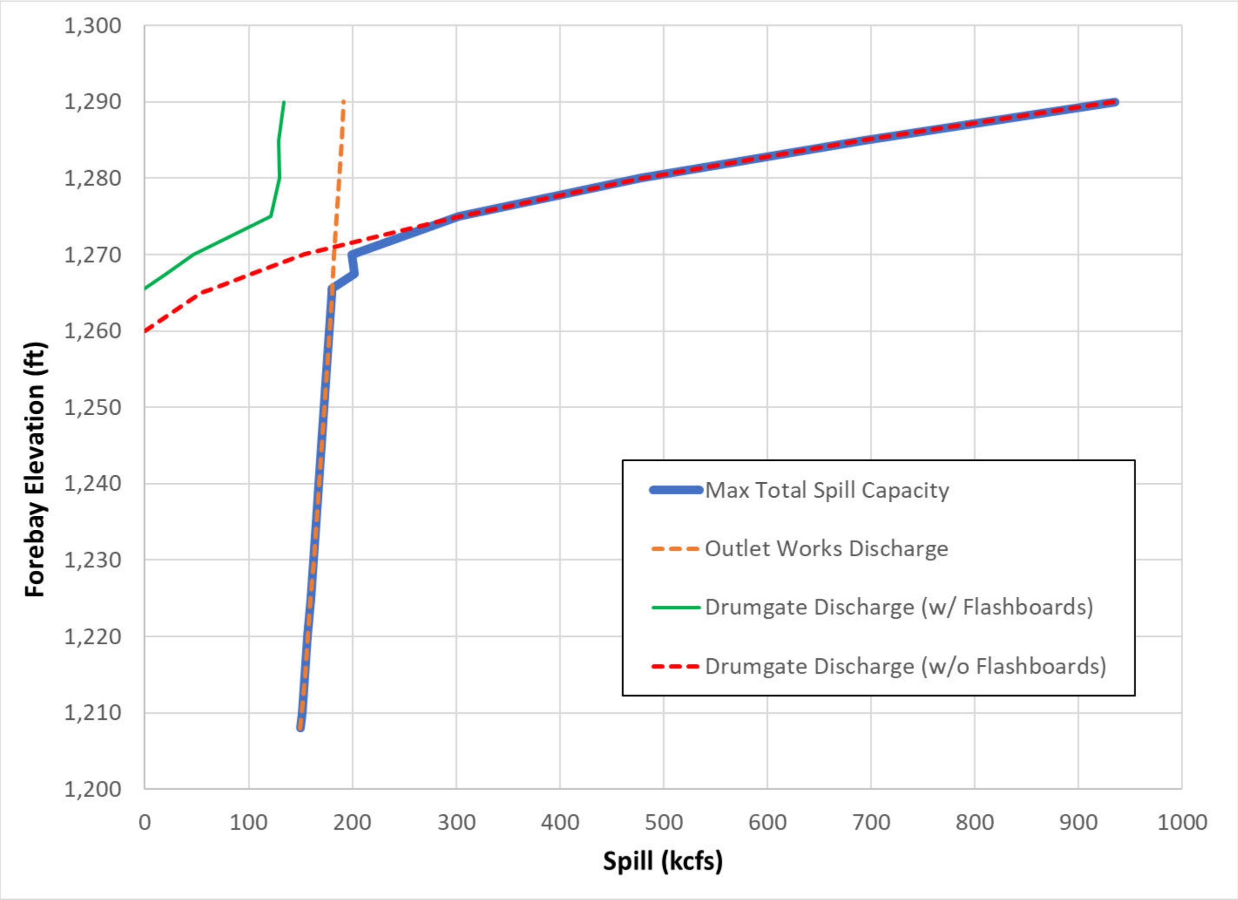


CHART 2-2
GRAND COULEE DAM SPILL CAPACITIES

f) Powerhouse. The power generating facilities at GCL consist of the following four powerhouses:

- The Left Powerhouse (LPH), located at the toe of the Main Dam on the west side of the spillway.
- The Right Powerhouse (RPH), located at the toe of the Main Dam on the east side of the spillway.
- The Nathaniel Washington Power Plant (WPP), or Third Powerplant, is located on the downstream face of the Forebay Dam on the east side of the river.

- The John W. Keys III Pump Generating Plant (P/G Plant), located on the west (left) side of the reservoir, located immediately upstream of the left abutment of the dam.

The LPH and RPH as constructed contained a total of eighteen 108,000 kW units, nine in each powerhouse. These units were rewound to increase their rating to 125,000 kW each, for a total of 2,250,000 kW for the 18 units. The LPH also contains three small station service units of 10,000 kW each, increasing the total rating of the LPH and RPH to 2,280,000 kW. As constructed, the WPP contained a total of three 600,000 kW units and three 700,000 kW units. The 700,000 kW units were rewound to increase their rating to 805,000 kW each, increasing the WPP total rating to 4,215,000 kW. WPP information is displayed on Plate 2-4.

The P/G Plant has six pumps rated at 65,000 horsepower, two pump-generators rated at 67,500 horsepower, and four pump-generators rated at 70,000 horsepower. The pump-generator units are capable of either pumping water up to Banks Lake via the feeder canal or generating power from water discharging back through the feeder canal from the lake. In generating mode, each of these units has a rating of 50,000 kW for a total of 300,000 kW for the P/G Plant. The six pumps are powered by a direct connect to Generators 1, 2, and 3 located in the LPH. When Lake Roosevelt is below El 1,240 feet, the pump-generators cannot pump at full design capacity. When this occurs, the plant may not be able to meet the full irrigation demand and Banks Lake may be drafted to meet these demands. Due to limited generation during times when Lake Roosevelt is below approximately El 1230 ft, bringing all six pumps back online after a forced outage is not likely until Lake Roosevelt refills above approximately El 1230 ft causing potential impacts to Banks Lake elevations and/or Columbia Basin Project water deliveries.

TABLE 2-3

GRAND COULEE DAM POWERPLANT PERFORMANCE TABLE

Forebay Elevation (ft)	Powerplant Capacity (ksfd*/ft)	Powerplant Discharge (kcfs/0.1)	Powerplant Efficiency (H/K**, Approximate)
1,210	23.7	569	18.9
1,215	24.8	595	19.1
1,220	25.9	622	19.4
1,225	26.8	643	19.8
1,230	27.7	665	20.4
1,235	29.2	701	20.6
1,240	30.8	739	20.9
1,245	31.7	761	21.2
1,250	32.4	778	21.5
1,255	33.4	802	21.9
1,260	34.4	826	22.5
1,265	35.4	850	22.8
1,270	36.2	869	23.4
1,275	37.4	898	23.6
1,280	38.6	926	23.8
1,285	39.6	950	24.2
1,290	40.5	972	24.7

*ksfd: thousand second-foot-days, or one thousand cubic feet per second in 24-hour period.
**H/K: Powerplant efficiency based on available capacity.

Additional hydroelectric power facility components are detailed below:

(1) Switching Equipment. The switchyards at GCL are located on the hills west of the dam, above the left abutment. One switchyard has 11.95 kilovolt (kV) distribution and four 115 kV transmission lines; one switchyard has 230 kilovolt generation (from eighteen 125,000 kW units) and eleven transmission lines; the third switchyard has 525 kilovolt generation (from six WPP Units) and six transmission lines. The 11.95kV and 230kV switchyards are located approximately 0.5 miles away, immediately above the feeder canal. The 500kV switchyard is located approximately four miles away, along State Highway 174, on the upper plateau.

(2) Transformers. There are electrical connections through transformers between the 115 and 230 kilovolt switchyards and the 230 and 525 kilovolt switchyards.

g) Forebay and Tailwater Gages.

(1) Forebay Gage. The stilling well for the reservoir water level indication is located in the Main Dam, Block 12, El 1295. A reflex radar Unit (USBR) and a data recorder (USGS) are mounted on top of the stilling well. The reflex-radar system is based on the principle of time domain reflectometry. Low power electromagnetic pulses of one nanosecond are pulsed into the Forebay Stilling Well, guided by two conductors. Reflection of these pulses and the time required is used to electronically calculate the level of the water. This system is insensitive to pressure or temperature variations and is not influenced by the stilling well shape.

(2) Tailwater Gage. Primary tailwater level indication is taken from a stilling well, located on a Highway 155 bridge pier, immediately downstream of the dam. A reflex-radar unit is mounted on top of the stilling well. The analog output from the tailwater reflex-radar unit is sent through a signal splitter, located inside the station service benchboard.

2.04 Related Control Facilities. The project contains several administrative, shop, and maintenance buildings.

The Columbia Basin Project has multiple associated facilities related to managing the Project's irrigation water delivery system from Banks Lake including Pinto Dam on Billy Clapp Lake, O'Sullivan Dam on the Potholes Reservoir, Soda Lake, and Scooteney Reservoir.

2.05 Real Estate Acquisition Lands along the reservoir right bank (Okanogan and Ferry counties) are mostly property of the Confederated Tribes of the Colville Reservation (CTCR) and lands along the left bank (Grant, Lincoln, and Stevens counties) are mostly public property and managed as the Lake Roosevelt National Recreation Area (NRA) with a section of the left bank upstream of the confluence with the Spokane River being the property of the Spokane Tribe of Indians (STI). The NRA consists of a narrow band of land that extends upland from the maximum high-water mark of the reservoir (El 1,290). The NRA encompasses all the lands that were acquired or withdrawn by Reclamation for construction of the reservoir. The CTCR and the STI manage the lands on their tribal reservations and the NPS manages the lands in the NRA. Reclamation retains management of the dam, its immediate area, and some other locations deemed necessary for operating the reservoir.

2.06 Public Facilities. Public facilities operated in conjunction with the project include viewing platforms and a visitor's center building located near the dam that was built in the late 1970's as part of the dam's WPP expansion.

Lake Roosevelt is approximately 150 miles long and extends nearly to the Canadian border. The lake has approximately 600 miles of shoreline and a large portion of the shoreline is managed as the Lake Roosevelt NRA. Lake Roosevelt NRA provides opportunities for boating, fishing, swimming, camping, canoeing, and hunting. From 1946 until 1990, the NRA was managed solely by the NPS. In 1990, cooperative management was established between NPS, the CTCR, and the STI. A list of NPS recreation services is provided in Table 2-4and shown on Plate 2-10.

a) Grand Coulee Dam Visitor Center. The U.S. Bureau of Reclamation operates the Grand Coulee Dam Visitor Center and provides interpretive exhibits. Tours of the dam are also provided, and a laser light show is projected on to the downstream face of the dam during evenings in the spring/summer months (see Plate 2-2 for Visitor Center location).

b) Fisheries. Lake Roosevelt contains many fisheries managed by both State and Tribal entities including populations of Rainbow Trout, Kokanee Salmon, Walleye, White Sturgeon, and Smallmouth Bass.

c) Campgrounds/Marinas/Boat Launches. Multiple campgrounds, marinas, and boat launches are located around the Lake Roosevelt area (see Table 2-4 and Plate 2-10).

d) Ferries. The Keller Ferry and Inchelium-Gifford Ferry both operate on Lake Roosevelt and provide access to the Confederated Tribes of the Colville Reservation via State Route 21 and Washington State Highway 25, respectively.

TABLE 2-4

GRAND COULEE PROJECT RECREATION SERVICES (NPS)

Recreation Area Services

The boat ramp elevation figure is the minimum water level at which a boat may be launched.

Lower Lake Roosevelt

	Crescent Bay 1265'	Spring Canyon 1222'	Keller Ferry 1229'	Hanson Harbor 1253'	Jones Bay 1268'	Lincoln 1245'	Hawk Creek 1281'	Seven Bays 1227'
Campground (tent sites)		•	•		•		•	•
Campground (trailer sites)		•	•				•	•
Campground (group sites)		•	•					
Waste disposal (trailer)		•	•					
Picnic area		•	•					
Telephone		•	•					•
Drinking water		•	•				•	•
Marina			•					•
Boat launch	•	•	•	•	•	•	•	•
Boat fuel			•					•
Waste disposal (boat)		•	•					•
Winter boat launch		•	•			•		•

Spokane River Arm

	Two Rivers 1280'	Fort Spokane 1247'	McCoys	Porcupine Bay 1243'
Campground (tent sites)	•	•		•
Campground (trailer sites)	•	•		•
Campground (group sites)		•		
Waste disposal (trailer)	•	•		•
Picnic area		•		•
Telephone	•	•		•
Drinking water	•	•		•
Marina	•			
Boat launch	•	•		•
Boat fuel	•		•	
Waste disposal (boat)	•			
Winter boat launch	•	•		

Upper Lake Roosevelt

	Hunters 1232'	Gifford 1249'	Cloverleaf	Daisy (boat launch) 1265'	Daisy (town)	French Rocks 1265'	Bradbury Beach 1251'	Haag Cove	Kettle Falls 1234'	Marcus Island 1281'	Kamloops	Kettle River	Napoleon Bridge 1280'	Evans 1280'	Snag Cove 1277'	North Gorge 1280'	China Bend 1280'
Campground (tent sites)	•	•	•					•	•	•	•	•		•	•	•	
Campground (trailer sites)	•	•						•	•	•	•	•		•	•	•	
Campground (group sites)	•								•					•			
Waste disposal (trailer)	•	•							•	•				•			
Picnic area	•	•	•	•			•	•	•	•				•			
Telephone					•				•								
Drinking water	•	•	•				•	•	•	•	•	•		•	•	•	
Marina									•								
Boat launch	•	•		•		•	•		•	•			•	•	•	•	•
Boat fuel					•				•								
Waste disposal (boat)									•								
Winter boat launch	•	•		•			•		•								

SECTION 3. HISTORY OF PROJECT

3.01 Authorization for Project. Grand Coulee Dam (GCL) was initially authorized by Public Law 74-409, under the Rivers and Harbors Act of 1935 for the multiple purposes of generation of electric energy, flood risk management, improvement of navigation, and irrigation. The Columbia Basin Project Act of March 10, 1943 (57 Stat. 14) reauthorized the project, bringing it under the provisions of the Reclamation Project Act of 1939 as well. Units 7, 8, and 9 of the Right Powerhouse were authorized by a finding of feasibility approved by the Secretary of the Interior on January 5, 1949. Construction of the Washington Power Plant (WPP), then called the Third Powerhouse, was authorized by Public Law 89-448 (80 Stat. 200) dated June 14, 1966, as amended by Public Law 89-561 (80 Stat. 714) dated September 7, 1966.[6]

3.02 Planning and Design. During the early 20th century, the Reclamation Service (now Bureau of Reclamation) conducted multiple investigations to consider irrigating the Columbia River's surrounding dry farming fields with water from the river itself, but the Columbia River's deep canyon onto the surrounding area's plateaued surface made such plans infeasible at the time.

The GCL project site at the head of the upper Grand Coulee was first proposed as a location for a high dam on the Columbia River in 1918 due to the unique geological features of the area. Due to the height of the irrigable lands on the plateau above the Columbia River, the high dam would generate power that would then be used to pump water from the reservoir up behind a smaller dam to be stored for irrigation use. At the same time, a competing plan to irrigate the surrounding area involved the removal of water from Albeni Falls on the Pend Oreille River in

[6] A U.S. District Court also confirmed in 1980 that the project is subject to the Fish and Wildlife Coordination Act of August 12, 1958 (72 Stat. 563, Public Law 85-624).

Idaho through a series of diversion structures. Local interests debated the two plans until money was appropriated by Congress in the late 1920's to conduct comprehensive studies of both plans. The Army Corps of Engineers conducted field surveys of the area beginning in 1928 and submitted a report in 1931 favoring the construction of the high dam at the GCL project site.

In early July 1933, a contract was signed between the State of Washington and Bureau of Reclamation that allowed for the preparation of plans, surveys, and the commencement of preliminary work at the site. On August 30, 1935, President Roosevelt signed the Rivers and Harbors Act into law, federally authorizing the Grand Coulee Dam project. The Columbia Basin Project Act was subsequently signed into law on March 10, 1943, "authorizing and re-authorizing" Grand Coulee under the Reclamation Project Act of 1939, based on the feasibility findings the Interior Secretary presented to Congress, and the Rivers and Harbors Act of 1935.

3.03 Construction. Construction of the original project began with groundbreaking ceremonies at the site on July 16, 1933. Excavation work began in early to mid-1934 and multiple towns were built in the area to house the dam construction workers and their families. Despite the ongoing problem of landslides due to excavation work, the east and west coffer dams were completed in 1935 and official concrete placement at the dam began on December 6, 1935. Construction at the dam site continued for over 4 years, with periodic work stoppages due to cold weather during the winter months until the concrete placement was largely completed by September 1940.

The first power was generated at the dam on January 21, 1941, and the last of the original 18 units (Right and Left Powerhouses) began production in 1950. Pumping for irrigation commenced in 1951 at the John W. Keys III Pump Generating Plant. Six pumps (P-1 through P-

6) were installed from 1951 to 1953. In addition, six pump-generators were installed from the mid-1970`s (P/G-7 and P/G-8) to the early 1980s (P/G-9 through P/G-12).

Construction of the Third Power Plant and Forebay Dam commenced in 1967 with the first unit (G-19) commissioned in 1975 and the last (G-24) in 1980. The 18 original generators in the Right and Left Powerhouses have had the stator windings replaced, increasing their ratings from the original 108,000 kW to 125,000 kW. The last three generators in the Third Power Plant (G-22, G-23, and G-24) had their stators and cores replaced increasing their ratings from 700 MW to 805 MW at 825.6 MVA and power factor of 0.975. All banks of the original transformers in the Left Powerhouse have been replaced with their ratings increased to between 129,000 and 150,000 kV amperes. Turbine runners for units G-1 through G-18 were replaced between 2000 to 2010.

The degraded condition of high voltage cables that transmitted power from the Third Power Plant to the switchyard constituted an unacceptable risk for loss of generation. The nine oil-filled cables for G-19, G-20, and G-21 had been operated near or above their continuous current rating for 30 years and were replaced with new overhead lines by December 2012. The removal of the existing oil filled cables was completed by December 2013.

The third power plant began an extensive overhaul and modernization in 2010, including work on the six generating units, turbines, shafts, and auxiliary equipment.

The pump/generating plant began an overhaul and modernization effort in 2012 with work focused on upgrading and refurbishing/replacing existing components as needed for the six pumps and six pump-generating units.

In 2018, Reclamation began an effort to overhaul and modernize the 18 generating units in the left and right powerhouses. The modernization and overhaul work will include work on the generators, windings, stator core, penstocks, exciters, iso-phase bus, and internal and external cranes.

3.04 Related Projects.

a) Columbia River System. GCL is an integral project of the Columbia River system. Operation is coordinated with other system projects. See references listed in section 1.03 for more detailed information on the relationship between Grand Coulee and Columbia River system operations.

b) Chief Joseph Dam & Reservoir. Initially authorized as Foster Creek Dam and Powerhouse, Chief Joseph Dam (CHJ) is the closest project downstream of GCL. The 6 mile-long tailwater reach below GCL is subject to backwater effects from Lake Rufus Woods, the reservoir created by CHJ. CHJ is owned and operated by USACE Seattle District.

c) Hugh Keenleyside Dam. Initially designated as Arrow Dam, Keenleyside Dam is upstream of GCL on the Columbia River approximately 30 miles north of the international boundary with Canada and five miles upstream from Castlegar, British Columbia. Keenleyside was built by BC Hydro in accordance with the Columbia River Treaty. In 1999, the Columbia Power Corporation (a crown corporation owned and controlled by the Province of BC) with its partner the Columbia Basin Trust began to construct the Arrow Lakes Generating Station which went into operation in 2002.

d) Other Projects. Several other water resource projects are being undertaken in the Columbia River Basin both as part of Reclamation's Columbia River Water Management Program and separate from it, including some projects that are being undertaken jointly by the Washington State Department of Ecology and Reclamation. These projects include:

   - Potholes Reservoir Supplemental Feed Route

- Odessa Subarea Special Study
- Columbia-Snake River Irrigators Association Voluntary Regional Agreement
- Columbia River Mainstem Off-Channel Storage Options
- Lake Roosevelt Remedial Investigation and Feasibility Study

<u>3.05 Dam Safety History/Issues.</u> Grand Coulee Dam has a Dam Safety Priority Rating (DSPR) of 3 (Moderate to High Priority). The key justifications for this rating are the total annualized life loss is more than one half an order of magnitude above the Public Protection Guidelines and the annualized failure probability is very close to the Public Protection Guidelines. Since the total annualized life loss is above guidelines, there is increasing justification to reduce or better understand the risks.

[redacted]

[redacted]

[redacted]

<u>3.06 Principal Regulation Issues.</u> The drawdown of Lake Roosevelt can cause landslide issues and therefore the rate of drawdown is generally limited per Reclamation guidelines to a maximum of 1.5 ft per any 24-hour rolling period (see Exhibit 3-1). The higher the lake is, the more flexibility there is for exceeding the draft rate guidance for Lake Roosevelt if required for special circumstances. Additional monitoring for landslide issues will be required during these special circumstance time periods. The most severe landslides occur at elevations below El 1,230.

When the reservoir reaches El 1,229, the ability to use the Inchellium-Gifford Ferry is impacted as the ferry may be shut down due to low reservoir levels and therefore cuts off an important transportation route of the eastern portion of the Confederated Tribes of the Colville Reservation from vital services (hospital, schools, supplies etc.). The ferry operational pool level is determined by the function of the vehicle ramp elevation. Low reservoir levels also affect the operability of the John W. Keys III pump-generating plant, as described in Section 2.03.

Periods of forced spilling at GCL as the result of system FRM requirements may result in elevated Total Dissolved Gas (TDG) levels downstream of GCL that can exceed the State of Washington water quality criteria for TDG saturation. Any spilling that GCL must do through the outlet tubes can result in high levels of TDG below the project. Spilling via the outlet tubes occurs when GCL must release water to meet downstream FRM requirements and the Lake Roosevelt water surface is below El 1,265.5 (spillway crest). High TDG from use of the outlet tubes impacts Rufus Woods Lake directly downstream of the GCL project, where a commercial net pen fishery exists. Elevated TDG levels can persist for some distance downstream through the Columbia River.

However, spillway deflectors in place at Chief Joseph Dam have been effective for TDG abatement since their construction in 2008.

Reclamation attempts to operate GCL to refill Lake Roosevelt to an elevation of 1,283 feet by September 30 at the request of tribes to aid resident fish, including access to shoreline and tributary habitat. To maintain power generation flexibility, the Lake Roosevelt elevation objective of 1,283 feet or higher by the end of September may be delayed to no later than the end of October. Delaying refilling to an elevation of 1,283 feet allows more operational flexibility for hydropower generation by relaxing restrictions on seasonal pool elevations at Grand Coulee Dam. In most years, meeting the targeted elevation of 1,283 feet by the end of September is anticipated, but in drier years when the summer flow augmentation objective is El 1,278 feet (at the end of August) refilling to El 1,283 feet affects hydropower generational flexibility. In these years, the requirement is not until the end of October, but the project will be operated to refill to an elevation of 1,283 feet as soon as practical.

SECTION 4. WATERSHED CHARACTERISTICS

<u>4.01 General Characteristics.</u> The Columbia River is the fourth largest river in North America (by volume) and together with its tributaries forms the dominant water system in the Pacific Northwest Region. The Columbia River is 1,215 miles in length, with approximately 470 miles in British Columbia, Canada and 745 miles in the United States. Originating in Columbia Lake on the west slope of the Rocky Mountain Range in British Columbia, the river enters the United States in the northeastern corner of the State of Washington. The Columbia River flows approximately 150 miles south and west to the site of Grand Coulee Dam and then continues to flow southeasterly to its confluence with the Snake River near Richland, Washington in a sweeping curve called Big Bend. It turns westward for another 320 miles forming the Washington-Oregon border before flowing into the Pacific Ocean near Astoria, Oregon.

The river drains approximately 260,000 mi^2 mostly in the states of Washington, Oregon, Idaho, Montana, and southern British Columbia, with small areas in Wyoming, Nevada, and Utah. Of this total, 74,700 mi^2 (29%) are located upstream from GCL, with 39,000 mi^2 (15%) located in Canada. Principal tributaries upstream of GCL include the Kootenai River, Pend Oreille River, and Spokane River. The Kootenai (Kootenay in Canada) River rises in British Columbia, flows into the United States, flows back into British Columbia, then joins the Columbia River 30 miles north of the International Boundary. The Pend Oreille River which includes the Clark Fork and Flathead Rivers as tributaries, originates in Montana and Canada and flows through Idaho and Washington and then joins the Columbia River at 1.5 miles north of the International Boundary before crossing into Washington State. The Spokane River is, relatively, a minor tributary sourcing at Coeur d' Alene Lake in Idaho. Columbia Basin drainage areas upstream of GCL, in both the United States and British Columbia, are listed in Table 4-1.

TABLE 4-1

COLUMBIA RIVER BASIN – DRAINAGE AREAS

Location	**United States**	**Canada**	**Total**
	mi^2	mi^2	mi^2
Kootenai River Watershed	5,250	14,050*	19,300
Clark Fork – Pend Oreille Watershed	24,757	1,203	25,960
Kettle River Watershed	1,023	3,177	4,200
Spokane River Watershed	6,600		6,600
Columbia River @ International Boundary (USGS gage)			59,700
Columbia River @ Grand Coulee Dam (USGS gage)			74,700

**Note: Area includes 8,985 square miles above Libby Dam*

4.02 Topography. The Grand Coulee is a prehistoric riverbed 52 miles long, 1.5 to 5 miles wide, and at places nearly 1,000 feet deep that was gouged into the Columbia Plateau during periodic outburst floods from massive glacial Lake Missoula, which was located upriver in present-day Montana during the Pleistocene. In forming the canyons of the Grand Coulee, a tandem of two cascades cut deep into the landscape. The larger one flowed over an 800-foot waterfall which eroded the rocks away as it cut through the valley where Grand Coulee Dam now sits. The second cascade eroded the southern end of the Grand Coulee, forming Dry Falls, located just south of Coulee City, which is about 400 feet high and 3.5 miles downstream of Grand Coulee Dam and Lake Roosevelt, a reservoir created by GCL. The region is bounded on the north and west by the Cascade Range and borders the Pend Oreille basin on the east; the Columbia River

Plateau dominates the southern landscape in the region. The greatest concentration of agricultural fields occurs south of GCL. The vegetated hills predominate north of the reservoir. The highest point in the region is in the Cascade Range at approximately 9,500 feet, and the lowest elevation occurs along the Columbia River near Priest Rapids Dam at approximately 400 feet.

4.03 Geology and Soils. The Columbia Basin upstream of GCL is in the northern Rocky Mountain physiographic province, a region characterized by rugged highlands and intermountain basins. Rocks are mainly ancient argillitic and quarzitic materials, but a portion of the basin contains slightly younger metamorphosed sedimentary rocks and granite. GCL is near the boundary of two geologic zones: the Okanogan Highlands to the northeast, and the Columbia Plateau to the southwest. The dam sits on the solid granitic rock of the Okanogan Highlands, while the Columbia Plateau to the South consists of layers of softer basalts. The granitic Okanogan Highlands is an area characterized by moderately steep, forested slopes and broad rounded summits up to 7,000 feet in elevation. The Columbia Plateau is composed of Miocene basaltic lava flows with an aggregate thickness up to about 6,000 ft. The Columbia River in the Grand Coulee region was carved between these two geologic zones. The landscape that is currently visible in the area is the result of the most recent Ice Age Floods which shaped this landscape approximately 13,000 years ago.

4.04 Sediment. The reach of the Columbia River between the U.S.-Canada border and GCL is a bedrock-controlled river, lacking a thick alluvial cover (Whetten, Kelley, and Hanson 1969). The drainage basin of Lake Roosevelt behind GCL contains a wide variety of igneous, metamorphic, and sedimentary rocks, as well as unconsolidated surficial deposits. Primary mechanisms of sediment delivery are landslides and bank erosion that contribute fine-grained sediment that is mostly transported in suspension. Some landslides along the Columbia River within Lake

Roosevelt existed before the construction of GCL and are a few hundred to a few thousand years old (Pardee 1918; Kiver and Stradling 1995); other landslides appear to have been associated with destabilization of the landscape during glaciation (Flint and Irwin 1939; Jones et al. 1961). More than 500 landslides also formed along the shoreline of Lake Roosevelt in response to the filling of the reservoir and fluctuating water level (Cox et al. 2005).

The Spokane River contributes the largest amounts of suspended sediment to Lake Roosevelt (Whetten, Kelley, and Hanson 1969), but coarse sediment contributions that would tend to form a sediment delta are limited.

Since the late 1800s, large amounts of slag have been released into the upper Columbia River from an upstream smelter operation in Canada. Because Lake Roosevelt has a high sediment trapping efficiency, much of the incoming slag has been retained within Lake Roosevelt, particularly in the upstream reaches (Teck 2017). As a result, bed and bank sediments in Lake Roosevelt contain elevated metals. Farther downstream, the riverbed is primarily silt and clay in the middle and lower Lake Roosevelt (lacustrine) reaches (Whetten, Kelley, and Hanson 1969; Windward Environmental LLC 2017).

4.05 Climate.

a) General. The Columbia River Basin lies in a climatic region meteorologically dominated by the Aleutian low and the Pacific high. The climate ranges from a moist, mild maritime condition near the mouth of the river to a relatively cool desert climate in some of the inland valleys of eastern Oregon and southern Idaho. The headwaters of the Columbia River and its major tributaries are in high-elevation and snow-dominant watersheds. Snow-dominant watersheds are sufficiently cold in the winter to allow for precipitation to fall in the form of snow and for that snow to accumulate and remain until temperatures rise in the spring and summer. High-elevation summers tend to be short and cool, while the lower-elevation interior regions are subject to greater temperature variability.

The north-south Cascade Range, the Blue and Wallowa Mountains of northeast Oregon, and the Rocky Mountains at the eastern and northern boundaries of the basin strongly influence climate in the Columbia River Basin. The basin is generally cooler and wetter on the western side of the Cascades and warmer and drier to the east toward the Rocky Mountains. The two important runoff patterns in the basin are the snowmelt runoff in the interior east of the Cascade Range and the rainfall runoff of the coastal drainages west of the Cascades. A summary of climatological data at specific locations throughout the basin for temperature, precipitation and snowfall is shown on Table 4-2.

TABLE 4-2

SUMMARY OF CLIMATOLOGICAL DATA

Station			Annual Precipitation (inches)		Annual Snowfall (inches)		Annual Temperature (°F)		
Name	**Climate ID (BC)/ COOP ID (USA)**	**Period of Record[a]**	**Mean**	**Greatest**	**Least**	**Mean**	**Mean**	**Extreme Maximum**	**Extreme Minimum**
Castlegar (BC)	1141460†	1965 – 2020	28.45	42.44	26.70	84.55	47.65	104	-23
West Glacier (MT)	248809‡	1948 – 2020	29.46	42.16	52.5	127.29	47.22	100	-36
Kalispell Glacier (MT)	244558‡	1896 – 2020	15.65	25.23	2.00	55.46	43.38	105	-38
Spokane Int. (WA)	457938‡	1889 – 2020	16.06	26.07	6.40	42.16	48.16	108	-25
Northport* (WA)	455946‡	1899 – 2020	18.27	28.19	3.30	48.95	47.54	110	-32
Coulee Dam 1 SW** (WA)	451767‡	1934 – 2020	10.39	20.37	0	13.72	50.13	113	-17
The Dalles*** (OR)	358407‡	1893 – 2020	13.18	23.87	0	18.84	54.04	115	-25

†Values taken from Government of Canada Climate Data, climate.weather.gc.ca
‡Values taken from NOAA's National Center for Environmental Information, www.ncei.noaa.gov
a=All gaging stations are active as of January 2021.
**Northport is the first meteorological station located in the U.S. below the Canadian border on the Columbia River.*
***Grand Coulee Dam 1 SW located at Dam.*
**** The Dalles is a key control point for Columbia River system located approximately 192 miles upstream of the mouth.*

b) Temperature. The climate in the GCL locality is semi-arid and typical of a temperate desert climate. Air temperatures within the Columbia River Basin are controlled by latitude, elevation, local topography, distance from the Pacific Ocean, as well as by air mass and season of the year. An important aspect of basin temperature to the regulation of GCL lies in the effect of temperature and solar radiation on snowmelt. The shape, timing, and peak discharge of the spring runoff hydrograph of the Columbia River at GCL are determined to a considerable degree by the sequence of temperatures during the spring and early summer. In addition, temperatures in the region have a pronounced effect on electric power demand and therefore on the need for power generation at GCL and other hydroelectric projects which serve the area. Summers in the GCL locality are typically warm and very sunny with an average high temperature of 84.2° F and average low temperatures of 56.1° F, while winters are relatively mild with average high temperatures of 35.4° F and average low temperatures of 24.0° F. Table 4-3 shows mean monthly temperatures for representative stations in the basin for the available period of record.

TABLE 4-3

MEAN MONTHLY TEMPERATURE (^{O}F)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Castlegar†	27.8	31.3	39.0	47.3	55.9	62.5	68.7	68.2	58.6	46.2	36.8	28.3	47.7
West Glacier‡	22.7	26.4	33.0	41.7	50.9	57.8	64.0	62.9	53.4	42.5	31.6	24.3	47.2
Kalispell Glacier‡	21.8	25.8	33.8	43.5	51.9	58.4	65.2	63.7	54.1	43.2	32.0	24.4	43.4
Spokane Int. ‡	27.6	32.1	39.4	47.3	55.5	62.3	70.2	68.9	59.8	48.3	36.4	29.4	48.2
Northport‡*	25.7	30.4	39.2	48.5	56.9	63.1	69.4	67.9	59.3	47.1	35.5	28.3	47.5
Coulee Dam 1 SW‡**	27.0	32.6	41.1	49.8	58.5	65.6	73.1	72.1	63.7	50.9	37.5	29.4	50.1
The Dalles‡***	35.0	39.70	46.7	53.6	60.7	67.1	73.4	72.6	65.0	54.5	43.4	37.0	54.0

†Values taken from Government of Canada Climate Data, climate.weather.gc.ca
‡Values taken from NOAA's National Center for Environmental Information, www.ncei.noaa.gov
**Northport is the first meteorological station located in the U.S. below the Canadian border on the Columbia River.*
***Grand Coulee Dam 1 SW located at Dam.*
**** The Dalles is a key control point for Columbia River system located approximately 192 mile upstream of the mouth downstream of Grand Coulee Dam.*

c) Rainfall. Most of the annual precipitation in the basin occurs in the fall through early spring, with the largest share falling as snow in the mountains. This moisture, stored during the winter as snowpack, is released as snowmelt in the spring and early summer. Average annual precipitation at Grand Coulee Dam is about 10.63 inches per year. Table 4-4 shows mean monthly precipitation for representative stations in the basin for the available period of record.

TABLE 4-4

MEAN MONTHLY PRECIPITATION (INCHES)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Castlegar†	3.08	2.08	2.49	2.07	2.53	2.66	1.57	1.25	1.59	2.22	3.41	3.66	28.45
West Glacier‡	3.41	2.35	2.17	1.92	2.57	3.41	1.61	1.48	2.01	2.60	3.17	3.29	29.46
Kalispell Glacier‡	1.4	0.99	1.0	1.07	1.73	2.28	1.09	1.06	1.24	1.09	1.40	1.44	15.65
Spokane Int.‡	1.98	1.54	1.47	1.11	1.41	1.21	0.52	0.60	0.78	1.22	2.07	2.23	16.06
Northport‡ *	2.03	1.41	1.42	1.38	1.81	2.09	1.01	1.00	1.13	1.56	2.14	2.31	18.27
Coulee Dam 1 SW‡**	1.08	0.92	0.89	0.85	1.15	1.00	0.45	0.42	0.49	0.77	1.22	1.38	10.39
The Dalles‡***	2.46	1.75	1.22	0.71	0.58	0.51	0.15	0.24	0.52	1.02	2.20	2.49	13.18

†Values taken from Government of Canada Climate Data, climate.weather.gc.ca
‡Values taken from NOAA's National Center for Environmental Information, www.ncei.noaa.gov
**Northport is the first meteorological station located in the U.S. below the Canadian border on the Columbia River.*
***Grand Coulee Dam 1 SW located at Dam.*
**** The Dalles is a key control point for Columbia River system located approximately 192 mile above upstream of the mouth.*

d) Evaporation. Average annual pan evaporation based on data from the Western Regional Climate Center (*wrcc@dri.edu/Climate*) at the Lind 3NE experimental station, with a period of record of 1931-2005, is estimated to be about 54.7 inches. A seasonal distribution is not available, but most of this evaporative loss occurs from April through October, peaking in July and August. Evaporative loss from November through March is negligible. Average monthly evaporation values (Class A evaporation pan) are 5.35, 8.02, 9.40, 12.02, 10.44, 6.87, and 2.59 inches for April, May, June, July, August, September, and October, respectively. According to the Western Regional Climate Center, pan evaporation values should be multiplied by 0.70 to 0.80 to estimate evaporation from naturally existing surfaces such as lakes. Applying a typical pan coefficient of 0.7 to observed average annual pan evaporation of 54.7 inches suggests an annual evaporative loss from GCL of about 38 inches.

e) Snow. The headwaters of the Columbia River and its major tributaries are in high-elevation and snow-dominant watersheds. Snowfall usually begins in early fall (September – November) and snow depth in the higher elevations increases to maximum amount usually in April. The mountain ranges within the Columbia River Basin typically receive 100 to 200 inches of snow annually. Most of the accumulated winter snowpack throughout the basin is melted in the spring from late March through April. The summer is generally snow free except for occasional mountain storms and snowpack remains only at the highest elevations. Mean monthly snowfall amounts for representative stations in the Columbia River Basin are presented in Table 4-5. There is no SNOTEL station near the Grand Coulee site to estimate the average annual snow water equivalent water content. The closest SNOTEL station is located in a region upstream of GCL at Moses Mountain. The average snow water equivalent recorded at this station is 14.80 inches, which is based on the seasonal average of the 30-year period from 1991 through 2020.

TABLE 4-5

MEAN MONTHLY SNOWFALL (INCHES)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Castlegar[†]	25.59	12.40	6.65	0.78	0.04	0.00	0.00	0.00	0.00	0.70	12.82	26.91	84.55
West Glacier[‡]	36.42	21.85	14.15	3.21	0.44	0.13	0.00	0.00	0.10	2.05	16.05	35.15	127.29
Kalispell Glacier[‡]	14.55	9.81	6.28	1.96	0.51	0.19	0.00	0.00	0.11	1.40	8.21	14.05	55.46
Spokane Int.[‡]	12.92	7.79	3.65	0.57	0.06	0.00	0.00	0.00	0.04	0.31	5.54	11.68	42.16
Northport[‡*]	17.87	8.73	2.57	0.12	0.00	0.00	0.00	0.00	0.00	0.20	5.94	17.00	48.95
Coulee Dam 1 SW[‡**]	6.27	2.72	0.67	0.03	0.00	0.00	0.00	0.00	0.00	0.03	1.33	4.60	13.72
The Dalles[‡***]	9.61	4.24	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.02	2.20	4.72	18.84

[†]*Values taken from Government of Canada Climate Data, climate.weather.gc.ca*

[‡]*Values taken from NOAA's National Center for Environmental Information, www.ncei.noaa.gov*

**Northport is the first meteorological station located in the U.S. below the Canadian border on the Columbia River.*

***Grand Coulee Dam 1 SW located at Dam.*

**** The Dalles is a key control point for Columbia River system located approximately 192 mile above upstream of the mouth.*

f) Wind. The wind speed is quite variable across the basin, but most valley areas have less than 10 mph average wind speeds for the year. Some of the deeper, more sheltered valleys probably have annual average wind speeds as low as 5 or 6 mph. The AgriMetric station at the Grand Coulee Dam has daily average wind speed and direction data recorded from 2002 through 2019 and the monthly averages for wind speed and direction are shown in Table 4-6a and Table 4-6b respectively.

