DRAFT

Analysis of Impacts of Flow Augmentation from Smith and Bybee Lakes on North Slough Dissolved Oxygen Conditions

Final page #'s, Table of contents, & some final figure captions will be done after draft comments are received.

SW

Joanna: Also, Jim Morgan would be interested in reviewing.

Scott A. Wells
Associate Professor of Civil Engineering

Department of Civil Engineering
Portland State University
Portland, Oregon 97207-0751

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Acknowledgements

The support and tireless work of Chris Berger and Mark Boyko at Portland State University is gratefully acknowledged. METRO staff also were instrumental in the success of this project: Ms. Joanna Karl, project manager, Mr. Dennis O'Neil, and Mr. Jim Morgan.

A series of reports have been written on Columbia Slough at Portland State University. A listing of some of these reports are shown below:

Report Number	Date	Title	Author(s)	Research Sponsor
EWR-1-92	2/92	Assessment of Management Alternatives for Water Quality Improvement in the Columbia Slough System, Vol. 1 & Vol. 2	Wells, S.	City of Portland
EWR-2-92	3/92	Lower Columbia Slough System Field Data Summaries - August 1990 through June 1991	Wells, S.	City of Portland
EWR-3-92	3/92	User's Manual for the Columbia Slough Model Using CE-QUAL-W2	Wells, S.	City of Portland
EWR-4-92	3/92	Storm Runoff and CSO Simulation in the Lower Columbia Slough	Laliberte, D.	City of Portland
EWR-5-92	3/92	Bybee and Smith Lake Discharge Models	Laliberte, D.	City of Portland
EWR-6-92	5/92	St. John's Landfill and Columbia Slough System Water Quality Database	Collins, D. and Wells, S.	METRO
EWR-8-92	8/92	Analysis of Management Alternatives for Improving Water Quality in North Slough Adjacent to the St. John's Landfill	Wells, S.	METRO
EWR-5-93	10/93	Predicting Seepage of Leachate from the St. Johns Landfill to Ground and Surface Water Systems	Schock, Kevin A. (Thesis advisor: S. Wells)	METRO
EWR-2-94	4/94	Upper and Lower Columbia Slough Water Level Test: September 1 through October 29, 1993	Wells, Scott A. Berger, Chris	City of Portland Bureau of Env. Services
Upcoming reports:				
EWR- - 95	3/95	Calibration and Verification of the Lower and Upper Columbia Slough Models for 1992 through 1994	Wells, S. and Berger, C.	City of Portland
EWR- -95	3/95	Modeling the Hydraulcs of the Discharge Structure at the end of North Slough	Boyko, M. and Wells, S.	METRO
EWR- -95	4/95	Analysis of the Upper and Lower Columbia Slough During the 1994 Water Level Test	Wells, S. and Berger, C.	City of Portland

1. INTRODUCTION

The North Slough, shown in Figure 1, is a dead-end sidearm of the Lower Columbia Slough in Portland, Oregon. This arm is about a mile long and is adjacent to the St. John's Landfill and Smith and Bybee Lakes. A water control structure regulates water levels in Smith and Bybee Lakes and allows water to leave the Lakes and drain into North Slough. A flap gate on the water control structure prevents water from going from North Slough to Smith and Bybee Lakes.

Other significant inflows to the Lower Columbia Slough besides the tidal flow from the Willamette River are thirteen combined sewer oveflows (CSOs),numerous storm water inflows, and flow from the Upper Columbia Slough. In Wells et al (1994), much of the problems with algae in the Lower Columbia Slough were a result of nutrient and algae loading from the Upper Columbia Slough. Excessive bacteria (fecal coliform) in the Lower Columbia Slough are primarily from CSOs. The City of Portland has agreed to eliminate the frequency of CSO discharges and is working on how to improve the conventional water quality of the Upper and Lower Columbia Sloughs.

Water movement in the North Slough arm is dependent on 2 primary mechanisms: (i) tidal flushing from the Willamette River and Lower Columbia Slough and (ii) outflow from Smith and Bybee Lakes. Prior to 1986 (??), no water control facility existed at the end of North Slough. Because of perceived problems with avarian botulism in Smith and Bybee Lakes during the summer periods when water levels were low and mud flats were exposed, a dike and a simple control structure were built at the east end of North Slough to keep water levels high in Smith/Bybee Lakes. This control structure, though, did not prevent water from going from North Slough to the Lakes. In a letter report, Wells (1991) showed that flow, laden with bacteria from CSOs, was allowed to go into Smith and Bybee Lakes from North Slough. This report is included in Appendix A.

A new water control structure was built in 1991 that did not allow water from North Slough to enter the Lakes. This structure was also supposed to have better operational control over the water levels in the Lakes. Details of this new water control structure is found in Boyko (1995).

Low dissolved oxygen values have been reported in North Slough during 1990 and 1991 - see Appendix A and Wells (1992a). Figure 2 shows low dissolved oxygen concentrations in North Slough for 1993 and 1994. Typically, dissolved oxygen values decrease as the east end of North Slough (ENS) is approached. Dissolved oxygen values below 3 mg/l are not uncommon. As discussed in Wells (1992b), this is related to a lack of tidal mixing as ENS is approached.

In order to understand and try to solve this and other water quality problems in North Slough, several water quality and model studies of the Lower Columbia Slough system

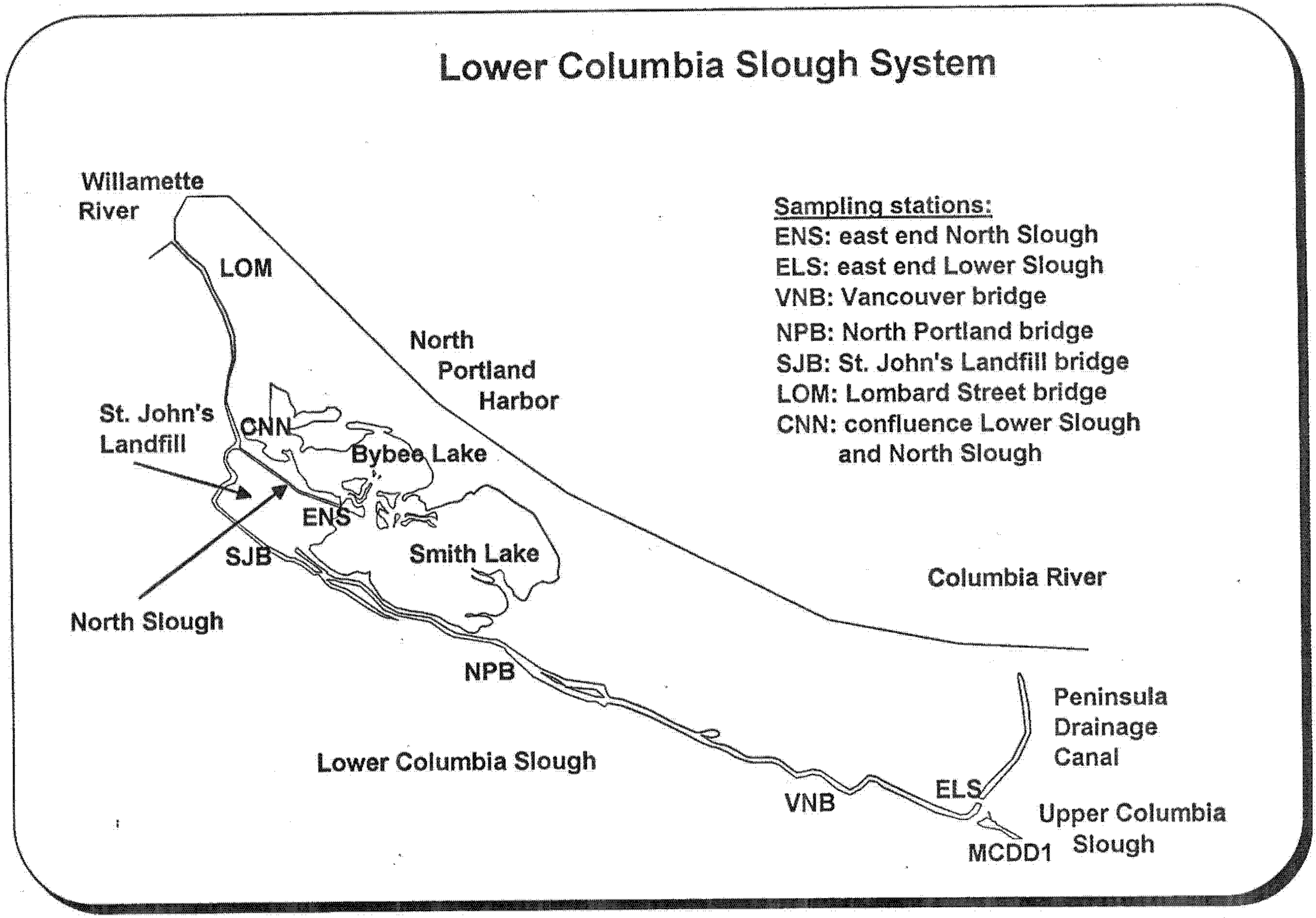


Figure 1. The Lower Columbia Slough.

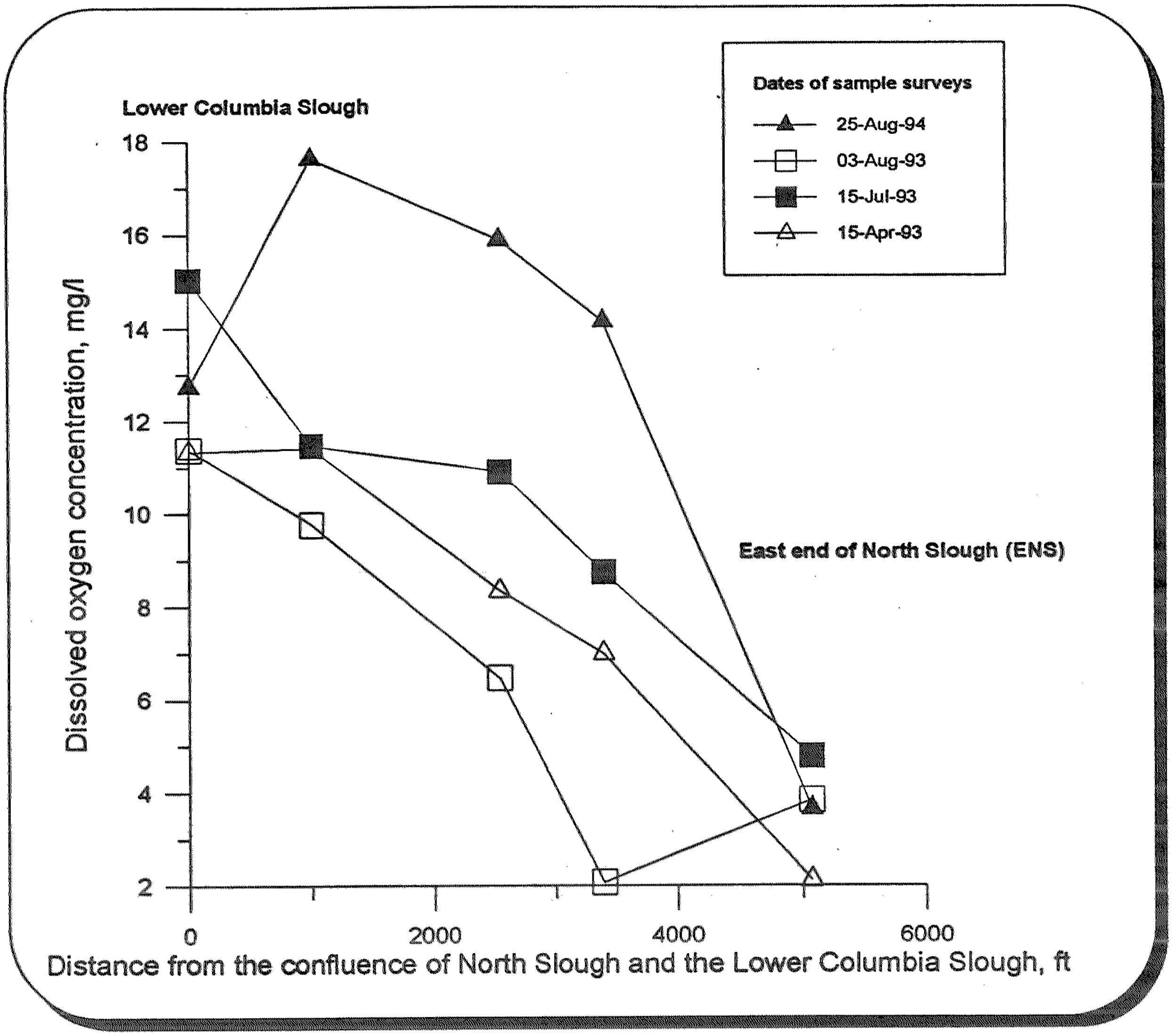


Figure 2. Variation of dissolved oxygen along North Slough in 1993 and 1994.

have been performed: Brown and Caldwell (1989), City of Portland (1989), Wells (1992b), Laliberte (1992), Wells (1992c), Wells, Berger, and Staats (1993), Wells and Berger (1994), HDR (1994). Other studies about water quality in the Slough system are currently being conducted by the City of Portland and METRO concerning sediment contamination and estimates of the flux of contaminants from the landfill.

The purpose of this study then was to examine flow augmentation as a means of enhancing mixing at the east end of North Slough and reducing the low dissolved oxygen at ENS.

Review of earlier model studies

An analysis of prior work done by Wells (1992b) shows how various alternatives affected the dilution of a tracer (analogous to leachate from the landfill entering North Slough at ENS) at different points along North Slough. The management alternatives considered during this study were (i) existing condition, (ii) removal of a sunken barge about 1500 ft from the Lower Columbia Slough, (iii) removal of dike and water control structure at end of North Slough, and (iv) removal of dike and water control structure at end of North Slough and removal of the barge. Table 1 shows these results for typical late winter/early spring high water elevations and Table 2 shows these results for typical summer low water conditions.

Table 1. Relative dilution capacities of North Slough for high-water, late winter, early spring conditions.

Management alternative	Dilution capacity* at East end of North Slough (ENS)	Dilution capacity* at the mid-point of the North Slough
Existing condition	1	1
Removal of barge	1.09	1.18
Open lakes to North Slough	61.3	43.2
Open lakes to North Slough and barge removal	73.4	48.9

* dilution capacity is defined as being equal to 1 for the existing case and the capacities are based on calculations of average dilution of a conservative tracer with the mathematical model discusssed in Wells (1992b). All numbers greater than "1" indicate greater dilution than present conditions. A number of "10" indicates 10 times more dilution is achieved with that alternative compared with the existing situation.

Table 2. Relative dilution capacities of North Slough for low-water, summer conditions.

Management alternative	Dilution capacity* at East end of North Slough (ENS)	Dilution capacity* at the mid-point of the North Slough
Existing condition	1	1
Removal of barge	1.01	1.05
Open lakes to North Slough	5.3	8.05
Open lakes to North Slough and barge removal	6	8.8

In these simulations, removal of the dike and the water control structure at the end of North Slough provided significant water volume such that the dissolved oxygen levels in North Slough were significantly improved.

In the model developed by Wells (1992b), the sediment oxygen demand rates for North Slough were increased from the rest of the Lower Slough to account for significant dissolved oxygen depletion. Appendix B shows the input control file used in the model simulation and shows that values of sediemnt oxygen demand in the Lower Slough were from 0.5 to 2.0 $g/m^2/day$, while those in the North Slough were as high as 5 $g/m^2/day$.

2. MODEL SIMULATIONS

Four model simulations were made with the updated Lower Columbia Slough model evaluating the impact of flow augmentation on North Slough. The Lower Slough and Upper Slough models were recalibrated to improved water quality and flow data from 1992 to 1994 in Wells and Berger (1995). This revised calibration supercedes the work done in an earlier study by Wells (1992b). Improvements were made in the following areas: flow rates and pollutant loading from the Upper Slough was now computed from continuous model simulations, CSO flows were from the more recent SWMM model simulations, water quality variables were calibrated to both synoptic and continuous field data over extended time periods. The Lower Slough hydraulic model is largely unchanged from the 1992 simulations. Common run parameters for the simulations in this study are shown below in Table 3.

Table 3. Model simulation parameters.

Parameter(s)	Value(s) during simulation
Time period of simulation	Julian day 210 through Julian day 245 (July 28, 1992 through September 1, 1992)
Number of CSO and storm water events	1
Date of CSO/storm water event and rainfall amount	Julian day 219 (August 6, 1992)/ 0.5 inch rain in 11 hours
Water quality conditions in Smith/Bybee Lakes (based on water quality data taken during 1992 and other representative years):	
Dissolved oxygen	7.7 to 10.5 mg/l
NO3-N	0.02 mg/l
NH4-N	0.05 mg/l
PO4-P	0.02 to 0.04 mg/l
algae (biomass mg/l)	3.0 mg/l
algae (chlorophyll a)	45 ug/l
alkalinity	80 mg/l as CaCO3

Parameter(s)	Value(s) during simulation
inorganic carbon	9.48 to 23.2 mg/l
pH	7.1 to 10.5
BOD-soluble	5 mg/l
detritus-particluate BOD	20 mg/l
temperature	19 to 22.1 °C
Maximum and minimum tidal conditions during simulation period:	
High water	7.4 ft MSL
Low water	2.7 ft MSL
Initial water quality conditions in the Lower Slough:	
Dissolved oxygen	13.0 mg/l
NO3-N	1.5 mg/l
NH4-N	0.1 mg/l
PO4-P	0.05 mg/l
algae (biomass mg/l)	4.0 mg/l
algae (chlorophyll a)	60 g/l
alkalinity	60 mg/l as CaCO3
inorganic carbon	14.53 mg/l
pH	8.2
BOD-soluble	2.0 mg/l
detritus-particluate BOD	0.67 mg/l
temperature	22.5°C

Table 4 shows the variability in flow from Smith and Bybee Lakes for Runs 1 through 4. This variability in flow rates was based on the typical range of flows possible with full water storage in the summer (see discussion on availabile storage and flows in Section 4).

Table 4. Variation of flow rate from Smith/Bybee Lakes for each run number.

Run number	Flow from Smith/Bybee Lake into North Slough
1	0 cfs (0 m^3/s)
2	10 cfs (0.283 m^3/s)
3	25 cfs (0.708 m^3/s)
4	75 cfs (2.125 m^3/s)

The water surface variation at Lombard Street bridge at the mouth of the Lower Columbia Slough during the model simulations is shown below in Figure 3.

