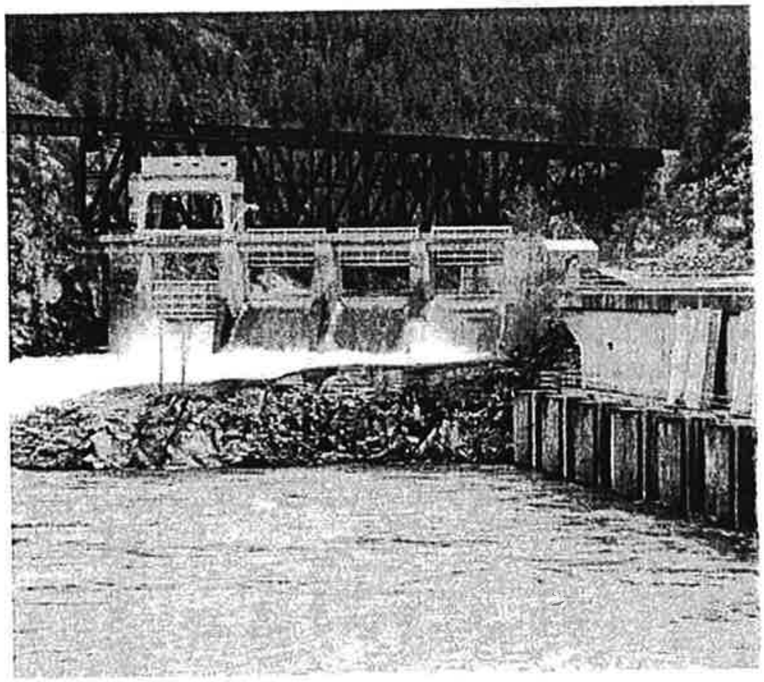
BOX CANYON HYDROELECTRIC PROJECT
FERC No. 2042

TOTAL DISSOLVED GAS ABATEMENT PLAN



Prepared for

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1.0 INTRODUCTION

The Washington Department of Ecology (WDOE) issued a 401 water quality certification for the Box Canyon Hydroelectric Project (Project) (FERC No. 2042), as an amended order dated February 21, 2003. As a condition of certification, the Public Utility District No. 1 of Pend Oreille County (District) shall prepare an abatement plan for complying with water quality standards for total dissolved gas (TDG) pressure. The draft plan shall be submitted to WDOE within 30 days of the date FERC issues a new license for the project. The FERC issued a new license for the Box Canyon Project on July 11, 2005. This plan is being submitted to the WDOE as part of the compliance with the 401 certification.

1.1 Water Quality Standards

The Washington State Water Quality Standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, water body classifications, and numeric and narrative water quality criteria for surface waters of the state. A revised version of the standards was adopted in 2003 and is currently awaiting approval by U.S. EPA.

Under the new standards, the mainstem Pend Oreille River is protected for "non-core salmon and trout."

Waters within Box Canyon Reservoir are Class A waters as defined in Chapter 173-201A of the Washington Administrative Code.

Total dissolved gas is the amount of air held in saturation in the water. Criteria in the standards are in terms of percent of saturation pressure relative ambient barometric pressure. The State standard for TDG states that TDG measurements shall not exceed 110 percent at any point of measurement.

The Kalispel Tribe has adopted water quality standards, which U.S. EPA approved on June 24, 2004. This water quality monitoring plan only addresses conditions of the Washington State 401 Water Quality Certificate.

1.2 Background

Water quality data from the Pend Oreille River shows that at certain times TDG levels exceed state water quality standards. Therefore, the state of Washington has included the Pend Oreille River on Ecology's draft 2002/2004 303(d) list. The Pend Oreille River is listed for TDG on the State of Idaho's 1998 303(d) list of impaired waters. Monitoring data also show that TDG in the Pend Oreille River exceeds water quality criteria in British Columbia, and may contribute to impairment of the Columbia River south of the Canadian border (Pickett *et al.*, 2004; NWPCC, 2003).

1.3 Sources of Dissolved Gas

Dissolved gas supersaturation can result from a wide variety of both man-made and natural causes. Hydroelectric and impoundment dams are known to sometimes cause high levels of TDG. Other sources include TDG associated with warm water discharges from cooling facilities (e.g., nuclear and fossil fuel power generating plants), oxygen production by aquatic plants (enhanced by nutrients associated with industrial effluents, municipal discharges, and agricultural runoff), solar heating of water bodies, ingestion of air into pumping systems, supplemental oxygen in hatcheries, and air lift reaeration systems.

Of the many possible sources of TDG supersaturation, the discharge of water through dams has received the greatest attention in the literature. In these hydraulic structures, TDG supersaturation is caused by the entrainment of air in water released over dam spillways, through low-level ports, or through turbo machinery associated with power generation. In dam spillways, air is entrained in falling water, which plunges to depth in pools at the base of the dam. There, under elevated hydrostatic pressure, air (in the form of bubbles) is forced into solution at pressures of several atmospheres.

When water is discharged through turbines and low-level ports of other projects, air is occasionally entrained in vortices near the port or turbine intakes (Johnson 1988). Under conditions of elevated hydrostatic pressure near the face of turbine blades or in the discharge from low-level ports, air is again forced into solution under hydrostatic pressures of several atmospheres. Low water conditions in forebay reservoirs can enhance vortex formation and dramatically increase air entrainment. Data to date indicate that air entrainment through the turbines is not an issue for the Box Canyon Project.

1.4 Project Description

The Box Canyon Hydroelectric Project is a "run-of-the-river" development. The principal structures, shown on Figure 1, are the main spillway-dam and the powerhouse, which are connected by the forebay channel. The Project has a maximum gross head of 46 feet, a minimum operating head of about 15 feet, and a design turbine discharge of approximately 27,400 cfs.

The main spillway, shown on Figure 2, consists of four bays each 40 feet wide with a crest at El. 1970. In each bay are gates 40 feet wide and 62 feet high, constructed of welded steel plate. Three of these gates are sectionalized into three leaves that are 20 feet-8 inches high. The top leaf of the fourth bay (located furthest left looking downstream) is further sectionalized into two 10 feet-4 inch high leaves. The top elevation of the gates, when they are all installed, is El. 2032.0. These gates stack one on top of the other to form the dam. The gate leaves are raised with a 100-ton gantry crane, which rides on a deck 90 feet above the spillway crest.

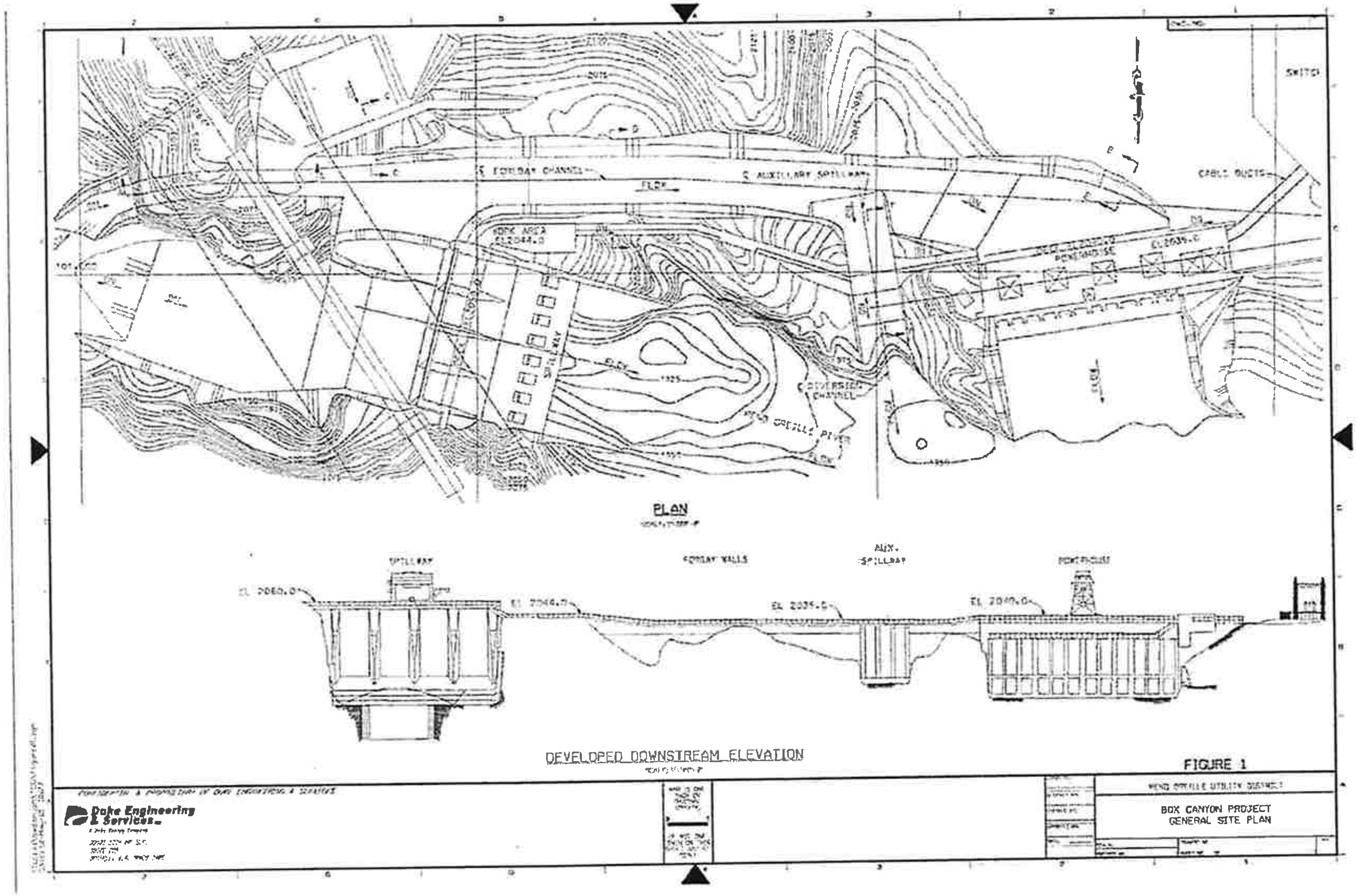

Figure 1. General Site Plan

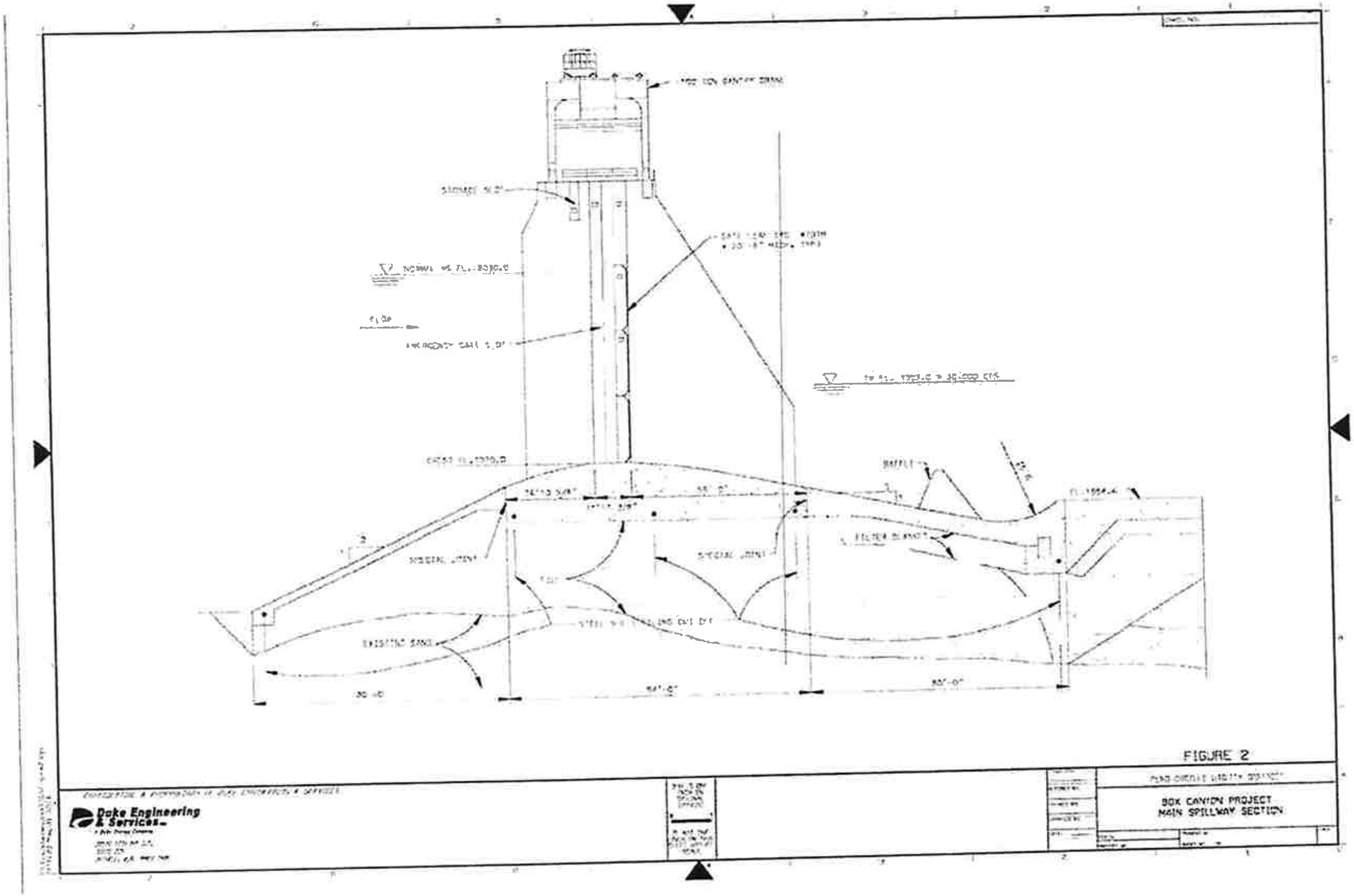

Figure 2. Main Spillway Section

The spillway was designed so that it causes no increase in backwater, over that recorded before the spillway was built, during periods when all spillway gates are removed. The spillway is capable of passing a design Probable Maximum Flood (PMF) of 350,000 cfs.

