#677

SEP 15 1982

ACRES

OFFICE MEMORANDUM

TO:	J.W. Hayden	Date:	September 13, 1982
FROM:	G. Krishnan	File:	P5700.14.53
SUBJECT:	Susitna Hydroelectric Project Nitrogen Supersaturation Studies		

Enclosed is a copy of the final draft of the report on Gas Concentration and Temperature of Spill Discharges Below Watana and Devil Canyon Dams.

Please note that no graphics efforts have been spent on getting the figures in the Acres standard format. This has been postponed until after your review of the material and advice on the inclusion of any field measurements of natural supersaturation in the river. Messers M. Bell and J. Douma had expressed an interest to receive copies of this report. Please advise if this can be done at this time.

G. Krishnan

GK:ccv
Enclosure

cc: J.D. Lawrence
A.F. Coniglio
K.R. Young
W. Dyok/D. Crawford

GAS CONCENTRATION AND TEMPERATURE OF SPILL DISCHARGES BELOW WATANA AND DEVIL CANYON DAMS

1 - INTRODUCTION

Supersaturation of atmospheric gases (especially nitrogen) in hatchery and aquarium facilities was first noted in the 1900's (1) and was ascribed as causing the condition in fish known as gas bubble disease. Supersaturation caused by entrainment of air in waters spilled over dams on the Columbia River was recognized as a problem for anadromous fisheries in the river in 1965. A comprehensive study (2) of dissolved gas levels in the Columbia River showed that waters plunging below spillways was the main cause of supersaturation in the river waters. Several later studies have confirmed the harmful effects of nitrogen supersaturation to fisheries. The tolerence of fish to levels of nitrogen supersaturation depends on the time of exposure, age, and species of the fish; dissolved nitrogen levels referenced to surface pressure above 110 percent are generally considered harmful (3). The state of Alaska water quality criterion is set of 110% for total gas saturation in its waters.

With this background, the potential problem of supersaturation of spill waters from the proposed Watana and Devil Canyon developments on the Susitna River was recognized early during the feasibility studies. Alternative spillway facilities were studied to minimize such a potential problem, and a scheme comprising fixed cone valves and overflow spillway was selected for each development based on detailed discussions with environmental study groups.

This report describes the selected spillway schemes briefly and presents the analyses and field investigations carried out to assess the performance of the proposed schemes with respect to gas supersaturation in spill waters. A related concern on temperature of spill waters is also discussed.

A summary of the studies undertaken and the important conclusions are presented in Section 2. A short description of the proposed schemes is given in Section 3. Section 4 details the engineering analyses carried out. Results of these analyses, field investigations, and their interpretation are presented in Section 5. The next section presents the major conclusions drawn from these studies. Appendix A comprises the field study report and Appendix B deals with the temperature of spill waters, its impacts downstream, and possible reservoir operation scenarios to minimize such impacts.

2 SUMMARY

Relatively little information is available in the literature on the performance of fixed-cone valves to reduce gas supersaturation in their discharges. Published studies (4) on the aeration efficiency of Howell Bunger valves (the more commonly known type of fixed-cone valves) were reviewed, and a theoretical assessment of the performance of the proposed valve layouts was made based on the physical and geometric characteristics of diffused jets discharging freely into the atmosphere. Results of a companion study on assessment of scour hole development below high-head spillways (5) were used to estimate the potential plunging of the valve discharges into tailwater pools at the proposed developments, and the resulting supersaturation in the releases was calculated. Specific field tests were conducted at the Lake Comanche Dam on the Mokelumne River in California (6) to study jet characteristics and the efficiency of the existing Howell Bunger valves in reducing supersaturation level in the reservoir releases.

The analyses indicate that no serious supersaturation of nitrogen is likely to occur in the releases from the proposed Watana and Devil Canyon developments for spills up to 1:50 year recurrence interval. Field test results tend to confirm some of the assumptions made in the theoretical analysis with respect to jet shape, diffusion, and gas concentration in the valve discharges. Several assumptions and approximations, albeit conservative, have been made in the analyses which should be confirmed in later study phases, perhaps in a physical model. For the purpose of feasibility studies, however, it is felt that the analyses adequately support the proposed schemes for their intended purpose.

A related question of the temperature of spill waters and its effects on the downstream water temperature has been analyzed and detailed in Appendix B. Simulation studies of the two-reservoir operations indicate that continuous (24 hour) spills would occur in the month of August in 30 out of 32 years of simulation and in 18 out of 32 years in September for the Case "C" operation which maintains a minimum instantaneous flow of 12,000 cfs in August at Gold Creek. This spill frequency is simulated for a system energy demand in the year 2010 (Bettelle forecast) and assumes that the entire demand is met by

Watana and Devil Canyon developments where possible. The spills will be greater and more frequent in the years between 2002 (Devil Canyon commissioning) and 2010. When Watana alone is operational (between 1993 and 2002), less frequent spills are simulated to occur. Reservoir operation studies are currently being refined to finalize acceptable downstream flows.

Temperature of spill waters at Watana is expected to be close to that of power flow, and hence, it is not expected to create temperature problems downstream when Watana is operating alone (1993-2002) or when it spills into Devil Canyon. At Devil Canyon, however, spill temperature is expected to be close to 39°F compared to a power flow temperature of 48-49°F in August and 45°F in September. This is based on the conservative assumption that the temperature of spill water does not increase significantly while in contact with the atmosphere despite the highly diffused valve discharge. It is, therefore, considered necessary to keep the spill from Devil Canyon to a minimum to avoid unacceptably low downstream temperatures. The analyses indicate that by operating Devil Canyon to meet most or all of the base load demand and with Watana generating essentially to meet peak demands and spilling continuously when necessary, it would be possible to maintain downstream flow temperatures below Devil Canyon close to that of power flow while reducing spill frequency considerably.

During major floods (1:10 year or rarer), there will be significant spills from Devil Canyon in addition to the power flow resulting in cold slugs of water downstream for a few days. It will be necessary to establish criteria for acceptability of lower temperatures for short durations in August and September in consultation with fisheries study groups and concerned agencies. Currently, downstream water temperature analyses are being refined, and when the results are available, the above spill temperatures and duration should be reviewed to confirm downstream temperatures during normal power operation as well as flood events. If the projected temperature regime downstream is unacceptable, alternative means to remedy the situation should be considered. These may include provision of higher level intakes to several or all fixed-cone valve discharges at Devil Canyon, multilevel power intake at Devil Canyon, limited operation of main overflow spillway (for floods 1:50 year or more frequent) to improve temperature without serious increase in nitrogen supersaturation, etc.

3 SCOPE OF ANALYSES

The objective of the analyses presented in the following sections is to provide an assessment of the performance of the fixed-cone valves in their proposed configuration with respect to their potential in reducing gas concentration in spill waters from the Watana and Devil Canyon developments. The analysis is a theoretical study supplemented by available field information on performance of these valves for aeration. Field measurements were conducted on the Howell Bunger valves at the Lake Comanche dam on the Mokelumne River in California. Results of the tests are interpreted to confirm some of the study assumptions.

A related question of temperature of spill waters is analyzed in Appendix B. The data for the analyses has been drawn from the Feasibility Report (7).

4 - SCHEME DESCRIPTION

This section presents a short description of the selected spillway and outlet facilities for the proposed Watana and Devil Canyon developments.

4.1 - Scheme Description

Selection of the discharge capacity and the type of spillway and outlet facilities has been based on project safety, environmental, and economic considerations. At each development, a set of fixed-cone valves is provided in the outlet works to discharge spills up to 1:50 year recurrence interval. The main spillway comprises a gated control structure and a chute with a flip bucket at its end. This facility has a capacity to discharge, in combination with the outlet works, the routed design flood which has a return period of 1:10,000 years. A fuse plug with an associated rock-cut channel is provided to discharge flows above the design flood and up to the estimated probable maximum flood at the dam. Detailed descriptions of the facilities are presented in the Feasibility Report (7).

The primary purpose of the outlet facility is to discharge the spill waters up to 1:50 year recurrence in such a manner as to reduce potential supersaturation of the spill with atmospheric gases, particularly nitrogen. This frequency was adopted after discussions with environmental study groups as an acceptable level of protection of the downstream fisheries against the gas bubble disease. A set of fixed-cone valves were selected to discharge the spills in highly diffused jets to achieve significant energy dissipation without provision of a stilling basin or a plunge pool where potentially large supersaturation develops. The valves have been selected to be within current world experience with respect to their size and operating heads. At Watana, six 78 inch diameter valves are provided and are located about 125 ft above average tailwater level in the river. The design capacity of each valve is 6,000 cfs. At Devil Canyon, seven fixed cone valves with a total design capacity of 38,500 cfs are provided at two levels within the arch dam, four 102 inch valves at the high level some 170 ft above average tailwater level, and three 90 inch valves about 50 ft above average tailwater level. The lower valves have a capacity of 5,100 cfs each and the higher ones 5,800 cfs each. In sizing these valves, it has been assumed that the valve gate opening will be restricted to 80% of full stroke to reduce vibration.

5 - ENGINEERING ANALYSES

This section details the analyses carried out to estimate potential supersaturation in the releases from the Watana and Devil Canyon developments when the reservoirs spill.

5.1 - Available Data

Fixed cone valves have been used in several water resource projects for water control, energy dissipation, and aeration of discharge waters, and data on their performance for such operations is readily available. However, no precedence has been reported on the use of such valves for reducing or eliminating gas supersaturation in spill waters. Manufacturer's catalog information on Howell Bunger valves and Boving Sleeve type discharge regulators (both particular types of fixed cone valves) and the Tennessee Valley Authority Study (4) on aeration efficiency of Howell Bunger valves form the specific data available. Theoretical analyses were carried out based on the geometric and physical characteristics of diffused jets discharging freely into the atmosphere.

5.2 - Field Data Collection

A review of existing facilities where a potential for spilling during the spring of 1982 existed was made, and the Lake Comanche dam, on the Mokelumne River in California, was selected as a feasible site for specific testing.

The Comanche Lake dam is of the rockfill type with outlet facilities fitted with four Howell Bunger valves. These valves are located at the toe of the dam and spray the discharge into confined concrete conduits before releasing the water to the stream.

Outflow through the valves was around 4,000 cfs during the test on May 28, 1982. Water samples were collected at several depths in the reservoir near the valves and at downstream locations and analyzed for nitrogen and oxygen concentrations. Details of the test procedure and results are presented in Appendix 1.

5.3 Method of Analysis

(a) Flow from the fixed cone valves leaves the structure as a free-discharging jet diffusing radially at the cone angle. The path of the jet depends on the energy of flow available at the valve and the angle at which the jet leaves the valve (assumed as 45°). Referring to Figure 5.1, the path of the trajectory is given by the following equation (8):

$$y = x \tan \theta - \frac{x^2}{k(4 H_n \cos^2 \theta)} \quad (1)$$

where:

θ = angle of the jet to the horizontal;

k = a factor to take account of loss of energy and velocity reduction due to the effect of air resistance, internal turbulences, and disintegration of the jet (assumed at 0.9);

H_n = net energy of the jet, ft.

The proposed valve operation restricts the opening of the valve gate to 80% of full stroke. This may be interpreted as equivalent to producing an additional head loss in the system, thereby reducing the discharge to 80% of the theoretical capacity. The general discharge equation for the valve:

$$Q_T = CA \sqrt{2g\ h_n} \quad (2)$$

may then be written as:

$$Q_D \doteq 0.8\ Q_T = CA \sqrt{2g\ (\cdot 8)^2\ h_n} \quad (2a)$$

$$= CA \sqrt{2g \times \cdot 64 \times h_n} \quad (3)$$

where:

Q_T = theoretical capacity of valve, cfs;
A = area of valve, ft;
C = coefficient of discharge ($\sim$ .85 for fixed-cone valves);
h_n = net head upstream of valve, cfs;
Q_D = design capacity of valve, cfs.

Equation (1) may be rewritten now as:

$$y = x \tan \theta - \frac{x^2}{k \quad 4 \times (0.64 \times h_n) \times \cos^2 \theta} \qquad (4)$$

Referring to Figure 5.1, the longitudinal throw of the jet is calculated with θ=45° and -45° while its laterial throw calculated when θ=0°.

Vertical rise of the jet above the valve is calculated as a simple projectile subject to gravity and neglecting air friction to yield a conservative value.

(b) Potential Plunging Depth of Jet(s) Into Tailwater Pool

As part of the feasibility studies of the Watana and Devil Canyon developments, a study was made by Acres on the scour hole development below high head spillways, and the results therefrom have been used to estimate the potential plunging of the jets from the fixed cone valves into tailwater. Figure 5.2 presents a definition sketch for the study carried out for a typical flip bucket spillway configuration. It may be readily observed that significant differences exist between a "solid" jet leaving a flip bucket and the diffused discharge jet from the fixed-cone valves in the available energy and its concentration in the jet for scouring downstream or plunging into the tailwater pool. Equation (5) was developed in the above mentioned studies to estimate scour depth for a solid jet:

$$y = 0.24\, q^{0.65}\, H^{0.32} \qquad (5)$$

where:

y = estimated scour depth, ft;
q = unit discharge, cfs/ft;
H = net fall of the jet, ft.