TABLE 4-6a

MEAN MONTHLY WIND SPEED (MILES/HR)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Coulee Dam 1 SW	4.22	4.04	4.70	4.52	4.12	4.25	4.25	3.99	3.97	4.41	4.79	4.73	4.33

Computed mean Monthly value from daily values

TABLE 4-6b

MEAN MONTHLY WIND DIRECTION (DEG AZIMUTH)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Coulee Dam 1 SW	210	198	163	156	157	172	182	179	183	180	201	223	184

Computed mean Monthly value from daily values

g) Climate Preparedness. The Corps Climate Preparedness and Resilience Policy Statement (27 June 2014), states that the Corps will integrate climate change preparedness and resilience planning and actions in all activities for the purpose of enhancing the resilience of our built and natural water-resource infrastructure to reduce the potential vulnerabilities of that infrastructure to the effects of climate change and variability. Extensive climate assessments have been performed in this region and have been published in the latest Environmental Impact Statement (EIS) for the Columbia River System. Chapter 4 of the EIS includes the results and conclusions from these studies.

A summary of observed trends in primary and secondary climate variables in the Columbia River Basin indicates that temperatures have increased over the period of record and are expected to continue to increase. As a result of these rising temperatures, other aspects of the environment are changing as well, such as receding glaciers, diminishing snow cover, shrinking sea ice, rising sea levels, and increasing atmospheric water vapor. According to the 2017 Fourth National Climate Assessment Volume 1, annual trends of earlier spring snow melt and reduced snowpack in the CRT is likely to decline, winter streamflows will tend to increase, peak seasonal snowmelt will tend to occur earlier in the spring and summer flows will likely decrease.

A summary of projected trends in primary and secondary climate variables in the Columbia River Basin for the 2020 - 2049 timeframe (referred to as the 2030's) was presented in the RMJOC 2018 Report as follows:

> Temperatures in the region have warmed about 1.5 degrees Fahrenheit since the 1970s. They are expected to warm another 1 to 4 degrees Fahrenheit by the 2030's.
>
> Warming in the region is likely to be greatest in the interior with a greater range of possible outcomes. Less pronounced warming is projected near the coast.
>
> Future precipitation trends are more uncertain, but a general upward trend is likely for the rest of the twenty-first century, particularly in the winter months. Already dry summers could become drier.
>
> Average winter snowpack is very likely to decline over time as more winter precipitation falls as rain instead of snow, especially on the United States side of the Columbia River Basin.
>
> By the 2030's, higher average fall and winter flows, earlier peak spring runoff, and longer periods of low summer flows are very likely.

Based on the above observations and projections precipitation increases, along with a warming of temperatures, which could have profound implications on both magnitude and seasonality of future streamflows for hydro-regulation operations and planning. The cumulative streamflow projections in the middle Columba River Basin near GCL show modest change, as snowpack at high mountain elevations of the upper basin display less sensitivity to lower amounts of warming. However, a shift toward earlier spring and summer streamflow volumes is projected. Some projections indicate higher spring freshet peaks, which tend to occur 1 or 2 weeks earlier by the 2030s as precipitation increases in this part of the basin and the climate warms. Nearly all projections indicate decreased volume of flow in summer months.

The Water Control Plan (Section 7), including the drought contingency plan for Grand Coulee Dam has considered these observations and projections to the extent practicable. The operating plan includes integrated strategies for adaptation (i.e., manage unavoidable impacts) and mitigation (i.e., avoid unmanageable impacts). The Water Control Plans will be reviewed periodically and updated as needed to manage climate change and variability impacts.

4.06 Storms and Floods. The storms in the Columbia Basin, including the area around GCL, vary from intense local thunderstorms to large-scale fronts. Runoff from these events do not normally affect the operation of the Middle and Lower Columbia River projects due to the relatively small volumes of water contributed to the mainstem.

Flooding due to late spring snowmelt runoff is the primary concern on the Middle and Lower Columbia and generally occurs in May and June. High flows at GCL result primarily from spring snowmelt originating in the upper Columbia Basin with the peaks and volumes largely dependent upon the extent of the snow cover, the temperature sequence, and operations of upstream projects. The most extreme spring runoff occurs when there is a strong peak snowmelt runoff, combined with runoff from heavy spring rains, which occurred in the spring of 1948. The two highest peak flows recorded at Grand Coulee are 725,000 cfs (The Dalles is 1,240,000 cfs) which occurred June 1894 and 637,800 cfs (The Dalles was 1,010,000 cfs) which occurred May/June 1948.

Occasionally there are moderately high winter flows when extensive winter rainstorms occur over the lower basin below Grand Coulee. These winter storms occur in November through February. The larger or extreme winter flood events are generally a function of preexisting conditions such as saturated or frozen soils, extensive snow cover at lower elevation, with a warm moist Pacific air mass bringing precipitation, (in the form of atmospheric rivers), and melting of the low-level snow. In addition, the winter peak flows for local tributaries west of the Cascade Range are also driven by atmospheric river storms and add to flows on the mainstem Columbia.

a) June 1894. The historical flood of 1894 is recognized as the largest known flood to occur at the Grand Coulee Dam site with an estimated peak discharge of 725,000 cfs based on high-water marks (no stream gage was available in the vicinity of GCL at that time). However, a peak discharge of 1,240,000 cfs was recorded at The Dalles station downstream of the Grand Coulee Dam site. The snowfall over all of the Columbia River drainage basin had been exceptionally heavy during the previous winter. This flood completely wiped out the town of Cascades, located near today's Bonneville Dam.

b) May-June 1948. The 1948 flood is considered the largest and most disastrous flood in terms of monetary damages with an estimated peak discharge of 637,800 cfs at GCL. However, a peak discharge of 1,010,000 cfs was recorded at The Dalles station downstream of GCL. A critical feature of the flood was the long duration of peak or near-peak stages on the Columbia. This flood completely inundated the city of Vanport, which is now the location of Portland International Raceway and the Huron Lakes Golf Course. The Columbia River at Vancouver

(VANW) crested at 30.8 feet (Columbia River Datum)[7] on June 1 and at 31.0 feet (Columbia River Datum) on June 13, the highest stage since the late 1800s. The discharge was about 1,000,000 cfs for almost a month. The city of Vanport was constructed in 1943 to house families of workers at the wartime Kaiser Shipyard. A poorly constructed levee surrounding the community failed dramatically on May 30th, rapidly inundating and destroying Vanport. At least 15 people died in the flood, and the city was a complete loss. Flooding also occurred in several other communities downstream of Portland/Vancouver on both the Oregon and Washington banks of the river. Source of data is:

http://www.floodsafety.noaa.gov/states/or-flood.shtml.

The highest known floods and seasonal maximum discharges for the ten highest known floods on the Columbia River at Grand Coulee Dam and at The Dalles, are listed in Table 4-7. These discharges are USGS peak stream flows which do include effects of upstream diversions and storage projects, over the 1952-1974 period.

[7] The Columbia River Datum is 1.82 feet (a stage reading of 0 is 1.82 feet above sea level, or more specifically NGVD29). The Columbia River at Vancouver gage uses the Columbia River Datum.

TABLE 4-7

TEN HIGHEST FLOODS - COLUMBIA RIVER AT GRAND COULEE, WA & THE DALLES, OR

Order	Date of Discharge	Grand Coulee Dam (cfs) Gage# 12436500	Date of Discharge	Dalles Dam (cfs) Gage# 14105700
1	June 1894*	725,000	June 06, 1894	1,240,000
2	June 12, 1948	638,000	May 31, 1948	1,010,000
3	June 08, 1956	522,000	June 02, 1956	823,000
4	June 25, 1950	508,000	June 25, 1950	744,000
5	June 09, 1961	503,000	June 08, 1961	699,000
6	June 15, 1913*	492,000	June 12, 1913	759,000
7	June 01, 1928	490,000	May 29, 1928	766,000
8	June 23, 1933	469,000	June 18, 1933	722,000
9	June 25, 1967	429,000	June 10, 1967	622,000
10	June 28, 1959	426,000	June 23, 1959	555,000

** Flood discharges for 1894 and 1913 are estimated from historical information.*

4.07 Runoff Characteristics. The Columbia River annually provides an average of 129 million acre-feet of runoff volume according to the Northwest River Forecast Center (NWRFC). The bulk of the runoff comes in the spring and early summer when snow melts in the many mountain ranges of the Columbia River Basin. Headwaters of the Columbia River normally begin their seasonal snowmelt runoff in late March, April, or early May; streamflow continues to rise usually peaking in late May or early June as warming temperatures cause basin-wide melting. A slow recession normally occurs during the late summer and fall as the high- level snowpack is gradually depleted. According to Reclamation, the average discharge at Grand Coulee over a period of years is approximately 110,000 cubic feet per second and the annual volume inflow has varied from a minimum of 48.5 million acre-feet to a maximum of 111.8 million acre-feet (Reclamaation 2021).

The ten highest April – August runoff volumes for the Columbia River at Grand Coulee Dam are listed in Table 4-8.

TABLE 4-8
TEN HIGHEST APRIL THROUGH AUGUST RUNOFF VOLUMES AT GRAND COULEE DAM (GCDW1)

Rank	Water Year	Volume (MAF)*
1	1997	83.273
2	2012	79.729
3	2011	74.947
4	1976	74.798
5	1956	72.909
6	1996	72.006
7	1954	71.912
8	1999	70.918
9	1991	70.150
10	1950	69.729

**Values prepared from Monthly Runoff Information available at Northwest River Forecast Center.*

Table 4-9 lists the average monthly regulated streamflow at GCL for the 1961 – 2019 period of record, reported at the GCL AgriMet station.

TABLE 4-9

AVERAGE MONTHLY REGULATED STREAMFLOWS

Month	Regulated (cfs)
October	76,045
November	79,517
December	91,075
January	93,821
February	88,639
March	86,028
April	103,115
May	165,440
June	200,960
July	145,564
August	123,865
September	107,028
Average	**80,163**

**Values extracted from Water Year reports published between 1961-2019 by Bureau of Reclamation.*

The estimated monthly inflow volume frequencies at GCL based on the period 1961 to 2020 are shown in Table 4-10. The streamflow statistics along the mainstem at selected sites upstream and downstream of GCL are shown in Table 4-11.

TABLE 4-10

MONTHLY INFLOW FREQUENCY VOLUME

AT GRAND COULEE DAM (1000 AC-FT) PERIOD OF RECORD 1961-2020

Month	Frequency of Occurrence in Years					
	2	5	10	25	50	100
	Percent Chance Exceedance					
	50%	20%	10%	4%	2%	1%
January	2,311	3,034	3,576	4,334	4,956	5,628
February	2,361	3,258	3,884	4,713	5,357	6,025
March	3,432	4,650	5,532	6,733	7,693	8,712
April	7,020	8,907	9,962	11,125	11,889	12,582
May	15,872	19,104	21,158	23,687	25,536	27,364
June*	18,049	22,341	24,969	28,106	30,335	32,487
July*	10,910	13,746	15,552	17,775	19,399	21,002
August*	5,711	6,891	7,712	8,794	9,633	10,502
September*	3,408	4,120	4,633	5,328	5,880	6,460
October	2,821	3,543	3,988	4,521	4,901	5,268
November	2,694	3,573	4,182	4,984	5,606	6,250
December	2,322	3,076	3,666	4,522	5,246	6,049

*Note: * At 15% significance level, negative trends were observed for June (p-value=0.03), July (p-value =0.11), August (p-value=0.001), and September (p-value=0.02). To be conservative, the trend in the time series was removed by applying linear regression to the entire dataset and establishing a reference using the last 30 years of record. This method (detrend) conserved the mean of the time series. The final Flood frequency analysis were performed using the detrend time series.*

TABLE 4-11

COLUMBIA RIVER REGULATED STREAMFLOW STATISTICS [a, b, c]

USGS Gage No.	**12399500**	**12438000**	**12472800**	**14105700**
Location	International Boundary	Bridgeport, WA	Below Priest Rapids Dam, WA	The Dalles, OR
Drainage Area - (mi^2)	59,700	75,700	96,000	237,000
Period of Record (Water Year)	1965 - 2020	1965 - 2020	1965 - 2020	1965 - 2020
Oct	74,500	73,200	78,800	111,700
Nov	77,300	83,900	91,400	128,500
Dec	88,600	97,200	104,500	150,400
Jan	89,800	104,700	111,800	167,300
Feb	80,400	104,800	112,100	176,400
Mar	72,500	102,400	110,600	189,500
Apr	79,400	108,000	122,300	219,300
May	134,400	136,600	165,100	287,900
Jun	173,100	156,300	187,500	298,200
Jul	138,000	133,000	146,600	196,800
Aug	105,500	104,900	109,500	140,900
Sep	79,400	74,600	77,900	108,700
Mean Annual	99,400	106,800	118,200	181,300
Max Annual	132,800	149,500	169,000	298,200
Min Annual	60,800	70,700	75,700	108,700
Max Daily	434,000	422,000	483,000	622,000
Min Daily	21,500	22,300	36,800	47,600
Peak Flow	438,000	432,000	506,000	622,000
Date	6/25/1967	6/25/1967	6/26/1967	6/10/1967

a. Table values are in cfs unless otherwise noted
b. Mean monthly observed values for stated period of record (includes regulation effects)
c. Data taken from USGS website https://nwis.waterdata.usgs.gov

4.08 Water Quality.

a) Classification. The waters of the mainstem of the Columbia River, including waters directly above and below GCL, are classified according to current beneficial uses under Washington Administrative Code (WAC), Title 173, Chapter 173-201A titled "Water Quality Standards for Surface Waters of the State of Washington." The entire Chapter (Chapter 173-201A) contains information outlining classifications, definitions, antidegradation provisions, types of pollution and related water quality standards (WQS), variances and other pertinent information that can be found at:

https://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A.

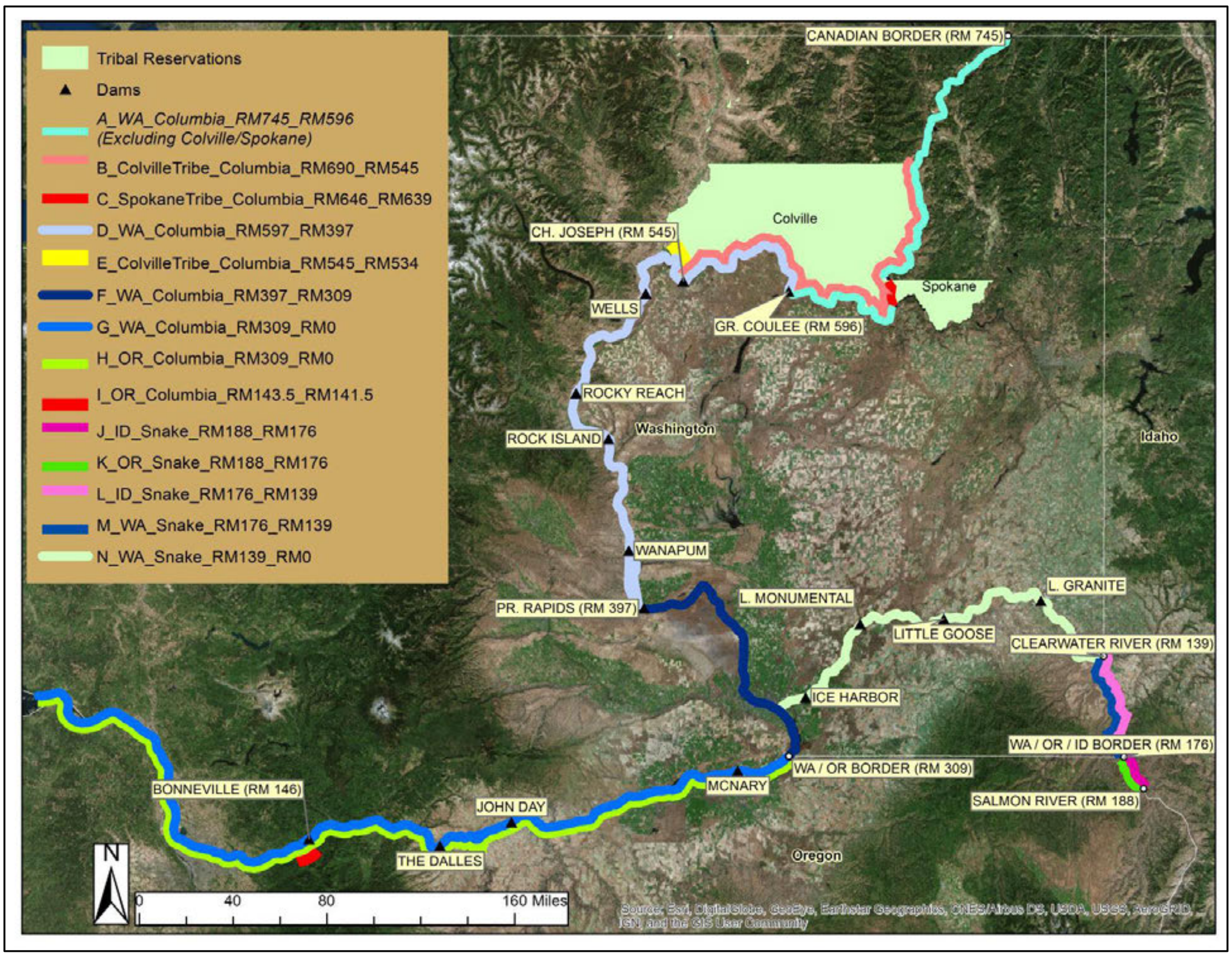
Table 602 of the WAC describes uses of the river, for which specific water criteria are assigned. Below Grand Coulee Dam, between Grand Coulee and Chief Joseph dams, aquatic life uses (ALU) are defined as “Spawning and Rearing”; above the dam, between Grand Coulee Dam and the Canadian border, ALUs are described as “Core Summer Habitat.” Primary Contact Recreation, water supply and miscellaneous uses are also ascribed in both these sections of the river. The specific water quality criteria that relate to these uses are found in WAC 173-201-200 titled “Fresh water designated uses and criteria.” Washington State water quality standards for the above-mentioned uses are presented in this subchapter for various parameters such as: temperature, dissolved oxygen, bacteria, pH, turbidity, total dissolved gas, and other contaminants of concern.

Additionally, tribal water quality standards apply to waters above and below Grand Coulee Dam. Both the Spokane and Colville tribes set their own standards, which in some cases, are more stringent than Washington’s standards. Careful attention is necessary to understand which criteria (e.g. State or Tribe) apply based upon location and time of year, since some criteria such as temperature can vary based upon season. The Spokane Tribe classifies waters in Lake Roosevelt between its reservation boundary and the Colville’s reservation boundary as Class AA (pristine). The Colville has defined the waters between its boundary all the way to Chief Joseph Dam as either Class I (very good) or Class II (good) waters.

Figure 4-1 and Table 4-12 list appropriate jurisdiction by river mile. Current Colville tribal water quality standards can be found at: https://www.epa.gov/wqs-tech/water-quality-standards-regulations-confederated-tribes-colville-reservation. Spokane tribal water quality standards can be found at: https://www.epa.gov/wqs-tech/water-quality-standards-regulations-spokane-tribe.

FIGURE 4-1

COLUMBIA AND SNAKE RIVER TEMPERATURE WQS JURISDICTIONS AND RIVER MILES



Source: WA River Miles and Reservations from ECY, Dams from ACE, OR/ID River Miles from R10 GIS Team. Map created by Martin Merz, EPA R10 ORISE

TABLE 4-12

SUMMARY OF TEMPERATURE WQS FOR COLUMBIA AND SNAKE RIVERS, INCLUDING AQUATIC LIFE USES, NUMERIC CRITERIA AND NARRATIVE CRITERIA.

Map	Jurisdiction	River Miles	Narrative Criterion	Numeric Criterion	Aquatic Life Use
A	*Washington*	*Canadian Border (745) to Grand Coulee Dam (596) (excluding RM 646.5-639)*	*Natural Conditions*	*16°C 7-DADM*	*Core Summer Salmonid Habitat*
B	*Colville Tribe*	*N. Reservation Boundary (690) to Chief Joseph Dam (545)*	*Natural Conditions*	*16°C 1-DMax.* [1] *(CTCR 4-8)*	*Class I*
				18°C 1-DMax. [2] *(40 CFR 131.35)*	*Class II*
C	*Spokane Tribe*	*Reservation Boundary (646.5) to Reservation Boundary (639)*	*No Natural Conditions*	*16.5°C 7-DADM (June 1 - Sept 1); 13.5° C 7-DADM (Sept 1 – Oct 1 & April 1 – June 1); 11°C 7-DADM (Oct 1 – March 31)*	*Class AA*
D	*Washington*	*Grand Coulee Dam (596) to Priest Rapids Dam (397)*	*Natural Conditions*	*17.5°C 7-DADM*	*Salmonid spawning, rearing and migration*
E	*Colville Tribe*	*Chief Joseph Dam (545) to Okanogan River (534)*	*Natural Conditions*	*18°C 1-DMax* [3] *(40 CFR 131.35 & CTCR 4-8)*	*Class II*
F	*Washington*	*Priest Rapids Dam (397) to WA/OR Border (309)*	*Natural Conditions*	*20°C 1-DMax*	*Salmonid spawning, rearing and migration*
G	*Washington*	*WA/OR Border (309) to Pacific Ocean (0)*	*Natural Conditions*	*20°C 1-DMax*	*Salmonid spawning, rearing and migration*

[1] Averaging period not provided – interpreted as daily maximum (*1-DMax*) [2] Averaging period not provided – interpreted as daily maximum (*1-DMax*) [3] Averaging period not provided – interpreted as daily maximum (*1-DMax*)

b) <u>Total Dissolved Gas (TDG).</u> Elevated TDG levels can lead to a condition called gas bubble trauma or gas bubble disease (GBD). Factors that affect the vulnerability of fish to GBD include TDG level, temperature, duration of exposure (especially gas levels above 120%), recovery time following exposure, fish species, fish life stage and size, fish behavior, and fish location in the water column and river cross-section. Water quality standards for Washington State, the Colville Tribe, and the Spokane Tribe have an identical TDG criterion: 110% of saturation not to be exceeded at any point of measurement. The criteria for Washington State and the Colville Tribe do not apply to flows above the seven-day, ten-year frequency flow (7Q10). In addition, special limits for TDG are established as a special condition in Washington rules, to allow higher criteria with specific averaging periods during periods of spill for fish passage if approved within a gas abatement plan.

c) Temperature. Water temperature in the Columbia River downstream from GCL exceeds permissible levels for trout and salmon during the summer and fall because of the thermal shift that occurs because of the existence of FDR. Due to the size of the reservoir and associated increase in residence time for incoming waters, high and low temperature periods are shifted from those naturally occurring in the river. The reservoir is slower to warm in the spring and slower to cool in the fall as incoming cold or warm water takes on average 36 days in June and 76 days in September to travel through the reservoir (Thermal Regime of the Columbia River at Lake Roosevelt, USBR, June 2018).

4.09 Channel and Floodway Characteristics. GCL serves a key role in the flood risk management (FRM) strategy of the Columbia River Basin because of its size and location. Flood risks are managed in the Columbia River Basin by a system of FRM storage reservoirs, which in total provide approximately 40 MAF of storage capacity to manage system and local flood risks. This is compared to an average annual runoff volume of 129 MAF in the basin. The ability of the system of reservoirs to manage flood risk is further limited by the ability to predict, or forecast, the volume and shape of runoff each flood season. With an active storage capacity of 5.349 MAF and as the closest reservoir with significant storage to The Dalles, GCL offers the greatest opportunity to influence the flow relatively quickly in the lower Columbia. The channel between GCL and The Dalles is relatively straight, and the cross sections are deep and fairly uniform. At medium stages the flow becomes turbulent with high velocities. The hydraulic travel time from GCL to The Dalles is approximately 1 day for in-bank flows. The Dalles Dam is an important system FRM control point used in determining system FRM operations including the regulation of reservoir storage in GCL.

4.10 Upstream Structures. A list of primary dams and reservoir projects located upstream of GCL is provided in Table 4-13.

TABLE 4-13

DAMS & RESERVOIRS UPSTREAM OF GCL

Project Name	River	Owner Operator	Construction Completed	Purpose *	Drainage Area (sq mi) **	Usable Storage (Million acre-feet)
Mica Dam	Columbia	B.C. Hydro	1973	F P	8,100	12.000
Revelstoke Dam	Columbia	B.C. Hydro	1984	F P	10,300	-----
Keenleyside Dam	Columbia	B.C. Hydro	1968	F I P R N	14,100	7.100
Duncan Dam	Duncan	B.C. Hydro	1967	F I P	930	1.400
Libby Dam	Kootenai	USACE Seattle District	1973	F P	8,985	4.980
Corra Linn Dam^	Kootenay	FortisBC	1932	F I P	17,600	-----
Hungry Horse Dam	South Fork Flathead	Bureau of Reclamation	1953	F I P	1,650	2.982
SKQ Dam	Flathead	Energy Keepers, Inc.	1938	F P R	7,100	1.219
Thompson Falls Dam	Clark Fork	NorthWestern Corp	1915	P	21,080	Run of River
Noxon Rapids Dam	Clark Fork	Avista	1959	P	21,830	Run of River
Cabinet Gorge Dam	Clark Fork	Avista	1952	P	22,070	Run of River
Albeni Falls Dam	Pend Oreille	USACE Seattle District	1955	F P N	24,200	1.155
Box Canyon Dam	Pend Oreille	Pend Oreille County PUD	1955	P	24,900	Run of River
Boundary Dam	Pend Oreille	Seattle City Light	1967	P	25,200	Run of River
Seven Mile Dam	Pend Oreille	B.C. Hydro	1979	P	25,770	Run of River
Waneta Dam	Pend Oreille	Teck Resources and BC Hydro	1954	P I	26,000	-Run of River

Based on table prepared by Seattle District using data from "Authorized and Operating Purposes of Corps of Engineers Reservoirs" dated July 1992 and "2000 Level Modified Streamflows" dated May 2004.

** F =Flood Control. I =Irrigation. P =Power. R =Recreation N=Navigation*

*** Drainage areas are approximate*

^ Corra Linn Dam is the first of five dams located on the lower portion of the Kootenay River in Canada. The other four dams are Upper Bonnington, Lower Bonnington, South Slocan, and Brilliant. Water can be released from Kootenay Lake either through Corra Linn Dam or by utilizing the Kootenay Canal. Water that is sent through the Kootenay Canal returns to the Kootenai River between South Slocan and Brilliant. For simplicity, only Corra Linn Dam is listed in this table.

<u>4.11 Downstream Structures.</u> A list of primary dams and reservoir projects located downstream from GCL is provided in Table 4-14.

TABLE 4-14

COLUMBIA RIVER MAINSTEM

DAMS & RESERVOIRS DOWNSTREAM OF GCL

Project Name	Owner Operator	Construction Completed	Purpose *	Drainage Area (sq mi) **	Usable Storage (million acre-feet)
Chief Joseph Dam	USACE Seattle District	1961	P I R	75,400	Run of River
Wells Dam	Douglas County PUD	1967	P F R	86,100	Run of River
Rocky Reach Dam	Chelan County PUD	1961	P F R	87,800	Run of River
Rock Island Dam	Chelan County PUD	1933	P	89,400	Run of River
Wanapum Dam	Grant County PUD	1964	P F R	90,700	Run of River
Priest Rapids Dam	Grant County PUD	1961	P F R	96,000	Run of River
McNary Dam	USACE Walla Walla District	1957	P N	214,000	Run of River
John Day Dam	USACE Portland District	1971	F P N	226,000	0.534
The Dalles Dam	USACE Portland District	1960	P N	237,000	Run of River
Bonneville Dam	USACE Portland District	1938	P N	240,000	Run of River

Based on table prepared by Seattle District using data from "Authorized and Operating Purposes of Corps of Engineers Reservoirs" dated July 1992 and "2000 Level Modified Streamflows" dated May 2004.

** F =Flood Control. I =Irrigation. P =Power. R =Recreation N=Navigation*
*** Drainage areas are approximate*

Several small run-of-river powerplants downstream of Kootenay Lake in British Columbia and offstream storage and pondage reservoirs on the Spokane, Lake Chelan, Yakima, and Snake Rivers are not included in Tables 4-13 or Table 4-14.

4.12 Economic Data.

a) Population. GCL is located in rural, eastern Washington, 85 miles northwest of Spokane, Washington. This section will only address population centers along the mainstem Columbia River. A major population center in this region is the Tri-Cities area that consists of Kennewick, Pasco, and Richland, Washington. The estimated population of communities in the middle Columbia Basin is 284,937, of which 29,798 are in the FEMA flood hazard area. This region includes primarily rural areas which include an estimated population of 16,000 people, of which 7,000 are located in the FEMA flood hazard area. The largest population center in the region is Kennewick, Washington (population 82,000), and its suburbs. Communities that intersect this section of the Columbia River system, as well as populations that fall within FEMA flood hazard areas in the middle Columbia Basin are listed in Table 4-15. There are also a number of tribes with reservation lands and off-reservation trust lands in in this region, including the Confederated Tribes of the Colville Reservation (CTCR), the Spokane Tribe of Indians, and the Coeur d'Alene Tribe.

TABLE 4-15.

COMMUNITIES WITHIN MIDDLE COLUMBIA RIVER BASIN 100- AND 500-YEAR FLOODPLAINS

Community	2017 Estimated Population1/	Estimated Population Within Flood Hazard Area4/	Columbia River Mile
Kennewick, WA3/	81,646	4,656	334.5
West Pasco, WA2/	3,739	35	334.8
Pasco, WA3/	73,013	390	337.5
Richland, WA3/	56,243	1,244	343.6
Desert Aire, WA2/	2,141	38	402.0
Vantage, WA2/	80	0	421.0
Rock Island, WA	1,015	211	459.7
South Wenatchee, WA2/	1,681	507	467.2
East Wenatchee, WA	13,983	3,959	469.6
Wenatchee, WA	33,962	18,357	471.0
Sunnyslope, WA2/	3,562	58	473.8
Entiat, WA	1,223	0	487.3
Chelan Falls, WA2/	365	0	503.1
Chelan, WA	4,146	45	503.9
Brewster, WA	2,343	75	531.8
Bridgeport, WA	2,555	161	544.9
Coulee Dam, WA	1,079	4	596.9
Grand Coulee, WA	1,042	8	597.6
Inchelium, WA2/	409	41	681.4
Barney's Junction, WA2/	147	0	705.9
Marcus, WA	193	0	711.5
Barstow, WA2/	60	7	718.3
Northport, WA	310	2	738.8
Rural Areas	**15,747**	**7,114**	
Total	**284,937**	**29,798**	

Notes:
1/ Source: U.S. Census Bureau (2017) or latest available data.
2/ Source: ESRI data that is derived from U.S. Census data for unincorporated areas that are census-designated places.
3/ Some portions of the Tri-Cities area are located in the lower Columbia River and some in middle Columbia River. Reported populations are included in one region only (to avoid double counting).
4/ Includes 1% and 0.2% annual chance exceedance flood hazard areas. Populations within the 1% annual chance exceedance (100-year) and 0.2% annual chance exceedance (500-year) flood zones were estimated with GIS software using U.S. Census block data in conjunction with FEMA flood insurance rate map (FIRM) data.
Populations located outside of community boundaries but within the hydrologic and hydraulic modeling area are considered as rural.

b) Agriculture. Grand Coulee Dam provides water to irrigate about 720,000 acres with diversions occurring between March through October via canals and other means. GCL supports nearly

6,000 farms with more than 60 varieties of crops including potatoes, peppermint, apples, wheat, and corn.

c) Flood Damage. GCL plays a key role in flood risk management within the Columbia River Basin and offers a significant opportunity to reduce flood damages in the lower Columbia, compared to other projects in the system. The major U.S. federal flood storage projects upstream of GCL are Libby and Hungry Horse. The lower Columbia River Basin includes the major metropolitan area of Portland, Oregon, including suburbs, as well as Vancouver, Washington. It also includes the town of Longview, Washington, as well as The Dalles, Oregon.

The total population of the lower Columbia River Basin is approximately 1.4 million, with an estimated population within the FEMA-defined flood hazard area of 90,000. The largest population residing in the FEMA-defined flood hazard area is in Longview, Washington, where an estimated population of 33,000 resides in the flood hazard area. An additional 18,000 people in Portland, Oregon, also reside in the flood hazard area. The lower Columbia basin includes rural areas with an estimated population of 44,000 people, of which 12,000 are located within the flood hazard area. There are also several tribes with reservation lands and off-reservation trust lands in the lower basin, including the Confederated Tribes and Bands of the Yakama Nation, the Cowlitz Indian Tribe, the Confederated Tribes of the Warm Springs Reservation of Oregon, and the Confederated Tribes of the Umatilla Indian Reservation.

Computations for damages prevented have not been consistently developed prior to 2015; however, flood damages prevented data is available for 2015-2020. The flood damages prevented data are based on a consistent method for allocating damages prevented between reservoirs and levees, as well as distributing damages prevented amongst upstream reservoirs. The methods have been used for the annual flood damage reduction reports submitted to

Congress. For information purposes, the 2015-2020 data are provided in Table 4-16. All damages prevented values are in 2020 dollars.

TABLE 4-16
FLOOD DAMAGES PREVENTED GRAND COULEE (SYSTEM FLOOD CONTROL) (2020 COST LEVEL)[1]

Year	Real ($1000)
2015	9,100
2016	53,955
2017	416,316
2018	80,226
2019	42,218
2020	284,409

[1]Information provided by HQUSACE from Annual Flood Damage Reduction Report to Congress
Note: Damages prevented include system FRM benefits downstream to the mouth of the Columbia River. Prices have been updated to 2020 Fiscal Year.

SECTION 5. DATA COLLECTION AND COMMUNICATION NETWORKS

5.01 Hydrometeorological Stations.

a) Facilities. This section describes the hydrometeorological stations in the 74,700 mi^2 Columbia River and tributaries area upstream from GCL. A primary resource facilitating the availability of Columbia River Basin hydrometeorological data is the Hydrometeorological Committee (CRTHC), described further in Chapter 9.

There is an extensive system of active hydrometeorological (hydromet) stations in the Columbia River Basin. These include climate gages managed by the National Oceanic and Atmospheric Administration (NOAA); stream and lake gages managed by the United States Geological Survey (USGS); lake level gages owned and operated by Reclamation providing information on forebay and tailwater elevations; and snow stations managed by the Natural Resources Conservation Service (NRCS). Some stream gaging stations are equipped with automated water quality or water temperature sensors. The Water Survey of Canada operates and maintains stream gaging stations in the portion of the Columbia River Basin which lies in Canada. A brief description of the various entities and their role in the collection and reporting of hydrometeorological data is provided in the paragraphs below.

(1) National Weather Service (NWS). NWS collects data from weather stations throughout the United States. Locations of active and discontinued weather stations in the Pacific Northwest and the Columbia River Basin and their records are available in NWS publications. Current weather conditions for Grand Coulee Dam are available from the NWS Spokane, WA forecast area and can be accessed from https://www.wrh.noaa.gov/otx/current.php. NWS along with NOAA provides

comprehensive snow information that is available from the National Operational Hydrologic Remote Sensing Center (NOHRSC) at https://www.nohrsc.noaa.gov.

(2) The Western Regional Climate Center (WRCC). The WRCC disseminates high quality climate data and information pertaining to the western United States. It is managed by NOAA's National Climatic Data Center (NCDC). The website https://www.wrcc.dri.edu/ provides access to data for many active and discontinued stations. Hourly images and data from Remote Automatic Weather Stations (RAWS) and Meteorological Aerodrome Reports (METAR) for Washington and the Columbia Basin are available at https://www.raws.dri.edu/ .

(3) Northwestern Division, Columbia Basin Water Management (CBWM). CBWM provides public access to project data on their web page at:

https://www.nwd.usace.army.mil/CRWM/Water-Control-Data/

(4) Local Weather Data Collected by Project Staff. The local watershed surrounding Lake Roosevelt is an arid area with low annual precipitation (both rainfall and snowfall). As a result, active weather recording in the vicinity of GCL is limited to the weather data collected at GCL and CHJ (a Corps project downstream of GCL) by project staff. Hourly and daily summaries of temperature, precipitation, snowfall, and general weather conditions are collected and transmitted to the NWS for archiving and publication. These gages are maintained by the Reclamation staff at GCL and USACE staff at CHJ.

(5) Natural Resources Conservation Service (NRCS). The NRCS operates and maintains automated SNOTEL snowpack recording stations and manual snow-course measuring stations throughout the Columbia Basin in the United States. Snow data from automated recording sites are automatically transmitted via the NRCS Snow Course Telemetry

System (SNOTEL) https://www.wcc.nrcs.usda.gov/snow/ to local NRCS centers for processing and publication for public use. These data are reported on NRCS websites and published in their snow survey publications. Because of the low elevations of the GCL local watershed and lack of seasonal snowpack, there are no NRCS stations in the vicinity of GCL.

(6) Meteorological Service of Canada (MSC), Environment Canada. This agency is Canada's source for meteorological information. The Service monitors water quantities, provides information and conducts research on climate, atmospheric science, air quality, ice and other environmental issues, making it an important source of expertise in these areas. Canadian Ministry of Environment maintains snow survey stations in the upper Columbia River basin. The URL is:

https://www.canada.ca/en/services/environment/weather.html

(7) Government of British Columbia, Ministry of Water, Land and Air Protection, River Forecast Centre (RFC). RFC collects and interprets snow, meteorological and streamflow data to provide warnings and forecasts of stream and lake runoff conditions around the province. Most of the meteorological and streamflow data are collected by other agencies, but the RFC is the lead agency in the province for the collection, quality control, analysis and archiving of snow data. The URL is

https://www.env.gov.bc.ca/rfc/.

(8) The United States Geological Survey (USGS). USGS has operated and maintained streamgaging stations in the Columbia River Basin in Idaho, Montana, and Washington since the early 1900's to provide streamgage data for public use. USGS surface water records are published in their annual Water Resource Data Reports at

https://wdr.water.usgs.gov/. Realtime gage readings are reported on their website at the following address: https://nwis.waterdata.usgs.gov. The USGS office in Kalispell, Montana, the USGS office in Sandpoint, Idaho, and the USGS field office in Spokane, Washington should be notified concerning any streamgage operation or maintenance problems. There are two USGS streamgages located near GCL. The discharges reported at these gages are calculated by the project staff at the dams. The USGS does not report real-time data for these gages. Realtime hourly data are available for the last eight days on the NWD website at the following address:

https://www.nwd.usace.army.mil/CRWM/Water-Control-Data/Project-Data/.

Daily discharges are transmitted to the USGS for publication (for data access, see website addresses in paragraphs below).

(a) Columbia River at Grand Coulee Dam, WA (USGS #12436500). Inflow into Rufus Woods Lake (CHJ) and outflow at GCL is provided by this gage which is located on pier 3 on the west side of the bridge on State Highway 155, about 3,200 ft downstream from GCL. Major water diversions for irrigation are made at GCL and in British Columbia upstream of the GCL gage. Drainage area is 74,700 mi^2. Period of record is as follows: April 1913-June 1923 (monthly discharges only), July-December 1923, January 1924-May 1928 (monthly discharges only), and June 1928 to the present. Mean daily discharge for the period of record from 1923-2021 is 34,206 cfs. Project outflow is affected by backwater from Rufus Woods Lake and as a result, the discharge from GCL is computed as flow through turbines plus spill, similar to the procedure used at CHJ. The daily data can be accessed at the following website:

https://waterdata.usgs.gov/wa/nwis/dv/?site_no=12436500&referred_module=sw

(b) Columbia River at Bridgeport, WA (USGS #12438000). This gage is located 1.6 mi downstream from CHJ. Drainage area is 75,700 mi^2. Period of record is April 1952 to the present. Daily mean discharge is 25,318 cfs during the 69-year period from 1952-2021. Water level at this station is affected by backwater from Lake Pateros, the reservoir behind Wells Dam, and the gage site is used only for water quality sampling and similar activities. Streamflows at CHJ are manually computed each hour using a table lookup process that uses tabular relationships between hydraulic head, power generation, and discharge, then adding spillway discharge, if any. The process involves two table lookup sets, one for the "old" units #1-16 and the one for the "new" units #17-27. The head-power-discharge relationships described above are developed by Portland District's Hydroelectric Design Center (HDC) from turbine prototype and Gibson test data for each of the three turbine ratings. The daily data can be accessed at the following website:

https://waterdata.usgs.gov/wa/nwis/dv/?site_no=12438000&referred_module=sw

(9) Water Survey of Canada. Stations for stream gage and surface water data for British Columbia are operated, maintained, and published by the Water Survey of Canada. The hydromet data can be accessed at the following website:

https://wateroffice.ec.gc.ca/

b) Reporting. Data for the Reclamation-operated lake level gages providing forebay and tailwater elevations are reported hourly; data from these gages are stored in the Corps Regional Water

Control Data System (RWCDS) database at this time-step and are reported at this time-step on the Corps' public access water management website. Data from the non-Corps sensors are reported at different time-steps depending on the type of data and operating agency, although, in general, reporting time-steps are hourly or more frequent. Data collected at the Reclamation-operated lake level gages are reported to the closest hundredth of a foot. The reading at the forebay lake level sensor, which is the gage Reclamation uses as the official lake level reading in Lake Roosevelt, is checked periodically using a manual observation since this is the sensor used to maintain the desired water surface elevation for project operations.

c) Maintenance. Maintenance at the Reclamation-operated lake level gages is performed on an as-needed basis, but generally is required infrequently as these types of sensors use relatively simple technology and are inherently low maintenance.