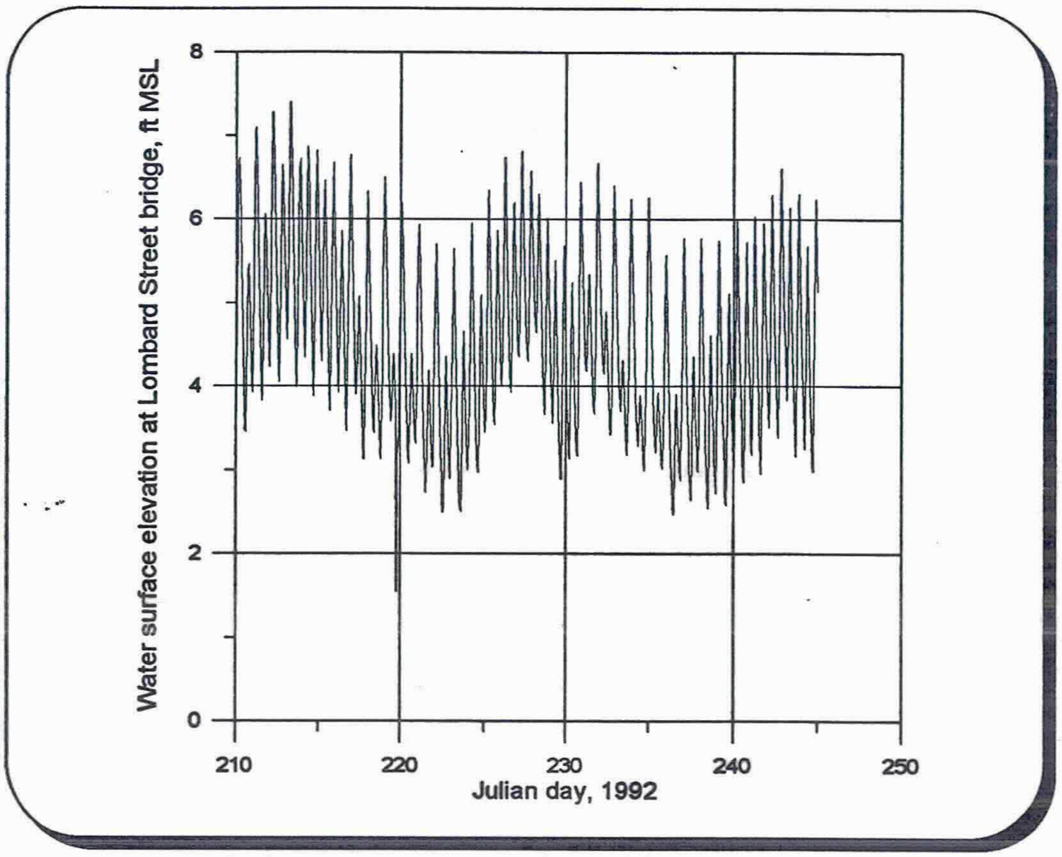


Figure 3. Water surface variation between July 28, 1992 and September 1, 1992 during simulation period of model runs.

Results of each model run were evaluated (i) by comparing vertically average water quality parameters at several control points in the Lower Slough: East end of North Slough (ENS), mid-point along North Slough between Columbia Slough and Smith/Bybee Lakes, entrance to North Slough at the Columbia Slough (CNN), and at St. John's Landfill bridge (SJB), and (ii) by comparing the dynamic model predictions over a two week segment with computer animation.

Also, environmental performance criteria were developed for North Slough and the Lower Columbia Slough to evaluate the average volume of the system in violation of dissolved oygen, algae, pH, or coliform water quality goals.

Volume Weighted Environmental Performance Criteria

Environmental performance criteria were developed to evaluate quantitatively differences in water quality impacts of various model simulations. This attempt to create an environmental performance criterion was first discussed in Wells and Berger (1993). The development here is an extension and improvement on that work.

Conceptually, these performance criteria provide the user with an evaluation technique to compare the frequency and range of violation of a water quality goal for each management strategy simulated. These criteria determine what fraction of the system volume is in violation of a water quality goal or standard. For example, for dissolved oxygen the environmental performance criteria is a statistic which shows how much of the volume of the Lower Columbia Slough or the North Slough on average over the simualtion period was less than the "violation" limit of 5.0 mg/l. A histogram statistic shows what percentage of the dissolved oxygen was between 5.0 and 4.8, 4.8 and 4.6, etc. The final statistic shows what the average of the "violation" was for the entire simulation period. Table 5 shows the violation limit and histogram interval for each parameter tabulated for both the North Slough and the Lower Columbia Slough.

Table 5. Violation limits and histogram intervals for volume weigheted environmental performance criteria.

Parameter	"Violation" limit	Histogram interval (20 histogram divisons)
Dissolved oxygen	5.0 mg/l	0.4 mg/l
pH	8.5	0.4
coliform bacteria	200 col/100 ml	2 (multiplicative factor)
algae	15 ug/l chlorophyll a	10 ug/l
velocity	0.0 m/s	0.01 m/s

Average concentration of the violation was determined from

$$C_{volume} = \frac{\sum_{i=1}^{nt}\sum_{j=1}^{nc}(C_{ij}Vol_{ij}\Delta t_i)}{\sum_{i=1}^{nt}\sum_{j=1}^{nc}(Vol_{ij}\Delta t_i)}$$

where nt: number of model time steps for the model simulation period

nc: number of violations of concentration above or below the "violation" limit

C_{ij}: concentration at time level i and cell j in "violation" of "violation" limit

Vol_{ij}: volume of cell j at time level i where water quality standard is in violation

Δt_i: time step at time level i

The average volume in violation for the entire system was determined from

$$Volume_{fraction} = \frac{\sum_{i=1}^{nt}\sum_{j=1}^{nc}(Vol_{ij}\Delta t_i)}{\sum_{i=1}^{nt}(\sum_{k=1}^{n} Vol_{ik})\Delta t_i}$$

where n: number of model cells at time level i

k: index for cell number

Vol_{ik}: volume of cell k at time level i

The above equation was also used for the histogram intervals where the average volume in violation for a specific range of the violation was calculated.

3. MODEL RESULTS

Figures 4 through 7 show the dissolved oygen concentrations (vertical, volume weighted averages) at the east end of North Slough (ENS), the mid-point of North Slough, and the entrance to North Slough in the Lower Columbia Slough for run numbers 1 through 4, respectively.

Figures 8 through 11 show the environmental performance criteria for North Slough for runs 1 through 4, respectively. Figures 12 through 15 show the environmental performance criteria for the Lower Columbia Slough for runs 1 through 4, respectively.

Tables 6 through 9 show vertical, volume weighted averages of several water quality parameters at seven different control points along the Lower Columbia Slough and North Slough for runs 1 through 4, respectively.

Also, visualization tools showing the impact of the increased flow from Bybee Lakes on North Slough dissolved oxygen conditions for Runs 1 through 4. The computer animation were snapshots of the longitudinal and vertical variation in dissolved oxygen and water level at intervals of 0.07 days (1.7 hours) for a 2 week period from Julian day 214 (August 1, 1992) through Julian day 228 (August 15, 1992). This period was chosen because of the large file size for one run - 10 MB uncompressed (only 1.4 MB compressed to fit onto a single 1.44 MB floppy disk).

Run 1

In Figure 4 for Run 1 (no flow from the lakes), dissolved oxygen at ENS was very low - an average of 3.7 mg/l over the model period. At the mid-point along North Slough, the dissolved oxygen was influenced by tidal exchange as evidenced by the period of fluctuation of oxygen levels. The reduction of dissolved oxygen moving east along North Slough reflects data trends shown in Figure 2. The average volume of North Slough in violation of the target of 5 mg/l was 27% according to Figure 8.

Of interest also in Figure 4 is the lower dissolved oxygen at the entrance to North Slough around Julian day 221 because of the CSO event on Julian day 219. This CSO event only slightly impacted dissolved oxygen conditions in North Slough because of limited tidal circulation.

Run 2
As the flow from Bybee Lakes was increased to 10 cfs in Run 2 (Figure 5), the dissolved oxygen at ENS improved to ana verage of 7.2 mg/l (reflecting the higher dissolved oxygen in Bybee Lake), but the oxygen levels at the mid-point of the North Slough were reduced from an average of 7.2 mg/l to 5.1 mg/l. Overall though, according to Figure 9, the volume of North Slough in violation of the dissolved oxygen goal was 19%. Hence, increased flow augmentation improved the overall dissolved oxygen in the North Slough. As shown in the computer animation, this increased flow moved the region of lower dissolved oxygen further toward the west (as also indicated in the model result in Figure 5). The field data in Figure 2 sometimes shows this same trend, such as on August 3, 1993 when there was flow from the Lakes during the drawdown experiment.

Run 3
Increasing the flow from the lakes to 25 cfs in Run 3 (Figure 6), continued to improve the overall dissolved oxygen conditions in North Slough at both ENS (average dissolved oxygen over simulation period of 8 mg/l) and at the mid-point of the North SLough (average dissolved oxygen of 6.4 mg/l). The lower dissolved oygen occurs further from the east end becasue of sediment oxygen demand occurring as the flow moved from east to west. According to Figure 10, the volume of North Slough lower than 5 mg/l of dissolved oxygen was reduced to 5%.

Run 4
As expected, increasing the flow to 75 cfs in Run 4 (Figure 7) further brought the North Slough dissolved oxygen to more closely mimic the dissolved oxygen conditions in Smith and Bybee Lakes. For this simulation, the volume of North Slough lower than 5 mg/l of dissolved oxygen was reduced to almost 0% according to Figure 11. Interestingly, by increasing the flow from the Lakes, the water is held back in the Lower Columbia Slough somewhat resulting in a slight increase in chlorophyll a growth at SJB from 70 to 72 ug/l (see Tables 6-9) and a slight increase in the volume of violation of the chlorophyll a standard in the Lower Slough from 80.5% to 83.4% (see Figures 12-15). This impact was also reported by Wells (1992b) when Smith and Bybee Lakes were open to North Slough.

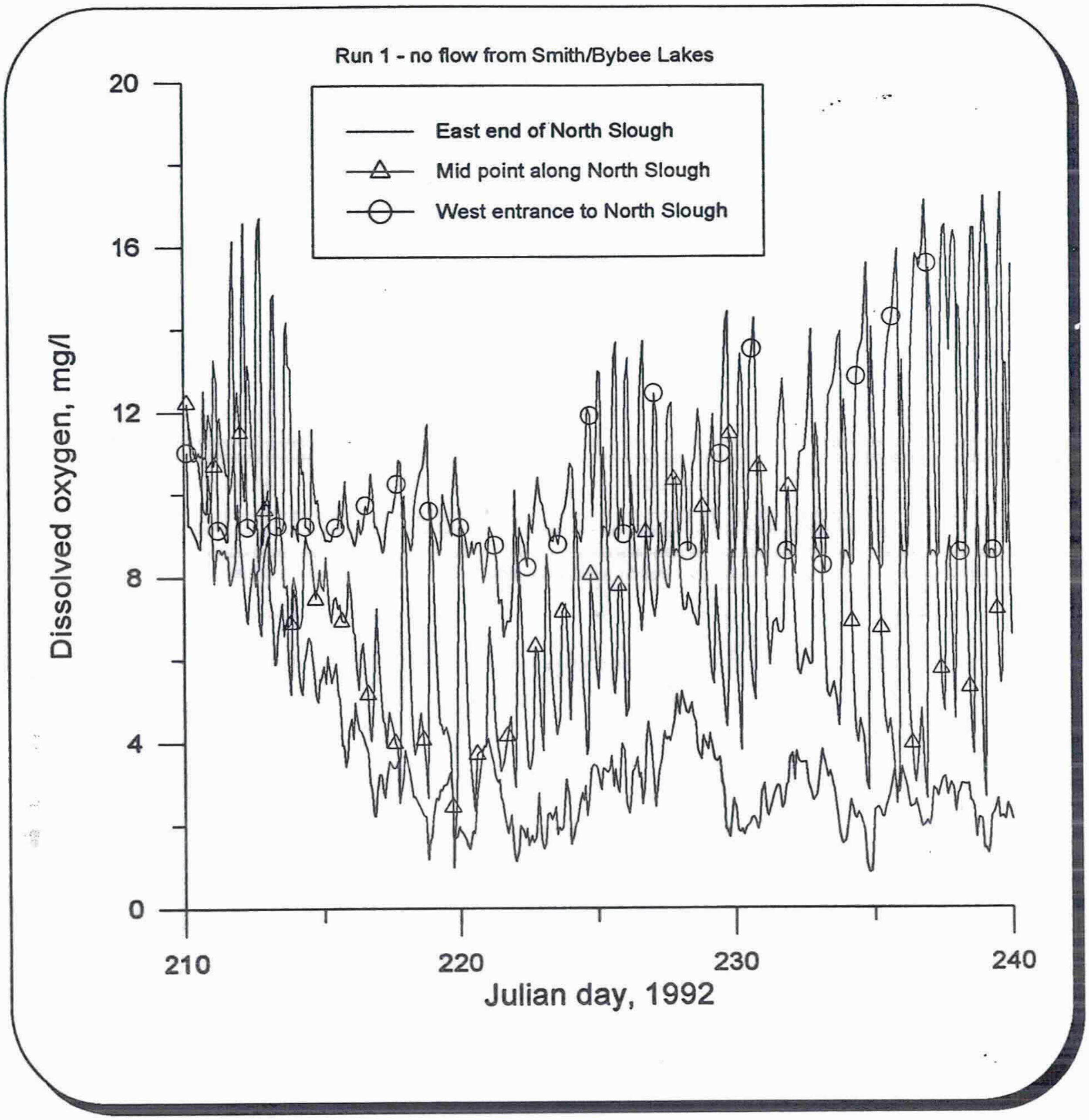


Figure 4. Vertical average dissolved oxygen concentrations at 3 control points along North Slough during the simulation period for Run 1.

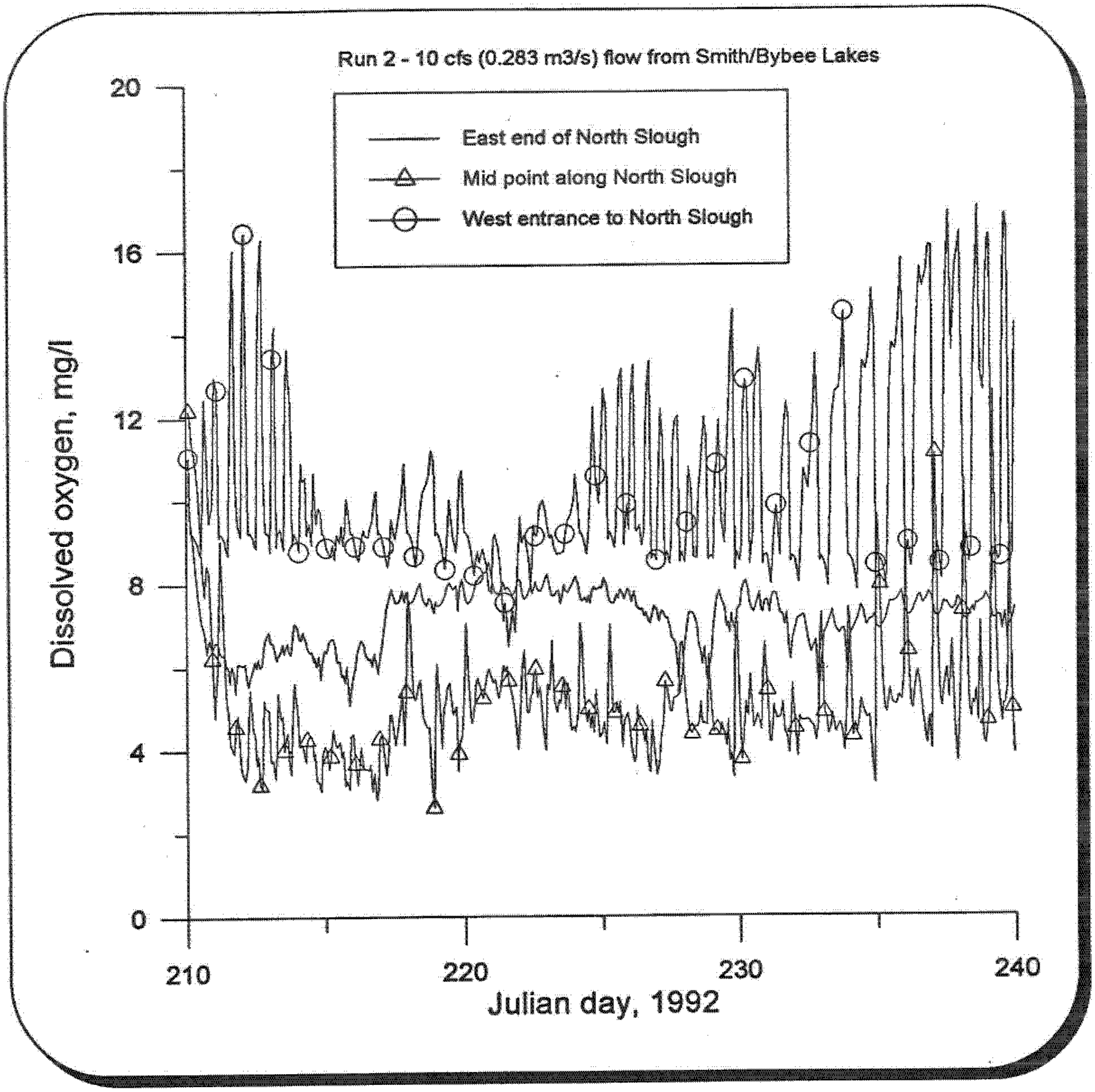


Figure 5. Vertical average dissolved oxygen concentrations at 3 control points along North Slough during the simulation period for Run 2.

