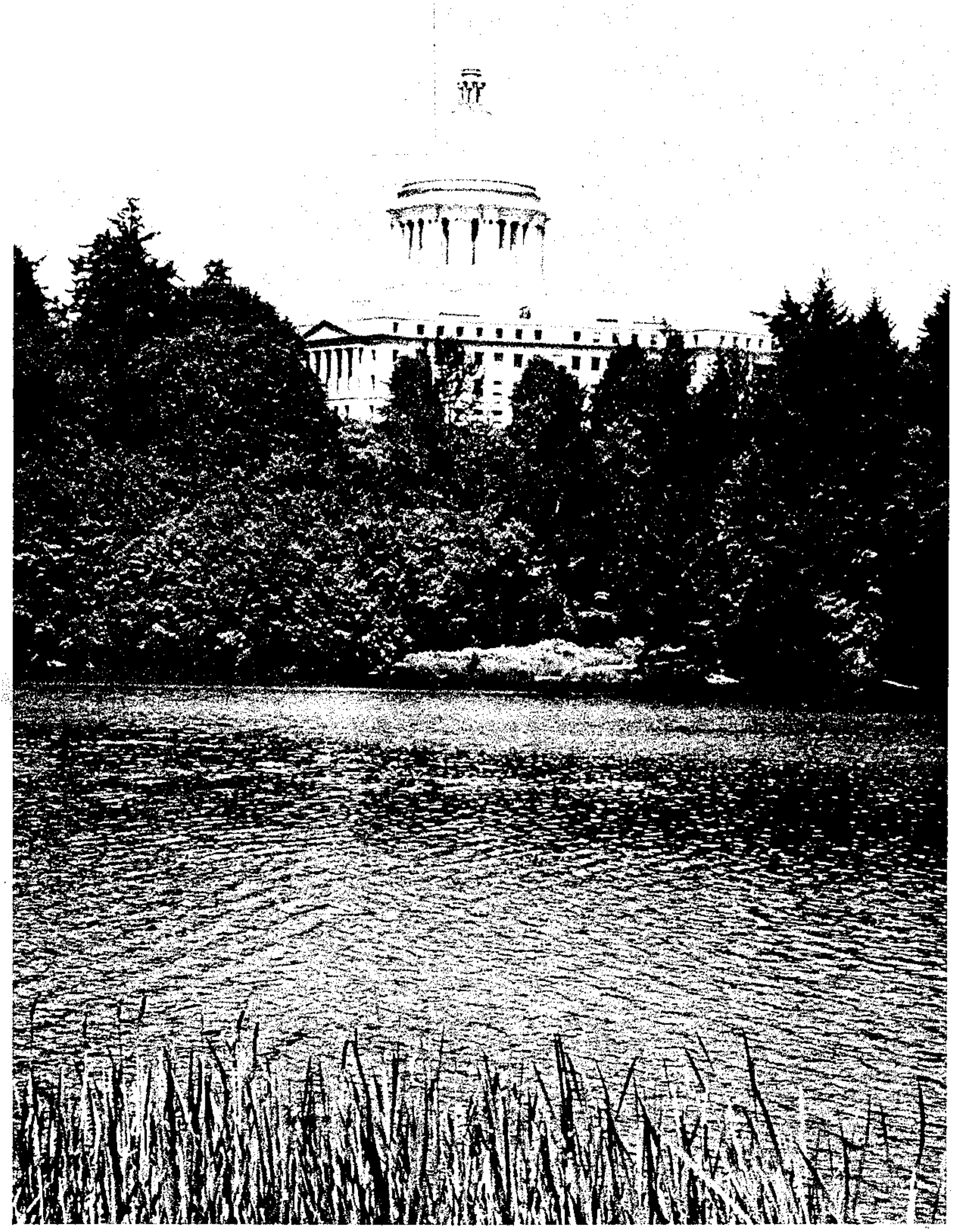

HYDRAULIC AND WATER QUALITY RESEARCH STUDIES OF CAPITOL LAKE SEDIMENT AND RESTORATION PROBLEMS
OLYMPIA, WASHINGTON

College of Engineering
Washington State University

September, 1975

PROJECT REPORT

HYDRAULIC AND WATER QUALITY RESEARCH STUDIES AND ANALYSIS OF CAPITOL LAKE SEDIMENT AND RESTORATION PROBLEMS
OLYMPIA, WASHINGTON

Prepared by Members of the
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of the
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Prepared for the

State of Washington

Department of General Administration

Olympia, Washington

Project 7374/9, 12-1310

September, 1975

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The following list of Washington State University personnel were responsible for the various components of the project:

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TABLE OF CONTENTS

Page

Page

Page

LIST OF FIGURES

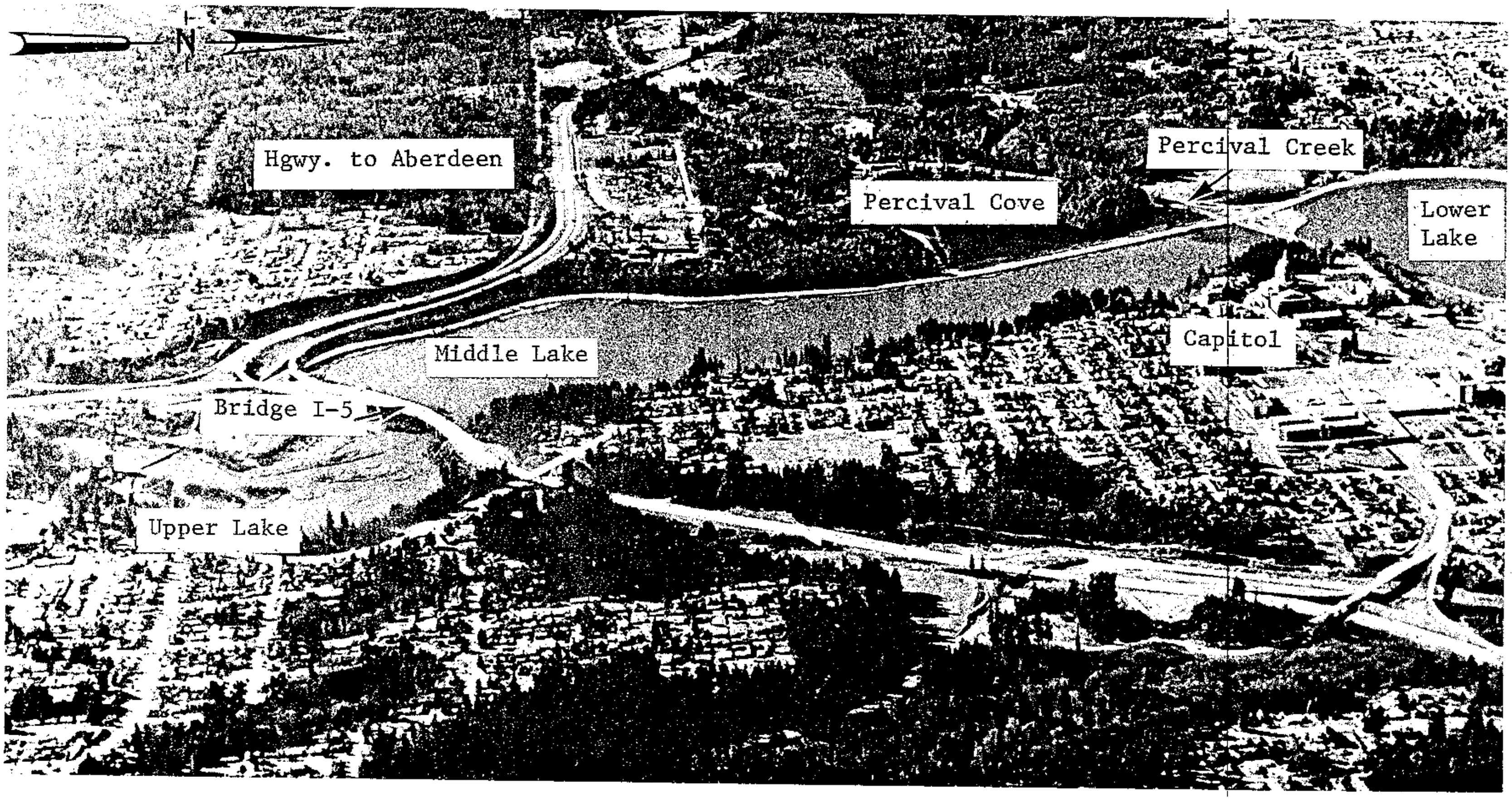
Page

APPENDICES

Page

LIST OF TABLES

APPENDICES



CAPITOL LAKE IN OLYMPIA, WASHINGTON, LOOKING WEST DURING THE SUMMER OF 1973

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the sedimentation, water quantity and water quality studies, and interaction during the project with the various agencies and groups having an interest in Capitol Lake, the following conclusions and recommendations have been developed. Detailed background information is in the body of the report.

1. Capitol Lake is a valuable and versatile resource to the State of Washington due to its location in the capitol city, its aesthetic appeal, its good water quality, and as an integral component of the capitol campus.

   VALUABLE RESOURCE OF GOOD QUALITY

2. The lake, as an integral part of the Deschutes River, has been established as a Class A water system by the Washington Department of Ecology.

   CLASS A

3. In addition to its inherent aesthetic appeal, two major uses of the lake (public recreation and anadromous fish rearing) establish the general requirements for water quality maintenance.

   MAJOR USES

4. According to the criteria of nutrient loading and surface area to volume ratio, the lake would be expected to be relatively eutrophic, tending to support significant rooted weed and floating algae populations. However, the very short hydraulic retention time, compared to other lakes of similar morphology, substantially reduces the potential for algae growth problems.

   SHORT RETENTION TIME ENHANCES QUALITY

5. Several physical features of the lake are dominant in establishing the fundamental character of the lake and its overall quality.

   PHYSICAL FEATURES

5a. The lake is essentially a *wide spot* at the mouth *of the river* with an artificial boundary (the dam) maintaining the interface between fresh and salt water.

WIDE SPOT
IN RIVER

5b. The *salt water barrier* is and has been *managed* to allow an *annual influx* of salt water for anadro*mous fish release that also appears to be important* to controlling development of rooted aquatic plants. This control is of particular importance in the Lower and Middle Basins.

SALT WATER
BARRIER

5c. The *Deschutes River*, contributing approximately 90 percent of total water input to the lake, is *relatively nutrient rich* and carries a *relatively high sediment load*, both varying in proportion to flow rate.

NUTRIENTS
AND
SEDIMENT
HIGH

5d. The *lake serves as a settling basin* for most of the river's sediment load and the annually deposited sediments have a significant influence on the character of the biological system in the lake.

SEDIMENT AND
BIOLOGICAL
SYSTEM

5e. Hydrographic characteristics of the river are such that the lake is *annually flushed* and portions are *scoured by flood flows* about ten times larger than the mean annual flow. This *flushing* is *important to limiting* the build up of *organic detritus* in the bottom of the lake.

FLUSHING
AND
DEPOSITION

6. The complete dredging of Capitol Lake to its *pre-dam depth* and volume conditions is not necessary to enhance the utility of the lake. The reduction in depth of the Middle (and especially the Lower) Lake has not seriously impaired their usefulness except in a few localities. The sand bar which has formed just downstream of the Highway I-5 bridge is an example of one of the local problems. Also, *increasing* the *lake*

DREDGE TO
ENHANCE
UTILITY

volume increases the detention time of flow through the lake, thereby decreasing the flushing efficiency. Therefore, it is recommended that:

6a. The Upper Lake should be dredged to serve as an effective sediment trap for coarser materials while maintaining much of the Upper Lake in its present state for passive forms of recreation.

DREDGE THE
UPPER LAKE AS
SEDIMENT TRAP

6b. The Middle and Lower Lakes should be dredged according to physical needs for removing hazards, providing shoreline access and economically balancing dredging with fills.

OTHER LAKES
DREDGE AS
NEEDED

7. Effects of dredging on water quality and major lake uses are not expected to be significant:

7a. Mean residence time in the lake will be increased in proportion to the increase in lake volume by dredging. In a well-mixed system such an increase would favor the development of increased algae growth. However, due to the relatively poor mixing in the lake (particularly during low flow/high productivity periods) the change in mean residence time is not expected to produce significant long-term changes in weed and algae growth patterns in the lake.

EFFECTS OF
DREDGE ON
RESIDENCE
TIME AND
WEED GROWTH

7b. One of the major changes to be made in the lake is to alter the natural sediment deposition pattern so as to minimize continued filling of the lake after the initial dredging. Continued annual sediment deposition is judged to be a significant factor in limiting rooted weed development particularly in the Middle Lake. The effect of proposed dredging and sediment removal facilities will be to trap and remove heavier sediment components in the Upper Basin. Lighter sediment fractions are expected to continue to be deposited particularly

ALLOW FINE
SEDIMENTS
TO KEEP
DOWN WEED
GROWTH

through the south end of the Middle Basin where the effect on limiting weed growth is most significant.

7c. Permanent changes in the characteristics of bottom substrate, particularly as related to bottom organism habitat, are not expected to result from planned restoration measures.

NOT CHANGE
BOTTOM
HABITAT

7d. Chemical composition of bottom sediment samples taken from areas to be dredged in the Upper (south) and Middle Basins indicates that temporary impairment of water quality may be expected during initial restoration dredging. Adverse effects on water quality can be minimized if appropriate attention is given to scheduling and management of dredging and filling operations. Dredging conducted toward the end of the annual high flow period is suggested.

AVOID
ADVERSE
EFFECTS
DURING
DREDGING--
SCHEDULE AS
HIGH RECEDES

8. Bottom sediment samples taken from areas of the Upper and Middle Basins where dredging is anticipated have been analyzed for composition as a function of depth.

BOTTOM
SEDIMENTS
CONSISTENT

8a. Nutrient and organic composition is relatively independent of sediment depth.

8b. Variation of sediment composition with depth is not of sufficient magnitude to warrant establishing dredging depths on this basis.

9. Light penetration observations, particularly in the Middle Basin, suggest that light limitation alone would probably not be sufficient to control weed growth at depths as great as 20 feet or more.

LIGHT
PENETRATION
AND WEEDS

BASES FOR DREDGING

10. Items 8 and 9 above indicate that depth of planned dredging should be established on factors other than potential biological or water quality effects (i.e., physical, economical, boating needs, etc.). The primary biological effects are those related to weed and algae growth, and potential effects on natural fish ~~food organisms and fish habitat. As pointed out in~~ Item 9, the deepest dredging considered cannot be justified solely for minimizing weed growth. Shallower depths favor both economics and fish and fish food habitat. Thus, depth decisions will presumably be made to optimize these considerations with recreational requirements.

COOLER WATER--RETAIN DEEP CHANNEL

11. The generally acceptable pattern of water quality through the Middle and Lower Basins, established in part by the gradual dispersion of cooler river water which follows the deep channel even into the Lower Basin, suggests the advisability of not disrupting river water channelization completely within the Middle Basin. Thus, the dredging depth profiles in the Middle Basin should recognize this factor and retain a deep channel throughout the basin length.

HIGH QUALITY MAINTAINED

12. The combination of the above characteristics, under normal hydrographic conditions and annual salt water flushing, can be expected to maintain relatively high quality conditions in the lake without significant problems of aquatic plants or algae blooms.

ANNUAL DRAWDOWN BENEFICIAL

13. The annual drawing down of Capitol Lake is essential to initiate the movement of juvenile salmon from Percival Cove into Puget Sound. Associated water quality benefits are discussed under water quality

conclusions. This type of management practice, when conducted in a coordinated fashion to benefit both fisheries and recreation, is a beneficial action not normally available in most lakes. Therefore, it is recommended that the drawdown and flushing of Capitol Lake should continue on a designed schedule based on ~~Department of Fisheries recommendations as they re~~late to Deschutes River streamflow and optimum salmon size for release into Budd Inlet.

ANNUAL
DRAWDOWN
BENEFICIAL

14. Annual influx of salt water near the commencement of the weed growth season is judged to be a significant factor in controlling development of rooted aquatic vegetation. Continuation of this management practice--allowing salt water flushing to as high an elevation as possible--is strongly recommended.

FLUSHING
WITH
SALT WATER

15. The shoreline fills, considered as alternate disposal sites for dredged materials in the Middle and Lower Lakes, will have little effect on the circulation pattern. Some of the other alternative fills, such as the two in the southwest corner of the Middle Lake will both help and hinder the circulation depending on their size and location. Therefore, it is recommended that only fill A1 (medium sized) be placed in the Middle Lake and that fill B (north of A1) not be placed. Fill B has a tendancy to impair the circulation pattern in the southwest corner of the Middle Lake, whereas fill A1 improves the circulation. All other fills in the Middle and Lower Lakes will have very little, if any, effect on lake circulation and no adverse effects locally on flow.

SHORELINE
FILLS:
SOME HELP,
SOME HINDER

16. The effects of all suggested lake fill locations have little potential for adverse effects on water quality,

FILLS AND
QUALITY

FILLS AND QUALITY

but fills will reduce areas now available for fish rearing and boating. The importance of using lake shoreline areas for dredge spoil deposition because of economic considerations is recognized as is the potential benefit of providing additional shoreline area for recreational use. Similarly, it is important ~~to recognize potentially adverse effects of reducing~~ lake surface area on fisheries and recreational uses of the lake.

MAN-CAUSED SEDIMENT IN PERCIVAL CREEK

17. The transitional exposure of raw earth and loose, unprotected fills in subdivisions in the Percival Creek drainage basin can create a serious sediment problem in the Percival Cove fish rearing area. Every reasonable step should be taken by the appropriate jurisdictions to guarantee that potential man-caused erosion is minimized through the use of protective devices such as sediment trap areas at the construction site, and at the mouth of Percival Creek.

FISH REARING AND FUTURE WATER QUALITY

18. Fish rearing activities contribute significant quantities of nutrients and organic materials to the lake system with potential for increasing weed and algae growth. However, under normal hydrographic conditions and at current levels of fish rearing, significant water quality impairment has not been observed. Should fish rearing activities be increased in magnitude, further studies should be conducted to properly detail the impact on water quality.

FUTURE I-5 BRIDGE WORK

19. It is anticipated that future modifications to the highway I-5 bridge over the outlet of the Upper Lake will need to be made. The hydraulic model studies of the Upper Lake have shown that the highest velocities occur in the vicinity of the bridge opening. The new

configuration of the Upper Lake has been designed to reduce, or not increase, any local velocities which now exist. Therefore, in designing for the widening of the I-5 bridge, it is recommended that consideration be given to the protection and maintenance of flow patterns, especially just south of and through ~~the bridge, so that the sediment trapping efficiency~~ is not reduced and the island geometry is not altered.

HYDRAULIC AND WATER QUALITY RESEARCH STUDIES AND ANALYSIS OF CAPITOL LAKE SEDIMENT AND RESTORATION PROBLEMS
OLYMPIA, WASHINGTON

I. INTRODUCTION

A. Authority

In response to a request from Governor Daniel J. Evans dated February 8, 1974, a proposal for sedimentation, water quantity and water quality research studies of Capitol Lake was submitted to the Department of General Administration on March 3, 1974. A contract to conduct these laboratory and field investigations was approved by the Department of General Administration and Washington State University in mid-April, 1974, and the project was completed June 30, 1975.

B. Situation

As shown in Figure 1, Capitol Lake consists of three basins formed by transportation corridors. The upper basin of the lake, situated south of the highway I-5 bridge and fill, has formed a partial trap for sediment transported by the Deschutes River. A smaller amount of sediment enters the middle basin of Capitol Lake seasonally from Percival Creek on the west side of the lake.

Historical details on the sediment accumulation problem in Capitol Lake are well documented.[1,2,3] The completion of the dam across the Deschutes River tidal basin at 5th Avenue in 1951 formed Capitol Lake as a large sedimentation basin for the Deschutes River, Percival Creek and local runoff. The distribution of sediment was strongly modified by construction of the highway

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[1] Wilson, John A., "Reconnaissance Geologic Investigation on the Siltation Problem of Capitol Lake, Olympia, Washington," for Washington Department of Fisheries by the Soil Conservation Service, October, 1970.

[2] Walker and Byrne, "Hydrographic Survey of Capitol Lake, Olympia, Washington," for the General Services Administration of Washington, November 5, 1970.

[3] Byrne, Patrick J., "Engineering Investigation for Rehabilitation of Capitol Lake, Olympia, Washington," Vols. I and II, April, 1973.

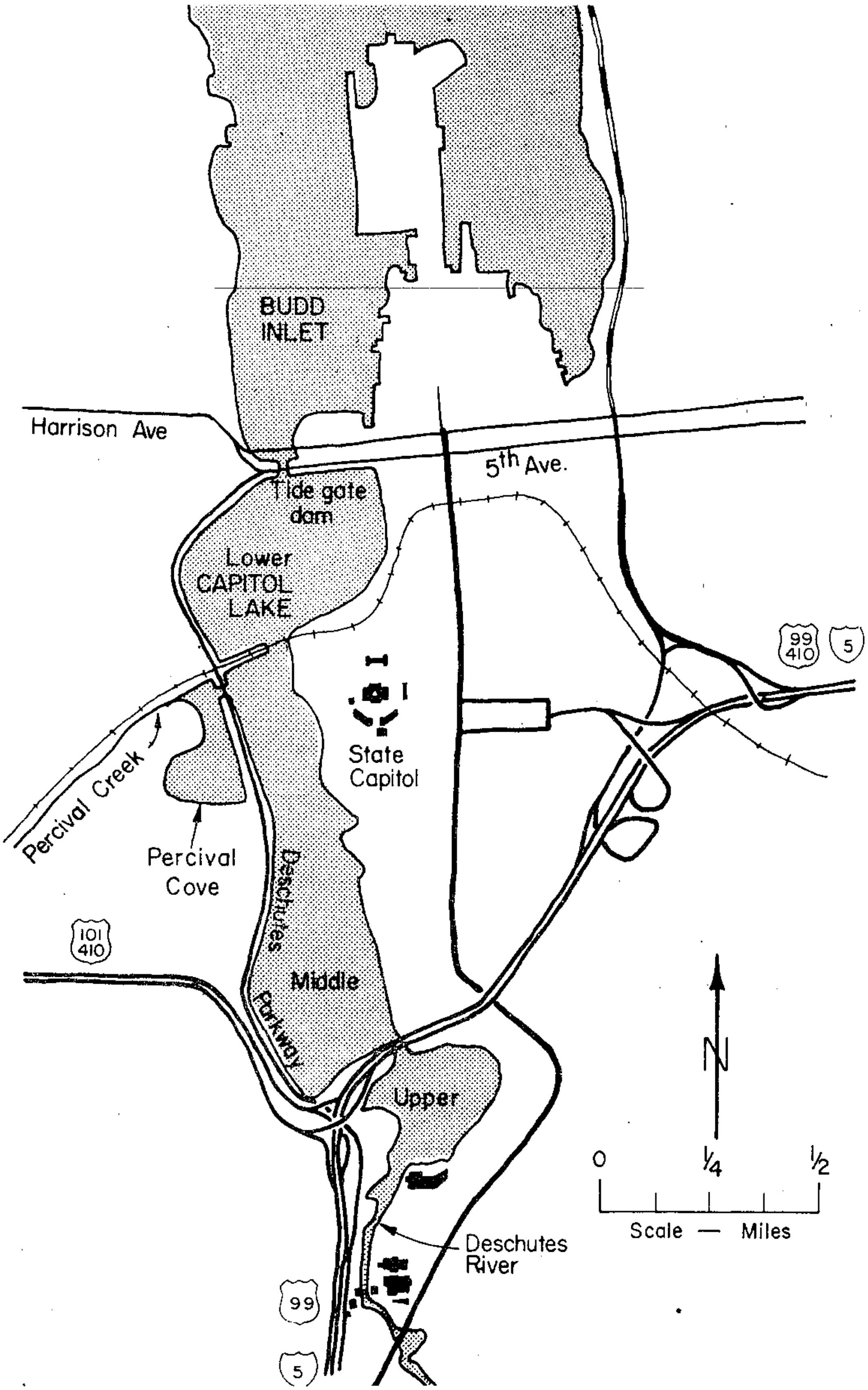

Fig. 1. Location Map of Capitol Lake, Olympia, Washington

I-5 fill which formed the upper basin in 1956 and has provided a primary sedimentation basin for the Deschutes River. Fine sediment is transported into the middle and lower portions of Capitol Lake, and during high flow periods some suspended sediment is transported through the lake into Budd Inlet.

In recent years the accumulation of the sediment in the upper basin has come to a balanced condition with the Deschutes River flows. As a result, depending on the amount of discharge in the Deschutes River, varying amounts of sediment are being transported through the upper basin into the middle basin. This deposition downstream (north) of the highway I-5 bridge severely limits the utility of the middle basin of Capitol Lake. The increased deposition in the Middle Lake is indicative of the fact that the upper basin no longer serves as a sedimentation basin for the rest of Capitol Lake. These sediment conditions can be observed in Figure 2.

A basin geometry similar to that of the upper Capitol Lake exists on a smaller scale at the mouth of Percival Creek. The cove was formed by the construction of the Deschutes Parkway, and this portion of the lake has been used in recent years by the Department of Fisheries to rear fingerling salmon. The relative amount of natural sediment load transported by Percival Creek into Capitol Lake is almost insignificant compared to the amount deposited from the Deschutes River. But, urban development in the Percival Creek drainage basin is creating the potential for a man-generated increase in sediment, and developers are utilizing construction methods, as recommended by regulatory agencies, to minimize any increases in sediment load.

The potential demand for use of Capitol Lake and its setting in the capitol city of the State of Washington make it an important resource to be enhanced and maintained. The accumulation of sediments, primarily from the Deschutes River basin, coupled with nutrient inflow, has created the potential for adverse water quality conditions which would further reduce the utility of the lake. Therefore, based on the recommendations of the consulting engineer who evaluated the conditions in the lake in 1973, research studies were undertaken to address the sediment, water quantity and water quality problems in detail.

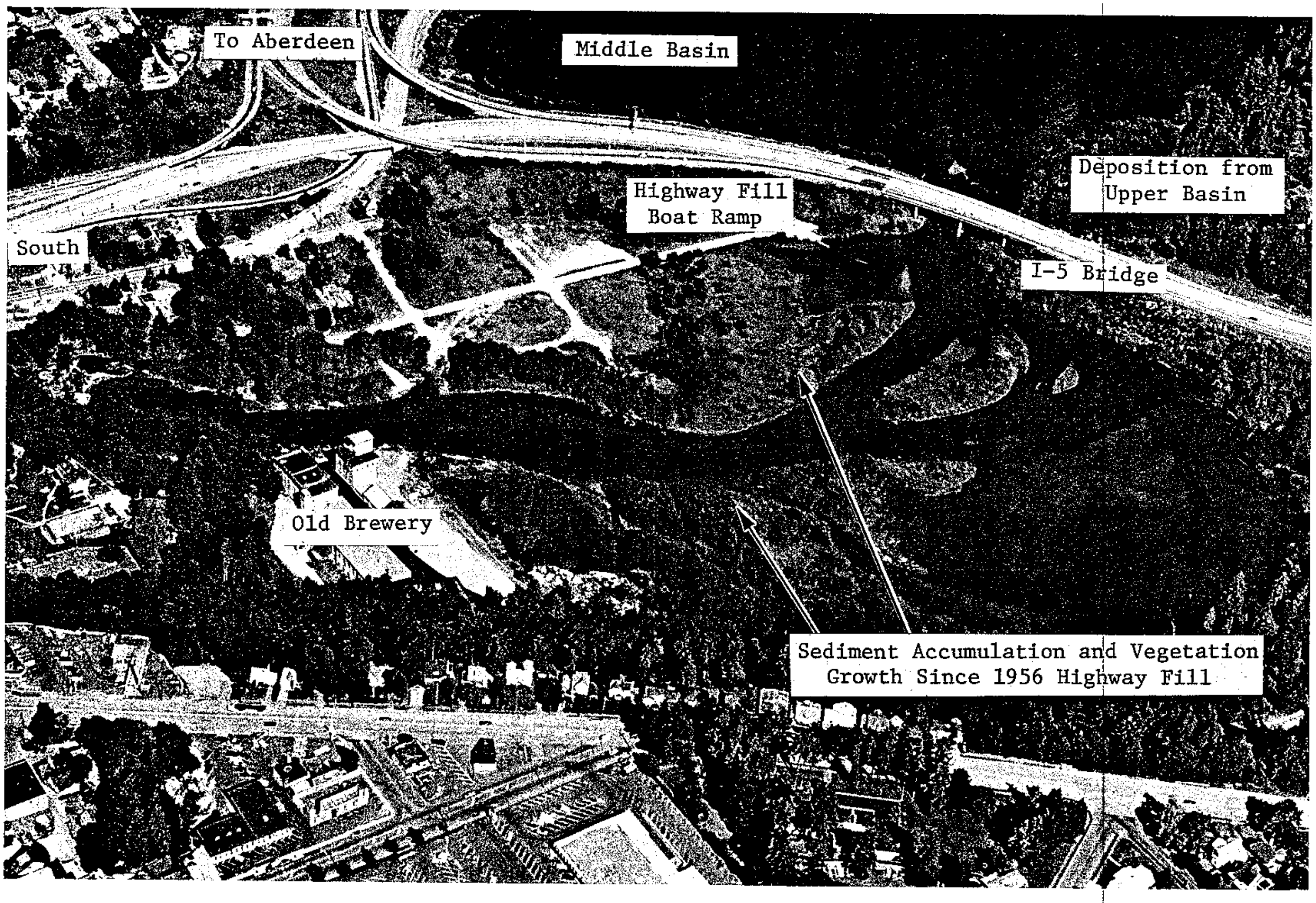

Fig. 2. Sediment Deposition in the Upper and Middle Basins of Capitol Lake Near Olympia, Washington, as Observed on July 17, 1974

C. Summary of Research Study Components

The common objective of the sedimentation, water quantity and water quality phases of this project was to provide a data base and recommentations upon which planning, design and management decisions could be made for the dredging, maintenance and improved utilization of Capitol Lake. The interrelations of the various research project phases are presented diagrammatically in Figure 3.

The sediment study was undertaken first and with the most concentrated effort so that the preliminary report could be submitted by August 15, 1974, for preparation of the dredging budget request to the Legislature.[4] The sediment transport characteristics of the Deschutes River and Percival Creek were evaluated, and a hydraulic model study was conducted of the upper basin to determine the most natural way to use this basin as a sediment trap for the rest of the lake. In addition, methods for performing maintenance dredging were evaluated. These aspects were reported in supplements to the August 15 report.[5,6] Also, all the sediment study results were combined into a summary report.[7]

The water quantity study was undertaken to evaluate the water balance of the entire Capitol Lake watershed including the Deschutes River and Percival Creek. The topics addressed as part of this study were: the determination of the magnitude and time distribution of streamflow into Capitol Lake; the construction and testing of a hydraulic model of the lake to determine the effects of dredging and/or filling; and to determine the flushing and detention characteristics of various discharges for use with the results of the water quality study to recommend management practices.

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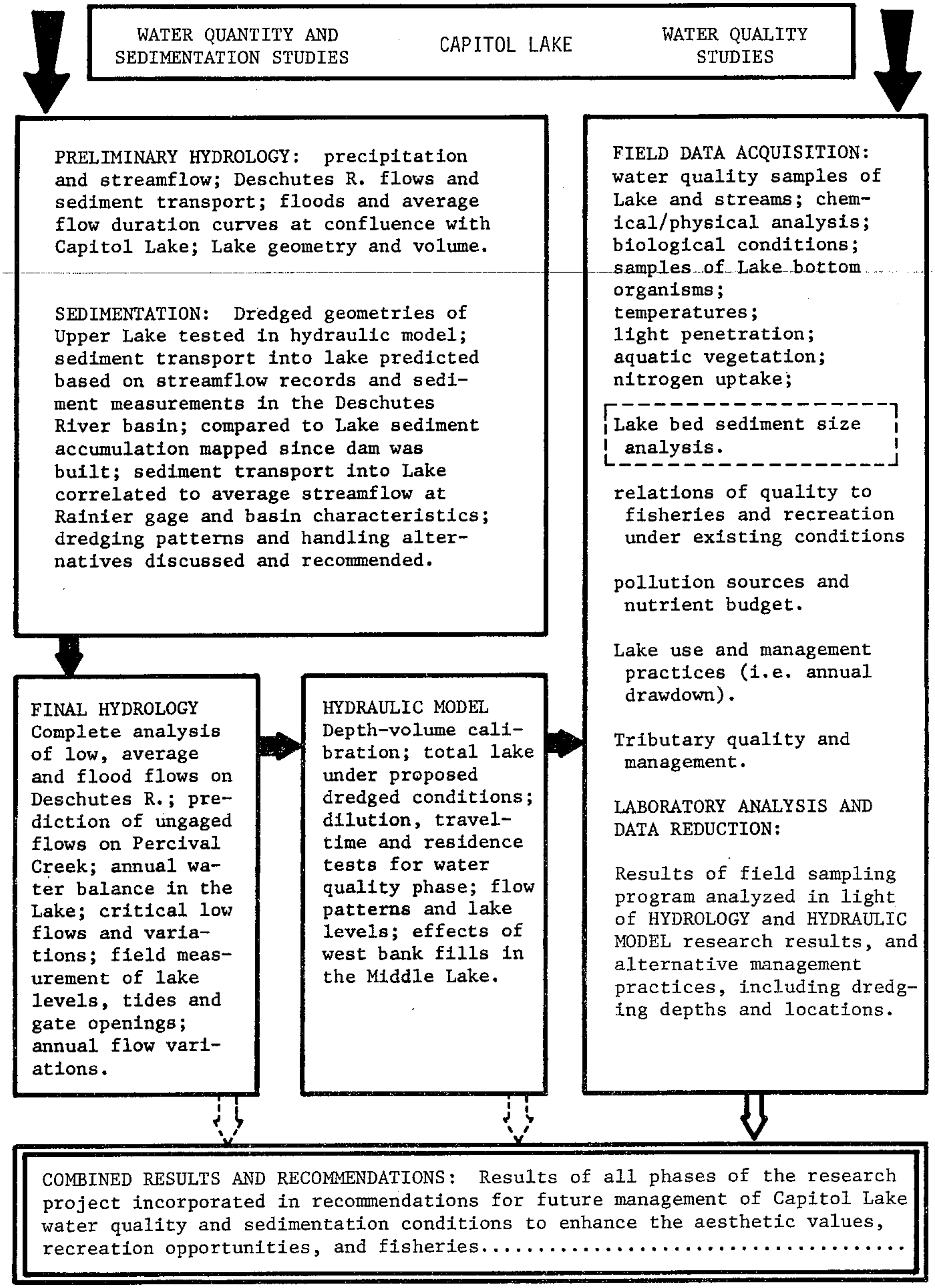
[4] Mih, Walter C. and Orsborn, J. F., "Preliminary Report on Sediment Removal and Maintenance System for the Upper Basin of Capitol Lake, Olympia, Washington," R. L. Albrook Hydraulics Laboratory, Washington State University, Research Project 7374/9,12-1310A, August 15, 1974.

[5] ________, Research Project 7374/9,12-1310A, Supplement No. 1 to Preliminary Sediment Report, September 6, 1974.

[6] ________, Research Project 7374/9,12-1310A, Supplement No. 2 to Preliminary Sediment Report, September 13, 1974.

[7] Orsborn, John F., "Summary Report on Sedimentation Studies of Capitol Lake, Olympia, Washington," R. L. Albrook Hydraulics Laboratory, Washington State University, Pullman, December 20, 1974.



WATER QUANTITY AND SEDIMENTATION STUDIES

CAPITOL LAKE

WATER QUALITY STUDIES

PRELIMINARY HYDROLOGY: precipitation and streamflow; Deschutes R. flows and sediment transport; floods and average flow duration curves at confluence with Capitol Lake; Lake geometry and volume.

SEDIMENTATION: Dredged geometries of Upper Lake tested in hydraulic model; sediment transport into lake predicted based on streamflow records and sediment measurements in the Deschutes River basin; compared to Lake sediment accumulation mapped since dam was built; sediment transport into Lake correlated to average streamflow at Rainier gage and basin characteristics; dredging patterns and handling alternatives discussed and recommended.

FINAL HYDROLOGY
Complete analysis of low, average and flood flows on Deschutes R.; prediction of ungaged flows on Percival Creek; annual water balance in the Lake; critical low flows and variations; field measurement of lake levels, tides and gate openings; annual flow variations.

HYDRAULIC MODEL
Depth-volume calibration; total lake under proposed dredged conditions; dilution, travel-time and residence tests for water quality phase; flow patterns and lake levels; effects of west bank fills in the Middle Lake.

FIELD DATA ACQUISITION: water quality samples of Lake and streams; chemical/physical analysis; biological conditions; samples of Lake bottom organisms; temperatures; light penetration; aquatic vegetation; nitrogen uptake;

Lake bed sediment size analysis.

relations of quality to fisheries and recreation under existing conditions

pollution sources and nutrient budget.

Lake use and management practices (i.e. annual drawdown).

Tributary quality and management.

LABORATORY ANALYSIS AND DATA REDUCTION:

Results of field sampling program analyzed in light of HYDROLOGY and HYDRAULIC MODEL research results, and alternative management practices, including dredging depths and locations.

COMBINED RESULTS AND RECOMMENDATIONS: Results of all phases of the research project incorporated in recommendations for future management of Capitol Lake water quality and sedimentation conditions to enhance the aesthetic values, recreation opportunities, and fisheries..................................

Fig. 3. Capitol Lake Project Phases

Aspects of the water quality study were designed to: (1) evaluate present conditions of the water in the lake and its tributaries; and (2) evaluate future water quality conditions based on: (a) various modifications to the lake (i.e., dredging); and (b) the institution or continuation of various management practices (i.e., annual drawdown and flushing of the lake with salt water from Budd Inlet). Components of this phase of the study included: (1) existing physical-chemical and biological characteristics of the lake water and bottom sediments; (2) sampling the water quality conditions in the Deschutes River and Percival Creek; (3) completing laboratory analyses on the field data; and (4) incorporating the field data results with the results of the hydraulic model tests into recommendations for future management of Capitol Lake.

D. Report Format

Because of the widespread and general interest in Capitol Lake, this report has been arranged in a series of brief summary chapters, in parallel with a series of appendices which contain technical details and data. The water quality aspects, which are discussed in Chapter VI, are preceded by brief sections which discuss the physical, biological, hydrological, and geological characteristics of the lake and its watershed because of their relationships to water quality in Capitol Lake. These introductory sections in Chapter VI will allow those persons interested primarily in water quality to be aware of the other aspects of the total study without reading the other chapters except to ascertain technical details as might be needed to assist in understanding the water quality information.

II. CAPITOL LAKE DRAINAGE BASIN DESCRIPTION

Chapter Summary

The physical setting of Capitol Lake, formed by construction of the 5th Avenue dam in 1951, is reviewed with respect to how the drainage basin influences the water and sediment balance in the lake. The dominant stream in the Capitol Lake basin is the Deschutes River, but Percival Creek and its watershed have a similar set of problems on a smaller scale in the vicinity of Percival Cove such as sediment deposition. The formation of Capitol Lake with the dam created a settling pond for sediments entering from the watershed. The construction of the highway I-5 fill and bridge in 1956 forming the upper lake created a settling basin for larger sediments. Thus, the distribution pattern of sediments as it was occurring from 1951-56 was sharply modified by the highway fill.

The man-made origins of these sediments are primarily the upper watershed of the Deschutes River and the urbanizing areas of Percival Creek basin. Although no detailed study has been completed on the amount of natural sediment and the amount of man-made sediment generated in each basin, any reduction will assist in the maintenance of Capitol Lake. This is particularly true in Percival Cove where improved circulation is planned by diverting Percival Creek flows into and possibly through the cove. Increased sediment concentrations would reduce the benefits desired by flushing the cove with creek flow.

The water quality of Capitol Lake is generally good throughout most of the year. Due to the fact that Capitol Lake is an impoundment at the mouth of the Deschutes River, and the tributary streamflow is large relative to the volume of the lake (rapid rate of exchange), the water quality in the lake is controlled in large part by the quality of the Deschutes River and Percival Creek. Biological influences in the lake with a potential for contributing to water quality problems will be the greatest during low flow periods in the Deschutes River when the rate of exchange is the least.

A. General Basin Description

The total drainage basin which supplies water to Capitol Lake above the 5th Avenue dam consists of:

- the Deschutes River Basin (162 sq mi);
- the Percival Creek Basin (13 sq mi including the Black Lake and Trosper Lake branches);
- the east and west shores of the lake (1.6 sq mi); and
- the surface area of Capitol Lake (0.44 sq mi)

for a total of 177 square miles. The discharges of the Deschutes River and Percival Creek are the main sources of supply with the Deschutes River providing approximately 20 times as much average flow as Percival Creek. The relative location of the watershed to Capitol Lake is shown in Figure 4.

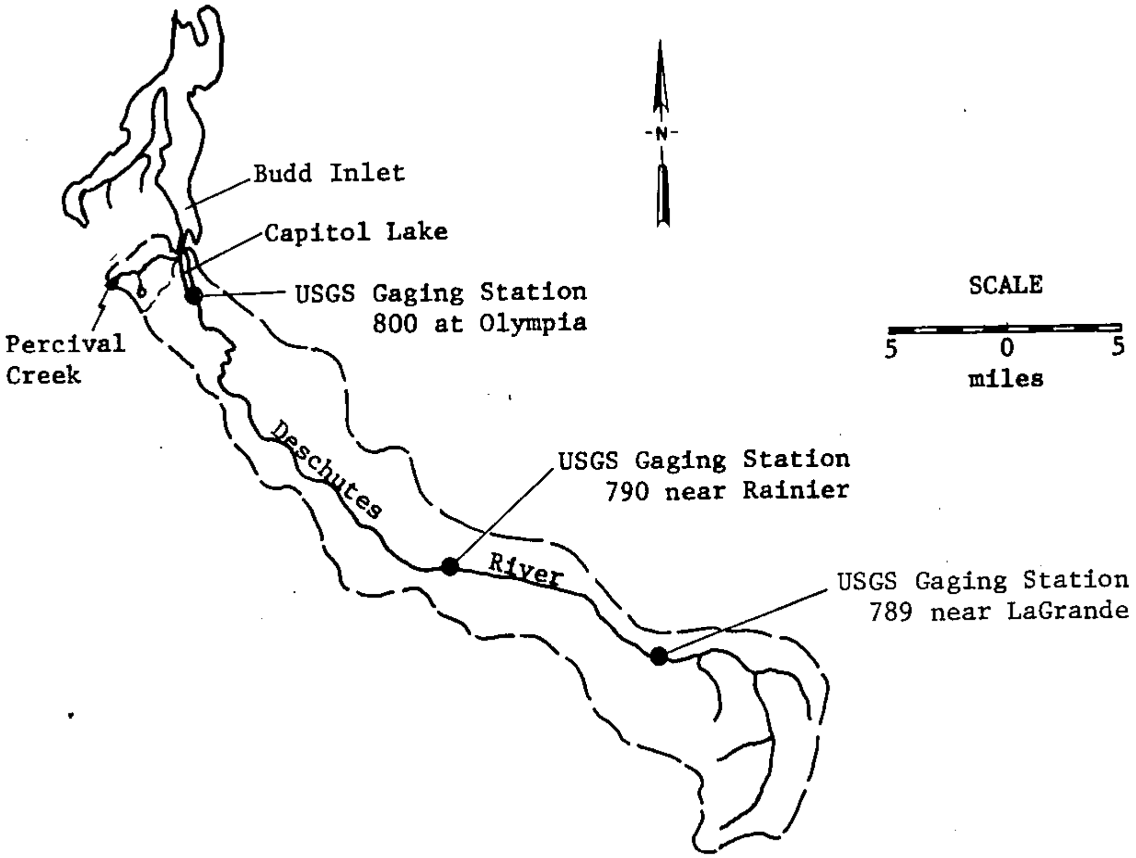


Fig. 4. Capitol Lake Drainage Basin

Climate, geology, soils and land use are basin characteristics that contribute to streamflow and the establishment of water quality in surface waters tributary to a downstream impoundment such as Capitol Lake.[8,9,10]

1. Climate

The climate of the Capitol Lake area is typical of the entire Puget Sound Region and is characterized by mild, wet winters and warm, dry summers. Normal temperature ranges and precipitation characteristics reflect the moderating influence of the predominantly marine weather system. Daytime temperatures fluctuate around 40 to 52°F during the winter, and in the 70's to 80's during the summer months. The nighttime temperatures generally fall into the low 30's during the winter and in the 40's and 50's during the summer. Occasional continental air masses invade the area and are responsible for unusually high summer, or low winter, temperatures. The average annual precipitation is about 50 inches, 85 percent of which falls during the months from October through April. The remaining summer months usually receive two inches of rainfall or less per month. Prevailing winds are from the south and southwest. Selected climatological data from the Olympia Airport are presented in Table 1.

2. Geology

The Deschutes River Basin lies within an area geologically referred to as the Puget Trough. The area is locally bounded by the Cascade Range to the east and south and by the Coast Range to the west. Although the boundaries of the basin are mountainous, nearly two-thirds of the basin is comprised of gently sloping prairie lands which were formed as a result of periods of intermittent glacial activity. Wallace and Molenaar[11] describe the basin as

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[8] Puget Sound Task Force, PNRBC, "Comprehensive Study of Water and Related Land Resources--Puget Sound and Adjacent Waters, State of Washington," See Appendix III, "Hydrology and Natural Environment," and Appendix V, "Water-Related Land Resources," 1970.

[9] Grant, Arvid and Assoc., Inc., "Water Pollution Control and Abatement Plan for Deschutes River Basin," June, 1974.

[10] Thurston Regional Planning Council, "Thurston County: Natural Resources and Environment," Olympia, Washington, December, 1970.

[11] Wallace, E. F., and Molenaar, D., "Geology and Ground-Water Resources of Thurston County, Washington," Water Supply Bulletin No. 10, Vol. 1, Washington State Division of Water Resources (Dept. of Conservation) in cooperation with U.S. Geological Survey, 1961.

Table 1.

Selected Climatological Data
from the Olympia, Washington, Airport Weather Station*

	ANN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Temperature (°F)													
Average Daily Maximum	62.2	45.1	49.6	54.5	62.3	68.6	72.6	79.7	78.9	72.6	62.3	52.4	47.5
Average Daily Minimum	39.3	31.1	32.2	34.0	37.6	41.6	45.5	48.0	47.8	44.4	40.5	35.2	33.9
Extreme High	100	60	72	76	81	90	94	100	100	94	82	69	58
Extreme Low	3	4	12	14	24	26	31	35	34	27	20	18	3
Precipitation (in.)													
Normal Total	52.37	7.85	6.62	5.40	2.96	2.01	1.79	0.76	0.89	2.09	5.28	7.67	9.05
Maximum Month	19.84	19.84	13.18	10.13	4.78	5.83	6.48	2.68	5.45	5.23	10.08	15.51	14.32
Minimum Month	0.00	0.84	2.54	0.48	0.37	0.15	0.04	T	0.00	0.06	1.55	1.39	2.28
Wind (mph)													
Mean Speed	6.7	7.5	7.3	7.5	7.3	6.6	6.5	6.0	5.8	5.5	6.1	6.7	7.5
Maximum Speed	60	55	45	50	46	39	32	39	26	35	58	60	41
Direction	SSW	SSW	SSW	SSW	SW	SW	SSW	SW	SW	SW	SSW	SW	SSW

*Table II-2, Page II-8, Reference 9.

"...predominantly a drift-covered glacial plain rimmed on the western, southern, and southeastern sides by low lying, maturely disected hills underlain by deposits of Tertiary age." They further report, "...except for numerous scattered 'islands' of older consolidated rocks, the entire basin has been partly filled with unconsolidated fluvial and glacial materials of Pleistocene age." The geology of the area in the vicinity of Capitol Lake is largely comprised of the unconsolidated fluvial and glacial materials.

Five distinct geologic formations have been mapped for the area which include alluvium (Qal), recessional outwash (Qvr and Qvr_1), advance outwash and Colvos sand (Qva), till (Qvt), and volcanic rocks (Tv) [see Figure 5].[12] Out of the five formations, recessional outwash occurs most extensively in the Capitol Lake area, underlying nearly all of the terraine of the east, west, and south sides of the lake. This formation consists of glaciofluvial materials which were deposited during the recession of the Vashon glacier, and includes poorly sorted gravel and sand (Qvr) and sandy and silty outwash with lenses of gravel (Qvr_1). The advance outwash and Colvos sand formation (Qva) extends as a narrow band along the western margin of Capitol Lake and along the Percival Creek stream channel. These materials are also of glaciofluvial origin and were deposited during the advance of Vashon glacier. The alluvial deposits (Qal) which occur along the northeast margin of Capitol Lake and within the limits of the Deschutes River flood plain to the south are relatively fine-grained materials which have been laid down as a result of sedimentation. Deposits of compacted gravelly clay or till (Qvt) occur in areas to the north and southwest of Capitol Lake. There are also two volcanic rock "islands" which lie to the south and southwest (Tv in Figure 5).

3. Soils[13]

The soils of the Capitol Lake area are typical of the soils that occur in the entire Puget Sound region. They have been significantly conditioned

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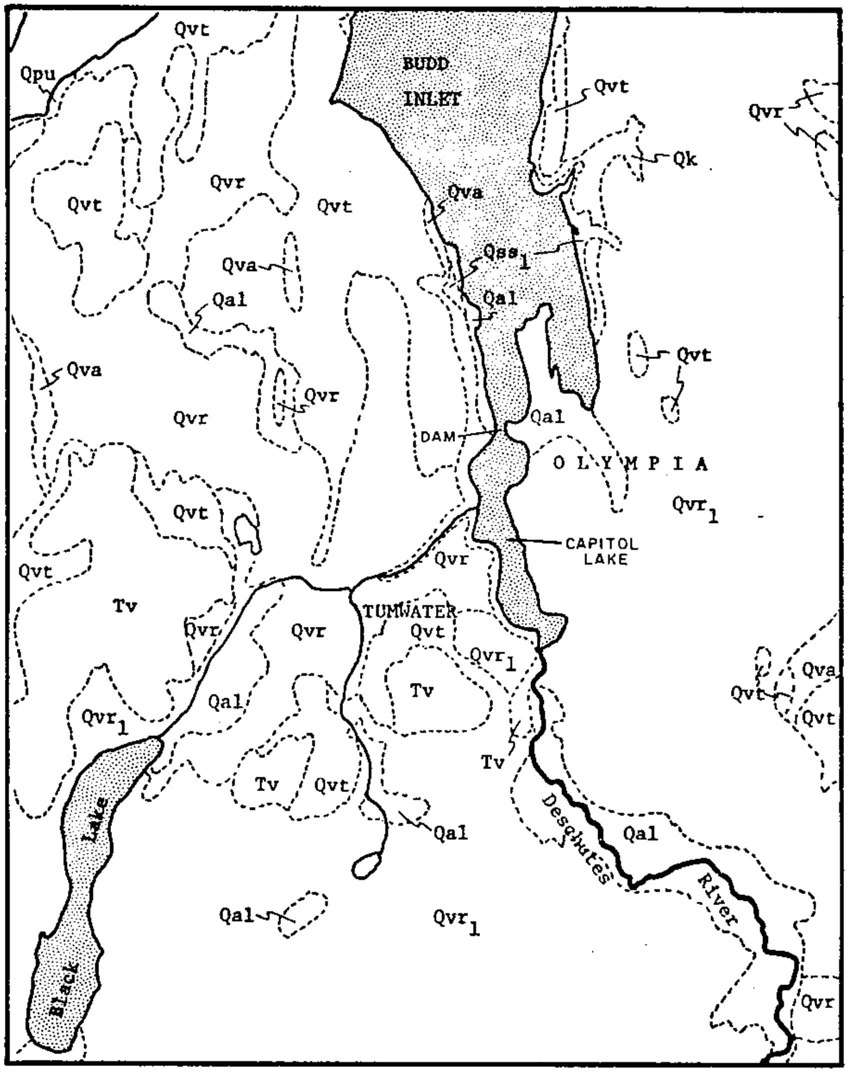
[12] Noble, J. B., and Wallace, E. F., "Geology and Ground-Water Resources of Thurston County, Washington," Water Supply Bulletin No. 10, Vol. 2, Washington State Division of Water Resources (Dept. of Conservation) in cooperation with U.S. Geological Survey, 1966.

[13] Glassey, T. W., et al., "Soil Survey of Thurston County, Washington," U.S. Soil Conservation Service (Dept. of Agriculture) in cooperation with Washington Agricultural Experiment Station, Series 1947, No. 6, 1958.



Explanation of symbols, Figure 5.