Weather stations are operated and maintained by NOAA. The NRCS operates and maintains snow measurement stations in and around the basin. The USGS operates and maintains stream gages in the United States portion of the Columbia River Basin, and the Water Survey of Canada provides the same service for stations in the portion of the Columbia River Basin in Canada.

5.02 Water Quality Stations.

a) Facilities. Total Dissolved Gas (TDG) and temperature readings are measured hourly at two gages: Grand Coulee Forebay (FDRW) and Grand Coulee Tailwater (GCGW). The forebay station is located mid-river and the tailwater station is located 6 miles downstream from the dam on the left bank. Parameters transmitted from both stations include: Probe Depth in feet, Water Temperature in ^{o}F, Barometric Pressure in mm of Hg, and TDG in percent saturation. Data are recorded hourly and then transmitted every four hours by a data collection platform via the Geostationary Operational Environmental Satellite (GOES) to the Division's RWCDS where data are stored in the Columbia River Operational Hydromet Management System (CROHMS) database. The Seattle District Water Management Section is in charge of this program.

b) Reporting. Data at the two automated stations are collected year-round at an hourly time-step and are transmitted to the RWCDS database for archival. These data are also posted to the Corps' public access water management website. These data are available to the public on the Northwestern Division website at:

https://www.nwd.usace.army.mil/CRWM/Water-Quality

c) Maintenance. Station maintenance at the two automated stations is performed bi-monthly year-around. Station maintenance typically consists of cleaning the probes of algal growth and checking instrument calibration. Reclamation maintains these gages to meet requirements for downstream operations.

5.03 Sediment Stations. Not applicable to Grand Coulee Dam.

5.04 Recording Hydrologic Data. Hydrologic information is recorded as it is received by the Corps' Water Management offices as follows:

a) Regional Water Control Data System (RWCDS). The Corps' hydromet data management policies and procedures for Grand Coulee Dam are based on the Corps' RWCDS, a regional water resource data management program. The RWCDS is a system that collects, acquires, stores and computes data for real-time modeling and decision support for water control in the Northwestern Division. Northwestern RWCDS consists of three geographic nodes and is operated regionally by the following four water management offices: Northwestern Division

(CENWD), Portland District (CENWP), Seattle District (CENWS) and Walla Walla District (CENWW).

CENWS uses RWCDS for management of hydromet data associated with reservoir regulation and water resource projects within their jurisdiction. It should be noted that prior to about 2010, the RWCDS was known as the WCDS, Water Control Data System.

The Corps' Hydrologic Engineering Center report, Water Control Data System (WCDS), Past, Present, and Future, RD #39, dated September 1995, describes the WCDS as follows: "The WCDS is an automated information system that supports the Corps of Engineer water control mission including the hardware, software, manpower, and other resources required to acquire, develop, maintain, and operate the system. The WCDS includes the collection, acquisition, retrieval, verification, storage, display, transmission, interpretation, and archival of information needed to carry out the Corps' water control mission. The WCDS is a nationwide integrated system of hardware and software that allows users access to virtually any data and information in the system. A suite of software gives users the ability to display, manipulate, disseminate, interpret, and transmit information throughout the Corps and to any other interested user".

The RWCDS system includes computers, servers, database, related equipment, and software programs to receive, process, manage, and archive hydromet data for water resource projects in its jurisdiction. The CROHMS database is a primary component of the RWCDS data management operation.

(1) <u>CROHMS.</u> The Columbia River Operational Hydromet and Management System (CROHMS) is a multiple-agency, centralized computer management facility for fully automatic data collection, transmission, and processing of hydromet data. CROHMS was first conceived in 1967 to manage the increased volume of real-time water resource data associated with regulation of Pacific Northwest rivers and reservoir systems. Prior to 1967, data was collected and reported to Portland over telephone and teletype circuits commonly known as the Columbia Basin Teletype system (CBT). The teletype system continued to function up until 1998 when it migrated to a web-based system. The CBT is now the Columbia Basin Telecommunications System. CROHMS was formalized by the Federal water resource agencies in an agreement known as the CROHMS Memo of Understanding. As part of this agreement, each participating agency maintains specific data collection networks required for their specific functions. CROHMS is now incorporated within the Corps' RWCDS data management system and is reformatted to RWCDS's Data Storage System (DSS) format. Water resource projects contained in the original CROHMS and their identification codes and data parameters are essentially unchanged. Field data are now transmitted to NWD's RWCDS unit for processing, archiving and use by all CROHMS participants. Offices with operational hydromet data networks linked to CROHMS are the Corps' Seattle District, Walla Walla District, and Portland District, BPA, Reclamation, the USGS, and the NWS Northwest River Forecast Center (NWRFC), Portland, Oregon office.

b) Data Processing and Storage. Currently in Seattle District, data processing and storage occurs within the RWCDS/CWMS system. CWMS is a decision support system that can expand and enhance the information readily available to USACE regulators who must make decisions about operation of Federal water management facilities or who must monitor and approve such decisions made by operation partners. The RWCDS VMs allow users to retrieve and review CROHMS data for reporting, viewing, and editing. In the RWCDS system, data is collected via various means (i.e., SFTP, GOES satellite, Columbia Basin Telecommunications network (CBT) and web messenger) into the regional Data Exchange VMs (RWCDS DX1 and RWCDS DX2). The DX system collects data and transfers these data into the CWMS database (an Oracle database), at which point data are corrected and computations are made. Data are distributed via the Data Dissemination (DD) system, which is used to generate and publish reports. The CENWD RWCDS system consists of three mostly identical nodes (CENWP, CENWS, and CENWW) that are synchronized for COOP (Continuity of Operations) purposes. The file systems on each node are kept mostly identical to the others by synchronizing the file system on a schedule and installing the same versions and configurations of each software package. The databases are kept consistent by using a 3-way bi-directional replication. Available streamflow and elevation data for the Columbia River Watershed can be viewed by Corps staff in graphical or tabular formats on Corps-issued computers. Data posted to the Corps' public website can be viewed in graphical or tabular format for up to seven days, data for longer periods can be obtained by Corps staff from the CWMS Oracle database. The public can also access data from the Corps CWMS database using the CWMS database query tool. In addition to the Corps CWMS database, the USGS maintains a permanent record of data collected at all stations they operate and maintain. The USGS public website at https://nwis.waterdata.usgs.gov provides access to nearly all data, except for some special cases that require special handling.

5.05 Communication Network. The CENWS office and GCL use communications through land lines, as well as the data network between Seattle and Portland. The project operator can be reached on the public (Commercial) line. GCL also has two satellite phones that can be used as a means of backup telephone communication. The CBT is also used for the normal day-to-day communications with the project, primarily as a means of communicating desired dam operations (i.e., powerhouse discharge and spill quantity) to the project operators. The project also has several radios that can be used for communication, although these are generally used for on-site and local area communication.

5.06 Communication with Project.

a) Between Regulating office and Project Office. Communications between Reclamation and GCL is accomplished primarily by telephone, CBT and email (see contact references in Pertinent Data section). Flow schedules are pre-coordinated with the GCL operator and then submitted to the CBT. If the communication network is down, satellite phones can be used as an alternate means of communication.

b) Between Regulating/Project Office and Others. Communications between GCL, Reclamation, BPA, CBWM, and others is accomplished primarily by telephone and email.

Flow schedules/guidance are posted to CBT and other shared website locations. If the communication network is down (listed in Section 5.05), satellite phones can be used as an alternate means of communication.

5.07 Project Reporting Instructions. Powerhouse operators send hourly and daily powerhouse data through the CBT network. Hourly powerhouse data includes power discharge, mean spillway discharge, powerhouse forebay elevation at the beginning of the hour, powerhouse tailwater elevation at the beginning of the hour, surplus generation capability at the end of the hour from on-line units, number of on-line units, and number of available units. Daily powerhouse data include total generation, total station service usage, daily mean inflow, daily mean total discharge, daily mean power discharge, daily mean spillway discharge, reservoir elevation at the end of the day, daily mean forebay elevation, and daily mean tailwater elevation. Generation, powerhouse flow, forebay elevation, and tailwater elevations are all reported to the operators via the Generic Data Acquisition and Control System (GDACS) output in the project control room. Flows are calculated manually or automatically using lookup tables. All data is stored in the Columbia River Operational Hydromet Management (CROHMS) database. Hourly and daily average values are transmitted to the Corps over the CBT messenger system. The GCL control room also keeps hard copy forms available for recording summary power and water data.

5.08 Warnings. The GCL Emergency Action Plan (EAP) provides notification protocol for special operations and emergencies. CENWS has multiple copies including one located in the CENWS-RCC.

SECTION 6. HYDROLOGIC FORECASTS

<u>6.01 General.</u> Reclamation is responsible for the routine regulation of GCL. Spring snowmelt runoff forecasts and flood discharge forecasts for GCL are developed by the National Weather Service's (NWS) Northwest River Forecast Center (NWRFC) and coordinated with Reclamation as needed. Reclamation uses NWS forecasts in their reservoir management decision process.

a) <u>Role of USACE.</u> The Corps' Northwestern Division Reservoir Control Center (CENWD-PDW-R) routinely coordinates with the NWRFC on a daily basis during winter and spring flood seasons and is primarily responsible for providing reservoir regulation guidance to Grand Coulee during periods of flooding. At times when special streamflow regulation is required to meet at-site and downstream discharge requirements, regulation assistance to Reclamation is available from NWRFC and CENWD-PDW-R. These two organizations support Reclamation by providing flood risk management (FRM) forecasts for Grand Coulee, conducting special hydrologic investigations, coordinating with state agencies and the public to address water resources concerns and conflicts relating to FRM, and by providing support to CENWD in case of special requests or problems. The Corps' Northwestern Division, Hydrologic Branch (CENWD-PDW-H) supports the NWRFC during the spring snowmelt runoff season by investigating special runoff conditions throughout the Columbia River system and issuing FRM operating requirements.

b) <u>Role of the National Weather Service.</u> The NWRFC in Portland, Oregon is the agency primarily responsible for weather and streamflow forecasting in the Pacific Northwest. It is staffed 12 hours a day (6 am to 6 pm) year around except during flood periods when the Center is staffed 24 hours a day. Information and support assistance in case of emergency are provided for both periods.

6.02 Flood Condition Forecasts. Short-to-long range forecasts of streamflow rates, projected runoff volumes, and reservoir conditions are provided by the NWRFC.

The NWRFC streamflow forecast is generated using Community Hydrologic Prediction System (CHPS) for the short (10-day) and longer-term (120-day) forecasts. At reservoirs, NWRFC forecasts inflow, elevation, and discharge that is shared with USACE through direct access to their CHPS model and server. The short-term streamflow forecasts utilize current antecedent conditions throughout the basin combined with 10-day precipitation and temperature forecasts. The 10-day forecast is used by National Weather Service Weather Forecast Offices as guidance for flood warning programs. The longer-term streamflow forecasts are generated using the Ensemble Streamflow Prediction (ESP) component of CHPS. Seasonal Water Supply forecasts prepared by the NWRFC for a variety of locations in the Columbia River Basin, including The Dalles, are also based on ESP sequences. Hydrologic data

a) Requirements. To determine the FRM drawdown requirements for GCL and assess future flood conditions, a seasonal water supply forecast for unregulated flow at The Dalles for the April-August period is necessary. The water supply forecast is used in conjunction with the GCL Storage Reservation Diagram. Projected space available at upstream storage projects in the Columbia River System is also needed to assess whether under-drafted conditions may exist in the basin. Short-term and longer-term streamflow forecasts for the system are also used to prepare for possible flood conditions and real-time regulation of active flood events. An extensive system of active hydrometeorological (hydromet) stations, as described in Section 5.01, is used in the development of flood condition forecasts. The system includes precipitation stations, Snow Course Telemetry System (SNOTEL) sites, and manual snow course stations that are used to develop seasonal water supply forecasts.

b) Methods. The NWRFC in 2011 started using the Ensemble Streamflow Prediction (ESP) method in CHPS. CHPS is a modular forecast system that allows users to choose from various models or algorithms to simulate hydrologic conditions for a particular river basin. CHPS is made up of hydrologic models; including the Sacramento Soil Moisture model, the Snow-17 Accumulation and Ablation model, the API model, routing algorithms, and reservoir regulation schemes. Several algorithms in the earlier Streamflow Synthesis and Reservoir Regulation (SSARR) program have been adapted to operate within CHPS including the reservoir regulation and river reach routing components. This collection of interrelated pieces of software comprises three basic components: Calibration, Interactive Forecast System (IFP), and Ensemble Streamflow Prediction System (ESP). The longer-term streamflow forecasts are generated using the Ensemble Streamflow Prediction (ESP) component of CHPS. With ESP, the current antecedent conditions are combined with historical weather data. With each year of forcing, an output streamflow forecast is created. Each forecast is then taken together to produce the ensemble forecast that is expressed as exceedance probabilities. Statistics can then be applied to the hydrographs to look at potential water scenarios. The NWRFC's seasonal water supply forecasts are also generated using the ESP component of CHPS. Additional details are provided below in Section 6.04.

c) Schedule for Producing Forecasts. The schedule for producing forecasts varies depending on the time of year and circumstances. Daily, the NWRFC produces forecasts in 6-hour time steps for the short-term forecast period and long-term ESP forecasts. USACE and Reclamation update reservoir regulation for the short-term forecast period generally twice per week and more frequently as needed during an active flood event. The frequency at which seasonal water supply forecasts are produced by the NWRFC can vary and is described further in Section 6.04.

6.03 Conservation Purpose Forecasts.

There are no conservation purpose forecasts for Grand Coulee Dam.

6.04 Short and Long-Range Forecasts. Northwest River Forecast Center uses the Community Hydrologic Prediction System (CHPS) to forecast both short-term and long-range forecasts of streamflow and runoff for the Columbia River Basin. CHPS is a lumped physically-based model that uses mathematical equations to represent physical processes of the hydrologic cycle. The system consists of components that model snowpack, soil moisture, time of concentration of flow, reservoir operations, and river routing. CHPS has been calibrated for 178 sub-basins in the Columbia River basin above The Dalles. During calibration, 38 years of precipitation, temperature and flow data were used to develop model parameters (1981 - 2018).

Bonneville Power Administration (BPA) utilizes CHPS in their forecast development process. In operational use, both the NWRFC and BPA use CHPS independently. Observed and forecast weather data are input to the model. Precipitation and temperature data up to the current date are input. Hydrologists may make adjustments to model states and inputs over the past five to ten days to improve the simulated streamflow to better match observed flows. BPA meteorologists forecast future precipitation and temperature that hydrologists input to the model to generate streamflow forecasts. BPA produces daily streamflow forecasts in hourly time steps out 14 days into the future. The NWRFC produces streamflow forecasts in 6-hour time steps for the next 10 days.

The NWRFC uses model output as primary guidance when issuing an inflow forecast. However, NWRFC staff use other available information and data, as well as their own experience, to adjust model output before issuing a hydrologic forecast. The USACE uses streamflow forecasts from the NWRFC to evaluate operations that meet system and project objectives.

The NWRFC now uses ESP for all of its water supply forecasting products and uses a weather forecast to establish basin conditions as the foundation for the ESP forecasts. The NWRFC generates ESP hydrologic forecasts which include 10-day and 0-day precipitation forecasts (QPF) as well as a new blended model for their deterministic forecast. The 50% probability (representing the expected value) seasonal volume forecast for The Dalles (ESP with 10 days QPF) is used as the official water supply forecast to determine GCL's FRM draft requirement.

a) Requirements. These short and long range forecasts utilize NRCS SNOTEL and snow gage data collected during the winter snow accumulation along with 10 days precipitation and temperature forecasts. Input to the 10- and 120-day forecasts includes antecedent soil moisture, snowpack and precipitation data, observed streamflows, quantitative precipitation and temperature forecasts, and the planned regulated releases from reservoirs in the watershed are furnished by CENWD-PDW-R. See Section 6.02 for more details.

b) Methods. NWRFC develops short and long range forecasts for selected locations on the Columbia River and its tributary rivers using CHPS. See Section 6.02 for more details.

6.05 Drought Forecasts. During low runoff years Reclamation and BPA coordinate the operation of Grand Coulee to best manage drought conditions. Internal BPA forecasts, NWRFC ESP forecasts, and data from 10-day products or modified flows are used to plan operations.

6.06 Water Quality Forecasting. Forecasted conditions are used at GCL to manage total dissolved gas (TDG) levels by adjusting spill levels. The Corps sets caps for lack of load spill at GCL to manage system-wide TDG as outlined in the Water Management Plan.

a) Requirements. The Water Management Plan includes short-term water quality forecasting considerations for Columbia River Basin projects. Water temperature and TDG data is used at project locations with water supply forecasts to inform water management decisions for the upcoming year.

b) Methods. System TDG (SYSTDG) is a real-time operational tool for modeling TDG levels based on the observed and forecasted conditions and used to adjust spill levels in furtherance of the goal to meet applicable TDG standards. SYSTDG is a custom model for the CRS. It uses total spill, spill pattern, hydrology, weather, and water temperature as explanatory variables for TDG generation and transport.

SECTION 7. WATER CONTROL PLAN

<u>7.01 General Objectives.</u> Grand Coulee Dam (GCL) is operated as part of a coordinated system known as the Columbia River System (CRS). The CRS includes 14 dams and their associated reservoirs, two of which are operated by U.S. Bureau of Reclamation (Reclamation): GCL and Hungry Horse Dam. The U.S. Army Corps of Engineers (Corps), Reclamation, and Bonneville Power Administration (BPA), termed the "Action Agencies"[8], manage the operation and maintenance of the CRS according to each Agency's authorities to meet the multiple of the CRS. GCL plays a prominent role in the coordinated CRS because of its size (5.349 million acre-feet [MAF] of usable storage in Lake Roosevelt) and its key location as the largest significant storage reservoir upstream of The Dalles, such that it can influence flow relatively quickly in the lower Columbia. GCL is the largest CRS project used for Flood Risk Management (FRM) and is a key generator for hydropower. Additionally, GCL serves as the primary water diversion facility for the Columbia Basin Project and its irrigation system.

Today, Reclamation operates GCL for FRM, hydropower generation, irrigation, recreation, and fish and wildlife. The reservoir is operated in coordination with the Corps for FRM and BPA for power production. Reclamation also coordinates with state and federal fish and wildlife agencies to release flows for fish in the Columbia River or to store water in the reservoir for resident fish.

The primary objective of the water control plan for GCL is to efficiently regulate waters of the Columbia River for the authorized purposes of irrigation, FRM and hydroelectric power

[8] Reference to Reclamation, the Corps, and BPA as the "Action Agencies" is consistent with ESA terminology. Reference to these agencies may also be referred to as the "co-lead agencies", which is consistent with NEPA terminology, and was used in the 2020 Columbia River System Operations Environmental Impact Statement (EIS).

production. Recreation, fishing, and water quality in Lake Roosevelt and the Columbia River downstream of the project are all taken into consideration when scheduling project regulation. Implementation of the Biological Opinions in the CRS is coordinated annually and in-season through the Technical Management Team (TMT). A description of the TMT is provided in Section 9.02.

Benefits from regulation at the project are realized by: coordinating FRM with other storage reservoirs in the Columbia River basin to obtain the best control of flood flows in the lower Columbia; coordinating power operations in accordance with the Pacific Northwest Coordination Agreement; and coordinating annual and in-season operations concerning BiOp implementation with the Technical Management Team (TMT).

Reservoir levels in Lake Roosevelt vary greatly during normal operations and with changes in year-to-year water conditions. Annual operation follows a four-season cycle: September through December (Fall Operations), January through April (Storage Evacuation Operations), May through mid-July (Refill Operations), and mid-July through August (Summer Operations). When possible, the lake is near full during the summer, when recreation demand is the highest.

7.02 Constraints. Reservoir regulation at GCL is scheduled within the constraints listed below. Constraints for operation for fish and wildlife are included in Section 7.08.

a) Key Reservoir Elevations

Normal Reservoir Operating Range.............................. El 1,208 to El 1,290 ft

Normal Full Pool... El 1,290 ft

Minimum Operating Pool... El 1,208 ft

b) Minimum Daily Average Flow. Grand Coulee does not have a minimum average daily flow requirement. In the past, the existence of a 30 kcfs minimum daily average flow from the Grand

Coulee Project was related to a 36 kcfs minimum discharge below Priest Rapids Dam, which is owned by Grant County Public Utility District and located on the middle Columbia River. However, the current FERC license governing Priest Rapids Dam no longer contains the 36 kcfs minimum discharge requirement. Before the Priest Rapids discharge requirement was lifted, Generally, a minimum outflow of 30 kcfs from GCL was enough to provide the 36 kcfs minimum discharge below Priest Rapids Dam when it was required.

c) Draft Limits. The current planned draft rate limit for Lake Roosevelt is 0.8 feet per day. The maximum draft rate limit for Lake Roosevelt is 1.5 feet per 24 hours, or as coordinated with Reclamation's Columbia Pacific Northwest (C-PN) Water Management Group, a rate intended to help protect against potential landslides and the erosion caused by rapidly drawing down the reservoir. BPA may request an exceedance to this draft rate to meet increased power demand (e.g., during a winter cold snap), or the Corps may make a request to meet FRM requirements. In all cases, draft rate exceedance requests must be approved by Reclamation, and additional monitoring for erosion and landslides is required. Draft rates should not exceed 2 feet per 24 hours even if a draft rate exceedance is granted. Additional monitoring, including aerial surveillance is required when the reservoir is drafting more than 1.5 feet per 24 hours. Monitoring at more frequent intervals is required as the reservoir elevation drops. Below 1,240 feet, no draft greater than 1.5 feet in 24 hours should be considered and all other reasonable actions should be exhausted prior to requesting approval from Reclamation for exceedance.

d) Tailwater Drawdown Limits. Constraints for tailwater drawdown are described below.

The following guidelines are to be followed exactly and are the primary responsibility of the Assistant Dispatcher.

(1) Absolute minimum tailbay. El. 951; regardless of calculations below.

(2) Tailbay Hourly Drawdown Limit:

Above El. 962 - 5.0 ft/hour

El. 957 - El. 962 - 4.0 ft/hour

El. 953 - El. 957 - 3.0 ft/hour

El. 951 - El. 953 - 2.0 ft/hour

(3) Slide Event. If slide movement occurs, (a) raise to El. 957 or (b) if operation is at or above El. 957, hold that elevation.

Allowable minimum tailbay elevation is the HIGHER elevation of A, B, or C as computed below:

A = The average tailbay elevation for the previous 24- hour period minus 11 feet.

B = The average tailbay elevation for the previous 5-day period minus 11 feet.

C = Elevation 951 feet.

e) Powerhouse Capacity. Unit capacities can be a constraint on project operations. General information is listed below. See Section 2.03, Plate 7-4, and Plate 7-7A through Plate 7-7D for more detailed information.

(1) Right and Left Power Plants

18 units @ 125.0 MW ……………………………………………….………2,250 MW

3 station service units @ 10 MW ……………………………….……………30 MW

(2) Third Power Plant (also called Washington Power Plant)

3 units @ 690 MW………………………………………………...…………2,070 MW

3 units @ 805 MW…………………………………………………..……….2,415 MW

(3) John W. Keys III Pump Generating Plant (JWKIII)

6 pumps ……………………………………………………………………...see Table 7-1

2 pump/generators

Pump capacity ……………………………………………………………….see Table 7-1

Generating capacity @ 50 MW……………………………………………...…100 MW

4 pump/generators

Pump capacity …………………………………………………...……..see Table 7-1

Generating capacity @ 53.5 MW……………………………………………...214 MW

TABLE 7-1

JOHN W. KEYS III PUMP-GENERATING PLANT PUMPING CAPACITIES FOR VARIOUS LAKE ROOSEVELT WATER SURFACE ELEVATIONS

Lake Roosevelt (ft)	P 1-6 Capacity (cfs)	PG 7-8 Capacity (cfs)	PG 9-12 Capacity (cfs)	Total Capacity (cfs)
1,290	10,500	3,800	7,600	21,900
1,263	9,300	3,500	6,800	19,600
1,240	8,400	-	6,000	14,400
1,210	6,600	-	-	6,600
1,208	6,000	-	-	6,000

7.03 Overall Plan for Water Control Management.

Throughout the year, Lake Roosevelt levels fluctuate from operations for irrigation, hydropower, and fish flows, in addition to FRM needs. Water is generally pumped as needed to Banks Lake to support irrigation in the Columbia Basin Project. The irrigation season is generally from March through October. The four-season annual operation cycle is described below:

a) Fall Operations (September through December). GCL (Lake Roosevelt) does not have a fall FRM draft requirement, and minimal FRM operations occur during this period. Operations for other purposes, including power generation and water releases to help benefit chum salmon spawning and rearing areas in the mainstem Columbia River (see Section 7.08), typically draw down Lake Roosevelt below full pool by the end of December. When winter flood events do occur in the lower Columbia River, GCL is operated to reduce discharges by storing water in Lake Roosevelt.

b) Storage Evacuation Operations (January through April). During storage evacuation operations, GCL (Lake Roosevelt) is drafted based on seasonal water supply forecasts and other conditions in the basin to prepare for high spring flows and reduce the potential for flooding. Additional drawdown of Lake Roosevelt during this period for hydroelectric power, gate maintenance, navigation, or fish operations may also be required. Lake Roosevelt is drafted for FRM according to the storage reservation diagram in Plate 7-1. In order to maximize operating flexibility for GCL, the SRD adjusts FRM space based on current water supply forecasts and projected drafts at upstream storage projects. If one or more storage projects are under drafted then the GCL required draft will be increased to offset the under draft.

c) Refill Operations (May through mid-July). The CRS storage projects, including GCL, are operated in a coordinated manner during the refill period. The projects on the Columbia River operate together to meet a target flow (controlled flow) at The Dalles Dam, while refilling reservoirs during the refill period. The controlled flow may be modified throughout the refill period in response to changing forecasts and reservoir storage conditions. The first controlled flow of the runoff season is known as the Initial Controlled Flow (ICF). The ICF is a calculated flow used in conjunction with daily unregulated flow forecasts and available reservoir storage to determine when to start refill to assure a high probability of achieving total refill while managing flood risks.

When unregulated flows at The Dalles Dam begin to exceed the ICF, refilling of the reservoirs can commence. Refilling at Lake Roosevelt can start 2 days prior (corresponding to the water travel time from GCL to The Dalles Dam) to the date the unregulated flow at The Dalles is projected to exceed the ICF.

During the refill period, the outflow from the reservoir is kept lower than the inflow to the reservoir, allowing the water level in the reservoir to increase and refill, eventually reaching its targeted refill elevation when the risk of flooding has significantly decreased. Reclamation typically targets refilling Lake Roosevelt after the Fourth of July holiday, but in wetter water years, refilling can be delayed until mid-July to manage flows at The Dalles. GCL outflow helps support Priest Rapids fall Chinook salmon seasonal flow objectives (April 10-June 30), described further in Section 7.08. GCL's refill elevation objective is adjusted to reduce impacts on spring flows consistent with the Lake Roosevelt Incremental Storage Release Project (LRISRP) and to reduce impacts from future water supply development.

d) Summer Operations (Mid-July through August). GCL is operated during the summer (July and August) to help meet flow objectives for juvenile salmon out-migration. As described further in Section 7.08, GCL drafts to support salmon flow objectives during July-August with a variable draft limit of El 1278 to El 1280 feet by August 31 based on water supply forecast.

7.04 Standing Instructions to Project Operator. Operation of the physical facilities to accomplish water management objectives are the responsibility of the GCL project personnel. Such operation will be in accordance with the GCL operation and maintenance (O&M) manuals. Standing Operating Procedures (SOP) for the safe operation of the project are maintained by the Project Engineer. In an emergency, the Emergency Action Plan (EAP) should be followed.

7.05 Flood Risk Management. Grand Coulee Dam is authorized to provide FRM in the Columbia River Basin. The CRS storage projects operate in a coordinated manner to minimize flood consequences in local areas and in the lower Columbia River. Operations may vary from year to year based on forecasted water conditions and are adjusted throughout the year to meet changing conditions including those caused by weather. A gage located at The Dalles, Oregon, is a system FRM control point for the Columbia River Basin.

a) FRM Calculation at Grand Coulee. FRM draft requirements are determined from the Grand Coulee Storage Reservation Diagram (Plate 7-1) and based upon official water supply forecasts of unregulated April – August flow at The Dalles, Oregon. If one or more storage projects are under-drafted, then the Grand Coulee dam minimum required draft is adjusted in response to the under-draft when appropriate. The Corps and Reclamation have agreed to coordinate and apply, in an adaptive manner, the Grand Coulee FRM operations as described in the CRSO FEIS and ROD, and any updates thereto. Annual FRM operations are described as part of the Overall Plan for Water Control Management in Section 7.03. The procedure for determining GCL FRM draft requirements is provided in Exhibit 7-1

(1) Draft Rate. The storage reservation diagram (Plate 7-1) is designed to draft no more than 0.8 feet per day. This planned draft rate reduces the risk of landslides along the shoreline. The 0.8 feet per day draft rate may be exceeded, when necessary, to achieve the required FRM drafts. Further details are in Sec. 7.02 Constraints.

(2) FRM system shifts. The Action Agencies look for opportunities to temporarily shift CRS FRM requirements from Brownlee Reservoir (owned by Idaho Power) and Dworshak (owned by USACE) to Grand Coulee to provide more water for flow augmentation in the lower Snake River during spring migration when possible. The shift allows operations to

draft Grand Coulee more deeply in the winter to keep Brownlee and Dworshak reservoirs at higher levels. Consideration of these FRM shifts by the Corps includes an analysis of impacts to FRM and will not be implemented if FRM would be compromised. Reclamation must also be able to accept these shifts. The reservoirs must return to their unshifted FRM space requirements by April 30.

(3) Flood Storage Capacity. Pool elevations range from El 1,208 ft at minimum flood pool to El 1,290 ft at normal full pool. Storage capacity between these elevations is 5.349 MAF. The GCL Elevation Capacity Curve is shown in Plate 7-3. GCL has an active storage of 5.349 MAF and is authorized to use all 5.349 MAF for FRM purposes.

7.06 Recreation. While recreation is not an authorized project purpose, Reclamation operates Lake Roosevelt for recreation purposes when possible. To facilitate access to boat launches and marinas, and allow optimal use of beaches and campgrounds, Reclamation tries to maintain a buffer below full pool going into the Fourth of July holiday.

7.07 Water Quality. GCL is regulated to comply with the Endangered Species Act and the Clean Water Act. The Columbia River from the Canadian Border to the Snake River confluence is listed on the CWA 303(d) list due to temperature and TDG levels exceeding state water quality standards.

a) Temperature. Operations to regulate water temperature are enacted throughout the CRS but Grand Coulee is not operated to manage temperature downstream of GCL. Lake Roosevelt is weakly stratified, has a relatively short water retention time, and cannot provide a significant temperature reduction benefit.

b) Total Dissolved Gas (TDG). Water quality standards for Washington State, the Colville Tribe, and the Spokane Tribe have an identical TDG criterion: 110% of saturation not to be exceeded at any point of measurement. Under the current operating plan, TDG downstream of Grand Coulee Dam ranges from 95 percent to 125 percent; historically TDG in excess of 125 percent has been recorded and is still possible depending on inflowing TDG and flow conditions. Spill at GCL is managed in coordination with the Corps' Chief Joseph Dam to reduce TDG generation. Flow deflectors on the spillway at Chief Joseph Dam reduce generation of TDG and are efficient at stripping and reducing TDG in water spilled at Chief Joseph Dam. To the extent possible, power generation is shifted to GCL and spill is shifted to Chief Joseph Dam to minimize TDG generation.

7.08 Fish and Wildlife. The project is operated to comply with the biological opinions (2020 USFWS BiOp and 2020 NMFS BiOp) under the Endangered Species Act. The 2020 USFWS BiOp ("Endangered Species Act - Section 7 Consultation Biological Opinion U.S. Fish and Wildlife Service Reference: 01EWFW00-2017-F-1650, Columbia River System Operations and Maintenance of 14 Federal Dams and Reservoirs," dated July 24, 2020) establishes objectives for local fish species and replaced the 2000 and 2006 USFWS BiOps. The 2020 NMFS BiOp ("Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response, Continued Operation and Maintenance of the Columbia River System," dated July 24, 2020) establishes objectives for anadromous species and replaced the 2019 NMFS BiOp.

Please refer to current Biological Opinions for updated information on ESA operations. Operations can also change as coordinated in the Technical Management Team (TMT) annual Water Management Plan or as coordinated in-season through TMT. The Action Agencies will continue to work collaboratively with regional sovereign parties to adaptively manage the implementation of system operations related to fish through various policy and technical teams, collectively referred to as the Regional Forum. The primary component of the Region Forum that focuses on fish operations is the TMT.

The TMT is an inter-agency technical group comprised of sovereign representatives responsible for making in-season recommendations to the Action Agencies, or AAs (Corps, BPA, and Reclamation) on dam and reservoir operations in an effort to meet the expectations of the applicable BiOps (listed above) and accommodate changing conditions, such as water supply, fish migration, water quality and maintenance issues. The TMT consists of representatives from the Action Agencies, NMFS, USFWS, the states of Oregon, Washington, Idaho, and Montana, and Tribal sovereigns. The TMT develops the Water Management Plan annually to describe the plan to operate the Columbia River System consistently with the most recent BiOps.

This section describes how to implement BiOp discharge and ramping rate requirements that are in the current BiOps described above, which is subject to change as consultation documents, including BiOps, are updated. The following are the minimum flows and reservoir elevation targets which are included (by reference)[9] in the 2020 BiOps:

Draft to support salmon flow objectives in July and August with a variable draft of El 1,278 to El 1,280 feet by August 31 based on the final July forecast for runoff at The Dalles. Grand Coulee will operate to refill after the Fourth of July holiday each year to provide summer flow augmentation, except as specifically provided by the TMT. Grand Coulee will be operated during the summer (July and August) to help meet the flow objectives for juvenile salmon out-migration. Grand Coulee will draft to support salmon flow objectives during July-August with variable draft limit of El 1278 to El 1280 feet by August 31 based on the water supply forecast. If the Final April

[9] The 2020 USFWS BiOp and the 2020 NMFS BiOp both state that additional specificity and a more detailed description of the Proposed Action can be found in the BA and in the associated BA clarification letter from the Action Agencies, and that BA, and associated clarification letter, are incorporated by reference.

through August forecast (issued in July) for The Dalles is equal to or greater than the 30-year April through August average volume then Lake Roosevelt's draft limit will be El 1280 feet. If the forecast is less than the 30-year April through August average volume, the draft limit will be El 1,278 feet. Table 7-2 shows the end of August Targets based on the April to August runoff forecast at The Dalles. (The current 30-year average volume for the period 1991-2020 is 92 MAF.) These draft limits will be modified to implement the Lake Roosevelt Incremental Storage Release Project; (LRISRP), this operation will be coordinated with TMT to draft an additional 1 to 1.8 ft by the end of August.

Table 7-2

GRAND COULEE END OF AUGUST ELEVATION TARGETS

The Dalles July April-August inflow forecast (MAF)	Grand Coulee forebay target elevation on August 31 (ft)
< 92	1278
≥ 92	1280

Operate to support tailwater elevations below Bonneville Dam from November through early April to support chum spawning and incubation when necessary and possible. The Grand Coulee and Bonneville Projects are operated to support chum spawning and protections at the Ives Island complex below the Bonneville Project. There are two phases of the chum operations: spawning (typically in early November to late December) and incubation/egress (typically from late December to early April). The yearly operation is coordinated through the TMT and described in the annual Water Management Plan and seasonal updates.

After chum spawning is complete in late December, the AAs coordinate with the TMT to establish the minimum tailwater elevation necessary to protect the incubating eggs until fry have emerged from the gravel, or by April 10, whichever comes first.

Operate to support Priest Rapids fall Chinook salmon seasonal flow objectives (April 10-June 30). Grand Coulee provides flow to help meet the 135 kcfs flow objective for anadromous salmon and steelhead. If water year conditions do not allow operators to meet the 135 kcfs objective, a flow lower than the objective is used and gradually increased when possible. During dry years, the initial flow typically begins at around 90 kcfs and ramps up incrementally based on the water supply forecast, the timing of the juvenile fish migration, and streamflow conditions. Table 7-3 summarizes Priest Rapids flow objectives and practical limitations to support fall Chinook Salmon.

TABLE 7-3

MINIMUM FLOWS AT PRIEST RAPIDS

APRIL 10 – JULY 30 WITH GRAND COULEE DAM SUPPORT

Water Year Type	Required Flow at Priest Rapids from April 10 – July 30 (kcfs)
Wet	135
Average	135
Dry	90 (Gradually increase if and when possible)

a) <u>Operations to Benefit Non-Anadromous Fish.</u> Operations to benefit non-anadromous fish include the following:

Reclamation attempts to operate Grand Coulee Dam to refill Lake Roosevelt to an elevation of 1,283 feet or higher by September 30 (or as coordinated in season) at the request of tribes to aid resident fish, including access to shoreline and tributary habitat. To maintain power generation flexibility, the Lake Roosevelt elevation objective of 1,283 feet or higher by the end of September may be delayed to no later than the end of October. In most years, meeting the targeted elevation of 1,283 feet by the end of September is anticipated, but in drier years when the summer flow augmentation objective is 1,278 feet (at the end of August) refilling to 1,283 feet affects hydropower generation flexibility. In these years, the refill requirement is delayed until the end of October, but the project will be operated to refill to an elevation of 1,283 as soon as practical. Table 7-4 shows the timeline for refilling Lake Roosevelt to El 1,283 ft depending on available water supply.

TABLE 7-4

GRAND COULEE TIMING FOR REACHING EL 1,283 FT

Grand Coulee Forebay Target elevation on August 31	Date to Reach El 1,283 ft
1,280 (Typical Year)	September 30th
1,278 (Dry Year)	October 31st at the Latest

b) April 10 elevation objective. Fish operations in January through April are to support chum operations and maintain 85% probability of reaching the April 10 elevation objective to provide more water for spring flows. Maintaining an 85% probability of reaching the April 10 elevation objective is achieved by operating between the Upper Rule Curve (URC)[10] as an upper elevation limit and the Variable Draft Limit (VDL) as a lower elevation limit for the reservoir from January through March. See Section 7.10(c) for information on VDLs. Reclamation computes GCL's April 10 elevation objective by linear interpolation between the March 31 and April 15 forecasted FRM elevations based on the NWRFC March official April-August water supply forecast at The Dalles. The March forecast is used for the calculation of the April 10, exact date to be determined in-season, elevation objective to allow enough time to react and to plan GCL operations accordingly. Currently the April forecast that is available on the 3rd working day of the month is utilized, after which the Corps calculates FRM elevations. This

[10] URC – Upper rule curve, which is the FRM requirement.

usually means that final April 15 and April 30 FRM elevations are released around the 5th working day of April at the earliest. It is notable that even modest changes in The Dalles water supply forecast can produce significant changes in the FRM elevations for GCL. To achieve final April FRM targets, actual GCL elevations on April 10 may be below or above the April 10 objective depending on draft rates and water supply conditions and will be coordinated in-season.

7.09 Water Conservation/Water Supply. GCL is authorized for the storage and delivery of water for irrigation and other beneficial uses. The Columbia Basin Project (CBP) includes 330 miles of main canals, 1,990 miles of smaller canals, and 3,500 miles of drains and wasteways served by more than 240 pumping plants that carry water to some 10,000 farms. The Columbia Basin Project currently has water rights for 3.318 MAF and NEPA compliance to deliver 3.363 MAF of water for irrigation of 720,000 acres and for M&I purposes. Water for the Odessa Subarea and Lake Roosevelt Incremental Storage agreement are included in the 3.363 MAF, as is an additional 45,000 acre-feet identified in the CRSO FEIS.