This equation was modified to take account of the maximum discharge intensity, q^1 in cfs/ft^2 of the fixed cone valves assuming the longitudinal spread of the solid jet as equal to its flow depth at the toe of the flip bucket (Figure 5.2). This assumpation is expected to yield a conservative estimate of the scour depth for diffused jets. The fall height H was taken as the drop of the diffused jet from the highest point of its rise to the tailwater pool (Figure 5.1). With these modifications, equations (6) and (7) were developed to estimate the scour depth due to the valve discharges at Watana and Devil Canyon, respectively.

$$y_W = .24\ (q^1{}_W)^{0.92}\ H_W{}^{0.32} \qquad (6)$$

$$y_{DC} = .24\ (q^1{}_{DC})^{0.98}\ H_{DC}{}^{0.32} \qquad (7)$$

W and DC represent Watana and Devil Canyon, respectively.

Scour depths, as calculated by equations (6) and (7), give an estimate of the depth to which water may plunge should the jet fall into a tailwater pool instead of on solid ground. The values y_W and y_{DC} are calculated for the highest intensity $q^1{}_W$ or $q^1{}_{DC}$ when all the jets are operating at each of the developments and taken as the plunge depth of the jets.

5.4 - Supersaturation of Spills

(a) Gas Concentration in Valve Discharges

Results of the Lake Comanche dam tests indicate that the Howell Bunger valves have been successful in preventing supersaturation of the spills and, to some extent, have reduced the gas concentration in the spill waters.

The Tennessee Valley Authority studies which were conducted to assess aeration efficiency of the Howell Bunger valves, suggest that the discharge from the valves are well aerated. The test results indicated that small supersaturation (101-102%) of oxygen may be found in the spills but suggested that this may be due to calculation procedure used. The report concluded that since saturation concentrations were not measured in the field, it is not certain whether supersaturation acually occurred in the runoff downstream.

Based on the above test results, it has been conservatively assumed that a 100% saturation level of atmospheric gas is likely to exist in the valve discharges at Watana and Devil Canyon.

(b) Supersaturation Due to Plunging

Each component of gas in the atmosphere will dissolve in water independently of all other gases and, when at equilibrium (i.e. saturation condition) with the air, the pressure of a specific dissolved gas is equivalent to its partial pressure in the air. Approximating one atmospheric pressure to 34 ft head of water, the above relationship translates roughly to 3% saturation per foot of hydrostatic head. Thus, it may be extended that fully saturated water mass when plunging into a pool would develop a supersaturation of gas at the rate of 3% per foot of plunge provided that adequate supply of air is entrained.

(c) Gas Concentration in Downstream Discharges

Average power flows at the two developments during spills have been estimated in the reservoir simulation studies. For the current analyses, it is conservatively assumed that these powerhouse discharges will be fully saturated. Estimates of final gas concentrations in the total downstream discharges is calculated assuming the laws of dilution to hold for mixing discharges at different gas concentrations.

It is assumed that spills from Watana will get completely mixed in the Devil Canyon storage during their passage through 26 miles of reservoir and that no supersaturation would build up in the reservoir due to Watana spills.

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Calculations

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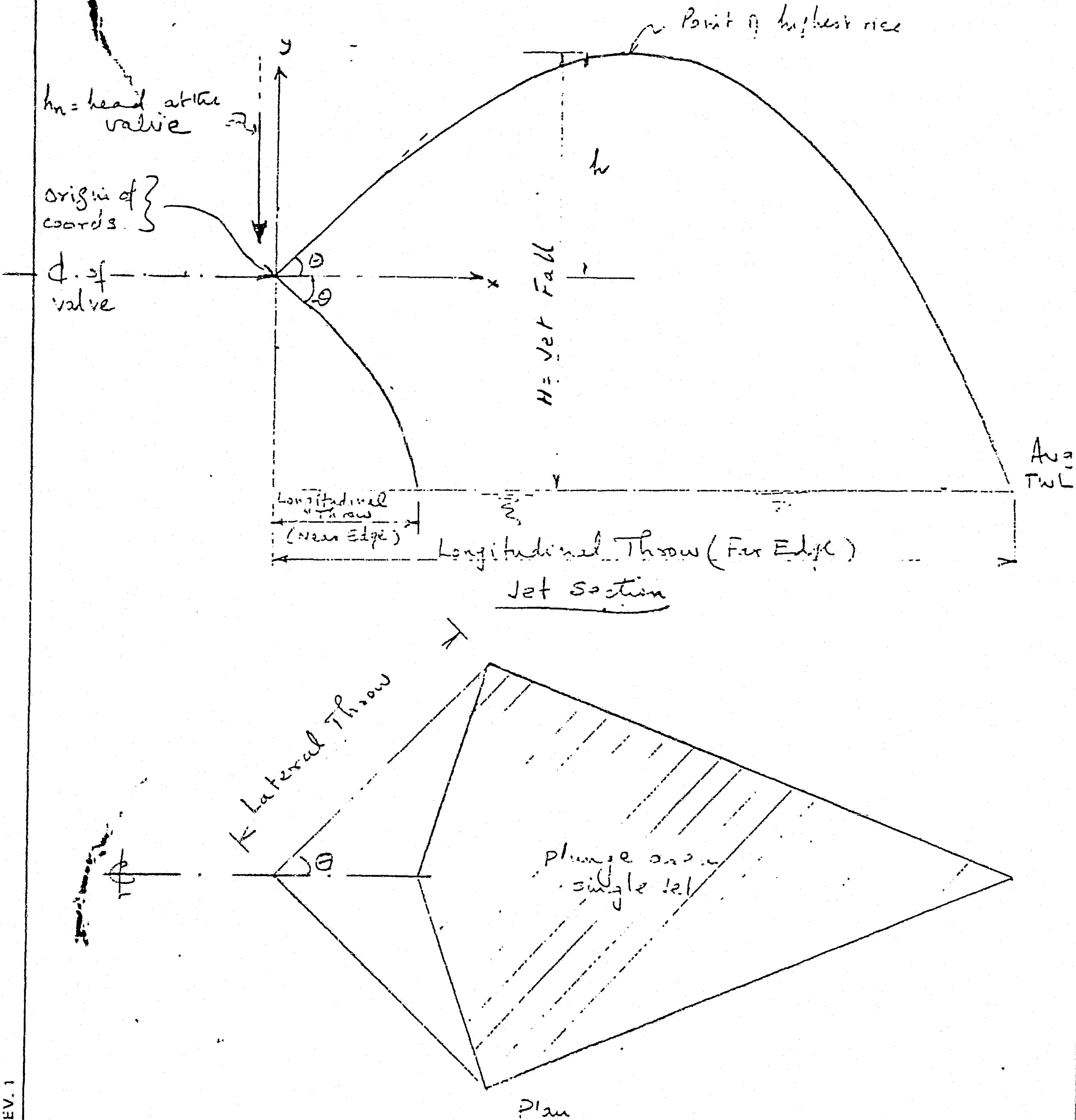

DEFINITION SKETCH FOR DIFFUSED JET

FIGURE 5.1

Calculations

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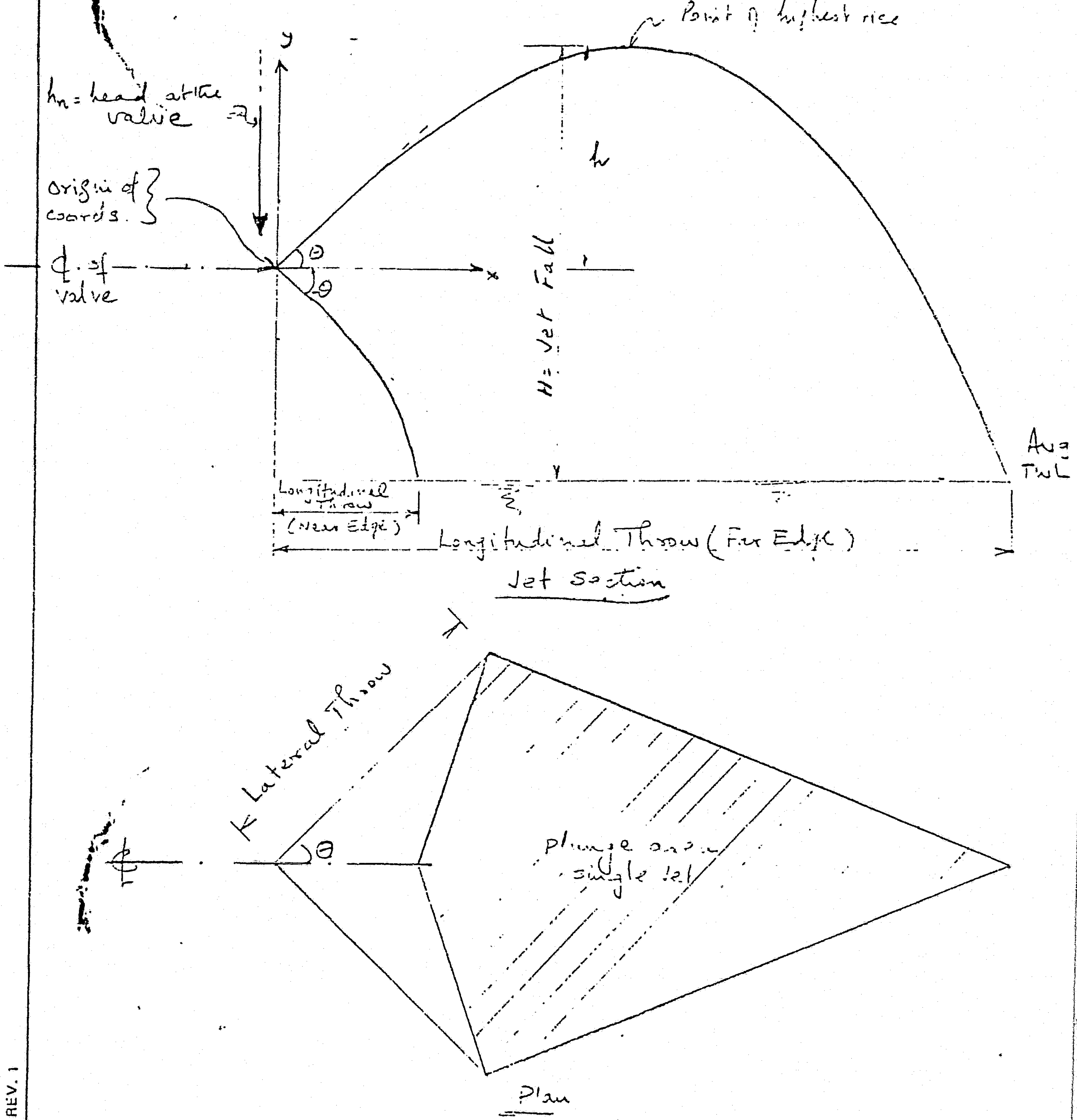

DEFINITION SKETCH FOR DIFFUSED JET

FIGURE 5.1

FORM NO. 152 REV. 1

Calculations

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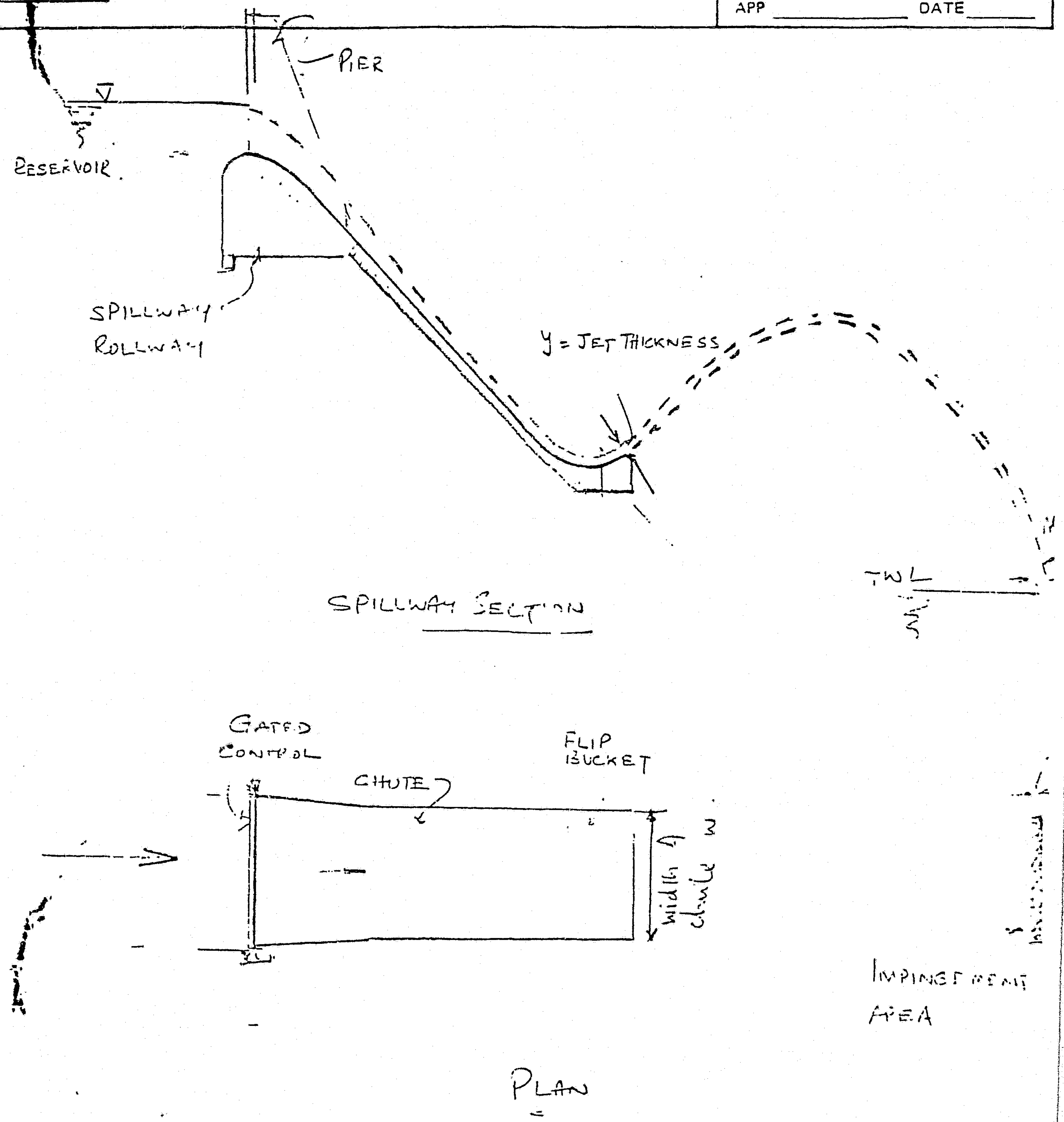