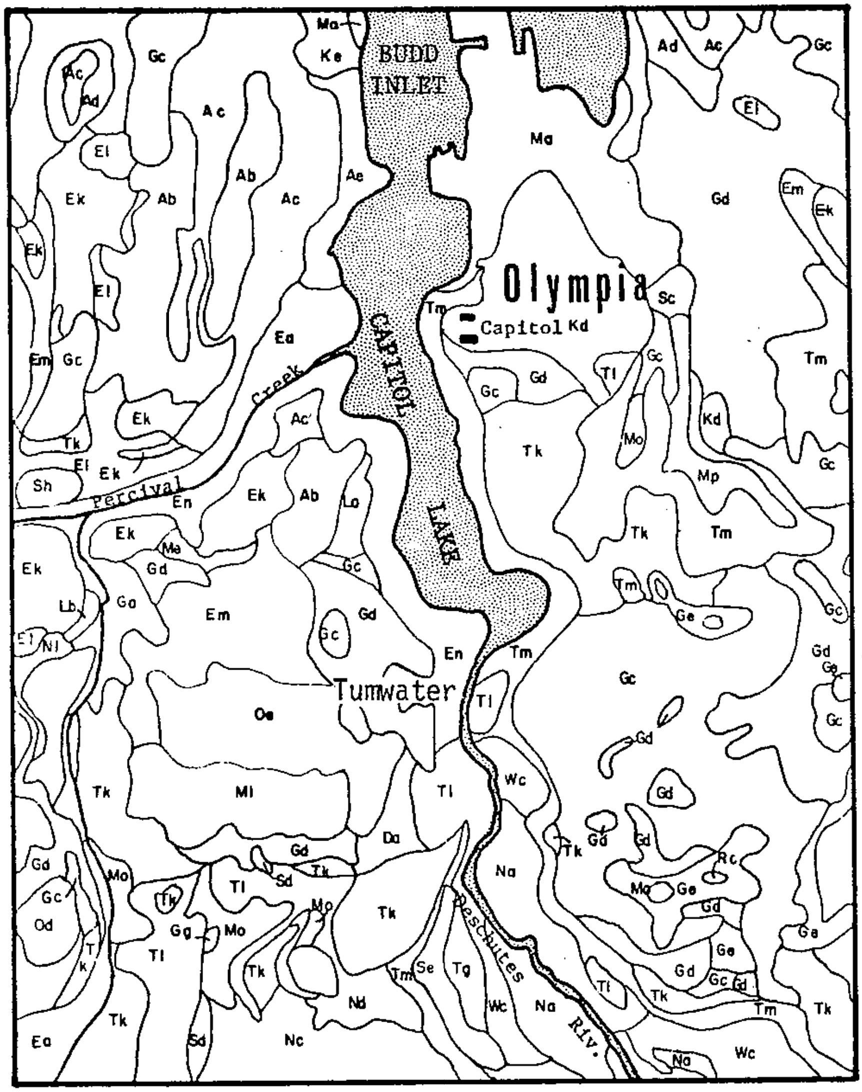
Recessional outwash **Qvr** **Qvr₁**	**Glaciofluvial materials deposited during recession of the Vashon glacier. Qvr, gravel and sand, poorly sorted, usually above water table but excellent aquifer where below water table. Qvr_1, sandy and silty outwash with lenses of gravel. Frequently kettled. Produces moderate amount of ground water except in Peninsular Area. Usually overlies till or recessional gravel.**
Volcanic rocks **Tv**	**Chiefly volcanic rocks of the Northcraft and Crescent (?) Formations but includes intrusive bodies not mapped separately. None important as aquifers.**
Till **Qvt**	**In most places a compacted gravelly clay but also includes uncompacted ablation till. Acts as relatively impermeable barrier when below water table.**
Alluvium **Qal**	**Predominantly fine-grained floodplain deposits of detritus and peat. Also includes some lake deposits, marine alluvium, and artificial fill. Locally yields much water to wells.**
Advance outwash and Colvos Sand **Qva**	**Glaciofluvial sand and gravel deposited by advancing Vashon glacier. Also includes Colvos Sand which conformably overlies Kitsap Formation. Important aquifer where below water table.**

Fig. 5. Geological Formations, Capitol Lake and Vicinity[12]

by a high rainfall environment and are generally quite acidic. Three-fourths of the soils have developed from glacial drift and they are shallow, coarse-textured, and low in fertility. The remaining soils have developed from weathered bedrock, old valley fillings, lake-laid sediments, recent alluvium, and organic accumulations. The majority of the soils are brown to yellowish brown in color, although soils of lighter and darker coloration do occur, and they exhibit a wide range of drainage characteristics. There are six prevalent soil types which occur in the Capitol Lake area, including Alderwood gravelly sandy loam, Everett gravelly sandy loam, Giles fine sandy loam, Kitsap silt loam, made land, and Tumwater loamy fine sand (see Figure 6).

Everett gravelly sandy loam occurs extensively along the western margin of Capitol Lake, occupying a broad strip of terrain from the southern limit of the lake, northward to include the southern third of the area on the west side of the lower basin. This soil type also occurs as a wide band following Percival Creek in a parallel fashion for some distance to the west. The soils thus far described have slopes of between 30 and 40 percent (En designation) and, for the most part, no development has occurred in these areas. More extensive sections of Everett gravelly sandy loam occur in areas of more gradual relief (0-3 percent, 3-15 percent, 15-30 percent, designations Ek, El, and Em, respectively) beyond the immediate Capitol Lake area to the west. Everett gravelly sandy loam has developed from loose, gravelly, poorly assorted glacial drift and is distinguishable from Alderwood soils by its substratus of loose gravel. All of the soils in this series are loose, porous, and excessively drained and exhibit dryness during summer months. Runoff in these areas is medium and erosion is usually well controlled by vegetation.

Except for the lower basin, the entire hilly margin of the east side of Capitol Lake is occupied by Tumwater loamy fine sand. Soils of relatively steep slope (15-30 percent, designation Tm) occupy the undeveloped strip marginal to the lake while areas of more gradual terrain (0-3 percent, designation Tk) underlie concentrated development in the City of Olympia immediately east of the lake. As is explicit in the name, this soil is



Key to Symbols, Figure 6

Ab	Alderwood gravelly sandy loam, 0-3% slopes
Ac	Alderwood gravelly sandy loam, 3-15% slopes
Ad	Alderwood gravelly sandy loam, 15-30% slopes
Ae	Alderwood gravelly sandy loam, 30-50% slopes
Ek	Everett gravelly sandy loam, 0-3% slopes
El	Everett gravelly sandy loam, 3-15% slopes
Em	Everett gravelly sandy loam, 15-30% slopes
En	Everett gravelly sandy loam, 30-40% slopes
Gc	Giles fine sandy loam, 0-3% slopes
Gd	Giles fine sandy loam, 3-15% slopes
Kd	Kitsap silt loam, 3-15% slopes
La	Lynden loamy sand, 0-3% slopes
Ma	Made land
Ml	Melbourne stony loam, 15-30% slopes
Oe	Olympic stony clay loam, 15-30% slopes
Tk	Tumwater loamy fine sand, 0-3% slopes
Tm	Tumwater loamy fine sand, 15-30% slopes

Fig. 6. Soil Types in the Capitol Lake Area

comprised of a loamy sand and occurs with a predominantly sand substratum. Runoff is slow and permeability is very rapid in both upper and lower strata.

A rather sizable area of Kitsap silt loam (Kd, 3-15 percent slopes) underlies much of the downtown area of Olympia and is separated from Capitol ~~Lake only by the narrow hilly margin of Tumwater soil described above.~~ Kitsap soils are gravel free and have developed from stratified, glacial, lake-laid sediments. Runoff is slow, drainage is medium, and the soil is generally saturated during much of the winter and spring.

Another type of soil which is abundantly distributed in areas west of Capitol Lake is Alderwood gravelly sandy loam. Although these soils occupy the steep slopes (30-50 percent, designation Ae) along the northern two-thirds of the west side of the lower basin, they generally occupy areas of more gentle relief (0-3 percent, 3-15 percent, designations Ab and Ac, respectively), and are separated from direct contact with the lake by hilly Everett soils. Alderwood soils have developed from gravelly till materials derived from a variety of rocks and are associated with a strongly cemented substratum which may lie between 24 and 48 inches below the surface. Runoff from Alderwood soils is slow to medium, depending on slope, and although the cemented substratum restricts downward water movement, internal drainage is reportedly medium. Concentrated urban/suburban development is also associated with these soils.

Soils of Giles fine sandy loam series occur rather extensively to the southeast and southwest of Capitol Lake in areas which also exhibit urban/suburban type development. Soils of this series have developed mainly from sandy outwash materials, but there are layers of silt and very fine sand in the lower subsoil and substratum. Although water movement is somewhat impeded by the finer structure of these soils, internal drainage is medium. These soils generally occur on gradual relief of 0-3 percent slopes (Gc), although areas of more pronounced relief also occur (3-15 percent slopes, Gd). Runoff from Giles soils is generally slow.

Finally, there is a category of soils referred to as made land (Ma) which occupies the majority of the eastern shore of the lower basin and underlies a sizable portion of the central business district of Olympia. This soil is characterized as made land since it consists primarily of dredgings hauled up from Budd Inlet.

4. Land Use

Land use in the Capitol Lake area consists predominantly of commerical and industrial use and urban and suburban residential occupation. Figure 7 illustrates the concentrated development which occupies all but the central portion of the west side of Capitol Lake, and it is under development. Urban centers occupy the areas to the north and east of the lower basin, and to the south and southeast of the upper basin, and the majority of remaining development is residential.

Transportation corridors also account for a good deal of land use in the Capitol Lake area. Most significant are the Deschutes Parkway along the western shoreline of the lake, the Northern Pacific railroad which crosses the lake between the lower and middle basins, and Interstate 5 which crosses over the lake between the upper and middle basins.

There are two parks located on Capitol Lake, one on the southwest side of the lower basin and one which extends from the north to the east side of the lower basin. The latter is a heavily used park which includes a swimming area and access to small sailboats for use on the lower basin. In addition to these parks a public boat launch is also located on the west side of the upper basin where boaters, skiers, and fishermen are provided access to the middle basin.

B. Geomorphic Features of the Basin

The Deschutes River basin is approximately ten times as long as it is wide with a majority of the relief being concentrated in the Bald Hills along the southern topographic divide. The maximum elevation in this area is 3840 ft at Cougar Mountain. The major portion of the river fall occurs in

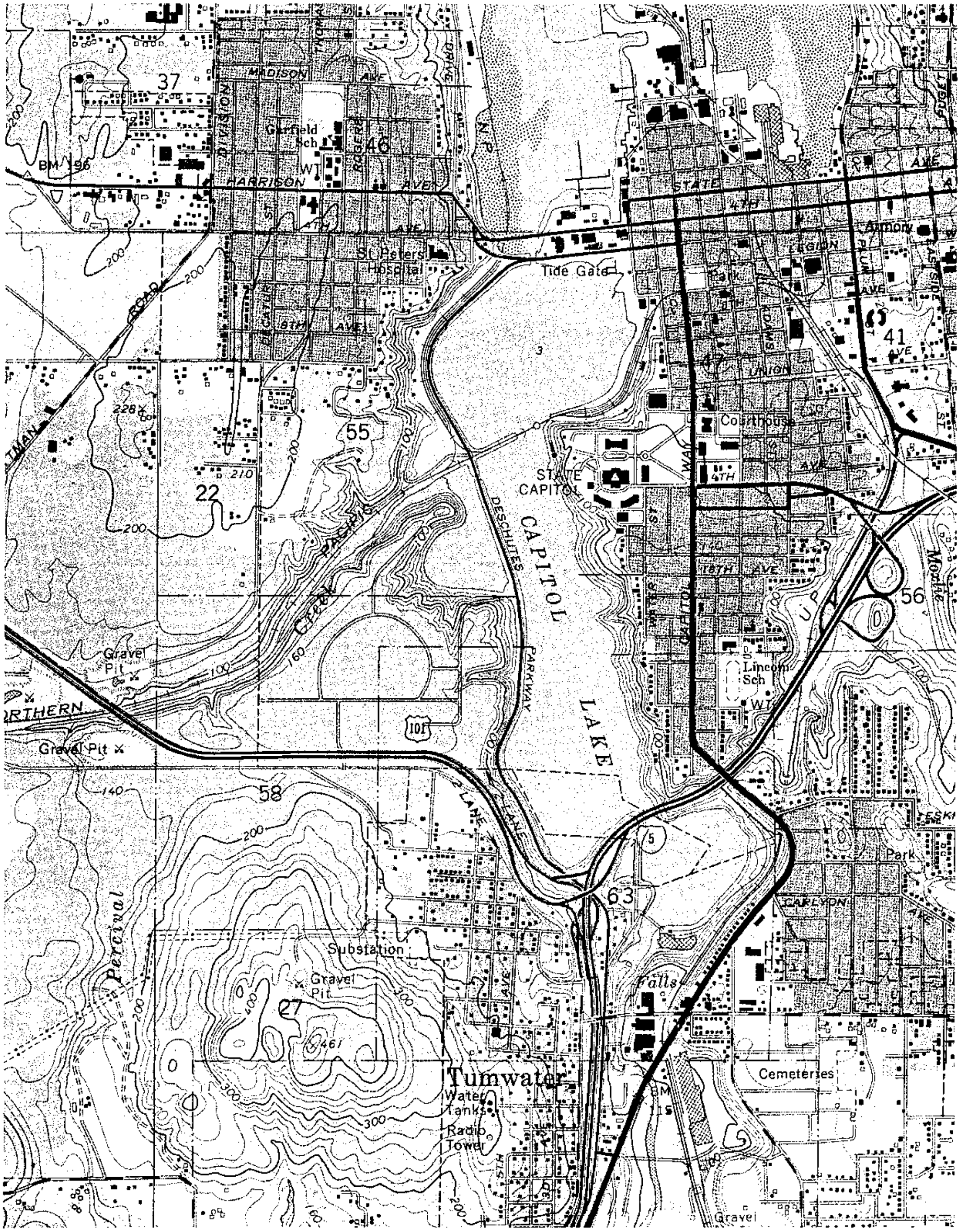


Fig. 7. Capitol Lake and Vicinity, Topography and Population Distribution

about the first ten miles below the headwaters. As a result, most of the drainage network is developed in the same area. The lengths of streams, elevation changes and drainage areas for the three gaging stations shown in Figure 4 are tabulated in Table 2.

The stream lengths and upper basin elevation were determined from 1:62500 scale U.S. Geological Survey topographic maps. The drainage areas and gage elevations are those published by the USGS in their annual Water Supply Papers. Because the basin is merely increasing in drainage area as one moves downstream from the LaGrande gage to Rainier and to Olympia, the upper headwater elevation remains a constant in Table 2.

Table 2.

River Basin Parameters of Deschutes River and Percival Creek Entering Capitol Lake

Gage Station (No.)	L1 (mi)	LT (mi)	Upper Elev. (ft)	Gage Elev. (ft)	Relief H (mi)	Basin Area, A (sq mi)
LaGrande (12078902)	38.6 Σ=38.6	61.5 Σ=61.5	2550	549	0.38	56.2
Rainier (12079000)	11.2 Σ=49.8	24.1 Σ=85.6	2550	350	0.42	89.8
Olympia (12080000)	8.9 Σ=58.7	29.1 Σ=114.7	2550	95	0.47	160.0
Percival Cr. at Capitol Lake	3.8	4.2	200	0*	0.04	13.0

Nomenclature: L1 = length of first-order (unbranched perennial streams;

LT = total length of perennial streams;

Upper Elevation = highest average contour around headwaters;

H = Relief--difference in elevation between headwaters and gage (or outlet, for ungaged basin); and

A = drainage area defined by topographic divide above gaging station or basin outlet; and

* = Outlet Elevation.

C. Physical Description of Capitol Lake and the Sediment Problems

Prior to completion of the 5th Avenue dam in 1951, the Capitol Lake area was a tidal flat. Although the flow of the Deschutes River and Percival Creek was influenced in this flat by the elevations of the tides, the general deposition pattern of sediments carried by the two streams took place further north than where they are now deposited. Actually, downtown Olympia, the Port area, and much of the shore around the south end of Budd Inlet was formed or underlain by alluvial deposits primarily laid down by flow from the Deschutes River. Under pre-1951 conditions, and during periods of high flow when sediment loads were the greatest, the Deschutes River had enough momentum and carrying capacity to dominate the tides and move sand and finer sediments well out into Budd Inlet.

Capitol Lake is merely a wide place in the former Deschutes River tidal flats. Construction of the dam changed the effective slope of the river to zero, except during times of higher flows when the automatic dam gates stay open most of the time and the mean flow-through velocity in the lake is large enough to carry fine sediments. During these flows the velocity scours the lake bed around the east side of the upper basin and through constrictions such as the I-5 highway bridge and the railroad bridge at the north end of the middle basin. As the flow area expands downstream of these constrictions, larger sized sediments are deposited first, some finer materials are deposited in quieter, eddying areas such as the southwest corner of the middle basin, and some of the very fine sediments are carried through the gates and out of the lake. The gates are designed to automatically release flow when lake levels exceed tide levels.

The dam raised the average level of the water in the tidal flat at the mouths of the Deschutes River and Percival Creek; the opportunity for these streams to deposit materials was moved upstream and the base levels of the streams were raised. In addition, the railroad and highway fills tend to cause the same effects, but to a varying degree. The existing effects of the railroad fill of the Middle Lake are minor because only fine sediments are carried that far, and actually it reduces the amount of sediment being deposited in the Lower Lake.

The effects of the I-5 highway fill on the sediment deposition pattern in the last twenty years has been much more dramatic. The accumulation of sediment between 1964 and 1970 in the Upper Lake which was formed by the highway fill is shown in Figure 8. The Upper Lake has essentially come into balance with the varying amounts of sediments which are carried into it each year. Although there continues to be a buildup of finer materials in a few recessed areas (such as the boat ramp and low lying areas submerged by floods) a majority of the material is carried out of the Upper Lake into the Middle Lake under existing conditions.

Though a free-flow condition has been provided through the bridge opening, the highway fill has raised the base level of the Deschutes River above that increase caused by the dam. During periods of high flow the water is raised behind the highway fill higher than the lake level would have been without the fill. Thus, as the Upper Lake has become more filled with sediments, the main river channel has taken the longer route around the east shore, braided channels have formed and reformed, and excess coarse sediment has been passed into the Middle Lake.

Recognizing these conditions has made it possible to consider the use of the Upper Lake as a sedimentation basin for the rest of the lake. To achieve this requires rearrangement of some of the channels and islands into a geometry more suitable for the accumulation and removal of the sediment. Finer materials will continue to be carried out into Budd Inlet during higher flows, with some reduced deposition occurring in the Middle and Lower Lakes. It is recognized also that the Upper Lake has been transformed into a wildlife area and is a place of historical interest. Thus, the dredging and filling of certain areas of the Upper Lake will be designed in consideration of maintaining and enhancing the natural setting and leaving the areas of historical interest undisturbed.

The decrease in volume of Capitol Lake which has occurred since formation of the lake is summarized in Table 3. The first value for the years 1950-55 shows an average rate of accumulation of 1,420,000 cubic feet per year. The average river discharge of the Deschutes River at Olympia during this period was approximately 425 cfs. During the period of the second entry (1949-70),

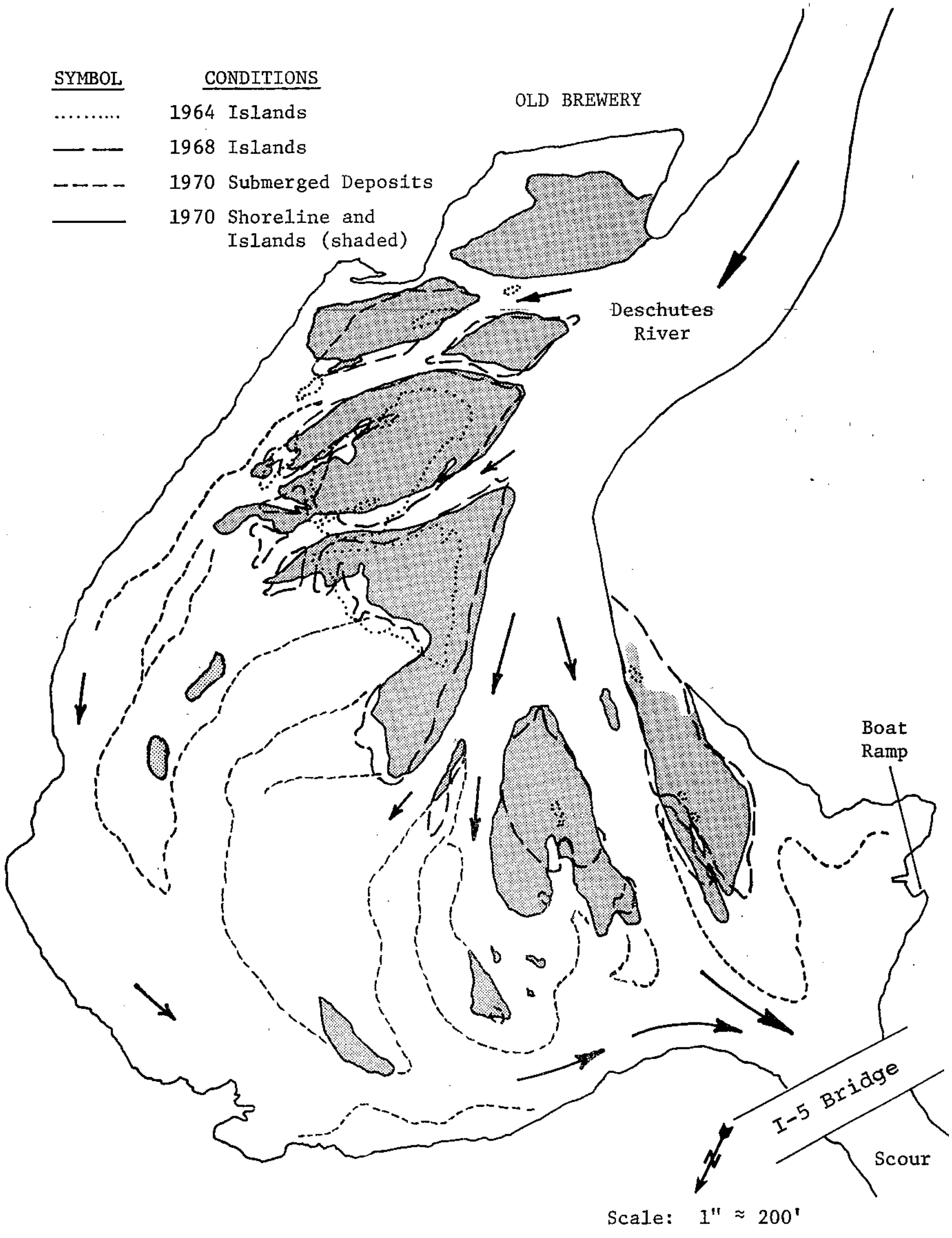


Fig. 8. Sediment Deposition Pattern and Island Growth in Upper Capitol Lake for the Period 1964-70 (Composite of drawings from "Saving a Beautiful Lake," Capitol Lake Coordinating Committee, 1975)

which included the 1950-55 period, the average rate of accumulation was approximately 1,100,000 cubic feet per year and the average river discharge was about 388 cfs. The third value of 810,000 cubic feet per year of accumulation shown in Table 3 was based on the recent Geological Survey study.[14]

E. Water Balance and Flow Through the Lake

In an average year, for an assumed existing lake volume of 2200 acre-feet (95,832,000 cubic feet), and with an average annual flow of 430 cfs from

Table 3. Sediment Accumulation Rates in Capitol Lake, Washington

Period	Information Source	Computation Basis	Total Accumulation (cu ft)	Average Annual Rate (cu ft/year)
1950-55 (6 years)	SCS[1] (1970) for DOF[a]	Lake Volume Change	8,520,000 (195.6 acre-ft in 6 years)	1,420,000 (32.6 acre-ft per year)
1949-70 (18 years since dam built in 1951)	Walker and Byrne[2] for DGA[b] (1970)	Lake Volume Change	20,000,000 ($739,000\ yd^3$ in 18 years)	1,110,000 ($41,000\ yd^3$/yr; 25 acre-ft/yr)
-	Nelson,[14] USGS for DOE[c] (1973)	Suspended Sediment Measurements	-	810,000 ($30,000\ yd^3$/yr; 18 acre-ft/yr) (25,000 tons at 60 lb/ft^3 assumed wet specific weight

[1,2,14] Refer to references.

[a] Department of Fisheries (DOF)

[b] Department of General Administration (DGA)

[c] Department of Ecology (DOE)

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[14] Nelson, Leonard M., "Sediment Transport in Streams in the Deschutes and Nisqually River Basins, Washington, Nov., 1971 - June, 1973," U.S. Geological Survey. Prepared in cooperation with the State of Washington Department of Ecology, Open File Report, Tacoma, Washington, 1973.

the Deschutes River and Percival Creek, the volume of Capitol Lake is exchanged (on the average) 130 times per year, or about once every three days. Although this is an average value, it does indicate that there is the potential for rapid displacement of lake water by inflow from the two streams on a yearly basis. The average annual flow into the lake can be expected to vary by as much as ±40 percent, making the highest and lowest exchange rates about 180 and 80 times per year for average annual flows of 600 and 260 cfs, respectively.

During high flow periods the rate of exchange is increased, and for an average flood flow of 3900 cfs, the lake volume has the potential for being exchanged once every seven hours or 3.5 times per day. Recessed, quiet areas would not be exchanged this rapidly. But the critical period is during the summer when inflow from the two streams can be as low as 80 cfs, and precipitation can be zero for weeks at a time.

Under summer conditions the Deschutes River and Percival Creek flows are available to exchange the lake volume only once every 14 days. The actual exchange is less efficient under low flow than under high flow conditions. Recessed areas such as the southwest corner of the Middle Lake, Percival Cove, and the east and west edges of the Lower (North) Lake receive very little exchange and circulation during low flow periods. During high flows these areas tend to accumulate fine sediments and debris, and during low flow periods the same areas tend to have the least exchange with the streamflow that is moving through the lake.

In visualizing Deschutes River flow through the lake, it tends to move along the east bank (refer to Fig. 8) in the Upper Lake once it passes the old brewery. A small amount of flow passes through the secondary channel directly towards the I-5 bridge opening, but a majority of the flow follows the center channel and leaves the Upper Lake in a deeply scoured channel between the east embankment of the I-5 fill and the island opposite the boat ramp.

As the flow enters the Middle Lake (refer to Fig. 1) it tends to adhere to the east (right) bank and expand towards the west shore, coming in contact with that shore about half-way to Percival Cove and forming a large eddy near the Deschutes Parkway in the southwest corner of the Middle Lake. Approaching the railroad trestle and fill the flow recontracts and accelerates to pass through the opening.

In the Lower Lake the higher velocity flow tends to go almost directly north to the outlet gates in the dam. Two large eddies are formed, one in either half of the Lower Lake. During periods when the outlet gates are closed, this flow pattern is greatly reduced in extent and activity because the inflow is going into temporary storage as the lake rises in elevation and the outflow is zero.

Typical streamflows are summarized in Table 4 and the ratios of Deschutes River flows to the estimated values for Percival Creek are given to show their relative general importance to the production of sediments, nutrients and flushing capability.

Table 4.

Typical Deschutes River and Percival Creek Flows

Name of Flow	Symbol	Deschutes River (cfs)	Percival* Creek (cfs)	Ratio D/P	Detention Time** (days)
Average Annual	QAA	405	30	13.5	2.6
Average Flood (2-yr)	QF2	3900	150	26.0	0.3
100-yr Flood	QF100	7400	360	20.6	0.2
Average Low (2-yr, 7-day)	Q7L2	96	8.4	11.4	10.7
10-yr Low (10-yr, 7-day)	Q7L10	80	7.1	11.3	12.8
20-yr Low (20-yr, 7-day)	Q7L20	74	6.7	11.0	13.8
Lowest Recorded	Q7L(min)	66	5.2	12.7	15.7

*Percival Creek flows based on correlations with stream gages in the vicinity (see Hydrology section of this report).

**Detention time (theoretical) = (1970 lake volume)÷ Deschutes River + Percival Creek flow rates; 1970 lake volume = 96.44×10^6 cu ft, or 1116.35 cfs-days at -3.5 ft, Olympia datum.

There is an additional flow into the lake due to runoff from the small areas east and west of the lake (1.60 sq mi) and due to precipitation directly on the lake (0.44 sq mi). For an average annual precipitation of about 55 inches per year this amounts of about 56,000,000 cubic feet per year, or less than one additional lake exchange compared to the 120 times by the Deschutes River and 10 times by Percival Creek. The evaporation from the lake averages about 20 inches per year between April and September (one-fourth of a lake volume) based on the recorded values at the Puyallup Experiment Station. Details of the water balance and monthly exchange rates for various lake volumes are discussed in Chapter III, Section C-2, Volume Exchange in Capitol Lake.

III. HYDROLOGY OF CAPITOL LAKE AND ITS DRAINAGE BASIN

Chapter Summary

Definition of hydrologic aspects of Capitol Lake is essential to characterization of sediment transport and deposition and to complete the characterization of water quality relationships. Fortunately, the U.S. Geological Survey maintained a gaging station on the Deschutes River at Olympia from 1951-54 and 1958-63. A stream gaging station has been maintained near Rainier continuously since 1949. By developing relationships between flows at the Olympia and Rainier gages for the period 1951-54 and 1958-63, it was possible to extend the records at Olympia and thus allow for a better analysis of average flows and flow variability for the Deschutes River which provides Capitol Lake with over 90 percent of its annual inflow.

Percival Creek watershed provides only seven percent of the flow into Capitol Lake, and very few stream gaging measurements are available. Only about 40 miscellaneous measurements have been made at five sites and only one low flow measurement has been made near the mouth of the creek where it enters Percival Cove. Therefore, the average, low and flood flows for Percival Creek were estimated based on relationships developed for stream gaging stations on Goldsborough, Skookum, and Woodland Creeks.

This chapter is presented in two parallel sections--one for the hydrology of the Deschutes River Basin and one for the Percival Creek Basin. A third section of this chapter discusses the physical features of the lake, its hydrology and regulation with the tide gates at the dam. Stream section topics include: precipitation and average annual streamflow characteristics, including a streamflow summary; drainage basin characteristics related to flows; floods; and low flows.

A. Hydrology of the Deschutes River Basin

1. Precipitation and Streamflow Characteristics

The average annual precipitation on the Deschutes River Basin is 52 inches per year. This is equivalent to an average annual volume of 19,515,600,000 cubic feet (146,400,000,000 gallons) of which about 14,000,000,000 cubic feet (104,300,000,000 gallons) enter Capitol Lake as average annual streamflow.

The average annual precipitation varies between a low of 45 inches per year to a high of 65 inches per year.[8,14] The lowest amount of precipitation occurs in the relatively flat country just south and east of Olympia. This dip in precipitation as one moves up the Deschutes River watershed from Capitol Lake is shown in Figure 9 in the upper graph at a distance of 10

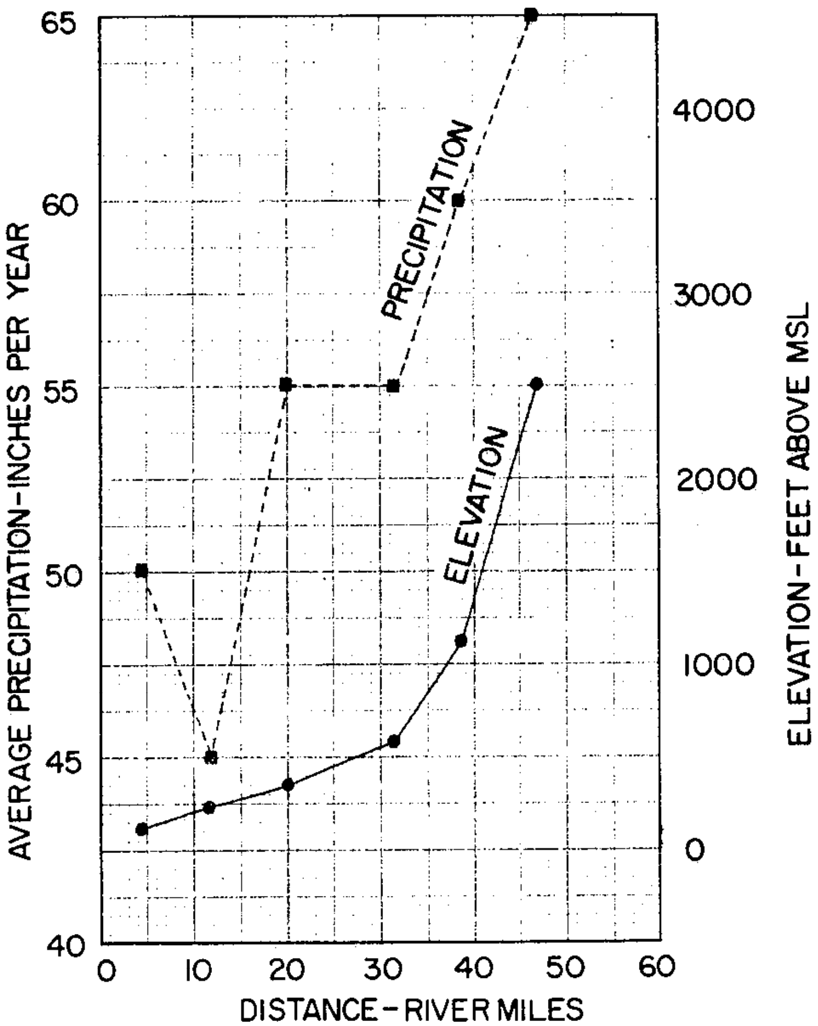


Fig. 9. Effect of Elevation on Precipitation for the Deschutes River Basin Along a Line from Outlet of Capitol Lake to the Headwaters (Precipitation Profile Based on Figure 1 in Reference 14)

miles up the river. The long-term variation in monthly and annual precipitation at the Olympia Airport is presented in Table 5. The average annual precipitation at the airport has varied between a minimum of 36.38 inches per year in 1973 and a maximum of 69.93 inches the year before.

The location of the Capitol Lake watershed with respect to Percival Creek, the Deschutes River, the Nisqually River, and Mineral Creek is shown in Figure 10. The symbols for the gaging stations near LaGrande, Rainier, and Olympia are a triangle (△), circle (○), and square (□), respectively. This symbolism was developed for use in this report to signify and correspond to the increasing drainage (and symbol) area as one moves in a downstream direction from the uppermost gage near LaGrande to the lowest gage near Olympia. These symbols are as shown for these stations in Figure 10 and are used throughout this report.

The sediment characteristics of the Nisqually and Deschutes River basins were recently studied in detail by the U.S. Geological Survey.[14] The sediment characteristics of the Deschutes River, as they affect Capitol Lake, are discussed in the next chapter and Appendix B.

The average annual flow characteristics of Mineral Creek in the Upper Nisqually River basin are similar to those of the Deschutes River at Olympia as is shown in Figure 11. Initial estimates of the average annual flow of the Deschutes River at Olympia for the periods of missing records (i.e., 1955-57 and 1964-73) were made using the Mineral Creek values. Later, a more accurate relationship was developed for average daily flows between the Olympia and Rainier gaging stations on the Deschutes River. The combined relationships between annual precipitation at the Olympia Airport Station and the Mineral Creek Station, and the average annual streamflows of Mineral Creek and the Deschutes River at Olympia and Rainier are shown in Figure 12.

Miscellaneous measurements have been made recently on the Deschutes River near LaGrande in connection with the sediment studies.[14] A regional relationship between average annual flow and the multiple of average annual

Table 5. Long-Term Average Monthly Precipitation at Olympia Airport Weather Bureau Station

WATER YR.	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1949	4.35	10.19	12.11	0.69	9.96	3.75	1.52	1.54	0.72	0.51	0.82	1.39	47.55
1950	5.24	12.33	10.73	9.31	9.66	10.13	3.10	0.79	0.86	1.35	1.47	2.19	67.16
1951	9.20	9.49	9.16	10.59	11.28	5.89	0.54	1.91	0.05	0.28	0.54	2.83	61.76
1952	6.95	7.32	5.80	5.65	3.96	3.13	2.25	0.85	1.22	0.10	0.74	0.43	38.40
1953	1.55	1.39	8.65	19.84	5.12	3.55	2.58	2.72	1.50	0.27	1.63	2.68	51.48
1954	6.85	7.79	9.42	11.96	8.40	3.13	4.07	1.63	3.36	0.82	1.74	1.89	61.06
1955	3.38	7.87	6.99	3.01	5.23	4.76	4.19	1.35	0.71	2.68	0.02	1.84	42.03
1956	9.31	12.18	12.59	10.75	3.93	8.27	0.37	0.30	2.57	0.38	0.88	2.30	63.83
1957	9.52	2.81	9.36	3.02	5.88	7.43	1.72	1.42	1.78	0.97	0.87	0.66	45.44
1958	4.74	4.05	8.91	7.87	6.40	2.29	4.39	1.47	1.65	T	0.62	1.52	43.91
1959	5.41	12.35	8.43	8.91	4.53	4.63	4.51	1.45	1.85	0.30	0.70	4.26	57.33
1960	3.92	10.36	7.50	6.35	5.93	6.12	4.53	3.50	0.59	T	1.16	1.21	51.17
1961	5.84	11.33	3.89	8.69	13.18	6.26	3.29	2.93	1.05	0.80	1.01	0.33	58.60
1962	4.97	6.78	8.25	3.22	3.72	3.82	4.50	1.81	0.89	0.14	3.17	2.45	43.72
1963	6.00	15.51	5.81	3.47	6.42	5.10	4.13	1.76	0.63	1.48	0.79	2.16	53.26
1964	5.98	10.32	5.55	15.13	2.54	4.47	1.58	0.98	2.35	1.07	1.47	2.26	53.70
1965	1.79	9.18	9.11	9.37	4.93	0.48	3.61	1.89	0.33	0.48	2.05	0.60	43.82
1966	3.30	5.84	7.81	7.89	3.38	7.28	1.71	1.30	1.28	1.34	0.68	1.95	43.76
1967	4.38	8.16	11.53	12.21	3.58	4.31	2.88	0.25	1.49	0.02	T	1.36	50.62
1968	10.08	3.90	5.94	9.04	7.83	6.53	3.02	2.57	2.43	0.89	5.45	2.51	60.19
1969	6.07	7.96	9.95	9.45	3.41	2.90	3.44	2.07	1.68	0.50	0.18	5.23	52.84
1970	2.69	3.60	7.24	12.48	4.30	3.07	4.76	1.21	0.14	0.16	0.15	3.20	43.00
1971	2.71	7.40	14.32	11.15	4.41	9.11	2.78	1.50	3.00	0.78	0.71	3.06	60.93
1972	4.43	7.59	9.18	12.43	11.06	10.01	5.87	0.83	1.07	1.72	0.70	5.04	69.93
1973	0.85	4.17	10.66	5.66	1.71	3.02	2.23	2.66	2.60	0.05	0.59	2.18	36.38
Monthly Average	5.20	7.99	8.76	8.73	6.03	5.18	3.10	1.63	1.43	0.68	1.13	2.22	52.07
% of year	9.98	15.35	16.81	16.76	11.58	9.94	5.96	3.13	2.75	1.31	2.16	4.27	100.00

Units are inches; T is trace.

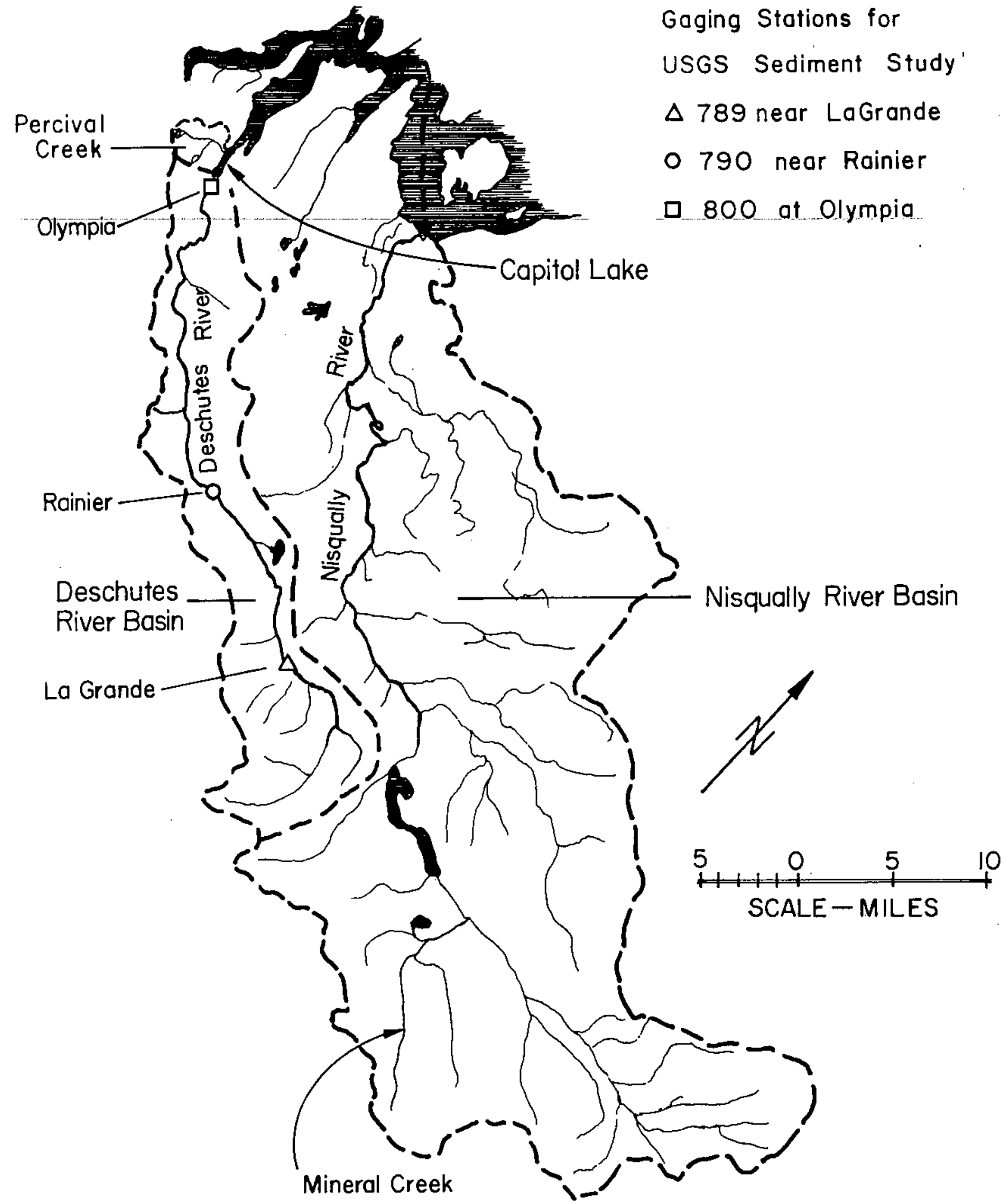


Fig. 10. The Capitol Lake and Nisqually River Watersheds

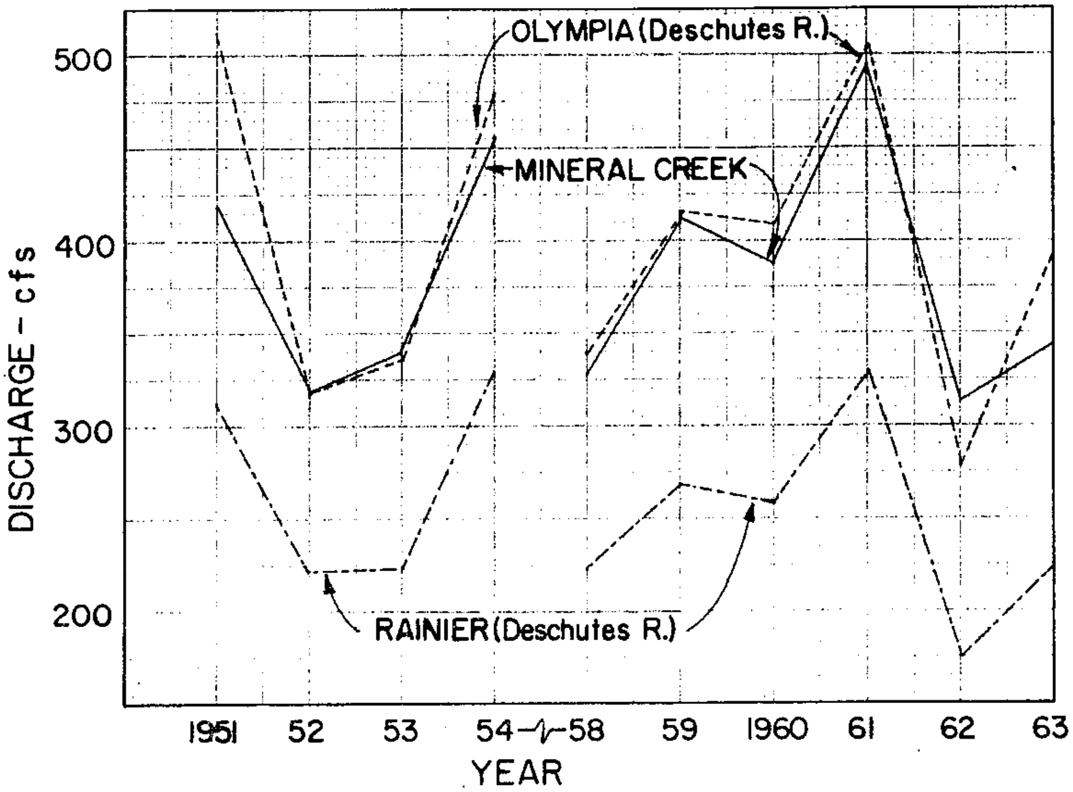


Fig. 11. Average Annual Flow of Deschutes River at Rainier and Olympia, and for Mineral Creek in the Nisqually River Basin Between 1951 and 1963

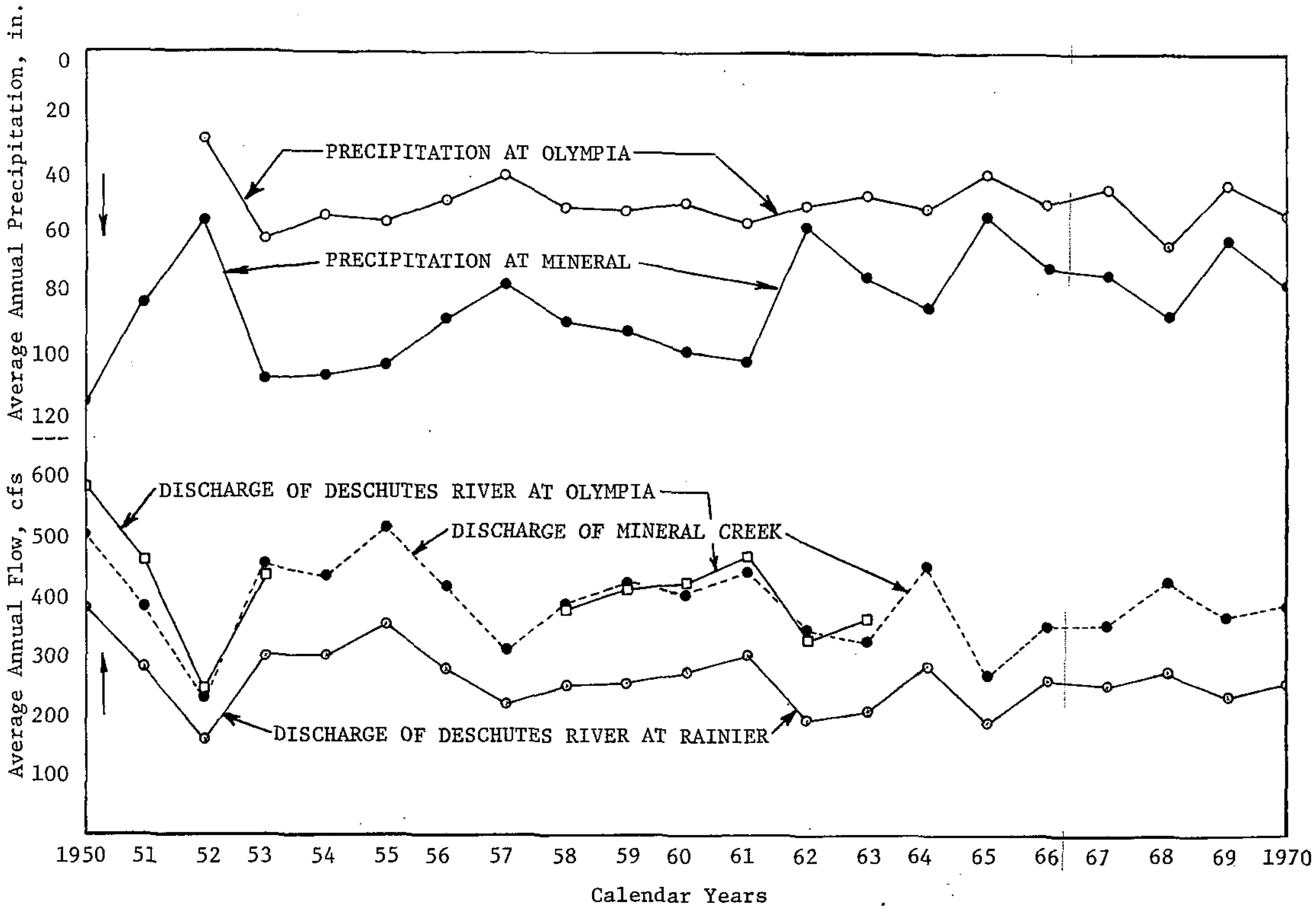


Fig. 12. Yearly Variation in Precipitation at Olympia and Mineral, and Yearly Variation in Streamflow of Mineral Creek and the Deschutes River at Olympia and Rainier, 1950-70

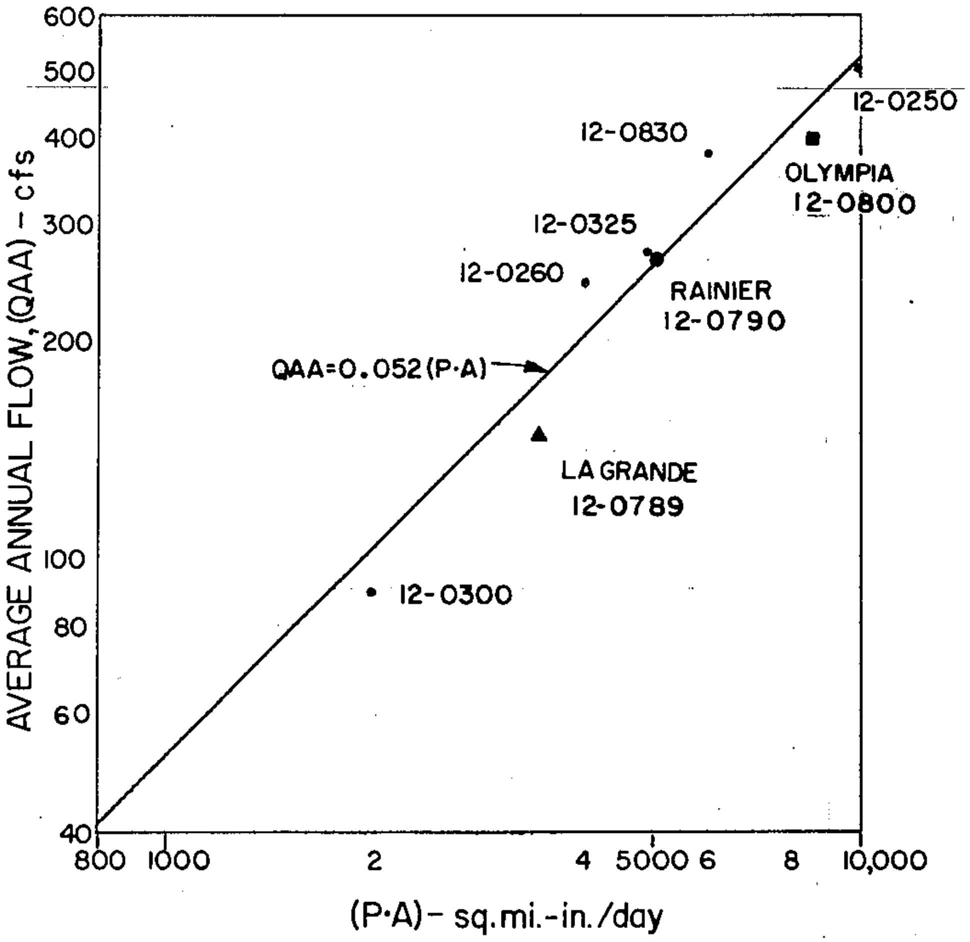
precipitation and drainage area has been developed for gaging stations on the Deschutes River and on other nearby streams and is presented in Figure 13. The average annual flow for the period of record was used and the LaGrande and Olympia gaging periods were drier than the longer period for the gage at Rainier. Thus, their plotting points are below the regional graph for stations with longer records.