7.10 Hydroelectric Power. Hydroelectric production is an authorized project use. The Grand Coulee Dam Powerplant complex consists of three powerhouses with 24 generating units (six in the Third Powerplant [TPP], and 9 in the Left Powerplant and 9 in the Right Powerplant) with a total generating capacity of around 7,000 MW. There are an additional six pump generators in the JWKIII PGP (at about 50 MW each), and if also including the station service units there are a total of 33 generating units. Turbine performance curves for all generating units are included in Plates 7-7A through 7-7D.

In the Pacific Northwest, maximum powerloads occur during the winter while maximum unregulated power potential occurs during the spring snowmelt runoff. Storage reservoirs, such as the Grand Coulee Dam project, help adapt the natural power potential to the shape and timing of the power demand by storing water during the spring runoff when powerloads are relatively low and releasing stored water during the winter (period of low natural streamflow in the Columbia basin) when the electric load is high. Due to the complex reservoir storage refill/evacuation operation and the large number of Federal, public, and private hydropower operators in the system, nearly continuous day-to-day scheduling and coordination are conducted to satisfy the multipurpose needs of the Columbia River. The primary power objective--meeting system electrical loads--is accomplished by regulation of system storage reservoirs, such as Grand Coulee Dam project, to achieve maximum use of reservoir storage while targeting reservoir refill and providing sufficient FRM storage.

a) Seasonal Power Regulation. Seasonal storage regulation is designed to increase natural streamflows in the Columbia River system during the wintertime to meet increased winter powerloads. Actual regulations must also be responsive to relatively rapid changes in load conditions and system power capability due to unseasonal weather, power outages, flood conditions, and other circumstances. To understand and evaluate system power regulations under the wide range of load/resource possibilities, power planners have developed computerized models of the Columbia River system for planning and real-time regulation applications.

b) Coordination.

(1) Bonneville Power Administration. BPA is responsible for coordinating, scheduling, marketing, and distributing hydroelectric power generated in the FCRPS. BPA is also linked with other electric power systems outside the Pacific Northwest and routinely coordinates, markets, and exchanges power with these entities. CRS power generation is

coordinated by BPA so that the system is operated to optimize power operations within the constraints of the other purposes.

(2) <u>Corps.</u> Section 7 of the Flood Control Act of 1944 directs the Secretary of the Army to prescribe regulations for the use of storage allocated FRM. FRM regulation for GCL is implemented by the Division Reservoir Control Center (CENWD-PDW-R) in conjunction with Reclamation's water management staff in the Boise, Idaho office. This coordination includes routine monitoring of Reclamation's plans for operation of GCL for non-FRM purposes. Detailed FRM coordination and support for GCL is available through the Corps' NWD-RCC and NWD-HE Branches (CENWD-PDW-R and CENWD-PDW-H, respectively).

(3) <u>Western Power Pool (WPP).</u> Reclamation is a member of the WPP. WPP is the coordination group that serves as a forum in the electric industry for reliability and operational adequacy issues in the Northwest. WPP has the primary administrative and technical responsibility for coordinating seasonal hydropower operations in the Pacific Northwest pursuant to the Pacific Northwest Coordination Agreement (PNCA) (See Section 9.02).

(4) <u>Variable Draft Limits (VDL).</u> VDLs are period-by-period draft limits from January 1 - March 31. The VDL operation provides flexibility in generation, FRM objectives and minimum downstream flow requirements for migrating ESA listed fish. VDLs are based on:

- The April 10 elevation objective which is calculated from the forecasted March 31 and April 15 FRM elevations
- Statistical inflow volumes (85% exceedance for GCL)

- Actual downstream flow objectives

The VDL is not a mandatory draft elevation and operation above the VDL is acceptable as long as it is not a higher elevation than the FRM curve, the Firm Energy Load Carrying Capability (FELCC) is already being met, and downstream flow objectives are also being served. The latter is achieved by operating between the Upper Rule Curve (URC) as an upper limit and the Variable Draft Limits (VDL) as a lower operating limit for the reservoir and will continue to target April 10th for the calculation. As explained in Section 7.08, Reclamation computes GCL's April 10 elevation objective by linear interpolation between the March 31 and April 15 forecasted FRM elevations based on the NWRFC March official April-August water supply forecast at The Dalles.

VDLs are calculated monthly from January through March after updated volume forecasts and FRM elevations have been issued. The VDL at the end of a period (e.g., January 31) is computed to determine the lowest elevation where the outflow requirements and the April 10 elevation objective can be achieved using an 85% probable inflow volume.

7.11 Navigation. While GCL is authorized for navigation, there is no specific reservoir regulation associated with the purpose.

7.12 Drought Contingency Plan. GCL is operated as part of the Columbia River reservoir system under all conditions, including droughts. A detailed Drought Contingency Plan (DCP) for the entire Columbia River system is presented in Section XII of the *Columbia River Basin, Master Water Control Manual,* dated December 1984, and is applicable to GCL. The 30-page DCP is a detailed guideline for operation of the Columbia River reservoir system under adverse streamflow conditions. The plan addresses historical droughts, drought forecasting techniques, drought impacts and operational requirements for the system and individual drought management stations.

As of the writing of this document, an updated Master Water Control Manual is under preparation.

7.13 Flood Emergency Action Plans. Reclamation will use the most recent Emergency Action Plan from the C-PN Regional Dam Safety Group.

7.14 Other.

a) Outlet Rating Curve. The GCL outlet rating curve is shown in Plate 7-4. This plate shows the combined capacity of the 40 regulating outlets. The regulating outlets are used to discharge water downstream when the forebay elevation is below 1265.5 feet, at which point the drum gates are inoperable.

b) Tailwater Rating Curve. A tailwater rating curve for GCL is shown in Plate 7-5. Please note that the actual outflow from GCL is computed as described in Section 5.01 and not with the tailwater rating curve.

c) Spill. Spill at Grand Coulee Dam occurs when total outflow exceeds powerhouse capacity during high flows typically observed in the spring and early summer. Spill can also occur during lack of market conditions when there is no demand for additional electricity and hydropower production is unnecessary. When Grand Coulee is required to spill to achieve flow or FRM elevation requirements, spill can cause TDG to exceed 130 percent in some cases. The outlet tubes, and to a lesser extent the drum gates, are known to produce elevated TDG when in operation. When reservoir elevations are greater than 1265.5 feet, the 11 drum gates can be used to discharge water downstream. The drum gate rating curve is shown in Plate 7-6. The drum gates generate much less TDG than the outlet tubes and are the preferred outlet when available.

d) Routine Maintenance. With peak discharge occurring in the spring, routine maintenance is limited, to the extent possible, to minimize the number of units that must be worked on so that as much water as possible can be passed through the turbines. Routine maintenance does not affect flow, but increased spill could periodically result in elevated TDG saturations above the Washington State water quality maximum standards.

e) Drum Gate Maintenance. Reclamation's Operations and Maintenance Program requires periodic inspections and dam safety maintenance for the eleven 135-foot-long, 28-foot-high drum gates. Inspection and maintenance activities can only occur when Lake Roosevelt is at or below El 1,255 feet with the goal of being below that elevation for 8 weeks. Drum gate maintenance is planned to occur periodically during a period between March and May, to coincide with the FRM drawdown of the lake. However, during dry years, FRM operations will not draft Lake Roosevelt low enough for a long enough period of time to perform necessary maintenance on the drum gates. During extended droughts or even in normal water years, when FRM operations do not require the reservoir to draft below El 1,255 feet, a forced draft may be required to perform maintenance.

7.15 Deviation from Normal Regulation. Reclamation is occasionally requested to authorize, coordinate, and conduct special regulations that deviate from the Water Control Plan for GCL in the reservoir or tailwater area. Except as noted below, prior approval by Reclamation in cooperation with the BPA and Corps (only if hydropower or FRM is affected) is required for all special regulation affecting GCL.

a) Emergencies. In the event the project's structural integrity is or could be threatened, or if outflows will or could endanger downstream human life or property, the procedures, outlined in the Reclamation Publication, Standing Operating Procedures, Emergency Action Plan (EAP), are to be followed. Specifically, the plan is to be implemented in the following situations:

(1) Uncontrollable Emergency. Defined as a condition in which the occurrence of a significant hazard to life and property is certain to occur, and no time is available to repair or modify operational procedures to prevent dam failure.

(2) Controllable Emergency. Defined as a condition, not normally encountered in the routine operation of the dam, in which the occurrence of a significant hazard to life and property is possible unless timely repairs and/or modification to operational procedures are conducted. Time must be available to conduct corrective actions.

(3) Post-Earthquake. Condition immediately following a noticeable earthquake at the dam.

(4) Security Alert. Condition at the project caused by an incident that threatens the project security.

(5) Excessive Release. Releases that exceed routine operational criteria during non-flood periods. The EAP describes procedures and means of initiating operation, repairs, and notifying pertinent parties of the hazard. The procedures have been coordinated with Reclamation elements and relevant non-Reclamation authorities and are updated periodically. Their prompt use is essential for minimizing hazards to affected life and property. The EAP also provides procedures to be followed in the event of a security alert and also addresses operational procedures during times of national emergency.

b) Abnormal Conditions. Should a condition(s) occur or appear to be developing, other than those described above, which requires operational modification, the Project Engineer or powerplant operator will promptly contact the project superintendent's office to report the field conditions and receive instructions. BPA and other parties upstream and downstream of the project that are possibly affected by the condition will also be informed as soon as possible. When immediate action is required to protect life and valuable property, the Project Engineer will not wait for instruction. Instructions for the proper response to conditions such as failure of operating facilities, accidents, and power failures are included in the Standing Operating Procedures, Emergency Action Plan on file at GCL.

c) Planned Deviations. Although they are not considered emergencies, situations occasionally occur that require temporary deviations from the normal regulation of the project. Construction activities such as utility stream crossings, bridgework, and other miscellaneous in-stream construction activities account for the majority of deviations. Changes in releases are also sometimes necessary during maintenance for periods from a few hours to a few days, and each request is evaluated based on its own merits. Consideration is given to upstream watershed conditions, potential flood threat, conditions of the reservoir and river below GCL, and possible alternative measures. In the interest of maintaining good public relations, these requests are satisfied provided there are no adverse effects in overall operation for the project's authorized purposes.

7.16 Rate of Release Change. N/A

SECTION 8. EFFECT OF WATER CONTROL PLAN

8.01 General. GCL provides key storage for flood risk management and river flow management along the Columbia River, in addition to recreation and navigation opportunities.

The federal dams in the Northwest supply over one quarter of the region's power under average water conditions (Bonneville 2019). Of the 14 federal dams operated as a coordinated system (the CRS), GCL is the largest power generator, with nearly 1/3 the total power capacity for the entire CRS. In fact, GCL is the largest power generating facility in the United States and among the largest in the world. Grand Coulee's generators return revenues to the U.S Treasury each year nearly equal to the entire budget of the Bureau of Reclamation (Reclamation, 1998).

The storage capacity at GCL is integral to the Columbia River System's ability to minimize flood risk downstream at The Dalles. The provision of water for irrigation allows a range of crops to grow in the central Washington region including forage and cereal crops, fruit, vegetables and seed crops.

As an instream flood storage project, GCL changes the timing, duration, and volume of both flow and sediment conveyed to the downstream Columbia River. Implementation of the project has resulted in the decreases of anadromous and resident fish stocks. ESA actions related to listed fish species have been enacted in the CRS.

8.02 Flood Risk Management. Design flood material is not available for Grand Coulee Dam. The annual exceedance probability (AEP) of peak flows for GCL is included on Plate 8-1.

8.03 Recreation. The large size, quality of water, scenic beauty, extensive shoreline and surrounding land that is publicly owned and accessible, make Lake Roosevelt a popular recreation location in the region. Lake Roosevelt spans over 150 miles from Grand Coulee Dam to the U.S.-Canada border and features more than 600 miles of shoreline. The Colville National Forest, Colville Indian Reservation, Spokane Indian Reservation, and historic Fort Spokane are adjacent to the lake. Recreational access is managed by the National Park Service (NPS), Confederated Tribes of the Colville Reservation, and the Spokane Tribe of Indians. Lake Roosevelt National Recreation Area, the portion of the lake managed by NPS, receives much of the annual visitation; mostly for camping, fishing, swimming, boating, and picnicking. Common sport fish caught in Lake Roosevelt include rainbow trout, kokanee, northern pike, burbot, white sturgeon, walleye, and perch. Access to the lake for recreation is restricted during drawdowns, and the minimum usable water elevations vary across boat ramps at the reservoir. The Grand Coulee laser light show and dam tours are also popular visitor attractions.

Over the past decade, Lake Roosevelt National Recreation Area has brought between 1.2 and 1.8 million visitors per year (National Park Service[11]). Visitation occurs throughout the year, but June, July, and August are the most popular months. At full pool (1,290 feet), there is over 600 miles of shoreline. Lake Roosevelt National Recreation Area features shoreline that varies from several feet adjacent to the high water line to approximately 0.5 mile. In most cases, the minimum shoreline is determined by the El 1,310-foot contour. The Recreation Area has 22 boat launch ramps with minimum boat launch lake elevations ranging from as high as 1,288 feet to as low as 1,222 feet. Boat launch ramps include adjacent vehicle and boat trailer parking. NPS manages 26 designated campgrounds (17 drive-in and 9 boat-in) with over 600 individual sites, swim beaches, and three concessionaire-operated marinas providing moorage, boat rental, fuel, supplies, and sanitary services.

[11] Visitation statistics from https://irma.nps.gov/STATS/Reports/Park/LARO accessed 6 August 2022

8.04 Water Quality. Water quality parameters pertaining to Grand Coulee Dam are grouped as those relevant to water temperature, Total Dissolved Gas (TDG) saturation, or other physical, chemical, and biological processes.

a) Water Temperature. Grand Coulee is considered a unique storage project, as it has relatively low retention times due to the large amount of flow through the project. This short retention time results in very weak thermal stratification, and homogenous temperatures at penstock intake depths.

Although temperature profiles at the Grand Coulee Dam forebay indicate that thermal stratification may occur in the late summer months (Reclamation, 2000; LRFEP; 2008 EIS), in general, the short retention time in Lake Roosevelt results in weak thermal stratification (2020 CRSO EIS). At Grand Coulee Dam, there is little opportunity to manage downstream water temperatures as Lake Roosevelt is weakly stratified. This results in Grand Coulee releasing the coolest water possible in the summer months, based on constraints for generation reliability, voltage stability, and TDG standards. Because of the weak stratification, discharged water temperatures lag the warming/cooling trends observed in the inflow, at the U.S.-Canada border, and tend to be cooler in the spring and warmer in the fall than inflowing conditions.

Water temperature downstream of Lake Roosevelt generally ranges from 37.4 degrees F (3 degrees C) in winter to about 68 degrees F (20 degrees C) in summer. The different intake depths for the power plant flows suggest that using preferential power plant operations could influence water temperatures downstream from the dam. However, Reclamation (2000) reported that the limited volume of cool water in the reservoir could not provide significantly cooler summertime releases for prolonged periods. The volume of cool water in the reservoir is limited because flood risk management activities release a large amount of the cool water and the remaining cooler water is removed in the spring and early summer due to the large volumes of water that are released each month (Reclamation, 2000).

There are no major inflows to the river in the 6-mile reach of the river between Grand Coulee Dam and the downstream temperature gage, and therefore temperatures measured at the gage represent the temperature of the water released from Lake Roosevelt plus any heating or cooling that occurs within the first 6 miles downstream of the dam (2008 EIS).

b) Total Dissolved Gas. Total dissolved gas (TDG) levels below Lake Roosevelt are affected by the volume of water released from Grand Coulee Dam and the manner in which the water is released (passed through generating units, spilled through the drum gates, or spilled through the regulating outlets). Spill at Grand Coulee Dam occurs when total flows exceed powerhouse capacity during high flows typically observed in the spring and early summer. Spill can also occur during lack of market conditions when there is no demand for additional electricity and hydropower production is unnecessary. Often in high-flow years water flowing into Lake Roosevelt across the U.S.-Canada border is in excess of 110 percent TDG. When Grand Coulee is required to spill to achieve flow or FRM elevation requirements spill can exceed 130 percent TDG in some cases. The outlet tubes, and to a lesser extent, the drum gates, at Grand Coulee Dam are known to produce elevated TDG when in operation. When reservoir elevations are greater than El 1265.5 feet, the 11 drum gates can be used to discharge water downstream. The drum gates generate much less TDG than the outlet tubes and are the preferred outlet when available. The 40 regulating outlets are used to discharge water downstream when the forebay elevation is below El 1265.5 feet, at which point the drum gates become inoperable. Under the current operations, TDG downstream of Grand Coulee Dam ranges from 95 percent to 125 percent; historically TDG in excess of 125 percent has been recorded and is still possible under the current operations depending on inflowing TDG and flow conditions.

c) Other Physical, Chemical, and Biological Processes. Historically, pollution from mining and smelting, as well as the atmospheric deposition of mercury, has impacted water quality in Lake Roosevelt. Metals have contaminated bed sediments, and mercury cycling has become more of a concern. The presence of these pollutants has contributed to fish consumption advisories due to bioaccumulation. These pollutants have likely migrated downstream through Lake Roosevelt. Trace elements have been found in Rufus Woods Lake sediments, suggesting that high flow events may push metal contaminants past Grand Coulee at times. Additionally, dioxin discharge from pulp and paper mills and other sources has occurred in the system causing EPA to issue a TMDL for dioxin for the Columbia River below Grand Coulee Dam, as well as portions of the Snake River. The current operation of Grand Coulee Dam is not predicted to affect mercury cycling. Turbidity from bank erosion within Lake Roosevelt is correlated to the rate of drawdown and refill at Grand Coulee Dam. The draft rate utilized in developing the current Storage Reservation Diagram (SRD) for Grand Coulee Dam (Plate 7-1) shows a more gradual drawdown rate than historical operations (prior to 2021) and may result in lower turbidity throughout the reservoir.

8.05 Fish and Wildlife. GCL's large storage capacity (5.349 MAF) supports the CRS to meet flow strategies that achieve flow management for power production, flood risk management, and water supply with flows to benefit both resident and anadromous ESA-listed species. Development of Variable Draft Limits allow flexibility for power generation while protecting the ability to meet the April 10 elevation objective at GCL with an 85% confidence. The stored water from the April 10 elevation objective benefits juvenile anadromous fish migration. Storage capacity at GCL provides flows from the start of chum spawning in November through the end of chum emergence (approximately April) in order to maintain sufficient water depth to protect chum spawning and incubation habitat at the Ives Island complex below Bonneville Dam.

Current operations limit habitat and spawning success effects, particularly during above average water years. Increased flexibility of refilling Lake Roosevelt during the month of October, depending on annual water conditions, can result in increased stranding of kokanee and burbot eggs, and potential increased spawning habitat access issues for redband rainbow trout and some kokanee. Mitigation measures provide a minor beneficial effect to these fish. Current Operations support both wild and hatchery-raised kokanee, redband rainbow trout and hatchery rainbow trout as well as non-native warmwater game species such as walleye, smallmouth bass, and northern pike.

8.06 Water Conservation/Water Supply. The provision of water for irrigation supplies the Columbia Basin Project that produces potatoes, sweet corn, onions, seed and other specialty crops, grapes, fruit, dry beans, grain alfalfa, hay and ensilage crops. Water diverted from Lake Roosevelt at the John W. Keys Pumping Plant is for agricultural and Municipal and Industrial (M&I) use to the Columbia Basin Project with a portion returning to the river as return flow. Current operations provide the ability to change the timing of delivery of water supply as the demand arises during the irrigation season (March to October).

8.07 Hydroelectric Power. GCL provides base load generation and reserve capacity for the FCRPS. The average annual generation of the Grand Coulee Powerplants is about 20 billion kilowatt-hours, which is a large share of the power requirements for the Northwest. The third power plant alone can produce enough energy to meet the needs of Portland, Oregon, and Seattle, Washington. Annual generation since 1998 is summarized in Table 8-1. GCL is projected to continue to provide the equivalent level of service.

TABLE 8-1. HYDROELECTRIC POWER GENERATION AT GCL POWERPLANT

Year	MWH[a]
1998	19,856,960
1999	24,192,564
2000	20,733,034
2001	12,608,542
2002	20,005,100
2003	18,002,949
2004	17,920,895
2005	19,213,641
2006	20,227,447
2007	20,511,686
2008	18,615,956
2009	17,258,606
2010	16,043,896
2011	23,573,201
2012	25,277,441
2013	21,717,548
2014	21,223,901
2015	19,753,511
2016	20,129,984
2017	22,834,482
2018	22,372,954
2019	17,021,429
2020	21,359,140
2021	19,160,980

[a]Source: BPA

<u>8.08 Navigation.</u> Two ferries operate on Lake Roosevelt: the Keller Ferry and Inchelium – Gifford Ferry. Both ferries carry normal highway traffic. The Keller Ferry is operated by the Washington Department of Transportation as a link on rural State Route 21 and provides access to the Colville Indian Reservation. It can run throughout the entire operating range of the reservoir, from El 1,208 to El 1,290 feet. The Inchelium- Gifford Ferry provides access to the Colville Indian

Reservation from Washington State Highway 25 and provides an important transportation connection for medical services and local schools. This ferry cannot operate below El 1,229 feet. Under historic operating conditions, the reservoir is below 1,229 feet for approximately 27 days of the year. The drawdown of Lake Roosevelt in wet years (the wettest 20 percent of years as measured at The Dalles) can affect the Inchelium-Gifford Ferry.

8.09 Drought Contingency Plans. GCL is operated as part of the Columbia River reservoir system under all conditions, including droughts. Refer to the Columba River System Drought Contingency Plant (DCP) presented in Section XII of the Columbia River Basin Master Water Control Manual. The plan addresses historical droughts, drought forecasting techniques, drought impacts, and operational requirements for the system and individual drought management stations. As of the writing of this WCM, an updated Master Water Control Manual is under preparation.

8.10 Flood Emergency Action Plans. Refer to the most recent GCL Emergency Action Plan (EAP) for details on flood emergency planning. While the EAP does not in and of itself direct operations at GCL, it does detail the responses and notifications required under various states of emergency.

8.11 Frequencies.

a) Inflow Probability. The Lake Roosevelt inflow frequency curve is shown in Plate 8-2. The volume inflow frequency is shown in Plate 8-3. The inflow for both of these charts represents regulated inflow. The regulations for this were taken from the Preferred Alternative in the 2020 CRSO EIS, which used the 2010L Modified Streamflow.

b) Regulated Streamflow Characteristics. The frequency of flooding has been reduced downstream as a result of operations at Grand Coulee Dam and other dams in the basin.

Average monthly discharge at GCL for regulated and natural conditions are presented in Table 8-2.

TABLE 8-2. AVERAGE MONTHLY DISCHARGE AT GCL, NATURAL AND REGULATED CONDITIONS (CFS).

Month	Regulated [a]	Natural[a]
October	61,485	54,930
November	93,664	48,830
December	100,611	44,693
January	112,166	40,680
February	128,351	41,106
March	100,787	48,737
April	101,316	87,940
May	141,823	207,552
June	153,455	312,907
July	131,896	235,763
August	105,857	137,629
September	65,621	82,084

[a] Data provided by USACE NWD from 2020 CRSO-EIS Study, Preferred Alternative, using 2010L modified streamflow (1928-2008)

Hydrographs of regulated conditions at Grand Coulee Dam for example water years [2000-2001], [2006-2007], and [1996-1997], reflecting low, average, and high runoff conditions, are shown on Plate 8-4, Plate 8-5, and Plate 8-6, respectively.

c) Pool Elevation Duration and Frequency. Lake Roosevelt Elevations fluctuate on average 42.7 feet throughout a single year. The 1 percent exceedance, median and 99 percent exceedance pool elevations versus time are presented in Plate 8-7. In general, pool elevation is high in June through July and declines sharply during the storage evacuation period between January and April. The pool is refilled to near full capacity by the end of June, or shortly thereafter, and roughly maintains a high pool elevation through September with a slight dip in July and August. The Lake Roosevelt Summary Elevation Hydrograph is shown in Plate 8-8 and presents pool elevation through the year for 1-, 25-, 75-, 99-, and median exceedance levels.

d) Key Control Points. GCL plays a large part in the system FRM operation of the Columbia River Basin. The flow measured at The Dalles is used as a system FRM control point. The annual peak frequency for spring and winter events at The Dalles is displayed in Plate 8-9.

SECTION 9. WATER CONTROL MANAGEMENT

9.01 Responsibilities and Organization.

a) General. Grand Coulee Dam project is a major project in the system of reservoirs developed to manage and control Columbia River water resources. Extensive planning and coordination of this reservoir system is accomplished to accommodate the diverse ownership, multiple water resource functions, system requirements, and miscellaneous special needs. Involved agencies and details of the coordination process are described below.

b) Principal Agencies. The following agencies and regional organizations are involved in planning, scheduling and operating the Columbia River water resource system. Reclamation, Corps, and BPA are referred to as the "Action Agencies" and USFWS and NMFS are referred to as the "Services" when dealing with matters associated with the ESA.

(1) U.S. Bureau of Reclamation (Reclamation). Reclamation owns and operates GCL for the authorized purposes of irrigation, FRM and hydroelectric power production. Recreation, fishing, and water quality in Lake Roosevelt and the Columbia River downstream of the project are all taken into consideration in project regulation. The United States Department of the Interior, Bureau of Reclamation, Columbia-Pacific Northwest Region, Boise, Idaho office is responsible for the management of the Grand Coulee Dam project. This management responsibility (regulation, operation, and maintenance of the project functions, facilities, and lands) is the overall responsibility of the C-PN Regional Director and specific personnel within their staff. The Grand Coulee Power Office Manager (supervised by the Regional Director) and their staff are responsible for day-to-day regulation, operation, and maintenance of the Grand Coulee Dam project in accordance with existing Bureau of Reclamation criteria and agreed upon interagency regulation

criteria for the system and also in accordance with regulations prescribed by the CENWD for flood control storage space. These operations are coordinated through the Water Management Group which the Regional Director oversees. The Technical Service Center in Denver, Colorado provides technical support services for operation and maintenance of Reclamation projects. The Center also periodically examines all major structures, performs dam safety studies, reviews dam behavior data, and provides technical advice and assistance in the solution of operating and maintenance problems.

(2) U.S. Army Corps of Engineers (Corps). Section 7 of the Flood Control Act of 1944 (58 Stat.890,33 U.S.C. 709) directs the Secretary of the Army to prescribe regulations for flood control (now referred to as flood risk management). Direct responsibility for the regulation of GCL FRM is assigned to the Northwestern Division Office (CENWD) which coordinates and cooperates with many other agencies and groups to accomplish effective and efficient regulation.

In May 1968, the Chief of Engineers approved the formation of a Reservoir Control Center in the North Pacific Division (now Northwestern Division) identified as CENWD-PDW-R and assigned the responsibility for FRM regulation activities in NWD to the Division Engineer. Additional details of the Corps' water management history and organization are provided in the report, Reservoir Control Center, Guidance Memorandum, U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon, January 1972. The Seattle District Hydraulics and Hydrology Branch includes a Reservoir Control Center which is not formally identified but is referred to as NWS-RCC to distinguish it from the Reservoir Control Center (CENWD-PDW-R) in the Northwestern Division office in Portland, Oregon. The NWS-RCC provides flood control regulation at Corps and non-federal dams in western Washington under the direction of CENWD. Seattle District's Water Management Section supports Columbia Basin Water Management (CENWD-PDW, CENWD-PDW-R, and CENWD-PDW-H) in the FRM regulation at water projects in the Columbia River including GCL by assisting in special reservoir operations, public coordination, preparation of reservoir regulation related studies, and preparation of reservoir regulation manuals.

(3) Bonneville Power Administration (BPA). BPA is the marketing agency for power generated at Federal projects in the Pacific Northwest. The agency has constructed and maintains the nation's largest network of long-distance high-voltage transmission lines. The transmission facilities and the Federal electric generating projects they interconnect are known as the Federal Columbia River Power System (FCRPS). Reclamation coordinates with the BPA Power Generation and Short-term Planning (PGSP) on regulation decisions that affect power generation. Power is scheduled and dispatched by BPA from the Dittmer Control Center, Vancouver, Washington.

(4) National Marine Fisheries Service (NMFS). NMFS is responsible for the protection, conservation, and recovery of marine and anadromous fish species listed under the ESA. NMFS consults with the Action Agencies on the operation of the Columbia River System and its potential effects on listed marine and anadromous species. NMFS is responsible for the protection, conservation, and recovery of marine and anadromous fish species listed under the ESA. NMFS consults with the Action Agencies on the operation of the Columbia River System and its potential effects on listed marine and anadromous species.

(5) U.S. Fish and Wildlife Service (USFWS). At the Federal level, the USFWS is the agency primarily responsible for ensuring the conservation and management of the nation's wild

birds, mammals, and sport fishes for both their recreational and economic values. The regional office is located at Portland, Oregon. The following are included in the USFWS major program areas: Technical assistance to Federal, state, and private organizations in the development and administration of sport fish and wildlife management programs; administration and operation of a national system of fish hatcheries engaged in the propagation and distribution of sport fish; and cooperation with other Federal and non-Federal agencies engaged in water resource development projects to determine the effects of such projects on fish and wildlife resources and recommend measures for the protection and improvement of these resources.

c) Support Agencies. The following agencies collect data and provide information used in the regulation of GCL.

(1) National Weather Service (NWS). The NWS operates numerous stations in or near the Columbia River basin which provide data used in planning and scheduling regulation at GCL. Refer to Section 5 for additional details.

(2) Northwest River Forecast Center (NWRFC). In 1948, the National Weather Service, formerly the U.S. Weather Bureau, was authorized to develop a modern river forecast program for the United States. The Portland NWRFC was established in January 1950 and began limited forecasting in 1951. The NWRFC provides a daily forecast, the 10-day outlook, quantitative precipitation forecasts, and other river forecast products including seasonal water supply forecasts. Reclamation provides daily hydrometeorological data through the CROHMS communication system which is used by the NWRFC for Columbia River forecasts

(3) U.S. Geological Survey (USGS). The USGS Water Resources Division collects and processes water quality and quantity records for stations in the Columbia River basin including the Grand Coulee Dam project.

(4) National Resource Conservation Service (NRCS). The NRCS operates, maintains, and publishes records for numerous snow courses in or near the Columbia River basin which provide data used in water resource management.

d) Canadian Agencies.

(1) Federal. Meteorological data is collected and published by the Atmospheric Environment Service in Canada. Surface water data is collected and published by the Inland Waters Directorate, Water Resources Branch, Water Survey of Canada.

(2) Provincial. The British Columbia Ministry of Environment (ME) provides indirect support to the Grand Coulee Dam project through the following four branches: Water Management Branch (WMB), Waste Management Branch, Fish and Wildlife Branch (FWB), and Aquatic Studies Branch (ASB).

(3) BC Hydro. BC Hydro, a crown corporation, directs operations of several large hydro projects in Canada.

e) State Agencies. The Washington Department of Fish and Wildlife, Montana Department of Fish, Wildlife, and Parks (MDFW&P) and the Idaho Department of Fish and Game have the primary authority for regulation and management of fish and wildlife resources within their state boundaries. These agencies collect data and conduct studies to evaluate the effect of the Grand Coulee Dam project in their respective areas, to exchange information with the Bureau of Reclamation, and to make recommendations as to potentially beneficial changes in project regulation.

9.02 Interagency Coordination.

a) Northwest Power and Conservation Council (NWPCC). The Pacific Northwest Electric Power Planning and Conservation Act of 5 December 1980 established an eight-member Pacific Northwest Electric Power Planning Council (now known as the Pacific Northwest Power and Conservation Council) comprised of two voting members representing each state--Washington, Oregon, Idaho, and Montana. Although initially governors designated one of their two representatives to serve only 2 years, each member currently serves a term of 3 years. Convinced that regional electric energy planning should be placed firmly in the hands of the people of the Pacific Northwest, Congress made each council member an officer of his respective State. The Council was initially formed in April 1981. The initial tasks of the Council were to (l) adopt a fish and wildlife program by 15 November 1982 and (2) prepare a regional electric power and conservation plan by April 1983. The adopted fish and wildlife program was developed to protect, mitigate, and enhance fish and wildlife--including related spawning grounds--on the Columbia River and its tributaries. Under the program, flows of sufficient quality and quantity must be provided between hydroelectric facilities to improve production, migration, and fish habitat as required to meet sound biological objectives. Investigations are currently in progress to determine the potential contribution by the Grand Coulee Dam project to meet the objectives of the program.

b) Western Power Pool (WPP). The WPP is a voluntary organization comprised of major generating utilities serving the Pacific Northwest, British Columbia and Alberta. Smaller, principally non-generating utilities in the region participate indirectly through the member system with which they are interconnected. The Pool, formerly known as the Northwest Power

Pool, was originally formed in 1942, when the federal government directed utilities to coordinate operations in support of wartime production.

c) Regional Forum. The Action Agencies perform regional coordination of CRS water management/reservoir regulation, fish passage operations and maintenance activities, fish passage capital improvements and related research, monitoring, and evaluations through the established Regional Forum. The Regional Forum is a system of interacting technical work groups that operate under the direction of the Regional Implementation and Oversight Group (RIOG). The RIOG provides policy level interagency coordination among federal, state and tribal sovereigns. The group provides resolution for issues elevated by technical work groups, reviews updates to the Fish Operations Plan, and engages during key decision milestones (e.g. Water Management Plan guidance).

There are several working groups and teams, including the RIOG, and include: Technical Management Team, System Configuration Team, Studies Review Work Groups, Fish Facility Design Review Work Group, and Fish Passage Operations. See Figure 9-1 for coordination sequencing and a summary of group responsibilities.

The Technical Management Team (TMT) is the primary group responsible for optimizing passage conditions for juvenile and adult anadromous salmonids and resident fish, and a description of agency team members and team responsibilities is included below.

(1) Technical Management Team. The TMT is an inter-agency technical group comprised of sovereign representatives responsible for making in-season recommendations to the AAs (Corps, BPA, and Reclamation) on dam and reservoir operations in an effort to meet the expectations of the applicable BiOps (listed above) and accommodate changing conditions, such as water supply, fish migration, water quality and maintenance issues.

The TMT includes representatives from Tribal sovereigns and states. The AAs develop, and TMT reviews, the Water Management Plan annually to describe the plan to operate the Columbia River System consistently with the most recent BiOps..

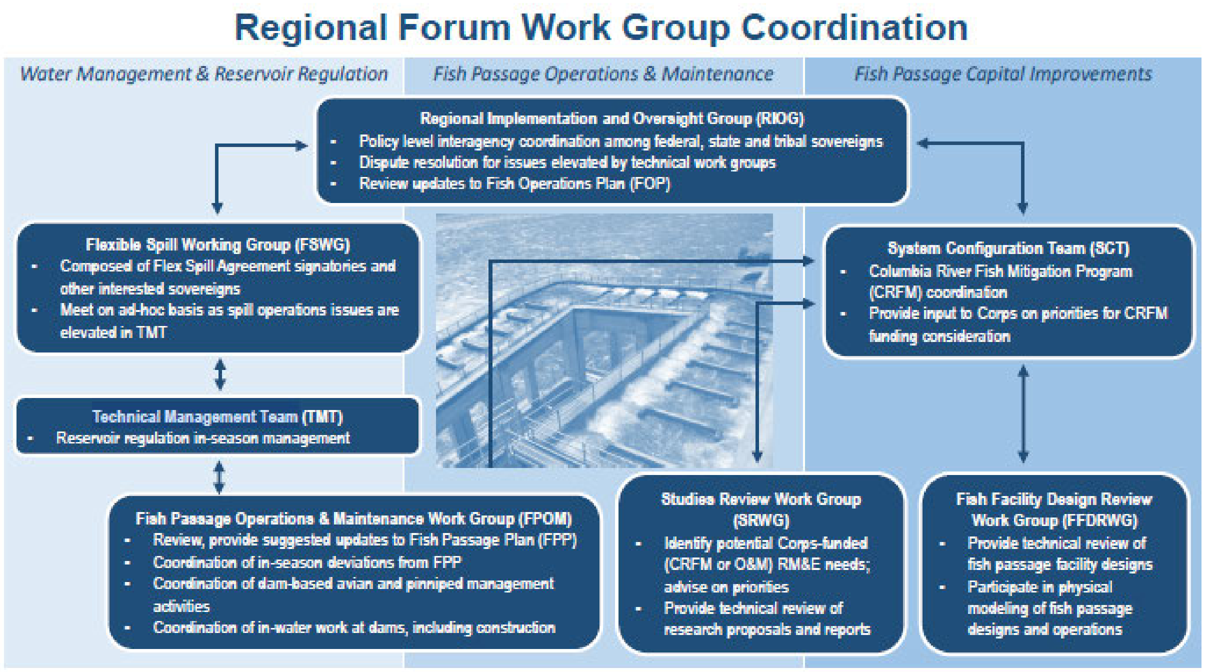


FIGURE 9-1. REGIONAL FORUM WORK GROUP COORDINATION.

9.03 Interagency Agreements.

a) Columbia River Treaty (CRT). In 1964 a treaty was ratified by the governments of Canada and the United States which provided for the development of storage reservoirs in Canada, and cooperative measures for hydroelectric power generation and flood risk management which make possible other benefits as well. As part of the Treaty, Canada was required to build three large storage dams (Duncan, Keenleyside, and Mica) on the upper reaches of the Columbia River in British Columbia. The Treaty also granted the United States permission to build Libby Dam on the Kootenai River in Montana (called Kootenay River in Canada). The three Canadian reservoirs provide improved streamflow in both countries, and the Treaty requires Canada to operate these reservoirs on a coordinated basis with the United States for flood control and hydropower, and for the United States to compensate Canada for a portion of those benefits, or certain other costs depending on the operation.

The coordinated operations and most other duties of the Treaty are implemented by entities from each country. The United States Entity is comprised of the administrator of BPA and the CENWD Commander. The Canadian entity includes British Columbia Hydro, the provincial power-utility. Treaty coordinated operation plans for the Canadian projects affect Grand Coulee Dam because of its location in the system.

b) Pacific Northwest Coordination Agreement (PNCA). The PNCA is the formal contract of the WPP for coordinating the seasonal operation of the generating resources of the member systems for the best utilization of their collective reservoir storage. The agreement became effective on January 4, 1965, and was updated in December 1995 (effective August 1, 2003). Parties to the PNCA coordinate the operation of their respective systems to (1) entitle each system to its optimum firm load-carrying capability, (2) provide optimum firm load-carrying capability for the coordinated system, and (3) produce the optimum amount of usable secondary energy for each system consistent with the PNCA objectives.

c) 2019-2021 Spillway Operations Agreement. This agreement, signed by the states of Washington and Oregon, the Nez Perce Tribe, and the Federal Action Agencies, establishes a flexible spill operation intended to: 1) provide fish benefits (increasing spill levels to improve juvenile passage conditions and survival rates and adult returns, 2) provide Federal power system benefits, and 3) provide operational flexibility.

d) Lake Roosevelt Incremental Storage Release Project Memorandum of Understanding. A memorandum of understanding regarding the Lake Roosevelt Incremental Storage Release Project (LRISRP) was signed by the State of Washington, Reclamation, and the Columbia

Basin Irrigation Districts in December 2004. In December 2007, Water Resource Management Agreements supporting the incremental storage releases from Lake Roosevelt were signed by the State of Washington, the Confederated Tribes of the Colville Reservation, and the Spokane Tribe of Indians.