The spillway's concrete crest and downstream apron shape are streamlined for performance efficiency. The downstream apron is 80 feet long. The apron was designed with a shallow flip bucket at the sill and baffles, both of which reduce bottom velocities sufficiently to prevent scour of the heavy riprap and natural boulder bed downstream from the apron.

The headwater level, which is controlled by the spillway gates, is held at about El. 2030 for flows up to nearly 60,000 cfs, then is lowered at higher flows to prevent upstream flooding. This is illustrated by the spillway rating curve shown on Figure 3. The level of the tailwater is characterized by the tailwater rating curve, shown on Figure 4. Tailwater levels, influenced by the downstream Boundary Hydroelectric Project (FERC No. 2144), fluctuate on a daily basis. The relationship between headwater and tailwater levels, and the elevations of the spillway gate leaves is an important aspect in evaluating TDG contributions by the Project. Significant is the tops of the bottom leaves, El. 1990.7, which are always submerged by tailwater at river flows greater than 30,000 cfs. This means that TDG levels are not significantly increased when the top and middle gate leaves have been removed from the spillway because no air is entrained by flow over the tops of the bottom leaves. This gate configuration occurs when river flows reach approximately 80,000 cfs. Therefore, this flow represents the upper flow limit above which TDG increases do not occur.

At flows of 60,000 cfs, the four top gate leaves are completely removed from the four spillway bays. Middle gate leaves are raised as flows exceed 60,000 cfs, causing a portion of the spill to be submerged by tailwater, which in turn begins to lower TDG contributions.

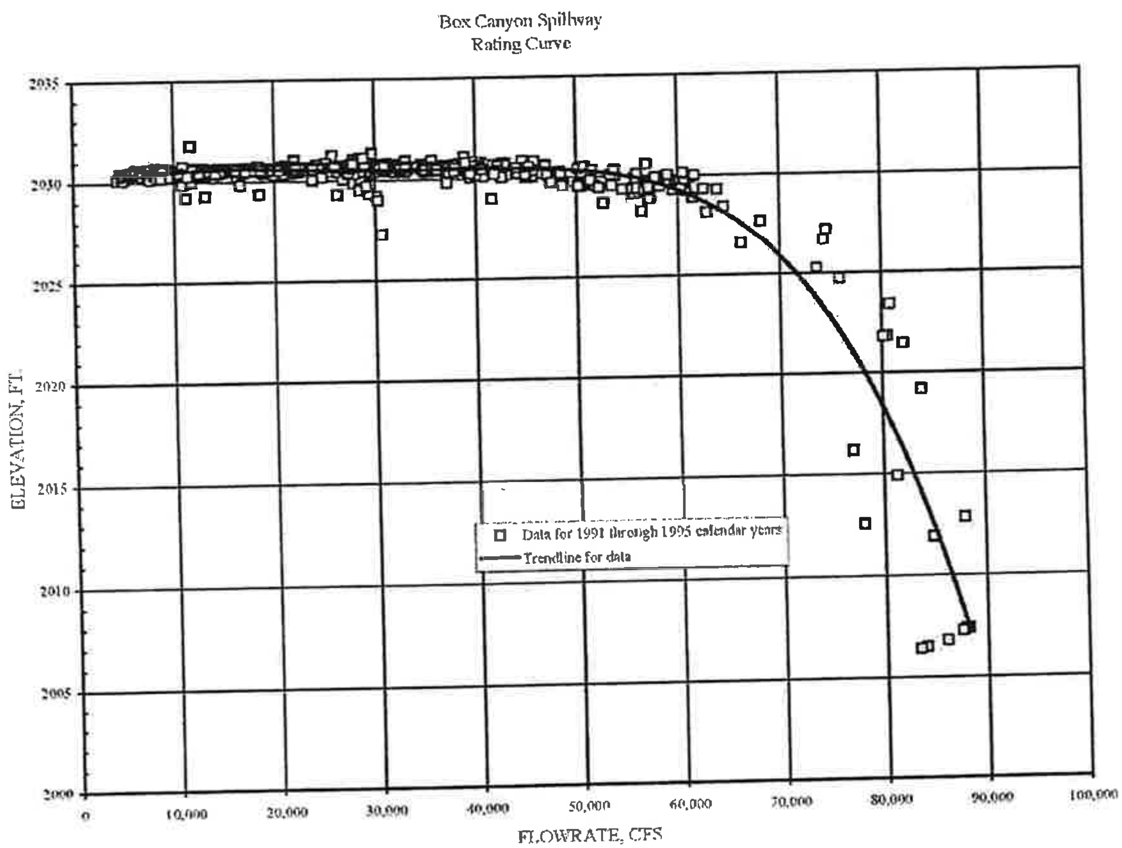

Figure 3

Figure 3. Spillway Rating Curve

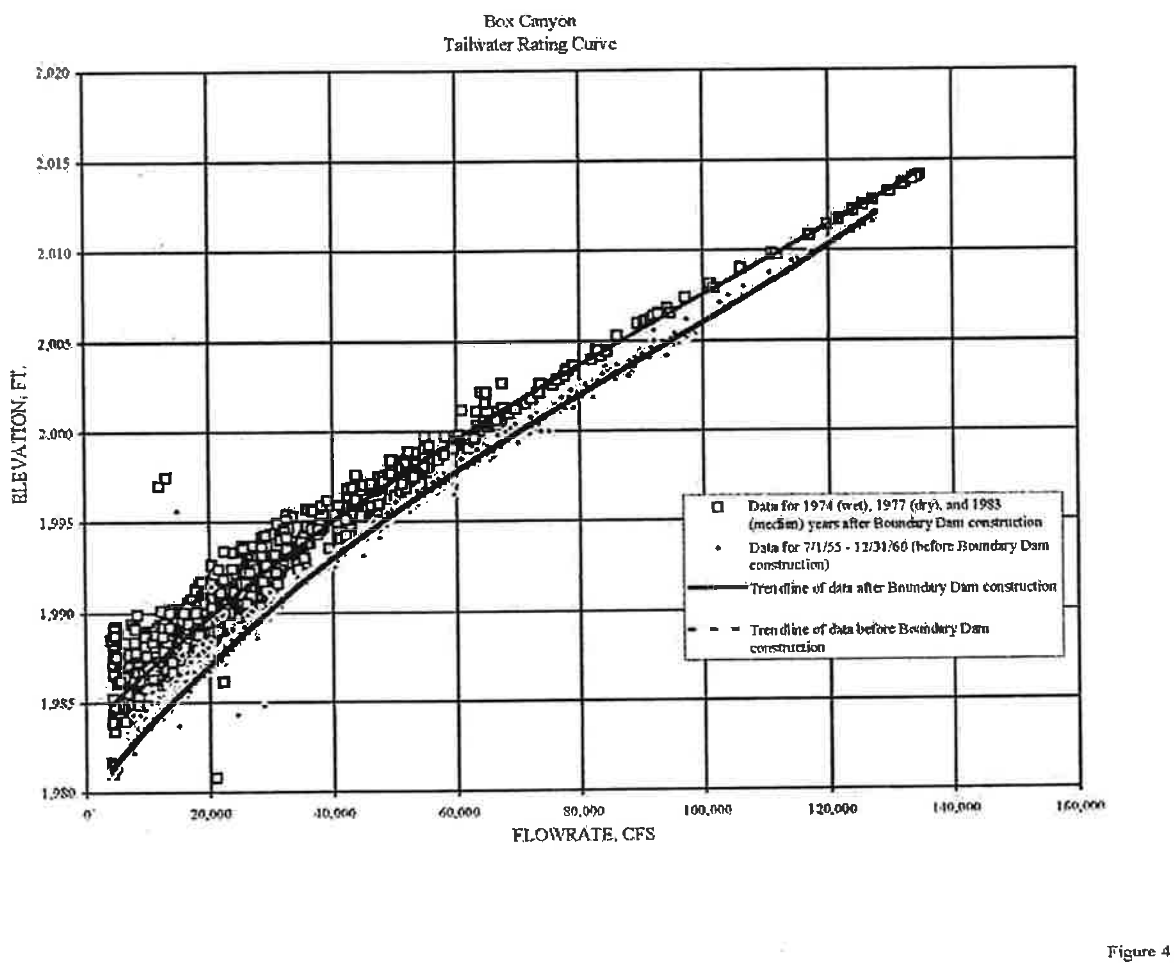

Figure 4. Tailwater Rating Curve.

2.0 EXISTING CONDITION FOR TDG

The District has monitored TDG at three locations on the Pend Oreille River since 2001 (DE&S 2001a; DE&S 2001b; FADES 2002; EESC 2003; EESC 2005). These three locations are at Newport, Box Canyon Dam forebay, and Box Canyon Dam tailrace. The U.S. Army Corps of Engineers has monitored TDG at the USGS flow gage just upstream of the Idaho state line near Newport. Washington Department of Ecology conducted TDG monitoring at several locations within Box Canyon Reservoir during 2004 (Pickett 2004).

Before it reaches Box Canyon Dam, the Pend Oreille River has relatively high dissolved gas concentrations at certain times of the year from the effects of upstream dams. Spilling at the Project can increase dissolved gas levels in the water. River flows in excess of the Project's turbine capacity (27,400 cfs) are spilled, and historically spill occurs at Box Canyon about 28% of the time. Currently, TDG increases due to plunging spillway discharges have been measured when river flows are between approximately 27,400 cfs and 30,000 cfs. Spill occurs more frequently during April, May and June. When spill does occur, it eventually mixes with water that passes through the turbines, which has lower gas levels, moderating the TDG increase.

Water is discharged from Box Canyon Dam through both the spillway and the turbine tailrace when total flow exceeds 27,400 cfs. At lower flows during normal operation, all the water passes through the turbines. TDG levels immediately downstream of the turbines are essentially unchanged from forebay TDG levels for all flows through the turbines. Data demonstrate that the turbines do not contribute to gas supersaturation (District 2000). The fact that there has been little wear on the turbine blades supports this conclusion since air entrainment typically causes pitting of the turbine blades. Preliminary investigations have identified that spillway and turbine tailrace discharges do not fully mix for a considerable distance downstream of Box Canyon Dam. A distinct lateral gradient exists within a mile downstream of the dam when significant spill over the spillgates is occurring. Total gas pressure is greatest along the eastern (right bank) side of the river where the spillgate flow is directed. The interface between spill and turbine tailrace flow is dependent upon the volume of spill relative to turbine capacity. Total gas pressure still shows a lateral gradient where measured approximately four miles downstream of the dam. TDG levels become uniform laterally before River Mile (RM) 29 just upstream of Metaline. Bends in the river between RM 31 and RM 29 are conducive to lateral mixing. Monitoring indicates that a vertical TDG gradient does not exist (District 2000). Both the spillway flow and the turbine discharge are each well mixed within themselves and do not appear to slide over one another as flow progresses downstream. Mixing is lateral along an increasingly diffuse interface in a downstream progression. In some hydroelectric plants, the mixing can be very rapid depending on water velocities, river depth, and bathymetry. For example, the turbine and spill flows below McNary Dam on the Columbia River appear to be well mixed within a few miles downstream of the dam (COE 1995). On the other hand, spill and turbine flows associated with the Ice Harbor Dam on the Snake River are poorly mixed for many miles downstream (COE 1995). As a result, the impacts of TDG supersaturation on fish can vary dramatically from one side of the river to the other (COE 1996).

Downstream of Box Canyon Dam, gas supersaturation caused by operation of this Project does not affect the west bank waters until lateral mixing occurs.

Forebay TDG measurements at Box Canyon Dam typically range from 98% to about 120% saturation. Downstream (one mile below spillway) TDG levels have been recorded as high as 139% saturation. During non-spill events at Albeni Falls Dam, TDG levels were similar between Newport and Box Forebay. During spill events at Albeni Falls, a small amount of off-gassing occurs as flow traverses Box Canyon Reservoir. In 2002 a 3.3% increase to 8.9 % reduction in TDG saturation was recorded from Newport to Box Canyon Dam forebay, the mean reduction was 3.0 % TDG saturation (21.5 mm Hg TDG). Gas supersaturation within BCR is attributable to the influence of aquatic plants on dissolved oxygen during certain times of the year as well as dissolved gases introduced from upstream hydroelectric projects.

