Chief Joseph Dam
Columbia River, Washington

GAS ABATEMENT STUDY
General Reevaluation Report

Final

US Army Corps of Engineers
Seattle District

May 2000

INSERT BLANK PAGE

TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

1. INTRODUCTION

In recent years, the combination of higher than average flow conditions requiring flood control spills, and Endangered Species Act (ESA) efforts requiring spill for fish passage have magnified the dissolved gas supersaturation problem throughout the Columbia River system. Total Dissolved Gas (TDG) supersaturation occurs when water, passed over a dam's spillway, plunges deep into the stilling basin where pressures force air bubbles into solution. Large quantities of dissolved air, sometimes referred to as nitrogen supersaturation, can result in gas bubble disease, which can be harmful to aquatic organisms, including fish.

Current state and federal water quality standards for TDG concentrations are 110 percent saturation except when stream flow exceeds a 7-day average, 10-year flood event. The TDG levels downstream of Chief Joseph Dam frequently exceed this standard. In particular, very high levels of TDG were observed below Chief Joseph and Grand Coulee Dams in 1996 and 1997.

High levels of TDG produced at one dam tend to persist far downstream. An exception to this rule would be where the river is free-flowing and natural river features with shallow areas promote off-gassing, such as in the Hanford Reach of the Columbia River. Below Chief Joseph Dam, however, with five pools of slack water behind the five dams, high loading of TDG resulting from operation at Chief Joseph Dam remains as water passes through the powerhouses of downstream dams (see Section 4.3.2). This is particularly significant in light of the recent designation of ESA-listed fish stocks within the study area. Chief Joseph Dam is the upper boundary for the Upper Columbia River Evolutionarily Significant Unit (ESU) for steelhead, as well as the Upper Columbia River ESU for spring chinook. These ESUs were listed as "endangered" under the ESA on August 18, 1997, and March 16, 1999, respectively. Bull trout have also been listed as "threatened" within the Columbia River basin, which includes the study area.

These ESA designations add tremendously to the significance of potential impacts from high TDG releases at Chief Joseph Dam. At present, the dam does not have a means of preventing gas supersaturation under spill conditions. In an effort to improve water quality, the Corps of Engineers undertook this study to identify appropriate cost-effective gas abatement solutions. The study benefited from the extensive work of the team involved in the Columbia River Fish Mitigation Program's Dissolved Gas Abatement Study, including Walla Walla and Portland Districts and the Corps Waterways Experiment Station (WES).

1.1 Study Authority

Authority for the Chief Joseph Dam Gas Abatement Study and any subsequent construction is provided by the Fish and Wildlife Coordination Act. Following ESA listing of Columbia and Snake River system steelhead populations as threatened and endangered, the National Marine Fisheries Service (NMFS) issued the Supplemental Biological Opinion for Operation of the Federal Columbia River Power System regarding these populations on May 14, 1998 (1998 BiOp). The 1998 BiOp identifies actions to be taken to avoid jeopardizing steelhead populations, including the following:

> "The Action Agencies, in coordination with National Marine Fisheries Service and the Regional Forum, shall jointly investigate operational and structural gas abatement measures at Grand Coulee and Chief Joseph Dams as part of the system-wide evaluation of gas abatement measures."

> "The action agencies shall coordinate with the Dissolved Gas and System Configuration Teams to identify gas abating alternatives, future actions, implementation schedules and future funding requirements for gas abatement at Grand Coulee and Chief Joseph Dams. The action agencies shall seek Congressional authority and funding, as necessary, to implement the selected preferred alternatives."

1.2 Study Purpose and Scope

1.2.1 Study Goal

The purpose of the Chief Joseph Dam Gas Abatement Study is to identify and examine alternatives to provide the Corps of Engineers better opportunities to meet environmental stewardship responsibilities in the area of water quality. The ultimate goal of the study is to identify means for reducing TDG contributions from Chief Joseph Dam, to the extent economically, technically, and biologically feasible.

1.2.2 Study Scope

In pursuit of goals and objectives, the study aims to address concerns posed in the 1998 BiOp regarding impacts of high TDG levels on ESA-listed fish stocks in the Columbia River System. The scope of the 1998 BiOp directive was broad and recommends study of both structural and operational solutions. The BiOp states: "Lower dissolved gas levels from Grand Coulee and Chief Joseph Dams would reduce background TDG levels caused by these projects…". It has been shown that this background TDG passes throughout the system far below the Chief Joseph Dam tailwater. Reducing background TDG contributions from Chief Joseph is expected to limit the duration of exposure of adult steelhead to high dissolved gas concentrations and to improve passage survival of juvenile steelhead and salmon by allowing increased spill at downstream projects.

While the 1998 BiOp addresses only anadromous fish, there is now more attention to resident fish. Several reports address resident fish kills in Rufus Woods Lake. Bull trout, known to recently use at least one of Lake Pateros's tributaries, have been listed as "threatened" by the US Fish and Wildlife Service and are protected under the Endangered Species Act. Plates 1-1 through 1-4 show the study area, including these lakes.

The scope of structural alternatives to attain reductions in TDG levels addressed within this study is limited to Chief Joseph Dam. The scope of operational alternatives includes changes at both Chief Joseph and Grand Coulee Dams. While the scope of impacts addressed in the study focuses on water quality (and resultant fishery) impacts immediately below Chief Joseph Dam, downstream impacts throughout the Columbia River system are also addressed. Because TDG at Chief Joseph Dam is dependent in part on TDG inputs from Grand Coulee Dam, the scope also includes impacts of operation at Grand Coulee. Joint operation of the two projects has been discussed in several forums:

- At a September 1998 meeting of the Corps, Bureau of Reclamation (BOR) and Bonneville Power Administration (BPA), BOR proposed a study of placing flow deflectors at Chief Joseph for gas abatement purposes in lieu of deflectors at Grand Coulee.

- In response to language in the 1998 BiOp, the Corps, Bureau of Reclamation and Bonneville Power Administration initiated a system study to examine joint operation of

Chief Joseph and Grand Coulee Dams in January 1999. Within this system study, a numerical model (SYSTDG) of TDG was developed. Section 4.3.2 of this GRR includes results of the system study that pertain to Chief Joseph and Grand Coulee Dams.

- At a meeting of the NMFS Regional Forum in the late 1999, BOR supported the joint operation of Chief Joseph and Grand Coulee Dams in a discussion of the Chief Joseph Gas Abatement Study.

1.3 Study Area

The study area lies within the Upper Columbia River Basin, part of the Columbia and Snake River system, which drains most of the Pacific Northwest (Plates 1-1, and 1-2). Chief Joseph Dam is located at river mile 545 on the Columbia River, near Bridgeport, Washington. The primary area of study ranges from Grand Coulee Dam at the upstream end to the Wells Dam forebay at the downstream end (Plates 1-3 and 1-4). Chief Joseph Dam is located 51 miles downstream of Grand Coulee Dam and 30 miles upstream of Wells Dam. Because dissolved gas from Chief Joseph Dam can persist far downstream, the study area also includes the Columbia River downstream of Chief Joseph Dam through Priest Rapids Dam (see Plate 1-2).

The pool behind Chief Joseph Dam is called Rufus Woods Lake. The reach from Chief Joseph to Wells Dam includes Lake Pateros, the Wells Dam reservoir. There are no major tributaries to the Columbia River between Grand Coulee and Chief Joseph, but flows from the Okanogan and Methow Rivers enter the Columbia between Chief Joseph and Wells Dam downstream.

1.4 Columbia River System Uses

The Columbia River is a complex and heavily utilized resource in the Pacific Northwest. The region depends on the river for much of its energy through hydroelectric generation, food and fiber through irrigation, transportation through navigation, recreation, fisheries, and to a lesser extent municipal and industrial water supply. Development of dams and storage reservoirs within the basin has taken place to meet the often competing uses of the river and its major tributaries. How these various projects are operated determines the extent to which certain river uses can be met.

The existing Columbia River Hydropower System has been developed in the last 65 years by Federal and non-Federal interests. This hydropower system presently accounts for nearly 80% of the energy development in the Pacific Northwest. There are two types of projects in the Columbia River System: run-of-river and storage. Run-of-river projects have limited opportunity for reservoir regulation since they have little storage capability and have been developed primarily for hydropower. Chief Joseph Dam is a run-of-river project that was authorized 100% for hydropower production. Rather than storing water, run-of-river projects must pass water at essentially the same rate that it enters. Storage projects alter streamflow patterns, providing power peaking capability, as well as seasonal flow alteration for regional benefits such as flood control, water supply for irrigation, and flow augmentation for fish migration. Grand Coulee Dam, upstream of Chief Joseph Dam, is a storage project. Wells Dam, downstream of Chief Joseph, is a run-of-river project.

Chief Joseph and Grand Coulee are both part of the Federal Columbia River Power System. The regional power system is supplied with electricity that is generated at both hydroelectric and thermal-electric powerplants. An essential component to the regional power system is the transmission system that extends from generation sources to users. Transmission is accomplished by a complex network of powerlines and substations that extend throughout the region and on to California. Many of these lines are owned and operated by the Bonneville Power Administration (BPA). BPA markets all of the power produced at the Federal projects and exchanges power from the non-Federal utilities over its grid. This extensive grid has contributed significantly to the development of the coordinated operation of all generating facilities to meet the loads of the region.

All major reservoirs of the Columbia River system are operated in a coordinated manner in an effort to maximize utilization of the reservoirs. This coordinated operation occurs consistent with the operating constraints that exist for each project. These constraints are established either through physical plant limitations or legally established limits through the authorizing documents or FERC licensing for individual projects. Other factors serve as targets for operation at each facility including state water quality standards concerning TDG.

1.5 System Operation

Historically, the two dominant functions of the reservoir system in the Columbia River Basin have been power generation and flood control. Others added in recent years include the need to maintain high flows in certain seasons to aid the downstream migration of juvenile salmon and steelhead and the need to maintain higher lake levels for resident fish. The Corps of Engineers began to look at gas abatement in the 1970's. At Chief Joseph, the forebay dissolved gas sensor was added in the mid-1980's and the tailwater sensor (below the spillway) was added in 1997 (see Plate 1-5 for sensor locations). The high levels of TDG recorded by the downstream sensor led to refinement of operation at Grand Coulee and Chief Joseph for water quality (TDG reduction) starting in 1997. This monitoring of TDG in the study area since 1997 is a significant issue for this study and defines the baseline condition.

The following paragraphs describe the contributions of hydropower, flood control, and fish passage operations to TDG.

The demand for water from the reservoirs for power generation occurs throughout the year. It reaches a peak in winter, when homes and businesses need heating, and in summer for air-conditioning. Demand is lowest in spring. Thus, from the standpoint of power generation, the objective of storage reservoir operation is to store snowmelt runoff in the spring and early summer, for release from storage in the fall and winter when streamflows are lower and power demand is higher. On a daily basis, power demand is generally higher during the day and lower at night. In most water years, this can result in the need to occasionally spill water at Chief Joseph and Grand Coulee at night, contributing to high TDG levels. Without a load for the power, it cannot be passed through the power units.

The goals of hydropower operation are generally compatible with flood control requirements. The primary goal of flood control is to reduce high streamflows during the spring runoff to protect areas below dams. Reservoir levels in storage projects are drawn down preceding the runoff season to provide storage for high spring flows. If snowmelt and runoff occur too quickly, floods can occur requiring spill, which in turn can result in high TDG levels.

Significant portions of salmon and steelhead migrations (both upstream and downstream) occur during the spring and summer in the Columbia-Snake River System. The success of juvenile migration downstream through the Columbia and Snake River hydropower projects in the spring and summer has been the focus of a multi-billion-dollar effort over recent years. To improve juvenile fish survival, changes have been made in the operation of the lower Columbia River projects that affect operations at Chief Joseph and Grand Coulee Dams. In the early 1980's the Northwest Power Planning Council, in consultation with Congressional leaders, project operators, fishery agencies, Indian Tribes, and Northwest utilities, established the Water Budget.

It is a specific amount of water used to increase river flow during the spring, when many juvenile salmon use snowmelt runoff to migrate to the sea. The increased flow adds momentum through the series of reservoirs, to help “flush” fish down the river and reduce their exposure to predators and other hazards. Providing the Water Budget sometimes requires water to be spilled from reservoirs, aiding in fish passage but contributing to higher TDG concentrations.

1.5.1 Ongoing System Operation Approaches

In March 1998, the System Configuration Team and the Dissolved Gas Team, two coordination groups of the National Marine Fisheries Service (NMFS) Regional Forum, were given the task to begin developing a system-wide approach to dissolved gas management and abatement for the entire Columbia Basin. Previous and ongoing efforts have concentrated on reducing dissolved gas levels at individual dams or through particular river reaches, such as the lower Snake and Columbia Rivers. This new system-wide effort, on the other hand, aims to characterize the location and extent of dissolved gas level produced by dams on the mainstem and major tributaries of the Columbia and Snake Rivers. The geographic scope of this cooperative effort includes river basins in British Columbia, Canada and the states of Oregon, Washington, Idaho and Montana.

Two separate studies have begun with the goal of assessing TDG from a system perspective. The Transboundary Gas Group was formed in 1998 to work on a comprehensive system-wide evaluation that encompasses the entire Columbia River Basin and involves the work of numerous Canadian and U.S. agencies and utilities. In response to the 1998 Supplemental BiOp, which requested that the Action Agencies jointly investigate gas abatement measures at Grand Coulee and Chief Joseph Dams, a smaller effort focusing on mainstem Columbia and Snake River dams within the U.S. was initiated in January 1999. The Corps, Bureau of Reclamation, and BPA are jointly working on a system study to evaluate the gas abatement relationships at 15 dams from Grand Coulee to the mouth and including the lower four Snake River Dams (Plate 1-9). Results of the Chief Joseph Dam Gas Abatement Study will be included in these larger, system-wide evaluations.

1.6 Chief Joseph Dam Project Description

Chief Joseph Dam was constructed from 1949 to 1958 for the purpose of hydropower generation. Secondary purposes of the facility include irrigation and recreation. The run-of-river dam consists of a 19-bay gated concrete gravity spillway, which abuts the right bank and connects to a curved non-overflow concrete section founded on a rock outcropping. The intake structure and powerhouse follow a downstream alignment and connect to the left abutment by means of a curved concrete gravity non-overflow dam. A project plan, and spillway plan, section and elevation are shown on Plates 1-5 through 1-7. Plate 1-8 provides an aerial view of the facility.

The Chief Joseph Dam forebay (Rufus Woods Lake) receives all flows from Grand Coulee Dam with the exception of water diverted into Banks Lake. The volume of this diversion is insignificant relative to spill season flows in the larger runoff years when gas abatement would play a larger role. Chief Joseph Dam discharges into the forebay of Wells Dam (Lake Pateros). Lake Pateros can encroach, or backwater, up to the powerhouse of Chief Joseph, thereby decreasing power produced at Chief Joseph Dam. Douglas County PUD, owners of Wells Dam, reimburses the Corps and BPA for lost energy due to this encroachment. The reimbursement is in the form of energy which BPA markets and that energy is credited to the Chief Joe account. The maximum operating pool at Wells Dam is elevation 781.

Chief Joseph Dam has a 27-unit powerhouse with two station service generators. Sixteen units were installed during initial construction. Eleven additional turbine generators were installed by 1979 to meet peak regional power demands and to reduce the frequency of spill. The initial sixteen units have 88,250-kilowatt generators and the additional eleven have 100,000-kilowatt generators with a nameplate capacity of 2,402,000 kilowatts. The station service units are used for power at the project. The powerhouse has a total capacity of 219,000 cubic feet per second (cfs). The powerplant produces enough power to supply the electrical needs of over 1.5 million people.

In order to produce additional power, Rufus Woods Lake was raised 10 feet in February 1981. Since the early 1980's, Chief Joseph Dam is normally operated within a 6-foot elevation range close to the full pool elevation of 956 feet.

1.7 Climate

Chief Joseph Dam is located east of the Cascade Mountains in a near desert environment. Mean annual rainfall is 7-8 inches and mean annual snowfall is about 18 inches. Average daily high temperatures range from less than 30^{o} F in January to over 90^{o} F in August. Likewise, average daily low temperatures range from less than 20^{o} F in January to roughly 65^{o} F in August. Extreme values range from –15 ^{o} F to over 110 ^{o} F and diurnal temperature fluctuations of 30^{o} F or more are not uncommon. Weather statistics collected from 1961 to 1990 at the Ephrata, Washington airport are shown in Plate 1-10.

1.8 Prior Studies and Reports

US Army Corps of Engineers, Seattle District, Initial Appraisal Report, Total Dissolved Gas Abatement at Chief Joseph Dam, May 1998.

The Initial Appraisal Report documents the preliminary phase of study for the Chief Joseph Dam Gas Abatement Study. The report presents the identification of preliminary alternatives and documents the criteria for and results from initial screening. The report presents recommendations for further study. Much of the assumptions and findings of the report are documented in this General Reevaluation Report.

US Army Corps of Engineers, North Pacific Division Hydraulic Laboratory, Spillway Modifications for Chief Joseph Dam; Columbia River, Washington – Hydraulic Model Investigation; May 1979.

This report presents findings of a hydraulic study of spillway modifications to increase power production by raising the level of the forebay pool and adding generating units. The pool was to be raised 10 feet initially and later an additional 14 feet. The analysis included study of a flow deflector on the spillway just below tailwater to divert the nappe of discharges as large as the 10-year flood along the surface of the tailwater in the stilling basin to reduce the amount of air forced into solution.

U.S. Department of the Interior, Bureau of Reclamation, Structural Alternatives for TDG Abatement at Grand Coulee Dam (Preliminary Concepts Report), February 1998.

This study identified structural solutions to address high TDG generation at Grand Coulee Dam. The report presents 8 alternatives, similar to those addressed in the Chief Joseph Dam GRR study. The report provides preliminary cost estimates and a comparison of alternatives. The study was used as a reference in the Chief Joseph GRR study.

Bonneville Power Administration, US Army Corps of Engineers, and US Bureau of Reclamation. 1995. Columbia River System Operation Review, Final Environmental Impact Statement. DOE/EIS-0170. Portland, OR.

In 1995, an environmental impact statement for the System Operation Review was completed concerning operation of the 14 Federal Columbia River Power System dams. The water quality analysis (Appendix M) examined dissolved gas, and predicted that under the preferred alternative, dissolved gas generation by Chief Joseph Dam would not exceed 120% saturation, and would exceed 110% saturation from 18 to 69 days per year. The preferred alternative was adopted as the current operational regime. It is primarily based on the 1995 Biological Opinions of the National Marine Fisheries Service (NMFS, 1995) and the US Fish and Wildlife Service (Dwyer, 1995) concerning effects of dam operation on endangered salmon and sturgeon.

National Marine Fisheries Service. 1995. Endangered Species Act - Section 7 Consultation, Biological Opinion, Reinitiation of Consultation of 1994-1998 Operation of the Federal Columbia River Power System and Juvenile Transportation Program in 1995 and Future Years. Northwest Region, Seattle, WA, March 2, 1995.

National Marine Fisheries Service. 1998. Endangered Species Act Section 7 Supplemental Biological Opinion on the Operation of the Federal Columbia River Power System including the Smolt Monitoring Program and Juvenile Fish Transportation Program: A Supplement to the Biological Opinion Signed on March 2, 1995, for the same projects [Consultation number 1005]. Northwest Region, Seattle, WA, May 14, 1998.

The 1995 BiOp and 1998 Supplemental BiOp provided the impetus for the Chief Joseph Dam Gas Abatement Study. Actions directed by the BiOps, included identification of alternatives, future actions, and implementation schedules for gas abatement at Chief Joseph and Grand Coulee Dams. The BiOp also directed the action agencies to seek Congressional authority and funding to implement selected alternatives.

Independent Scientific Advisory Board for the Northwest Power Planning Council. 1998. Review of the U.S. Army Corps of Engineers' Capital Construction Program, Part II.B. Dissolved Gas Abatement Program.

This report presents the findings of the ISAB's evaluation of how the Gas Abatement Program at mainstem dams fits within the context of the Columbia River Ecosystem. The report makes the recommendation that "the Corps should continue its Gas Abatement Program to reduce dissolved gas supersaturation levels in the mainstem Columbia and Snake Rivers…".

2. BASELINE (WITHOUT PROJECT) CONDITIONS

2.1 Existing Conditions

This section describes existing baseline conditions within the study area. Specific categories of conditions include hydrology, hydraulics, system operating practices, water quality, environmental resources, hydropower production, recreation, and irrigation. The existing and without project conditions are used to compare against with project conditions of each alternative solution to identify impacts.

2.1.1 Hydrology

The climate in the Columbia River Basin ranges from a moist, mild maritime condition near the mouth of the river to a near desert climate in some of the inland valleys to the east of the Cascades. The Cascade Mountain Range separates the coast from the interior and has a strong influence on the climate of both areas. East of the Cascades, most of the precipitation falls as snow in the mountains. Snow accumulates and water is held in natural storage until temperatures rise, causing the spring runoff. Streamflows begin to rise in mid-April, reaching a peak flow during May or early June. Fluctuations in streamflow are caused by variations in sunlight and air temperature. Occasionally, rainfall adds to the runoff. Rain and snowmelt over the low-lying portions of the basin in the winter can raise streamflows and cause flooding.

Peak inflow to Chief Joseph Dam was significantly reduced by the addition of upstream storage projects (upstream of Grand Coulee in the Upper Columbia Basin). The last of these projects was completed in 1974. Consequently, discharge frequency relations based on data points prior to 1974 are no longer relevant. The 1-day and 7-day discharge-frequency relations based on the period of record from 1974-1997 are shown in Plates 2-1 and 2-2. The 10-year 7-day flow is significant in that flows above this level that occur during flood conditions are not subject to state and federal water quality standards. Results from the Initial Appraisal Report efforts (see Section 1.8) were based on a 10-year 7-day discharge of 250,000 cfs. During the course of this study, the State of Washington finalized their methods for determining the 10-year 7-day flow.

Based on this recent information, the 10-year 7-day flow used for the remainder of the study has been calculated to be 241,000 cfs. The 10-year 1-day discharge is 254,000 cfs.

Seven-day average peak flows provide a useful way to examine frequency of spill at Chief Joseph Dam. The 7-day peak, rather than the 1-day peak, relates more closely to the large volumes of water over several days in the river during the snowmelt season. For this purpose, the years after 1980 when the additional power units were completed are most relevant. The volume of water and number of days on which spill occurs are highly variable (Plate 2-3). The years during which spill occurs have 7-day average peak flows that are roughly 2-year events (170,000 cfs) or greater. The years with large spills that would impact water quality have 7-day average peaks that are 4-year events (205,000 cfs) or greater.

2.1.2 Hydraulics

Chief Joseph Dam has a 27-unit powerhouse and a 19-bay gated concrete gravity spillway, which abuts the right bank. The powerhouse has a total capacity of 219,000 cfs and can generate up to 2.5 million kilowatts. Each of the 19 spillway bays is controlled by a 36-foot wide by 58-foot high tainter gate. In total, the bays are designed to pass releases up to 1,200,000 cfs, the probable maximum flood (PMF), at a maximum water surface elevation of 958.8 feet. The spillway consists of a standard ogee shape, high overflow structure with a crest elevation of 901.5 feet.

The spillway chute slopes at 143 percent into a hydraulic jump stilling basin, which is a 167-foot-long horizontal concrete apron with a single row of baffles and a stepped end sill. The invert of the basin apron is at elevation 743 feet. The stilling basin was designed to provide adequate hydraulic energy dissipation for all flow conditions up to the design discharge.

2.1.3 Water Quality

2.1.3.1 Chief Joseph Dam Inflow TDG

Inflow into Grand Coulee's reservoir, Lake Roosevelt, experiences high dissolved gas levels as a result of dam operations upstream in both Canada and the United States. Grand Coulee's powerhouses transfer high TDG levels from Lake Roosevelt to Rufus Woods Lake where TDG levels routinely are above state and federal standards. Rufus Woods Lake backwaters to the tailrace of Grand Coulee Dam. The lack of free-flowing river between Grand Coulee and Chief Joseph limits the reduction in TDG via off-gassing to the atmosphere between the two dams. Chief Joseph Dam is a run-of-river project with little usable storage. High flows from Grand Coulee pass through the pool unchanged. Low power demand during the higher spring flows results in more spill and less power generation during the nighttime hours. Rufus Woods Lake has a maximum storage capability of 593,000 acre-feet at an elevation of 956 feet. Although the project is not regulated for flood control, project discharge during flood control operations is specified by the Corps of Engineers Reservoir Control Center.

2.1.3.2 TDG Measurements

TDG sensors are permanently installed in the dam forebay near the left bank by the powerhouse and close to the right bank, ¾-mile downstream from the dam (sensor location shown on Plate 1-5). The downstream sensor was installed in 1997 and spill pattern tests were conducted to determine the flow characteristics below Chief Joseph Dam. A near-field test was conducted in June 1999 to further examine gas production dynamics. The study was directed at describing spatial and temporal dynamics in TDG both near the structure and downstream in the receiving waters. The production and transfer of dissolved gas is thought to be a function of the unit spillway discharge, spill pattern, spillway geometry, stilling basin and tailwater depth, flow conditions, forebay TDG concentration, project head differential, and water temperature. The June 1999 field test deployed data logging sensors as shown on Plates 2-4, 2-5, and 2-6 that collected TDG saturation data every five minutes for a week. In addition, velocity measurements were collected throughout Lake Pateros using a highly accurate Acoustic Doppler Current Profiler.

Dissolved gas studies at Chief Joseph Dam have determined that the downstream sensor measures TDG levels in the spilled water before it mixes with powerhouse flow. A model study on spillway modification, completed in 1979, confirms these observations. Plate 2-7 shows stilling basin and tailwater velocities under a very large flow of 440,000 cfs with all 27 units and 19 spillway bays operational. TDG resulting from spill is also dependent on tailwater depth. Other parameters influence TDG to a lesser extent.

May and June of 1997 were periods of large spill all over the Columbia River Basin. Dissolved gas levels as high as 144 percent were measured at the downstream monitoring site in June during flood control operations (Plate 2-8). This corresponded to an extended 2-day spill of approximately 170,000 cfs. These high TDG levels triggered much of the concern over dissolved gas at Chief Joseph Dam. The 7-day peak flow in 1997 (297,000 cfs with a return period of ~33 years) is much higher than the design flow of this dissolved gas abatement study (241,000 cfs). However, during the 1997 spill season (March – June), 75 percent of the hourly flows were less than or equal to the design flow of 241,000 cfs and as such provide a useful set of data for examining spill when total river flow is within the design conditions.

2.1.3.3 The Spillway

The spillway at Chief Joseph Dam behaves similarly to spillways at other dams in that dissolved gas supersaturation is closely related to unit flow over the spillway (expressed as cfs/ft) and depth of the stilling basin. Because of the depth of the stilling basin at Chief Joseph (40+ feet), higher unit flows result in deeper plunges and thus entrain more gas. If inflow to Rufus Woods Lake were to meet the state standard of 110 percent, Chief Joseph Dam would be able to release only about 10,000 cfs without raising gas levels downstream (Plate 2-9).

Examination of the data collected in 1997 and in the 1999 near-field study revealed an influence of tailwater depth on TDG resulting from spill. Plate 2-10 shows TDG as a function of both spill and tailwater depth. The curves were empirically developed based on the two data sets.

2.1.3.4 The Powerhouse

A transect study of the tailrace in May 1997 and the near-field study of June 1999 verified TDG levels found in the forebay are passed through the powerhouse to the tailrace. Forebay levels of dissolved gas passed to Chief Joseph Dam from Grand Coulee Dam during the 1997 spill season ranged from a low of 103% in early March to a high of 136% in early June. Under flow conditions similar to the 7-day, 10-year flow of 241,000 cfs, forebay TDG was about 123%. Although the 7-day peak in June 1997 was much higher than flow conditions assumed for this study, flows less than 241,000 cfs were observed during 75% of the spill season.

2.1.3.5 Water Quality Assumptions

To establish the without project condition, an existing condition time series of hourly TDG values was computed for the mixed river below both Chief Joseph and Grand Coulee Dams using a weighted average of forebay TDG, spill rate, power release, and observed spill TDG. As an example of this calculation, an average forebay TDG concentration of 123 percent was assumed. The characteristic relationship for spill and TDG (Plate 2-9) yields 134 percent for a spill of 80,000 cfs. TDG levels produced by operation of the existing structure are calculated to be 127 percent in the mixed river a few miles below Chief Joseph Dam when this spill is added to a power release of 170,000 cfs (Plate 2-11). This value was used throughout the Initial Appraisal Report to compare the predicted TDG benefit for each alternative with respect to the existing conditions. However, for this General Reevaluation Report, a more sophisticated model of gas production and transfer based on 1997 data and the June 1999 near field study has been developed for Grand Coulee and Chief Joseph Dams. This model uses the weighted average method described above to develop a time series of TDG values below Grand Coulee and Chief Joseph Dams for the baseline condition and for each of the final alternatives.

2.1.3.6 Tributaries Below Chief Joseph Dam

The Methow and Okanogan Rivers below Chief Joseph Dam have a minor dilution effect on downstream TDG levels. Wells Dam is also a run-of-river project and backwaters up to Chief Joseph, so there is little chance for significant off-gassing downstream of Chief Joseph Dam. A small amount of off-gassing may occur in Lake Pateros, the reservoir of Wells Dam, where the river widens and is much shallower near Brewster Flats.

2.1.3.7 Columbia River Fish Mitigation Total Dissolved Gas Program

Voluntary spill is currently used at most of the mainstem Columbia and Snake River dams to meet passage goals of juvenile salmonids. Unfortunately, the large spillway releases result in high concentrations of total dissolved gas supersaturation. Voluntary spillway releases for fish passage are often limited in order to comply with water quality standards pertaining to TDG concentrations.

Before the Columbia River fish mitigation program, the Corps of Engineers watched for compliance and documented deviations, but rarely modified operations based on TDG concentrations. After the 1995 Columbia River Biological Opinion, the Corps instituted a policy on voluntary spill for fish passage, and spill caps were established for the Lower Columbia River to keep TDG at or below state waiver values. The States generally issue water quality waivers for the Lower Columbia and Snake dams allowing up to 115 percent forebay and 120 percent tailwater saturation during the fish passage season. Exceedance of the waivers leads to restricted spill, normally starting the next day. Criteria include a daily (12 highest hours) average limited to 115/120 percent and a highest (1 or 2 hour) TDG concentration limited to 125 percent. Involuntary spills, caused by high runoff, emergencies, or scheduled operation and maintenance, are normally not subject to any restriction. While Chief Joseph Dam is not specifically mentioned in the water quality variance issued for Lower Columbia River dams with fish passage, it is assumed that the waiver extends upriver to Chief Joseph. The State of Washington Department of Ecology has supported installation of flow deflectors at Chief Joseph Dam as a gas abatement method. The Department of Ecology is aware of the limitations of flow deflectors in meeting a standard of 110% in the higher flow range. Ecology's support extends to this alternative, which is likely to meet a gas level of 120% in the higher flow range.

2.1.4 Fish and Wildlife

2.1.4.1 Fish

There are several species of fish above and below Chief Joseph Dam; many of which were introduced from outside the Columbia basin. Table 2.1 lists species presence in the mid-Columbia River and the three uppermost US mainstem reservoirs. Some of these species are more subject to disease from exposure to dissolved gas than are others. The salmonids and other pelagic or surface-oriented species are among these.

Of special concern for this study are several stocks of anadromous and resident fish which are listed as threatened or endangered under the Endangered Species Act and which also occur in the vicinity of (and/or downriver from) Chief Joseph and Grand Coulee Dams. These Evolutionarily Significant Units (ESUs) or populations of threatened and endangered fish within the study area include:

Species	**ESU or population**	**Spawning Migration in Columbia River**	**Spawning**
Steelhead (endangered)	Upper Columbia	July-June	March-July
Chinook (endangered)	Upper Columbia spring	March-June	Aug-Sept
Bull trout (threatened)	Columbia basin	n.a.	Sept-Oct

Table 2.1 - Fish Species from the Columbia River (Lake Rufus Woods, Lake Roosevelt, and Lake Pateros)**

Family / Species	Mid-Columbia	Lake Pateros	Lake Rufus Woods	Lake Roosevelt
Petromyzontidae—Lampreys				
Pacific lamprey (*Entosphenus tridentatus)**	X	X		
Acipenseridae—Sturgeons				
White sturgeon (*Acipenser transmontanus*)*	X		X	X
Salmonidae—Whitefish, Trout, Salmon, Char				
Mountain whitefish (*Prosopium williamsoni*)*	X	X	X	X
Lake whitefish (*Coregonus clupeaformis*)*		X	X	X
Cutthroat trout (*Oncorhynchus clarki*)*			X	X
Rainbow trout (*Oncorhynchus mykiss*)*	X	X	X	X
Kokanee (*Oncorhynchus nerka*)*	X		X	X
Sockeye salmon (*Oncorhynchus nerka*)*	X			
Chinook salmon (*Oncorhynchus tshawytscha*)*	X	X		
Coho salmon (*Oncorhynchus kisutch*)*	X	X		
Steelhead (*Oncorhynchus mykiss*)*	X			
Brown trout (*Salmo trutta*)			X	X
Bull trout (*Salvelinus confluentus*)*	X		X	X
Brook trout (*Salvelinus fontinalis*)			X	X
Esocidae—Pikes				
Northern pike (*Esox lucius*) (unconfirmed)			X	
Cyprinidae—Minnows				
Chiselmouth (*Arcocheilus aleutaceus*)*	X	X	X	X
Carp (*Cyprinus carpio*)	X	X	X	X
Peamouth chub (*Mylocheilus caurinus*)*	X	X	X	X
Northern pikeminnow (*Ptychocheilus oregonensis*)*	X	X	X	X
Speckled dace (*Rhinichthys osculus*)*			X	
Redside shiner (*Richardsonius balteatus*)*	X	X	X	X
Chub (unknown)				
Catostomidae—Suckers				
Sucker spp. (*Catostomus* spp.)*		X		
Longnose sucker (*Catostomus catostomus*)*			X	X
Bridgelip sucker (*Catostomus columbianus*)*	X	X	X	X
Largescale sucker (*Catostomus macrocheilus*)*	X	X	X	X
Ictaluridae—Catfishes				
Black bullhead (*Ictalurus melas*)	X			
Brown bullhead (*Ictalurus nebulosus*)	X	X		
Yellow bullhead (*Ictalurus natalis*)		X		
Gadidae—Cods				
Burbot (*Lota lota*)*			X	X
Gasterosteidae—Sticklebacks				
Threespine stickleback (*Gasterosteus aculeatus*)*	X			
Percopsidae—Troutperches				
Sandroller (*Percopsis transmontana*)	X			
Centrarchidae—Bass and Sunfishes				
Black crappie (*Pomoxis nigromaculatus*)		X	X	
Largemouth bass (*Micropterus salmoides*)		X		
Smallmouth bass (*Micropterus dolomeui*)	X	X		X
Pumpkinseed (*Lepomis gibbosus*)	X	X		X
Bluegill (*Lepomis macrochirus*)	X	X		
Percidae—Perches				
Yellow perch (*Perca flavescens*)		X	X	X
Walleye (*Stizostedion vitreum*)		X	X	X
Cottidae—Sculpins				
Prickly sculpin (*Cottus asper*)*		X	X	
Paiute sculpin (*Cottus beldingi*)*				X
Torrent sculpin (*Cottus rhotheus*)*			X	
Sculpin (*Cottus* spp.)*	X			

** Indicates species native to the Columbia basin.*

***Table from Chief Joseph Dam Dissolved Gas Abatement Draft Environmental Assessment, February 2000*

2.1.4.1.1 Threatened and Endangered Fish

The following paragraphs provide general information about these three species of listed fish and their presence within the study area:

Bull Trout: Bull trout distribution includes the areas below Chief Joseph Dam in the mid-Columbia River and associated tributaries. Bull trout are also thought to be present in Lake Rufus Woods. Of the tributaries in the mid-Columbia River, the Wenatchee, Entiat, and Methow Rivers have the best recorded populations of bull trout. Bull trout were also documented in the Okanogan River in 1953, but little information has come from that drainage recently. Bull trout found in the mainstem Columbia River are typically seen in fish ladder sightings at Wells Dam and other projects downstream of Chief Joseph Dam. Little information has been documented for bull trout habitat resident in the larger river systems of the Pacific Northwest. However, research from small rivers and tributaries does point to specific habitat requirements of bull trout. Temperature, channel stability, winter high flows, summer low flows, substrate, cover, and the presence of migration corridors consistently appear to influence bull trout distribution or abundance.

Upper Columbia River Steelhead: Wild steelhead runs into the Wenatchee, Entiat, and Okanogan rivers reached such low levels by the mid 1990s that the NMFS listed them as endangered (NMFS, Federal Register, Vol. 62. No 159, August 18, 1997). Although runs were seriously depleted by commercial harvest in the late 1800s and early 1900s, the Wenatchee, Entiat, Methow, and Okanogan rivers are still the primary producers of steelhead in the Middle Columbia River near the project area. The Okanogan River is now the uppermost tributary of the Columbia used by steelhead. Poorly screened or unscreened irrigation diversions on tributaries and the mainstem downstream of Chief Joseph Dam, inadequate flows and damage to spawning and rearing areas by logging, livestock, and mining caused further decline of the steelhead runs. All of the upper Columbia subbasins are supplemented with hatchery fish from broodstock collected at Wells Dam (NPPC, 1991). Although the population is extremely small, steelhead from the Okanogan River are the most likely to become available to the project area. Tribal catch records represent the best current information for steelhead presence upstream of the Okanogan River and areas adjacent to the project.

Upper Columbia River Spring Chinook: Spring chinook salmon of the Upper Columbia River have been listed as endangered under the ESA. This ESU covers the project area up to the base of Chief Joseph Dam. The Entiat and Methow Rivers are the two rivers closest to the project area that support spring chinook populations. Upriver spring chinook migrate through the Columbia River from March through June. Spawning timing ranges from August to September. All upper Columbia River spring chinook likely to be found in the project area are of native origin. The Okanogan River does have a chinook population; however, it is a summer-run chinook stock not currently afforded protection under the ESA.

2.1.4.1.2 Presence of Endangered Fish in Study Area

Counts are kept on anadromous fish transiting Columbia River dams. Table 2-2 details recent trends in counts of salmonid adults and jacks at four of the five mid-Columbia public utility dams downstream from Chief Joseph Dam. Plates 2-12 and 2-13 present trends from this data for the listed stocks (spring chinook and steelhead) at Wells, Rocky Reach and Rock Island Dams.

Table 2.2 - Adult Fish Counts at Mid-Columbia River Dams (1994-1998)

Year	Species and run	Counts by Project			
		Wells	Rocky Reach	Rock Island	Priest Rapids
1994	CHINOOK	8266	12064	24364	32892
	Spring	258	360	2038	3127
	Summer	4991	6176	13179	15500
	Fall	3017	5528	9147	14265
	Jacks	948	1437	3198	3097
	STEELHEAD	2183	2818	5620	6706
	SOCKEYE	1666	1680	11368	12385
	COHO	3	6	18	0
	Adults	3	6	18	
	Jacks				
1995	CHINOOK	4345	9614	21571	30542
	Spring	107	248	934	1208
	Summer	3056	4704	11319	12608
	Fall	1182	4662	9318	16726
	Jacks	505	1226	4680	3994
	STEELHEAD	945	1758	4175	4357
	SOCKEYE	4892	4988	9462	9186
	COHO			6	11
	Adults				11
	Jacks				
1996	CHINOOK	3694	9797	18079	26836
	Spring	387	569	2150	2183
	Summer	2390	5230	10272	11328
	Fall	917	3998	5657	13325
	Jacks	427	808	2211	1283
	STEELHEAD	4127	5774	7305	8376
	SOCKEYE	17701	21741	29500	29453
	COHO				6
	Adults				5
	Jacks				1
1997	CHINOOK	4461	11352	22747	33036
	Spring	971	1866	6205	6788
	Summer	2723	6308	11574	13616
	Fall	767	3178	4968	12632
	Jacks	338	1470	1496	1948
	STEELHEAD	4107	6722	7726	8948
	SOCKEYE	25754	30485	41504	45412
	COHO	8		5	26
	Adults	3		5	25
	Jacks	5			1
1998	CHINOOK	5205	11804	20888	29415
	Spring	30	816	3241	4161
	Summer	3970	7032	12854	13988
	Fall	1205	3236	4793	11266
	Jacks	915	792	2164	2242
	STEELHEAD	2668	4442	4962	5837
	SOCKEYE	4669	5682	9334	10769
	COHO				30
	Adults				30
	Jacks				0

Table 2.3 shows 5-year average juvenile outmigration totals for chinook (age 0 and age 1), steelhead, sockeye, and coho at Rock Island dam, below Chief Joseph Dam. Chinook and steelhead migrate from the Methow and Okanogan Rivers through Wells Dam (between Rock Island and Chief Joseph Dams) but no counts are kept at the dam. The outmigration totals displayed in Table 2.3 for Rock Island include those fish.

