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HYDRAULIC AND HYDROLOGIC MODEL OF THE FLOW CONTROL STRUCTURE AT SMITH AND BYBEE LAKES

by

MARK BOYKO

Technical Report EWR-7-95

A research project report submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

CIVIL ENGINEERING

Portland State University
1995

ENVIRONMENTAL AND WATER RESOURCES ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING
PORTLAND STATE UNIVERSITY
PORTLAND, OREGON 97207-0751

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TO THE DEPARTMENT OF CIVIL ENGINEERING:

The faculty advisor approves the research project report of Mark Boyko submitted September 28, 1995.

Scott A. Wells

Dr. Scott Wells
Faculty Advisor

APPROVED:

Dr. Franz Rad
Department Head

ACKNOWLEDGEMENT

I would like to thank Dr. Scott Wells for his patience and understanding during a very difficult part of my life. Without his help and support I could never have finished this report.

1.0 INTRODUCTION

The Metropolitan Service District (METRO) is responsible for managing Smith and Bybee Lakes and the closure and long term management and monitoring of the St. John's Landfill. As part of the management process, METRO decided to investigate the possibility of constructing a flow augmentation structure to allow water from the Columbia River to enter the Smith and Bybee Lake system and exit the lake system via the existing flow control structure between Bybee Lake and the North Slough. The flow of water from the lakes into the North Slough would have a flushing effect which would improve the water quality of the North Slough, specifically the dissolved oxygen concentrations, to the levels of Smith and Bybee Lakes. The flow augmentation would take place during the late summer and early fall. This time period is when the North Slough experiences its worst water quality due to low flows associated with the low tidal levels of the Willamette River. This process would flush out the North Slough and possibly improve its water quality characteristics.

The goal of this research was to predict the inflow from the Columbia River through a flow augmentation structure to the lake system and then to predict the outflow to North Slough.

2.0 THE SMITH AND BYBEE LAKE SYSTEM AND SURROUNDING AREA

Figure 1 shows the orientation of the Columbia River, Lower Columbia Slough, North Slough, St. John's Landfill, and Smith and Bybee Lakes. Smith and Bybee Lakes are shallow and hydraulically connected. The Columbia River is North-East of the lake system and reaches its closest point near the northern most point of Smith Lake (approximately 1600 feet). The North Slough is hydraulically connected by a flow control structure to the Lower Columbia Slough at the east end of North Slough and borders Bybee Lake along its southwestern shore. The St. John's Landfill is bordered by the North Slough, the Lower Columbia Slough, and Smith and Bybee Lakes. The Columbia River, Lower Columbia Slough, and North Slough are all tidally influenced.

3.0 MODEL CONCEPT

Table 1 shows water quality data for Smith and Bybee Lakes and North Slough. The most significant indicator of poor water quality is the dissolved oxygen (D.O.) concentration. The lowest recorded D.O. concentration in North Slough between April 1993 and August 1994 was 2.1 mg/l on April 15, 1993. On the same day the D.O. concentrations at Smith and Bybee lakes were 10.62 and 9.98, respectively. Hence, flushing the North Slough with water from the lakes would improve the North Slough's water quality. Wells (1995) discusses in detail the impact of this flushing on North Slough water quality. Figure 2 shows the conceptual model. Figure 3 shows a flowchart of the model concept. Flow into the lake system would occur when the water surface elevation (WSE) in the Columbia River exceeds that of the lake system. The two options for the proposed inflow structure are an open channel or a closed channel (e.g., culvert). Flow into the North Slough would occur when the lake system WSE exceeds that of the North Slough which is influenced by the head in the Columbia River.

ABSTRACT

A computer model was created to estimate the amount of water that would enter the Smith and Bybee Lake system through a proposed flow augmentation structure connected to the Columbia River and leave the lake system through the existing flow control structure at the end of the North Slough. The model was calibrated with lake level data from the drawdown of the lakes in the Fall of 1993. Calibration included evaporation and precipitation.

Lower Columbia Slough System

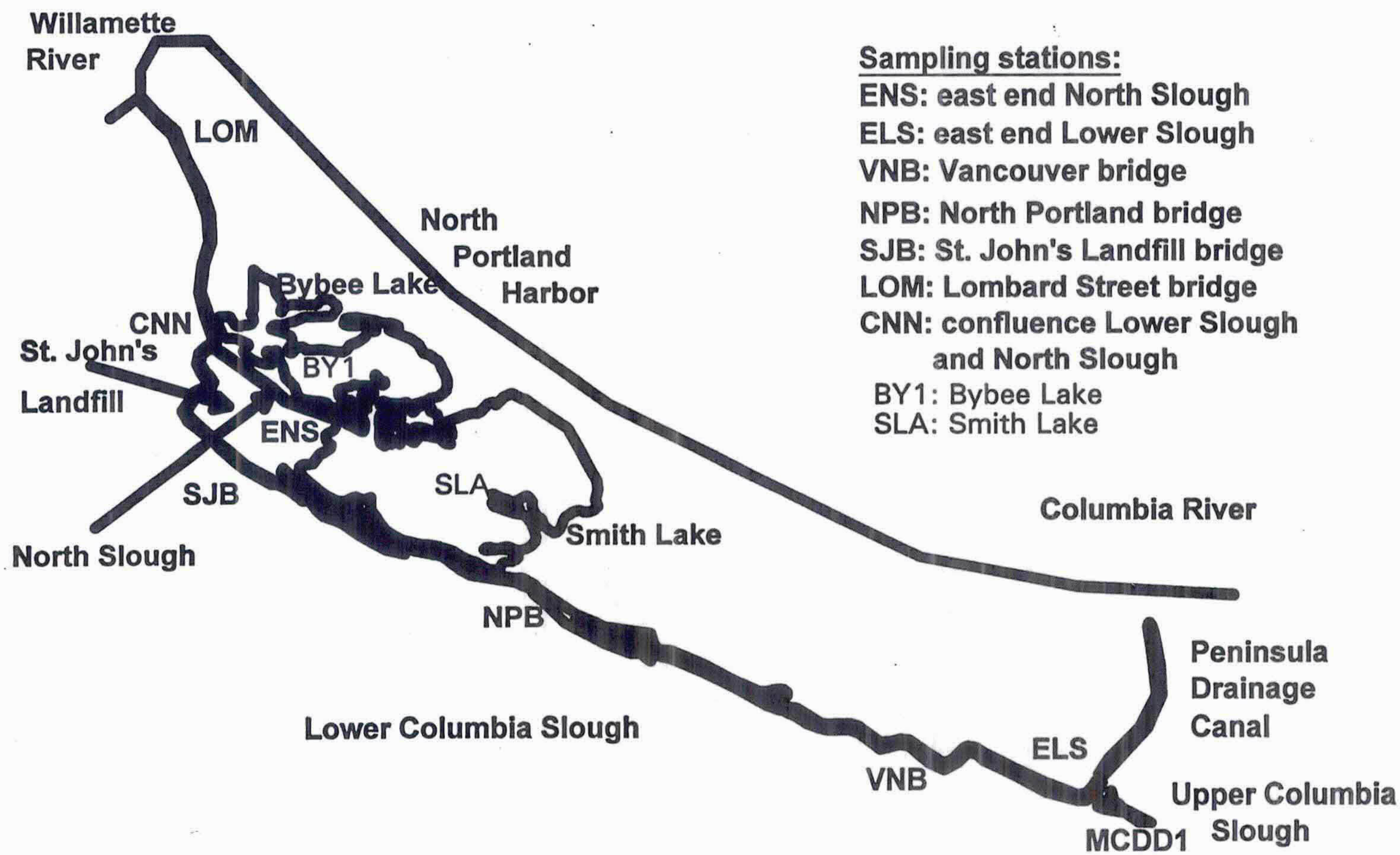


Figure 1: Lower Columbia Slough System

Table 1
Water Quality Data for Smith & Bybee Lakes and the North Slough

Date	Station	Time	Temp. (°C)	pH	Dissolved Oxygen (percent of saturation)	Dissolved Oxygen (mg/l)
15-Apr-93	SL-A	12:00	12.54	7.12	100	10.62
15-Apr-93	BY1	13:00	12.89	7.26	94.5	9.98
15-Apr-93	ENS	13:50	12.9	6.84	20	2.11
06-May-93	SL-A	12:10	16.21	8.07	100.6	9.87
06-May-93	BY1	13:00	16.45	9.01	123	12.01
06-May-93	ENS	15:00	16.75	7.41	71.1	6.89
27-May-93	SL-A	10:30	21.11	7.7	85.5	7.57
27-May-93	BY1	11:05	21.01	7.45	94.2	7.46
27-May-93	ENS	11:40	20.18	7.7	103.4	9.29
10-Jun-93	SL-A	10:45	18.49	7.52	79	7.4
10-Jun-93	BY1	11:10	19.06	7.69	88.3	8.15
10-Jun-93	ENS	11:35	18.87	7.1	56.3	5.23
01-Jul-93	SL-A	10:45	20.67	7.47	88	7.98
01-Jul-93	BY1	11:20	21.52	7.55	89.3	7.89
01-Jul-93	ENS	12:40	21.01	7.12	77.5	6.91
15-Jul-93	SL-A	10:20	19.53	7.09	83.6	7.7
15-Jul-93	BY1	11:00	19.77	7.09	80	7.33
15-Jul-93	ENS	11:40	19.51	6.73	51.9	4.77
03-Aug-93	SL-A	12:45	24.85	8.15	108.1	8.91
03-Aug-93	BY1	13:30	26	7.98	102.5	8.28
03-Aug-93	ENS	14:20	25.67	7.04	47.3	3.84
20-Aug-93	SL-A	11:20	21.64	7.78	97.1	8.53
20-Aug-93	BY1	12:00	22.46	7.59	94.7	8.19
20-Aug-93	ENS	14:05	22.87	6.8	70.6	6.06
30-Aug-93	BY1	15:45	22.74	8	107.7	9.29
30-Aug-93	ENS	16:00	25.14	7.79	139.4	11.49
31-Aug-93	BY1	9:40	20.62	7.06	79.4	7.12
31-Aug-93	ENS	10:12	20.81	7.21	84.8	7.58
09-Sep-93	SL-A	12:30	23.34	8.74	130	11.07
09-Sep-93	BY1	13:30	24.02	8.01	104.2	8.75
09-Sep-93	ENS	14:30	25.03	7.64	102.7	8.47
20-Sep-93	SL-A	11:45	16.37	7.27	70.4	6.93
20-Sep-93	BY1	12:40	17.29	7.23	75.1	7.23
20-Sep-93	ENS	13:30	14.8	7.04	91.3	9.28
08-Oct-93	SL-A	12:43	15.77	7.38	68.1	6.76
08-Oct-93	BY1	13:30	16.26	7.65	68.4	6.73
08-Oct-93	ENS	14:15	16.93	7.23	88	8.53
09-Feb-94	SL-A	13:25	2.75	7.5	101.3	13.63
09-Feb-94	BY1	14:15	3.19	7.56	104.3	13.9
09-Feb-94	ENS	12:20	3.44	7.16	86.5	11.45
25-Aug-94	SL-A	13:30	21.15	9.25	88.5	8.73
25-Aug-94	BY1	14:00	21.85	9.14	87.5	7.64
25-Aug-94	ENS	11:05	19.98	7.56	39.7	3.65