The flow-duration curves for the Deschutes River at the Olympia and Rainier gages are presented in Figures 14 and 15. These curves are based on the long-term annual time distribution of average flows ranging from floods to low flows for the period of record at each station. Of importance in these figures is the small percentage of time that the discharge exceeds a value of 1000 cfs. For example, in Figure 14 at Olympia, 1000 cfs is equaled or exceeded only about eight percent of the time. As is discussed in Appendix B on sediment transport, these flows which occur only eight percent of the time transport 80 to 85 percent of the sediment into Capitol Lake. In Figure 15 at Rainier, flows of 1000 cfs or greater occur only about four to five percent of the time, but they transport about the same 80 to 85 percent of the average annual sediment load in the Deschutes River at Rainier. It is important to note that the average annual flow occurs only about 30 percent of the time at Olympia and at Rainier.

A summary of some of the more important streamflows in the Deschutes River at the Olympia and Rainier gaging stations is presented in Table 6.

The recorded and extrapolated average annual flows for the period 1931-60 at the Olympia gaging station on the Deschutes River are shown in Figure 16. This figure displays the range of average flows which can be expected to occur in the Deschutes River. The mean flow of 388 cfs for the period of 1931-60 is less than the mean flow of 405 cfs in Table 6 because the period of record for 405 cfs is 1951-63 and does not include the drier cycle in the 1930's.

General relations between annual peak discharges and annual minimum discharges at the Olympia and Rainier stream gages for the years 1951-54 and 1958-63 are shown in Figure 17.



Gage No.	River	Station Location	Area (sq mi)
120250	Newaukum	Near Chehalis	155.0
120260	Skookumchuck	Near Centralia	61.7
120300	Rock Creek	At Cedarville	24.8
120325	Cloquallum Cr.	At Elma	64.9
120830	Mineral Cr.	Near Mineral	75.2

Fig. 13. Average Annual Flow Related to Average Annual Precipitation and Drainage Area for Deschutes River Stream Gages and Other Stream Gages in the Region of Western Washington, South Puget Sound

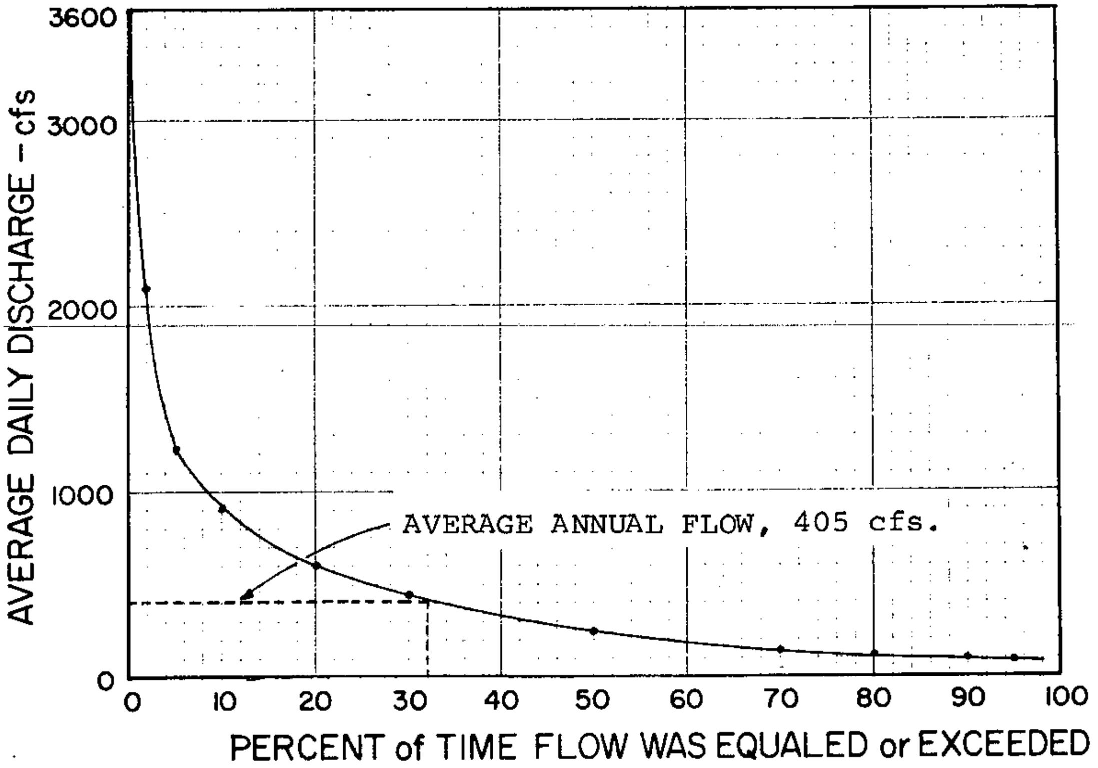


Fig. 14. Flow Duration Curve for Gaging Station near Olympia on the Deschutes River (1951-54, 1958-63)

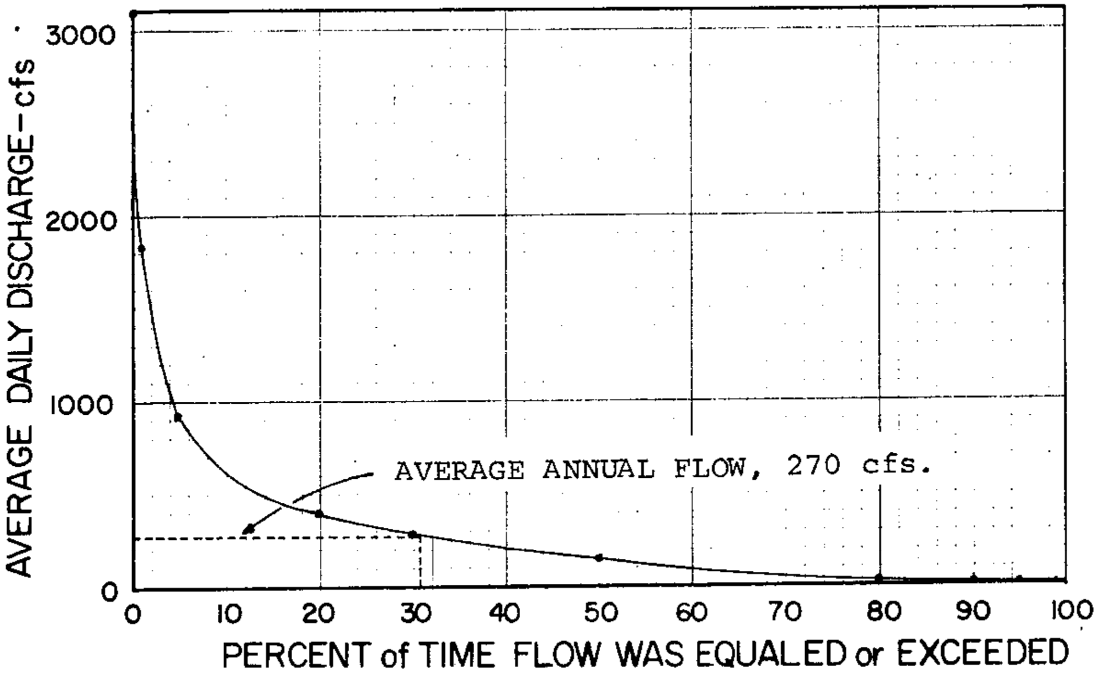


Fig. 15. Flow Duration Curve for Gaging Station near Rainier on the Deschutes River (1950-64)

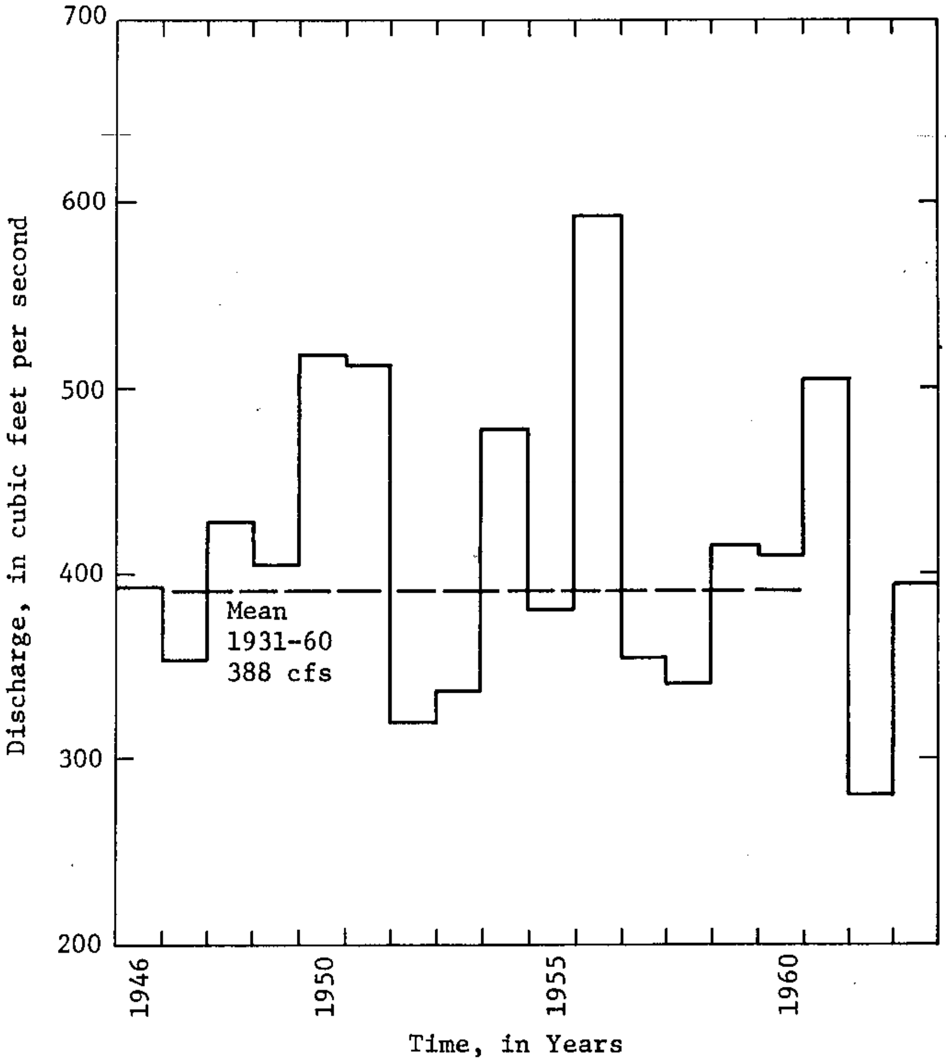


Fig. 16. Mean Annual Discharges for the Deschutes River at Olympia, Gage No. 800*

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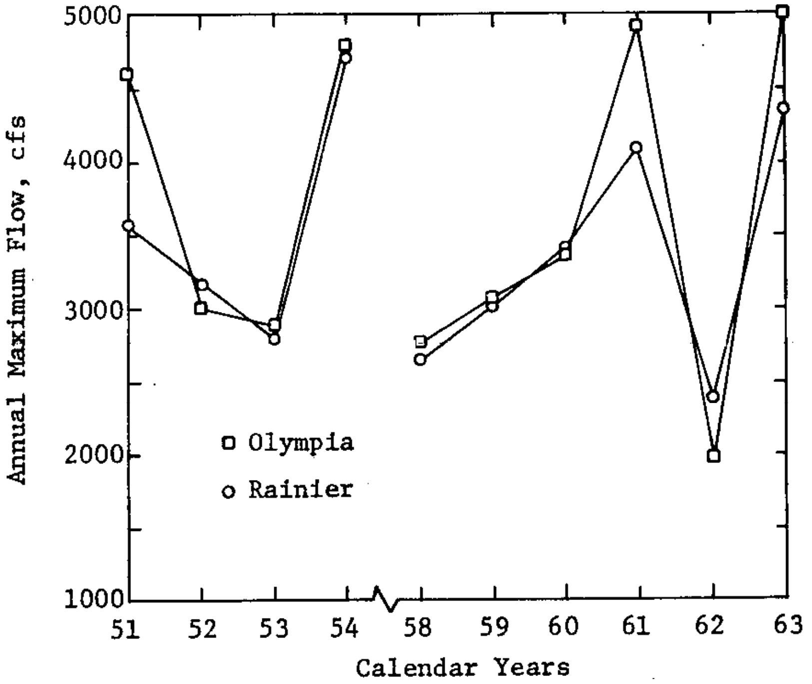
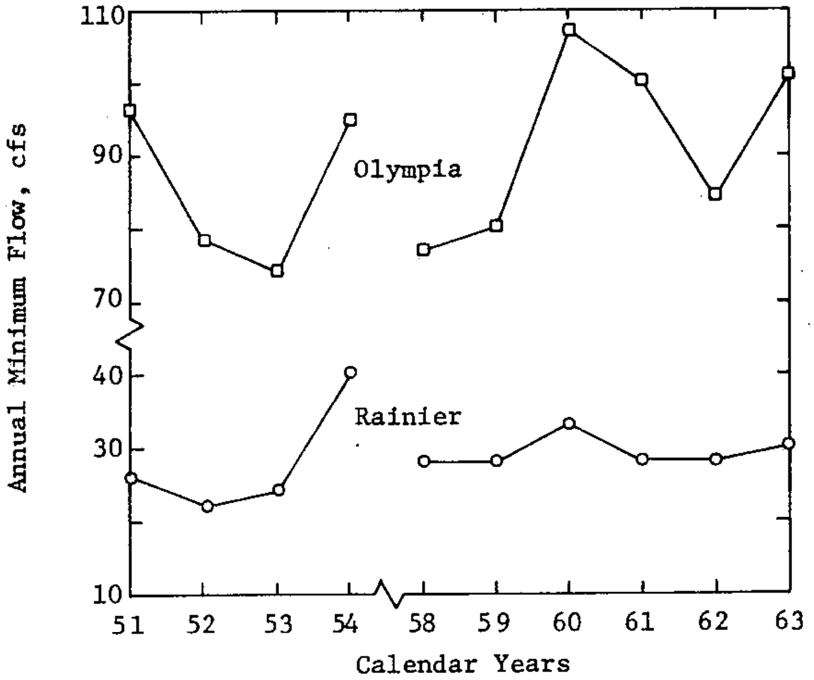
*Fig. 96, page 148 in Ref. 8; records extrapolated from period 1951-54, 1958-63 for Puget Sound Study.



a. Annual Maximum Flow of Deschutes River at Rainier and at Olympia, 1951-54, 1958-63



b. Annual Minimum Daily Flows of the Deschutes River at Rainier and at Olympia, 1951-54, 1958-63

Fig. 17. Annual Maximum Peak Flows and Annual Minimum Daily Flows, Deschutes River at Rainier and at Olympia

Table 6.

Summary of Flows for the Deschutes River[15,16] at the Olympia and Rainier Gaging Stations

Name of Flow	Symbol	Olympia Sta.800 (cfs)	Rainier Sta.790 (cfs)
Average Annual	QAA	405	270
Average Flood (2-yr)	QF2	3900	3610
100-yr Flood	QF100	7400	6300
Average Low (2-yr, 7-day)	Q7L2	96	32
10-yr Low (10-yr, 7-day)	Q7L10	80	26
20-yr Low (20-yr, 7-day)	Q7L20	74	24
Lowest Recorded	Q7L(min)	66	16

Recorded and extrapolated data and details on the hydrology of the Deschutes River basin, including estimated flows for the missing years of record at the Olympia gaging station (No. 800) are presented in Appendix A.

2. Basin Characteristics of the Deschutes River Related to Streamflow

As was shown in Figure 9, elevation plays an important part in the distribution of precipitation and thus the streamflow in the Deschutes River basin. Also, the drainage patterns of streams are indicative of the geology and runoff characteristics. As a result, relationships can be developed between geomorphic (landform) parameters and characteristic streamflows such as flood, average, and low flows. A typical set of geomorphic parameters have been developed for the three Deschutes River gaging stations near LaGrande, Rainier, and Olympia, and are presented in Table 7.

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[15] Collings, M. R., "A Proposed Streamflow-Data Program for Washington State," U.S. Geological Survey, Open-File Report, 1971.

[16] U.S. Geological Survey, "Water Resources Data for the State of Washington, Part 1, Surface Water Records," Selected years.

Table 7.

Characteristics of Deschutes River Basin Above Capitol Lake

Gage Station (No.)	L1 (mi)	LT (mi)	Upper Elev. (ft)	Gage Elev. (ft)	Relief H (mi)	Basin Area, A (sq mi)
LaGrande (12078900)	38.6 Σ=38.6	61.5 Σ=61.5	2550	549	0.38	56.2
Rainier (12079000)	11.2 Σ=49.8	24.1 Σ=85.6	2550	350	0.42	89.8
Olympia (12080000)	8.9 Σ=58.7	29.1 Σ=114.7	2550	95	0.47	160.0

Nomenclature:
L1 = length of first-order (unbranched perennial streams;
LT = total length of perennial streams;
Upper Elevation = highest average contour around headwaters;
H = Relief--difference in elevation between headwaters and gage (or outlet, for ungaged basin); and
A = drainage area defined by topographic divide above gaging station or basin outlet.

Relationships between total stream length (LT), drainage area (A), and the multiple of average annual precipitation and drainage area (P•A) are shown in Figure 18. Earlier (in Fig. 13) the relationship between average annual flow (QAA), and the annual volume of precipitation falling on the basin in the study area (P•A), was shown to be

$$QAA = 0.052(P \cdot A) \qquad (1)$$

The graphical relationship for stream length and average annual precipitation volume in Figure 18 is

$$LT = 0.21(P \cdot A)^{0.70} \qquad (2)$$

Rewriting Eq. (1) to define (P•A) yields

$$(P \cdot A) = QAA/0.052 \qquad (3)$$

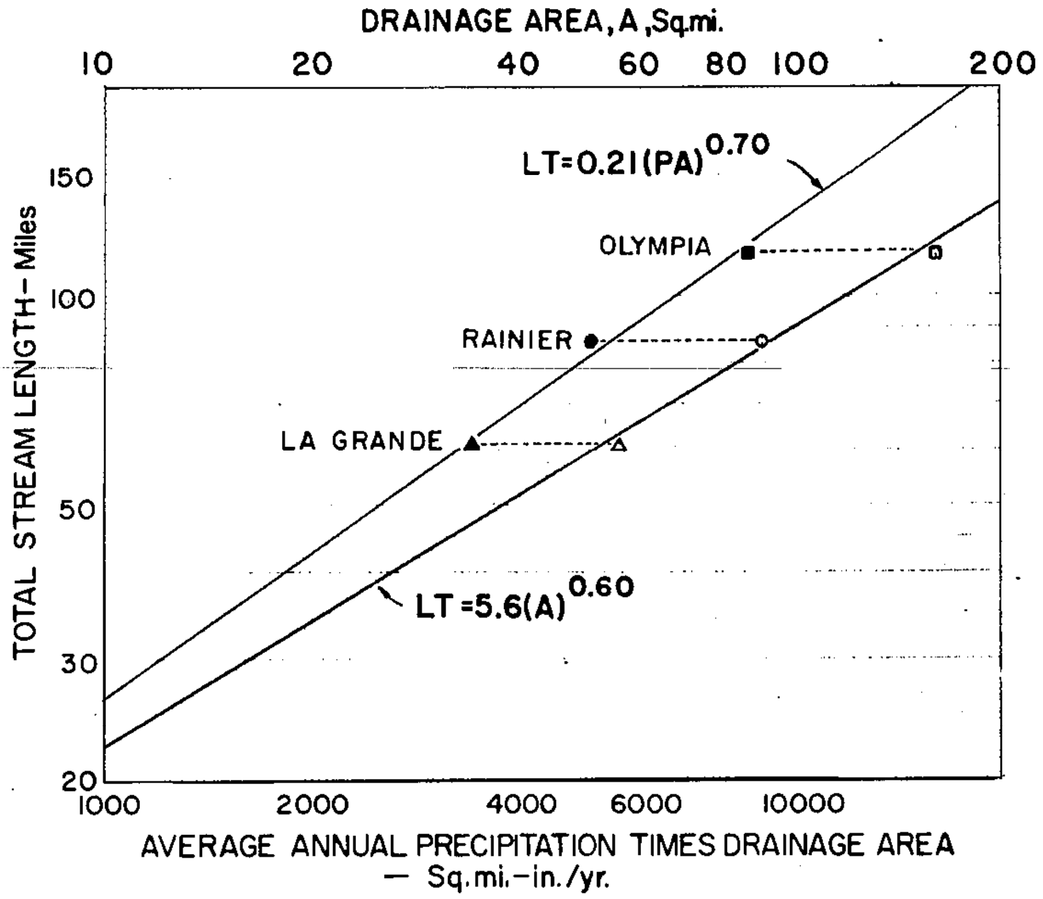


Fig. 18. Total River Length Versus Annual Precipitation Times Drainage Area for Deschutes River Basin Study Area

and Eq. (2) yields

$$(P \cdot A) = (LT/0.21)^{1.43} \qquad (4)$$

Combining Eqs. (3) and (4) allows for the determination of average annual streamflow (QAA) in terms of the total stream length (LT) by

$$QAA = 0.052(LT/0.21)^{1.43} \qquad (5)$$

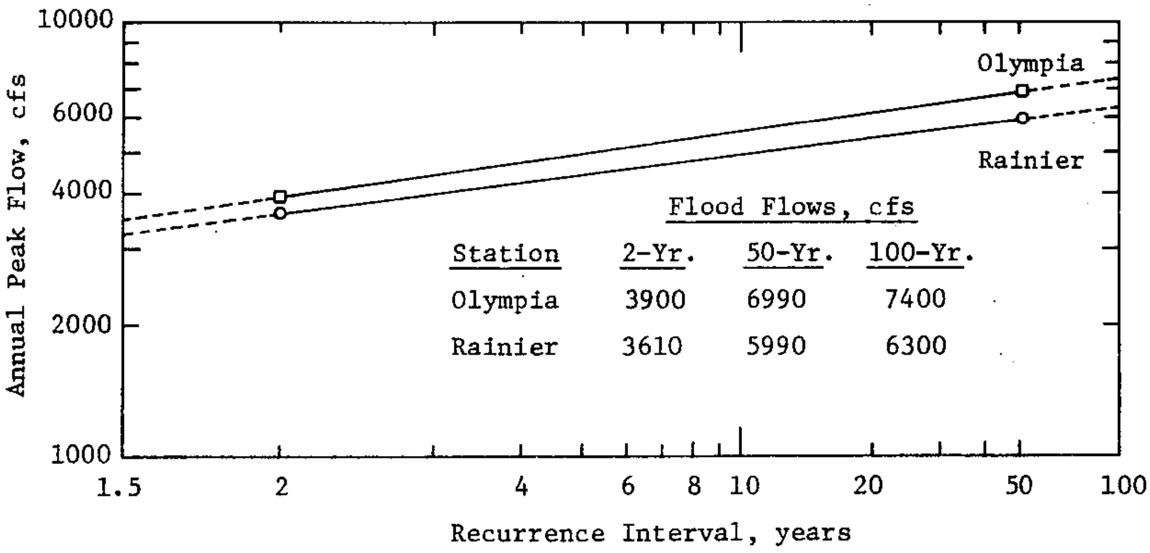
Reducing this further yields

$$QAA = 0.50(LT)^{1.43} \qquad (6)$$

Other relationships have been developed between streamflows, geomorphic parameters, and the suspended sediment load in the Deschutes River. These sediment relationships are used to verify and predict sediment loads entering Capitol Lake from the Deschutes River in Chapter IV and Appendix B. Also, basin geomorphic parameters are used to estimate the low flow frequency curve and the average annual flow in Percival Creek in Part B of this chapter.

3. Floods in the Deschutes River

Although the more critical water quality conditions in Capitol Lake arise during the low-flow, low-precipitation and high-temperature months of July, August, and September, the annual floods are important from the standpoint of the sediment which they bring to the lake, and debris and high water problems. The flood frequency curves for the Rainier and Olympia gaging stations on the Deschutes River are presented in Figure 19. Values of the 2-year and 100-year frequency floods at Olympia are 3900 and 7400 cfs, respectively.



Flood Flows, cfs

Station	2-Yr.	50-Yr.	100-Yr.
Olympia	3900	6990	7400
Rainier	3610	5990	6300

Fig. 19. Flood Frequency Curves, Deschutes River at Olympia and Rainier

The largest flood recorded at the Olympia gage during its period of operation was 6650 cfs on January 26, 1964. On January 15, 1974, the largest peak flow of 7780 cfs was recorded at Rainier. The average daily flow on January 15 was 4870 cfs, and the estimated average flow was about 5070 cfs at the Olympia site. Based on relationships between peak floods and maximum daily flows, the peak discharge at the discontinued Olympia gaging station site on January 16 would have been about 6400 cfs. It was during this storm that the bridge across the Deschutes River at the inlet to the Upper Lake near the old brewery was destroyed. The fact that the flood flow at Olympia was estimated to be smaller than at Rainier is not unusual due to sharply reduced precipitation in the lower basin and delay due to valley storage.

The activity of this flood in the Upper Lake is shown in Figure 34 in Chapter IV of this report. A typical flood hydrograph of the Deschutes River at Olympia is shown in Figure 20 for the period between January 16

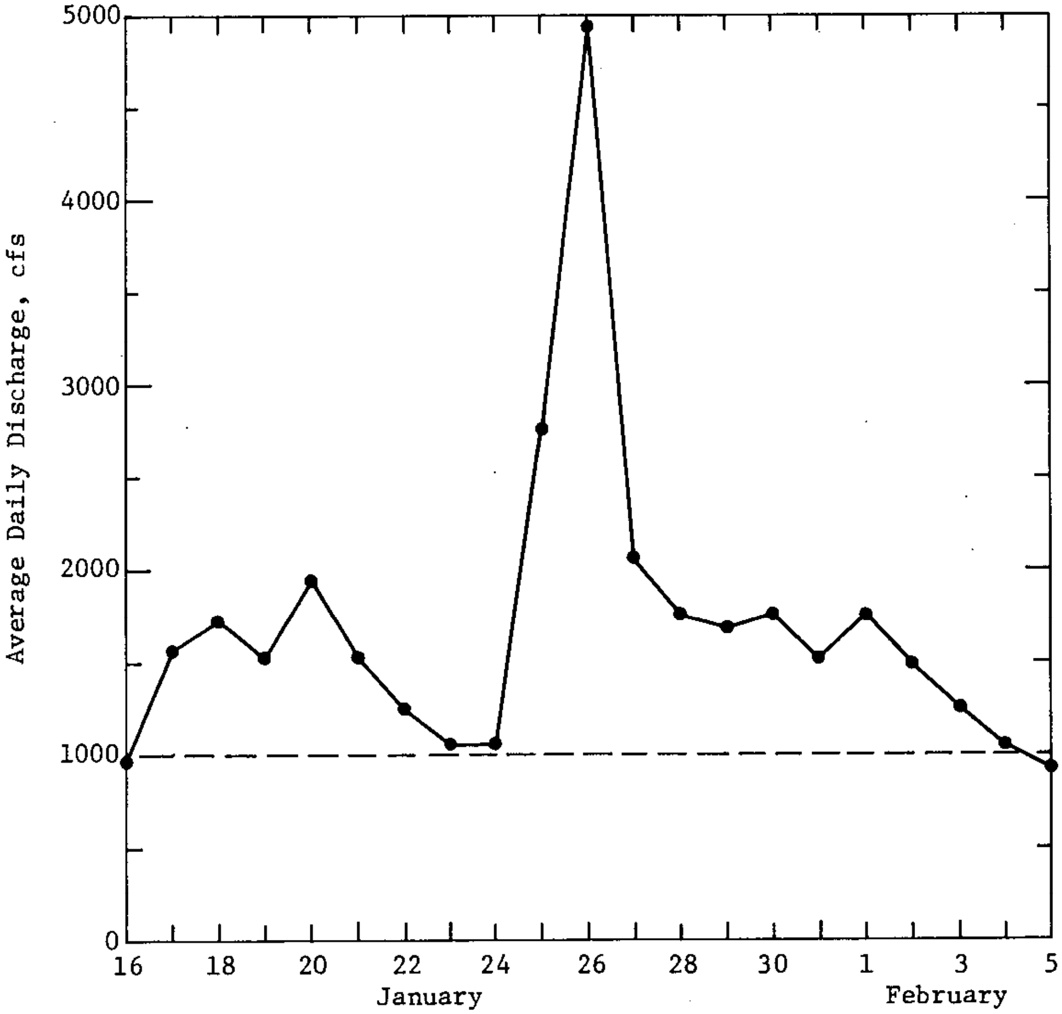


Fig. 20. Hydrograph of Daily Flows in Deschutes River Near Olympia, Washington, January 16 to February 5, 1964

and February 5, 1964. Some peak flows were recorded in the 1940's, and a summary of the time of occurrence and flows for floods at the Rainier and Olympia gaging stations for common years of record are presented in Table 8. Most floods in the Deschutes River occur between mid-November and mid-February following a warming trend with rains at higher altitudes on top of previously precipitated snowfall. Note that during several of the years the flood at Olympia is smaller than the flood at Rainier.

Table 8.

Peak Flood Flows at the Rainier and Olympia Gages on the Deschutes River, 1945-1964

Water Year	Rainier Gage 790 Date	Rainier Gage 790 Peak Flow (cfs)	Olympia Gage 800 Date	Olympia Gage 800 Peak Flow (cfs)
1946	--	--	12/29/45	3270
1947	--	--	1/26/45	4750
1951	2/9/51	3570	2/10/51	4600
1952	1/30/52	3160	1/31/52	2990
1953	1/9/53	2770	1/10/53	2870
1954	12/9/53	4750	12/10/53	4780
1955	2/8/55	3260	2/9/55	3540
1956	12/12/55	5620	12/13/55	6080
1957	2/24/57	3760	2/25/57	4210
1958	12/26/57	2620	12/26/57	2720
1959	11/12/58	3050	11/13/58	3040
1960	11/21/59	3360	11/21/59	3340
1961	11/25/60	4070	11/25/60	4920
1962	12/21/61	2360	12/21/61	1940
1963	11/26/62	4340	11/26/62	5000
1964	1/25/64	5160	1/26/64	6650

4. Low Flows in the Deschutes River

As shown in Table 6, the low flows in the Deschutes River at Rainier and Olympia are:

	FLOWS, cfs			Min.
Station (No.)	Q7L2	Q7L10	Q7L20	Rec.
Rainier (0790)	32	26	24	16
Olympia (0800)	96	80	74	66

The 2-year low flow is the long-term average (50 percent chance each year), the 10-year value is used in water quality standards (exceeded 90 percent of the years) and the 20-year value is the value that has a 5 percent chance of occurring in any year. The low flow frequency curves for the two gaging stations are presented in Figure 21, and the annual minimum flows for the common period of record are presented in Table 9.

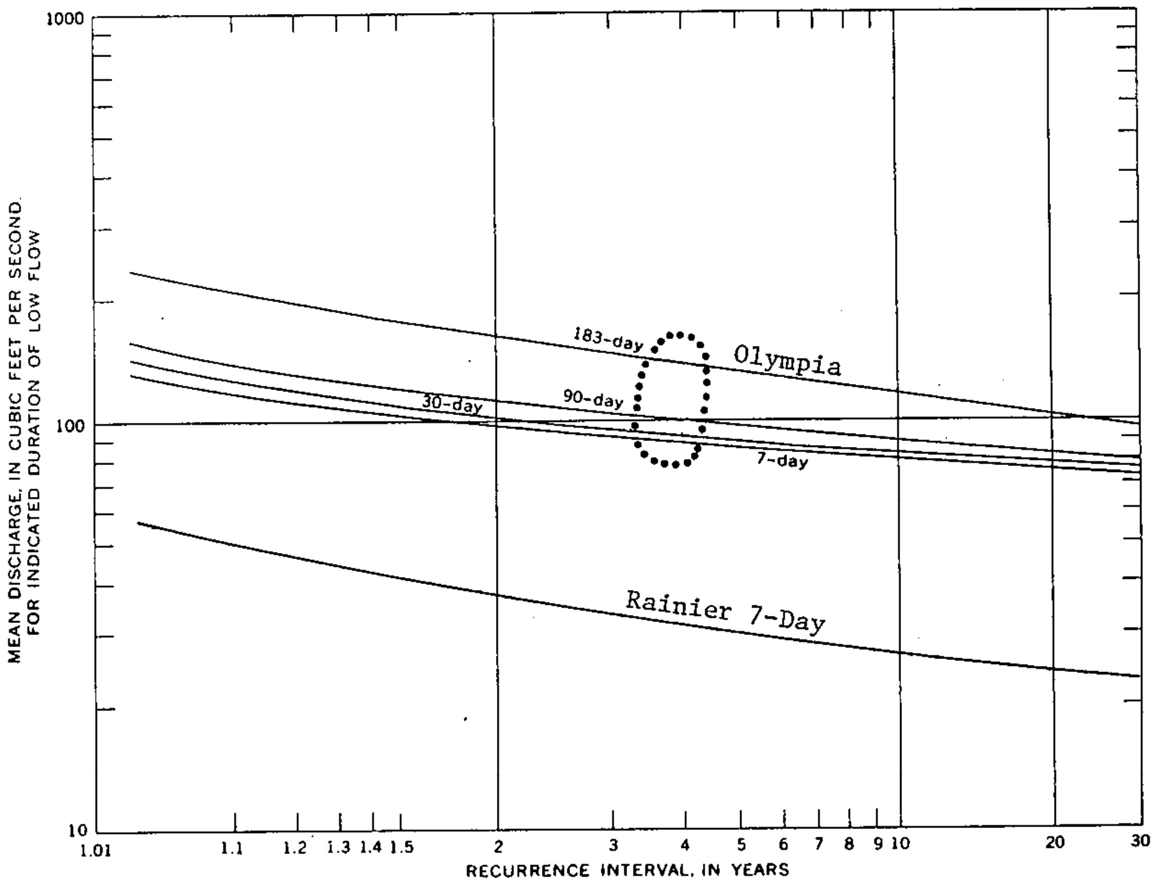


Fig. 21. Low Flow Frequency Curves for the Deschutes River at Olympia for Selected Time Periods, and the 7-Day Average Low Flows at Rainier (Based on Fig. 101, page 154, Ref. 8)

Table 9.

Annual Minimum Average Daily Flows at the Rainier and Olympia Gages on the Deschutes River, 1951-64

Water Year	RAINIER GAGE 790 Minimum Flow (cfs)	OLYMPIA GAGE 800 Minimum Flow (cfs)
1951	26	96
1952	22	77
~~1953~~	~~24~~	~~74~~
1954	40	95
1955	36	--
1956	33	--
1957	29	--
1958	28	77
1959	28	80
1960	33	107
1961	28	100
1962	28	84
1963	16	101
1964	31	103

An earlier analysis of the low flows in the Deschutes River has shown that they occur predominantly between August 16 and October 21.[17]

B. Hydrology of Percival Creek Drainage Basin

1. Section Summary

Percival Cove, located at the mouth of Percival Creek, is of importance as a component of the Capitol Lake complex because the Cove is a productive salmon-rearing facility. Operationally, the Cove is related closely to Capitol Lake: (1) during times of high water when suspended sediment from the Deschutes River enters the Cove; and (2) when the lake is lowered in order to drain the Cove, send the young salmon into Budd Inlet and flush salt water back into Capitol Lake to inhibit aquatic weed growth.

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[17] Orsborn, John F., et al., "A Summary of Quantity, Quality and Economic Methodology for Establishing Minimum Flows," State of Washington Water Research Center, Report No. 13, Vol. 1, June, 1973.

Existing hydraulic conditions are not optimal for using the Cove as a rearing facility. The Department of Fisheries is seeking to improve these conditions by enhancing the circulation pattern of Percival Creek flow through the Cove and by installing an outlet structure to regulate flow during the drawdown of Capitol Lake. Although these particular details were not addressed in this study, the general hydraulics of Percival Creek inflow, circulation and drawdown were considered.

The total basin of Percival Creek, measured above its point of entry into Percival Cove in Capitol Lake as shown in Figure 22, has an area of 13.0 square miles. The area is drained by two major tributaries which have their origins in Black Lake and Trosper Lake. Only miscellaneous streamflow measurements have been made occasionally by the Geological Survey at the points near the confluence of the two branches noted in Figure 22 and at three other less frequently used stations as discussed under "Low Flows." Therefore, the various flows of interest in Percival Creek, such as floods, annual averages and low flows, had to be estimated based on relationships developed between gaging stations on basins of similar size and location.

These correlations with streamflows at gaging stations in nearby basins, and with drainage basin parameters, have allowed for a rather detailed hydrologic analysis of Percival Creek which is covered in the following sections on "Precipitation and Streamflow Characteristics" including a flow summary, "Basin Characteristics of Percival Creek Related to Streamflows," "Floods in Percival Creek," and "Low Flows in Percival Creek." Technical details on the hydrologic analysis of Percival Creek and its drainage basin are included in Appendix A.

2. Precipitation and Streamflow Characteristics

The average annual precipitation on the Percival Creek drainage basin is about 55 inches per year based on an analysis of the precipitation records at the Shelton, Elma and Olympia Airport weather stations, as summarized in Table 10. With its drainage basin of 13.0 square miles, this provides an annual volume of 1.656 billion cubic feet per year (12.42 billion gallons) of which about 55 percent, or 910.8 million cubic feet (6.813

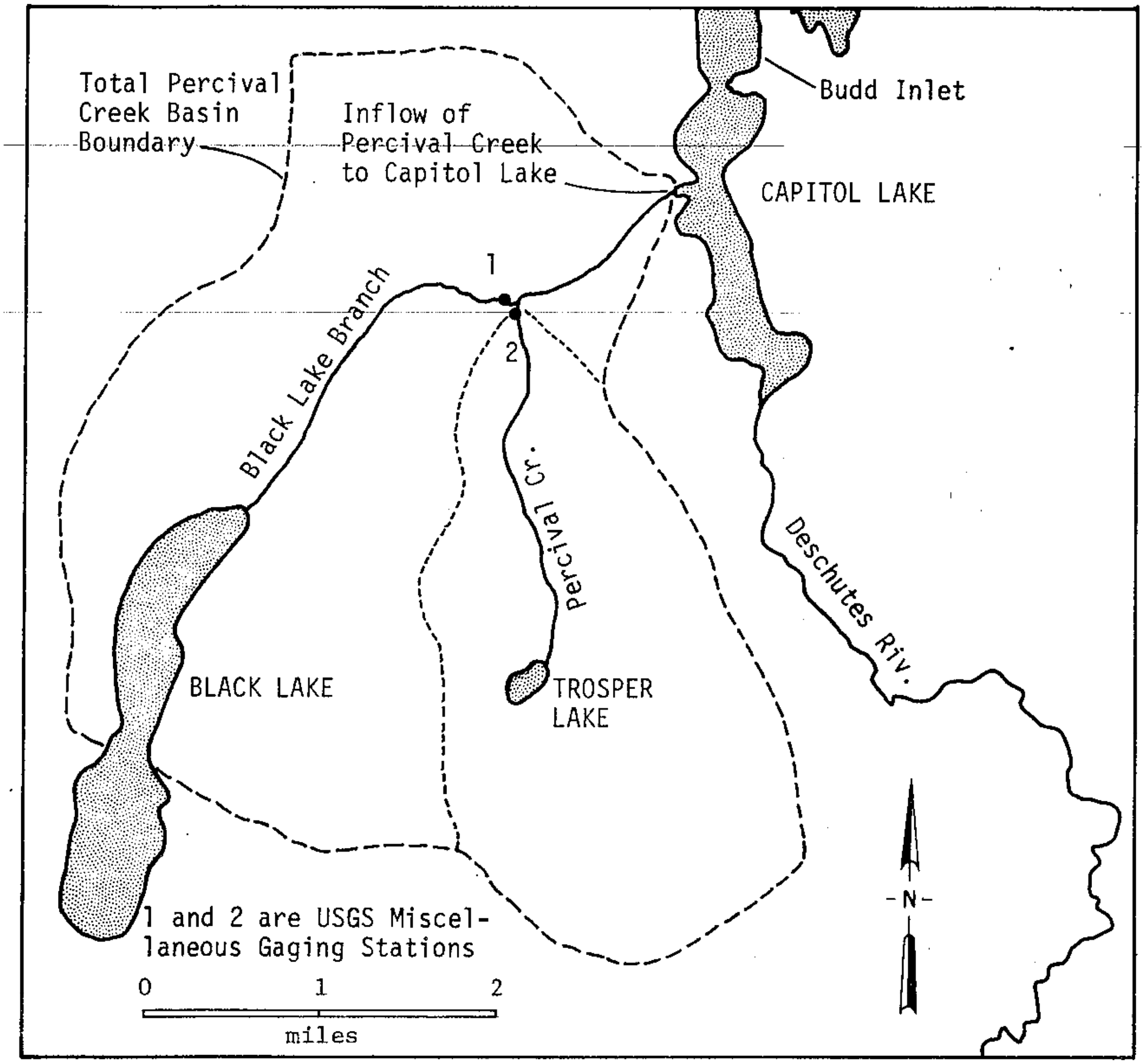


Fig. 22. Percival Creek Drainage Basin Above Percival Cove and Capitol Lake

Table 10. Monthly Average Precipitation at Shelton, Elma and Olympia Airport Weather Stations Used to Determine Runoff Coefficients on Skookum, Goldsborough and Percival Creeks, Water Years 1952-1958

Yr.	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
SHELTON													
52	8.75	9.75	6.40	8.91	4.34	4.65	3.08	0.87	1.36	0.71	1.61	0.34	50.77
53	2.02	1.85	10.95	25.06	6.20	4.22	3.62	3.00	1.80	0.44	1.05	3.37	63.58
54	6.88	9.24	12.25	15.69	11.13	4.37	5.19	0.91	3.16	0.76	2.12	1.88	73.58
55	3.92	13.06	9.17	4.40	6.93	7.62	5.52	0.74	0.72	2.97	0.03	1.57	56.65
56	12.88	17.01	15.26	13.80	4.92	12.65	0.46	0.82	3.62	0.34	0.99	2.36	85.11
57	10.79	3.19	12.03	4.64	8.54	10.53	2.95	1.60	2.02	1.28	1.78	0.48	59.83
58	6.27	5.85	11.71	12.27	8.98	3.66	7.04	1.42	1.30	0.01	0.67	2.07	61.25
mean	7.36	8.56	11.11	12.11	7.29	6.81	3.98	1.34	2.00	0.93	1.18	1.72	64.40
ELMA													
52	10.92	8.08	8.78	8.52	4.54	4.13	2.88	1.58	2.28	0.30	1.78	0.37	54.16
53	1.63	1.72	11.28	23.61	6.54	4.51	3.60	3.68	2.40	0.24	1.14	3.23	63.58
54	5.84	8.82	12.24	14.89	11.10	4.57	5.19	1.39	2.60	2.02	2.90	2.39	73.95
55	4.65	10.19	8.90	5.88	6.77	7.32	7.19	1.51	1.20	3.41	0.08	2.52	59.42
56	12.34	14.65	14.01	12.75	7.82	13.16	0.48	1.39	3.86	0.56	0.98	3.27	85.27
57	11.83	4.46	11.22	4.97	8.57	11.16	4.03	1.54	1.64	1.02	1.92	0.35	62.89
58	7.30	6.05	13.44	11.49	9.21	3.97	6.25	1.14	2.61	0.02	0.82	3.48	65.78
mean	7.78	7.71	11.41	11.73	7.82	6.97	4.23	1.75	2.37	1.08	1.37	2.20	66.40
OLYMPIA AIRPORT													
52	6.95	7.32	5.80	5.65	3.96	3.13	2.25	0.85	1.22	0.10	0.74	0.43	38.40
53	1.55	1.39	8.65	19.84	5.12	3.55	2.58	2.72	1.50	0.27	1.63	2.68	51.48
54	6.85	7.79	9.42	11.96	8.40	3.13	4.07	1.63	3.36	0.82	1.74	1.89	61.06
55	3.38	7.87	6.99	3.01	5.23	4.76	4.19	1.35	0.71	2.68	0.02	1.84	42.03
56	9.31	12.18	12.59	10.75	3.93	8.27	0.37	0.30	2.57	0.38	0.88	2.30	63.83
57	9.52	2.81	9.36	3.02	5.88	7.43	1.72	1.42	1.78	0.97	0.87	0.66	45.44
58	4.74	4.05	8.91	7.87	6.40	2.29	4.39	1.47	1.65	--	0.62	1.52	43.91
mean	6.04	6.20	8.82	8.87	5.56	4.65	2.80	1.39	1.83	0.75	0.79	1.62	49.45

billion gallons) enters Capitol Lake. The runoff in Percival Creek as a percent of precipitation is about 15 percent less than that of the Deschutes River.

The relationship between average annual streamflow (QAA) and the long-term mean volume of annual precipitation falling on the various watersheds in the vicinity is summarized in Table 11 and presented graphically in Figure 23. The locations of Goldsborough Creek, Skookum Creek, and Woodland Creek with respect to Percival Creek are shown in Figure 24. The low, average and flood flow relationships for Percival Creek were estimated using the data primarily from these three basins. Woodland Creek has lakes in its headwaters, as does Percival Creek, but Woodland Creek has less average annual precipitation and somewhat different geologic conditions.

A summary of the estimated flows for Percival Creek is given in Table 12. The variations in average monthly flow are summarized for Goldsborough, Skookum, Woodland, and Percival Creeks in Figure 25.

The estimated average duration curve for Percival Creek is shown in Figure 26. It is based on the two-year flood, the average annual flow and the two-year low flows as listed in Table 12. Methods used to determine the flood flows and low flows are discussed in the following sections and in Appendix A.

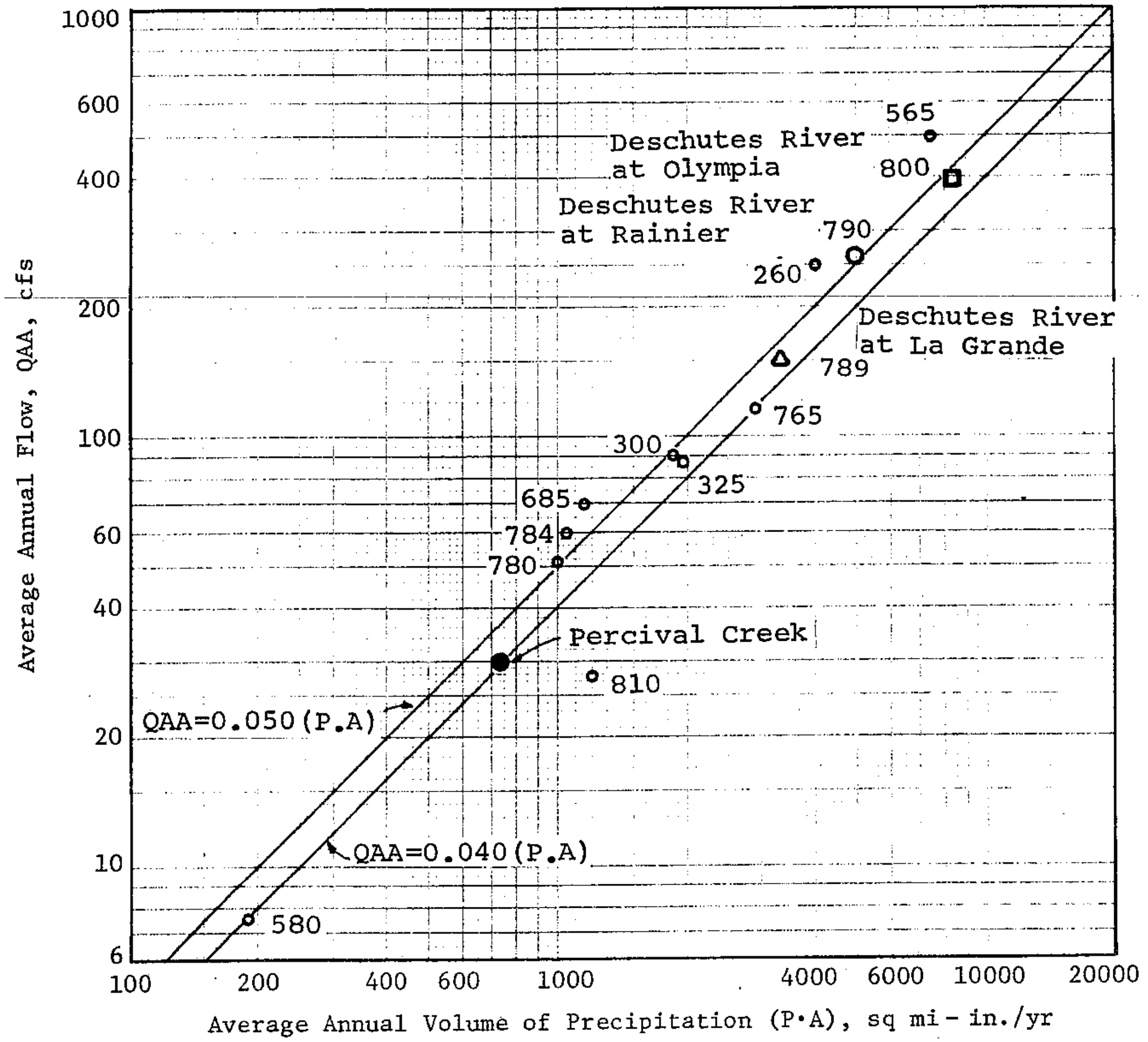
3. Basin Characteristics of Percival Creek Related to Streamflow

Referring to the Percival Creek basin map shown in Figure 22, the main tributaries which join about one mile above Percival Cove are outlets from Black Lake and Trosper Lake. The Black Lake outlet has a man-made control structure, but miscellaneous low-flow measurements indicate some natural ground-water flow exists in the channel. The profiles of Percival Creek and the two branches are shown in Figure 27. For purposes of clarity, the term "Percival Creek" is used to denote the entire stream network above Pervical Cove in Capitol Lake, although the denoted Percival Creek runs from Trosper Lake to Percival Cove as was shown in Figure 22.

Table 11.

Basin Drainage Area, Precipitation, and Average Annual Flows

Station Number and Name		Basin Area A, sq mi	Precip. P in.	P•A	Average Annual Flow QAA, cfs	Period of Record
Percival Creek at Cove		13.0	55	715	30	--
120810	Woodland Creek	24.3	50	1215	27	1950-69
784	Kennedy Creek	17.4	60	1044	61	1960-71
565	Skokomish N. Fork	57.2	149	8523	500	1924-73
580	Deer Meadow Creek	1.8	90	119	7	1952-73
300	Rock Creek	24.8	80	1984	88	1944-70
780	Skookum Creek	17.2	58	998	54	6/51-11/58
765	Goldsborough Creek	42.0	78	3276	117	1951-70
790	Deschutes River near Rainier	89.8	58	5200	268	1950-74
800	Deschutes River at Olympia	160.0	50	8500	402	1946-54,58-63
685	Dewatto River	18.4	60	1104	69	1947-54,57-73
720	Chico Creek	15.3	56	856	34	1947-50,61-73



Gage No.	River	Gage Location	Area, sq mi
120260	Skookumchuck River	near Centralia	61.7
300	Rock Creek	at Cedarville	24.8
325	Cloquallum Creek	at Elma	64.9
565	Skokomish North Fork	near Hoodsport	1.8
580	Deer Meadow Creek	near Hoodsport	1.8
685	Dewatto River	near Dewatto	18.4
765	Goldsborough Creek	near Shelton	42.0
780	Skookum Creek	at Kamilche	17.2
784	Kennedy Creek	near Kamilche	17.4
789	Deschutes River	near La Grande	56.2
790	Deschutes River	near Rainier	89.8
800	Deschutes River	near Olympia	160.0
810	Woodland Creek	near Olympia	24.3
---	Percival Creek	near Olympia	13.0

Fig. 23. Average Annual Flow Related to Average Annual Volume of Precipitation for Gaging Stations in the Vicinity of Capitol Lake and Percival Creek

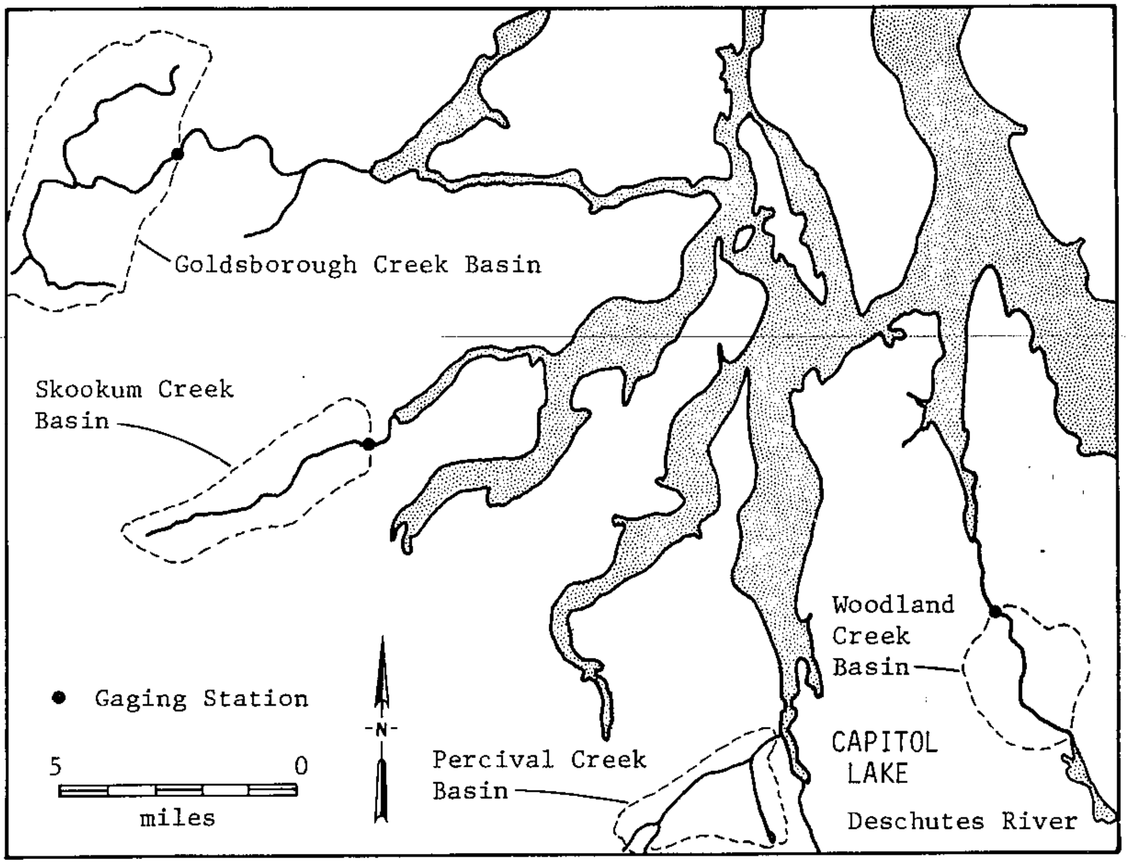


Fig. 24. Streams and Gaging Stations Used to Estimate and Verify Flows in Percival Creek

Table 12.