Table 2.3 – Juvenile Salmon 5-Year Average Outmigration Totals

Dam	Chinook 0+	Chinook 1+	Steelhead	Sockeye	Coho
Rock Island	18507	38447	32268	18117	30282

2.1.4.1.3 Effects of Gas Supersaturation on Fish

Fish in supersaturated water may suffer high levels of dissolved gas in their bloodstreams, resulting in gas bubble trauma (GBT) symptoms and physiological damage. GBT can result in injury and/or death in various ways. As gas leaves solution in blood vessels (such as in gills), it can block them, restricting blood flow in a condition similar to decompression sickness, or "the bends," in human divers. It may also embolize out of solution into other tissues, such as skin and eyes. Such bubble formation, in addition to causing tissue damage, may also make organisms buoyant, disorienting them and increasing their susceptibility to predation, or allowing them to be swept out of their normal habitat.

The analysis of risk of physiological injury resulting from exposure to TDG considers the exposure history of migrants during the whole of their passage through the federal hydropower system. The reason is that, unlike processes responsible for physical injury, which are specific to a particular location, TDG, while generated at dams, is propagated throughout the system and constitutes a threat to fish health considerably beyond the point of generation.

The health risk of TDG exposure drops considerably as dissolved gas concentration drops close to the water quality standard. The Corps recent Dissolved Gas Abatement Study (DGAS) on the Lower Columbia System found that at 120% TDG, only fish located in the upper meter (3.28 feet), or less, of the water column for extended periods are at any risk from GBT. In addition, the likelihood of developing GBT at TDG levels less than 120% appears to be low.

The initial physiological response of fish to exposure to high TDG conditions is the formation of bubbles in the fish's vascular system followed by a period of growth, which depending on several factors, can eventually lead to development of GBT symptoms and death. Following the onset of development of GBT symptoms, the evolution of GBT is almost totally dependent on the depth of the fish relative to the level of TDG.

A small change in depth could mean the difference between the continued development of GBT symptoms or reduction in symptoms. Organisms deeper than one to two meters (the "compensation depth") in the water column may escape the impacts of dissolved gas supersaturation. This is because the solubility of gas increases as depth (and therefore water pressure) increase. The pressure inside an organism is the same as that in its environment. As long as gases can remain in solution in an organism's blood or tissues, it is under decreased risk of bubble formation.

Not all organisms can escape the effects of high TDG. Those that normally are found near the water surface, or in shallow water, such as near the margins of the water body below a source of high TDG, may be unable to avoid it. Fish such as juvenile salmon, and larvae and fry of other species, often are associated with river margins and shallow water. Because of this, strong concern exists in most situations where gas supersaturation occurs. The susceptibility of salmonids in the study area to gas bubble disease is underscored by the fact that many juveniles of these species are in the river in spring, the time of greatest likelihood of spill and thus gas supersaturation.

2.1.4.1.4 Observed Gas Bubble Trauma in Study Area

Fish are reared commercially in net pens by 2 companies in Lake Rufus Woods. At this time, only rainbow and steelhead trout are reared, though coho and Atlantic salmon (*Salmo salar*) have also been raised. Net pen operators have reported problems in past years from high TDG below Grand Coulee Dam (Shallenberger, 1997; Aquatechnics, 1998; DeLano, 2000)

Large numbers of fish have been killed as a result of spill from Grand Coulee Dam (AquaTechnics, Inc., 1998). In May and June 1997, wild fish were observed dead or dying almost daily with acute GBT symptoms. They included walleye, kokanee, rainbow trout, sculpin, carp, sucker, and whitefish species.

Well over 100,000 captive steelhead at Columbia River Fish Farms and Global Aqua facilities in Lake Rufus Woods were killed in 1996 and 1997. Daily average TDG measurements in the Chief Joseph Dam forebay ranged from about 122% to 136% from mid-May through June 1997.

Dell et al. (1975) documented gas bubble disease symptoms as a result of spill in the five mid-Columbia Public Utility District reservoirs in 1974. The fish they sampled came primarily from water less than 15 feet deep. Table 2.4 gives overall gas level and GBT incidence results. Of all fish sampled (32,289) in the five reservoirs, 10% (3,221) had GBT symptoms. Resident fish numbered 29,273, with 10.6% (3,093) exhibiting GBT symptoms. Juvenile chinook, coho, and sockeye numbered 2,521; of those, 4.2% showed GBT symptoms.

Table 2.4 - Gas levels in Mid-Columbia Reservoirs (1974)

Month	Gas saturation levels*	GBD incidence**
May	122.6 (117.5-126.9)%	17.4%
June	126.1 (121.3-131.9)%	21.0%
July	124.8 (119.5-131.7)%	9.7%
August	117.4 (106.7-123.8)%	0.5%

**Numbers are average (range)*

*** Percent of total fish caught which exhibited GBD symptoms*

2.1.4.1.5 Fish Presence During Periods of Spill

Smolt indices by species and dissolved gas levels over time for 1997 and 1999 are shown on Plate 2-14, at Rock Island Dam in the mid-Columbia River reach (the closest project for which data were available).

Plates 2-15 and 2-16 show adult fish indices and dissolved gas over time in 1997 and 1999, respectively, at Wells Dam (Univ. of Washington, 2000). Dissolved gas measurements were sporadic in 1999 at the counting station.

2.1.4.2 Wildlife

The project vicinity is host to a number of terrestrial species, including mammals and birds, which may use the river for feeding or transportation. Of these, the organisms that feed on aquatic species are potentially affected by dissolved gas conditions, because of short and long term effects on prey species. Those predators include raptors such as osprey and eagle, and other birds such as mergansers and gulls. Losses of fish may indirectly harm some of these species.

Wildlife in this area includes mule deer, white-tailed deer, black bear, coyote, beaver and a variety of waterfowl, raptors (birds of prey) and many species of upland birds. Because the vegetation of this area will not support large wildlife populations, the vegetation that grows along the shoreline becomes even more important in providing a food source and protective cover for wildlife.

Raising Rufus Woods Lake 10 feet in 1981 flooded 550 acres of this vegetation. To make up for this loss, the Corps established 16 wildlife sites, totaling 750 acres, along the lakeshore. At some of these sites, fences were built to keep out domestic livestock. The Corps built irrigation systems and planted trees and shrubs to attract wildlife into these areas. Perch poles for eagles and other raptors were erected in the river and two islands were built along with goose nesting tubs to provide safe nesting sites. The operation and maintenance of the wildlife areas is directed by the Corps with most of the routine fieldwork being done under contract with the Colville Confederated Tribes.

Wildlife listed under ESA in the project area includes the peregrine falcon (endangered) and the bald eagle (threatened). Both of these species consume fish. The peregrine falcon has been seen on rare occasion flying overhead, but does not appear to nest or winter in the area. The bald eagle, a threatened species, winters regularly along Rufus Woods Lake (October through April). Approximately 35 bald eagles are observed each winter using the snags along the reservoir. The eagles feed primarily on chukar, American coots, waterfowl, fish, and carrion. Bald eagles are seldom observed in the area outside of winter.

2.1.5 Hydropower Production

Chief Joseph Dam has a 27-unit powerhouse with two station service generators. Sixteen units were installed during initial construction. Eleven additional turbine generators were installed by 1979 to meet peak regional power demands and to reduce the frequency of spill. In order to produce additional power, Rufus Woods Lake was raised 10 feet in February 1981. The initial sixteen units have 88,250 kilowatt generators and the additional eleven have 100,000 kilowatt generators for a total nameplate capacity of 2.5 million kilowatts; that's enough power to light 25 million 100-watt light bulbs. The value of the electricity produced at Chief Joseph Dam exceeds $200 million annually.

Chief Joseph Dam was authorized to operate within the 930 to 958 foot range. However, due to environmental concerns it is now operated within a 6-foot elevation range close to the full pool elevation of 956 feet. Limiting the pool operating range may have a significant effect on TDG by limiting Chief Joseph Dam’s ability to attenuate high flows that may result from power peaking operations at Grand Coulee. Drawdown below 950 feet is prohibited from 15 February through 15 May to protect Canada geese during nesting periods. Land bridges allowing predators access to nesting areas are formed below this water level. Fluctuations of more than 6 feet lead to erosion damages that affect cultural resource sites and residential developments. In April 1997, Water Management at the Corps of Engineers North Pacific Division concurred with Seattle District findings and recommended adoption of the reservoir operating limits of 950 to 956 feet from 15 February to 15 October. In addition to providing for goose nesting and other environmental concerns, this operation protects cultural resources that could be exposed to erosion and acute bank instability in the Elmer City area below Grand Coulee Dam.

2.1.6 Recreation

Chief Joseph Dam offers several recreational activities on-site. The Chief Joseph Dam Visitor Center is located inside the powerhouse. Viewing windows overlook the turbines, and exhibits explain the Columbia River, hydropower production, archaeology, wildlife, and other topics. A slide show is available that highlights the dam’s history. An orientation area downstream of the dam on the right bank and a Spillway Viewpoint above the right training wall allow views of the spillway and powerhouse. The Upstream Boat Ramp offers boat access to Rufus Woods Lake.

Other nearby recreational facilities include Bridgeport State Park and the Town of Bridgeport. Bridgeport State Park is located two miles upstream of the dam. The park offers a sandy swimming beach, boat launching facilities, picnic areas and a campground. Right next door to the park is a nine-hole golf course. The Corps constructed the park, which is now run by the Washington State Parks and Recreation Commission. The Town of Bridgeport offers camping, picnic areas, boating and swimming. Two boat ramps furnish access to Lake Pateros

2.1.7 Cultural Resources

Chief Joseph Dam is within the historical ancestral home territory of bands of three member Tribes (Sinkaiuse, Sanpoil/Nespelem, and Sinkaietk) of the Confederated Tribes of the Colville Reservation, which is headquartered in Nespelem, Washington. The entire north half of the project is within the bounds of the Reservation and includes Tribal trust and individual allotment lands administered by the CCT, and the south half is on lands ceded by various Executive and Congressional actions. Historically, the Tribes used the project area for the full range of their annual activities. They continue to exercise hunting, fishing, and gathering rights within it, and maintain special interest in how the Corps manages wildlife and cultural resources.

Since the mid-1970s, the Seattle District has sponsored a program at Chief Joseph Dam to identify, test, and recover data from cultural resource sites that could be affected by construction and operations. Testing at about 100 of the prehistoric sites (there are nearly 300 prehistoric and historic sites) identified their age and importance. This supported a formal determination in 1978 that the Rufus Woods Lake Archeological District, which encompasses the entire Chief Joseph Dam project, was eligible for the National Register of Historic Places. The determination of eligibility provided sufficient protection of the cultural resource sites; therefore, formal nomination was not pursued.

Between 1978 and 1980 the Corps of Engineers sponsored an extensive archaeological program to excavate prehistoric sites on the shores of Rufus Woods Lake. These sites included housepit villages, temporary camps and rock art and provide the major source of information about the early history of the Sanpoil and Nespelem Tribes who are members of the Colville Confederated Tribes.

The archaeological program, carried out in close cooperation with the Colville Confederated Tribes, was done before the 1981 raising of Rufus Woods Lake. This work has resulted in a better understanding of the culture and lifestyles of some of the earliest inhabitants who lived in this area 7,000 years ago. The program significantly advanced knowledge of regional prehistory through production of over 25 technical reports and compilation of a large, carefully organized collection of artifacts and data.

Since the 1980s, four major sites have received bank protection. One of the more prominent aspects of the past and present program is close coordination and cooperation with the Colville Confederated Tribes.

3. PLAN FORMULATION AND WITH-PROJECT CONDITIONS

3.1 Problems and Opportunities

Changing regional water resource demands have resulted in an operating environment with an increased tendency to require spill at Chief Joseph Dam than in the past. Spill can lead to increases in total dissolved gas (TDG) saturation levels, which can be harmful to fish. Installation of gas sensors in the Chief Joseph tailwater in 1997 indicated high levels of TDG (in excess of state and federal water quality standards) below the dam during spill. Current state and federal water quality standards for total dissolved gas concentrations are 110 percent saturation except when stream flow exceeds a 7-day average, 10-year flood event. From a system perspective, a dam producing high TDG contributes to water quality problems beyond its own tailwater because high levels of TDG produced at one dam tend to persist far downstream, being passed through downstream powerhouses.

Specific problems addressed by the study include:

- High TDG levels and the impacts on endangered species downstream in Lake Pateros
- High TDG levels and the impacts on fish upstream in Lake Rufus Woods
- High TDG levels and the impacts on endangered species in the Columbia River downstream of Chief Joseph Dam

Opportunities to address these problems include:

- Reduce generation of TDG at Chief Joseph Dam
- Reduce input of TDG to Chief Joseph from Grand Coulee Dam
- Reduce net contributions of TDG from Chief Joseph Dam and Grand Coulee Dam to downstream reaches

3.2 Planning Objectives

In Section 1, the overarching goal of the study was identified as follows: "to identify means for reducing TDG contributions from Chief Joseph Dam to the extent economically, technically, and biologically feasible". In pursuit of this goal, the following planning objectives were identified:

- To reduce air entrainment through structural modifications
- To reduce the frequency of spill through system or operational changes

To accomplish these goals and objectives, the study team identified the following task areas:

- To identify and evaluate structural and non-structural modifications to provide gas abatement at Chief Joseph Dam
- To evaluate the gas abatement benefits achieved under a joint Chief Joseph and Grand Coulee Dam operational modification
- To continue to examine the range of capabilities provided by Chief Joseph Dam in the context of optimized system operation

Accomplishment of these tasks and the results of evaluations are documented in the following sections.

3.3 Formulation of Alternative Solutions

The study team identified the first phase of plan formulation as the Initial Appraisal. As part of this initial appraisal, a wide array of structural and operational alternatives was considered for improving TDG at Chief Joseph Dam. Consistent with the planning objectives, alternatives were identified ranging from structural and operational measures at Chief Joseph Dam to system-wide operational changes. Table 3.1 lists the 18 preliminary alternatives identified and evaluated in the initial appraisal phase. The following pages provide descriptions of each of the 18 alternatives.

Table 3.1 – Preliminary Alternatives

Alternative 1	Spillway Flow Deflectors
Alternative 2	Increase Reservoir Operating Level Fluctuations
Alternative 3	Operate the Hydropower Units Inefficiently
Alternative 4	Raise Tailrace
Alternative 5	Raise Stilling Basin
Alternative 6	Pumped Storage
Alternative 7	Increase Powerhouse Hydraulic Capacity
Alternative 8	Siphon for Irrigation
Alternative 9	Spill During Maximum Power Generation/Extend Daily Spill/Market Power at Night
Alternative 10	Unplug Sluices in Spillway
Alternative 11	Swap Power for Spill with Downstream Dams
Alternative 12	Side Channel Canal
Alternative 13	Raise Control Flows at the Dalles
Alternative 14	Modify Operation at Grand Coulee Dam
Alternative 15	Baffled Spillway
Alternative 16	Degas at Brewster Flats
Alternative 17	Enclose Stilling Basin
Alternative 18	Combination of Alternatives 3, 11, 13, and 14

3.3.1 Alternative #1 - Spillway Flow Deflectors

This measure consists of modifying the spillway with flow deflectors to reduce the plunge depth of spill discharge. Placing the flow deflectors just below the tailwater will generate skimming flows along the water surface of the stilling basin and reduce the amount of gas forced into solution. Deflectors will be required on all of the spillway bays to prevent unstable flow conditions. Nineteen deflectors will provide degassing capability up to the 7-day, 10-year event. A hydraulic model investigation for flow deflectors at Chief Joseph Dam was completed in 1979. The study found that deflectors were effective in producing skimming flow conditions with all flows of a 10-year frequency or less when 18 or more powerhouse units were operating. The Wells Dam pool was assumed to be at elevation 779. The optimum design was a horizontal deflector 12.5 feet long at elevation 775 (see Plates 3.1 through 3.3).

This model study is still applicable to the dam structurally, however the flow frequency may not be accurate due to changes in system management. Additional model studies were conducted in this general reevaluation study to refine the design elevation, transition radius, and number and length of deflectors based on current operating criteria. This alternative has proven effective at reducing TDG at other dams and the initial appraisal report recommended it for further consideration.

3.3.2 Alternative #2 - Increase Reservoir Operating Level Fluctuations

Chief Joseph Dam is normally operated within a 6-foot elevation range close to the full pool elevation of 956 feet for the primary purpose of meeting BPA power requirements. Flexibility to draw the forebay below elevation 950 exists during the 4 winter months (15 October to 15 February). Flexibility is very limited during the eight warmer months because of the large number of conflicting interests. In April 1997, Water Management at the Corps North Pacific Division and Seattle District recommended adoption of the reservoir operating limits of 950 to 956 feet from 15 February to 15 October to address environmental, cultural resource, and erosion concerns as described in Section 2.1.5 of this report. At this time, elevation 930 is the minimum allowable reservoir operating level. By operating Chief Joseph Dam more like a re-regulating dam, project operations could be redefined to allow regular forebay fluctuations of 20 to 30 feet. This change would allow the project to release flows without using the spillway. This alternative has numerous environmental and economic impacts in the forebay and thus was not recommended for further consideration by the initial appraisal report.

3.3.3 Alternative #3 - Operate the Hydropower Units Inefficiently

This alternative would require the project to operate additional units at lower output thereby meeting power generation requirement but doing it less efficiently. The result is greater passage of flow for the same amount of electrical output. This alternative may have merit for cases when the flow to be passed is minimal (2,000 to 4,000 cfs). The benefit would be less spill and therefore less supersaturation. However, at the reduced megawatt output levels resulting from operation of the additional units, all units would be close to unstable operation. The initial appraisal report recommended further consideration of this alternative. The report added that additional study would be required to determine if this project operation change would be warranted and suggested that the alternative may be more effective when combined with other alternatives.

3.3.4 Alternative #4 - Raised Tailrace

A shallow tailrace area (depth of 15 feet for all discharges) immediately downstream of the stilling basin would have the effect of increasing the rate at which flows would degas. The area downstream of the stilling basin would be filled with material sized to withstand the project design flood flows. This alternative has many uncertainties as to effectiveness, cost, and maintenance based on the geometry of Chief Joseph Dam and was not recommended for further consideration by the initial appraisal report.

3.3.5 Alternative #5 - Raised Stilling Basin

Raising the stilling basin to a depth of approximately 20 feet reduces the plunge depth for spill discharge. Chief Joseph Dam has a 167-foot long by 915-foot wide stilling basin with an invert elevation of 743 feet. The stilling basin would have to be filled with at least 20 feet of material and capped with concrete to raise the basin floor to an acceptable depth. A negative step would also be constructed immediately downstream in order to provide effective energy dissipation. There would be power losses associated with this alternative. This alternative has many uncertainties as to effectiveness, cost, and maintenance and was not recommended for further consideration by the initial appraisal report.

3.3.6 Alternative #6 - Pumped Storage

In the early 1980’s, the Rufus Woods Lake Pumped Storage study looked at constructing a pumped storage project at Jordan Creek, at a cost of $700 million. The project would require construction of a 900-acre upper reservoir located approximately 2 miles east of Chief Joseph Dam. Rufus Woods Lake would be used as the lower reservoir. The project could provide up to 3,000 MW of peak generating capability on a weekly or seasonal cycle. This alternative would provide more project operation flexibility since water could be stored and released when required to avoid spill. Pumped storage projects depend on availability of off peak energy for operation, which would not be a problem with current energy demand characteristics. However, construction of a pumped storage plant was determined to be cost prohibitive and the alternative was not recommended for further consideration by the initial appraisal report.

3.3.7 Alternative #7 - Increase Powerhouse Hydraulic Capacity

This alternative involves increasing the powerhouse hydraulic capacity by adding an additional unit to the project. Since Chief Joseph Dam is a peaking operation, spill usually occurs when there is a lack of demand for power. Unless demand goes up at night, an additional unit would not reduce TDG levels. Because of high initial construction costs and limited usefulness in solving the current TDG problem, this alternative was not recommended for further consideration by the initial appraisal report.

3.3.8 Alternative #8 - Siphon for Irrigation

Construction of a siphon for irrigation on the right bank would transfer flows from the forebay without increasing the TDG level. The existing irrigation system that is downstream of the dam would be replaced with this system. Unfortunately, the amount of water used for irrigation is negligible in terms of TDG effect for the cost of construction and maintenance. For these reasons, this alternative was not recommended for further consideration by the initial appraisal report.

3.3.9 Alternative #9 - Spill During Maximum Power Generation/Extend Daily Spill Duration/Market Power at Night

This alternative would require changing operation at Grand Coulee and Chief Joseph to spill more consistently even flows during the day and at night, or to time spills in a more effective manner from a TDG perspective. Total river flow (spill and power release) during the day would be higher than under current operation, while flows at night would be lower. While the overall effect on gas reduction would be small, this alternative would avoid the very high TDG levels associated with short, but very large spills that can occur in the early morning hours when demand is low. Larger spill during the day would increase TDG less, because it is diluted by larger powerhouse flow. In addition, it is worth examining market incentives for nighttime power usage, in order to maximize powerhouse operations, thereby minimizing spill. The initial appraisal report recommended this alternative be carried forward for further consideration.

3.3.10 Alternative #10 - Unplug Sluices in Spillway

Chief Joseph Dam has 12 sets of low level temporary sluices that were plugged with concrete after original project construction. Each sluice is 8 feet wide by 16 feet high with an invert elevation of 769 feet. There are no gates or operators associated with these sluices. This alternative would unplug a number of the sluices, install gates, operators, venting, and a steel liner. An upstream bulkhead and downstream cofferdam would be required to remove the concrete plugs. Extensive concrete removal within the monolith would also be needed to modify the sluices for emergency and regulating gates. This alternative was not recommended for further consideration by the initial appraisal report because of the high construction cost.

3.3.11 Alternative #11 - Swap Power for Spill with Downstream Dams

The new ESA listings may require additional spill for fish at downstream projects. Since intentional fish passage does not currently exist at Chief Joseph Dam (while there is no intentional fish passage, some unquantified level of entrainment undoubtedly occurs) and since there is the ability to generate more power, a swap might meet many needs. A power for spill swap could be made with either a degassing or a fish passage project downstream. Many of the downstream projects have been, or are about to be, rehabilitated to reduce TDG levels resulting from spill. It may soon be feasible to increase spill at these dams. By maximizing power generation at both Grand Coulee and Chief Joseph, a significant reduction in system TDG levels could be achieved. Within the mid Columbia system reimbursement for power losses is a standard practice. In the current ESA environment, additional power production at dams without juvenile fish passage concerns could be viewed as a fish mitigation option. This alternative was recommended for further consideration under a system-wide analysis in the initial appraisal report. Further evaluation of the alternative should consider that the Confederated Colville Tribes (CCT) are interested in anadromous fish passage at Chief Joseph Dam. As of March 2000, the Corps is entering an initial cost-shared study of the subject with CCT.

3.3.12 Alternative #12 - Side Channel Canal

This alternative would require construction of a side channel that would run parallel to the riverbank. Water would enter the canal upstream and be transported around the dam and discharged back into the river downstream of Chief Joseph Dam. It may be possible to modify

Foster Creek for this purpose. Diverting 50,000 cfs of water would be required. With this alternative releases could be made at night with minimal impact to peaking operation. If baffles were added to the canal, flows could enter the river downstream at a lower TDG concentration, depending on channel geometry. This alternative would probably require land acquisition. A number of roads and utilities would have to be relocated. This alternative has many uncertainties as to effectiveness at what cost but should be considered further if Foster Creek were an option. The initial appraisal report recommended the alternative for further consideration.

3.3.13 Alternative #13 - Raise Control Flows at the Dalles

Raising the control flow at the Dalles could reduce the needed draft from Grand Coulee in the spring. This would help to reduce TDG levels that result from "premature spilling," or "spill now to prevent spill later". Considering the ecological impacts of high TDG levels, this is a relatively simple alternative that deserves further study, particularly in combination with alternative #14. This alternative may require a new system flood control study with emphasis on the stage damage. The initial appraisal report recommended this alternative for further consideration. This alternative will be considered in a new flood control study outside the scope of this Chief Joseph Dam gas abatement general reevaluation study in response to the 1995 and 1998 BiOps.

3.3.14 Alternative #14 - Modify Operation of Grand Coulee Dam

This alternative would reduce dissolved gas below Chief Joseph Dam by reducing TDG production at Grand Coulee Dam and by reducing the frequency and volume of pre-emptive spill from Grand Coulee that must be subsequently spilled at Chief Joseph. Drawdown for flood control at Grand Coulee would be shifted to a slightly earlier schedule in order to reduce the frequency and volume of spill when the reservoir elevation is below 1260 feet. When the reservoir elevation is between 1260 and 1290 feet, spill would pass through the drum gates. Drawdown of the reservoir below elevation 1260 feet would be achieved primarily with powerhouse flow in order to avoid using the highly saturating sluices (outlet works).

The Bureau of Reclamation has reported that the outlet works at Grand Coulee saturate TDG to a much higher level than the drum gates, 170 percent and 140 percent respectively. In light of this, Grand Coulee Dam should be operated such that the outlet works are rarely, if ever, used and evacuation below elevation 1260 feet should be achieved with powerhouse flow. This alternative should be studied further in combination with alternative #13. A new system flood control study would be required. The alternative was recommended for further consideration in the initial appraisal report.

This alternative has a secondary and potentially important benefit to temperature management in the Columbia River. Lake Roosevelt thermally stratifies in the spring. Because there is no selective withdrawal structure at Grand Coulee, releases through the powerhouse and sluices draw water from below the thermocline. As the summer progresses and cold water is withdrawn, the thermocline lowers until the powerhouse and sluices are withdrawing much warmer water. On the other hand, adoption of this alternative would allow advection of heat by releasing warm surface water from the reservoir, thereby preserving the cool water below the thermocline for release later in the summer. This method is essentially a selective withdrawal system with fixed ports.

3.3.15 Alternative #15 - Baffled Spillway

This alternative consists of adding baffles to the lower portion of the spillway. With this alternative, the TDG levels are reduced by stripping gas from solution as water passes down the face of the spillway. With a high forebay, a baffled spillway is one of the best structural alternatives for TDG reduction. In the case of Chief Joseph Dam, cavitation damage due to the high velocity ogee crest spillway would be too severe to warrant further consideration of this alternative. The initial appraisal report did not recommend this alternative for further consideration.

3.3.16 Alternative #16 - Degas at Brewster Flats

It has been suspected that some degassing takes place prior to reaching the Wells Dam forebay. Based on the geometry of the river, the initial assumption was that this degassing takes place at the Brewster Flats area of Lake Pateros, where the river is wide and approximately 20 feet deep in the old river channel, and less than 10 feet deep across most of the Brewster Flats area. Alternative 16 assumes that by extending the shallow depth downstream there would be an increased opportunity to reduce gas levels prior to reaching Wells Dam. It may be possible to add degassing features such as a negative step within this area. The initial appraisal report recommended this alternative for further consideration, suggesting further study.

3.3.17 Alternative #17 - Enclose Stilling Basin

This measure consists of enclosing the stilling basin behind a small dam where flows would be forced over the top of the dam to degas. At Chief Joseph Dam the spillway and powerhouse are separated by a non-overflow section, which lessens the impact of adding the dam. This alternative would be able to handle all design flows although it is not known whether the required TDG level can be met. Construction costs would be high due to the size of the cofferdam and amount of material needed to build the dam itself. Additional studies would be required to determine the extent of benefits with this costly alternative. The initial appraisal report did not recommend this alternative for further consideration.

3.3.18 Alternative #18 - Combination of Alternatives 3, 11, 13, 14

This particular combination of project and system operational alternatives is but one example that could be examined. Alternative 3 is a project operational change aimed at putting more water through the powerhouse by operating the power units less efficiently. Alternatives 11, 13, and 14 target changes in power distribution and spill in the Columbia Basin. Both Grand Coulee and Chief Joseph would need to be incorporated in the changes in order to achieve the estimated reduction in TDG levels. This alternative was recommend for further consideration by the initial appraisal report.

3.4 Initial Appraisal Screening – Screening Phase 1

Each of the 18 alternatives from the initial appraisal phase were evaluated based upon the following nine screening criteria:

- Project impact
- Cost
- Water quality benefits
- Biological benefits
- Feasibility
- Timeliness
- Upstream and downstream effects
- Acceptability
- Maintenance requirements

The results of this initial screening are provided in the matrix of alternatives in Table 3.4. A description of each criterion follows:

3.4.1 Project Impact

This criterion addresses the degree to which the alternative impinges on existing project purposes (hydropower, irrigation, and recreation).

○ Symbolizes a high degree of impact
◗ Denotes a medium impact
● Represents a low impact

3.4.2 Cost

For this study, the initial cost criteria are quantified as:

○ Represents costs over $20 million
◗ Represents costs of $2 million to $20 million
● Represents costs from zero to $2 million

3.4.3 Water Quality Benefits

Water quality benefits are defined as decreases in mixed river TDG (flow weighted average of TDG in power generation flow and spill), either through reduction of TDG through structural means, reduction of TDG through project operational changes, or reduction of TDG through system operational changes. Water quality assumptions, outlined in previous sections, have been used to estimate the without-project baseline TDG (without-project condition) and TDG with an individual alternative in place (Tables 3.2 and 3.3).

- ● Alternatives that significantly reduce TDG: 1, 4, 5, 15, 16, and 17.
- ◗ Alternatives that do not reach the goal, but that do lower TDG below the spillway or in the mixed river downstream: 2, 6, 9, 10, 11, 12, 13, and 14.
- ○ Alternatives that do not lower TDG: 3, 7, and 8.

Forebay TDG is an estimate of what would have arrived at Chief Joseph's Forebay from Grand Coulee Dam. For most alternatives, it is 123%, the observed value in 1997 when the total river flow was 250 kcfs. For some alternatives, gas abatement at Grand Coulee is assumed and the value is 115%. TDG inflow from the powerhouse at Chief Joseph Dam is always the same value as observed in the forebay. Flows in Table 3.2 are as described in Section 2.1.3.5 of this report. TDG from spill is based on information that was available at the time the Initial Appraisal Report (IAR) was written: Plate 2-9 and the Columbia River Fish Mitigation Program's Dissolved Gas Abatement Study, Phase I report. The mixed river TDG (Table 3.2) is based on a weighted average of spill, TDG produced by the spillway, powerhouse flow, and TDG passing through the powerhouse (Plate 2-11). A description of the baseline assumptions for the IAR can be found in Section 2.1.3.5 of this General Reevaluation Report.

Because the baseline forebay TDG is high (123%), some alternatives lower the TDG in the spilled water. For example, supersaturated water passing over a spillway crest is agitated enough to allow gases to come out of solution. When that water plunges in a stilling basin, air is forced into solution and the water becomes supersaturated again. The degree to which it is supersaturated (TDG increases) is a function primarily of stilling basin and tailwater geometry. If flow deflectors are in place, plunging is reduced. Hence, re-saturation may occur to a lesser percentage than was present in the forebay.

Table 3.2 - Summary of Estimated TDG Levels Resulting from each Alternative

Alter-native	Forebay TDG (percent saturation)	TDG from Powerhouse Flow (percent saturation)	TDG Abatement Powerhouse Flow (cfs)	TDG from Spillway (percent saturation)	TDG Abatement Spillway Flow (cfs)	Mixed River TDG (percent saturation)	TDG change (percent saturation)
Baseline	**123**	**123**	**170,000**	**134**	**80,000**	**127**	**0**
1	123	123	170,000	112	80,000	119	-8
2	123	123	220,000	123	40,000	123	-4
3	123	123	174,000	133	76,000	126	-1
4	123	115	170,000	115	80,000	115	-12
5	123	115	170,000	115	80,000	115	-12
6	123	123	170,000	123	80,000	123	-4
7	123	123	170,000	134	80,000	127	0
8	123	123	174,000	133	76,000	126	-1
9 day	123	123	220,000	138	130,000	129	2
9 night	123	123	120,000	120	30,000	123	-4
10	123	123	170,000	123	80,000	123	-4
11	115	115	220,000	120	30,000	116	-11
12	123	123	170,000	123	80,000	123	-4
13	115	115	170,000	129	50,000	118	-9
14	115	115	170,000	129	50,000	118	-9
15	123	123	170,000	112	80,000	119	-8
16	123	115	170,000	115	80,000	115	-12
17	123	115	170,000	115	80,000	115	-12
18	115	115	230,000	115	10,000	115	-12

Any reductions in TDG at Grand Coulee Dam will have immediate results downstream of Chief Joseph with *no* changes, either structural or operational at Chief Joseph. The portion of the flow passing through the powerhouse would retain this same reduced TDG level. Under the TDG abatement flows, every 5 percent reduction of inflow TDG would yield a 3 percent reduction of outflow TDG (Table 3.3).

Table 3.3 - TDG Levels below Chief Joseph Dam

(TDG levels below Chief Joseph Dam resulting solely from reduction in TDG supersaturation of inflow to Rufus Woods Lake)

TDG from Powerhouse Flow (percent saturation)	TDG Abatement Powerhouse Flow (cfs)	TDG from Spillway (percent saturation)	TDG Abatement Spillway Flow (cfs)	Mixed River TDG (percent saturation)	TDG change (percent saturation) from baseline
Baseline 123	**170000**	**134**	**80000**	**127**	**0**
120	170000	134	80000	124	-3
115	170000	134	80000	121	-6
110	170000	134	80000	118	-9
105	170000	134	80000	114	-13

3.4.4 Biological Benefits

Anadromous Fish. In the 1995 BiOp, NMFS identified a five-part approach for applying jeopardy standards to ESA implementing regulations. This same approach has been selected by NMFS for use in developing guidelines associated with the newly listed Upper Columbia River ESU of steelhead. As part of this approach, NMFS has stated that the Action Agencies, in coordination with the Regional Forum, shall jointly develop and implement gas abatement programs at Grand Coulee and Chief Joseph Dams, respectively, with appropriate structural modifications and operational measures.

Gas abatement studies have been requested for all Federal Columbia River Power System (FCRPS) dams including Chief Joseph and Grand Coulee, even though there is no intentional fish passage in this reach. TDG generated by these dams contributes to system TDG and reduces the ability to provide fish protective spill at downstream dams. For reference, scientific evaluations have been conducted to balance benefits to salmon migration through increased spill and associated mortality from elevated incidence of gas bubble disease.

ESA areas of interest to Chief Joseph Dam include the Upper Columbia River ESU for steelhead, and the Upper Columbia ESU for spring chinook; both ESUs are listed as “endangered”. The term Evolutionarily Significant Unit (ESU) is not a geographic distinction within which more than one species exists, but rather a genetic distinction within individual species. The Upper

Columbia ESU for steelhead, and the Upper Columbia ESU for chinook both include Chief Joseph Dam. Also important to the study are the Columbia Basin population of bull trout, which have been listed as "threatened" throughout the basin (including in the vicinity of Chief Joseph Dam).

Resident Fish. High TDG levels at Chief Joseph Dam have been recorded both upstream in the project forebay and downstream in the stilling basin. High forebay and reservoir TDG levels can prove harmful to fish. TDG concentrations in the 120 percent to 125 percent range and above are known to be lethal to farmed and wild fish under conditions existent in Rufus Woods Lake.

This report focuses on changes at Chief Joseph Dam and altered TDG levels downstream. Chief Joseph has no salmon outmigration and improvements in water quality should benefit resident fish. The proposed operational and system-wide alternatives have been evaluated relative to impacts to resident fish at the project and downstream.

Structural alternatives to alleviate TDG levels at the project and downstream could create a potential for injury to resident fish. These potential impacts would be seen only in cases where structural modifications at the project create turbulence or physical changes to the spillway or stilling basin. Even so, impacts would be minor and affect only those fish that are inadvertently passed over the spillway during high flows.

With some alternatives there is an added benefit brought about by an operational change. An example would be the downstream benefit from better temperature control.

○ Denotes that the alternative does negatively impact fish
◗ Symbolizes no fish effect
● Represents a fish benefit from the alternative

3.4.5 Feasibility

This criterion evaluates the feasibility of the alternative from a design, construction, and operations perspective. Complexity is a consideration along with reliability for the expected range of operating conditions.

○ Denotes that the alternative does not appear feasible
◗ The alternative appears feasible but will require additional study to verify
● Symbolizes the alternative is feasible

3.4.6 Timeliness

Timeliness represents the time required to implement the alternative.

○ Implementation will take 4 to 6 years
◗ Implementation will take 1 to 4 years
● Implementation can occur within 1 year

3.4.7 Upstream and Downstream Effects

In some cases a viable alternative has negative effects either upstream or downstream of the project. This criterion addresses these effects.

○ Symbolizes that the alternative has serious negative effects
◗ Represents an alternative that has some effects that can be mitigated
● Denotes an alternative with no negative effects

3.4.8 Accepted Solution

This criterion quantifies the confidence associated with a given alternative.

○ This alternative has low confidence as an accepted alternative
◗ This is a lower confidence alternative that needs additional evaluation
● This alternative is a proven method/technology

3.4.9 Maintenance

This criterion addresses the maintenance effect of the alternative.

○ The alternative greatly increases project maintenance
◗ The maintenance effect is minor
● This alternative has no negative maintenance effect

Table 3.4 - Initial Appraisal Evaluation Matrix

Alternative	Objective	Category	1	2	3	4	5	6	7	8	9
1.Spillway Flow Deflectors	Reduce Air Entrainment	Structural	●	○	●	◗	●	◗	●	●	◗
2. Increase Reservoir Operating Level Fluctuations	Reduce Frequency of Spill	System Operation	○	◗	◗	○	○	◗	○	○	○
3. Operate Hydropower Units Inefficiently	Reduce Frequency of Spill	Project Operation	◗	●	○	◗	●	●	●	◗	◗
4. Raised Tailrace	Reduce Air Entrainment	Structural	○	○	●	◗	○	○	◗	○	◗
5. Raised Stilling Basin	Reduce Air Entrainment	Structural	○	○	●	◗	○	○	◗	○	◗
6. Pumped Storage	Reduce Frequency of Spill	Structural	◗	○	◗	◗	○	○	○	○	○
7. Add Additional Unit	Reduce Frequency of Spill	Structural	●	○	○	◗	○	○	●	◗	○
8. Siphon for Irrigation Right Bank	Reduce Frequency of Spill	Structural	◗	◗	○	◗	◗	◗	◗	◗	○
9. Spill During Maximum Power Generation	Reduce Air Entrainment	System Operation	◗	●	◗	◗	◗	●	○	◗	◗
10. Unplug Sluices	Reduce Air Entrainment	Structural	●	○	◗	◗	○	○	●	○	○
11. Swap Power for Spill with Downstream Dams	Reduce Frequency of Spill	System Operation	●	◗	◗	●	◗	◗	●	◗	●
12. Side Channel Canal	Reduce Air Entrainment	Structural	●	○	◗	◗	◗	◗	◗	○	◗
13. Raise Control Flows at the Dalles	Reduce Frequency of Spill	System Operation	●	●	◗	◗	◗	◗	◗	○	●
14. Modify Operation of Grand Coulee Dam	Reduce Frequency of Spill	System Operation	●	●	◗	●	◗	◗	◗	○	●
15. Baffled Spillway	Reduce Air Entrainment	Structural	○	○	●	◗	○	◗	●	○	○
16. Degas at Brewster Flats	Reduce Air Entrainment	Structural	◗	○	●	◗	◗	◗	◗	○	◗
17. Enclose Stilling Basin	Reduce Air Entrainment	Structural	●	○	●	◗	◗	○	●	○	○
18. Combination (3, 11, 13, 14)	Reduce Frequency of Spill	System Operation	◗	●	●	●	◗	◗	◗	○	◗

CRITERIA: **1)** Project Impact **2)** Cost **3)** WQ Benefits **4)** Biological Benefits **5)** Feasibility **6)** Timeliness **7)** U/S and D/S Effects **8)** Accepted Solution **9)** Maintenance
IMPACT RATING SCALE: ● Positive ◗ Neutral ○ Negative

3.5 Conclusions from Initial Appraisal Screening

Based on the alternative evaluation summarized in Table 3.4, a number of structural and operational alternatives were recommended for further consideration. An Initial Appraisal Report (IAR) was developed and an overview of the report was presented at a combined meeting of the System Configuration Team (SCT) and the Dissolved Gas Abatement Team (DGT) on May 20, 1998. The IAR recommended the following 9 alternatives for further consideration:

Structural Alternatives:

- Spillway Flow Deflectors
- Side Channel Canal
- Degas at Brewster Flats

Project Operational Alternatives:

- Operate Hydropower Units Outside Peak Efficiency Range*

System Operational Alternatives:

- Spill During Maximum Power Generation*
- Swap Power for Spill with Downstream Dams
- Raise Control Flow at the Dalles*
- Modify Operation of Grand Coulee Dam*
- Combination of those alternatives denoted by an "*" above

The initial appraisal recommended that operational measures that could be implemented immediately should be a short term priority and that short term priority be given to near field TDG studies. The initial appraisal also recommended a system-wide analysis to examine operational alternatives, including modification of flood control operations and shift in spill priority, be pursued as part of the ongoing system TDG efforts.

3.6 Comments on the Initial Appraisal Report

The Corps received both verbal and written comments concerning the IAR. The following includes a summary of comments presented at the July meeting of the System Configuration Team:

- The Columbia River Intertribal Fisheries Commission concurs with many other regional agencies in support of efforts to fast-track flow deflectors.