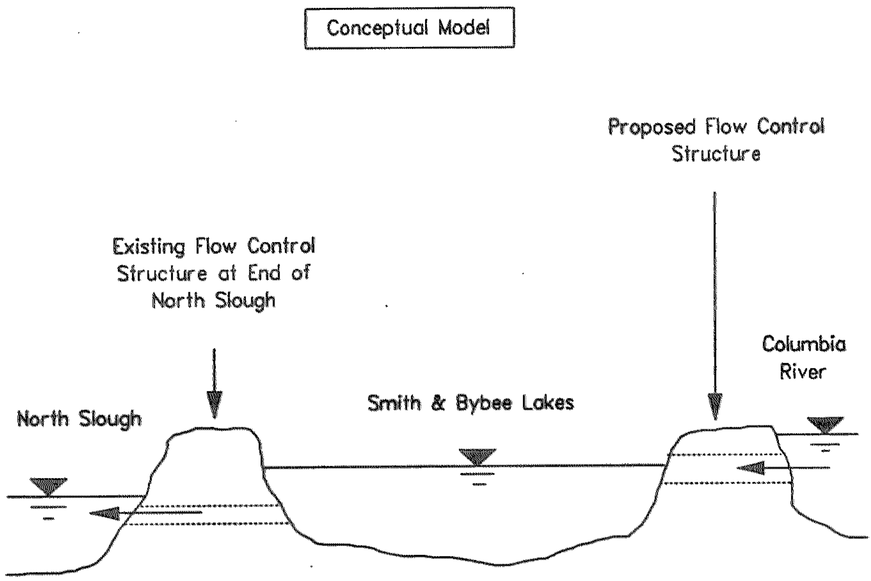


Figure 2: Conceptual Model

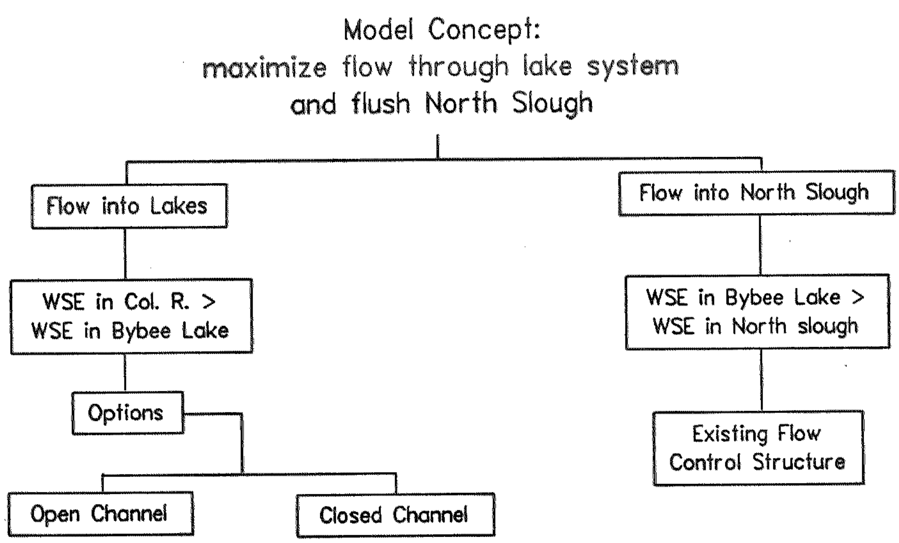


Figure 3: Conceptual Model Flowchart

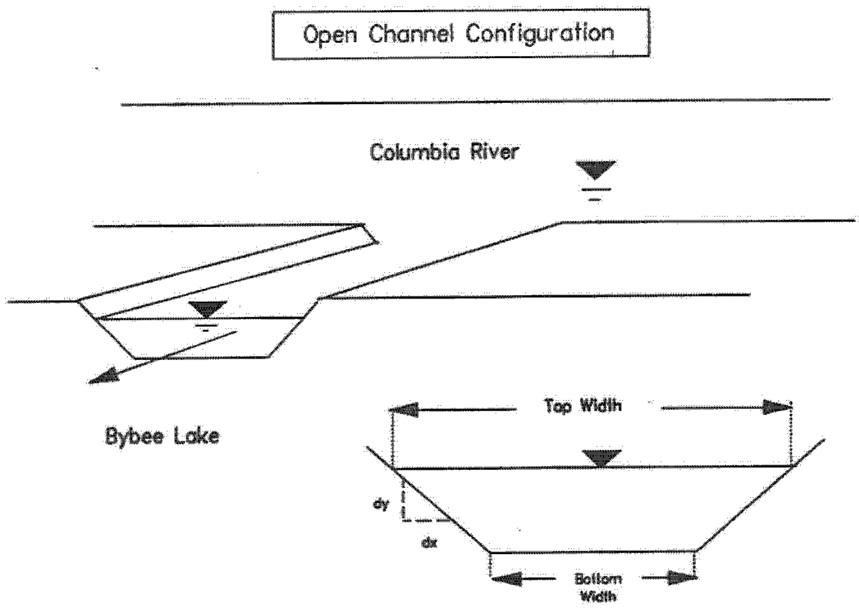


Figure 4: Open Channel Configuration

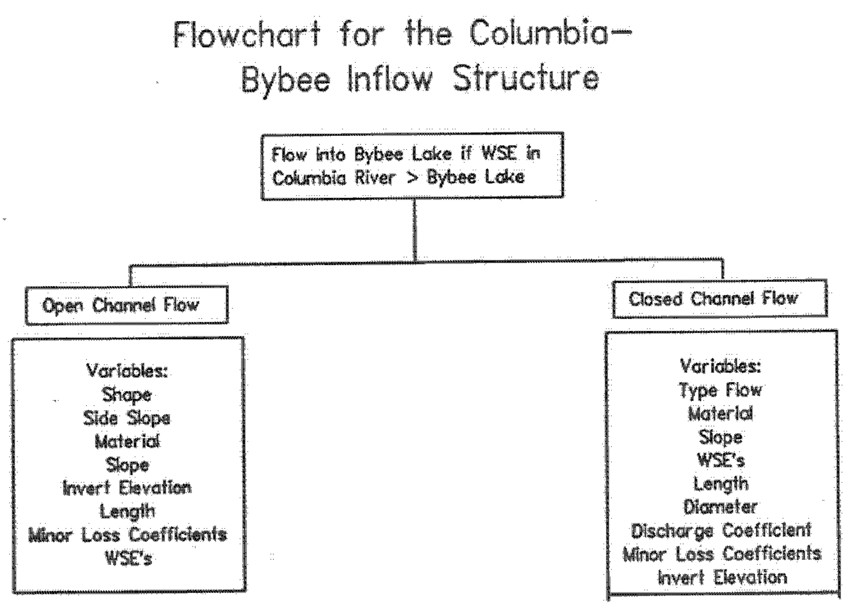


Figure 5: Open and Closed Channel Variables

The open channel configuration between the Columbia River and Smith Lake evaluated was a trapezoidal channel. Trapezoidal shaped channels are the hydraulically most efficient shape. Figure 4 shows this configuration.

Figure 5 shows the variables used in the hydraulic model for both the open and the closed channel configurations.

Figure 6 shows the existing flow control structure at Bybee Lake and the North Slough. It has a two inlets for water from the lakes; one higher than the other. A flap gate on the North Slough end prevents water from North Slough from entering the lake system.

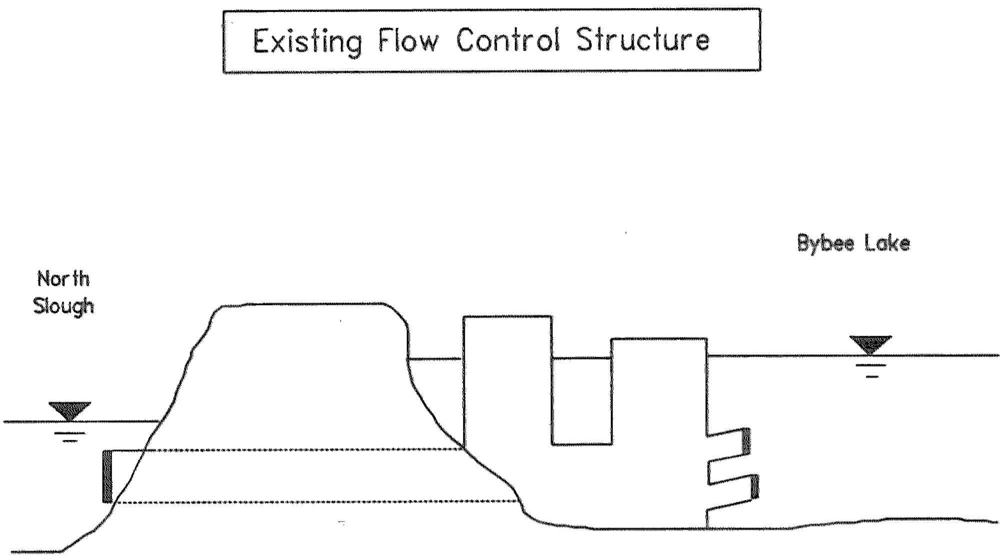


Figure 6: Existing Flow Control Structure

4.0 MODEL METHODOLOGY

4.1 Objective

The objective of the model was to predict the inflow to the lake system from an open or closed channel, incorporating gravity flow from the Columbia River. The outflow from the lake system to the North Slough would then be estimated based upon the head of the lake system and the design of the existing flow control structure. An estimate of the water losses of the lake system due to evaporation and of the water gains through precipitation were also made. The model was calibrated using

using meteorological and lake system water surface level data recorded during the drawdown that took place between September - November 1993.

4.2 Assumptions

The model did not account for groundwater flow into or out of the lake system. (The results presented in the water balance model below seem reasonable without additional losses or gains from groundwater.) The evaporation and precipitation estimates were based on meteorological data collected by the National Weather Service at Portland International Airport and was assumed to be representative of the Smith and Bybee Lakes area. Runoff from precipitation was not included in the model.

4.3 Input Data

Water surface elevation data have been collected by Portland State University (PSU) at the east end of the North Slough and in the lake system. The U.S. Army Corps of Engineers (COE) provided historical water surface elevation data for the Columbia River. Meteorological data were from the National Weather Service at the Portland International Airport. These data (file NOAAMOD.DAT), the average daily temperature, average dew point, precipitation, and average wind speed, were input data to the model, HYDRO.FOR, which calculated the precipitation and evaporation water losses and gains.

4.3.1 Evaporation Model

The evaporation in a lake system can be approximated by the following equation (Gupta, 1989):

$$E_{day} = 0.0138 e_a (1 - RH)(1 + 0.0098 W)$$

where

E_{day} = evaporation per day (inches)
e_a = saturation vapor pressure at the mean air temperature (mm Hg)
RH = Relative Humidity
W = wind speed (miles/day)

The saturation vapor pressure was calculated from the following equation (Linsley et al, 1982):

$$e_a = 25.4 * (-0.132579 + 0.014123 * T_a - 0.000233125 * T_a^2 + 2.98306 * 10^{-6} * T_a^3)$$

where

e_a = saturation vapor pressure at the mean air temperature (inches Hg)

The relative humidity, RH, can be approximated by the following equation (Linsley et al, 1982):

$$RH = 100\left(\frac{112 - 0.1T_a + T_d}{112 + 0.9T_a}\right)^8$$

where

T_a = air temperature (°C)
T_d = dewpoint temperature (°C)

The output file from the program HYDRO.FOR, HYDRO.DAT, provided the evaporation and precipitation in inches per day. This file was used in the main model, MODEL.FOR, in the SUBROUTINE EVAPPREC (Appendix D).

4.3.2 Lake System

Prior studies (Fishman 1987) have established relationships between the lakes water surface elevation and volume. From these data a mathematical relationship was developed using the graphing software, SURFER, such that for any lake water surface elevation the volume and surface area can be estimated (Figure 7).

A regression analysis was performed on the area and volume of the lakes as a function of water elevation. The regression formula for volume as a function of water level was:

$$vol = -1757.08 + 10.7763 * h + 50.5127 * h^2$$

where

vol = lake volume (acre-feet)
h = water surface elevation (feet MSL)

The regression equation for lake surface area as a function of water elevation was:

$$area = -4151940 - 9228770 * h + 3632870 * h^2 - 292929 * h^3 + 7310.35 * h^4$$

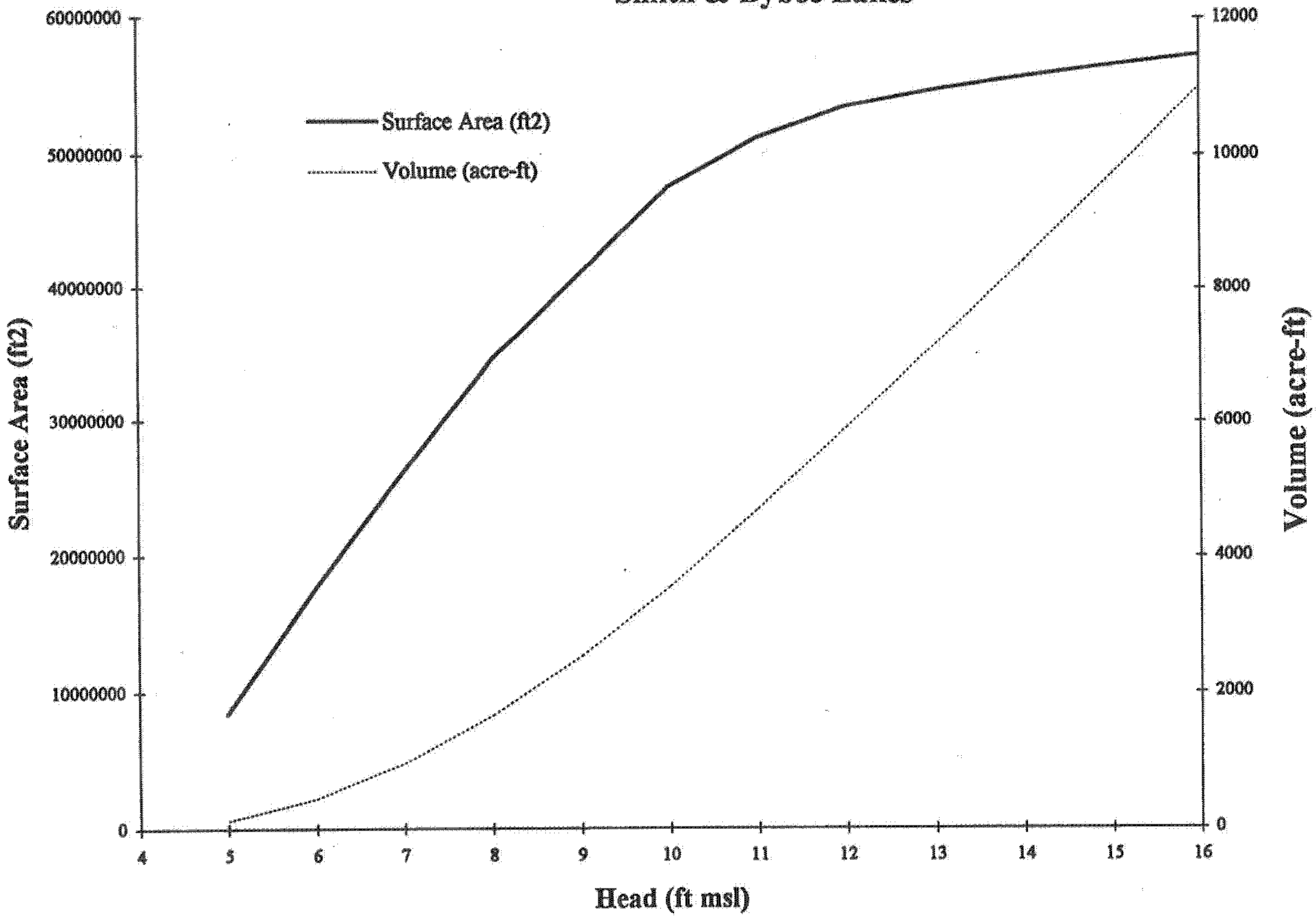
where

area = lake surface area (ft^2)
h = water surface elevation (feet MSL)

These regression equations were determined using GRAPHER's curve fitting functions.