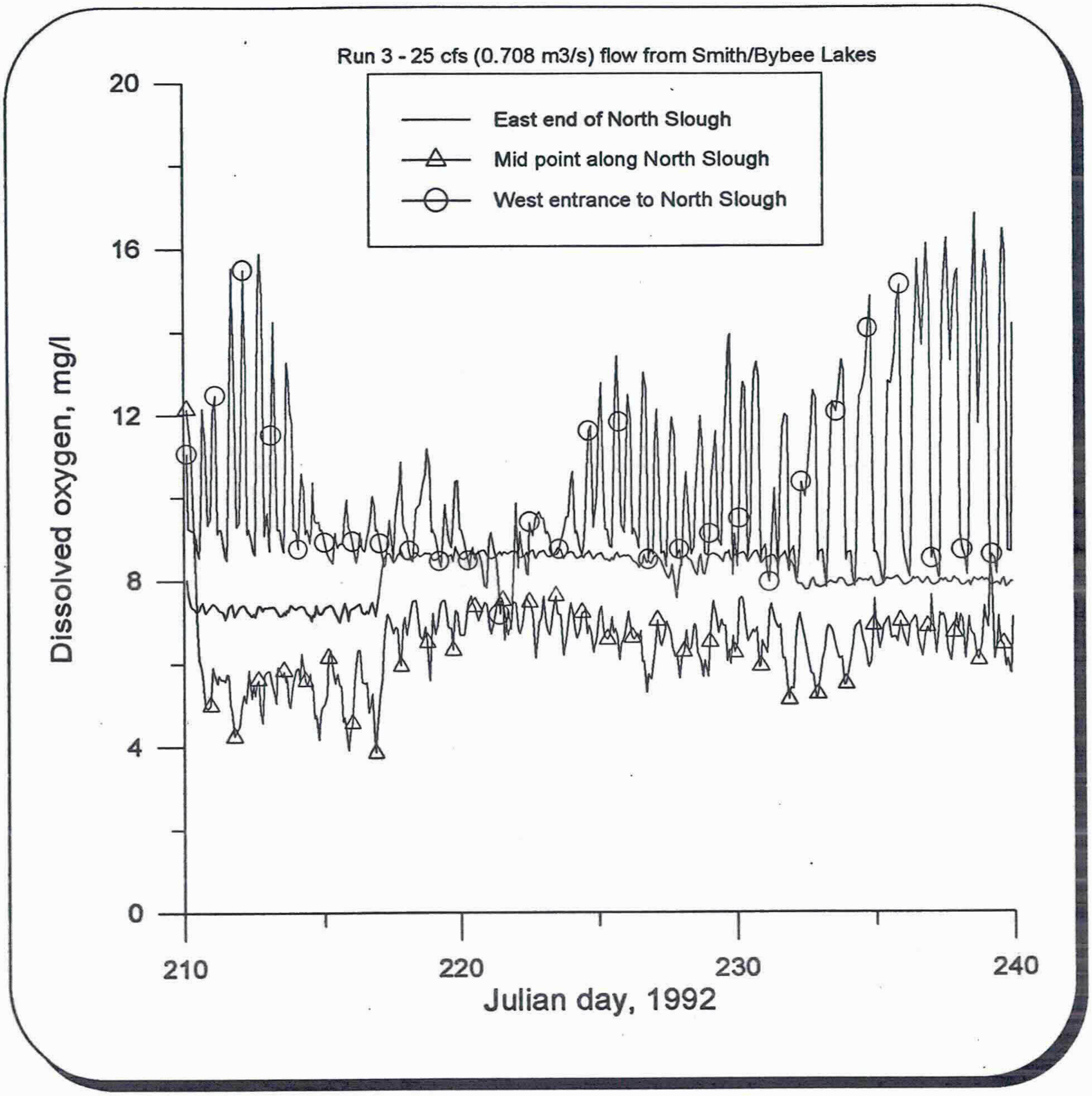


Figure 6. Vertical average dissolved oxygen concentrations at 3 control points along North Slough during the simulation period for Run 3.

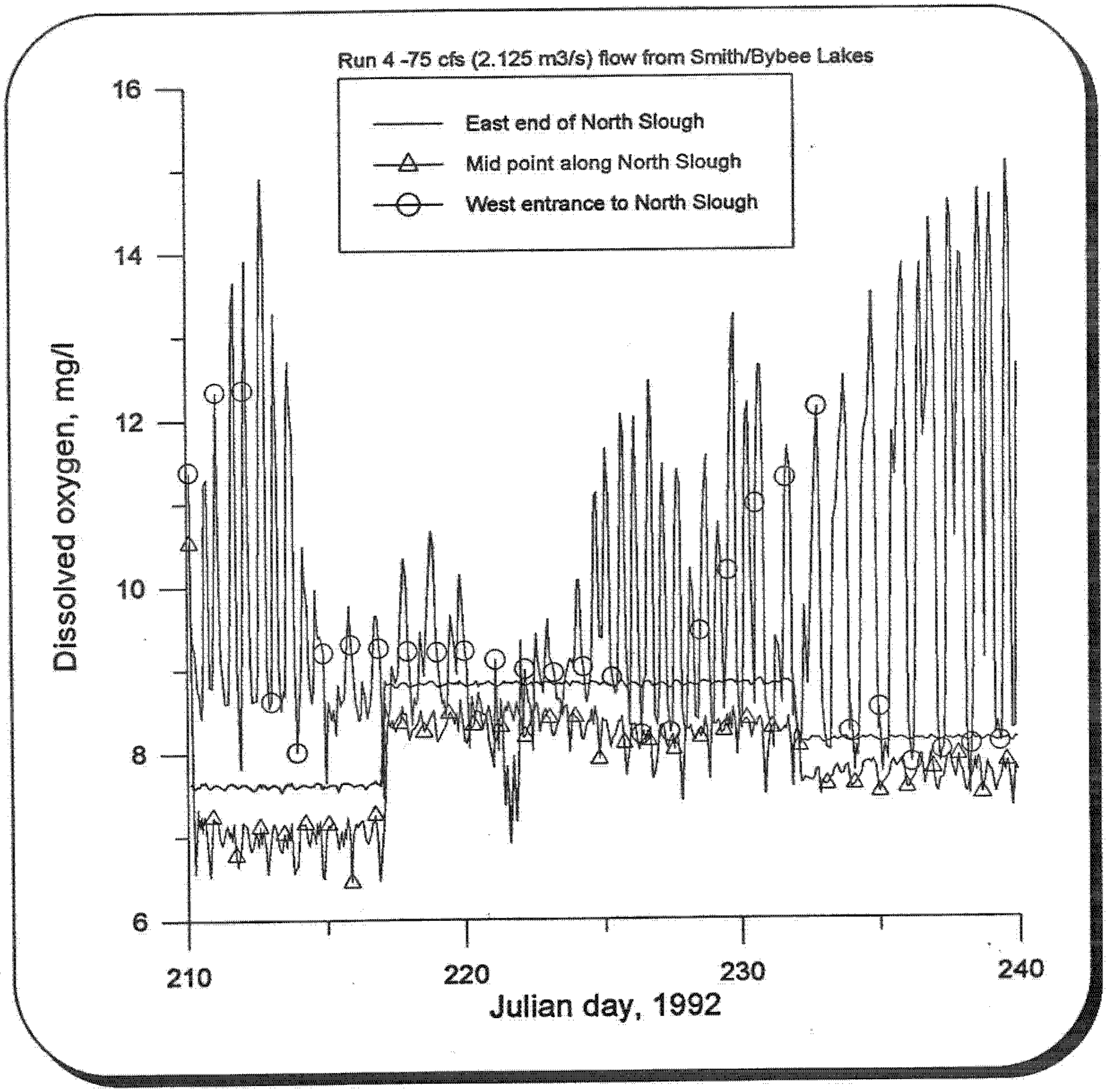
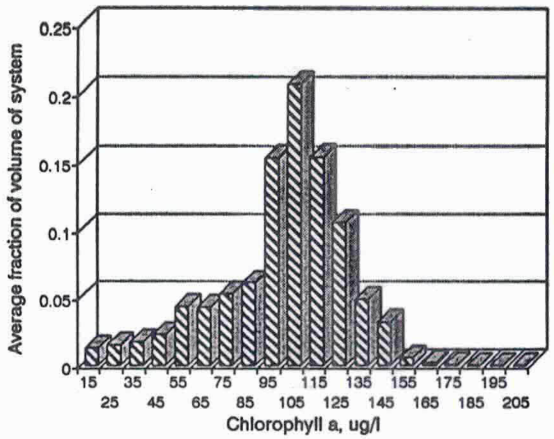


Figure 7. Vertical average dissolved oxygen concentrations at 3 control points along North Slough during the simulation period for Run 4.

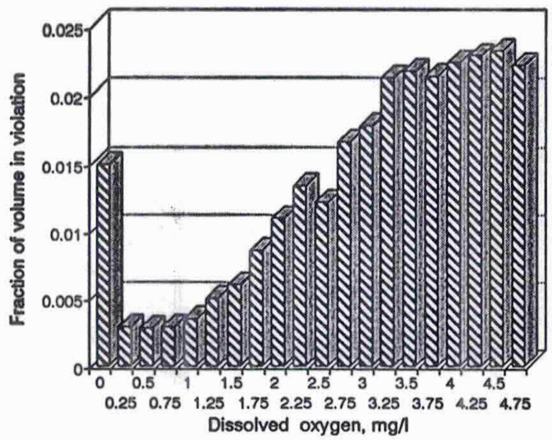
Chlorophyll a : Goal < 15 ug/l chlorophyll a

Total fraction in violation:	0.9756
Average of violation:	103.5 ug/l



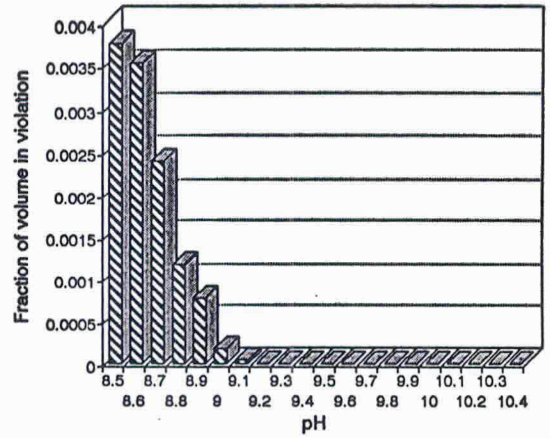
Dissolved oxygen : Goal > 5 mg/l

Total fraction in violation:	0.2721
Average violation:	3.21 mg/l



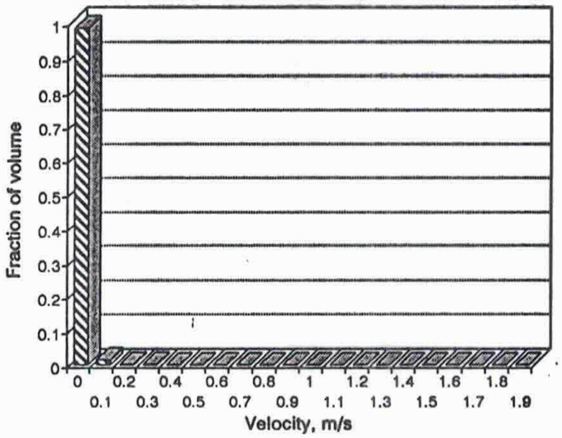
pH : Goal < 8.5

Total fraction in violation:	0.01187
Average violation:	8.688



Velocity

Total fraction:	1
Average velocity:	0.02357 m/s



Coliform : Goal < 200 col/100 ml

Total fraction in violation:	0.235
Average violation:	5581 col/100ml

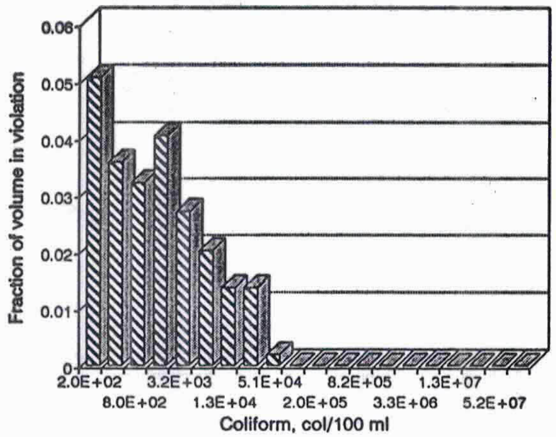
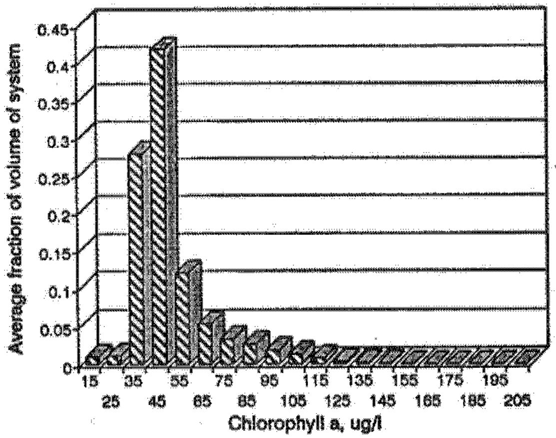


FIG 8 N.S. Run 1

NC1

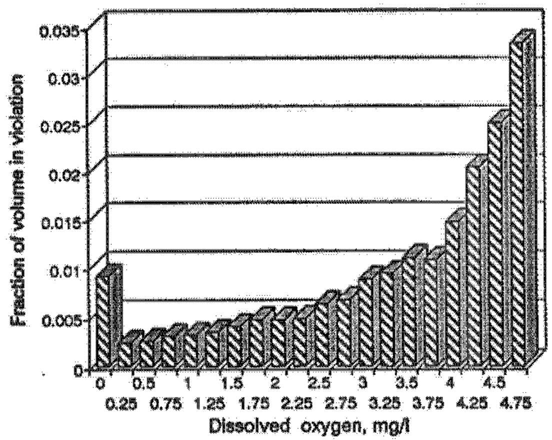
Chlorophyll a : Goal < 15 ug/l chlorophyll a

Total fraction in violation:	0.9853
Average of violation:	53.97 ug/l



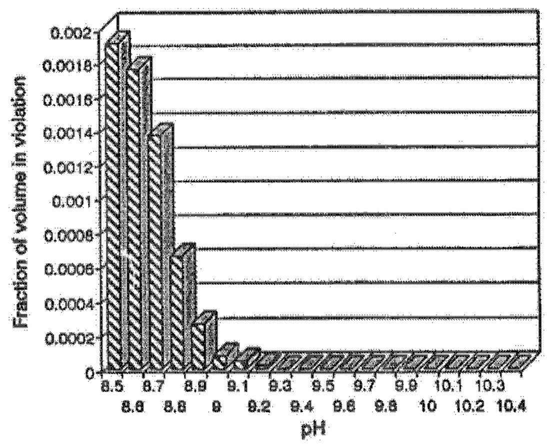
Dissolved oxygen : Goal > 5 mg/l

Total fraction in violation:	0.1879
Average violation:	3.485 mg/l



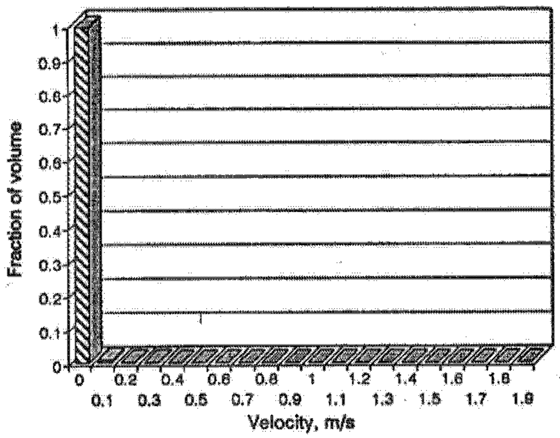
pH : Goal < 8.5

Total fraction in violation:	0.006076
Average violation:	8.685



Velocity

Total fraction:	1
Average velocity:	0.02818 m/s



Coliform : Goal < 200 col/100 ml

Total fraction in violation:	0.1064
Average violation:	5403 col/100ml

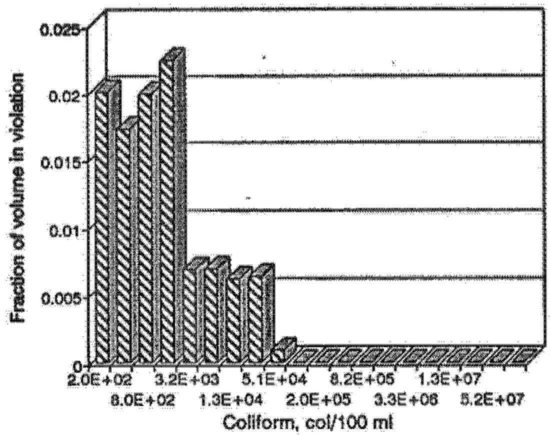
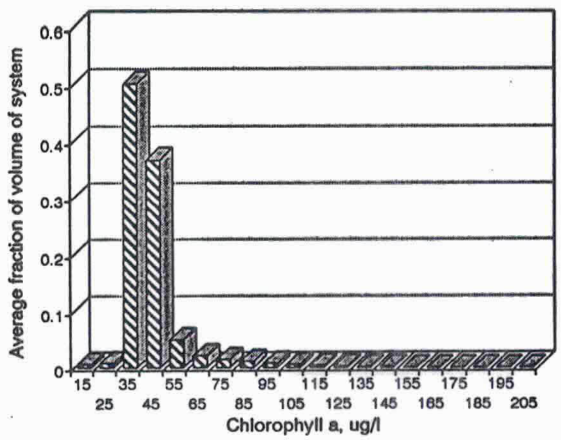


FIG 9. NS Run 2

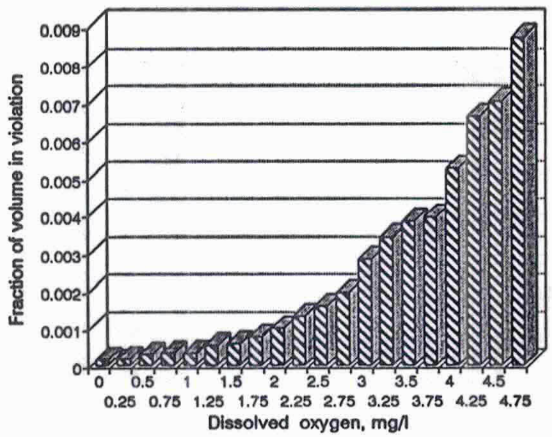
Chlorophyll a : Goal < 15 ug/l chlorophyll a