- Comments were received jointly from the Confederated Tribes of the Colville Reservation and the Washington State Department of Ecology. The agencies want the project objective to be changed to "reduce total dissolved gas to 110 percent" rather than "reduce TDG to the extent economically, technically, and biologically feasible." The agencies also identified a need for the Corps to complete a gas abatement plan for approval by these agencies.

- With respect to the alternatives identified in the IAR, the Colville Tribes and Department of Ecology requested further exploration of several alternatives in the IAR:

  - Raised Tailrace
  - Raised Stilling Basin
  - Unplug Sluices in Spillway
  - Side Channel Canal
  - Enclosed Stilling Basin

  However, these agencies are most interested in the alternative identified as "side channel canal", if it is found to provide opportunities for fish passage at Chief Joseph Dam.

- Several comments identified a need for stronger justification for the 80,000 cfs design flow for dissolved gas abatement alternatives.

- NMFS suggested that system operational changes be examined holistically before making structural changes, and that the study carry forward essentially the same alternatives as identified in the IAR. Specifically, NMFS' letter to the Corps contained the following:

  "While NMFS endorses site specific studies of TDG levels during spill operations, we would object to implementation of abatement options without first addressing integrated system-level review of existing sites where spill occurs, and determination of whether there is system operational flexibility to shift spill from one site to another. In that context, we believe the Chief Joseph appraisal report is an important first step. However, a decision to implement abatement measures at Chief Joseph should not be made until similar reports at all Mid-Columbia dams have been completed and system options have been integrated and prioritized. "

- In reference to the Lower Columbia and Snake Rivers, NMFS stated at a recent System Configuration Team (SCT) meeting that they consider flow deflectors to be a critical short-term modification that should be fast-tracked.

- Several comments suggested that flow deflectors might not be necessary on all spillbays as a way to reduce costs.

- The DGT suggested that a newer design of flow deflectors might be more effective than the 1979 design.

- Several comments suggested that the performance of flow deflectors was overestimated in the IAR.

- The study team received comments indirectly from the Bonneville Power Administration (BPA). In a letter to NMFS, BPA favored moving directly forward with installation of flow deflectors ("flip lips") at CHJ for the following reasons:

  - It may substantially improve dissolved gas management on a system-wide basis and in a cost-effective manner;
  - It is the only action justified for implementation in the near term; and
  - It would save both time and expense of a long study.

- In a report released on 29 September 1998, the Independent Scientific Advisory Board (ISAB) reviewed the Corps' Dissolved Gas Abatement Program. While this program specifically addresses the lower eight Snake and Columbia River dams, some of the ISAB comments pertain to dissolved gas abatement in the entire basin. For example,

  - The objective of reducing TDG to the Clean Water Act standard of 110% during times when water is spilled at dams is unattainable even with major reconfiguration of the hydropower system. Attainment of the standard should be considered a policy issue and separated from technical considerations.
  - A few critical studies would be useful to refine estimates of the biologically acceptable TDG level, now believed to be about 120%, as a goal for near-term abatement efforts. These studies are considered valuable, but not necessary for the program to proceed.
  - Installation of proven technologies, such as flow deflectors, should proceed with all possible speed as an interim measure, regardless of decisions about future hydrosystem configuration.

3.7 Focusing of Alternatives – Screening Phase 2

The Agency comments described above were helpful in focusing the next screening phase of the study. In this second iteration of screening, the nine recommended alternatives in the IAR were further evaluated to assess their effectiveness, efficiency, and acceptability. In this screening phase, the number of alternatives to be considered further was reduced to three. The following paragraphs summarize the rationale for screening alternatives from further examination.

Operate Hydropower Units Outside Peak Efficiency Range. Upon further evaluation, it was determined that by itself, this alternative has insignificant benefits for dissolved gas reduction. At best, an additional 4000 cfs could be run through the power units, resulting in a TDG decrease of about one percent. A major drawback to this alternative is increased unit maintenance. Screening phase two did not recommend this alternative for further consideration.

<u>Spill During Maximum Power Generation.</u> Upon further evaluation, it was determined that this alternative would fluctuate flows even more dramatically than under current power-peaking operations, resulting in damage to the fisheries in the Hanford Reach. The 1998 BiOp requires that flows in the Hanford Reach of the Columbia River be maintained at as constant levels as possible. Screening phase two did not recommend this alternative for further consideration.

<u>Swap Power for Spill with Downstream Dams.</u> Upon further evaluation, it was determined that implementation of this alternative is already occurring through use of the Spill Priority List to maximize the effectiveness of existing dissolved gas abatement structures. This list includes both federal and non-federal dams in the basin. While swapping power for spill with dams downstream of Chief Joseph was identified as out of scope for this study, it was decided to evaluate further the merits of swapping power for spill with Grand Coulee Dam (upstream) in a "Joint Operation Alternative".

<u>Raise Control Flows at the Dalles.</u> Upon further evaluation, it was determined that this alternative is being examined by the Northwest Division office of the Corps and is not within the scope of this study. A roughly estimated cost of study has been identified as five million dollars due to the large number of elements in the study (system-wide flow modeling, flood damage assessment, estimating costs for dike strengthening/extension, etc.).

<u>Modify Operation of Grand Coulee Dam.</u> This alternative has been identified for reformulation into the "Joint Operation Alternative".

3.8 Remaining Alternatives

To compare the benefits of the three remaining alternatives, a numerical rating of the alternatives matrix in the Initial Appraisal Report was applied. "Flow deflectors" scored an *order of magnitude higher* than did "side channel canal" and "degas at Brewster Flats." The reasons for the fairly substantial difference in scores are summarized below.

<u>Flow Deflectors.</u> This alternative is a known solution with a high degree of gas abatement benefits. It increases flexibility for spill and power generation within the Federal Columbia

River Power System. The cost for installation at Chief Joseph Dam is estimated to be $28.4 million (year 2000 cost level).

It has been suggested that the Corps examine flow deflector installation on fewer than all 19 bays. For example, flow deflectors on the center ten bays. There are both advantages and disadvantages to such a configuration. The major advantages are reduced construction time and cost. However, flow deflectors are inexpensive relative to other solutions. Cofferdam construction represents a significant part of the cost, so the savings realized with installation of fewer flow deflectors would depend on the cofferdam design.

Screening phase two recommended evaluation of the disadvantages of installing fewer than 19 deflectors. With such a configuration, the spillway would not be as effective at reducing TDG. Damage from high flows to the stilling basin would likely increase. Cost savings may be lost in subsequent repair costs of stilling basin damage. (See Section 3.13.1.4 for further discussion of partial bay flow deflector installation).

Lower Monumental Dam on the Snake River provides an example of the damage that can occur when spillway bays with flow deflectors are operated next to bays without flow deflectors. Lower Monumental Dam has flow deflectors installed on only the center of the spillway. When adjacent bays are used, a non-uniform flow condition exists. Debris brought into the stilling basin by deflector bays is caught in the turbulence of non-deflector bays and erodes the stilling basin. At Lower Monumental Dam, a hole has been ground into the stilling basin that most likely will require a costly repair.

Side Channel Canal. The side channel canal alternative would divert spill through a shallow, gently sloped canal between the forebay and the river below the dam. Foster Creek is the most obvious location for the canal to flow into the river.

The major drawback to this solution is the high cost. While costs for this alternative at Chief Joseph Dam have not been detailed, the estimated cost for similar structures at other dams can provide some insight to the cost at Chief Joseph Dam. For a smooth side channel to degas 96,000 cfs to 110% at Lower Granite Dam, the cost would be $302M for design and construction. At Chief Joseph Dam, the design flow would be less, but the channel would be longer to accommodate twice the head. If a baffled side channel is used, the unit flow can be reduced, for a cost of $230M at Lower Monumental. A baffled side channel at Bonneville Dam for 150,000 cfs is estimated to cost $706M.

Some support for the side channel alternative is based upon the opportunity for providing fish passage at Chief Joseph Dam. Because of design requirements, a baffled side channel at Chief Joseph Dam is likely to be incompatible with fish passage. Fish would get caught in the turbulence and slammed against the baffles. It is unknown if resident fish would be similarly affected at Chief Joseph Dam. Smooth-crested side channels are less damaging to fish but are less effective at gas abatement.

In either case, the cost is estimated to be at least ten times the cost for flow deflectors. The limited real estate opportunities would lead to a complicated and long pre-construction phase. Screening phase two recommended that this alternative should be considered a long-term (greater than ten years) alternative.

Degas at Brewster Flats. The last structural alternative identified in the Corps' study of Chief Joseph Dam is a proposal to raise the riverbed in the Brewster Flats area about 10 miles downstream of the dam. A shallow sill in this area would widen the river, decrease water pressure, and allow dissolved gasses to dissipate. This alternative may impact the project with an associated loss of power generation due to an increased tailwater. It may be infeasible due to complicated real estate issues. It would require extensive flood control studies of the Brewster Flats area.

Subsequent to the initial appraisal report, a field study examined existing degassing in the Brewster Flats area in an effort to identify factors responsible for the apparent reduction in gas levels between Chief Joseph and Wells Dams. Dilution by lower TDG powerhouse flow and by tributary flow account for the greatest reduction. The field study concluded some additional reduction in TDG due to coolness of tributary inflow, differential transport through the Brewster Flats area, wind, and a minor amount of in-pool degassing.

This alternative does not degas between the dam and Brewster Flats, a 10-mile stretch of the river that includes the mouth of the Okanogan River, an important stream for threatened steelhead. Under this alternative, adult and juvenile steelhead would need to navigate a short stretch of highly gassed river to enter or exit the Okanogan.

This alternative does not reduce gas production at Chief Joseph Dam, although it does reduce TDG levels in the forebay of Wells Dam (30 miles downstream) and beyond. This alternative is highly unconventional and untested. Due to the expected high cost and study/design complications, screening phase two recommended that the alternative should be considered a long-term (greater than ten years) alternative.

3.9 Discussion of the Remaining Alternatives under Joint Operation

Thus far, studies have identified structural and operational alternatives for dissolved gas abatement. The least costly would be the installation of flow deflectors at Chief Joseph Dam. A joint study between Chief Joseph and Grand Coulee has varying implications for each structural alternative at Chief Joseph Dam. Any joint operation alternative would have to address the ramification on power revenue allocation, transmission issues, and potential for increased maintenance costs.

Flow Deflectors. The spillway at Chief Joseph Dam has three advantages that would positively contribute to the design and function of flow deflectors: 1) only one type of gated outlet, 2) an operating head that varies within only 6 feet, and 3) a tailwater elevation that varies relatively little. Installation of flow deflectors at Grand Coulee Dam would cost much more and would be less effective (based upon comparison with preliminary cost estimates provided in the report Structural Alternatives for TDG Abatement at Grand Coulee Dam, prepared by the Bureau of Reclamation in 1988). The head behind the dam is a critical feature in the design of flow deflectors. At Grand Coulee, flow deflectors would need to be effective for an operating head that can vary as much as 82 feet. Furthermore, Grand Coulee has outlets at three different elevations all on the same face of the spillway, a complication in the design of deflectors. Because of the high unit flow through the outlet tubes at Grand Coulee, flow deflectors would not degas as well as at Chief Joseph with its much lower unit flow.

Under a joint operation alternative, Chief Joseph would spill more while Grand Coulee would generate more. This sort of pooling of resources at Chief Joseph to achieve gas reduction at both projects would require a greater volume of spill at Chief Joseph with less gas production.

Side Channel Canal. If joint operation is assumed, with more generation at Grand Coulee, then more spill at Chief Joseph can be expected. The side channel canal would need to be larger to accommodate this additional spill. To degas this additional flow would require a side channel canal 60 percent wider and more costly than in the examples given in Section 3.8 above.

Degas at Brewster Flats. A shift in generation to Grand Coulee and spill to Chief Joseph would result in less gas saturation below Grand Coulee and more gas saturation below Chief Joseph. This would be a benefit to resident fish in Rufus Woods Lake. The impact to steelhead migrating into and out of the Okanogan River would be greater, because TDG levels between Chief Joseph Dam and Brewster Flats would be higher than under current conditions. To reach the same gas level reduction with joint operation as under operation of Chief Joseph alone would require a more extensive structure, resulting in a higher cost.

3.10 Conclusions – Screening Phase 2

From the perspective of engineering feasibility, known technology, implementation timeliness, and cost-effectiveness, flow deflectors were found to offer the best potential for reducing TDG at Chief Joseph Dam. It was recommended that flow deflectors be the focus of further evaluation. Due to the interagency and Tribal interest (in impacts to existing treaty fishing sites and potential future fish passage - See Section 3.13.2.3) in the side channel canal, it too was recommended for further examination.

Some key conclusions from Screening Phase 2 include:

- In terms of solving the problem at Chief Joseph Dam in isolation, flow deflectors appear to offer the best TDG reduction for the least cost.

- In terms of joint operation with Grand Coulee Dam, installing flow deflectors at Chief Joseph Dam would be much less costly and more effective than installing them at Grand Coulee. Because Chief Joseph and Grand Coulee utilize many of the same transmission lines, this would be a good fit within the hydropower generation system.

- In terms of a basin-wide approach, flow deflectors at Chief Joseph Dam would offer the opportunity to transfer a very large amount of spill to a relatively low-gassing dam, while allowing more power generation and therefore less gassing at other projects. Flow deflectors at Chief Joseph would expand flexibility for spill and power generation in the entire Columbia River hydropower system.

3.11 Screening Phase 2 Recommendations

This second screening phase resulted in the recommendation of three alternatives for further detailed examination, two structural and one operational. It was recommended that the study proceed with the modeling and design of flow deflectors, including an evaluation of installation on fewer than all 19 spillbays. Coincident with this fast-track approach, the continued evaluation of the viability of the side channel option as a long-term alternative to achieve 110% TDG was recommended. The newly formulated Joint Operation Alternative was also recommended for study and evaluation. It was also recommended that the downstream impacts of any change to Chief Joseph Dam TDG generation be evaluated from a system perspective.

3.12 Array of Final Alternatives

The iterative screening processes resulted in the identification of two structural alternatives for further detailed examination. Both these alternatives were determined to be combinable with the operational alternative resulting in four alternative plans. Including the no-action alternative, there are five alternatives for detailed evaluation. These alternatives are listed and described in more detail below:

1. No Action Alternative
2. Chief Joseph Dam Flow Deflectors Alternative
3. Chief Joseph Dam Side Channel Canal Alternative
4. Chief Joseph Dam and Grand Coulee Dam Joint Operation Alternative (no flow deflectors)
5. Chief Joseph Dam and Grand Coulee Dam Joint Operation and Chief Joseph Dam Flow Deflectors Combination Alternative

Evaluation of these alternatives required additional detailed analyses of future without-project and future with-project conditions to support plan recommendation.

3.13 Final Alternatives Evaluation

Following completion of the Initial Appraisal Report (IAR) in May 1998 and subsequent iterations of screening, the Seattle District conducted a number of additional studies to better define the TDG in the river in the without-project condition, and the expected performance of the final array of alternatives.

3.13.1 Flow Deflectors

3.13.1.1 Spillway Deflector Engineering Evaluation

The District initiated two physical model studies at the Corps' Waterways Experiment Station (WES) in Vicksburg, MS. A 1:40-scale physical sectional model was used to select a spillway deflector design (Plate 3-4). This sectional model includes two complete spillway bays with adjacent piers and a half of each bay adjacent to the complete bay. This model was used to evaluate and select the most effective spillway flow deflector design (in terms of size, shape, and location on the spillway) to produce a stable skimming flow regime, which is used as an indicator of a reduction in gas saturation levels. Various designs were evaluated based on the flow conditions in and downstream of the stilling basin through observing aerated flow patterns, dye movement, and point velocity measurements. The existing without-deflector condition and one deflector design were selected for detailed evaluation and performance comparisons including installation of pressure cells to document the pressures at selected locations on and in the vicinity of the deflector and the stilling basin baffle blocks.

Performance curves for short, medium and long deflectors were developed. Additional evaluation and documentation is underway and should be completed by the end of FY 2000. The size, shape, and location of the proposed deflector being used for the structural design are based on this most recent model study. However, since the final hydraulic and hydrodynamic load data are not yet complete, hydraulic load data from the previous model study are still being used for this study. Data from the most recent model study will be used for the final structural design.

A 1:80-scale physical general model, also at WES, was used to begin to: (1) evaluate the with-deflector condition performance characteristics of the stilling basin, (2) the potential to transport material into the stilling basin and (3) identify any unacceptable flow conditions due to the three-dimensional characteristics of the spillway and powerhouse flows. The proposed general model includes the spillway, powerhouse (downstream side detailed only), and the channel for about 2,500 feet downstream from the spillway. Recently observed damage to the stilling basin following the spill operations during the 1997 snow melt season supports the need for this model, which will be used to document the three-dimensional flow conditions downstream of the spillway for various flow combinations involving the spillway and the powerhouse.

The existing spillway design and the deflector design selected from the section model will be installed in this model and flow conditions will be evaluated to determine impacts of the deflectors on stilling basin performance, flow conditions in the channel downstream of the basin, and transport of abrasive material into the stilling basin under various powerhouse operating plans, spillway bay operating plans, and deflector configurations. Flow conditions will be documented using dye, surface confetti, and point velocity measurements. The area immediately downstream of the end sill will be constructed with a moveable bed to assist in qualitatively evaluating the movement of bed material. If adverse flow conditions are identified, corrective activities can be identified and may include design modifications and/or optimizing spillway bay operation patterns. A number of spillway bay operation and powerhouse flow combinations will be evaluated. Construction of the model is complete and calibration is underway. Evaluation and data documentation will be completed in late FY 2000.

3.13.1.2 Spillway Deflector Cost Evaluation

A preliminary cost estimate of $28.4 million (year 2000 cost level) has been prepared for construction of the spillway flow deflector based upon structural designs and civil engineering analyses. This figure accounts for construction and placement of a moveable cofferdam, preparation and drilling of the spillway face for deflector attachment, and flow deflector construction.

3.13.1.3 Spillway Deflector Environmental Evaluation

3.13.1.3.1 Reductions in Dissolved Gas Concentrations Above Chief Joseph Dam

The flow deflector-only alternative does not affect TDG upstream of the dam.

3.13.1.3.2 Reductions in Dissolved Gas Concentrations Below Chief Joseph Dam

The effects of flow deflectors on the TDG downstream of Chief Joseph Dam can be seen in terms of the TDG production curves for the spillway itself and in the total TDG in Lake Pateros downstream. The effect of flow deflectors on the TDG production curves is shown in Plate 3-5. The existing conditions curve (based on near-field model studies) shows that in order to keep TDG from the spillway below 120%, spills must be limited to less than 20 kcfs – a value that is clearly impractical given diurnal spill requirements.

With spillway flow deflectors, Chief Joseph Dam would be expected to have a gas production curve similar to that seen at other dams on the Snake and Columbia Rivers for the same unit flow (flow per foot width of spillway). The gas production curves for flow deflectors show that TDG levels of 120% and less are expected for spills up to 133 kcfs.

The effect of flow deflectors in Lake Pateros is shown on a frequency basis in Plate 3-6 and as a time series in Plate 3-7. In terms of frequency, the flow deflector alternative reduces the 120% TDG exceedance from 45% (without-project conditions) to 31% of the recorded spills, giving a net reduction of 14% of recorded flows. At the more stringent 110% TDG threshold, the exceedances are roughly 65% in both with- and without-project conditions. Reductions are tabulated for levels ranging from 100% to >130% in Table 3.5. In the 1997 time series (Plate 3-7) there were 413 hours (i.e. approximately 17 days) during the season in which the deflector alternative alone would have reduced TDG levels in Lake Pateros from above 120% to something less, with an average reduction of 7%.

Table 3.5 - TDG Reduction in Lake Pateros due to Flow Deflectors

Number of Days and % Time that TDG is Greater Than a Given Threshold March through June 1997, Below Chief Joseph Dam (Lake Pateros)						
TDG (% Saturation)	Existing Conditions		With Flow Deflectors (Designed for 150 KCFS)		Net Reduction in TDG	
	Days	% Time	Days	% Time	Days	% Time
100	122	100	122	100	0	0
105	101	82	101	82	0	0
110	80	66	80	65	0	0
115	70	58	62	51	8	7
120	55	45	37	31	17	14
125	43	35	1	1	42	34
>130	5	4	0	0	5	4

3.13.1.4 Consideration of Partial Bay Deflector Installation

Installation of deflectors on fewer than 19 bays was considered within this study. The greatest drawback identified was the loss of gas abatement benefits due to the increase in unit flow (flow per foot of spillway width). The highest gas abatement benefits would be achieved with joint operation and flow deflectors. Joint operation of Grand Coulee and Chief Joseph would increase the volume of spill at Chief Joseph (Plate 3-8). Flow deflectors are expected to abate TDG to 120% for a spill of about 7 kcfs per bay (Plate 3-5) based on TDG values for the same unit spill (spill per foot width of spillway) seen at dams in the Lower Snake and Columbia Rivers. With ten deflectors, only 70 kcfs (approximate) would be abated, which covers only 40% of the spills during the 1997 spill season (under joint operation) when flows were below 241 kcfs (the 7-day, 10-year flow). A full complement of deflectors would abate gas up to 80% of that time. In addition to lesser gas abatement benefits, partial bay deflector installation would require pier extensions with resulting increased costs.

3.13.1.5 Flow Deflector Conclusions and Recommendations

It is recommended that flow deflectors installed on all bays be included in further cost effectiveness evaluations and considered for implementation at Chief Joseph Dam.

3.13.2 Side Channel Canal

To further evaluate the feasibility of a side channel canal, preliminary designs were developed to assess the alternative locations and configurations of a canal. Also evaluated were the environmental effects of the canal. The design flow (50 kcfs is significantly less than the flow for which flow deflectors would be effective (133 kcfs). The smaller design is adequate for the purpose of this design, to examine constructability and to identify major issues, albeit at a lower level of design.

3.13.2.1 Side Channel Canal Engineering Evaluation

Left Bank - Geotechnical and Hydraulic Considerations. This section presents a cursory review of the geotechnical and hydraulic considerations of a concept design to further assess the feasibility of this alternative. Plan views of the concept design and schematic drawings are presented in Plates 3-9 through 3-11. The left bank was initially chosen in favor of the right bank because of the extensive seepage control mechanisms in place on the right bank and to take advantage of the natural drainage provided by Foster Creek; however, a right bank alternative is also presented.

To permit the diversion of 50,000 cfs, the concept design places a 300 ft. wide, rock lined/concrete channel with an invert elevation of 928 ft. NGVD approximately 1400 ft. upstream of the powerhouse. The channel leads to a control structure containing five 50 ft. x 30.8 ft. tainter gates and then to the first of two baffled chutes. These chutes are designed to dissipate energy, aerate the water and lower the TDG. The water then enters a 600 ft. wide stilling basin, the lower section of which is in the Foster Creek Meadow. From the stilling basin, the channel follows the Foster Creek drainage down to the Columbia River. The second baffled chute is 500 ft. from the river.

If this left bank alternative were fully developed, numerous issues would have to be addressed. For example, the following geotechnical and hydraulic considerations would require further analysis. Construction of the canal requires a cofferdam in Rufus Woods Lake. Excavation of the canal would present water pressure / seepage questions in the left abutment area. Construction of large gate structures and baffle chutes raise questions of foundation conditions. Containment of 50,000 cfs of water requires massive training walls. Historically, the flow of Foster Creek has periodically risen to damaging levels and eroded large quantities of material. The bluffs supporting the visitors' center and leading down from State Highway 17 to the Foster Creek Meadow consist of loose sands and gravels. Construction of the canal would require the replacement of one bridge with two bridges on Pearl Hill Road. The alternative would require extensive road realignment. The powerhouse access bridge would also have to be replaced which could mean relocating the project warehouse. Several electrical transmission towers would have to be relocated. An extensive geotechnical exploration of the canal location would be necessary to determine slope stability, seepage prevention alternatives, soil/rock strength and bearing capacity, erosion protection, and suitable excavation zones and techniques.

A detailed hydraulic analysis of the effects of the canal would also have to be performed for several reasons. Construction of the cofferdam may adversely impact the water flowing to the powerhouse. Entry of water from the canal into the tailrace will lower the momentum of the mainstem river slowing the flow and causing a rise in the tailwater. A flow of 50,000 cfs may erode the opposing right bank as well as cause scouring at the State Highway 17 bridge piers.

Right Bank - Geotechnical and Hydraulic Considerations. As a complement to the left bank concept design, this section presents a cursory review of the geotechnical and hydraulic considerations of a concept design on the right bank. Plan views of the concept design and schematic drawings are presented in Plate 3-12.

To permit the diversion of 50,000 cfs, the concept design places a 300 ft. wide, 852 ft. long concrete channel with a crest elevation of 938.5 ft. NGVD between the spillway and the right abutment. The channel would consist of a 664 ft. baffled chute constructed at a 4:1 slope and a 75 ft. stilling basin. Intake monoliths 1 through 4 were originally built in the non-overflow section of the spillway, but are not an active part of the spillway. These currently inactive structures would be used as the foundation for the channel intake structure. Three, 50 ft. x 38 ft. tainter gates would be used to control the flow in the channel.

If this right bank alternative were fully developed, numerous issues would also have to be addressed. For example, seepage treatments consisting of impervious fill and a seepage blanket exist in the right abutment and extend upstream along the right bank. Disruption of this barrier integrity without adequate control could seriously aggravate the seepage problem through the right abutment. Therefore, any construction beyond the spillway limit into the seepage blanket portion of the right embankment would require detailed analysis and the construction of additional treatments.

Shortly after dam construction, a 900-ft. seepage relief tunnel was constructed from monolith 5 into the right hillside downstream of the dam. The tunnel contains 22 relief wells and currently produces a flow on average of 25 cfs (down from 93 cfs measured after dam construction). Thus, analysis and design of a channel on the right bank would have to encompass modifications to the lower section of the relief tunnel.

Lastly, several years ago orchard irrigation by landowners on the terrace above the right abutment necessitated the construction of an interceptor drain on the hillside above the stilling basin. Therefore if this alternative were further developed, an extensive geotechnical exploration of the canal location would be necessary to determine slope stability and seepage control as well as channel foundation conditions and erosion protection.

A detailed hydraulic analysis of the effects of the canal would also have to be performed for the same reasons as those given for the left bank option. Construction of the cofferdam in the stilling basin may adversely impact water flowing from the powerhouse, and flow of 50,000 cfs may cause erosion along the downstream river banks and scouring at the State Highway 17 bridge piers.

3.13.2.2 Side Channel Canal Cost Evaluation

The total cost required to adequately design and construct a side channel on the left bank is far reaching, and is in all probability greater than ten times the cost of the spillway deflector alternative. Due to the obvious high cost of this alternative, standard feasibility level geotechnical and hydrologic investigations and studies were not conducted nor were corresponding cost estimates prepared.

As with the side channel on the left bank, the total cost to adequately design and build a channel on the right bank is likely to exceed ten times the cost of the spillway deflector alternative. Hence, this alternative was not fully developed. Standard feasibility level geotechnical and hydrologic investigations and studies were not conducted nor were corresponding cost estimates prepared.

3.13.2.3 Side Channel Canal Environmental Evaluation

The side channel alternative must consider several environmental issues. First, the left bank alternative would impact Foster Creek, which may be habitat for anadromous fish, possibly steelhead, which is listed as endangered under the Endangered Species Act. The right bank downstream of the dam is a historic tribal fishing site. Thus, the impact of the channel on tribal fishing rights is also an element that would require further investigation. Either of these situations, especially the Foster Creek impact, would complicate the study, and probably require an Environmental Impact Statement, greatly lengthening the study period and increasing the cost. It would potentially also complicate consultation under the Endangered Species Act, because of a possibility of adverse effect.

Second, a side channel canal would need to be designed and constructed with consideration toward possible fish entrainment effects, again complicating the environmental analysis and mitigation efforts. Third, design and construction of a side channel canal would need to account for future possible anadromous fish passage past Chief Joseph Dam. Fish passage is a stated desire of the Colville Confederated Tribes. However, achieving it is a matter of regional public policy and considerable technical challenge. Policy issues will probably take years to work out. Technical issues would also take time, and would not be surmountable within the study timeframe. It would be unwise to design a side channel canal without including, or being able to eliminate without good reason, fish passage as a benefit. This issue is problematic in that the characteristics of a side channel that would be god for gas abatement are typically bad for fish passage. A side channel canal constructed without planning for fish passage may in fact preclude one or more viable options later.

3.13.2.4 Side Channel Canal Hydraulic Evaluation

In the IAR it was assumed that the side channel canal would meet dissolved gas objectives by meeting the design flow. Subsequent hydraulic evaluation has identified a limitation in the flow capacity of the Foster Creek channel width that would allow for a baffled chute with only a 50 kcfs capacity. This capacity constraint means that the side channel canal is not a viable stand-alone alternative for reducing dissolved gas levels. This alternative would abate gas for only 50% of the observed 1997 spill when the total river flow was within the design parameters (241kcfs). Under the joint study, the side channel would only abate gas for 30% of the anticipated flows. This alternative in combination with flow deflectors would be more effective but would not provide enough additional benefits to override the issues associated with the side channel canal.

3.13.2.5 Side Channel Canal Conclusions and Recommendations

Because of the environmental, engineering and cost issues outlined, a side channel canal should not be considered further for purposes of this study.

3.13.3 Chief Joseph / Grand Coulee Dam Joint Operation

3.13.3.1 Joint Operation Engineering Evaluation

Under joint operation, the total flow (powerhouse plus spill) through each project would remain the same. The change would be in the relative amount that is spilled. The total amount of energy produced by the two projects together also remains the same. To maintain a “power neutral” status in the 2-project system, the differences in their hydraulic heads and turbine characteristics were taken into consideration in the shift of generation and spill.

In formulation of this alternative, it is assumed that Grand Coulee powerhouse hydraulic capacity is 250 kcfs during the spill season. Similarly, Chief Joseph Dam powerhouse hydraulic capacity is assumed to be 200 kcfs during the spill season. Under joint operation, spill from Grand

Coulee is reduced. Instead of passing over the spillway, flows are put through the powerhouse up to a total generation flow of 250 kcfs. During times when the total river flow is greater than 250 kcfs, or when power demand is very low, the extra water would be spilled at Grand Coulee. When shifted, a spill of 10 kcfs at Grand Coulee would translate to a spill of almost 20 kcfs at Chief Joseph.

Under joint operation, spill at Chief Joseph is increased, because generation has been shifted to Grand Coulee. Occasionally during the 1997 spill season, this operation would result in very little power generation at Chief Joseph.

Joint operation is a good opportunity for several reasons:

- Grand Coulee is able to put the 7-day, 10-year flow of 241 kcfs entirely through its powerhouse.
- Structural alternatives for gas abatement at Grand Coulee Dam would cost significantly more than they would at Chief Joseph Dam.
- Flow deflectors at Chief Joseph would have much greater gas abatement benefits than at Grand Coulee.

Table 3.6 provides a summary of 1997 spills, including spill volume and power generation.

Table 3.6 – 1997 Spill Statistics at Chief Joseph Dam

	EXISTING CONDITION		**OPERATIONAL CHANGE**			
	Percent of time spill occurred	*Volume of water spilled*	*Percent of time spill would occur*	*Volume of water spilled*	*Power Shifted*	*Average Power Shifted*
Chief Joseph Dam	63%	10,300 thousand acre-feet	65%	18,800 thousand acre-feet	1,170,000 MW-Hr	400 MW
Grand Coulee Dam	60%	5,800 thousand acre-feet	17%	1,100 thousand acre-feet	1,170,000 MW-Hr	400 MW

3.13.3.2 Joint Operation Cost Evaluation

No changes in operation and maintenance costs are identified for the Joint Operational Alternative at this time. It is anticipated that there may be increased O&M costs at Grand Coulee related to additional power generation and there is a possibility of additional maintenance costs at Chief Joseph Dam related to the increased use of the spillway.

3.13.3.3 Joint Operation Environmental Evaluation

3.13.3.3.1 Reductions in Dissolved Gas Concentrations Above Chief Joseph Dam

The effects of the joint operation alternative on TDG levels above Chief Joseph Dam (Rufus Woods Lake) are shown on a frequency basis in Plate 3-13 and as a time series in Plate 3-14. In terms of frequency, the without project condition shows that TDG exceeds the 120% threshold during 46% of the recorded spills in the 1997 season. With joint operation, the exceedance is reduced to 9% of the recorded spills and net reduction can be characterized as 38% of hourly flows. At the more stringent 110% TDG threshold, the exceedances are 67% without project and 60% with project and net reduction is 7% of the recorded flows. Reductions for TDG levels ranging from 100% to >130% are shown in Table 3.7.

Table 3.7 - TDG Reduction in Rufus Woods Lake due to Joint Operation

Number of Days and % Time that TDG is GREATER THAN a Given Threshold March through June 1997, Above Chief Joseph Dam (Rufus Woods Lake)						
TDG (% Saturation)	Existing Conditions		Joint Operation		Net Reduction in TDG	
	Days	% Time	Days	% Time	Days	% Time
100	122	100	122	100	0	0
105	101	83	91	75	10	8
110	82	67	73	60	10	8
115	68	56	51	42	18	14
120	57	46	11	9	46	38
125	40	33	0	0	40	33
>130	8	7	0	0	8	7

In terms of the 1997 time series (Plate 3-14) there were 1100 hours (i.e. approximately 46 days) during the season in which the joint operation would have reduced the TDG from above 120% to something less, with an average reduction of 11%.

3.13.3.3.2 Reductions in Dissolved Gas Concentrations Below Chief Joseph Dam

The effects of the joint operation alternative on TDG levels below Chief Joseph Dam are shown on a frequency and time series bases in Plates 3-6 and 3-7, respectively. In terms of frequency, the flow deflector alternative reduces the 120% TDG exceedance from 45% (without-project conditions) to 42% of the recorded spills, giving a net reduction of 3% of the recorded flows. At the more stringent 110% TDG threshold, the exceedances are 66% without project and 62% with project and the net reduction is 4% of the recorded flows. The data is also tabulated for levels ranging from 100% to >130% in Table 3.8. Note that for TDG levels greater than 127%, the joint operation actually increases TDG below the Dam. This change would have affected roughly 20% of the recorded spills in the 1997 season (Plate 3-6)

Table 3.8 - TDG Reduction in Lake Pateros due to Joint Operation

Number of Days and % Time that TDG is GREATER THAN a Given Threshold March through June 1997, Below Chief Joseph Dam (Lake Pateros)						
TDG (% Saturation)	Existing Conditions		Joint Operation		Net Reduction in TDG	
	Days	% Time	Days	% Time	Days	% Time
100	122	100	122	100	0	0
105	101	82	98	80	3	2
110	80	66	76	62	4	3
115	70	58	66	54	4	3
120	55	45	52	42	3	2
125	43	35	37	30	6	5
>130	5	4	14	11	-9	-7

In the 1997 time series (Plate 3-7) there were 78 hours (i.e. approximately 3 days) during the season in which joint operation alone would have reduced TDG levels in Lake Pateros from above 120% to something less, with an average reduction of 5%.

3.13.3.4 Joint Operation Conclusions and Recommendations

It is recommended that Joint Operation be included in further cost effectiveness evaluations and considered for implementation at Chief Joseph and Grand Coulee Dams.

3.13.4 Joint Operation and Flow Deflectors Combination

3.13.4.1 Combination Engineering Evaluation

No additional engineering evaluations from those described for the Joint Operation Only alternative and the Flow Deflectors at Chief Joseph Dam Only alternative are required for the combination of the two alternatives.

3.13.4.2 Combination Cost Evaluation

The cost of the combination is estimated at $28.4 million (year 2000 cost level). This corresponds to the preliminary cost estimate for installing flow deflectors at Chief Joseph Dam.

3.13.4.3 Combination Environmental Evaluation

The combined effects of the joint operation alternative and flow deflectors on TDG levels below Chief Joseph Dam are shown on a frequency and time series basis in Plates 3-6 and 3-7 respectively. In terms of frequency, the flow deflector alternative reduces the 120% TDG exceedance from 45% (without-project conditions) to giving a net reduction of 45% of the flows. At the more stringent 110% TDG threshold, the exceedances are 66% without project and 57% with project and a net reduction is 9% of the recorded flows. Data for TDG levels ranging from 100% to >130% are shown in Table 3.9

Table 3.9 - TDG Reduction in Lake Pateros due to Joint Operation and Flow Deflectors

Number of Days and % Time that TDG is GREATER THAN a Given Threshold March through June 1997, Below Chief Joseph Dam (Lake Pateros)						
TDG (% Saturation)	Existing Conditions		With Joint Operation and Flow Deflectors (Designed for 150 KCFS)		Net Reduction in TDG	
	Days	% Time	Days	% Time	Days	% Time
100	122	100	122	100	0	0
105	101	82	98	80	3	2
110	80	66	70	57	10	9
115	70	58	21	17	50	41
120	53	45	0	0	53	45
125	43	35	0	0	43	35
>130	5	4	0	0	5	4

In the 1997 time series (Plate 3-7) there were 1263 hours (i.e. approximately 53 days) in which joint operation combined with flow deflectors would have reduced TDG levels in Lake Pateros from above 120% to something less, with an average TDG reduction of 12%.

3.13.4.4 Combination Conclusions and Recommendations

It is recommended that the Flow Deflector and Joint Operation Combination be included in further cost effectiveness evaluations and considered for implementation at Chief Joseph Dam.

3.13.5 Summary of Water Quality Effects of Final Alternatives

The reduction in the exceedance of given TDG thresholds below Chief Joseph Dam resulting from each of the three alternatives is summarized in Table 3.10. Table 3.11 provides the same summary information for TDG levels above Chief Joseph Dam. Plates 3-15 and 3-16 display the data graphically.

Table 3.10 - TDG Reduction Below Chief Joseph Dam Summary Table

(Number of Days and % Time that TDG is GREATER THAN a Given Threshold March through June 1997)

Below Chief Joe Dam (Lake Pateros)											
TDG (% Saturation)	Existing Conditions			Deflectors Only			Net Reduction				% Reduction in Time in Exceedance of TDG level
	Hours	Days	% Time	Hours	Days	% Time	Hours	Days	% Time		
100	2927	122	100	2927	122	100	0	0	0		0%
105	2413	101	82	2412	101	82	1	0	0		0%
110	1920	80	66	1916	80	65	4	0	0		0%
115	1690	70	58	1488	62	51	202	8	7		12%
120	1308	55	45	895	37	31	413	17	14		32%
125	1020	43	35	24	1	1	996	42	34		98%
>130	112	5	4	0	0	0	112	5	4		100%

Below Chief Joe Dam (Lake Pateros)											
TDG (% Saturation)	Existing Conditions			Operational Change Only			Net Reduction				% Reduction in Time in Exceedance of TDG level
	Hours	Days	% Time	Hours	Days	% Time	Hours	Days	% Time		
100	2927	122	100	2927	122	100	0	0	0		0%
105	2413	101	82	2353	98	80	60	3	2		2%
110	1920	80	66	1828	76	62	92	4	3		5%
115	1690	70	58	1590	66	54	100	4	3		6%
120	1308	55	45	1239	52	42	69	3	2		5%
125	1020	43	35	888	37	30	132	6	5		13%
>130	112	5	4	328	14	11	-216	-9	-7		-193%

Below Chief Joe Dam (Lake Pateros)											
TDG (% Saturation)	Existing Conditions (Measured Data)			Both Deflectors and Operational Change (Modeled Data)			Net Reduction				% Reduction in Time in Exceedance of TDG level
	Hours	Days	% Time	Hours	Days	% Time	Hours	Days	% Time		
100	2927	122	100	2927	122	100	0	0	0		0%
105	2413	101	82	2349	98	80	64	3	2		3%
110	1920	80	66	1676	70	57	244	10	8		13%
115	1690	70	58	494	21	17	1196	50	41		71%
120	1308	55	45	0	0	0	1308	55	45		100%
125	1020	43	35	0	0	0	1020	43	35		100%
>130	112	5	4	0	0	0	112	5	4		100%

Table 3.11 - TDG Reduction Above Chief Joseph Dam Summary Table

(Number of Days and % Time that TDG is GREATER THAN a Given Threshold March through June 1997)

Above Chief Joe Dam (Rufus Woods Lake)											
TDG (% Saturation)	Existing Conditions (Measured Data)			Operational Change (Modeled Data)			Net Reduction				% Reduction in Time in Exceedance of TDG level
	Hours	Days	% Time	Hours	Days	% Time	Hours	Days	% Time	Hours	
100	2927	122	100	2927	122	100	2927	0	0	2927	0%
105	2429	101	83	2191	91	75	2429	10	8	2191	10%
110	1973	82	67	1743	73	60	1973	10	8	1743	12%
115	1643	68	56	1222	51	42	1643	18	14	1222	26%
120	1356	57	46	257	11	9	1356	46	38	257	81%
125	970	40	33	0	0	0	970	40	33	0	100%
>130	197	8	7	0	0	0	197	8	7	0	100%

3.14 Cost Effectiveness and Incremental Cost Analysis

To conduct cost effectiveness and incremental cost analyses of the project alternatives, it was selected to use TDG reduction as the output measure. Specifically, because the critical threshold for fish health has been identified as 120% TDG supersaturation, the output measure used was the *Reduction of Time in Exceedance of 120% TDG* below Chief Joseph Dam. A secondary criterion used was the *Reduction of Time in Exceedance of 120% TDG* above Chief Joseph Dam. In the preliminary cost estimates, costs occur only with implementation of the Flow Deflectors. Table 3.12 presents the summary cost and output information for all remaining alternatives:

Table 3.12 – Summary of Costs and Outputs

Alternative	Cost	Output (Below Dam)	Output (Above Dam)
No Action	0	0%	0%
Joint Operation Only	0	5%	81%
Flow Deflectors Only	28,375,000	32%	0%
Combination of Joint Operation and Flow Deflectors	28,375,000	100%	81%

3.14.1 Analysis Above Chief Joseph Dam (Lake Rufus Woods)

Table 3.10 demonstrates that an 81% reduction in time of exceedance of 120% TDG supersaturation level is achievable in Lake Rufus Woods through the Joint Operation Alternative or the Combination of Joint Operation and Flow Deflectors at Chief Joseph Alternative. If concerned only with water quality in Lake Rufus Woods, implementing the Joint Operation Only alternative would be the only cost effective option. As the primary concern of the study is water quality below Chief Joseph Dam, reductions in 120% TDG exceedance in Rufus Woods Lake are used as a secondary consideration in this study.