The TDG levels at Box Canyon tailrace are influenced by forebay TDG levels, amount of spill, the ratio of spill to total discharge, the change in elevation from the forebay to the tailrace, and possibly, the spillway gate configurations. In general, the increase in TDG from Box Canyon forebay to Box Canyon tailrace versus spill exhibits a parabolic pattern. TDG peaks when the spill ranged between 40,000-60,000 cfs. Once all the gates are removed from the spillway, only a slight increase in TDG below the spillway has been observed. The difference could be due to instantaneous variability rather than an effect of the dam. Loss of head eliminates the primary mechanism for gas entrainment. At a river flow of 80,000 cfs, only the bottom spillway gate leaves are in place and these are fully submerged so that there is no more air entrainment At higher flows, turbulence created as water passes through the canyon itself and through the open spill gates where only the dam piers remain in the water would tend to strip dissolved gas, not increase TDG.

The spillway TDG percent saturation increases approximately 2.4% above the forebay TDG saturation when the total river flow at Box Canyon is 30,000 cfs, which is a flow that is just slightly larger than the existing turbine capacity. Gas saturation increases sharply as the spill volume increases. At a flow of 35,000 cfs, TDG percent saturation levels for the spillway increase by 10.5%. At a river flow of 50,000 cfs, the spillway TDG percent saturation is about 25% higher in the spillway than in the forebay.

The District has been monitoring TDG and related water quality parameters at Box Canyon Dam since 1999 (District 2000; DE&S 2001a; DE&S 2001b; FADES 2002; EESC 2003; EESC 2005). TDG data are recorded at 15-minute intervals in the forebay and approximately 1 mile downstream of the spillway. All available TDG data for Box Canyon Dam that satisfied QA/QC procedures were used to develop a predictive relationship between spill flow and gas saturation. A third order polynomial equation was derived to describe the non-linear relationship between the change in %TDG and the spill flow rate. Figure 5 shows the TDG saturation data (change in percent saturation from the forebay to below spillway) and the best fit polynomial curve. The change in percent saturation (Delta %TDG) as a function of spill flow is quantified in Table 1, which updates a similar table reported in (An Evaluation of Alternatives to Mitigate Total Dissolved Gas [TDG] at Box Canyon Hydroelectric Project: District 2001). The latter was based on daily averaged data from 1999 and 2000. The revised polynomial curve relationship was used to update the analysis of TDG abatement measures.

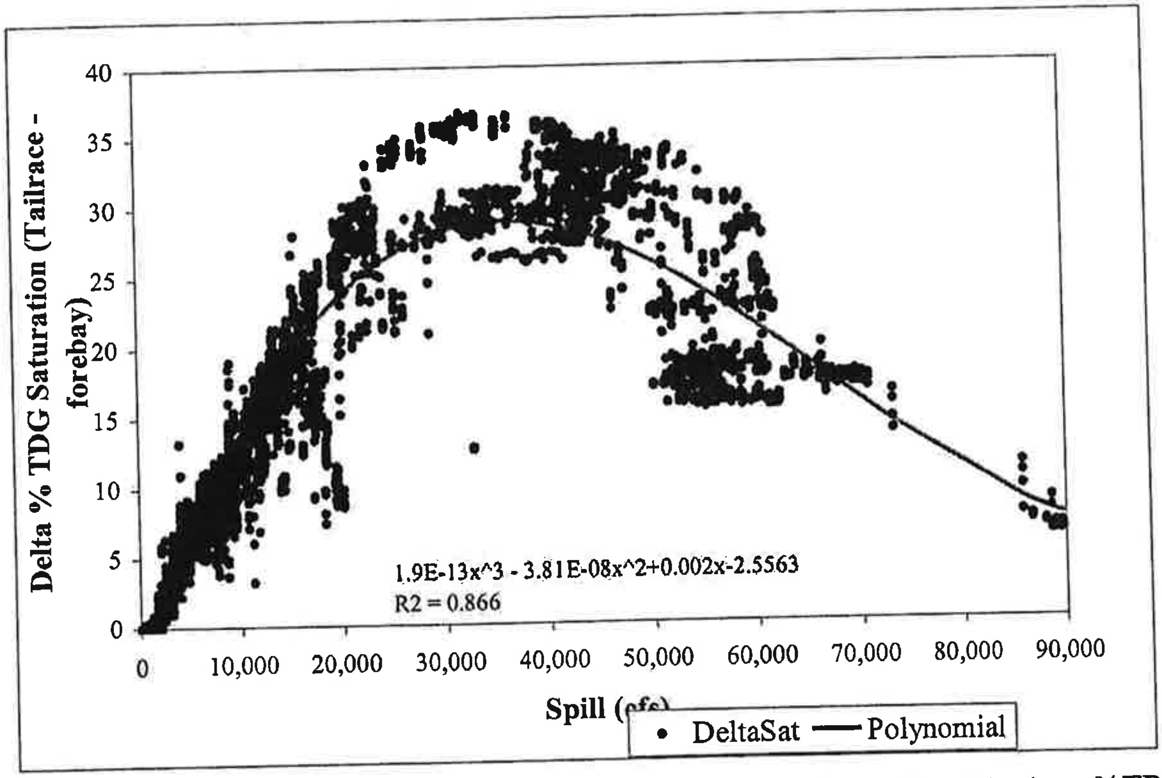

Figure 5. Change in percent saturation total dissolved gas (tailrace %TDG minus %TDG forebay) as a function of spillway flow for existing condition based on TDG monitoring 1999 – 2004

Table 1. Existing Turbine Capacity

River Flow (cfs)	Forebay Gas Saturation (%)	% of Time River Flow is Exceeded	Turbine Flow (cfs)	Spillway Flow (cfs)	Spillway Gas Saturation (%)
27,400	110	28.1	27,400	0	107.4
30,000	110	23	27,400	2,600	112.4
40,000	110	15	27,400	12,600	127.0
50,000	110	10	27,400	22,600	135.4
60,000	110	6.5	27,400	32,600	138.7
70,000	110	4.2	18,000	52,000	135.1
80,000	110	3	8,000	72,000	124.9
90,000	110	1.5	0	90,000	110.0[1]

[1] *Data show an increase in %TDG of up to 7% when gates are fully open; however, these increases are likely due to temporal variability and not a consequence of the project*

3.0 TDG ABATEMENT MEASURES

The District filed an evaluation with FERC of alternatives to mitigate TDG at Box Canyon Hydroelectric Project (District 2001). The following alternatives were evaluated for eliminating or reducing TDG levels at Box Canyon Dam.

- Turbine upgrades;
- Auxiliary spillway bypass;
- Structures in the tailrace;
- Replacement of flip buckets with flip lips;
- Low water ports;
- Stilling basin modifications;
- Chemical or gas injection techniques.

The District is upgrading the turbines based on engineering recommendations made during a comprehensive study of possible additions and upgrades to the generation equipment. The turbine upgrade will increase the hydraulic capacity of the Project to 32,400 cfs and reduce the duration of TDG spill to about 17.5% of the time annually. Upgrading the turbines provides significant TDG reduction, is cost effective, and has the best cost to benefits ratio of any alternatives studied. This upgrade will also provide fish migration benefits, supported by the FERC. The alternatives analysis also identified an auxiliary spillway bypass as an additional measure for further gas abatement. Operation of the auxiliary spillway involves structural modifications and installation of gates and hoisting equipment, and is the most effective for avoiding spill and improving TDG levels beyond the improvements yielded by the turbine upgrade. When the combined flow capacity of the upgraded turbines and auxiliary bypass is exceeded, reductions in downstream TDG levels from spill may be reduced through careful selection of gate settings, and via changes in downstream river water mixing conditions.

The TDG Abatement Plan consists of four primary actions:

- Upgrade turbines
- Complete final engineering design, modeling, and installation of auxiliary bypass using preliminary 27-foot-tall gate configuration
- Further analyze spill gate configuration to identify gate settings that reduce gas generation for both existing project configuration and after completion of other abatement measures
- Implement the TDG elements of the Water Quality Monitoring Plan.

3.1 Turbine Upgrades

An increase in powerhouse hydraulic capacity by upgrading the Project's generating equipment will reduce TDG levels in two ways. First, increasing flow through the powerhouse reduces the volume amount and duration of spill. Second, the additional turbine flow increases the proportion of low-TDG flow which will further dilute spillway discharges.

The upgrade study, which was completed as part of the FERC relicensing process (see Appendix A-1 of the License Application), found that modern turbine technology offers an opportunity to upgrade the existing machines to take advantage of improved efficiency and increased output. Based on that study, the District will upgrade all four turbines with new high efficiency runners and rewind all four generators to increase their maximum generating capacity from 18 MW to 22.5 MW each. Water flow through the plant will increase from 27,400 cfs now to about 32,400 cfs after the upgrades are completed. Main transformer rewinds would also be necessary to accommodate the increased generating capacity of the units. Miscellaneous work to the main bus work inside the powerhouse and the control systems would be performed at the same time. Upgrade work will take place over a 7-year period, with one unit upgraded per year after design and model testing are completed, beginning in 2006. No new structures would be built as part of the upgrade and no construction work in the river is necessary. No changes in reservoir operation or river water levels will result from these upgrades. The plant would continue to operate as it always has, within the same backwater curves and same constraints on water levels. Therefore, no additional flooding of lands would occur and no upstream environmental impacts would result from these changes.

Upgrading the turbines is expected to provide significant environmental benefits by reducing dissolved gas levels downstream of the plant. The duration of spilling water will be reduced by the increased turbine capacity. The Project will begin to spill water at 32,400 cfs instead of 27,400 cfs. The range of TDG-generating flows will be 32,400 cfs to 80,000 cfs. This range of flow occurs about 17.5% of the time based on the flow duration curve shown in Figure 6. Therefore, upgrades will reduce the annual frequency of TDG-generating flow by 30 percent (from 25% of the time to 17.5% of the time). The curves plotted in Figure 7 illustrate the effect of the 5,000 cfs additional capacity of the turbines on spillway TDG levels as a function of time. The curves are based on the developed relationships between river flow, spillway flow and spillway TDG levels and the flow duration curve.

The data for these relationships are summarized in Table 2.

Table 2. Upgraded Turbine Capacity

River Flow (cfs)	Forebay Gas Saturation (%)	% of Time River Flow is Exceeded	Turbine Flow (cfs)	Spillway Flow (cfs)	Predicted (or expected) Spillway Gas (%)
32,400	110	20.5	32,400	0	110.0
40,000	110	15	32,400	7,600	120.5
50,000	110	10	32,400	17,600	131.9
60,000	110	6.5	32,400	27,600	137.6
70,000	110	4.2	20,000	50,000	135.9
80,000	110	3	10,000	70,000	125.9
90,000	110	1.5	0	90,000	110.0

This comparison shows the turbine upgrades can reduce the amount of time TDG exceeds 110% saturation to 17.5% of the time from its current duration of 25% of the time. The overall improvement in TDG levels for the mixed flow with upgraded turbines is estimated to be 23.8% based on the numerical difference in area under the curves shown in Figure 7. Net TDG levels during spill events are expected to be further reduced by increased dilution of the spillway flow with a larger proportion of powerhouse discharge. When spill does occur, it blends with water that passes through the turbines, which has lower gas levels. The upgraded turbines, which have more capacity, also supply more of this low gas blending water when spill is occurring, producing a further benefit.

The estimated cost of upgrading the turbines as recommended in the Upgrade Study for relicensing is approximately $15.7 million in year 2002 dollars plus engineering and financing costs, for a total investment of about $17.5 million. Current estimates are about $25 million, or as much as $29 million if fish-friendly turbine technology is applied to the new turbines.