DEFINITION SKETCH FOR 'SOLID JET FROM CHUTE - FLIP BUCKET SPILLWAY

FIGURE S.2

FORM NO. 152 REV. 1

6 RESULTS

Table 6.1 presents the results of the analyses carried out to assess the performance of the fixed cone valves at the proposed Watana and Devil Canyon developments in relation to the potential gas supersaturation of spill waters. Figures 6.1 and 6.2 present the jet interference pattern and the areas of impingement.

Estimated supersaturation in the spill discharges with a recurrence interval of 1 in 50 years is 101% at Watana and 102% at Devil Canyon. For more frequent spills, these concentrations are expected to be somewhat lower due to lower intensity of spill discharge and consequent lower plunge in the tailwater pool. For spills of rarer frequency, the main chute spillway will operate leading to potentially greater supersaturation in the downstream discharges.

Results of spill temperature analysis is presented in Appendix B.

TABLE 6.1 - RESULTS OF ANALYSES

Description	Watana Valves	Devil Canyon Valves Upper Level	Devil Canyon Valves Lower Level
1. Valve Parameters			
Diameter of fixed cone valves-inches	78	102	90
Number of valves	6	4	3
Design capacity-cfs	4,000	5,800	5,100
Elevation of valve centerline-ft	1,560	1,050	930
Elevation above average tailwater-ft	105	170	50
Net head (h_n) at the valve-ft	508	365	450
Angle of valve discharge with horizontal-degrees (assumed)	45	45	45
2. Jet Geometry			
Longitudinal throw-near edge-ft	91	130	46
Longitudinal throw-far edge-ft	676	550	564
Lateral throw-ft	351	378	228
Impingement area of single jet-ft^2	145,200	112,250	83,400
Impingement area of all jets-ft^2	221,300	173,250	
Maximum fall of jet (H)-ft	359	353	275
3. Jet Characteristics			
Average intensity of discharge of single jet cfs/ft^2	0.028	0.052	0.061
Maximum intensity (q^1) when all jets are operating cfs/ft^2	6 x 0.028 = 0.168	4 x ·052 + 3 x ·061 = 0.391	
Estimated plunge depth-ft	0.3	0.62 ($H=353^1$)	
4. Supersaturation Estimates (1:50 year flood)			
Design valve discharge-cfs	24,000	38,500	
Assumed simultaneous power flow-cfs	7,000	3,500	
Total downstream discharge-cfs	31,000	42,000	
Assumed gas concentration in power flow-percent and valve discharge at valve-%	100.0	100.0	
Maximum gas concentration in valve discharge below dam-%	100.9	101.9	
Maximum gas concentration in total downstream discharge-%	100.7	101.7	

7 CONCLUSIONS

1. The analyses described above indicate that the proposed fixed-cone valves would adequately prevent serious gas supersaturation in spill waters up to a recurrence interval of 1:50 years.

2. Several assumptions have had to be made in the analyses with respect to jet characteristics and its potential plunge into tailwater pool. Field test results available are only indicative of the valve performance. In particular, the configuration of the proposed valves set high above the tailwater pool and their free discharge with the atmosphere differ significantly from the Lake Comanche dam arrangement and the TVA test facility. In view of the nature of analyses and lack of precedence for the proposed valve arrangement, it is recommended that a physical model study be carried out to confirm the performance of the valves.

Calculations	
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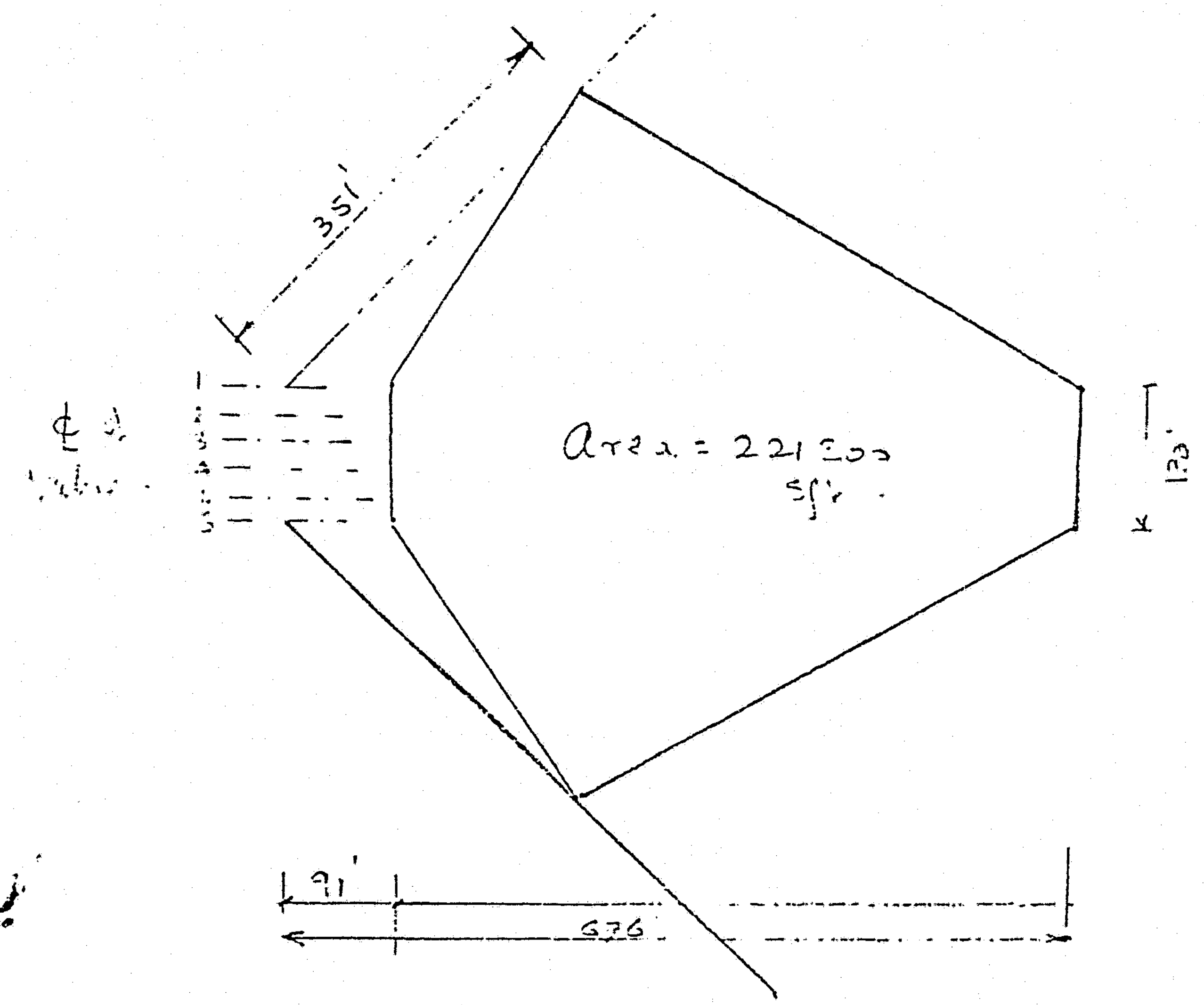

VALVE DISCHARGE PATTERN AND IMPINGEMENT AREA FOR [illegible]

FIGURE 6.1

FORM NO. 152 REV. 1

Calculations

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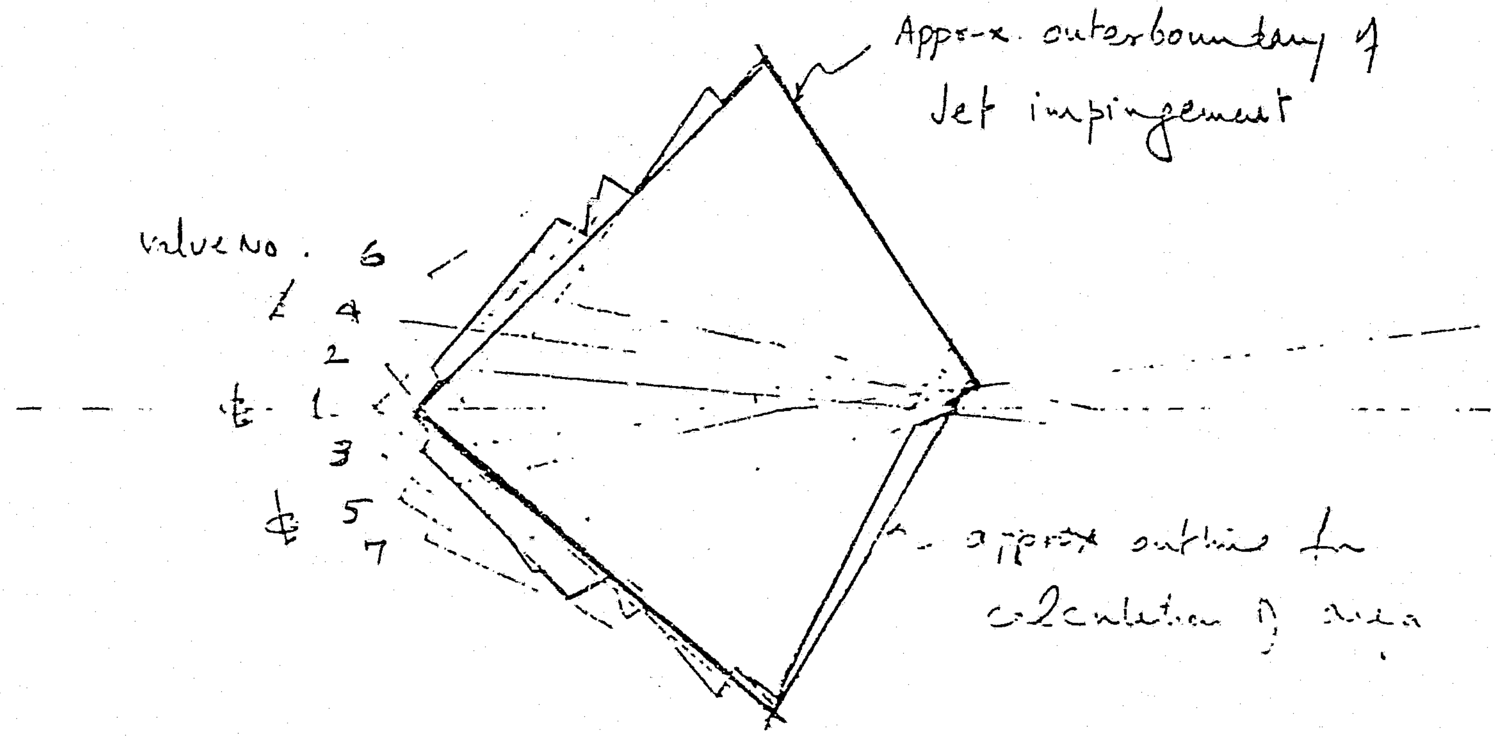

Ref. Plate 32
Vol. 3. Feasibility Report

0 15' 30'
scale.

When all 7 valves are operating -
total area of impingement ≃ $\frac{550 \times 630}{2}$ = 173250 sft.