3.14.2 Analysis Below Chief Joseph Dam

Table 3.10 demonstrates that a 5% reduction in exceedance of 120% TDG below the dam is attainable with the Joint Operation Only Alternative at no cost. By adding flow deflectors to the Chief Joseph Dam, the reduction in exceedance of 120% TDG increases to 32% at a preliminary cost estimate of $28.4 million (year 2000 cost level). If flow deflectors are installed and the joint operation alternative is implemented, 100% reduction in exceedance of the 120% TDG level can be attained at no additional cost. Therefore it would not make economic sense to install the flow deflectors without implementing the joint operation alternative.

In summary, two cost effective alternatives exist for reducing exceedance of the 120% TDG level:

- Joint Operation Only and
- Joint Operation with Flow Deflectors at Chief Joseph Dam Combination

The incremental costs and incremental outputs of these two alternatives are presented in Table 3.13. An incremental cost graph is presented as Plate 3-17.

Table 3.13 – Incremental Cost Analysis

Alternative	Total Cost*	Incremental Cost*	Total Output (Below Dam)	Incremental Output	Incremental Cost per Unit*
No Action	0	0	0%	0	n.a.
Joint Operation Only	0	0	5%	5%	$0 per percentage point reduction
Combination	28,374,860	0	100%	95%	$298,680 per percentage point reduction
**Costs are at year 2000 cost level*					

3.14.3 Conclusions

The cost effectiveness evaluation identified that the Joint Operation Only alternative provided fish and wildlife benefits by reducing harmful levels of supersaturated gas in Lake Rufus Woods (above Chief Joseph Dam) at no cost. The alternative reduces exceedance of harmful gas thresholds in Lake Rufus Woods by 81% and Lake Pateros (downstream of Chief Joseph Dam) by 5%. If no other actions were taken, this plan involving shifting spill from Grand Coulee Dam to Chief Joseph Dam would be desirable and cost effective. However, to respond to the BiOp and reduce harmful TDG conditions for threatened and endangered fish, additional action is required at Chief Joseph Dam. The addition of flow deflectors at Chief Joseph Dam reduces the exceedance of harmful gas thresholds in Lake Pateros by an additional 95% (for a total reduction of 100%) at an estimated cost of $28.4 million (year 2000 cost level).

4. DESCRIPTION OF RECOMMENDED PLAN

4.1 Recommended Plan

Based upon the engineering, environmental and economic evaluations conducted for the Chief Joseph Dam Gas Abatement Study, it is recommended that the Combination of Flow Deflectors at Chief Joseph Dam and Joint Operation of Grand Coulee and Chief Joseph Dams be implemented.

This is the most cost effective alternative for addressing the concerns of the 1998 BiOp regarding the water quality impacts of Chief Joseph Dam on threatened and endangered fish stocks in the Columbia River Basin. The alternative reduces the percent time in exceedance of the 120% TDG (based upon modeling of the 1997 spill season) threshold by 100%. The 120% TDG goal has been determined by scientific studies and accepted by the Northwest Power Planning Council's Independent Scientific Advisory Board. The preliminary project cost is significantly less than the cost of several other alternatives screened out in the study for cost, engineering, and environmental reasons.

4.2 Cost of Recommended Plan

A preliminary MCACES cost estimate of $28,374,860 million (year 2000 cost level) has been developed for the recommended plan. This cost estimate is rounded to $28,400,000 for cost reporting. The components of this cost estimate are displayed in Table 4.1. The cost estimate includes construction of a cofferdam, and its placement at each of 19 bays for incremental construction of the flow deflector. The estimate also includes construction of the flow deflectors at each bay. The estimate includes activities to mitigate for erosion or other damages resulting from the structural modification. A 5% contingency is applied to the overall estimate. 15% design contingencies are applied to cofferdam and flow deflector construction activities.

Table 4.1 - Cost Breakdown for Recommended Plan

Item	*Estimated Cost**
Fabricate Floating Cofferdam (with 15% design contingency)	2,586,960
Place Cofferdam at Bay 1 (with 15% design contingency)	266,260
Construct Flow Deflector at Bay 1 (with 15% design contingency)	444,810
Refloat Coffer Dam at Bay 1 (with 15% design contingency)	90,060
Modify Cofferdam Side Frames (with 15% design contingency)	37,950
Place Cofferdam (Remaining 18 Bays) (with 15% design contingency)	5,214,340
Construct Flow Deflectors (Remaining 18 Bays) (with 15% design contingency)	9,819,100
Refloat Coffer Dam (Remaining 18 Bays) (with 15% design contingency)	1,621,160
SUBTOTAL Chief Joseph Gas Abatement Features	20,080,640
Mobilization & Demobilization	265,090
Upstream / Downstream Bank Protection (with 15% design contingency)	1,315,680
Mitigation (of impacts on existing project)	3,000,000
SUBTOTAL Chief Joseph Dam Gas Abatement Project	24,661,410
Escalation (3.38%)	832,630
SUBTOTAL	25,494,040
Contingency (5%)	1,274,700
SUBTOTAL	26,768,740
Supervision, Inspection, and Overhead (6%)	1,606,120
TOTAL PROJECT COSTS	28,374,860

** All costs displayed are at year 2000 cost level. For cost reporting, total project cost estimate is rounded up to $28.4 million.*

4.3 Environmental Benefits of Recommended Plan

4.3.1 Benefits in Project Vicinity

In Lake Rufus Woods (above Chief Joseph Dam), the recommended plan reduces the percent of time in exceedance of 120% TDG by 81%. This will have positive impacts on fish species within the lake by limiting their exposure to harmful gas levels. Widespread fish kills have been documented in Lake Rufus Woods during recent high-spill years (e.g., 1997). The reduction in TDG will also have economic benefits by reducing kills within fish pen in the lake.

In Lake Pateros (below Chief Joseph Dam), the recommended plan reduces the percent of time in exceedance of 120% TDG by 100%. The project would benefit threatened and endangered species, which pass through the lake on their way to tributaries and habitat. Because the gas production at Chief Joseph Dam persists far downstream, reduction in TDG level at Chief Joseph provides water quality improvements far below the dam.

4.3.2 Downstream Benefits

The 98 BiOp directed the Action Agencies to develop a plan of action to achieve TDG reductions in the Columbia-Snake River System. In response to the BiOp, the Corps of Engineers, Bureau of Reclamation, and Bonneville Power Administration undertook a joint study of system-wide TDG contributions and relationships. To conduct this reconnaissance level systematic study, a modeling tool named SYSTDG, funded by BPA and the Corps, was developed by the Corps of Engineers Research and Development Center (formerly Waterways Experiment Station).

SYSTDG was developed to examine spill management and power production scenarios at 16 hydropower dams in the Columbia-Snake River System. The 16 dams included 11 dams in the Federal Columbia River Power System (FCRPS) (including Chief Joseph and Grand Coulee Dams) and the 5 dams operated by the Washington Public Utility Districts (PUDs) downstream of Chief Joseph Dam. The upstream boundaries of the model are Grand Coulee Dam on the Columbia River and Dworshak Dam on the Snake River. The downstream boundary is River Mile 120 below Bonneville Dam on the Columbia River. The SYSTDG model predicts TDG in the tailwater and forebay of each dam based upon the following parameters:

- Boundary Conditions (total river flow and TDG levels at Grand Coulee and Dworshak Dams)
- Operations at Each Dam (power generation flow and spill flow, which can be specified by user or determined by model)
- Gas production equations for each dam
- Gas Dissipation and transport through pools

For the Chief Joseph Dam Gas Abatement Study, a shortened version of the SYSTDG model was developed that focused on the Mid-Columbia reach from Grand Coulee Dam through Priest Rapids Dam. The model was applied to examine operational and structural alternatives at Chief Joseph and Grand Coulee for gas abatement. The model used 1996 and 1997 flow data to examine the downstream impacts of the final set of alternatives from the feasibility study:

- No Action Alternative
- Chief Joseph Dam Flow Deflectors Alternative
- Chief Joseph Dam and Grand Coulee Dam Joint Operation Alternative (no flow deflectors)
- Chief Joseph Dam and Grand Coulee Dam Joint Operation and Chief Joseph Dam Flow Deflectors Combination Alternative *(recommended alternative)*

Application of the SYSTDG model to examine the effects of the alternatives found that ESA-listed fish passing through the zone of influence of the alternatives would experience lower TDG levels. Affected tributaries include the Okanogan, Methow, Wenatchee, and Entiat Rivers. Plates 4-1 and 4-2 show the magnitude of the TDG reduction resulting from implementation of the recommended alternative from the Grand Coulee Dam tailwater through Priest Rapids Dam tailwater. Using 1997 river flows, the preferred alternative would reduce gas supersaturation by 8 percent in the pools above and below Chief Joseph Dam. The reduction in gas below each of the subsequent dams would decrease until Priest Rapids Dam. At the tailwater of Priest Rapids Dam, there would be no difference between the existing condition and the preferred alternative.

The magnitude of TDG reduction resulting from implementation of the recommended alternative is dependent on the data set used in the SYSTDG model. Suitable data sets exist for the years 1996 through 1999. Any year in which spill occurs would show the same trend seen in Plates 4-1 and 4-2. However, non-spill years, such as 1998 and 1999, would show no difference between the alternatives. The volume of water and number of days on which spill occurs are highly variable (Plate 2-3). The years during which spill occurs have 7-day average peak flows that are roughly 2-year events (170,000 cfs) or greater. The years with large spills that would impact water quality have 7-day average peaks that are 4-year events (205,000 cfs) or greater. Hence, the Mid-Columbia River would be expected to experience benefits of the preferred alternative every two to four years.

4.4 Environmental and Regulatory Compliance

A Draft Environmental Assessment has been prepared pursuant to NEPA for the structural and operational modifications proposed to Chief Joseph Dam. Seattle District has distributed a public notice describing the Study and final alternatives to solicit input and concerns. The District believes that the NEPA documentation for the proposed actions can be satisfied with an Environmental Assessment rather than an Environmental Impact Statement based upon the record of other flow deflector project already constructed or under construction in the Columbia River Basin. It is also expected an EA will be appropriate because the overall effect will be a benefit to the environment, and to the stocks of fish listed under the Endangered Species Act in the study area. Construction methods are being formulated to avoid in-water work to the extent possible. This effort has documented regional support, especially that of the National Marine Fisheries Service. The draft EA has been distributed for public and agency review and comments have been received and addressed.

4.5 Structural Modification Description

4.5.1 Flow Deflectors

Configuration of the proposed deflector is shown on attached Plate 4-3. The arrangement shown is a result of physical model studies conducted at the Waterways Experiment Station. The proposed deflector lip is at elevation 779.0 msl. The bottom of the deflector is at elevation 768.0 msl. At most normal operating conditions, the top of the deflector will be submerged. The actual depth of submergence is relative to total dam discharge at Chief Joseph Dam and pool elevation behind Wells Dam. Deflectors are proposed for construction of all 19 bays of the spillway.

It is proposed that the deflector be constructed of concrete. This material has been used to construct deflectors at other dams on the Columbia/ Snake River system. Because of the relatively high hydraulic forces associated with the proposed deflector configuration, it is proposed that the deflector be anchored to the spillway face with drilled-in prestressed anchors. The physical dimensions of the deflector and hydraulic forces to be used for the conceptual design were defined by the study's H&H analyses, documented in the Hydrology and Hydraulics Appendix.

4.5.2 Cofferdam

Construction of the deflector will require the use of a cofferdam to insure the necessary concrete quality. The cofferdam is shown in Plate 4-4. Because of the large range of tailwater elevations, some trade off must be made between risk of flooding the cofferdam and maximum discharges.

Tailwater elevations are the main variable in determining the required height of cofferdam and contractor working conditions. For the purposes of this study, maximum design tailwater elevation was set at 793.0 fmsl. Top of cofferdam elevation was set at 800.0 fmsl to allow seven foot of freeboard for waves in the tailwater area.

The cofferdam is shown as a floating system that spans between internal struts and bottom bearing/reaction plates when dewatered. Wing walls are shown on each side. The previously cast deflector side will have a corresponding cutout. These wingwalls are shown to be separate non-floating pieces that are lowered into place after the main floating cofferdam is positioned. An additional horizontal strut is shown to resist the hydrostatic forces against the wingwalls. Since the forces are slightly unequal due to the deflector on one side, the unequal forces could be resisted by the upper cofferdam strut reaction plates.

4.5.3 Construction Sequence

As shown on Plate 4-5, the construction sequence is simply a) Set cofferdam including wing walls on previously placed bearing/reaction plates, b) Construct flow deflector between monolith joints, and c) Move cofferdam ahead and repeat process.

The operations shown will require a contractor derrick barge, deck barge for storing cofferdam wing walls, reinforcing and formwork, and some method of delivering concrete to the work area either by a barge supported concrete plant or bucket or highline arrangement. In addition to the equipment noted above, a separate work platform would be required to construct the cofferdam bearing/reaction plates ahead of the cofferdam work.

A critical element of the deflector construction will be drilling the holes for the anchoring tendons. The Cofferdam has been shown to be larger than the deflector to accommodate small drill rigs that utilize down-hole hammers. These drill rigs will have to be supported on temporary scaffolding within the work area. Placing and grouting the prestressing tendons must also be done within the confines of the cofferdam. The high loads required and the restricted work area will preclude the use of prestress bars (Dywidag). Consequently, multi strand wire tendons are recommended.

4.6 Operational Modification Description

The operational change recommended involves shifting spill from Grand Coulee to Chief Joseph Dam whenever possible. This action is "power neutral" in that it is not expected to effect total power generation from the two facilities or impact the transmission infrastructure. Adding the operational change with the installation of flow deflectors at Chief Joseph Dam allows for greater flexibility and effectiveness at reducing TDG concentrations from both facilities. This is underscored by the fact that Grand Coulee is able to pass the full 7-day average flow upon which state and Federal water quality standards apply through its powerhouse. The additional spill required at Chief Joe to pass this volume of water would spill over the new flow deflectors, keeping TDG at lower levels.

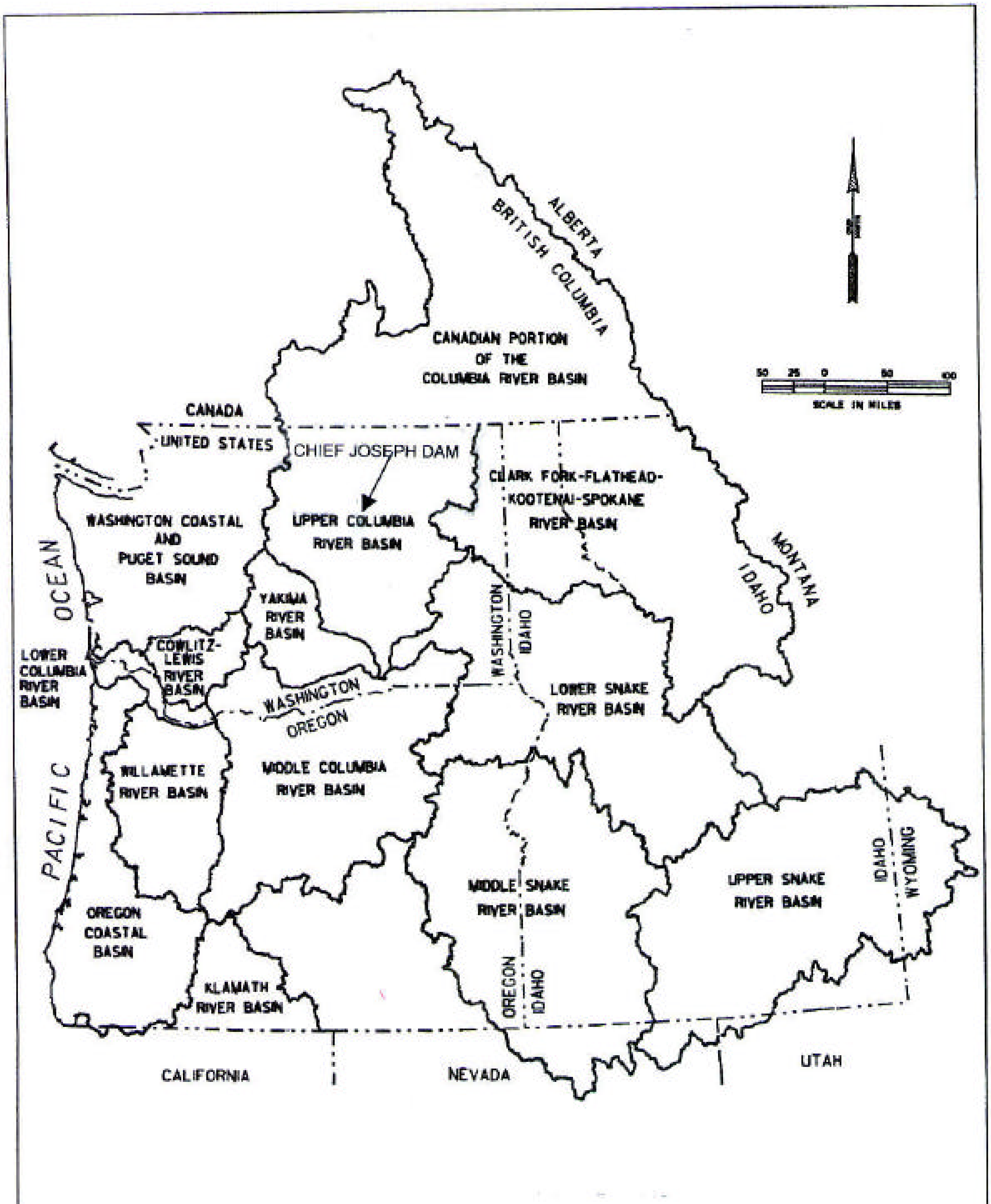
4.7 Implementation of Recommended Plan

To implement the recommended plan, construction funding will be requested through the Corps Construction General program. Detailed construction plans and specifications will be prepared during the Preconstruction Engineering and Design (PED) Phase followed by the project's Construction Phase. The PED phase is estimated to cost $ 600,000 and scheduled for completion in FY 2002. Construction is scheduled for initiation in FY 2002. Funding required to initiate construction and staging is estimated at $200,000 in FY 2002.

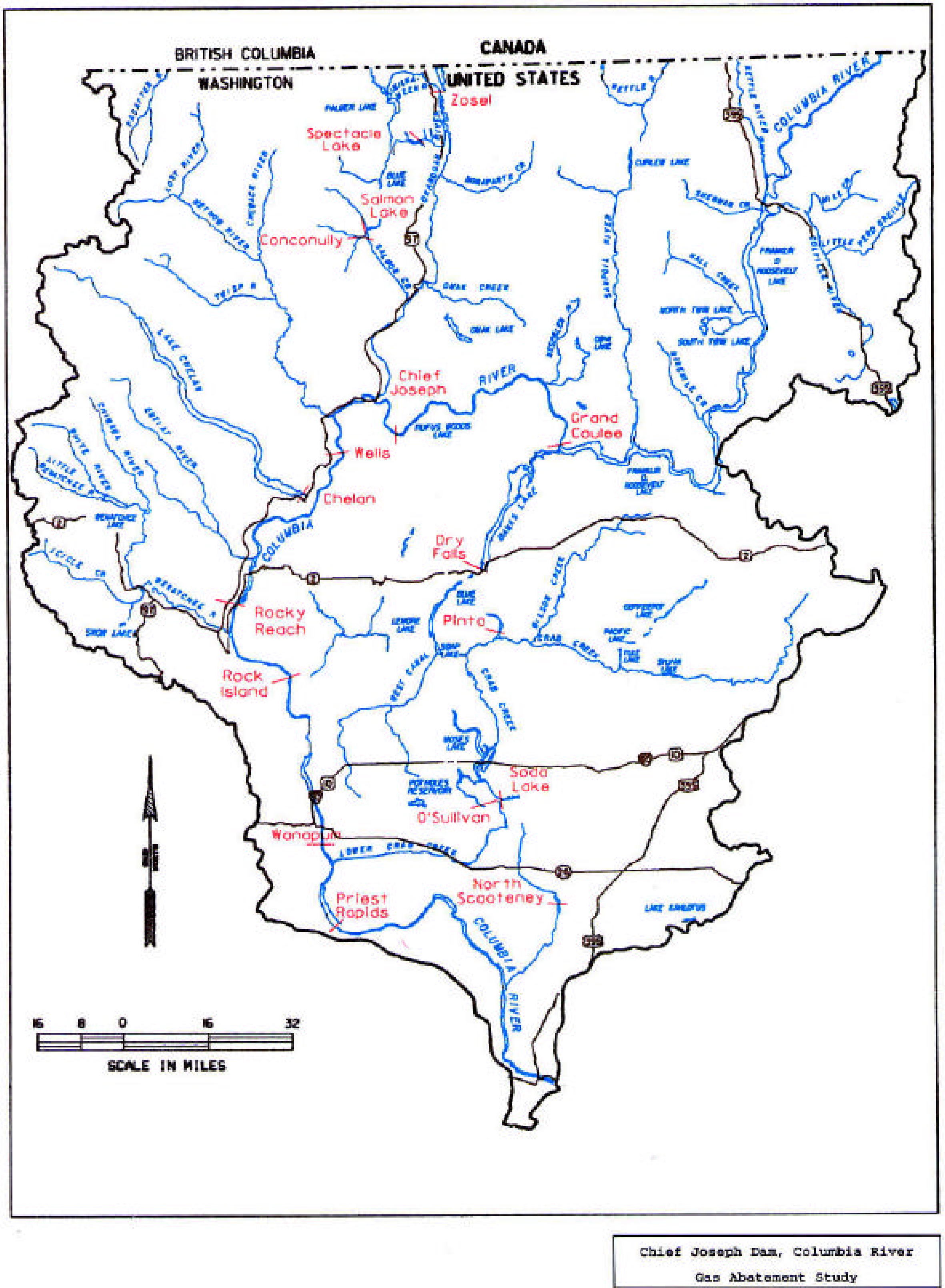
To address concerns, including worker safety, construction is likely to be limited to an 8-month construction season from 1 July to February 28. This would keep the likelihood of spill during the construction window down to a very low and acceptable level. This schedule would leave approximately 64 weeks over 2 years to complete construction. Construction is scheduled for completion during the July 2003 – February 2004 construction season. Table 4.2 Displays the schedule, funding requirements, and non-federal reimbursement for implementation of the recommended alternative for gas abatement at Chief Joseph Dam.

Table 4.2 – Implementation Schedule and Funding Requirements

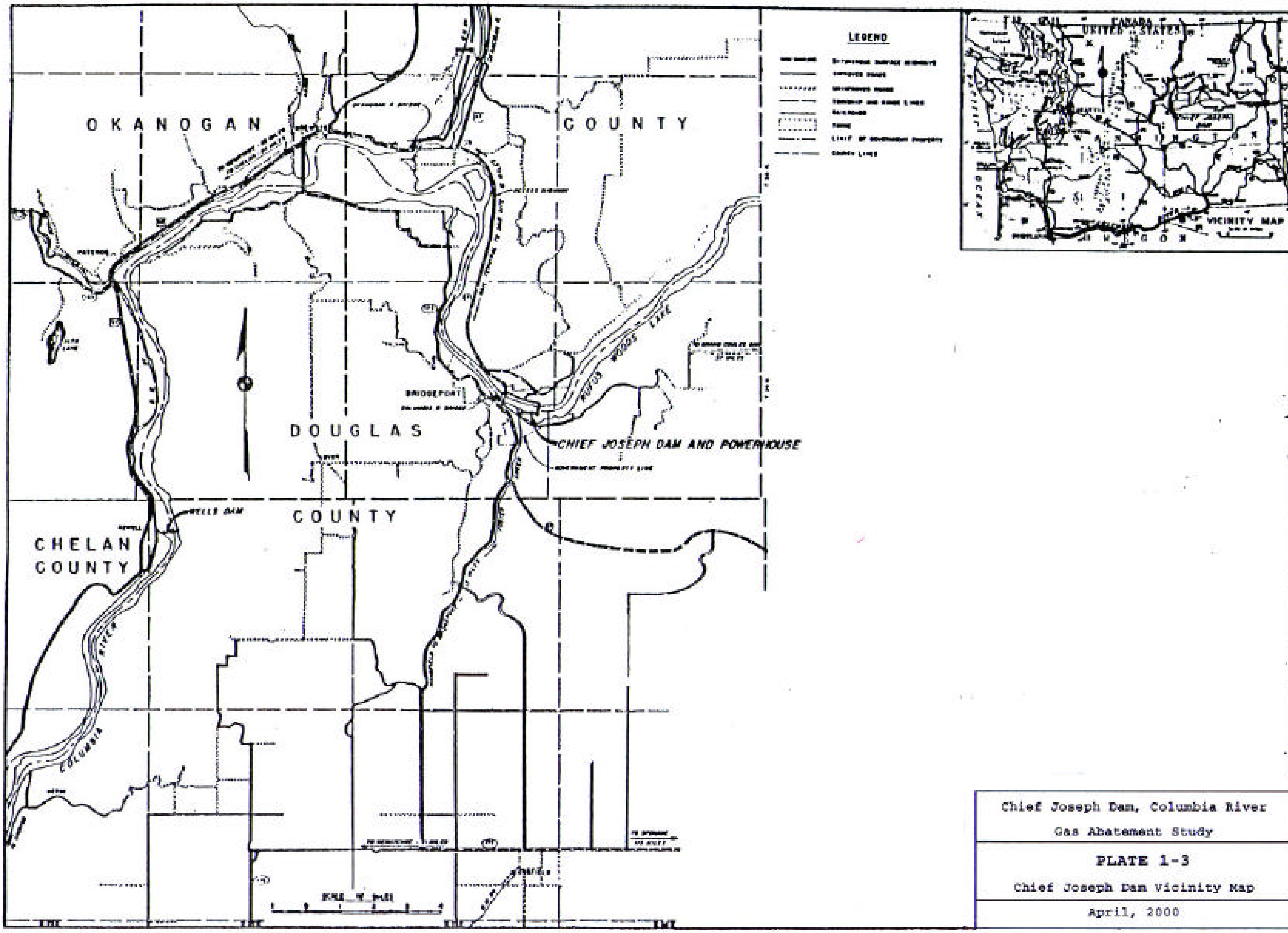
Allocation through FY 2001	$ 0
Allocation requested for FY 2002 (PED and contract startup, staging)	$ 800,000
Allocation requested for FY 2003 (Construction)	$ 13,800,000
Allocation requested for FY 2004 (Construction)	$ 13,800,000
Total Allocation requested FY 2002 - 2004	$ 28,400,000
Estimated Total Appropriation Requirement	$ 28,400,000
Future Non-Federal Reimbursement (BPA)	$ 28,400,000
Estimated Federal Cost (Ultimate)	$ 0
Estimated Non-Federal Cost (Ultimate)	$ 28,400,000



Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 1-1 Columbia/Snake Drainage Basins
April, 2000



Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 1-2
Upper Columbia River Basin (USA)
April, 2000



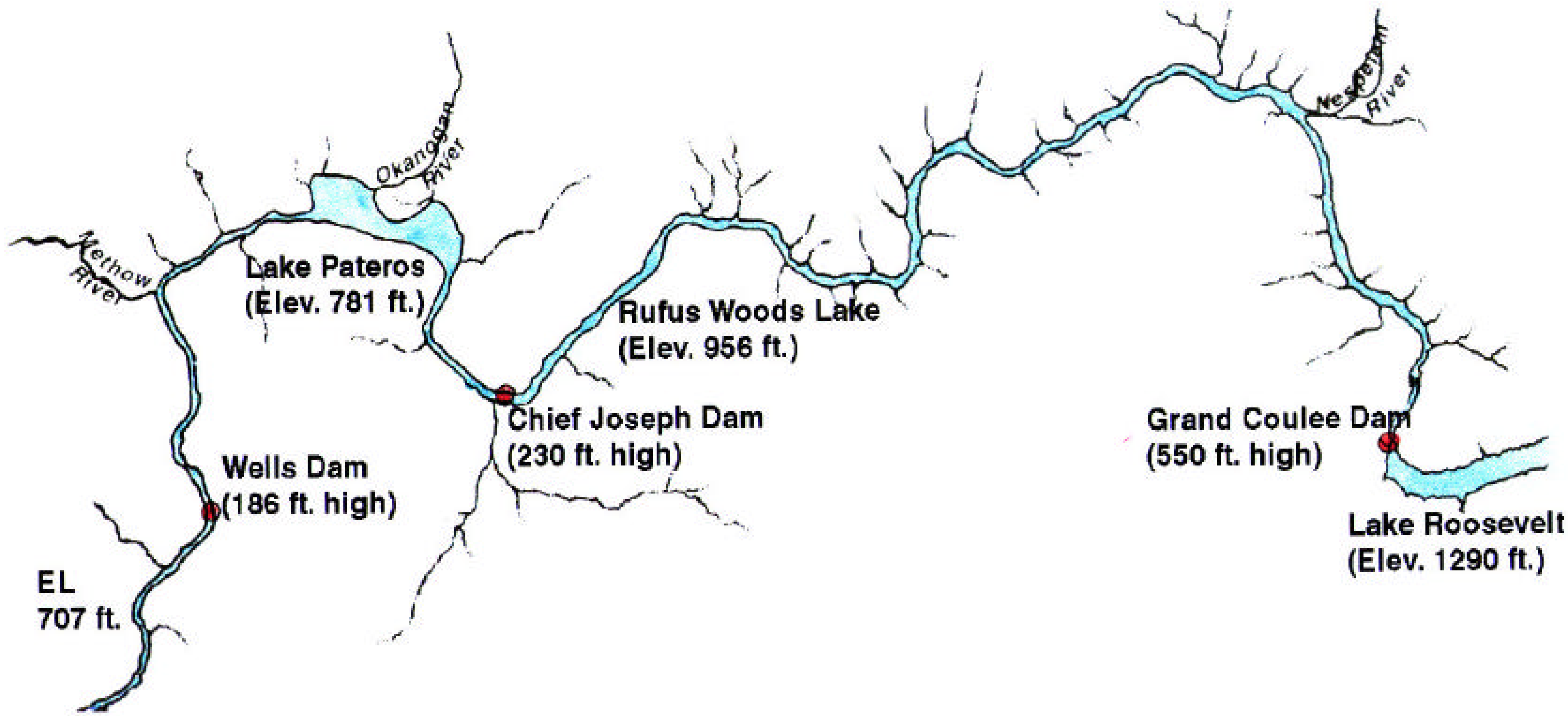
Chief Joseph Dam, Columbia River

Gas Abatement Study

PLATE 1-3

Chief Joseph Dam Vicinity Map

April, 2000



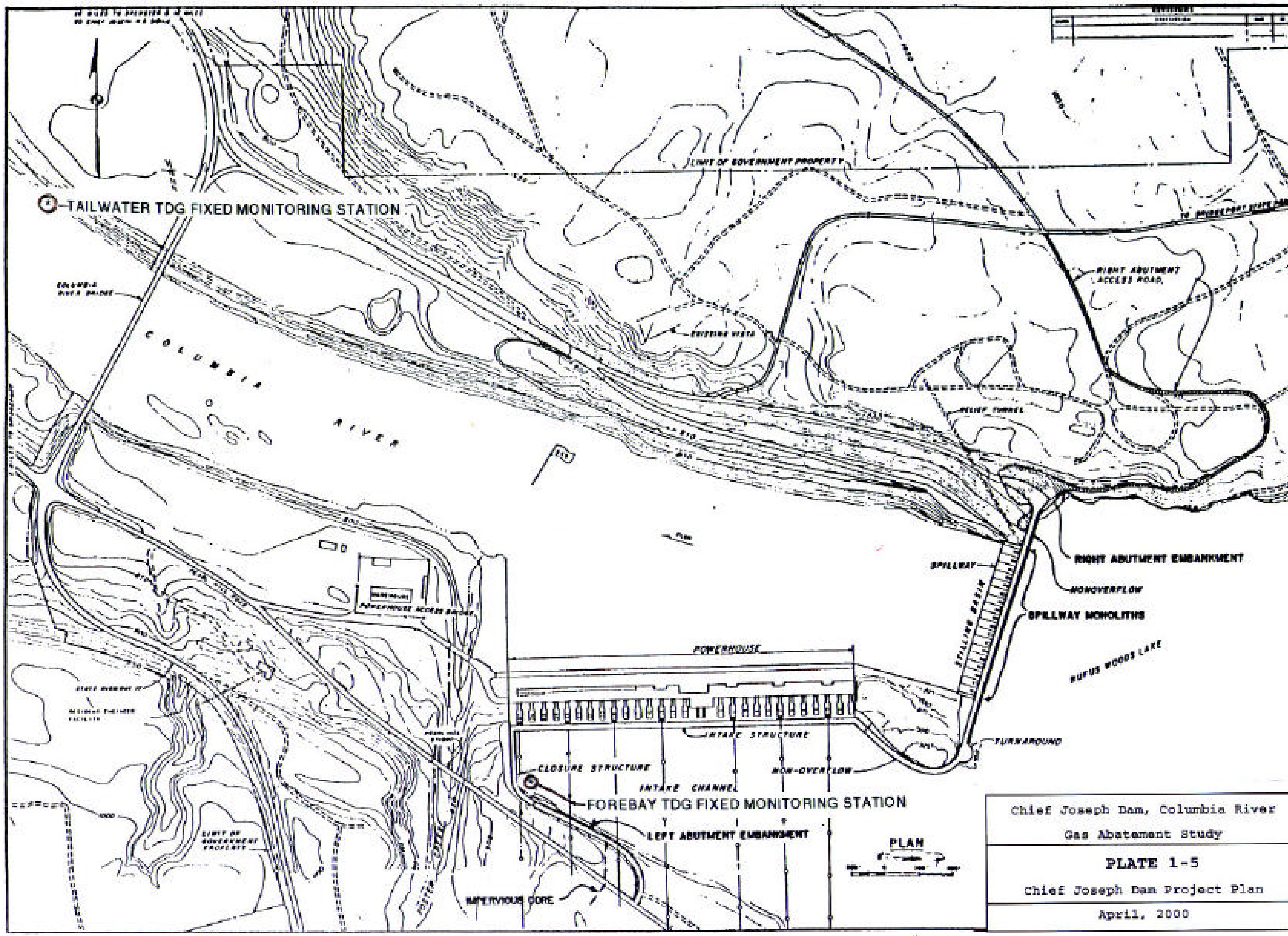
Chief Joseph Dam, Columbia River

Gas Abatement Study

PLATE 1-4

Upstream/Downstream Dams

April, 2000



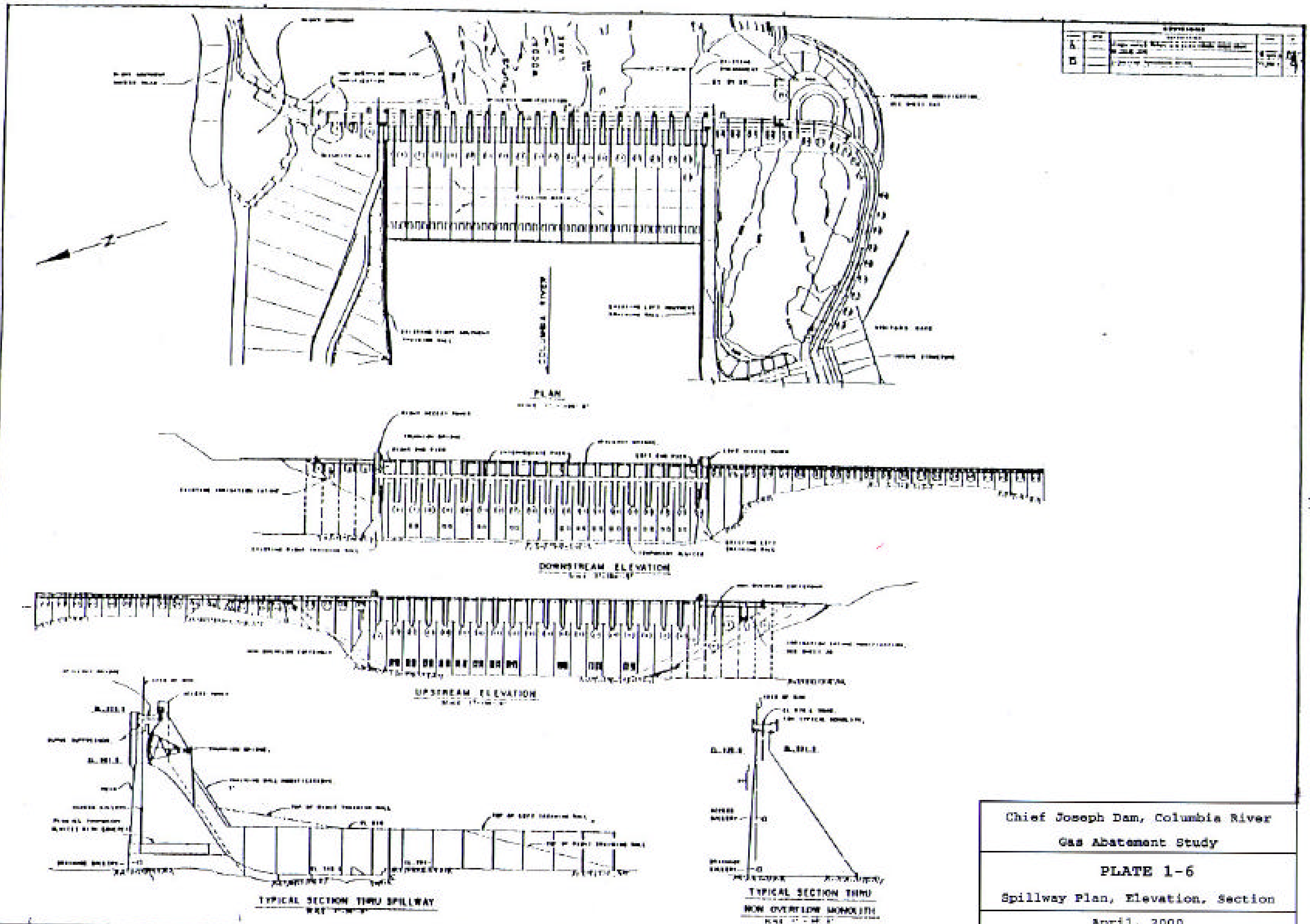
Chief Joseph Dam, Columbia River

Gas Abatement Study

PLATE 1-5

Chief Joseph Dam Project Plan

April, 2000



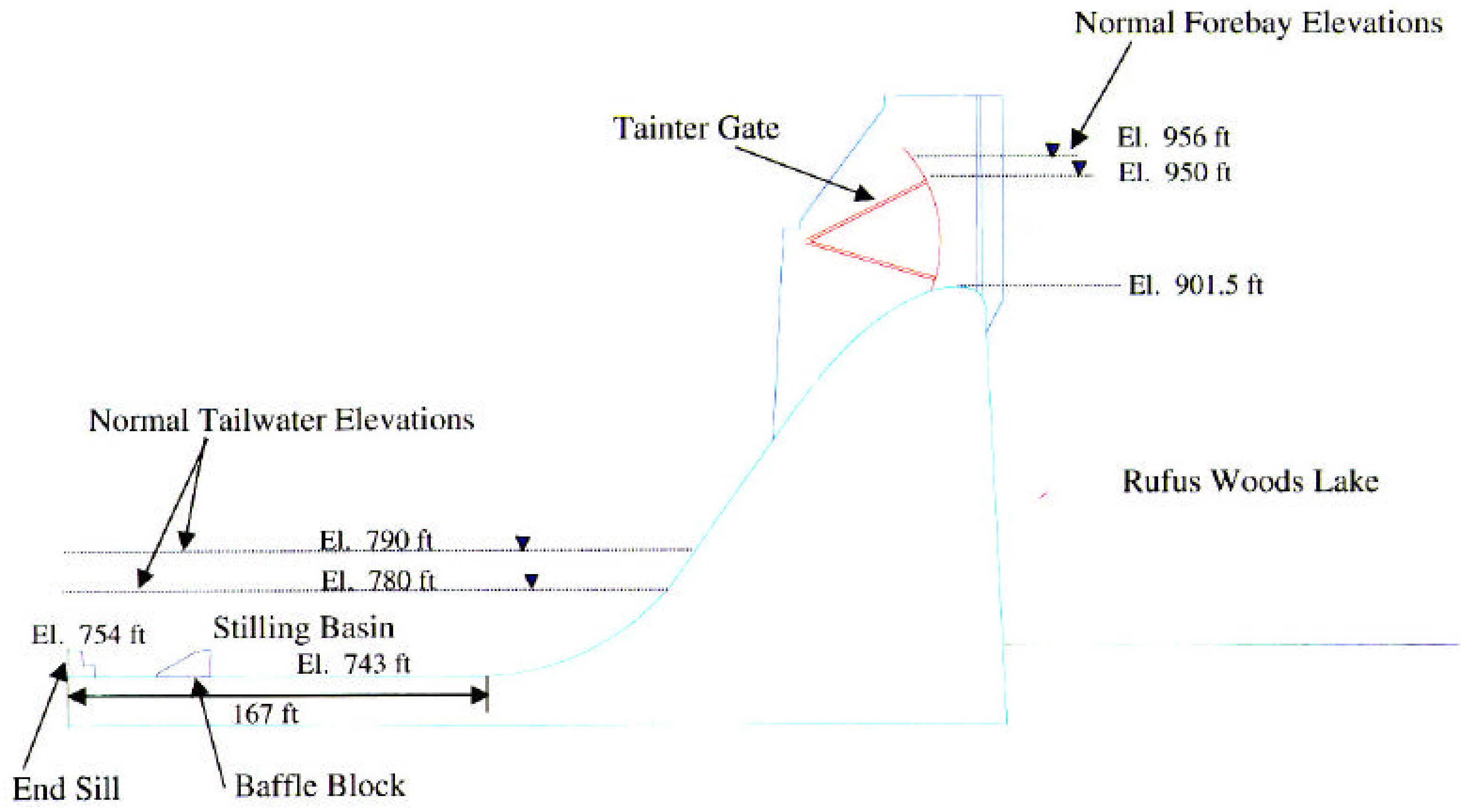
Chief Joseph Dam, Columbia River

Gas Abatement Study

PLATE 1-6

Spillway Plan, Elevation, Section

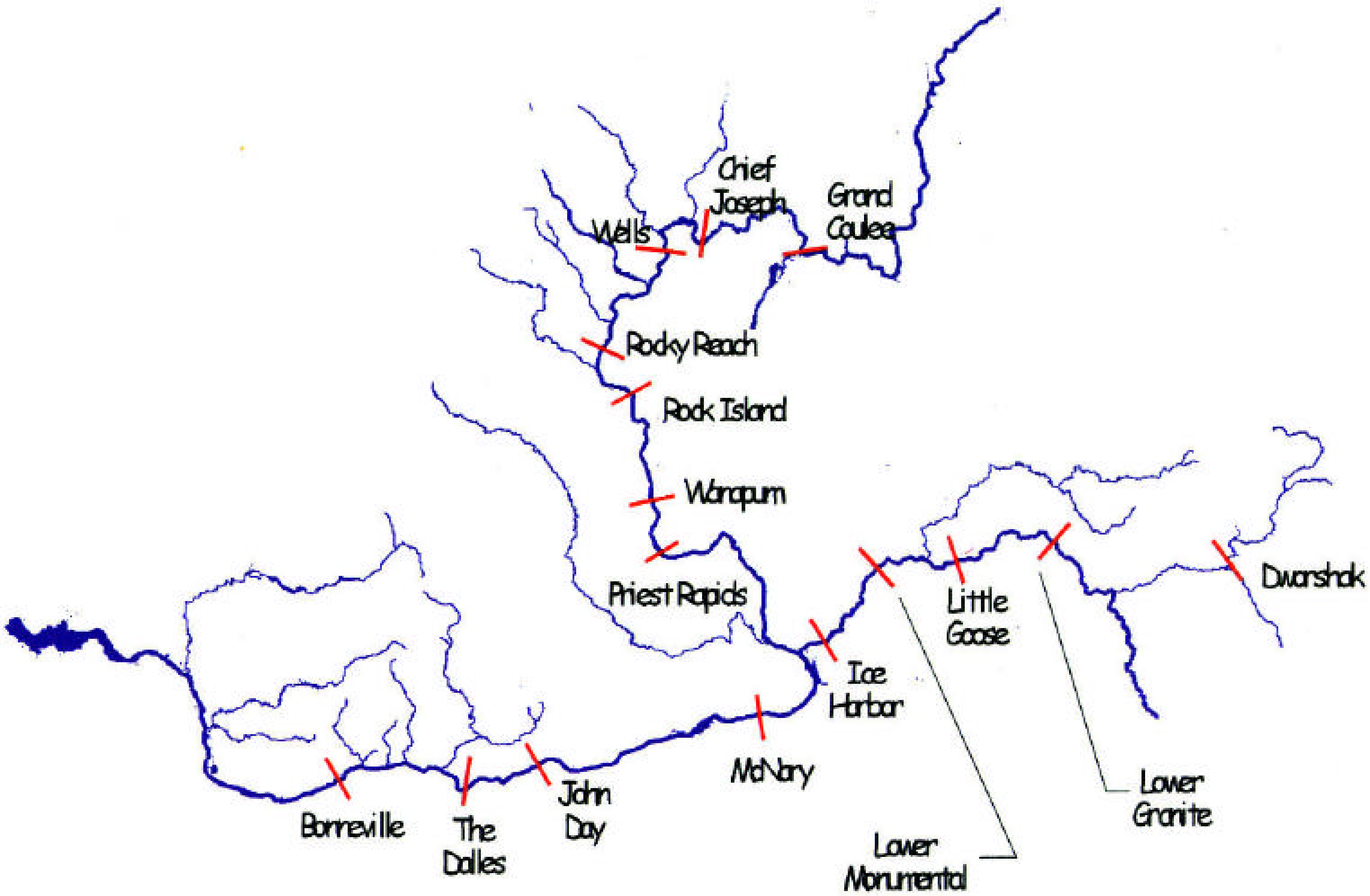
April, 2000



Profile View of Chief Joseph Spillway with Typical Water Surface Elevations.