Figure 7

Smith & Bybee Lakes



4.3.3 Proposed Flow Augmentation Structure*

The location for the flow augmentation structure was initially chosen at the location of the shortest distance between the Columbia River and the lake system. The distance was approximately 1600 feet. The model had the options of using an open channel or a closed channel (culvert). Common variables for each configuration were the invert elevation of the channel at the Columbia River, invert elevation where the channel meets the lake system, length, slope, Manning's roughness coefficient (a function of the channel material), and an estimate of a discharge coefficient to apply to the one way flow gate where the channel terminates at the lake system.

The open channel had the following variables: channel side slope, bottom width. The open channel was assumed to be constructed of concrete. The closed channel had the following additional variables: type of material (i.e., concrete or corrugated metal) and diameter.

The open channel flow calculations were made in the SUBROUTINE OPENC in the program MODEL.FOR. The fundamental equation applied was Manning's equation for steady, open channel flow (Gupta, 1989):

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}$$

where

Q= discharge (cubic feet per second [cfs])
A = cross sectional area of discharge (ft^2)
R = Hydraulic Radius (ft)
S = channel slope (ft/ft)

The closed channel flow calculations were based on fundamental culvert design equations. In this model the three types of flow used were types 3, 4, and 5. Figures 8-10 show the possible flow situations. For Type 3 culvert flow, the flow was estimated by the following equation (Gupta 1989):

$$Q = C_d A_{exit} \sqrt{2g(H + z - h_{inlet} - h_{exit} - h_{culvert}}$$

where

Q= discharge (cubic feet per second [cfs])
C_d = discharge coefficient
A_{exit} = cross sectional area of discharge (ft^2) at exit
g = gravitational acceleration (ft^2/s)
h = height of Columbia WSE above the channel exit invert
h_{inlet} = inlet head loss
h_{exit} = exit head loss
$h_{culvert}$ = head loss through the culvert

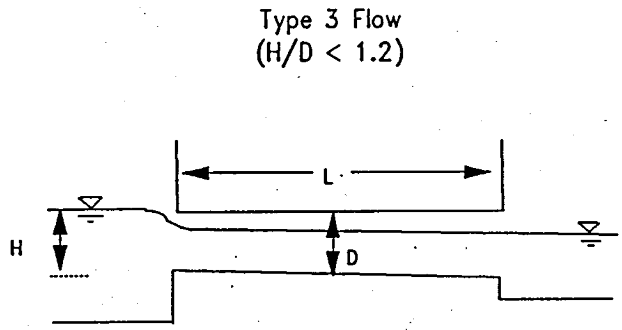


Figure 8: Type 3 Culvert Flow

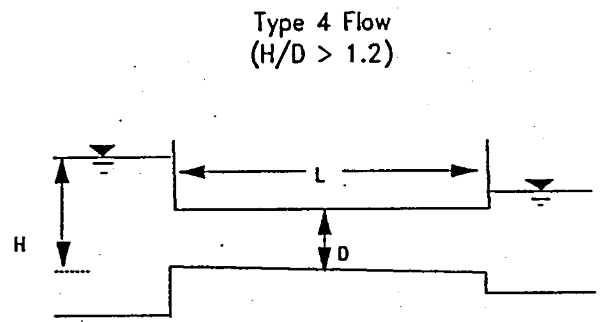


Figure 9: Type 4 Culvert Flow

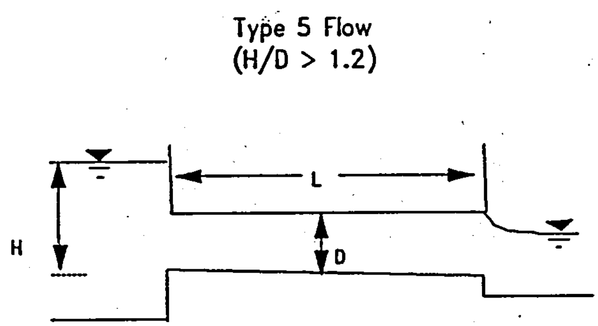


Figure 10: Type 5 Culvert Flow

For Type 4 culvert flow, the flow was estimated by the following equation (Gupta 1989):

$$Q = C_d A_c \sqrt{\frac{2g(h - h_{exit})}{1 + 29C_d^2 n^2 L / R_c^{4/3}}}$$

where

Q= discharge (cubic feet per second [cfs])
C_d = discharge coefficient
A_c = cross sectional area of culvert (ft^2)
g = gravitational acceleration (ft^2/s)
h = height of Columbia WSE above the channel exit invert
h_{exit} = exit head loss
n = Manning's roughness coefficient for the culvert material
L = length of culvert (ft)
R_c = hydraulic radius of the culvert

For Type 5 culvert flow, the flow was estimated by the following equation (Gupta 1989):

$$Q = C_d A_c \sqrt{\frac{2g(h - D)}{1 + 29C_d^2 n^2 L / R_c^{4/3}}}$$

where

Q= discharge (cubic feet per second [cfs])
C_d = discharge coefficient
A_c = cross sectional area of culvert (ft^2)
g = gravitational acceleration (ft^2/s)
h = height of Columbia WSE above the channel exit invert
D = diameter of the culvert (ft)
n = Manning's roughness coefficient for the culvert material
L = length of culvert (ft)
R_c = hydraulic radius of the culvert

The determination of which type of flow to use was based on the water surface elevations at both ends of the culvert.

4.3.4 Flow Control Structure Between North Slough and Bybee Lake

The existing flow control structure, Figure 6, consists of a 62.5 ft. long corrugated metal pipe (CMP) with a 60 inch diameter. At the North Slough end is a flap gate that prevents water from the North Slough from entering the lake system. There is a high flow overflow segment, an adjustable weir, and a canal gate. The adjustable weir has a minimum elevation of 8.4 ft. mean sea level (MSL) and water reaches the weir through a 36 inch diameter grated intake with an invert elevation (i.e.) of 6.9 ft. MSL.

The water reaches the canal gate through a 30 inch diameter g/rafed intake with an invert elevation of 5.5 ft. MSL. For lake levels below 5.5 ft. MSL there will be no flow through the structure.

4.3.4.1 Adjustable Weir

The adjustable weir was modeled as a weir with two end contractions (Figure 11). The following equation was used to estimate the flow over the weir (Gupta, 1989):

$$Q = \frac{2}{3} C_d \sqrt{2g}(L - 0.2H)H^{3/2}$$

where,

Q = discharge (cfs)
C_d = discharge coefficient
g = gravitational acceleration (ft^2/s)
H = upstream head above the weir (ft)

In the development of this equation it was assumed that the upstream velocity was zero. Head losses due to the intake structure will be accounted for in the weir discharge coefficient. The adjustable weir has a maximum elevation of 13.4 ft. mean sea level (MSL) and a minimum elevation of 8.4 ft. MSL..

4.3.4.2 Canal Gate

The canal gate (Figure 12) consists of a 30 inch circular opening that is covered by a circular plate. The circular plate can be raised to open the canal gate. The canal gate was modeled as a sluice gate. The following equation was used to estimate the discharge through the canal gate (Gupta, 1989):

$$Q = C_g A \sqrt{2gh}$$

where,

Q = discharge (cfs)
C_g = discharge coefficient
g = gravitational acceleration (ft^2/s)
h = upstream head over the gate (ft)

As with the adjustable weir, the head losses due to the intake structure will be accounted for in the canal gate discharge coefficient.

5.0 ESTIMATE OF FLOWS FROM COLUMBIA RIVER TO SMITH LAKE

5.1 Variables Used

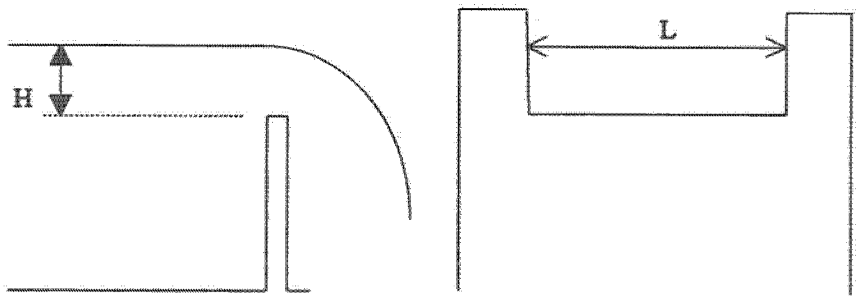


Figure 11: Weir Configuration

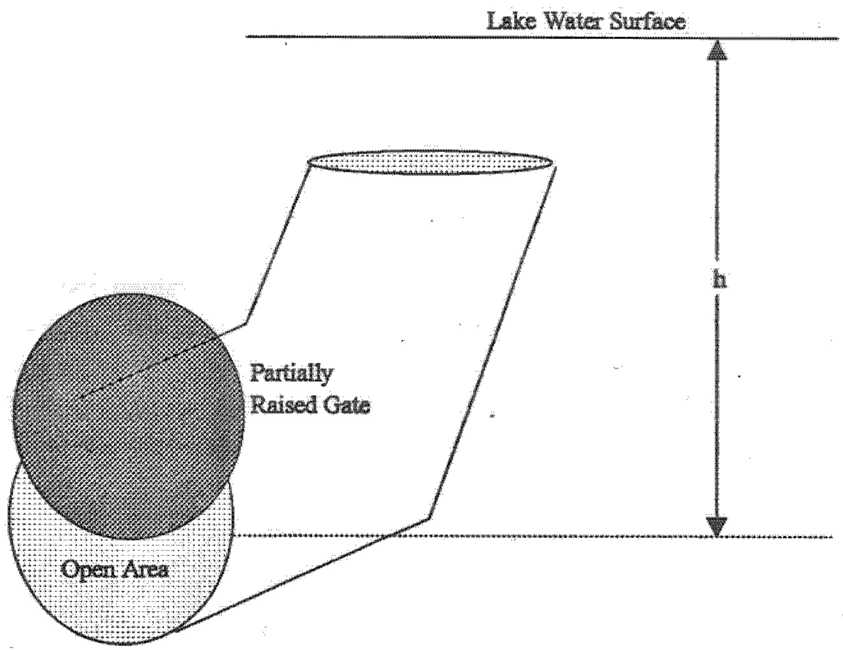


Figure 12: Canal Gate Configuration

For both open and closed channel configurations of the proposed flow augmentation structure a slope of 1 foot per 1000 feet was chosen. This is a very mild slope and initially chosen to minimize the vertical drop over the length of the channel (1.5 ft drop over a length of 1500 ft.). For the open channel the bottom width was varied from 10 - 20 ft. and a constant side slope of 1:1 was used. For the closed channel a diameter of 6 - 12 feet was used. The Manning's roughness coefficients were chosen as mid points in their ranges for the types of materials. The invert elevation of both channels at the Columbia River was initially set to 9 ft MSL. This was set because 1600 ft from the Columbia River would be at the 9 ft MSL contour in Smith Lake (see Figure 13). The initial discharge coefficients used for both the weir and the canal gate were 0.6 which was based upon typical coefficients for those types of structures (Gupta 1989).

The water surface elevation data for the Columbia River and North Slough was from December 3, 1992 - February 11, 1993.

5.2 Results

It was immediately apparent that the closed channel configuration was impractical as evident in the very small rise in the lake levels. No significant flow was reaching the lake system. This was due to the much smaller cross-sectional area of the discharge for a circular channel as opposed to a trapezoidal channel at the same invert elevations. The model was run for the open channel configuration with varying bottom widths and entrance invert elevations. And the canal gate was varied for closed, half open, and fully opened configurations. The weir was set at the lowest point, 8.4 ft. MSL. The model predicted very little change in flow through the canal gate from half open to fully open. It also predicted very little net inflow from the Columbia River during this time period. Appendix A contains some representative graphs of the results (note that the time axis is in Julian day and corresponds to the time period of from December 3, 1992 - February 11, 1993).

Historical Columbia River peak daily head data were obtained from the U.S. Army Corps of Engineers (COE). Figure 14 show the data mean daily peak head covering the years 1973-1990. These data show that the Columbia River water surface elevation is very low during the time period of late summer and early fall. The historical data indicate the impracticability of using a flow augmentation structure that relies on gravity flow during low-water periods.

6.0 CALIBRATION OF HYDRAULIC MODEL BETWEEN BYBEE LAKE AND NORTH SLOUGH

6.1 Calibration Data

METRO performed a drawdown test on the lake system from September - November 1993. Besides taking water quality data, water levels in the lakes and North Slough were recorded. The North Slough water surface elevation data from the same time period were also used. The results of the drawdown test and final model calibration are shown in Figure 15. Figure 16 shows the final model output of predicted lake level and discharge through the existing flow control structure.

