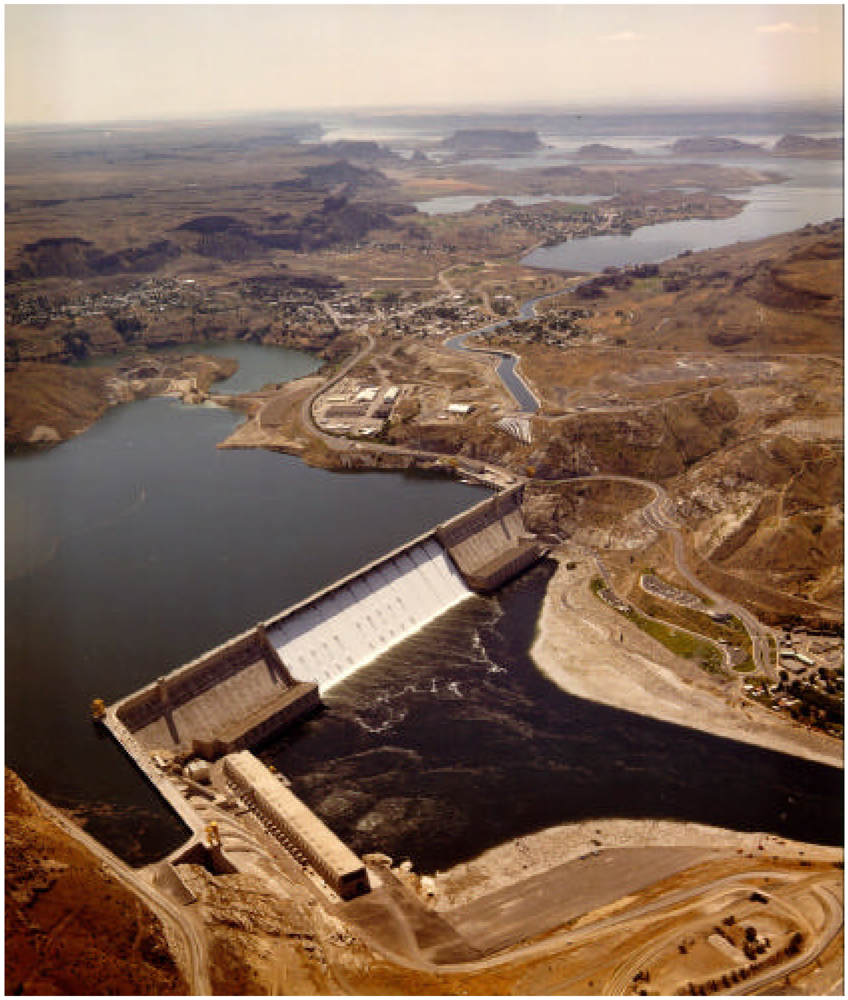
Review of Past Studies and Data Related to Temperature Management Options for the Columbia River below Grand Coulee Dam, Washington



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Scope of Work

The purpose of this study is to prepare a summary of data available for future studies related to temperature management at Grand Coulee Dam. The scope of work for this project is summarized as follows:

C Summarize work from Washington State University (Dr. Funk), who has conducted several limnological studies of Lake Roosevelt.

C Summarize EPA's development of temperature models of the Columbia River and Lake Roosevelt.

C Summarize the work done by McKenzie and Laenen to document the quality of temperature data at Canada/US boundary (CIBW) at Northport, WA; below Grand Coulee Dam (GCGW); and Grand Coulee Dam's forebay (FDRW).

C Document the Reclamation's Grand Coulee Dam Forebay temperature profiling site and data collection program.

C Provide a preliminary evaluation of selective withdrawal characteristics of Grand Coulee Dam.

Background

Project Purposes - The Columbia Basin Project is a multi-purpose development using part of the resources of the Columbia River in the central part of the State of Washington. The key structure, Grand Coulee Dam, is on the main stem of the Columbia River about 90 miles west of Spokane, Washington. An extensive irrigation project extends 125 miles southward on the Columbia Plateau to the vicinity of Pasco, Washington, which is located near the confluence of the Snake and Columbia Rivers. The irrigation facilities are designed to deliver a full water supply to 1,095,000 acres of land previously used only for dry farming or grazing. Of the 1,095,000 acres, approximately 550,000 are currently irrigated. Power production facilities at Grand Coulee Dam are the largest in North America.

The Dam and Powerplants - Grand Coulee Dam is the largest concrete structure ever built. The dam raises the water surface 350 feet above the old riverbed. The structure is 5,233 feet long, 550 feet high, and contains 11,975,500 cubic yards of concrete. In mid-1970s, Grand Coulee dam was modified with the addition of the Third Powerplant. A 1,170-foot-long, 201-foot-high forebay dam was built along the right abutment approximately parallel to the river and at an angle of 64 degrees to the axis of Grand Coulee Dam.

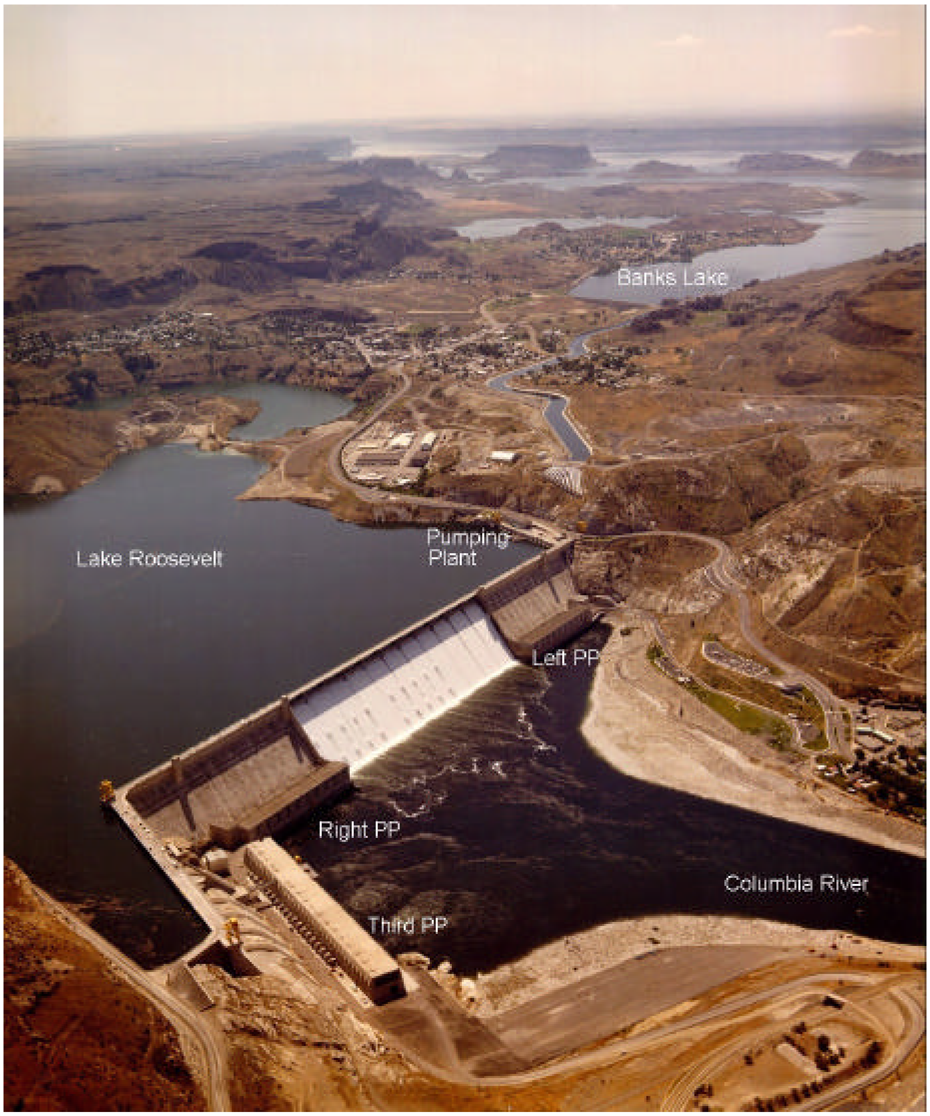

Figure 1. Aerial view of Grand Coulee Dam, forebay, afterbay, and Banks Lake.

The power facilities at Grand Coulee Dam consist of a powerplant on both the left and right sides of the spillway on the downstream face of the dam. The Third powerplant is located on the downstream face of the forebay dam, and the pump-generating plant is located on the left abutment of the dam (see figure 1). The release capacity for the Third powerplant's 6 units is 35,000 ft^3/sec per unit for a total of 210,000 ft^3/sec. The Left and Right powerplants consist of nine units each with a total capacity of 45,000 ft^3/sec for each plant. Grand Coulee Dam also features a pump-generating plant which can move water into and out of Banks Lake. Banks Lake is a 27-mile-long reservoir which stores irrigation water for the Columbia Basin Project. The active storage for Banks Lake is 715,000 acre-ft. The pump-generating plant has 6 pumps with a capacity of 1,600 ft^3/sec each. There are 6 pump-generators with a capacity of 1,700 ft^3/sec each. A typical pumping capacity is 21,300 ft^3/sec at a head of 280 ft, with all 12 pumps in service.

Summary of Grand Coulee Dam's Intake Configuration - In order to evaluate the potential for selective withdrawal operations at Grand Coulee Dam, it is necessary to know the number, size, and centerline elevations for the numerous intakes. The Left and Right powerplant intakes are 15 ft wide by about 30 ft high and are centered at elevation 1041 ft. The Third powerplant intakes are 29 ft wide by about 43.5 ft high and are centered at elevation 1130 ft. The Banks Lake pump-generator intakes dimensions were not available (the intake pipe is 14 ft in diameter) and the intake centerline is at elevation 1193.3 ft.

There are two levels of river outlets with the upper outlet intakes located at elevation 1136.7 ft and the lower outlet intakes located at 1036.7 ft. The forty river outlets are controlled by 8.5 ft ring seal gates. A third set of river outlets located at elevation 935.7 ft were removed from service when the Third powerplant was constructed. The outlet gates are designed to provide for a total maximum discharge of 265,000 ft^3/sec with all gates open and the reservoir water surface at elevation 1291.7 ft. Grand Coulee's service spillway releases are controlled using eleven 135-ft-long, 28-ft-high drum gates which can be set at variable elevations between 1260 and 1288 ft. The maximum spillway capacity is 1 million ft^3/sec. Intakes for the station service units are considered to be insignificant and were not researched for this study.

The Reservoir - The Franklin D. Roosevelt Reservoir (also known as Lake Roosevelt) is a 150-mile-long storage reservoir formed by the closure of Grand Coulee Dam in northern Washington State. The reservoir is fed by a 76,880-mi^2 watershed which encompasses parts of Washington, Idaho, Montana, and British Columbia, Canada. Lake Roosevelt inflows are dominated by two major tributaries, the Columbia and Spokane Rivers. The reservoir has a minimum and maximum pool elevations of 1208 and 1290 ft, respectively. Lake Roosevelt has an active capacity of 5.1 million acre-ft and a total capacity of 9.7 million acre-ft at maximum pool elevation.

Temperature Issues - The temperature standard on the Columbia River, as required by the Clean Water Act states that temperatures should not exceed 68 EF (20EC). Temperatures recorded by the U.S. Army Corps of Engineers, during the summer of 1998, indicate that there are areas on the Columbia River below Grand Coulee Dam which routinely exceed 74 EF. These high water temperatures can have significant impacts on fish and wildlife habitat in the Columbia River system. For this reason the EPA, along with other groups, is interested in ways of reducing the temperature in the Columbia River and its tributaries. As part of this effort, Reclamation evaluated the potential for using selective withdrawal techniques at Grand Coulee Dam to manage temperatures in the Columbia River. Grand Coulee is a natural candidate for selective withdrawal because Lake Roosevelt is the only mainstem reservoir with storage capacity. Reclamation has initiated a temperature monitoring program and has performed some preliminary selective withdrawal analyses to evaluate operational changes which may provide some temperature benefits.