Low, Average and Flood Flows Estimated for Percival Creek at its Confluence With Percival Cove

Name of Flow	Symbol	Flow (cfs)
Average Annual	QAA	30
Average Flood (2-yr)	QF2	150
100-yr Flood	QF100	360
Average Low (2-yr, 7-day)	Q7L2	8.4
10-yr Low	Q7L10	7.1
20-yr Low	Q7L20	6.7
Estimated Minimum	Q7L (min)	5.2

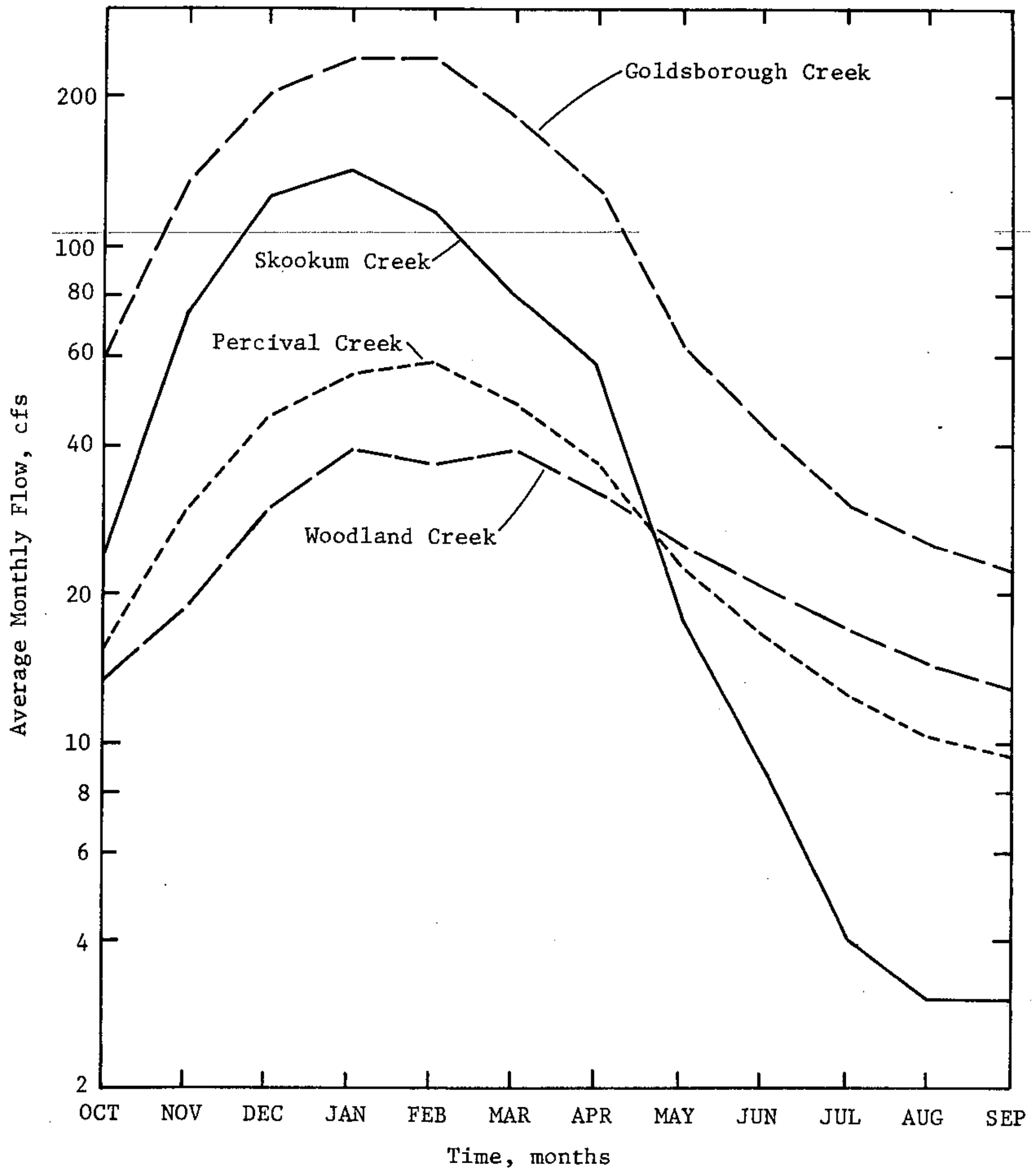


Fig. 25. Average Annual Hydrographs for Goldsborough, Skookum and Woodland Creeks to Show Monthly Flow Variations Compared with Predicted Percival Creek Flows

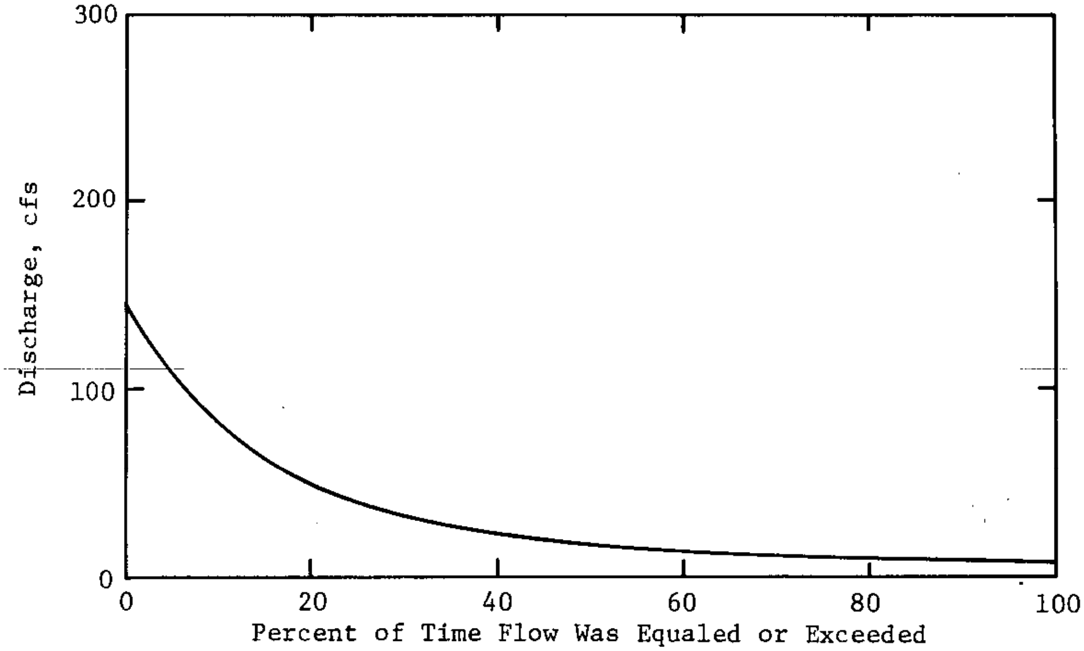


Fig. 26. Estimated Average Duration Curve, Percival Creek at Its Confluence with Percival Cove

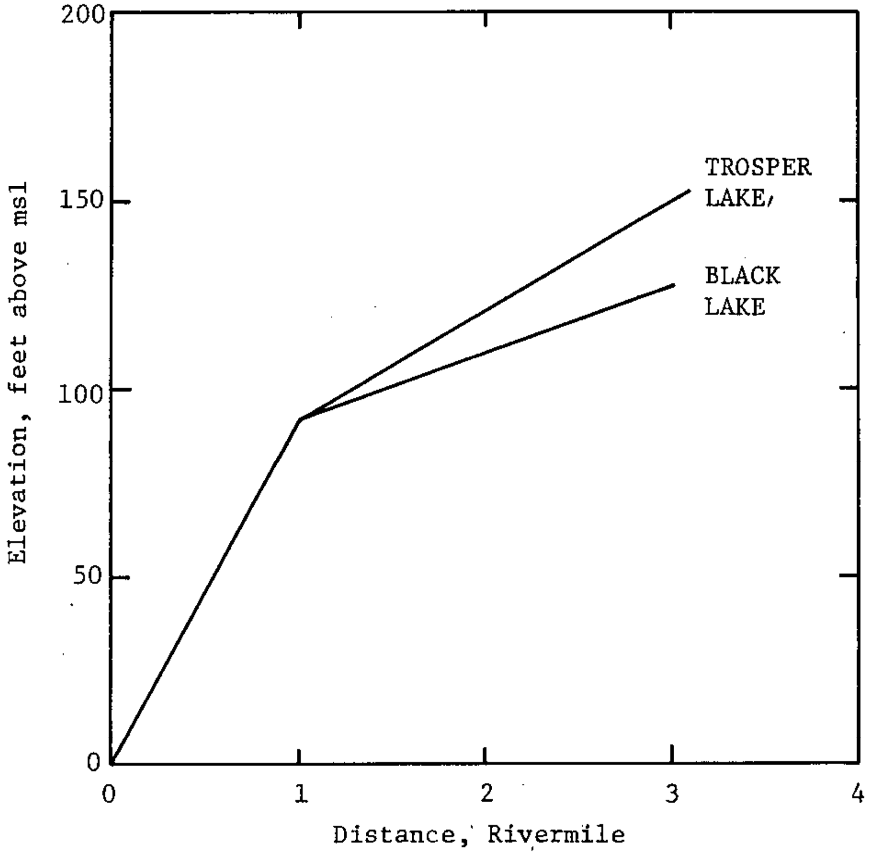


Fig. 27. Elevation and Distance from Percival Cove to the Headwaters of Percival Creek at Trosper and Black Lakes

The drainage basin characteristics for Percival Creek as well as for Skookum, Goldsborough, and Woodland Creeks are summarized in Table 13. The stream lengths (L1, LT), relief (H), and drainage area (A) are used to predict the low flows in Percival Creek based on the relationships between the low flows and basin characteristics in the three basins with gaging stations. The average annual flows and low flows are used to predict the flood flows based on regional relationships, as discussed in the next section.

Table 13.

Drainage Basin Characteristics for Percival Creek and Similar Streams

Station (Number)	L1* mi	LT* mi	Upper Elev, ft	Gage Elev, ft	Relief H*, mi	Basin Area A, sq mi
Percival Cr. at Capitol Lake Inlet	3.8	4.2	200	msl*	0.083	13.0
Skookum Creek (780)	5.0	5.0	800	35	0.145	17.2
Goldsborough Creek (765)	15.7	18.2	500	205	0.056	42.0
Woodland Creek (810)	6.0	6.2	200	25	0.033	24.3

*L1 is the length of first-order (unbranched) streams in the basin.

LT is the total length of all streams in the basin above the point of interest.

msl is mean sea level.

H (relief) is the difference between the elevation of the highest continuous contour in the upper part of the basin and the gage elevation; also the total available energy in the basin for water flow.

4. Floods in Percival Creek

Although one would consider the natural flood flows in Percival Creek as not being a very severe problem, urban development could alter this situation radically in the near future. Details of this problem have been addressed in a separate study which investigated the probable increased runoff due to urbanization of the area north of Percival Creek.[18] Under full urban development, the 100-year storm would generate about a tenfold increase in flow over natural conditions.

The estimated natural peak flood frequency curve for Percival Creek is presented in Figure 28. The details of methods used to determine the various flood flows are discussed in Appendix A.

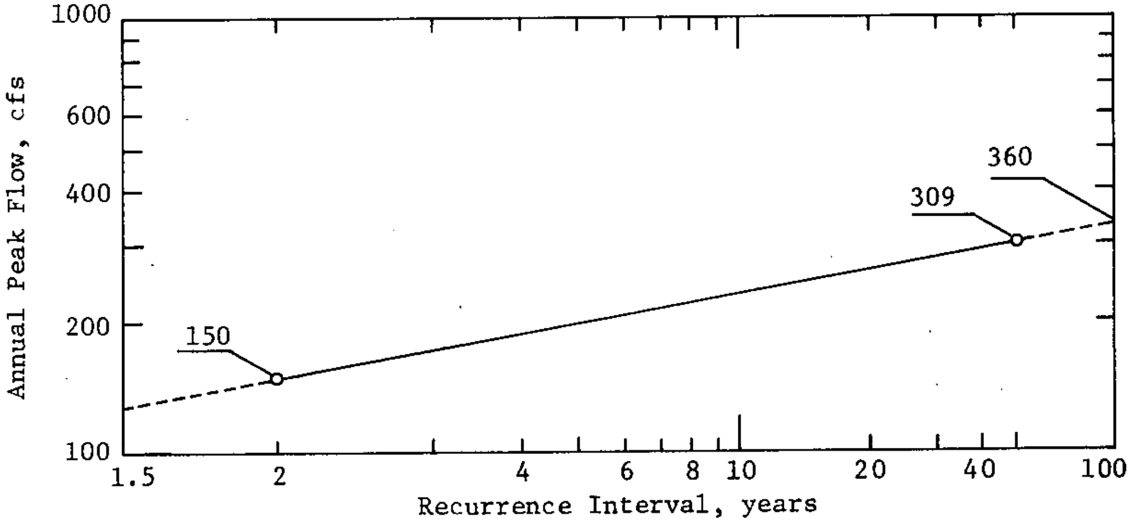


Fig. 28. Flood Frequency Curve for Percival Creek at Percival Cove

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[18] Kramer, Chin and Mayo, Inc., "An Engineering Study of the Percival Creek Drainage Basin," prepared for the City of Olympia, Washington, Feb., 1973.

5. Low Flows in Percival Creek

Some of the miscellaneous measurements taken of streamflow in the Percival Creek basin and flows measured the same day in Woodland and Goldsborough Creeks are presented in Table 14. The locations of gaging stations 1 and 2 are shown in Figure 24, and the measured flows include only the contributions of the two branches. Some of the flows in Table 14 for the Black Lake outlet are artificial releases from the control structure, but those measured during August and September, except for a few, are representative of current natural conditions.

The relationships between flows in the branches of Percival Creek and in Woodland and Goldsborough Creeks were investigated to help predict the amount of low flow which can be expected to occur in Percival Creek at Percival Cove. The geomorphic characteristics of the Percival Creek basin were used to estimate the low-flow frequency curve for Percival Creek. This curve was compared with the low-flow frequency curves for Goldsborough, Woodland, and Skookum Creeks, as shown in Figure 29.

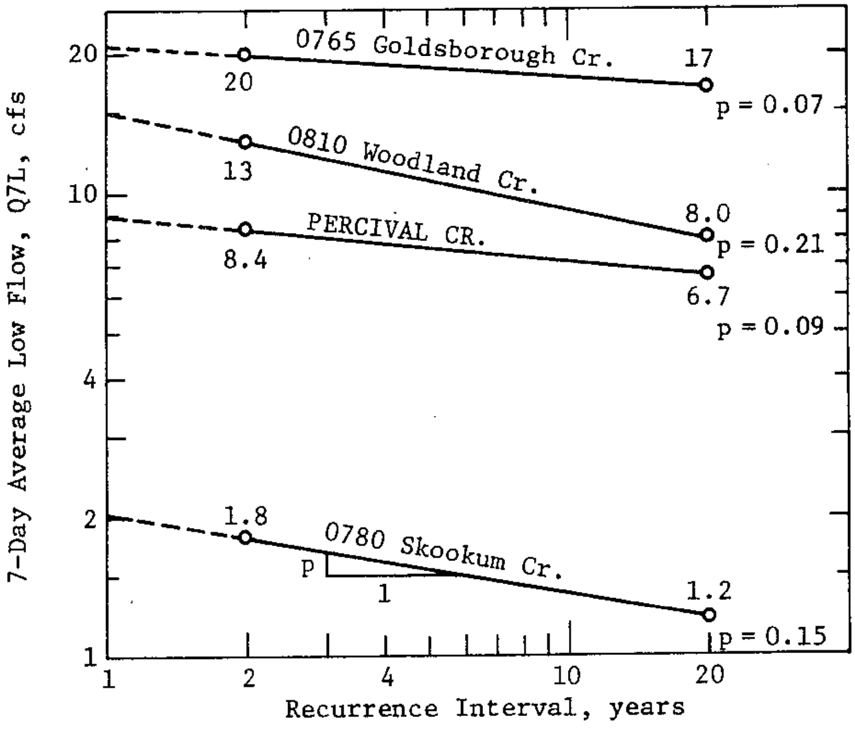


Fig. 29. Predicted Percival Creek Low Flow Frequency Curve Based on Measured Values at Goldsborough, Woodland and Skookum Creeks Gaging Stations

Table 14. Miscellaneous Streamflow Measurements on Percival Creek Branches Correlated Against Woodland Creek and Goldborough Creek Gaged Flows

Date	Black Lake (1) Outlet	Percival Creek (2) Trosper Lake	Total	Woodland Creek	Goldsborough Creek
5-17-63	33.1	5.7	39.1	30	68
7-09-65	8.9	2.1	11.0	13	28
9-24-65	5.9	2.0	7.9	12	21
8-16-66	5.3	1.4	6.7	10	20
8-11-67	5.0	2.4	7.4	12	21
9-09-68	15.6	2.6	18.2	14	25
8-14-69	6.0	2.6	8.6	16	23
5-07-70	25.0	5.2	30.2	--	68
8-14-70	4.9	1.6	6.5	--	21
5-12-71	29.2	5.6	34.8	--	75
Location	(1) SW¼SE¼, Sec.21, T.18 N., R.2 W. at Mottman Rd. crossing 1.7 mi SW of State Capitol. (2) S.Line, SE¼SE¼, Sec.21, T.18 N., R.2 W. at Mottman Rd. crossing 1.5 mi SW of State Capitol.				

C. Physical Characteristics and Hydrology of Capitol Lake

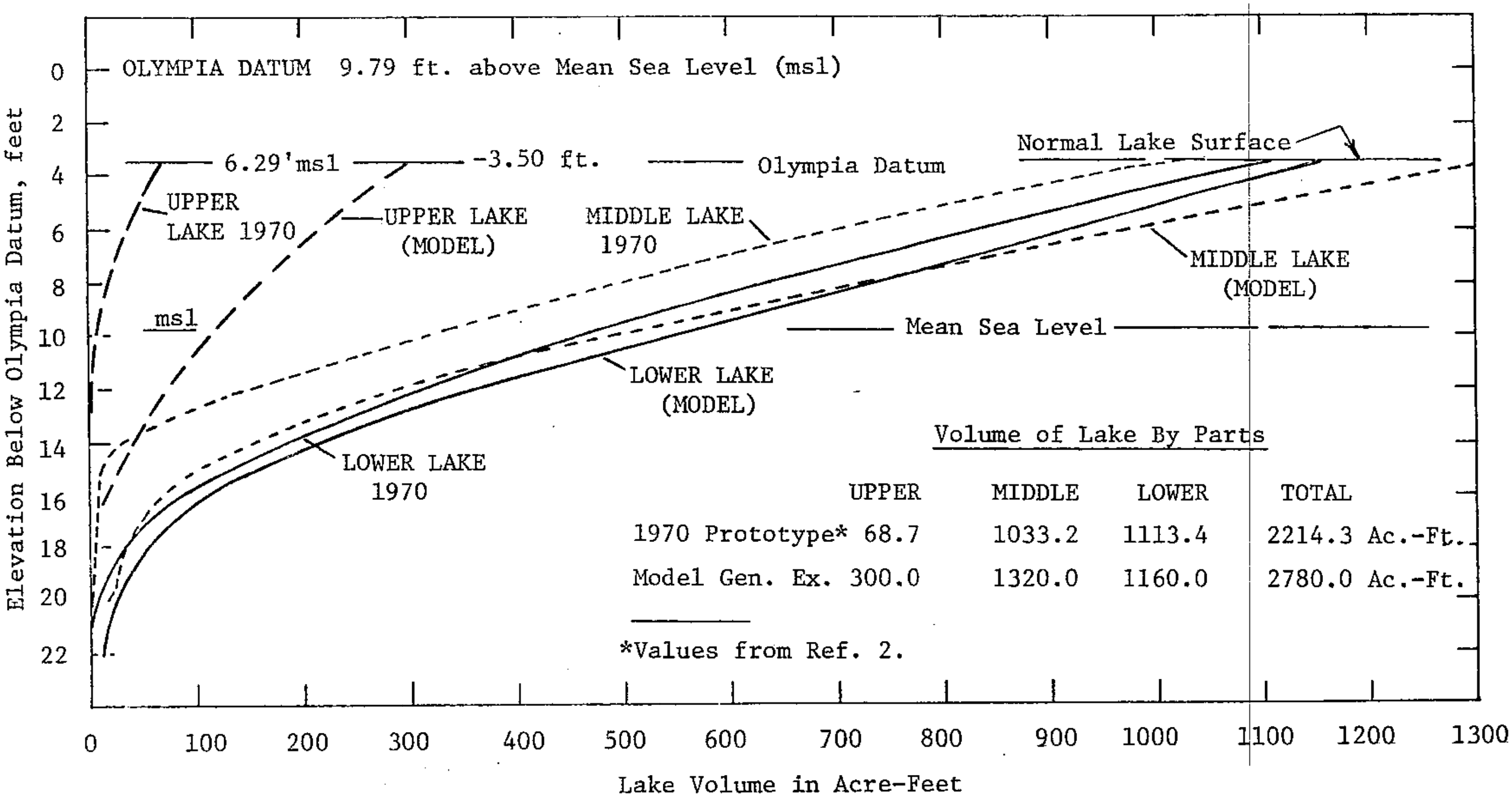
1. Geometry of Capitol Lake

The surface area of Capitol Lake, shown in Figure 30 as a recent composite of aerial photographs, is about 0.44 square miles (282 acres). The mean water surface elevation as controlled by the gates at 5th Avenue is -3.5 ft below the Olympia datum which is 9.79 ft above mean sea level. Therefore, the normal lake level for which the gate operation has been designed is 6.29 ft above mean sea level. Details on the gate operation are presented in Section 3b in Appendix A.

The volumes of the various parts of the total lake are shown in Figure 31. The hydraulic model basin volumes are larger than those for the prototype. This is due to the fact that in the model: (1) the Upper Lake was dredged to the anticipated conditions for serving as a sediment trap; (2) the Middle Lake was dredged just downstream of the highway I-5 bridge to provide an additional sediment trap for heavier materials passing through the Upper Lake and to a more uniform depth; and (3) the model Lower Lake is slightly larger than the prototype due to an anticipated desire to dredge to a uniform depth to remove bottom muds and reduce light penetration. The decision to build the hydraulic model to anticipated dredged conditions was made after discussion with the sponsor and the consultant. The effects of various dredging volumes are discussed in the next section in connection with the water balance in Capitol Lake.

As noted in other parts of this report, final results of the studies indicated that uniform dredging of bottom muds need not be a requirement for improving water quality conditions. Final dredging designs to enhance the utility of the Middle and Lower Lakes will probably increase the volumes of these lakes by an amount close to the increase in the hydraulic model volume over 1970 conditions. Details of dredging the Upper Lake are discussed in Appendix B, Sediment Information, and general dredging effects are discussed in the next section.

Fig. 30. Recent Composite Aerial Photograph of Capitol Lake Showing Deposition, Channel and Fill Areas (From the Capitol Lake Coordinating Committee, 1975)



Volume of Lake By Parts

	UPPER	MIDDLE	LOWER	TOTAL
1970 Prototype*	68.7	1033.2	1113.4	2214.3 Ac.-Ft.
Model Gen. Ex.	300.0	1320.0	1160.0	2780.0 Ac.-Ft.

*Values from Ref. 2.

Fig. 31. Depth to Volume Relationship for Capitol Lake

2. Volume Exchange in Capitol Lake

The monthly mean, high and low flow rates for the Deschutes River at Olympia are presented in Table 15 for the period of 1952-54 and 1958-64 at gaging station 120800. Also included are the mean monthly flows at the discontinued Olympia station site as estimated using the 1973 through January, 1975, flow records at the Rainier gage (120790). In addition, the estimated long-term monthly mean, high and low flows for Percival Creek, based on the average monthly flows in Table A17 and on the recorded high and low flows in the Deschutes River at Olympia, are tabulated in the lower part of Table 15. The precipitation source of this streamflow and its monthly variability are represented by the precipitation data for the Olympia Airport station in Table 16 in addition to two representative years of evaporation data. As shown earlier in Table 5, 1972 was the year of highest precipitation on record (69.93 inches), and 1973 was the lowest (36.38 inches) at Olympia. In spite of this, 31 percent deviation about the mean precipitation of 52.07 inches per year, the total evaporation varied by a maximum of about 5 percent between the two years. The monthly maximum variability in evaporation between the two years was 37 percent during April which is not a high evaporation month. During the high evaporation month of July, the variability was only 4 percent of the average for the two years.

The estimated mean, maximum and minimum monthly rates of Capitol Lake volume exchange are presented in Table 17. The dominant influence of the Deschutes River inflow on the volume exchanges of Capitol Lake is obvious, especially during the summer months of July, August and September. The results of Table 17 are arranged to display the differences in the number of monthly exchanges which can be expected to occur for four different volumes of Capitol Lake.

(1) 1970 conditions with a volume of 2200 acre-ft;

(2) 1949 conditions, assuming complete dredging to an original volume of 2672 acre-ft;

(3) the total dredging of the lake to a volume of 2780 acre-ft (as was done in the model) using the Upper Lake as a sediment trap, and uniformly dredging the Middle and Lower Lakes; and

Table 15. Monthly Flow Variation and Extremes of the Deschutes River at Olympia, and Percival Creek Estimated Monthly Flows and Extremes*

Month	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Mean
For Period of Record 1952-54 and 1958-64 (Ref. Table A1, App. A) (120800):													
Mean	172	492	587	792	796	528	476	312	197	138	109	108	391
High	247	919	893	1308	1302	981	676	433	246	162	127	152	620
Low	77	86	242	419	303	376	304	217	146	109	87	81	204
Ratio Hi:Lo	3.2	10.7	3.7	3.1	4.3	2.6	2.2	2.0	1.7	1.5	1.5	1.9	3.2
Differ. Hi-Lo	170	833	651	889	999	605	372	216	100	53	40	71	417
Mean Values Estimated with Eq. A1 Based on Daily Flows at Rainier Gage (120790):													
1973	100	209	828	658	295	380	230	213	178	115	77	98	282
1974	176	880	1051	1331	898	906	627	378	297	217	120	92	581
1975	92	468	722	1186	-	-	-	-	-	-	-	-	-
PERCIVAL CREEK ESTIMATED FLOWS:													
Mean	15.4	29.7	45.1	55.7	58.4	47.9	36.1	22.3	16.4	12.3	10.4	9.4	30.0
High	22.1	55.5	68.6	92.0	95.5	89.0	51.3	31.0	20.5	14.4	12.1	13.2	47.6
Low	6.9	5.2	18.5	29.7	22.2	34.2	23.3	15.5	12.0	9.6	8.1	7.0	14.9

*Flows are given in cubic feet per second.

Table 16. Monthly Precipitation and Evaporation Means and Extremes at Olympia Airport and Puyallup Experiment Station

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	Mean
Precipitation at Olympia:													
Mean	5.20	7.99	8.76	8.73	6.03	5.18	3.10	1.63	1.43	0.68	1.13	2.22	4.34
High	10.08	15.51	14.32	19.84	13.18	10.13	5.87	3.50	3.36	2.68	5.45	5.23	9.10
Low	0.85	1.39	3.89	0.69	1.71	0.48	0.37	0.25	0.05	T	T	0.33	0.83
Ratio Hi:Lo	11.9	11.2	3.7	28.8	7.7	21.1	15.9	14.0	67.2	-	-	15.8	16.44
Differ. Hi-Lo	9.23	14.12	10.43	19.15	11.47	9.65	5.50	3.25	3.31	2.68	5.45	4.90	8.26
Evaporation at Puyallup Experiment Station 2W:													Total
1972	1.32					1.45e	2.21	4.38	4.06	6.23	5.39	2.69	
	(0.92)					*(1.01)	(1.55)	(3.07)	(2.84)	(4.36)	(3.77)	(1.88)	19.40
1973	-					1.76e	3.19	4.13	3.84	5.98	4.49	2.77	
	-					(1.23)	(2.23)	(2.89)	(2.69)	(4.19)	(3.14)	(1.94)	18.31

All units are in inches.
T *is* trace.
*Values in parentheses are 0.7 x (measured potential evaporation).
e denotes estimated value of evaporation.

Table 17. Estimated Mean Volume Exchange and Variability for Capitol Lake

Factor/Month	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
(Days in Month)	(31)	(30)	(31)	(31)	(28)	(31)	(30)	(31)	(30)	(31)	(31)	(30)
(Flow, Precipitation and Evaporation Units are Acre-feet)												
Deschutes R. Flows (+):												
Mean	10561	29225	36042	48629	44098	32419	28274	19157	11702	8473	6693	6415
High	15166	54589	54830	80311	72463	60233	40154	26586	14612	9947	7798	9029
Low	4729	5108	16701	25727	16786	23086	18058	13324	8672	6693	5342	4811
Percival Creek Flows (+):												
Mean	946	1764	2769	3420	3235	2941	2144	1369	974	755	639	558
High	1357	3297	4212	5649	5291	5465	3047	1903	1218	884	743	784
Low	424	309	1136	1824	1230	2100	1384	952	713	589	497	416
Direct Precipitation on Lake (+):												
Mean	122	188	206	205	142	122	73	38	34	16	27	52
High	237	364	336	466	309	238	138	82	79	63	128	123
Low	20	33	91	16	40	11	9	6	1	--	--	8
Evaporation from the Lake Surface (-):												
Mean	11	--	--	--	--	26	44	70	65	100	81	45
High	22	--	--	--	--	29	52	72	67	102	88	46
Low	0	--	--	--	--	24	36	68	63	98	74	44

Number of Volume Exchanges in Lake Per Month for Various Lake Volumes:

Vol. 2200AF±	Mean	5.3	14.2	17.7	23.8	21.6	16.1	13.8	9.3	5.8	4.2	3.3	3.2
(1970	High	7.6	26.5	27.0	39.3	35.5	30.0	19.7	13.0	7.2	4.9	3.9	4.5
Conditions)	Low	2.4	2.5	8.2	12.5	8.2	11.4	8.8	6.5	4.2	3.3	2.6	2.4
Vol. 2672AF±	Mean	4.4	11.7	14.6	19.6	17.8	13.3	11.4	7.7	4.7	3.4	2.7	2.6
(1949	High	6.3	21.8	22.2	32.4	29.2	24.7	16.2	10.7	5.9	4.0	3.2	3.7
Conditions)	Low	1.9	2.1	6.7	10.3	6.8	9.4	7.3	5.3	3.5	2.7	2.2	1.9
Vol. 2780AF±	Mean	4.2	11.2	14.0	18.8	17.1	12.8	11.0	7.4	4.6	3.3	2.6	2.5
(Hydraulic	High	6.0	21.0	21.4	31.1	28.1	23.7	15.6	10.7	5.7	3.9	3.1	3.6
Model)	Low	1.9	2.0	6.5	9.9	6.5	9.1	7.0	5.1	3.4	2.6	2.1	1.9
Vol. 2540AF±	Mean	4.6	12.3	15.4	20.6	18.7	14.0	12.0	8.1	5.0	3.6	2.9	2.8
(Recommended	High	6.6	22.9	23.4	34.0	30.7	26.0	17.0	11.2	6.2	4.3	3.4	3.9
Dredging)	Low	2.0	2.2	7.1	10.9	7.1	9.9	7.6	5.6	3.7	2.9	2.3	2.0

(4) recommended dredging to a volume of about 2540 acre-ft using the Upper Lake as a sediment trap and dredging the Middle and Lower Lakes only enough to remove hazards and improve access conditions. It is assumed under these general recommended dredging conditions that the dredging of the Middle and Lower Lakes will increase their volumes only by the net difference between the total amount of material dredged and the amount of shoreline fill which is placed below the water surface.

3. Field Data on Lake Levels, Tides and Gate Openings

Three recording devices were installed in the field during this project to develop data for determining:

(1) variations in Capitol Lake levels as a function of flow in the Deschutes River (used to verify model operation and to determine volume of daily exchange of lake water);
(2) the actual openings of the gates related to lake and tide levels; and
(3) the tide levels on the Budd Inlet side of the gates.

The locations of the three sets of recording instruments were at points 1, 2 and 3 as shown in Figure 32, the powerhouse, the gate house, and the salt water end of the spillway. Data were taken during the following periods:

Station	Data	From	To
1	Lake Levels	9-27-74	6-30-75
2	Gate Openings	10-04-74	6-30-75
3	Tide Levels	1-25-75	6-30-75

These three types of data were required in order to provide a method to check the rate of inflow and outflow to and from the lake. The discontinuation of the stream gaging station on the Deschutes River at Olympia caused some difficulty, but by using the slope of the lake level records, the net volume change in the lake could be determined. The U.S. Geological Survey provided streamflow data from the Rainier gage from October, 1974, through February, 1975, which included high and low flow seasons.

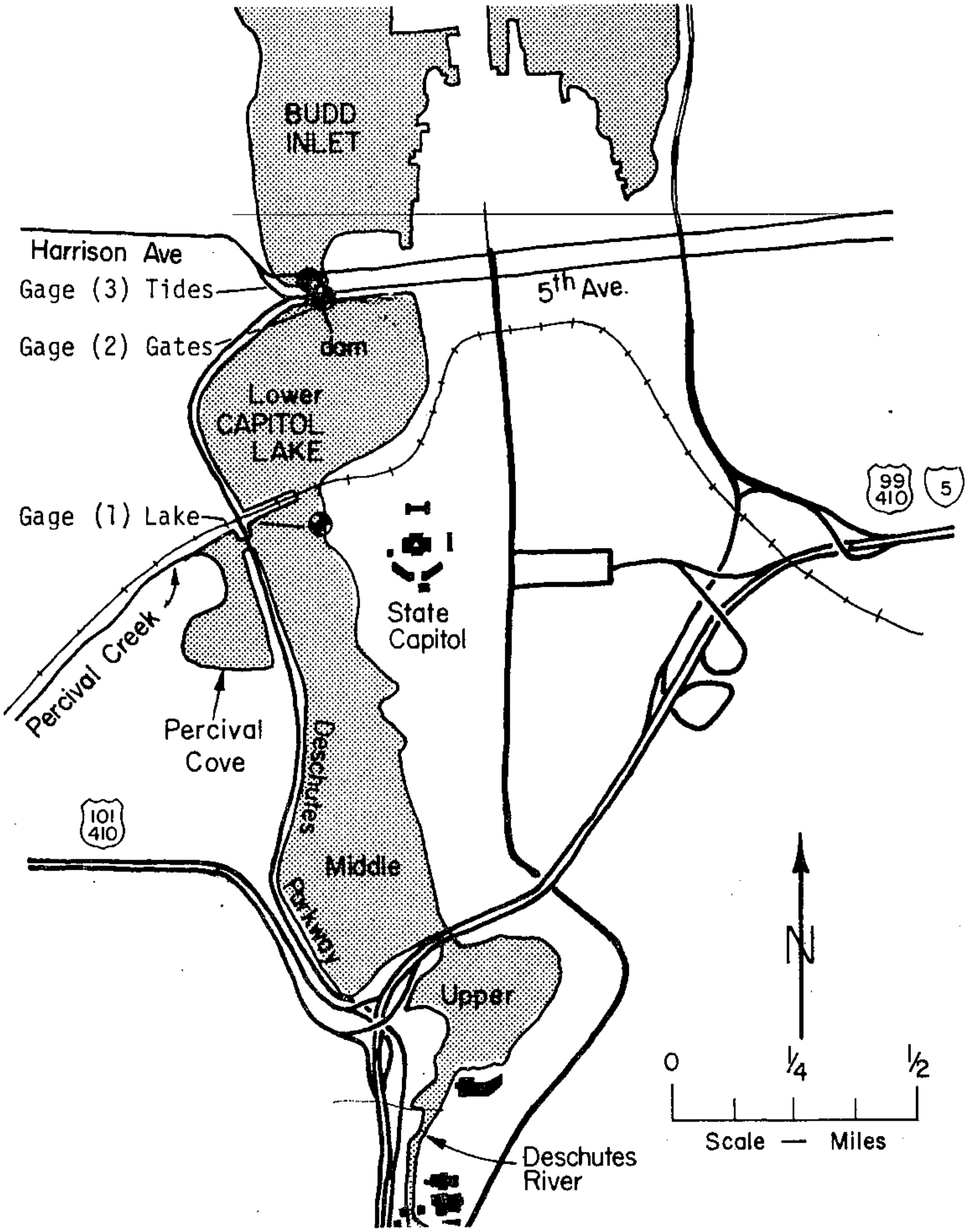


Fig. 32. Locations of Lake Level, Gate Opening, and Tide Monitoring Instruments

A sample of how the lake inflow and outflow change as a function of flow in the Deschutes River is shown in Figure 33. The estimated flows in the Deschutes River at Olympia in the fall of 1974 are presented in Table 18. The data derived from the records of lake levels, Deschutes River flows, and inflow-outflow relations for a sample period in November, 1974, are presented in Tables A20 and A21 of part 3a of Appendix A. A discussion of the tide gate operating procedures is presented in part 3b of Appendix A.

Table 18.

Estimated Deschutes River Flows Into Capitol Lake
Based on Flows Measured at Rainier Gaging Station
Sample Period Oct.-Dec., 1974

Date	Flow (cfs)	Date	Flow (cfs)
Oct 9	81	Nov 7	290
10	81	8	241
11	85	9	211
12	87	10	277
13	83	11	217
14	83	12	177
15	81	13	157
16	81	14	141
17	79	15	130
18	77	16	123
19	77	17	128
20	81	18	528
21	85	19	560
22	83	20	1044
23	81	21	2197
24	81	22	1222
25	81	23	1125
26	79	24	1205
27	79	25	944
28	102	26	704
29	209	27	549
30	137	28	445
31	114	29	382
Nov 1	148	30	334
2	137	Dec 1	300
3	114	2	295
4	104	3	282
5	106	4	369
6	112	5	423

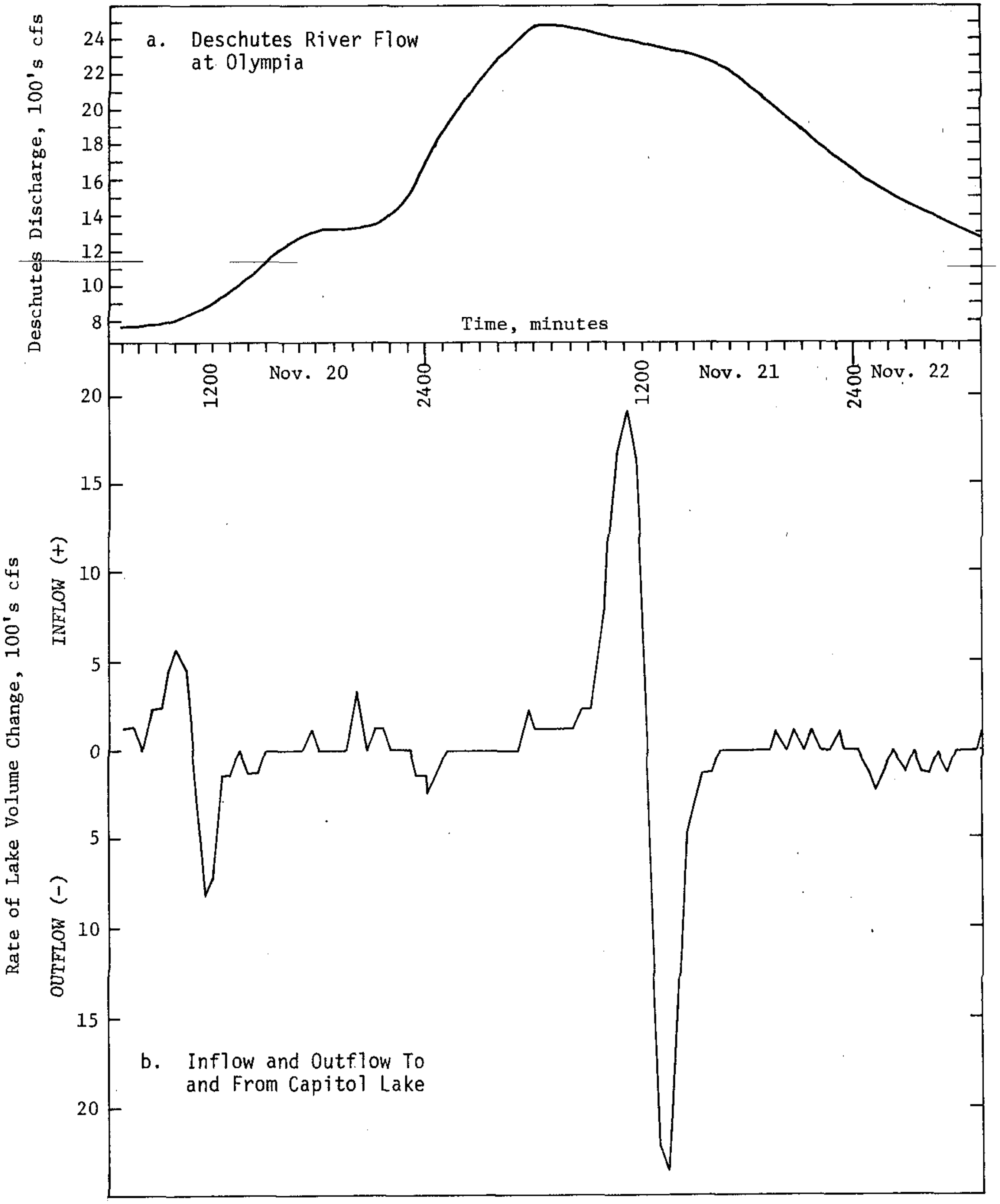


Fig. 33. Estimated Inflow of Deschutes River to Capitol Lake and Hourly Rate of Change in Flow Into and Out of Capitol Lake Based on Lake Level Records and the Change in Lake Volume

IV. SEDIMENTATION STUDIES

Chapter Summary

The accumulation of sediment in Capitol Lake has become of increasing concern in recent years to the Capitol Lake Coordinating Committee, the Capitol Committee, the Department of General Administration, and other interest parties in Olympia and nearby communities. Reconnaissance studies of the problem were conducted in 1970 to determine the source and extent of the siltation problem.[1,2] In 1973 a very comprehensive engineering study was conducted using the 1970 hydrographic information to determine how the sediment could be removed and a possible site for its disposal, and to provide preliminary cost estimates for dredging the lake to 1949 depth conditions and maintaining those conditions.[3]

The construction of the Highway I-5 fill and bridge in 1956 formed Upper Capitol Lake. Since 1956 this part of the lake has served as a sedimentation trap for heavier and larger materials entering the lake from the Deschutes River. Finer suspended materials are carried into the Middle and Lower Lakes, and even into Budd Inlet during very large floods. A similar, but much smaller problem, occurs in the northwest corner of the Middle Lake at the mouth of Percival Creek. The Upper Lake has become so filled with deposits and vegetation that high river flows sweep sediment downstream into the Middle Lake where the accumulation just below the highway bridge is causing a hazard. Table 19 summarizes how the sediment accumulation between 1949 and 1970 has affected the volume and depth of Capitol Lake. The 1973 engineering report included the recommendation that hydraulic and other environmental studies be undertaken.[3]

The primary purpose of the hydraulic studies was to determine how the Upper Lake could be best dredged so as to serve as a settling basin for the rest of the lake. Because of the necessity to meet Legislative deadlines for lake dredging estimates, the sedimentation studies were conducted rapidly and reported on between August 15 and September 13, 1974. The sedimentation study results and recommendations are presented in summary form in later sections of this chapter. Details are discussed in Appendix B and portions of Appendices A (Hydrology) and C (Hydraulic Model). The recommendations of the original sedimentation studies were reviewed and discussed by representatives of the

Table 19. Sediment Accumulation in Capitol Lake, Olympia, Washington*

	North Basin	Middle Basin	Upper Basin	Capitol Lake
1970 Surface Area, acres	104.56	145.95	28.58	283.75
1949 Volume, acre-ft	1191.14	1189.87	291.31	2672.32
1970 Volume, acre-ft	1113.37	1033.19	67.69	2214.25
Change in Volume, acre-ft	77.77	156.68	223.62	458.07
Percent Change Volume	6.40	13.20	77.00	17.10
Average Water Depth 1949, feet	11.40	8.20	8.75	9.40
Average Water Depth 1970, feet	10.60	7.10	2.04	7.80
Sediment Accumulation, cubic yards	125000.00	252000.00	362000.00	739000.00
Percent of Total Sediment	16.90	34.20	48.90	100.00
Average Yearly Accumulation, cubic yards				41000.00

*This table is reproduced from Reference 2.

Department of General Administration, the consultant, and engineers from the Albrook Hydraulics Laboratory at Washington State University in December, 1974. At that time the summary report of the sedimentation studies was presented.

A. Components of the Sedimentation Studies

The sedimentation studies included the following components, the details of which are contained in the sedimentation study preliminary report and as presented in Appendix B.[4,5,6]

(1) Review and analysis of Deschutes River streamflow records.

~~(2) Review and analysis of Deschutes River sediment transport information.[14]~~

(3) Determination of seasonal and long-term precipitation characteristics in the Deschutes River drainage basin.

(4) Construction and verification of a hydraulic model of the upper basin of Capitol Lake.

(5) Testing of the hydraulic model to determine the best ways to dredge the Upper Lake so that it will serve as an efficient sedimentation basin for the rest of the lake.

(6) Development of a method for estimating future sediment loads entering Capitol Lake based on streamflow records at the Rainier gaging station.

(7) Calculation of sediment load in the Deschutes River based on the average streamflow duration curve at the Olympia gaging station* for comparison with measurements made of sediment accumulation in Capitol Lake.

(8) Acquisition and analysis of bottom deposit sediment samples in the Upper and Middle Lakes to determine the size distribution and percentage of each size for materials carried into Capitol Lake by the Deschutes River.**

(9) Consideration of different methods of performing maintanance dredging.

B. Results of the Study Components

(1) Although the Deschutes River gaging station at Olympia was in operation only during the period of 1946-54 and 1958-63, a relationship for determining the flow at Olympia based on the flow at the Rainier gage was developed. Using this flow relationship the daily flow records at Olympia have been estimated for the period 1964-73.

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*The stream gaging station for the Deschutes River at Olympia was discontinued in 1964.

**Some sediment analyses were made in the Lower Lake during studies reported in Reference 3, and others were made as part of this study.

(2) The timely completion of the U.S. Geological Survey report on sediment load in the Deschutes River provided sufficient data to develop equations for predicting future sediment loads entering Capitol Lake based on recorded streamflows at the Rainier gage.[14]

(3) The anticipated future sediment load entering Upper Capitol Lake was defined also in terms of the precipitation records at the Olympia ~~Airport gage.~~

(4) The sediment scour and deposition areas in the hydraulic model of the Upper Lake were verified by:
   a) constructing the model to 1970 conditions (island and shore geometries);
   b) operating the model for typical flood conditions and sediment concentrations; and
   c) noting that the model islands, deposition and scour areas adjusted themselves to current 1974 geometries.

(5) The results of the hydraulic model studies of sediment movement and deposition in the Upper Lake showed:
   a) where bank protection will be needed;
   b) how large an area should be dredged to provide a natural settling basin; and
   c) which channel and island changes will be necessary for the Upper Lake to function most effectively as a sedimentation basin.

(6) The accounting of sediment inflows in the future will make it possible to keep a rough balance on the net accumulation of sediment in the lake based on differences between inflows and the amount removed by maintenance dredging each year.

(7) Having common periods of record, before the gaging station on the Deschutes River at Olympia was discontinued, made it possible to develop relationships between the flows at Rainier and Olympia. Extending the records at Olympia based on Rainier provided a better estimate of long-term average sediment inflow conditions and the variability in those sediment loads. For example, although the average sediment load would be about 40,000 cubic yards per year, it has been as low as 4,000 and as high as 60,000 cubic yards per year.

(8) The particle-size determinations of the deposition in the Upper and Middle Lakes provided information for design of new channel arrangements, deposition areas, and velocities based on the settling characteristics of the particles.

(9) Alternative methods for conducting maintenance dredging, primarily of the Upper Lake, included:
   ~~a) a fixed-manifold pipe system buried in the designed accumulation~~
   area; and
   b) a more flexible system using a small commercial dredge (i.e., "Mudcat") which could be used elsewhere in Capitol Lake, and which is recommended.

The initial dredging, requiring larger equipment, should be conducted by a dredging contractor as suggested in the consultant's 1973 report.[3]

C. Recommendations

The following recommendations dealing with initial and maintenance dredging are based on:

(1) the combined results of studies described in detail in References 1-6;

(2) the desires of interest parties and agencies to restore and maintain Capitol Lake at higher standards;

(3) the efficacy of modifying and utilizing the Upper Lake as a natural sediment trap, thus requiring that some dredging and channel changes be made; and

(4) the benefits of maintaining, or enhancing, the existing "natural" conditions of Upper Lake which have developed since the construction of the highway fill.