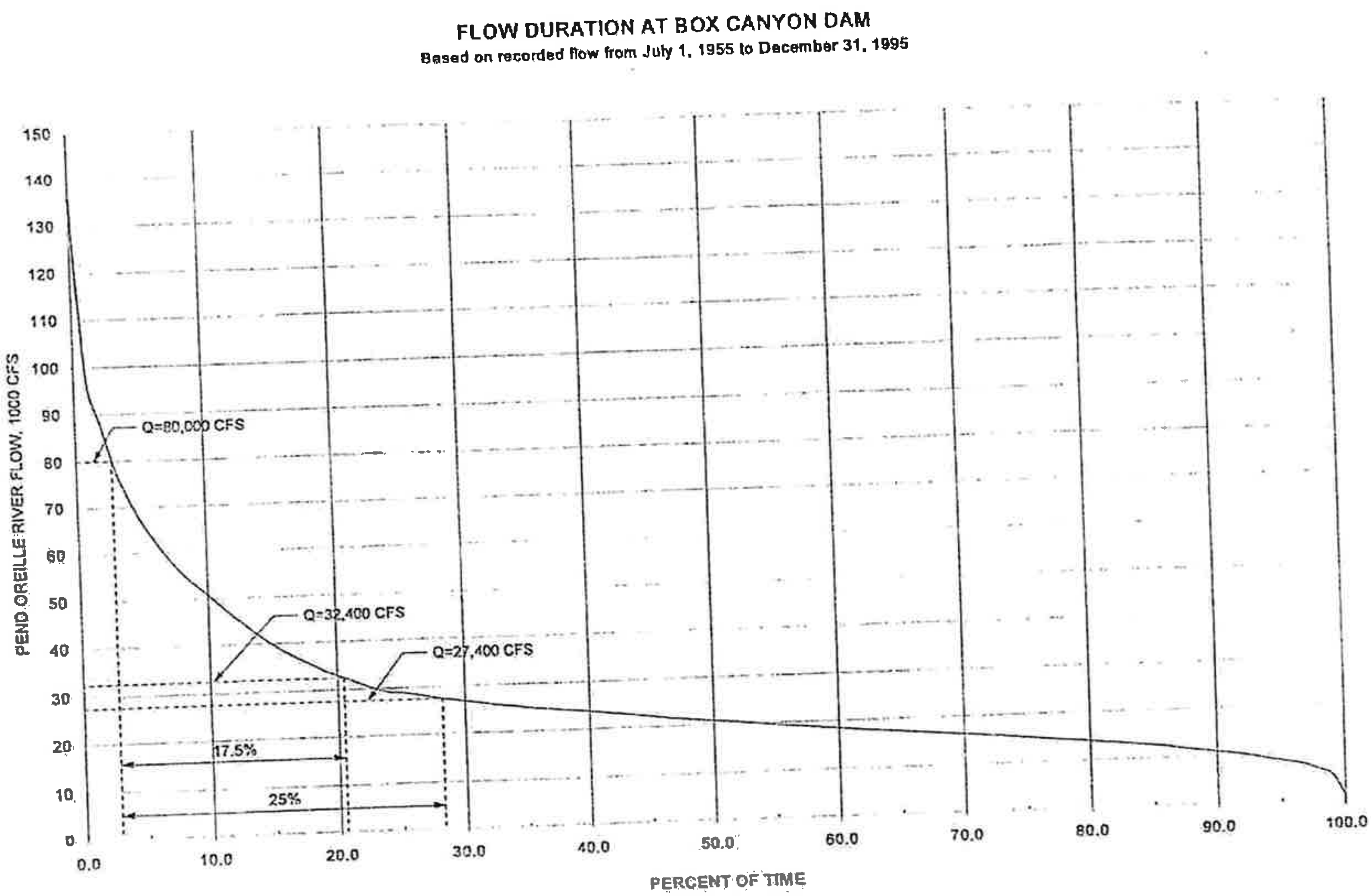

Figure 6. Flow Duration Curve Pend Oreille River at Box Canyon Dam, 7/1/55-12/31/95

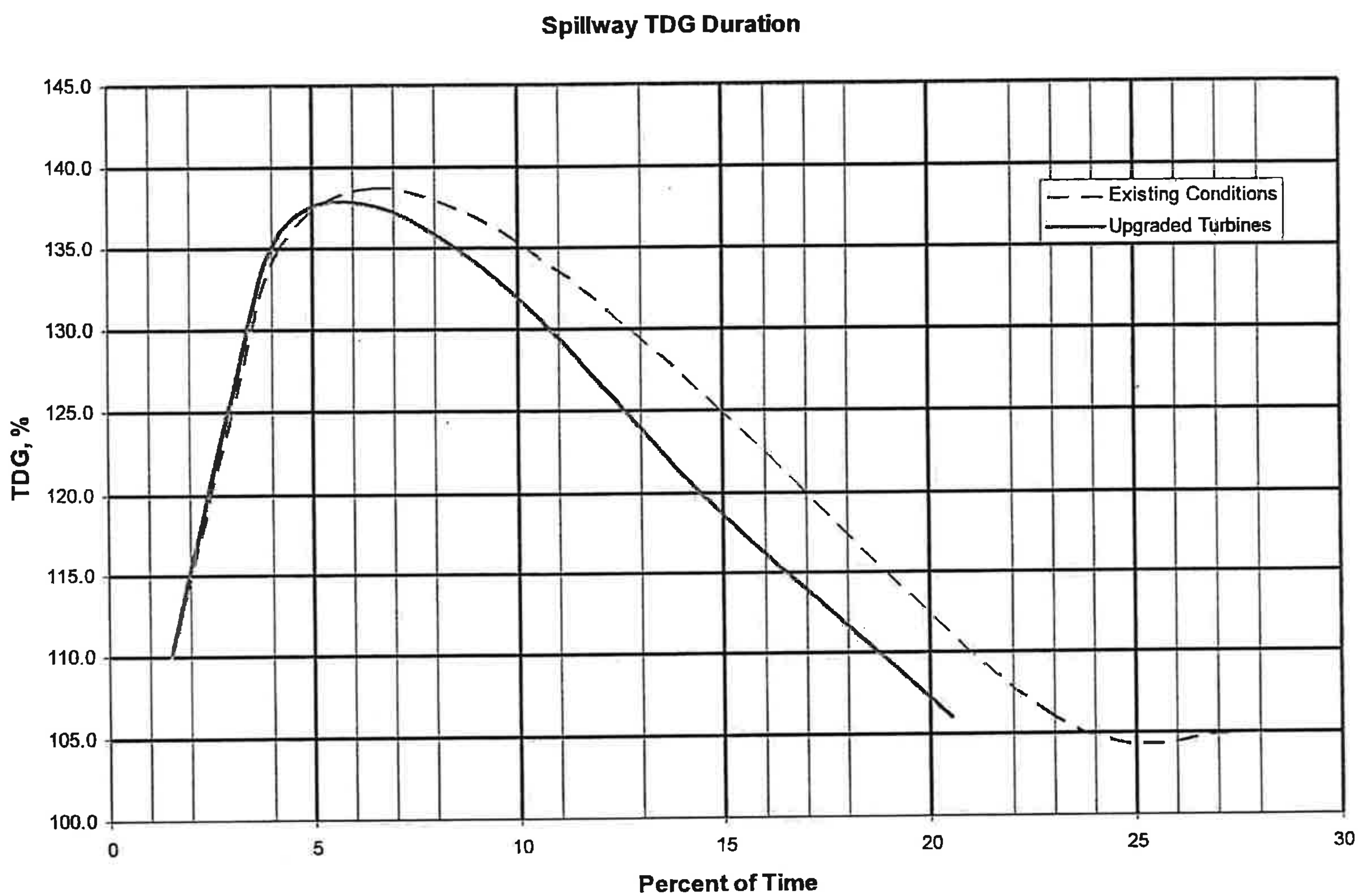

Figure 7. Spillway TDG Duration

3.2 Auxiliary Spillway Bypass

The auxiliary spillway is located in the forebay channel between the main dam-spillway and powerhouse. The structure consists of three bays, each being 14 feet wide between concrete piers, and a thick concrete base slab at El. 1967. In each bay are stoplogs. The auxiliary spillway was located in an area of low rock in order to minimize excavation of the forebay channel and assist in diversion of the river during construction of the main spillway. The auxiliary spillway was intended to augment the capacity of the main spillway during large flows but only a small quantity of water can be discharged due to the small head available through this structure at extreme high river flows. It also was intended to serve for flushing trash or floating ice from the forebay and for minor regulation of flows, but it has not been necessary to operate it in that way. In addition, the auxiliary spillway was designed to serve as an intake structure if the District should decide to install an additional generating unit in the future.

The auxiliary spillway can be redesigned and used to bypass flows around the main dam-spillway to reduce TDG levels downstream from the Project. Spill at the main spillway can be avoided until the combined capacity of the turbines and auxiliary spillway is reached. Currently, the auxiliary spillway is controlled with stoplogs. If vertical steel gates are installed, replacing the stoplogs, then they could be operated like a sluice and the water discharging beneath them would not entrain air that causes saturation levels to rise.

The water surface elevation at the auxiliary spillway is slightly less than that at the main spillway due to headlosses in the forebay channel. This elevation hovers around El. 2030 for flows up to about 50,000 cfs and then begins to drop off as river flows increase above 50,000 cfs. The tailwater at the auxiliary spillway is essentially the same as at the main spillway. The approximate tailwater elevation for 30,000 cfs is El. 1992, which is 25 feet above the auxiliary spillway sill elevation. Therefore, if gates were installed then the discharge would be submerged. This is a favorable condition for releasing flow without contributing TDG to the water.

Several factors affect the design and size of gates for the auxiliary spillway bays. The capacity of the forebay channel is limited by the amount of headloss available. Power generation is reduced by additional headloss due to "pushing" more water through the forebay channel and out through the gates. The gates must be capable of regulating flow in the same manner as the main spillway gates to avoid adverse backwater effects upstream from the Project. The height of the spillway and required capacity of the gate hoist system also affect the practical size of gates that could be installed. The height of the spillway openings is 68 feet. A 34 foot-high gate would be the tallest that could be completely opened without sticking up above the deck elevation (El. 2035.0).

The upper limit of forebay capacity is estimated to be about 70,000 cfs based on computed headloss and assuming 20,000 cfs through upgraded turbines and 50,000 cfs through the auxiliary spillway. (Note that turbine peak flow capacity falls below 32,400 cfs as the forebay level drops and the tailwater level rises.) Under this flow condition, the water surface elevation upstream of the auxiliary spillway is estimated to be El. 2023.0. At the main spillway, the water level would back up to El. 2027.6, which is right where it needs to be to prevent upstream flooding. For forebay flows slightly above 70,000 cfs, the water surface elevation at the main dam becomes too high, and would result in upstream flooding, because the available headloss in the forebay channel is too low to pass flows higher than 70,000 cfs. (Available headloss means the difference in water surface elevation that is required between the beginning of the forebay channel and the auxiliary spillway to "push" the water through the channel. Also, discharge through the gates depends on both upstream and downstream water depths. Therefore, the water surface elevation at the main dam is based on the depth of water required upstream of the gates plus headloss due to channel friction between the dam and gates. It should also be noted that the Project's annual energy production will be reduced due to the additional headloss in the forebay.)

Discharge curves for three 14-foot-wide gates were developed and are shown in Figure 8. One curve relates gate height to maximum gate discharge. The other curve relates gate height to the maximum river flow that can be passed through both the gates and upgraded turbines without spilling water at the main spillway. This river flow is assumed to also be the maximum that could be passed without entraining air and producing high TDG. For example, three 27-foot-high gates can pass a maximum of 27,600 cfs when the upgraded turbines passing 32,400 cfs. This combination could pass as much as 60,000 cfs without entraining air. A further increase in flow reduces the net head and discharge through the gate because of higher tailwater levels.

Mixing of flows from turbines, gates and spillway is assumed and weighted average gas levels were computed for various gate sizes and a range of river flows. The mixing effect on TDG levels depend on the ratio of spillway flow to combined turbine and gate flow, and the low-TDG turbine and gate flow has greater affect in diluting lower spillway flows. The weighted average TDG resulting from mixing is calculated as follows:

Mixed TDG= [(Forebay TDG * (Turbine + Gate Flow)) + (Spillway TDG * Spillway Flow)]/Total Flow

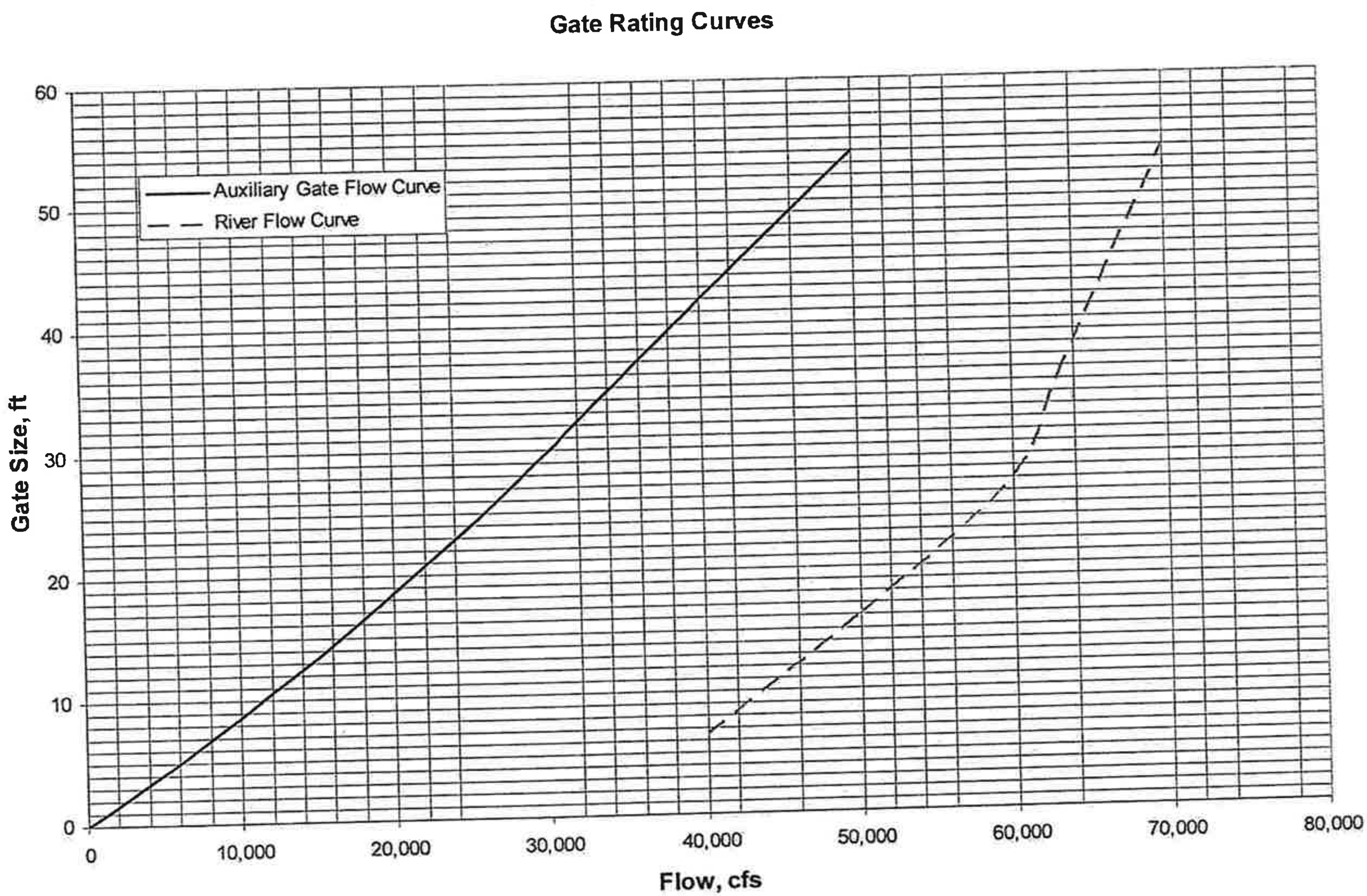

Figure 8. Gate Discharge Curves

Tables 3 - 9 summarize TDG scenarios for various river flows and gate sizes.