Conclusions

A review of temperature studies and available data have resulted in the following conclusions concerning the potential for managing release temperatures at Grand Coulee Dam:

C There have been many studies of Lake Roosevelt's physical limnology and they have all reported that Lake Roosevelt is thermally stratified for the months of July through September. Limnological studies conducted before and after the construction of the Third powerplant have not identified any significant changes to the reservoir's thermal regime attributed to operation of the Third powerplant.

C There is a vast quantity of Columbia River temperature data from total dissolved gas monitoring stations upstream and downstream of Grand Coulee Dam. This data is useful in studying the long-term effects of dam operations on the temperatures in the Columbia River. However, without detailed powerplant and spillway operation records it is difficult to determine if release temperature fluctuations are caused by using the Left or Right powerplants instead of the Third powerplant, or if they are simply a result of reduced flow rates or other environmental factors. Other factors that need to be included in the operation records are the use of the Banks Lake pumping plant, spillway, and outlet works.

C In order to perform a selective withdrawal evaluation for Grand Coulee Dam, detailed hourly operational records of which facilities were used to release water into the Columbia River and Banks Lake are required. Without this information, only inferences of selective withdrawal capability can be made by examining existing Columbia River temperature and total discharge records.

C Temperature models being developed by the EPA can be a valuable resource in evaluating operational changes and their effects on Columbia River temperatures and the reservoir stratification. These models will have to be used to study a wide range of operational scenarios and their impacts on Lake Roosevelt and Columbia River temperatures.

C Results from a series of one-dimensional selective withdrawal model runs indicated that there is a potential for a 4EF reduction in release temperatures if the Left and/or Right powerplants are used instead of the Third powerplant. However, additional studies are necessary to determine the duration of these temperature reductions.

Temperature Data and Resources Available

A compilation of project contacts, Internet-available resources, and Reclamation's internal data are summarized as follows:

- The Spokane Tribes provided data at several profiling sites (Keith Underwood) which covers the years 1988 to 1998. This data was collected as part of the Lake Roosevelt Monitoring Program (LRMP). In the early years of this program the data are sparse, but the data is informational. This data set includes Hydrolab data from the many sites that are shown on figure 2 and described in Table 1. Figure 3 contains a plot of temperature profiles from 1996 through 1998 at site 9 which is the forebay of Grand Coulee Dam. This figure illustrates the relatively short period of time when Lake Roosevelt is thermally stratified and how much warmer the reservoir was in 1998 when compared to the previous two years. *Note:* that this data set only contains data in the top 100 ft of the reservoir which limits it usefulness for selective withdrawal studies.

Table 1. Lake Roosevelt Temperature Profile Data from Spokane Tribes Lake Roosevelt Monitoring Program (LRMP)

Location code	Location Name (See Figure 3)
ST- 0	Evan's Landing
ST- 1	Kettle Falls (Upstream of Colville R.)
ST- 2	Gifford
ST- 3	Hunters
ST- 4	Porcupine Bay (Spokane R.)
ST- 5	Little Falls Dam (Spokane R.)
Conf. (ST)	0.5 mi Above Spokane R. Confluence (Columbia Arm)
ST- 6	Seven Bays
Hawk Cr. (ST)	Hawk Creek
ST- 7	Keller Ferry
ST- 8	In Sanpoil River (0.5 mi above Conf w/Columbia R.)
ST- 8a	Columbia R. 0.5 mi Above Sanpoil Confluence
Sanpoil R.(ST)	Furthest downstream flowing portion of Sanpoil R.(varys w/lake level)
ST- 8b	Columbia R. at the mouth of Sanpoil R. (Prior to 1997)
ST- 9	Spring Canyon

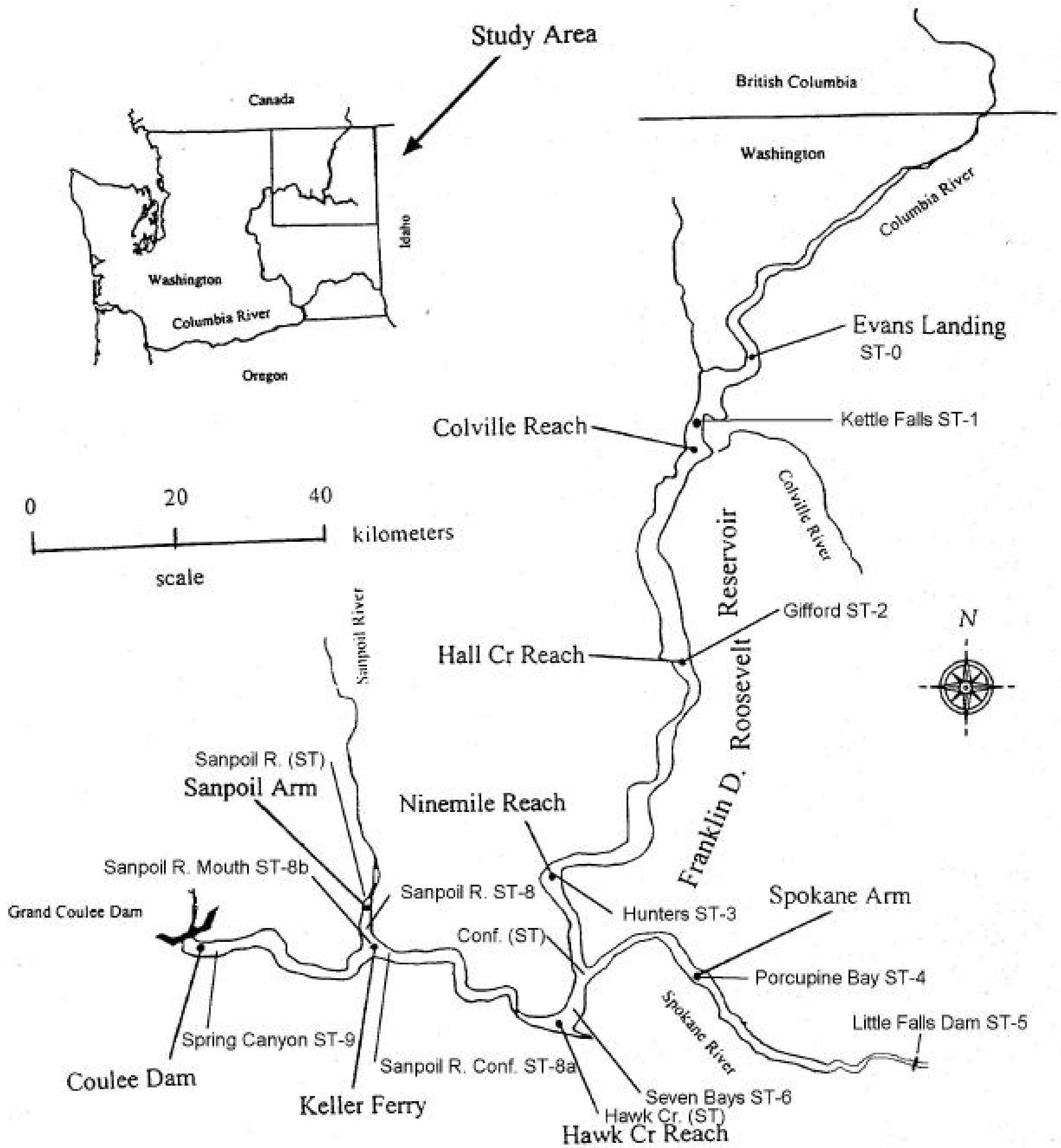

Figure 2. Temperature profiling sites for the Spokane Tribe's Lake Roosevelt Monitoring Program (LRMP) and Washington State Univ. limnological evaluation (Wilson 1996). LRMP sites are denoted using ST- #.

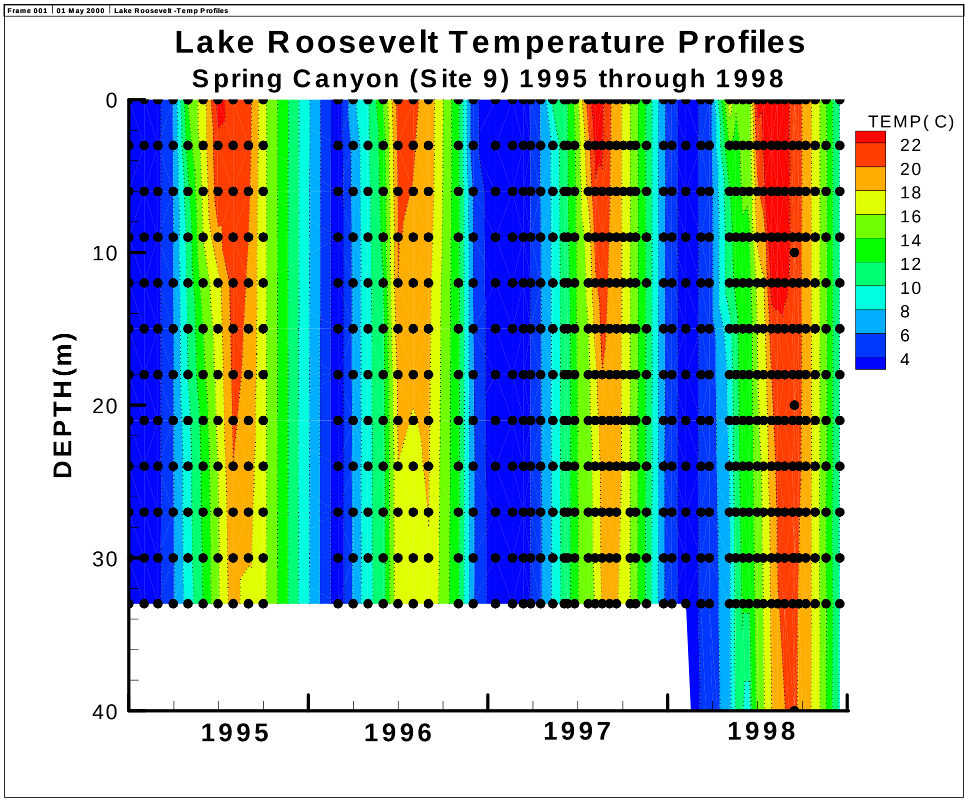

Figure 3. Sample of temperature profiles collected by Spokane Tribes in the forebay of Grand Coulee Dam. The black dots represent points where data were collected.

• Mr. Bob Matson (GCP-3640, 509-633-9204) is the contact for Grand Coulee Powerplant operations data. Mr. Matson said that it is a very rare situation when all Third powerplant units are idle and all the releases are through the Left and Right powerplants. Mr. Matson also verified that powerplant operations data which document which specific units are running are not currently being collected. Detailed operations data will be required to determine if operating the Left and Right powerplants only will significantly lower Grand Coulee release temperatures.

C Reclamation has installed temperature loggers at various depths in the forebay of Grand Coulee Dam. This monitoring program was initiated in August 1998 and a nearly continuous record of hourly forebay temperature profiles has been collected through 1999. The profiling site is located 900 ft upstream from the Left Powerplant intakes. The purpose is to collect hourly temperature profiles which can be used in a one-dimensional selective withdrawal model and to verify/calibrate the EPA's CE-Qual-W2 model of Lake Roosevelt. The selective withdrawal model is being used to evaluate the selective withdrawal potential at Grand Coulee Dam. The author (Tracy Vermeyen, D-8560, tvermeyen@do.usbr.gov) has all the temperature profile data stored in a spreadsheet/database. This temperature monitoring program will be continued for the foreseeable future. A plot of the forebay temperature profiles collected to-date is shown in figure 4. Figure 4 illustrates the drawdown of the reservoir for flood control storage in the winter and how most of the coldest water is released and how the reservoir is filled with warmer water in the spring.