VALVE DISCHARGE PATTERN
IMPINGEMENT AREA FOR
DEVIL CANYON

FIGURE 6.2

FORM NO. 152 REV. 1

REFERENCES

1. Gorham, F.P., The Gas Bubble Disease of Fish and Its Cause, Bull. U.S. Fish Comm. 19(1899):33-37.

2. Ebel, W.J , Supersaturation of Nitrogen in the Columbia River and Its Effect on Salmon and Steelhead Trout, U.S. Fish and Wildlife Service, Fish Bull. 68:1-11.

3. U.S. Department of the Army, Engineering and Design, Nitrogen Supersaturation, ETL-1110-2-239, September 1978.

4. Tennessee Valley Authority, Progress Report on Aeration Efficiency of Howell Bunger Valves, Report No. 0-6728, August 1968.

5. Acres, Susitna Hydroelectric Project, Scour Hole Development Downstream of High Head Dams, March 1982.

6. Ecological Analysts Inc., California, Lake Comanche Dissolved Nitrogen Study, June 1982 (see Appendix A).

7. Acres, Susitna Hydroelectric Project, Feasibility Report, March 1982.

8. U.S. Department of the Interior, Design of Small Dams, Bureau of Reclamation, Water Resources Technical Publication, 1977.

APPENDIX A

LAKE COMANCHE
DISSOLVED NITROGEN STUDY

Prepared for

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Prepared by

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June 1982

Nitrogen gas in the deep water of a reservoir may be slightly super-saturated due to the hydro-static pressure of the overlying water (Wetzel, 1975). Therefore water flowing from a dam with a deep intake may contain a super-saturated concentration of nitrogen. If this excess nitrogen gas is not rapidly released into the atmosphere, it may cause nitrogen gas bubble disease in fish residing below the dam outfall (Conroy and Herman, 1970).

A study was conducted at Lake Comanche Dam, Mokelumne River, California, to determine the efficiency of the Howell-Bunger Valve in removing super-saturated dissolved nitrogen (N_2) from the dam's tailwater.

The valves spray outfall water into concrete conduits before releasing the water to the stream. This was observed and photographed at Lake Comanche Dam on 28 May, 1982 ~~1981~~, at a flow of 4000 cfs into the Mokelumne River (see accompanying photos). This creates a turbulent and aerated flow with the purpose of facilitating nitrogen gas release to the atmosphere.

By sampling nitrogen gas in the reservoir near the intake, and at several locations below the outfall valves, the efficiency of the valve was obtained.

METHODS

In order to determine nitrogen gas concentrations at various depths in the reservoir, water samples were collected in Lake Comanche approximately 50 m from the dam directly over the river channel on 28 May 1982. A Van Dorn Bottle was lowered from a boat to collect water samples at depths of 0, 10, 20, 30, and 38.4 m. As reported by East Bay Municipal Utility District the dam intake was at a depth of 38.4 m (126 ft) at the time of the sampling.

Once taken aboard, each sample was poured with minimum turbulence into an airtight bottle and capped in a manner that left no air bubbles in the bottle. Bottles were placed in a cooler for transportation to the lab. Studies conducted by Steve Wilhelms of the Hydraulic Laboratory, U.S. Army Waterway Experiment Station, Vicksburg, Mississippi (personal communication) indicate that brief exposure of deep water samples to atmospheric conditions has little effect on nitrogen gas concentrations. However, he has found that periods of exposure to atmospheric air bubbles during transportation can cause significant changes in nitrogen gas concentrations, hence the need for removing all air bubbles before transportation. Excess water remaining in the Van Dorn Bottles was measured for temperature. The atmospheric pressure measured on site at the time of sampling was 753 mm.

At the tailwater below the dam, water was collected by immersing the sample bottles under the water and capping them in a manner that left no air bubbles in the bottles. Samples were taken at the outfall, 100 m below the outfall, and 200 m below the outfall. Water temperatures were taken at each of these locations. Bottles were placed in a cooler for transportation to the lab. At the time of sampling, the outfall flow was 4,000 cfs. The atmospheric pressure was 753 mm.

The water collected was analyzed for nitrogen gas (N_2) and oxygen (O_2) in a California State Certified Water lab using a Carle Model 8700 Basic Gas Chromatogram with a thermal conductivity conductor several hours after collection.

RESULTS

Location	Depth (m)	Temperature (°C)	N_2 (mg/l)	N_2 % Saturation	O_2 (mg/l)	O_2 % Saturat
Reservoir	0	22.0	14.9	101	9.2	105
	10	14.5	17.0	100	9.3	90
	20	13.2	17.3	99	10.0	94
	30	11.0	17.9	99	10.2	93
	38.4	10.0	18.5	101	9.3	82
Dam Tailwater						
At Valve	0	10.2	17.7	97	11.1	94
100 m downstream	0	10.5	17.3	95	11.2	98
200 m downstream	0	11.5	17.9	97	10.9	98

References

Conroy, D.A., and R. L. Herman. Textbook of Fish Diseases. 1970. T.F.H. Publications, Jersey City, New Jersey. 302 pp.

Wetzel, R. G. 1975. Limnology. W.B. Saunders Company, Philadelphia. 743 pp.

APPENDIX B

SPILLS AT WATANA AND DEVIL CANYON DEVELOPMENTS

B.1 - OPERATION OF WATANA AND DEVIL CANYON COMBINED (Beyond Year 2002)

(a) Spill Quantities and Frequency

The monthly reservoir simulation studies calculate spill volumes as the flow required to be discharged from the dam to satisfy downstream requirements less the maximum turbine capacity, and does not restrict the turbine flow in relation to the actual energy demand of the system. Total energy production, as calculated, is the energy potential of the schemes. Usable energy is then calculated as the potential or the maximum energy demand, whichever is smaller. The turbine flows are not readjusted to the level of usable energy production. Tables B.1 to B.9 present selected results of the reservoir simulation studies which indicate this.

Tables B.10 to B.12 are developed from the reservoir simulation studies for adjusted turbine flows for two alternative generation patterns at Watana and Devil Canyon for the months of August and September when spills are most likely to occur. Alternative A assumes that whenever the potential energy generation from Watana and Devil Canyon developments is greater than the usable energy level, each development will share the usable energy generation in proportion to their average heads. However, in the months when Watana outflow, as simulated, is not sufficient to generate energy in proportion to its average head, Devil Canyon will make up this difference. This operation is required in such years when Devil Canyon is being drawn down to meet the minimum downstream flow requirements (years 1, 2, for example). Alternative B assumes that Devil Canyon would generate all the energy possible consistent with downstream flow requirements, and Watana would only operate to make up the difference in years when energy potential is greater than usable. This assumes that all the energy from Devil Canyon is useable as base load on a daily basis. Battelle load forecast (1981) tends to confirm this assumption for the year 2010. However, during earlier years, such operation may not be fully possible.

It may be readily seen from Tables B.10 to B.12 that frequency of continuous spills (24 hours) from the reservoirs in the months of August and September is significantly greater than presented by the reservoir simulation (Tables B.3 and B.6).

The analyses summarized in Tables B.10 to B.12 indicate that Devil Canyon would spill in 30 out of 32 years in August and 16 out of 32 years in September for the Case "C" operation which maintains a minimum instantaneous flow of 12,000 cfs in August at Gold Creek. For downstream discharge requirements greater than 12,000 cfs at Gold Creek, it is estimated that the frequency of spills may not be increased significantly. However, the volume of spills will be larger to make up for increased flow requirement. The above spill frequency is simulated for a system energy demand in the year 2010 (Battelle Forecast) and assumes that the entire demand is met by Watana and Devil Canyon developments where possible. The spills will be greater and more frequent in the years between 2002 (Devil Caryon commissioning) and 2010.

It may be seen that operation Alternative 2, which provides for maximum possible energy generation from Devil Canyon while Watana is allowed to spill, results in significantly reduced spill frequency from Devil Canyon. This type of operation is expected to be advantageous with regard to downstream water quality (see Section B.2).

Several intermediate distributions of generation between Watana and Devil Canyon is also possible. A recommended operation will be derived after finalizing the downstream flow requirements and the refined temperature modeling studies which are currently in progress.

(b) Spill Quality

(i) Spill Temperature

Figures B.1 and B.2 are extracts from the project Feasibility Report (7) and present simulated temperature profiles in the Watana and Devil Canyon reservoirs for the months June to September. Refinement of reservoir temperature modeling is currently in progress, but the differences between the revised profiles are not expected to be very significant from the ones presented here for these months.

Temperature of spill waters at Watana is expected to be close to that of power flow, and hence, it is not expected to create temperature problems downstream when Watana is operating alone (1993-2002) or when it spills into Devil Canyon. At Devil Canyon, however, spill temperature is expected to be close to 39°F compared to a power flow temperature of 48-49°F in August and 45°F in September. This is based on the conservative assumption that the temperature of spill water does not increase significantly while in contact with the atmosphere despite the highly diffused valve discharge. It is, therefore, considered prudent to keep the spill from Devil Canyon to a minimum to maintain as high a downstream temperature as possible during spills.

The operation Alternative 2 indicates that by operating Devil Canyon to generate as much as possible during these months and with Watana generating essentially to meet peak demands and spilling continuously when necessary, it would be possible to maintain downstream flow temperatures below Devil Canyon close to that of power flow.

During major floods (1:10 year or rarer frequency), there will be significant spills from Devil Canyon (see Tables B.10 and B.11) in addition to the power flow resulting in cold slugs of water downstream for a few to several days. It will be necessary to establish criteria for acceptability of lower temperatures for short durations in August and September in consultation with fisheries study groups and concerned Agencies. Currently, downstream water temperature analyses are being refined, and when the results are available, the above spill temperatures and duration should be reviewed to confirm downstream temperatures during normal power operation as well as flood events. If the projected temperature regime downstream is unacceptable, alternative means to remedy the situation should be considered. These may include provision of higher level intakes to several or all fixed-cone value discharges at Devil Canyon, multilevel power intake at Devil Canyon, limited operation of main overflow spillway (for floods 1:50 year or more frequent) to improve downstream water temperature without serious increase in nitrogen supersaturation, etc.

(ii) Gas Supersaturation

It does not appear (from Table 6.1) that there would be significant advantage in spilling from Watana as compared to spills from Devil Canyon in terms of gas concentration.

B.2.1 OPERATION OF WATANA ALONE (1993-2002)

Before Devil Canyon is commissioned, Watana would operate alone, and spills required to maintain downstream flows will have to be made through the fixed-cone valves. Reservoir simulations indicate that, generally, spills would be of lower magnitude during this operation due to greater percentage of flow being used to generate usable energy.

It is believed that the river reach of some 30 miles between Watana dam and Devil Canyon would lessen the impact of spill temperature and gas concentration below Devil Canyon and would pose less problems, if any, compared to the case when Devil Canyon development is also commissioned.