Table 3. TDG for 6.5 ft gates

River Flow (cfs)	Turbine Flow (cfs)	Aux Gate Flow (cfs)	Spillway Flow (cfs)	Spillway TDG %	Forebay TDG (%)	Mixed TDG (%)	Time Flow is Exceed (%)
0	0		0			105.0	100.0
5,000	5,000		0			105.0	98.5
10,000	10,000		0			105.0	93.0
20,000	20,000	0	0	0.0	105.0	105.0	53.0
30,000	30,000	0	0	0.0	106.0	106.0	23.0
40,000	32,400	7,600	0	0.0	108.0	108.0	15.0
50,000	32,400	7,250	10,350	124.3	110.0	113.0	10.0
60,000	32,400	6,600	21,000	134.4	110.0	118.5	6.5
70,000	20,000	5,650	44,350	137.8	110.0	127.6	4.2
80,000	10,000	0	70,000	125.9	110.0	123.9	3.0
90,000	0	0	90,000	110.0	110.0	110.0	1.5

Table 4. TDG for 16 ft gates

River Flow (cfs)	Turbine Flow (cfs)	Aux Gate Flow (cfs)	Spillway Flow (cfs)	Spillway TDG %	Forebay TDG (%)	Mixed TDG (%)	Time Flow is Exceed (%)
0	0		0			105.0	100.0
5,000	5,000		0			105.0	98.5
10,000	10,000		0			105.0	93.0
20,000	20,000	0	0	0.0	105.0	105.0	53.0
30,000	30,000	0	0	0.0	106.0	106.0	23.0
40,000	32,400	7,600	0	0.0	108.0	108.0	15.0
50,000	32,400	17,600	0	0.0	110.0	110.0	10.0
60,000	32,400	16,300	11,300	125.5	110.0	112.9	6.5
70,000	20,000	13,900	36,100	138.9	110.0	124.9	4.2
80,000	10,000	0	70,000	125.9	110.0	123.9	3.0
90,000	0	0	90,000	110.0	110.0	110.0	1.5

Table 5. TDG for 27 ft gates

River Flow (cfs)	Turbine Flow (cfs)	Aux Gate Flow (cfs)	Spillway Flow (cfs)	Spillway TDG %	Forebay TDG (%)	Mixed TDG (%)	Time Flow is Exceed (%)
0	0		0			105.0	100.0
5,000	5,000		0			105.0	98.5
10,000	10,000		0			105.0	93.0
20,000	20,000	0	0	0.0	105.0	105.0	53.0
30,000	30,000	0	0	0.0	106.0	106.0	23.0
40,000	32,400	7,600	0	0.0	108.0	108.0	15.0
50,000	32,400	17,600	0	0.0	110.0	110.0	10.0
60,000	32,400	27,600	0	0.0	110.0	110.0	6.5
70,000	20,000	23,500	26,500	137.2	110.0	120.3	4.2
80,000	10,000	0	70,000	125.9	110.0	123.9	3.0
90,000	0	0	90,000	110.0	110.0	110.0	1.5

Table 6. TDG for 35 ft gates

River Flow (cfs)	Turbine Flow (cfs)	Aux Gate Flow (cfs)	Spillway Flow (cfs)	Spillway TDG %	Forebay TDG (%)	Mixed TDG (%)	Time Flow is Exceed (%)
0	0		0			105.0	100.0
5,000	5,000		0			105.0	98.5
10,000	10,000		0			105.0	93.0
20,000	20,000	0	0	0.0	105.0	105.0	53.0
30,000	30,000	0	0	0.0	106.0	106.0	23.0
40,000	32,400	7,600	0	0.0	108.0	108.0	15.0
50,000	32,400	17,600	0	0.0	110.0	110.0	10.0
60,000	32,400	27,600	0	0.0	110.0	110.0	6.5
65,000	32,400	32,600	0	0.0	110.0	110.0	5.3
70,000	20,000	30,500	19,500	133.4	110.0	116.5	4.2
80,000	10,000	0	70,000	125.9	110.0	123.9	3.0
90,000	0	0	90,000	110.0	110.0	110.0	1.5

Table 7. TDG for 54 ft gates

River Flow (cfs)	Turbine Flow (cfs)	Aux Gate Flow (cfs)	Spillway Flow (cfs)	Spillway TDG %	Forebay TDG (%)	Mixed TDG (%)	Time Flow is Exceed (%)
0	0		0			105.0	100.0
5,000	5,000		0			105.0	98.5
10,000	10,000		0			105.0	93.0
20,000	20,000	0	0	0.0	105.0	105.0	53.0
30,000	30,000	0	0	0.0	106.0	106.0	23.0
40,000	32,400	7,600	0	0.0	108.0	108.0	15.0
50,000	32,400	17,600	0	0.0	110.0	110.0	10.0
60,000	32,400	27,600	0	0.0	110.0	110.0	6.5
70,000	20,000	50,000	0	0.0	110.0	110.0	4.2
80,000	10,000	0	70,000	125.9	110.0	123.9	3.0
90,000	0	0	90,000	110.0	110.0	110.0	1.5

Table 8. TDG for No Gates w/ upgraded turbines

River Flow (cfs)	Turbine Flow (cfs)	Aux Gate Flow (cfs)	Spillway Flow (cfs)	Spillway TDG %	Forebay TDG (%)	Mixed TDG (%)	Time Flow is Exceed (%)
0	0		0			105.0	100.0
5,000	5,000		0			105.0	98.5
10,000	10,000		0			105.0	93.0
20,000	20,000	0	0	0.0	105.0	105.0	53.0
30,000	30,000	0	0	0.0	106.0	106.0	23.0
32,400	32,400	0	0	0.0	106.0	106.0	20.5
40,000	32,400	0	7,600	118.5	108.0	110.0	15.0
50,000	32,400	0	17,600	131.9	110.0	117.7	10.0
60,000	32,400	0	27,600	137.6	110.0	122.7	6.5
70,000	20,000	0	50,000	135.9	110.0	128.5	4.2
80,000	10,000	0	70,000	125.9	110.0	123.9	3.0
90,000	0	0	90,000	110.0	110.0	110.0	1.5

Table 9. TDG for Existing Conditions

River Flow (cfs)	Turbine Flow (cfs)	Aux Gate Flow (cfs)	Spillway Flow (cfs)	Spillway TDG (%)	Forebay TDG (%)	Mixed TDG (%)	Time Flow is Exceed (%)
0	0		0			105.0	100.0
5,000	5,000		0			105.0	98.5
10,000	10,000		0			105.0	93.0
20,000	20,000	0	0	0.0	105.0	105.0	53.0
27,400	27,400	0	0	0.0	105.0	105.0	28.1
30,000	27,400	0	2,600	106.0	106.0	106.0	23.0
40,000	27,400	0	12,600	125.0	108.0	113.3	15.0
50,000	27,400	0	22,600	135.4	110.0	121.5	10.0
60,000	27,400	0	32,600	138.7	110.0	125.6	6.5
70,000	18,000	0	52,000	135.1	110.0	128.7	4.2
80,000	8,000	0	72,000	124.9	110.0	123.4	3.0
90,000	0	0	90,000	110.0	110.0	110.0	1.5

These scenarios were developed from the relationships between river flow and duration, upgraded turbine capacity and estimated spillway and forebay gas levels. The gate sizes shown are the height dimension for 14-foot widths, and the gate flow is total for three gates. The forebay and spillway TDG values are based on developed curves presented previously in Figure 5. The mixed TDG is the weighted average of the spillway and forebay TDG. The TDG in the discharge from the auxiliary spillway and upgraded turbines is assumed to be the same as the forebay TDG.

To graphically represent the TDG scenarios for various gate sizes, Figure 9 shows a plot of mixed TDG levels as a function of time. The curves in this figure illustrate the effect of bypassing flow around the main spillway through gates of various sizes and capacities, and upgrading the turbines. Figure 10 displays the %TDG for the mixed flow as a function of total river flow.

Table 10 summarizes anticipated TDG improvements, over existing conditions, for various gate sizes and river flows. Options to increase the capacity of the selected size of the alternate bypass gates will be evaluated during final design.

Table 10. Summary of TDG levels for alternate gate configurations

Gate Size (ft)	Max. Gate Capacity (cfs)	Turbine Flow (cfs)	Total Flow Passing With No Added Gas (cfs)	Expected Amount of Time Gas is Added (%)	Peak TDG Expected for Mixed Flow (%)	Overall TDG Reduction (%)
None	None	27,400	27,400	26.6	128.7	0
None	None	32,400	32,400	19	128.5	23.8
6.5	7,600	32,400	40,000	8.5	127.6	47
16	17,600	32,400	50,000	5.0	124.9	67
27	27,600	32,400	60,000	3.8	123.9	77.7
35	34,300	28,700	65,000	3.8	123.9	82.6
54	50,000	20,000	70,000	2.7	123.9	86.9