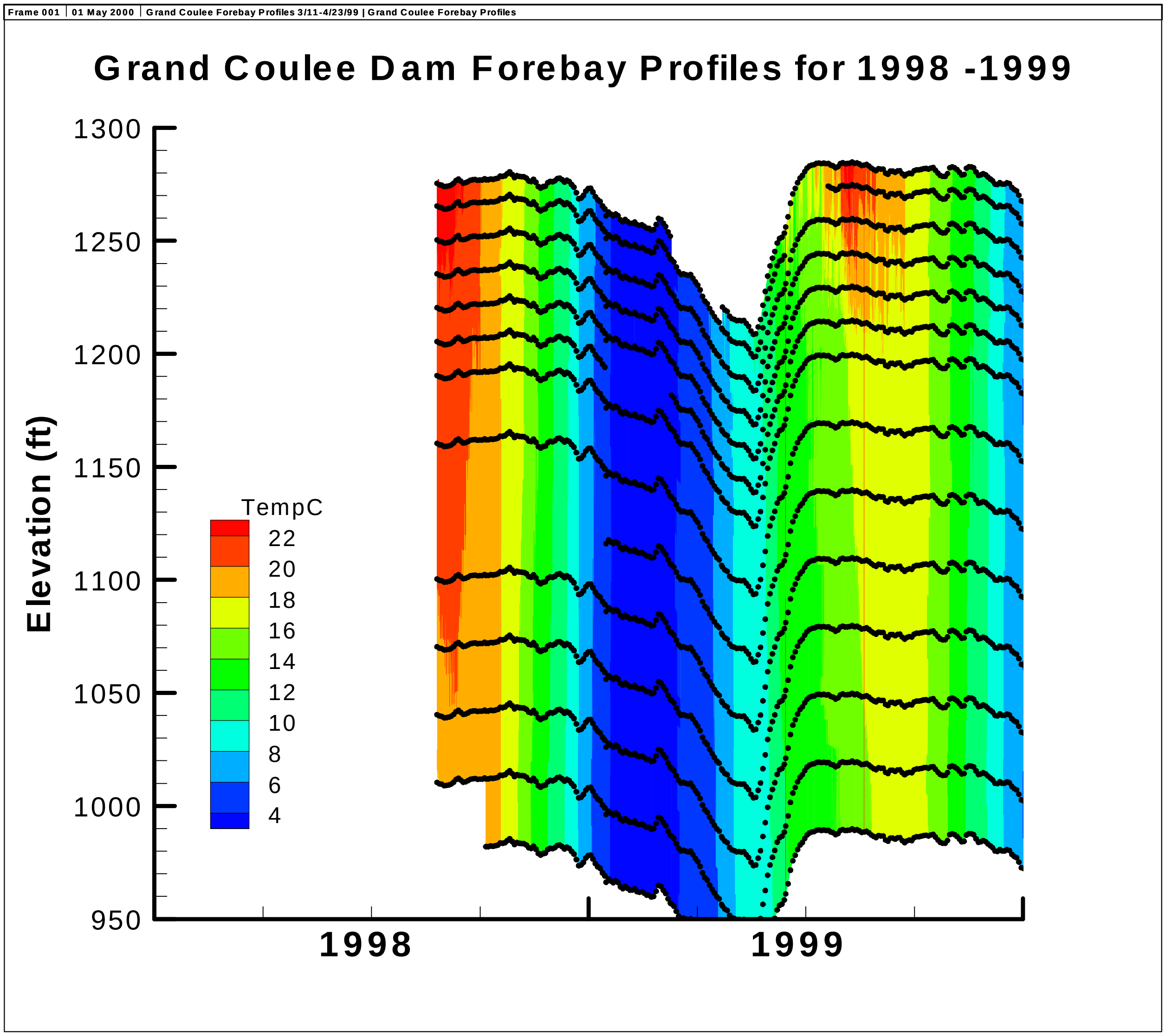

Figure 4. Plot of Grand Coulee forebay temperature profiles from August 1998 to December 1999. The black traces are the locations of individual temperature sensors. Note how much warmer the reservoir was in the summer of 1998 when compared to 1999.

C John Yearsley, EPA (206) 553-1532 is the contact for Columbia River Temperature

Modeling and Lake Roosevelt Modeling using CE-Qual-W2. The EPA's river model may help quantify the cooling capacity of power operations and define how long this change in temperature persists downstream. The magnitude of temperature reduction would have to be determined with a series of operational tests. The temperature improvement could then be monitored using the existing Gas Monitoring Network. Reference: Columbia River Temperature Assessment: Simulation Methods, December 1999, US EPA Region 10, 1200 Sixth Ave, Seattle Washington 98101. Information on these activities can be found on the Internet at: http://epainotes1.rtpnc.epa.gov:7777/R10/ecocomm.nsf/ecoweb/+temperature

- Two EPA Columbia/Snake River Mainstem Water Temperature Workshops were held in 1997 and 1998. Summary reports of the workshops are available on EPA's web site: http://epainotes1.rtpnc.epa.gov:/R10\ecocomm.nsf/ecoweb/+issues

- The EPA Region 10 website address is: http://www.epa.gov/r10earth/data/sdata/sdata.htm. On this site you will find metadata on stream temperature monitoring activities in the Pacific Northwest. This metadata includes location information, database descriptions, and individual contact information for these activities. It also includes instructions and data templates for submitting your own data for inclusion on the site. The data are submitted from a variety of sources, including McKenzie and Laenens's contracted work, individual submissions, and STORET database files. Currently, the site contains information for those drainages that constitute the Upper Columbia Basin, above the Snake River confluence (N Idaho and NE Washington).

- Columbia River Basin Water Temperature Data Analysis by McKenzie and Laenen and are available at: http://www.epa.gov/r10earth/offices/oea/temperature/Tdata.html

- U.S. Army Corps of Engineers website for water quality data (mainly from their dissolved gas monitoring stations) on the Columbia and Snake Rivers: http://www.nwd-wc.usace.army.mil/TMT/tdg_data/months.html

- U.S. Army Corps of Engineers website for real-time provisional water quality data contains data on operations, TDG monitoring data, general reports for the Upper Columbia River is: http://www.nwd-wc.usace.army.mil/report/columbia.htm#upcol

- A map of the Columbia River system and the dissolved gas monitoring stations (figure 5) is available on the U.S. Army Corps of Engineers site: http://www.nwd-wc.usace.army.mil/TMT/1998/tdg_data/gasmap.html

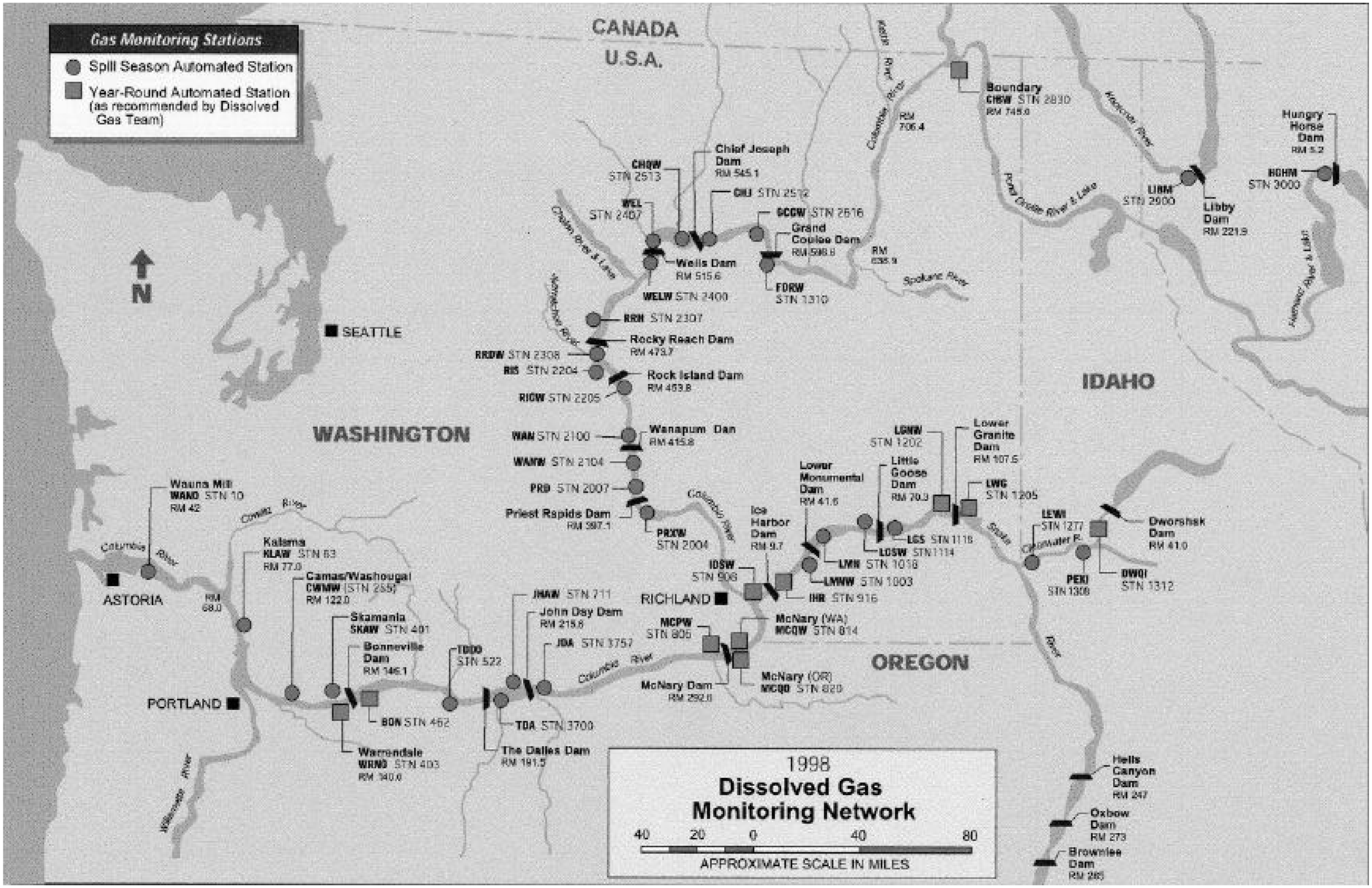

Figure 5. A map of the Columbia River system and the dissolved gas monitoring network.

- DART's hourly water quality site: http://www.cqs.washington.edu/dart/hgas_com.html can be used to get 1995-2000 data for the Columbia River below Grand Coulee Dam (GCGW), the Columbia River at the international boundary (CIBW), Grand Coulee Forebay (FDRW), Chief Joseph's Tailbay (CHQW) and Forebay (CHJ), and all other TDG sites. This data can be easily downloaded from the web or the user can generate plots of the data. It seems that data reported here is a pared down version of the U.S. Army Corps of Engineers reports.

- General information about Grand Coulee Dam operations and powerplants is stored available on USBR's power program website: http://www.usbr.gov/power/data/sites/grandcou/grandcou.htm

- General Background information on Grand Coulee Dam is available on Reclamations's Project Data website: http://www.usbr.gov/cdams/dams/grandcoulee.html

Summary of Limnological Studies of Lake Roosevelt

The most recent limnological evaluations of Lake Roosevelt are being conducted by Professors William Funk and Steve Juul from Washington State University. The most recent limnological sampling was conducted in October of 1997 and 1998. Date reports on these field trips are available from Mr. Dan Guptil (GCP-5200) at Reclamation's Grand Coulee Project Office.

A very informative resource is a literature review and report by Rene Derewetzky (Derewetzky, R.F., W.H. Funk, and S.T.J. Juul. 1993) which was prepared for the Lake Roosevelt Water Quality Council. Another comprehensive literature survey and compilation of abstracts for reports relating to Lake Roosevelt was prepared by D.H. Bennett and R.G. White (1997). This report was prepared for Reclamation, but was not available in the Reclamation's Denver Library. The Pacific Northwest regional library may have this report.

The following is a summary of the literature review and results from a recent report by Greg Wilson, and Professors W. Funk and S. Juul from Washington State University (Wilson 1996) on the limnology of the Upper Columbia River basin. The report material was reproduced and edited to focus on the physical limnology of Lake Roosevelt.

Summary of "*Limnological Evaluation of the Upper Columbia River Basin*"

The Franklin D. Roosevelt Reservoir was created in 1942 following the completion of Grand Coulee Dam across the Columbia River. It is the largest lake in Washington and one of the largest artificial lakes in the U.S. (Johnson *et al.*, 1989). It extends approximately 243 km northeast from the central Washington town of Grand Coulee to the Canadian border. The reservoir's watershed encompasses an area approximately 200,000-km^2 (USGS 1993) extending from Washington into Idaho, Montana, and the Canadian province of British Columbia.