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 1-7 Spillway Profile
April, 2000

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 1-8 Aerial Photograph, Chief Joseph Dam
April, 2000

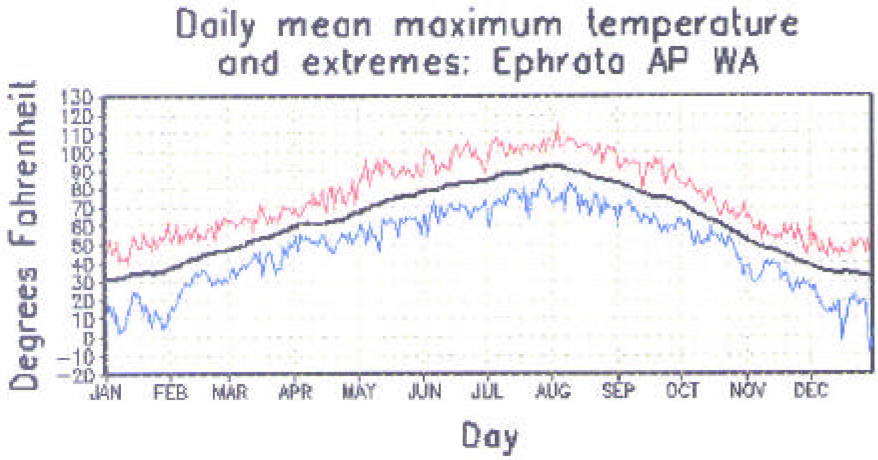


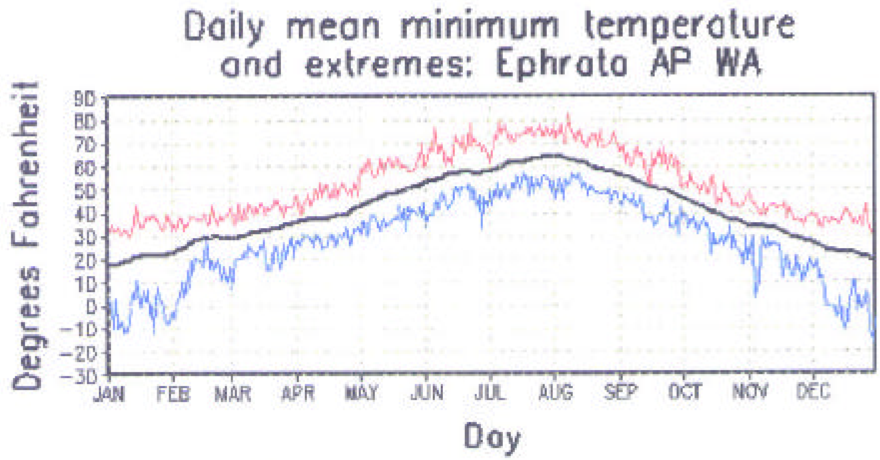
Chief Joseph Dam, Columbia River
Gas Abatement Study

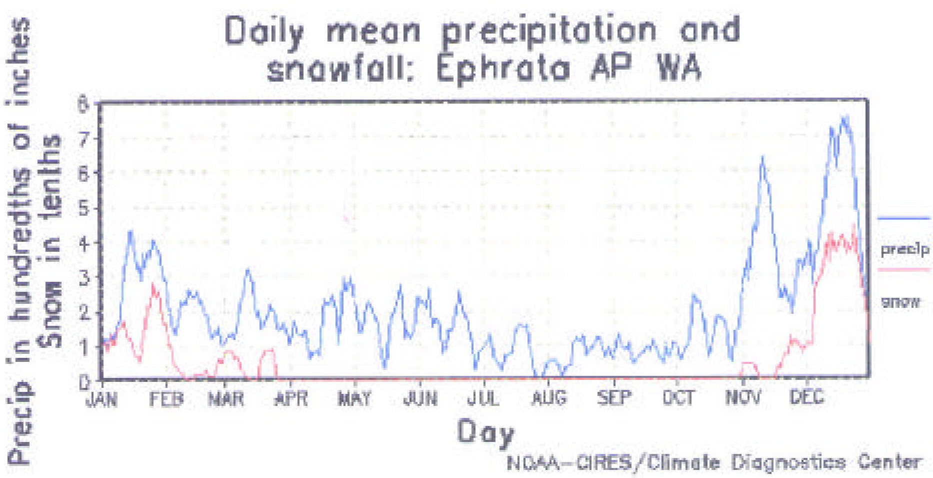
PLATE 1-9

Columbia/Snake Dams

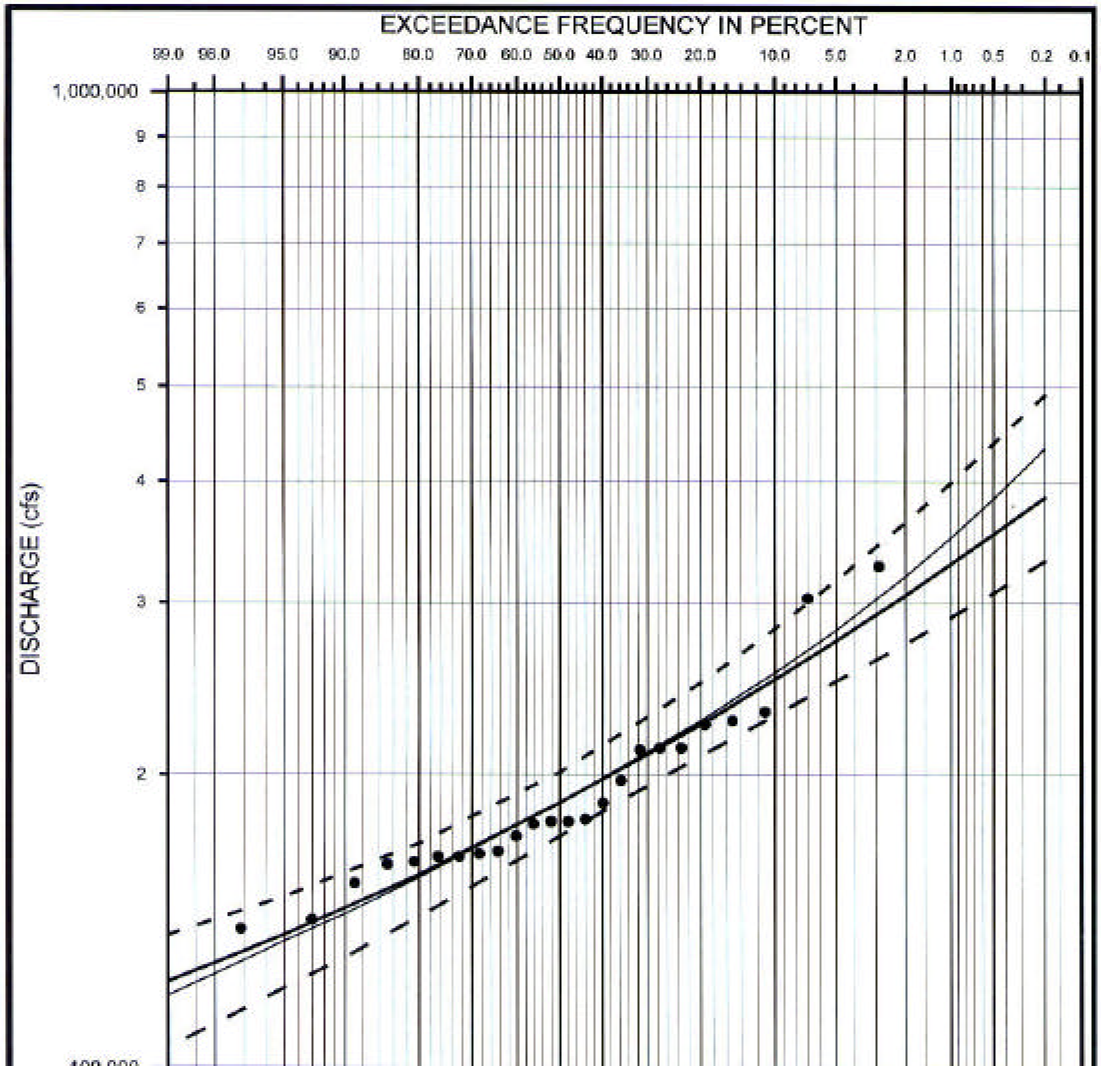
April, 2000







Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 1-10 Daily Weather Data-Ephrata, WA
April, 2000



HEC-FFA COMPUTED CURVE
EXPECTED PROBABILITY ADJUSTMENT
5% CONFIDENCE LIMITS
95% CONFIDENCE LIMITS
MEDIAN PLOTTING POSITIONS

LOG TRANSFORM SYSTEMATIC STATISTICS		NUMBER OF EVENTS	
MEAN=	5.2772	HISTORIC EVENTS=	0
ST. DEV.=	0.0916	HIGH OUTLIERS=	0
COMPUTED SKEW=	1.0722	LOW OUTLIERS=	0
REGIONAL SKEW=	-0.1800	ZERO OR MISSING=	0
ADOPTED SKEW=	0.4000	SYSTEMATIC EVENTS=	24

CHIEF JOSEPH OBSERVED INFLOWS
ANNUAL WATER YEAR MAXIMUM 1 DAY INFLOWS
DATA OBTAINED FROM NORTHWEST DIV. DATABASE

CORPS OF ENGINEERS, SEATTLE DISTRICT
10 DECEMBER 1999
BASIN AREA= 74,700 SQ MI
WATER YEARS OF RECORD
1974-97

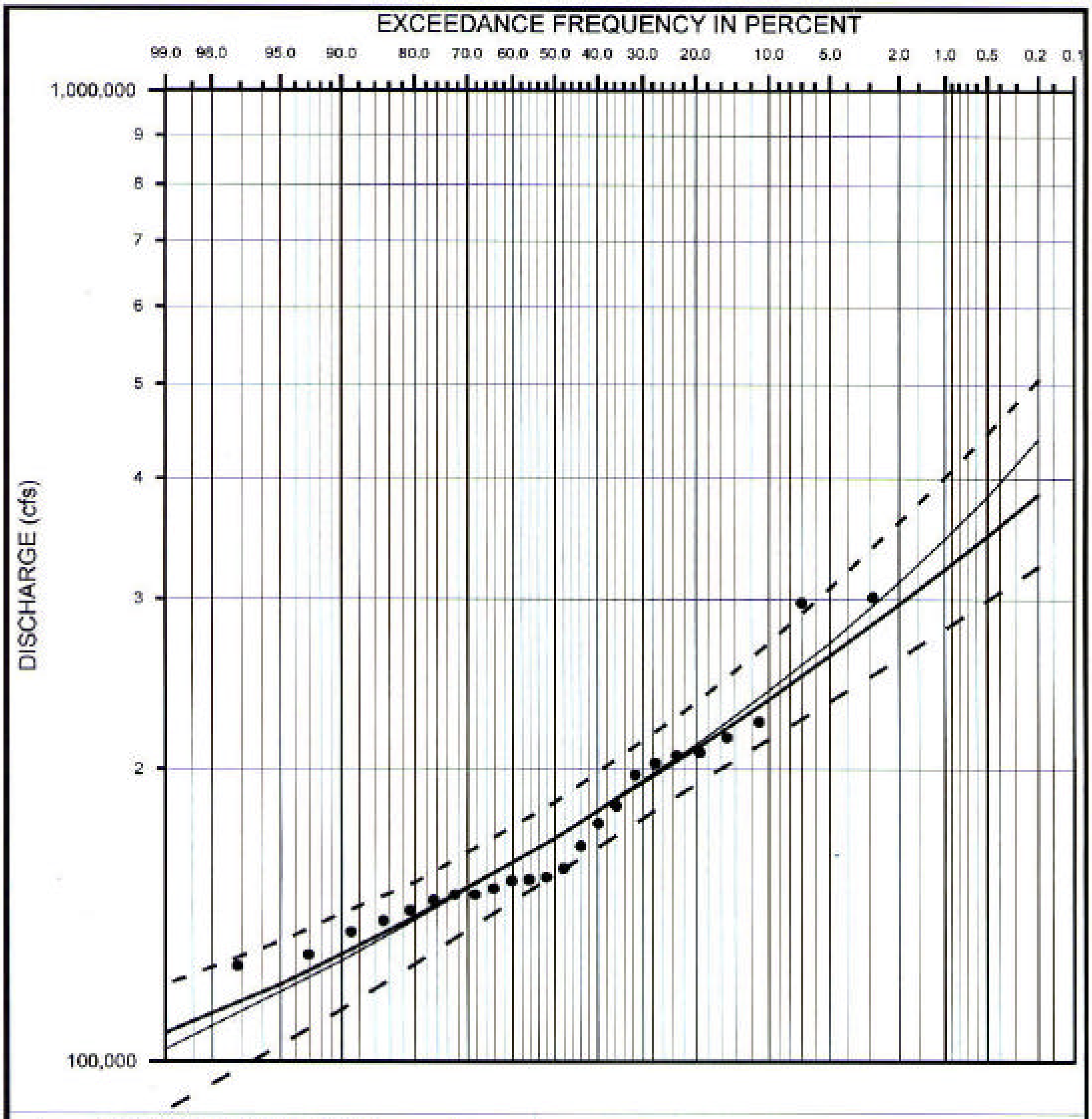
APPROVED BY:

Chief Joseph Dam, Columbia River
Gas Abatement Study

PLATE 2-1

1-Day Discharge-Frequency Curve

April, 2000



HEC-FFA COMPUTED CURVE
EXPECTED PROBABILITY ADJUSTMENT
5% CONFIDENCE LIMITS
95% CONFIDENCE LIMITS
MEDIAN PLOTTING POSITIONS

LOG TRANSFORM SYSTEMATIC STATISTICS		NUMBER OF EVENTS	
MEAN=	5.2376	HISTORIC EVENTS=	0
ST. DEV.=	0.1033	HIGH OUTLIERS=	0
COMPUTED SKEW=	0.9594	LOW OUTLIERS=	0
REGIONAL SKEW=	-0.1800	ZERO OR MISSING=	0
ADOPTED SKEW=	0.4000	SYSTEMATIC EVENTS=	24

CHIEF JOSEPH OBSERVED INFLOWS
ANNUAL WATER YEAR MAXIMUM 7 DAY INFLOWS
DATA OBTAINED FROM NORTHWEST DIV. DATABASE

CORPS OF ENGINEERS, SEATTLE DISTRICT
17 APR 1998
BASIN AREA= 74,700 SQ MI
WATER YEARS OF RECORD
1974-97

APPROVED BY:

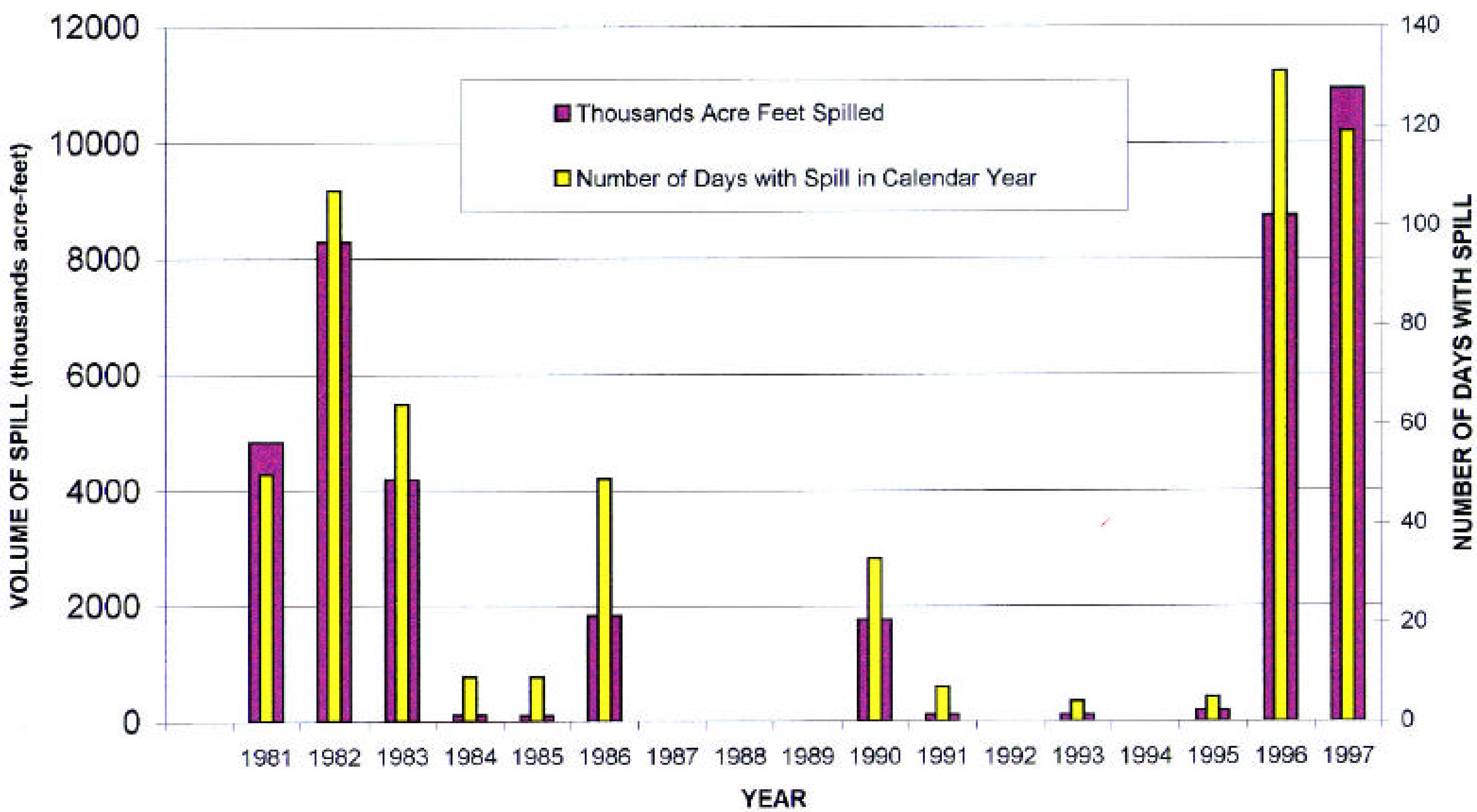
Chief Joseph Dam, Columbia River
Gas Abatement Study

PLATE 2-2

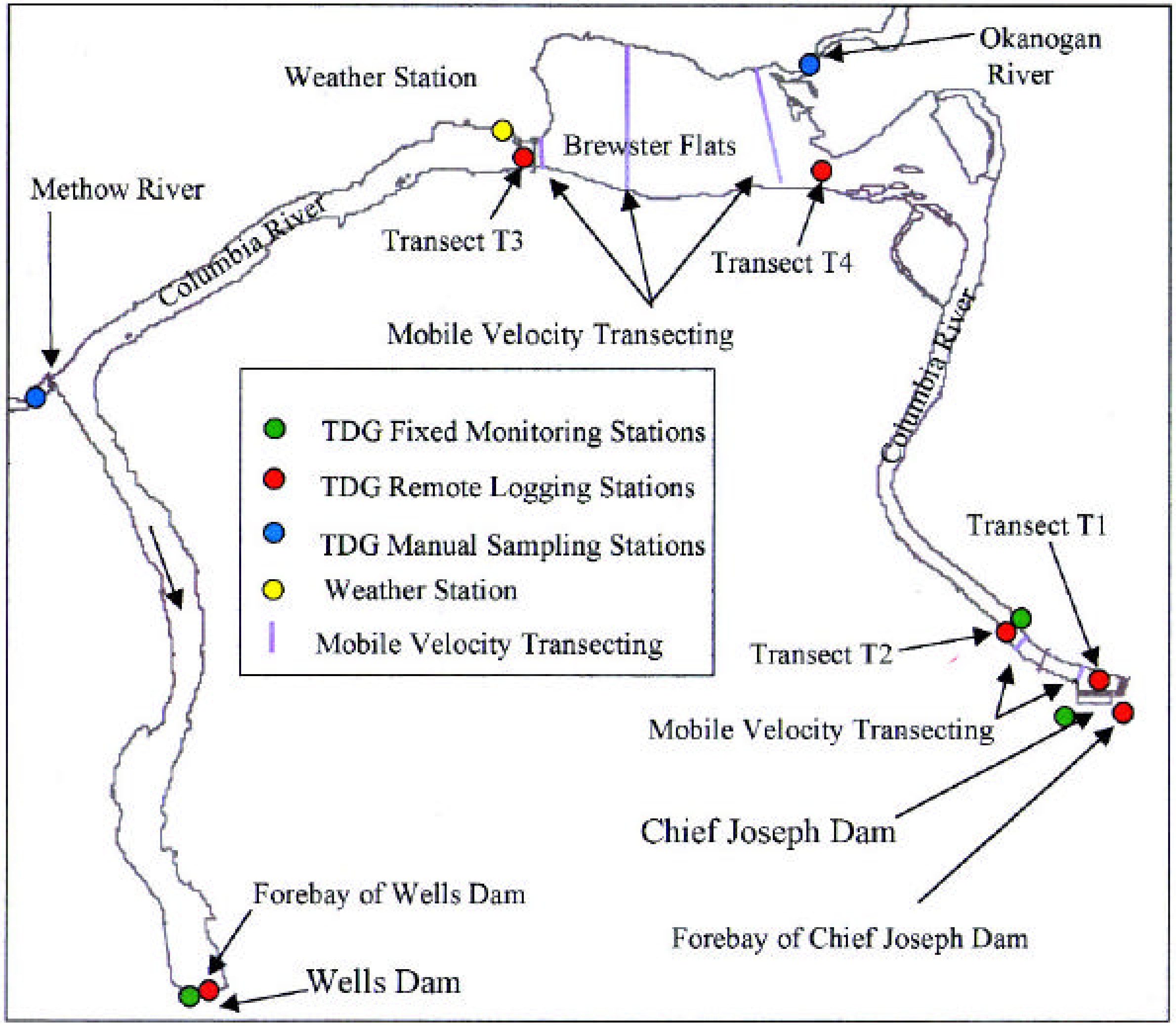
7-Day Discharge-Frequency Curve

April, 2000

SPILL VOLUME AND NUMBER OF DAYS, YEARS 1980 - 1997



Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-3 Spill History 1980-1997
April, 2000



Total Dissolved Gas, Weather, and Velocity Monitoring Locations in Columbia River, June 6-10, 1999.

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-4 Near-Field Study Test Sampling Stations
April, 2000

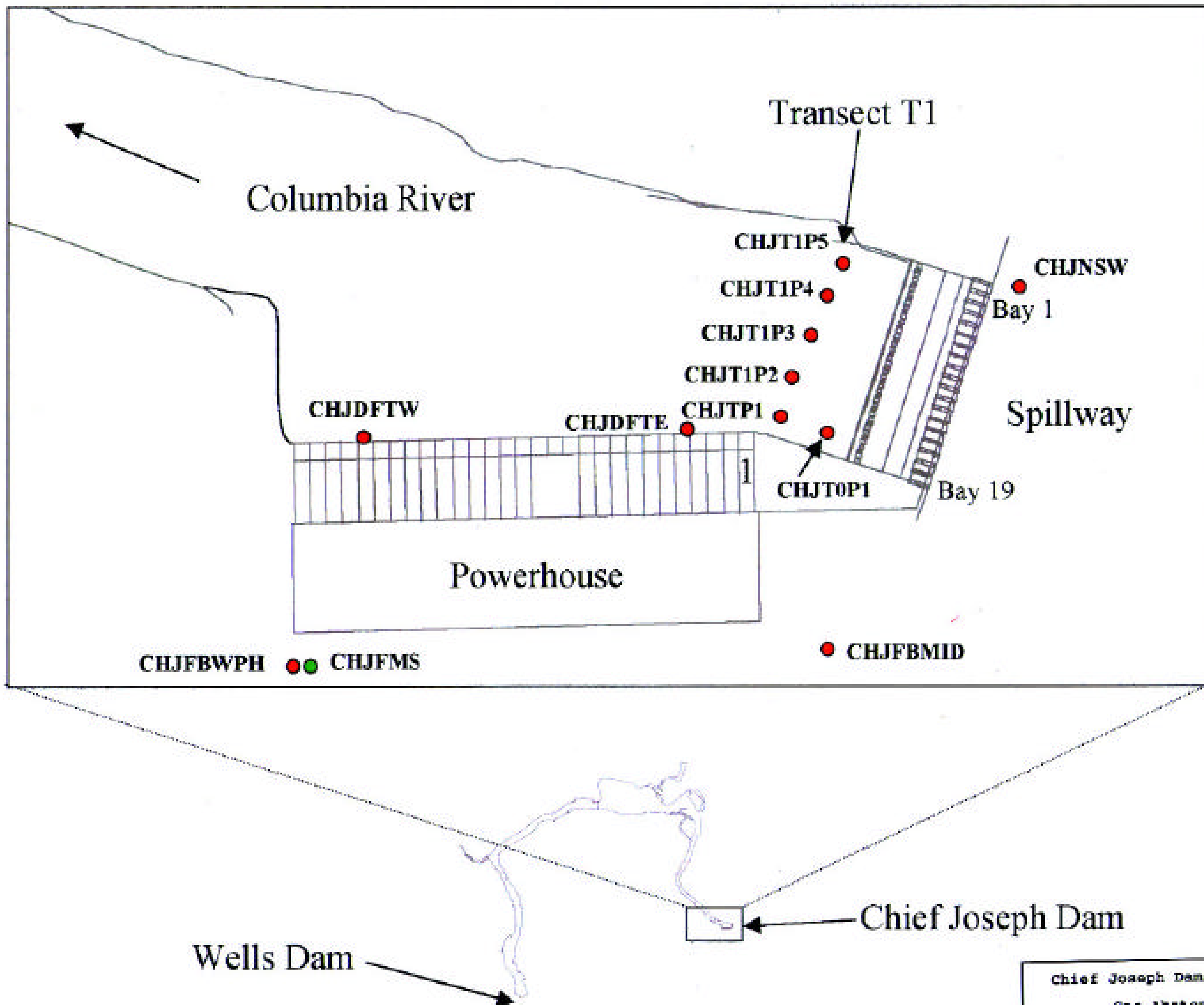


Figure 5. Total Dissolved Gas Monitoring Stations in the Forebay and Downstream of Chief Joseph Dam, June 6-10, 1999.

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-5 Near-Field Study Forebay and Tailwater Sensors
April, 2000

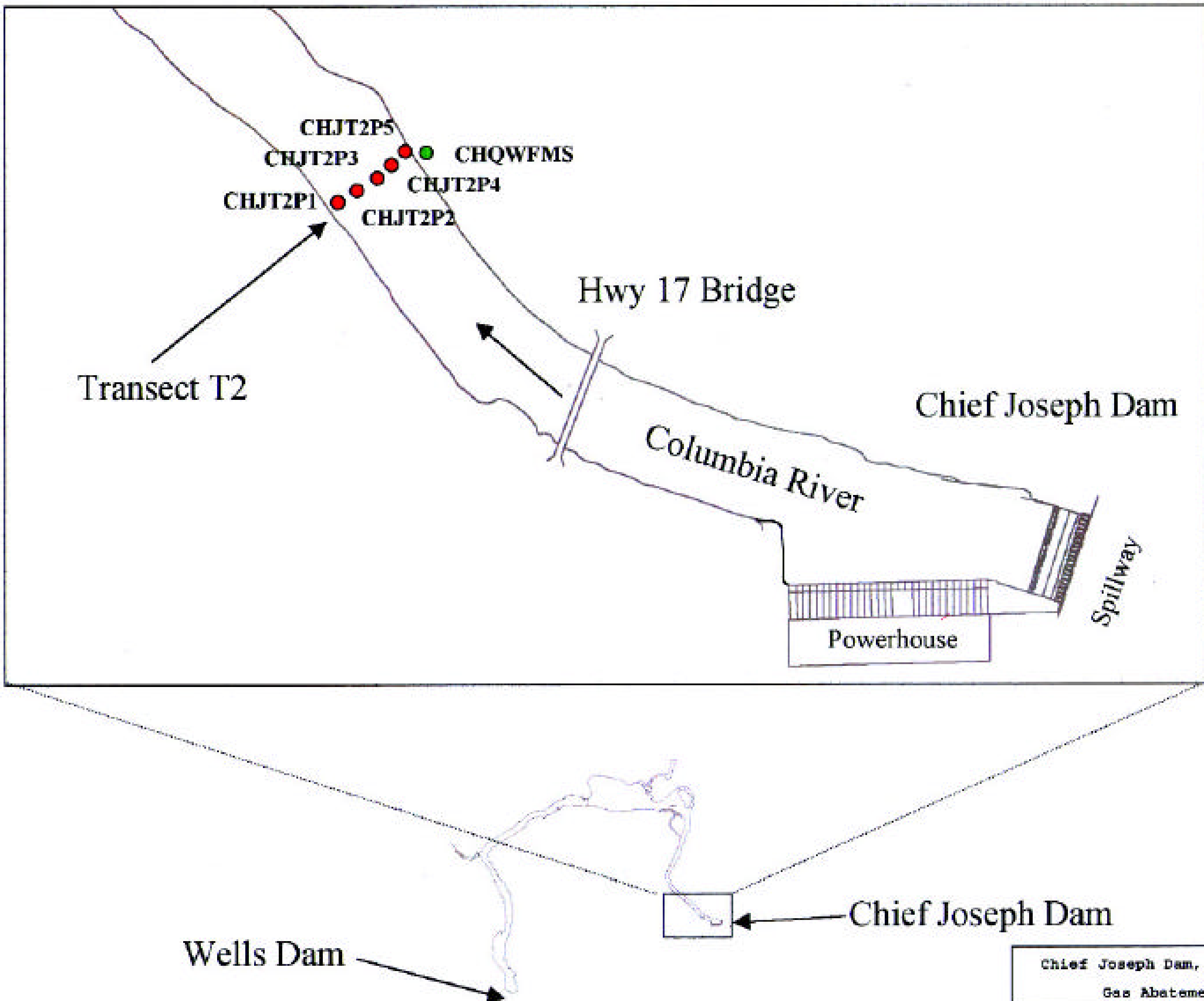
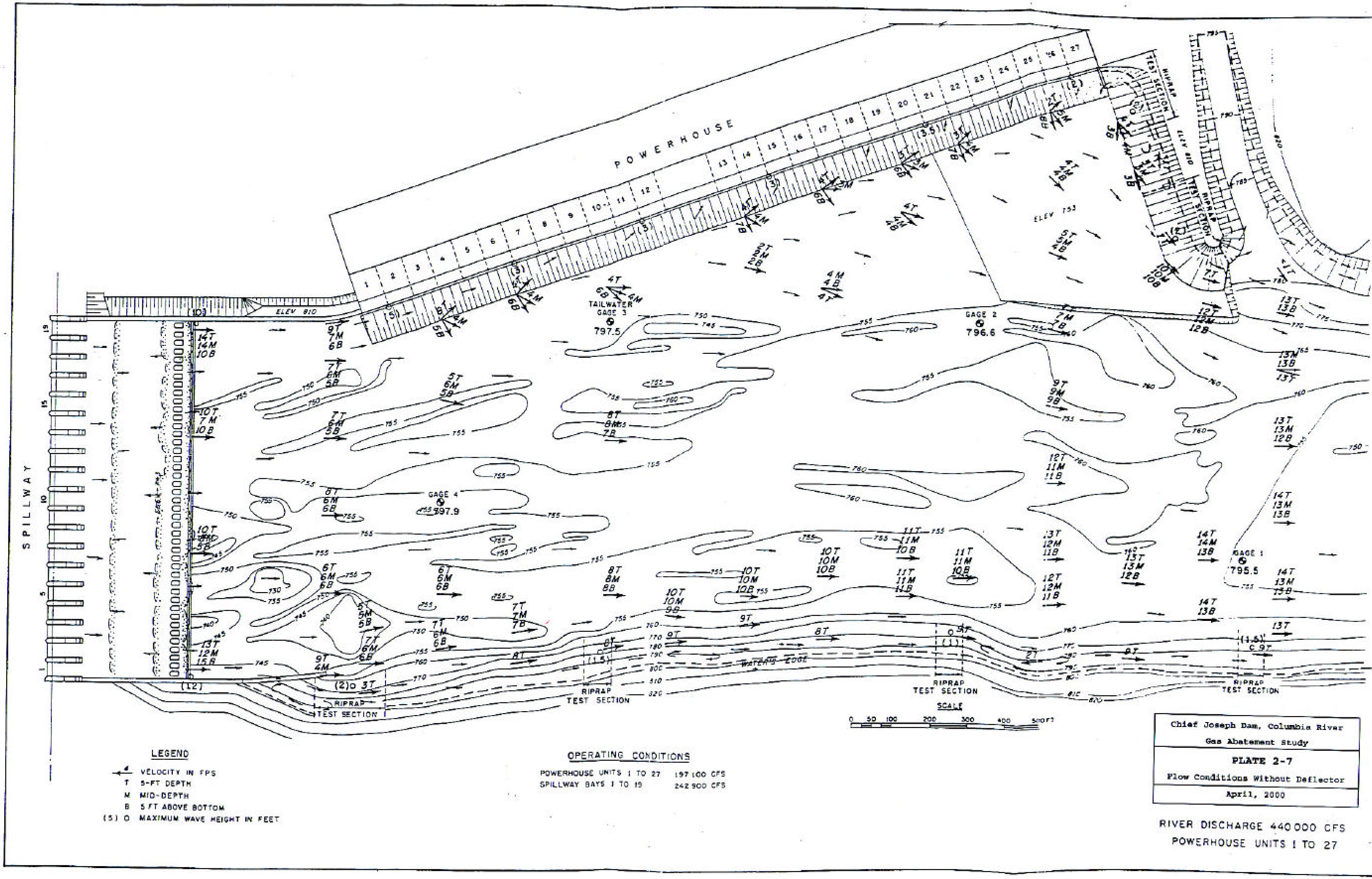
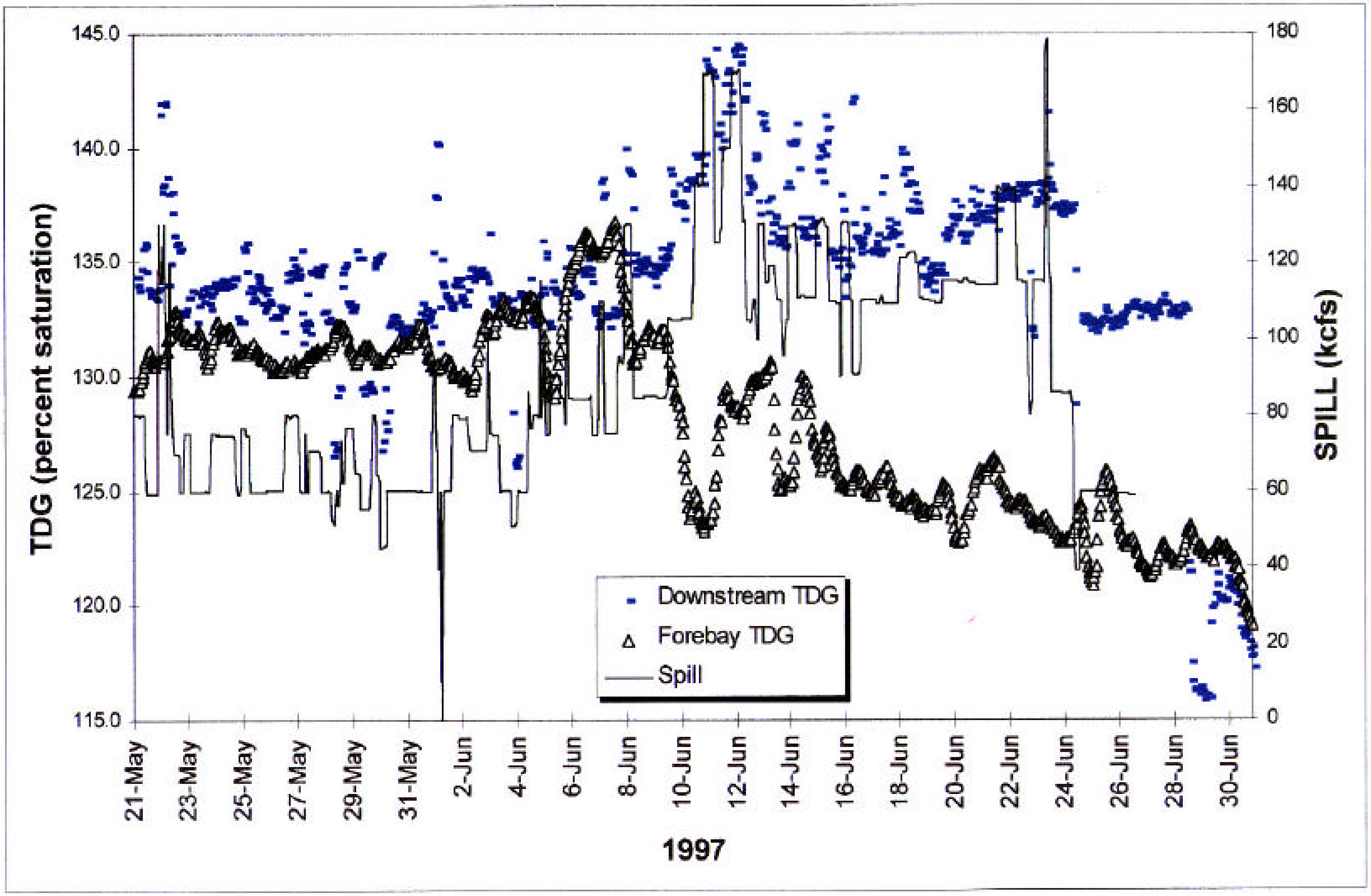