Total fraction in violation:	0.9941
Average of violation:	48.48 ug/l



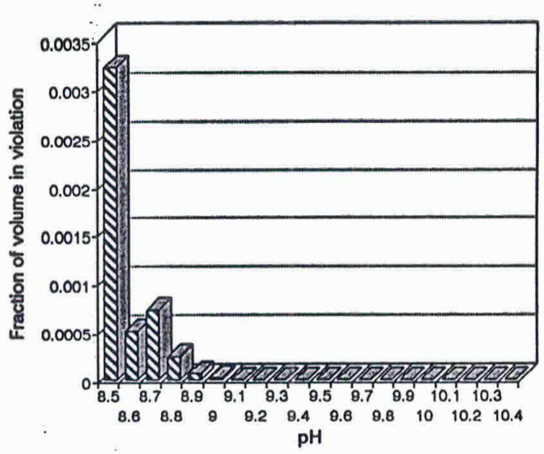
Dissolved oxygen : Goal > 5 mg/l

Total fraction in violation:	0.05036
Average violation:	3.849 mg/l



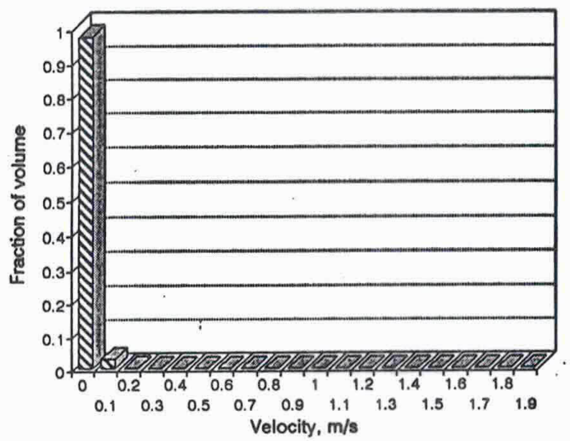
pH : Goal < 8.5

Total fraction in violation:	0.004765
Average violation:	8.597



Velocity

Total fraction:	1
Average velocity:	0.03941 m/s



Coliform : Goal < 200 col/100 ml

Total fraction in violation:	0.05852
Average violation:	4441 col/100ml

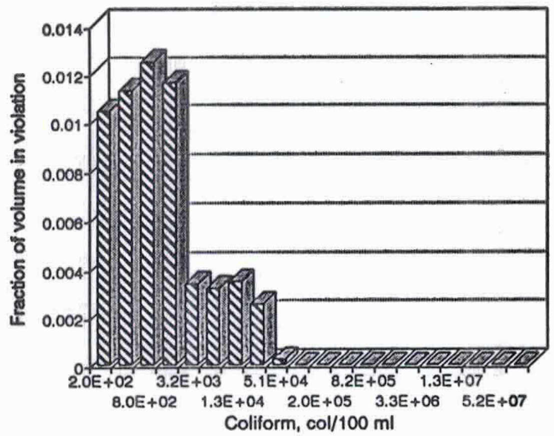
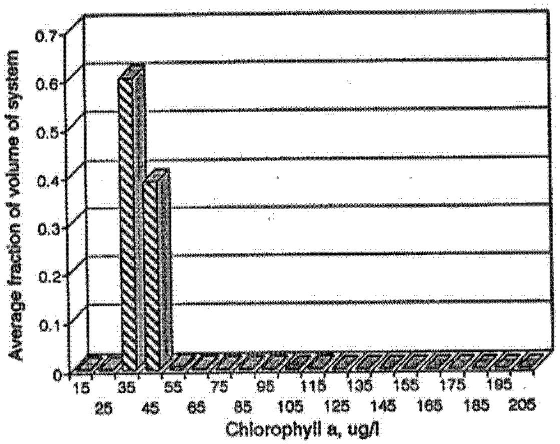


Fig 10 NS ~~[illegible]~~ Run 3

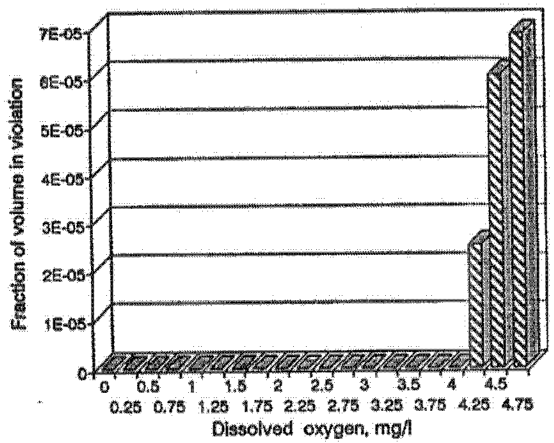
Chlorophyll a : Goal < 15 ug/l chlorophyll a

Total fraction in violation:	0.9999
Average of violation:	45.37 ug/l



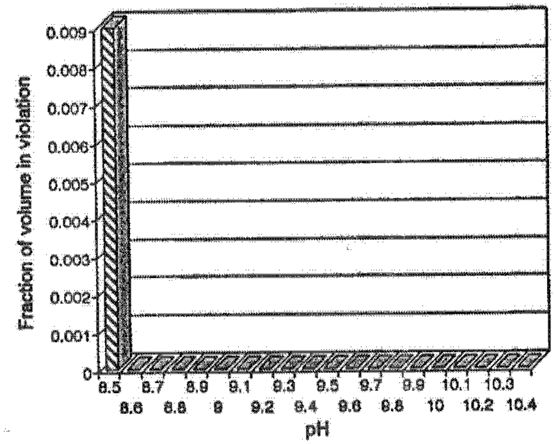
Dissolved oxygen : Goal > 5 mg/l

Total fraction in violation:	0.000154
Average violation:	4.7 mg/l



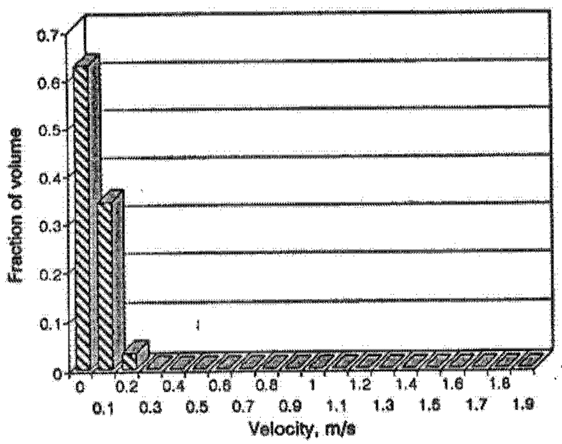
pH : Goal < 8.5

Total fraction in violation:	0.008989
Average violation:	8.516



Velocity

Total fraction:	0.9999
Average velocity:	0.09225 m/s



Coliform : Goal < 200 col/100 ml

Total fraction in violation:	0.00647
Average violation:	556.9 col/100ml

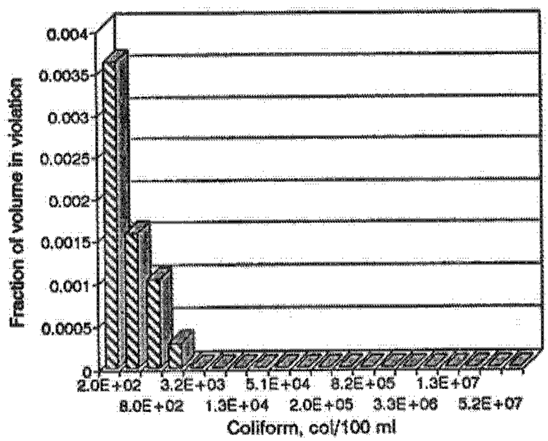
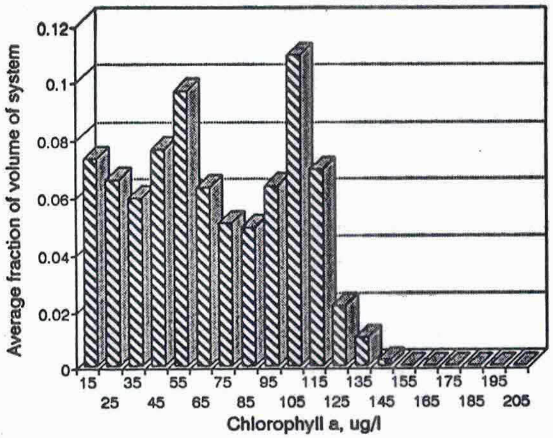


Fig 11 NS Run 4

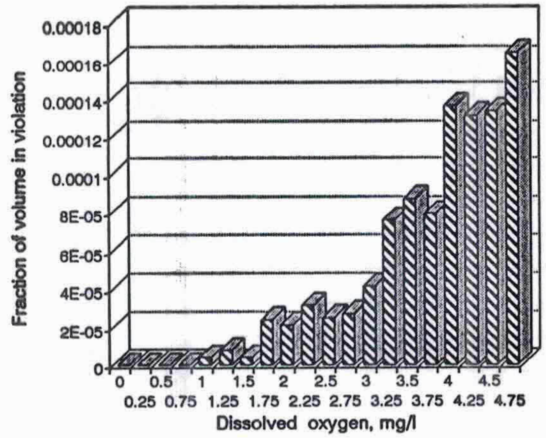
Chlorophyll a : Goal < 15 ug/l chlorophyll a

Total fraction in violation:	0.8046
Average of violation:	73.41 ug/l



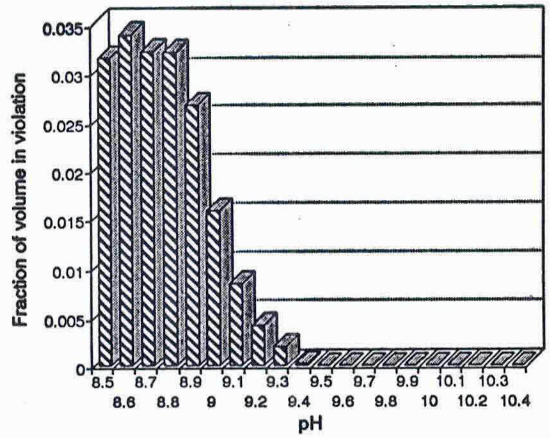
Dissolved oxygen : Goal > 5 mg/l

Total fraction in violation:	0.000994
Average violation:	3.924 mg/l



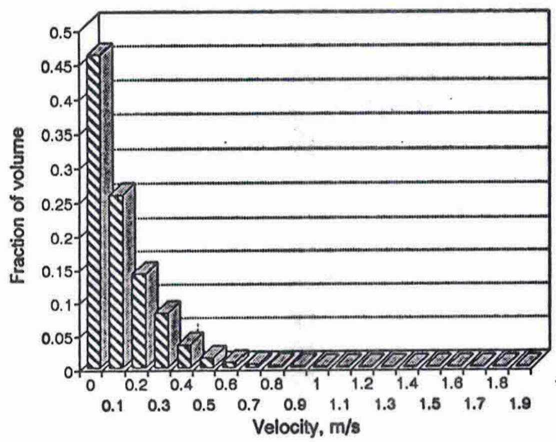
pH : Goal < 8.5

Total fraction in violation:	0.1874
Average violation:	8.806



Velocity

Total fraction:	0.9998
Average velocity:	0.1596 m/s



Coliform : Goal < 200 col/100 ml

Total fraction in violation:	0.1973
Average violation:	19510 col/100ml

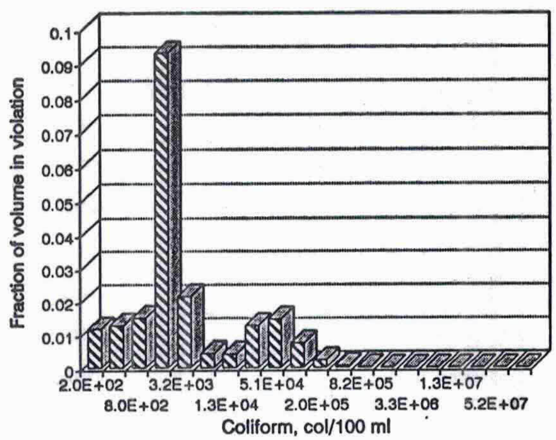
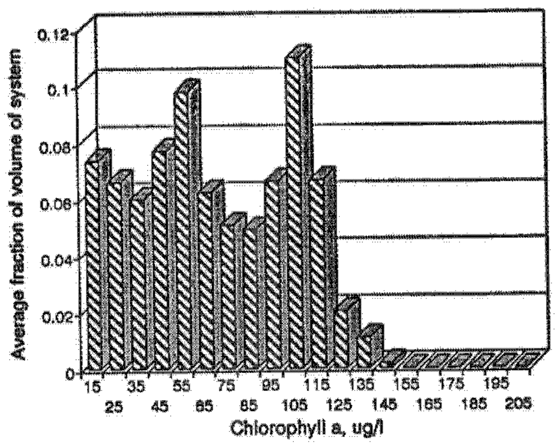


Fig 12 Lower Slough Run 1

CS1

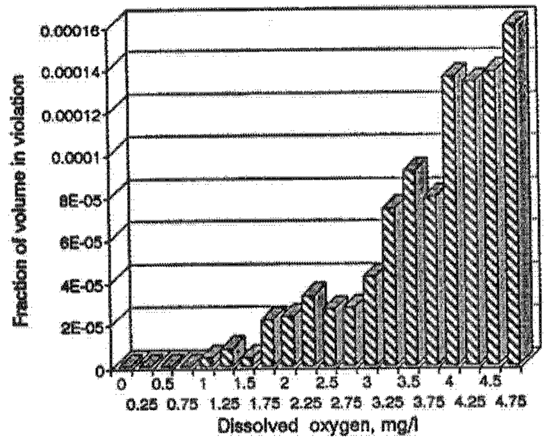
Chlorophyll a : Goal < 15 ug/l chlorophyll a

Total fraction in violation:	0.8085
Average of violation:	73.15 ug/l



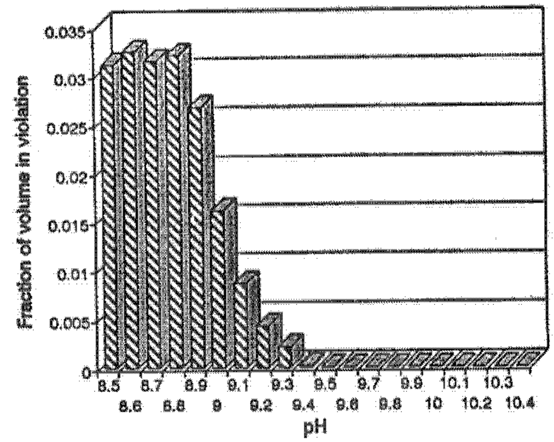
Dissolved oxygen : Goal > 5 mg/l

Total fraction in violation:	0.000995
Average violation:	3.924 mg/l



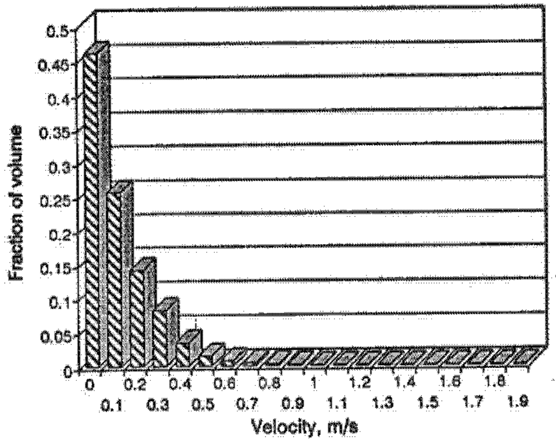
pH : Goal < 8.5

Total fraction in violation:	0.1845
Average violation:	8.809



Velocity

Total fraction:	0.9998
Average velocity:	0.1598 m/s



Coliform : Goal < 200 col/100 ml

Total fraction in violation:	0.195
Average violation:	19740 col/100ml

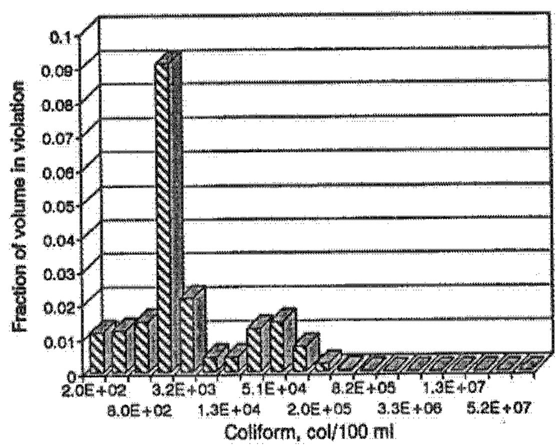
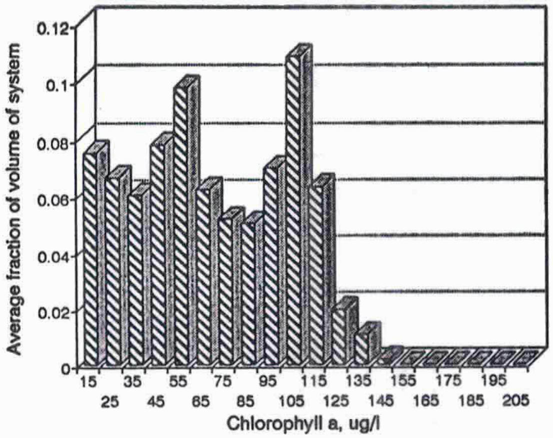


Fig 13 Lower Slough Run 2

CS 2

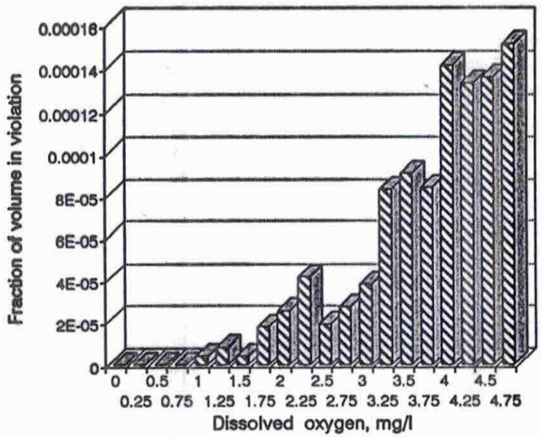
Chlorophyll a : Goal < 15 ug/l chlorophyll a