Inflow to Roosevelt Reservoir is dominated by its two major tributaries, the Columbia and Spokane Rivers, which account for approximately 89 and 7% of the yearly inflow to the reservoir, respectively. The remaining 4% is contributed by the Kettle, Colville, and Sanpoil Rivers, along with numerous small streams (Stober *et al.*, 1981). U.S. Geological Survey (USGS) flow records for 1978-94 show the average monthly inflow from the Columbia River is over 90,000 ft^3/sec, with a maximum of 137,000 ft^3/sec in June, and a minimum of 75,000 ft^3/sec in September. The monthly average inflow from the Spokane River during the same period was 7,000 ft^3/sec, with a maximum of 15,000 ft^3/sec in May, and a minimum of 2,000 ft^3/sec in August. Seasonal flow variations result in the Spokane River contributing between 2 and 15.6% of the inflow to the reservoir in any given month.

The inflows to the reservoir, outflows through the dam and to Banks Lake, combined with pool elevations have resulted in monthly average hydrologic residence times ranging between 14 and 87 days since 1978. Since 1992, residence times have remained above 30 days, the Bureau of Reclamation's desired minimum. During the study period, the minimum pool elevation and residence time were 1262 ft M.S.L. and 32 days, respectively.

The shoreline of the reservoir is sparsely populated, with most of the 2,400 population concentrated in the communities of Grand Coulee, Kettle Falls, Gifford, and Northport (Washington State Data Book, 1991). Although the reservoir was created for hydroelectric power generation, irrigation, flood control purposes, increasing use is being made of the reservoir and its watershed for recreation. The dam's closure of the Columbia River eliminated the anadromous fish populations (principally steelhead and Chinook salmon from the area, but resident game fish populations have since been established and are responsible for attracting a large percentage of the recreational visits to the reservoir. This increase in popularity has placed Lake Roosevelt fifth among the most visited state or federal parks in Washington (Washington State Data Book, 1991).

Roosevelt Reservoir flooded the deep, narrow, river valley of the Columbia River, creating a unique aquatic environment with limnological characteristics similar to both those of a lake and a river system. At full pool (surface elevation 393 m), it contains about 1 1.23 x 10^9 m^3 of water with a mean depth of 36 m and a maximum width of 3.1 km. For additional morphometric information see Stober *et al.* (1981) and Welch *et al.* (1992). Hydrologic residence times in the reservoir vary with withdrawal rates, lake elevation, and outflow, and have ranged between 14 and 87 days (mean of 44) since 1978. The reservoir is usually drawn down 20 meters between January and June in preparation for the spring runoff, with maximum pool elevation (El. 384 m or 1290 ft) usually maintained the rest of the year.

There have been few in-depth limnological investigations of the reservoir since its formation in 1942, due in part to its isolation, and lack of concentrated population and development within its watershed. The first studies were conducted by the U.S. Fish and Wildlife Service (Gangmark and Fulton, 1949) and the U.S. Department of Health, Education, and Welfare (1953) between 1948 and 1952. Productivity in the reservoir was apparently low as indicated by the plankton populations. Limnological studies conducted between 1955 and 1966 confirmed the low plankton populations and lack of planktivorous fish species (Robeck *et al.,* 1954; Kiser 1964; Earnest *et al.,* 1966)

Temperature regimes and density flow pattern studies were the focus of investigations conducted on the reservoir between 1965 and 1969 (Water Supply and Water Pollution Control Subcommittee, 1966; Jaske 1965 and 1966; Jaske and Goebel, 1967; Jaske and Snyder, 1967). The reservoir moderated the temperature extremes experienced on the Columbia River before construction of the dam. The maximum temperatures were reduced, the minimum temperatures were elevated, and fluctuations were reduced in discharged water. These temperature regimes and density current studies determined that the reservoir usually stratifies downstream during late summer and fills primarily by displacement. Stober *et al.* (1981) reported that in 1980 the thermal stratification was most developed in the lower reservoir, beginning at Ninemile Creek, and was less developed in the upper reservoir. Typically, thermal stratification is fully developed by late July, persisting well into September. Density currents which develop in the stratified reservoir were measured by Jaske (1965) and an idealized example is shown in figure 6. One of Jaske's conclusions is especially pertinent to this study and is:

> "Operational concepts which envision use of the storage capacity of Lake Roosevelt *to alter thermal conditions* either expected from storage upstream in Canadian Treaty Reservoirs or currently existing must be designed to cope with the actual flow regime discovered. It is quite apparent that the reservoir does fill by displacement from the North and does not develop a true density current regime of any significance. This does not preclude operational plans which would save cold water by curtailment of the annual spring draw-down for flood control if sufficient upstream storage volume can be found to supplant the volume currently drained each spring. *Retention of this cold water now discharged for flood control would restore some of the seasonal imbalance in Columbia River temperature currently existing*."

In Jaske's report: *An evaluation of the use of Selective Discharges from Lake Roosevelt to Cool the Columbia River* (February 1996), he stated that "The annual reduction of the Lake Roosevelt level for flood control seriously depletes the cooler water supply and causes a seasonal imbalance by forcing the storage of the hottest incoming water at the poorest possible time." Typical flood control operations involving spring draw down and summer filling of Lake Roosevelt with 8 to 16EC inflows.

Dissolved gas supersaturation became the focus of studies conducted between 1972 and 1976 (Seattle Marine Laboratories, 1972 & 1974; Meekin and Allen, 1974; U.S. Army Corps of Engineers. 1976). The studies concluded that during much of the year the reservoir was supersaturated with nitrogen gas, with saturation values in excess of 120% recorded for both dissolved oxygen and nitrogen. The source was believed to be dams located on the major reservoir tributaries.

In 1980, limnology returned to the forefront of studies on the reservoir. Stober *et al.* (1981) conducted the most comprehensive limnology study to be completed on the reservoir to that date. Physical, chemical, and biological parameters were sampled monthly, throughout the reservoir, over a period of ten months. The trophic state of the reservoir was classified as mesotrophic to slightly eutrophic based on phosphorus, nitrogen, primary productivity (by carbon-14 method), and chlorophyll-a levels.

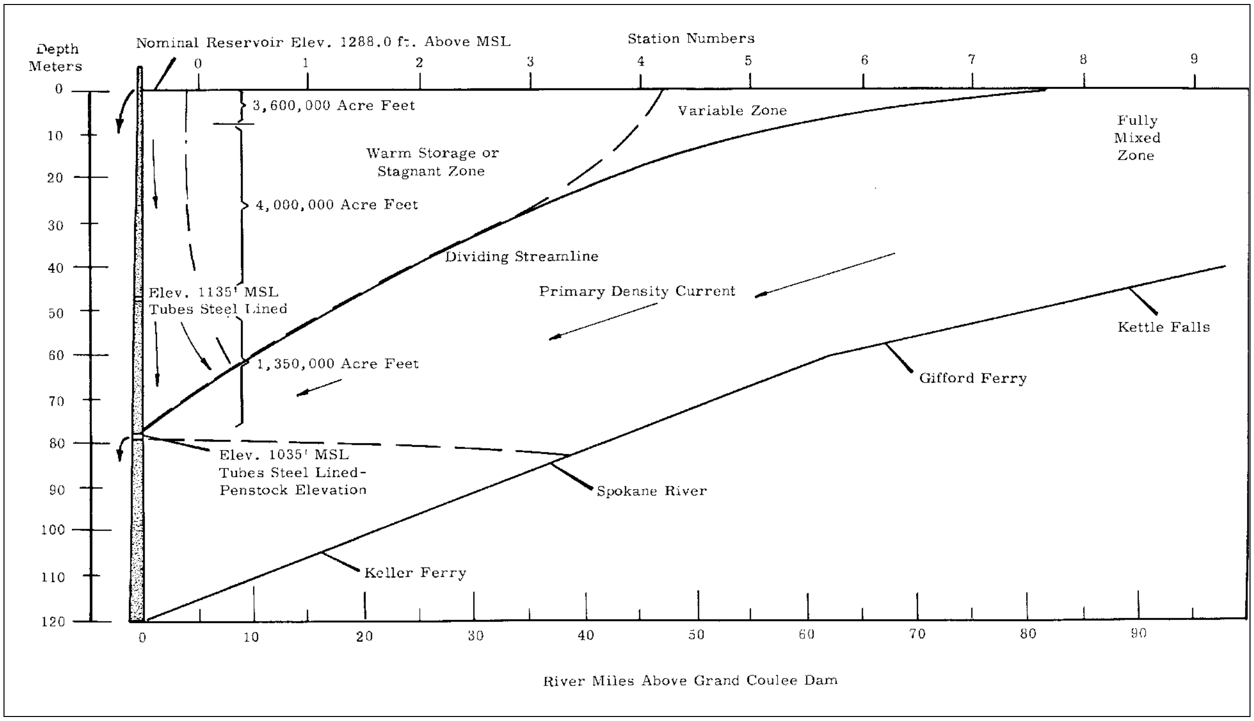

Figure 6. Idealized density currents and other reservoir data for Left and Right Powerplant operations with a thermally stratified reservoir. This figure was reproduced from a report by Jaske (1965). This study was conducted before the Third Powerplant was added to Grand Coulee Dam.

The U.S. Fish and Wildlife Service compiled a report between 1979-1983 (Beckman *et al.,* 1985), which outlined guidelines for the protection and enhancement of the sport fishery in the reservoir. A small sustained population of walleye *(Stizostedion vitreum vitreum)* had developed and was the focus of this investigation. Kokanee salmon *(Oncorhyncus nerka),* rainbow trout *(Salmo gairdneri)* and fall chinook salmon *(Oncorhynchus tshawytscha)* had been stocked in the past, but sustainable populations had fail to develop. The report concluded that spring draw-downs, and the resultant low retention times, limit buildup of nutrients and phytoplankton in the reservoir. The key recommendation in the study was to increase spring water retention times in order to increase nutrient assimilation, fish food production, larval fish habitat.

In response to the apparent reduction in nutrient loading to the Roosevelt Reservoir, Wilson (1996) designed a study to assess the current, and expose changes in, the limnology of the reservoir, and determine if there has been a shift in the trophic status. The current limnology and primary productivity of the reservoir was assessed by determining the spatial and temporal variations the major physical and chemical parameters; phytoplankton distribution, abundance, and species composition; the distribution, abundance and composition of the zooplankton community; and primary productivity by carbon-14 methods.

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Summary of Reclamation's 1964 study on Using the Proposed Third Powerplant to Modify Columbia River Temperatures

In the late 50's and early 60's Reclamation participated in a program at Grand Coulee Dam to minimize release of warm surface water from Lake Roosevelt during periods of maximum river temperatures. The program showed that an appreciable difference in downstream water temperatures could be achieved; however, the program was limited by the capacity of the outlets and the operations at the dam for power generation, etc. It was thought that changes in the facilities at the dam, such as construction of the Third Powerplant, could provide a means for further modifying temperatures in the river below, if the penstock intakes for the Third Powerplant were designed to draw water from a higher elevation than the existing plants, say from an elevation of about 1170 feet instead of 1040 feet. Upper level withdrawal would provide a means of delaying the withdrawal of the coldest water in the reservoir. Because of the interest in modification of river temperatures, the analysis of temperature changes was included as part of the feasibility study of the Third Powerplant (Petersen 1964).

Justification for additional generating facilities at Grand Coulee Dam was proposed based on the assumption that upstream storage and power developments envisioned in the proposed treaty with Canada would soon be achieved. Analysis of benefits included studies for the entire river system. Streamflow regulation studies for coordinated system power development and flood control were conducted. Two levels of projected water resources development were studied. One of the studies used streamflows to meet load requirements for 1972-73 conditions, and the second study was based on 1985 conditions of development.