9.04 Commissions, River Authorities, Compacts, and Committees.

a) Columbia River Treaty Hydrometeorological Committee. The Canadian and United States Entities of the Columbia River Treaty established the Hydrometeorological Committee (CRTHC) in 1968. The mandate of the CRTHC is primarily to be responsible for ensuring that hydrometeorological data required for the planning and operation of Treaty project facilities are collected and communicated to the Entities. This responsibility includes ensuring sufficient data are available for performing all required forecasts. The CRTHC makes recommendations concerning the development and operation of the hydrometeorological system established in accordance with paragraph 2 of Annex A to the CRT.

b) Columbia River Treaty Operating Committee. The committee is responsible for making the system regulation studies, preparing the operating plans, ensuring the plans are accomplished, and performing other duties as required by the entities. The United States section of the committee is comprised of the Chief of the NWD Columbia Basin Water Management, (co-chair) and the BPA Chief of the Branch of Power Resources (chair).

c) International Joint Commission (IJC). The IJC is a permanent body established under the provisions of the Boundary Waters Treaty of 1909 and consists of six commissioners: three Canadians and three Americans. The IJC's mission is to prevent and resolve disputes between the United States and Canada under the 1909 Boundary Waters Treaty and pursue the common good of both countries as an independent and objective advisor to the two governments. The

International Columbia River Board of Control was established by Order of the International Joint Commission dated 15 December 1941 to ensure the implementation of the provisions of that Order – which granted approval for the United States to construct and operate the Grand Coulee dam and reservoir (Franklin D. Roosevelt Lake) – and to continue to study the effect of the operation of the Grand Coulee dam and reservoir upon water levels at and above the international boundary. The 2-person Board keeps the IJC apprised of streamflow and water level data on both sides of the international boundary.

9.05 Non-Federal Hydropower. There are no applicable non-federal hydropower facilities associated with GCL.

9.06 Reports. Many reports are available online from the home page for the Columbia Basin Water Management Division, Northwestern Division, U.S. Army Corps of Engineers: https://www.nwd.usace.army.mil/CRWM/

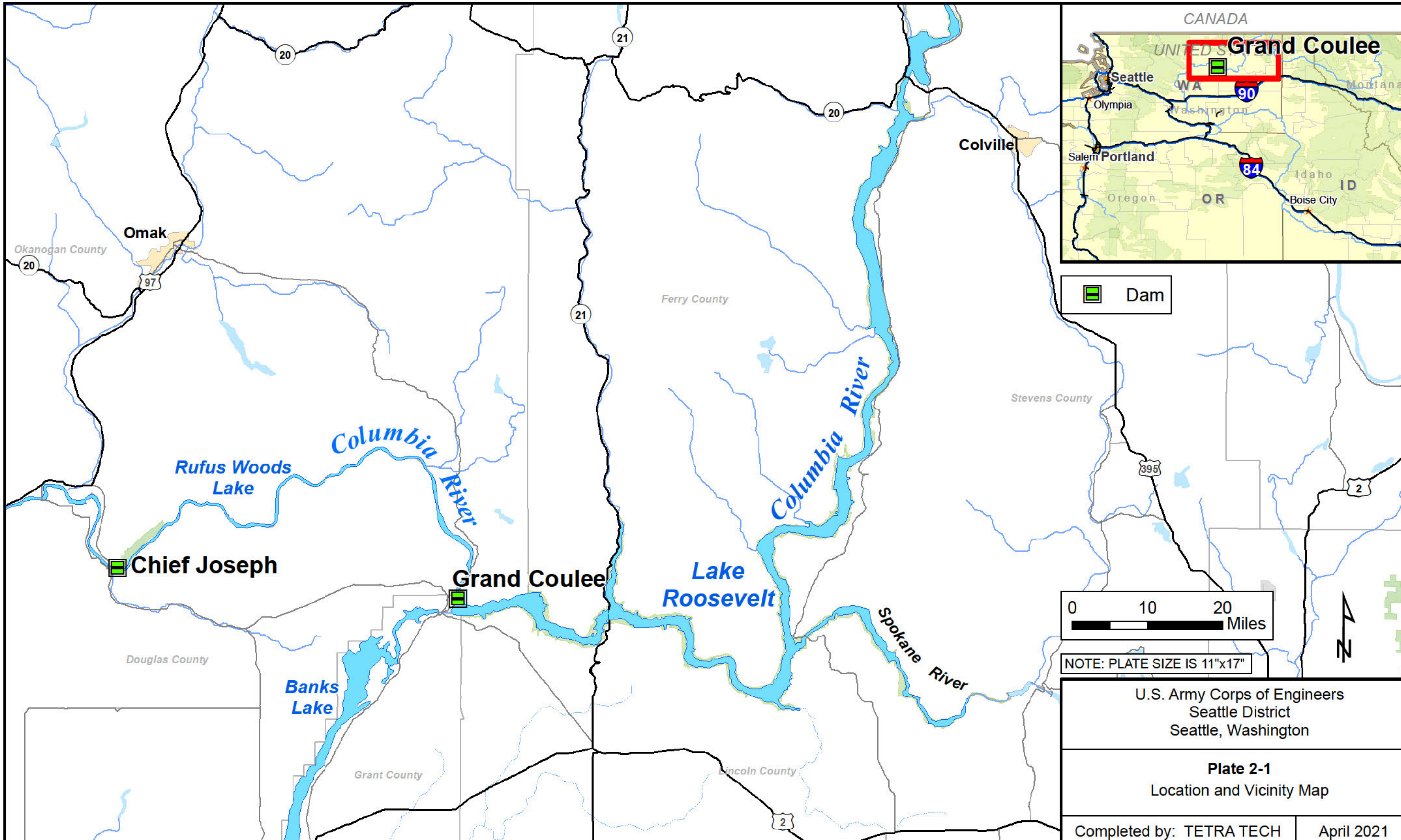
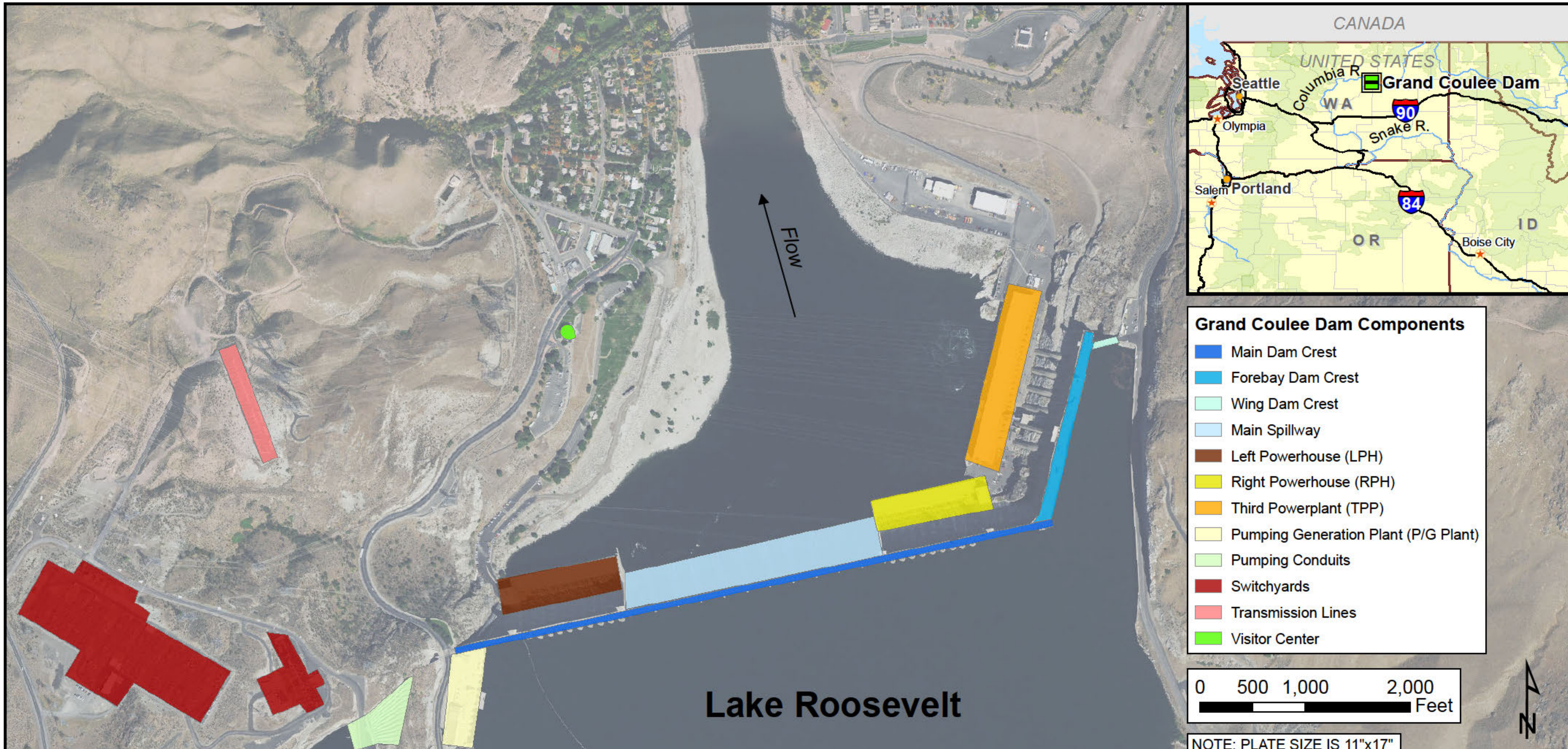

CANADA
UNITED S
Grand Coulee
Seattle
WA
90
Montana
Olympia
Washington
Salem
Portland
84
Idaho
ID
Oregon
OR
Boise City
Dam
Colville
Omak
Okanogan County
20
97
21
Ferry County
Stevens County
Columbia River
Rufus Woods Lake
Chief Joseph
Grand Coulee
Lake Roosevelt
Spokane River
Banks Lake
Douglas County
Grant County
Lincoln County
395
2
0 10 20 Miles
NOTE: PLATE SIZE IS 11"x17"
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington
Plate 2-1
Location and Vicinity Map
Completed by: TETRA TECH
April 2021

PLATE 2-1



NOTE: PLATE SIZE IS 11"x17"

U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 2-2
Grand Coulee Dam Components

Completed by: TETRA TECH | April 2021

PLATE 2-2

FIGURE 3

[redacted]

U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 2-3

Grand Coulee
Original Dam Sections

Notes

September 2022

[redacted]

U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 2-4

Grand Coulee
Forebay Dam and Third Power Plant

Notes

September 2022

[redacted]

U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 2-5

Grand Coulee
Spillway Drum Gate

Notes

September 2022

[redacted]

U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 2-6

Grand Coulee
Outlet Works Elevation 1050

Notes

September 2022

[redacted]

U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 2-7

Grand Coulee
Outlet Works Elevation 1150

Notes

September 2022

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U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 2-8

Grand Coulee
18’ Penstocks Elevations and Sections

Notes	September 2022

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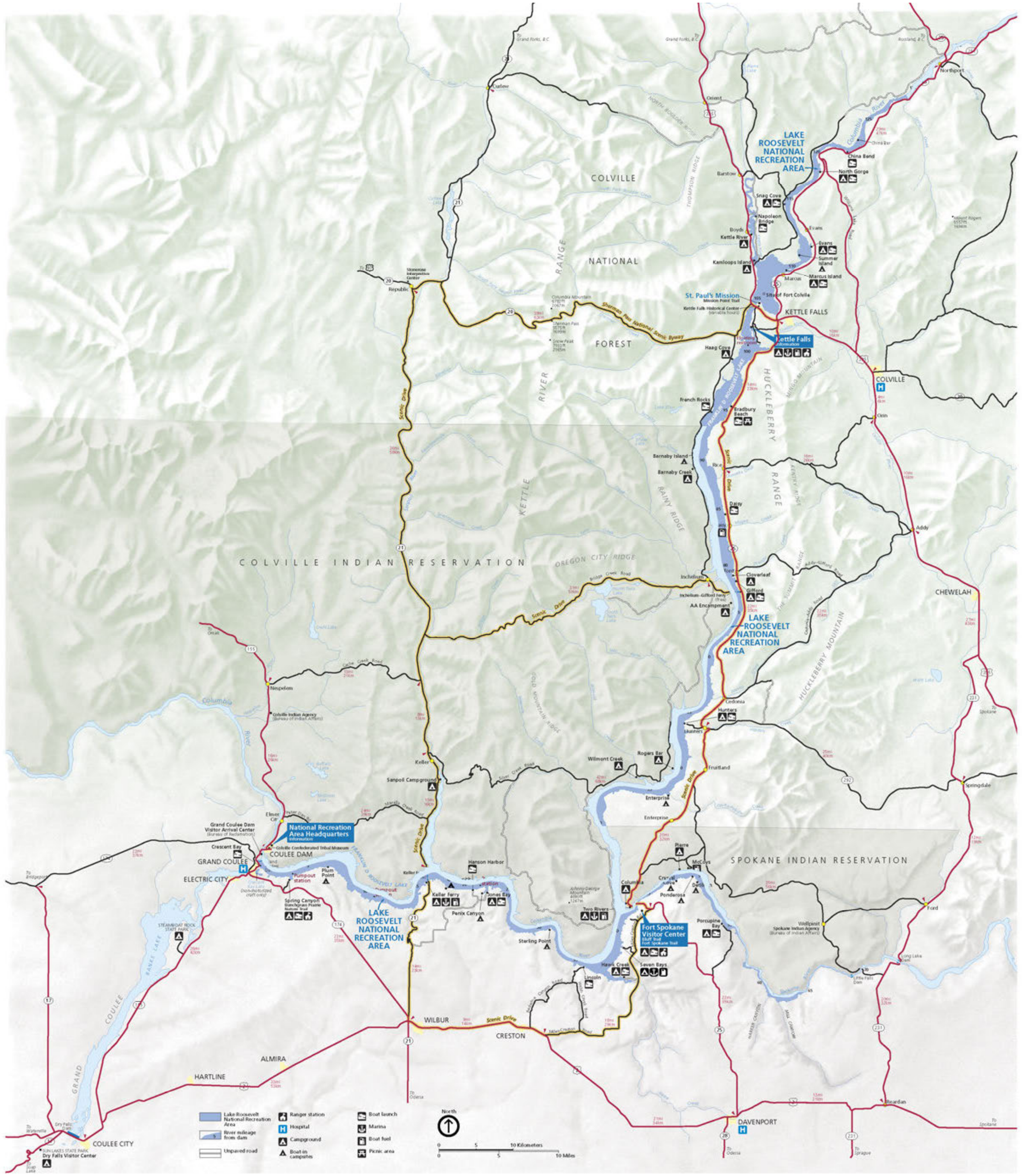
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 2-9

Grand Coulee
Main Unit Penstocks

Notes	September 2022



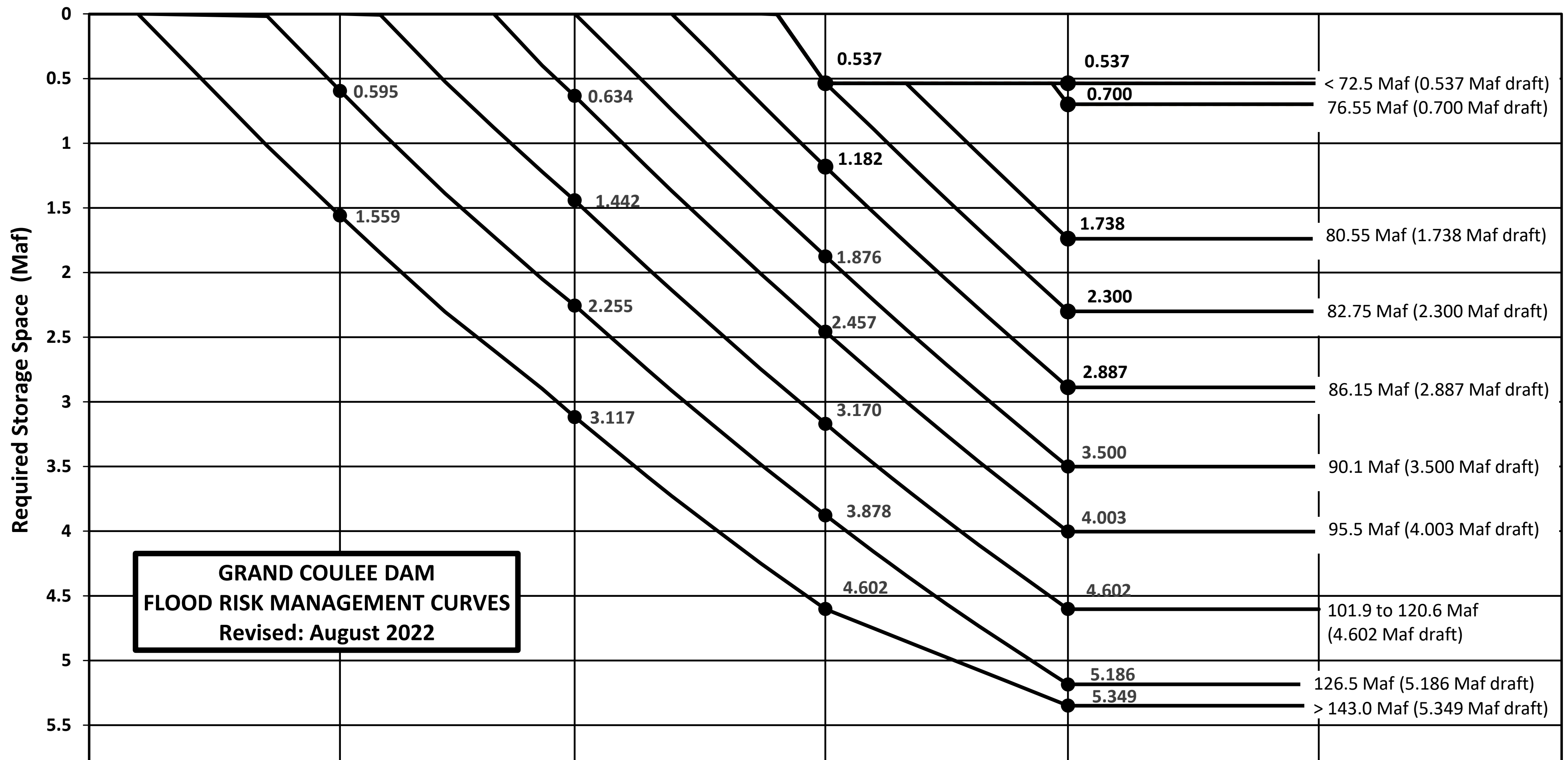
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 2-10

Grand Coulee
Public Facilities

Notes
Source: National Park Service

September 2022



1. Parameter values on curves are The Dalles April - August unregulated flow forecast.

2. This SRD reflects end of month flood risk management requirements by the Corps of Engineers. If one or more storage projects are under drafted then the Grand Coulee Dam required draft will be increased to offset the under draft.

3. The curves reflect a 0.8 ft/day draft rate. The lines that connect the end of month draft requirements represent a preferred drawdown rate that minimizes landslide risks as determined by USBR.

4. This SRD is a revision of the October 2020 SRD to reflect the October 2020 update of the Libby SRD.

JAN FEB MAR APR MAY JUN

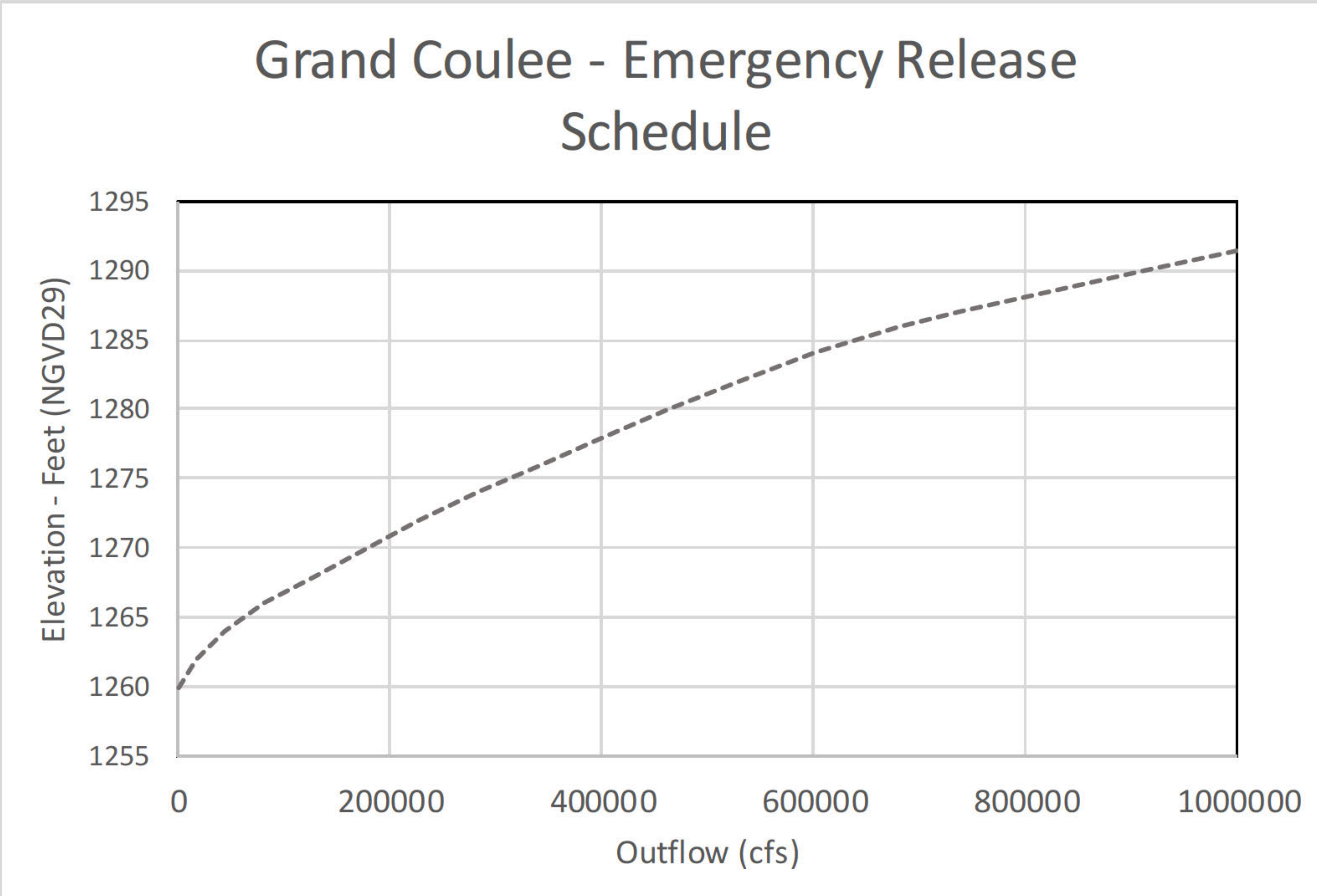
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 7-1

Grand Coulee
Storage Reservoir Diagram (SRD)

Notes

September 2022



Grand Coulee - Emergency Release Schedule	
Spillway	
Elevation (NGVD-ft)	Outflow (cfs)
935.8	0
1260	0
1262	16500
1264	45100
1266	81400
1268	127600
1270	177100
1272	227700
1274	282700
1276	339900
1278	401500
1280	462000
1282	530200
1284	599500
1286	679800
1287	738100
1290	912700
1291.5	1000000

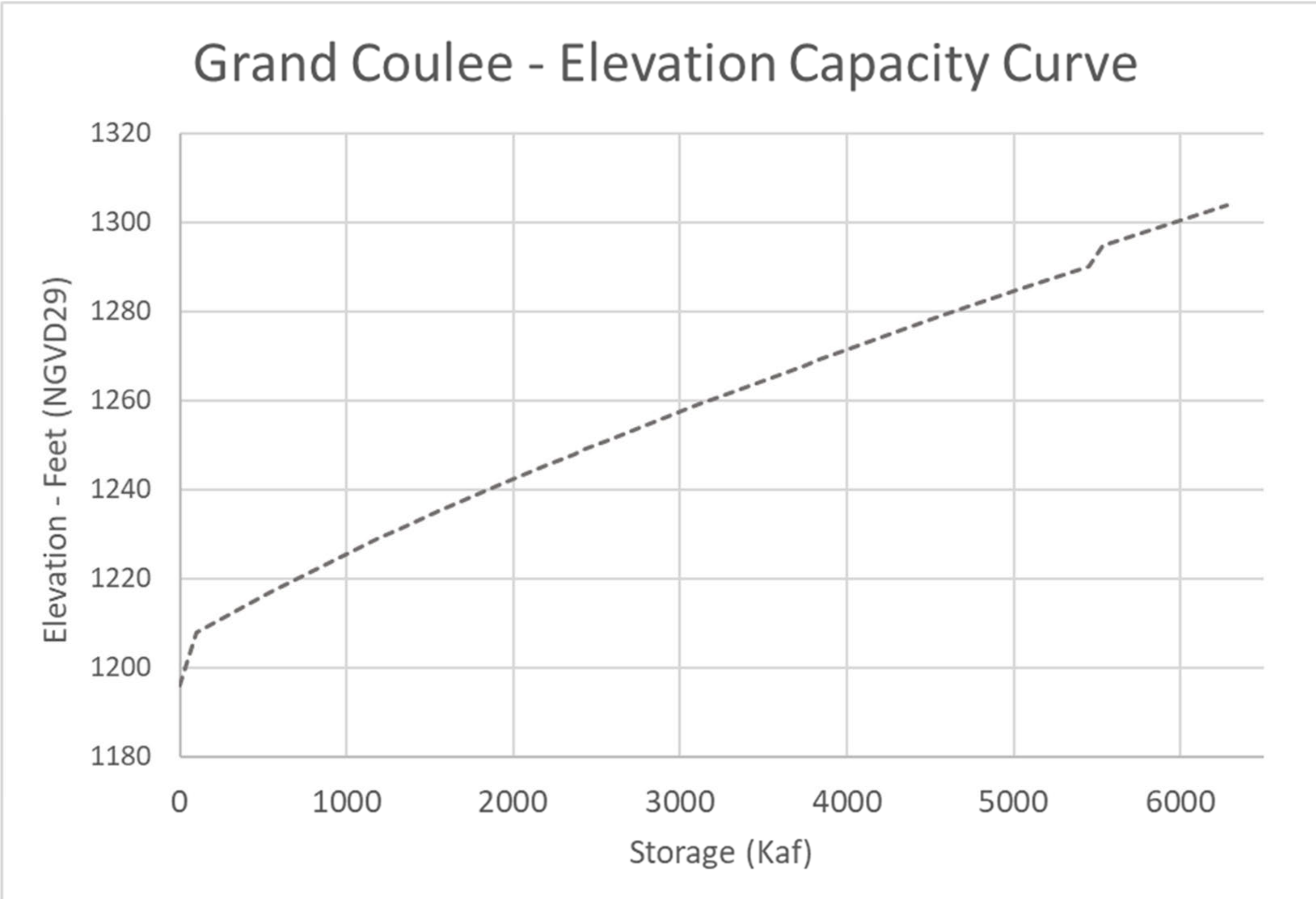
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 7-2

Grand Coulee
Emergency Release Schedule

Notes

September 2022



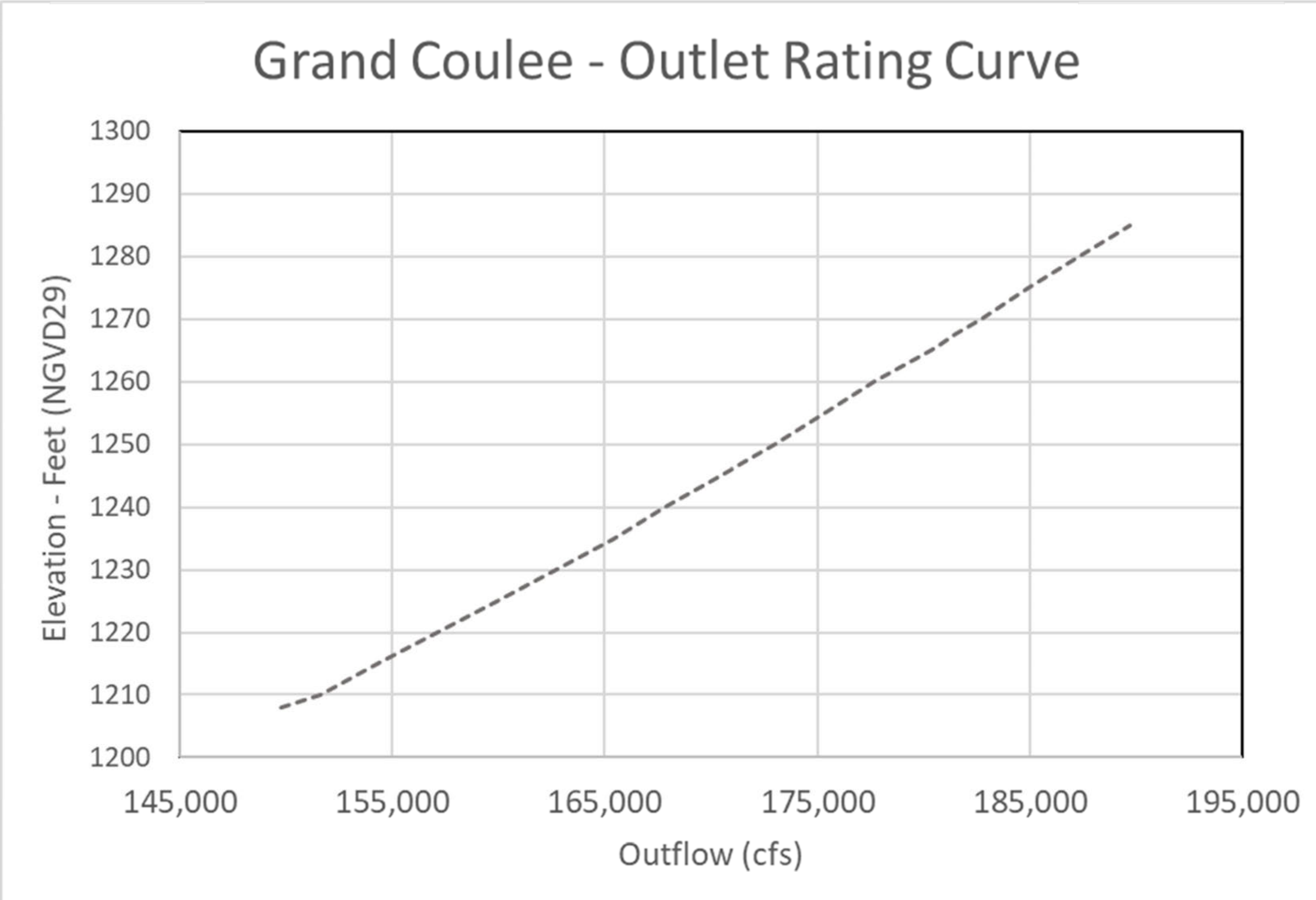
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 7-3

Grand Coulee
Elevation Capacity Curve

Notes

September 2022



Grand Coulee - Outlet Rating Curve	
Outlets	
Elevation (NGVD-ft)	Outflow (cfs)
1208.0	149,800
1210.0	151,600
1215.0	154,400
1220.0	157,100
1225.0	159,900
1230.0	162,700
1235.0	165,400
1240.0	167,800
1245.0	170,400
1250.0	173,000
1255.0	175,300
1260.0	177,700
1265.0	180,300
1265.5	180,600
1267.5	181,500
1270.0	182,700
1275.0	184,900
1280.0	187,300
1285.0	189,700
1290.0	191,900

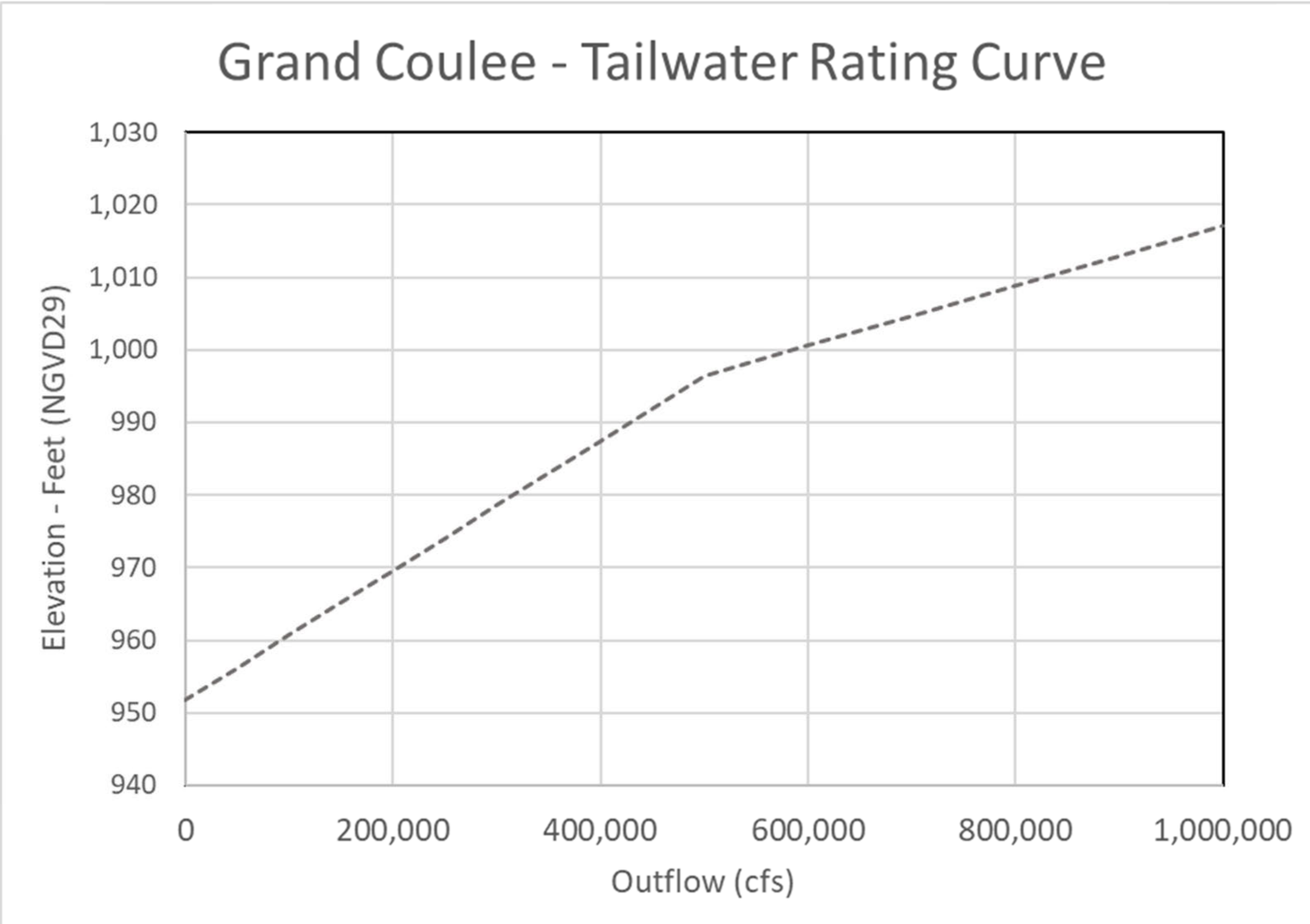
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 7-4

Grand Coulee
Outlet Rating Curve

Notes

September 2022



Grand Coulee - Tailwater Rating Curve	
Elevation (NGVD-ft)	Outflow (cfs)
951.8	0
956.2	50,000
960.7	100,000
965.2	150,000
969.6	200,000
974.1	250,000
978.6	300,000
987.5	400,000
996.4	500,000
1000.5	600,000
1004.7	700,000
1008.8	800,000
1012.9	900,000
1017.0	1,000,000

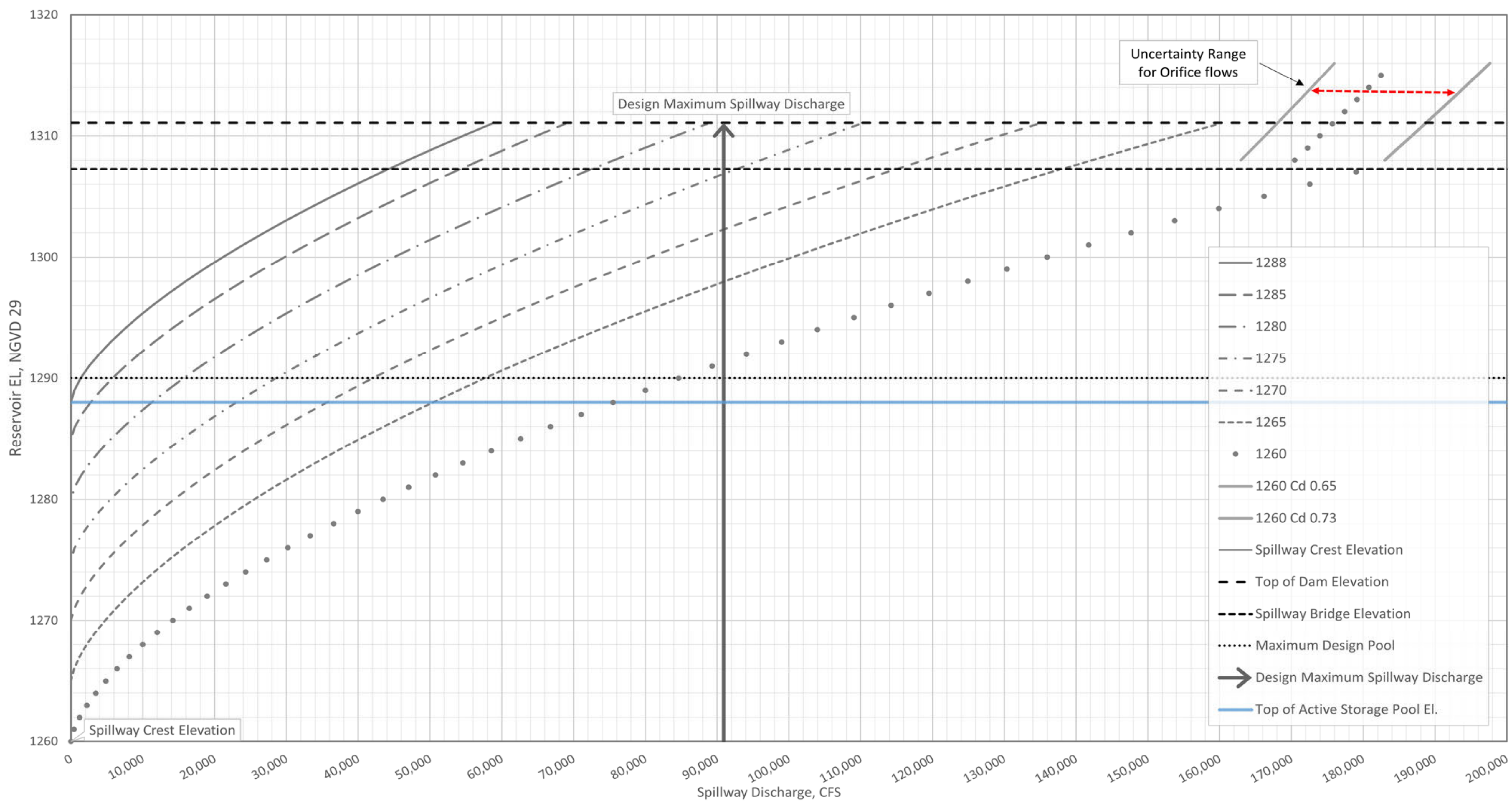
Note: Project outflow is affected by backwater from Rufus Woods Lake. Therefore, the discharge from GCL is computed as flow through turbines plus spill, rather than from this rating curve. See Section 5.01 of this Water Control Manual.