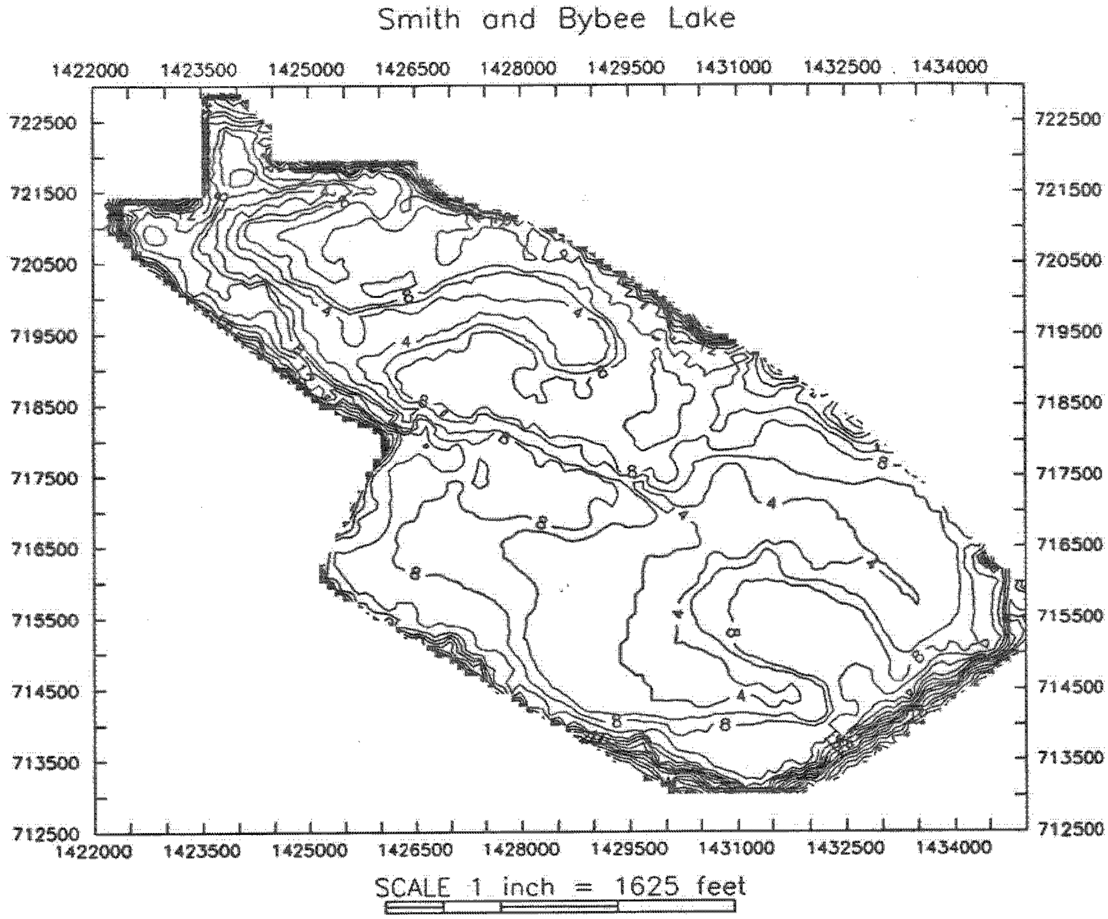


Figure 13: Smith and Bybee Lake Bathymetry

Figure 14

Columbia River Mean Daily Peak Head
1973 - 1990

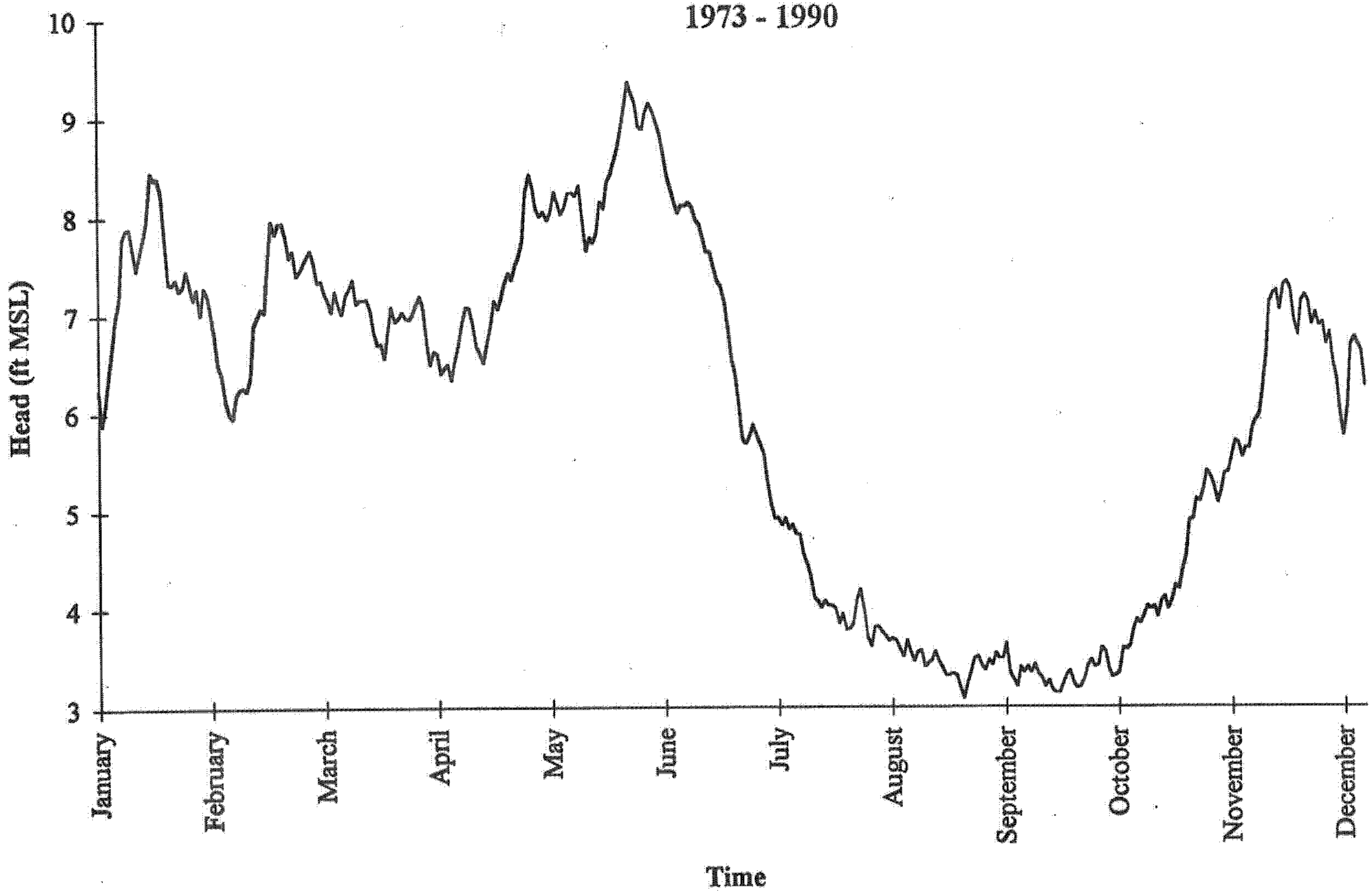


Figure 15

Model Calibration

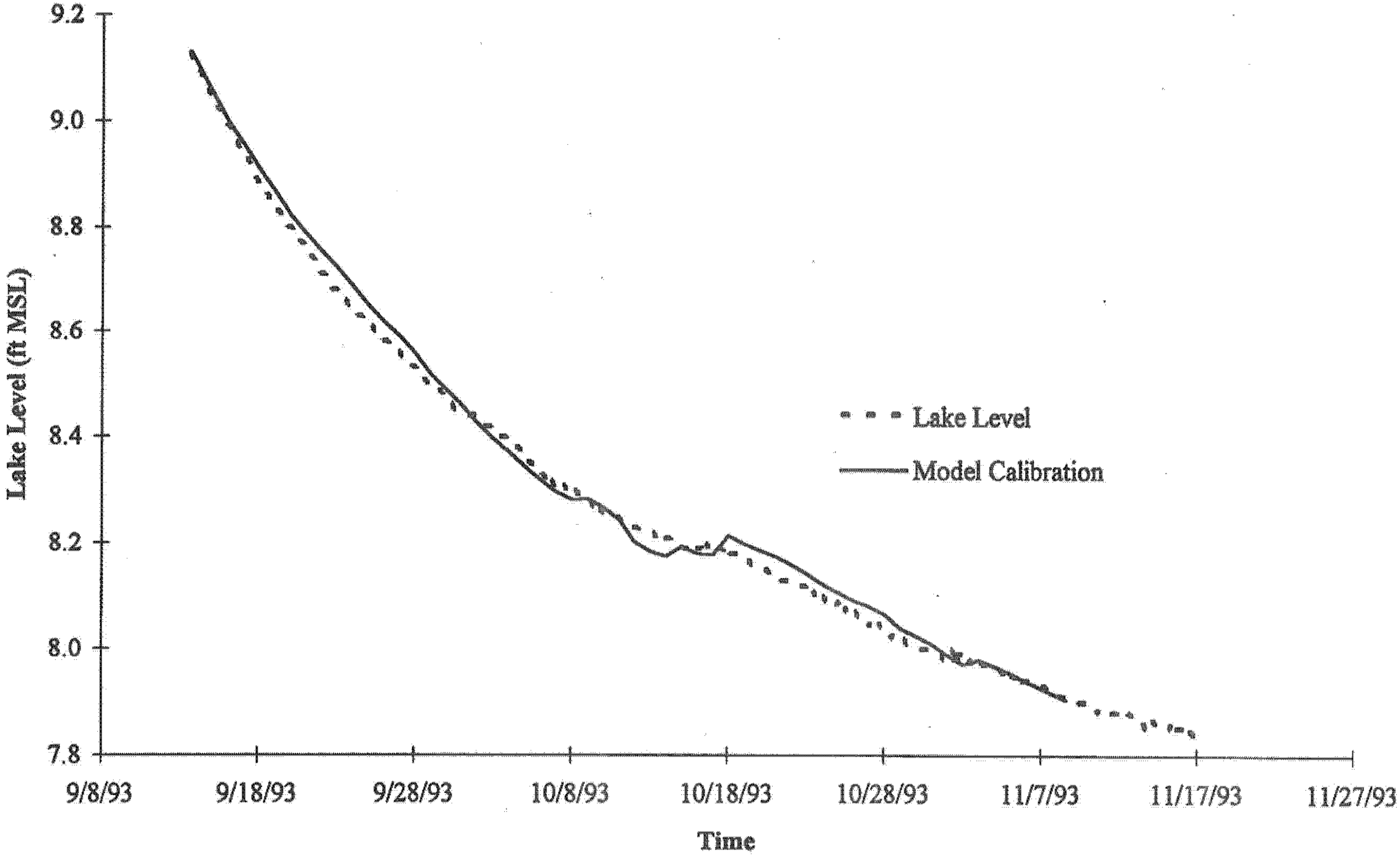


Figure 16

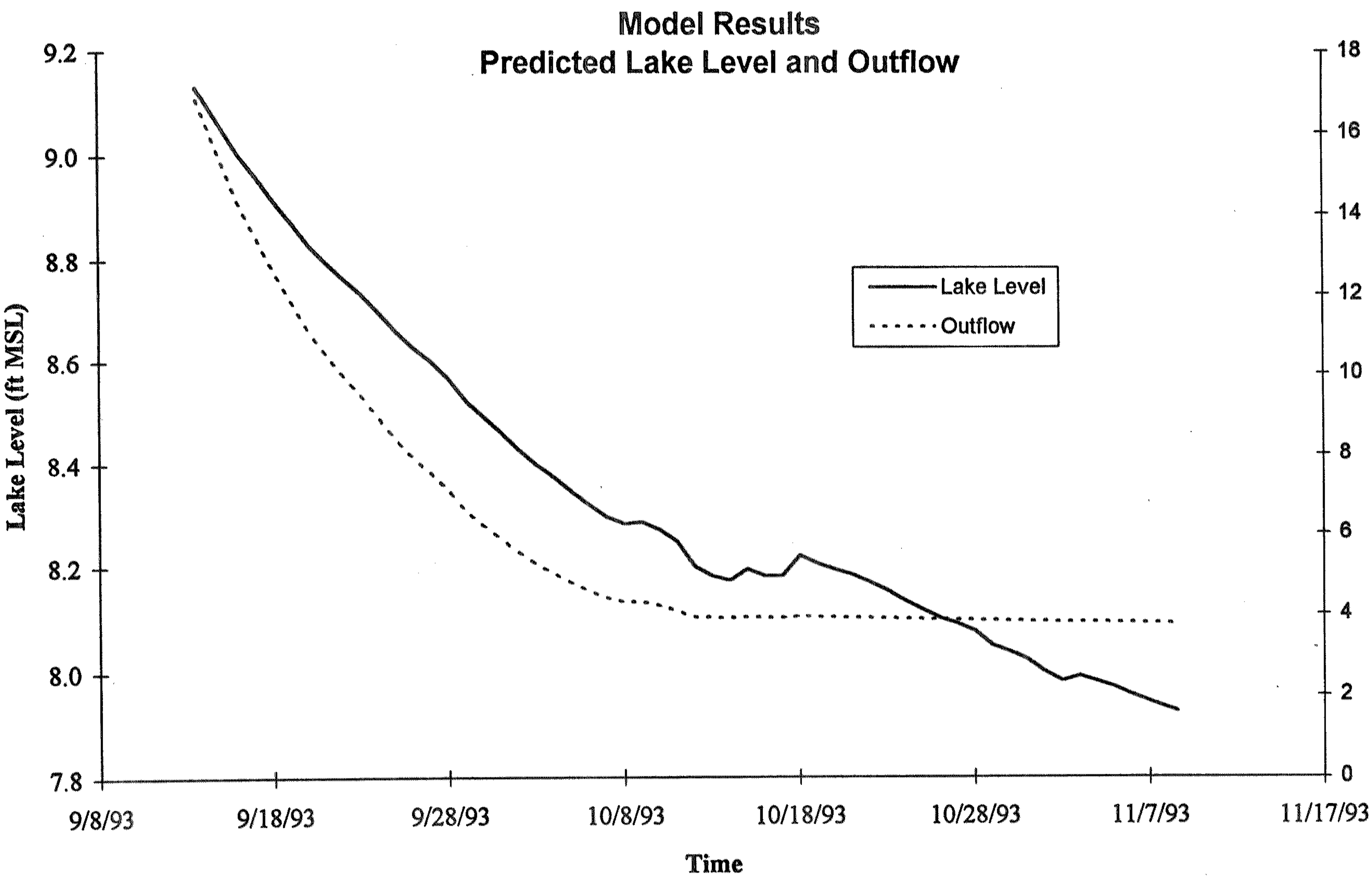

Model Results
Predicted Lake Level and Outflow
Lake Level (ft MSL)
9.2
9.0
8.8
8.6
8.4
8.2
8.0
7.8
Outflow (cfs)
18
16
14
12
10
8
6
4
2
0
Lake Level
Outflow
9/8/93
9/18/93
9/28/93
10/8/93
10/18/93
10/28/93
11/7/93
11/17/93
Time

Figure 17 shows the water losses through the flow control structure and through evaporation and the water gain through precipitation.