Table B.1 [illegible] Monthly Inflow

RESERVOIR 1

INFLOW (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	4719.9	2083.3	1168.9	815.1	611.7	559.1	680.1	8555.9	15432.1	17193.4	[illegible]	7320.4
2	3299.1	1107.3	906.2	808.0	673.0	619.8	1302.2	11649.8	18517.9	19786.6	16476.0	17205.5
3	4592.9	2170.1	1501.0	1274.5	841.0	735.0	803.9	4216.5	25773.4	22110.9	17356.3	11571.0
4	6285.7	2756.8	1281.2	818.9	611.7	676.7	1382.0	15057.2	21469.8	17355.3	16681.6	11513.5
5	4218.9	1599.6	1183.6	1067.6	603.1	638.2	942.6	11696.8	19476.7	16983.6	20420.6	9165.5
6	3859.2	2051.1	1549.5	1388.3	1050.5	866.1	940.6	6716.1	24851.4	23787.9	23537.0	13447.8
7	4102.3	1588.1	1038.6	816.9	754.6	694.4	716.3	12953.3	27171.8	25831.3	19153.4	13194.4
8	4208.0	2276.6	1707.0	1373.0	1189.0	935.0	945.1	10176.2	25275.0	19948.9	17317.7	14841.1
9	6034.9	2935.9	2258.5	1480.6	1041.7	971.5	1265.4	9957.8	22097.8	19752.7	18843.4	5978.7
10	3658.0	1729.5	1115.1	1081.0	949.0	694.0	685.7	10140.2	18329.6	20453.1	23940.4	12466.9
11	5165.5	2213.5	1672.3	1400.4	1138.9	961.1	1069.9	13014.7	13233.4	19506.1	19334.1	16085.6
12	6049.3	2327.8	1973.2	1779.9	1304.6	1331.0	1965.0	13637.9	22784.1	19839.8	19480.2	10146.2
13	4537.6	2243.4	1760.4	1608.9	1257.4	1176.8	1457.4	11333.5	36017.1	23443.7	19887.1	12746.2
14	5560.1	2508.9	1708.9	1308.9	1164.7	883.6	776.6	15299.2	20673.4	28767.4	21011.4	10800.0
15	5187.1	1789.1	1194.7	852.0	781.6	575.2	609.2	3578.8	42841.9	20002.6	14648.2	7524.2
16	4759.4	2368.2	1070.3	863.0	772.7	807.3	1227.4	16966.0	21213.0	23235.9	17491.1	15225.6
17	5221.2	1565.3	1203.6	1060.4	984.7	984.7	1338.4	7094.1	25939.6	16153.5	17390.9	9214.1
18	3269.8	1202.2	1121.6	1103.2	1031.3	689.5	849.7	13555.5	24711.9	21987.3	26104.5	13572.9
19	4019.0	1934.3	1704.2	1617.6	1560.4	1560.4	1576.7	12877.7	25704.0	22082.8	14147.5	7163.6
20	3135.0	1354.9	753.9	619.2	607.5	686.0	1261.6	9313.7	13962.1	14643.5	7771.5	4760.0
21	2403.1	1020.9	709.3	536.2	602.1	624.1	986.4	9536.4	14399.0	16410.3	16263.8	7224.1
22	3768.0	2496.4	1687.4	1097.1	777.4	717.1	813.7	2857.2	27612.8	21126.4	27446.6	12188.9
23	4979.1	2587.0	1957.4	1670.9	1491.4	1366.0	1305.4	15573.1	27429.3	19820.3	17569.5	10955.7
24	4301.2	1977.9	1246.5	1031.5	1000.2	873.9	914.1	7267.0	26659.3	16351.1	18016.7	8099.7
25	3056.5	1354.7	931.6	785.4	689.9	627.3	871.9	13889.0	14780.6	15971.9	13533.7	9786.2
26	3088.8	1474.4	1276.7	1215.8	1110.3	1041.4	1211.2	11672.2	26689.2	23430.4	15126.6	13075.3
27	5679.1	1601.1	876.2	757.8	743.2	690.7	1059.8	8938.8	19994.0	17015.3	18393.5	5711.5
28	2973.5	1926.7	1687.5	1348.7	1262.9	1110.8	1203.4	8569.4	31352.8	19707.3	16807.3	10613.1
29	5793.9	2645.3	1979.7	1577.9	1267.7	1256.7	1400.4	11231.5	17277.2	18385.2	13412.1	7132.6
30	3773.9	1944.9	1312.6	1136.8	1055.4	1101.2	1317.9	12349.3	22904.8	24911.7	16670.7	9096.7
31	6150.0	3525.0	2032.0	1470.0	1233.0	1177.0	1404.0	10140.0	23400.0	26740.0	18000.0	11000.0
32	6458.0	3297.0	1385.0	1147.0	971.0	889.0	1103.0	10406.0	17323.0	27840.0	31435.0	12026.0
AVE	4513.1	2052.4	1404.8	1137.3	978.9	898.3	1112.6	10397.6	23922.4	20778.0	18431.4	10670.4

Table B.2 Watana Power Flows. Case 'C' Operation

POWERHOUSE FLOW (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	5676.3	8474.4	11255.3	8391.9	7254.9	[illegible]	[illegible]	6551.7	5399.7	4546.3	[illegible]	4900.3
2	6234.5	7324.0	9102.0	8384.7	7326.2	6551.2	5554.2	7959.3	6844.1	4630.3	6576.8	13051.6
3	7568.3	9549.1	11617.4	8851.3	7494.2	6366.5	5457.6	6405.6	7359.9	5719.7	6135.3	10601.3
4	8661.8	10527.8	11397.6	8395.7	7254.9	6365.8	5846.8	9241.8	8943.6	4951.8	6326.2	8206.5
5	7194.3	8976.6	11300.2	8664.5	7456.3	6367.8	5404.4	7775.0	7262.2	4579.7	5917.9	7900.3
6	6834.6	9430.1	11665.9	8955.1	7703.7	6345.9	5610.4	5627.5	7933.7	6692.3	13289.8	13447.8
7	7077.7	8967.1	11155.0	8393.7	7408.0	6356.3	5422.2	8265.3	10712.1	6844.4	12744.0	13194.4
8	7163.4	9655.6	11823.4	8949.8	7842.2	6330.4	5719.3	7209.1	9552.7	6601.2	6328.7	14301.6
9	8605.9	10536.3	11738.1	9694.2	7694.9	6357.9	6051.0	7144.7	7949.2	5316.5	6441.1	5471.6
10	6643.4	9108.5	11231.5	8657.8	7602.2	6324.0	5417.5	7119.7	6419.6	4845.6	10300.0	12466.9
11	8140.9	9592.5	11788.7	8977.2	7792.1	6239.2	5861.9	8406.8	5632.4	4525.4	6136.6	12284.9
12	8931.7	9803.0	11622.3	9624.0	7958.0	6236.8	7139.7	6649.0	9142.5	5859.0	7837.0	10146.2
13	7613.0	9642.4	11876.8	9185.7	7910.6	6343.1	6468.3	7719.1	10656.2	9561.3	17662.2	12746.2
14	6535.5	9897.9	11825.3	8685.6	7637.9	6327.6	5475.6	9351.6	8663.7	5162.3	11610.3	10600.0
15	8162.5	9168.1	11311.1	8428.7	7434.8	6369.1	5452.9	5639.1	10761.9	9863.2	9051.8	7524.2
16	7734.8	9747.2	11166.7	8439.8	7425.9	6382.6	5820.5	7576.7	7613.9	6420.2	6734.3	16225.6
17	5196.6	8944.3	11320.0	8637.2	7637.9	6315.1	6179.7	6642.3	8515.5	4506.3	5003.3	5612.0
18	6245.2	8581.2	11238.0	8679.0	7684.5	6316.6	5591.2	8196.3	9716.6	6866.1	16260.0	13672.9
19	6994.4	9313.3	11820.6	9194.4	8213.6	6568.2	6751.4	8306.3	10193.5	7156.7	5880.7	6015.5
20	6110.4	8733.9	10870.3	8196.0	7260.7	6371.4	5736.1	6933.8	5600.2	4270.8	9821.8	5667.0
21	6385.6	7578.3	9136.9	8137.8	6651.3	6910.7	5961.7	4892.9	3631.4	5330.1	6283.8	4603.1
22	6198.0	7402.9	9021.9	8090.4	6016.0	6883.7	5897.4	5180.5	3262.7	6756.4	7536.6	4248.9
23	6163.2	7240.4	11277.0	9247.7	8144.6	6373.8	6480.1	9618.4	10679.2	7464.2	6595.5	10955.7
24	7276.6	9356.9	11362.9	8608.3	7653.4	6372.6	5581.6	7128.3	7541.5	4985.5	6715.3	5525.7
25	6196.2	7329.3	9516.4	8363.1	7343.1	6359.4	5595.7	8226.2	5565.6	3776.7	8232.6	4036.2
26	6243.9	7361.3	8813.6	7631.3	6351.8	6584.6	5620.6	8257.3	9538.8	7327.3	6402.3	12681.6
27	8654.5	8980.1	10992.6	8334.6	7396.4	6347.4	5564.0	6715.2	6784.5	4972.5	7569.4	5330.5
28	6157.1	7202.2	8673.1	8290.9	7856.1	6461.9	6023.4	6679.2	10725.5	7084.7	7247.5	10613.1
29	8769.3	10024.3	11855.3	9395.5	7920.9	6305.1	6541.2	7726.7	6311.4	4769.8	5470.6	5025.6
30	6096.7	7236.4	8767.4	7906.2	7708.6	6578.8	6007.2	8209.4	8874.4	7527.5	7878.1	9096.7
31	9099.8	10930.5	11921.9	9273.2	7886.2	6342.9	6415.4	7252.5	8524.9	8036.5	10151.7	11000.0
32	9082.6	11038.5	11501.4	8723.7	7624.2	6359.9	5799.2	7356.0	6092.8	7212.3	19391.0	12026.0
AVE	7346.5	8988.6	10944.3	8681.2	7543.7	6421.8	5872.6	7474.4	7895.0	6247.0	8846.7	9361.9

Table 2.2, Walane Monthly Spills

SPILLS (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2755.0	0.0
AVE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	86.1	0.0

Table E.1. [illegible] Monthly Energy Potential

ENERGY FROM RESERVOIR 1 (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	221.9	316.0	429.3	312.2	240.6	226.3	185.8	230.5	187.4	169.0	213.2	185.0	2921.2
2	243.1	273.5	345.4	312.0	241.6	235.0	189.9	201.0	239.2	180.6	253.6	495.4	3290.8
3	297.2	356.7	441.9	329.3	247.1	228.5	186.7	224.2	256.2	214.8	[illegible]	411.5	3434.3
4	348.9	395.6	433.5	312.4	239.6	228.4	200.0	327.4	314.9	187.7	244.5	311.9	3544.8
5	282.5	337.3	425.8	322.4	245.7	228.5	184.8	274.6	254.4	171.2	228.7	300.8	3260.9
6	268.4	354.2	413.7	333.6	[illegible]	227.8	193.3	232.6	276.4	252.2	517.5	[illegible]	3666.7
7	277.9	336.8	424.3	312.3	244.3	227.4	165.4	292.2	377.8	356.6	498.5	503.1	4016.7
8	262.1	362.7	449.7	333.0	256.6	227.3	195.7	254.3	326.2	226.4	245.9	545.0	3708.9
9	345.9	395.5	446.8	361.0	253.	228.2	207.1	252.0	278.1	199.7	249.9	208.5	3426.4
10	260.9	342.1	427.2	322.1	270.7	226.9	185.3	251.2	224.0	181.3	399.5	475.4	3545.7
11	319.7	360.3	448.4	334.0	257.0	227.6	200.6	297.4	196.3	166.1	236.2	466.5	3511.9
12	350.8	368.3	449.8	358.2	262.4	227.7	244.5	306.0	321.7	[illegible]	304.7	386.9	3801.1
13	299.0	362.2	451.8	341.8	260.9	227.8	221.4	273.6	378.9	384.5	694.2	486.0	4381.9
14	335.2	371.4	449.8	330.6	258.5	226.8	187.3	331.3	304.9	336.0	371.8	411.8	4117.5
15	320.5	344.4	430.2	313.6	215.2	228.5	186.4	193.6	279.6	379.7	354.6	285.9	3663.2
16	303.7	366.1	475.5	314.0	214.9	229.1	197.1	267.4	273.4	241.8	262.1	618.7	3745.9
17	321.9	336.0	430.6	321.4	251.9	226.7	211.5	233.4	257.2	169.1	231.6	213.1	3244.3
18	245.2	322.3	427.5	322.9	253.4	226.7	191.3	269.7	341.9	259.8	633.5	521.4	4035.7
19	274.7	349.8	449.6	342.1	270.8	235.9	231.2	293.7	359.1	271.1	228.9	229.1	3536.1
20	240.0	328.1	413.5	304.9	239.4	226.6	196.2	244.4	200.9	157.1	365.7	203.2	3121.9
21	234.8	265.6	323.7	281.1	202.8	228.4	186.4	158.1	116.9	164.7	256.9	162.1	2641.5
22	225.6	258.1	319.1	279.7	202.2	228.6	185.0	165.6	105.1	240.0	280.9	158.7	2648.0
23	239.6	270.6	428.5	344.1	268.6	226.9	221.9	341.0	378.7	264.0	335.2	417.8	3758.9
24	285.7	351.5	432.2	320.3	252.4	228.7	191.0	250.4	262.6	186.3	258.0	208.8	3227.9
25	241.6	273.9	361.3	311.2	242.1	234.6	191.2	290.5	194.1	140.2	312.6	150.2	2943.7
26	240.8	271.9	331.2	288.8	208.1	235.2	191.4	290.2	334.4	277.3	249.5	483.4	3402.3
27	339.9	337.3	418.1	310.1	243.9	227.8	190.3	236.6	235.6	185.5	290.5	200.6	3217.2
28	238.6	267.5	328.2	308.2	259.1	232.0	206.1	242.2	377.3	269.0	282.5	404.7	3415.4
29	344.4	376.5	451.1	349.7	261.2	226.5	224.0	272.8	220.2	[illegible]	[illegible]	188.5	3302.9
30	236.2	269.0	331.8	293.9	254.2	236.1	205.5	292.9	311.6	284.6	307.3	346.9	3370.0
31	357.4	410.6	453.6	345.1	260.1	227.8	219.6	255.8	298.6	304.0	396.4	419.5	3948.4
32	356.8	414.8	437.5	324.6	251.4	228.3	198.4	259.5	212.4	271.1	756.0	458.6	4169.3
AVE	286.9	336.0	414.5	321.6	247.7	229.2	199.8	262.7	276.2	234.8	342.1	355.4	3507.0