The period of time used for this temperature study was from April 1 to September 30. Beginning in April the surface of the reservoir, as well as inflows to the reservoir, becomes warmer due to solar heating. Since this warmer water is less dense than the cooler water below, it remains on the surface and the reservoir gradually becomes thermally stratified. The surface water increases in temperature at a rapid pace, while water in the bottom of the reservoir remains unchanged except as it is withdrawn and replaced by warmer water from above. Normally, the reservoir water reaches a maximum temperature in August or early September, and then by the end of September is already cooling rapidly.

A desirable operation for temperature control was to make the spring and early summer releases at Grand Coulee from the higher elevations of the reservoir, thus using warmer water at a time when river temperatures are acceptable. Then during the time of critical high river temperatures the releases would be changed so as to be drawing water from the bottom of the reservoir. This type of operation cannot be followed entirely because the amount of power production shown for Grand Coulee Dam in the system power studies was of a magnitude such that even in low runoff years the use of generating facilities could not be entirely selective for purposes of temperature control. As a result, it will be necessary for at least part of the time each year to use all three of the powerplants concurrently to meet the load and to provide the peaking power required. This will necessitate drafts on the reservoir which will reduce the control of water temperatures.

The distribution of releases between powerplants was made on the assumptions that: (1) from April through June the Third Powerplant would be operated to capacity, with Plants 1 and 2 meeting the balance of the load; (2) July being a borderline month temperature-wise, power would be generated in whatever ratio between the plants that would be most advantageous; and (3) in August and September Plants 1 and 2 would generate as much of the load as possible, with the Third Powerplant filling in occasionally. All values were found by averaging the results from 1946 and 1957, two years of approximately average runoff. The average of two years was used instead of selecting a single year to represent normal conditions in order to modify any unusual conditions that a single year might have. Releases include the Third Powerplant, and also as they could be made without the Third Powerplant. Total releases from the reservoir without the Third Powerplant are the same as with it, but because of the reduced capability the present generating facilities were used to capacity to meet as much of the load as possible and the surplus water was released from whatever outlets would be most advantageous. Study of this operation scenario illustrated the problem encountered when trying to save cool water in the bottom of the reservoir and at the same time generate power to meet a full load. Power requirements necessitate the withdrawal of water from the bottom of the reservoir through the Left and Right Powerplants in the following amounts:

April	1,760,000 acre-feet
May	2,810,000 acre-feet
June	3,100,000 acre-feet
July	3,220,000 acre-feet

In almost every month during the spring and early summer these withdrawals would mean the removal of most of the so-called "cool water" and replacement by either reservoir inflows or warm water from the upper part of the reservoir.

The results of this study indicated that the addition of the Third Powerplant at Grand Coulee Dam will not significantly reduce river temperatures during the critical months of August and September. Outflow temperatures during August and September are almost entirely the result of the assumption that the reservoire inflow during those months can and will flow beneath the waremer surface layer and enter the bottom two layers of the reservoir. Because of the great volume of water passing through the reservoir each month the operation of the outlets or powerplants in the spring and early summer have little effect on the river temperatures later in the season. The only exception is the surface layer which will change in temperature if the spillway is used instead of the Third Powerplant.

Ref: John Petersen, Hydraulic Engineer, US Bureau of Reclamation Memorandum, Regional Office, Region 1, Boise Idaho, dated March 2,1964).

Summary of EPA's Development of Temperature Models for the Columbia River and Lake Roosevelt.

The primary goal of the Columbia River Temperature Assessment: Simulation Methods (Yearsley 1999) was to develop a mathematical model that predicts temperature along the Columbia from Grand Coulee Dam to Bonneville Dam and along the Snake River from its confluence with the Grande Ronde River to its confluence with the Columbia. One of the major conclusions from this assessment is - “In the Columbia River, construction of Canadian dams and the operation of Grand Coulee Dam have an important role in the temperature of the Columbia River below Grand Coulee Dam.” This report also quantifies the temperature gain resulting from constructing dams below Grand Coulee on the Columbia River and below Lewiston, Idaho on the Snake River. This report also state that dams have a greater impact on river warming than do increased temperatures in major tributaries. However, the uncertainties in the model estimates of river warming are on the same order of magnitude as the estimated differences in temperatures for the “no dams” versus “with dams” comparisons.

A second model of Lake Roosevelt is also being developed to predict release temperatures from Lake Roosevelt. This two-dimensional reservoir simulation model was developed using a USCOE reservoir water quality model called CE-Qual-W2. Currently, the Lake Roosevelt model is still under development. For Reclamation’s purposes, these models may be useful to predict the impacts on the Columbia River temperatures if selective withdrawal or operational changes at Grand Coulee Dam can lower the release temperatures.

Ref: Yearsley, John, December 1999, Columbia River Temperature Assessment: Simulation Methods, U.S. EPA, Region 10, 1200 Sixth Avenue, Seattle, Washington 98101.

Columbia River Basin Water Temperature Data Analysis

A summary of the comprehensive temperature data review performed by two retired USGS hydrologists (Stuart McKenzie and Antonius Laenen) to document the quality of temperature data at Canada/US boundary (CIBW), at Northport, WA, below Grand Coulee Dam (GCGW), and Coulee Dam’s forebay (FDRW), and Chief Joseph’s forebay (CHJ) can be found in the appendix. An analysis of the maximum, minimum, and average daily temperature fluctuations for TDG stations below Grand Coulee Dam (GCGW) and Chief Joseph Dam (CHJ) showed that short-term reductions in release temperatures from Grand Coulee can be passed through Chief Joseph dam with a small increase in temperature (this analysis assumes that CHJ forebay temperatures are a good indicator of Chief Joseph Dam release temperatures). On a daily basis, Grand Coulee outflow temperatures can fluctuate by 2 to 4 EC, but the resulting fluctuations in forebay temperatures at Chief Joseph is about usually around 1 to 1.5EC (see table 2 and figure 7). This indicates that Grand Coulee release temperature fluctuations are attenuated by mixing as these flows pass through Chief Joseph’s reservoir (Rufus Woods Lake).

An important thing to note is that regardless of the water year type (wet or dry) there is little data available to determine the ability to pass *sustained* colder releases from Grand Coulee through Chief Joseph Dam. However, it is difficult to make a definitive conclusion without detailed operational data on which facilities were used at Grand Coulee to make the downstream releases. According to discussions with Kathy Frizell, D-8560, there are not detailed (hourly) records on individual generator usage or outlet works release levels. This information is critical in developing estimates of the duration of lowering release temperatures from Grand Coulee Dam.

Release temperature analysis for the months of May through August for the years 1984 through 1997 indicate that daily temperature fluctuations are primarily a function of powerplant operations-- that is hourly flow fluctuations and whether the Third powerplant was used exclusively or if the majority of the flow was passed through the Left and Right powerplants. Likewise, operation of the Banks Lake pumping plant and spillway releases may also be important factors.

Operational impacts on release temperatures were illustrated by abrupt changes in daily temperature fluctuations when Grand Coulee outflows remain relatively uniform (see figure 8). Figure 8 illustrates a trend which started in 1990 where CHJ temperatures were the nearly the same temperature as GCGW temperatures for the months of May through August. This trend appears to be a function of water year type (wet, average, or dry). For the years1984 to1990, the average flows were below 100 Kcfs (see table 2) and CHJ temperatures were usually 1 to 2EC warmer than GCGW temperatures. For the 1990's, average flows were greater than 130 Kcfs and CHJ temperatures were usually less than 0.5EC warmer than GCGW temperatures. While temperature fluctuations of 4EC do occur over a daily time frame, the question that needs to be answered is: can Grand Coulee's release temperature be lowered 3 to 4EC for a sustained period by changing powerplant operations? And if it is possible, how long (weekly or monthly time frame) will the cold water storage in Lake Roosevelt sustain the cold water releases? For example, an analysis of the temperature profiles collected by Reclamation in Grand Coulee's forebay during August 1999, showed that water 16EC and colder were depleted in a period of 27 days (figure 9). The total volume of cold water withdrawn from Lake Roosevelt was 3.3 million acre-ft or the equivalent of 61, 600 ft^3/sec. During most of the month of August, the average inflow temperature measured at the Canadian border (CIBW) were was 17EC which indicates that there is no inflow of water colder than 16EC. Consequently, the removal of the 16EC water is a good estimate of the residence time for this cold water volume. This rapid reduction in the cold water storage is most likely generated by combined operation of the Third, Left and Right powerplants. However, without detailed powerplant operations data it is not possible to determine if this cold water could have been reserved for use in September.

The travel time of water released from Grand Coulee Dam to when it is passed through Chief Joseph is a function of flow rate. In wet years, like the 1995, travel times are 2.0 to 2.5 days. As a result, there is little temperature gain during the short travel time associated with high flow rates. The average daily discharge through Grand Coulee Dam for 1995 was 105.1 Kcfs. On the other hand, during dry years, like 1985 and 1988, travel times are closer to 3.0 days and the temperature gain can be as much as 2.5EC. The average daily discharge through Grand Coulee Dam for 1988 was 82.7 Kcfs. Other factors like meteorological conditions also important when discussing the temperature gain of water in the Columbia River. For example, 1998 was considered a wet year with average flows of 124Kcfs, but in July, August and September reservoir temperatures and releases temperatures were much warmer than average. In 1999, the average monthly release temperatures at GCGW and CHJ are different by 1.15, 1.03, and 0.83 EF for July, August, and September, respectively. It is interesting that the ÄT (T_{CHJ}- T_{GCGW}) decreases with a gradual increase in release temperatures (figure 10). The reason for this is the reservoir stratification is usually strongest in July and August and gradually breaks down in September. Figure 10 also illustrates the dynamic nature of outflow and release temperatures at Grand Coulee Dam.

Table. 2. Comparison of maximum daily temperature fluctuations (Delta (Ä)T=T_{max}-T_{min}) for a given year using data collected at TDG stations GCGW and CHJ for the years 1984 through 1997. Data in **bold** indicate times when peak fluctuations coincided (accounting for travel time) below both dams. Also included is the average daily flow for the months May through August

Date	ÄT at GCGW	Date	ÄT at CHJ	Comments	Average Flow (kcfs) from May through August
7/26/84	**1.7EC**	**7/28/84**	**1.0EC**	No data after 7/31	113.7
7/15/85	2.2	5/30/85	1.3	0.3EC on 7/17/85	82.3
7/01/86	2.5	4/6/86	4.1	0.8EC on 7/3/86	105.6
7/24/87	2.8	8/12/87	1.7	1.0EC on 7/26/87	95.1
7/04/88	2.7	7/10/88	1.6	1.2EC on 7/6/88	82.7
7/07/89	2.9	6/26 & 7/25/89	1.5	1.0EC on 7/9/89	84.9
7/27/90	**3.9**	**7/30/90**	**1.2**		132.4
7/25/91	2.4	No data	--		136.9
8/03/92	3.6	No data	--		101.4
6/25/93	4.5	5/17/93	1.7	0.7EC on 6/28/93	95.8
8/03/94	3.8	6/01/94	1.6	0.8EC on 8/05/94	100.8
8/03/95	3.6	6/10/95	1.3	1.1EC on 8/6/95	105.1
8/10/96	2.0	7/28/96	1.1	1.18EC on 7/28/96	162.2
8/16/97	**2.4**	**8/18/97**	**0.9**	**0.9EC on 8/7/94**	194.7