6.2 Calibration

The model was calibrated by adjusting the discharge coefficients for the weir and canal gate. When the lake system water surface elevation was below the weir elevation, the outflow was only from the canal gate. During calibration it became evident that the weir's elevation was closer to 8.2 ft MSL rather than the 8.4 ft MSL specified in the engineering plans. Metro had surveyed the structure in 1993. During the survey it was noted that the corner of the structure where the weir is located was approximately 0.2 feet below the specified plan elevation. The model was adjusted to reflect a weir elevation of 8.2 ft MSL. The discharge coefficients used in the final calibration were 0.65 and 0.07 for the weir and canal gate, respectively. The discharge coefficient for the weir was in the typical range (Gupta 1989). The discharge coefficient for the canal gate seemed low, and probably reflect the entrance losses, gate losses, and exit losses. Other losses occurred due to plant matter and debris build up on both of the entrance grates.

7.0 CONCLUSION

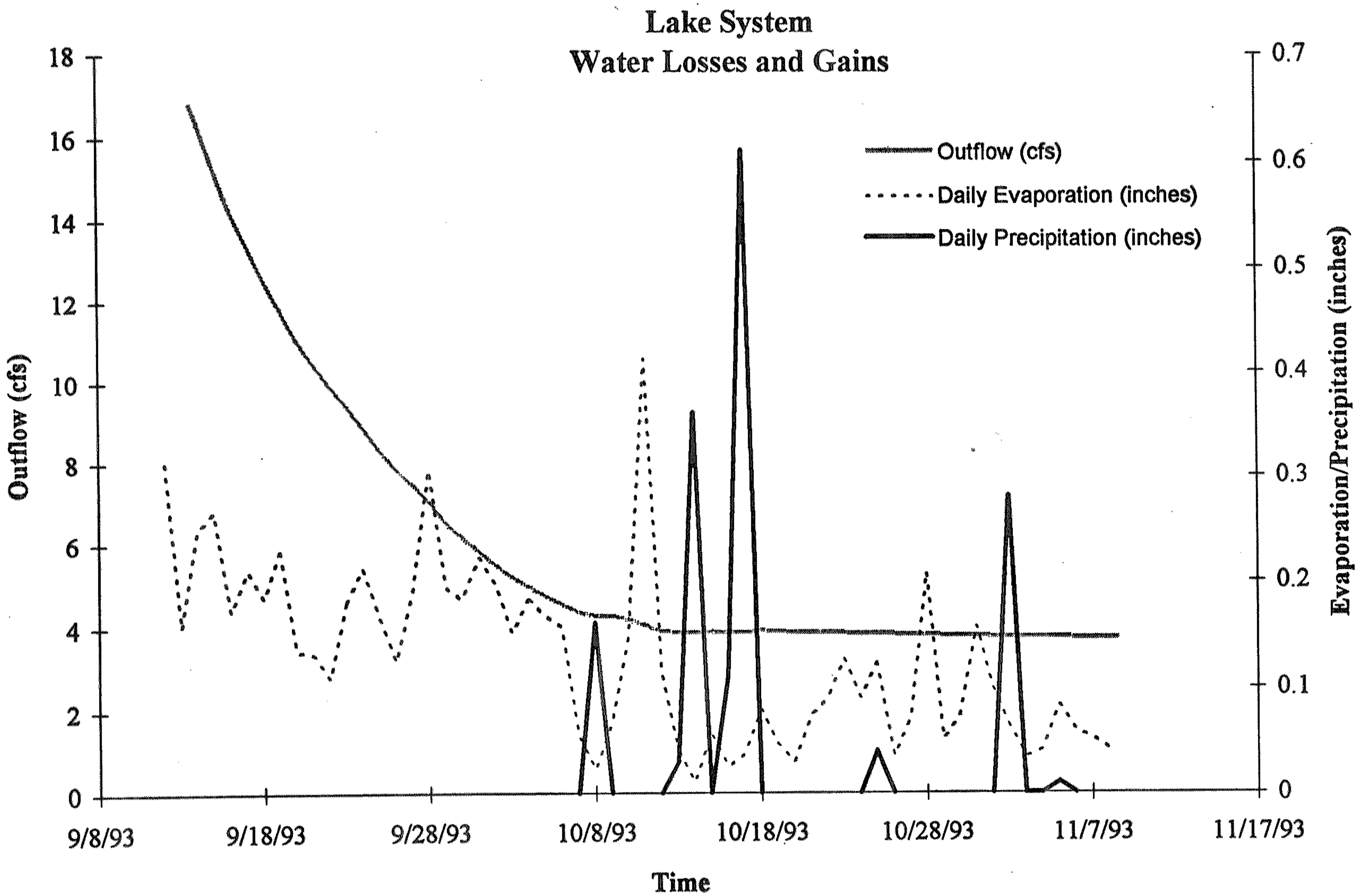
The proposed flow augmentation structure was impractical due to low Columbia River water surface elevations during the period of late summer and early fall and the shallow lake system. The low water surface elevation in the Columbia River did not provide enough head for gravity flow into the lake system and then out through North Slough. Any flow augmentation during this time period would require pumping water.

The calibration results do not indicate that any significant amount of water is entering or exiting the lake system through groundwater interactions during the drawdown period.

A program, PUMP.FOR (provided in Appendix C), calculates the net volume, length of time, and increase in water surface elevation of the lake system for a known pumping rate. If water could be pumped into the lake system it could allow for the flushing of the North Slough.

The total amount of precipitation during the drawdown period was 1.6 inches. The estimated loss through evaporation was approximately 7.5 inches. Although it was difficult to predict the amount of rainfall, the amount of rainfall relative to the evaporation was comparatively small. If the model is run for a representative year of meteorological data, it could be used to reasonably predict the drawdown of the lakes during low precipitation periods. The outflow through the structure could also be used as input data to a water quality model of the North Slough.

Figure 17


Lake System
Water Losses and Gains
Outflow (cfs)
Daily Evaporation (inches)
Daily Precipitation (inches)
Outflow (cfs)
Evaporation/Precipitation (inches)
Time
0
2
4
6
8
10
12
14
16
18
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
9/8/93
9/18/93
9/28/93
10/8/93
10/18/93
10/28/93
11/7/93
11/17/93

References:

Gupta, R.S., Hydrology and Hydraulic Systems, Prentice Hall, New Jersey, 1989.

Linsley, R.K., Kohler, M.A., Paulhus, J.L.H., Hydrology for Engineers, McGraw-Hill, New York, 1982.

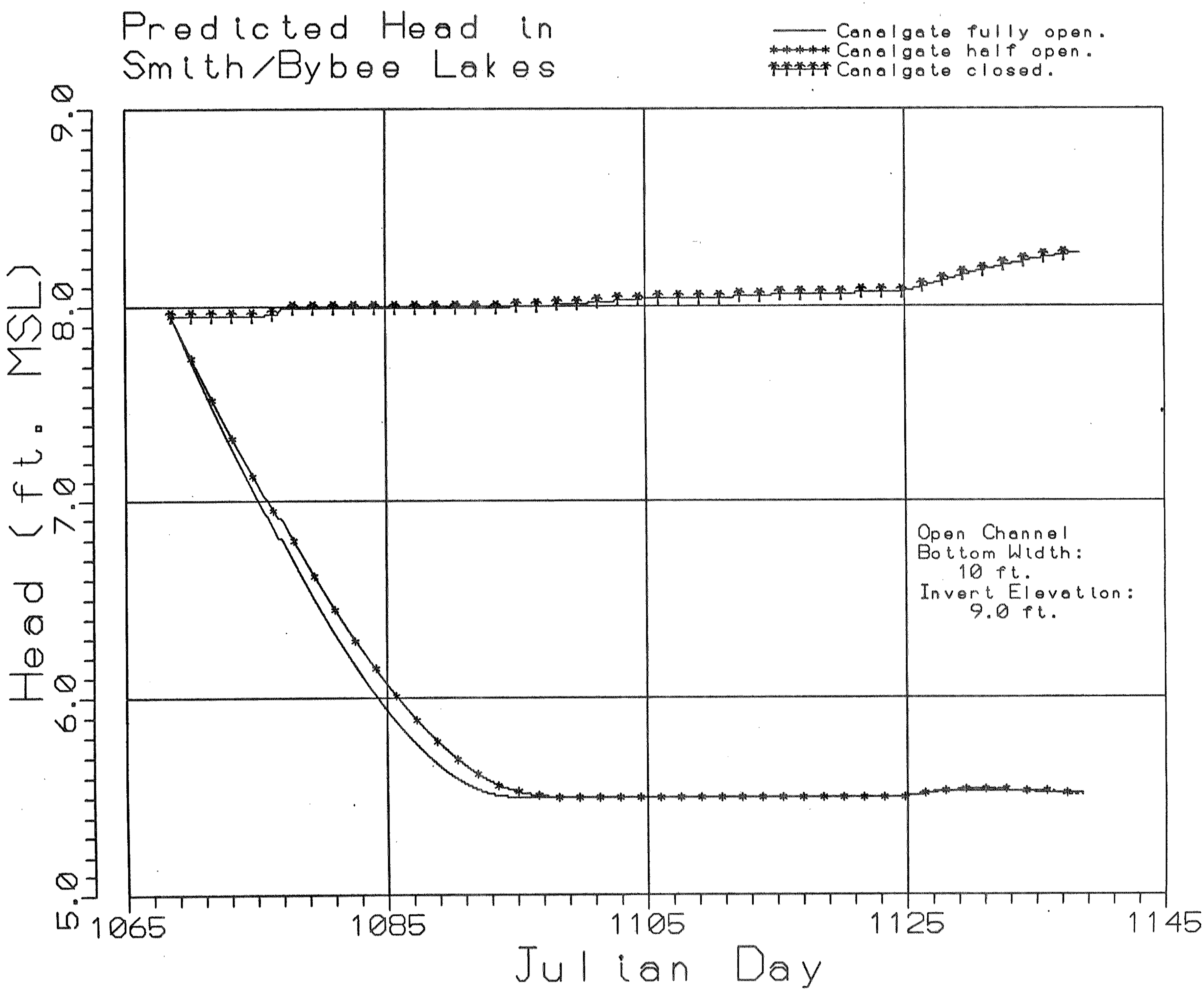
Fishman Environmental Services and Ogden Beeman & Associates, Inc., Smith and Bybee Lakes Environmental Studies, submitted to the Port of Portland and the City of Portland, 1987.

Wells, S., personal communications, 1995.

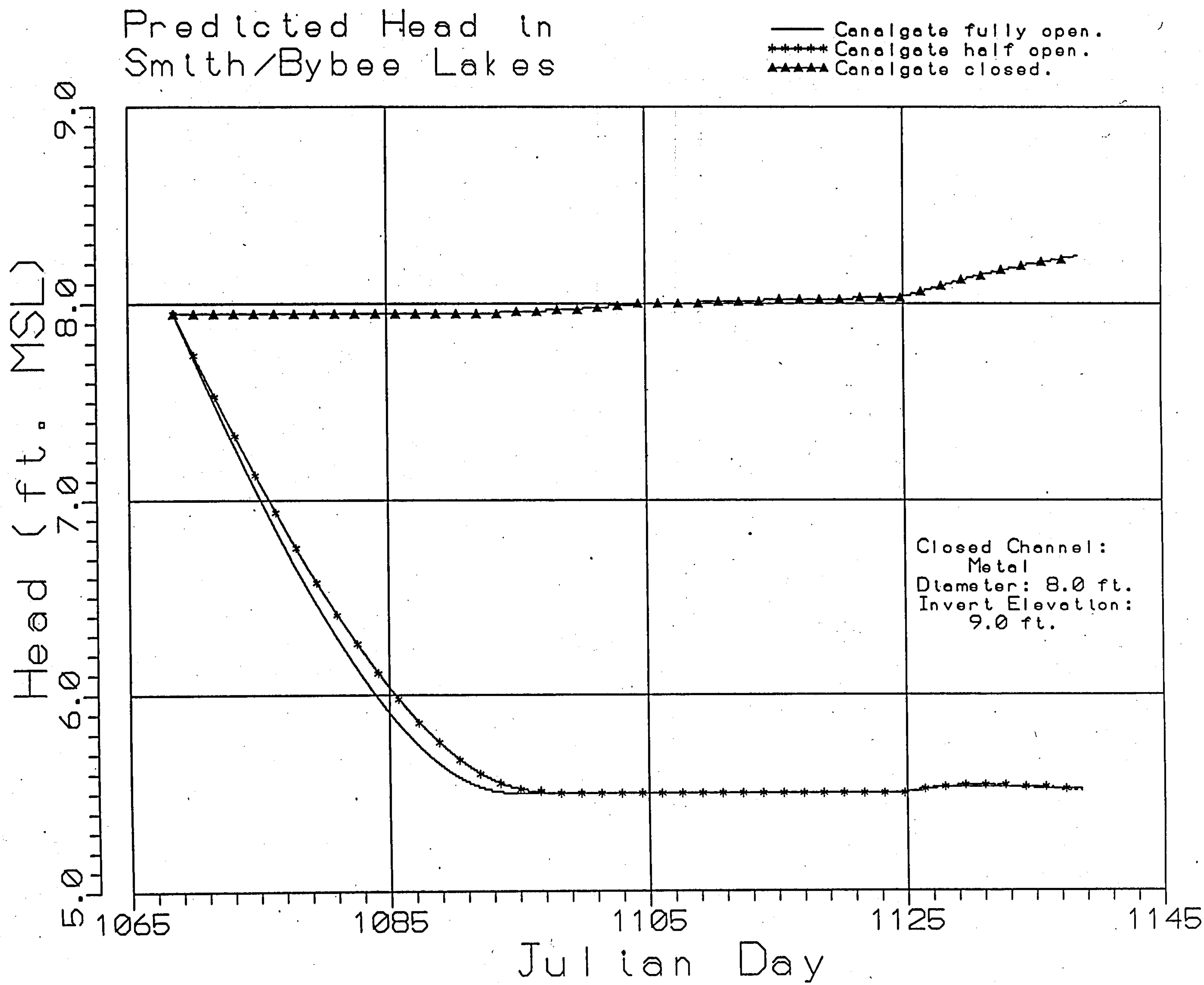
Wells, S., Analysis of Impacts of Flow Augmentation from Smith and Bybee Lakes on North Slough Dissolved Oxygen Conditions, Technical report EWR-1-95, Department of Civil Engineering, Portland State University, 1995.