Table B.5 Devil Canyon Power Flows Case C Operation

POWERHOUSE FLOW (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	6714.6	8795.5	11456.9	8528.1	7386.9	6464.1	7456.8	6562.3	7436.2	8363.4	10940.6	6149.8
2	6587.4	7447.9	8923.1	7913.3	6437.6	6628.5	5756.6	5581.7	8304.7	8585.9	10860.0	11307.8
3	8203.6	9918.0	11873.9	9060.5	7596.4	6460.1	7410.6	6845.9	8026.9	8470.5	10777.2	10293.7
4	10113.7	11010.3	11666.8	8576.4	7398.8	6461.6	7674.9	10136.6	12704.7	8564.0	10597.0	8149.3
5	6996.7	9300.3	11503.5	8800.9	7582.9	6459.0	7470.7	9540.0	10980.6	6374.1	9971.6	8219.9
6	7812.3	9885.8	11984.4	9225.9	7926.4	6483.4	7693.4	6475.1	11134.2	9117.2	13763.2	13763.2
7	7629.8	9167.6	11323.0	8498.5	7546.3	6494.2	7449.6	9466.8	13763.2	12225.1	13763.2	13763.2
8	8217.2	10152.8	12103.0	9160.0	8042.1	6500.8	7761.6	7682.3	12493.1	8379.6	10849.2	13763.2
9	10205.5	11187.3	12378.0	10012.1	7865.4	6470.1	8101.3	7211.8	10764.9	8463.1	10679.8	5936.8
10	6630.1	7603.1	11487.3	8893.7	7832.3	6507.9	7530.0	9055.7	9627.9	7970.4	13763.2	13763.2
11	9042.6	10001.7	12127.9	9263.0	7993.4	6490.9	7808.2	6343.2	7106.6	8539.3	10476.1	11848.1
12	10053.3	10241.8	12279.2	10062.6	8246.8	6646.7	9458.5	9217.5	13427.7	8679.8	11061.4	10623.9
13	8441.3	9923.1	12095.1	9372.8	8066.6	6486.6	8502.7	6732.5	13763.2	11586.2	13763.2	13763.2
14	9289.6	10075.0	12012.4	9072.7	8040.6	6450.4	7388.3	9925.7	12094.4	12483.3	13763.2	11777.2
15	8960.2	9464.4	11503.5	6554.7	7553.4	6457.7	7468.6	7870.5	12132.6	11706.9	11145.8	8765.1
16	8725.9	10024.1	11277.2	8502.1	7482.0	6442.4	7780.9	7053.5	10708.2	9360.0	10669.3	13763.2
17	9478.4	9286.8	11594.8	8855.5	7840.6	6517.8	8338.8	6457.9	13022.3	8256.2	10414.6	5594.3
18	6469.9	7809.7	11481.3	8934.7	7921.5	6516.2	7673.5	8252.0	12801.1	9962.0	13763.2	13763.2
19	7567.2	9582.5	12046.1	9428.0	8431.9	6786.5	8844.1	8637.8	13763.2	9944.9	10920.5	5909.9
20	6444.5	7253.0	10704.7	8263.4	7335.0	6455.0	7774.2	6825.8	6788.8	9214.3	11604.6	6202.5
21	6849.0	7703.1	9237.6	8258.5	6757.9	7016.4	6021.9	6078.1	6551.3	8062.2	10672.8	5822.5
22	7175.2	7986.3	9409 3	8312.1	6782.2	7033.4	6069.9	5751.2	6680.9	8571.6	10405.9	5596.0
23	6721.1	7565.7	9040.0	7932.2	6909.1	6667.6	6618.6	11597.8	13763.2	9360.4	11364.1	10206.1
24	7620.5	9533.8	11503.4	8716.6	7781.8	6453.7	7332.5	5913.4	10074.8	6901.8	11188.1	6152.0
25	6631.1	7437.5	6885.4	7868.1	6399.1	6601.6	5672.9	6786.2	7551.7	10230.6	11037.0	5620.1
26	6661.9	7506.3	9023.4	8024.3	6563.7	6815.1	5666.1	4914.7	13152.2	10084.9	10941.6	12038.9
27	9985.2	9232.0	11124.3	8473.6	7529.4	6481.9	7643.8	7258.4	9634.1	8892.6	11497.7	6082.3
28	6736.0	7667.2	9133.1	8054.9	6547.8	6712.1	5798.5	6296.2	13763.2	9117.9	11131.2	9519.0
29	9918.2	10589.6	12240.5	9692.0	8178.2	6529.6	8608.2	6364.3	7451.0	8639.0	10936.5	5973.4
30	6825.1	7615.8	9004.2	7977.8	6503.6	6642.3	5707.2	5464.0	9787.5	10078.6	10646.7	9828.7
31	9849.8	11367.2	12162.4	9458.7	8036.2	6486.9	8464.7	6665.3	11379.9	11298.5	12347.7	12342.0
32	9870.6	11447.3	11670.4	8863.7	7742.2	6467.9	7812.6	6801.7	8205.8	10608.3	13763.2	13493.0
AVE	8077.1	9180.8	11070.6	8769.1	7508.8	6565.2	7480.3	7467.7	10566.0	9454.2	11544.8	9668.6

Table 8.6 Devil Canyon Monthly Spills

SPILLS (CFS)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	949.2	226.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	914.2	0.0	2447.2	2732.6
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	970.7
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	963.2	1566.4
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1555.6	0.0	6253.7	1004.0
14	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2564.2	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2879.9
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6685.3	1965.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	188.4	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1416.5	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1216.2	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12217.9	0.0
AVE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	165.3	0.0	1002.2	354.5

Table K.7 Devil Canyon Monthly Energy Potential

ENERGY FROM RESERVOIR 2 (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	217.8	276.1	371.7	276.6	216.5	209.7	230.5	210.2	233.4	268.3	337.9	177.9	3026.5
2	196.0	214.4	266.1	237.7	176.7	202.9	170.5	175.9	260.7	274.7	336.9	344.3	2856.9
3	266.1	311.3	385.1	293.9	222.5	209.5	229.7	276.2	245.7	274.8	342.4	316.0	3375.2
4	328.1	345.6	378.4	278.2	216.8	209.6	244.1	324.8	398.6	274.5	331.1	247.7	3577.6
5	225.4	291.9	373.1	285.5	222.1	209.5	231.6	305.6	344.7	268.7	315.4	254.4	3327.8
6	253.4	310.3	388.7	299.2	232.3	210.3	236.5	207.4	349.5	295.7	446.4	432.0	3663.8
7	247.5	287.8	367.3	275.6	221.1	210.6	230.9	303.3	432.0	396.5	446.4	432.0	3851.1
8	266.5	318.7	392.6	297.1	235.6	210.8	240.6	246.1	392.2	271.5	344.9	423.9	3640.5
9	331.0	351.2	401.5	324.7	230.4	209.9	251.1	231.0	322.2	272.5	336.5	179.3	3441.4
10	206.8	235.9	372.6	288.5	229.5	211.1	233.4	290.1	302.2	258.2	445.8	432.0	3508.1
11	293.3	313.9	393.4	300.4	234.2	210.5	244.5	267.3	223.1	267.6	328.6	363.5	3440.4
12	326.1	321.5	398.3	326.4	241.6	215.6	293.2	295.3	421.5	288.0	355.2	330.0	3812.7
13	273.8	311.5	392.3	304.0	236.3	210.4	263.6	215.7	432.0	373.3	446.4	432.0	3891.3
14	301.3	316.2	389.6	294.3	235.6	209.2	229.5	318.0	379.6	404.9	446.4	369.7	3893.9
15	291.3	297.1	373.1	277.5	221.3	209.4	230.0	239.5	371.4	379.7	360.4	258.6	3509.3
16	283.0	314.6	365.8	275.8	219.2	209.0	241.2	225.9	336.1	304.3	342.5	427.6	3545.0
17	307.4	291.5	376.1	287.2	229.7	211.4	258.5	206.9	408.8	265.4	327.8	170.4	3341.1
18	207.3	243.6	372.4	289.8	232.1	211.3	237.9	264.3	401.8	323.1	446.4	432.0	3662.2
19	245.4	300.8	350.7	305.8	247.0	220.1	274.2	276.7	432.0	322.6	346.5	178.9	3540.7
20	203.6	224.4	346.7	268.0	214.9	209.4	241.0	199.4	213.1	304.6	348.3	176.6	2951.9
21	203.8	221.8	274.8	245.7	181.6	206.8	173.4	180.8	182.9	239.9	317.5	167.6	2598.7
22	213.5	230.0	260.0	247.3	182.3	209.3	174.8	171.1	192.4	255.0	309.6	164.0	2629.2
23	200.0	217.8	274.6	249.2	200.5	216.3	267.2	371.5	432.0	303.6	364.6	316.9	3414.2
24	247.2	299.2	373.1	262.7	228.0	209.3	233.5	189.4	316.3	283.3	341.0	177.1	3180.2
25	197.3	214.2	265.9	237.8	176.7	203.3	169.1	214.5	237.1	320.8	331.2	161.8	2729.6
26	198.2	216.1	268.5	238.7	176.9	202.8	168.9	152.8	412.9	327.1	348.4	370.9	3082.2
27	323.9	289.8	360.8	274.8	220.6	210.2	236.9	232.5	301.5	283.0	350.5	175.1	3259.7
28	200.4	220.8	271.7	240.7	179.6	206.1	173.0	199.6	432.0	295.8	355.2	294.0	3068.8
29	321.7	332.4	397.0	314.4	239.6	211.8	266.8	203.9	233.9	276.0	334.8	172.0	3304.3
30	203.1	219.3	267.9	237.5	176.8	201.9	168.4	171.9	306.8	326.9	344.7	307.9	2933.1
31	319.5	356.8	394.5	306.8	235.4	210.4	262.4	213.5	357.2	366.5	400.5	387.4	3611.0
32	320.2	359.3	378.5	287.5	226.8	209.8	242.2	217.9	257.6	344.1	446.4	423.6	3713.8
AVE	256.9	283.0	353.2	279.7	216.9	209.7	229.7	237.5	330.1	303.5	364.9	296.9	3361.9

Table B.8 Total Monthly Energy Potential
Watana + Devil Canyon

TOTAL ENERGY PRODUCED (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	439.7	594.0	800.9	588.8	457.0	438.0	416.4	440.7	420.9	437.3	551.1	363.0	5947.8
2	439.1	488.0	611.6	549.7	418.3	437.8	360.4	457.0	499.9	415.6	590.7	839.7	6147.6
3	563.3	670.0	827.0	623.2	469.7	438.0	416.4	500.5	501.9	489.5	580.6	729.5	6809.5
4	677.0	741.2	811.9	590.5	456.3	438.0	444.1	652.2	713.7	462.2	575.6	559.5	7122.4
5	507.9	629.2	802.9	607.8	458.0	438.0	416.4	580.2	599.1	439.9	544.1	555.3	6588.8
6	521.8	664.5	632.4	632.8	486.3	438.1	431.8	440.2	625.9	547.9	964.0	944.8	7530.5
7	525.4	624.6	791.6	587.9	465.4	438.0	416.4	595.4	809.9	733.2	944.9	935.2	7867.7
8	548.6	681.4	842.3	630.1	494.2	438.1	436.3	500.4	720.3	497.9	590.8	969.0	7349.3
9	676.9	746.6	848.3	685.7	484.2	438.1	438.2	483.0	600.3	472.2	586.5	387.8	6867.8
10	469.7	576.0	799.8	610.6	480.1	438.0	418.8	541.2	526.2	439.5	845.4	907.4	7054.8
11	613.0	674.2	841.8	634.4	491.1	438.1	445.1	564.6	419.4	435.7	564.8	830.0	6952.3
12	676.9	689.7	848.1	684.6	504.0	443.3	537.7	601.3	743.2	508.2	659.9	716.9	7613.7
13	572.8	673.7	844.[illegible]	645.8	497.2	438.2	485.0	469.3	610.9	757.8	1140.6	918.1	8273.2
14	636.5	687.6	839.4	624.9	494.0	438.1	416.4	649.3	664.6	740.9	1018.2	781.5	8011.4
15	611.8	641.4	603.3	591.1	466.4	438.0	416.3	433.2	750.9	759.4	715.0	545.5	7172.5
16	586.8	680.8	791.3	589.8	464.1	438.0	440.3	493.4	609.6	546.0	604.6	1046.3	7290.9
17	629.3	627.5	806.6	608.6	481.6	438.1	470.0	440.3	706.0	434.4	559.4	383.[illegible]	6585.4
18	452.6	565.9	799.8	612.7	485.5	438.1	429.2	554.1	743.7	582.9	1079.9	953.4	7697.9
19	520.1	650.6	840.3	647.9	517.9	456.0	505.3	570.4	791.1	593.7	575.4	408.0	7076.8
20	443.5	552.5	760.2	573.0	454.3	438.0	437.2	443.6	414.0	461.6	713.9	381.8	6073.8
21	438.6	467.4	598.5	526.8	384.4	437.2	359.8	338.9	299.7	424.6	614.4	329.8	5240.1
22	439.1	488.1	599.1	527.0	384.5	437.3	359.8	336.7	297.4	495.1	590.5	322.7	5277.2 FIRM
23	439.6	488.5	703.2	593.2	469.1	445.2	489.1	712.5	810.7	587.6	699.8	734.6	7173.1
24	532.9	655.7	605.3	603.0	480.3	438.1	424.5	439.8	576.8	469.6	599.1	385.9	6408.0
25	439.1	488.0	677.2	549.0	418.9	437.9	360.1	505.1	431.2	461.0	643.9	312.1	5673.3
26	439.0	488.1	599.6	527.6	385.0	438.0	360.3	443.1	747.2	604.4	597.9	854.3	6484.5
27	663.7	627.1	778.9	584.9	464.5	438.0	427.3	469.1	538.1	468.5	641.0	375.7	6476.9
28	439.0	488.3	599.9	548.9	438.6	438.1	379.1	441.7	809.3	564.8	637.7	698.7	6484.3
29	666.1	708.9	848.1	664.0	500.8	438.2	490.8	476.6	454.1	454.6	544.4	360.5	6607.2
30	439.3	488.3	599.7	531.4	431.0	438.0	373.9	464.8	618.4	611.5	652.0	654.8	6303.1
31	676.9	767.4	848.1	651.9	495.5	438.2	482.0	469.3	655.8	670.5	796.9	806.9	7759.4
32	677.0	774.1	816.0	612.1	478.2	438.1	440.6	477.4	470.0	615.2	1202.4	882.1	7883.2
AVE	543.8	618.9	767.7	601.2	464.6	438.9	429.5	500.2	606.3	538.2	707.0	652.3	6868.9

Table B.9 Total Usable Energy in Year 2010
Watana + Devil Canyon.