U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 7-5

Grand Coulee
Tailwater Rating Curve

Notes Source: CBSM CWMS 75% Build	September 2022



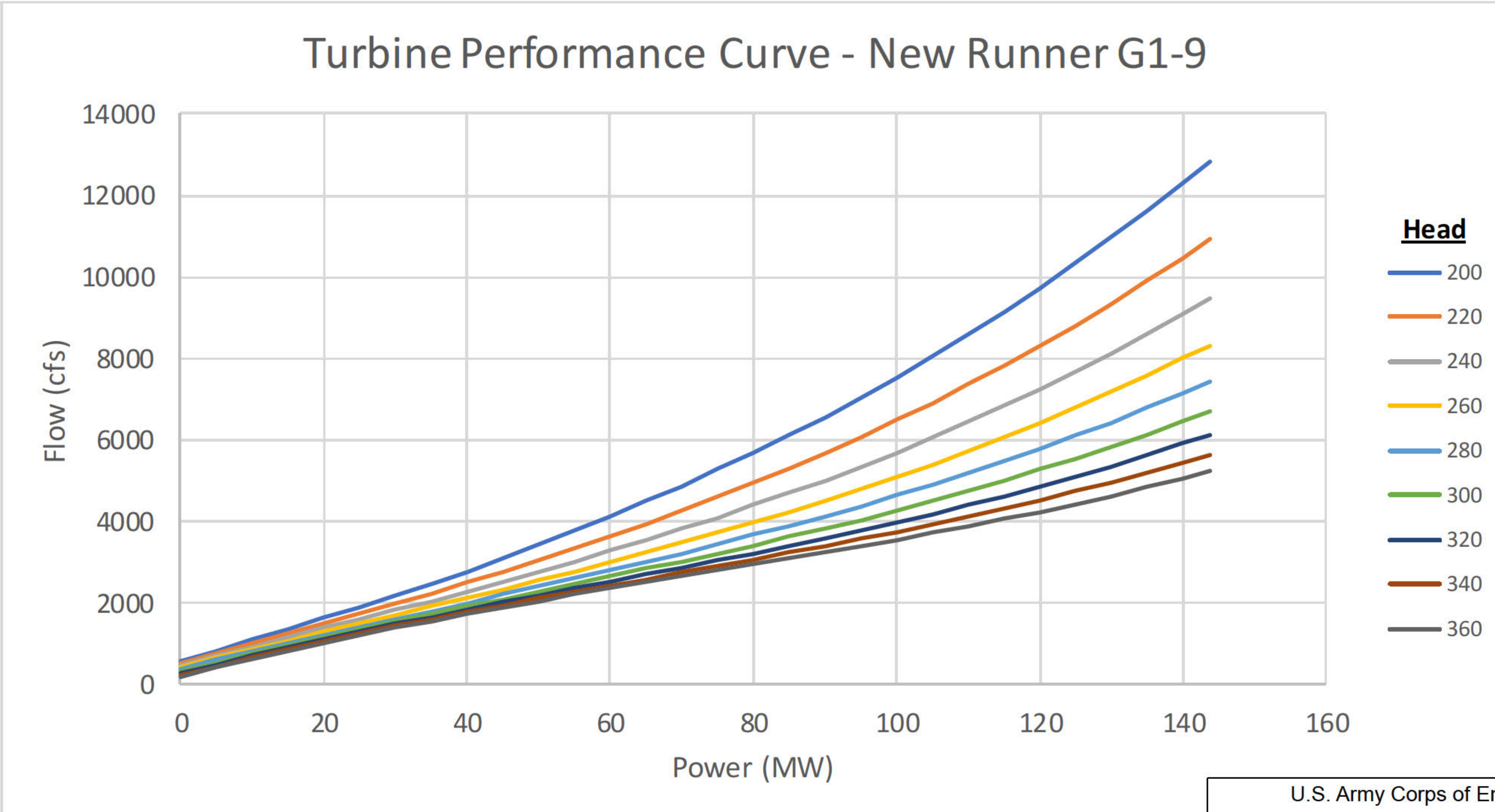
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 7-6

Grand Coulee
Drum Gate Rating Curves

Notes

September 2022



U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

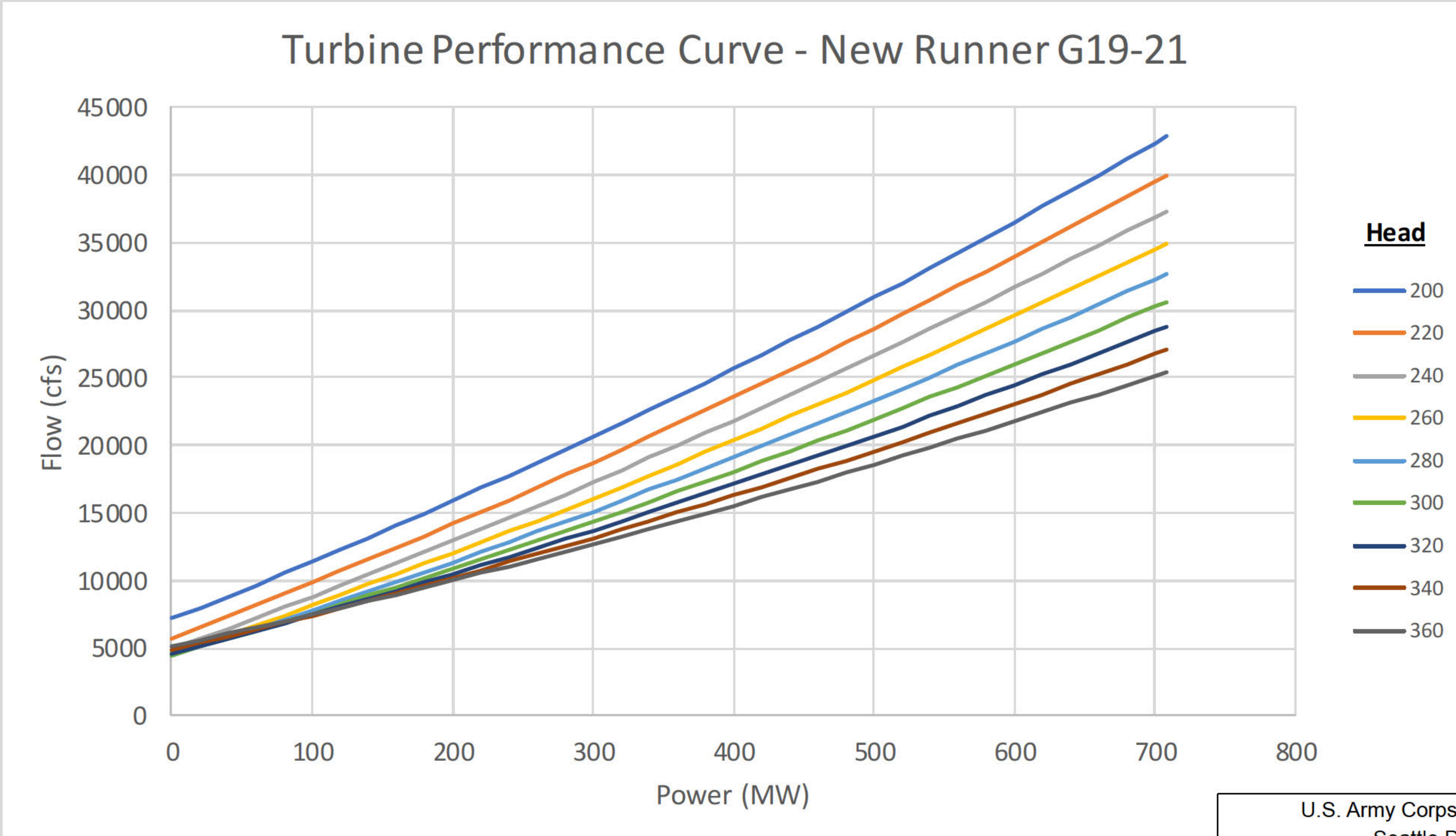
Plate 7-7 A

Grand Coulee
Turbine Performance Curves (G1-9)

Notes:

September 2022

U.S. Army Corps of Engineers Seattle District Seattle, Washington	
Plate 7-7 B Grand Coulee Turbine Performance Curves (G10-18)	
Notes:	September 2022



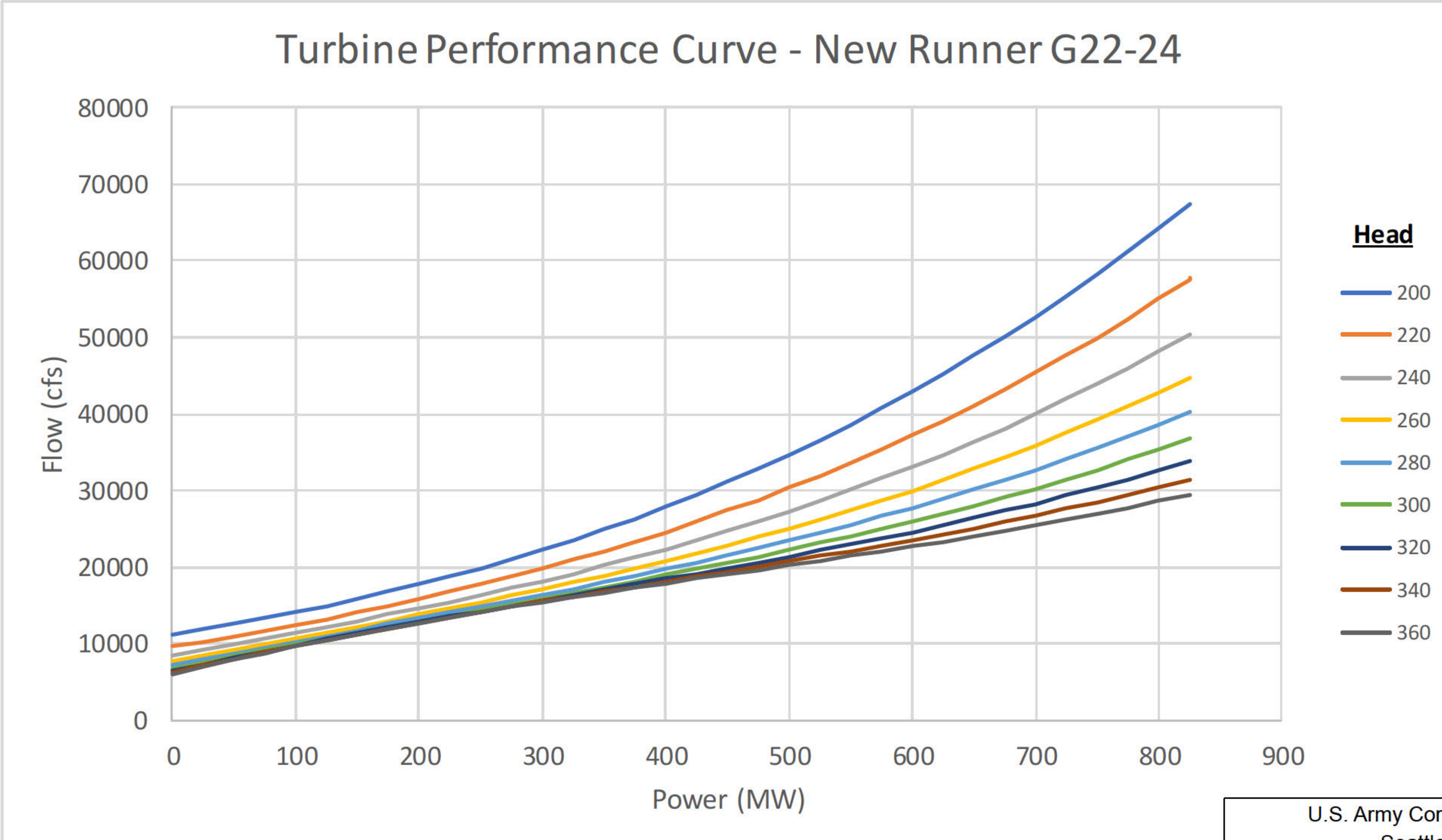
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 7-7 C

Grand Coulee
Turbine Performance Curves (G19-21)

Notes:

September 2022



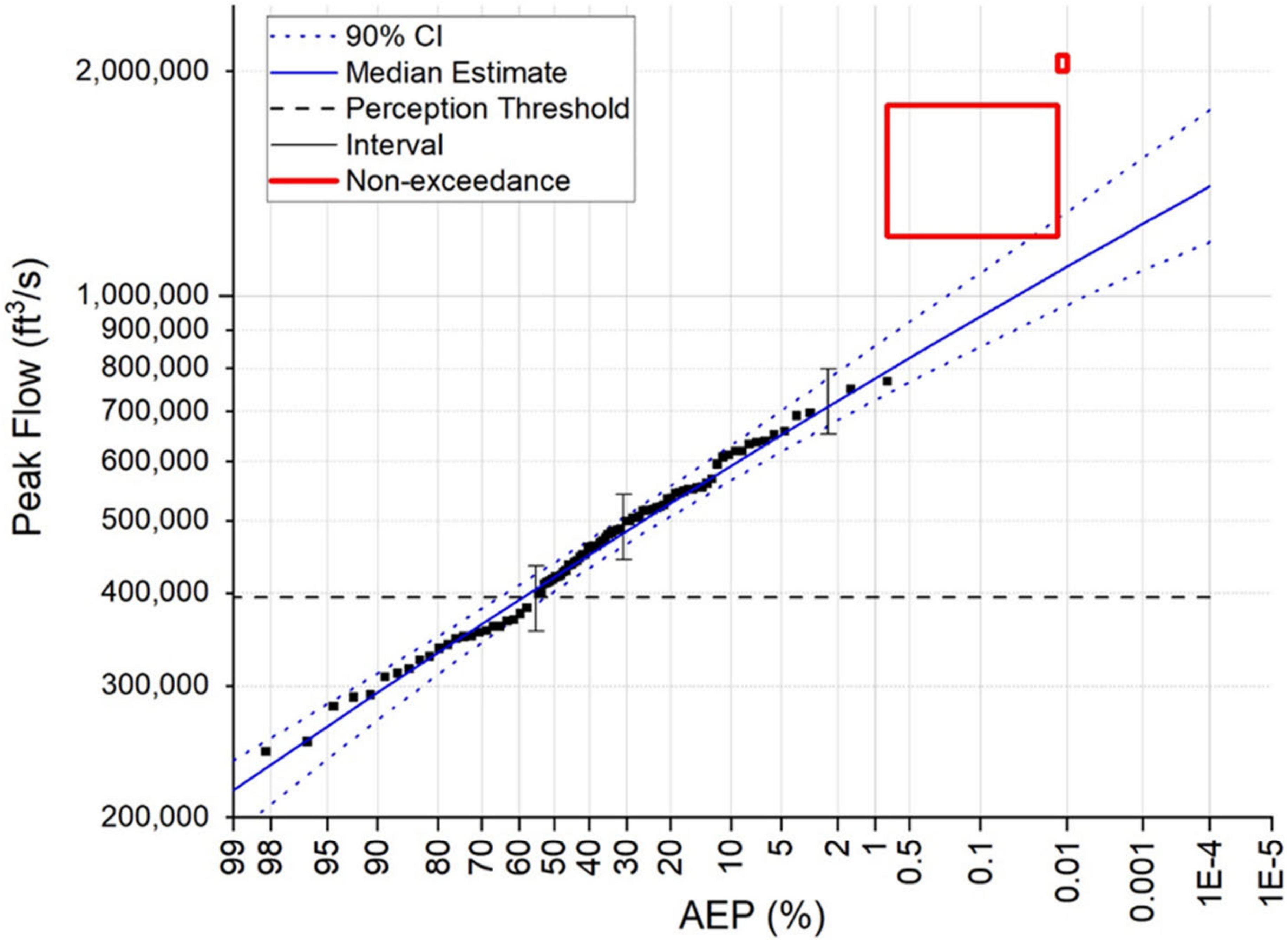
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 7-7 D

Grand Coulee
Turbine Performance Curves (G22-24)

Notes:

September 2022



AEP	Peak Flow (ft^3/s)		
	Median	Lower (5th)	Upper (95th)
1:2	419,900	401,670	438,730
1:10	591,710	565,660	630,130
1:20	650,530	618,140	700,670
1:50	722,820	680,870	790,640
1:100	774,840	724,430	856,520
1:200	825,280	766,080	922,330
1:500	890,230	817,600	1,009,100
1:1,000	938,410	855,270	1,073,950
1:2,000	985,970	891,750	1,139,420
1:5,000	1,048,140	938,610	1,227,920
1:10,000	1,094,780	972,450	1,296,390
1:20,000	1,141,180	1,006,180	1,364,530
1:50,000	1,202,250	1,049,220	1,457,580
1:100,000	1,248,320	1,080,380	1,528,200
1:1,000,000	1,401,100	1,180,100	1,774,500

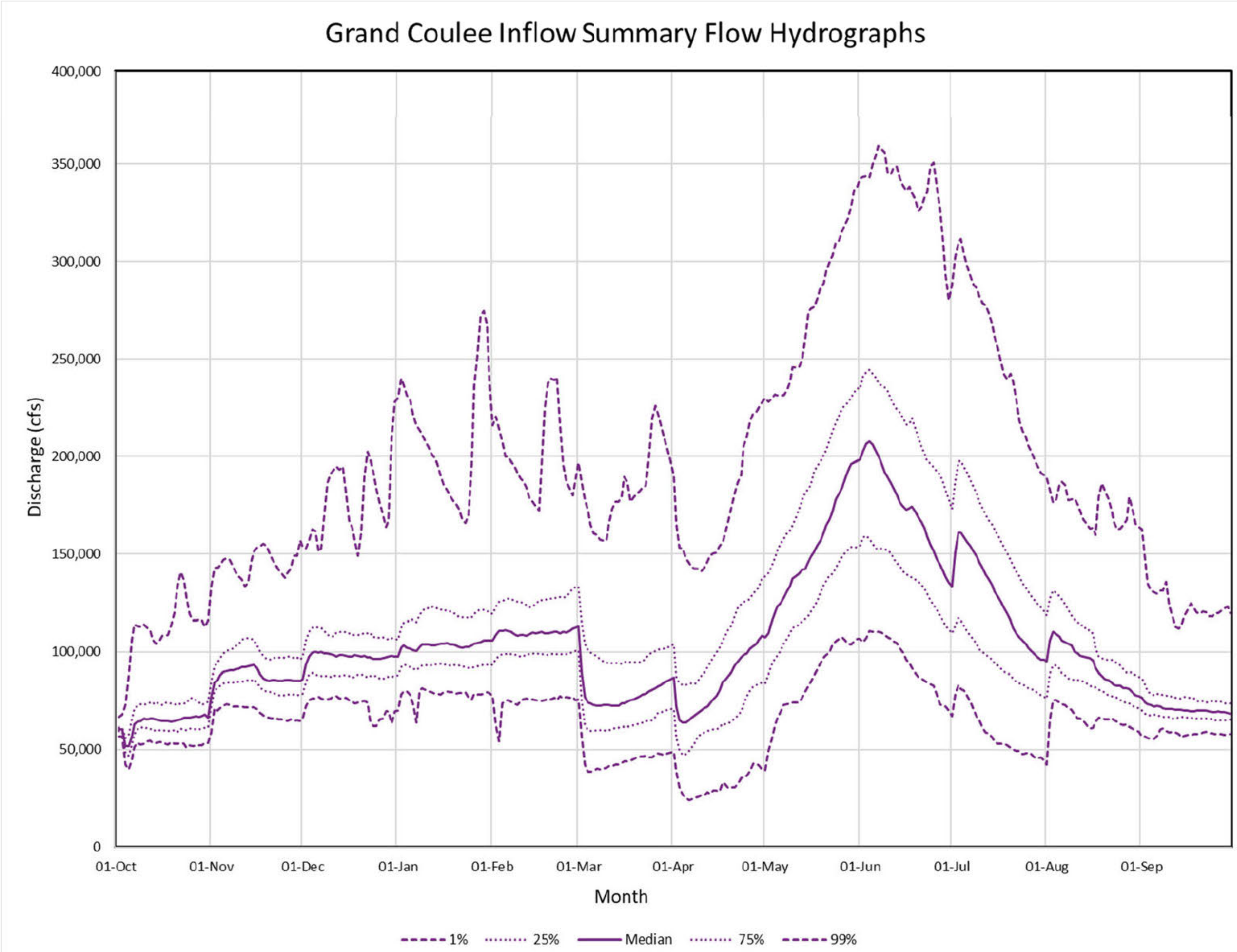
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 8-1

Grand Coulee
Peak Flow AEP

Notes
Source: USBR Provided Data
AEP=Annual Exceedance Probability

September 2022



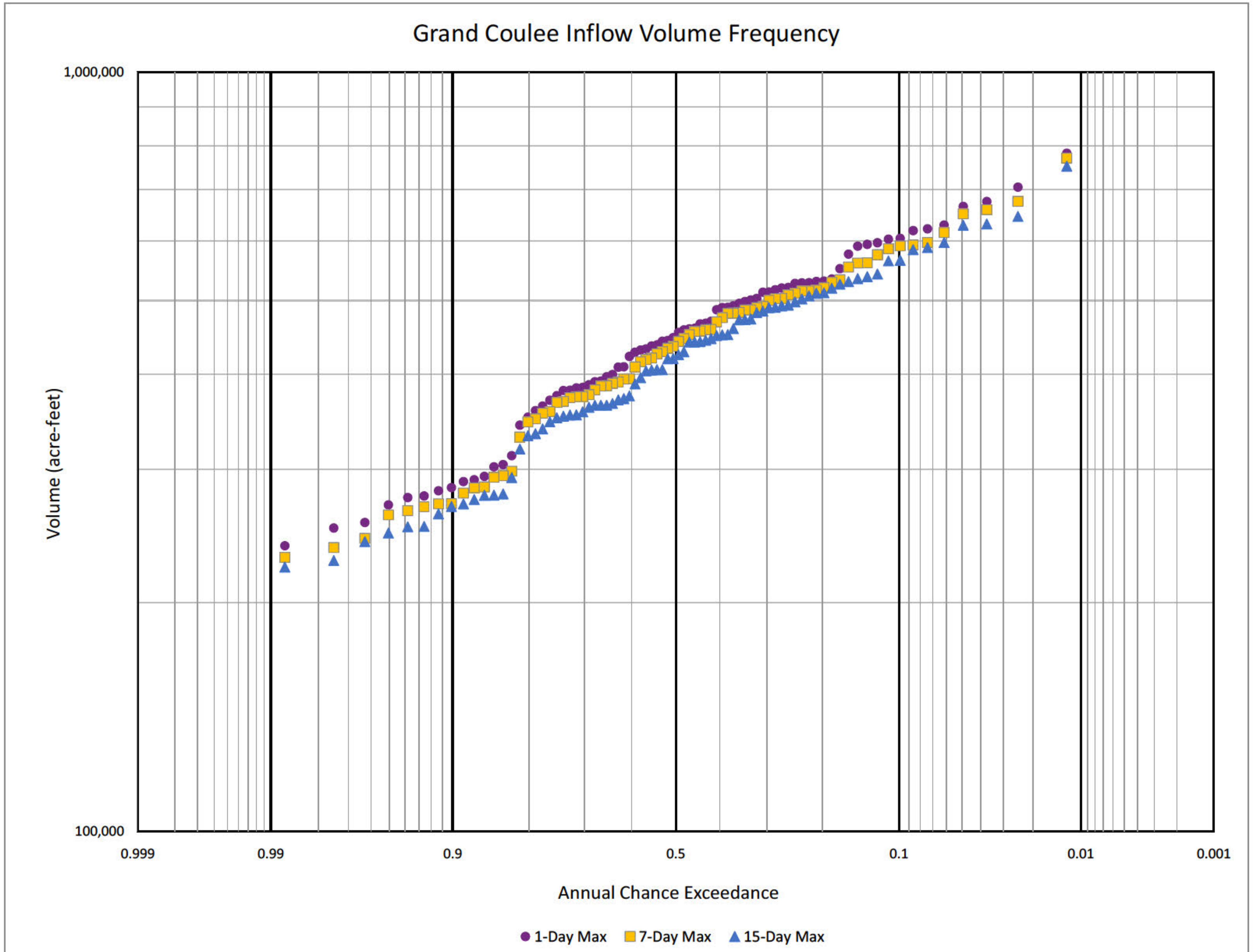
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 8-2

Grand Coulee
Inflow Summary Hydrographs

Notes
Data provided by USACE NWD from 2020 CRSO-EIS Study, Preferred Alternative, using 2010L modified streamflow (1928-2008).

September 2022



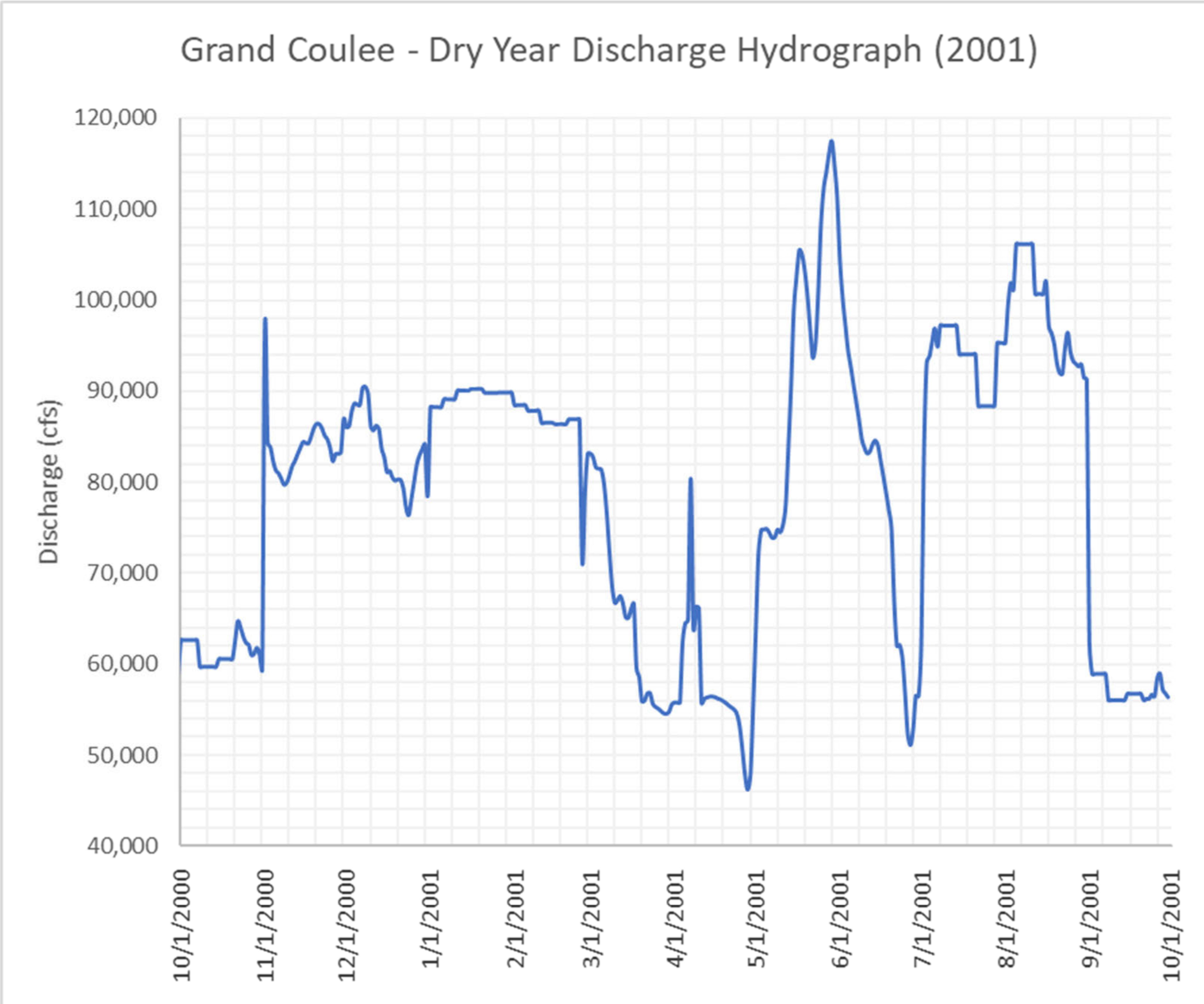
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 8-3

Grand Coulee
Volume Inflow Frequency

Notes
Data provided by USACE NWD from 2020 CRSO-EIS Study, Preferred Alternative, using 2010L modified streamflow (1928-2008).

September 2022

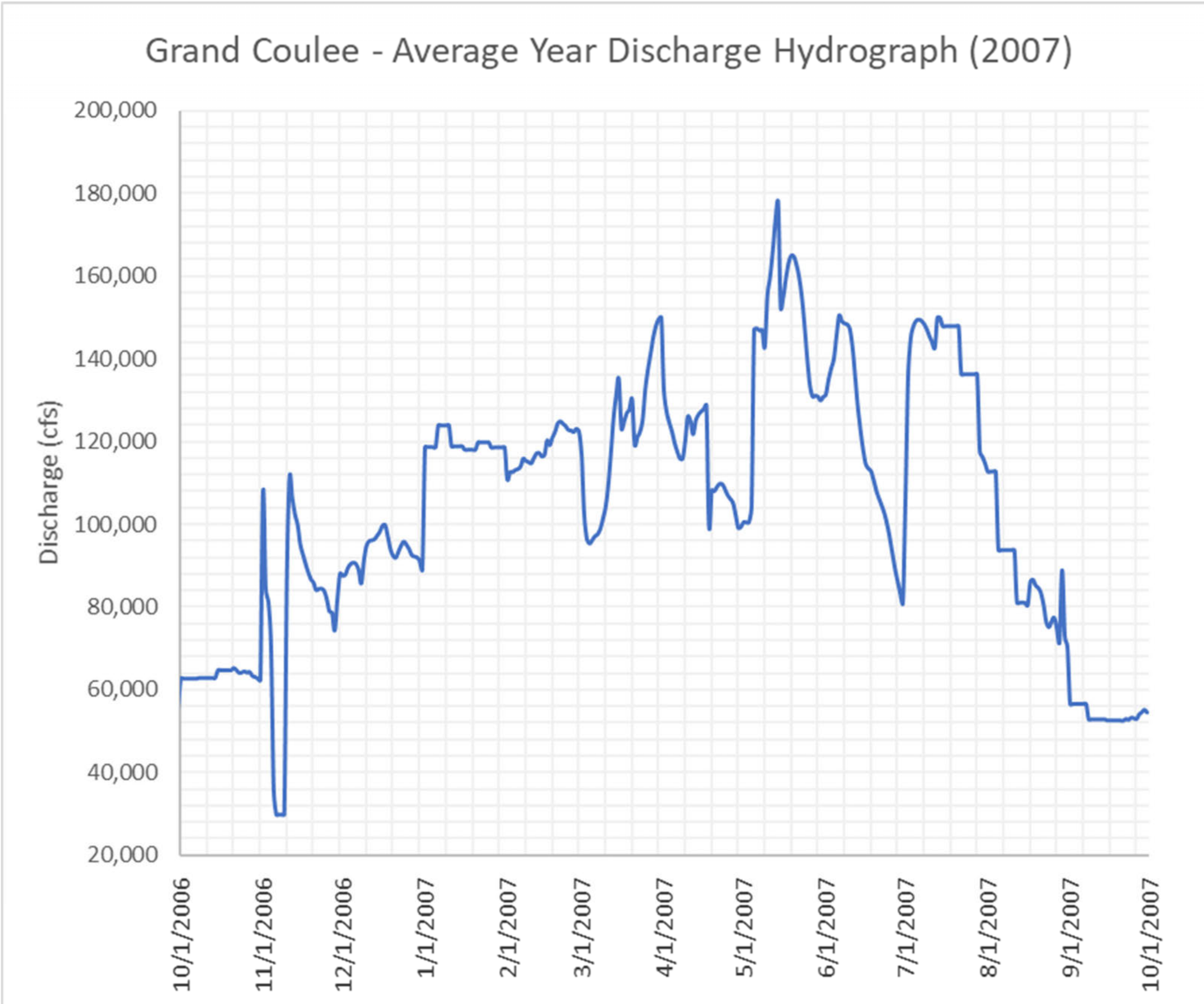


U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

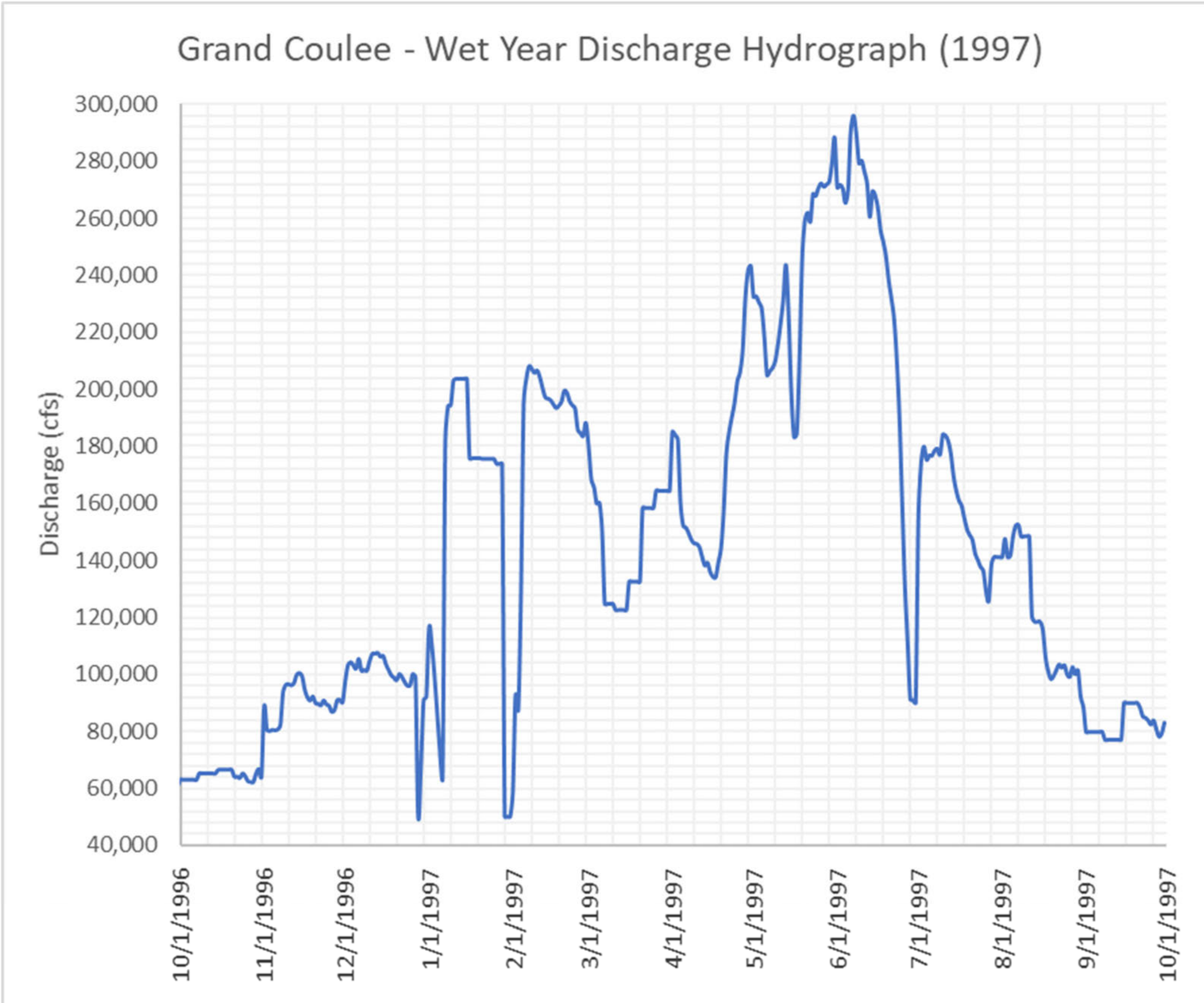
Plate 8-4

Grand Coulee
Dry Year Discharge Hydrograph (2001)

Notes	
Data provided by USACE NWD from 2020 CRSO-EIS Study, Preferred Alternative, using 2010L modified streamflow (1928-2008).	September 2022



U.S. Army Corps of Engineers Seattle District Seattle, Washington	
Plate 8-5 Grand Coulee Average Year Discharge Hydrograph (2007)	
Notes Data provided by USACE NWD from 2020 CRSO-EIS Study, Preferred Alternative, using 2010L modified streamflow (1928-2008).	September 2022



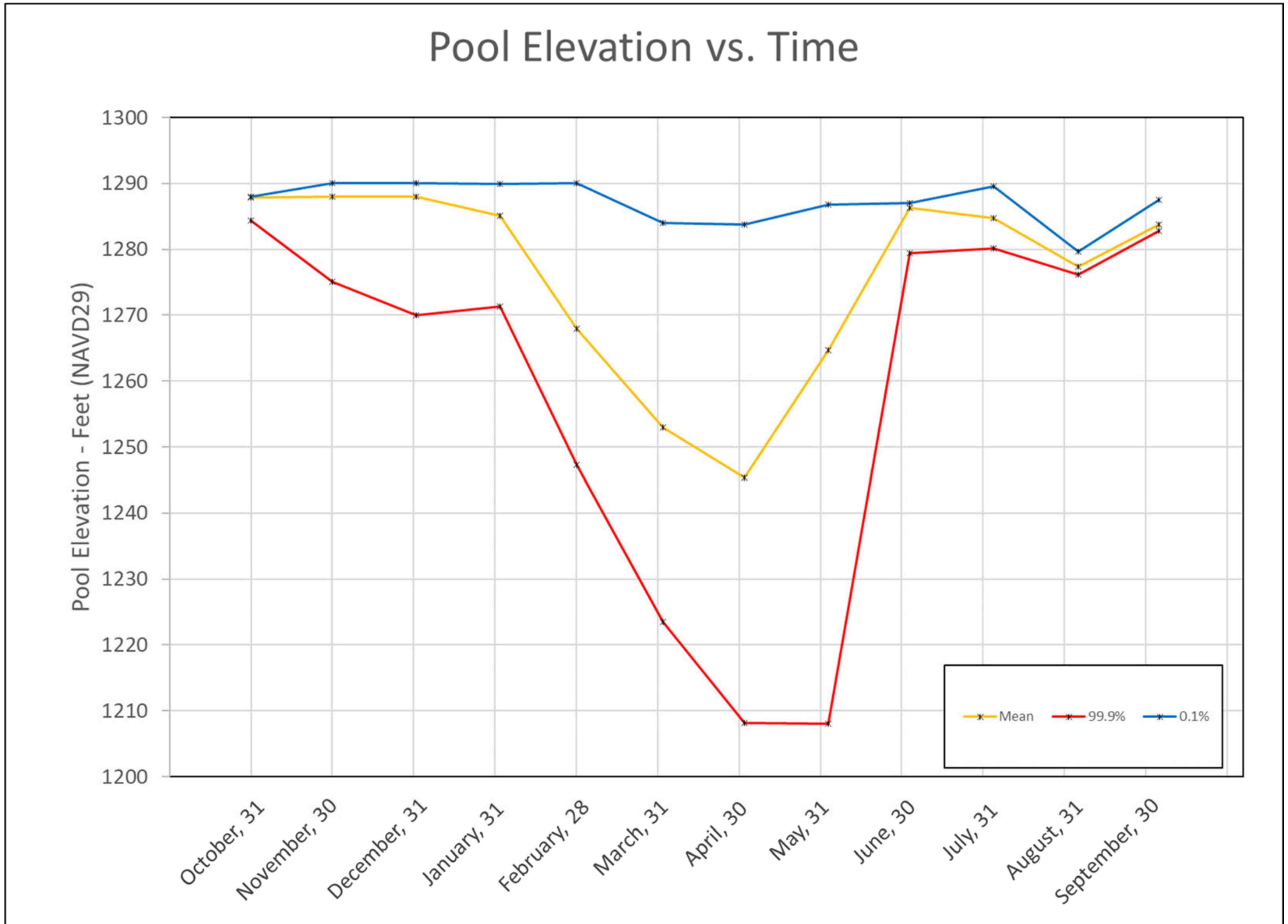
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 8-6

Grand Coulee
Wet Year Discharge Hydrograph (1997)

Notes
Data provided by USACE NWD from 2020 CRSO-EIS Study, Preferred Alternative, using 2010L modified streamflow (1928-2008).