Total fraction in violation:	0.8144
Average of violation:	72.83 ug/l



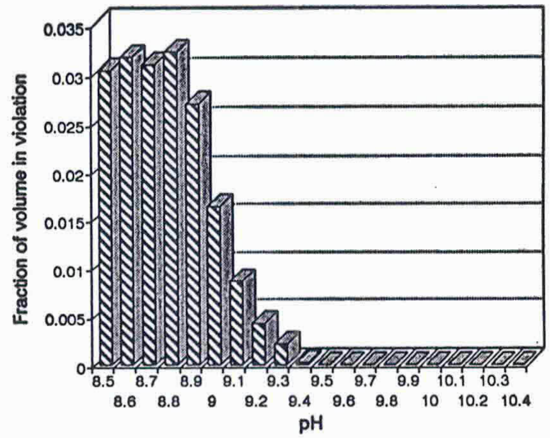
Dissolved oxygen : Goal > 5 mg/l

Total fraction in violation:	0.001002
Average violation:	3.912 mg/l



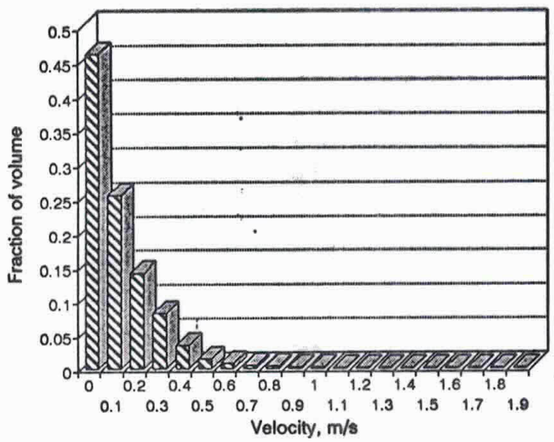
pH : Goal < 8.5

Total fraction in violation:	0.1838
Average violation:	8.812



Velocity

Total fraction:	0.9998
Average velocity:	0.16 m/s



Coliform : Goal < 200 col/100 ml

Total fraction in violation:	0.1925
Average violation:	19910 col/100ml

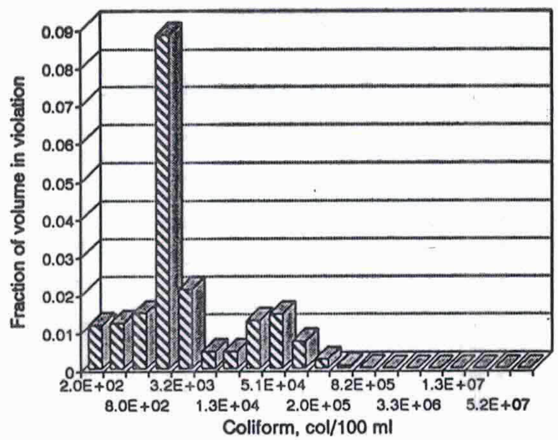
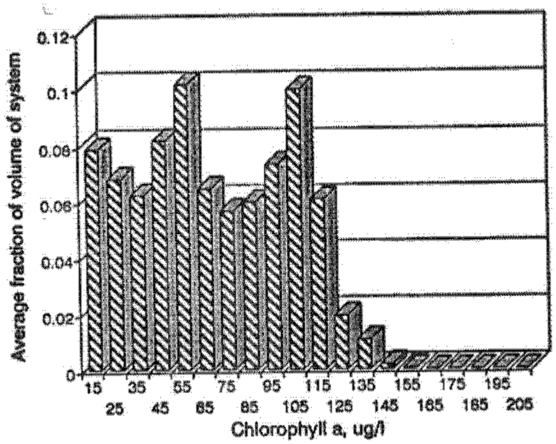


Fig 14 Lower Slough Run 3

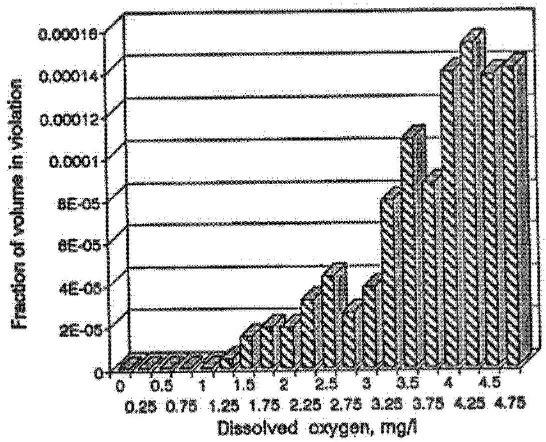
Chlorophyll a : Goal < 15 ug/l chlorophyll a

Total fraction in violation:	0.8343
Average of violation:	72 ug/l



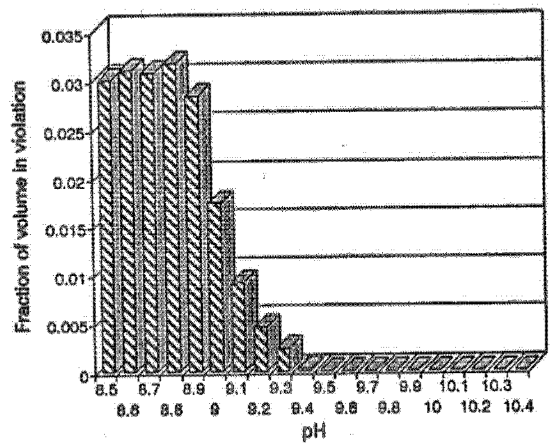
Dissolved oxygen : Goal > 5 mg/l

Total fraction in violation:	0.001036
Average violation:	3.898 mg/l



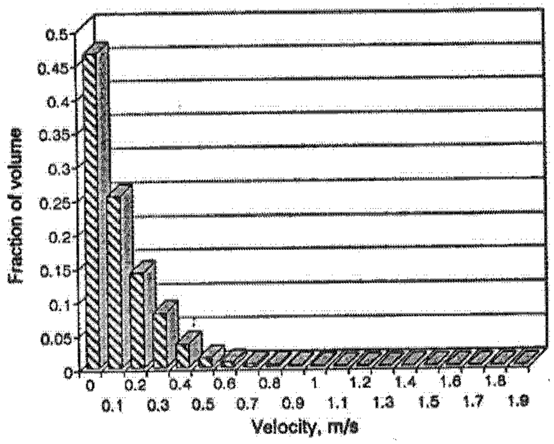
pH : Goal < 8.5

Total fraction in violation:	0.185
Average violation:	8.817



Velocity

Total fraction:	0.9998
Average velocity:	0.1604 m/s



Coliform : Goal < 200 col/100 ml

Total fraction in violation:	0.1837
Average violation:	20670 col/100ml

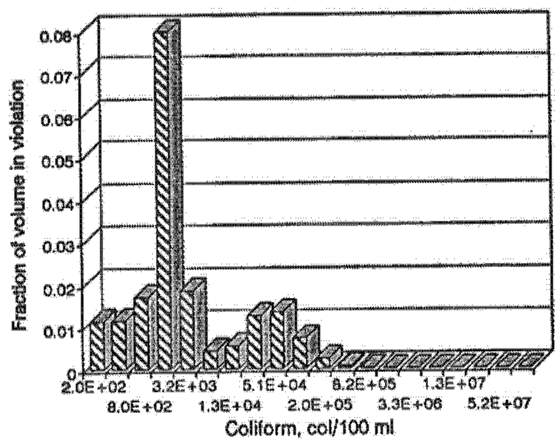


Fig 15 Lower Slough Run 4

CS4

Table 6. Vertical and temporal averages of water quality parrameters at several control points in the Lower Columbia Slough system for Run 1 (no flow from Smith/Bybee Lakes).

Parameter	ELS	VNB	SJB	CNN	ENS	mid North Slough	LOM
temperature oC	21.1	21.3	22.4	21.8	22.1	22.7	21.7
coliform, number/100 ml	34	6,403	4,080	3,220	438	1,620	2,405
soluble BOD, mg/l	4.5	4.4	4.2	4.7	3.2	7.2	4.9
algae, chlorophyll a, ug/l	35	47	70	49	115	104	26
PO4-P, mg/l	0.03	0.03	0.02	0.03	0.02	0.01	0.04
NH3-N, mg/l	0.17	0.19	0.21	0.19	0.28	0.26	0.14
NO3-N, mg/l	3.53	3.24	1.76	1.26	1.17	1.57	0.73
dissolved oxygen, mg/l	12.2	12.3	11.7	10.5	3.7	7.2	9.7
pH	7.47	7.8	8	7.9	6.94	7.16	7.93

Table 7. Vertical and temporal averages of water quality parrameters at several control points in the Lower Columbia Slough system for Run 2(flow of 10 cfs from Smith/Bybee Lakes)

Parameter	ELS	VNB	SJB	CNN	ENS	mid North Slough	LOM
temperature oC	21	21.3	22.4	21.8	21.2	21.7	21.7
coliform, number/100 ml	34	6,406	4,070	3,137	2	359	2,333
soluble BOD, mg/l	4.5	4.4	4.2	4.7	4.9	4.5	4.9

Parameter	ELS	VNB	SJB	CNN	ENS	mid North Slough	LOM
algae, chlorophyll a, ug/l	35	47	70	49	45	52	27
PO4-P, mg/l	0.03	0.03	0.02	0.03	0.03	0.02	0.04
NH3-N, mg/l	0.17	0.19	0.21	0.18	0.06	0.11	0.15
NO3-N, mg/l	3.53	3.24	1.76	1.22	0.03	0.29	0.72
dissolved oxygen, mg/l	12.1	12.3	11.7	10.4	7.2	5.1	9.6
pH	7.48	7.81	8	7.88	7.7	7.3	7.9

Table 8. Vertical and temporal averages of water quality parrameters at several control points in the Lower Columbia Slough system for Run 3(flow of 25 cfs from Smith/Bybee Lakes).

Parameter	ELS	VNB	SJB	CNN	ENS	mid North Slough	LOM
temperature oC	21	21.3	22.4	21.9	21.2	21.3	21.7
coliform, number/100 ml	34	6,409	4,038	2,975	1	45	2,273
soluble BOD, mg/l	4.5	4.4	4.2	4.7	5	4.8	4.9
algae, chlorophyll a, ug/l	35	47	71	49	45	46	27
PO4-P, mg/l	0.03	0.03	0.02	0.03	0.03	0.03	0.04
NH3-N, mg/l	0.17	0.19	0.21	0.18	0.05	0.08	0.14
NO3-N, mg/l	3.5	3.2	1.7	1.2	0.02	0.07	0.69
dissolved oxygen, mg/l	12.1	12.3	11.7	10.2	8	6.4	9.5

Parameter	ELS	VNB	SJB	CNN	ENS	mid North Slough	LOM
pH	7.48	7.81	8	7.85	7.9	7.56	7.89

Table 9. Vertical and temporal averages of water quality parrameters at several control points in the Lower Columbia Slough system for Run 4(flow of 75 cfs from Smith/Bybee Lakes)

Parameter	ELS	VNB	SJB	CNN	ENS	mid North Slough	LOM
temperature oC	21	21.3	22.3	21.8	21.3	21.3	21.8
coliform, number/100 ml	34	6,466	4,072	2,458	1	1	2,129
soluble BOD, mg/l	4.5	4.4	4.2	4.7	5	4.9	4.9
algae, chlorophyll a, ug/l	35	47	72	49	45	45	29
PO4-P, mg/l	0.03	0.03	0.02	0.03	0.03	0.03	0.04
NH3-N, mg/l	0.17	0.19	0.21	0.16	0.05	0.06	0.13
NO3-N, mg/l	3.5	3.2	1.7	0.95	0.02	0.02	0.6
dissolved oxygen, mg/l	12.1	12.3	11.6	9.8	8.4	7.8	9.4
pH	7.47	7.82	7.99	7.85	8	7.86	7.9

4. SUMMARY AND CONCLUSIONS

Model simulations were made assessing the improvement in dissolved oxygen concentrations in North Slough by using flow augmentation from Smith/Bybee Lakes. Table 10 shows a summary of the model runs looking at average dissolved oxygen at ENS and at the mid-point and the volme of North Slough in violation of the water quality goal of 5 mg/l dissolved oxygen. These simulations showed that flows above 25 cfs from Smith/Bybee Lake would significantly influence oxygen conditions in the North

Slough during low-water summer conditions if the dissolved oxygen of the inflow from Bybee Lake was typical of saturation or near saturation conditions.

Table 10. Summary of model simulations.

Run #	Flow rate, cfs, from Smith/Bybee Lake	% volume of North Slough in violation of water quality goal of 5 mg/l dissolved oxygen	Average dissolved oxygen concentration in mg/l at ENS	Average dissolved oxygen concentration in mg/l at mid-point along North Slough
1	0	27.2	2.7	7.2
2	10	18.8	7.2	5.1
3	25	5	8	6.4
4	75	0	8.4	7.8

Of concern though in this analysis was whether the Lakes could supply that amount of water during the summer time period. Figures 16 through 19 show how much water would be available from the Lakes given an initial water surface elevation and a final target water surface elevation (neglecting water inflows from precipitation, runoff, or groundwater and water losses from evaporation or groundwater recharge).

For example, in Figure 19, if the initial water level in the lakes was 8 ft MSL and the final target value was 4 ft MSL over a 90 day period, less than 16 cfs would be available for flow augmentation. But, for short critical time periods, there is sufficient storage to provide a good flush of North Slough periodically. If the lake levels were at 8 ft MSL at the beginning of the summer, about 25 cfs could be supplied for 30 days to lower the water level to 6 ft MSL. To lower the water level from 6 ft MSL to 4 ft MSL would provide another 20 cfs for a 30 day period.

Another question posed is whether the water control structure at the end of North Slough can deliver the water required. This is documented in a report by Boyko (1995). According to Morgan (1995), beavers were often involved in clogging the structure with sticks and debris to keep the lake levels high. Because of this, suggestions have been made to remove the existing water level control structure and replace it with a larger channel capable of allowing the lakes to respond to the tidal forcing.

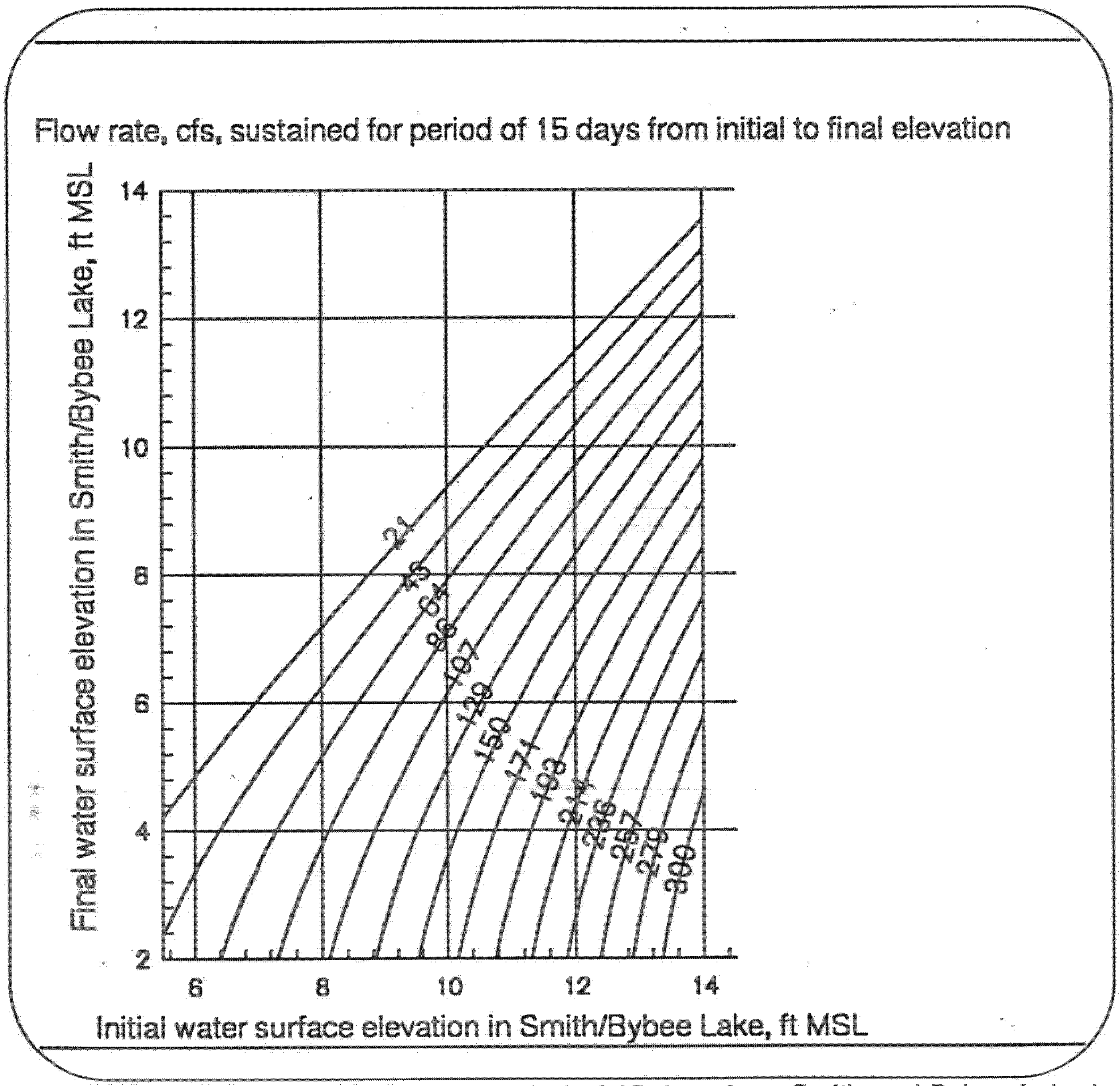


Figure 16. Flow rate available over a period of 15 days from Smith and Bybee Lake to North Slough.