TOTAL USABLE ENERGY (GWH)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	ANN
1	439.7	594.0	800.9	586.8	457.0	438.0	416.4	440.7	420.9	437.3	550.6	363.0	5947.2
2	39.1	488.0	611.6	549.7	416.3	437.8	360.4	457.0	499.9	455.6	550.6	576.0	5843.8
3	563.3	670.0	827.0	623.2	469.7	438.0	415.4	500.5	501.9	489.5	550.6	576.0	6626.0
4	677.0	741.2	811.9	590.5	456.3	438.0	444.1	543.1	532.8	462.2	550.6	559.5	6807.3
5	507.9	629.2	802.9	607.8	466.0	438.0	416.4	543.1	532.8	439.9	544.1	555.3	6485.4
6	521.8	664.5	832.4	632.8	466.3	438.1	431.6	440.2	532.8	520.8	550.6	576.0	6628.0
7	525.4	624.6	791.6	587.9	465.4	438.0	416.4	543.1	532.8	520.8	550.6	576.0	6572.5
8	548.6	681.4	842.3	630.1	494.2	438.1	436.3	500.4	532.8	497.9	550.6	576.0	6728.6
9	676.9	746.6	848.2	685.7	484.2	438.1	458.2	483.0	532.8	472.2	550.6	387.8	6764.2
10	469.7	578.0	799.8	610.6	480.1	438.0	410.8	541.2	526.2	439.5	550.6	576.0	6428.5
11	613.0	674.2	841.8	634.4	471.1	438.1	445.1	543.1	419.4	435.7	550.6	576.0	6662.6
12	676.9	689.7	848.1	684.6	504.0	443.3	537.7	543.1	532.8	508.2	550.6	576.0	[illegible]94.9
13	572.8	673.7	844.1	645.8	497.2	438.2	485.0	489.3	532.8	520.8	550.6	576.0	6826.0
14	636.5	687.6	839.4	624.9	494.0	438.1	416.4	543.1	532.8	520.8	550.6	576.0	6860.1
15	611.8	641.4	803.3	591.1	466.4	438.0	416.3	433.2	532.8	520.8	550.6	545.5	6551.3
16	586.8	680.8	791.3	589.8	464.1	438.0	440.3	493.4	532.8	520.8	550.6	576.0	6644.5
17	629.3	677.5	806.6	608.6	481.6	438.1	470.0	440.3	532.8	434.4	550.6	383.6	6403.3
18	452.6	565.9	799.8	612.7	485.5	438.1	429.2	543.1	532.8	520.8	550.6	576.0	6507.1
19	520.1	650.6	840.3	647.9	517.9	456.0	505.3	543.1	532.8	520.8	550.6	408.0	6693.5
20	443.5	552.5	760.2	573.0	454.3	438.0	437.2	443.8	414.0	461.6	550.6	381.8	5910.5
21	438.6	487.4	598.5	526.8	384.4	437.2	359.8	338.9	299.7	424.6	550.6	329.8	5176.3
22	439.1	466.1	599.1	527.0	384.5	437.3	359.8	336.7	297.4	495.1	550.6	322.7	5237.3
23	439.6	488.5	703.2	593.2	469.1	445.2	409.1	543.1	532.8	520.8	550.6	576.0	6351.1
24	532.9	650.7	805.3	603.0	480.3	438.1	424.5	439.8	532.8	469.6	550.6	385.9	6313.5
25	439.1	488.0	627.2	549.0	418.9	437.9	360.3	505.1	431.2	461.0	550.6	312.1	5580.0
26	439.0	488.1	599.6	527.6	385.0	438.0	360.3	443.1	532.8	520.8	550.6	576.0	5860.8
27	663.7	627.1	778.9	584.9	464.5	438.0	427.3	469.1	532.8	466.5	550.6	375.7	6381.2
28	437.0	488.3	599.9	548.9	438.6	438.1	379.1	441.7	532.8	520.8	550.6	576.0	5953.9
29	666.1	708.9	848.1	664.0	500.8	438.2	490.8	476.6	454.1	454.6	544.[illegible]	360.5	6607.2
30	439.3	488.3	599.7	531.4	431.0	438.0	373.9	464.8	532.8	520.8	550.6	576.0	5946.5
31	676.9	767.4	848.1	651.9	495.5	438.2	482.0	469.3	532.8	520.8	550.6	576.0	7009.4
32	677.0	774.1	816.0	612.1	478.2	438.1	440.6	477.4	470.0	520.8	550.6	576.0	6830.8
AVE	543.8	618.9	767.7	601.2	464.6	438.9	429.5	481.7	497.6	487.5	550.2	501.2	6382.9

FORECAST DEMAND ENERGY (GWH)

OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	
677.0	777.6	848.2	773.8	732.5	662.2	590.4	543.1	532.8	520.8	550.6	576.0	7784.9

Table B.10 Potential Spill from Devil Canyon in August

Year Simulated	Energy Potential GWh	Reservoir Operation A — Usable energy at Watana and Devil Canyon proportional to average heads: Usable energy Yr 2010 - GWh	Turbine Q cfs	Spill cfs	Reservoir Operation B — Maximum possible generation of usable energy at Devil Canyon: Usable energy Yr 2010 - GWh	Turbine Q cfs	Spill cfs
1	337.9	337.4	10725	16	337.9	10741	0
2	336.9	296.8	9567	1293	336.9	10860	0
3	342.4	312.4	9727	710	342.4	10727	0
4	331.1	306.1	9797	800	331.1	10597	0
5	315.4	315.4	9972	0	315.4	9972	0
6	446.4	250.3	7716	6992	446.4	13763	747
7	446.4	249.7	7678	6592	446.4	13763	2437
8	344.9	304.7	9534	1265	344.9	10849	0
9	336.5	300.7	9535	1135	336.5	10680	0
10	445.8	251.0	7738	5938	445.8	13763	253
11	328.6	314.4	10023	453	328.6	10476	0
12	355.2	249.1	7760	3306	355.2	11064	0
13	446.4	247.0	7678	12329	446.4	13763	6059
14	446.4	249.7	7698	3629	446.4	13763	[illegible]
15	360.4	247.0	7702	3444	360.4	11134	0
16	342.5	262.1	8165	2874	342.5	10564	0
17	327.8	319.0	10135	279	327.8	10415	0
18	446.4	250.2	7715	12733	446.4	13763	5655
19	546.5	321.7	10139	782	346.5	10730	0
20	348.3	245.8	8191	3414	348.3	11133	0
21	317.5	253.7	8528	2144	317.5	10673	0
22	309.6	269.7	9065	1341	309.6	10406	0
23	364.6	248.6	7748	3616	364.6	11334	0
24	341.0	292.6	9600	1522	341.0	[illegible]	0
25	331.2	243.1	8102	2935	331.2	11027	0
26	343.4	301.1	9456	1483	343.4	10982	0
27	350.5	260.1	8532	2966	350.5	11479	0
28	355.2	268.1	8402	3727	355.2	11131	0
29	334.8	334.8	10936	0	334.8	10937	0
30	344.7	249.8	7716	5421	344.7	10647	0
31	400.5	249.7	7725	4642	400.5	12342	0
32	446.4	250.1	7712	13257	446.4	13763	12312

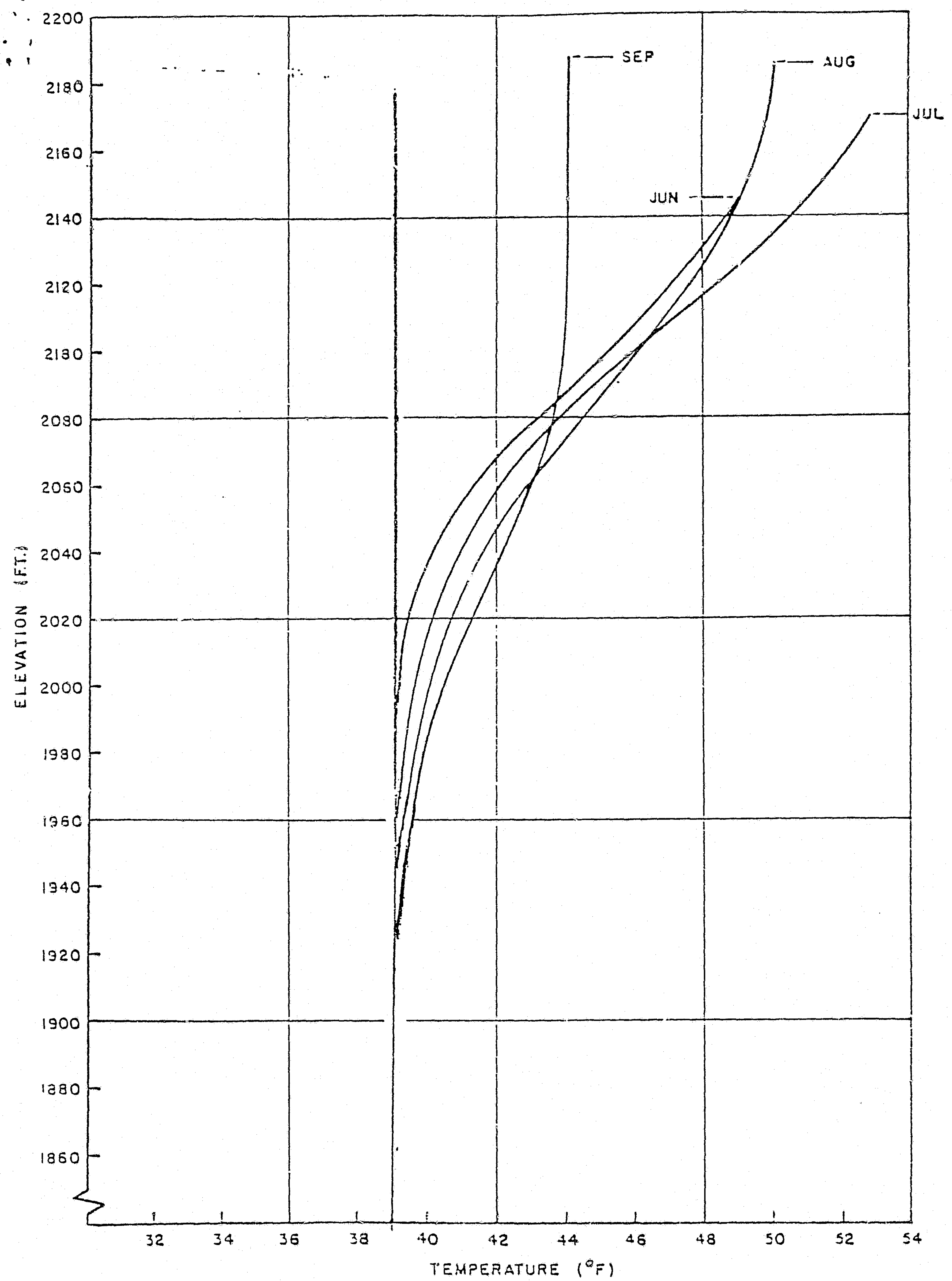
Table B.11 Potential Spill from Watana in August