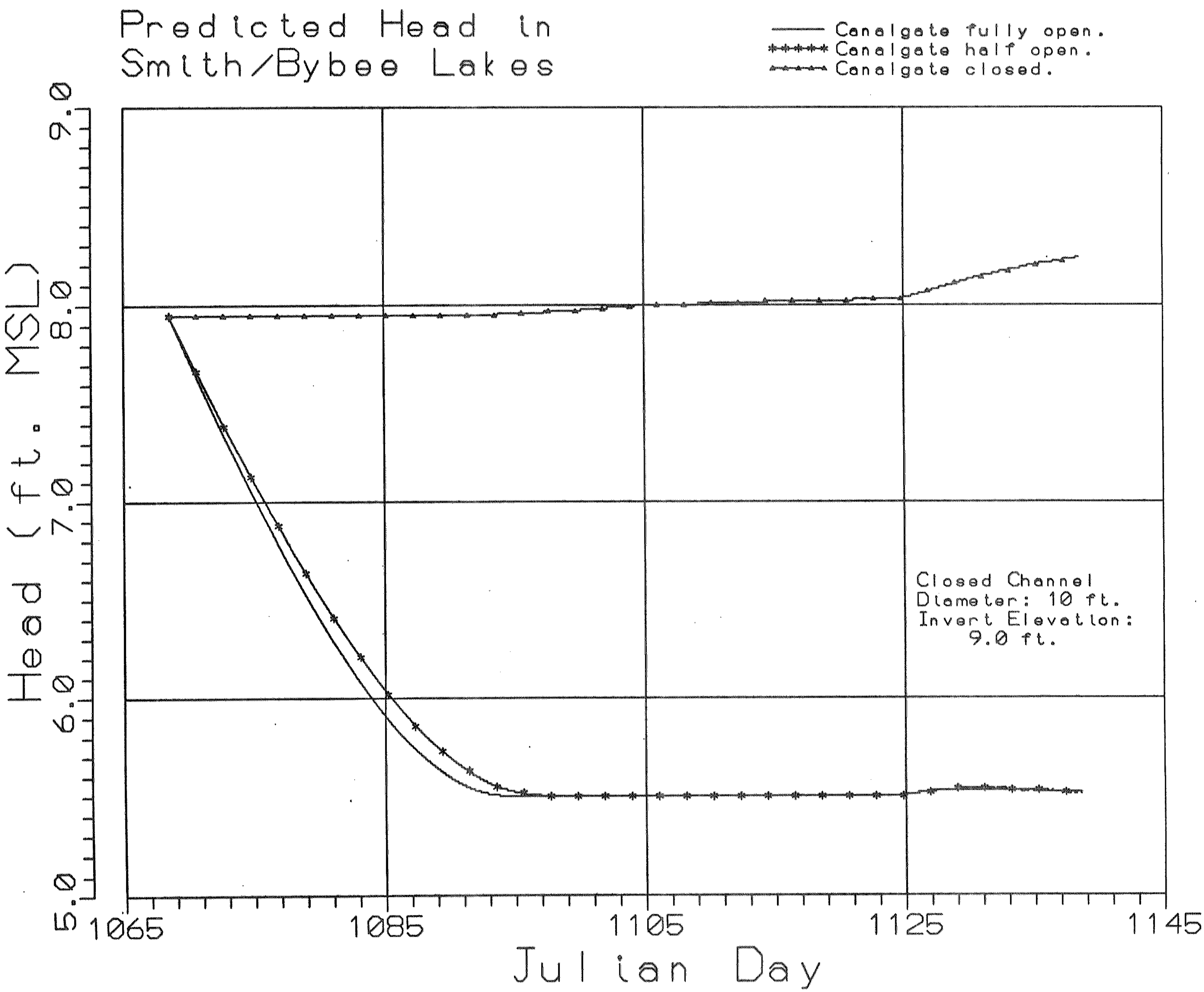
APPENDIX A

Initial Model Results



Predicted Head in
Smith/Bybee Lakes
Canalgate fully open.
Canalgate half open.
Canalgate closed.
Open Channel
Bottom Width:
10 ft.
Invert Elevation:
9.0 ft.
Head (ft. MSL)
9.0
8.0
7.0
6.0
5.0
1065
1085
1105
1125
1145
Julian Day


Predicted Head in
Smith/Bybee Lakes
Canalgate fully open.
Canalgate half open.
Canalgate closed.
Head (ft. MSL)
5.0
6.0
7.0
8.0
9.0
1065
1085
1105
1125
1145
Julian Day
Closed Channel:
Metal
Diameter: 8.0 ft.
Invert Elevation:
9.0 ft.


Predicted Head in
Smith/Bybee Lakes
Canalgate fully open.
Canalgate half open.
Canalgate closed.
Closed Channel
Diameter: 10 ft.
Invert Elevation:
9.0 ft.
Head (ft. MSL)
9.0
8.0
7.0
6.0
5.0
1065
1085
1105
1125
1145
Julian Day