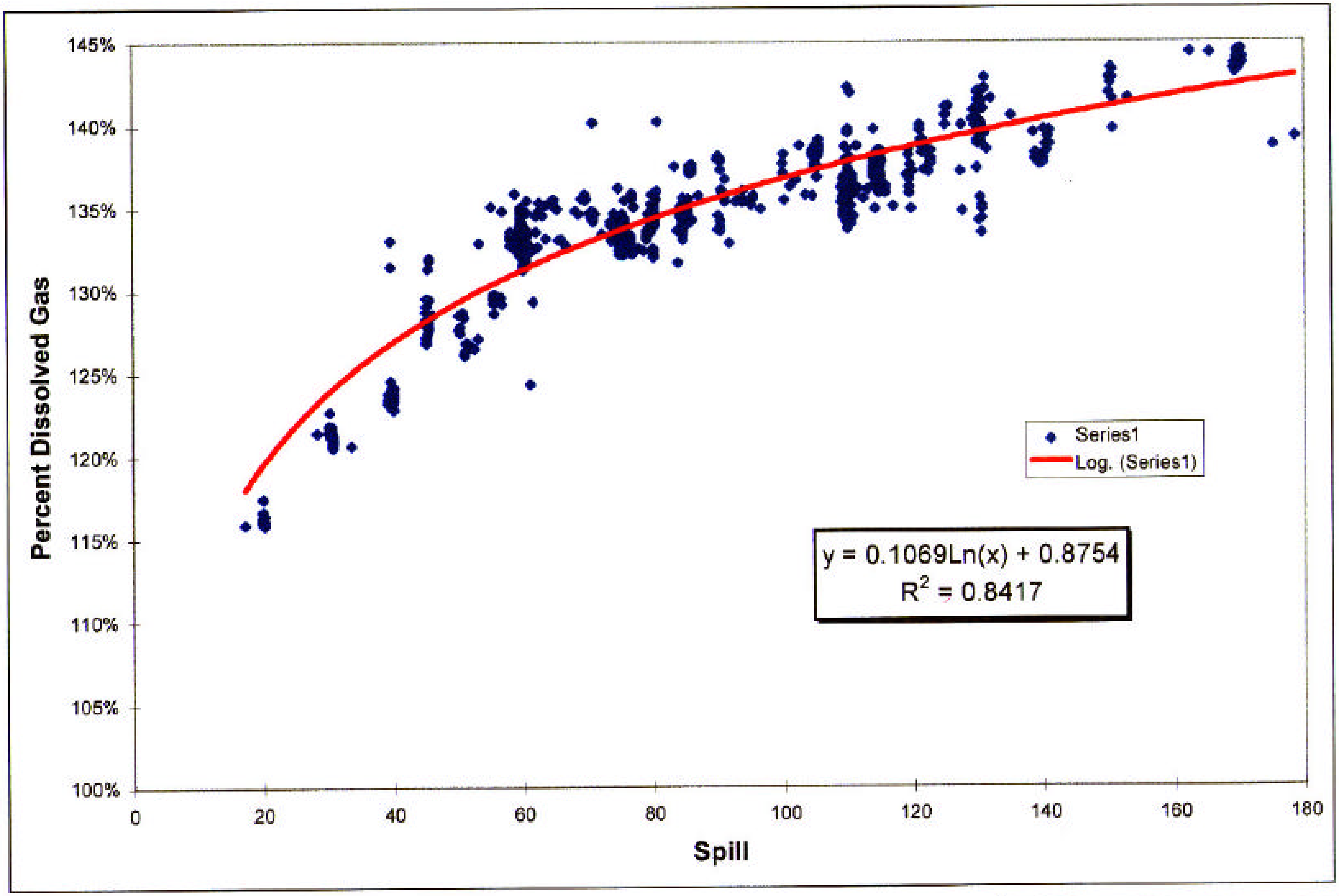
Figure 6. Total Dissolved Gas Monitoring Stations on Transect T2 Downstream of Chief Joseph Dam, June 6-10, 1999.

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-6 Near-Field Study, Transect 12 Sensors
April, 2000


POWERHOUSE
SPILLWAY
TAILWATER GAGE 3
797.5
GAGE 2
796.6
GAGE 4
797.9
GAGE 1
795.5
ELEV 810
ELEV 753
RIPRAP TEST SECTION
WATER'S EDGE
SCALE
0 50 100 200 300 400 500 FT
LEGEND
VELOCITY IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM
(5) O MAXIMUM WAVE HEIGHT IN FEET
OPERATING CONDITIONS
POWERHOUSE UNITS 1 TO 27 197 100 CFS
SPILLWAY BAYS 1 TO 19 242 900 CFS
Chief Joseph Dam, Columbia River
Gas Abatement Study
PLATE 2-7
Flow Conditions Without Deflector
April, 2000
RIVER DISCHARGE 440 000 CFS
POWERHOUSE UNITS 1 TO 27

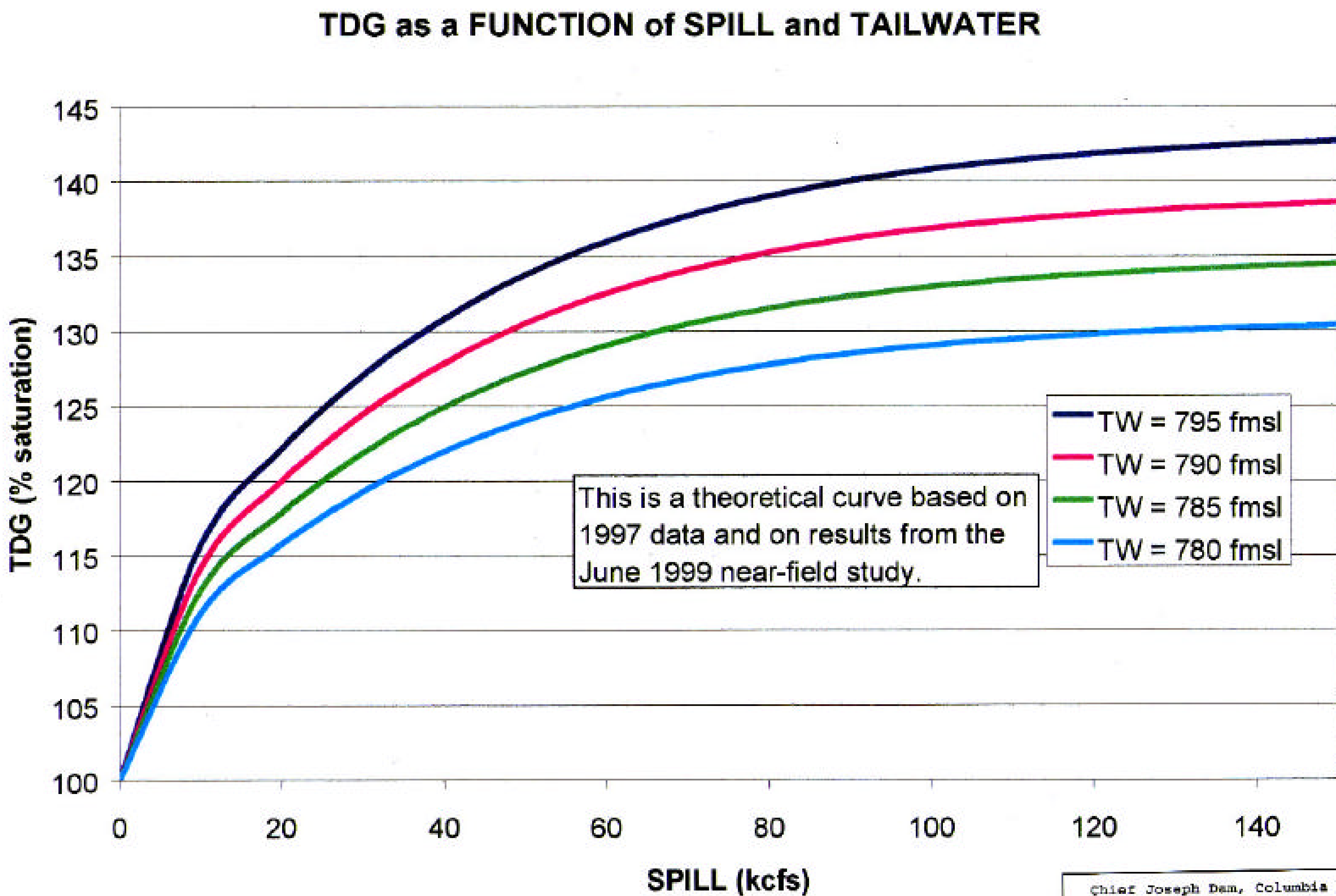


Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-8 Chief Joseph Dam Spill and TDG Time Series (1997)
April, 2000



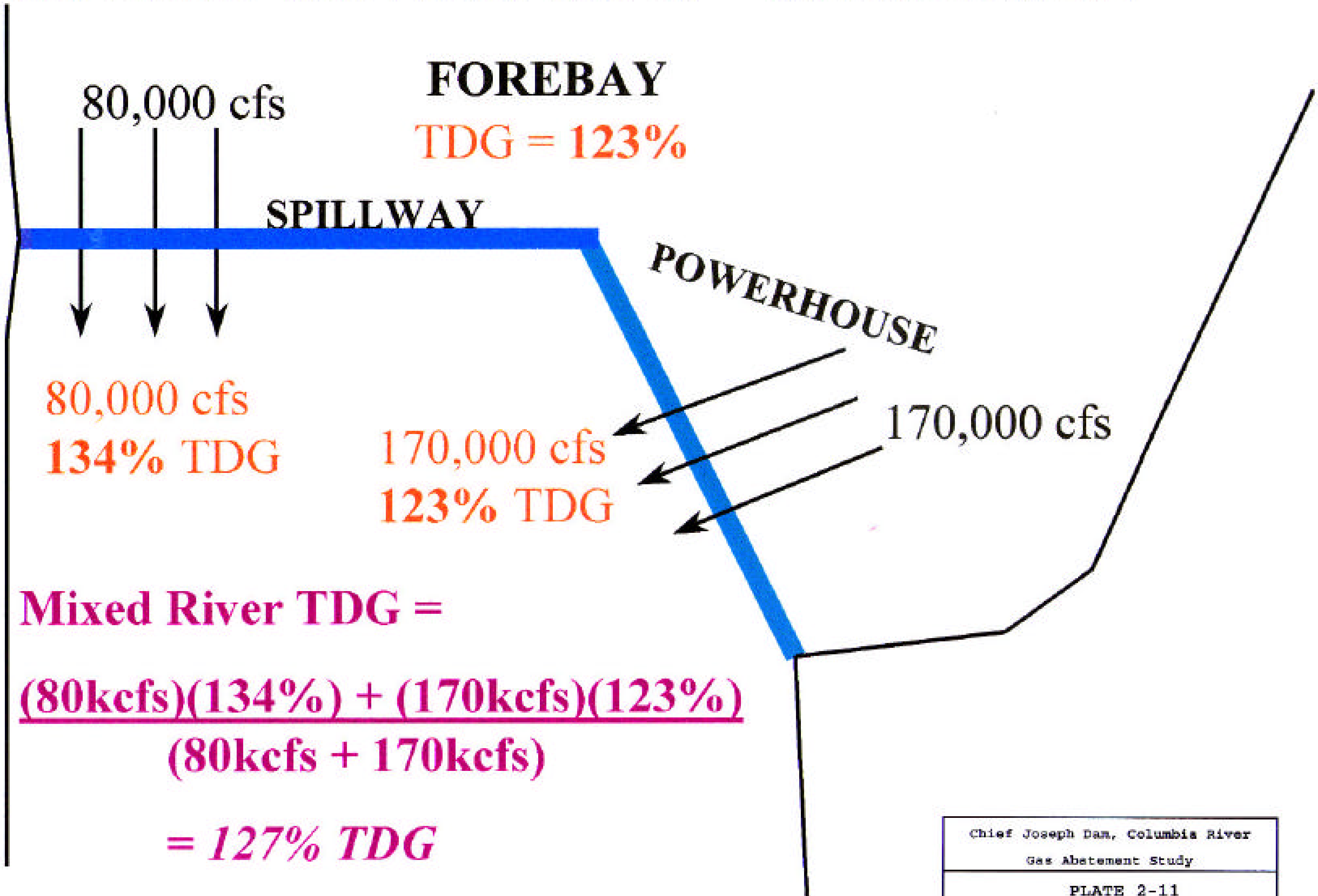
1997 Gas Production at Chief Joseph Spillway

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-9 Spill-TDG Function
April, 2000



Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-10 Empirically Developed TDG Function
April, 2000

MIXED RIVER TDG - BASELINE



Mixed River TDG =

$$\frac{(80\text{kcfs})(134\%) + (170\text{kcfs})(123\%)}{(80\text{kcfs} + 170\text{kcfs})}$$

$= 127\%\ TDG$

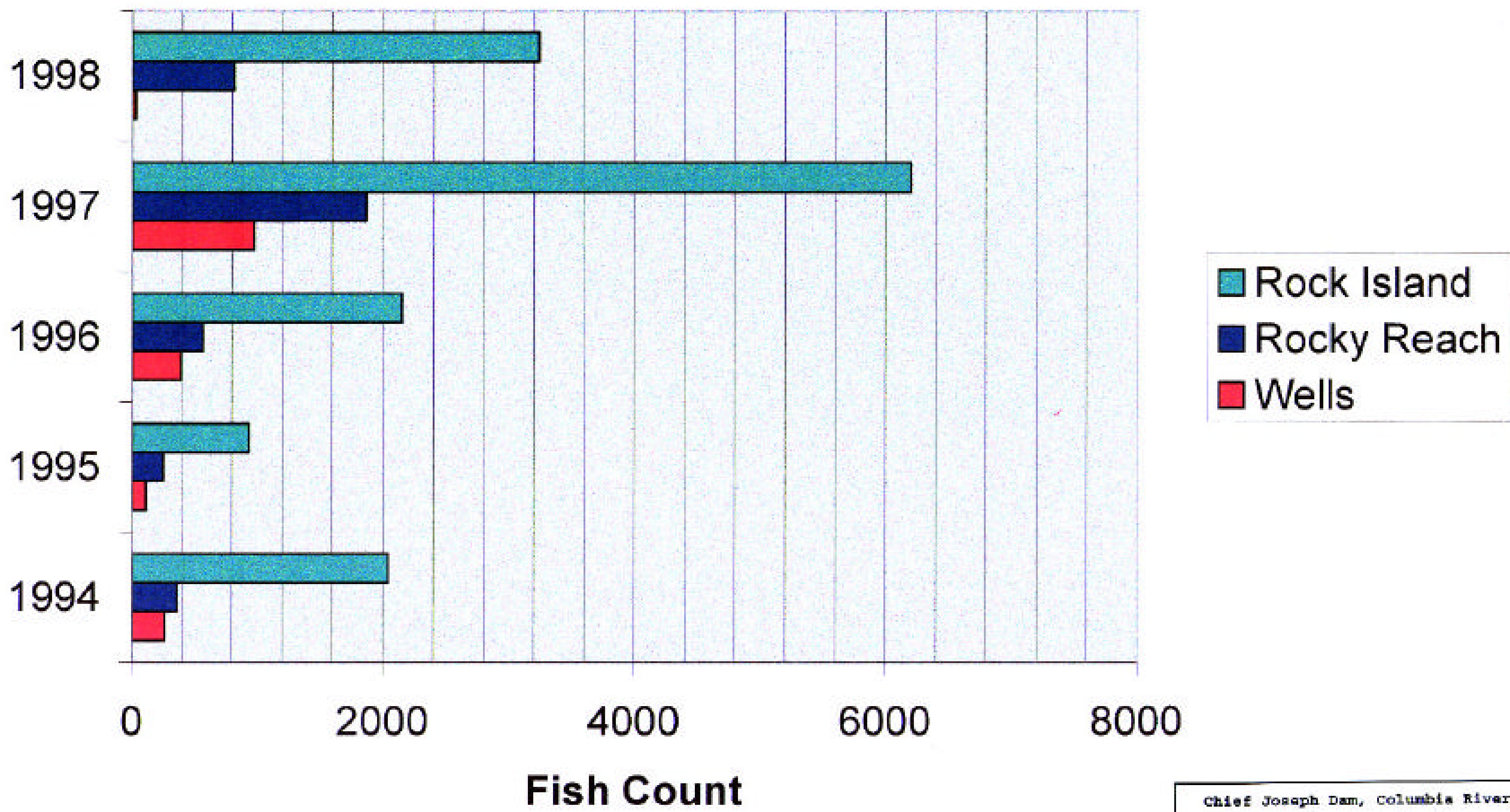
Chief Joseph Dam, Columbia River
Gas Abatement Study

PLATE 2-11

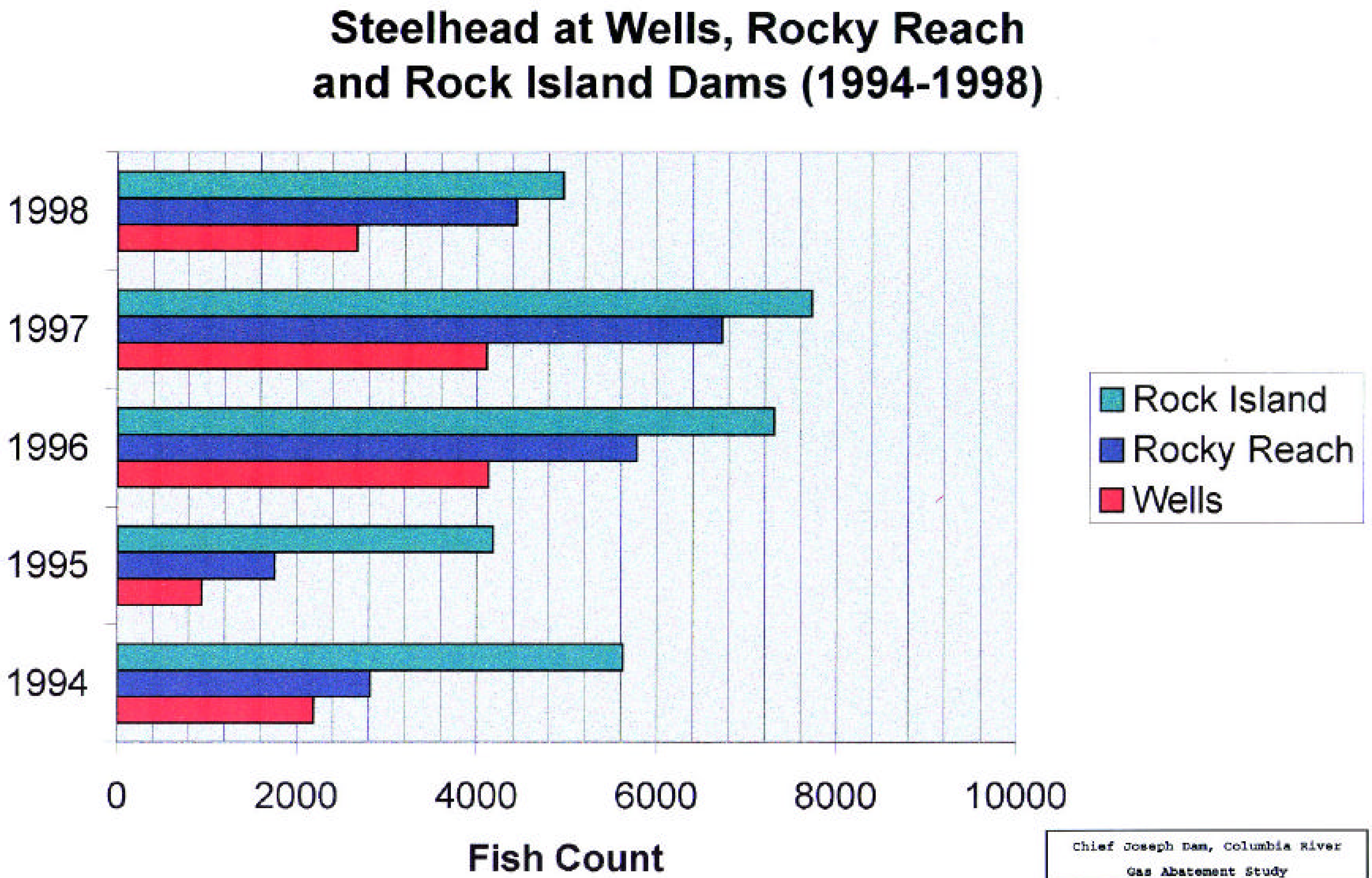
Baseline TDG-Chief Joseph Dam

April, 2000

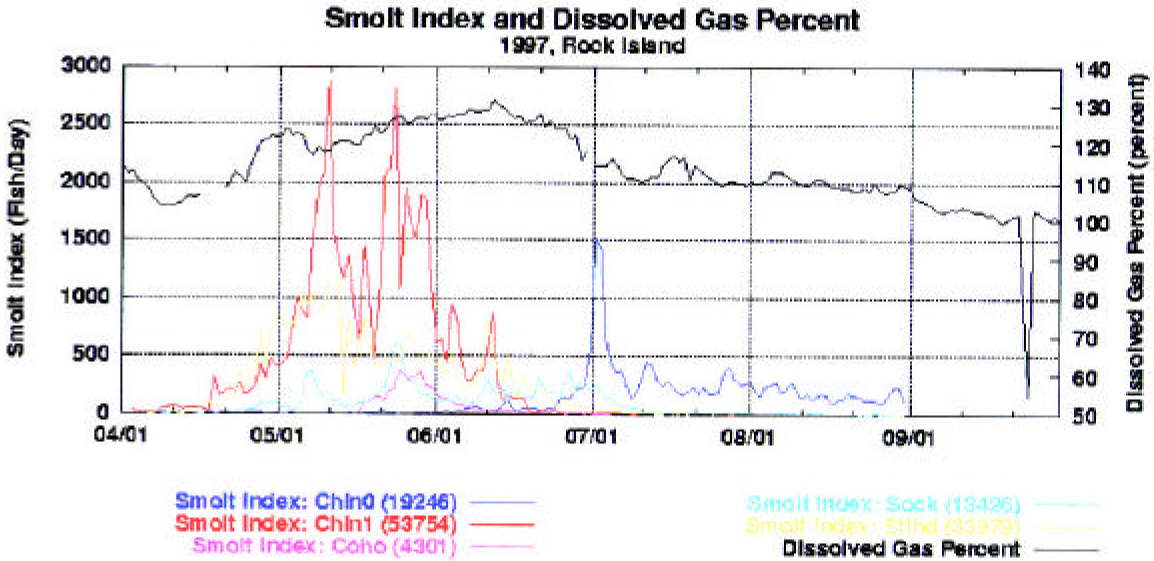
Spring Chinook at Wells, Rocky Reach and Rock Island Dams (1994-1998)

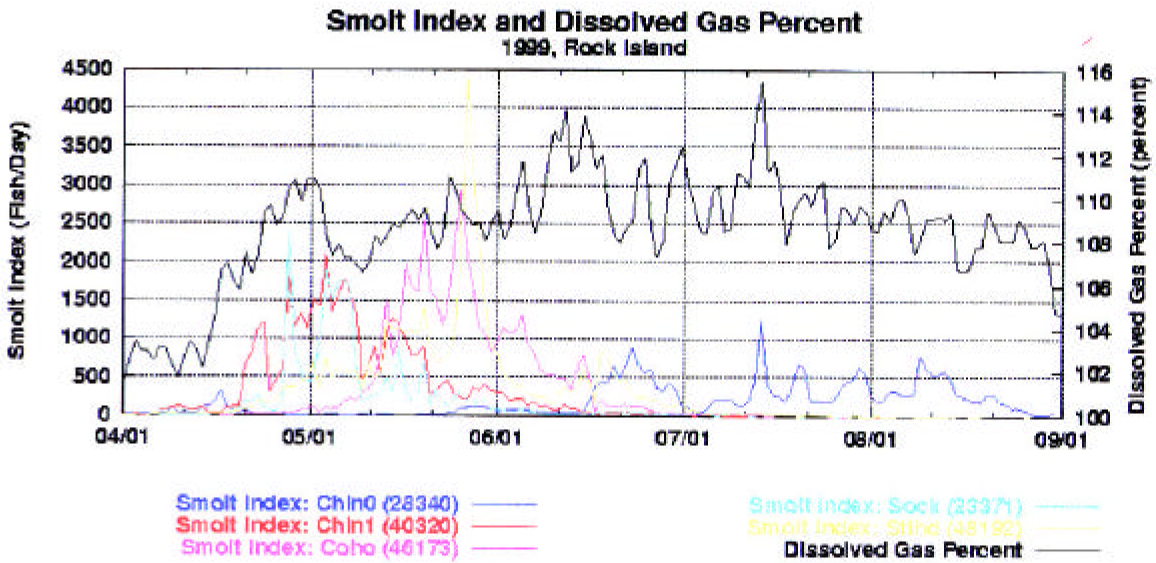


Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-12 Spring Chinook Fish Counts
(1994-98) April, 2000



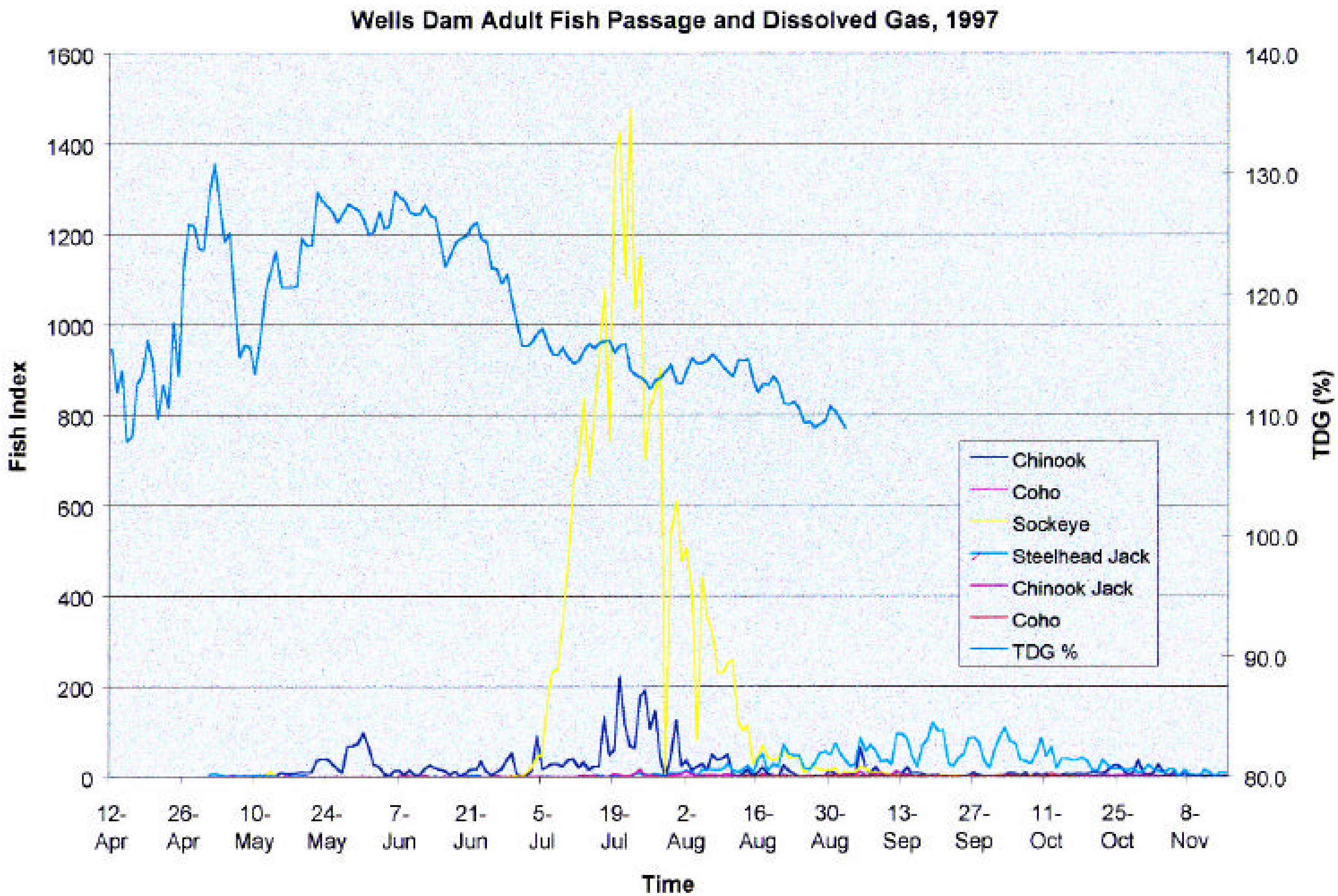
Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-13 Steelhead Fish Counts (1994-98)
April, 2000





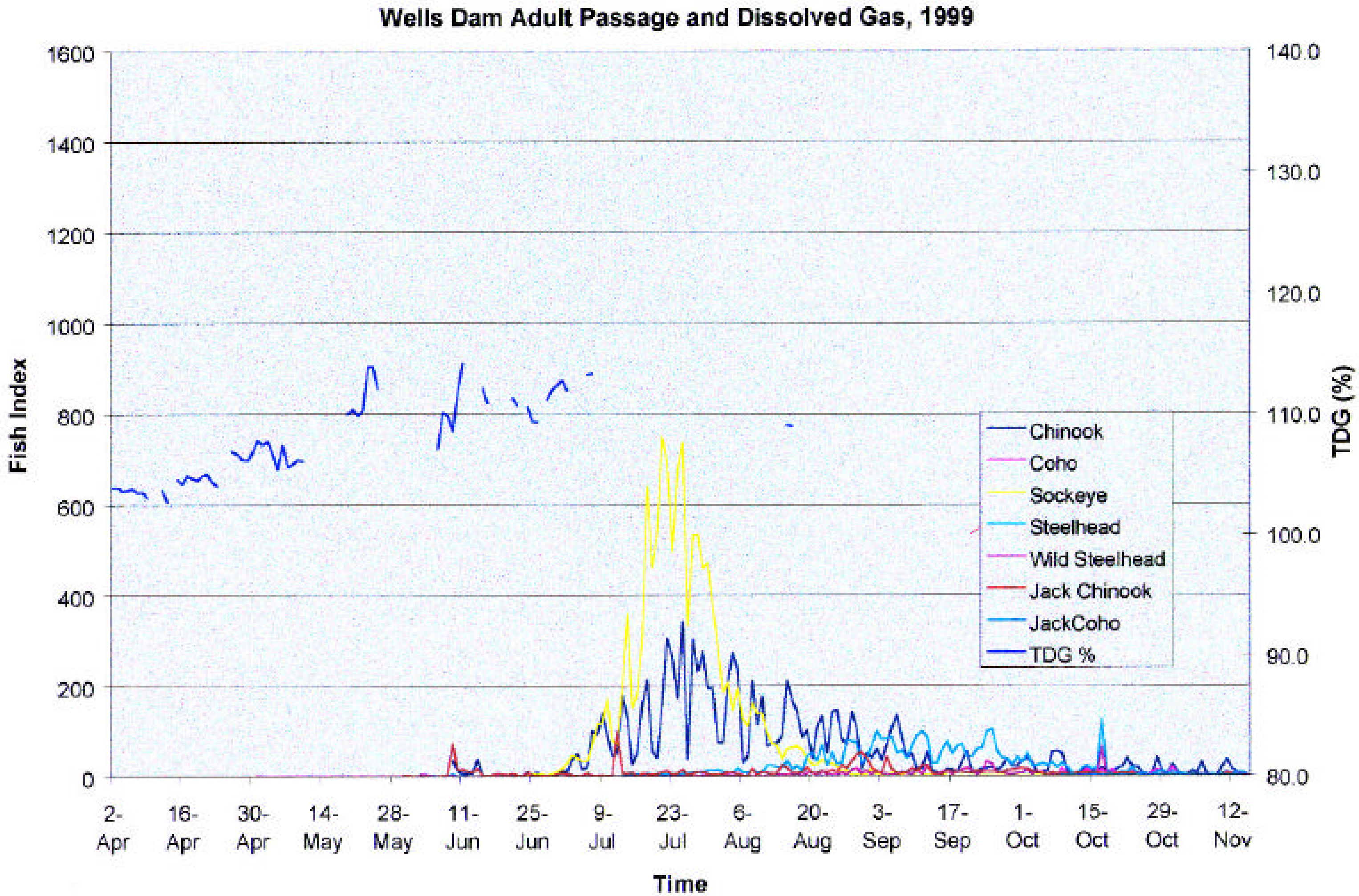
Note on these figures that the vertical scales are different from each other, and that gas levels were higher in 1997 than in 1999, but smolt counts were lower.

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-14 Smolt Presence and TDG (1997,99)
April, 2000



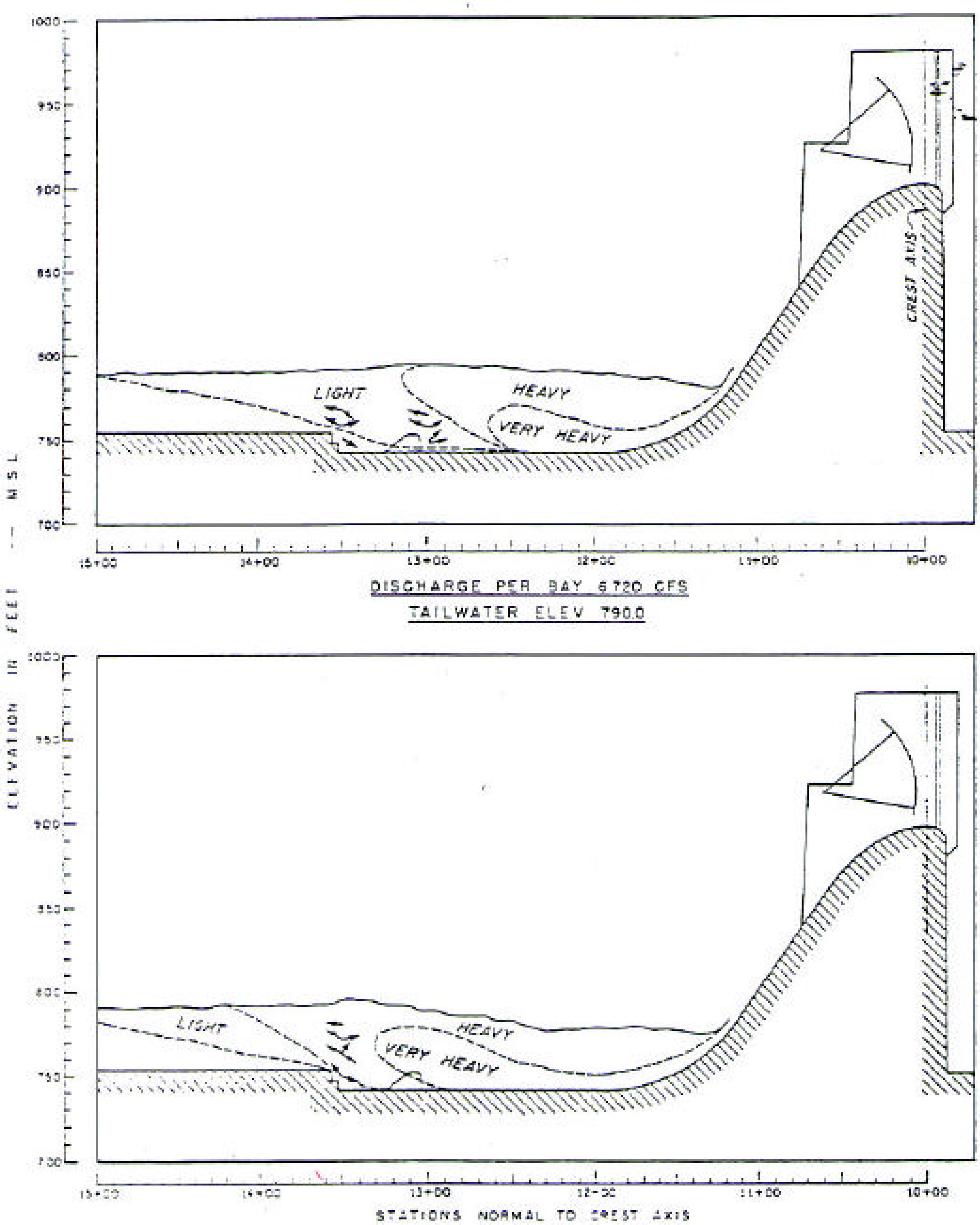
Adult fish passage at Wells Dam in 1997, with total dissolved gas (Univ. of Washington, 2000).