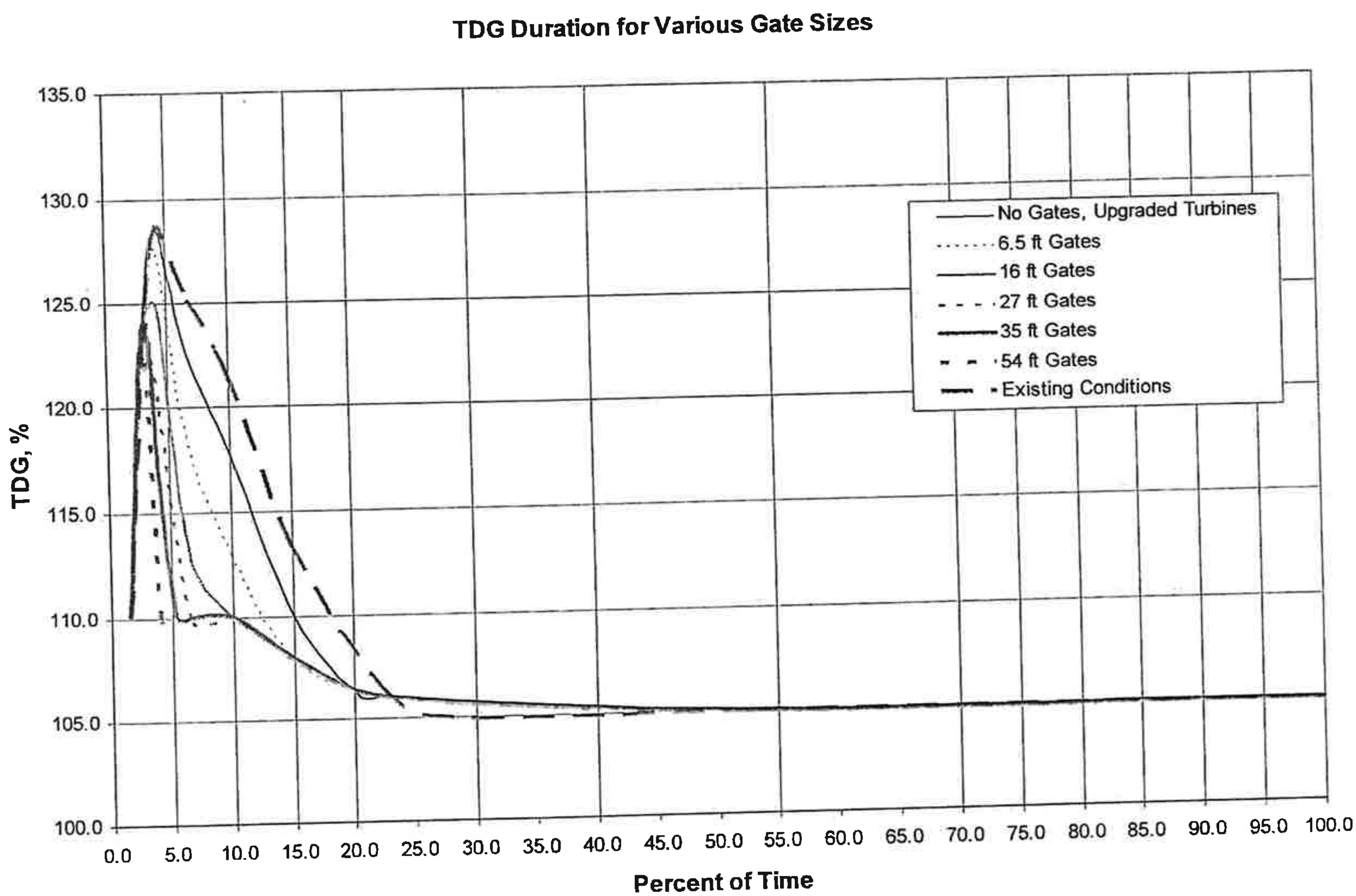

Figure 9. TDG Duration for various gate sizes

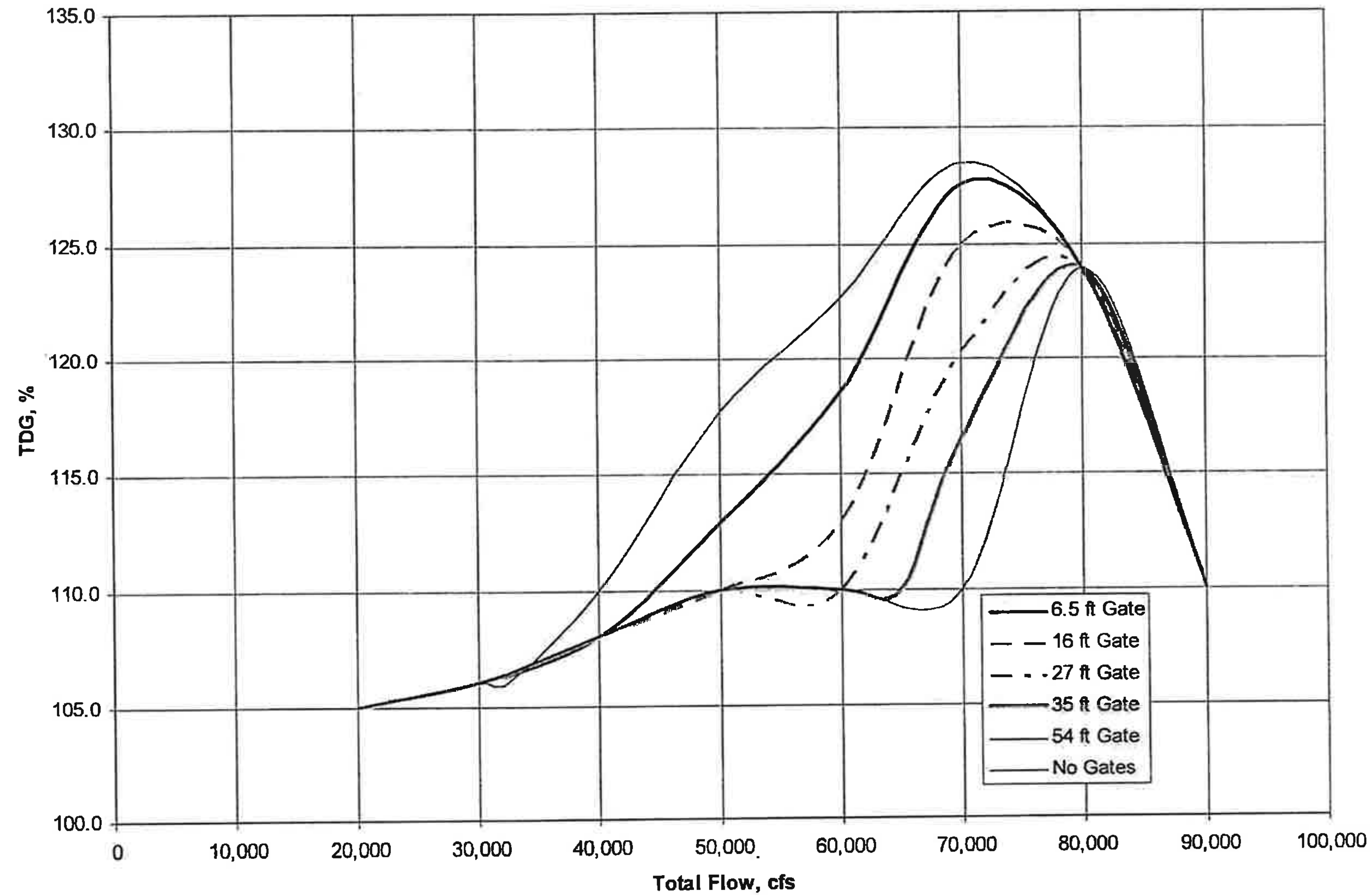

Figure 10. %TDG as a function of total river flow for various gate sizes

The expected amount of time gas is added is the percent of time from the flow duration curve between the total flow that can be passed without added gas above 110% and 80,000 cfs, beyond which the Project no longer contributes TDG to the flow. A flow of 80,000 cfs occurs or is exceeded about 3% of the time. The peak TDG expected for each size gate is based on the combined or mixed TDG resulting from mixing flow over the main spillway with the turbine and auxiliary spillway flow. It is assumed that the TDG contained in the discharge from the upgrade turbine and auxiliary spillway will mix well with the discharge over the main spillway. The overall TDG reduction, as a numerical percent, is the difference between the areas under the curves for each gate size and the curve for existing conditions shown in Figure 9. The area under the curve represents the total TDG on an annual basis.

If three 54-foot-high gates were installed, then the project would operate almost 99% of the time without contributing TDG. Overall, this option produces 83% less TDG (above 110% saturation) than the turbine upgrades alone (87% less than existing conditions) when turbine and spillway flows are mixed together. However, there are several disadvantages of the 54-foot gate size. The size is not practical for handling. At full opening, the gate would stick up 40 feet above the deck. A gantry crane having an estimated 280-ton capacity would be required for lifting a gate that size, and its operator would have to be more than 50 feet above the deck. The auxiliary spillway would need to be strengthened to handle the crane and gates. This size of gate offers little advantage over 35-foot-gates. 54-foot gates are more than 50% larger but can only pass 11% more flow (combined with the turbines), reduce TDG contribution duration by less than 2.5%, and the expected peak TDG is the same for both gate sizes.

A maximum of 65,000 cfs can be bypassed around the main spillway if three 35-foot gates are installed in the auxiliary spillway. This size of gate is reasonable from a handling and operational standpoint. Compared to 27-foot gates, 35-foot gates can handle 8.3% more total flow but are about 30% larger and reduce TDG duration by only 5% of the time. Based on this information, 27-foot gates have been selected for the analysis in this TDG Abatement Plan. A more detailed evaluation of hydraulic conditions in the forebay and at the spillway will be completed as part of the engineering design to select the final gate size. The 27-foot gate size does appear to have some advantages, in terms of TDG, over 16-foot size gate (11% less TDG duration relative to the 16-foot gages and 78% overall TDG reduction). However, 16-foot gates would cost $4-$5 million less including the difference in lost power)

The construction to install gates in the auxiliary spillway involves extending the existing main support piers, installing gate slots, a new concrete sill, and widening and strengthening the deck for the gate hoist equipment. The new gates would be constructed downstream of the existing stoplogs to avoid disrupting flow in the forebay during the work. A cellular sheetpile cofferdam in the river would be needed to allow the work area to be dewatered. The installation and removal of this type of cofferdam is significant in terms of construction work and cost. A conceptual plan and section of the work is shown in Figure 11.

Each gate will have a dedicated wire rope hoist for flow control and regulation. The wire rope hoist for operating the gates will consist of drums and a system of sheaves and blocks that are driven through an electric motor and arrangement of shafts, speed reducers, and spur or helical gears. The hoisting equipment will be located next to the gate or slot with controls located in the powerhouse control room. The required capacity of the hoists for the 27-foot gates is estimated to be 180 tons.

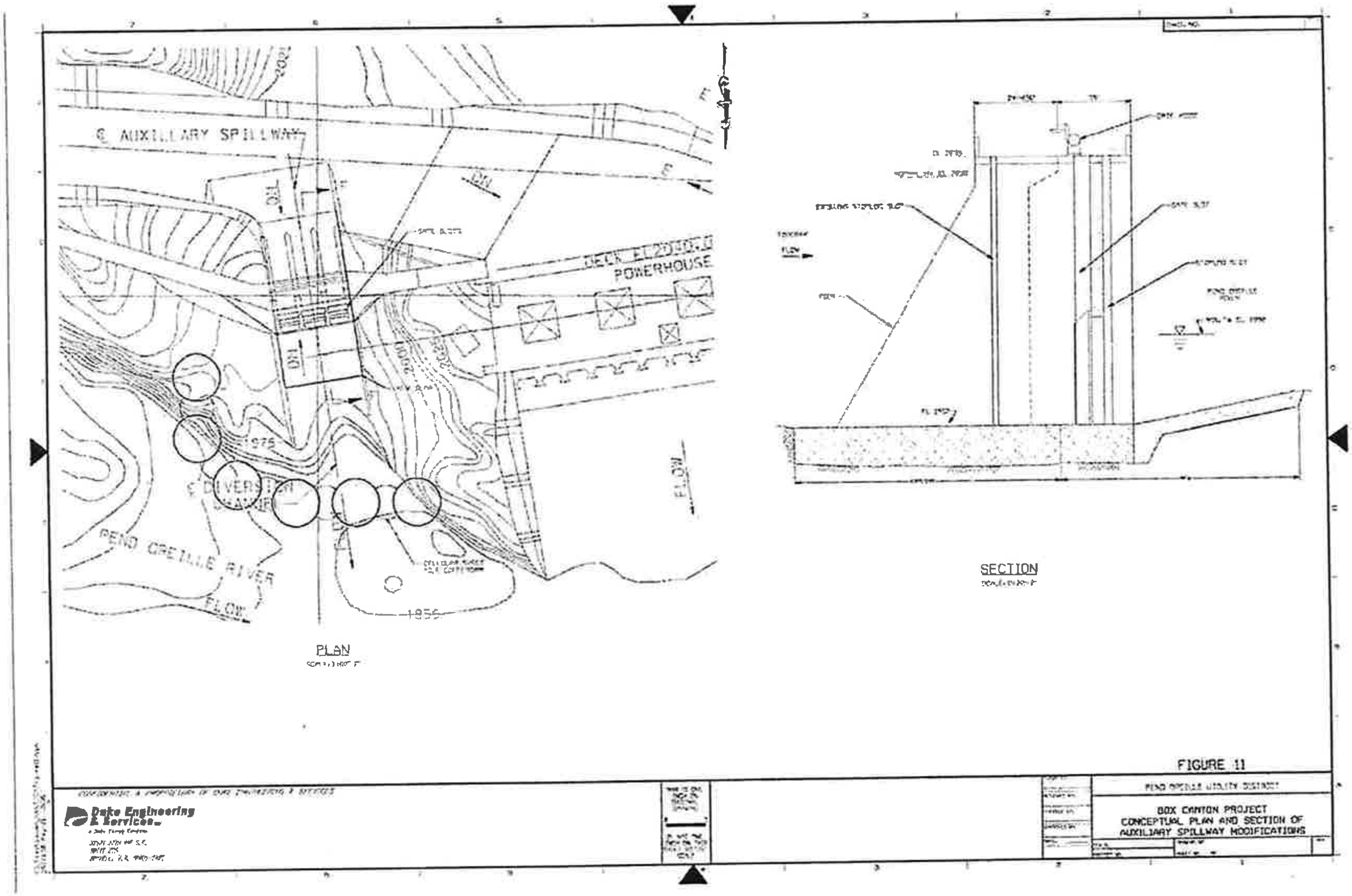

Figure 11. Auxiliary Spillway Modifications

The total estimated costs of this alternative are summarized in Table 11.

Table 11. Cost for TDG abatement measures

Auxiliary Spillway Gates				
Item	Quantity	Unit	Unit Cost, $	Total, $
Mobilization	1	LS	250,000	250,000
Cofferdam Template	1	LS	150,000	150,000
Cofferdam Sheetpiling *	34,000	SF	27	918,000
Cofferdam Fill *	10,100	CY	40	404,000
Rock Excavation	100	CY	100	10,000
Structural Concrete	1800	CY	450	810,000
3-27' H x 14' W Steel Gates	192,000	LB	5	960,000
Hoisting Equipment	3	EA	960,000	2,880,000
Electrical and Controls	1	LS	220,000	220,000
Engineering and Permitting	$6,602,000		20%	1,320,400
Contingency	$7,922,400		35%	2,772,840
Total Construction Cost				10,695,240
Lost Power Revenue (NPV)**				7,298,505
O&M (NPV)***				257,298
Annual Monitoring & Reporting (NPV) ****				514,595
Turbine Upgrades				17,500,000
Total Cost				**$36,265,638**

* Including removal
** 4364 MWH lost @ $65/MWH over 50 years at 3%
*** $10,000/yr at 3% over 50 years
**** $20,000/yr at 3% over 50 years

Note that this alternative will result on lost energy production at Box Canyon powerhouse due to increased head losses in the forebay channel. Our energy production model, CHEOPS, was used to calculate a loss in average annual energy production of 4364 MW-hr, which has a net present value of $6.6 Million, based on a 50-year project life and estimated cost of $65/MW-hr.