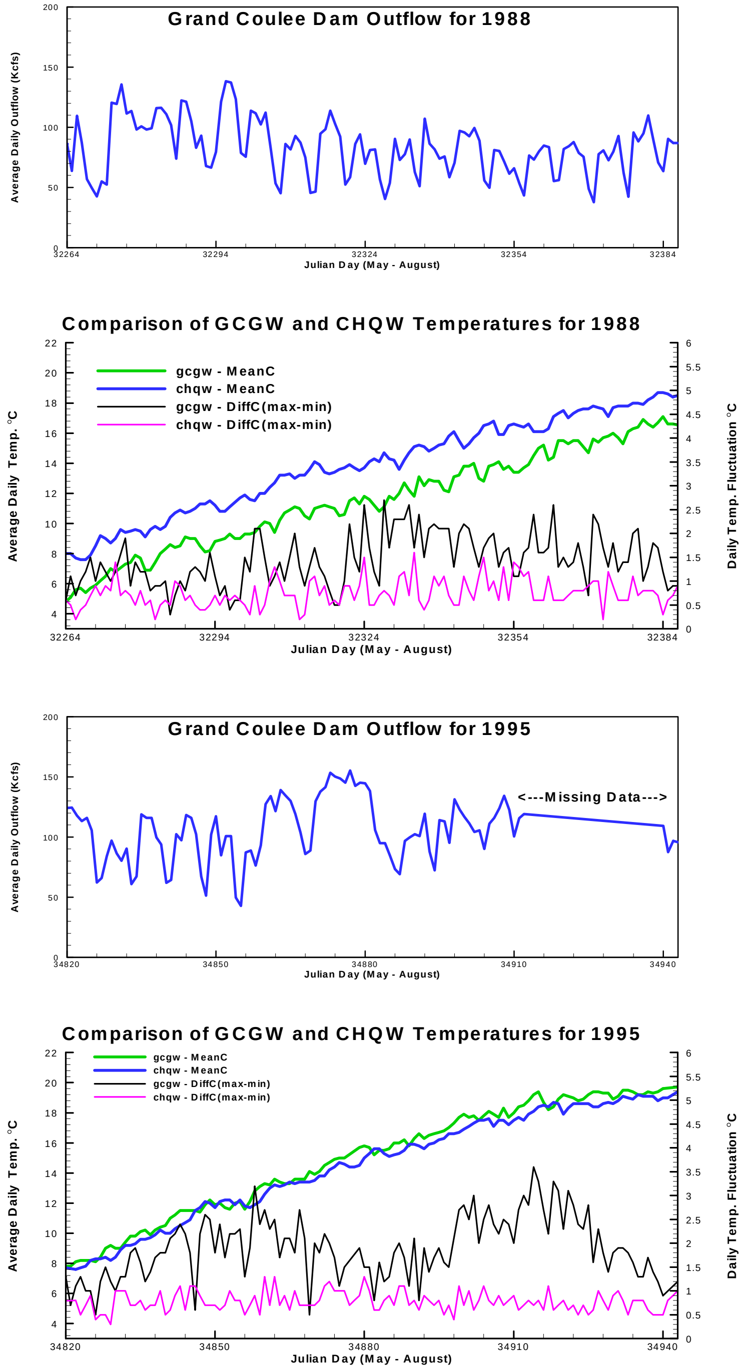

Figure 7. Comparison of average daily outflow temperatures and daily temperature fluctuations for Grand Coulee (GCGW) and Chief Joseph (CHJ) Dams. The outflows from Grand Coulee Dam are also shown. Note: CHQW on the plots should read CHJ.

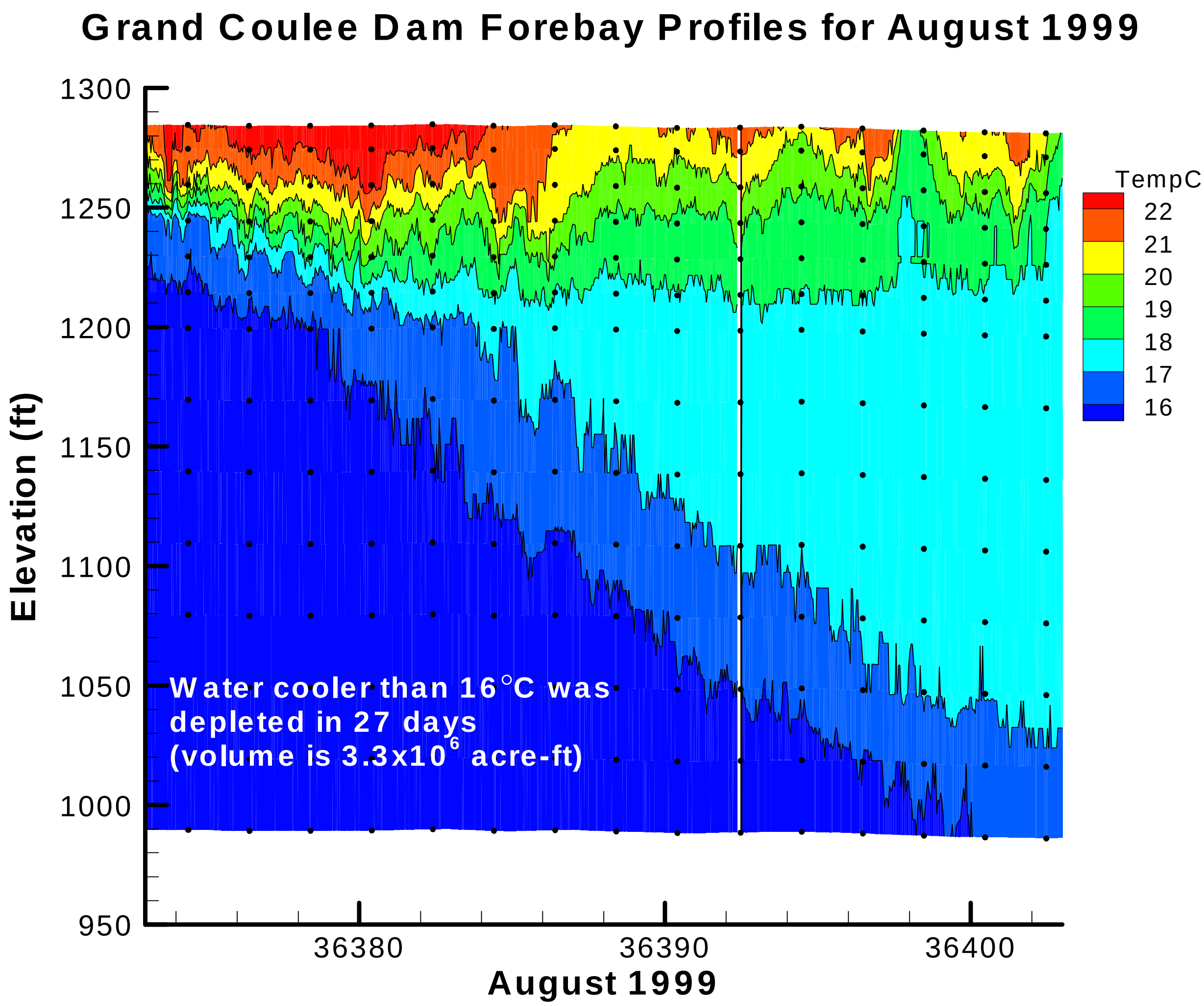

Figure 8. Reclamation's forebay temperature profiles indicate that water 16EC or colder was withdrawn from the reservoir in 27 days in August 1999. This represents a volume of 3.3 million acre-ft or an average withdrawal rate of 61,620 ft^3/sec.

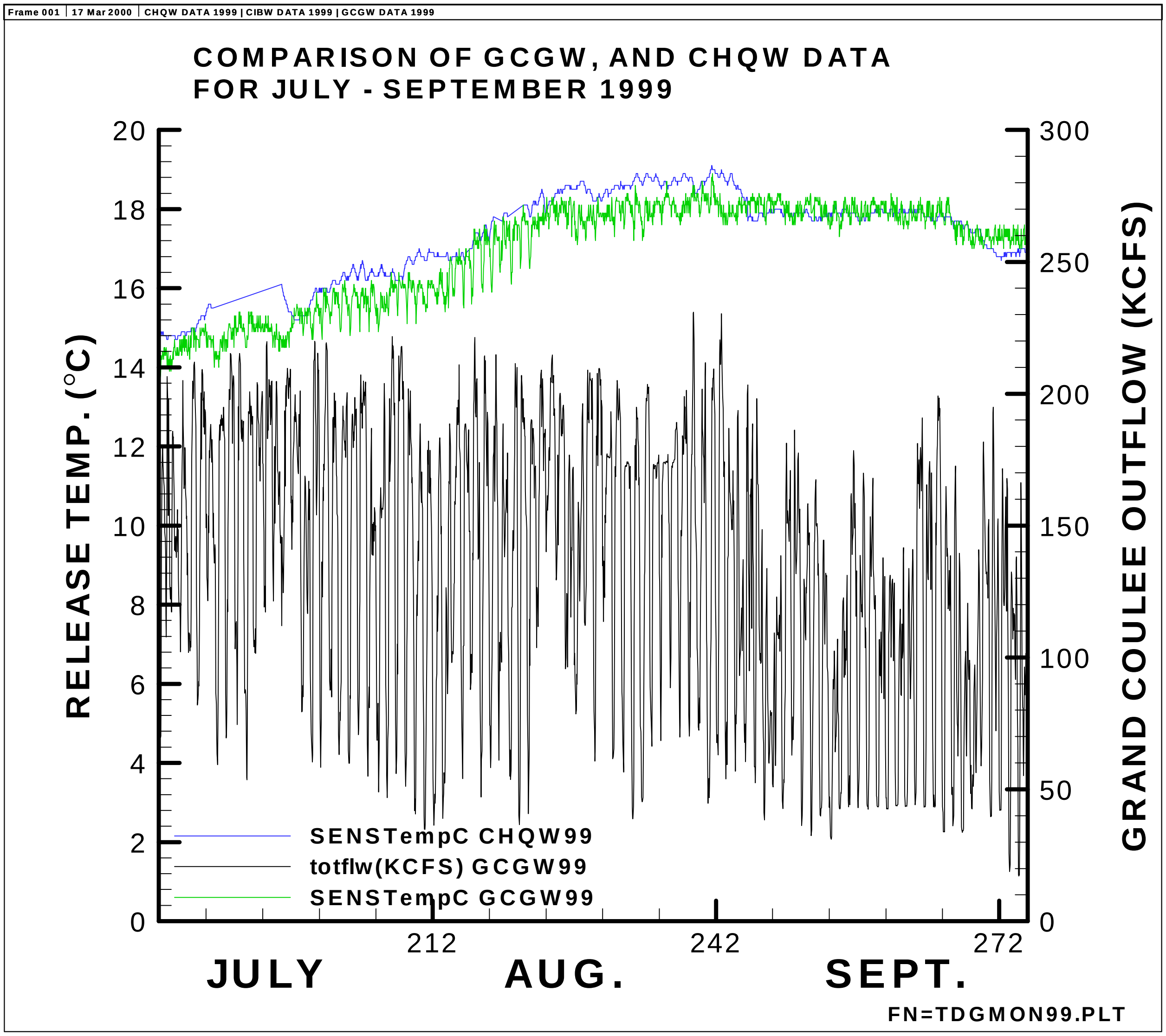

Figure 9. This plot shows the hourly variation in Grand Coulee Dam's outflow and release temperature along with the release temperature from Chief Joseph Dam for the months of July, August, and September 1999.

Selective Withdrawal Analyses Using the SELECT Model

A means of predicting the properties of selective withdrawal from a reservoir is helpful to properly design and efficiently operate a selective withdrawal facility. Significant research has been conducted on the characteristics of withdrawal from a stratified impoundment. Research by Bohan and Grace (1973) resulted in empirical equations which describe the withdrawal limits and velocity profiles which develop for a submerged intake in a stratified reservoir. These equations are used in a U.S. Army Engineers Waterways Experiment Station model called SELECT (USAEWES 1987). This model can be used to determine the withdrawal limits and velocity profiles for a given reservoir temperature profile. For example, this model can be used to determine the release temperature for

Third powerplant or the Left powerplant at Grand Coulee Dam.

The SELECT model was run for several days in 1998 and 1999 using forebay temperature profiles collected by Reclamation. SELECT was run to determine release temperatures from the Third, Left, and Right Powerplants and the Bank's Lake Pumps. The results of these model tests are summarized in table 3. Table 3 also shows the average daily release temperature measured at TDG monitoring station GCGW. It is interesting to note that the GCGW temperatures are significantly higher than the Third Powerplants release temperatures. This result indicates that SELECT cannot accurately reproduce the selective withdrawal characteristics of the Third powerplant's approach channel. The invert of the approach channel is at elevation 1110 ft and the intake centerline elevation is 1130 ft. In order to compute release temperatures that match GCGW temperatures, the Third powerplant's intake elevation have to be raised 70 to 80 ft. This type of error is expected when considering the empirical equations describing selective withdrawal were developed assuming infinite reservoirs with small intakes that had no vertical or lateral restrictions. The approach channel to the Third powerplant does not comply with these assumptions. The model assumptions are better suited to describe the intakes for the Left and Right powerplants. Using data in Jaske's report (1965) on density flows, SELECT was used to model Left and Right powerplant releases which were compared to actual release temperatures. The agreement between SELECT and Jaske's reported withdrawal temperature was 0.02 EC.