September 2022



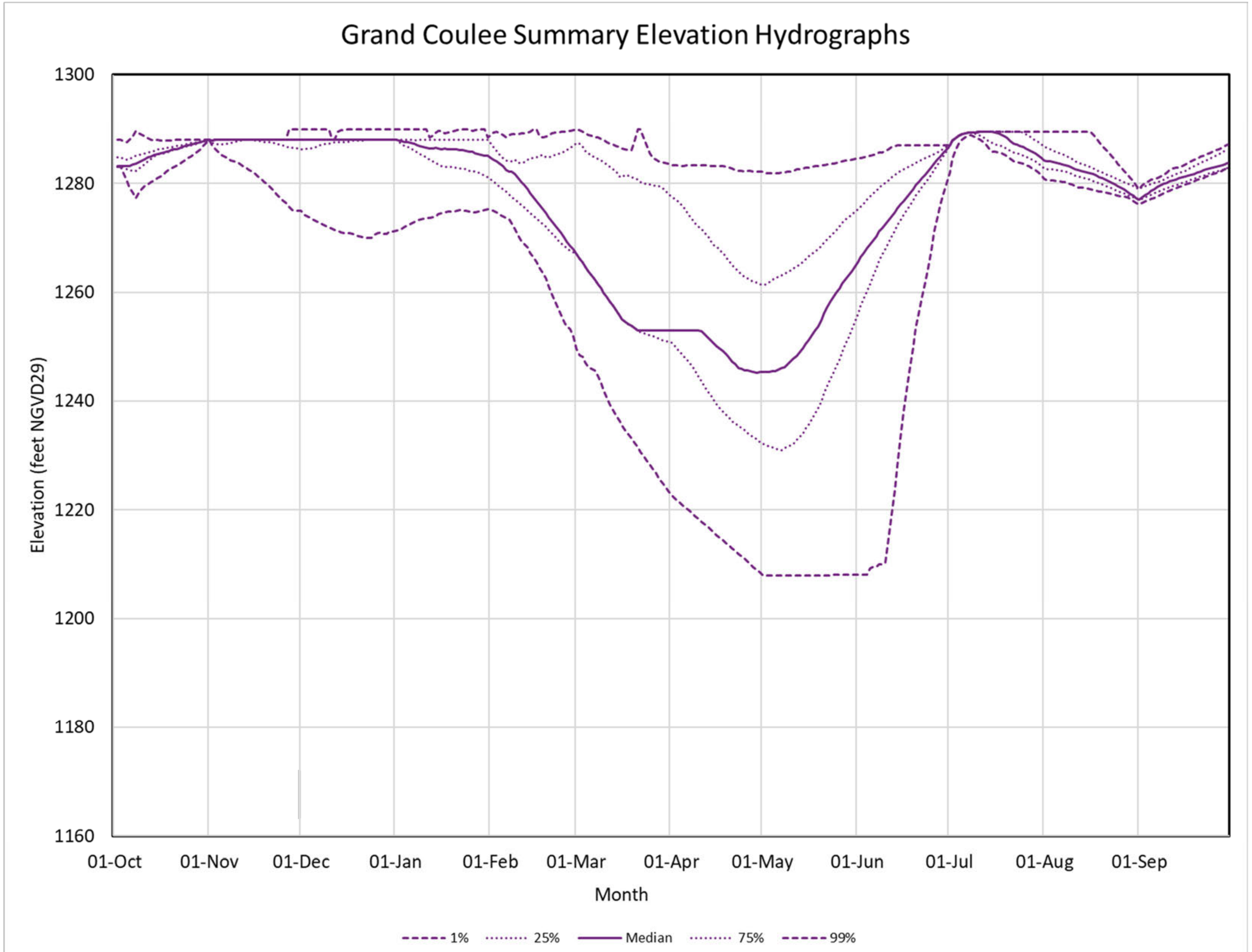
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 8-7

Grand Coulee
Pool Elevation v. Time

Notes
Data provided by USACE NWD from 2020 CRSO-EIS Study, Preferred Alternative, using 2010L modified streamflow (1928-2008).

September 2022



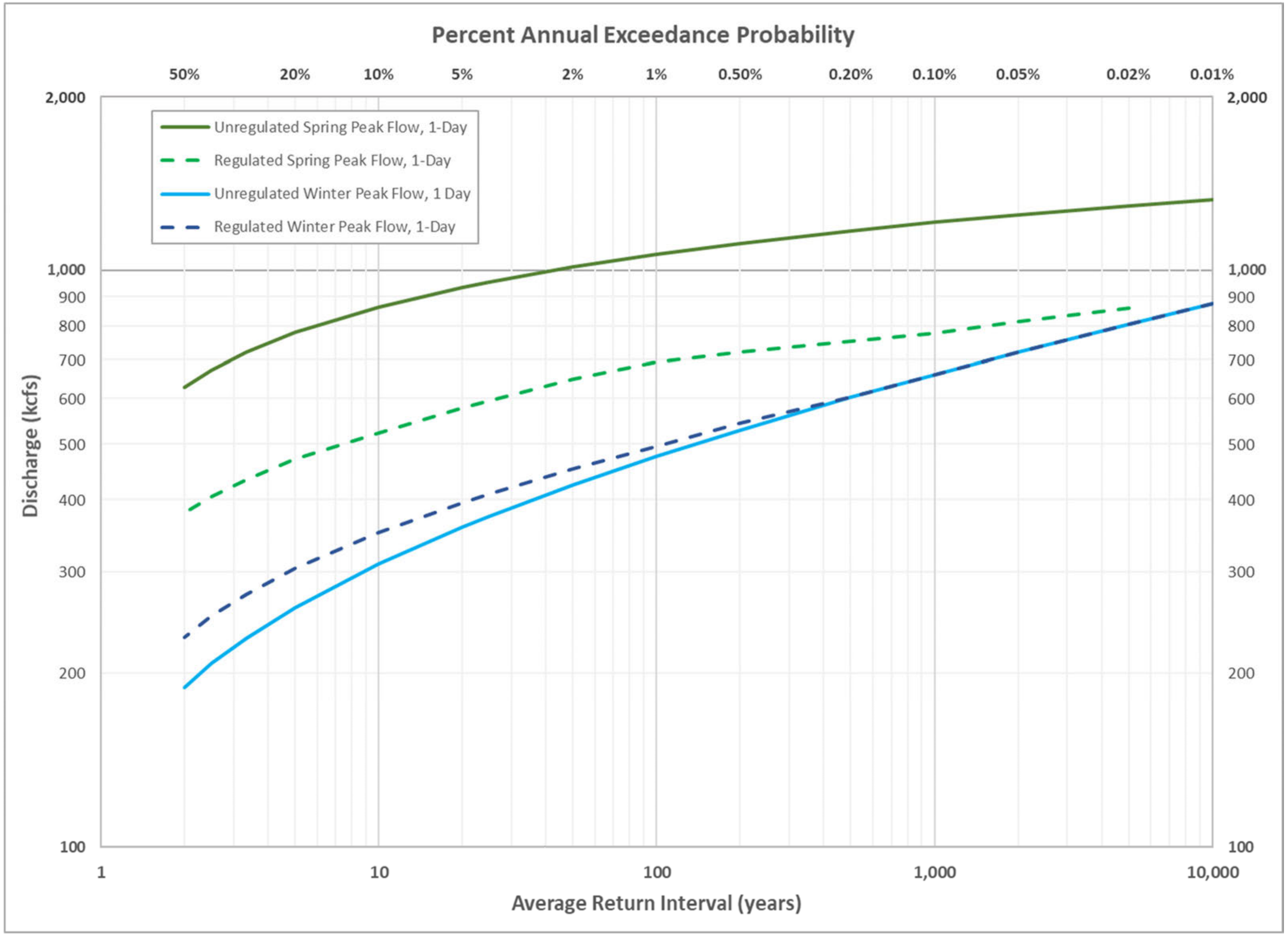
U.S. Army Corps of Engineers
Seattle District
Seattle, Washington

Plate 8-8

Grand Coulee
Summary Elevation Hydrographs

Notes
Data provided by USACE NWD from 2020 CRSO-EIS Study, Preferred Alternative, using 2010L modified streamflow (1928-2008).

September 2022



U.S. Army Corps of Engineers
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Seattle, Washington

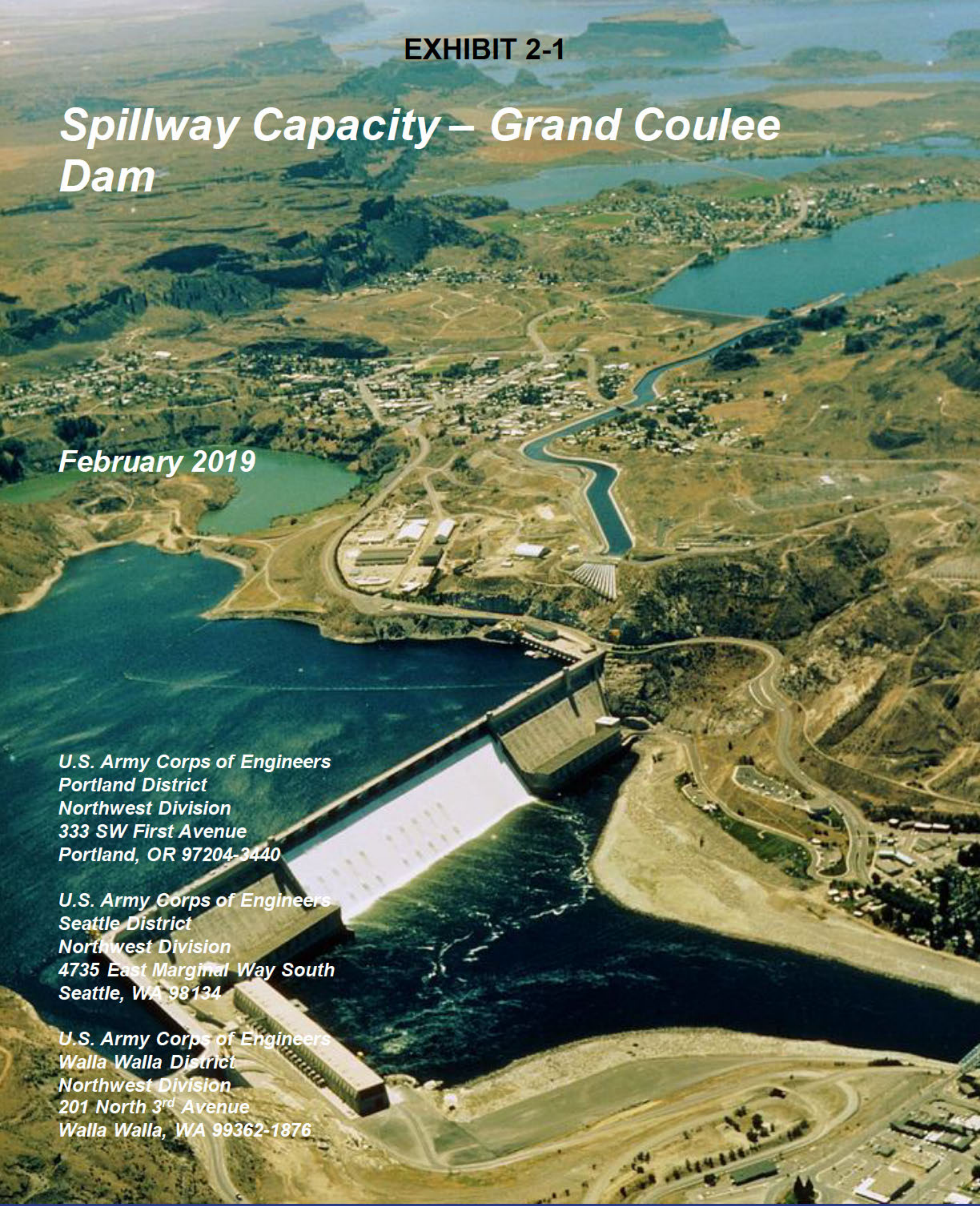
Plate 8-9
The Dalles
Unregulated and Regulated Flood
Flow Peak Frequency Curves

Notes
Data from Lower Columbia
Stage-Frequency Curve Study

September 2022

EXHIBIT 2-1

Spillway Capacity – Grand Coulee Dam



February 2019

U.S. Army Corps of Engineers
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Table of Contents

Figures

Tables

Project Overview and Spillway Orientation

Grand Coulee Dam and Franklin D. Roosevelt Lake is owned by the federal government, operated and maintained by the U.S. Bureau of Reclamation. The project has a drainage area of approximately 74,100 sq. miles with a maximum head of 30' over the spillway crest (gates closed). The concrete parabolic ogee spillway has a vertical upstream face and is controlled by 11 drum gates, each 135 feet wide that are separated by piers supporting a roadway across the dam. The drum gate is a type of gate that floats in a chamber and is buoyed into position by regulating the water level in that chamber.

Grand Coulee Dam, which provides 9.5 million sq. ft. of storage and has a generating capacity of 6,809 MW, is located on the Columbia River (RM 596.6) in northeastern Washington and is the largest part of the Columbia Basin Project. A photo of the dam is shown in Figure 1. The Columbia River makes a 90 degree sharp right bend before approaching the concrete gravity structure. It is estimated that the approach velocity is in the range of 4 ft/second to 6 ft/second.

The project provides flood control protection, power generation, recreation, water quality, and fish & wildlife benefits. The dam is a straight concrete-gravity structure with a maximum structural height of 550 feet with and a maximum spillway design capacity of 1,000,000 cfs. Pertinent data about the dam is provided in Table 1.

Figure 1: Reservoir Aerial Photograph

Table 1: Pertinent Data

Project Information Data Sheet		
Project name	Grand Coulee Dam	
Owner/Operator	U.S. Bureau of Reclamation	
District/Region	Pacific Northwest Region	
Major region	Columbia River	
Data entry datum	NGVD29	
Datum adjustment	Convert to NAVD88, by adding	3.93
Spillway classification	Ogee spillway	
Spillway function	Service spillway	
Control structure	Gated spillway	
Spillway crest profile	Concrete Ogee, Vertical US Face	

Rating Curve Data

There are 4 reports containing information for the spillway design and drum gate discharges for Grand Coulee Dam: (1) The 1935 Hydraulic Model Experiments for Design of Grand Coulee Dam, (2) the 1942 Hydraulic Laboratory Report No. 103 for Spillway and Outlets, (3) the 1953 Proceedings from the American Society of Civil Engineers Vol. 79 Rating Curves for Flow Over Drum Gates, and (4) USBR final published discharge rating curves with one foot gate opening increments for Grand Coulee Dam.

1935 Hydraulic Model Experiments for Grand Coulee Dam

The 1935 Hydraulic Model Experiments for Design of Grand Coulee Dam was used to aid in the final design of the spillway and outlets. The original design had 28' by 125' drum gates. The study was used to determine a crest shape which would coincide as nearly as possible to the natural trajectory of a freely falling jet. The study determined that the original curvature of the crest was too sudden near the downstream edge of the drum gate. To eliminate this pressure region, the radius of the large curve was lengthened, the axis of the crest moved upstream, and a parabolic curve introduced to connect the 66.25' curve to the 0.8 downstream slope of the spillway. Figure 2 displays the initial and final spillway crest shape design. Though this study was used to determine the crest shape, no discharge ratings were published as a part of this study.

Figure 2: Original and Final Design of Spillway Crest – 1935 Hydraulic Model Experiments

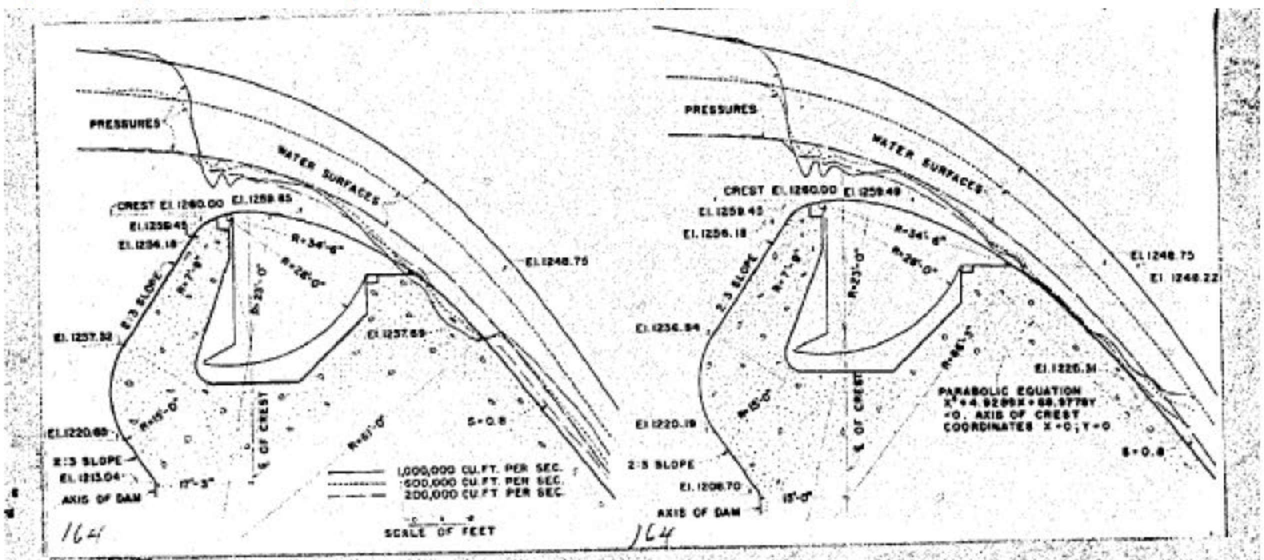


FIGURE 4 - ORIGINAL AND FINAL DESIGN OF SPILLWAY CREST

1942 Hydraulic Laboratory Report No. 103 for Spillways and Outlets

The 1942 Hydraulic Laboratory Report No. 103 for Spillways and Outlets was used to aid in the design of the outlet works for Grand Coulee Dam. The drum gate sizes had been modified and finalized as 11 gates of 28' by 135'. This study verified the design capacity of 1,000,000 cfs at a maximum water surface of 1290' (30' above spillway crest). This study was mainly used for the outlet works and spillway bucket design and had no other ratings for the spillway/drum gates.

Figure 3: Spillway Section for Grand Coulee Dam – 1942 Hydraulic Laboratory Report.

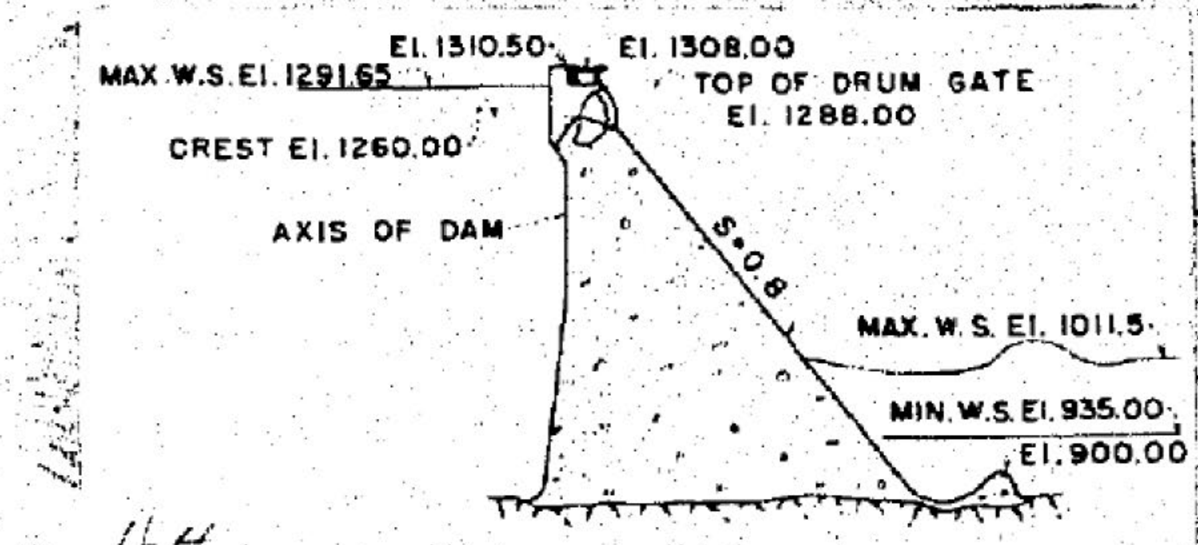


FIGURE 1 - SECTION THROUGH SPILLWAY SHOWING POSITION OF BUCKET

1953 Proceedings from the American Society of Civil Engineers Vol. 79 Rating Curves for Flow over Drum Gates

The 1953 Proceedings from the American Society of Civil Engineers Vol. 79 Rating Curves for Flow Over Drum Gates provided the method for developing rating curves for Grand Coulee and used Grand Coulee Dam as a basis for the study. The data for this study were obtained from hydraulic models of various sizes and scale. For Grand Coulee, a 1:30 scale physical model study was used with a maximum head on crest of 31.65'. This study produced drum gate coefficients for Grand Coulee Dam for various gate openings at various pool elevations and can be seen in Figure 4. Drum gates are unique, in that they go from an ogee crest weir when closed to a sharp crested weir when opened. These coefficients determined from the study were used for the development/validation of the Grand Coulee Spillway Rating Curve.

Figure 4: Drum Gate Coefficients for Grand Coulee Dam – 1953 Proceedings of the ASCE Vol. 79

TABLE 2.—DRUM GATE COEFFICIENTS[a]

Grand Coulee Dam (Washington)		Bhakra Dam (India)		Shasta Dam (California)		Hamilton Dam (Texas)	
Reservoir elevation, in feet	Coefficient, C_q	Reservoir elevation, in feet	Coefficient, C_q	Reservoir elevation, in feet	Coefficient, C_q	Total head on gate, in feet	Coefficient, C_q
GATE ELEVATION[b] 1260.0		GATE ELEVATION[b] 1552.0		GATE ELEVATION[b] 1037.0		GATE ELEVATION[b] 992.0	
1295	3.920	1580	3.680	1075	3.805	35	3.710
1290	3.842	1575	3.645	1070	3.835	30	3.645
1285	3.745	1570	3.550	1065	3.700	25	3.580
1280	3.635	1565	3.420	1060	3.675	20	3.500
1275	3.510	1560	3.275	1055	3.575	15	3.400
1270	3.352	1555	3.120	1050	3.465	10	3.290
1265	3.220			1045	3.335	5	3.160
GATE ELEVATION 1263.51		GATE ELEVATION 1557.0		GATE ELEVATION 1039.0		GATE ELEVATION 995.52	
1295	3.530	1580	3.430	1075	3.637	30	3.400
1290	3.442	1575	3.380	1070	3.565	25	3.310
1285	3.360	1570	3.295	1065	3.490	20	3.223
1280	3.280	1565	3.170	1060	3.417	15	3.150
1275	3.220	1560	3.040	1055	3.340	10	3.085
1270	3.182			1050	3.250	5	3.040
GATE ELEVATION 1267.02		GATE ELEVATION 1562.0		GATE ELEVATION 1041.0		GATE ELEVATION 999.0	
1295	3.530	1580	3.550	1075	3.530	25	3.450
1290	3.457	1576	3.355	1070	3.494	20	3.390
1285	3.380	1572	3.290	1065	3.432	15	3.300
1280	3.300	1568	3.345	1060	3.365	10	3.195
1275	3.213	1564	3.465	1055	3.200	5	3.080
1270	3.120						
GATE ELEVATION 1270.48		GATE ELEVATION 1567.0		GATE ELEVATION 1045.0		GATE ELEVATION 1006.0	
1295	3.600	1580	3.665	1075	3.637	18	3.640
1290	3.530	1577	3.650	1070	3.565	15	3.635
1285	3.462	1573	3.600	1065	3.490	12	3.605
1280	3.410	1570	3.535	1060	3.415	9	3.560
1275	3.375			1055	3.330	6	3.505
				1050	3.220		
GATE ELEVATION 1274.01		GATE ELEVATION 1572.0		GATE ELEVATION 1050.0		GATE ELEVATION 1013.0	
1300	3.725	1580	3.780	1075	3.717	12	3.718
1295	3.695	1579	3.755	1070	3.670	10	3.690
1290	3.662	1578	3.690	1065	3.615	8	3.645
1285	3.630	1577	3.500	1060	3.560	6	3.595
1280	3.600	1576	3.150	1055	3.495	4	3.530
GATE ELEVATION 1277.50				GATE ELEVATION 1055.0		GATE ELEVATION 1020.0	
1295	3.750			1075	3.854	6	3.630
1290	3.738			1070	3.827	5	3.610
1285	3.740			1065	3.800	4	3.540
1280	3.765			1060	3.780	3.5	3.400
				1055	3.763		
GATE ELEVATION 1281.02				GATE ELEVATION 1060.0			
1295	3.730			1075	3.645		
1292	3.708			1072	3.683		
1288	3.705			1069	3.740		
1283	3.725			1066	3.815		
				1063	3.920		
GATE ELEVATION 1284.50				GATE ELEVATION 1065.0			
1300	3.840			1076	3.810		
1296	3.830			1074	3.865		
1292	3.875			1072	3.910		
1288	3.950			1070	3.950		
GATE ELEVATION 1288.0							
1296	3.750						
1294	3.720						
1292	3.670						
1290	3.580						

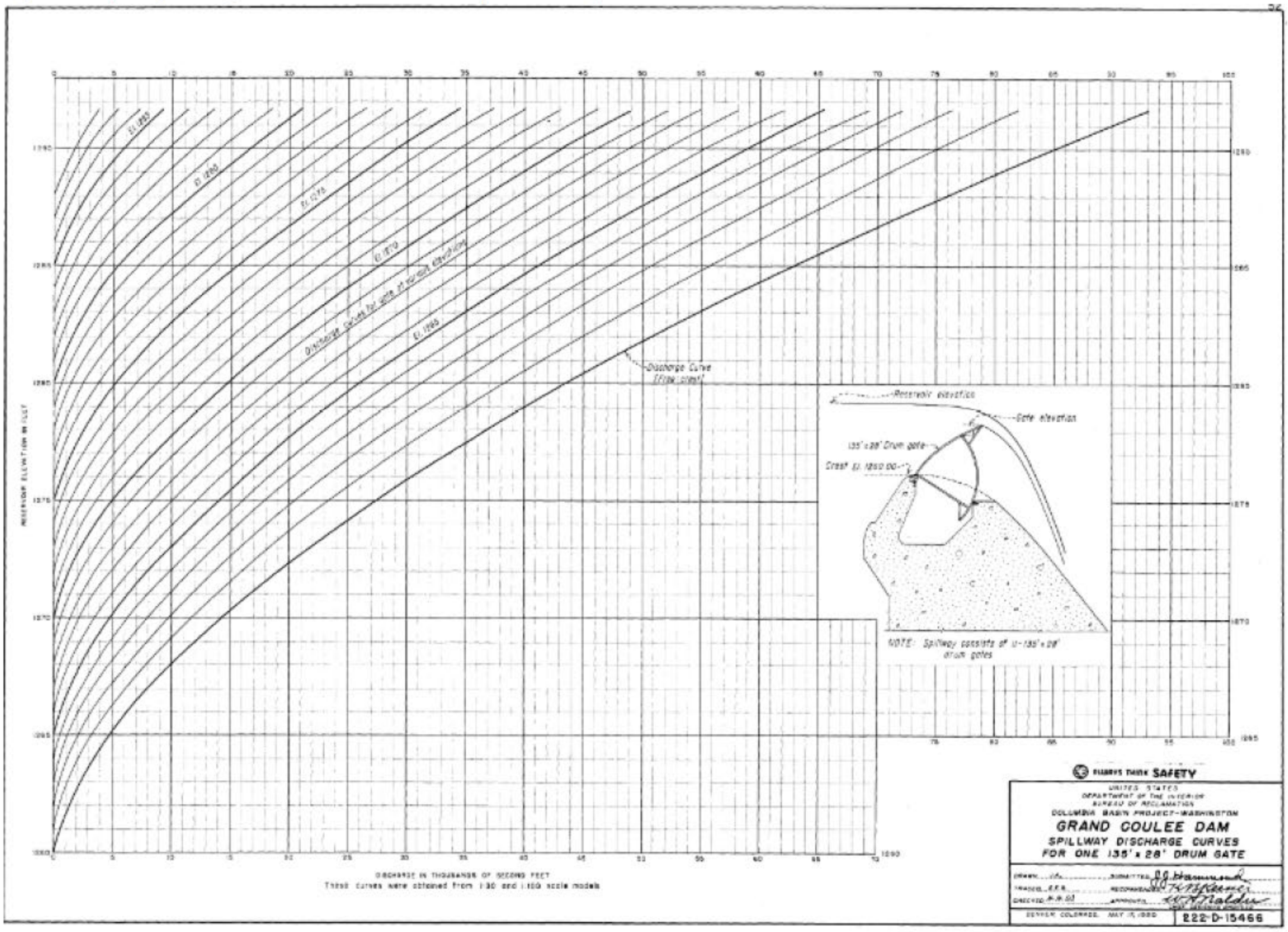
[a] Coordinates of curves prepared by plotting original data. [b] Gate down.

Current Spillway Ratings

The USBR has a published rating curve for Grand Coulee Dam with nominal gate openings. The ratings shown are stated to convey discharges for 1 28' by 135' drum gate.

The notes shown on the plate state that the rating curves are based on hydraulic model studies (1:30 and 1:100 scale models). The spillway crest elevation is labeled on the plate as 1260.0 MSL. The rating curves are displayed up to the maximum design pool of 1291.65 MSL.

Figure 5: Spillway Ratings for Grand Coulee Dam (USBR,1950)



Basis for Design Rating

Neither the published discharge rating curve nor the physical model studies have information with regard to the origin of the partial opening discharge ratings other than a figure depicting the curves. The notes shown on the plate state that the rating curves are based on hydraulic model studies (1:30 and 1:100 scale models). The rating curve is for 1 drum gate 28' by 135'. The published design spillway capacity for Grand Coulee Dam (all 11 drum gates) is 1,000,000 cfs at a maximum water surface of 1290' (30' above spillway crest).

The 1953 Proceedings from the American Society of Civil Engineers Vol. 79 Rating Curves for Flow Over Drum Gates provides the method for calculating discharge ratings for drum gates, and provides the discharge coefficients for Grand Coulee Dam for various gate openings at various pool elevations. The document states these coefficients were used with the standard weir equation to develop the ratings.

Spillway & Gate Geometry

Grand Coulee reservoir's as-built contract plans were supplied by the USBR and used to determine the relevant data associated with the drum gates, spillway crest profile, and spillway bridge obstruction. The elevation section drawing of the Grand Coulee spillway is shown in Figure 6. The shape of the spillway is defined with the equation in Figure 7.

Figure 6: As-built drawing of spillway and spillway bridge, elevation (NGVD) view

[redacted]

Figure 7: Parabolic equation for spillway shape at Grand Coulee Dam

Parabolic equation

$$x^2 + 4.9299x + 88.9778y = 0$$

Crest Discharge Coefficients

Discharge coefficients for various gate elevations with various pool elevations were provided from the 1953 Proceedings from the American Society of Civil Engineers Vol. 79 Rating Curves for Flow Over Drum Gates. These values are shown in Figure 4. Figure 8 displays the coefficients of discharge (Co) with respect to ratios of the design head (Ho). For a design head (Ho) of 40ft, the design coefficient of discharge (Co) is 3.84. Figure 9 displays the weir discharge equation used for the rating. Discharge coefficients for drum gates are unique, in that they transition from an ogee crest weir when closed to a sharp crested weir when opened

Figure 8: Spillway crest discharge coefficients, 1953 Proceedings of the ASCE Vol. 79

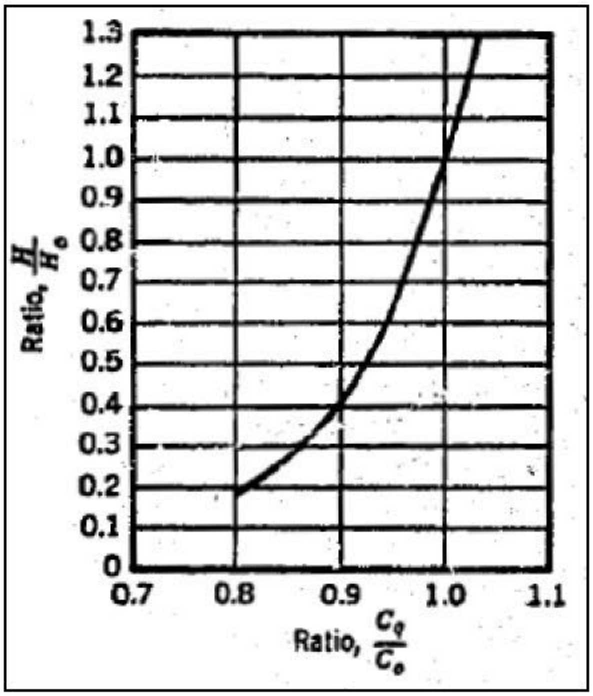


Figure 9: Equation for weir discharge

$$Q = CLH^{3/2}$$

in which Q = discharge in cfs

C = coefficient of discharge

L = length of spillway crest in feet

H = total head in feet on spillway crest (including velocity head of approach)

Pier and Abutment Classifications

The Grand Coulee piers have a maximum width of 15 feet and an elliptical shape as shown in Figure 10. No information on pier coefficients could be found in the as-builts or design reports. Based on the dimensions, the pier most closely matches a Type 3 pier from the HDC charts. The Grand Coulee abutments are best categorized as adjacent concrete defined by the same profile as the pier nose.

Figure 10: As-built Pier plan view (top),

[redacted]

2020 Spillway Rating Curve Study

Spillway Rating Curve Estimate

The spillway rating curves were computed using the Radial Gate Calculator Tool Version 001.xlsm spreadsheet. The tool utilizes industry standard computational methods and best available data e.g. abutment contraction, pier contraction, free flow discharge, orifice coefficients, and physical model study data when available. The project spillway satisfies all requirement for limitations and use. The spreadsheet had to be modified for the use of drum gates as described below.

The rating estimates do not incorporate overtopping discharges and are calculated on the basis of total spillway capacity, i.e. all gate bays. Since the Grand Coulee Dam has drum gates, all flows are actually free flow (until elevations get impacted by the spillway bridge). As the drum gate rises, it essentially raises the crest of the spillway. In an attempt to determine the best estimate for spillway rating, multiple sources of data were considered and compared for appropriateness and confidence. All coefficients were considered for validity and tested for sensitivity using the spreadsheet tool.

A summary of the geometry of Grand Coulee spillway and drum gates are shown in Table 2.

Table 2: Geometry data for Grand Coulee Dam

Top of dam	1315.01	elevation, feet-NAVD 88
Top of active storage pool	1291.93	elevation, feet-NAVD 88
Spillway crest elevation	1263.93	elevation, feet-NAVD 88
Maximum design pool, Hmax	1293.93	elevation, feet-NAVD 88
Verified Design head	40.00	feet
Spillway gate classification	Drum Gates	text
Number of gates	11	number/count
Gate width	135	feet
Maximum Gate Opening	28.0	nominal opening, feet
Pier Classification	Type 3	text
Number of Piers	10	number/count
Pier width	15	feet
Net spillway length	1485	feet

The ratings for the drum gates at Grand Coulee were estimated using the standard computation equations presented in EM-1110-2-1603 (USACE, 1992)) and in Figure 11. The methods for calculating the pier contraction and abutment coefficients used the Type 3 pier coefficients also from EM-1110-2-1603. The final rating can be found in Appendix A.

Figure 11: Discharge equations from EM-1110-2-1603

$$Q = CL_eH_e^{1.5}$$

where

Q = rate of discharge, cubic feet per second (ft^3/sec)
C = coefficient of discharge
L_e = effective length of the crest, feet
H_e = total specific energy above the crest, feet

$$L_e = L - 2(nK_p + K_a)H_e$$

where

L = net length of crest
n = number of piers
K_p = pier contraction coefficient
K_a = abutment contraction coefficient

The coefficient of dischage was developed from the list of discharge coeffecients for varios gate openings with various pool elevations from the 1953 Proceedings from the American Society of Civil Engineers Vol. 79 Rating Curves for Flow Over Drum Gates for Grand Coulee Dam. These values are presented in Figure 4. Bilinear interpolation was used to develop discharge coefficients for 1 foot increments of gate openings for each 1 foot of head based on pool elevation based on the coefficients from the ASCE report. These values were then used for the flow rating equation shown in Figure 11. The final spillway rating can be found in Appendix A.

Spillway Rating Curve Validation

The published USBR spillway rating curve for Grand Coulee Dam was used for baseline comparison. Validation metrics were based on comparing the computed estimate using the spreadsheet tool and the currently published USBR ratings. The validation results were based on an average difference for various pool elevations with various gate opening elevations. For the drum gates closed (Elevation 1260' NGVD29), the average difference was -0.11%. The average difference for raised drum gate conditions is -1.33%.

Table 4: Summary of validation using published USBR rating curve for 1 drum gate at Grand Coulee Dam

Drum Gate Crest Elevation (NGVD 29)	Study Estimate % Average Difference
1260.00	-0.11%
1265.00	-2.10%
1270.00	-1.86%
1275.00	-0.78%
1280.00	-1.82%
1285.00	-0.09%

[1] Drum gate in fully closed position

*Footnote * - Discharge coefficients based on 1953 ASCE publication*

*Footnote ** - Average differences were computed based on all average pool elevations*

*Footnote *** - Negative % differences resulted in a lower computed discharge than published*

Limitations and Uncertainties

There is high confidence in the flow curve due to the small differences compared to the USBR published curve. It is highly likely that the published USBR spillway rating curves are based on the equation shown in Figure 11 due to the fact that the computed rating curves matched so well to the published curves.

There is one uncertainty as far as the design head for the project. No available reports documented what the design head for the Grand Coulee spillway crest. The plan sheet indicates a max head is 30' (max WSEL of 1290 NGVD29 which is 30' above the spillway crest with gates close, while some reports indicate a max head of 31.65' (and this is also verified with the published rating curve going up to elevation 1291.65' NGVD29).

The design head verification in the spreadsheet was used to determine the design head for the spillway shape. Based on the equation found in Figure 7 for the shape of the spillway crest, the design head verification tool determined a design head of 40' when compared to a design head of 30' (Figure 12). If the design head could be verified through original design documents that would be beneficial. Further validation of the design head was used with the spillway crest discharge coefficient from the 1953 ASCE document. From this report, the design head developed from the verification in the spreadsheet was used to determine the spillway crest coefficients for the drum gate closed with various pool elevations and it match closely using a design head of 40' when compared to a design head of 30' (Figure 13).