3.3 Spillway Gate Settings

Spill will occur when the river flow exceeds 60,000 cfs, which is the design flow capacity for the upgraded turbines and the auxiliary bypass with 27-foot-tall gates. The 2002 annual report for TDG monitoring (FADES 2002) provided an analysis that suggests spill gate configuration can be modified to reduce the contribution to downstream TDG levels. TDG is just one of many considerations when selecting a gate configuration to pass a particular flow. Dam safety, balancing flow to minimize structural vibration, and operational constraints must also be considered. The following analysis of TDG production relative to gate configuration is preliminary. Further testing is necessary during future spills to confirm these trends; the analysis of gate settings and TDG should be treated as the basis for a working hypothesis at this time. The District will pursue further evaluation of gate configurations to reduce generation of dissolved gas at Box Canyon Dam. If preferred gate settings are identified that also are consistent with other operational constraints, the District will immediately implement use of these gate settings to reduce gas generation in the near term (prior to completion of turbine upgrades). The effectiveness of gate configurations may differ once turbine upgrades and the auxiliary bypass are completed since the downstream flow mixing patterns will likely be altered.

Box Canyon spillway consists of four bays. Segmented gates control the amount of spill within each bay; each gate has three segments (leaves), which can be sequentially removed to reduce forebay head elevation. Table 12 provides a description of commonly used spill gate configurations. Each gate setting has an alphabetical code that identifies the configuration of the gate leaves within that bay, crest elevation of the uppermost leaf, and gate rating curve. Bay 1 differs from the other three bays, as it has a split-leaf top segment. Due to the difficulty in adjusting the split-leaf top segment, Bay 1 is generally left in the F position.

Table 12. Description of Gate Settings by Bay at Box Canyon Dam.

Gate Setting	Bay	Gate Crest Elevation[1]	Vertical Opening Distance Between Top Two Leaves[2]	Description
A,B,C,D,E,F	1	A-C: 2021.67 D-F: 2011.33	A-C: 0'6"-6'5" D-F: 10'10"-16'9"	Split top leaf, Bay 1 only. When in position A-C, spill is limited to the upper ¼ of spillway while in D-F, spill is limited to the upper third of spillway
G,H,I,J,K,L	2,3,4	2011.33	0'6"-16'9"	Top leaf of gate is raised, spill is limited to the upper third of spillway
M,N,P,Q,R,S	1,2,3,4	1990.67	3' 4.5"-29'2"	Middle Leaf in Bay is raised with spill from the middle third of spillway
T,U,V	1,2,3,4	1970	10'0"-30'0"	Bottom Leaf in Bay is raised with spill from the lower third of spillway. *Gate settings not used in 2002.*
W	1,2,3,4	1970		Gate raised out of flow. When all four gates are at the W setting, project is at free-flow conditions.
Z	1,2,3,4	2032.00		Closed, no spill

[1] Crest elevation (ft AMSL) is defined as the uppermost elevation of the fully closed gate leaves; i.e., not inclusive of top leaf when uppermost leaf is partially or completely above the forebay water surface elevation.
[2] Spill may pass both through the opening and over the leaf above the opening when the opening is small and the uppermost leaf is not completely above the forebay water surface elevation.

The various gate settings reported by individual bay during the May-July 2002 spilling events are summarized in Table 13. In all, 83 different gate configurations were used during the 2002 TDG monitoring period.

Table 13. Gate settings and percent occurrence by bay at Box Canyon Dam for May through July 2002 Spill Season.

Bay 1		Bay 2		Bay 3		Bay 4	
Gate Setting	**%**	**Gate Setting**	**%**	**Gate Setting**	**%**	**Gate Setting**	**%**
Z	47.8	L	21.6	Z	32.2	Z	31.9
F	32.3	W	16.1	L	19.7	L	28.2
W	16.1	Z	15.1	W	16.1	W	16.6
N	1.6	H	12.5	S	9.1	J	7.4
S	1.8	I	12.4	J	6.4	H	3.9
C	0.008	S	9.0	H	3.6	S	3.3
D	0.004	J	5.8	I	3.6	N	2.8
		K	1.9	K	2.94	K	2.2
		N	1.4	R	1.34	I	1.4
		P	1.1	N	1.3	P	1.1
		Q	1.0	P	1.3	M	0.7
		M	0.8	M	0.9	Q	0.1
		R	0.6	Q	0.9	R	0.1
		G	0.2	G	0.17		

A multiple regression model approach was used to identify gate configurations and/or individual gate settings that may influence downstream total dissolved gas. The multiple regression model is defined below:

$$\Delta \text{TDGP} = (\Delta\text{Elevation} * 3.846) + (-0.007 * \text{Spill}) + (918.9 * \text{Spill Ratio})$$
$$R^2=0.84$$

where:

Δ TDGP = change in TDGP (mmHg) from Forebay to Tailrace
ΔElevation = Difference in head elevation (ft) from Forebay to Tailrace
Spill Ratio = Ratio of spill to total discharge

Due to the lack of independence among the variables, this model is not intended to be used for significance testing. Rather, the model served as a mathematical tool to identify patterns among those gate configurations that could influence total dissolved gas relative to other gate configurations regardless of flow, spill, and water surface elevation in the forebay and tailrace.

Both the gate settings (the individual gate designation within the four bays) and the gate configurations (gate settings in all four bays) were evaluated. The TDGP values obtained from the regression model (i.e. predicted value) were compared to the observed values. The difference between the observed and predicted values was evaluated at two levels. In the first level, the percent of observations, by gate setting and configuration, were calculated for the observed values that differed by >50 mm Hg than the predicted values. For the second evaluation level, the percent of observations, by gate setting and configuration, were calculated for the observed values that differed by >75 mm Hg than the predicted values. The two levels were chosen as they represent a considerable change in TDGP- approximately a 7% and 10% change in total dissolved gas saturation, respectively.

The multiple regression model identified 11 gate configurations that exhibited actual values that were higher than the predicted values by 50 mm Hg for all observations (Table 14). The gate configurations then were plotted on a graph of spill versus TDG to identify the spill conditions in which the specific gate configurations were used (Figure 12).

Using the multiple regression model, four gate configurations were identified, FLIH, FLIJ, FLII, FLIZ that produced more downstream total dissolved gas over similar spill ranges and net head than the gate settings FZJL, FZKL, and FZLL. Gate configurations such as FKIZ, FKLZ, and FJLZ exhibited higher TDG saturations, however, these gate configurations were very uncommon during the 2002 spilling events (Figure 12).

Table 14. Gate configurations most likely to influence downstream total dissolved gas by 50 to 75 mm Hg.

Gate Configuration	% Occurrence; Actual greater than Predicted		% Occurrence; Actual less than Predicted		Comment
	50 mm Hg	75 mm Hg	50 mm Hg	75 mm Hg	
FLIZ	100	0.0	0	0	Exhibit higher TDG during same net head and spill as FZJL, FZKL, FZLL
FLIK	100	100	0	0	
FLIJ*	100	100	0	0	
FLIH	100	12.5	0	0	
FLII	100	71.9	0	0	
FKIZ	100	25	0	0	Uncommon gate configurations, each configuration used less than 2 hours.
FKLZ	100	0	0	0	
FJLZ	100	0	0	0	
FLLK	100	0.0	0	0.	Gate configurations and TDG variable depending upon spill level
FLLJ	100	0.0	0	0	
FLLH	100	0.0	0	0	
FLKL	86	11.1	0	0	Gate configurations and TDG variable depending upon spill level
FLLL	58	33.5	0	0	

Table 14. Gate configurations most likely to influence downstream total dissolved gas by 50 to 75 mm Hg.

Gate Configuration	% Occurrence; Actual greater than Predicted		% Occurrence; Actual less than Predicted		Comment
	50 mm Hg	75 mm Hg	50 mm Hg	75 mm Hg	
FLNL	36	22.6	0	0	Gate configurations and TDG variable depending upon spill level
FLML	28	14.1	0	0	
FLIL	17	12.5	0	0	
FLPL	16	4.0	0	0	Gate configurations and TDG variable depending upon spill level.
FLQL	15	4.5	0	0	
ZGZZ	13	0	0	0	No pattern observed among gate configurations
FLLZ	13	0	0	0	
FJIZ	10	0	0	0	
FQLL	7	0	0	0	
SSSW	0	0	100	75	Used during high spill, low net head.
SSSS	0	0	100	100	
FMSL	0	0	88.9	69.4	Used at spill levels of 18,000-20000 cfs and 51,000-61,000 cfs.
FLSL	0	0	12	12	
ZZLL	0	0	8.0	1.1	No pattern observed.

*Uncommon gate configuration

Gate settings FLPL and FLQL indicate reduced gas saturation relative to other gate settings when spill ranged from 10,000-30,000 cfs. These same gate settings; however, resulted in relatively higher gas saturation at higher spills (48,000 cfs - 58,000 cfs). Similarly, FLIL, FLML, and FLNL tend to have lower total dissolved gas saturation than the partially closed gate configurations (ZZZ_ or ZZ_ _) at spills ranging from 8,500 cfs - 22,000 cfs. Nevertheless, at spills ranging from 35,000 cfs - 53,000 cfs, total dissolved gas for these gate configurations are associated with an increase of 200-250 mm Hg total dissolved gas in the tailrace.

FSLH and FSLP are gate configurations that are used during periods of low net head, and therefore most likely produce less gas due to the reduced difference in water surface elevation from the forebay to the tailrace rather than influenced by the gate configuration.

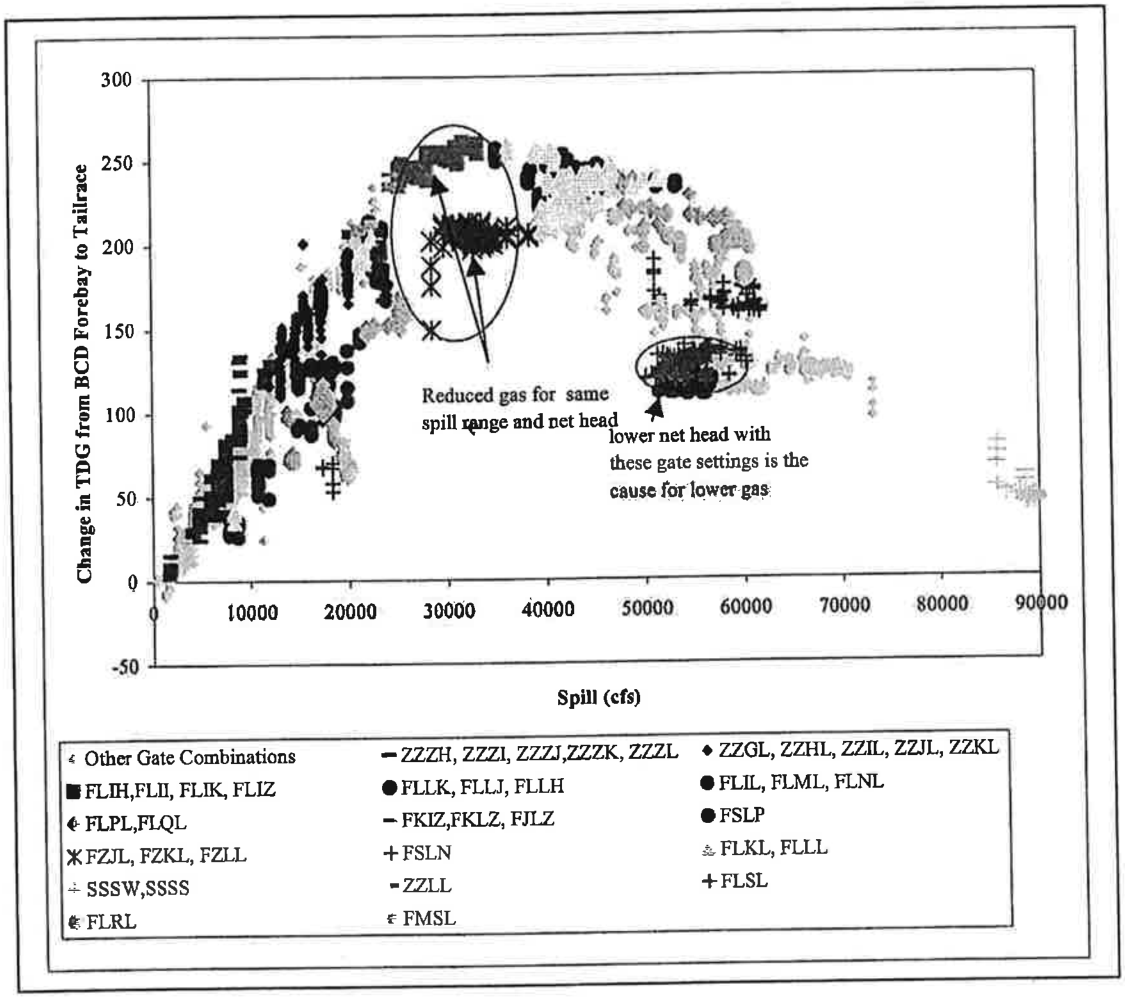

Figure 12. Spill Versus Change In Total Dissolved Gas From Box Canyon Forebay To Tailrace, April-July 2002.