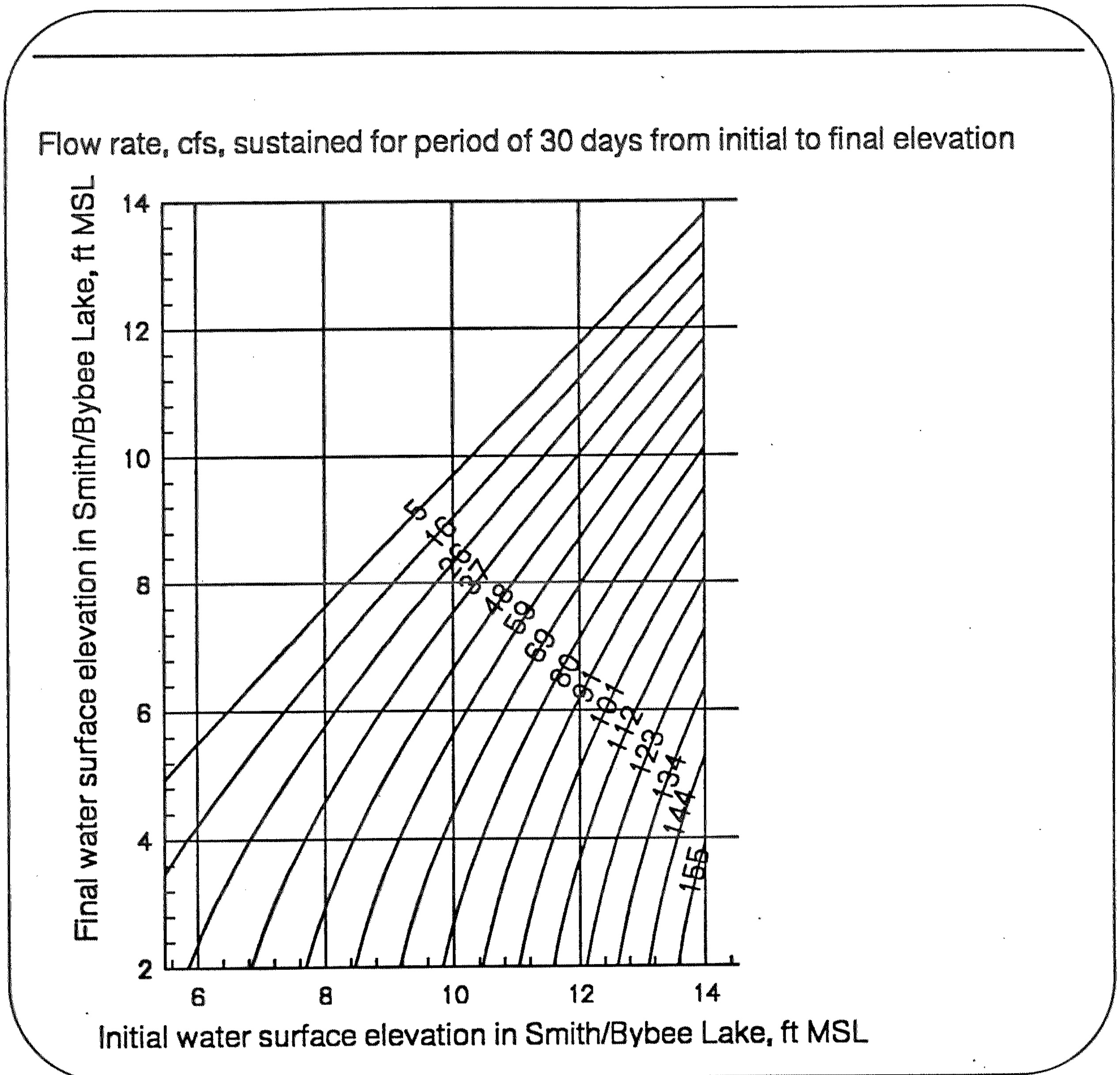


Figure 17. Flow rate available over a period of 30 days from Smith and Bybee Lake to North Slough.

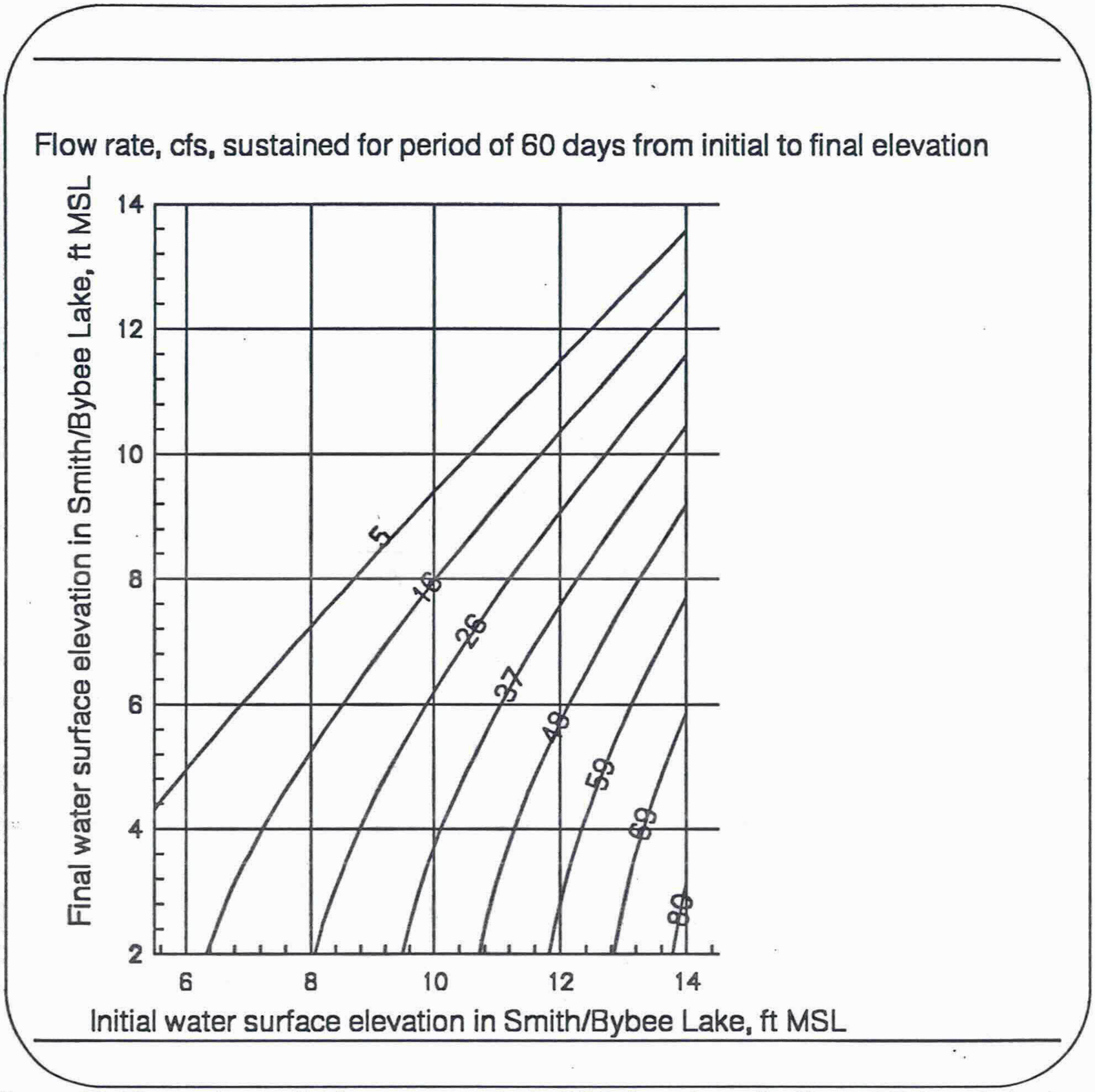


Figure 18. Flow rate available over a period of 60 days from Smith and Bybee Lake to North Slough.

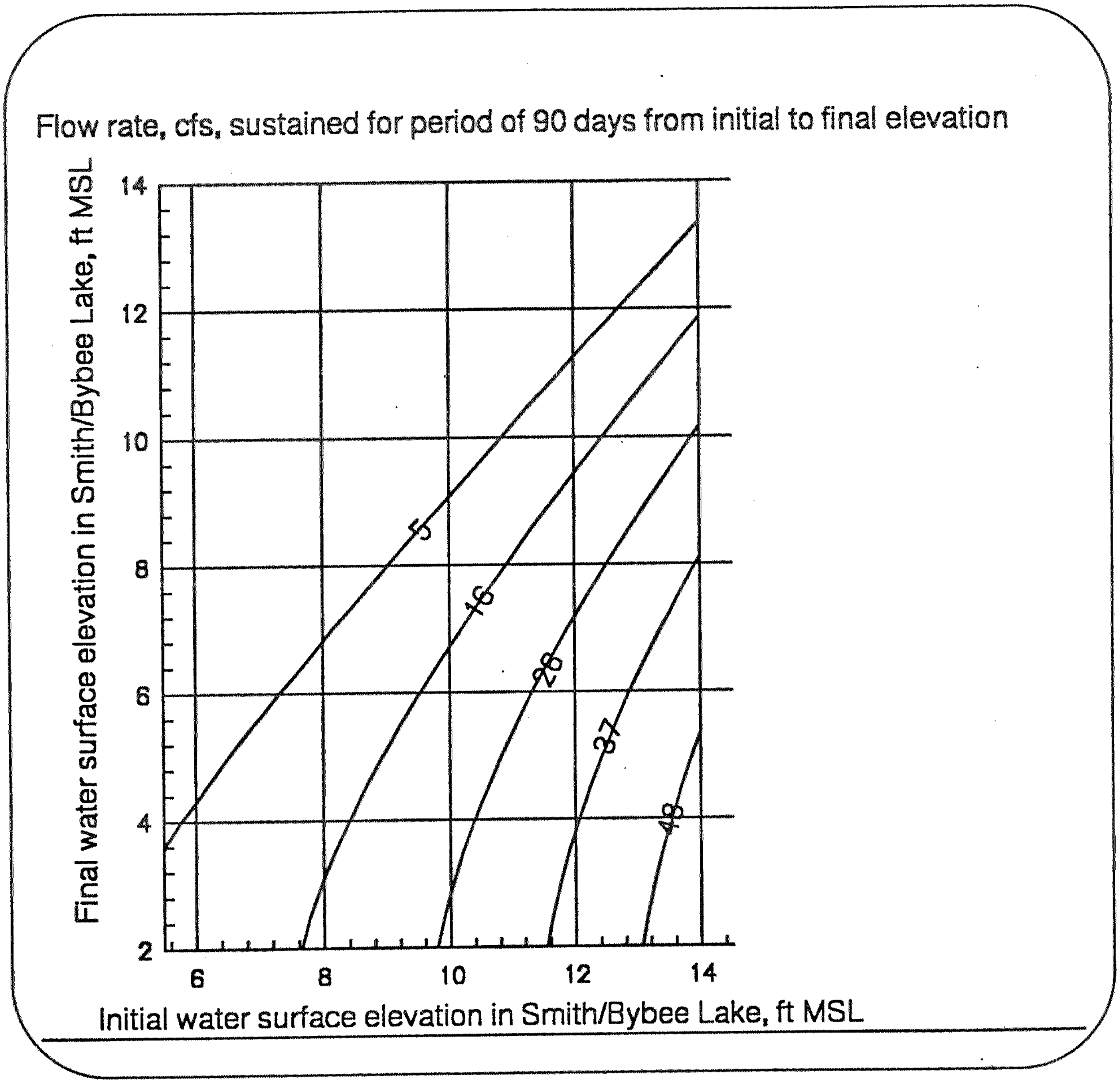


Figure 19. Flow rate available over a period of 90 days from Smith and Bybee Lake to North Slough.

Opening up the lakes to the North Slough would alleviate low dissolved oxygen problems because of additional dilution in North Slough but would not remove the source of the low dissolved oxygen. This source may be landfill leachate that is coming into the Slough through fractured media along the northern dike of the St. John's Landfill. Such seeps were evident in the summer of 1991 during a field trip by the principal investigator.

Flow augmentation will not be necessary if the dike and water control structure at the east end of North Slough are removed for a structure that will allow the lakes to have full tidal influence. But if the lakes are not to be re-connencted at the end of North Slough and flow augmentation is pursued for improving oxygen conditions, further sources of water may need to be pursued to allow for adequate augmentation volume.

Possibilities for further work on the North Slough system include the following:

1. Determine the source of the low dissolved oxygen (if landfill leachate, what can be done to reduce the source of the leachate ?)

2. Evaluate alternative sources of flow augmentation water - groundwater, Columbia RIver, Willamette River, or enhanced storage in Smith/Bybee Lakes (water levels are kept very high during winter to have adequate flow augmentation in the summer months)

3. Utilize the seepage estimates from work done by Li and co-workers at PSU with the water quality model to estimate impacts of this landfill leachate on the North Slough

4. Evaluate how landfill leachate would affect Smith/Bybee Lakes if the dike and water control structure are removed from the east end of North Slough by using results from Li and co-workers at PSU and the Lower Slough model with Smith/Bybee Lakes

5. REFERENCES

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APPENDIX A: Letter report submitted to METRO in 1991 concerning water quality in North Slough and impact of North Slough on Smith and Bybee Lakes with the old discharge control structure.

EFFECT OF CSO'S AND NORTH SLOUGH WATER QUALITY ON SMITH/BYBEE LAKES

Scott A. Wells
Department of Civil Engineering
Portland State University

I. NORTH SLOUGH WATER QUALITY

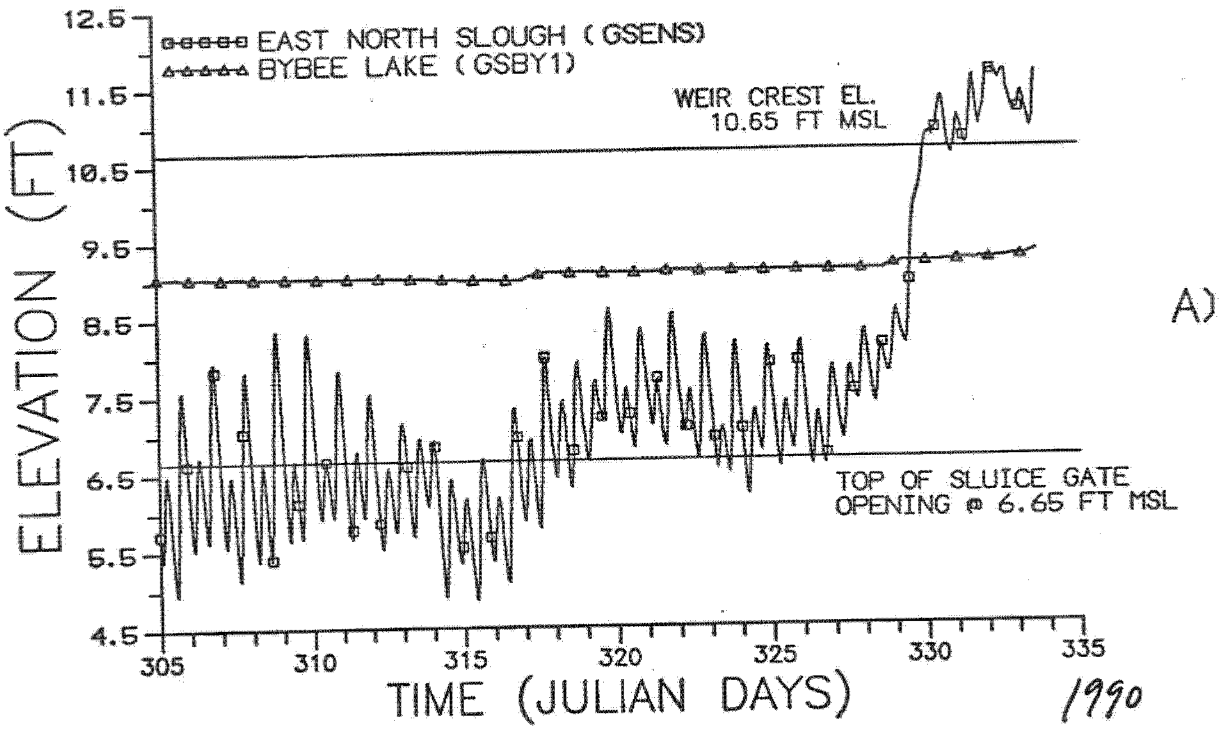
- degradation of North Slough water quality, very low dissolved oxygen even in winter
- cause (?): high landfill leachate COD
- solution (?): increase flows from Bybee Lake to North Slough
- lake water quality is affected when flow is from N. Slough to Bybee Lake

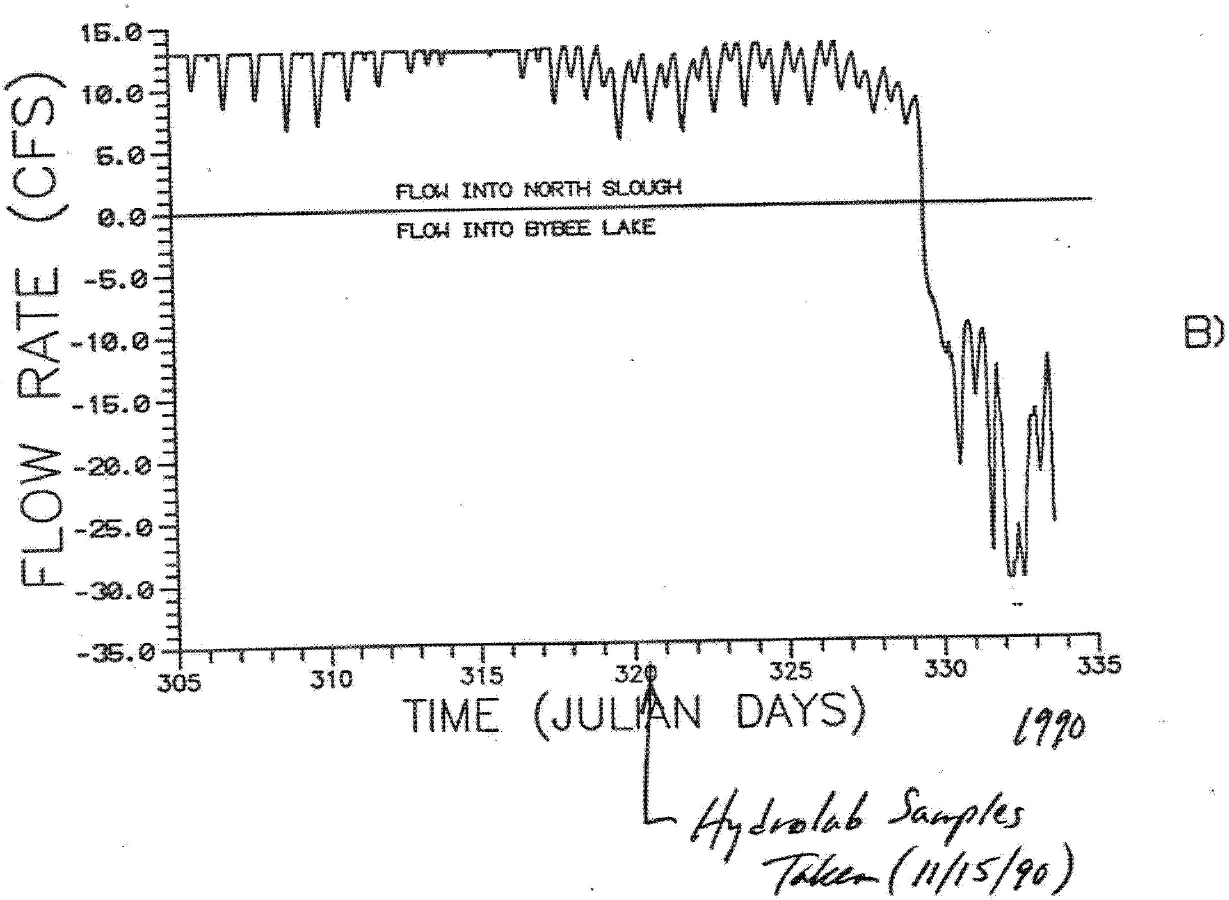
II. CSO's

- high coliform counts in Columbia Slough/North Slough during CSO events
- lake water quality is affected when flow is from N. Slough to Bybee Lake