Figure 12: Design head verification

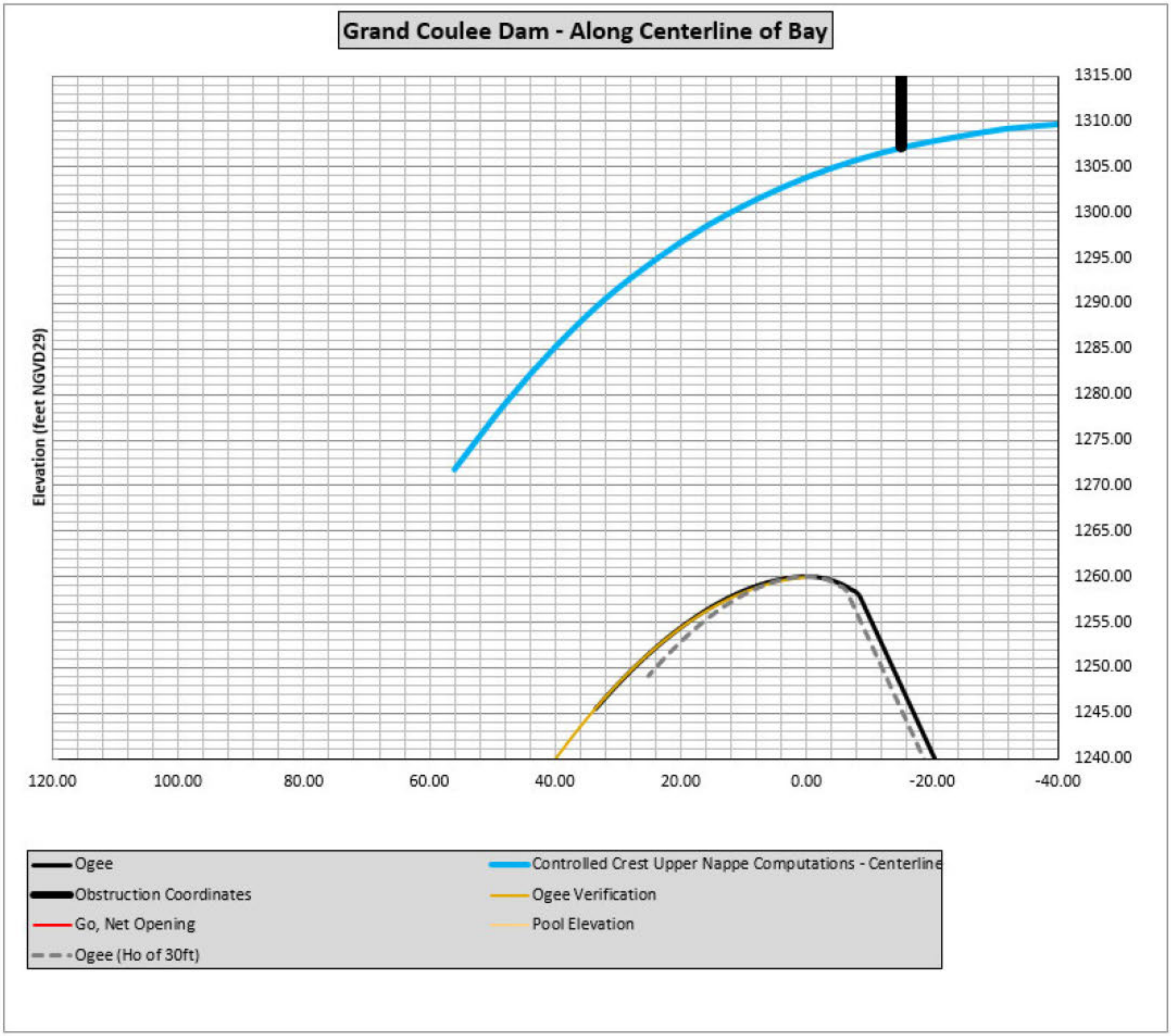
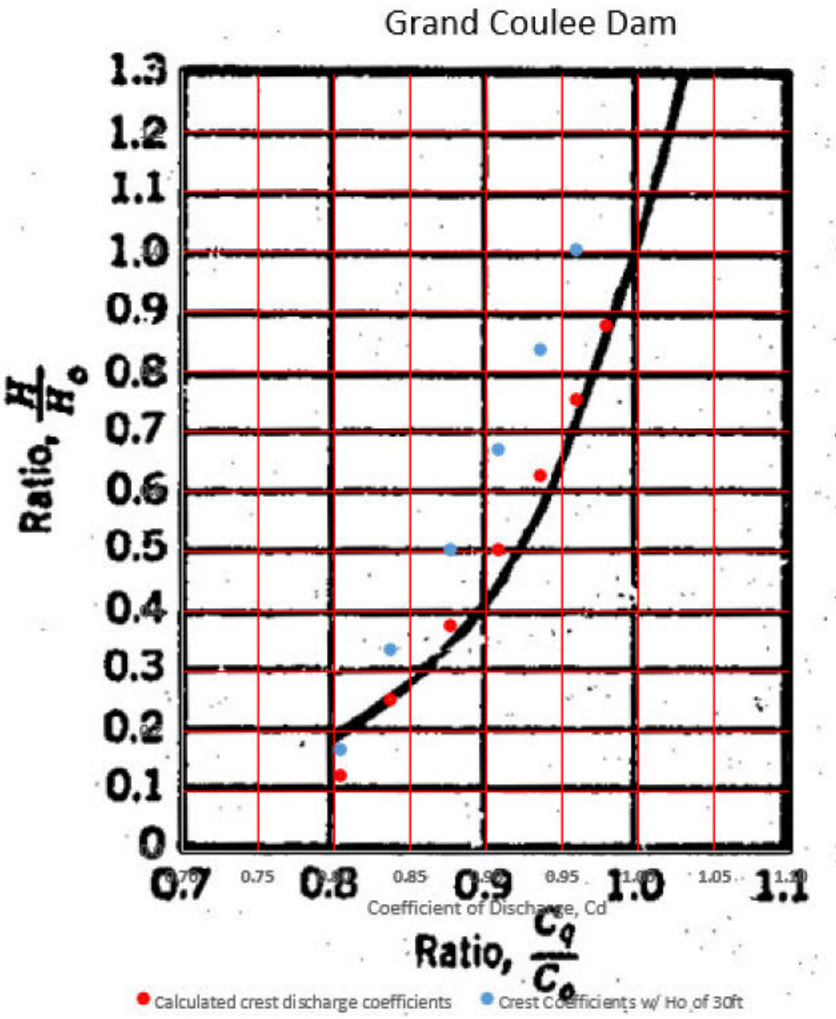


Figure 13: Spillway crest discharge coefficients comparison using design verification head



Spillway Rating Curve Extrapolation

Extrapolating Free Flow Ratings Up to Spillway Bridge

Since this dam has drum gates, the spillway flow is free flow up to the spillway bridge (1307.25' NGVD). The published Cd coefficients were linearly extrapolated for pool elevations above the max pool elevation of 1288' NGVD29.

Spillway Bridge Orifice Controls

There are no orifice flow conditions that were determined based on the original design since the dam has drum gates. There is a spillway bridge that has an arch frame supporting it (Figure 14) above the spillway crest. This further complicates when orifice flow occurs. While conditions will certainly be turbulent for when water contacts the arch frame, the elevation where the rating curve converts to orifice flow was determined to be where the bottom of the lower arch beam meets the spillway bridge deck, elevation 1307.25' NGVD29.

Since no orifice flow conditions were modeled for Grand Coulee Dam in the provided documents, there are no estimates for orifice flow coefficients. Guidance from EM-1110-2-1603 was used for determining the orifice flow coefficient to be used in the orifice flow equation. Based on the angle of the spillway crest to the location of the bottom of the spillway deck (1307.25' NGVD29), a discharge coefficient of 0.68 was determined from plate 6-1 of EM-1110-2-1603. Due to the high uncertainty in the orifice discharge coefficient, a range orifice coefficients from 0.65 to 0.73 were considered. It should be noted, orifice flows were only computed for the gate closed curve (spillway crest of 1260' NGVD29) as guidance will dictate that the drum gates be closed during such high pools. All other rating curves are using free flow eq uations for all elevations.

Figure 14: Spillway Bridge Geometry (NGVD)

[redacted]

Limitations and Uncertainties

The biggest uncertainty in the ratings are for the stages above 1290' NGVD29. This is where the spillway bridge frame starts to interact with the discharges. While an elevation of 1307.25' NGVD29 was selected for the start of orifice flow, this could in fact be at a lower elevation. This assumes that the flow is free flow over the spillway crest below this obstruction. Also, the orifice flow coefficients of discharge are unknown. A value of 0.68 was selected for the best estimate, but a range of values from 0.65 to 0.73 were considered to attempt to capture the uncertainty.

Another source of uncertainty is the design head for the spillway crest. None of the available documents provide information about the design head used for the design of the spillway crest. While there are design pools, this does not necessarily equate to design head. The design head verification tool in the spreadsheet was used to determine the design head of 40'. If the design head could be verified through original design documents that would be beneficial for the ratings.

References

Bradley, Josepth N. (February 1953). Rating Curves for Flow Over Drum Gates. *Proceedings American Society of Civil Engineers*, Volume 79.

USACE, Department of the Army, Headquarters. (1992, August 31). Hydraulic Design of Spillways: Engineering and Design Manual. *EM 1110-2-1603*

USBR, Department of the Interior (1935). Hydraulic Model Experiments for Deisign of Grand Coulee Dam. Denver, CO.

USBR, Department of the Interior (1942). Spillway and Outlets for Grand Coulee Dam. *Hydraulic Laboratory Report No. 103.* Denver, CO

USBR, Department of the Interior (1939). Columbia Basin Project - Grand Coulee Dam Design Drawings. Denver, CO.

USBR, Department of the Interior (Revised February 2019). Grand Coulee Dam Statistics and Facts. Denver, CO.

USBR, Department of the Interior (May 1950). Grand Coulee Dam Spillway Discharge Curves Denver, CO

Appendix A: 2020 Spillway Rating Curve Data

Spillway Rating Curve Table, All Gate Bays

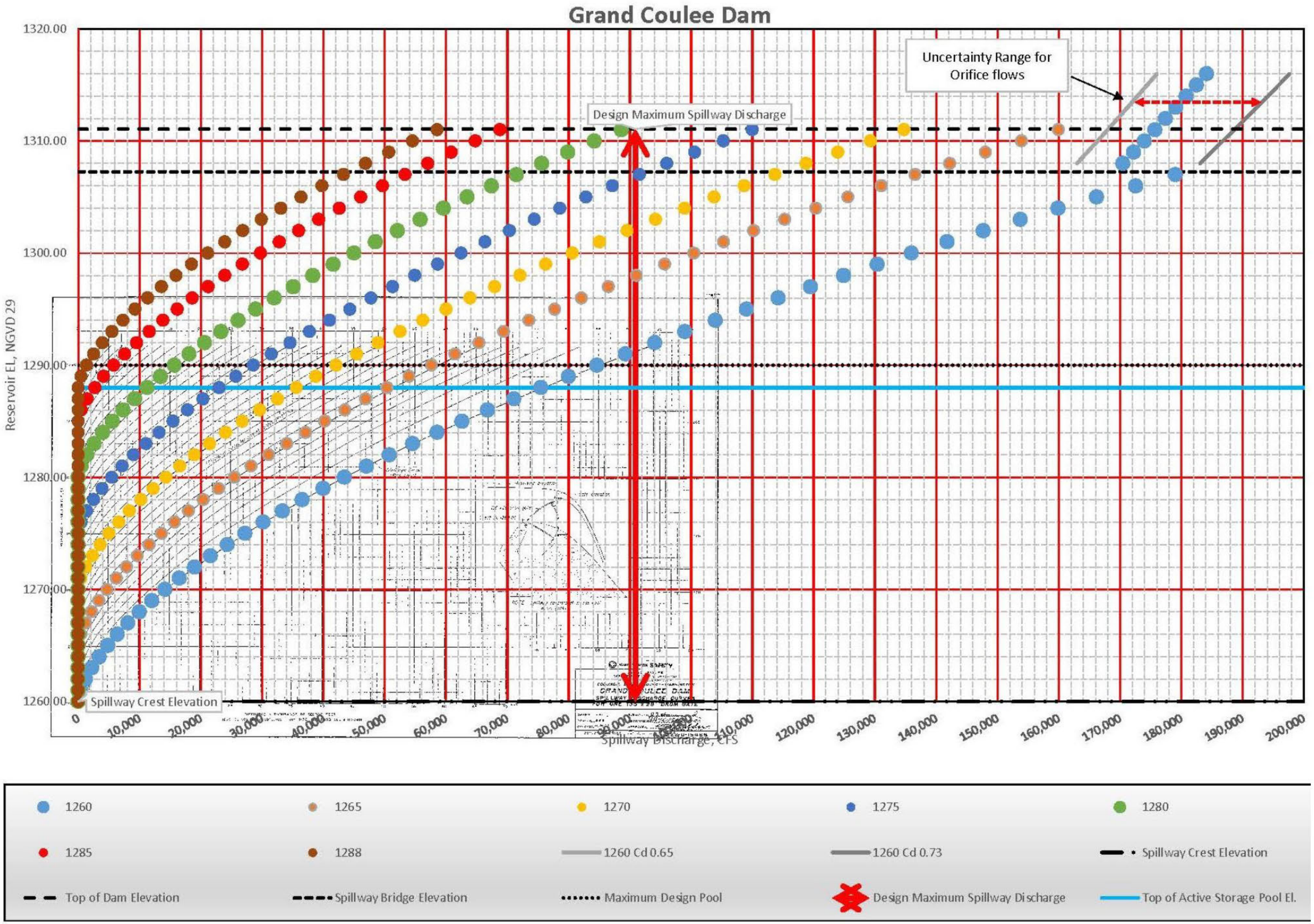
Table 5: Best Estimate Spillway Rating Curve Table for All Gate Bays

Grand Coulee Dam

Pool Elevation (NGVD 29)	Drum Gate Crest (NGVD 29)																												
feet	1260	1261	1262	1263	1264	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280	1281	1282	1283	1284	1285	1286	1287	1288
1260.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1261.0	4620	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1262.0	13150	4650	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1263.0	24330	13220	4660	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1264.0	37730	24410	13240	4660	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1265.0	53110	37790	24410	13210	4640	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1266.0	70320	53100	37710	24320	13130	4610	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1267.0	89260	70190	52910	37520	24170	13060	4580	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1268.0	109850	88940	69820	52540	37270	24050	13010	4570	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1269.0	132050	109290	88340	69230	52180	37130	23990	12990	4700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1270.0	155820	131170	108370	87440	68730	52040	37070	23970	13330	4810	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1271.0	181400	154720	129960	107120	86790	68610	52010	37080	24570	13640	4920	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1272.0	208570	179760	152970	128190	106260	86730	68630	52070	37960	25120	13930	5010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1273.0	237320	206280	177380	150590	127090	106290	86840	68790	53250	38770	25620	14190	5110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1274.0	267630	234260	203150	174260	149210	127250	106530	87120	70260	54320	39500	26090	14460	5200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1275.0	299510	263690	230260	199180	172580	149550	127660	106980	88890	71600	55280	40200	26570	14720	5290	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1276.0	332320	294260	258670	225510	197370	173240	150190	128270	109000	90460	72780	56240	40940	27050	14970	5390	0	0	0	0	0	0	0	0	0	0	0	0	0
1277.0	366570	326180	288370	253070	223390	198220	174060	150980	130570	110830	91870	74000	57260	41670	27520	15240	5480	0	0	0	0	0	0	0	0	0	0	0	0
1278.0	402240	359470	319350	281850	250620	224450	199250	175060	153530	132620	112450	93360	75340	58270	42390	27980	15470	5560	0	0	0	0	0	0	0	0	0	0	0
1279.0	439360	394090	351600	311810	279040	251930	225720	200470	177830	155800	134440	114220	95040	76660	59280	43050	28380	15680	5580	0	0	0	0	0	0	0	0	0	0
1280.0	477860	430060	385090	342960	308620	280620	253470	227210	203460	180290	157790	136480	116250	96700	77980	60150	43650	28740	15750	5560	0	0	0	0	0	0	0	0	0
1281.0	517370	467190	419970	375600	339680	310660	282470	255140	230360	206160	182580	160240	138980	118300	98340	79060	60930	44160	28850	15690	5540	0	0	0	0	0	0	0	0
1282.0	558240	505650	456080	409470	371930	341920	312700	284320	258540	233300	208660	185320	163100	141370	120270	99620	80010	61590	44310	28750	15630	5520	0	0	0	0	0	0	0
1283.0	600470	545410	493440	444510	405390	374370	344150	314740	287960	261700	236010	211700	188550	165840	143660	121720	100730	80820	61780	44160	28660	15580	5650	0	0	0	0	0	0
1284.0	644030	586470	532060	480750	439980	408030	376810	346390	318600	291320	264610	239340	215310	191650	168470	145280	122970	101660	81030	61580	44020	28570	15940	5770	0	0	0	0	0
1285.0	688980	628810	571910	518180	475760	442840	410670	379240	350450	322150	294420	268220	243320	218760	194610	170210	146640	124010	101900	80780	61390	43890	29180	16250	5880	0	0	0	0
1286.0	734810	672160	612840	556790	512740	478830	445650	413240	383540	354340	325660	298540	272720	247210	222080	196540	171790	147910	124380	101660	80570	61220	44780	29730	16530	5790	0	0	0
1287.0	781890	716790	655020	596580	550880	515990	481820	448390	417840	387730	358130	330080	303350	276910	250810	224150	198250	173180	148300	124060	101370	80320	62390	45570	30210	16310	5550	0	0
1288.0	830300	762640	698430	637560	590170	554310	519150	484720	453290	422320	391790	362840	335190	307820	280780	253010	225990	199760	173580	147890	123680	101040	81770	63420	46250	29840	15720	5370	0
1289.0	880040	809770	743030	679740	630640	593770	557640	522220	489920	458060	426670	396780	368230	339920	311930	283090	254950	227590	200170	173130	147520	123390	102820	83060	64310	45780	28900	15280	5240
1290.0	931100	858190	788870	723070	672290	634420	597280	560880	527720	494980	462690	431920	402420	373190	344260	314330	285100	256620	228010	199680	172720	147180	125370	104290	84110	63750	44540	28230	14990
1291.0	982420	907330	835740	767700	715250	676310	638050	600550	566600	533050	499920	468240	437830	407630	377750	346810	316550	287000	257200	227560	199260	172340	149320	126990	105460	83510	62320	43730	27850
1292.0	1034950	957580	883830	813540	759410	719330	680000	641370	606620	572270	538330	505740	474340	443220	412370	380420	349130	318550	287590	256670	227060	198790	174590	151030	128230	104880	82030	61500	43360
1293.0	1088690	1009040	933030	860600	804770	763530	723060	683350	647800	612630	577890	544390	512010	479890	448100	415140	382840	351230	319220	287180	256390	226900	201460	176660	152580	127850	103400	81080	60940
1294.0	1143520	1061700	983440	908770	851330	808920	767280	726430	690140	654160	618590	584180	550790	517680	484880	450960	417640	385020	351970	318870	286980	256310	229610	203560	178230	152220	126380	102480	80570
1295.0	1199500	1115450	1035030	958140	898990	855490	812670	770660	733580	696860	660470	625100	590680	556550	522750	487810	453530	419880	385840	351730	318770	286990	259000	231680	205090	177860	150720	125370	101860
1296.0	1256580	1170360	1087720	1008690	947840	903150	859240	816040	778170	740660	703510	667170	631630	596430	561580	525680	490400	455800	420790	385720	351750	318910	289590	260960	233100	204720	176450	149810	124860
1297.0	1314680	1226340	1141560	1060320	997860	951970	906870	862570	823920	785620	747670	710380	673690	637360	601440	564560	528310	492710	456810	420810	385890	352030	321680	291980	263010	233470	203920	175920	149500
1298.0	1373920	1283370	1196480	1113110	1048950	1001940	955640	910150	870830	831730	792980	754690	716850	679360	642300	604460	567230	530660	493830	457010	421150	386340	354950	324210	294160	263500	232770	203500	175720
1299.0	1434140	1341520	1252430	1166980	1101180	1052980	1005550	958850	918780	879010	839460	800130	761060	722430	684200	645350	607150	569590	531880	494230	457550	421810	389400	357610	326500	294800	262960	232510	203460
1300.0	1495710	1400660	1309520	1221880	1154490	1105130	1056500	1008680	967870	927330	887100	846710	806370	766490	727120	687250	648040	609510	570940	532510	494990	458430	424980	392170	360010	327300	294470	262910	232680
1301.0	1559480	1461140	1367590	1277910	1208820	1158330	1108540	1059520	1018080	976790	935800	894440	852770	811610	770980	730150	689920	650370	610970	571820	533540	496130	461700	427840	394650	360990	327240	294690	263350
1302.0	1624570	1523800	1427000	1334930	1264270	1212530	1161620	1111440	1069300	1027380	985630	943200	900260	857760	815850	773980	732780	692210	651970	612150	573140	534960	499490	464640	430400	395840	361260	327790	295460
1303.0	1690900	1587770	1488570	1393280	1320690	1267840	1215680	1164370	1121610	1078980	1036590	993060	948730	904970	861710	818790	776560	735010	693950	653470	613790	574880	538380	502480	467240	431820	396510	362200	328950
1304.0	1758710	1652990	1551440	1453780	1378440	1324100	1270820	1218260	1174920	1131670	1088560	1044030	998260	953090	908570	864580	821290	778700	736890	695800	655460	615880	578340	541400	505110	468920	432940	397900	363810
1305.0	1827880	1719680	1615550	1515570	1438300	1381650	1326880	1273200	1229200	1185370	1141630	1095990	1048830	1002230	956290	911340	866970	823340	780730	739130	698170	657930	619350	581370	544040	507060	470570	434860	400040
1306.0	1898080	1787720	1681140	1578600	1499450	1441310	1384230	1329050	1284530	1240030	1195700	1149010	1100350	1052350	1004970	958940	913610	868890	825520	783400	741930	701060	661390	622370	583990	546300	509320	473090	437590
1307.0	1969300	1856810	1748080	1643100	1561830	1502230	1443650	1386160	1340770	1295750	1250740	1203020	1152860	1103360	1054590	1007480	961070	915380	871240	828640	786650	745270	704490	664370	624940	586570	549230	512510	476480
1308.0	1875040	1928130	1817040	1709690	1626180	1564670	1504470	1445330	1398150	1352210	1306670	1257750	1206070	1155040	1104730	1056580	1009050	962250	917450	874380	831870	789950	748100	706870	666340	627360	589740	552660	516160
1309.0	1894470	1999220	1886270	1776810	1691570	1628420	1566470	1505860	1457850	1410130	1363680	1313750	1260410	1207900	1156090	1106870	1058340	1010450	964940	921590	878640	836220	793230	750930	709280	669670	631870	594510	557610
1310.0	1913700	2071430	1956270	1844950	1757990	1693510	1629920	1567560	1518780	1470220	1421980	1370600	1315730	1261550	1208260	1158020	1108410	1059530	1013330	969660	926430	883550	839380	795930	753210	713010	675100	637550	600350
1311.0	1932750	2144520	2027400	1913880	1825430	1759600	1694670	1630670	1580880	1531560	1482470	1428720	1371840	1316120	1261170	1209940	1159310	1109350	1062600	1018660	975090	931940	886570	841940	798060	757390	719450	681770	644380
1312.0	1951600	2218580	2099420	1983950	1893650	1826680	1760410	1695070	1644400	1594060	1544190	1488990	1429140	1371430	1314940	1262580	1210960	1159970	1112610	1068570	1024740	981250	934780	888940	843890	802720	764920	727200	689670
1313.0	1970280	2293660	2172410	2054920	1963000	1894520	1827100	1760420	1709210	1657980	1607090	1550460	1488540	1427860	1369370	1316050	1263300	1211330	1163440	1119280	1075340	1031570	983880	936950	890690	849050	811420	773830	736260
1314.0	1988780	2369740	2246440	2126870	2033240	1963460	1894530	1826710	1774970	1723190	1671410	1613080	1549080	1486320	1424870	1370150	1316440	1263340	1215010	1170840	1126770	1082890	1033960	985810	938440	896370	859020	821600	784140
1315.0	2007110	2447030	2321470	2199860	2104450	2033260	1963030	1893690	1841660	1789350	1737020	1677080	1610690	1545850	1482320	1425300	1370190	1316120	1267240	1223180	1179100	1135080	1085010	1035610	987030	944700	907710	870550	833250

	Free Flow Rating
	Spillway rating potentially impacted by orifice condition other than partial gate opening such as spillway bridge girder or other obstruction
	Discharge ratings do not include overtopping discharges, however these highlighted cells are above the top of dam
*Note 1	Discharge ratings are provided for the various pool elevations vs. the various drum gate crest elevations
*Note 2	Discharge ratings are based on one spillway bay
*Note 3	NOTES: Spillway rating curved compared for the computed estimate and the published spillway rating curve for 1 bay at Grand Coulee Dam. Due to this dam having drum gates, the spillway flow is free flow up to the spillway bridge (1307.25' NGVD). The published Cd coefficients were linearly extrapolated for the elevations of pool above the max pool of 1288' NGVD29. There are no orifice flow conditions that were determined based on the original design which means there are no estimates for orifice flow coefficients. A discharge coefficient of 0.68 was determined from plate 6-1 of EM-1110-2-1603. Due to there being a lack of confidence in the discharge coefficient for orifice flow, a range of flows were developed for a range of orifice coefficients of 0.65 to 0.73. Also, orifice flows were only computed for the gate closed curve (spillway crest of 1260' NGVD29) as guidance will dictate that the drum gates be closed during such high pools. All other rating curves are using free flow equations for all elevations.

Figure 15: Spillway Rating Curve Chart for One Gate Bay



Appendix B: District Quality Control

District Quality Control (DQC) – 100% REVIEW – Grand Coulee Dam Spillway Capacity

Reviewer: Chris Bahner (WEST Consultants, Inc.)

Review date: May 20, 2020

Documents submitted for review:

1. Pertinent Data worksheet within GrandCoulee_radialGateCalculator_Version001.xlsm
2. GrandCoulee_radialGateCalculator_Version001.xlsm - spreadsheet
3. Report titled "Spillway Capacity – Grand Coulee Dam.docx"

Supplemental data attachments:

1. Contract drawings for Grand Coulee Dam, GrandCoulee_as-builts.pdf
2. Spillway Rating Curve for Grand Coulee Dam, GrandCoulee_PulblishedSpillwayRatingCurve.pdf
3. ASCE Rating Curves for Flow Over Drum Gates, HYD-284_DrumGateRatingCurves.pdf

Steps for completing review:

Complete pertinent data sheet, using checkboxes found within Pertinent_Data worksheet.	May 20, 2020
Verify the correct discharge coefficients are being used for the corresponding crest category for the spillway gates on the Geometry Calculator Worksheet.	May 20, 2020
Verify that the geometry schematic reflects the gate radius, trunnion coordinates, and gate seat location that been entered.	May 20, 2020
Check to ensure that the hydraulic design head has been verified and the controlling orifice pool elevation has been computed on the HDH Verification and Nappe El worksheet.	May 20, 2020
Verify that the controlling orifice pool infomation has been entered correctly in the Rating Calculator Dashboard worksheet.	May 20, 2020
Verify that the appropriate selections have been made for the spillway, if user defined data was used then verify the input data on the Rating Calculator Dashboard worksheet.	May 20, 2020
Check the rating curve data entered on WCM Rating (Single Bay), and WCM Rating (All Bays).	May 20, 2020
Check to ensure that the validation comparisons are estimated appropriately within Validation Evaluation worksheet as well as documented in report appropriately.	May 20, 2020
If any modifications to the input data have changed based on supplemental data, then verify that the equations/data entered match the supplementary documentation.	May 20, 2020
Verify that the report reflects the rating curves estimates from spreadsheet calculator. Also verify that the recommended coefficients have been documented correctly.	May 20, 2020

Table 6: Completed Pertinent Data Checklist for Project Name

Project Information Data Sheet			Data Source	Checked?
Project name	Grand Coulee Dam		CRB_Ratings Scope_23Oct2019.docx	☑
Owner/Operator	U.S. Bureau of Reclamation		CRB_Ratings Scope_23Oct2019.docx	☑
District/Region	Pacific Northwest Region		CRB_Ratings Scope_23Oct2019.docx	☑
Major region	Columbia River		CRB_Ratings Scope_23Oct2019.docx	☑
Data entry datum	NGVD29			☑
Datum adjustment	Convert to NAVD88, by adding	3.93	Corpscon Version 6.0.1, using Lat,Long	☑
Spillway classification	Ogee spillway		As-Builts	☑
Spillway function	Service spillway		As-Builts	☑
Control structure	Gated spillway		As-Builts	☑
Spillway crest profile	Concrete Ogee, Vertical US Face		As-Builts	☑

Free Uncontrolled Discharge Parameters			Data Source	Checked?
Datum Adjustment	3.93	feet	Corpscon Version 6.0.1, using Lat,Long	☑
Top of dam	1311.08	elevation, feet-29	As-Builts (Sheet 1 of 15)	☑
Top of active storage pool	1288.00	elevation, feet-29	Area-Capacity	☑
Spillway crest elevation	1260.00	elevation, feet-29	As-Builts (Sheet 2 of 15)	☑
Upstream Channel Invert	910.00	elevation, feet-29	*Estimated from FactSheet	☑
Approach Depth	360	feet	USACE Drum Gate Ratings	☑
Maximum design pool, H_{max}	1290.00	elevation, feet-29	Area-Capacity	☑
Approach Velocity (Approximate)	6	feet/second	Calculated	☑
Maximum Total Energy, H_e	1290.56	elevation, feet-29	Calculated	☑
Design maximum spillway discharge	1,000,000	cfs	HYD-103	☑
Design head	40	feet	See note below	☑
Design head from HDC Sheet	40.0	feet	Calculated	☑
Upstream spillway slope	0.67	V:H	As-Builts (Sheet 1 of 15)	☑
Downstream spillway slope	0.8	V:H	As-Builts (Sheet 1 of 15)	☑
Abutment Radius	12.5	feet	As-Builts (Sheet 4 of 15)	☑
Ogee crest coefficient, A	1	unitless	Calculated	☑
Ogee crest coefficient, B	1.85	unitless	Calculated	☑
Ogee crest coefficient, C	40	unitless	Calculated	☑
Ogee crest coefficient, A/C	0.025	unitless	Calculated	☑
Spillway gate classification	Drum Gates	text	As-Builts (Sheet 8 of 15)	☑
Number of gates	11	#	As-Builts (Sheet 10 of 15)	☑
Gate width	135	feet	As-Builts (Sheet 8 of 15)	☑
Maximum Gate Opening	28	feet	As-Builts (Sheet 6 of 15)	☑
Pier type	Type 3/3A	text	As-Builts (Sheet 4 of 15)	☑
Number of Piers	10	#	As-Builts (Sheet 10 of 15)	☑
Pier width	15	feet	As-Builts (Sheet 5 of 15)	☑
Abutment Classification	Adjacent Concrete Abutment	text	As-Builts	☑
Net spillway length	1485.0	feet	Calculated from As-Builts	☑
Gate seat X coordinate	29.2	feet	Not applicatble - Prrovided info based ons-Builts (Sheet 1	☑ 15)
Gate seat Y coordinate	1248.807	elevation, feet-29	Not applicatble - Prrovided info based ons-Builts (Sheet 6	☑ 15)
Trunnion X coordinate	-3.50	feet	Not applicatble - Prrovided info based ons-Builts (Sheet 6	☑ 15)
Trunnion Y coordinate	1259.02	elevation, feet-29	Not applicatble - Prrovided info based ons-Builts (Sheet 6	☑ 15)
Trunnion Radius	34.3	feet	Not applicatble - Prrovided info based ons-Builts (Sheet 6	☑ 15)
Top gate lip, closed position	1290	elevation, feet-29	As-Builts (Sheet 8 of 15)	☑
Gate lip, open position	1248.22	elevation, feet-29	Not applicatble - Prrovided info based ons-Builts (Sheet 6	☑ 15)
Spillway Obstruction Y coordinate	1307.25	elevation, feet	As-Builts (Sheet 7 of 15)	☑
Spillway Obstruction X coordinate	-15.0098	feet	As-Builts (Sheet 7 of 15)	☑

Completed By:	Checked By:	Date:
Ryan Clark	Chris Bahner (WEST)	5/20/2020

Special Notes of Design Consideration:
None of the provided documents had an actual design head that was used for the design of the spillway. While there are design pools, this does not necessarily equate to design head. The design head verification tool in the spreadsheet was used to determine the design head used of 40'

DQC Review was completed on 20 May 2020.

Expired certificate X Ryan Clark Ryan Clark USACE, DSMMCX Signed by: CLARK.RYAN.L.1380367811	Recoverable Signature X Chris Bahner Chris Bahner WEST Consultants, Inc. Signed by: Chris Bahner

EXHIBIT 3-1

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Our copy

United States Department of the Interior

TAKE PRIDE IN AMERICA

BUREAU OF RECLAMATION
PACIFIC NORTHWEST REGION
FEDERAL BUILDING & U.S. COURTHOUSE
BOX 043-550 WEST FORT STREET
BOISE, IDAHO 83724-0043

IN REPLY REFER TO:

PN-230

JAN 15 1993

Memorandum

To: Project Manager, Grand Coulee WA

From: Assistant Regional Director, Boise ID

Subject: Guideline Considerations for Daily Drawdown Limits, FDR Lake, Grand Coulee Project Office, WA (Water Storage)

Bonneville Power Administration (BPA) is requesting flexibility of operations at Grand Coulee Dam to handle an unforeseen Arctic cold spell which may be of seven day's duration, per discussions with you and members of your staff. In order to consider this request, the standard drawdown criteria for Lake Franklin D. Roosevelt of 1.5 feet/24 hours would be exceeded. This standard per day drawdown limit of the reservoir water surface is chiefly to control rim stability and has proven long-term to be a good technical criteria Reclamation-wide. Some flexibility is possible as long as concurrent detailed shoreline inspections are accomplished, weather conditions are monitored, and no rigid schedules are mandated.

The higher the lake elevation is at the time the increased drawdown rate is requested, the more flexibility we have. Historically, the most severe landslide activity has occurred when lake elevations are below elevation 1230 feet. Increasing the drawdown rate will require higher levels of monitoring than are currently in place. We would be comfortable with the following criteria:

> <u>Elevations 1290 to 1260 feet</u>: Landslide risk at these elevations is minimal. Drawdown rates of up to two feet per day would have minimal impacts on the overall stability of the shoreline. Aerial inspection of the shoreline should be conducted prior to and after each seven days of operations at the increased drawdown rate and at lake elevation 1260 feet. The aerial inspection should include video and still photographic documentation.
>
> With the Lake elevation at 1260 feet, the results of the aerial inspection should be reviewed to determine the severity of the impact, if any, of accelerated drawdown on shoreline stability. Should the decision at that time be that an increased drawdown rate be continued, key areas along the shoreline should be targeted for more intense monitoring.

Elevations 1260 to 1240 feet: Shoreline stability at these intermediate lake levels is marginal at the current 1.5 feet/day drawdown limits.

Some slide activity has historically occurred at these lake elevations. That an increased drawdown rate at these lake elevations will have a negative impact on the stability of the shoreline is not questioned. Whether or not this decrease in stability poses an unacceptable risk is not clear.

Increased monitoring would be required to evaluate the impacts of the accelerated drawdown. Aerial inspection of the shoreline, the only feasible method, after each two days of operation at the accelerated drawdown rate would be required. Aerial photographic documentation, including video coverage, should be an included part of the aerial inspection.

Below elevation 1240 feet: At lake levels below elevation 1240 feet, an accelerated drawdown rate should not be considered. Historically, significant slide activity has occurred with increased severity as the lake level drops below elevation 1240 feet even at the current drawdown rate.

There are several areas along the shoreline where housing and/or roads could be endangered by slide activity, most notably on the San Poil River Arm, Seven Bays, along much of the Spokane River Arm, and along the Matney-Welty Bay area north of Kettle Falls.

These Guidelines are for the purpose of protecting the stability of FDR shoreline, yet providing flexibility for power operations. Timely geotechnical monitoring of the reservoir rim is the key to a successful implementation of accelerated drawdown cycles.

These guidelines are to be used only when emergency conditions threaten the stability of the hydro power system. They should be implemented only after a clear demonstration by BPA that they have taken all other reasonable and prudent actions to meet the emergency. The current 1 1/2 feet per day non power requirement will not be changed in the Pacific Northwest Coordination Agreement date submittals.

It should be remembered that the implementation of drawdown rates greater than 1 1/2 feet per day are to be used only on a case-by-case basis. Prior approval of each incident is necessary, either from the Project Manager or the Regional Director.

Kenneth R. Pedde

cc: Assistant Commissioner - Engineering and Research
  Attention: D-3610 (Fraser), D-3620 (Young)
Project Manager, Grand Coulee WA
  Attention: GCP-250 (Hansen)
PN-470

EXHIBIT 7-1

Procedure For Determining Grand Coulee Flood Risk Management Draft Requirements

1. Unadjusted Grand Coulee April 30 FRM Draft Requirement.

Determine the Grand Coulee April 30 Unadjusted Draft Requirement from Chart 1 using The Dalles April – August forecast as the independent (x-axis) variable. Use linear interpolation to obtain values between points.

2. Adjustment To Grand Coulee April 30 FRM Draft Requirement.

Use Chart 2 to compute the adjustment to the Grand Coulee April 30 Unadjusted Draft Requirement to offset under draft at upstream System reservoirs. If there is under draft at a reservoir, multiply the project specific weighting factor to find the reservoir's adjustment, and sum up all adjustments to find total adjustment. There is no adjustment to offset overdraft at a project.

Under draft is the volume of water projected to be in a reservoir's storage space on April 30 in excess of the required April 30 FRM draft, or base draft. April 30th FRM required drafts are determined in-season using seasonal water supply forecasts and drafts applicable for flood operations planning (usually contained in a storage reservation diagram in individual project water control manuals). For projects that refill using a flood control refill curve (FCRC): if a project begins refill prior to April 30th due to FCRC, then the April 30th FRM draft requirement for that project in Chart 2 would be 0. Project specific weighting factors are developed from an analysis of unregulated project inflows and unregulated The Dalles flows. Weighting factors and FRM required drafts are periodically updated based on long-term hydrologic trends.

3. Final Grand Coulee April 30 FRM Draft Requirement.

The final Grand Coulee April 30 FRM Draft Requirement is the sum of the Grand Coulee April 30 Unadjusted Draft Requirement and the adjustment, if any, computed in Step 2.

4. End Of Month Grand Coulee FRM Draft Requirement.

Use the Grand Coulee SRD (Plate 7-1), with the final Grand Coulee April 30 FRM Draft Requirement from Step 3 as the Parameter to determine the end of month draft requirements for the drawdown period. Use linear interpolation to obtain values between points. If there is a shift in storage space from Dworshak or Brownlee to Grand Coulee, apply the shift to the end of month Grand Coulee FRM draft requirements for January through April 15. All projects are unshifted by April 30.

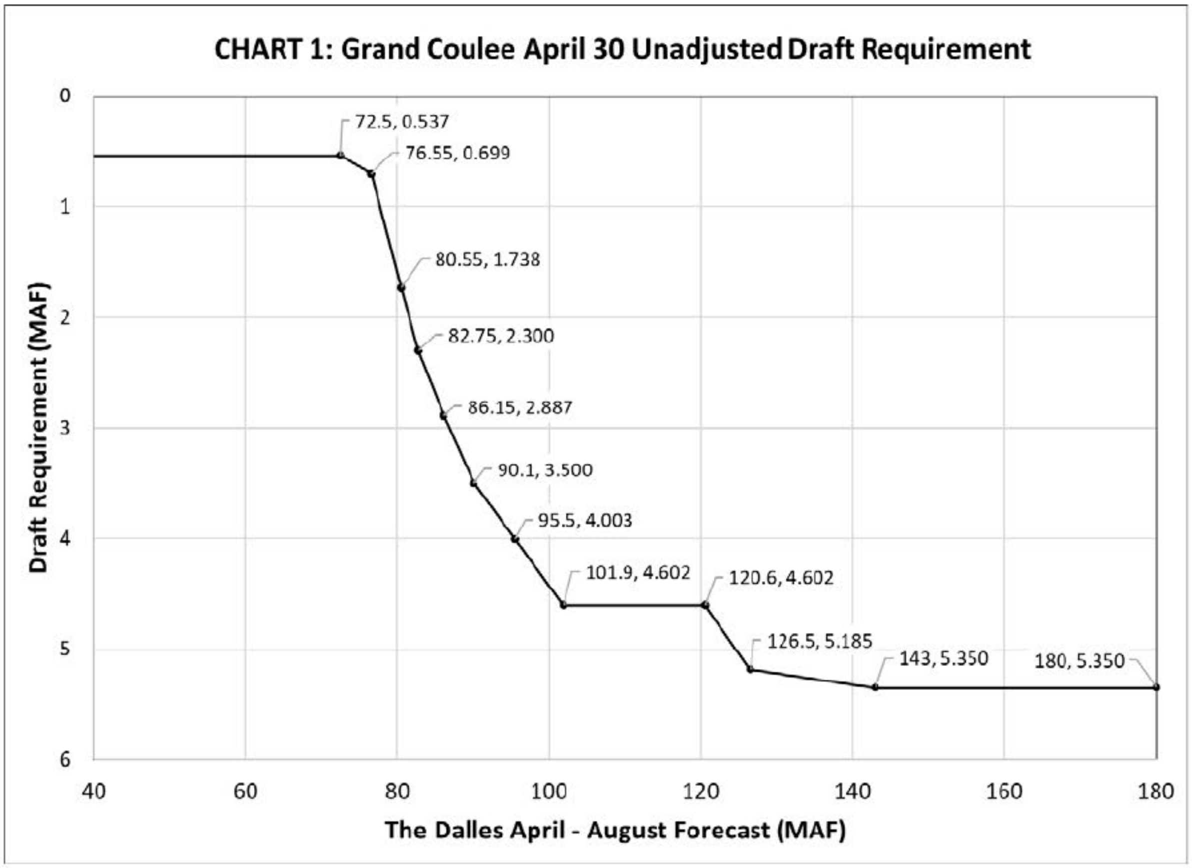

CHART 2: Computation of Grand Coulee FRM Requirement Adjustment For Upstream Project Under Draft

Project	April 30 FRM Req Draft (Maf) [Column 1]	Projected April 30 Draft (Maf) [Column 2]	Under Draft (Maf) [Column 3 = Max (0, Column 1 – 2)]	Weighting Factor [Column 4]	Adjustment (Maf) [Column 5 = Column 3 * 4]
Arrow Lakes					
Mica					
Duncan					
Libby					
Hungry Horse					
Dworshak					
Brownlee					
				Adjustment Total	
April 30 Unadjusted Draft Requirement (from Step 1)					
Final April 30 Draft Requirement (Sum of April 30 Unadjusted Draft Requirement and Adjustment Total)					