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-15 Adult Fish Passage, Wells Dam 1997
April, 2000



Adult fish passage at Wells Dam in 1999, with total dissolved gas (Univ. of Washington, 2000)

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 2-16
Adult Fish Passage, Wells Dam 1999
April, 2000



DISCHARGE PER BAY 9,150 CFS

TAILWATER ELEV 792.3

LEGEND

---------ZONES OF AERATION

NOTES

1. 19 - BAY SPILLWAY OPERATION
2. POOL ELEVATION 956.0

AERATION AND FLOW CONDITIONS IN STILLING BASIN

WITHOUT FLOW DEFLECTOR

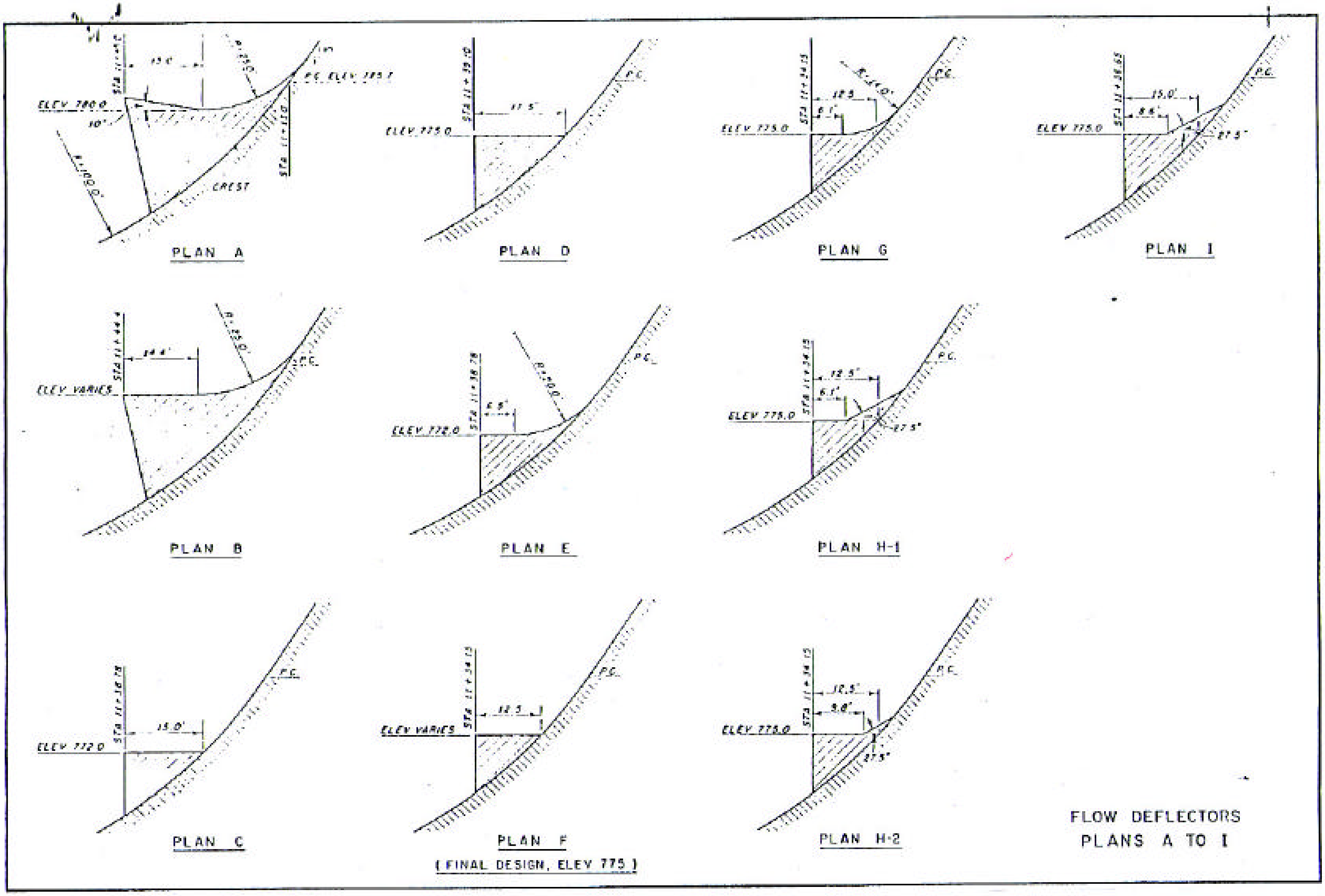
Chief Joseph Dam, Columbia River

Gas Abatement Study

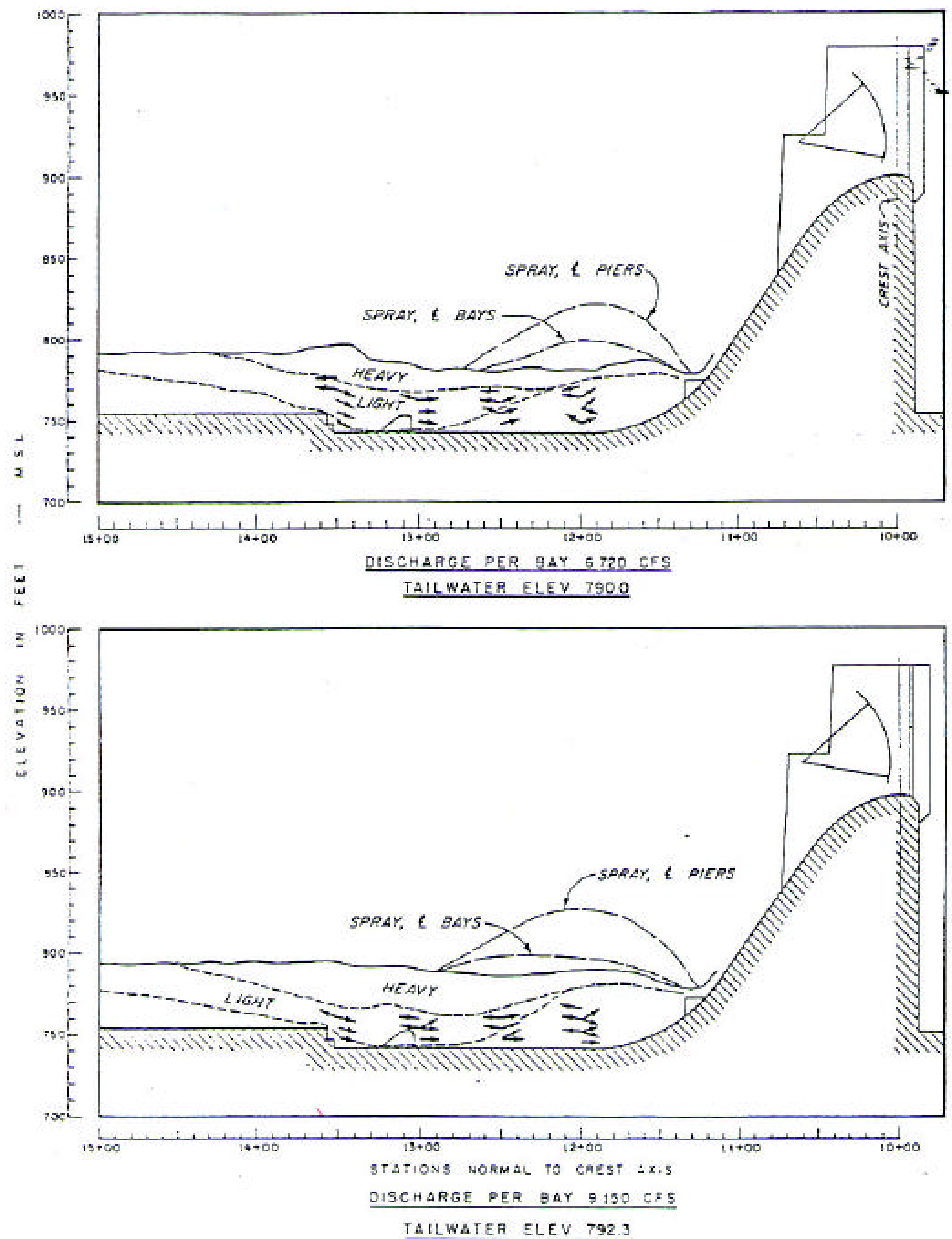
PLATE 3-1

Flow Conditions in Stilling Basin w/o Deflectors

April, 2000



Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 3-2
Flow Deflectors-Plans A-I
April, 2000



LEGEND

- - - - - - - ZONES OF AERATION

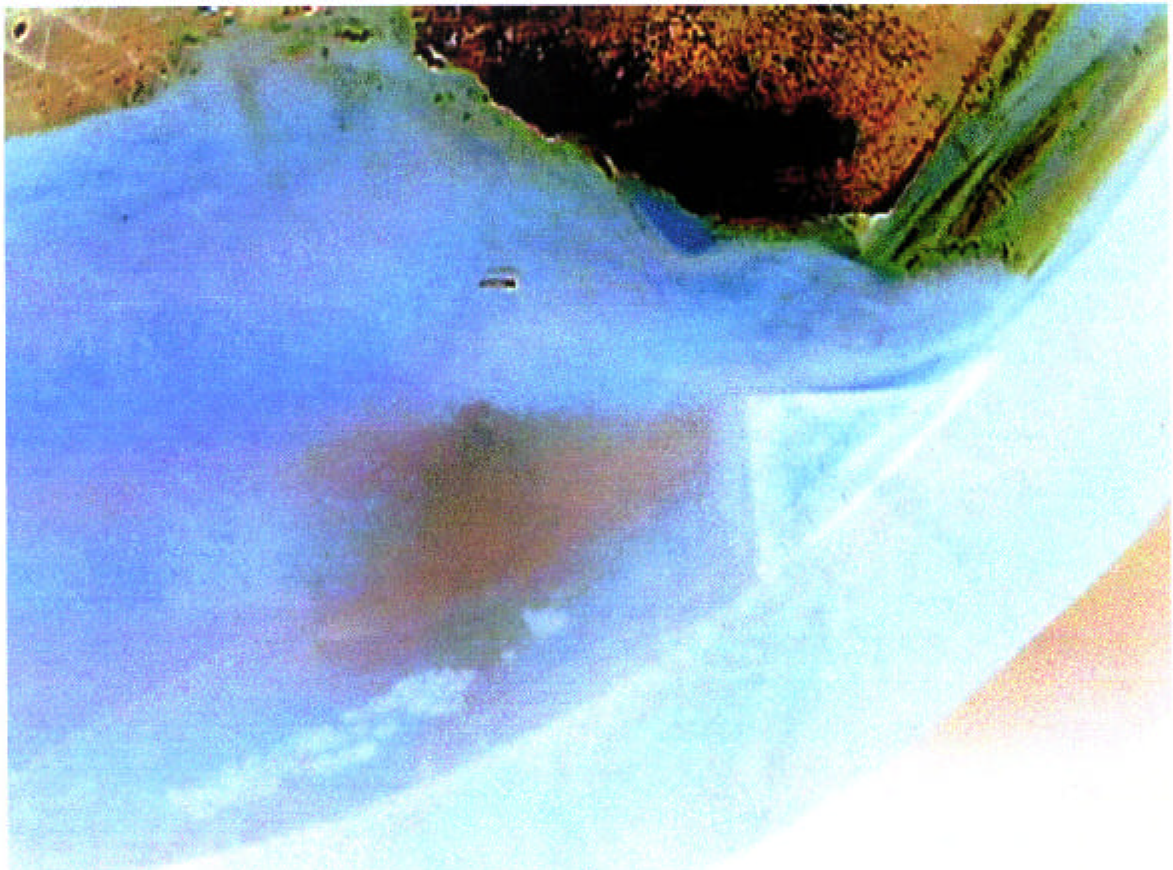
NOTES

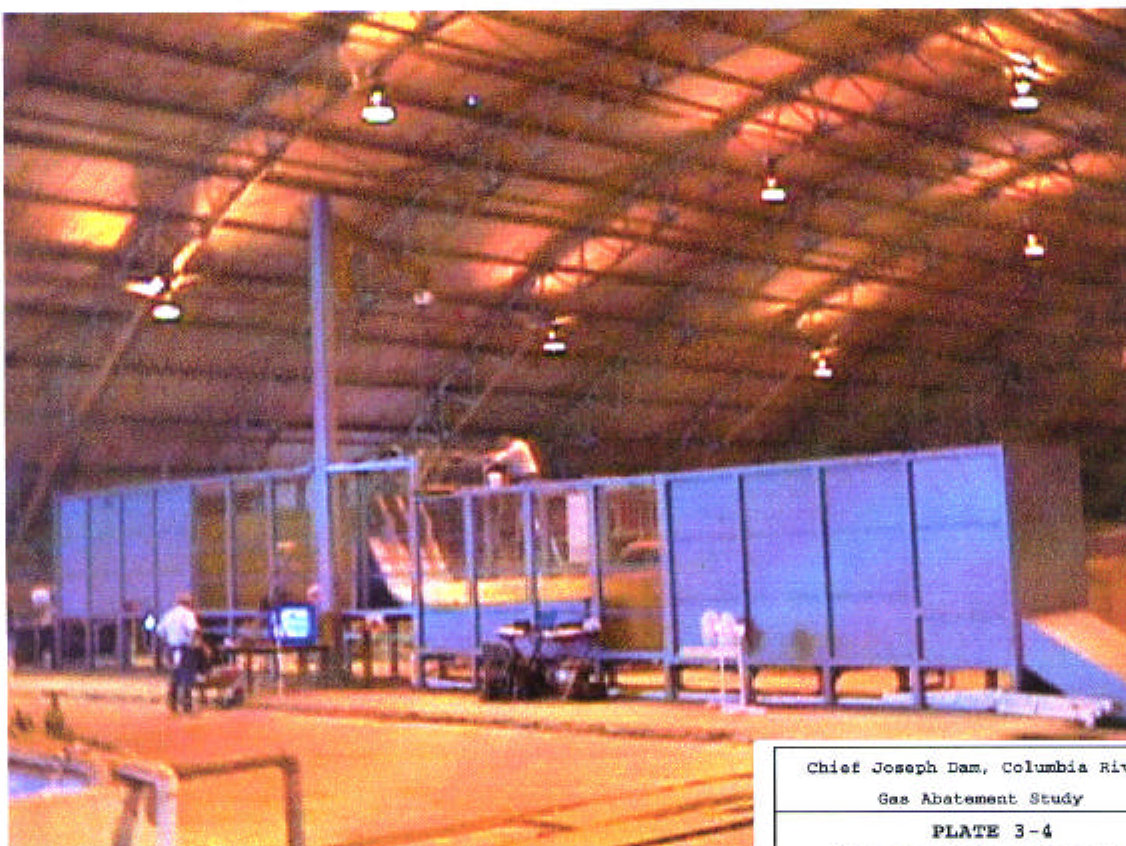
1. 19-BAY SPILLWAY OPERATION
2. POOL ELEVATION 956.0

AERATION AND FLOW CONDITIONS IN STILLING BASIN

PLAN F DEFLECTOR, ELEV 775 FINAL DESIGN

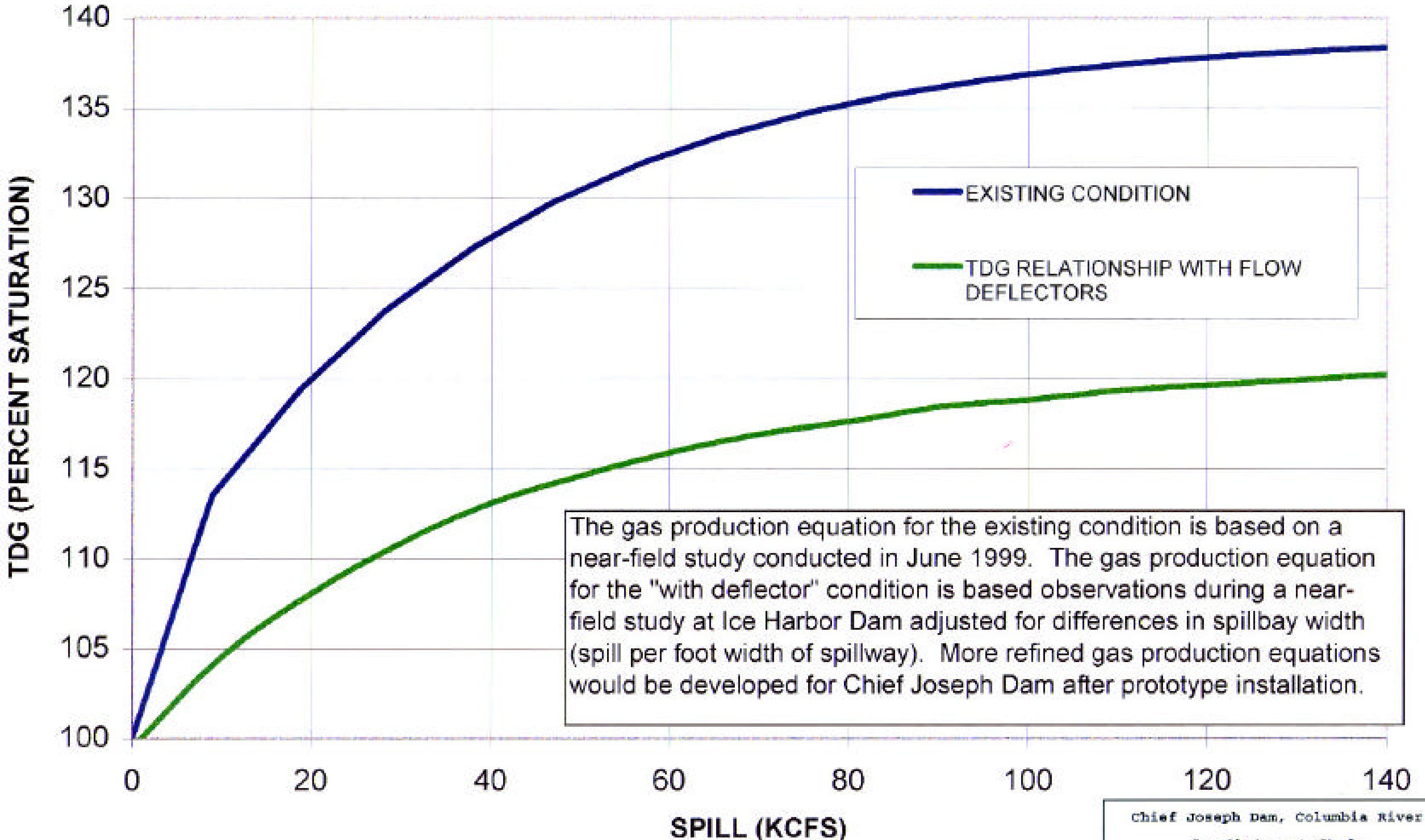
Chief Joseph Dam, Columbia River
Gas Abatement Study
PLATE 3-3
Flow Conditions in Stilling Basin w/ Deflectors
April, 2000





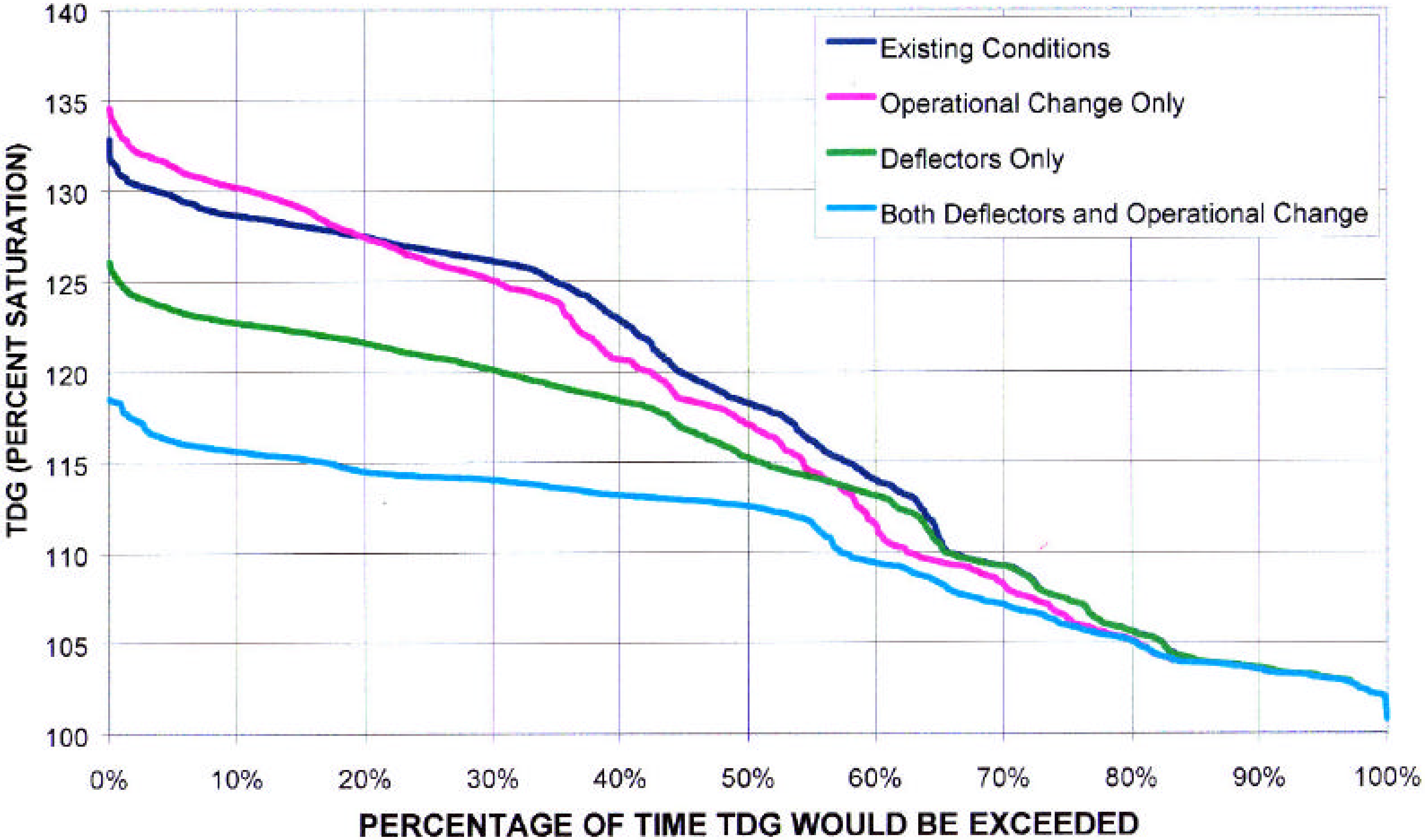
Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 3-4 Chief Joseph Flow Deflectors Physical Model
April, 2000

TOTAL DISSOLVED GAS (TDG) PRODUCTION CURVES FOR CHIEF JOSEPH DAM SPILLWAY AS A FUNCTION OF SPILL

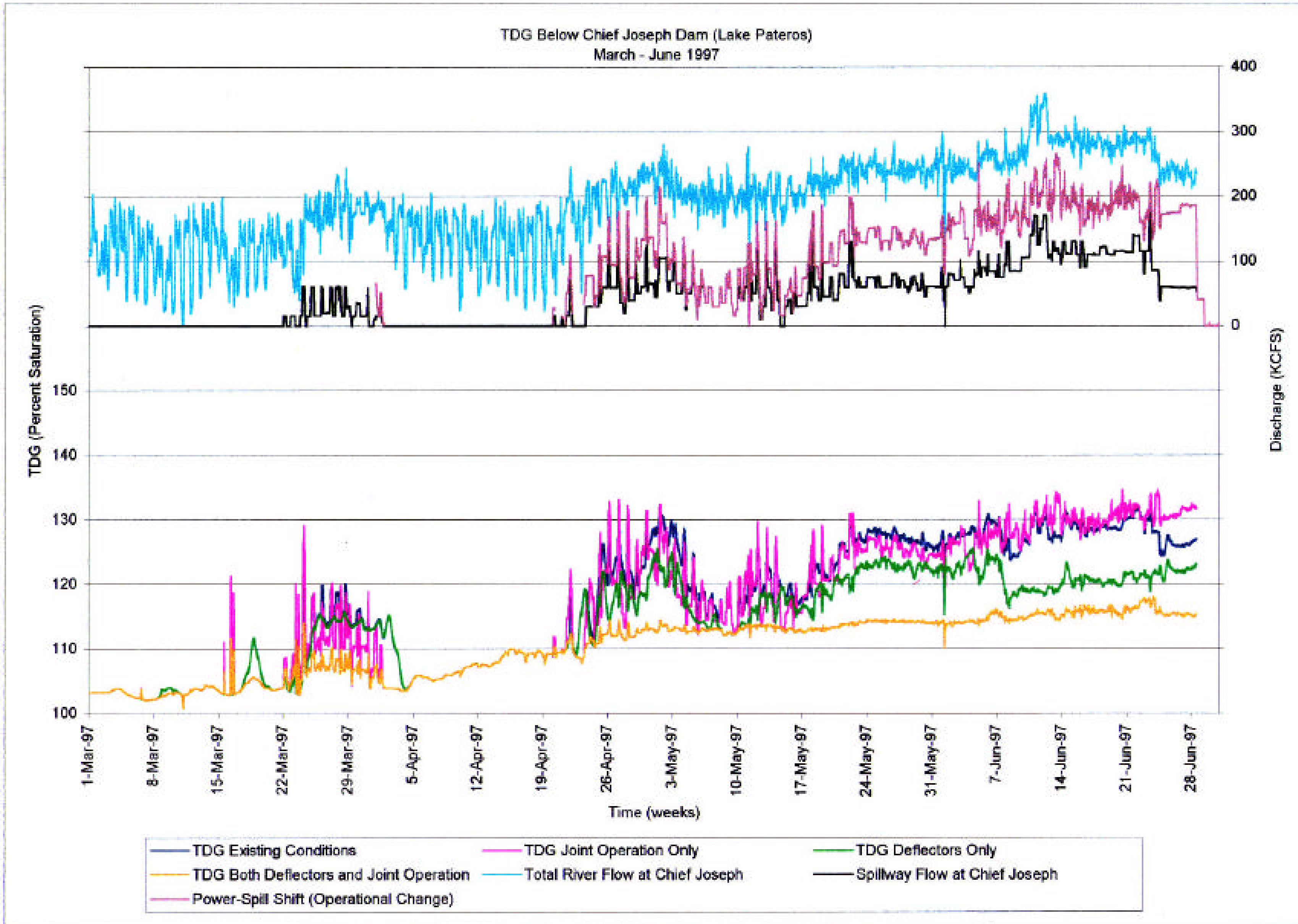


Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 3-5 TDG Production Curves
April, 2000

OUTPUT OF MODELED ALTERNATIVES:
TDG BELOW CHIEF JOSEPH DAM (LAKE PATEROS)
MARCH - JUNE 1997



Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 3-6 TDG at Chief Joseph (with Project)
April, 2000



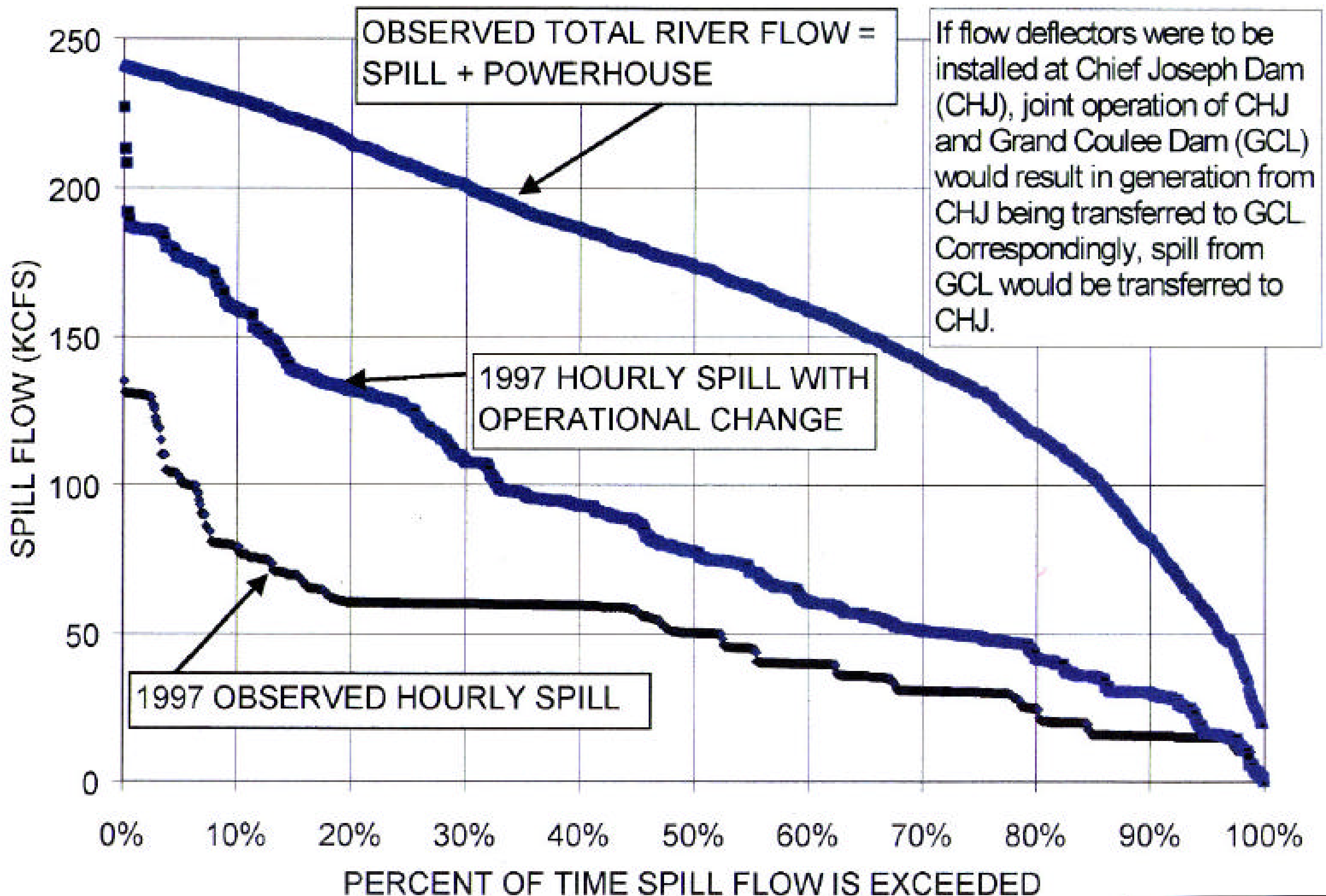
Chief Joseph Dam, Columbia River

Gas Abatement Study

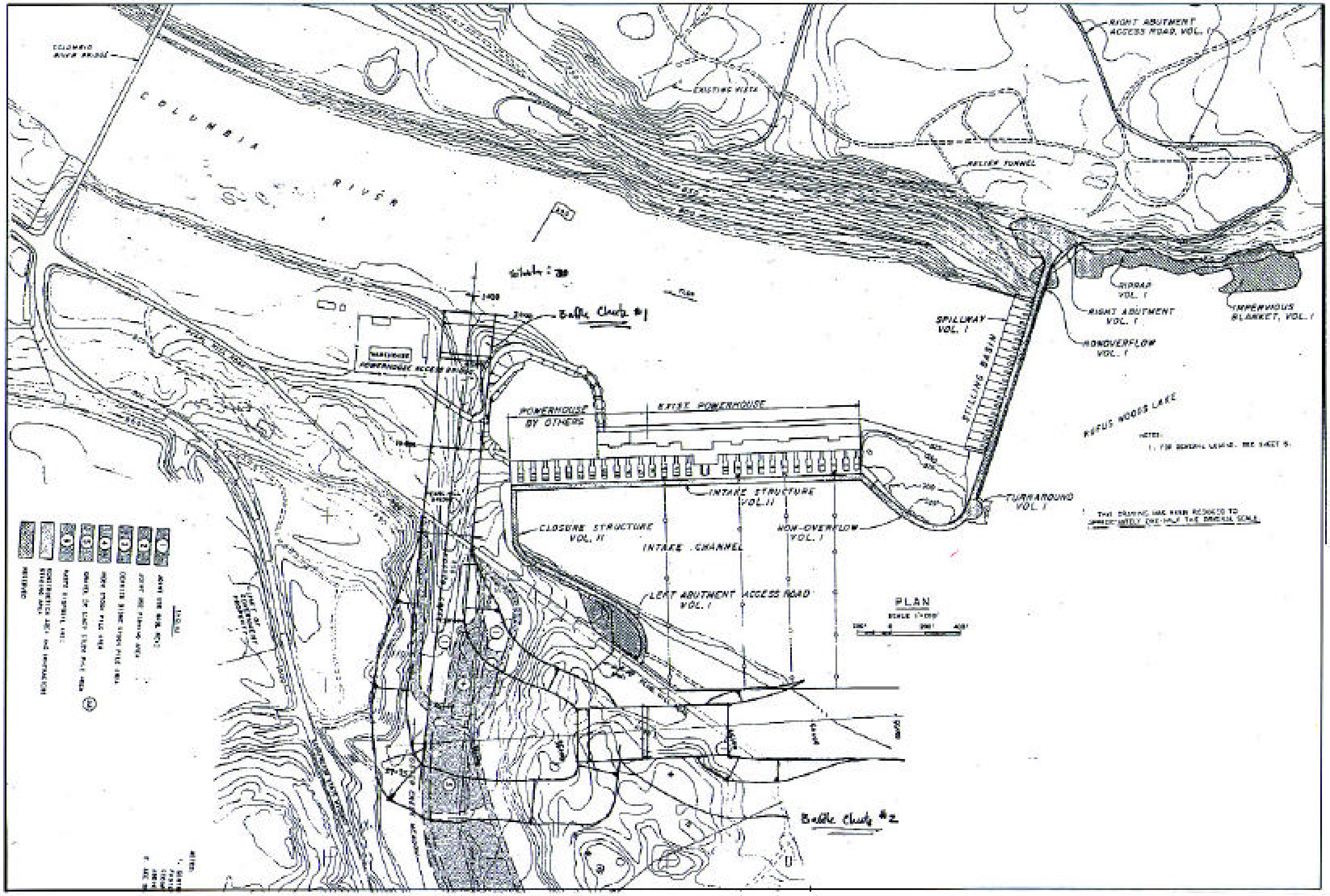
PLATE 3-7

TDG Below Chief Joseph Time Series

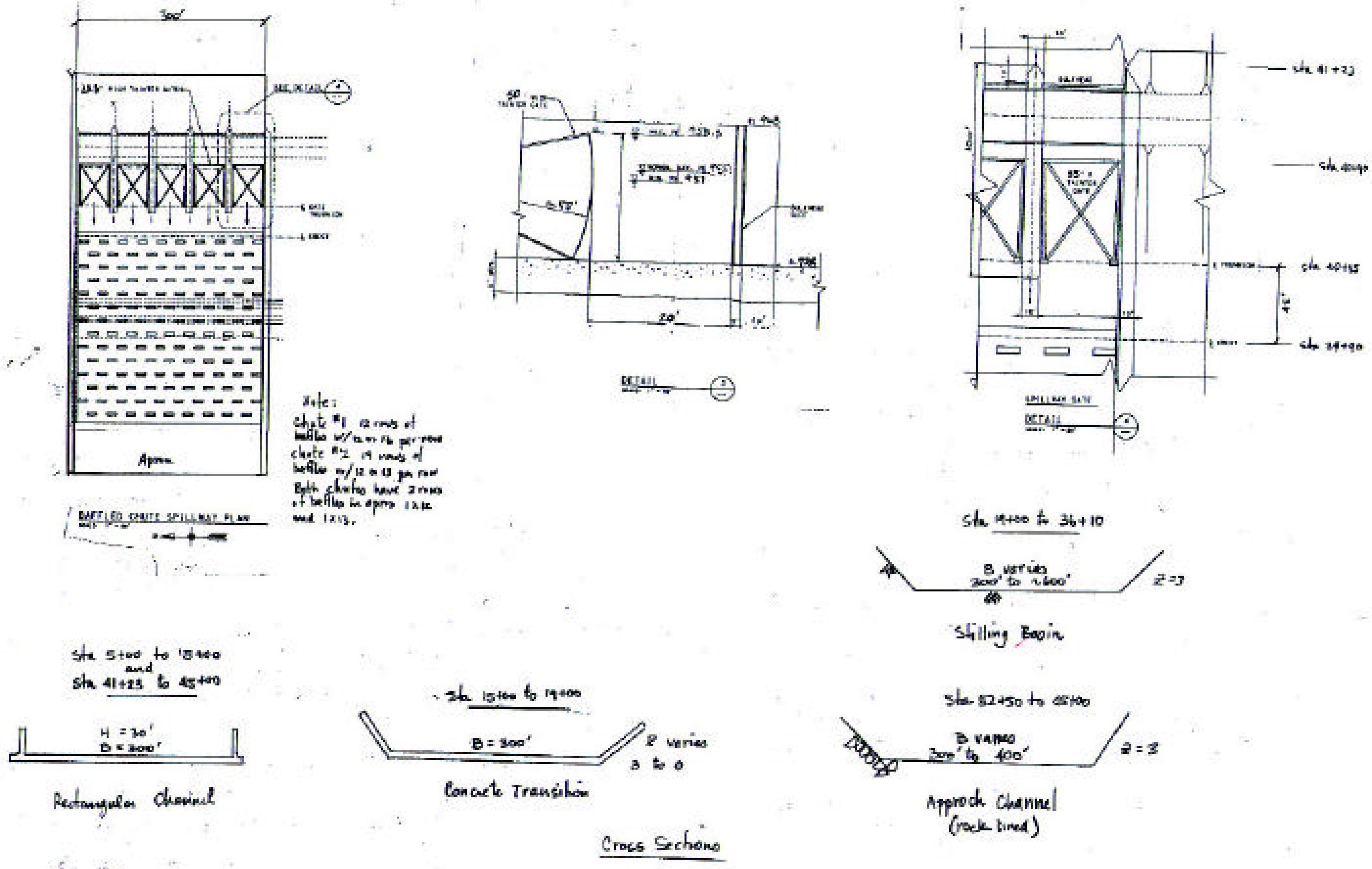
April, 2000



Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 3-8 Exceedance Percent for Spill at Chief Joseph Dam
April, 2000



Chief Joseph Dam, Columbia River
Gas Abatement Study
PLATE 3-9
Left Bank Side Channel Plan View
April, 2000