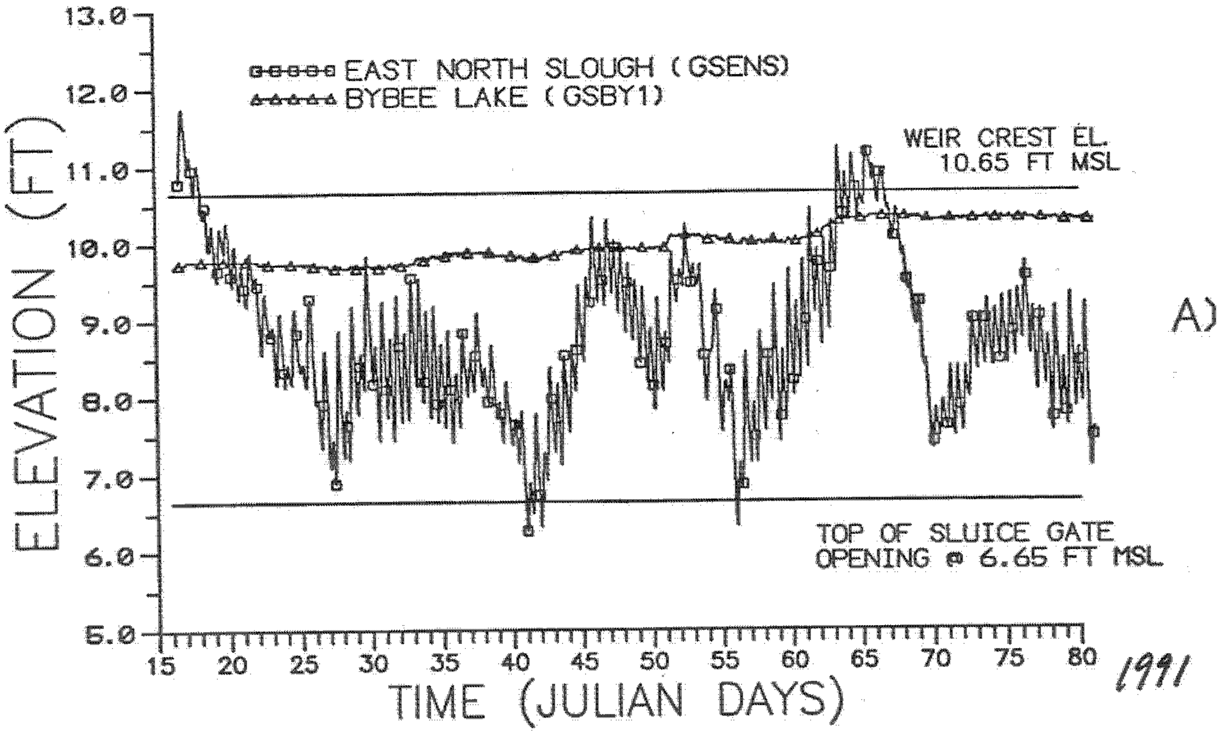
Station	Date	Coliform (col./100 ml)
E. North Slough	3/3/91 (9 am) JD = 62	0
Bybee Lake	3/3/91 (9 am) JD = 62	0
E. North Slough	3/4/91 (2 pm) JD = 63	24,800
Bybee Lake	3/4/91 (2:30 pm) JD = 63	800

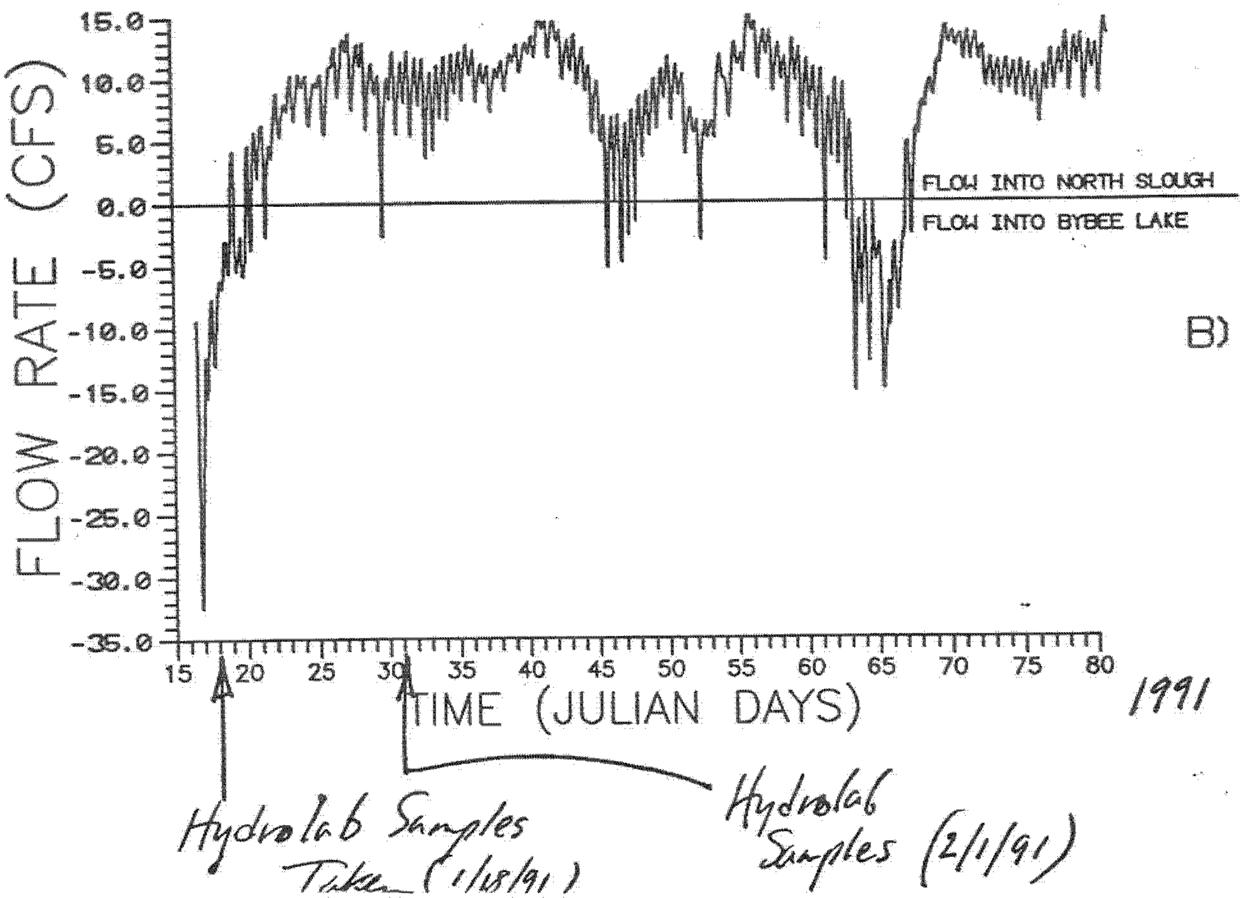
COMPARISON OF GAGE HEIGHTS AND FLOW RATES AT THE BYBEE LAKE FLOW STRUCTURE FOR THE PERIOD 11/01/90 THROUGH 11/29/90. A) COMPARISON OF GAGE HEIGHTS AT GSENS AND GSBY1 VS. TIME. B) ESTIMATED FLOW RATES VS. TIME FROM HYDRAULIC MODEL (QBYO.FOR) USING EXISTING CONDITIONS.



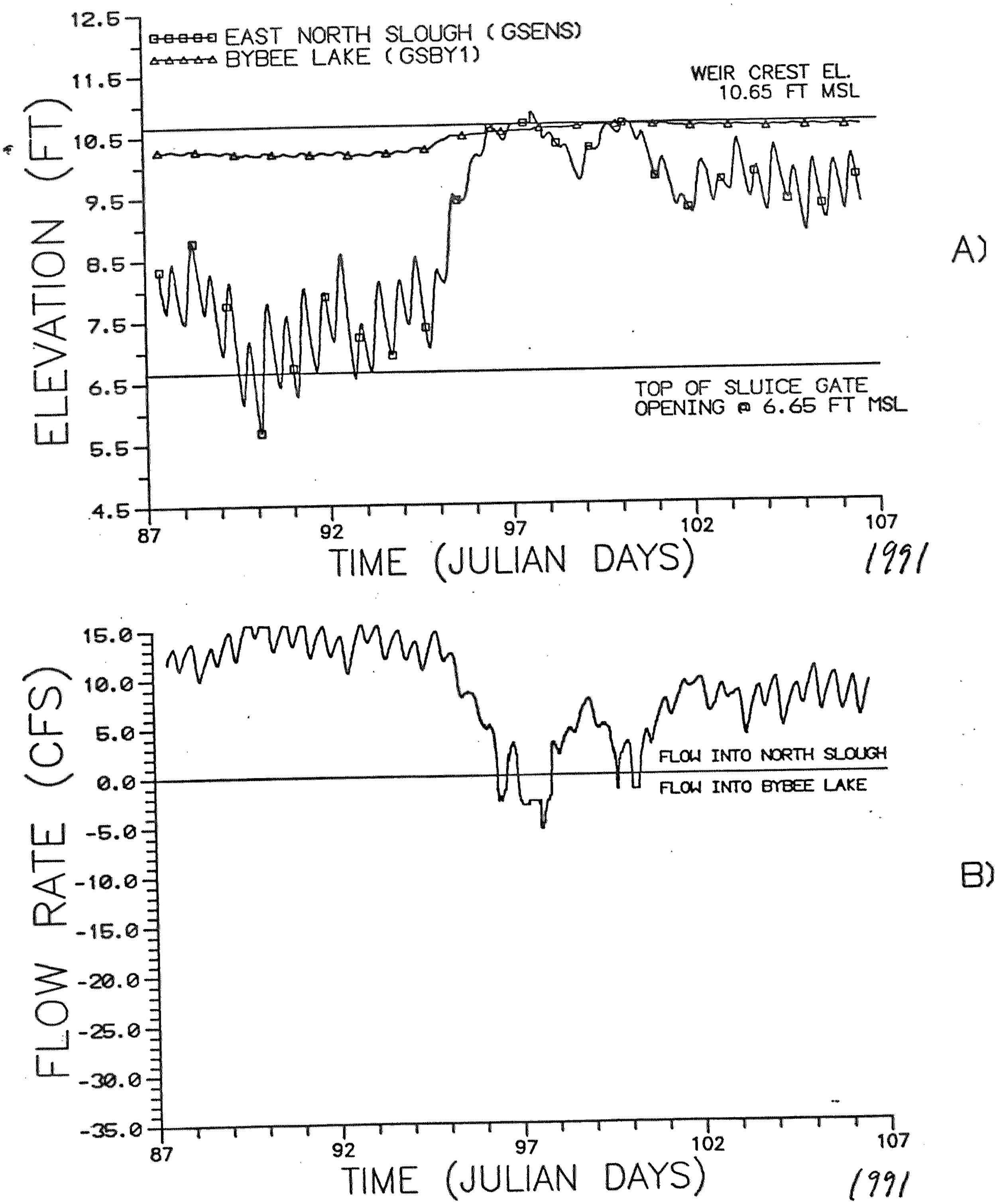


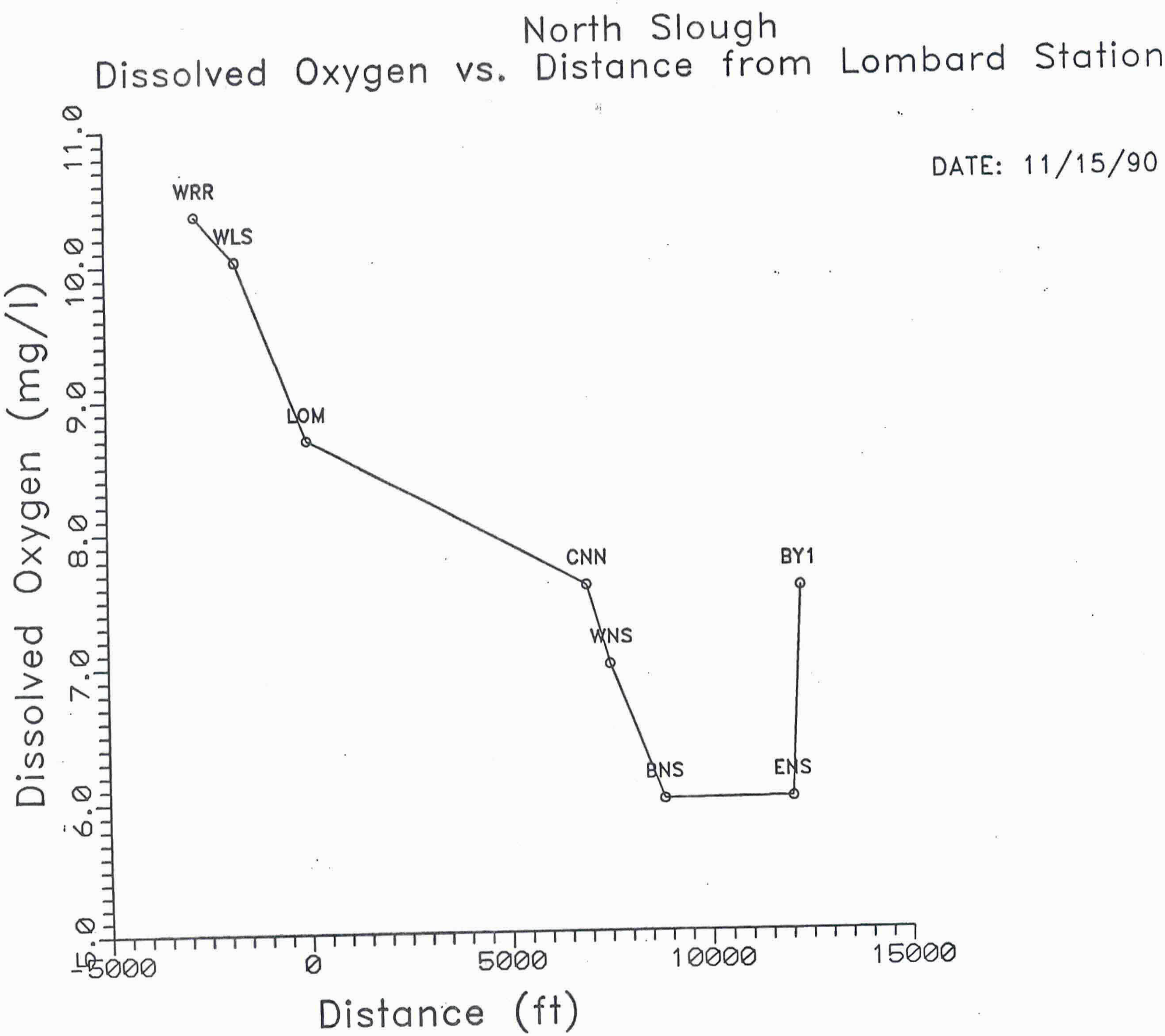
COMPARISON OF GAGE HEIGHTS AND FLOW RATES AT THE BYBEE LAKE FLOW STRUCTURE FOR THE PERIOD 1/16/91 THROUGH 3/20/91. A) COMPARISON OF GAGE HEIGHTS AT GSENS AND GSBY1 VS. TIME. B) ESTIMATED FLOW RATES VS. TIME FROM HYDRAULIC MODEL (QBY0.FOR) USING EXISTING CONDITIONS.

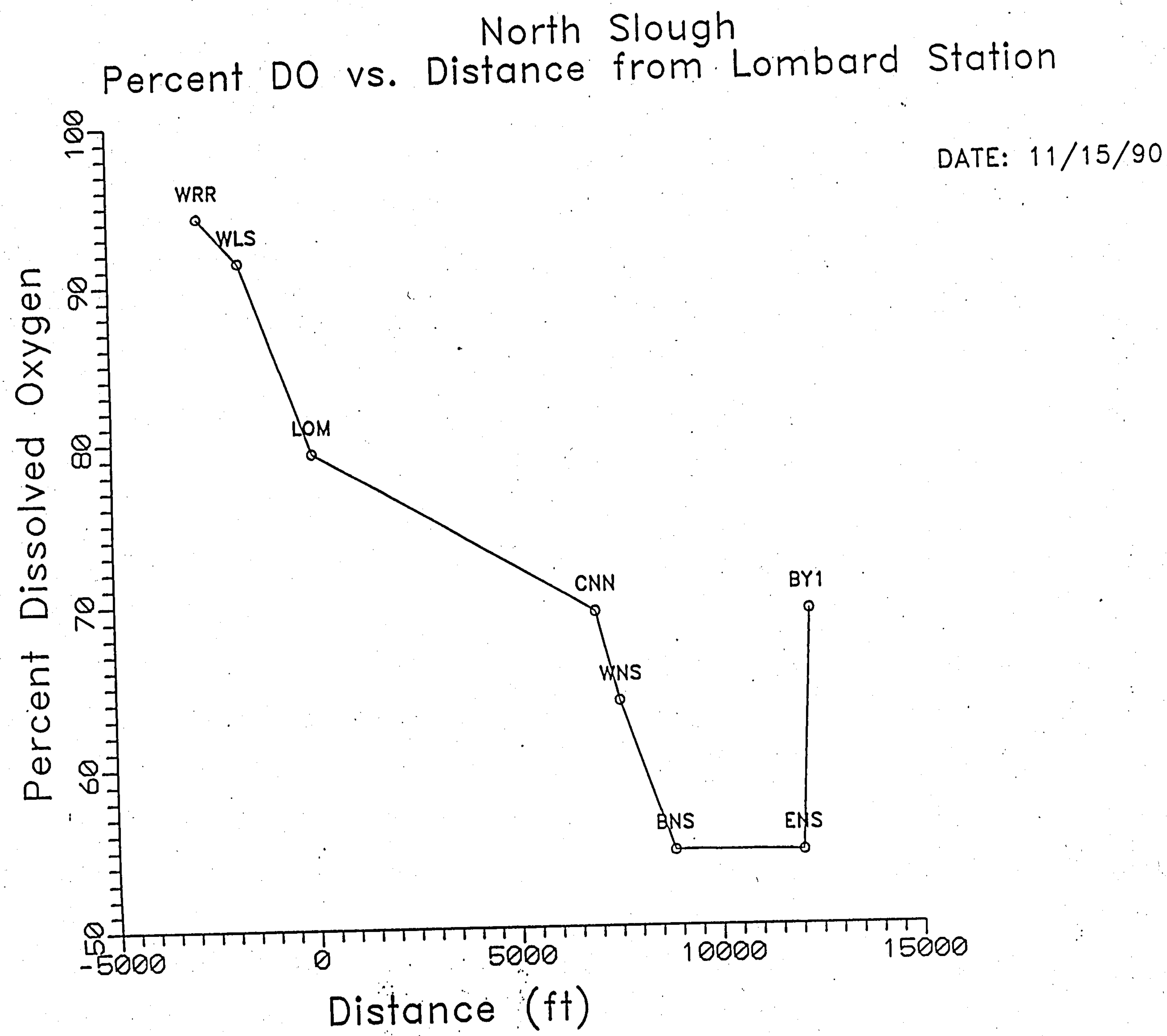




COMPARISON OF GAGE HEIGHTS AND FLOW RATES AT THE BYBEE LAKE FLOW STRUCTURE FOR THE PERIOD 3/28/91 THROUGH 4/16/91. A) COMPARISON OF GAGE HEIGHTS AT GSENS AND GSBY1 VS. TIME. B) ESTIMATED FLOW RATES VS. TIME FROM HYDRAULIC MODEL (QBY0.FOR) USING EXISTING CONDITIONS.