C-1. The Existing Conditions

The flow patterns and areas of inundation in the Upper Lake under high water are shown in Figure 34. The overlay information shows recommended geometric channel changes to improve the sedimentation characteristics. Under the existing arrangement of channels and islands, it is obvious from the diffusion of the foam on the surface that most of the flow

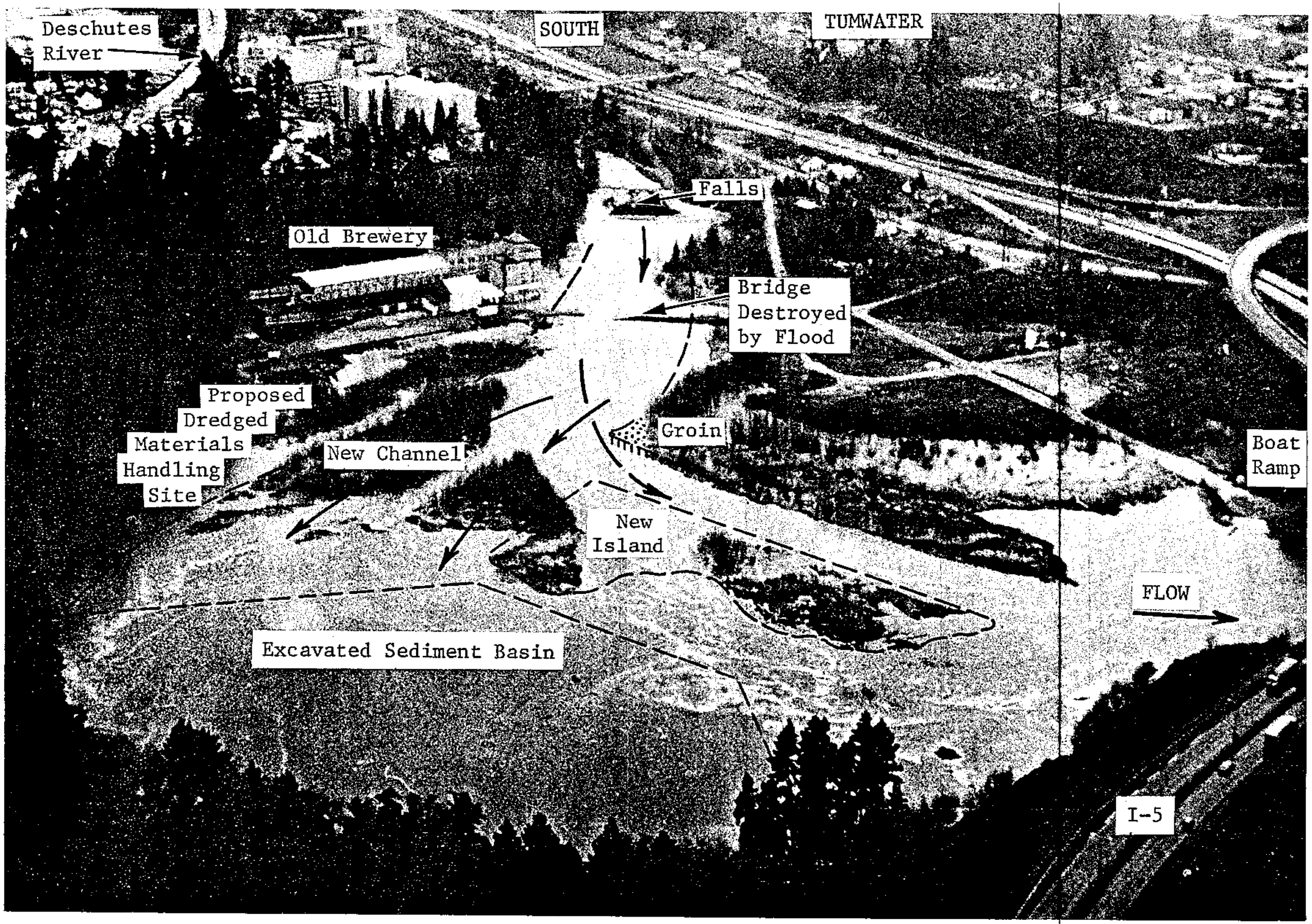

Fig. 34. Flow Pattern in the Upper Capitol Lake Basin During January 16, 1974, Flood with Recommended Changes Superimposed

travels quickly through the two main channels to the center right. From the hydraulic model studies it was determined that about 90 percent of the flow follows the main channels, flowing at velocities of about three to five feet per second. Very little of the sediment load has a chance to be carried into the quiet area behind the wedge-shaped island at center left and be deposited. Therefore, the most obvious changes in channel and ~~island configuration necessary to settle out the maximum amount of sedi-~~ ment will require:

(1) the confinement of most of the high flow to one major channel at the left; and

(2) the formation of a large, deep area in the wake of an island through which most of the flow will pass, where velocities will be very slow, and where a large percent of the larger sediment particles will be deposited.

The existing island and channel configurations are shown in Figure 35. The photograph in Figure 34 was taken from the lower left corner of Figure 35.

C-2. Recommended Dredging and Filling in Upper Lake[*]

The recommended changes in the Upper Lake are shown in Figure 36 in dashed lines superimposed on the existing geometry. The major phases of the recommended dredging in the Upper Lake are:

①[†] A uniformly, gradually expanding channel from the vicinity of the warehouse (old brewery) dredged to a depth of about 10 ft down past the two largest islands; protect the left bank with gabions at (1A).

② Install a groin to cause the passage of most of the flow down the new channel between the two larger islands.

③ Fill the low-lying area, or portions of it, downstream of the old brewery to serve as a materials handling site for disposal of dredged materials as part of the lake maintenance program. The fill should be high enough to prevent flooding of the handling facilities.

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[*] See Appendix B for technical details.

[†] The circled numbers in the text correspond to those circled numbers in Fig. 36.

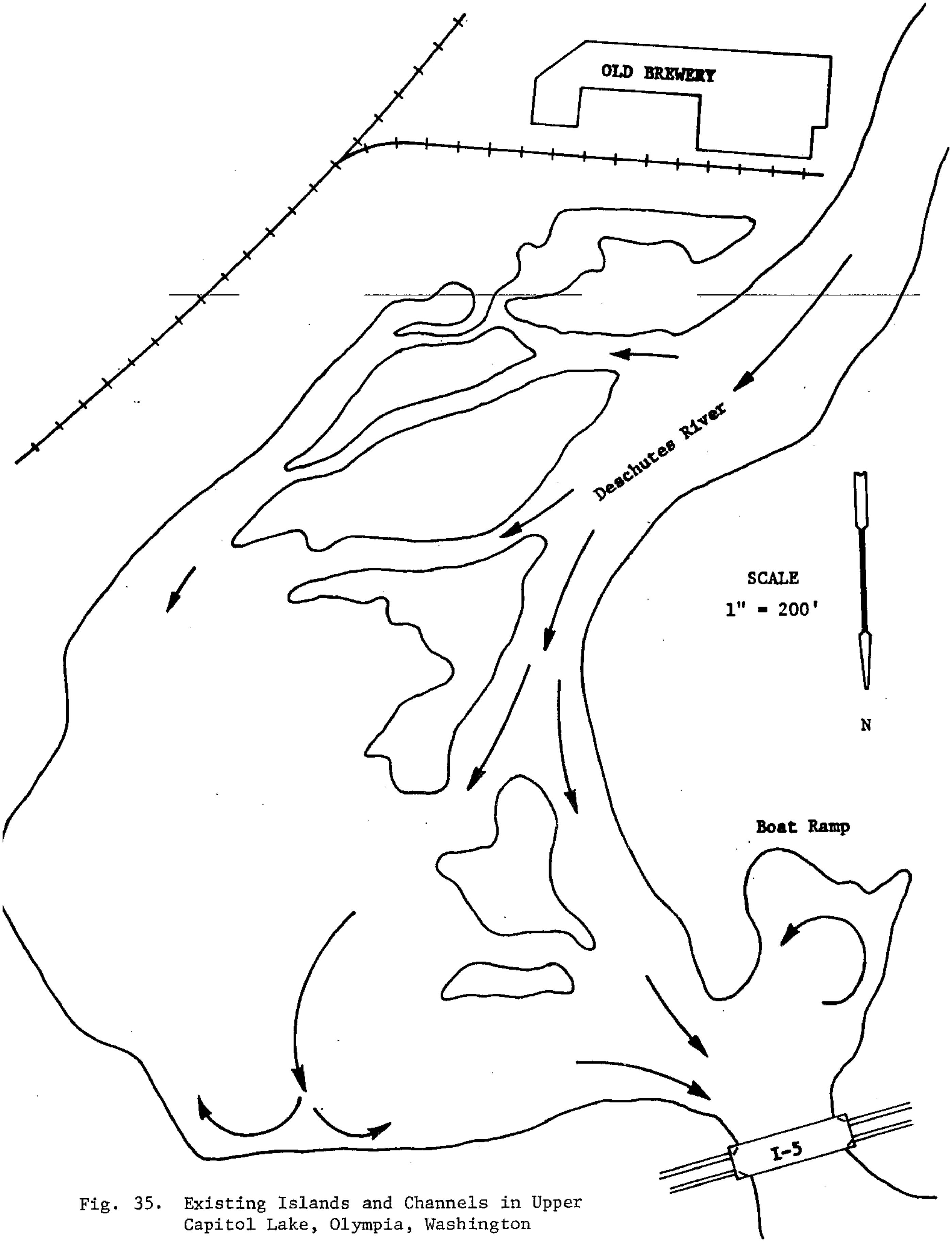

Fig. 35. Existing Islands and Channels in Upper Capitol Lake, Olympia, Washington

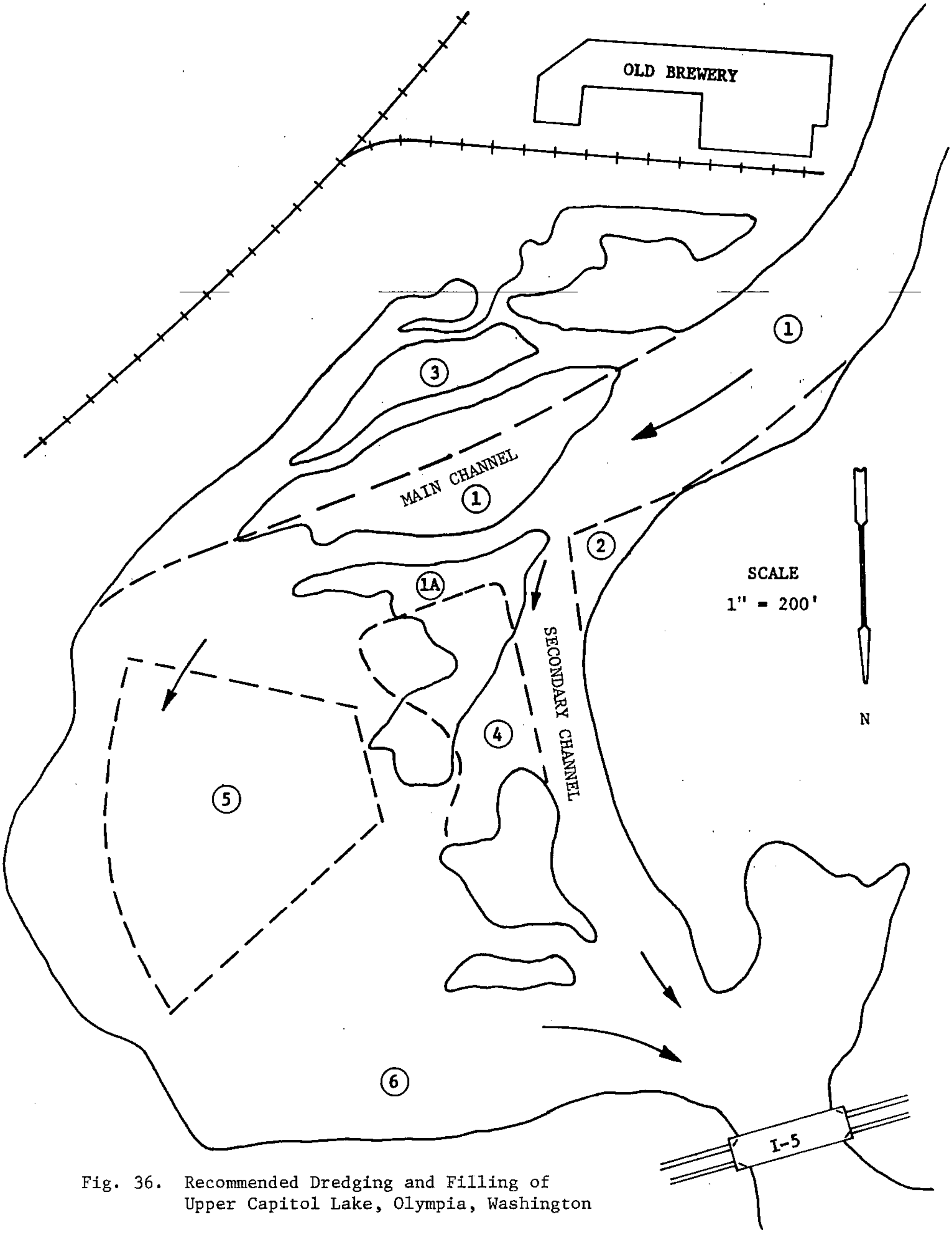

Fig. 36. Recommended Dredging and Filling of Upper Capitol Lake, Olympia, Washington

The facilities should be designed by a consultant to handle anticipated dredged materials. The nearness of the railroad makes this an ideal location for handling and removing the dredged material.

④ Fill the major channel between the two islands to provide a much longer travel path for the flow, and a much larger quiet area for sediments to be deposited.

~~⑤ Dredge a deeper area (15 ft minimum) behind the new island to provide~~ for slower velocities and improved settling conditions.

⑥ Leave the rest of the Upper Lake in essentially its existing state, except as discussed in the next section for recommendations on matters other than dredging.

Under these new conditions, the secondary channel flowing past new island ④ towards the boat ramp will tend to fill with heavier sediment particles early in flood periods, thereby forcing more flow to go behind the island and pass through the trap area ⑤. The secondary channel should receive regular maintenance dredging as should area ⑤.

D. Other Recommendations

(1) The initial dredging of the entire lake should be performed by a dredging contractor.

(2) Initial dredging should follow these general guidelines:

  a) the Upper Lake should be dredged as shown in Figure 36 for the reasons previously discussed based on the hydraulic design for sediment removal;

  b) the upper end of the Middle Lake, just downstream of the I-5 bridge, should be dredged to a minimum depth of 15 ft to provide for trapping sediment that spills out of the Upper Lake in the future, and to remove a boating hazard;

  c) the rest of the lake should be dredged only enough to provide needed fills for recreation areas, and balanced with considerations of economics, boating use, and fish rearing. As discussed in the Water Quality Section, uniform dredging is not required.

   d) the deep trench through the Middle Lake should be extended out of the sediment trap downstream of the highway bridge to carry cooler water to the Lower Lake in the summer.

(3) Hazards such as old pilings and tree stumps should be removed as part of the dredging operation.

(4) The dredging decisions regarding Percival Cove, which is used for raising fingerlings, should be made in consort with the Department of Fisheries' plans for the Cove; the amount of dredging is only a small fraction of the total lake, but the rearing area is an important asset of Capitol Lake.

(5) Although the Percival Creek drainage basin does not provide a lot of flow (an average of about 30 cfs as opposed to 400 cfs for the Deschutes River), there is a great potential for future sediment load in Percival Creek due to subdivision development in the basin. Controls of this sediment source should be initiated by the city and the county.

(6) Maintenance dredging should be handled on a regular basis by the Department of General Administration through the purchase of a small dredge ("Mudcat" type). This will provide a "clean" dredging operation and temporary closure of the basin to control turbidity which would not be necessary.

(7) An engineering preliminary design estimate should be made to develop cost figures for the initial dredging, maintenance dredging, and materials handling facilities for maintenance dredging.

(8) Some dredged materials should be utilized to develop recreation areas, such as in the southwest corner of the Middle Lake near I-5. Details of tests on the fills are discussed in Chapter V, "Hydraulic Model Studies."

(9) Boardwalks, a footbridge, and an observation platform should be constructed from the west shore of the small channel near the boat ramp (Figure 36) over to the newly formed island ④ for access to the new area for wildlife observation. The bridge should be above flood levels, and should allow for small boat access through this channel.

E. Alternatives

The two general alternatives to the recommended dredging program which were considered are: (1) More complete dredging of the entire lake back to 1949 pre-dam conditions; or (2) No dredging at all.

Alternative 1: Deeper Dredging of the Lake to 1949 Conditions

This was an initial alternative under consideration during and prior to 1973. But, as a result of the sedimentation and water quality studies, it has been determined that dredging to 1949 depths would not be as beneficial as selective dredging based on hydraulic and water quality design criteria, and fisheries needs. Complete dredging would decrease the efficiency of the Upper Lake as a sediment trap compared to selective dredging, and remove valuable wetlands. Deeper dredging of the Middle and Lower Lakes would not improve their utility because the recommended selective dredging provides adequate depths for boating, removes hazards, optimizes water quality conditions, and provides for leaving food producing areas for salmon. Some maintenance dredging will have to be performed, but this can be accomplished with the small dredge on a scheduled basis at less cost.

Alternative 2: No Dredging

Without dredging Capitol Lake at this time using an engineering design based on the recommendations in Section C-2, the following detrimental and hazardous conditions will result:

(1) The Upper Lake will become more completely filled with sediment, debris, brush and aquatic growth, and cease to function as a sediment trap for the rest of Capitol Lake.

(2) The sediment load which would have been dropped in the Upper Lake will accumulate in the Middle Lake, thereby decreasing its usefulness.

(3) More sediment will be transported into the Lower Lake as the Middle Lake fills.

(4) As all parts of the lake become more shallow, weed and algae growth will increase due to increased water temperatures and light penetration, and the water quality will be degraded.

(5) The rate of degradation of Capitol Lake will be accelerated due to the fact that an average annual inflow of sediment will decrease the remaining volume in the lake by a larger percentage each year.

Details of the studies conducted to provide the basis for recommendations presented in this chapter are presented in Appendix B, "Sedimentation ~~Studies," and in portions of Appendices A, "Hydrologic Analysis and Data,"~~ and C, "Hydraulic Model Study Details."

V. HYDRAULIC MODEL STUDIES

Chapter Summary

A hydraulic model of Capitol Lake was constructed at a horizontal scale of 1:200 and a vertical scale of 1:20 from the falls of the Deschutes River to the 5th Street dam. The model was constructed for two phases of testing: (1) sedimentation studies of the Upper Lake; and (2) dye studies of the hydraulic characteristics of the lake for use in the water quality studies, and to determine the effects of shoreline fills.

The sedimentation studies, using a movable bed sand model of only the Upper Lake, were completed in three stages between August 15 and September 13, 1974.[4,5,6] Field data were acquired for the completion and verification of the hydraulic model for the second phase of the testing program in the fall and winter of 1974-75. The results of the sedimentation studies were discussed with the sponsor and the consultant during the fall of 1974 and summarized in a report in December, 1974.[7] As a result of these discussions, and because of an optional dredging to 12 ft to reduce weed growth, and because of the desirability of building the model to the largest anticipated lake volume, it was constructed at a total volume of 2780 acre-feet. From this volume, conditions for lesser dredging volumes could be calculated using prototype flow conditions and model test results.

The field data showed that because of the way the tide gates are operated, the volume of water flowing into the lake in any twelve-hour period displaces an equal volume of water through the gates. Therefore the model was operated as a steady flow model at various discharges. The hydraulic-dye tests were run to determine: (1) travel times in the three parts of the lake and the total lake; (2) lake elevations for various flood flows; (3) flow patterns in the lake; (4) residence times and dilution rates for flushing efficiency at various flows; and (5) the effects of fills considered for the southwest corner of the Middle Lake. The hydraulic model and the testing program are discussed in the following sections of this chapter, and in Appendix C, "Hydraulic Model Study Details." The results of the sediment model studies are discussed in Chapter IV and Appendix C, and water quality aspects are discussed in Chapter VI.

A. Description of the Hydraulic Model

1. Geometry of the Model

The hydraulic model of Capitol Lake was built in two stages:

(a) the Upper Lake movable bed model was completed using a sand bed and fixed walls within the wooden shell of the entire model; and after the sediment tests were completed; and

(b) the entire lake model was constructed of a mixture of vermiculite and cement (Figure 37).

The volume of the model lake was built to reflect maximum anticipated dredging conditions, including using the Upper Lake as a sediment trap and dredging most of the rest of the lake to a uniform depth giving a total lake volume of 2780 prototype acre-feet at a normal water surface elevation of -3.5 ft (Olympia datum).

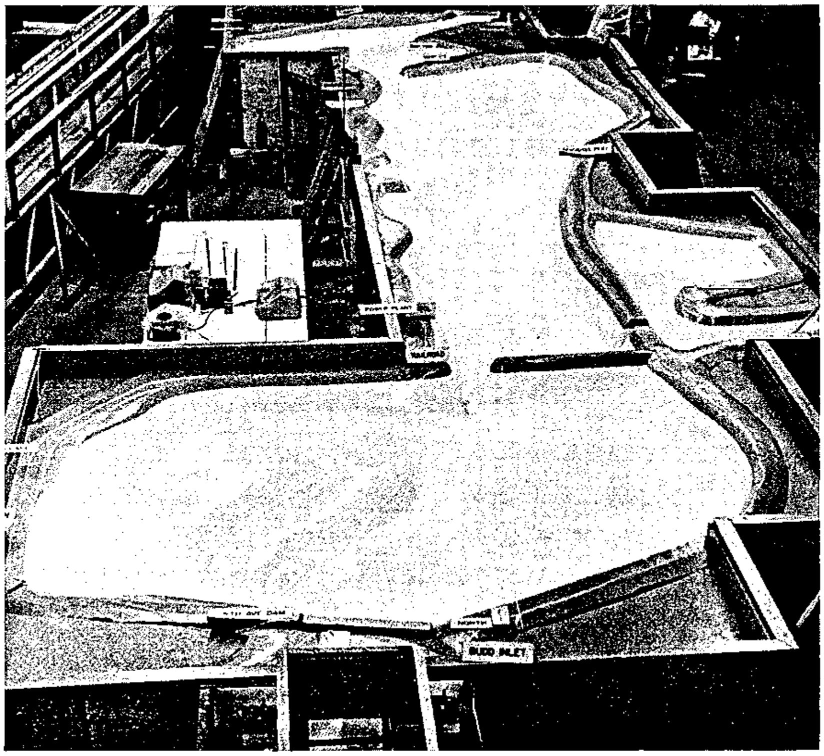

Fig. 37. Photograph of Hydraulic Model of Capitol Lake Looking South (Overall Size: 14 ft wide by 50 ft long. Recording Instruments Left Center)

2. Model Scale Ratios and Flows

The model was built at a horizontal scale of 200:1 and a vertical scale of 20:1. Using these scales and designing the model according to the Froude Law gave the ratios of prototype to model properties presented in Table 20.

~~Table 20.~~

Prototype to Model Ratios for Capitol Lake Hydraulic Model

Ratio	Equation	Values
Length		
Horizontal	$LRH = L_p:L_m$	200:1
Vertical	$LRV = L_p:L_m$	20:1
Volume	~~V~~R = $(LRH)^2(LRV)$	800,000:1
Velocity	$UR = U_p:U_m = (LRV)^{1/2}$	4.47:1
Discharge	$QR = Q_p:Q_m = (LRH)(LRV)^{3/2}$	17,888:1
Time	$TR = T_p:T_m = (LRH)/(UR)$	44.7:1

Definitions for Table 20:

L = length
R = ratio
H = horizontal
V = vertical
~~V~~ = volume
p = prototype
m = model
U = velocity
Q = discharge
T = time

The model was operated over a wide range of flows, but principally at the average low flow of 96 cfs in the Deschutes River and at the once-in-10-year (Q7L10) water quality standard low flow of 80 cfs. Although the model was not operated during a formal test at the 100-year flood flow, a typical flood flow from the 1964 gaging station records was run on a day-by-day selective flow basis to determine how the model operated under steady flow conditions. The range of flows in the Deschutes River and Percival Creek, and the prototype and model detention times are listed in Table 21.

Table 21.

Deschutes River and Percival Creek Flows, and Detention Time for Combined Flows in Prototype and Model

Name of Flow	Symbol	Deschutes River (cfs)	Percival Creek (cfs)	Ratio D/P (-)	Detention Time* Proto (Days)	Model (Min)
Average Annual	QAA	405	30	13.5	3.2	102.2
Average Flood (2-yr)	QF2	3900	150	26.0	0.3	10.6
100-yr Flood	QF100	7400	307	20.6	0.2	7.0
Average Low (2-yr, 7-day)	Q7L2	96	8.4	11.4	13.5	433.6
10-yr Low (10-yr, 7-day)	Q7L10	80	7.1	11.3	16.1	518.4
20-yr Low (20-yr, 7-day)	Q7L20	74	6.7	11.0	17.4	560.6
Lowest Recorded	Q7L(min)	66	5.2	12.7	19.7	634.7

*Detention time for prototype dredged to model configuration, Volume = 2780 ac-ft or 1401.6 cfs-days, divided by combined flow rate of Deschutes River plus Percival Creek.

The values in Table 21 are the same as those in Table 4 in Section I-E, except that the detention times in Table 21 are calculated for the prototype and the model on the basis of a total volume of 2780 acre-feet. The detention time, defined as the volume of the lake divided by the inflow rate, is a common linkage between the hydraulics (water flow efficiency) tests and the water quality (residence and dilution) tests. Tests conducted in the hydraulic model showed how the actual detention or residence times in the model vary from the theoretical prototype times. The relative efficiency of the inflow for flushing pollutants from the lake can be evaluated at various inflow rates in the Deschutes River and Percival Creek.

3. Model Data Acquisition

The sampling station locations used in the hydraulic model dye studies of Capitol Lake are shown in Figure 38. The geometry of the Upper Lake in

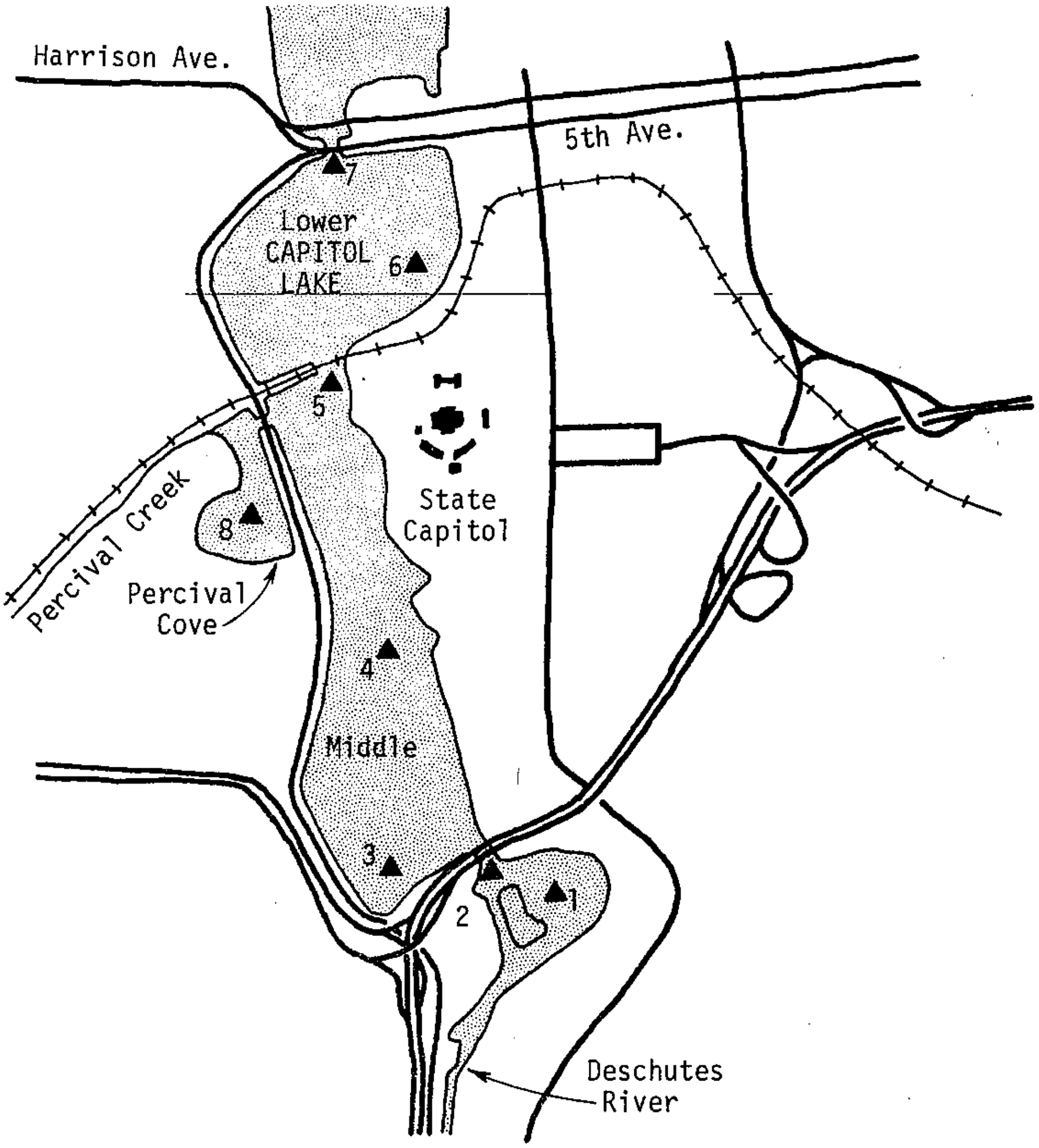

Fig. 38. Hydraulic Model Data Sampling Stations

the figure represents the shoreline and island configuration recommended in Chapter IV as a result of the sedimentation phase of the model study. The purposes for sampling at each of the stations are described in Table 22.

Table 22.

Sampling Station Function
Hydraulic Model of Capitol Lake
for Quantity and Quality Characteristics*

Station No.	1	2	3	4	5	6	7	8**
Station Functions (Test Data)								
a. Water Surface Elevations	X				X	X		
b. Travel Time***							X	
c. Residence Time		X			X		X	
d. Dilution Tests	X	X	X	X	X	X	X	X
e. Velocities (in bridge openings)		X			X			

*For fixed bed model as shown in Fig. 37. Only velocities, water surface elevations and flow patterns were measured in the moveable sand bed sedimentation model of the Upper Lake.

**Average dye concentration determined in Percival Cove at completion of dye dilution tests.

***Travel time is for Deschutes River flows to traverse the entire lake from the falls to the dam.

The tests involving the use of dyes to simulate pollutants were conducted using a Rhodamine-B dye and a Fluorometer to measure the concentrations. The travel and residence time tests were conducted by running a continuous outflow sample through the Fluorometer. The dye dilution tests were conducted by taking small samples at each station in Figure 38 at selected time intervals and then measuring the concentration of dye in the Fluorometer with the continuous flow sampling unit removed.

The decrease in dye concentration as a function of time identifies the relative flushing efficiency of the flow at various locations throughout the lake. The dye concentration sampling stations were selected on the basis of poor (stations 1, 3, 6 and 8) and good (stations 2, 4, 5 and 7) flushing characteristics.

Model discharges were measured using a magnetic flow meter for larger flows, and small, calibrated-in-place, in-line Pottermeters for the smaller flows.

B. Description of the Testing Program

The testing of the hydraulic model was divided into three phases: (1) sedimentation; (2) flow characteristics; and (3) water quality. The types, conditions and purposes of the various tests are summarized in the following sections.

1. Sedimentation Tests (Upper Lake)*

(a) Model Verification - model of Upper Lake operated with sand bed starting with pre-1970 geometry and developing scour and deposition areas similar to 1970 conditions.

(b) The division of flow among the various channels formed by the islands under 1970 conditions.

(c) Continuation of sediment transport tests to confirm the existing 1974 Upper Lake island and channel geometry; and

(d) Modification tests of the 1974 islands and shorelines to improve the sediment trapping efficiency of the Upper Lake and to consider the most efficient way(s) of subsequent maintenance dredging and dredged materials handling.

2. Hydraulic Flow Tests of Complete Lake Model

(a) Lake volume determinations for each part of Capitol Lake were made by sealing off each part, introducing a slow, accurately measured discharge, and recording the time required to reach pre-determined incremental elevations. The volumes of model lake parts determined in this manner (presented in Figure 31, Section C-1 of Chapter III), and at the normal water surface elevation of -3.5 ft (Olympia datum) are equal to:

Upper	Middle	Lower	Total
300 acre-ft	1320 acre-ft	1160 acre-ft	2780 acre-ft

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*Details of the sediment testing program in the Upper Lake model are presented in Appendix C, Part 1, Sedimentation. The results and recommendations are presented in Chapter IV, "Sedimentation Studies."

(b) Flood routing tests were run with representative flows from the period of January 13 through February 10, 1964, to determine the elevations at which the lake parts would stabilize for each flow between 620 and 4930 cfs. The results of these tests were compared with the elevations measured at the power plant water surface record (Gage No. 1, Fig. 29) for similar discharges for verification in the inflow-outflow character~~istics of the model operated with a steady discharge. The flood flow~~ tests were used also to observe general flow patterns through the lake and to identify areas which could present poor flushing conditions during the water quality dye studies at smaller discharges. During the flood flow tests, mean velocities were measured at the Highway I-5 and railroad bridge openings.

Prototype Discharge (cfs)	Model Velocity (fps)		Prototype Velocity (fps)	
AT THE BRIDGES . . .	I-5	RR	I-5	RR
2040	0.30	0.30	1.4	1.4
2740	0.36	0.40	1.6	1.8
4930	0.60	0.65	2.7	2.9

(c) Travel time tests for flows entering the Upper Lake and leaving the Lower Lake at the dam were conducted for flows ranging from 100 to 6000 cfs.

3. Dye Tests for Water Quality Phase

(a) Residence time tests were conducted by inserting a known quantity of dye into the upstream end of each part of the lake and continuously monitoring the dye concentration in the outflow from that particular part of the lake. These tests were used to evaluate the mixing characteristics of each part of the lake and to make an evaluation of the dead space (stagnant volume) of water. Tests were conducted at low, average and high flow rates of 96, 400 and 800 cfs which are the average low flow, the mean annual flow and a typical smaller flood flow for the Deschutes River.

(b) A flushing (dilution) test was conducted at the average low flow of 96 cfs by starting the test with the lake uniformly mixed with a known concentration of dye and zero discharge. The flow was set and the dye concentrations were sampled at stations 1 through 7 shown in Figure 38. This portion of the test program was similar to the methods used in an earlier study of Vancouver Lake, Washington.[19]

4. Middle Lake Dredged Fill Tests and Flow Visualization Dye Tests

A series of visual-photographic tests were conducted on a set of two fills in the southwest corner of Capitol Lake which are being considered to provide convenient dredge spoils areas and to serve as future recreational access points to the lake. Numerous other fills are being considered in the Middle and Lower Lakes and in Percival Cove, but these would make only minor changes in the shoreline configuration and would not affect the flow pattern in the lake. The two fills investigated in the hydraulic model have both beneficial and detrimental effects on the flow pattern in the southwest corner of the Middle Lake. These and other general results of the hydraulic model testing program are discussed in the next section of this chapter. The background information and more specific details of the hydraulic model studies are presented in Appendix C. A series of photographic dye tests was conducted of the flow patterns throughout the lake in conjunction with the fill tests in the Middle Lake. The results of these tests are presented in Part 4 of the next section.

C. Summary of Test Program Results

1. Upper Lake Sedimentation Tests (refer to Chapter IV and Appendix C for details): The final results of the sedimentation tests showed that by reshaping the existing islands in the Upper Lake, and dredging a deep sediment trap east of the newly-formed island, sediment deposition efficiency could be greatly enhanced. The recommended geometry is as presented in Figures 36 and 37 in Chapter IV.

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[19] Orsborn, John F., "Correlated Studies of Vancouver Lake--Hydraulic Model Study," EPA Project 16080 ERP, Report EPA-R2-72-078, October, 1972.

2. Hydraulic Flow Tests of Complete Lake Model: After the volumes of each part of the lake were accurately determined, the flood routing tests showed that the model, when operated at a constant discharge, would tend to stabilize itself in a manner similar to the prototype lake. Also, the rise in lake elevation caused by flood flows was determined in each part of the lake.

The results of the travel time tests, when compared with the theoretical detention time of the lake, showed that there is very little opportunity for mixing, dilution and flushing by low flows entering Capitol Lake from the Deschutes River. This comparison is summarized in Table 23, and the lack of mixing efficiency is obvious if one compares the prototype travel and detention times in Columns 3 and 4. If the inflow was efficiently displacing the lake volume, the travel and detention times would be very similar. But, as shown in Table 23, the detention time is ten times as long as the travel time at the lowest flow. This means that the flow is not expanding uniformly and filling the boundaries, but is short circuiting between the inlets and outlets of the three parts of the lake. This is especially true in the Lower Lake between the railroad bridge and the dam as will be discussed and shown in photographs in Part 4 of this results section.

Table 23.

Comparison of Travel Times and Detention Times
for Various Flows in the Hydraulic Model

Prototype Flow Rate (cfs)	Travel Time		Detention Time Prototype	
	Model (Min)	Proto (Hrs)	(Hrs)	(Days)
100	39.0	29.3	307	12.8
500	20.5	15.4	62	2.6
1500	7.5	5.6	21	0.9
3000	4.5	3.4	10	0.4
6000	3.0	2.2	5	0.2
Col. (1)	(2)	(3)	(4)	(5)

3. Dye Tests for Water Quality Phase

The details of the results and application of the residence time tests are presented in Chapter VI on water quality characteristics of the three parts of the lake. But the influence of the geometry on residence time and on flow pattern and other hydraulic characteristics such as short-circuiting and dead space, can be readily visualized in Figure 39. These three parts of Figure 39 are examples of the dye concentration sampled continuously at the outlets of each part of the lake after injection of the known quantity and concentration of dye at the upstream end of each part of the lake (time zero). The three portions of strip chart records exhibit characteristics which are indicators of the general flow patterns of each part of the lake. Note that the Lower Lake graph exhibits an increase in relative concentration beyond the first dye peak.

For example, the graphs for the Upper and Lower Lakes show that although the travel distance is about the same for both, the Upper Lake tends to short circuit through the secondary channel between the boat launch area and the new island. In a movable bed (prototype and first model) condition, this secondary channel tends to fill with sand during high flows, and therefore a majority of the flow will tend to follow the longest path behind the new island and along the south, east and northeast shores, except immediately after maintenance dredging of the secondary channel and before the next flood.

The large eddies which form in the southwest part of the Middle Lake are manifested in the cyclic peaking characteristics of the dye concentration in the middle graph of Figure 39. As flow moves past the eddy, stronger concentrations of dye are entrained and carried to the sampling station at the lower (north) end of the Middle Lake at the railroad bridge.

The results of the dye-dilution tests on flushing characteristics indicated results similar to those found in the residence time tests. Note in Figure 40 the cyclic characteristic of the outflow from the Middle Lake at station 5. Note also that the concentration of dye remains highest at sampling station 6 on the east side of the Lower Lake due to poor circulation in this area and at station 8 in Percival Cove.

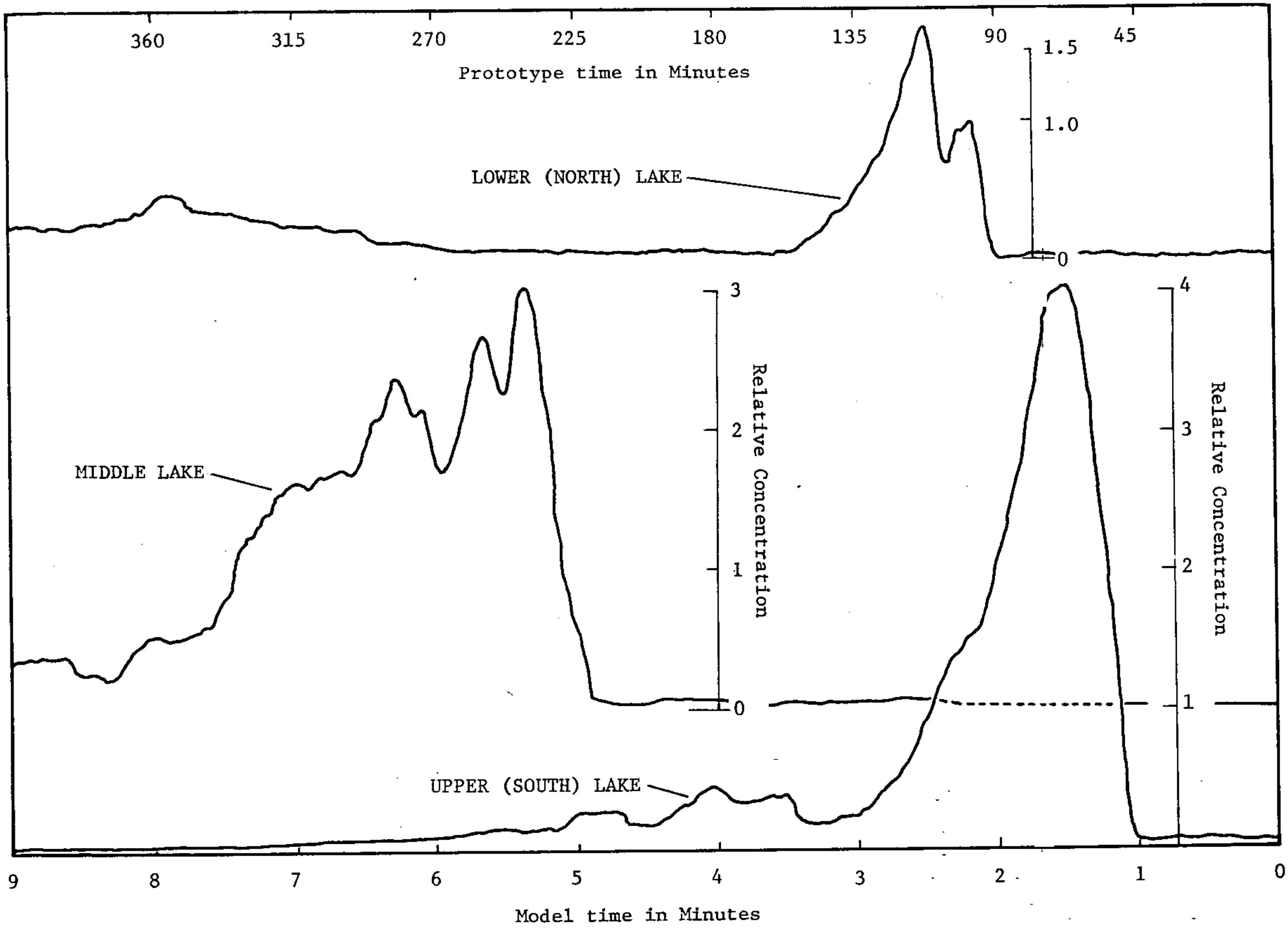

Fig. 39. Examples of Dye Concentrations Sampled Continuously at the Outlets of the Three Parts of Capitol Lake in the Hydraulic Model

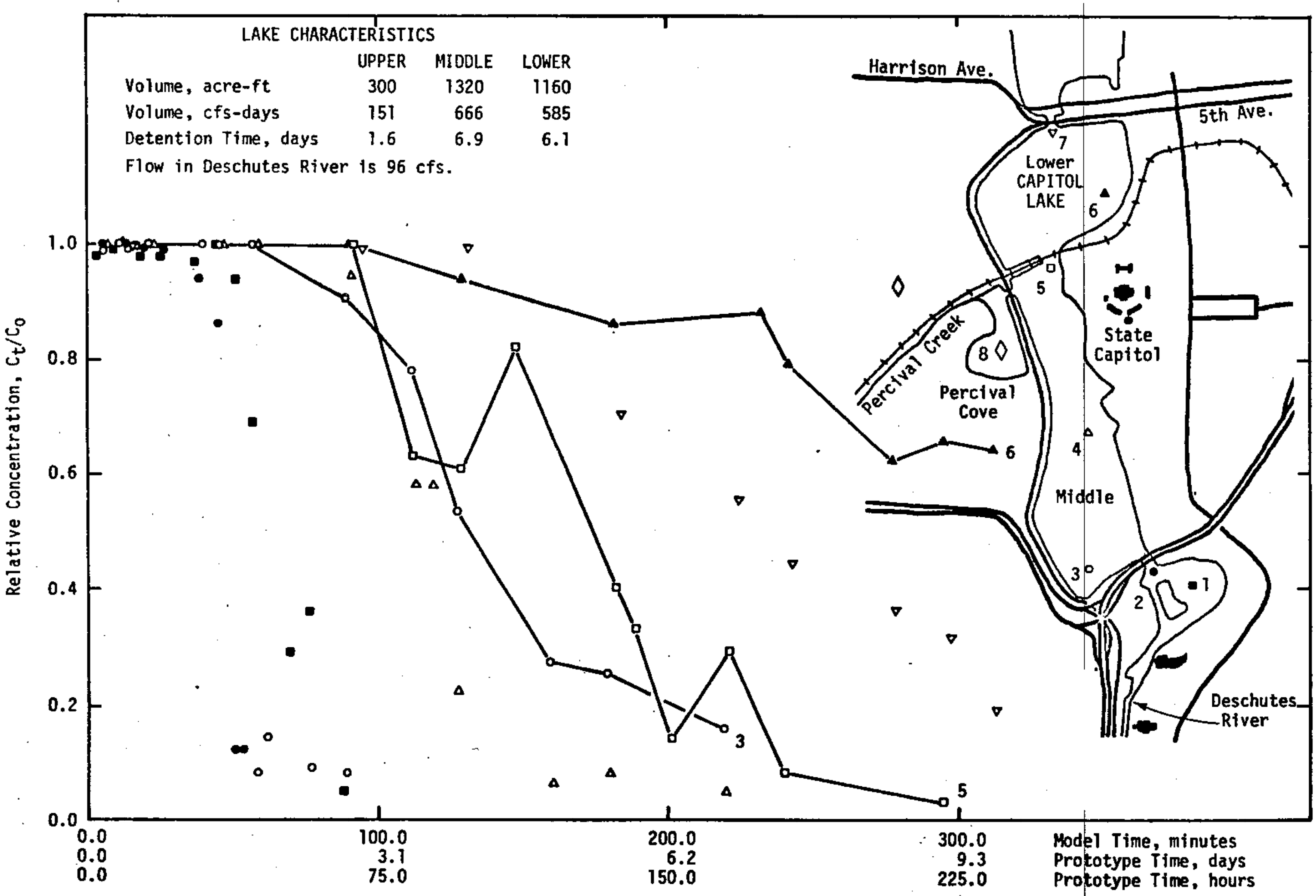

Fig. 40. Results of Dye Dilution Tests at Sampling Stations in the Capitol Lake Hydraulic Model

4-a. Results of Fill Tests in the Middle Lake

As shown in Figure 41, fill A1 improves the flow pattern in the southwest corner of the Middle Lake. Other fills in this area (A, A2 and A3) cause conditions which are either worse than for fill A1 or circulation is not improved significantly by additional filling. The southwest corner of the ~~Middle Lake is shown in Figure 42a without any fill. Note the shape of~~ the dark dye area and the shape of fill A1 in Figures 42a and in 41 and 42b.

The effects of fill B are shown in Figures 43a and 43b. After the flow leaves the Highway I-5 bridge opening, it expands towards the west bank of the Middle Lake (see flow arrows in Figure 41). As it approaches the point of fill B (Figure 43) the flow divides, part continuing downstream and part circulating back towards fill A1. In Figure 43b the clean area near fill B in the upper center of the photo is a dead space which would have poor circulation and exchange. If additional fill is desired in the B area, it is suggested that the dotted shape in Figure 41 be used instead of fill B.

4-b. General Flow Observation Tests

While the fill tests were being conducted, additional visual (photographic) dye tests were undertaken on critical flow characteristics throughout the lake.

In the Upper Lake, the dye concentration which has accumulated behind the new island in Figure 44a is a good indication of high sediment trap efficiency. Meanwhile, the area near the boat ramp in Figure 44b indicates from the similar type of dye accumulation that the boat ramp is becoming filled with silt. The tendency for the flow to cling to the east shore of the Middle Lake just downstream of the I-5 bridge is displayed in Figure 45. The leading edge of the dye is just beginning to expand towards the west bank and the point of fill B.

The direct path of the flow across the Lower Lake is indicated by the confetti line between the railroad bridge and the gate opening at the 5th Avenue dam in Figure 46. This path along the south to north axis of the

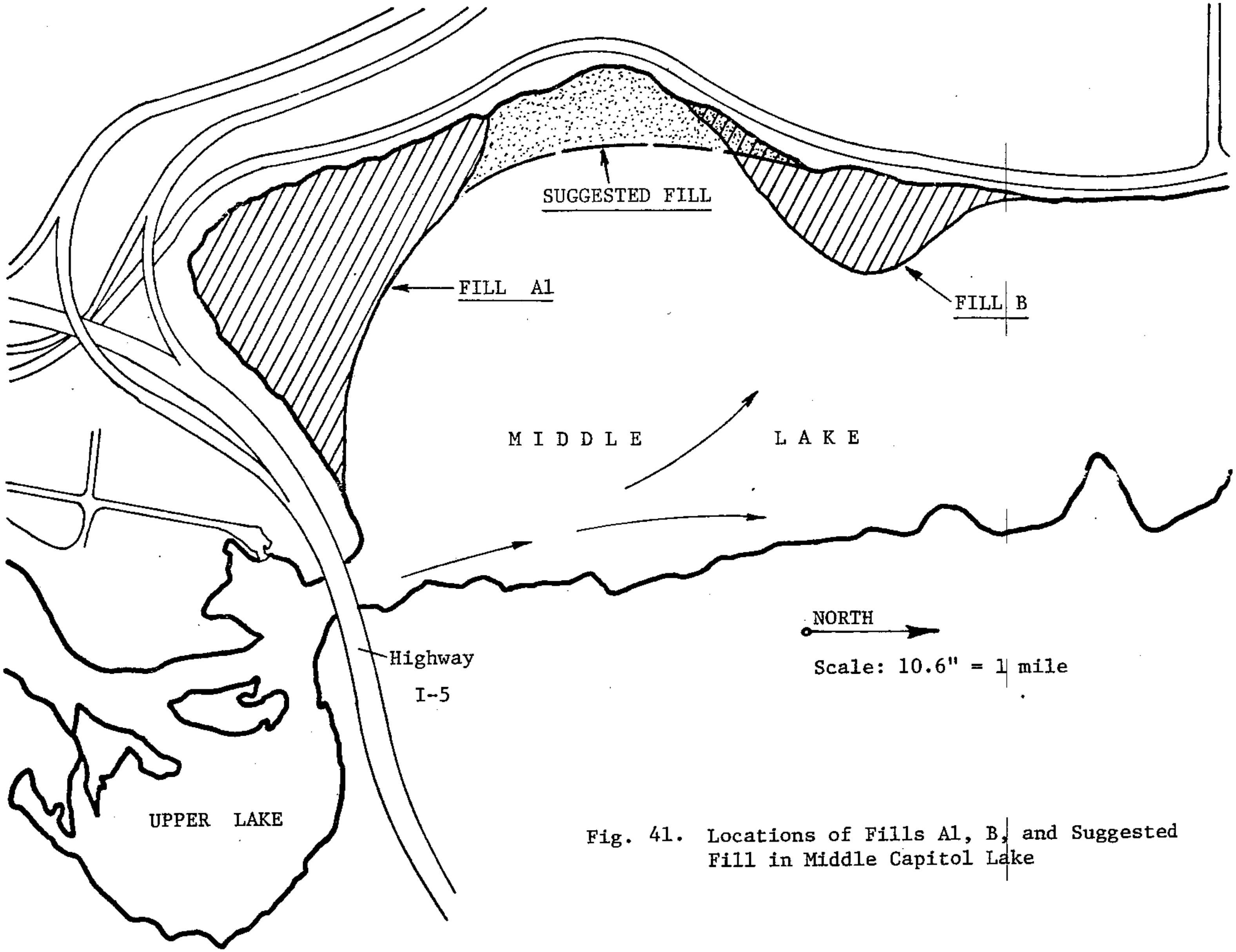

Fig. 41. Locations of Fills A1, B, and Suggested Fill in Middle Capitol Lake

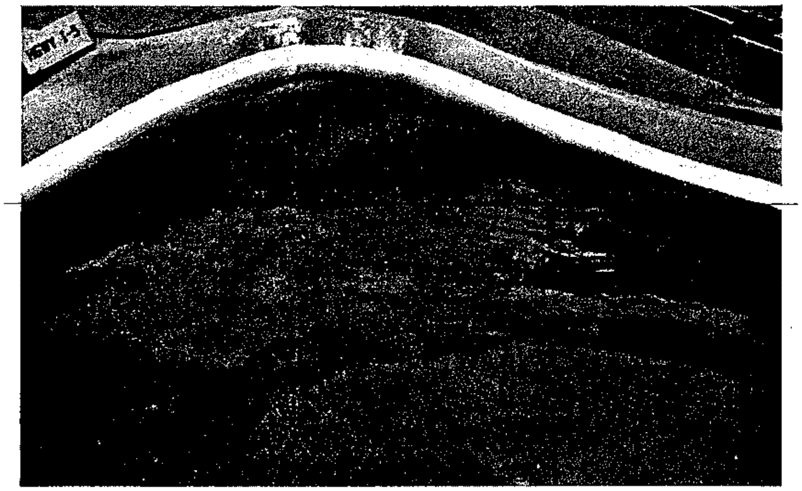

Fig. 42a. Dye Circulation Tests of the Southwest Part of Middle Capitol Lake in the Hydraulic Model

Fig. 42b. Dye Circulation Tests with Fill A1 Placed in the Southwest Corner of the Middle Lake in the Hydraulic Model

Fig. 43a. Dye Approaching Fill B on the West Shore of the Middle Lake in the Hydraulic Model

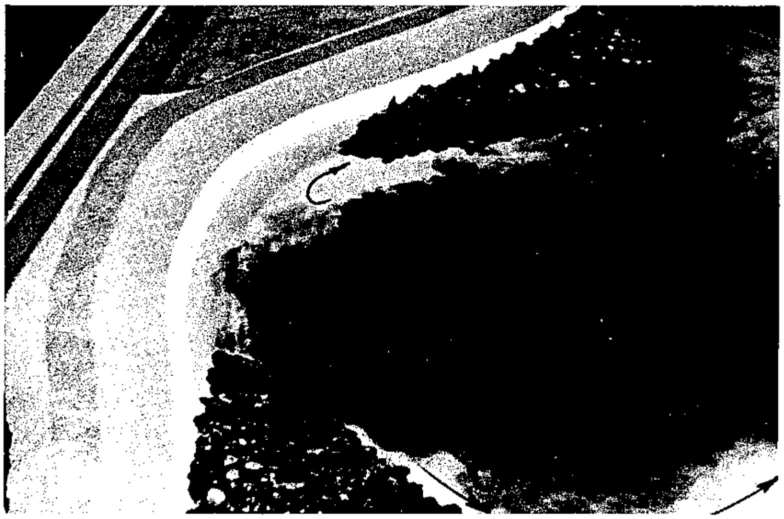

Fig. 43b. Poor Circulation Pattern Between Fills A1 and B in the Middle Lake Due to Fill B (Note the clear area near Fill B, upper center.)