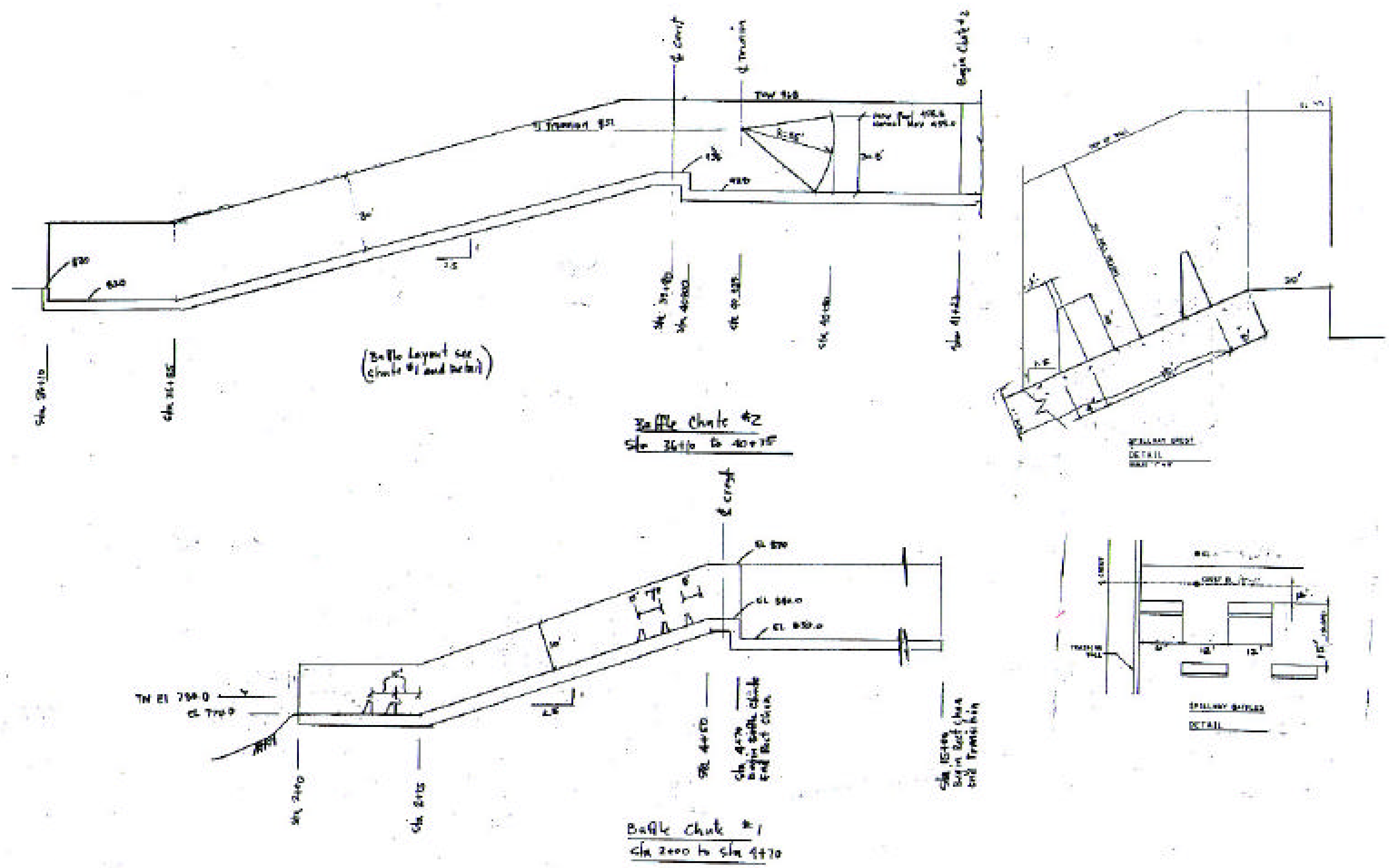
Chief Joseph Dam, Columbia River

Gas Abatement Study

PLATE 3-10

Left Bank Side Channel Sections

April, 2000



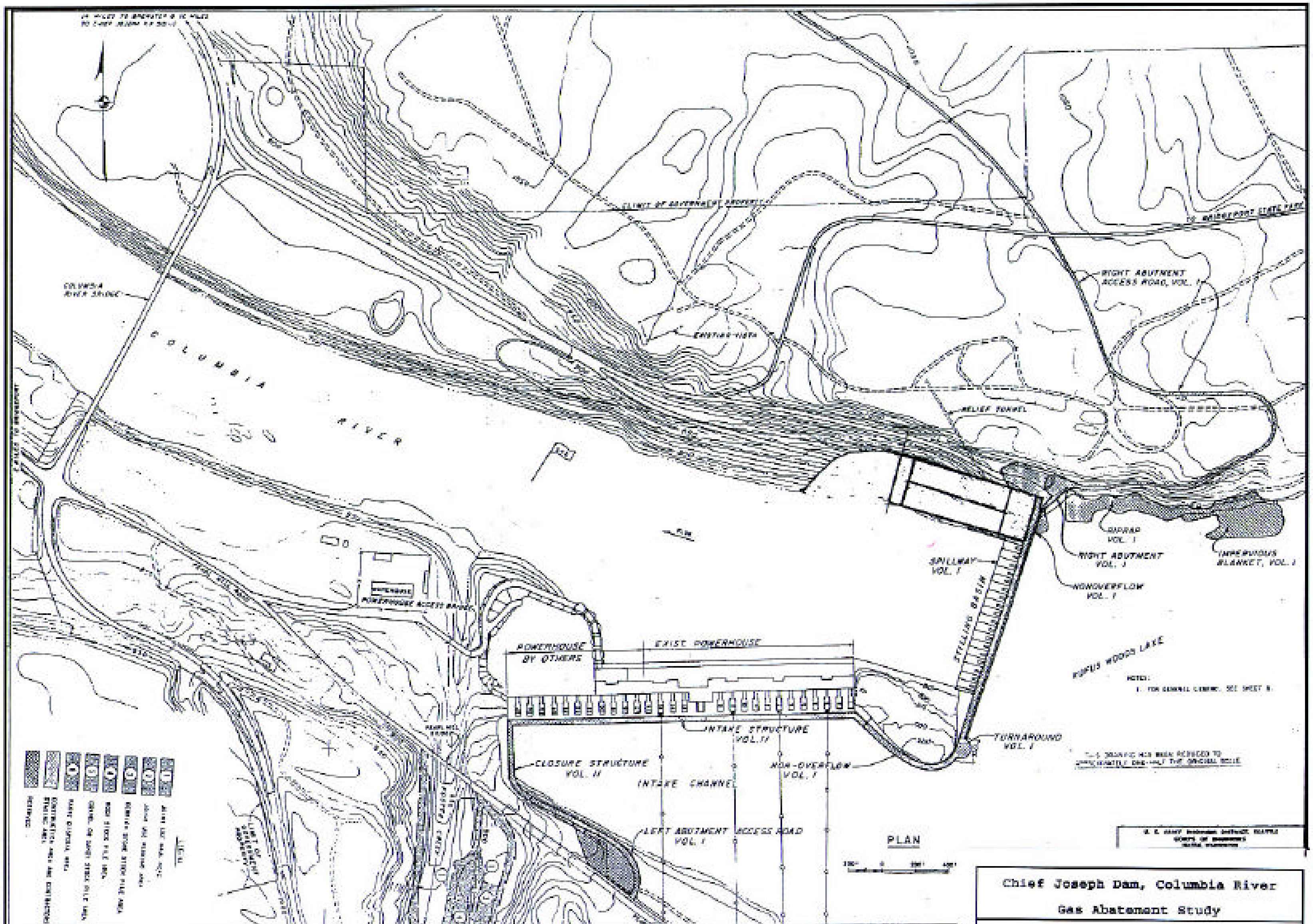
Chief Joseph Dam, Columbia River

Gas Abatement Study

PLATE 3-11

Left Bank Side Channel Profiles

April, 2000



Chief Joseph Dam, Columbia River

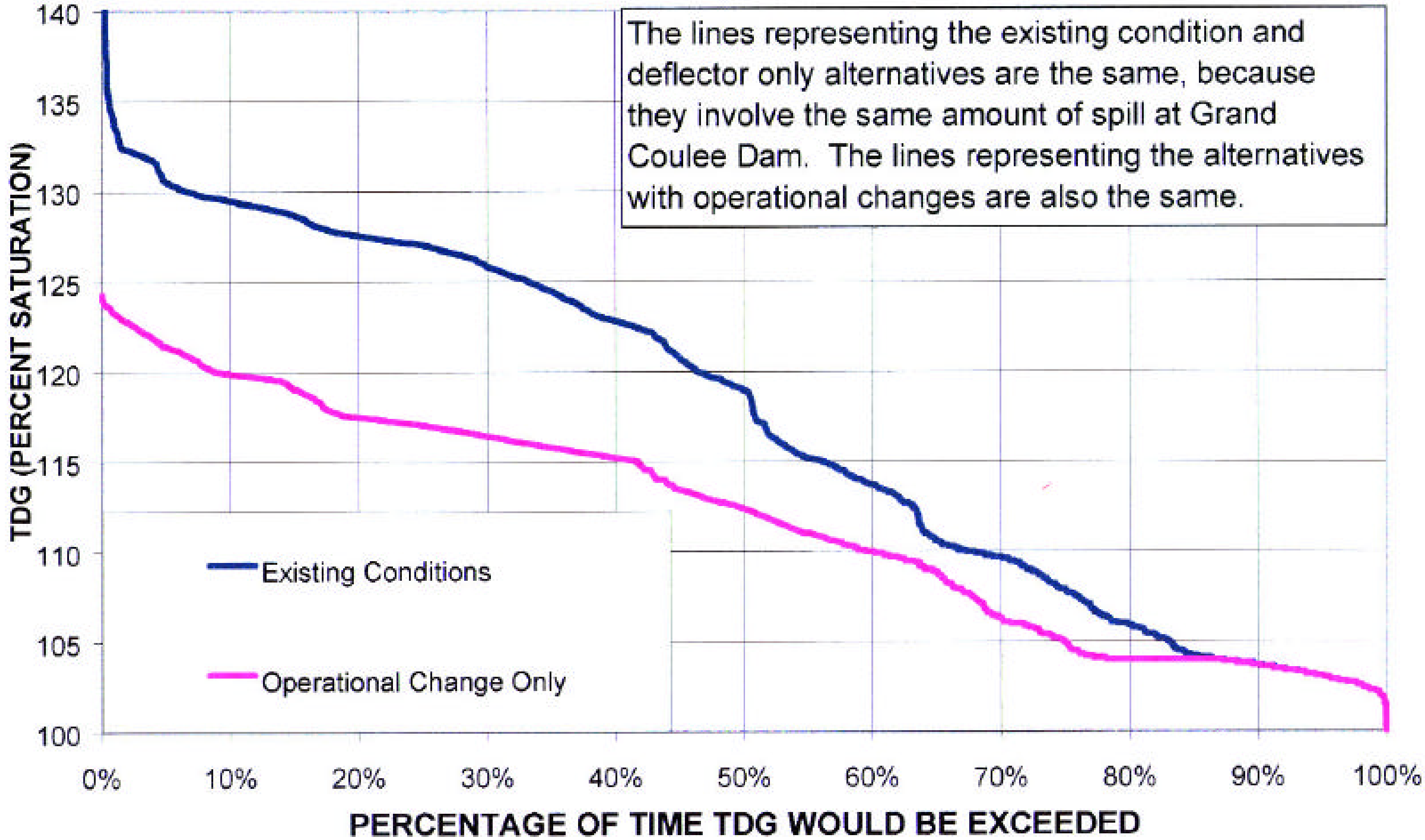
Gas Abatement Study

PLATE 3-12

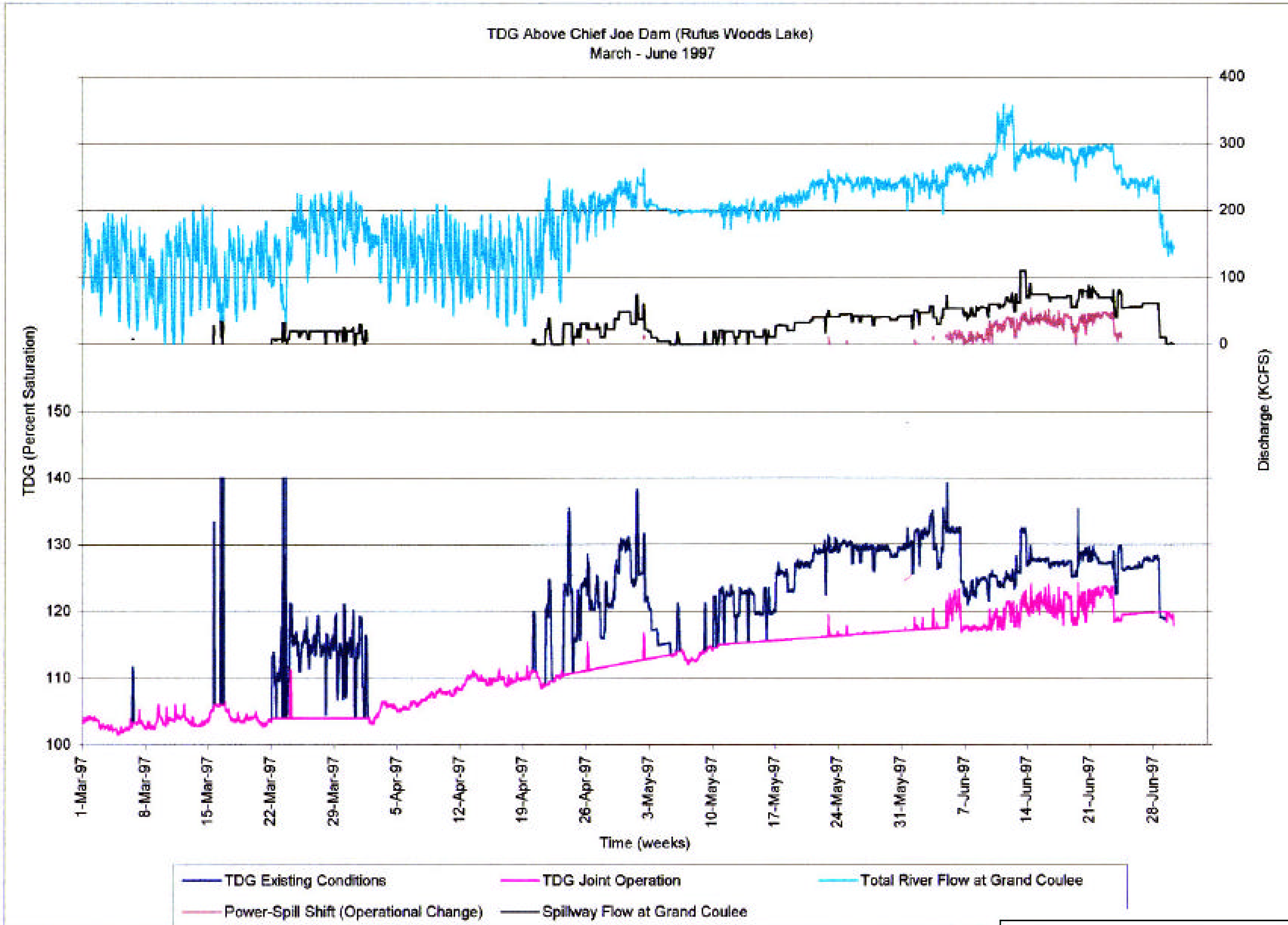
Right Bank Chute Alternative

April, 2000

OUTPUT OF MODELED ALTERNATIVES:
TDG BELOW GRAND COULEE DAM (RUFUS WOODS LAKE)
MARCH - JUNE 1997

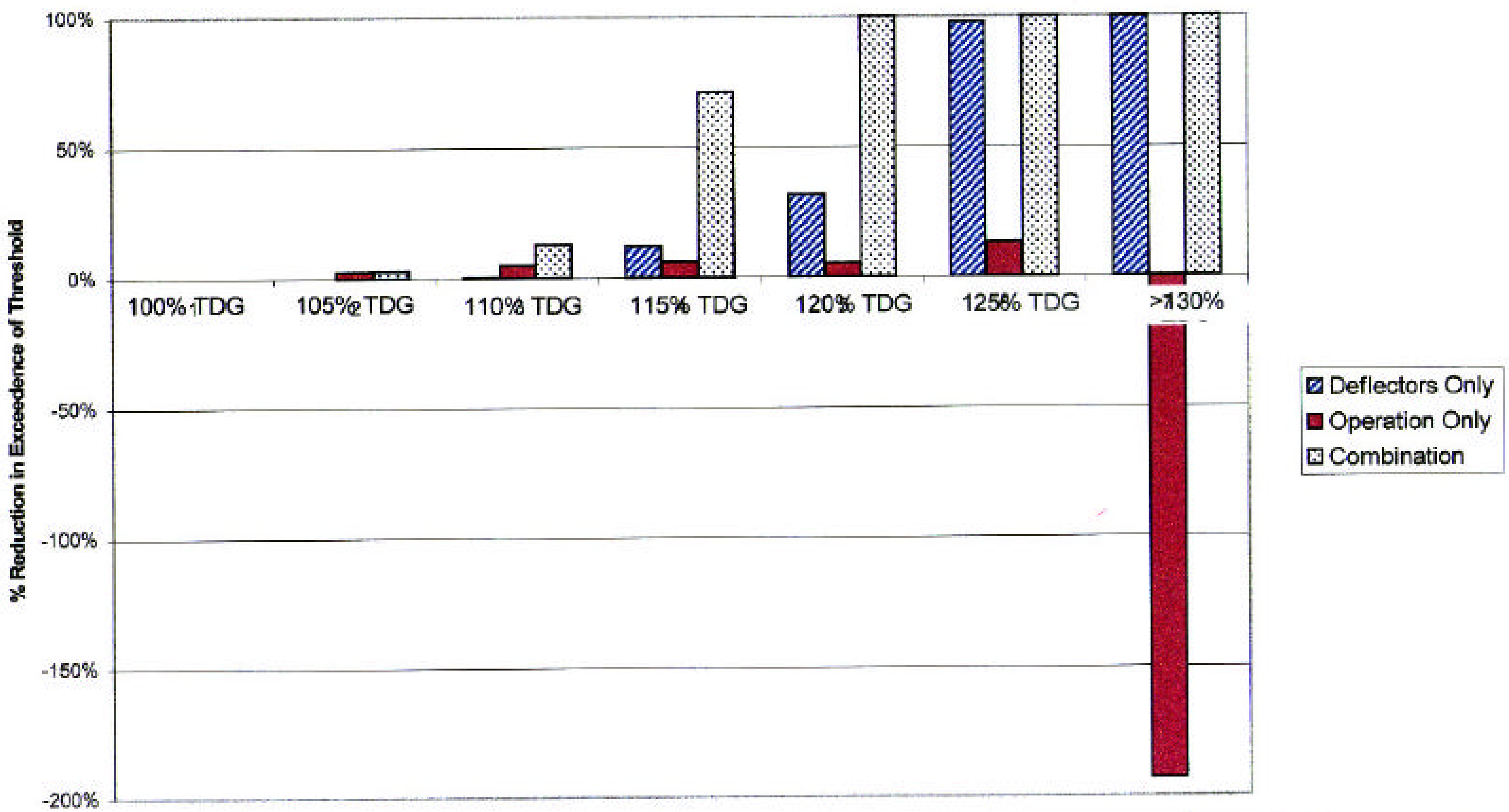


Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 3-13 TDG in Rufus Woods Lake (w/ Project)
April, 2000



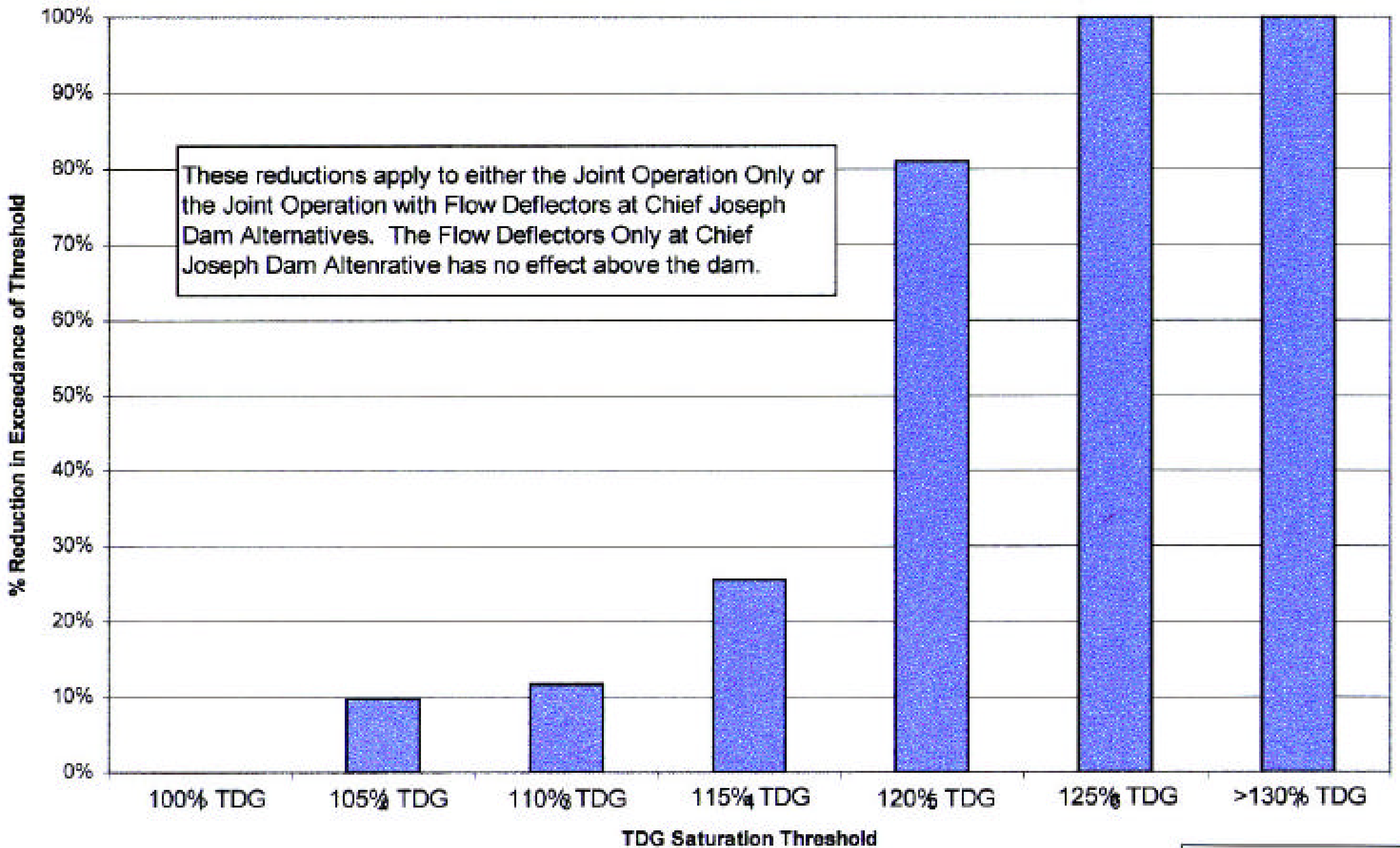
Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 3-14 TDG in Rufus Woods Lake Time Series
April, 2000

% Reduction in TDG Threshold Exceedence Below Chief Joseph Dam

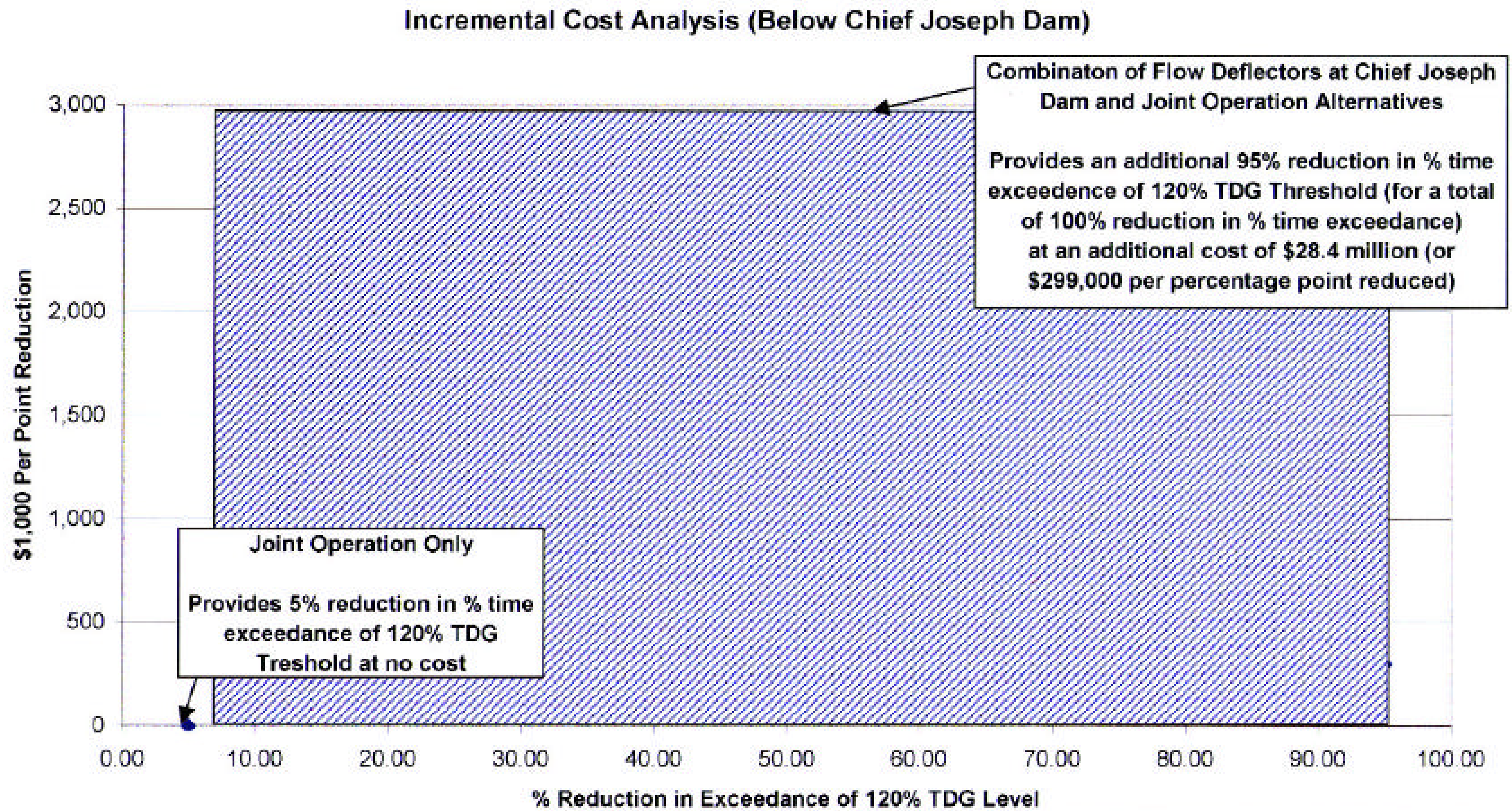


Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 3-15 Reduction in TDG Below Chief Joseph Dam (Tailwater Sensor)
April, 2000

% Reducution in Exceedence Above Chief Joseph Dam with Joint Operation



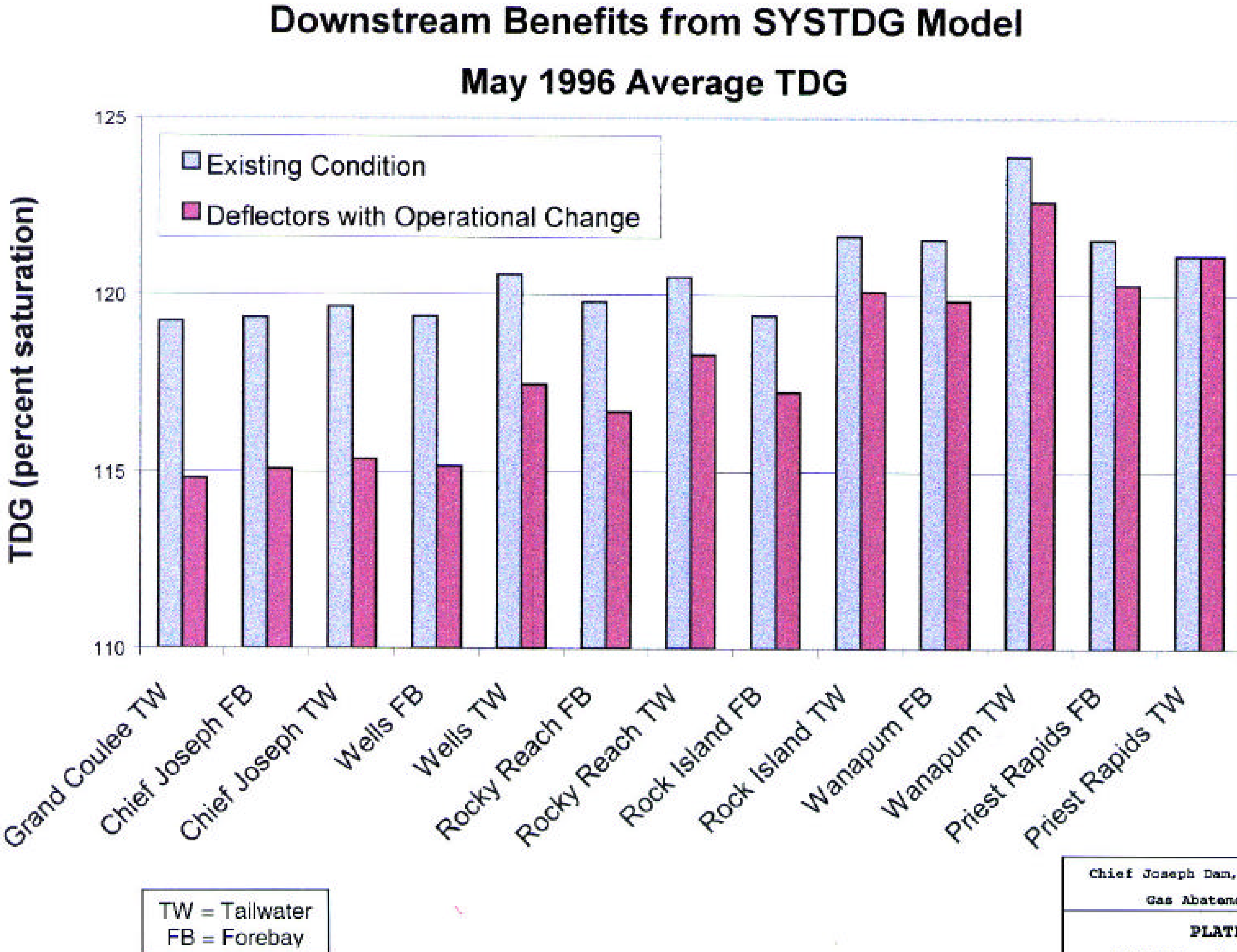
Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 3-16 Reduction in TDG Above Chief Joseph Dam (Forebay Sensor)
April, 2000



Chief Joseph Dam, Columbia River
Gas Abatement Study

PLATE 3-17
Incremental Cost Analysis

April, 2000



Chief Joseph Dam, Columbia River
Gas Abatement Study

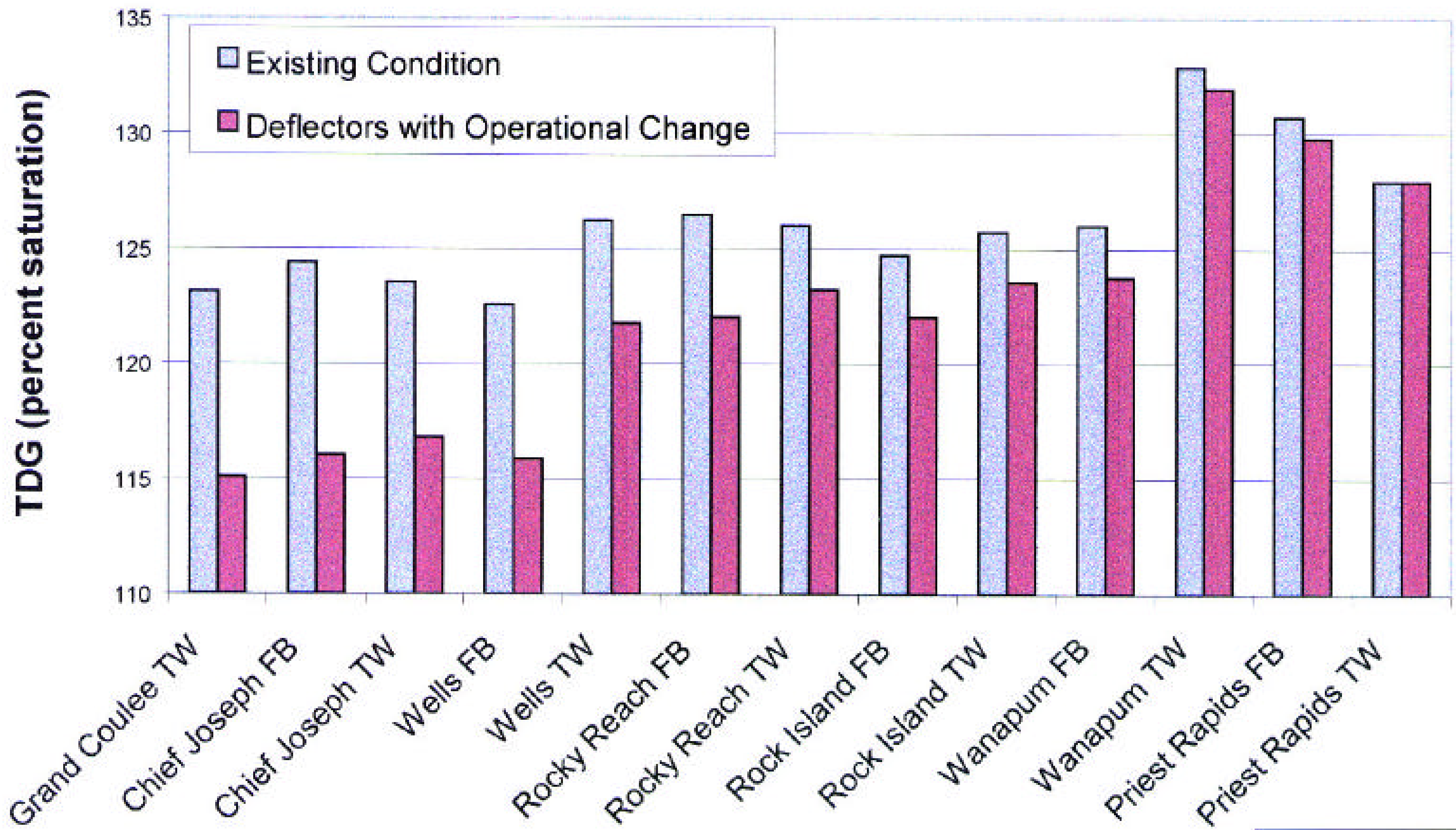
PLATE 4-1

SYSTDG Downstream Benefits
(May 1996 Flow Data)

April, 2000

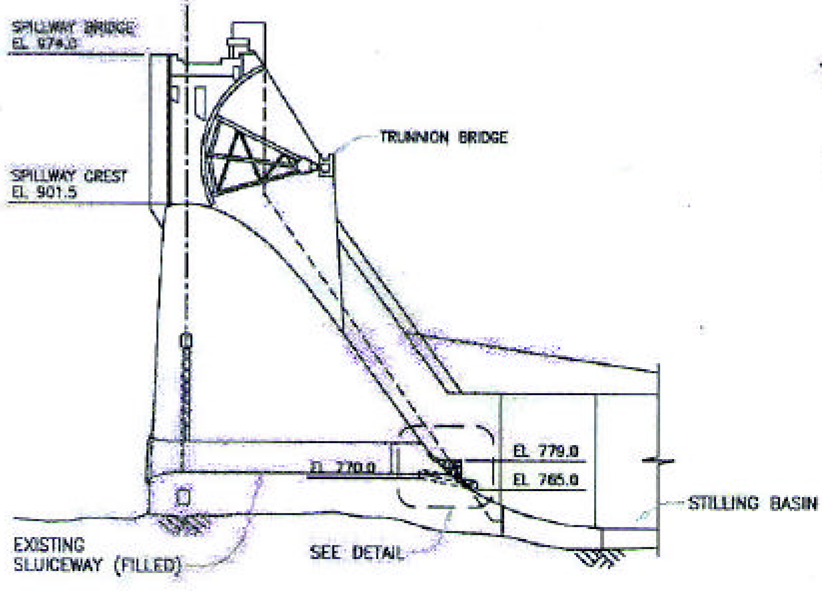
Downstream Benefits from SYSTDG Model

May 1997 Average TDG

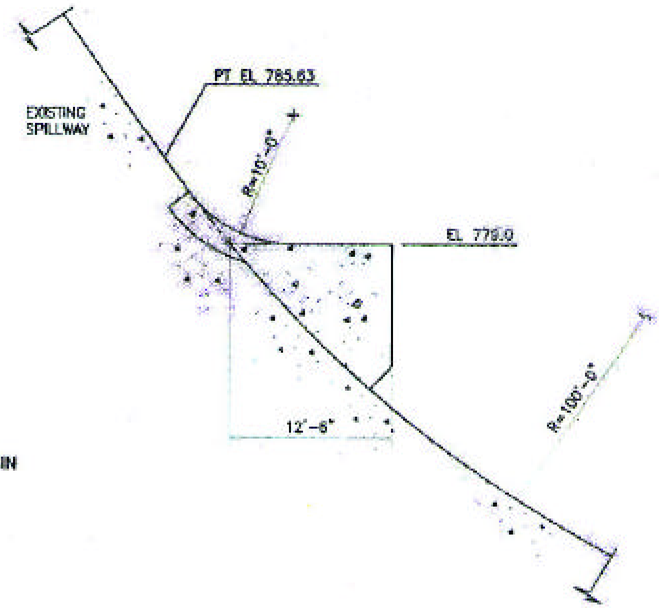


TW = Tailwater
FB = Forebay

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 4-2 SYSTDG Downstream Benefits (May 1997 Flow Data)
April, 2000

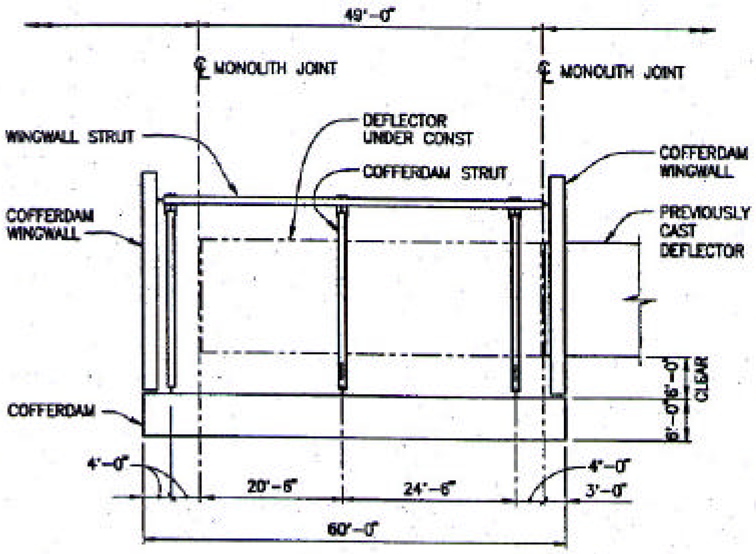


TYP SECTION THRU SPILLWAY
1"=50'

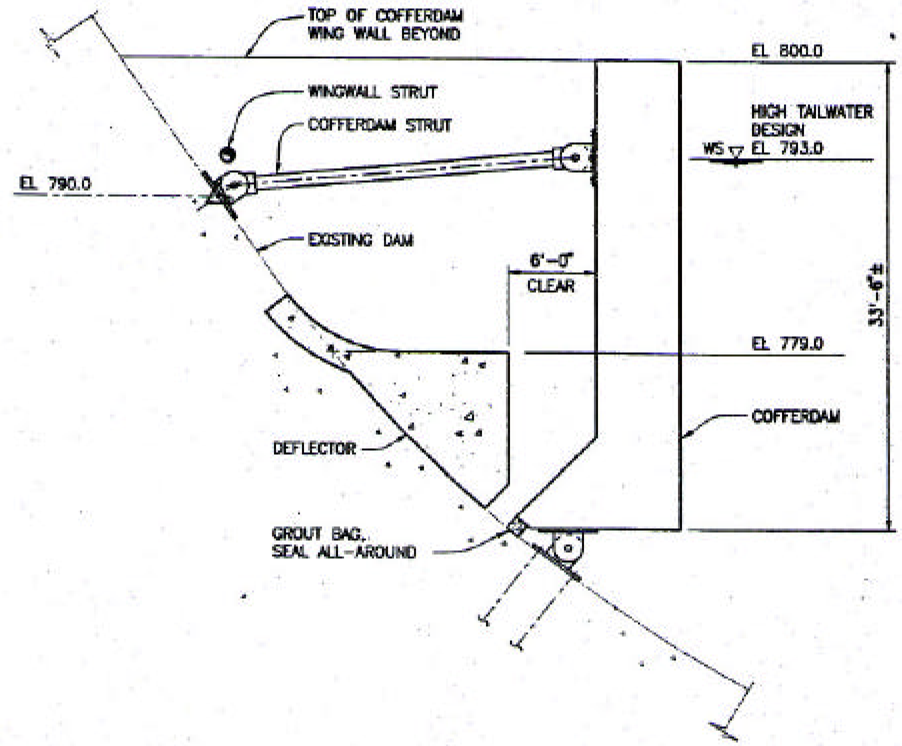


FLOW DEFLECTOR DETAIL
1/8"=1'-0"

Chief Joseph Dam, Columbia River Gas Abatement Study
PLATE 4-3 Flow Deflector Section and Detail
April, 2000



COFFERDAM PLAN
1/16"=1'-0"

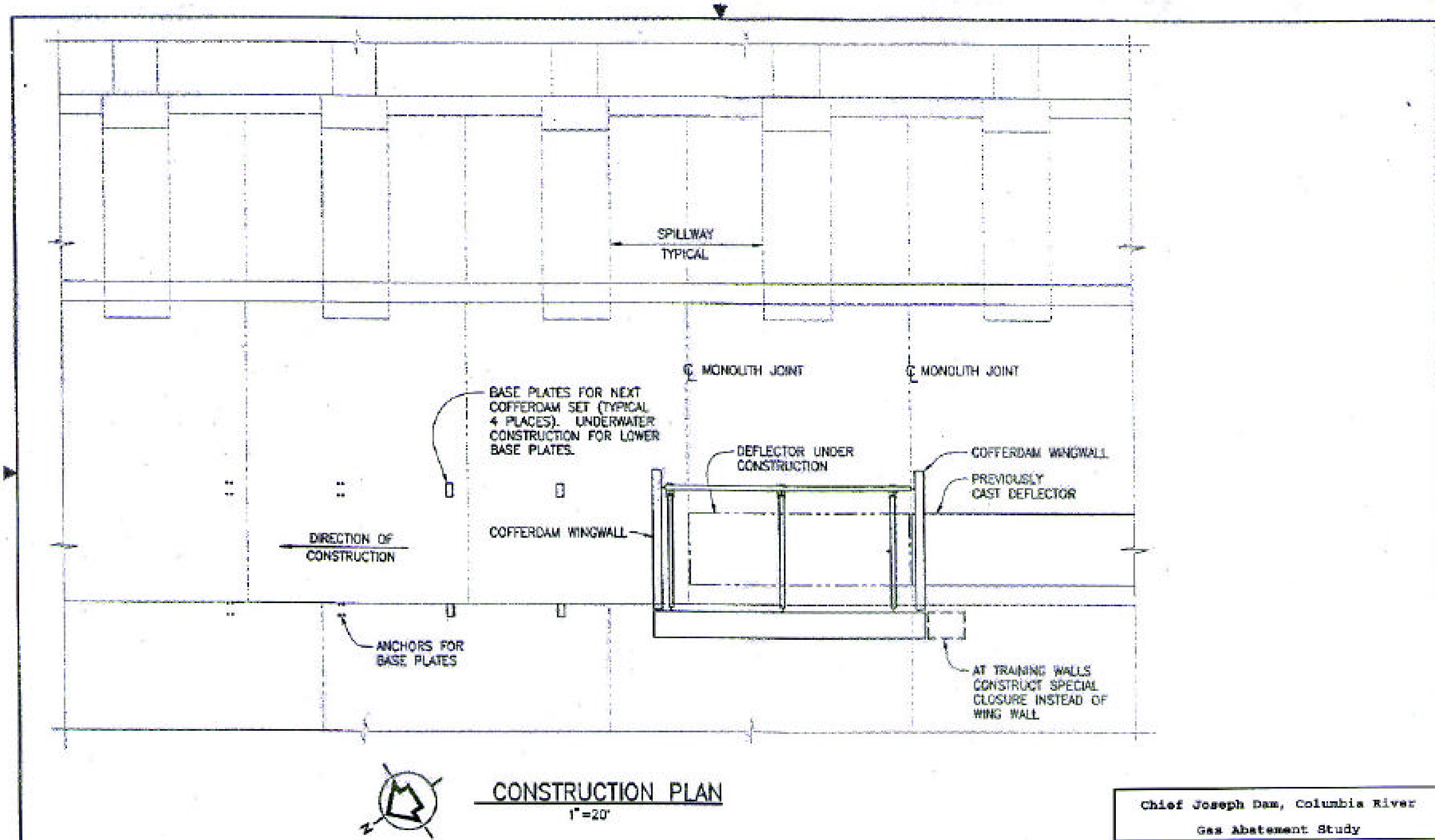


COFFERDAM SECTION
1/8"=1'-0"

Chief Joseph Dam, Columbia River
Gas Abatement Study

PLATE 4-4
Cofferdam Plan and Section

April, 2000



CONSTRUCTION PLAN
1"=20'

Chief Joseph Dam, Columbia River
Gas Abatement Study

PLATE 4-5

Flow Deflector Construction

April, 2000