Table 3. Results from SELECT modeling of various release options at Grand Coulee Dam along with the downstream temperature from monitoring station GCGW.

Date	Resel (ft)	Avg Daily Q (kcfs)	3rd PP Release Temp (EF)	Left and Rt PP Release Temp (EF) (up to 90K)	Banks Lake Pump Release Temp (EF) (up to 22K)	Avg. Daily GCGW Temp (EF)
8/28/98	1279	104.8	68.9	66.6	69.6	70.2
9/07/98	1280	73.3	69.3	67.5	69.7	70.8
9/17/98	1280	76.8	68.7	67.5	69.2	70.3
9/27/98	1282	62.0	67.4	67.0	67.7	68.5
1999 data						
7/27/99	1287	164	59.2	57.5	59.5	60.8
8/06/99	1289	136	60.6	58.9	60.7	62.6
8/16/99	1289	172	63.0	59.9	63.4	63.9
8/26/99	1287	155	63.8	62.3	63.8	64.3
9/05/99	1286	97	63.7	62.9	64.1	64.7

An important result from these model runs is that there is not much difference in release temperatures for the different powerplants at Grand Coulee Dam. The maximum difference is about

4EF during the periods of strongest reservoir stratification. The main factor for this small difference is the relatively weak thermal stratification which develops in Lake Roosevelt.

SELECT Model References

Bohan, J.P., and J.L. Grace. March 1973. *Selective Withdrawal From Man-Made Lakes.* Technical Report H-73-4, U.S. Army Engineer Waterways Experiment Station.

U.S. Army Engineer Waterways Experiment Station. March 1987. *SELECT: A numerical, one-dimensional model for selective withdrawal.* Instruction Report E-87-2.

Appendix

Summaries of the Middle Columbia River Temperature Analyses by Laenen and McKenzie

INTERNATIONAL BOUNDARY TDG (CIBW)

DATE COMPILED: April 3, 1998 AL
Revised: April 28, 1998 SWM

STATION LOCATION: at river mile 745.0, in slack water from Grand Coulee Dam.

DATA SOURCE: USACE, Northwestern Division, Portland, OR. Data collected by the Bureau of Reclamation.

BEGINNING DATA: July 27, 1984 ENDING DATA: Dec. 31, 1997 UNITS: Celsius

DATA DESCRIPTION: From 1984-91, hourly values, 5-12 times per day, and from 1992-97, hourly values for each hour; total of 60,135 values. Daily data file from 1984-97 is 2,191 values. Daily data file includes maximum, minimum, and mean daily values and the variability for the day.

TITLE OF FILE: Daily data: cibw_tdg84-97d.xls STATION CODE: CIBW
Hourly data: cibw_tdg84-97.xls

COMPLETENESS OF RECORD:

START	END	COMMENTS	*SUSPICIOUS RECORD*
7/27/84	7/31/84	9-12 hourly values per day	
4/1/85	5/24/84	9-12 hourly values per day	
8/1/85	8/31/85	9-12 hourly values per day	
10/1/85	12/13/85	9-12 hourly values per day	
4/1/86	7/8/86	9-12 hourly values per day	
8/8/86	8/31/86	9-12 hourly values per day	seems biased 3ºC high
4/15/87	7/24/87	9-12 hourly values per day	
5/14/88	8/31/88	9-12 hourly values per day	
4/21/89	8/24/89	9-12 hourly values per day	
4/17/90	8/29/90	9-12 hourly values per day	July-Aug seems biased low
4/26/91	9/9/91	9-12 hourly values per day	
10/1/91	10/31/91	9-12 hourly values per day	
4/17/92	10/4/92	24 hourly values per day	Sept seems biased low
4/15/93	7/26/93	24 hourly values per day	
3/9/94	9/14/94	24 hourly values per day	9/8-14 data deleted
5/3/95	9/25/95	24 hourly values per day	Aug-Sept seems biased low
3/8/96	12/31/97	24 hourly values per day	

VARIABILITY: Variability is within 0.5ºC most of the time. During the summer season, when there is regulation upstream and variable heating from the sum, the variation within a day can be as great at 3.2ºC. 1984-97 data were compared to 1960-70 data collected by the USGS and are more variable within a monthly time frame. This may be the result of greater regulation of the Canadian Dams.

BIAS: Records with 0.0ºC value, > 2 times adjacent values, and negative values have been removed. Temperatures from 8/14/85 to 8/31/85 seem abnormally high, but with no other comparisons, the record was not deleted. The temperatures from 9/8/94 to 9/14/94 were abnormally low and were deleted. Records were compared to the Similkameen River near Nighthawk, WA (12442500) to get a general idea of trends.

REPRESENTATIVE OF CROSS SECTION: There are no data sets during the 1984-97 time period to compare with this site. Pacific States Marine Fisheries Council data show 0.1 ºC variability between right, mid, and left channel readings in 1973.

GENERAL COMMENTS: The record is generally collected seasonally from April to September. Generally, from June through August, temperatures are often higher than at downstream locations, sometimes by 2-3ºC, and from September through November temperatures are lower than downstream locations, sometimes by 2-3ºC. These temperature modifications may be caused by water retention in Lake Roosevelt behind Grand Coulee Dam.

COLUMBIA RIVER AT INTERNATIONAL BOUNDARY, WA DATA COMPILED: May 2,1998 AL
Revised: May 29, 1998 SWM

STATION LOCATION: at river mile 745.0, 0.5 miles downstream from Pend Oreille River, on left bank. In 1974, data collection was begun at Northport, 10 miles downstream.

DATA SOURCE: USGS, Washington District, Tacoma, WA

BEGINNING DATA: Oct. 1, 1958 ENDING DATE: Sept. 30,1973 UNITS: Celsius

DATA DESCRIPTION: Daily instantaneous values; total of about 5,470 values.

TITLE OF FILE: cr-intbound.dat STATION NUMBER: 12399500

COMPLETENESS OF RECORD:

START	END	COMMENTS
10/1/58	12/5/58	
12/11/58	12/24/58	
1/3/59	2/8/59	
2/20/59	4/11/59	
6/5/59	6/22/59	
6/29/59	10/21/59	
11/8/59	12/4/59	
12/14/59	3/20/59	
3/28/59	1/3/61	
1/13/61	4/5/61	
4/18/61	11/27/61	
12/3/61	6/28/63	
7/6/63	1/21/64	
1/28/64	3/26/66	
4/7/66	822/71	
8/28/71	9/30/73	

VARIABILITY: Daily variability is usually about 0.5 ºC and up to 1 ºC during the heating and cooling season. Data are reported to the nearest 0.5 ºC.

BIAS: Because the Pend Oreille River enters into the Columbia River on the left bank just 0.5 upstream from the sampling point, there is probably a systematic bias to the data collected here, but it appears it may be small.

MONITORING SITE REPRESENTATIVE OF CROSS SECTION: Part of the USGS protocol was to insure the data were representative of the cross section. Pacific States Marine Fisheries Council data show 0.1 ºC variability between right, mid and left channel readings in 1973.

GENERAL COMMENTS: Daily mean values can be estimated by averaging the minimum and maximum values where the daily mean values are not available. Temperature data were collected at Northport from 1974-81, and are compatible for that section of river.

COLUMBIA RIVER AT NORTHPORT, WA **DATA COMPILED: April 13, 1998 SWM**
Revised: May 8, 1998 AL

STATION LOCATION: at river mile 735.1 at State Highway 25 bridge, on right bank.

DATA SOURCE: USGS, Washington District, Tacoma, WA

BEGINNING DATA: August 29, 1974 ENDING DATE: Sept. 23,1981 UNITS: Celsius

DATA DESCRIPTION: Daily instantaneous values during the 1974 water year (not on computer), minimum and maximum values during the 1975 water year, and minimum, mean, and maximum values during the 1976-81 water years; total of about 4,470 values.

TITLE OF FILE: cr-northport.dat STATION NUMBER: 12400520

COMPLETENESS OF RECORD:

START	END	COMMENTS
8/29/74	3/10/75	daily record
3/15/75	11/4/76	daily record
11/17/76	1/15/78	daily record
2/10/78	1/1/79	daily record
1/26/78	1/29/79	daily record
4/4/79	1/15/80	daily record
4/4/80	7/21/81	daily record
8/6/81	9/23/81	daily record

VARIABILITY: Daily variability is usually about 0.5 ºC and up to 1 ºC during the heating and cooling season. Data are reported to the nearest 0.5 ºC.

BIAS: Comparison for the 1974-81 water years with the Spokane River at Long Lake, WA (12433000) shows that the record trends are similar but that the Spokane River temperatures are generally 1-2 degrees warmer. In addition, the Northport record show some small swings of 1-2 degrees probably caused by upstream regulation.

MONITORING SITE REPRESENTATIVE OF CROSS SECTION: Part of the USGS protocol was to insure the data were representative of the cross section. Pacific States Marine Fisheries Council data show 0.1 ºC variability between right, mid and left channel readings in 1973.

GENERAL COMMENTS: Daily mean values can be estimated by averaging the minimum and maximum values where the daily mean values are not available.

SPOKANE RIVER AT LONG LAKE, WA **DATA COMPILED: Apr. 13, 1998 SWM**
Revised: May 6, 1998 AL

STATION LOCATION: at river mile 33.9, on left bank at Long Lake power house.

DATA SOURCE: USGS, Washington District, Tacoma, WA

BEGINNING DATA: July, 1959 ENDING DATE: Sept. 30,1981 UNITS: Celsius

DATA DESCRIPTION: Daily minimum and maximum values during the 1973-75 water years and daily minimum, mean, and maximum values during the 1976-81 water years; total of about 7,090 values.

TITLE OF FILE: spokane_r.dat STATION NUMBER: 12433000

COMPLETENESS OF RECORD:

START	END	COMMENTS
3/22/73	12/17/73	daily record
1/23/74	2/24/74	daily record
2/28/74	3/8/74	daily record
3/26/74	5/10/74	daily record
5/22/74	7/10/74	daily record
8/22/74	11/24/74	daily record
12/19/74	5/6/75	daily record
5/20/75	8/25/75	daily record
9/6/75	5/5/76	daily record
5/11/76	9/1/76	daily record
10/12/76	3/27/77	daily record
4/18/77	8/11/77	daily record
9/3/77	9/30/77	daily record
10/21/77	5/29/78	daily record
6/21/78	12/29/78	daily record
1/18/79	6/19/79	daily record
9/19/79	10/9/79	daily record
11/14/79	1/22/80	daily record
2/21/80	7/1/80	daily record
8/2/80	2/16/81	daily record
2/26/81	9/30/81	daily record

VARIABILITY: Daily variability is usually about 1.0 ºC and up to 2 ºC during the heating and cooling season. Data are reported to the nearest 0.5 ºC.

BIAS: Unable to determine because no comparable continuous record for these time periods is available.

MONITORING SITE REPRESENTATIVE OF CROSS SECTION: Part of the USGS protocol was to insure the data were representative of the cross section.

GENERAL COMMENTS: Daily mean values can be estimated by averaging the minimum and maximum values where the daily mean values are not available. Compared with temperatures on the main stem of the Columbia River at Northport, temperatures are generally warmer 0.0 - 1.0ºC from January to May, warmer 1.0 – 2.0ºC from June to August, and within 0.5ºC from September to December.

GRAND COULEE TDG FOREBAY (FDRW)

DATE COMPILED: May 26, 1998 AL
Revised:

STATION LOCATION: at river mile 596.4, about 0.5 miles upstream from dam on the right bank.