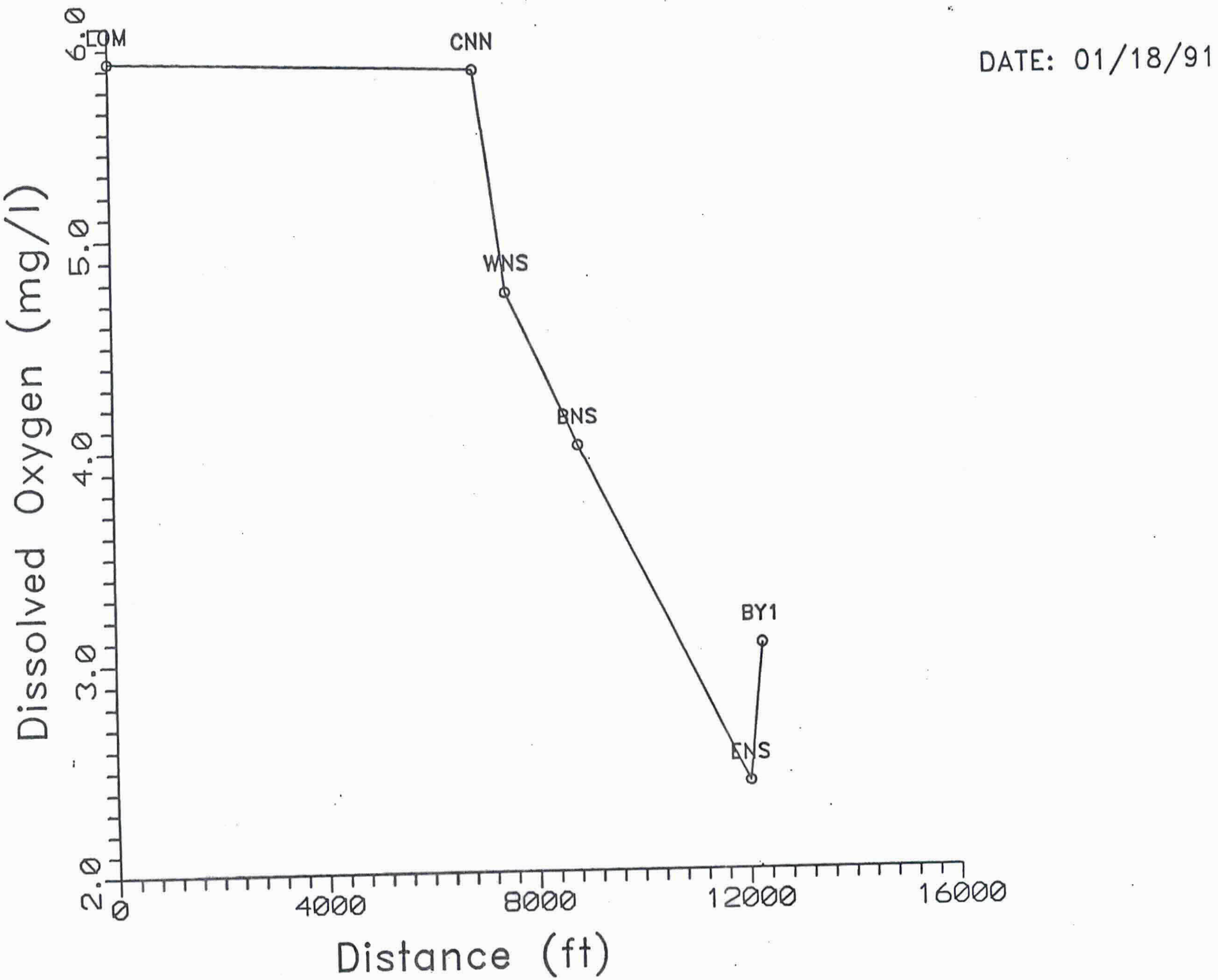



North Slough
Dissolved Oxygen vs. Distance from Lombard Station
DATE: 11/15/90
Dissolved Oxygen (mg/l)
Distance (ft)
WRR
WLS
LOM
CNN
WNS
BNS
ENS
BY1
11.0
10.0
9.0
8.0
7.0
6.0
5.0
-5000
0
5000
10000
15000

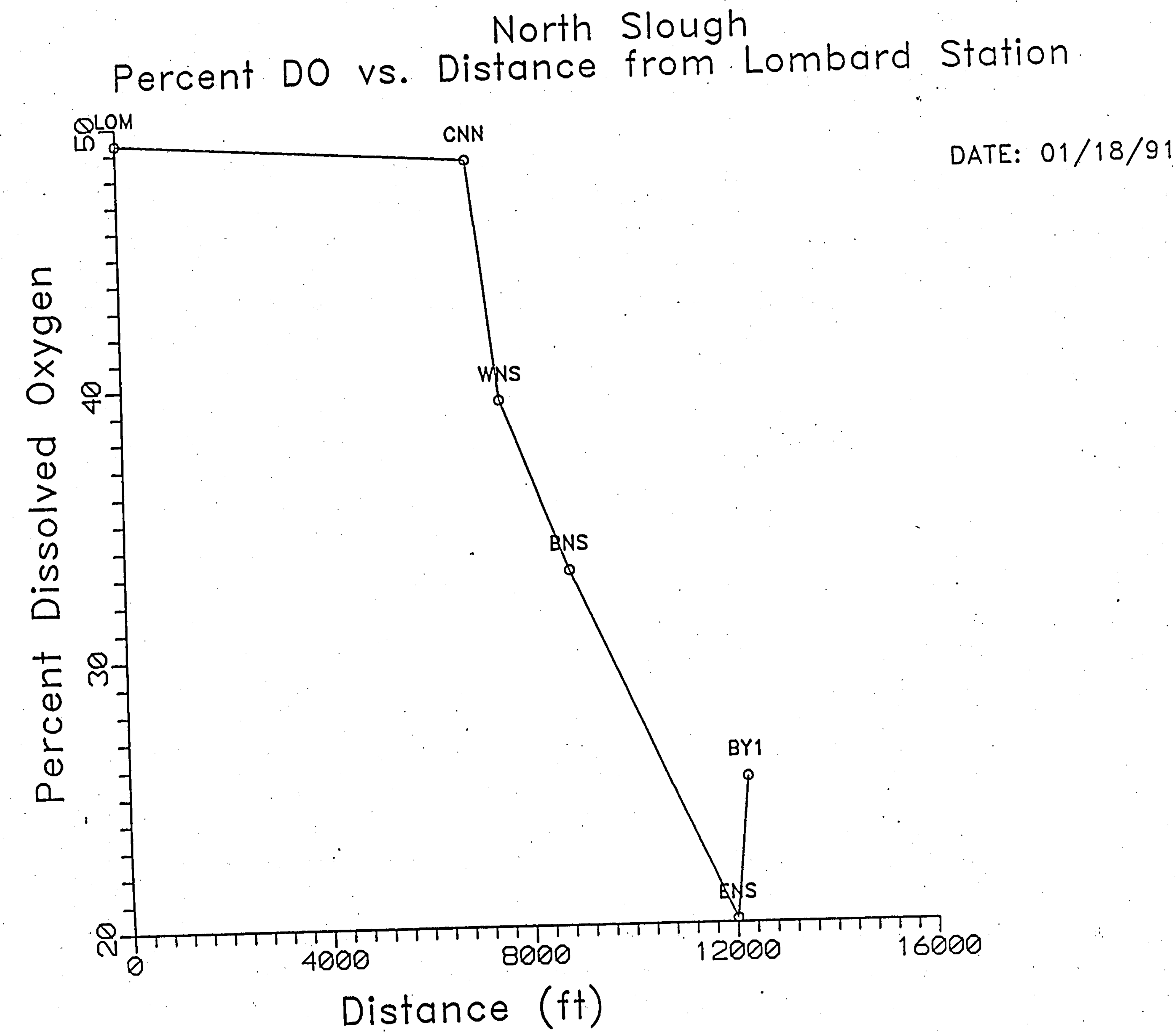

North Slough
Percent DO vs. Distance from Lombard Station
DATE: 11/15/90
Percent Dissolved Oxygen
100
90
80
70
60
50
-5000
0
5000
10000
15000
Distance (ft)
WRR
WLS
LOM
CNN
WNS
BNS
ENS
BY1

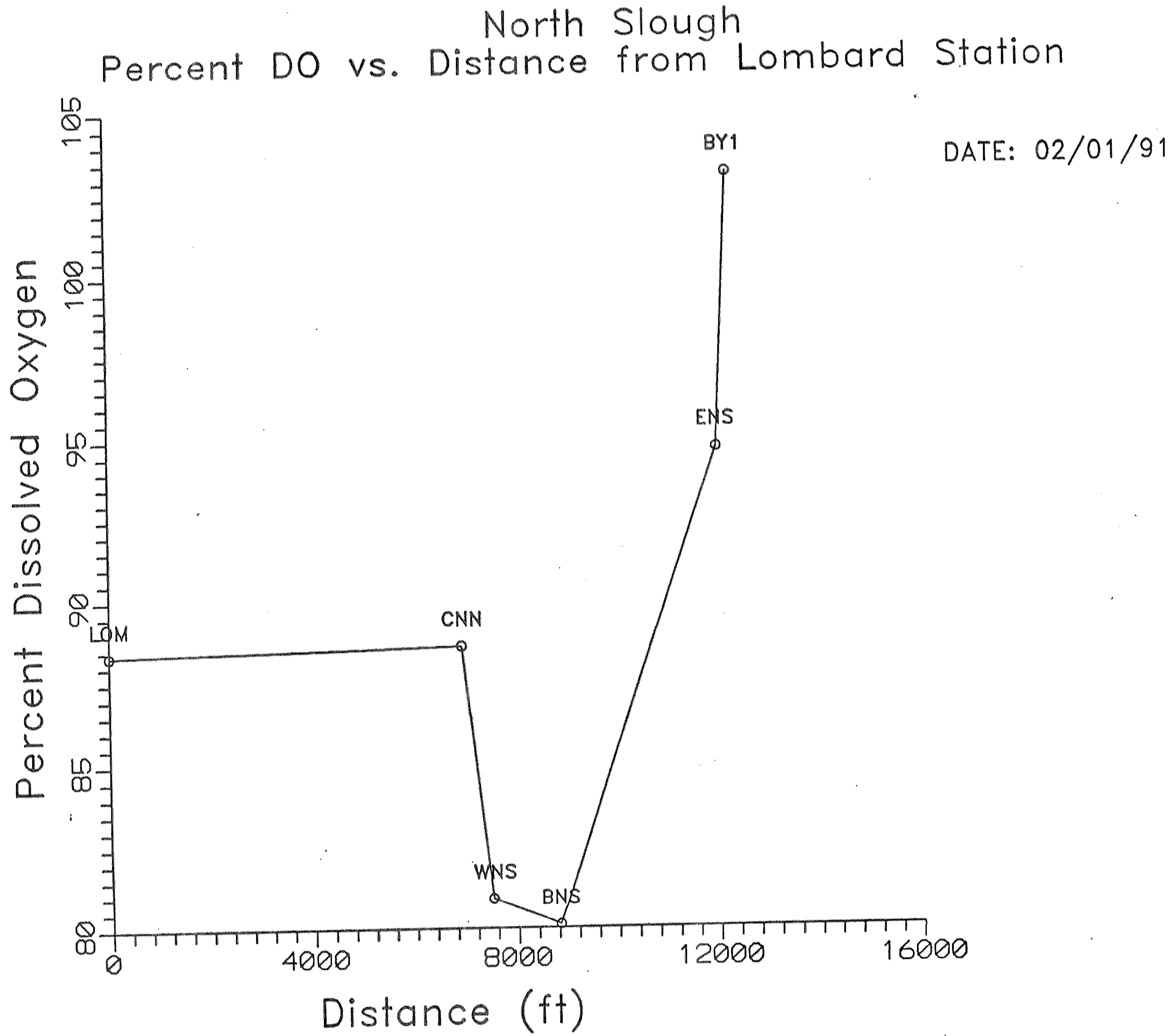
5

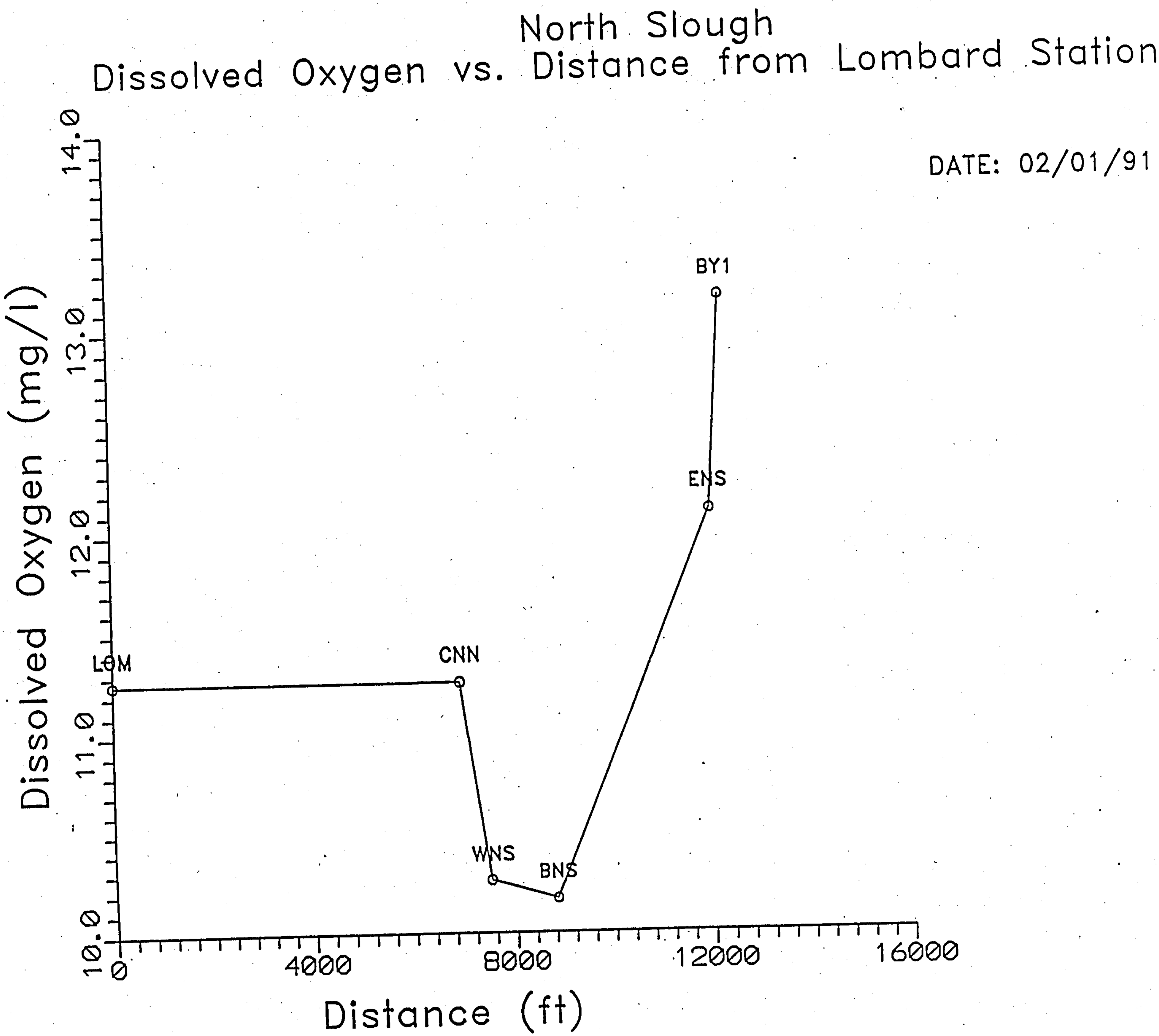
North Slough
Dissolved Oxygen vs. Distance from Lombard Station



9


North Slough
Percent DO vs. Distance from Lombard Station
DATE: 01/18/91
Percent Dissolved Oxygen
Distance (ft)
20
30
40
50
0
4000
8000
12000
16000
LOM
CNN
WNS
BNS
ENS
BY1


North Slough
Percent DO vs. Distance from Lombard Station
DATE: 02/01/91
Percent Dissolved Oxygen
Distance (ft)
80
85
90
95
100
105
0
4000
8000
12000
16000
LOM
CNN
WNS
BNS
ENS
BY1



North Slough
Dissolved Oxygen vs. Distance from Lombard Station
DATE: 02/01/91
Dissolved Oxygen (mg/l)
14.0
13.0
12.0
11.0
10.0
BY1
ENS
LOM
CNN
WNS
BNS
0
4000
8000
12000
16000
Distance (ft)