Year simulated	Energy Potential GWh	Reservoir Operation A — Usable energy at Watana and Devil Canyon Proportioned to average heads: Usable Energy Yr. 2010 – GWh	Turbine Q cfs	Spill cfs	Reservoir Operation B — Maximum possible generation of usable energy at Devil Canyon: Usable energy Yr. 2010 GWh	Turbine Q cfs	Spill cfs
1	213.2	213.2	5553	0	212.7	5540	13
2	253.8	253.8	6576	0	213.7	5537	1039
3	238.2	238.2	6135	0	208.2	5532	773
4	244.5	244.5	[illegible]	0	219.5	5077	547
5	228.7	228.7	5918	0	228.7	5918	0
6	517.5	300.3	7715	5575	104.2	2677	10613
7	498.5	300.9	7692	5072	104.2	2634	10100
8	245.9	245.9	6324	0	205.7	5214	1035
9	249.9	249.9	6461	0	[illegible]	5518	923
10	399.5	299.6	7724	2976	104.8	2702	7598
11	236.2	236.2	6134	0	220.0	5770	337
12	304.7	301.5	7755	82	195.4	5033	2511
13	694.2	301.6	7673	9989	104.2	2651	15011
14	571.8	300.9	7692	6926	104.2	2664	11952
15	356.6	301.6	7677	1353	190.2	4355	4117
16	262.1	262.1	6734	0	202.1	5347	1387
17	231.6	231.6	5993	0	222.8	5775	228
18	633.5	300.4	7710	8550	104.8	2733	14117
19	228.9	228.9	5880	0	204.1	5243	637
20	365.7	304.8	8136	1636	202.3	5433	4331
21	296.9	[illegible]	[illegible]	0	233.1	5504	[illegible]
22	280.9	280.9	[illegible]	0	241.0	6456	1071
23	335.2	[illegible]	7745	851	[illegible]	4770	3975
24	252.0	252.0	6715	0	204.6	5455	1230
25	312.5	307.5	8101	132	211.2	5775	2326
26	247.5	247.5	[illegible]	0	202.2	5138	1214
27	290.5	[illegible]	7567	[illegible]	209.1	5214	[illegible]
28	322.5	[illegible]	[illegible]	0	195.4	5015	2232
29	209.6	209.6	[illegible]	0	207.6	5471	0
30	307.3	300.8	7711	157	205.9	5372	[illegible]
31	396.4	300.7	7701	2451	157.1	[illegible]	[illegible]
32	756.0	300.5	7708	14438	104.2	2673	13473

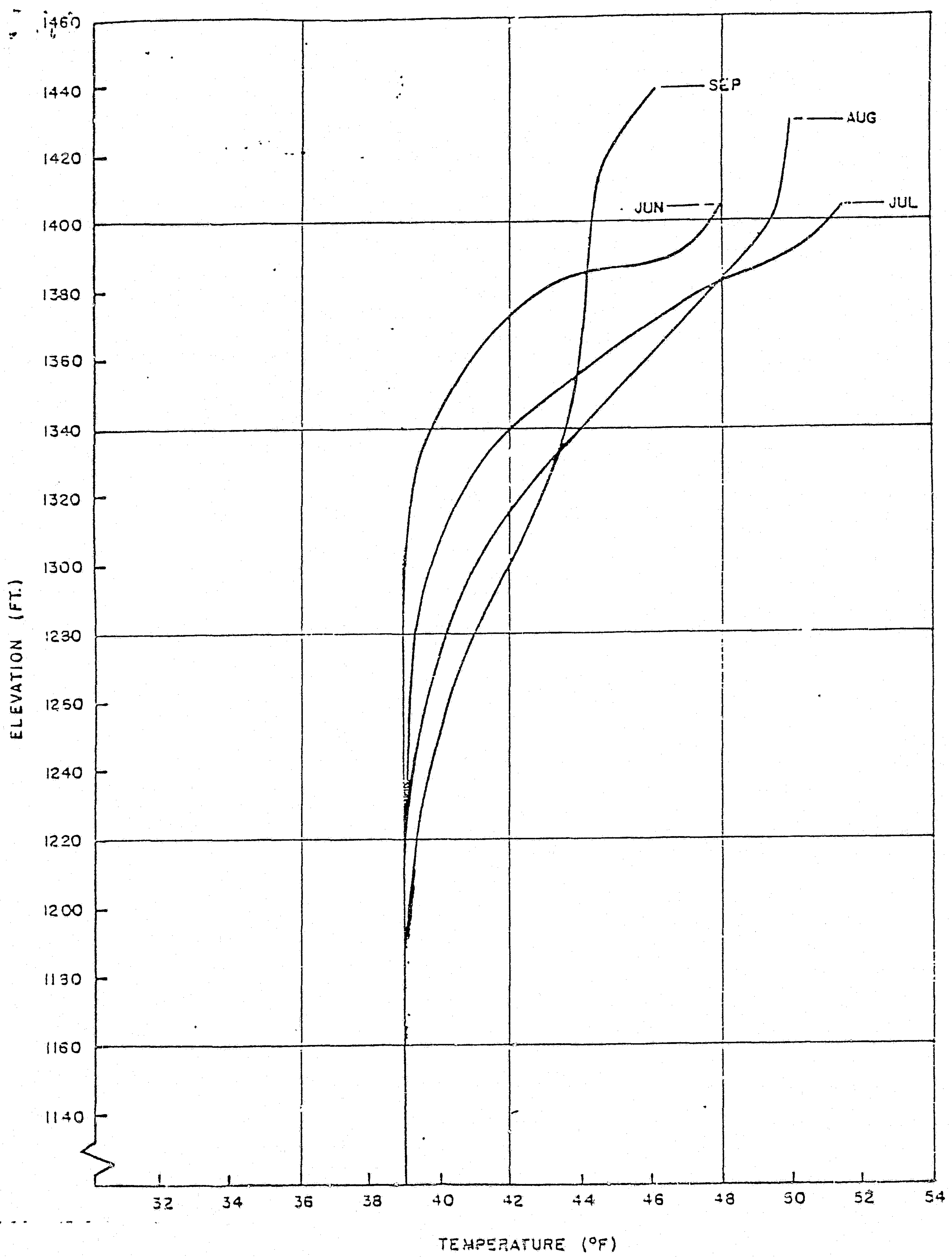
Table B.12 Potential Spills from Devil Canyon in September

Year simulated	Energy Potential GWh	Reservoir Operation A: Usable energy at Watana & Devil Canyon proportional to average heads — Usable energy yr. 2010 GWh	Turbine Q cfs	Spill cfs	Reservoir Operation B: Maximum possible generation of usable energy at Devil Canyon[1] — Usable energy yr. 2010 GWh	Turbine Q cfs	Spill cfs
1	177.9	177.9	6150	0	177.9	6150	0
2	344.3	245.0	8047	3231	344.3	11308	0
3	318.0	246.5	7979	2315	318.0	10274	0
4	247.7	247.7	8149	0	247.7	8149	0
5	254.4	254.4	8220	0	254.4	8220	0
6	432.0	242.6	7920	6069	432.0	13763	226
7	432.0	242.6	7920	8576	432.0	13763	2733
8	423.9	246.1	7990	6743	423.9	13763	771
9	179.3	179.3	5939	0	179.3	5939	0
10	432.0	242.6	7920	7409	432.0	13763	1533
11	363.5	246.1	8021	3227	363.5	11842	0
12	330.0	247.2	7611	2575	330.0	10624	0
13	432.0	242.6	7920	6847	432.0	13763	1004
14	367.7	242.6	7919	3858	367.7	11777	0
15	258.6	258.6	8265	0	258.6	8265	0
16	427.6	247.2	7957	5636	427.6	13763	2680
17	170.4	323.6	5594	0	170.4	5594	0
18	432.0	242.6	7920	7702	432.0	13763	1965
19	178.9	178.9	5910	0	178.9	5910	0
20	178.6	178.6	6202	0	178.6	6202	0
21	167.6	167.6	5823	0	167.6	5823	0
22	164.0	164.0	5696	0	166.0	5696	0
23	316.9	247.1	7758	5342	316.9	10206	0
24	177.1	177.1	6152	0	177.1	6152	0
25	161.8	512.1	5620	0	161.8	5620	0
26	370.9	246.1	7932	4051	370.9	12031	0
27	175.1	175.1	6082	0	175.1	6082	0
28	294.0	246.4	7978	1541	294.0	9619	0
29	172.0	172.0	5973	0	172.0	5975	0
30	307.9	248.3	7926	1902	307.9	9829	0
31	387.4	242.6	7920	4422	387.4	12342	0
32	423.6	242.6	7919	5574	423.6	13473	0

1 [illegible] potential energy as usable on a daily basis



WATANA RESERVOIR TEMPERATURE PROFILE



DEVIL CANYON RESERVOIR TEMPERATURE PROFILE

YEAR CONDITIONS JUNE THROUGH SEPTEMBER

JUL 06 1982

MILO C. BELL
Box 23
[illegible]

RECEIVED
JUN 14 1982
ACRES AMERICAN INCORPORATE

ALASKA POWER AUTHORITY
SUSITNA
FILE P5700
.11.51
SEQUENCE NO. 2244

MEMORANDUM

TO: G. Krishnan

DATE: June 9, 1982

SUBJECT: Lake Comanche Dissolved Nitrogen Study

I am enclosing a copy of the report on the nitrogen study, along with the only slides that were made. I want to get this to you as quickly as possible so have not had negatives made here. Do you mind having this done and sending them to me so the copies we have are complete.

① Pl. Register
② Circulate
File

being arranged

Pl. advise approval for making negatives of the slides (13 nos.)

approved 6/14

The information is being incorporated in my report on N2 Supersaturation

6/10/82

What were the conclusions of this study?

This is base data we requested & shows that the values do not cause any supersaturation & do help in reducing [illegible] somewhat. More significantly, they show that there is not much temperature diff[illegible]

This is rather serious [illegible]

ALASKA POWER AUTHORITY
SUSITNA
FILE P5700
.11.51
SEQUENCE NO. F.2551

ACTION	INFORM.	DISTRIB.	INITIAL
		CAD	
		JDG	
		JWH	
		JPS	
		IPGH	

W.D. Goldcamp

LAKE COMANCHE
DISSOLVED NITROGEN STUDY

Prepared for

Milo Bell
P.O. Box 23
Mukilteo, Washington 98275

Prepared by

Ecological Analysts, Inc.
2150 John Glenn Drive
Concord, California 94520

June 1982

Nitrogen gas in the deep water of a reservoir may be slightly super-saturated due to the hydro-static pressure of the overlying water (Wetzel, 1975). Therefore water flowing from a dam with a deep intake may contain a super-saturated concentration of nitrogen. If this excess nitrogen gas is not rapidly released into the atmosphere, it may cause nitrogen gas bubble disease in fish residing below the dam outfall (Conroy and Herman, 1970).

A study was conducted at Lake Comanche Dam, Mokelumne River, California, to determine the efficiency of the Howell-Bunger Valve in removing super-saturated dissolved nitrogen (N_2) from the dam's tailwater.

The valves spray outfall water into concrete conduits before releasing the water to the stream. This was observed and photographed at Lake Comanche Dam on 28 May, 1981, at a flow of 4000 cfs into the Mokelumne River (see accompanying photos). This creates a turbulent and aerated flow with the purpose of facilitating nitrogen gas release to the atmosphere.

By sampling nitrogen gas in the reservoir near the intake, and at several locations below the outfall valves, the efficiency of the valve was obtained.

METHODS

In order to determine nitrogen gas concentrations at various depths in the reservoir, water samples were collected in Lake Comanche approximately 50 m from the dam directly over the river channel on 28 May 1982. A Van Dorn Bottle was lowered from a boat to collect water samples at depths of 0, 10, 20, 30, and 38.4 m. As reported by East Bay Municipal Utility District the dam intake was at a depth of 38.4 m (126 ft) at the time of the sampling.

Once taken aboard, each sample was poured with minimum turbulence into an airtight bottle and capped in a manner that left no air bubbles in the bottle. Bottles were placed in a cooler for transportation to the lab. Studies conducted by Steve Wilhelms of the Hydraulic Laboratory, U.S. Army Waterway Experiment Station, Vicksburg, Mississippi (personal communication) indicate that brief exposure of deep water samples to atmospheric conditions has little effect on nitrogen gas concentrations. However, he has found that periods of exposure to atmospheric air bubbles during transportation can cause significant changes in nitrogen gas concentrations, hence the need for removing all air bubbles before transportation. Excess water remaining in the Van Dorn Bottles was measured for temperature. The atmospheric pressure measured on site at the time of sampling was 753 mm.

At the tailwater below the dam, water was collected by immersing the sample bottles under the water and capping them in a manner that left no air bubbles in the bottles. Samples were taken at the outfall, 100 m below the outfall, and 200 m below the outfall. Water temperatures were taken at each of these locations. Bottles were placed in a cooler for transportation to the lab. At the time of sampling, the outfall flow was 4,000 cfs. The atmospheric pressure was 753 mm.

The water collected was analyzed for nitrogen gas (N_2) and oxygen (O_2) in a California State Certified Water lab using a Carle Model 8700 Basic Gas Chromatogram with a thermal conductivity conductor several hours after collection.

RESULTS

Location	Depth (m)	Temperature (°C)	N_2 (mg/l)	N_2 % Saturation	O_2 (mg/l)	O_2 % Saturation
Reservoir	0	22.0	14.9	101	9.2	105
	10	14.5	17.0	100	9.3	90
	20	13.2	17.3	99	10.0	94
	30	11.0	17.9	99	10.2	93
	38.4	10.0	18.5	101	9.3	82
Dam Tailwater						
At Valve	0	10.2	17.7	97	11.1	94
100 m downstream	0	10.5	17.3	95	11.2	98
200 m downstream	0	11.5	17.9	97	10.9	98

References

Conroy, D.A., and R. L. Herman. Textbook of Fish Diseases. 1970. T.F.H. Publications, Jersey City, New Jersey. 302 pp.

Wetzel, R. G. 1975. Limnology. W.B. Saunders Company, Philadelphia. 743 pp.