Similar results were observed during the analysis of the gate settings. The data suggest that increased total dissolved gas pressure tends to occur when the water is released over the top leaf of the gate in Bays 2, 3, and 4, in particular, when Bays 2, 3, and 4 are in the L position (Table 15). The I position tended to produce more gas than predicted for Bays 3 and 4. Other positions include K, N, and P for Bay 3, and H and K for Bay 4. Data is inconclusive for Bay 1, as it remained in either the F position, entirely open (W) or closed (Z) for 95% of the spill events. Further testing is necessary during future spills to confirm these trends; the analysis of gate settings and TDG should be treated as the basis for a working hypothesis at this time.

Gate settings that tend to result in reduced gas pressure relative to predicted gas pressure are those settings in which the water was spilled in the lower portion of the spillway, such as in gate setting S for all bays, and gate setting N and W for Bay 4. The District currently operates the spill gate configuration to comply with backwater rule curves affecting maximum water elevation at Cusick (2041.0 ft) and no more than 2.0 ft of backwater at Albeni Falls. Gate opening configurations employed at Box Canyon Dam attempt to balance the spill horizontally across the spillway to the extent practicable. None of the middle gate leaves are removed until the top leaves from all four spill bays are removed. No bottom leaves are removed until all of the middle leaves are out of the water. The top split leaf in Bay 1 is not used to regulate spill but rather allows fine tuning the total spill. Gate adjustments are currently made to minimize moving of the crane and the crane is usually set in place at the end of the day work shift so that night operators can make adjustments without moving the crane. While it is important for structural stability reasons to balance spill across the bays, future modifications of gate configuration selection protocol are feasible using the existing equipment provided that rule curves are met. Some additional staffing time may be necessary when certain gate/spill configurations are selected.

Table 15. Gate settings most likely to influence downstream total dissolved gas by 50 and 75 mm Hg.

Bay	Gate Setting	Gate Position for Spill	% Occurrence; Actual greater than Predicted		% of Observations; Actual less than Predicted	
			>50 mm Hg	>75 mm Hg	>50 mm Hg	>75 mm Hg
	Z	Closed	0	0	1	0
	F	Top	19	7	2	1
	N	Middle	0	0	0	0
	S	Middle	0	0	100	77
1	W*	Open				
	Z	Closed	0	0	1	0
	L	Top	30	12	1	1
	H	Top	0	0	0	0
	I	Top	0	0	1	0
	J	Top	1	0	0	0
	K	Top	5	1	3	0
	S	Middle	0	0	7	5
	N	Middle	2	0	0	0
	P	Middle	0	0	0	0
	Q	Middle	3	0	0	0
2	W*	Open				
	Z	Closed	0	0	0	0
	L	Top	11	5	1	0
	J	Top	0	0	0	0
	H	Top	0	0	0	0
	I	Top	30	14	0	0
	K	Top	39	5	0	0
	S	Middle	1	0	18	14
	R	Middle	3	0	0	0
	N	Middle	36	23	0	0
	P	Middle	16	4	0	0
3	W*	Open				
4	Z	Closed	2	0	1	0

Table 15. Gate settings most likely to influence downstream total dissolved gas by 50 and 75 mm Hg.

Bay	Gate Setting	Gate Position for Spill	% Occurrence; Actual greater than Predicted		% of Observations; Actual less than Predicted	
			>50 mm Hg	>75 mm Hg	>50 mm Hg	>75 mm Hg
	L	Top	15	6	2	2
	J	Top	3	1	0	0
	H	Top	7	1	0	0
	K	Top	9	6	1	0
	I	Top	29	21	0	0
	S	Middle	0	0	2	2
	N	Middle	0	0	2	0
	P	Middle	0	0	0	0
	W	Open	0	0	100	75

*Occurred only when *all* gates were set at W. WWWW was not included in the analysis.

The analysis of the gate configurations and gate settings provides a framework for future investigations to identify those gate configurations that would produce the least amount of a dissolved gas at specific project water elevation, spill, and discharge levels. Therefore, several recommendations have been developed to assist in achieving the goal of reduced total dissolved gas levels in the Box Canyon Tailrace. The District's fixed station TDG monitoring stations in the forebay and tailrace provide data sufficient to complete the recommended testing of gate configurations. See the Water Quality Monitoring Plan for details on the District's TDG monitoring protocols. As spill occurs, the opportunity to further test and analyze gate settings will be pursued to refine the understanding of the effectiveness of managing gate configurations to reduce gas generation while also managing gates for all other operational constraints. Testing will specifically include:

- Monitor total dissolved gas in the tailrace and forebay of Box Canyon Dam during a one-day period when the total river flow and spill are maintained relatively constant while various gate changes are evaluated for gas production. The targeted spill range is 27,000 cfs to 38,000 cfs for testing gate settings FZJL, FZKL, FZLL (reduced gas production) and settings FLIH, FLIJ, FLII, FLIZ (relatively higher gas production for same spill volume and head).

- Monitor downstream total dissolved gas at specific gate settings at various discharge and spill levels to confirm the hypothesis that gate settings such as I for Bays 3 and 4; gate settings K, N, P for Bay 3; and gate settings H and K for Bay 4 tend to produce higher total dissolved gas levels downstream.

3.4 Monitoring

The combination of turbine upgrades and the 27-foot auxillary bypass gates will result in the Project not contributing to elevated TDG saturation 95% of the time. Prior to completion of the turbine upgrades and auxiliary bypass, it is impossible to accurately predict the downstream mixing pattern and the effect of mixing on downstream TDG gradients. The implementation schedule has been designed to include opportunity to evaluate TDG levels downstream of Box Canyon Dam with the abatement measures in place, while still providing time to implement additional measures, if needed, to achieve full compliance within the 10-year time frame specified in the 401 certification. Monitoring will be implemented according to the Water Quality Monitoring Plan for Box Canyon Hydroelectric Project.

4.0 SCHEDULE

The schedule for this abatement plan is designed to achieve compliance with the TDG standard within 10 years of the date FERC issued a new licence for the Project. The schedule for implementation of the TDG Abatement Plan has three phases. Note that the phases overlap in time.

4.1 Phase 1: Years 1-7

Phase 1 is primarily the installation of new turbines to increase flow through the plant and, thus, reduce the time spill occurs. At least 2 of these turbines also have to incorporate "fish-friendly" design features according to Article 405 of the new License for Box Canyon. Turbine upgrades at the Box Canyon Project are anticipated to be accomplished within the first seven years of the new license term. The schedule for completing the upgrades is consistent with the requirements of the Washington Department of Ecology 401 certification and the FERC license.

The turbines are planned to be upgraded one after the other at a pace of one turbine per year. However, the initiation of this sequence will take from 18 months to 3 years after the new license is issued. The installation work is planned to be done during the lowest flow time of the year, which is July through September. Because the time necessary for pre-design studies, fishery studies related to the "fish-friendly" design and design completion is approximately 24 months and parts delivery requires approximately 16 months, the shortest time possible before field installation of the first turbine begins would be about three and one-half years after license issuance. The first upgrade is not likely to be completed until the fall of 2009, with the other turbines being completed one in each succeeding year. All four should be complete by late summer of 2012, or seven years from License issuance.

Activities in Phase 1 include:

- Final design of turbine upgrades.
- Upgrade 4 turbines (1 turbine per year for four consecutive years). This will take from 5 to 7 years as discussed above.

- Continue monitoring TDG and other relevant water quality parameters at the forebay and tailrace fixed station monitor points.
- Monitoring will include further investigation of best configurations for existing spill gates to reduce tailrace TDG levels prior to completion of upgrades.
- Short duration TDG monitoring within turbine tailwater subsequent to completion of upgrades for all four turbines.
- Prepare and submit annual reports describing activities, progress, problems and recommended modifications for implementation of the Abatement Plan.

4.2 Phase 2 Years 6-10

Phase 2 will be the design and installation of the auxiliary bypass system adjacent to the powerhouse using the existing fifth unit bay. Construction of the bypass would start after the turbine upgrades were all complete, and when TDG testing of the effectiveness of the new turbines in lowering TDG is also completed. Construction of the bypass will require that a cofferdam be built at the upstream end of the powerhouse out into the river to isolate the now empty fifth-unit-bay next to the powerhouse and the project will be partially dewatered for approximately 18 months. It is anticipated for this work to occur in years 8 and 9 after obtaining the new license. Year 10 may be necessary to complete construction dependent upon work progress and runoff patterns that affect work scheduling. This system will be designed with three 27-foot-high roller gates that will allow discharge of water without spill over the dam, in excess of turbine capacity.

Activities in Phase 2 include:

- Final design of the auxiliary bypass.
- Preparation and submittal of JARPA
- Construction of auxiliary bypass.
- Once auxiliary bypass is complete, add additional fixed TDG monitoring stations within turbine tailwater and auxiliary bypass tailwater.
- Prepare and submit annual reports describing activities, progress, problems and recommended modifications for implementation of the TDG Abatement Plan.

4.3 Phase 3 Years 10 – 30

Phase 3 is monitoring the effectiveness of abatement measures implemented in Phases 1 and 2. The combined flow capacity of the upgrade turbines and auxiliary bypass will result in a project with gas-free impacts for flows up to 60,000 cfs. Spill at the dam would only occur at total river flows of between 60,000 and 90,000 cfs (which can occur about 6.5% of the time, on average years). This spill flow will be diluted by the 60,000 cfs of unaffected TDG discharge waters. At flows above 80,000 cfs, only the bottom leaves of the gates are in place and are fully submerged so the spill has no plunging character that contributes to gas supersaturation. Full compliance with State TDG standards could be possible, although monitoring is necessary to confirm compliance. Forebay and tailrace fixed station TDG monitoring points will be operated during the spill season; TDG monitoring methods and schedule are described in the Box Canyon Water Quality Monitoring Plan. If the monitoring data from these fixed stations indicate that compliance has not been achieved with the turbine upgrade and auxiliary bypass, then detailed TDG monitoring during the next spring spill season on a grid system will be conducted as described in the Water Quality Monitoring Plan.

Additional measures will be evaluated if monitoring determines that additional measures are necessary to achieve compliance with the water quality standard for TDG. It is impossible to describe additional measures, if any, until the turbine upgrades and construction of the auxiliary bypass are complete. Downstream mixing patterns cannot be adequately modeled to determine the TDG gradients that will occur over a range of operational flows. Phase 3 monitoring data will be used to demonstrate compliance or assist in the definition and design of additional measures necessary to achieve compliance.

If monitoring results document that compliance has not been achieved at the end of Phase 2 and Phase 3 assessments completed in consultation with the WDOE conclude that there are no reasonable additional measures to achieve compliance, then the District will initiate the preparation of a Use Attainability Analysis or provide scientific justification for a site-specific TDG criterion. A new FERC license for the Box Canyon Project was issued on July 11, 2005, and implementation of the TDG abatement plan is being initiated pursuant to the schedule indicated in WDOE 401 certification, beginning with submission of this plan for review not later than August 11, 2005. Table 16 summarizes milestones and the schedule for implementing the TDG abatement plan.

Table 16. Schedule for TDG Abatement

	Start Date	Completion Date	Activity
Phase 1	Year 1	Year 7	
	Year 1	Year 3	Testing of alternate gate settings for existing gates ; testing schedule is dependent upon river flow
	Year 1	Year 1	Final design turbine upgrades
	Year 2	Year 7	Install turbine upgrades
	Year 3	Year 7	Final design for auxiliary bypass
		Annually 4/1 – 10/31	TDG Monitoring in Box Canyon forebay
		Annually 4/1 – 7/15	TDG monitoring 1 mile downstream of spillway
	May Year 7	June year 7	Short duration TDG monitoring in turbine tailrace
	December Year 1	December year 7	Annual progress and monitoring report
Phase 2	Year 6	Year 9	Schedule will be accelerated if phase 1 requires less than 7 years
	Year 6	Year 7	Final design auxiliary bypass Prepare and submit JARPA
	Year 8	Year 10	Auxiliary bypass construction
		Annually 4/1 – 10/31	TDG Monitoring in Box Canyon forebay
		Annually 4/1 – 7/15	TDG monitoring in tailrace
	December Year 8	December year 9	Annual progress and monitoring report
Phase 3	Year 10	Life of License	

	Year 10	Annually 4/1 – 10/31	TDG Monitoring in Box Canyon forebay during spill season until WDOE determines monitoring is no longer needed
	Year 10	Annually 4/1 – 7/15	TDG monitoring within auxiliary spillway tailwater. turbine tailwater, and 1 mile downstream of spillway
	Year 13	Life of license	TDG monitoring at only one downstream location; subject to WDOE confirmation of abatement measures achieving compliance
	Year 11	Year 15	Evaluate the need and options for other reasonable TDG abatement measures
	Year 12	Year 15	Design and implement any necessary additional TDG abatement measures
	December Year 10	Life of License	Annual progress and monitoring reports until WDOE notifies District that TDG monitoring is no longer necessary
	Year 13	Year 13	TDG monitoring on downstream spatial grid if compliance is not met
	Year 15		Prepare Use Attainability Analysis (UAA) if compliance not met

5.0 CITATIONS

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