DATA SOURCE: USACE, Northwestern Division, Portland, OR; data collected by the Bureau of Reclamation

BEGINNING DATA: May 7, 1997 ENDING DATA: Oct. 13, 1997 UNITS: Celsius

DATA DESCRIPTION: For 1997, hourly values, for a total of 3,072 values. Daily data file includes maximum, minimum, and mean daily values and the variability for the day.

TITLE OF FILE: Daily data: fdr_tdg97d.xls
Hourly data: fdr_tdg97.xls

STATION CODE: FDR

COMPLETENESS OF RECORD:

START	END	COMMENTS	*Suspicious Record*
5/7/97 ----------------	6/28/97	hourly	
7/29/97 -------------	10/13/97	hourly	7/29 to 8/25

VARIABILITY: Variability is within 0.5ºC most of the time.

BIAS: Record is too short to observe bias.

REPRESENTATIVE OF CROSS SECTION: Unable to determine.

GENERAL COMMENTS: Data are collected at a minimum depth of 15 feet.

COLUMBIA R. AT GRAND COULEE DAM, WA

DATE COMPILED: April 13, 1998
SWM
Revised: May, 6, 1998

STATION LOCATION: at river mile 596.3, 0.5 miles downstream from dam, on right bank.

DATA SOURCE: USGS, Washington District, Tacoma, WA

BEGINNING DATA: Jul. 1,1974 ENDING DATE: Sept. 30, 1979 UNITS: Celsius

DATA DESCRIPTION: Daily observer readings and minimum and maximum values during the 1974-75 water years and minimum, mean, and maximum values during the 1976-79 water year; total of about 5,235 values.

TITLE OF FILE: cr-gcoulee.dat STATION NUMBER: 12436500

COMPLETENESS OF RECORD:

START	END	COMMENTS
7/18/74 --------------------	½/79	daily minimum-maximum record
1/9/79 ---------------------	9/30/79	daily minimum-mean-maximum record

VARIABILITY: Daily variability is usually about 0.5 ºC and up to 1 ºC during the heating and cooling season. Data are reported to the nearest 0.5 ºC.

BIAS: Compared with Rock Island scroll-case temperature data, temperatures are generally cooler 1.0 – 4.0ºC from April to September, warmer 0.0 – 1.0ºC from October to December, and within 0.5ºC from January to March. The data follow trends within the aforementioned bounds.

MONITORING SITE REPRESENTATIVE OF CROSS SECTION: Part of the USGS protocol was to insure the data were representative of the cross section. Pacific States Marine Fisheries Council PSMFC) data in 1973 shows the spill area to be 0.3 - 0.5ºC elevated over the left and right channels; in the spring and early summer, the left channel was 0.1 - 0.3ºC elevated above the right channel and in the late summer the right bank appeared to be elevated 0.1 - 0.2ºC above the left channel. About 7 miles downstream of Grand Coulee Dam, PSMFC data in 1973 show no bias between the left and right channels. About 14 miles downstream of Grand Coulee Dam at Nespelem River, PSMFC data in 1973 show no bias across the channel, what appears to be vertical differences of about 1.0ºC in June, and vertically mixed conditions the rest of the year.

GENERAL COMMENTS: Daily mean values can be estimated by averaging the minimum and maximum values where the daily mean values are not available. Compared with temperatures downstream at Rock Island Dam, the temperatures here are generally cooler in the spring and summer and warmer in the fall. Due to selective withdrawal releases from Lake Roosevelt, temperatures can be modified relative to incoming flows (Northport gage) up to 4.0ºC cooler from June to August, and 2.0 - 4.0ºC warmer from September to December.

GRAND COULEE TDG TAILRACE (GCGW)

DATE COMPILED: March 5, 1998 AL
Revised: April 4, 1998 SWM

STATION LOCATION: at river mile 590.3, on left bank

DATA SOURCE: USACE, Northwestern Division, Portland, OR; data collected by the Bureau of Reclamation

BEGINNING DATA: June 21, 1984 ENDING DATA: Dec. 31, 1997 UNITS: Celsius

DATA DESCRIPTION: From 1984-91, hourly values, 6-12 times per day, and from 1992-97, hourly values for each hour; total of 58,497 values. Daily data file from 1984-97 is 2,395 values. Daily data file includes maximum, minimum, and mean daily values and the variability for the day.

TITLE OF FILE: Daily data: gcgw_tdg84-97d.xls STATION CODE: GCGW
Hourly data: gcgw_tdg84-97.xls

COMPLETENESS OF RECORD:

START	END	COMMENTS	*Suspicious Record*
6/21/84	7/31/84	6-12 hourly values per day	
4/4/85	8/31/85	6-12 hourly values per day	
10/1/85	12/12/85	6-12 hourly values per day	record biased –1.0^{o}C
4/1/86	8/31/86	6-12 hourly values per day	record biased –2.0^{o}C
4/21/87	8/31/87	6-12 hourly values per day	
4/25/88	8/31/88	6-12 hourly values per day	record biased –1.0^{o}C
4/27/89	8/31/89	6-10 hourly values per day	record biased –1.5^{o}C
4/16/90	8/31/90	6-11 hourly values per day	
4/26/91	10/31/91	6-11 hourly values per day	
4/16/92	10/4/92	6-11 hourly values per day	
4/15/93	10/12/93	hourly	
3/5/94	9/20/94	hourly	
4/5/95	9/25/95	hourly	
3/8/96	10/7/96	hourly	
2/5/97	12/31/97	hourly	

VARIABILITY: Variability is within 0.5^{o}C most of the time. During the summer season, when there is regulation upstream and variable heating from the sun, the variation within a day can be as great at 2.3^{o}C.

BIAS: Record with 0.0^{o}C value, >2 times adjacent values, and negative values have been removed. The 1985 record from April 4 to December 12, appears to be biased at least –1.0^{o}C, and from October 1 to December 12, biased as much as –2.0^{o}C. The data from April 25, 1988 through August 31, 1988 seems biased about –1.5^{o}C.

REPRESENTATIVE OF CROSS SECTION: Data collected in the tailrace are generally cooler by -0.5 – 1.5^{o}C than downstream temperatures. The data are probably not representative of the mean in the river cross section for this location.

GENERAL COMMENTS: The record is generally collected seasonally from April to September. It is estimated to be within $\pm$0.5^{o}C except for the periods noted under bias. Due to selected withdrawals, temperature of flows released from Lake Roosevelt can be modified relative to incoming flows (Northport gage) up to 5.0^{o}C cooler in June-August, and 2.0 – 4.0^{o}C warmer September-December.

CHIEF JOSEPH SCROLL CASE TEMPERATURES

DATA COMPILED: 4/2/98 AL
Revised: 4/28/1998 SWM

STATION LOCATION: at river mile 545.1, on left side of dam

BEGINNING DATA: April 1, 1980 ENDING DATE: March 15, 1994 UNITS: Celsius

DATA SOURCE: USACE, Northwestern Division, Portland, OR; data collected by Seattle District

DATA DESCRIPTION: Instantaneous daily with some intervening days estimated and some days with more than one value; total of 4,480 values

TITLE OF FILE: chj_scr80-94.xls STATION CODE: CHJ

COMPLETENESS OF RECORD:

STARTING	ENDING	COMMENTS	Suspicious Record
4/1/80	10/30/80	daily record	
11/28/80	12/27/80	scattered values	
1/1/81	5/26/84	daily record	
6/4/84	7/30/84	scattered values	
8/1/84	10/15/84	daily record	
10/23/84	11/23/84	scattered values	
11/26/84	4/28/85	daily record	
10/18/85	3/25/87	daily record	
1/1/88	4/20/88	daily record	
5/23/88	9/2/88	scattered values	
12/1/88	4/24/90	daily records	
5/1/90	1/4/90	daily record	
1/8/90	3/15/94	scattered values	7/17 – 7/31/91

1994-97 data are available from paper copy only.

VARIABILITY: No daily variability assessment made. From 1980-92, data were generally collected at 16:00 with some values listed at 07:00 and 15:00 times. From 1993-94, data were generally collected at 08:00 with some values at 07:00 and 24:00.

BIAS: Values equal to 0.0ºC, multiples of adjacent values, negative values, and outliers have been removed. The bias is estimated to be generally about 0.2ºC higher than the TDG daily mean values.

MONITORING SITE REPRESENTATIVE OF CROSS SECTION: Pacific States Marine Fisheries Council (PSMFC) data for 1973 shows no bias between the powerhouse and spill sides of the forebay. There is some indication of vertical differences in June, July, and September, with the largest amounts being in July at 2.0 ºC.

GENERAL COMMENTS: The record is relatively complete and accurate from 1980-93. The data look to be recorded on a daily basis with no attempt to fill in missing readings with previous data (this normally gives a stair-step record with the same value repeated for several days). The data are not stair-stepped. The scroll case data tend to run about 0.2ºC higher than those total dissolved gas data collected in the forebay. Data are currently collected at a depth of about 50 feet and at the center of the powerhouse at cooling water header.

CHIEF JOSEPH TDG FOREBAY (CHJ) **DATE COMPILED: April 3, 1998 AL**

Revised: April 28, 1998 SWM

STATION LOCATION: at river mile 545.2, on left side of dam

DATA SOURCE: USACE, Northwestern Division, Portland, OR; data collected by the Seattle District

BEGINNING DATA: May 15, 1984 ENDING DATA: Sept. 13, 1997 UNITS: Celsius

DATA DESCRIPTION: From 1984-90, hourly values, 5-16 times per day; total of 11,175 values. From 1991-97, hourly values for each hour; total of 34,541 values. Daily data file from 1984-97 is 2,238 values. Daily data file includes maximum, minimum, and mean daily values and the variability for the day.

TITLE OF FILE: Daily data: chj_tdg84-97d.xls STATION CODE: CHJ
Hourly data: chj_tdg84-97.xls

COMPLETENESS OF RECORD:

START	END	COMMENTS	*Suspicious Record*
5/15/84 --------------	7/31/84	5-7 hourly values per day	
10/15/84 -----------	11/30/84	9-16 hourly values per day	
3/7/85 ----------------	9/26/86	5-12 hourly values per day	
4/21/87 ----------------	9/3/87	7-12 hourly values per day	
4/22/88 --------------	9/19/88	6-12 hourly values per day	
4/6/89 ----------------	9/12/89	5-10 hourly values per day	
4/16/90 --------------	9/13/90	6-11 hourly values per day	
missing 1991 and 1992 data			
4/15/93 -------------	10/12/93	24 hourly values per day	
3/4/94 -----------------	4/9/94	24 hourly values per day	
5/5/94 ----------------	9/21/94	24 hourly values per day	Data biased –2ºC to –1ºC.
5/3/95 ----------------	9/26/95	24 hourly values per day	
4/1/96 ----------------	9/16/96	24 hourly values per day	
5/5/97 ---------------	12/31/97	24 hourly values per day	

VARIABILITY: Variability is within 0.5ºC most of the time. During the summer season, when there is regulation upstream and variable heating from the sum, the variation within a day can be as great at 0.8ºC.

BIAS: Records with 0.0ºC value, > 2 times adjacent values, and negative values have been removed. March 7, 1985 through March 25, 1985 appears to be biased –2.0ºC. May 5, 1994 through September 21, 1994 appears to be biased from –2.0ºC to –1.0ºC. Data collected in the forebay are generally slightly cooler (–0.2ºC) than temperature data collected in the scroll case for most of the April-September periods.

REPRESENTATIVE OF CROSS SECTION: Pacific States Marine Fisheries Council (PSMFC) data for 1973 shows no bias between the powerhouse and spill sides of the forebay. There is some indication of vertical differences in June, July, and September, with the largest amounts being in July at 2.0 ºC. In the Chief Joseph tailrace, the water temperature in 1972 obtained from PSMFC is sometimes a little higher (.1- .3 ºC) higher on the powerhouse side relative to the spill side

GENERAL COMMENTS: Data are collected at a minimum depth of 15 feet. The record is generally collected seasonally from April to September. It is estimated to be within ±0.5ºC of the mean for the cross section except for the periods March 7-25, 1985, and May 5-September 21, 1994.