Fig. 44a. Dye Concentration Behind New Island in the Upper Lake Demonstrating the Deposition Area

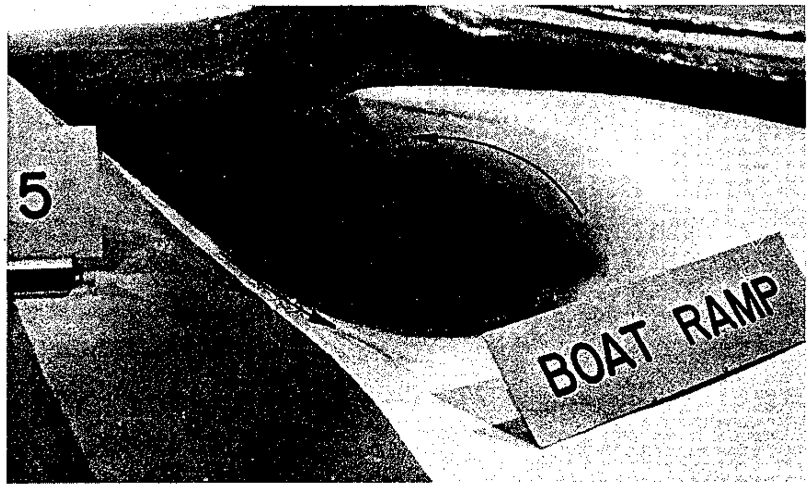

Fig. 44b. Dye Concentration in Boat Ramp Area of the Upper Lake in the Hydraulic Model Verifying the Existing Tendency for this Area to Fill with Silt

Fig. 45. Dye Plume Following East Bank of Middle Lake Downstream from Highway I-5 Bridge; Excavated Area in Hydraulic Model Is Center Left Beneath the Plume

Fig. 46. Confetti Path in Hydraulic Model Showing Flow Between the Railroad Bridge and the Dam; Lower Lake

Fig. 47. Dye "Islands" in Lower Lake Demonstrating Poor Circulation and Flushing in the Hydraulic Model

Lower Lake establishes two large eddies, one in the east and one in the west half of the Lower Lake. These eddies are denoted by the dark dye areas in Figure 47 looking northeast towards the swimming area which appears as a light area in the upper right background. The dye eventually accumulated in the swimming area as the test progressed indicating an area of poor circulation as confirmed by the dye dilution test results for ~~station 6 in Figure 40. Additional details on the hydraulic model flow~~ tests are presented in Appendix C, Part 2.

VI. WATER QUALITY STUDIES

A. Background

1. Introduction

~~The quality of water flowing through Capitol Lake is presently of interest~~ and concern because of its influence on the aesthetic value and general utility of the lake. Definition of current quality conditions, identification of existing and/or potential problem areas, and recommendation of methods and procedures for maintaining or enhancing existing water quality are the major functions of this portion of the study. Particular attention is given to water quality problems or improvements likely to result from lake restoration measures currently being planned.

The various uses of Capitol Lake have differing requirements for water quality, in addition to the overriding importance of aesthetic appeal, including recreation, ranging from passive pursuits to active water sports such as fishing, swimming and boating, and the large scale rearing of fish for sport and commercial purposes. In establishing water quality requirements for such a multipurpose water system, the use requiring highest quality will determine the standard. In compliance with the Federal Water Quality Act of 1965, standards have been established for all interstate and coastal waters of Washington to protect and maintain water quality required for intended uses of the water systems. A summary of Washington water quality classifications is given in Table 24.

Capitol Lake, as an integral part of the Deschutes River system, is a Class A water suitable for body contact water sports and salmonid fisheries (Table 25). The coliform standard is a requirement for protection of public health in view of intended water contact recreational use. The standards for dissolved oxygen, temperature, and pH relate primarily to maintenance of conditions required for a healthy biological

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[20] Puget Sound Task Force, PNRBC, "Comprehensive Study of Water and Related Land Resources--Puget Sound and Adjacent Waters, State of Washington," See Appendix XIII, March, 1970.

Table 24. State of Washington Water Quality Classification Summary[20]

Water Quality Standards	Class AA Extraordinary		Class A Excellent		Class B Good		Class C Fair	
	Fresh	Marine	Fresh	Marine	Fresh	Marine	Fresh	Marine
Coliform	50 MPN	70 MPN	240 MPN	70 MPN	1,000 MPN	1,000 MPN	1,000 MPN	1,000 MPN
Dissolved Oxygen	9.5 mg/1	7.0 mg/1	8.0 mg/1	6.0 mg/1	6.5 mg/1	5.0 mg/1	5.0 mg/1	4.0 mg/1
Temperature[1]	60°F	55°F	65°F	61°F	70°F	66°F	75°F	72°F
pH	6.5-8.5	7.8-8.5	6.5-8.5	7.8-8.5	6.5-8.5	7.8-8.5	6.0-9.0	7.0-9.0
Turbidity	5 JTU	5 JTU	5 JTU	5 JTU	10 JTU	10 JTU	10 JTU	10 JTU
Toxicity[2]	Shall be below those of public health significance, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.							
Aesthetic Values	Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.							

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[1] For all classes, the permissible increase in temperature over natural conditions is less than 1.8°F.

[2] Exact definitions of toxicity can be found in the Water Quality Standards.

Table 25.

State of Washington Class A Water Quality Standard:
Washington Administrative Code (WAC), WAC 173-201-030 (2)

CLASS A (Excellent)

(a) General characteristic. Water quality of this class shall meet or exceed the requirements for all or sub~~stantially all uses.~~

(b) Characteristic uses. Characteristic uses shall include, but are not limited to, the following:

- i. Water supply (domestic, industrial, agricultural).
- ii. Wildlife habitat, stock watering.
- iii. General recreation and aesthetic enjoyment (picnicking, hiking, fishing, swimming, skiing and boating).
- iv. Commerce and navigation.
- v. Fish and shellfish reproduction, rearing and harvest.

(c) Water quality criteria.

- i. Total coliform organisms shall not exceed median value of 240 (fresh water) with less than 20 percent of samples exceeding 1000 when associated with any fecal sources or 70 (marine water) with less than 10 percent of samples exceeding 230 when associated with any fecal sources.
- ii. Dissolved oxygen shall exceed 8.0 mg/l (fresh water) or 6.0 mg/l (marine water).
- iii. Total dissolved gas—the concentration of total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.
- iv. Temperature—water temperatures shall not exceed 60°F (fresh water) or 61°F (marine water) due in part to measurable (0.5°F) increases resulting from human activities; nor shall such temperature increases, at any time, exceed $t = 90/(T-19)$ (fresh water) or $t = 40/(T-35)$ (marine water); for purposes thereof "t" represents the permissive increase and "T" represents the water temperature due to all causes combined.
- v. pH shall be within the range of 6.5 to 8.5 (fresh water) or 7.0 to 8.5 (marine water) with an induced variation of less than 0.25 units.
- vi. Turbidity shall not exceed 5 JTU over natural conditions.
- vii. Toxic, radioactive, or deleterious material concentrations shall be below those of public health significance, or which may cause acute or chronic toxic conditions to the aquatic biota, or which may adversely affect any water use.
- viii. Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

community of a character consistent with passive recreation, boating, and fisheries uses of the lake. The aesthetic value specification has rather broad implications that may involve limitations on additional water quality parameters and perhaps even on some of the lake uses.

Water quality problems for the purposes of this study will be defined as existing when the specified water quality standards necessary for intended lake uses are not maintained. Identification of water quality problem areas requires thorough characterization of the various factors that contribute to water quality conditions. Water quality problems as defined herein result entirely from human activities. Water quality standards are not considered to be exceeded as a result of purely natural factors. High turbidity measured during floods is an example of this type of condition. Water quality problems resulting from human activities generally present more practical opportunities for management and are the major concern of this study.

In evaluating lake conditions for existing or potential problems, the transitory nature of water quality is very important to recognize. Water quality characteristics (physical, chemical, and biological) of lakes and streams regularly vary over diurnal and seasonal cycles. However, because these natural cycles are significantly influenced by climatic and hydrographic factors, water quality conditions throughout the annual cycle may vary from year to year. In Capitol Lake additional year-to-year water quality variations may result from several factors: continuing evolution of the lake from its original estuarine condition, evolution due to the progressive filling of the lake with fluvial sediments, changes in lake management practices, and changes in lake use patterns.

2. Water Quality Environment, Capitol Lake

Prevailing water quality conditions in virtually all lakes are influenced by their physical environment. The following review of the Capitol Lake environment is included to provide an overall perspective for evaluation of water quality.

Capitol Lake is a long narrow impoundment at the mouth of the Deschutes River. The lake-river system discharges into the southernmost end of Puget Sound where the man-made dam and tide gates separate it from the marine waters of Budd Inlet. The lake lies within the boundaries of the City of Olympia, Thurston County, Washington, and is incorporated in the State Water Resource Inventory Area 13.

Capitol Lake has existed as an impoundment for just 25 years since construction of the dam in 1951. The lake covers an area of approximately 280 acres and occupies a volume of slightly over 2200 acre-feet. The average water depth is just under 8 ft with a maximum depth of 22 ft and significant shallow flats ranging from 2 to 4 ft in depth. The bathymetric map of the lake, Fig. 48, shows the relatively deep original river channel passing through the lake to the outlet at the dam. Through much of the year the incoming river water is significantly colder than the lake water. The more dense river water tends to remain segregated from the lake in the deeper channel. The combination of the low depth to volume ratio, and the channelized lake configuration imparts to the lake characteristics. between those of a slow moving river system and a shallow lake system. During the high discharge months of October through April, riverine influences tend to be dominant; during low discharge months of May through September, conditions tend to be more lacustrine.

Capitol Lake is divided into four basins. The lower (north) basin was formed by construction of the railroad fill and trestle; Percival Cove was formed by placement of the Deschutes Parkway fill; and the middle and upper (south) basins were separated by the U.S. Interstate 5 highway fill and bridge. The water quality studies have focused on the three main lake basins. Although some data on Percival Cove were collected, resources available for the study did not permit its thorough characterization.

The upper (south) basin is the smallest and shallowest of the three main lake basins with an area of about 30 acres and a mean depth of just over two feet. This basin is the one most highly influenced by the river, receiving directly over 90 percent of the total tributary flow to the lake. It has also received the greatest sediment load, having experienced

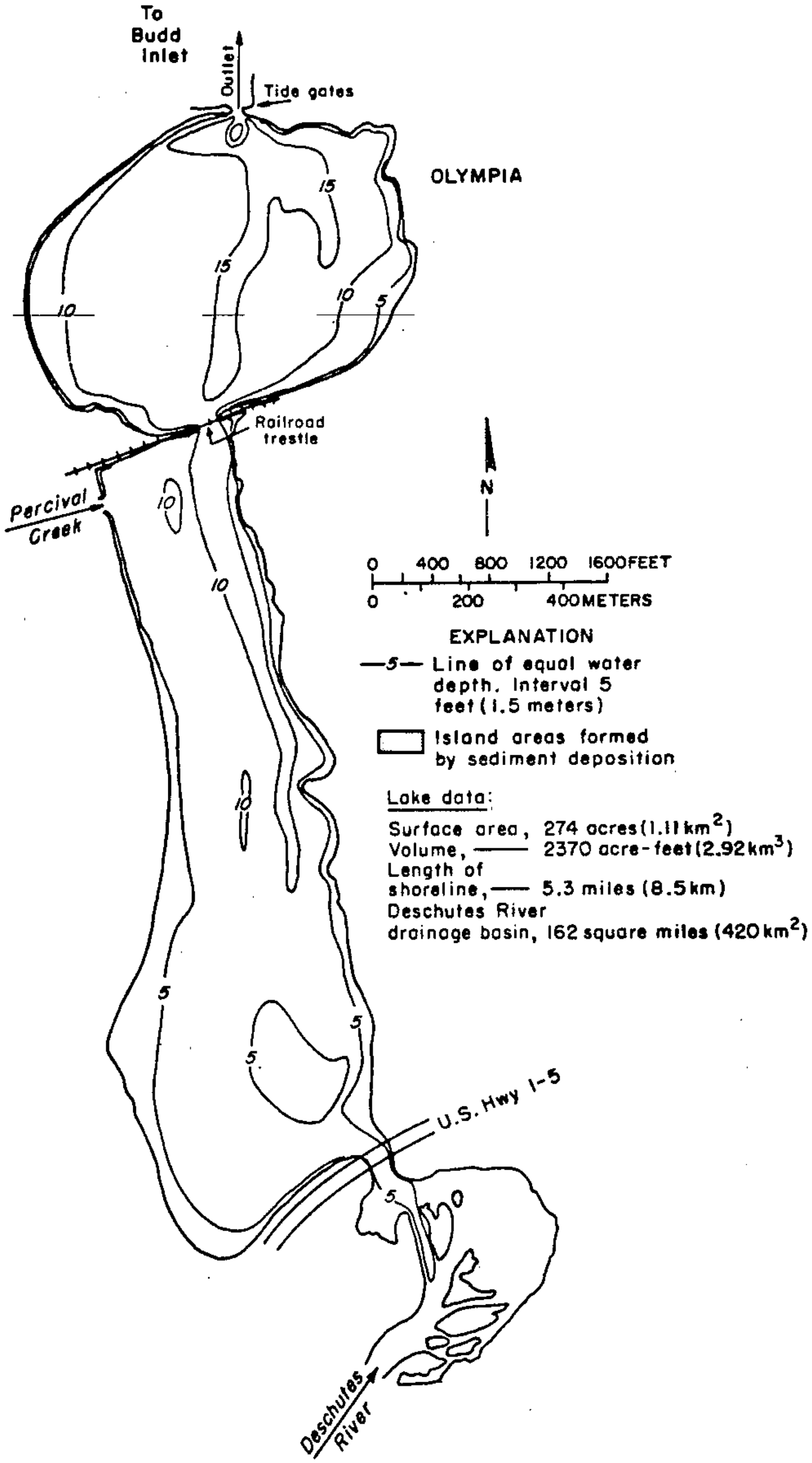

Fig. 49. Bathymetric Map of Capitol Lake at Olympia, Showing Areas of Sediment Deposition Below Mouth of Deschutes River--Survey Dec. 5, 1973, by U.S. Geological Survey

a reduction in volume of over 75 percent since formation of the lake. The upper basin is now the most riverine portion of the lake with two major channels and several islands of sand and gravel. The relatively swift water of the main channels provides for trout and seasonal salmon fishing.[21] However, decreasing water depths from progressive siltation is reported to be making fishing access by boat more difficult and hazardous. Shallow areas around the lake margin and islands have developed abundant cattail and willow growth. The vegetated character of the basin is visually attractive providing a measure of seclusion for visitors and providing good habitat for shore animals, birds, and water fowl. Location of the old brewery building, Tumwater Falls, and the lower end of the fish ladder over the falls at the upper end of the basin are additional attractions contributing to aesthetic quality.

The middle basin is the largest of the three main lake basins and intermediate in depth with an area of 146 acres and a mean depth of just over seven feet. The major flow from the upper basin enters the southeast corner of the long narrow approximately rectangular basin. Following an initial bow from the highway bridge toward the center of the basin, the old river channel returns about 300 yards north of the bridge and continues along the steep eastern margin of the basin to the railroad trestle. Sediments carried over from the upper basin are forming a shallow sandy fan of considerable size inside the basin inlet (Figure 48). About five percent of the flow to the basin enters from Percival Creek through Percival Cove at the northwest corner of the basin. The greater depth and volume of the middle basin render it more lacustrine in the nature of chemical and biological processes observable in it. Yet riverine influence is maintained in the deeper river channel throughout the year and throughout the basin during periods of high runoff. Shorelines around the entire basin are steep providing an essentially flat bottomed basin of relatively uniform depth. With the exception of the relatively shallow flats in the southwest corner and the growing sediment fan in the southeast corner, the configuration of this basin has been well suited to boating activities.

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[21] Williams, R. W., et al., "Catalog of Washington Streams, Vol. 1, Puget Sound Region," Management and Research Division, Washington Department of Fisheries, March, 1972.

Other major uses of the middle basin include fishing and fish rearing as well as providing a large scenic open water area in the center of the city and adjacent to the State Capitol grounds. The tree covered hillsides surrounding the lake and relatively weed-free waters and shoreline contribute greatly to the visual attraction of this basin. A number of private homes are located on the steep wooded hillside of the eastern lake margin including waterfront private holdings for three-quarters the distance from the highway bridge to the railroad trestle.

The lower (north) basin is similar in volume to the middle basin. Though smaller in surface area it is deeper having an area of 104 acres and a mean depth of approximately eleven feet. This basin is essentially circular with a saucer-like profile. The deeper river channel proceeds across the diameter of the basin in an almost due northerly direction terminating in the vicinity of the dam. The deepest areas of the entire lake, reaching just over 20 ft, are located along this channel. River influence in this basin is minimal, concentrated along the deeper channel, and is most prevalent during high flow periods. Shorelines around much of the basin (except for the south to southeast half-quadrant) are precipitous like those of the middle basin.

The upper and middle lake basins provide for removal of about 85 percent of the total sediment load to the lake. Accumulation of the remaining 15 percent in the lower basin has reduced its volume by just over six percent in 25 years. The lower lake basin has the largest share of recreational use of the entire system. Easy access to nearly the entire shoreline and public facilities have promoted use. A public swimming area is located along the northeast lake margin with an adjacent fishing pier extending toward deeper water.[22] Public picnicking facilities are located at the southwestern corner of the basin. Major lower basin uses include swimming, fishing, unmotorized boating, shoreline activities, and sightseeing. The public recreation facilities, easy access by city-center streets, appealing relatively weed-free appearance, and scenic views toward the Capitol ground, wooded hillsides, Budd Inlet, or downtown Olympia underscore the importance of maintaining high water quality.

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[22] Anon., "Saving a Beautiful Lake," Capitol Lake Committee, 1974.

3. Water Quality Environment, Tributaries

(a) Deschutes River: The Deschutes River is the major tributary to Capitol Lake, accounting for approximately 95 percent of the total yearly inflow to the lake. The river originates in the mountainous Bald Hills at the southern end of Thurston County and flows through a gently rolling glaciated plain along most of its length before entering the lower basin of Capitol Lake. The drainage area of the Deschutes as it enters the lake is 162 square miles.

The discharge from the Deschutes River varies considerably from season to season in response to weather changes. During the drier summer season, flows normally range between 80 to 150 cfs, while during the wetter winter-spring season, flows range between 600 to 1200 cfs (Figure 49). Maximum flows exceeding 5400 cfs and minimum flows of 66 cfs have been recorded.

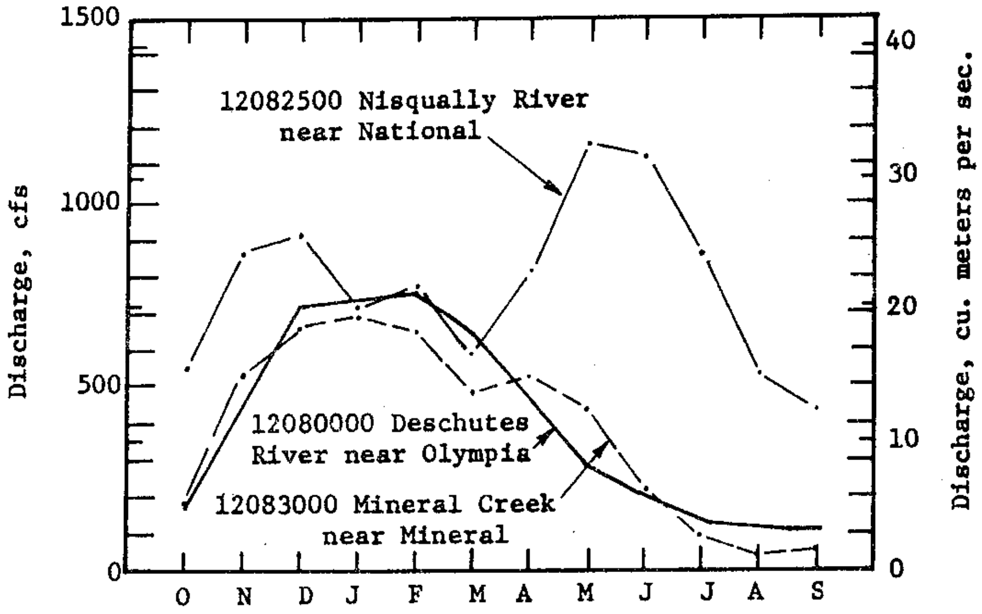

Fig. 49. Mean Monthly Discharges, Deschutes River Near Olympia (1931-60); Nisqually River Near National (1931-60); and Mineral Creek Near Mineral (1943-72)[14]

These fluctuations in streamflow are accompanied by corresponding changes in lake water residence time and rates of sedimentation. During high spring discharge the lake experiences very rapid exchange rates and the entire lake volume is displaced in approximately 12 hours when the flow rate is about 3000 cfs. Slower exchange rates are more common, however, taking approximately three days for complete exchange at the mean annual flow of 405 cfs, or a maximum of 15 days at a 20-year, 7-day low summer flow of 74 cfs. Such changes in flow rate and residence time imply corresponding adjustments in factors such as water temperature, dissolved oxygen, and changes in aquatic biota.

Although the discharge of the Deschutes River at Olympia only exceeds 1000 cfs about 8 percent of the time, 80 to 85 percent of sediment transport reportedly occurs at flows exceeding 1000 cfs.[4] The majority of the approximately 25,000 tons of sediment accumulated annually is deposited during times of high discharge in early spring. Approximately 740,000 cubic yards of sediment have been deposited by the Deschutes River since 1949, an amount which results in a loss of lake volume at about 25 acre-feet annually. Nelson[14] calculated in 1974 that, at this rate of deposition, the upper basin could be expected to be displaced by sediments within six to eight years; the middle basin could fill within 60 years; and the lower basin could be filled within 130 years.

In addition to the filling of Capitol Lake, the sediment load can cause important short- and long-term changes in water quality. Changes in dissolved oxygen, biochemical oxygen demand, temperature, and related factors may be affected on a short-term basis while accelerating eutrophication, reduction of fish spawning habitat, and increasing growth of aquatic weeds are some of the potential long-term consequences.

The chemical, physical and biological characteristics of the water of the Deschutes River are of major significance to water quality characteristics of the Capitol Lake impoundment. Residence time, sedimentation rate and changes in general chemical and biological factors in Capitol Lake are primarily dependent upon forces affecting similar characteristics of the Deschutes River.

(b) Percival Creek: Percival Creek which enters through Percival Cove is the only other natural tributary of Capitol Lake. It has a drainage area of 13 square miles located to the west and southwest of Capitol Lake. This area includes the 576-acre Black Lake and the 17-acre Trosper Lake. The creek flows through rolling hilly terrain of alternating pasture and forest land. Primary land use is in relatively small farming operations. Residences are scattered throughout the drainage area with heavier concentrations around the lakes and suburban development increasing with proximity to the Olympia-Tumwater-Capitol Lake area. Percival Creek has a mean annual flow of 27 cfs with flows ranging from 5 to 10 cfs in the summer and from 75 to 100 cfs in the winter. Maximum (100-year) flood flows are estimated to be about 300 cfs under natural conditions, but urbanization will tend to increase runoff rates.

The water quality in Percival Creek does not have a major effect on that of Capitol Lake because of its relatively small (6 percent) portion of total flow to the lake. It does, however, have a significant and controlling effect on water quality in Percival Cove.

(c) Other sources: Direct precipitation on the 0.44 square mile surface area averages 55 inches per year. Yearly evaporation from the lake surface averages about 20 inches per year leaving a net contribution from rainfall of 35 inches per year. This is equivalent to an average annual flow of 1.1 cfs or about one-fourth of one percent of the total average annual flow to the lake.

Borings in the lake bottom for soil surveys[12] have identified artesian aquifers at relatively shallow (<20 ft) depths below the lake bottom. It is presumed that net flow into the lake from such sources occurs. However, no estimates of such flow are available and total inflow and outflow records are not sufficiently detailed to permit such estimation.

Stormwater runoff enters the Capitol Lake directly from natural drainage and from a total of 14 storm drains serving the immediate vicinity. Plate III-200 in the previous Capitol Lake consulting report[3] details the location of these inputs. This figure also indicates that potential sanitary sewage discharge to the upper and lower basins exists from overflow pipes indicated in Fig. 50. Due to the minor magnitude of these lake inputs with respect to the surface inputs, the net effect of these flows on lake water quality is judged to be negligible.

4. Fish and Wildlife

Capitol Lake and its surroundings provide habitat for a wide variety of native fish, shore animals, resident and migratory birds, as well as for fish planted and raised for sport and commercial purposes.

a. Fish

Fish populations in Capitol Lake, particularly the salmonids, are of major importance to water quality considerations. Salmonids are among the most sensitive of all fish and require water of consistently high quality for survival and propagation. Maintenance of this fishery was a major consideration in establishing the Deschutes system as a Class A water. A somewhat competing consideration is the fact that the large numbers of fish raised in the lake require feeding operations which add significant quantities of nitrogen, phosphorus, and organic material to the lake. These materials, if not properly managed or maintained within limits of the lake to assimilate them, have potential for contributing to water quality degradation. Quantification of acceptable limits for fisheries input to the lake was not within the scope of this study. Such quantification would be recommended should major increases in the level of fish rearing be contemplated.

The Washington Department of Fisheries has managed the waters of Capitol Lake for fish production since the early 1950's and has released millions of chinook and coho fingerlings into Capitol Lake. During the period from 1967 to 1970, an average of 5,467,000 chinook were planted in Capitol

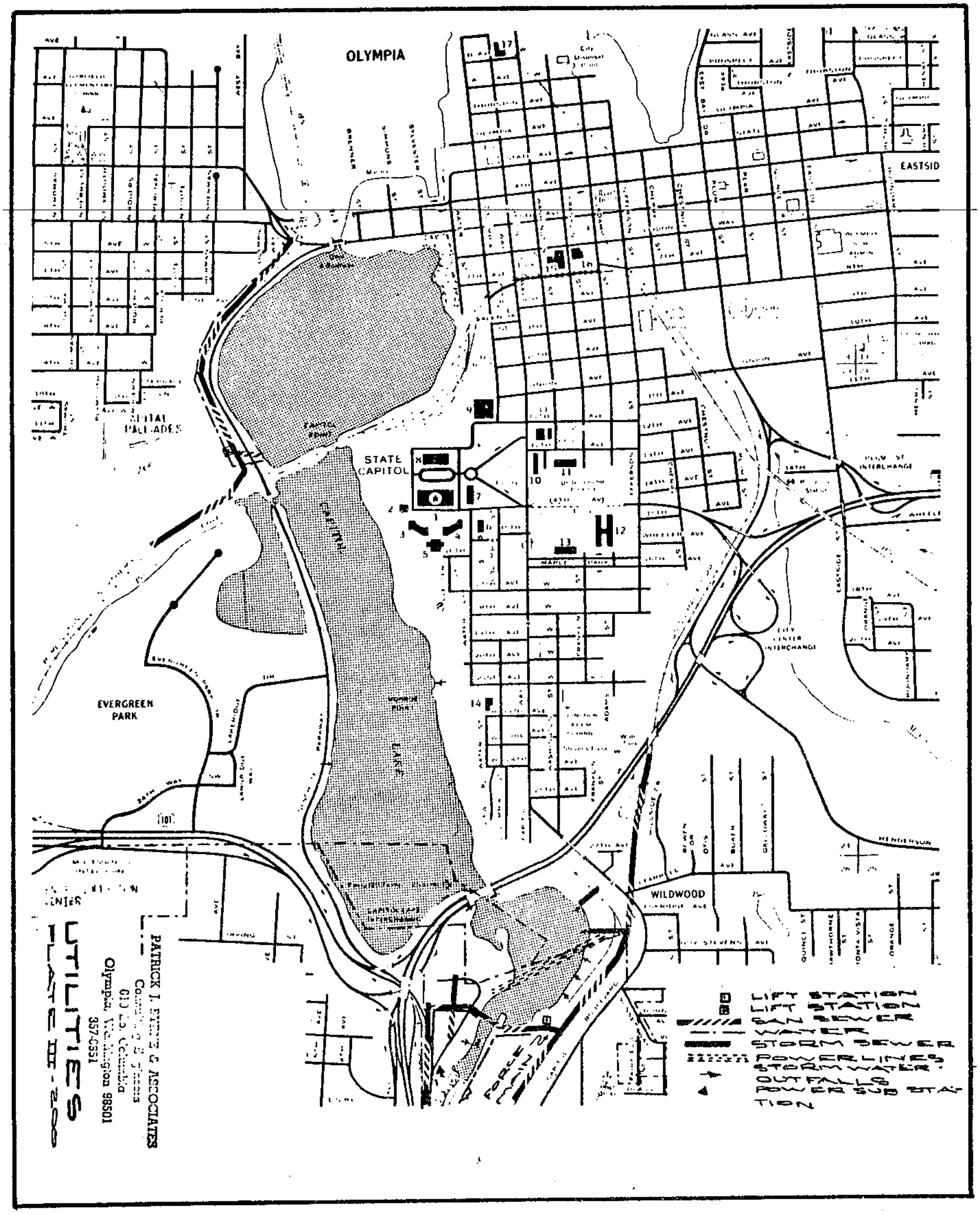

Fig. 50. Utilities in Capitol Lake Vicinity[3]

Lake annually. Lesser numbers of coho salmon have also been released. Williams, Laramie, and Ames[21] estimated that, for the five year period from 1965 to 1970, adult salmon production for the Deschutes River Basin averaged 48,400 chinook, 10,500 coho, and 23,000 chum salmon annually, and contributed between 37,800 and 79,500 fish to the harvest of various sport and commercial fisheries.

Sportfishing species in addition to the salmon include steelhead, cutthroat, and rainbow trout. Percival Creek is reported[18] to maintain native runs of all of the above species except chum salmon. The Washington Department of Game has supplemented natural populations with plants of cutthroat trout since the late 1960's.[23,24] Sportfishing only is allowed on Capitol Lake and moderate to intense activity normally occurs from late spring through mid fall.

Numerous fish species of lesser interest, referred to as scrap fish in "trout waters," are present in the lake system. Species reported[23,25] include the coarse scaled sucker, carp, catfish, redside shiners, and lesser numbers of largemouth bass, yellow perch, crappie, stickle back, and cottids. The Washington Department of Fisheries[26] has recommended management practices for minimizing populations of these scrap species as they compete with and prey on the salmonids being raised.

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[23] Finn, E. L., Jr., "Capitol Lake Fall Chinook Rearing Program," Unpublished Report, Washington Department of Fisheries, October, 1971.

[24] Finn, E. L., Jr., "Capitol Lake Fall Chinook Rearing Program," Unpublished Report, Washington Department of Fisheries, February, 1973.

[25] Finn, E. L., Jr., "Capitol Lake Fall Chinook Rearing Program," Unpublished Report, Washington Department of Fisheries, December, 1973.

[26] Finn, E. L., Jr., "A Manual for the Department of Fisheries Operations in Capitol Lake," Unpublished Report, Washington Department of Fisheries, September, 1973.

b. Wildlife

Wildlife found in and around Capitol Lake are typical of north coastal wetlands. The significance of wildlife is primarily aesthetic. A wide variety of shorebirds and water fowl are commonly found, partly attracted by the fish rearing operations. The Washington Department of Fisheries[23,24,25] has reported the presence of significant numbers of bufflehead, redbreasted and common mergansers, common gulls, bonapart gulls, and mallards with lesser numbers of grebes, common loons, belted kingfisher, and great blue heron.

Cattails, grasses, underbrush, and trees and found surrounding the lake with the normal variety of resident and migratory song birds throughout. Muskrat and beaver are active in the upper lake basin. Other wildlife are evidently limited to ubiquitous rodents.

5. Natural Vegetation

Over half of the shoreline of Capitol Lake and the hillsides rising above the lake is densely vegetated, typical of moist mild north coastal areas. The major unvegetated areas are the lower basin and Deschutes Parkway frontage, though the hillside along the west side of the middle and lower basins above the Parkway are almost entirely forested.

The natural vegetation of the area was originally dominated by Douglas fir in association with western red cedar, western hemlock, and deciduous trees such as red alder, Oregon maple, vine maple, madrona, and willow. However, the majority of the coniferous trees were logged out of the area during the early development of the county and most of the remaining forested areas are now dominated by the deciduous species listed above. The rich diversity of understory vegetation includes such plants as salal, blackberry, rose, Oregon grape, salmonberry, red huckleberry, and others. Common shrubs include cascara, dogwood, elderberry, wild cherry, service berry, hazelnut, and oceanspray. A number of genera of aquatic vascular plants also occur in, or along, the margin of Capitol Lake and include *Typha*, *Elodea*, *Potamogeton*, and other less abundant genera.

B. Water Quality History

1. Introduction

The water quality of a lake or stream expressed quantitatively and its general condition expressed in subjective terms according to community expectations are evolutionary. Historical records of water quality are ~~useful and important in any assessment of current condition of a body of~~ water in light of its unique evolution and current expectations. The following section summarizes available pertinent records of historical data on physical, chemical, and biological quality of Capitol Lake and its tributaries.

Available records of water quality in Capitol Lake and the Deschutes River are best described as scattered; virtually no quantitative records are available for Percival Creek. Earliest data for Capitol Lake, consisting mainly of biological observations, were taken by the Washington Department of Fisheries in the summer of 1955.[27,28] Subsequent fish rearing studies by the Department of Fisheries from 1968 through 1974[23-26,29-31] also include some data on various aspects of water quality. A survey of bacteriological quality in the lake was conducted in 1954 by the former Washington Water Pollution Control Commission.[32] Additional bacteriological

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[27] Engstrom-Heg, R., "Environmental Relationships of the Young Chinook Salmon in Capitol Lake and the Deschutes River System," State of Washington, Department of Fisheries, 1955.

[28] Engstrom-Heg, R., "Diet and Growth of Juvenile Salmon in an Esturial Impoundment," Washington Department of Fisheries, Fisheries Research Paper, Vol. 3, No. 1, August, 1968.

[29] Kral, K., "A Progress Report on the Water Weed Chemical Control Program in Capitol Lake, 1969," Unpublished Report, Washington Department of Fisheries, April, 1970.

[30] Travers, G., "Yearling Chinook Rearing Program at Percival Creek," Unpublished Report, Washington Department of Fisheries, June, 1974.

[31] Finn, E. L., Jr., and Tarr, M. A., "Chemical and Biological Factors for Consideration in the Management of the Deschutes River--Capitol Lake," Unpublished Report, Washington Department of Fisheries, March, 1975.

[32] Peterson, D. R., "Sewage Pollution in Capitol Lake and Budd Inlet," Unpublished Report, Washington Water Pollution Control Commission, 1954.

data have been taken by the Thurston County Health Department from 1963 to the present. Information on bottom sediment composition is available from studies conducted by other agencies.*

Available records of water quality in the Deschutes River up to 1969 were summarized in a 1970 report of the Pacific Northwest River Basins Commission.[20] Data on a variety of physical and chemical parameters were available from an upstream station (Rainier) from July, 1959, through August, 1962, and for a downstream station (Tumwater) from October, 1962, through 1969. Subsequent data on river water quality have been taken from 1970 to the present by a cooperative effort of the Department of Ecology and the U.S. Geological Survey. Additional data from two lower river stations (Gleason Rd. and Metalcraft Bridge) were taken by the Department of Fisheries in the year 1969-70.[31]

2. Water Quality Summary--Deschutes River and Percival Creek

a. Physical Characteristics

Physical quality characteristics of the Deschutes River are typical of the northern Pacific coastal mountain drainages, dominated by climatological factors, in particular, precipitation. Hydrologic patterns, detailed earlier in this report, follow the pattern of seasonal precipitation. The average seasonal flow pattern of the Deschutes is illustrated by variation of mean monthly discharge in Figure 51.

The greater variation occurring for individual water years in river discharge and other closely related water quality parameters is illustrated by Figures 52, 53, and 54. This summary of mean monthly and monthly cumulative discharge for the period of existence of Capitol Lake shows the magnitude of variation in discharge in individual years as well as variations occurring from year to year.

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*See Bibliography in Ref. 3.

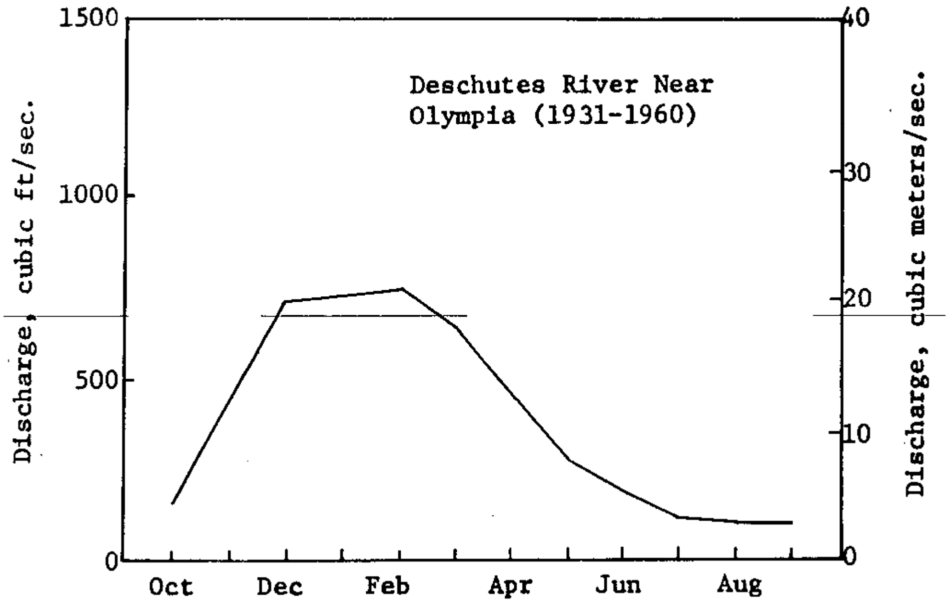

Fig. 51. Mean Monthly Discharge, Deschutes River Near Olympia (1931-1960)

Temperature and turbidity are the major physical quality characteristics of interest. Data from the Department of Fisheries Study in 1969-70[31] (Figure 55) illustrates the temperature variation observed. Discharge records (Figure 54) indicate that flow and variation for this period closely approximate long-term average conditions, thus temperatures observed may be considered typical. Observed river temperatures ranged from 3.6 to 15°C (38 to 63°F) with minimum temperatures observed in December through February and maximums occurring in June through August. Temperature differences between the two stations (Reichle Rd. @ RM-32 and just above Tumwater Falls @ RM-2.2) were slight though increasing with distance downstream. Maximum differences of 3-4°C were observed in midsummer and midwinter.

From the same study, data on total suspended solids (roughly equable to turbidity) is summarized in Figure 56. It is apparent that suspended solids in the river vary in direct proportion to discharge. In general, solids concentrations increased from the upstream to the downstream station with the effect most pronounced at highest discharge (62 mg/l vs 207 mg/l in January). Through the low discharge period, March-October,

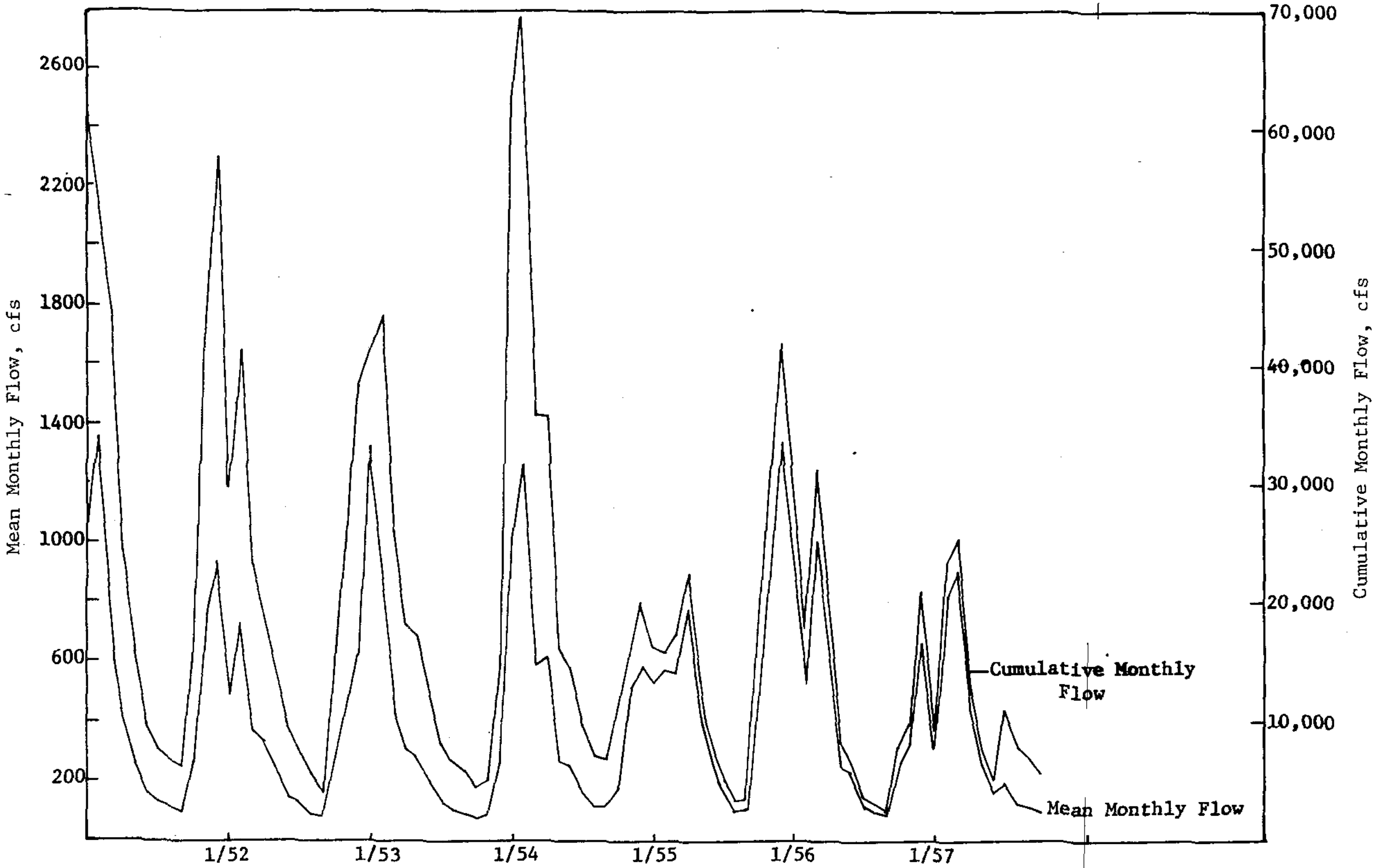

Fig. 52. Mean Monthly and Cumulative Monthly Discharge, Deschutes River at Olympia, 1951-57

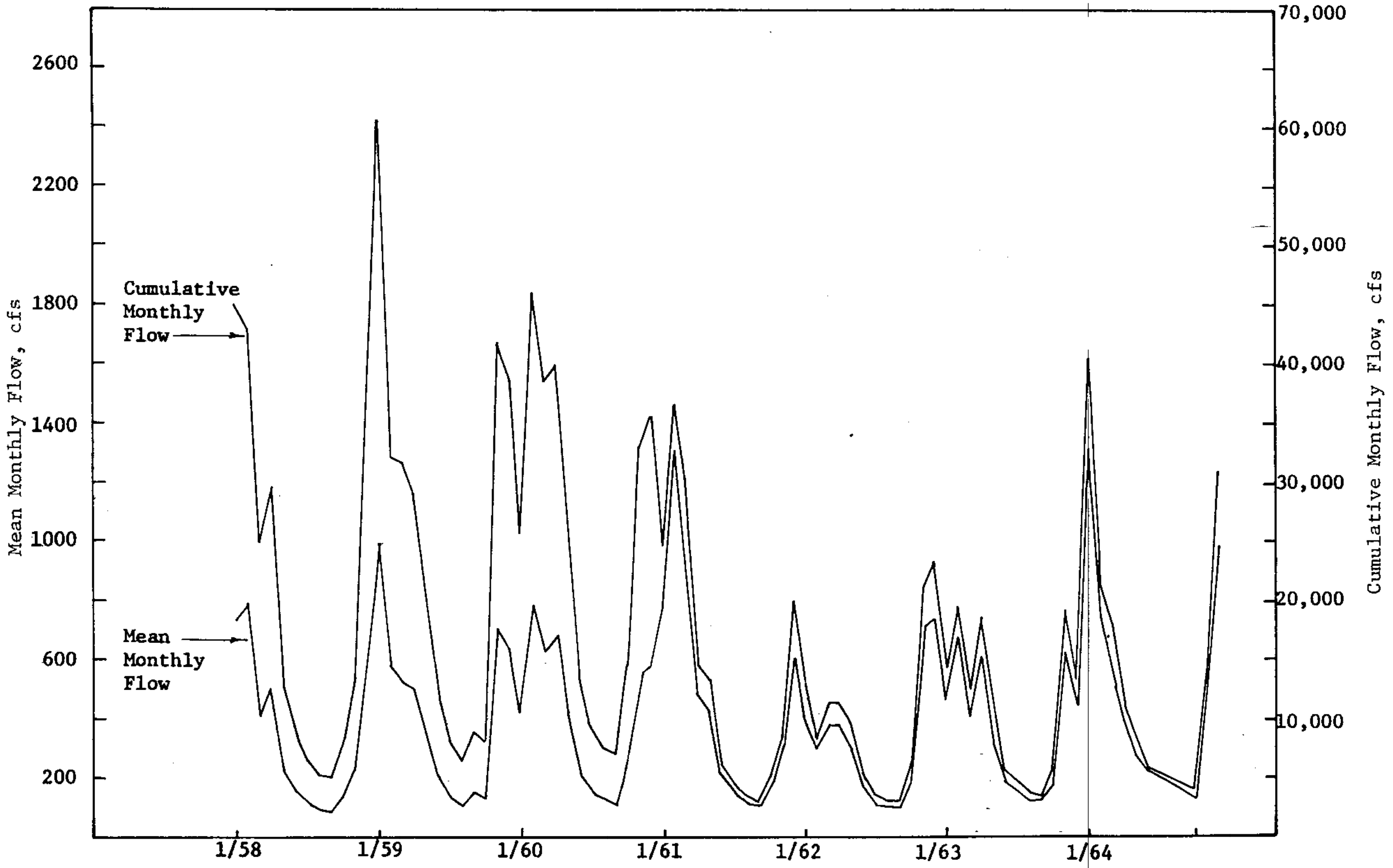

Fig. 53. Mean Monthly and Cumulative Monthly Discharge, Deschutes River at Olympia, 1958-64

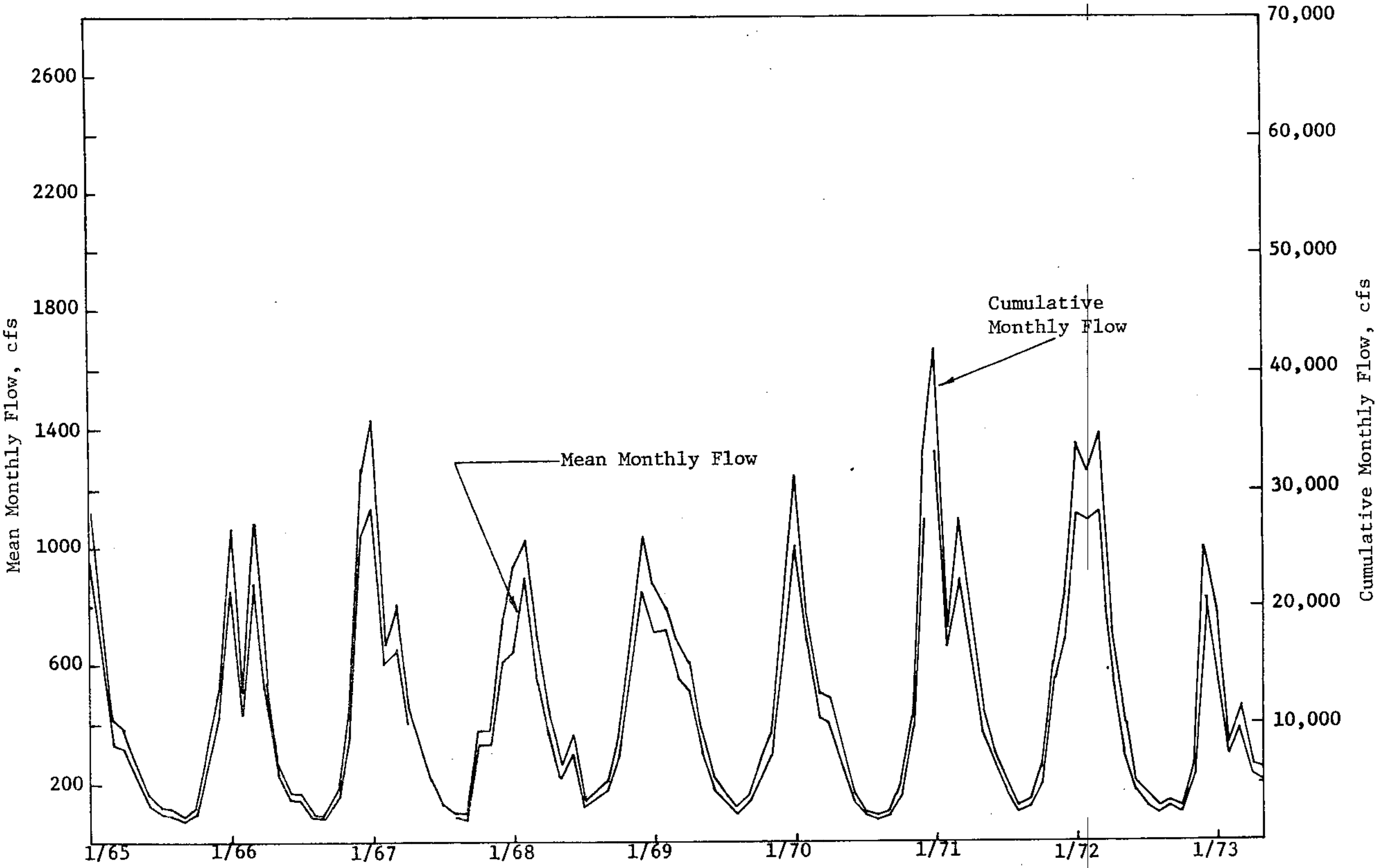

Fig. 54. Mean Monthly and Cumulative Monthly Discharge, Deschutes River at Olympia, 1965-73

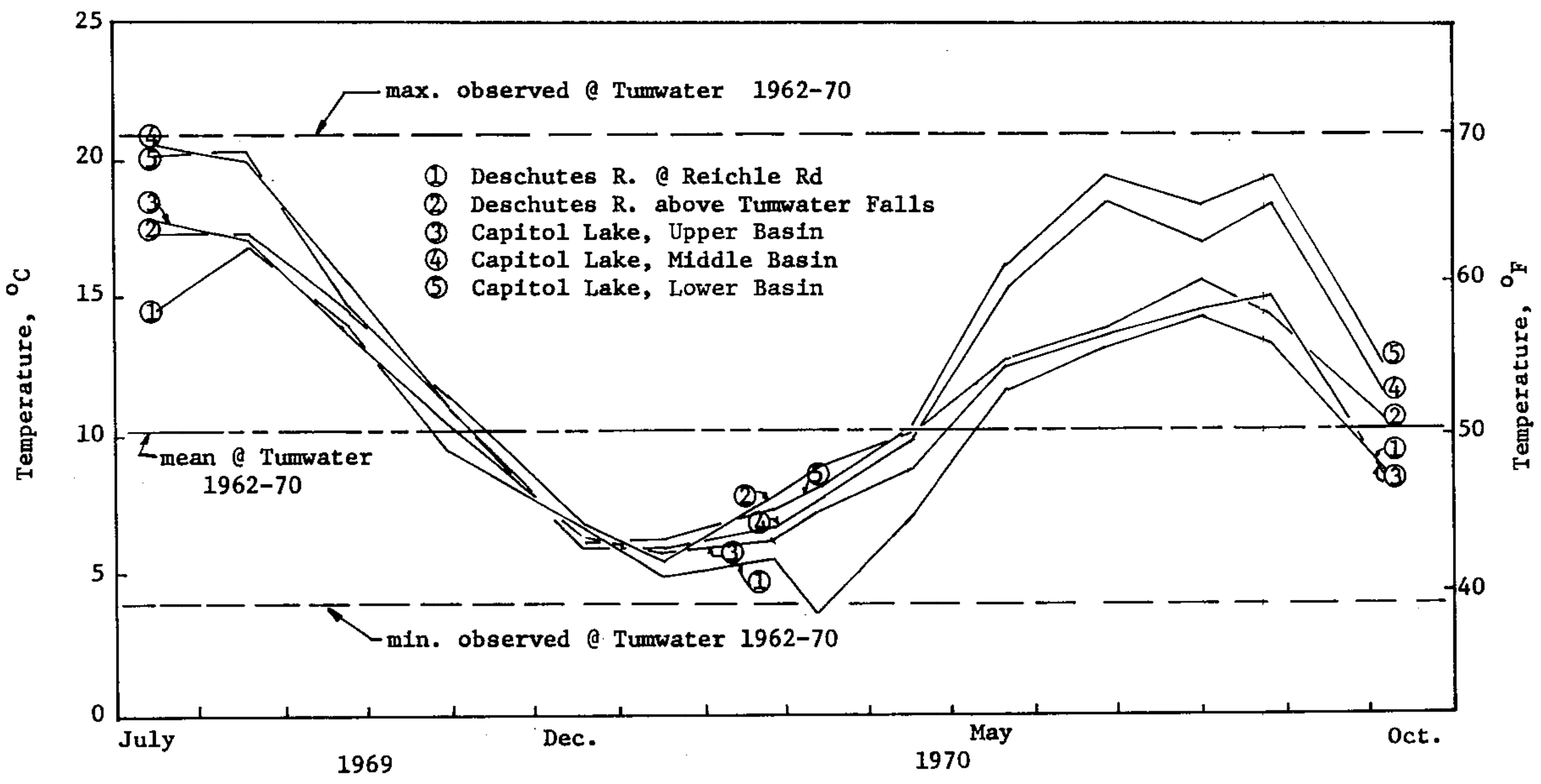

Fig. 55. Monthly Temperatures, Deschutes River and Capitol Lake, 1969-70

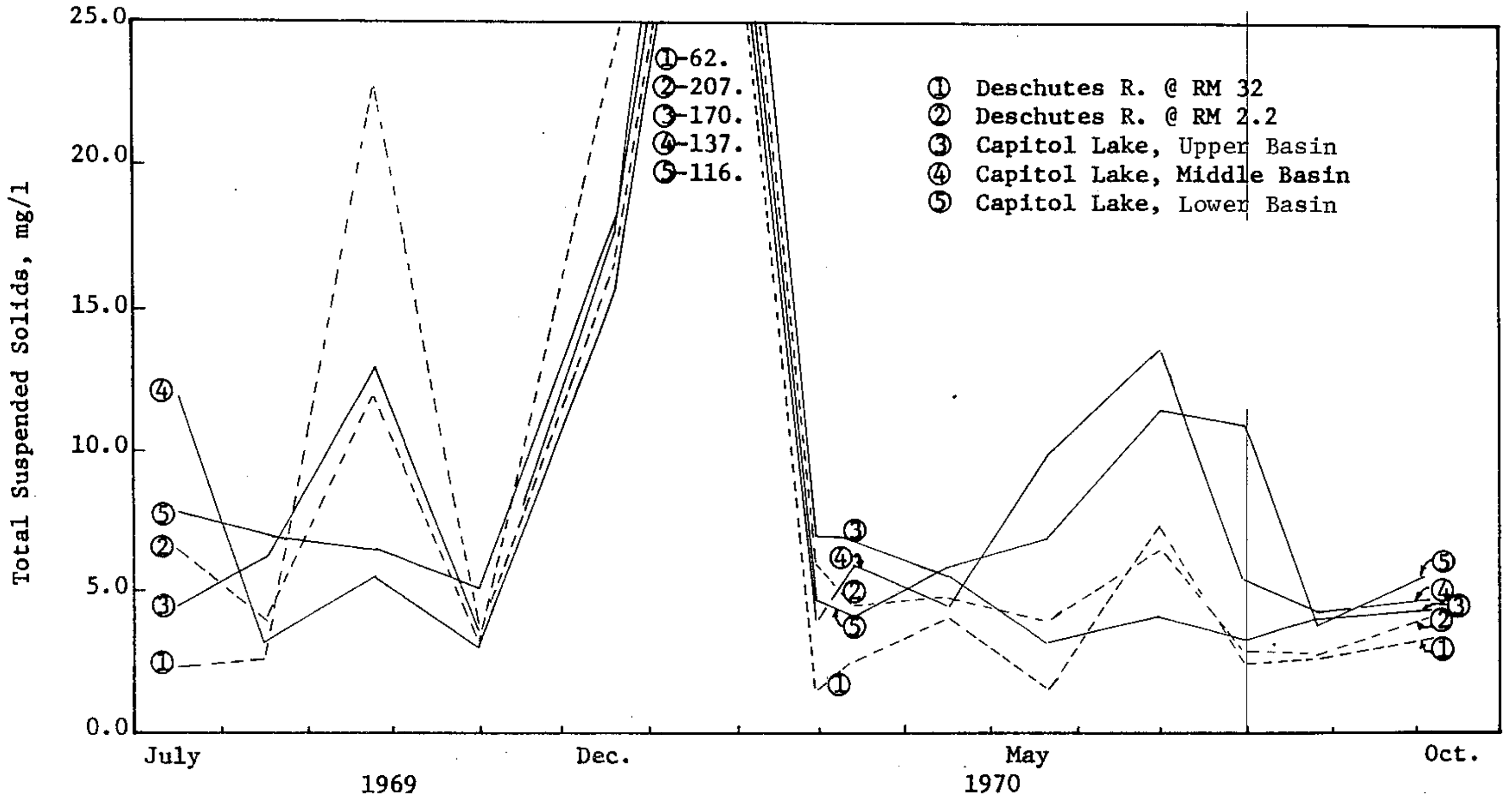

Fig. 56. Total Suspended Solids, Deschutes River and Capitol Lake, 1969-70

solids in the river remained below 5 mg/l with less than 2 mg/l difference between the upstream and downstream stations.

b. Chemical Characteristics

Chemical quality parameters of significance in the river include pH and dissolved oxygen, for which Class A standards are specified, and concentrations of nitrogen and phosphorus because of their generally critical importance to the growth of weeds and algae. A summary of water quality data for the Deschutes River by the Department of Ecology[20] is given in Table 26. Selected parameters from this table are summarized in detail with additional STORET data covering the period up to 1975 (Figure 57, 58, 59, and 60.