APPENDIX B

Program Code for Main Model

```
*       hcol - Col rv head                  jcol - Col Rv time index
*       hby  - Bybee Lake head              jdq  - diffq time ndex
*       hns  - North slough Head            jns  - NS time index
        PROGRAM model
        IMPLICIT DOUBLE PRECISION (A-H, O-z)
        Double precision jday,jns
        common jns(9000),hns(9000)
        real hday(122),time(5000),head(5000)
        REAL*8  mano, lo, kc, lc, manc, gatelevel
        character  channeltype, pipetype, gatestatus
*
        OPEN(UNIT = 21, FILE = 'ens06.dat', STATUS = 'OLD')
c      OPEN(UNIT = 24, FILE = 'colhd2.use',  STATUS = 'OLD')
c      OPEN(UNIT = 25, FILE = 'program.in',  STATUS = 'OLD')
        open(unit = 26, file = 'program.dat', status = 'unknown')
c      open(unit = 27, file = 'average.dat', status = 'unknown')
        open(unit = 28, file = 'hydro.dat',status='old')
*
* polynomial coefficients vol = -1757.08 + 10.7763*hth + 50.5127*hth**2
*   derived from the application of the "grapher" best fit 2nd degree
*   polynomial to the Fishman results.
*
        a=-1757.08
        b=10.7763
        c=50.5127
*
        print *, 'Cd weir:'
        write(*,*) '  '
        read *, cdweir
        write(*,*) '  '
        print *, 'Cd gate:'
        write(*,*) '  '
        read *, cdgate
        write(*,*) '  '
c
c      read(25,100)elevc,slopec,cdc,lc,diac,kc, elevo,slopeo,cdo,
c     +            lo,bo,dyo,dxo,mano,channeltype,pipetype,gatestatus,
c     +            gatelevel
100    format(6f10.4,/,8f10.4,/,a1,9x,a1,9x,a1,9x,f10.2)
*
c      WRITE (*,*) ' '
c      WRITE (*,*) ' What type of channel would you like to use? '
c      WRITE (*,*) '   Closed or open channel (C-closed, O-open)?'
c      WRITE (*,*) ' '
c      read(*,10) channeltype
c10    format(a4)
*
c      if(channeltype .eq. 'c')then
c         WRITE (*,*) ' Do you want a concrete pipe or a corrugated  '
c         write (*,*) '   metal pipe c-concrete, m-metal?'
c         WRITE (*,*) ' '
c         read (*,10) pipetype
c      endif
c      if(pipetype .eq. 'c') manc = 0.013
c      if(pipetype .eq. 'm') manc = 0.024
*
c      WRITE (*,*) ' '
c      WRITE (*,9)
c9     FORMAT(' Is the canal gate opened? (Y - yes, N - no).')
c      WRITE (*,*) ' '
```

```
c       READ (*,10) gatestatus
c
c set gatestatus = yes
c
          gatestatus = 'y'
*
c       WRITE (*,*) ' '
c       IF (gatestatus .EQ. 'y') THEN
c          WRITE (*,*) ' How much is it raised? ( Fully open is 2.5 ft.)'
c          WRITE (*,*) '      (Half of the area is 1.75 ft.)'
c          WRITE (*,*) ' '
c          READ (*,40) GATELEVEL
c          WRITE (*,*) ' '
c       ENDIF
*
          gatelevel = 2.5
*
c       if(gatestatus .eq. 'n')gatelevel = 0.0
*
c
c       WRITE (*,15)
c15     FORMAT(' Enter the heigth of the adjustable weir in feet.', /,
c      + '    Use a decimal point.', /,
c      + '    The minimum weir height elevation is 8.4 ft. and the', /,
c      + '    maximum is 13.4 ft.')
c       WRITE (*,*) ' '
c39     READ (*,40) WEIR
40     FORMAT(F5.2)
          weir = 8.2
*
c       IF (WEIR .LT. 8.4 .OR. WEIR .GT. 13.4) THEN
c       WRITE (*, 41)
c41     FORMAT( /, ' The number you entered was outside the operational',/
c      + , ' parameters.  Try again.', /)
c       GO TO 39
c       ENDIF
*
* read in the Col. Rv., North slough head data, their respective times in
*   Julian Day, and the diffq file with rspective time.
*
*        hcol - Col rv head                       jcol - Col Rv time index
*        hby  - Bybee Lake head                   jdq  - diffq time index
*        hns  - North slough Head                 jns  - NS time index
*
* read in the Bybee Lake head from the same file, 'model.dat', as the diffq
*
c301    format(9x,f8.3,13x,f5.2)
c302    format(f11.3,20x,f10.3,10x,f10.3)
c303    format(f8.3,5x,f5.2)
*
         do 304  i=1, 9000
         read(21,*, end=305) jns(i), hns(i), crap
         jns(i)=jns(i)-365
304    enddo
305    insend =i-1
*
*  read in data from hydrologic model, hydro.for. Julian day, evap.,
*    and prec.
*
*  read ind hydro.dat julian days and subtract 365 to math other data files
```

```
*
        do 306  i=1, 122
        read(28,*, end=333) hday(i),crap1,crap2
        hday(i)=hday(i)-365
306    enddo
333    ihydro =i-1
        rewind(28)
*
*
c       do 314  i=1, 7000
c         read(23,302, end=306)jdq(i), hby(i), diffq(i)
c314    enddo
c306    idqend =i-1
*
c       do 324  i=1, 7000
c         read(24,303, end=307)jcol(i), hcol(i)
c324    enddo
c307    icolend =i-1
*
308    write(*,*) ' '
        write(*,*) 'The data files have the following start/end times:'
        write(*,*) '  '
        write(*,309)jns(1), jns(insend)
        write(*,312)hday(1), hday(ihydro)
c       write(*,310)jdq(1), jdq(idqend)
c       write(*,311)jcol(1), jcol(icolend)
        write(*,*) '  '
*
309    format(' North Slough:', 2f11.3)
c310    format(' diffq/hby:   ', 2f11.3)
c311    format(' Col. River:  ', 2f11.3)
312    format(' Hydrologic Data:', 2f11.3)
*
*  Set the start time for the program.
*
c       if(jns(1) .ge. jcol(1) .and. jns(1) .ge. jdq(1))start = jns(1)
c       if(jcol(1) .ge. jns(1) .and. jcol(1) .ge. jdq(1))start = jcol(1)
c       if(jdq(1) .ge. jcol(1) .and. jdq(1) .ge. jns(1))start = jdq(1)
c       write(*,313)start
313    format(/,' start time:', f10.3)
*
c       if(jns(1) .ge. hday(1))start = jns(1)
c       if(hday(1) .ge. jns(1))start = hday(1)
c       write(*,313)start
*
         start = 986.625
*
*  Set the end time.
*
c       if(jns(insend).le.jcol(icolend).and.jns(insend).le.jdq(idqend))
c      +     end = jns(insend)
c       if(jcol(icolend).le.jns(insend).and.jcol(icolend).le.jdq(idqend))
c      +     end = jcl(icolend)
c       if(jdq(idqend).le.jcol(icolend).and.jdq(idqend).le.jns(insend))
c      +     end = jdq(idqend)
c       write(*,313)end
*
314    format(' end time:  ',f10.3, /)
*
        if(jns(insend).le.hday(ihydro)) end = jns(insend)
```

```
        if(hday(ihydro).le.jns(insend)) end = hday(ihydro)
        write(*,314)end
*
c       end = 1052.490
*
*   Use a 60 minute time increment (in Julian day)
*
*  n:  variable to interpolate:  1 = hcol
*                                2 = hns
*                                3 = diffq
*                                4 = hby
*  z:  returned variable
*
        dt = 1./24.
*
*  the first lake level is 9.13 ft msl
*
        hth = 9.13
*
        write(*,375)hth
375     format(/,' h1 = ',f6.2)
        totdt = (end - start)*24
        iend = int(totdt)
        tim = start


*
        sumout = 0.0
        sumin = 0.0
*
        do 400 i=1,iend
        flowin=0.0
        outflow=0.0
c         call inter(time,1,hc,icolend,insend,idqend)
         call inter(tim,hn,insend)
c         call inter(time,3,dif,icolend,insend,idqend)
*
*  calculate outflow
*
c       IF (GATESTATUS .EQ. y) THEN
        CALL CANALGATE(hth, QGATE, gatelevel,cdgate)
c       ELSE
c         QGATE = 0.0
c       ENDIF
*
*
        IF(HN .GE. hth .OR. hth .LT. 5.5) outflow = 0.0
*
        IF(HN .LT. hth) CALL WEIRFLOW (hth, QWEIR, WEIR,cdweir)
*
*
        IF(HNSLOSS .GE. 13.4 .AND. HNSLOSS .LT. hth) then
        CALL CULVERT (HNSLOSS, hth, QCUL)
        else
        qcul = 0.0
        ENDIF
*
        outflow = QGATE + qweir + QCUL
*
* calculate the inflow through the proposed structure
*
```

```
* c - closed,  o - open
*
c       if (channeltype .eq. 'c') then
c         call closed(flowin, hth, hc,elevc,slopec,cdc,lc,diac,
c      +                  kc,manc)
c       endif
*
c       if (channeltype .eq. 'o') then
c         call openc(flowin, hth, hc,elevo,slopeo,lo,bo,dyo,
c      +              dxo,mano)
c       endif
*
c       flowin = flowin + dif
*
* convert cfs to acre-ft for time increment dt
*
c         dvin = flowin*1.983471*dt
         dv = outflow*1.983471*dt
*
c call subroutine to read in hydrologic data for evaporation and
c     precipitation
c
         call evapprec(tim,hth,evap,prec,dt,hydvol)
         dv = dv + hydvol
* quadratic equation for smith/bybee lake vol vs elevation in ac ft vs ft msl
*     using the coefficients a, b, c.
*
         vol = a + b*hth + c*hth**2
*
*  inflow is considered positive
*
c         dv = dvin - dvout
         volnext = vol - dv
c
*
         tim=tim+365
         write(26,401)tim, hth, outflow,evap,prec
401     format(f8.3,2f8.4,2f7.5)
         tim = tim + dt -365
*
         hth=((-b/c)+sqrt(((b/c)**2)-4.*(a-volnext)/c))/2.
c       if(hth.lt.8.4)stop
*
*  calculate the averages of the flowin and flowout.
*
         sumout = sumout + outflow
c       sumin = flowin + sumin
*
400     continue
*
         end = real(iend)
         avgout = sumout/end
c       avgin = sumin/end
*
*
505     format(f5.0,3x,f8.4,3x,f4.2)
510     format(f9.3,3x,f8.4,3x,f9.8,3x,f9.8)
c        write(27,20)channeltype, pipetype, gatestatus, gatelevel,
c      +             weir, avgout
c20      format(' channeltype: ',a4,/,' pipetype: ',a4,/,
```

```
c     +        ' canalgate open: ',a4,/, ' gatelevel: ', f4.1,/,
c     +        ' weirheight: ', f5.2,/, ' avg. outflow: ', f7.2,/)
c     +        ' avg. inflow: ', f7.2,/)
*
c      write(27,100)elevc,slopec,cdc,lc,diac,kc, elevo,slopeo,cdo,
c     +            lo,bo,dyo,dxo,mano,channeltype,pipetype,gatestatus,
c     +            gatelevel
*
*
        stop
        END
*******************************************************************
        subroutine evapprec(tm,hd,ev,pr,dt,hydvol)
        IMPLICIT DOUBLE PRECISION (A-H, O-z)
*
* polynomial coefficients asurf (surface area)
*
        aa = -4151940
        bb = -9228770
        cc =  3632870
        dd = -292929
        ee =  7310.35
*
         rewind(28)
600     read(28,*)day,evapor,precip
         day=day-365.
         if(int(tm).eq.int(day))then
c  evap and pr are in inches - convert to feet
         ev=evapor*dt/12
         pr=precip*dt/12
         else
         go to 600
         endif
*
* hyd = hydrologic loss & gain
*
         hyd=ev-pr
         asurf=aa + bb*hd + cc*hd**2 + dd*hd**3 +
     +        ee*h d**4
* hydvol = volume of water (ft2) lost to evap & gained through precip.
         hydvol=hyd*asurf
* convert to acre-ft
         hydvol = hydvol/43560
         return
         end
*
        SUBROUTINE WEIRFLOW (HDBY, DISCH, WEIRHT,cdweir)
        IMPLICIT DOUBLE PRECISION (A-H, J-m, O-z)
        PARAMETER (PI = 3.14159)
c      cdweir = 1.0
*
*  Q1: Flow over the adjustable weir (sharp crested.)
*  Q2: Flow over the weir structure itself (sharp crested.)
*  Q3: Flow over the canal gate (broad crested.)
*  Q4: Flow over the overflow structure (sharp crested.)
*
*  Case 1a:
*
        IF (HDBY .LE. WEIRHT) THEN
         Q1 = 0.0
```

```
         Q2 = 0.0
         Q3 = 0.0
         Q4 = 0.0
         DISCH = Q1 + Q2 + Q3 + Q4
        ENDIF
*
        IF (HDBY .GT. WEIRHT .AND. HDBY .LT. 13.4) THEN
         Q1 = 2./3.*cdweir*4.*(2.*32.2)**0.5*(HDBY-WEIRHT)**1.5
         Q2 = 0.0
         Q3 = 0.0
         Q4 = 0.0
         DISCH = Q1 + Q2 + Q3 + Q4
        ENDIF
*
* Case 1b:
*
        IF (HDBY .GT. WEIRHT .AND. HDBY .GT. 13.4) THEN
         Q1 = 2./3.*cdweir*4.*SQRT(2.*32.2)*(13.401 - WEIRHT)**1.5
         Q2 = 2./3.*cdweir*5.75*(2.*32.2)**0.5*(HDBY-13.4)**1.5
         Q3 = 0.0
         Q4 = 0.0
         DISCH = Q1 + Q2 + Q3 + Q4
        ENDIF
*
* Case 1c:
*
        IF (HDBY .GT. 13.5) THEN
         Q1 = 2./3.*cdweir*4.*(2.*32.2)**0.5*(13.401 - WEIRHT)**1.5
         Q2 = 2./3.*cdweir*5.75*(2.*32.2)**0.5*(HDBY - 13.4)**1.5
         Q3 = 0.385*(2*32.2)**0.5*5.25*(HDBY - 13.5)**1.5
         Q4 = 0.0
         DISCH = Q1 + Q2 + Q3 + Q4
        ENDIF
*
* Case 1d:
*
        IF (HDBY .GT. 13.8) THEN
         Q1 = 2./3.*cdweir*4.*(2.*32.2)**0.5*(13.401 - WEIRHT)**1.5
         Q2 = 2./3.*cdweir*5.75*(2.*32.2)**0.5*(HDBY - 13.4)**1.5
         Q3 = 0.385*(2.*32.2)**0.5*5.25*(HDBY - 13.5)**1.5
         Q4 = 2./3.*0.62*PI*6.*(2.*32.2)**0.5*(HDBY - 13.8)**1.5
         DISCH = Q1 + Q2 + Q3 + Q4
        ENDIF
*
        RETURN
        END
*
************************************************************************
        SUBROUTINE CANALGATE (BYHEAD, QG, DIST,cdgate)
        IMPLICIT DOUBLE PRECISION (A-H, J-m, O-z)
*
*  This subroutine will estimate the flow through the canal gate.
*  The canal gate is modeled as a sluice gate.  The flow is derived
*     by applying the Bernoulli Equation.
*
*  The distance, DIST, is measured from fully opened.
*    So, 2.5 ft. is fully closed and 0.0 is fully open.
*
        PARAMETER (PI = 3.14159)
* cdgate is the estimated discharge coefficient for the canal gate.
```

```
* experience indicates this is low (4/17/94)
c      cdgate = 1.0
       D = 2.5 - DIST
       A = PI*(1.25**2-(D/2)**2)
       if(byhead .le. 5.5)then
       QG = 0.0
       else
       QG = cdgate*A*(2*32.2*(BYHEAD-4.75))**.45
       endif
       RETURN
       END
*
*************************************************************************
       SUBROUTINE CULVERT (S, BY, QC)
       IMPLICIT DOUBLE PRECISION (A-H, J-m, O-z)
*
*  This subroutine estimates the discharge through the structure when
*    the head in the North Slough is high enough to result in a Type 4
*    culvert flow condition with minor head losses due to the 60 inch
*    pipe and the flapgate.
*  CD = discharge coefficient.
*  HYDRAD = hydraulic radius of the pipe.
*  N = Manning's Coefficient.
*  L = length of pipe.
*  KM = minor head loss coefficient due to flap gate. (Assume = 0.45)
*
       PARAMETER (PI = 3.14159)
       CD = 0.7
       G = 32.2
       A = PI/4.*25.
       HYDRAD = 5./4.
       R = HYDRAD
       N = 0.013
       L = 60.0
       KM = 0.45
       if(by .le. s)then
       qc = 0.0
       else
       QC = CD*A*SQRT(2*G*(BY - S)/(1 + 29*CD**2*N**2*L/R**1.333 +
     + CD**2*KM))
       endif
*
       RETURN
       END
*
*************************************************************************
c      subroutine closed(qcol, hdby, hdcol,elev,slope,cd,l,dia,k,man)
c      IMPLICIT DOUBLE PRECISION (A-H, J-m, O-z)
c      real*8 k, l, losses, man
c      parameter(pi = 3.14159)
c      parameter(g = 32.2)
*
* elev = invert elevation at entrance
* elbyb = invert elevation at exit
*
*
* variables follow Gupta:Hydrology and Hydraulic Systems; pg. 656
*
*  h12 = entrance loss
*  h23 = pipe loss
```

```
*  hgate = exit loss
*
c      if(hdcol .le. hdby .or. hdcol .le. elev)then
c        qcol = 0.0
c        go to 888
c      endif
*
c      if(dia .eq. 0.0)then
c        write(*,*) ' dia = 0.0'
c        stop
c      endif
c      bigh = hdcol - elev
c      if(bigh .le. 0.0)then
c        qcol = 0.0
c        go to 888
c      endif
c      radius = dia/2.
c      z = slope*L
c      h1 = bigh + z
c      elbyb = elev - z
c      gamma = hdby + elbyb
c      tfour = elbyb + dia
c      if(hdby .lt. elbyb)then
c        h4 = 0.0
c      else
c        h4 = hdby - elbyb
c      endif
c      ratio = bigh/dia
c      hgate = 0.45*Cd**2
*
* ratio less than or equal to 1.2
*
c      if (ratio .le. 1.2) then
*
* Type 3 culvert flow - assume V1 = 0.0
*                     - assume flush connection at entrance (k = 0.5)
*                     - assume exit loss coefficient = 0.45
*                     - hgate =
*
c        if(bigh .gt. dia) bigh = dia
c        if(bigh .lt. radius) then
c          Ac = pi/2*(radius**2.-(radius-bigh)**2)
c          beta = acos((radius - bigh)/radius)
c          P = dia*beta
c        endif
c        if(bigh .gt. radius) then
c          Ac = pi/2.*(radius**2+(bigh - radius)**2)
c          beta = acos((bigh-radius)/radius)
c          P = dia*(pi-beta)
c        endif
c        if(bigh .eq. radius) then
c          ac = pi/2.*radius**2
c          p = pi*radius
c        endif
c        if(p .eq. 0.0)then
cc          write(*,*) 'p = 0.0'
c          stop
c       endif
c        R = Ac/P
c        if(r .eq. 0.0)then
```

```
c           write(*,*) ' r = 0.0'
c           stop
c         endif
c         h3 = hdby - elbyb
c         if(h3 .lt. 0.0) h3 = 0.0
c         h12 = k*Cd**2.
c         h23 = 29.*man**2*L*Cd**2/(R**(4/3))
c         losses = (hdcol - elev)+z-h3-h12-h23-hgate
c           if(losses .le. 0.0)then
c             qcol = 0.0
c           else
c             Qcol = Cd*Ac*sqrt(2.*g*losses)
c           endif
*
c         endif
*
*
c       if(ratio .gt. 1.2 .and. hdby .ge. tfour) then
*
* Type 4 culvert flow
*
* bigh = hdcol - elev
*
c         A = pi * radius**2
c         R = dia/4.
c         alpha = bigh+z-hdby-elbyb
c         if(alpha .le. 0.0)then
c           qcol = 0.0
c         else
c           Qcol = Cd*A*sqrt((2.*g*alpha)/(1.+29.*man**2*L*Cd**2/
c     +                R**(4/3) +0.45*Cd**2))
c         endif
*
c       endif
*
*
c       if (ratio .gt. 1.2 .and. hdby .lt. tfour) then
*
* Type 5 culvert flow
*
c         A = pi*radius**2
c         R = dia/4.
c         alpha = bigh+z-hdby
c         if(alpha .le. 0.0)then
c           qcol = 0.0
c         else
c           Qcol = Cd*A*sqrt(2.*g*alpha/(1.+29.*man**2*L*Cd**2/
c     +              R**(4/3)+0.45*Cd**2))
c         endif
*
c       endif
*
c888    return
c       end
*
*************************************************************************
c       subroutine openc(q, hdby, hdcol,elev,slope,l,bottom,dy,dx,man)
c       IMPLICIT DOUBLE PRECISION (A-H, J-m, O-z)
c       real*8 l, man
c       parameter(g = 32.2)
```