Total dissolved solids and closely related conductivity (Figure 57) are seen to vary in direct proportion to discharge. Total dissolved solids, a measure of the degree of mineralization of the water, ranged between 55 and 90 mg/l. By comparison it is reported[33] that among inland waters in the United States, five percent have dissolved solids concentrations less than 72 mg/l and 50 percent less than 170 mg/l.

Observed dissolved oxygen concentrations (Figure 58) have consistently met the Class A standard of 8.0 mg/l minimum. Concentrations are generally observed to be between 90 and 100 percent of saturation and thus will increase in absolute concentration with colder temperatures in winter and decrease with warmer water in summer.

Concentrations of the critical plant nutrients, nitrogen and phosphorus, recorded for the Deschutes at Olympia from 1962 to the present, are summarized in Figures 59 and 60. More detailed data taken by the Department of Fisheries in 1969-70[31] are summarized in Figures 61 and 62. Figures 59 and 60 show a mean nitrate-N concentration trending toward 0.3 mg/l and mean orthophosphate-P concentration of about 0.015. Figure 61

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[33] McKee, J. E., and Wolf, H. W., Water Quality Criteria, California Water Quality Control Board Publication No. 3-A, 1963.

Table 26. Water Quality, Deschutes River, 1959-70[20]

Item	Discharge (cfs)	Dissolved solids	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Postassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Cloride (CI)	Fluoride (F)	Nitrate (NO_3)	Specific Conductance (µmho)	Orthophosphate (PO_4)	Total phosphate (PO_4)	Silica (SiO_2)	Iron (Fe)	Boron (B)	pH	Color (standard units)	Turbidity (JCU)	Temperature (°C)	Dissolved oxygen	Oxygen saturation (%)	Total hardness	Noncarbonate hardness	Coliform (MPN)
		mg/1												mg/1									mg/1		mg/1		
DESCHUTES RIVER NEAR RAINIER																				JULY 1959 THROUGH AUGUST 1962							
Maximum	744	91	12.0	3.2	7.4	0.9	54	0	3.4	12.0	0.1	0.7	131	0.13	--	23.0	0.48	0.02	7.7	25	5	17.2	11.9	106	43	1	930
Mean	--	67	9.0	2.1	5.1	0.5	40	0	2.0	5.8	0.1	0.4	88	0.05	--	19.1	0.17	0.01		--	-	10.2	10.5	96	31	0	170
Minimum	36	46	5.5	1.0	3.1	0.2	27	0	1.0	2.0	0.0	0.1	55	0.00	--	16.0	0.03	0.00	6.9	5	0	5.9	8.0	68	19	0	0
Number	21	21	21	21	21	21	21	8	21	21	21	21	21	21	--	21	21	4	21	21	4	21	21	21	21	21	21
DESCHUTES RIVER AT TUMWATER																				OCTOBER 1962 THROUGH 1970							
Maximum	1750	89	12.0	3.8	7.1	1.2	52	0	3.8	11.0	0.1	1.6	122	0.12	--	25.0	0.88	0.03	7.8	20	30	20.1	11.7	118	46	3	2400
Mean	--	74	9.0	2.7	5.5	0.9	41	0	3.2	6.6	0.1	1.1	95	0.07	--	20.7	0.36	0.01	--	--	--	10.1	10.7	97	34	1	646
Minimum	175	54	5.5	1.7	3.8	0.4	25	0	2.2	2.5	0.0	0.6	59	0.00	--	16.0	0.16	0.00	6.6	5	0	4.0	8.7	88	20	0	0
Number	6	15	15	15	15	15	15	15	15	15	15	15	15	12		15	11	6	15	15	10	16	16	16	15	15	16

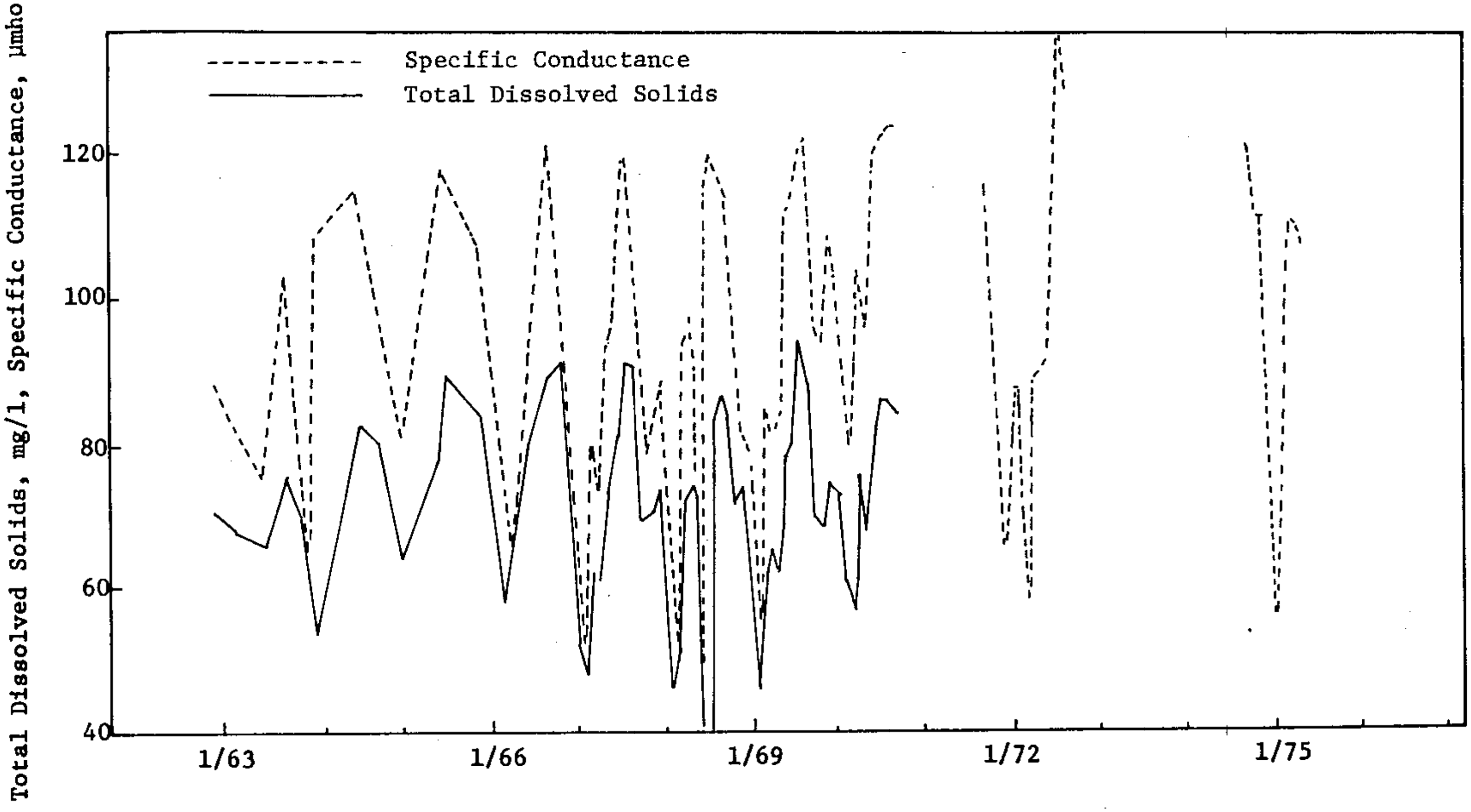

Fig. 57. Total Dissolved Solids and Specific Conductance, Deschutes River at Olympia, 1962–75

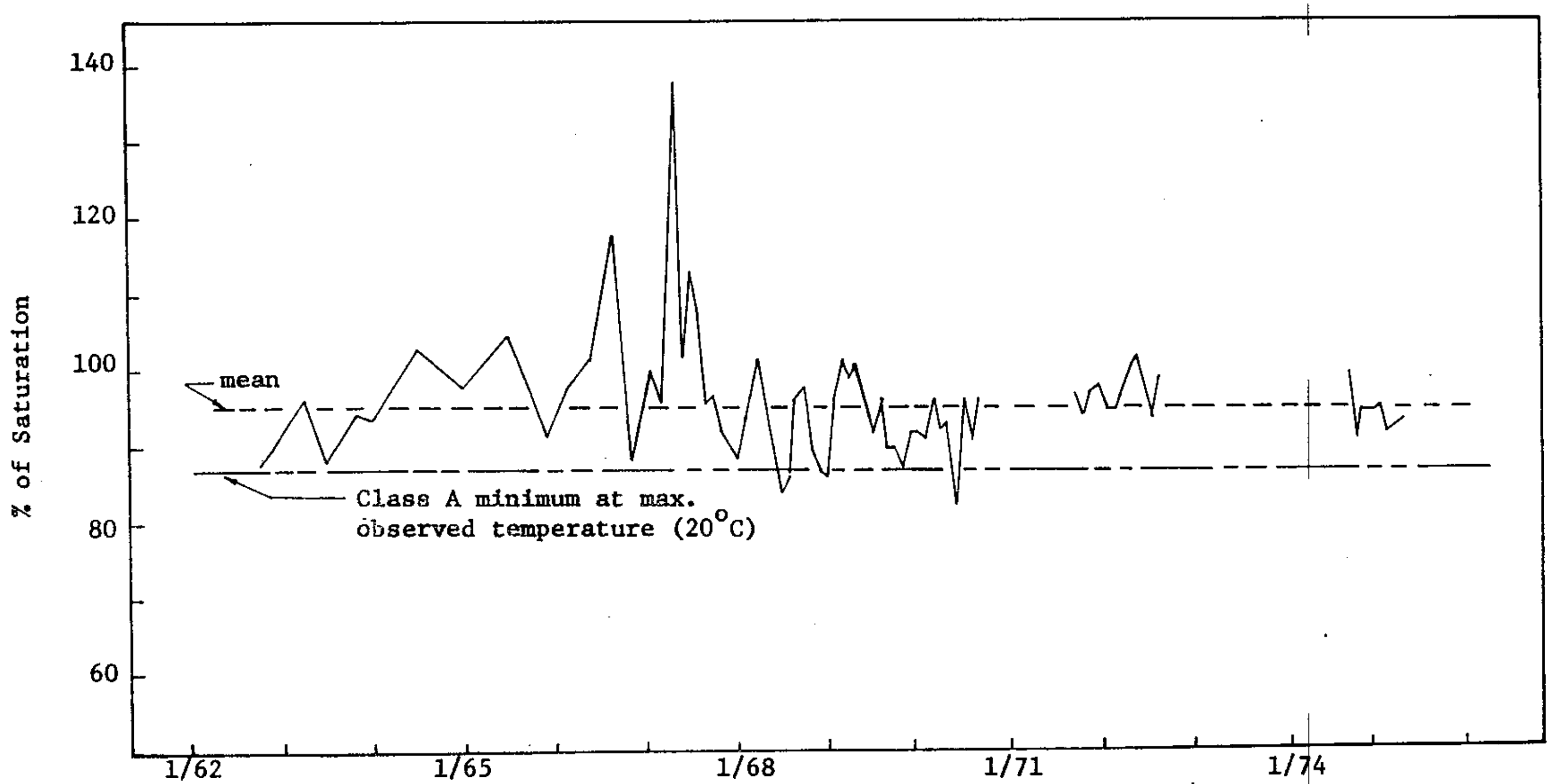

Fig. 58. Dissolved Oxygen, Percent of Saturation, Deschutes River at Olympia, 1962-75 (STORET)

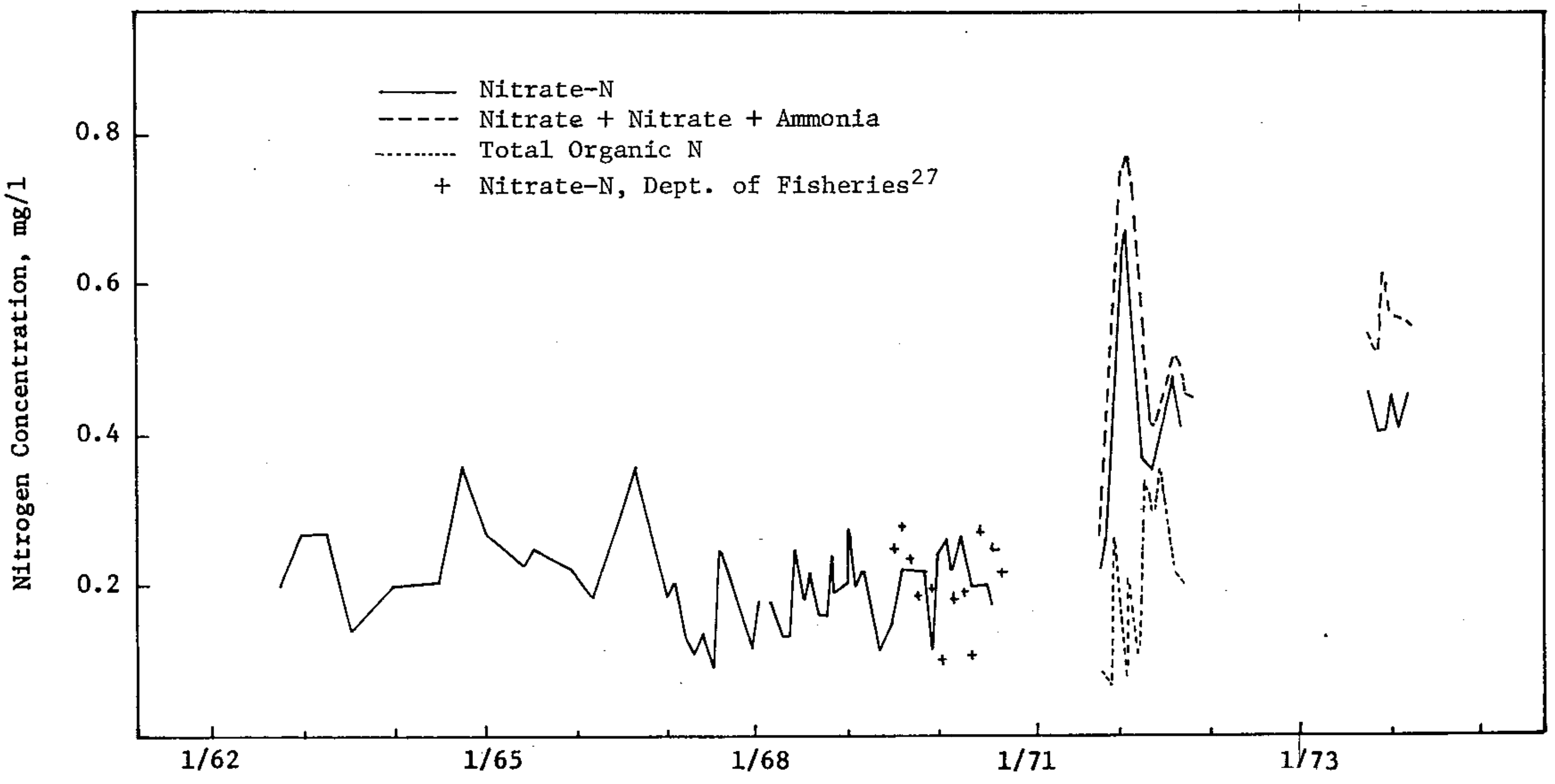

Fig. 59. Nitrogen Concentration, Deschutes River at Olympia, 1962-75 (STORET)

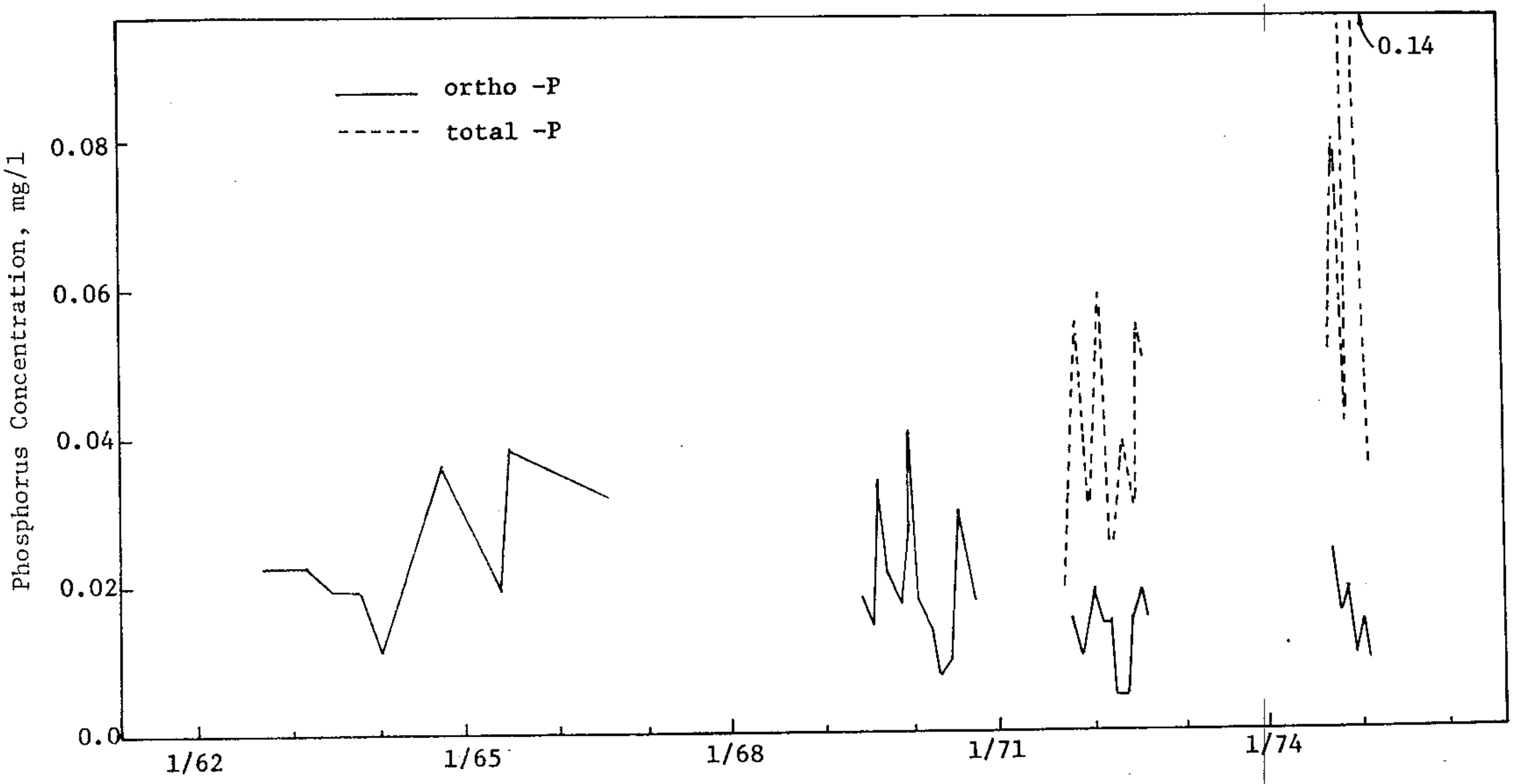

Fig. 60. Phosphorus Concentration, Deschutes River at Olympia, 1962-75 (STORET)

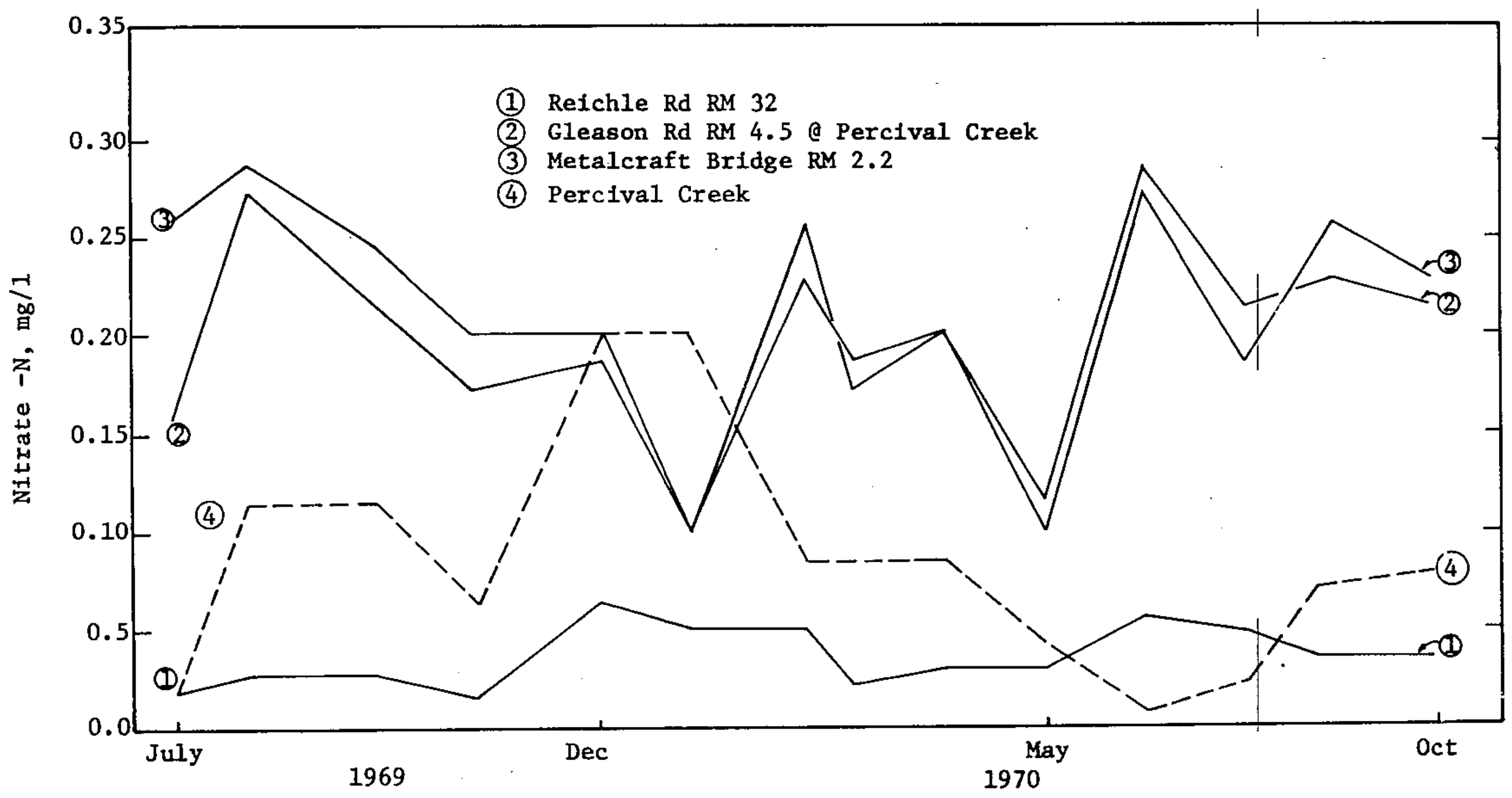

Fig. 61. Nitrate-N, Deschutes River and Percival Creek, 1969-70[32]

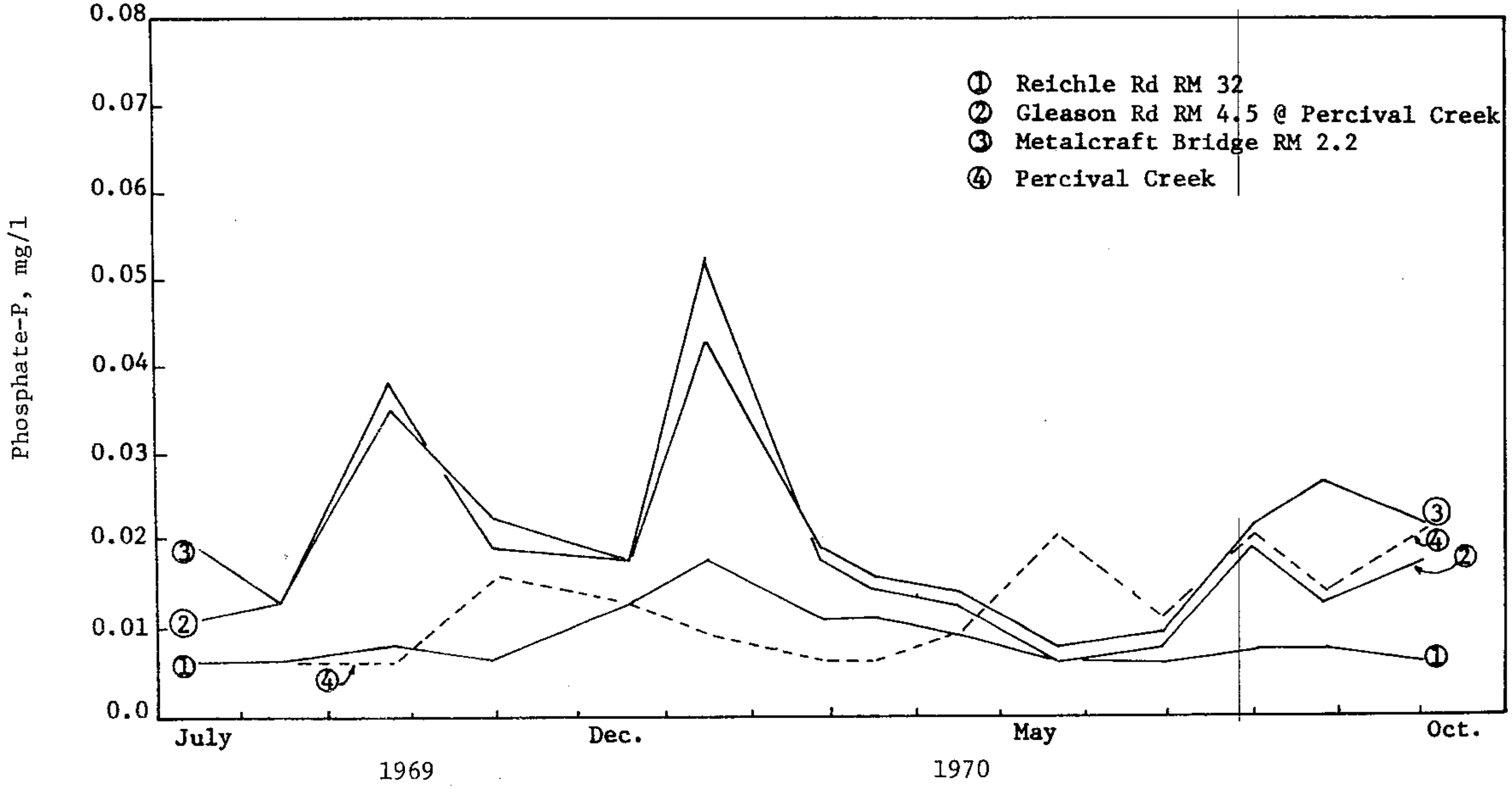

Fig. 62. Phosphate-P, Deschutes River and Percival Creek, 1969-70[32]

indicates a four to fivefold increase in nitrates as the river travels through the rural forest and agricultural land between RM-32 and RM-4.5. Phosphates also increase as the river approaches Tumwater although the magnitude is somewhat less than for nitrates. While variations in nitrate and phosphate concentrations are evident from Figures 61 and 62 it is difficult to assess their impact on the lake owing to lack of information on the complimentary inorganic and organic forms of these elements.

c. Biological Characteristics

Bacteriological quality of the Deschutes River varies widely. Data summarized in a recent river basin study[20] indicates that 50 percent of the samples taken between 1962 and 1970 at Olympia-Tumwater exceeded the Class A standard median value of 240 total coliforms. Moreover, 21 percent of the samples have exceeded 1000 total coliform and 14 percent exceeded 2400 total coliform. The impact of land use in the drainage between RM-32 and RM-4.5 is illustrated by the fact that 86 percent of the samples taken at RM-32 fell within the Class A standard.

The fish population in the river is the only other portion of the biological community for which significant records are available. Fish native to the Deschutes River system are summarized in Table 27.[21]

Table 27

Native Fish, Deschutes River System

Lampetra planeri, Block	brook lamprey
Salmo clarki clarki, Richardson	coastal cutthroat trout
Prosopium williamsoni	Rocky Mountain whitefish
Richardsonius balteatus	redside shiner
Apocope oscula nubila	blacksided dace
Gasterosteus aculeatus	three-spined stickleback
Cottus asper	prickly sculpin
Castostomus macrocheilus	coarse-scaled sucker

Fish introduced to the Deschutes River system (Table 28) include species of commercial and sport significance and some additional less desirable species. The earliest attempt to develop a chinook run in the Capitol Lake area occurred in 1951 with the release of 250 females allowed to spawn naturally in the Capitol Lake-Percival Creek area.[34] Chinook and other migratory species access to the Deschutes headwaters and to the Percival Creek drainage was provided by construction of fishways in the Capitol Lake Dam, Tumwater Falls and in impassible portions of Percival Creek.

Table 28

Non-Native Fish, Deschutes River System

Scientific Name	Common Name
Oncorhynchus tshawytscha	chinook salmon
Salmo gairdneri	rainbow trout
Oncorhynchus kitsutch	silver salmon
Oncorhynchus keta	chum salmon
Cyprinus carpio	carp
Ictalurus nebulosus	catfish
Micropterus salmoides	large-mouth bass
Lepomis gibbosus	sunfish

2. Water Quality Summary--Capitol Lake

a. Physical Characteristics

Physical water quality characteristics of Capitol Lake of interest and for which usable records exist include temperature and turbidity or suspended solids concentration. These characteristics are expected to vary as

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[34] Fitzgerald, J., "Deschutes Progress Report, 1956," Unpublished Report, Washington Department of Fisheries, 1956.

influenced by incoming flow from the Deschutes, by seasonal variations in climatological factors, and by the physical characteristics of the lake itself.

Temperature of water in Capitol Lake is expected to fall generally within the range of temperatures observed in the Deschutes River as it enters the lake. Temperatures in the Deschutes at Tumwater from 1962-70 were seen to range from 4 to 20°C with a mean of 10°C (Table 27). Temperatures recorded monthly in Capitol Lake from July, 1969, to October, 1970 (Figure 55) fell within this range. As can be seen from the figure, temperatures in the lake varied over the seasonal cycle, always within 3-5°C of the temperature in the river just above the inlet. A gradual warming of the water as it passes from the upper to the lower basin is evident in summer periods, the largest increase (2-3°C) occurring in the middle basin. Vertical temperature stratification with establishment of an identifiable thermocline has never been reported to occur in any of the three basins. However, segregation of cooler denser river water in the vicinity of the deeper river channel along the eastern side of the middle basin and through the center of the lower basin was reported by Engstrom-Heg.[27] This condition was reported to persist throughout the summer months.

Turbidity in Capitol Lake, as illustrated by data from the 1969-70 Department of Fisheries study,[31] can be seen to follow conditions in the river, particularly during periods of high discharge (Figure 56). During high flow, solids were observed to decrease from the upper to the lower basin (170 mg/l, 137 mg/l, 116 mg/l) due to settling processes in the lake. During the summer period, when incoming suspended solids were very low, solids concentrations were observed to increase through the lake. The increasing solids during this period were undoubtedly due largely to algae growth as supported by chlorophyll-A measurements to be discussed subsequently.

b. Chemical Characteristics

As in tributaries to the lake, chemical quality parameters of interest include those for which specific standards exist, pH and dissolved oxygen, and parameters closely related to or having a significant influence on the visual or aesthetic quality of the lake; plant nutrients (nitrogen and phosphorus) and indicators of algal activity, chlorophyll-A. Data on these characteristics from the Department of Fisheries study in 1969-70[31] are summarized in Figures 63, 64, and 65.

As shown in Figure 63, pH of water in the upper basin closely follows that in the Deschutes River just upstream, though a measurable increase of up to one-half pH unit was observed in the upper basin in the peak of the growing season. Overall, incoming pH can be seen to vary by approximately one unit from 7.3 to 8.3 through the 16 months of observation. Chlorophyll-A and pH are presented together in Figure 63 because of their close association in lakes, attributable to the influence of controlling biological processes. Chlorophyll-A is a green pigment in plants and is an indicator of the general level of algal activity in lakes. The growth of algae in lakes requires dissolved carbon dioxide and as this is removed from the water the pH is increased. This interaction is clearly evident in Figure 63. In the winter period when photosynthetic activity and algal growth is minimal little difference in pH and chlorophyll-A is observed through the lake. In the summer increasing photosynthetic activity from upper to lower lake is evidenced by increasing pH and chlorophyll-A measurements. In comparison to other lakes the observed summer season level of chlorophyll-A, ranging from 5-15 mg/m^3 is in the range of meso-eutrophic or moderately productive lakes.[35] The peak value of nearly 50 mg/m^3 observed in the lower basin at the end of July, 1970, is well within the range typical of eutrophic or highly productive lakes. This observation suggests the potential for heavy algal growth in the lake when growing conditions are optimal, i.e., low flows, warm, clear and calm weather.

Nitrogen and phosphorus concentrations of water flowing into the through Capitol Lake in the 1969-70 period are shown in Figures 64 and 65.

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[35] Vollenweider, R. A., "Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters, With Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication," O.E.C.D., Paris, September, 1968.

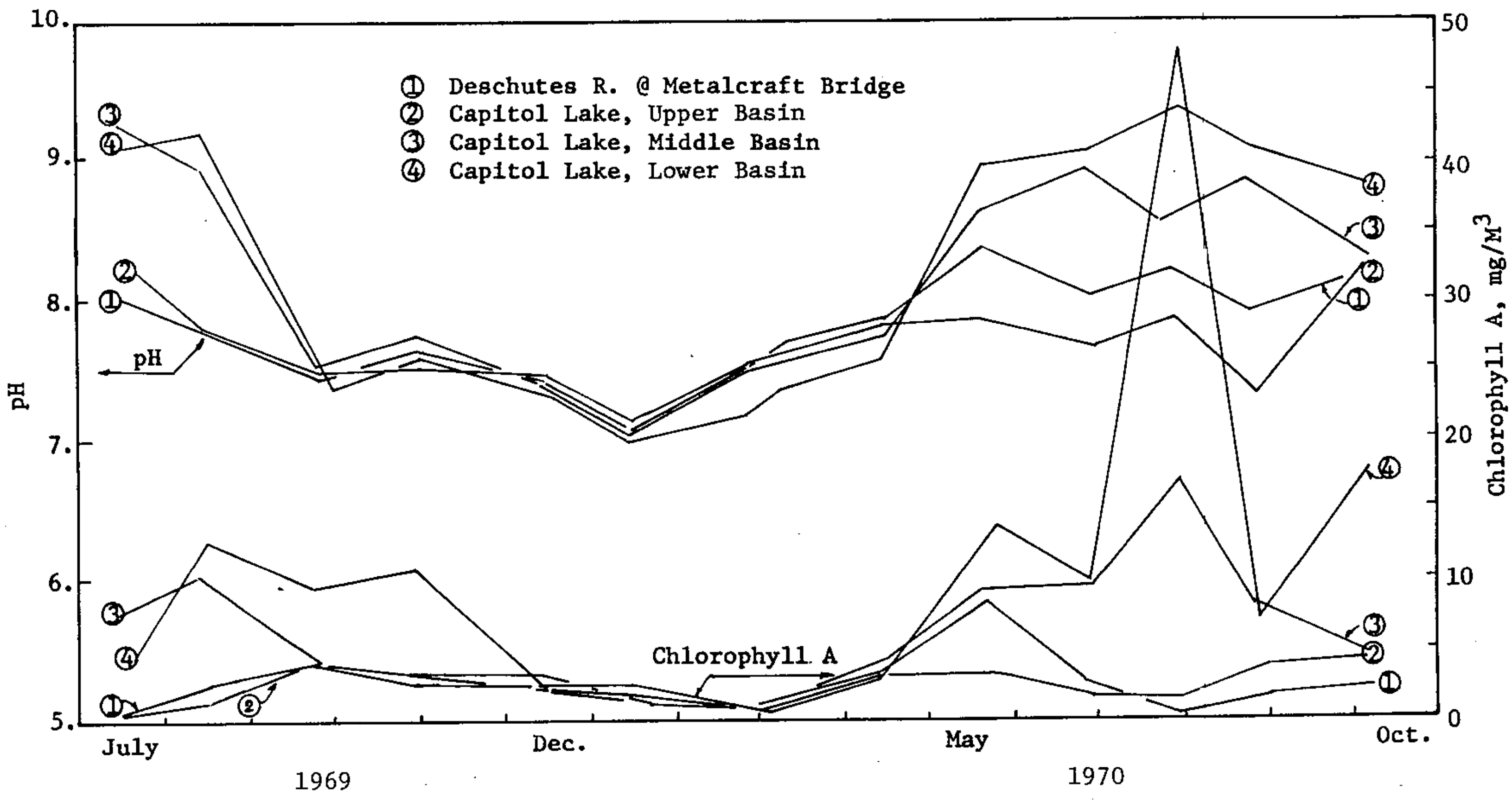

Fig. 63. Mean Monthly pH and Chlorophyll-A at Surface, 1969-70

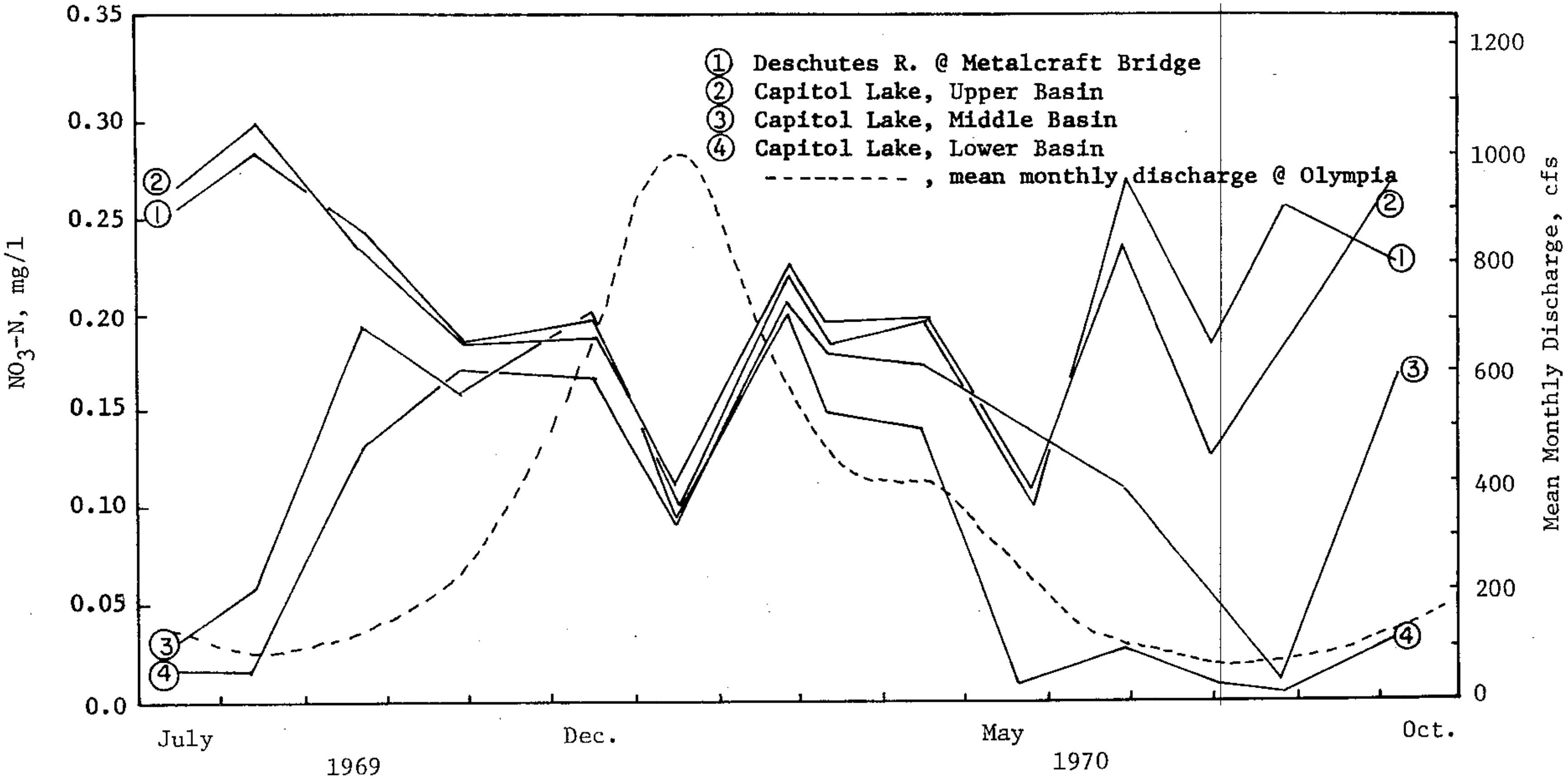

Fig. 64. Mean Monthly Nitrate Nitrogen at Surface, 1969-70

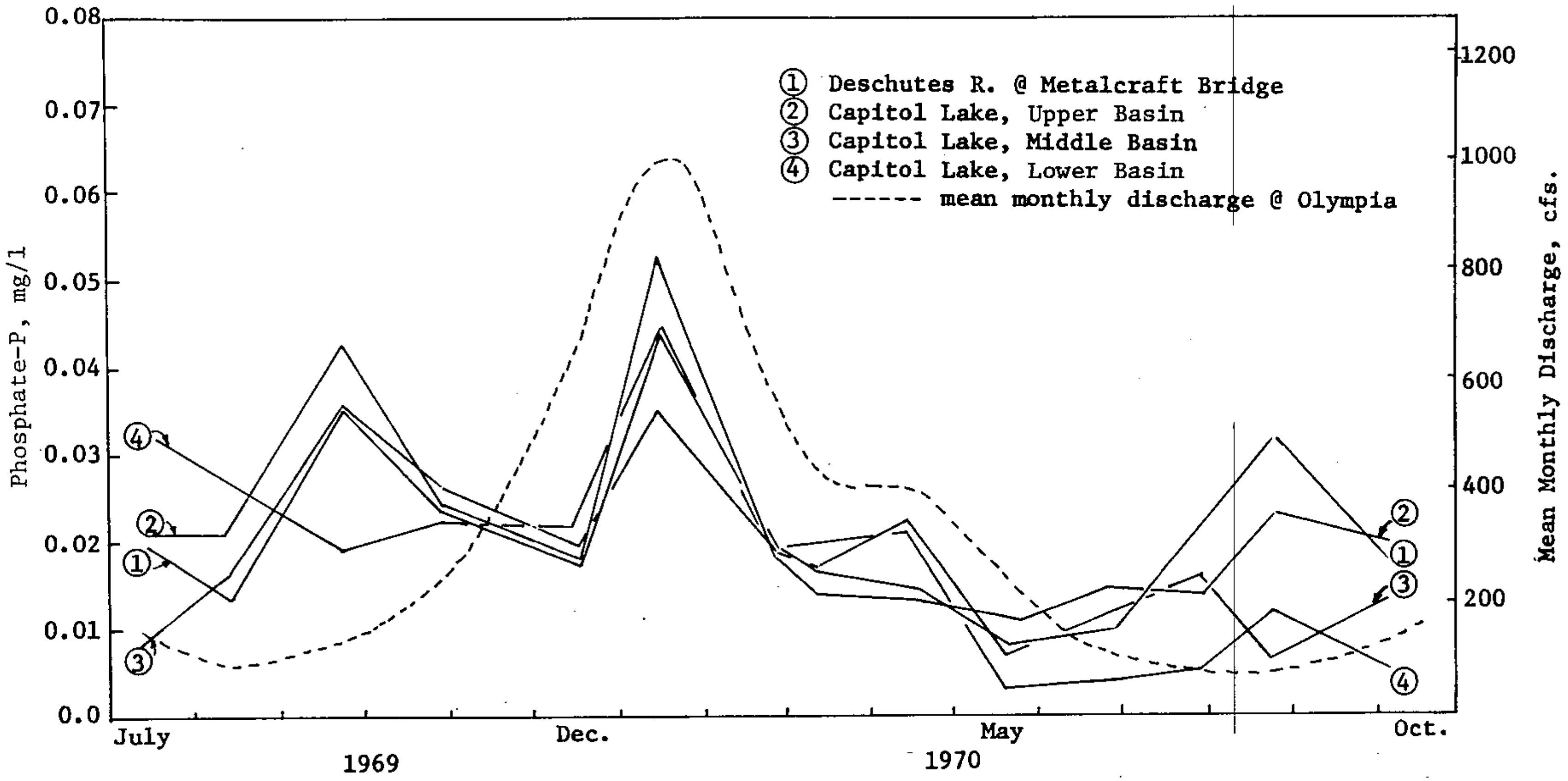

Fig. 65. Mean Phosphorus at Surface, 1969-70

Comparison of nutrient concentrations to the superimposed hydrographs shows that incoming phosphorus concentrations followed river discharge quite closely through summer and winter periods. On the basis of the direct relation shown between flow and phosphorus it appears as if phosphorus loading (pounds of P/unit volume) decreases during critical summer months. However, without information on particulate and organic phosphorus entering the lake this conclusion cannot be drawn.

While flow and nitrate concentration are shown to be inversely related (Figure 64), if nitrate loading (the product of flow and concentration) is computed it can be seen that nitrogen loading to the lake also varies in direct proportion to discharge. Compared to soluble orthophosphorus loading, the nitrate nitrogen loading was observed to be relatively greater through the 1970 summer period.

c. Biological Characteristics

Bacteriological records exist for most of Capitol Lake's history. In a survey of sewage pollution in Capitol Lake and Budd Inlet conducted by the Washington Water Pollution Control Commission in 1954,[32] bacteriological data for 18 stations in and around the lake were summarized for 1953 and 1954 (Table 29). Sampling station locations are given in Figure 66.

Data summarized in Table 29 show bacteriological quality in the lake in 1953-54 to be relatively poor. Data from stations 9, 10, 11 and 12 surrounding the present swim area indicate that the water was not of bathing quality at that time. It is pointed out in the accompanying WWPCC report that the lake was at that time receiving considerable sewage discharge that no longer enters the lake. Bacteriological records for Capitol Lake maintained by the Thurston-Mason County Health Department covering the period from 1963 to present are tabulated in Appendix D (Table D1). The records show considerable variation in coliform counts over the period of record for samples taken from the present swimming area. Data for summer swimming seasons since 1969 indicate that the Class A standard of total coliforms/100 ml has been met consistently since that time.