APPENDIX C

Program Code for PUMPIN.FOR

```
*
c         IF(N-2)1001,1002,1003
c         if(n.eq.4)go to 1004
*
c1001     DO 1021 n=1,ic
c         X(n)=jcol(n)
c         Y(n)=hcol(n)
c1021     enddo
c         ny = ic - 1
c         GO TO 1050
*
        if(n .eq. 2)then
1002    DO 1022 n=1,in
        X(n)=jns(n)
        Y(n)=hns(n)
1022    enddo
        ny = in - 1
        endif
c         GO TO 1050
*
c1003     do 1023 n=1,id
c         x(n)=jdq(n)
c         y(n)=diffq(n)
c1023     enddo
c         ny = id - 1
c         go to 1050
*
c1004     DO 1024 n=1,id
cc          x(n)=jdq(n)
c         y(n)=hby(n)
c1024     enddo
c         go to 1050
*
c1050     CONTINUE
*
* Linear interpolation.
*
        do 1040 n = 2, ny
        if(t .eq. x(n)) z = y(n)
        if(t .lt. x(n) .and. t .gt. x(n-1)) then
          dx = x(n-1) - x(n)
          if(dx .eq. 0.0) then
            write(*,*) 'dx = 0.0'
            stop
          endif
          dy = y(n-1) - y(n)
          slope = dy/dx
          z = y(n-1) + slope*(t - x(n-1))
        endif
1040    enddo
*
        return
        END
```

```
      PROGRAM pumpin
      IMPLICIT DOUBLE PRECISION (A-H, J-m, O-z)
*
*
* polynomial coefficients vol = -1757.08 + 10.7763*hth + 50.5127*hth**2
*   derived from the application of the "grapher" best fit 2nd degree
*   polynomial to the Fishman results.
*
      a=-1757.08
      b=10.7763
      c=50.5127
*
*
c50    FORMAT(F5.2)
*
*
*
      write (*,*) 'Enter the initial head:'
      write(*,*) ' '
      read(*,*) hi
      write(*,*) ' '
      write(*,*) 'Enter the desired head:'
      write(*,*) ' '
      read(*,*) head
      write(*,*) ' '
      write (*,*) 'Enter the time period in days:'
      write(*,*) ' '
      read (*,*) days
      write(*,*) ' '
*
*
*
* convert cfs to acre-ft for time increment dt (days)
* pump = pumping rate in cfs
*
      volfinal = a + b*head + c*head**2
      volinit = a + b*hi + c*hi**2
      dvol = volfinal - volinit
      dvol1=dvol*43560.
*
*  calculate the pumping rate in cfs for steady state
*  .504167 converts the acre-ft/days to cfs
*
      pump = dvol/days*.5041687

*
* quadratic equation for smith/bybee lake vol vs elevation in ac ft vs ft msl
*     using the coefficients a, b, c.
*
*
        write(*,10) hi
        write(*,20) days
        write(*,30) head
        write(*,40) pump
        write(*,50)dvol
        write(*,60)dvol1
*
10        format(' Initial head:   ' f5.1 ' ft')
20        format(' Time period:    ' f5.1 ' days')
30        format(' Desired head:   ' f5.1 ' ft')
```

```
*
* hc = channel head = hdcol - elev
*
c       hc = hdcol - elev
c       if(hc .le. 0.0)then
c          qcol = 0.0
c          go to 777
c       endif
c       if(slope .eq. 0.0) then
c         write(*,*) 'slope = 0.0'
c         stop
c       endif
c       if(man .eq. 0.0) then
c         write(*,*) 'man = 0.0'
c         stop
c       endif
c       if(dy .eq. 0.0)then
c         write(*,*) 'dy = 0.0'
c         stop
c       endif
c       if(hdcol .le. elev .or. hdcol .le. hdby)then
c         qcol = 0.0
c         go to 777
c       endif
c       z = slope*L
c       A = (bottom + hc*dx/dy)*hc
c       theta = atan(dx/dy)
c       if(cos(theta) .eq. 0.0) then
c         write(*,*) 'cos(theta) = 0.0'
c         stop
c       endif
c       P = bottom + hc/cos(theta)
c       R = A/P
c       vel = (1.486/man)*r**(2/3)*slope**.5
c       hgate = vel**2/2/g
c       hin = hdcol - hgate
c       if(hin .le. hdby) then
c          q = 0.0
c       else
c          Q = A*vel
c       endif
*
c777   return
c       end
*
*************************************************************************
        SUBROUTINE INTER(T,Z,in)
        IMPLICIT DOUBLE PRECISION (A-H, J-m, O-z)
        common jns(9000),hns(9000)
c    +         hby(7500),diffq(7500)
        real x(9000), y(9000)
C  INTER INTERPOLATES INPUT DATA TO OBTAIN
C
C
C  t:  time in Julian day, head in ft MSL, or diffq.
C  n:  variable to interpolate:  1 = hcol
C                                2 = hns
c                                3 = diffq
c                                4 = hby
C  z:  returned variable
```

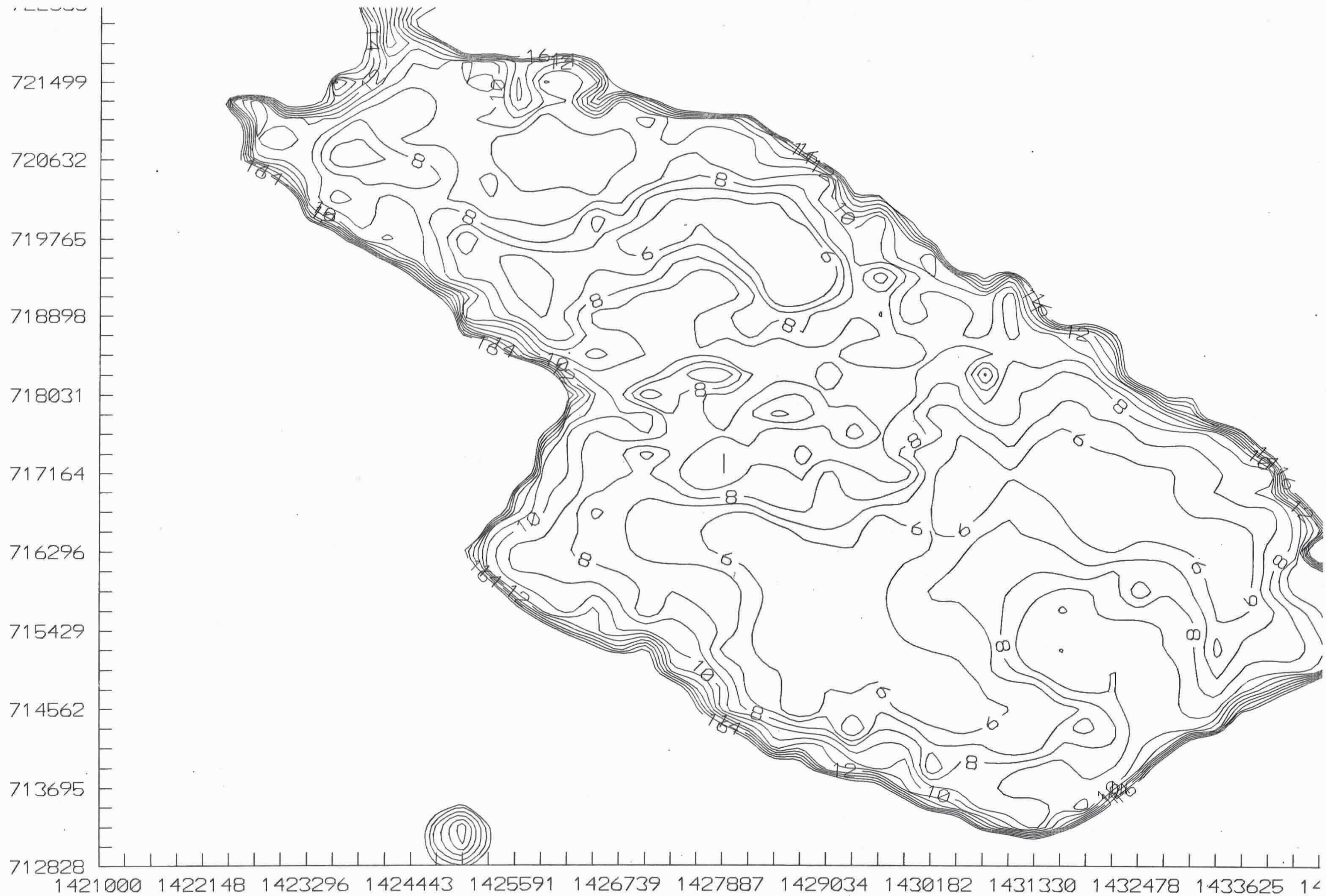
```
40       format(' Required pumping rate:  'f5.1 ' cfs')
50       format(' Volume Pumped: 'f5.0 ' acre-ft')
60       format(' Volume Pumped: 'g8.3 ' cubic ft')
      write(*,*) ' '
*
*
*
      STOP
      END
```

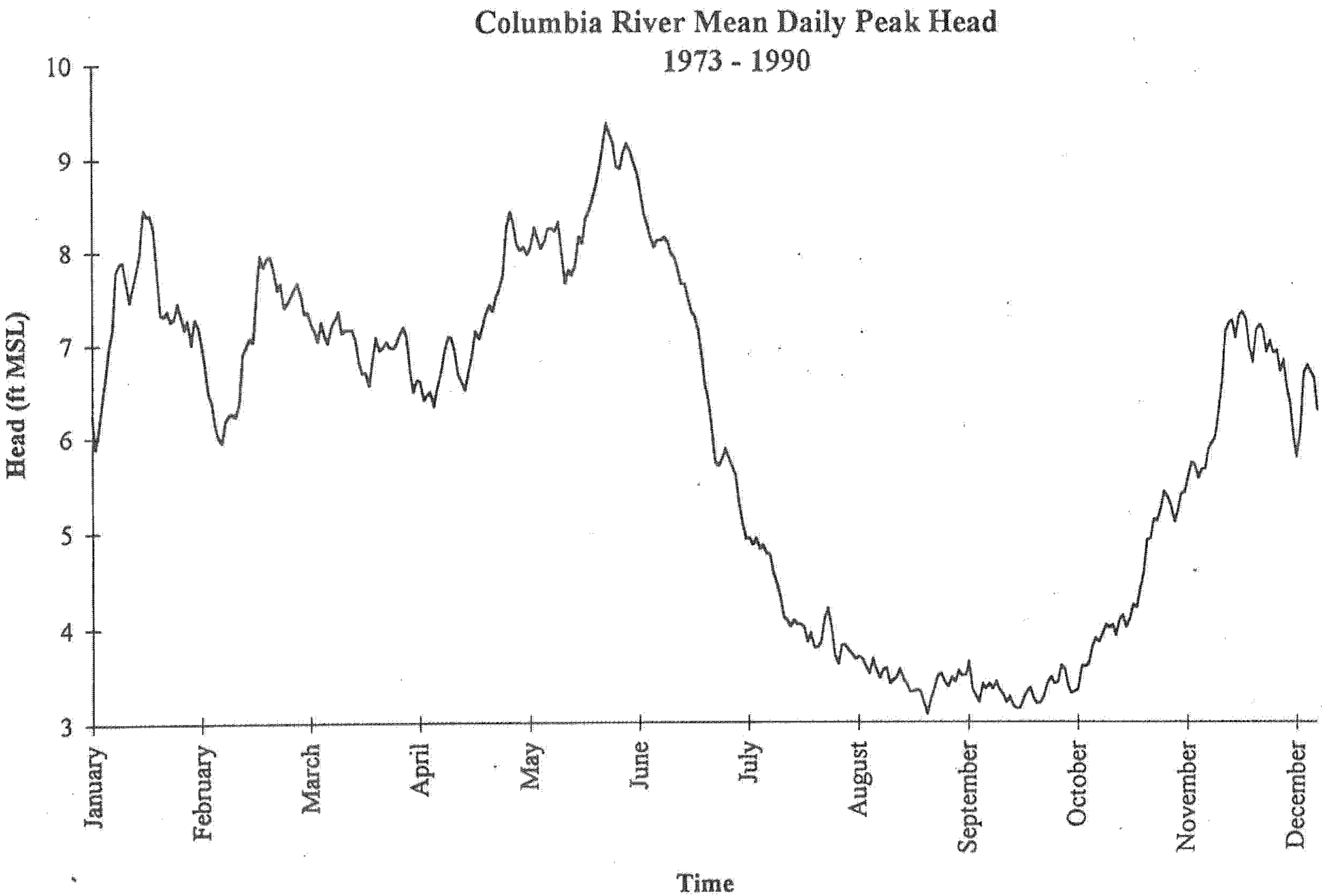
APPENDIX D

Program Code for HYDRO.FOR

```
* this program reads input data and converts it to julian day (1990),
*    evaporation and precipitation in inches
*
      open(unit=10,file='noaamod.dat',status='old')
      open(unit=11,file='hydro.dat',status='unknown')
10    read(10,*,end=200)dayj,daym,tair,tdew,prec,wind
      tcair=(tair-32)/1.8
      tcdew=(tdew-32)/1.8
      rh=((112.-0.1*tcair+tcdew)/(112+0.9*tcair))**8
      ea=-0.132579+0.014123*tair-0.000233125*tair**2+2.98306e-6*tair**3
*convert ea to mm of hg
      ea=ea*25.4
* convert wind speed from mph to mpd
      wind=wind*24
      evap=0.35*ea*(1-rh)*(1+0.0098*wind)
*concert mm/d to inch/day
      evap=evap/25.4
      dayj=dayj+1096
      write(11,100)dayj,evap,prec
100   format(f5.0,3x,f8.4,3x,f4.2)
      go to 10
200   stop
      end
```

B Y + SM.PLT


721499
720632
719765
718898
718031
717164
716296
715429
714562
713695
712828
1421000
1422148
1423296
1424443
1425591
1426739
1427887
1429034
1430182
1431330
1432478
1433625
6
8
10
12
16


Columbia River Mean Daily Peak Head
1973 - 1990
Head (ft MSL)
10
9
8
7
6
5
4
3
January
February
March
April
May
June
July
August
September
October
November
December
Time