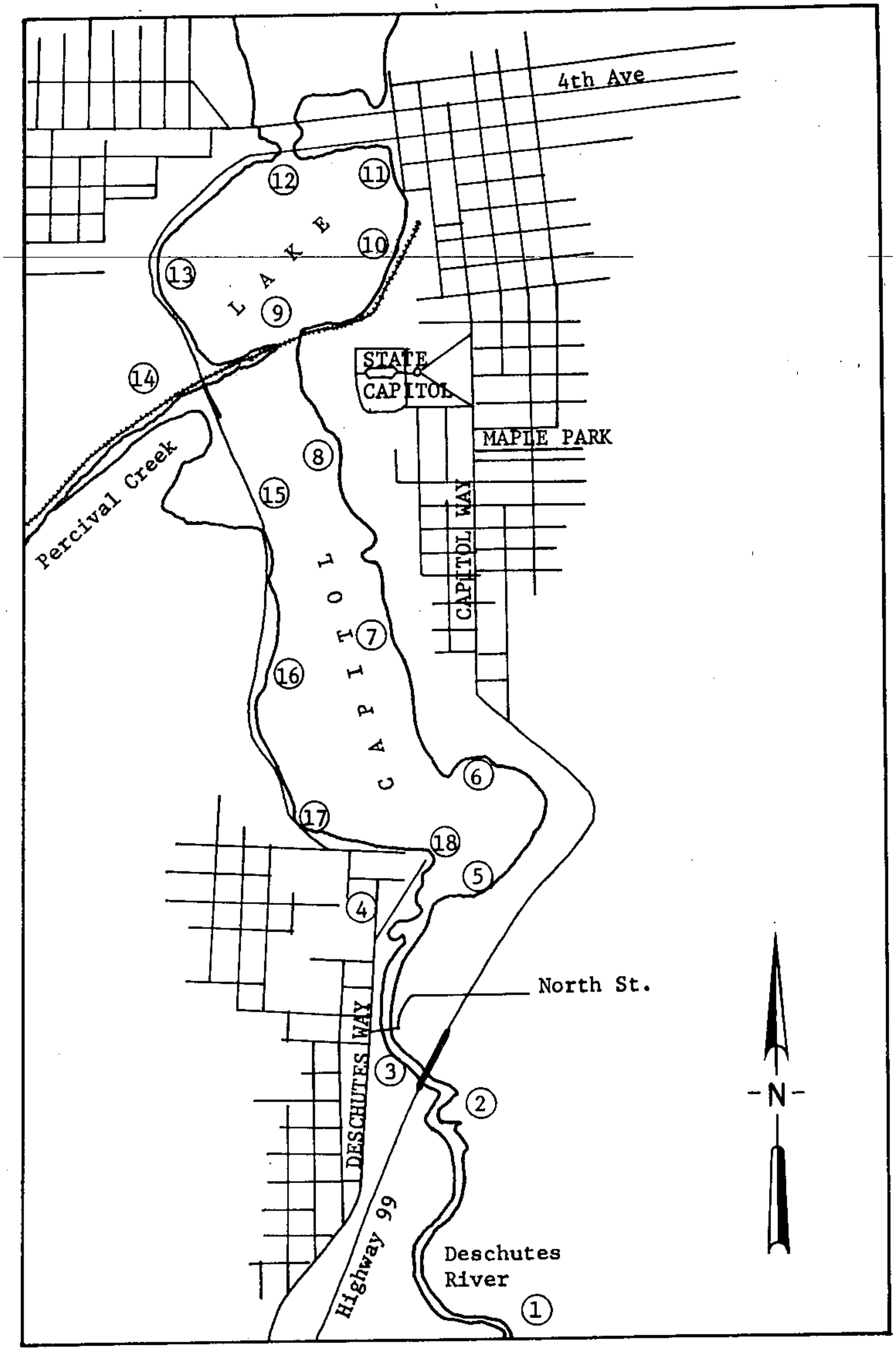

Fig. 66. Sampling Stations for Bacteriological Survey,[32] 1953-54, Deschutes River and Capitol Lake Survey Area

Table 29.
Bacteriological Quality, Capitol Lake, 1953-54

Station	7-23-53	7-13-54	10-21-54	Location
1		62	62	Control station on Grange Hall Road.
2		690	690	Swimming area - under highway 99 bridge.
3		620	24,000	Dam crest.
4	24,000	24,000	6,900	Power house basin.
5	620	230	24,000	Offshore - General Metalcraft.
6	230	620	2,400	Offshore - in cove.
7	1,300	2,400	6,900	Offshore - foot of 22nd Ave. N.
8	60	6,900	620	Offshore - below Legislative Building.
9		620	1,300	Railroad bridge.
10	620	6,900	24,000	Vicinity - Railroad station.
11		2,400	620	Vicinity - Capitol City Forging & Western Heating.
12	60	230	2,400	Lake Outlet - tide gate.
13	23	2,400	230	Offshore - foot of 10th Ave. W.
14	2,400	60	230	Percival Creek.
15	2,100		6,900	Opposite Station 8.
16	620		6,900	Opposite Station 7.
17	230	230	2,400	In cove - foot of Irving St.
18	5,000	620	6,900	Offshore - Point at foot of Simmons Road.

No quantitative data is available on algae composition of Capitol Lake. Engstrom-Heg[27] mentions heavy blooms of *Spirogyra sp*. and *Volvox sp*. during 1955. The maximum *Volvox sp*. counts occurred in the Percival Cove area at 70 colonies/liter. Kral[29] noted heavy growths in *Cladophora sp*. in the middle and upper basins in 1969.

Historical data for zooplankton composition and numbers were provided solely in a limnological report by Engstrom-Heg.[27] Samples taken with a Clarke-Bumpus sampler fitted with a No. 0 net (0.569 mm mesh) provided the following information on dominant zooplankters and the time of maximum abundance; in the north basin *Daphnia pulex* (5.1/liter on July 18), *Bosmina coregoni* (2.0/liter on June 28). Other cladocerans including *Sida chrystallina*, *Simocephalus sp*., and *Ceriodaphnia sp*. were grouped together in tabulation and peaked on July 18 at 0.1/liter. Dominant copepods were *Diaptomus oregonensis* (1.0/liter on July 18), *Epischura nevadensis* (6.0/liter on August 18), and *Cyclops biscuspidatus* (0.2/liter on September 19). The same organisms were found at a middle basin station but in lower numbers.

The benthic population for the summer of 1955 was dominated by the chironomial Chironomus tentans.[27] Other organisms present indicated by capture in dredge samples or fish stomach analysis were the chironomid genera Tanytarsus sp., Cryptochironomus sp., Procladius sp.; also present were oligochetes, a marine polychete, and a cladoceran Graptalaberis testudinaria. Quantitative data for Chironomus tentans during the summer and fall of 1955 indicated an average density of 40 fourth instar organisms per square foot with a maximum of 65.3 per square foot. Quantitative data on the occurrence of other organisms were not given.

Public complaints about the rooted macrophytes in 1969 led to a three-year program of macrophyte control.[23,29] The principal noxious species were Elodea canadensis and Potomageton pectinatis. The principal areas of infestation appeared to be along the east side of the middle basin, the ski launch area in the southwest section of the middle basin, and the boat launch area of the upper basin. No quantitative data are given on the density of the macrophyte growths. A one-year growing season chemical treatment was tried and was largely unsuccessful. Salt water flushing in the spring used since 1970 has succeeded in controlling but not eliminating macrophyte growth.

d. Lake Bottom Composition

Three studies of various areas of the bottom of Capitol Lake have been reported from which information on bottom composition is available.

Prior to the construction of Interstate Highway 5 across the upper end of Capitol Lake the State Highway Department conducted a foundation boring survey. Seventeen borings were made to depths ranging from 25 to 275 feet below the lake bottom existing at that time. The composition of sediments in the upper 20 feet recorded in the drilling records[3] is summarized in Table 30. Locations of the borings are given in Figure 67.

In 1955 the composition of Capitol Lake bottom was described as follows:[27] "The bottom in most places consists of soft clayey mud, although there are

Table 30.

Washington Department of Highways Foundation Borings[3]

Test Hole No.	Depth ft	Description	Depth ft	Description
1	0-2	silty sandy gravel	2-3.5	gray silty gravelly sand
2	0-3	silty sandy gravel		
3	0-1	brown sandy top soil	1-17	rusty brown silty medium ~~sand--trace gravel~~
4	0-2	brown silty sand	2-8.5	rusty brown silty medium sand--trace gravel
5	0-3.5	brown organic sandy silt		
6	0-1.5	brown organic gravelly silt	1.5-14	brown gravelly sand
7	0-3	brown sandy silt		
8	0-5	brown gravelly silty sand		
9	0-5	brown gravelly silty fine sand		
10	0-5	fill material--loose gravel		
11	0-5	brown gravelly silty sand		
12	0-2	brown silty sandy gravel	2-10.5	brown silty fine sand--trace gravel
13	0-5	brown sandy organic silt		
14	0-2.5	brown organic silt--peat	2.5-10	gray clayey sand & gravel
15	0-4	brown sandy organic silt		
16	0-3	black organic silt	3+	gray silty sand & gravel (till)
17	0-6.5	black organic silt	6.5-12	gray silty sand-gravel
1B	0-2.5	brown gray organic clay silt	2.5-10	brown gray organic silt--shells
2B	0-8	soft gray black organic silt--shells		
3B	0-9	soft sandy silt--shells		
4B	0-16.5	soft organic sandy silt--some wood and shells		
5B	0-10	organic clayey silt		
6B	0-5	soft organic silt--wood chips		
7B	0-15	soft sandy clayey silt--wood chips		
8B	0-1.5	brown silty sand--gravel	1.5-8.5	brown silty sand
20B	0-1.5	gravelly coarse sand, blue-gray silt--trace sand	1.5-6	blue-gray medium sand--trace gravel
21B	0-1	gravelly coarse sand	1-6	blue silt, trace sand

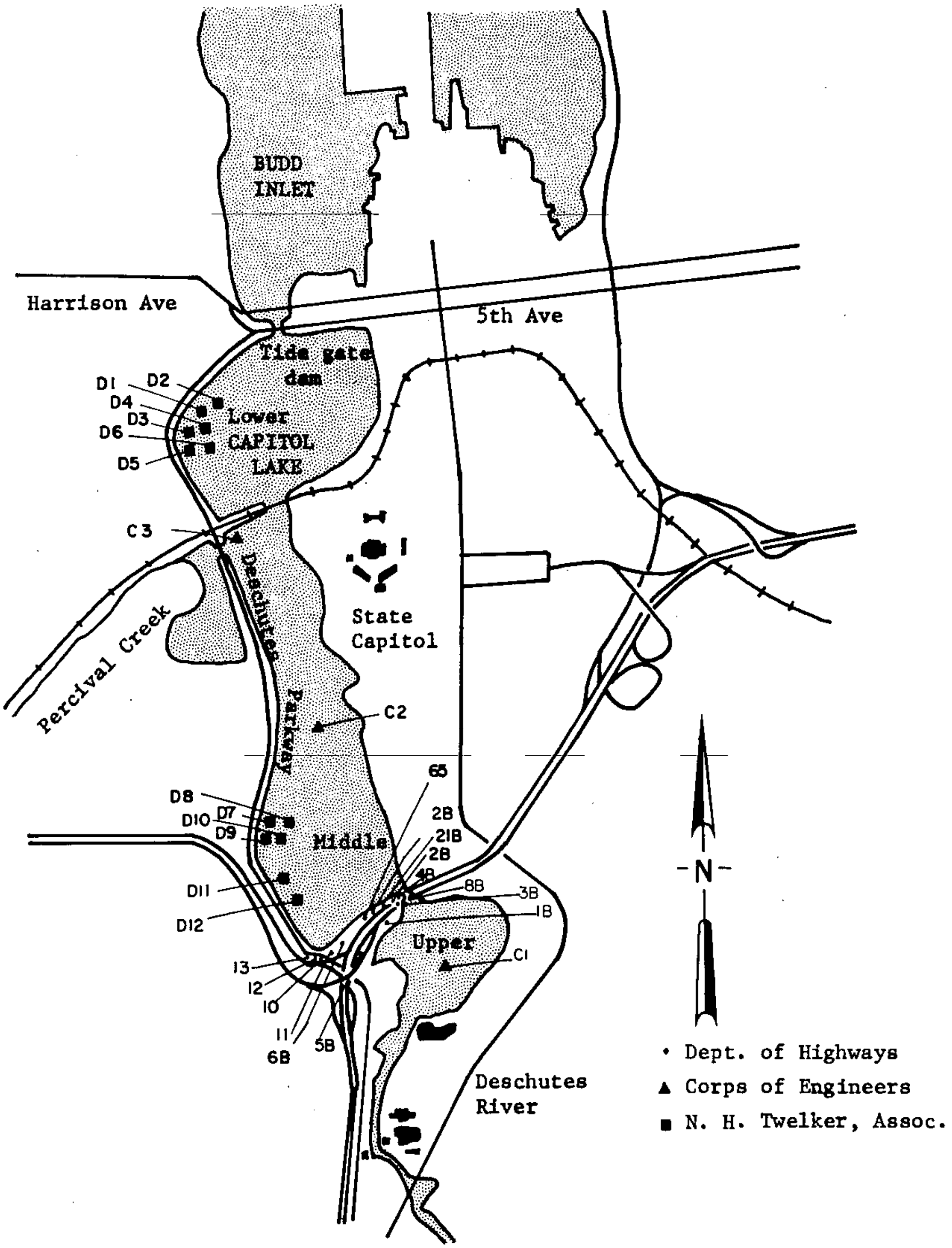

Fig. 67. Location of Borings, Capitol Lake

some patches of sand, and considerable beds of old marine shells (chiefly Mytilus and Macoma)."

In September of 1965, following an earthquake that caused portions of the Deschutes Parkway fill to collapse into the Lake, Neil H. Twelker and Associates, Consulting Soils Engineers[3] made 12 borings in the middle and lower lake (Figure 67). Qualitative observations of bottom composition in the surface layers at these locations are as summarized in Table 31.

In mid-1971 three samples of bottom sediment taken from locations in the upper and middle basins were taken by the U.S. Army Corps of Engineers.[3] These samples were analyzed for a variety of physical and chemical characteristics. The results of the analyses are summarized in Table 32.

For the sake of comparison, data on sediment composition in Budd Inlet are included in Appendix D (Table D2). Analyses are from dredge samples of bottom material collected and analyzed by the U.S. Environmental Protection Agency.[36]

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[36] O'Neal, G., and Sceva, J., "The Effects of Dredging on Water Quality in the Northwest," Environmental Protection Agency, Region X, July, 1971.

Table 31.

Capitol Lake Bottom Logs, N. H. Twelker and Associates[3]

Hole No.	Depth ft	Description	Depth ft	Description
D-1	0-9.8	dark gray black very soft fine sandy silt		
D-2	0-1	silty sand and gravel fill	1-28	gray very loose sandy silt
D-3	0-24	gray very loose sandy silt		
D-4	0-2	gray very loose slightly sandy silt	2-6.5	gray loose clean medium sand
D-5	0-15.5	gray very loose sandy silt		
D-6	0-16	gray very loose silt		
D-7	0-16.5	gray very loose slightly clayey silt		
D-8	0-14.5	gray very loose silt		
D-9	0-0.5	brown silty loose medium sand	0.5-6	gray clear loose medium sand
D-10	0-5.8	gray clean loose medium sand		
D-11	0-11.3	brown fairly clean medium sand with gray silt layers and gravel mixed (disturbed)		
D-12	0-22	gray very loose sandy silt with occasional layers of clean gray medium dense medium sand		

Table 32.

Capitol Lake Dredge Samples, Corps of Engineers, May, 1971[3]

Results:	SAMPLE LOCATION (1)	(2)	(3)
Total solids gm/kg	636	709	681
Volatile solids percent (dry basis)	5.7	1.6	2.1
Chemical oxygen demand gm/kg	30.1	24.0	21.1
Initial oxygen demand gm/kg	0.20	0.13	0.05
Oxygen-reduction potential millivolts	202	169	210
Grease gm/kg	0.18	0.10	0.13
Sulfide mg/kg	6.7	5.8	5.0
Turbidity JTU, 15% solution			
1 hour settling	1400	650	180
6 hour settling	1300	600	220
24 hour settling	650	250	112

C. Capitol Lake Water Quality, 1974-75

1. Data Collection

Sampling locations in Capitol Lake and a suitable sampling schedule were selected following an initial reconnaissance survey conducted at the end of April, 1974. Adjustments in the initial plan were made during the course of the study as required.

Influent to the lake was monitored at sampling stations (Figure 68) located at the upstream end of the upper basin and in Percival Creek at the inlet to Percival Cove. Occasional samples were taken from the Deschutes River at the Waldrick Rd. bridge, RM-15.2, and at the outlet of Black Lake, the source of Percival Creek.

Sampling stations were established in each of the three basins of the lake (Figure 68) to enable characterization of changes in water quality taking place through the lake system. The station in the upper basin was located at the inlet end primarily to define influent water quality. The middle and lower lake stations were established in the approximate center of the basins as this appeared to provide representative characterization of basin water quality without undue attention to local variations.

Samples of direct runoff to the middle basin were collected and analyzed during the January sampling trip that coincided with a winter rainstorm.

A total of eight sampling and field water quality surveys were planned and carried out during the course of the study. Field work was conducted in April, May, June, July, August, October, and November of 1974, and in January, 1975.

Parameters measured throughout the study included physical, chemical, and biological quality characteristics of water and lake bottom sediments. Parameter measurements were made both in the field and the laboratory depending on analytical requirements. Details of sampling and analytical procedures are provided in Appendix D (Table D3).

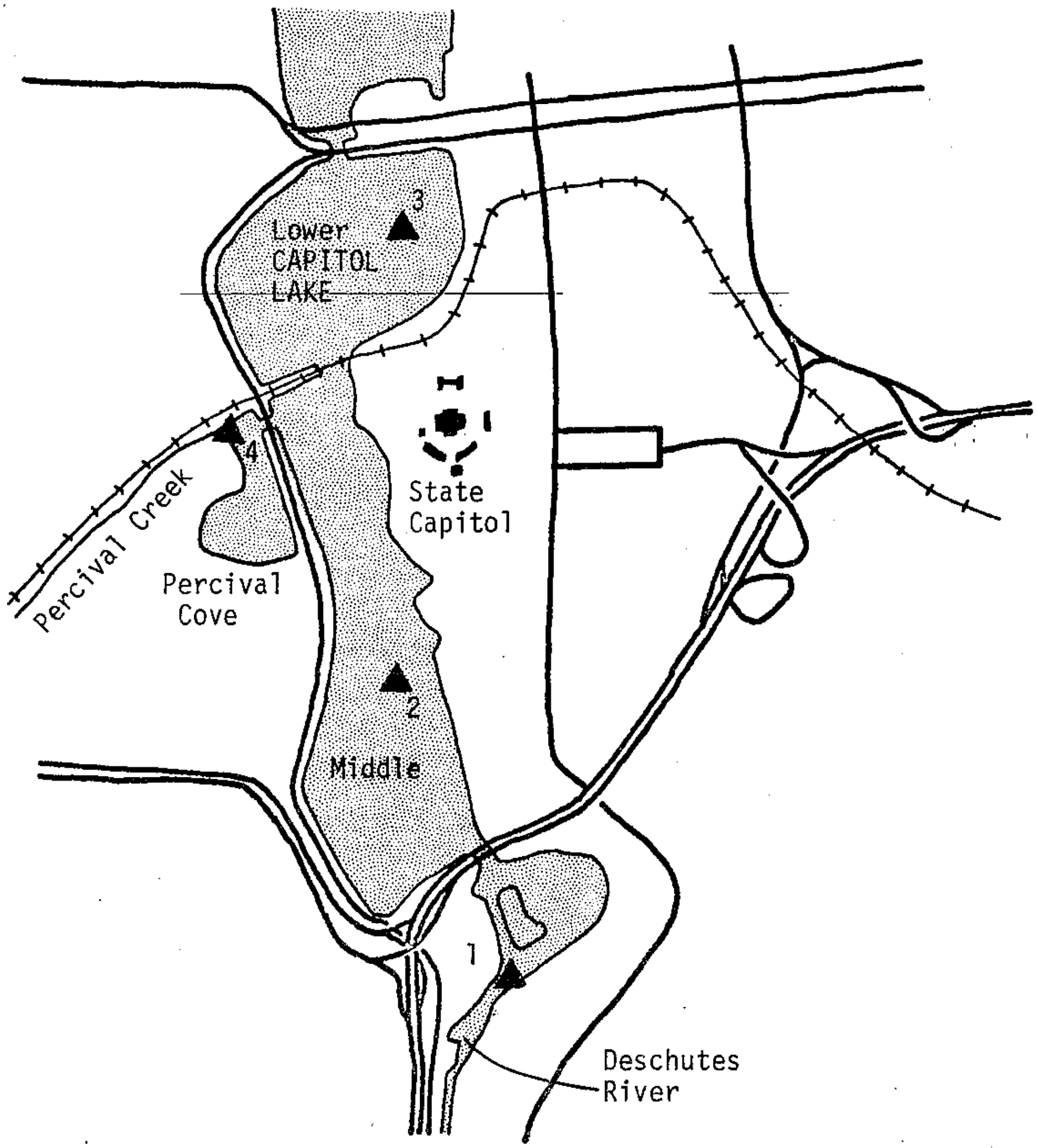

Fig. 68. Capitol Lake Study Sampling Locations

The following physical and chemical parameters were measured during each sampling period: alkalinity, ammonia nitrogen, free carbon dioxide, chemical oxygen demand, chloride, dissolved oxygen, Kjeldahl nitrogen, light penetration, nitrate nitrogen, nitrite nitrogen, orthophosphate, pH, specific conductance, sulfate, suspended solids, temperature, and turbidity. Diurnal analyses of metabolic indicators (pH, CO_2, D.O.) were conducted in July and August.

Lake bottom sediments were collected and analyzed for nitrogen and phosphorus, pH, chemical oxygen demand, and oxidation reduction potential.

Biological parameters measured include phytoplankton and zooplankton identification and enumeration, benthic invertebrate identification and enumeration, algal primary productivity by C_{14} uptake and chlorophyll-A extraction, and a macrophyte survey for location and identification. Bacteriological data on the lake was obtained from the Thurston-Mason County Health Department and from the U.S. Geological Survey.

Background information and data on various aspects of lake water quality were obtained from the Washington Departments of Fisheries and Ecology.

2. Physical and Chemical Water Quality

The collected results of detailed monthly measurements of over 20 physical and chemical water quality parameters for the various lake stations and tributaries are given in Tables D4 through D7 (Appendix D). A summary of key parameters, including the range and mean values of all observations, is presented in Tables 33 and 34.

Mean monthly discharge of the Deschutes River at Olympia, as derived earlier in this report, and monthly temperatures measured in the three lake basins are given in Figure 69. The maximum and minimum flows computed for the period of the study were 1186 cfs in January, 1975, and 92 cfs in September and October, 1974. The resulting mean flow over this period was 500 cfs, 25 percent higher than the mean annual flow. Water

Table 33.
Summary of Physical and Productivity Parameters
Capitol Lake and Tributaries (April 1974 - January 1975)

Range and Mean Values, mg/l

	(a) pH				(b) D.O.				(c) Temperature °C			
Station	n	min	max	mean	n	min	max	mean	n	min	max	mean
Deschutes R.	6	7.2	8.1	7.7	7	8.6	12.9	10.8	7	4.4	18.0	13.0
Percival Ck.	6	7.1	9.0	7.7	7	8.6	12.1	10.2	7	3.8	23.0	13.7
Upper Basin	6	7.2	8.1	7.7	7	8.4	12.9	10.8	7	4.4	18.0	13.0
Middle Basin	6	7.1	9.2	8.4	7	10.0	15.2	12.2	7	4.4	23.0	14.1
Lower Basin	6	6.9	9.4	8.4	7	11.4	13.1	12.3	7	0.5	24.0	14.2

	(d) C_{14}-productivity mg/M^3				(e) V.S.S.				(f) COD			
Station	n	min	max	mean	n	min	max	mean	n	min	max	mean
Deschutes R.					5	0.0	16.5	3.4	1	10.3	10.3	10.3
Percival Ck.					2	10.8	12.1	11.5	6	1.0	25.2	12.0
Upper Basin	5	0.3	58.0	13.6	5	0.0	14.3	2.98	6	2.2	24.0	8.1
Middle Basin	8	0.0	118.1	52.3	4	0.0	16.9	5.2	5	3.8	26.0	11.0
Lower Basin	12	0.5	81.7	35.9	5	0.0	16.4	3.8	6	5.0	25.6	12.2

Table 34.
Capitol Lake and Tributaries (April 1974 - January 1975)

Range and Mean Values, mg/l

	(a) O - PO_4 - P				(b) T - PO_4 - P				(c) NH_3 - N			
Station	n	min	max	mean	n	min	max	mean	n	min	max	mean
Deschutes R.	2	0.01	0.02	0.02	2	0.03	0.04	0.03	2	0.03	0.06	0.04
Percival Ck.	8	0.01	0.03	0.02	8	0.01	0.06	0.04	3	0.05	0.12	0.08
Upper Basin	8	0.02	0.07	0.04	8	0.01	0.11	0.06	3	0.04	0.12	0.07
Middle Basin	8	0.01	0.04	0.02	8	0.01	0.13	0.06	3	0.04	0.16	0.08
Lower Basin	8	0.01	0.04	0.02	8	0.01	0.12	0.05	3	0.04	0.16	0.08

	(d) NO_2 + NO_3 - N				(e) Kj - N				(f) T - N			
Station	n	min	max	mean	n	min	max	mean	n	min	max	mean
Deschutes R.	2	0.16	0.19	0.17	2	0.16	0.16	0.16	2	0.32	0.45	0.38
Percival Ck.	8	0.00	0.54	0.19	8	0.10	0.57	0.36	8	0.33	1.11	0.54
Upper Basin	8	0.00	0.41	0.28	8	0.15	0.32	0.20	8	0.15	0.71	0.47
Middle Basin	8	0.00	0.36	0.19	8	0.25	0.52	0.52	8	0.35	0.64	0.48
Lower Basin	8	0.00	0.38	0.14	8	0.25	0.48	0.33	8	0.30	0.62	0.47

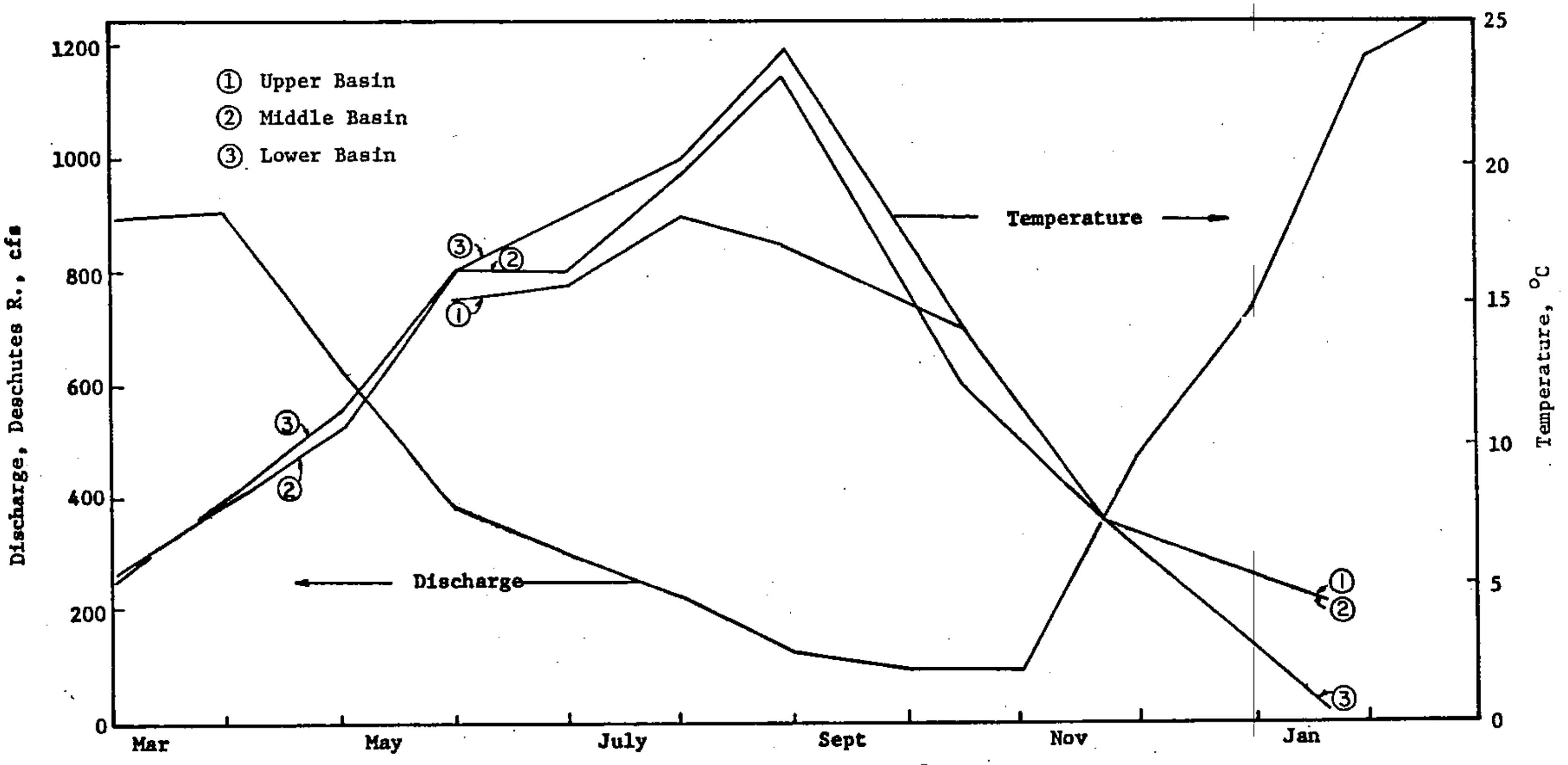

Fig. 69. Discharge, Deschutes River at Olympia; Temperature, Capitol Lake, 1974-75

temperature in the three lake basins ranged from a high of 23.5°C in the lower basin in September, 1974, to 0.5°C in the lower basin in January. The average water temperature for the period was approximately 11°C. A small but measurable temperature differential was observed between the three lake basins during the summer period from May to September. In this period the temperature increased from 1 to 5°C as the water flow progressed from upper to middle to the lower basin.

Particulate solids observations are summarized in Figure 70. Total suspended solids, related to turbidity as shown in Figure 71, ranged from 2 to 12 mg/l during the May to October dry weather period (Figure 69) with corresponding turbidity measurements ranging from 1 to 3 FTU. During this period total solids were observed generally to increase from upper to middle to the lower basin with volatile solids (VSS) accounting for 50 to 75 percent of the total solids. The observed increase occurring in the growing season should be attributable to an increase in the plankton populations. Although this does not appear to be supported by the reported volatile solids data, the lack of agreement is apparently due to difficulties experienced with the volatile solids determinations made in August and October. This is supported by the agreement observed between suspended solids and total COD as will be subsequently discussed. As can be seen from Figure 70, solids concentrations observed during the period of high discharge (November and January) were 5 to 10 times the levels observed earlier. Also, at this time the volatile solids accounted for only 15 to 20 percent of the total indicating the predominantly inorganic nature of the wet weather solids load. Secchi Disc and submarine photometer light penetration measurements (Figures 70 and 72) show a close correlation to observed suspended solids variation. Light penetration was highest in early spring when runoff had decreased from maximum winter levels but before summer algae growth. Light levels were observed to be lower in summer and diminished in the middle and lower basins over that observed in the upper basin. Lowest light penetration was observed during the highly turbid high runoff period (November through January). It should be noted that even under the lowest light penetration conditions observed during the summer growing season (May through October), a minimum of 30 percent light transmittance was observed at the bottom of the middle

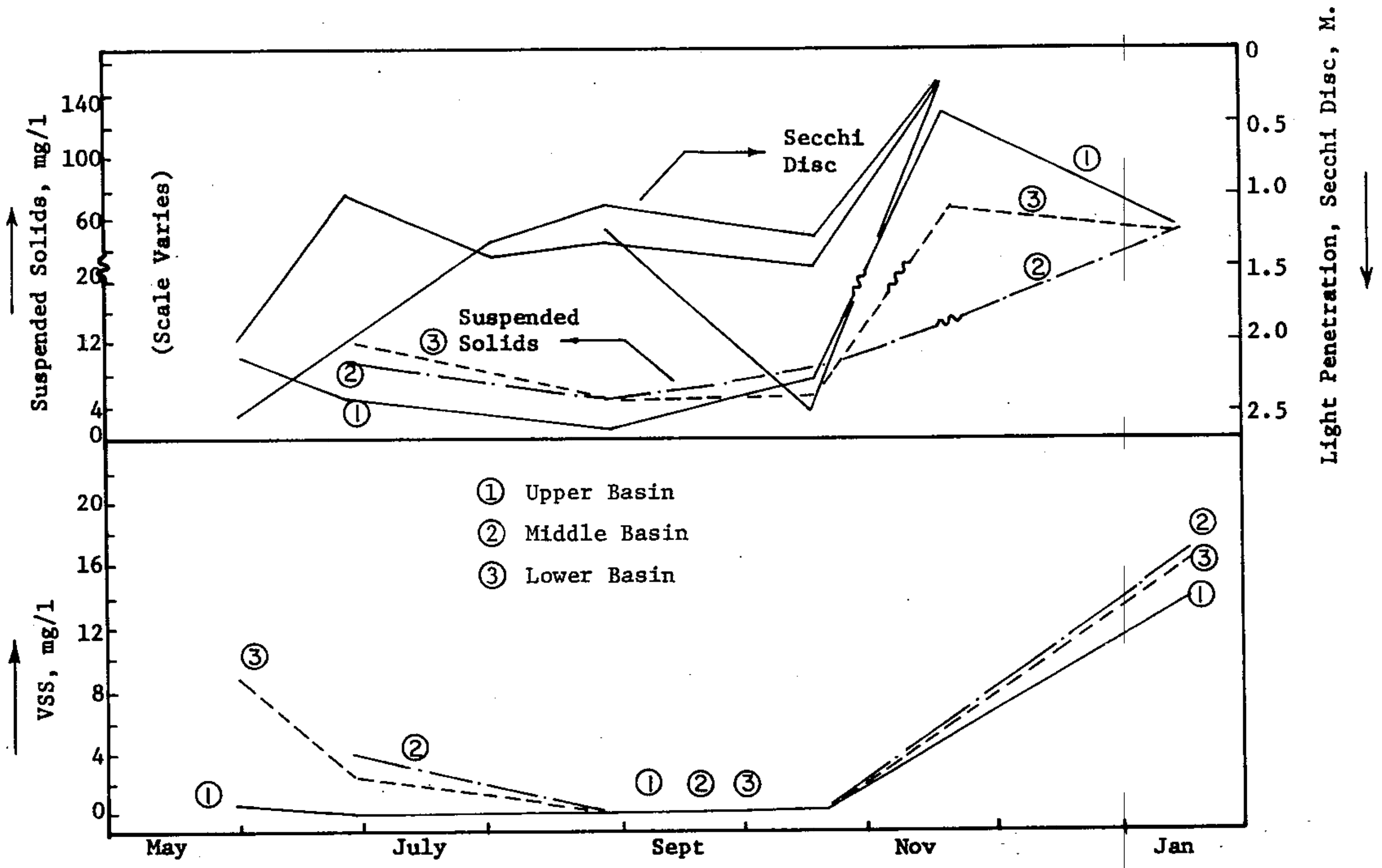

Fig. 70. Suspended Solids Concentrations, Capitol Lake, 1974-75

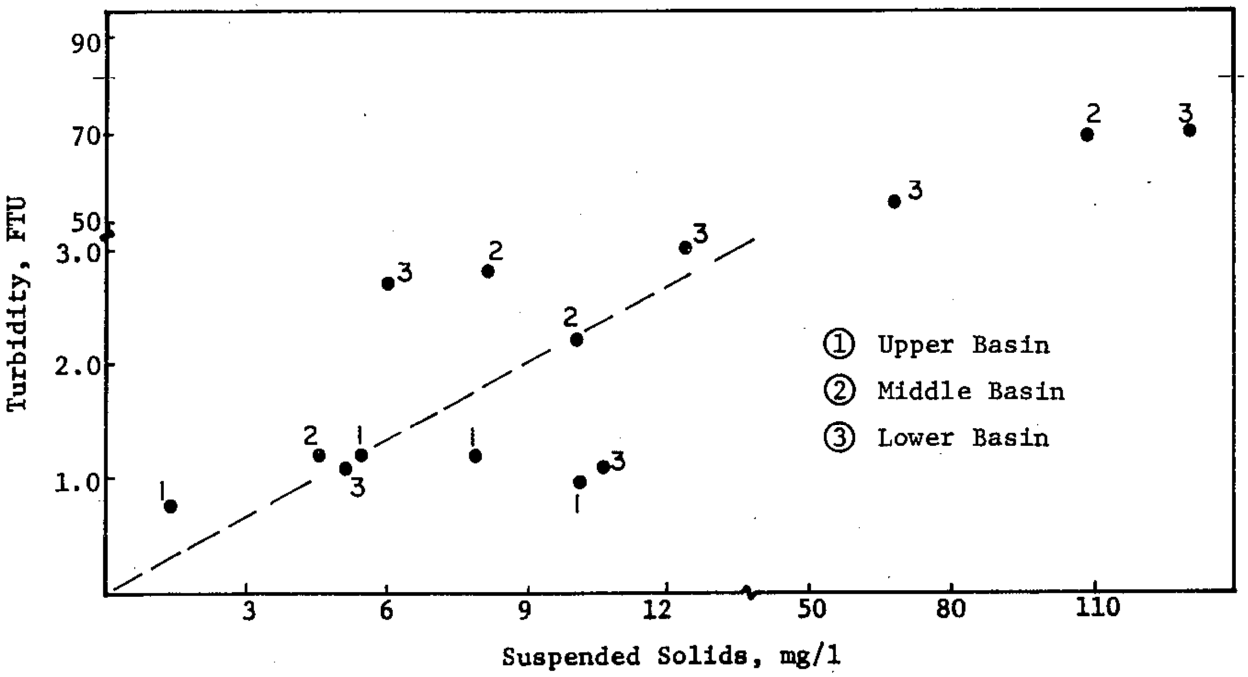

Fig. 71. Turbidity - Suspended Solids Correlation, Capitol Lake, 1974-75

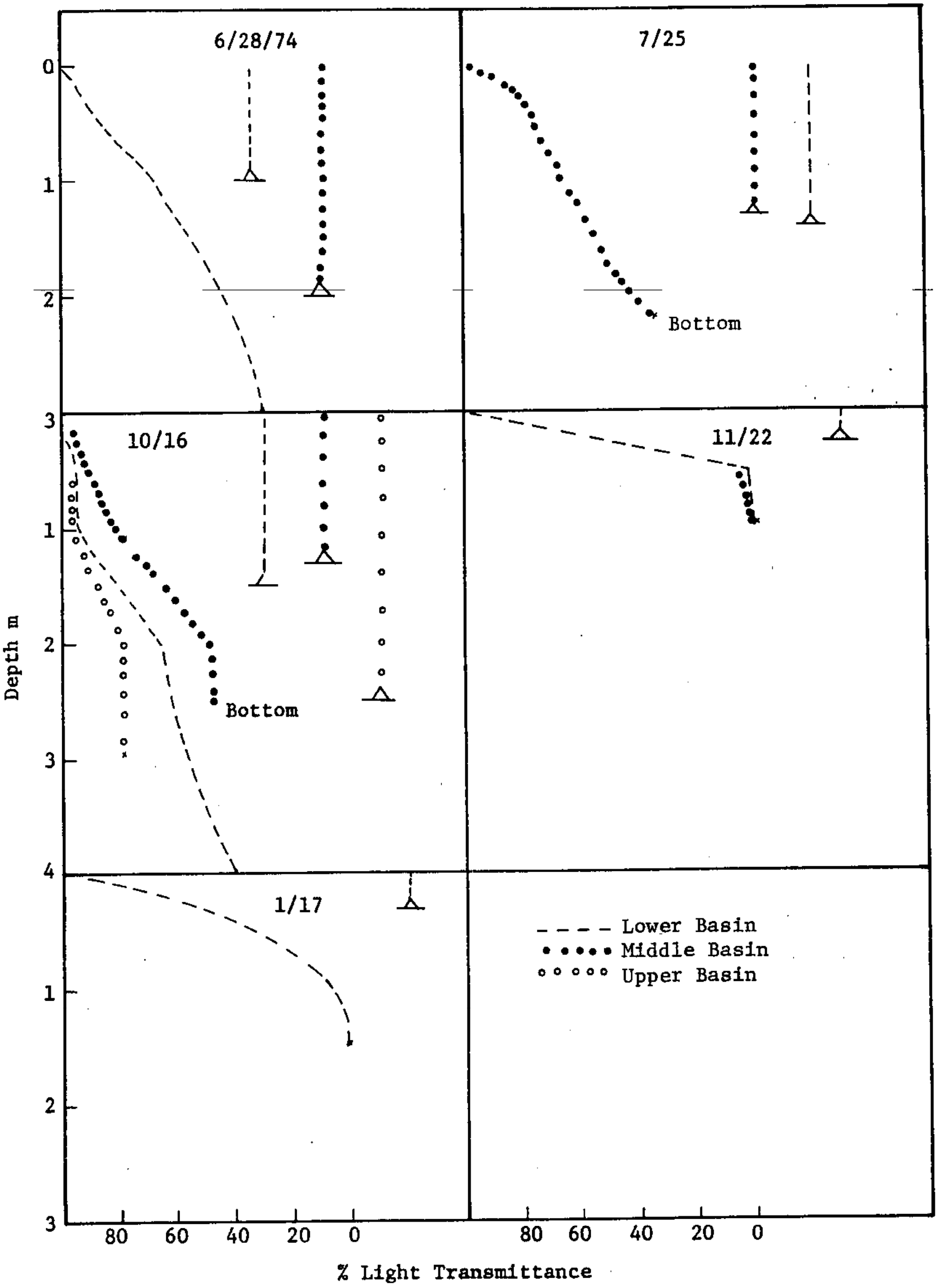

Fig. 72. Light Penetration in Capitol Lake (6/28/74 - 1/17/75) Measured with a Submarine Photometer

and lower basins. By comparison, heavy aquatic weed growth has been observed[37] in lakes of similar depth to Capitol Lake where only three to five percent light transmittance was available during the comparable time of year.

The degree of mineralization or the general magnitude of dissolved chemical water quality components is indicated by electrical conductivity and chloride concentration, summarized in Figure 73. In general the incoming Deschutes River water and water through the lake has a low degree of mineralization typical of unpolluted coastal mountain streams. Observed conductivity ranged from 50 to 250 μmho/cm. During most of the year the conductivity varied little ranging from 90 to 120 μmho/cm in the summer and between 50 and 100 μmho/cm when diluted by higher runoff in the winter period. The higher conductivity and chloride measurements observed in October and November are likely due to salt water entering the lake through the tide gates.

The Deschutes River water and water through Capitol Lake is soft with total hardness (Table 35) ranging from 25 to 50 mg/l as $CaCO_3$. The waters are also poorly buffered with total alkalinity (Figure 74) ranging from 25 to 60 mg/l as $CaCO_3$. A slight increasing trend was observed during the dry weather period followed by a sharp decline in November at the outset of the high runoff period.

Table 35.
Total Hardness, Deschutes River* and Capitol Lake**, 1974-75

	2/74	8/74	10/74	11/74	12/74
Deschutes River	--	--	50	35	30
Upper Basin	--	--	--	--	--
Middle Basin	31	49	--	--	--
Lower Basin	31	46	--	--	--

*Washington Dept. of Ecology, unpublished STORET data.
**U.S. Geological Survey, unpublished data.

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[37] Bhagat, S. K., et al., "Study of Silver Lake Eutrophication--Current Problems and Possible Solutions," Completion Report for DOE Project W-16, State of Washington Water Research Center, Pullman, July, 1975.

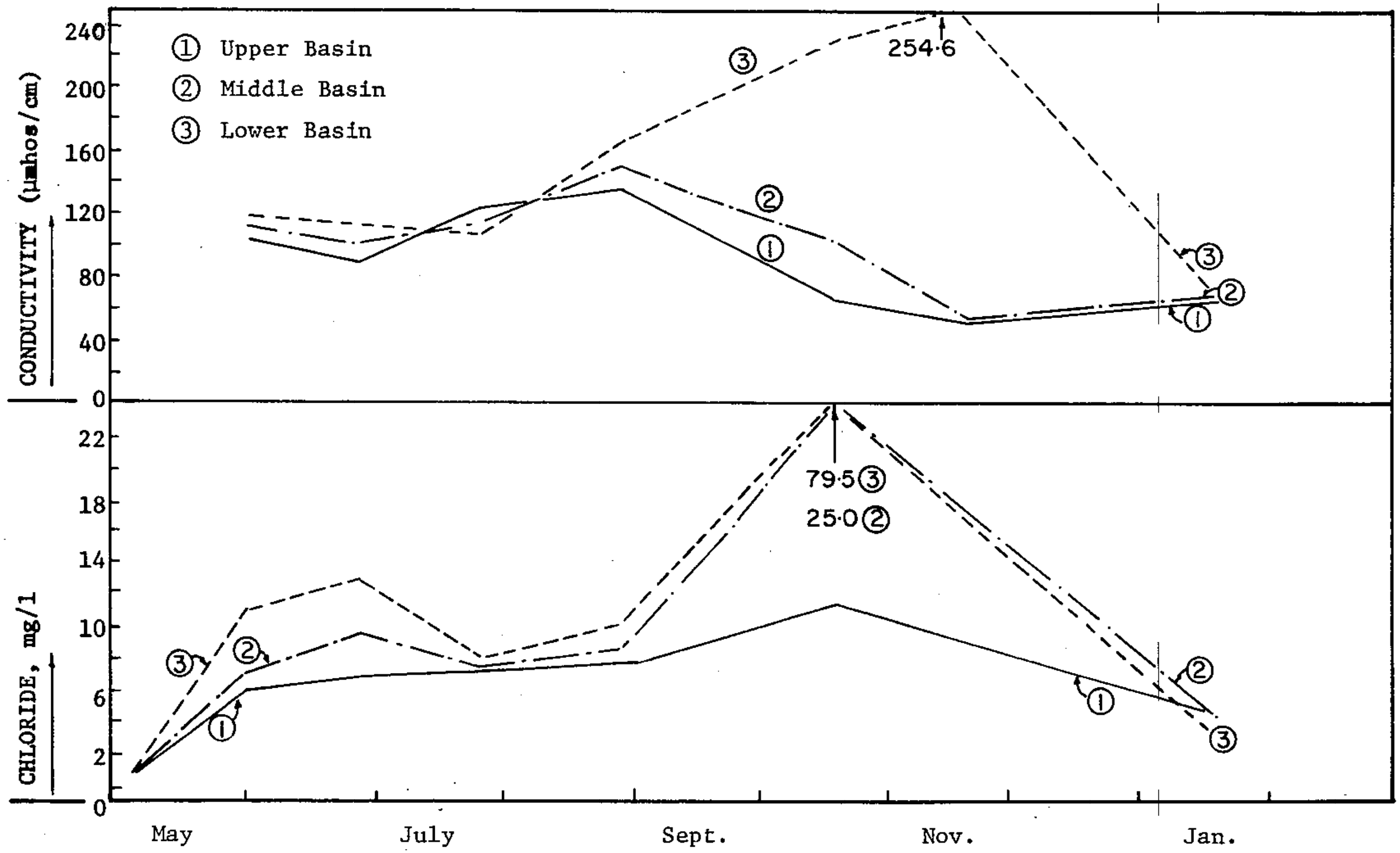

Fig. 73. Dissolved Solids, Capitol Lake, 1974-75

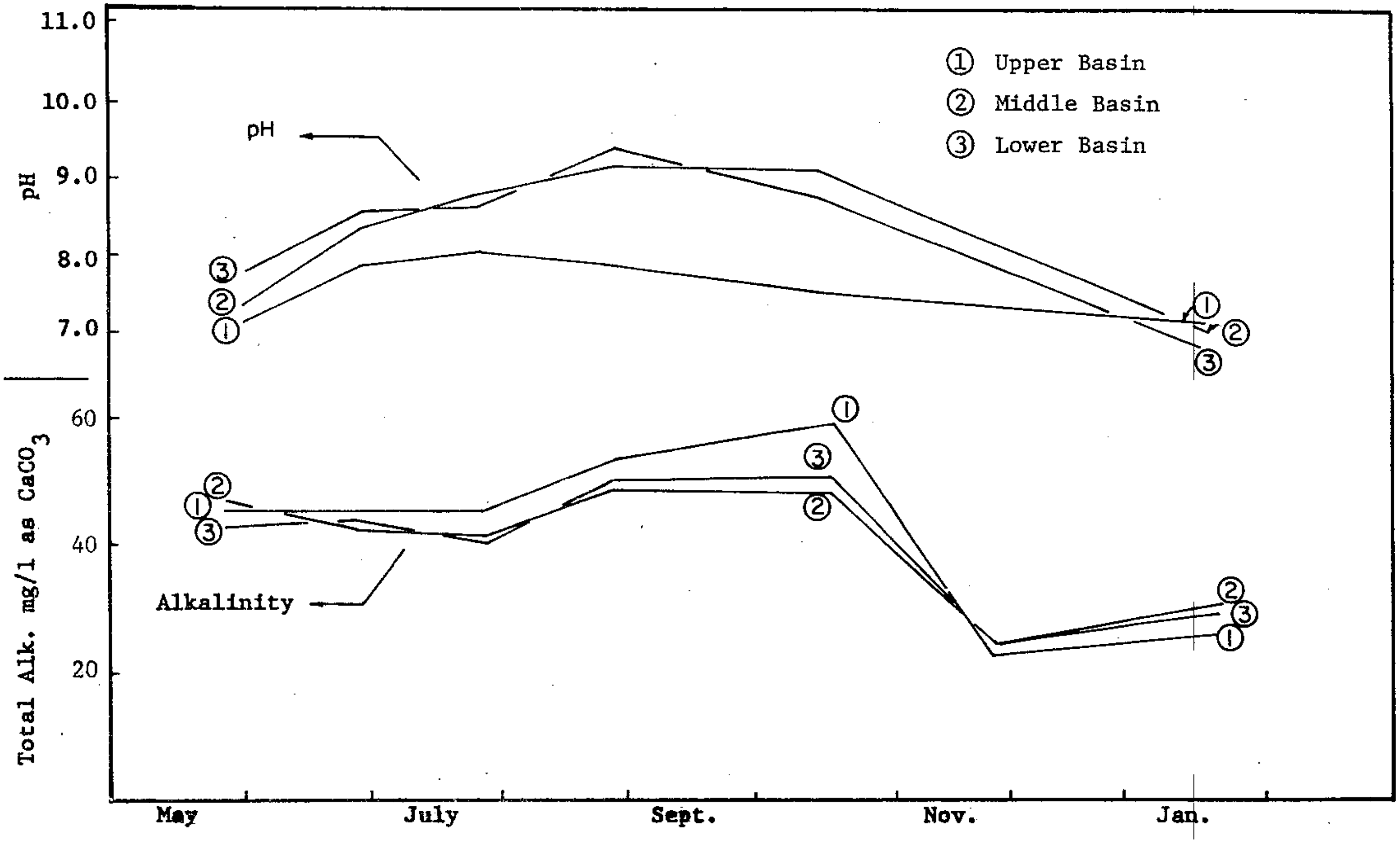

Fig. 74. Alkalinity and pH, Capitol Lake, 1974-75

Concentrations of the critical plant nutrients, nitrogen and phosphorus are summarized in Figures 75 and 76. Orthophosphate-P concentrations ranged from 0.001 to 0.06 mg/1 while total-P ranged from 0.01 to 0.13. The average ortho-P levels averaged from 40 to 60 percent of the total-P concentrations. Two trends were evident from the data: 1) Concentrations of both ortho-P and total-P increased steadily through the dry weather period, decreasing markedly after the onset of the rainy season; and 2) Concentrations of both ortho-P and total-P were observed to decrease as water moved progressively from the upper, to middle, to the lower basin. Although phosphorus concentrations were observed to increase through the dry period, a computation of total phosphorus loading to Capitol Lake in terms of pounds-P per day (Figure 77) shows the loading to be nearly constant through the May-October dry weather growing season. The constant loading results from the steadily decreasing flow during this period. The observed decreasing trend of ortho-P concentrations through the lake from south to north is attributable to biological uptake. This is illustrated by the increasing trend observed in the (total-P)-(ortho-P) fraction (Figure 75), essentially the organic phosphorus fraction. The decreasing trend observed in total-P from south to north in the lake is similarly attributable to a gradual settling out of phosphorus converted to particulate matter partially by chemical and partially by biological processes.

Inorganic nitrogen, nitrate + nitrate + ammonia, and organic nitrogen, kjeldahl - N - ammonia, concentrations are summarized in Figure 76. Influent inorganic and organic nitrogen concentrations were observed to be relatively constant throughout the study. However, a computation of total nitrogen loading to the Capitol Lake system (Figure 77) shows a decreasing trend from approximately 750 to 250 lb/day over the May to October growing season. The effects of biological uptake of inorganic nitrogen and conversion to organic nitrogen with flow from south to north in the lake are clearly evident from Figure 75.

Trends similar to those observed above for nitrogen and phosphorus indicating the predominant influence of biological processes on water quality

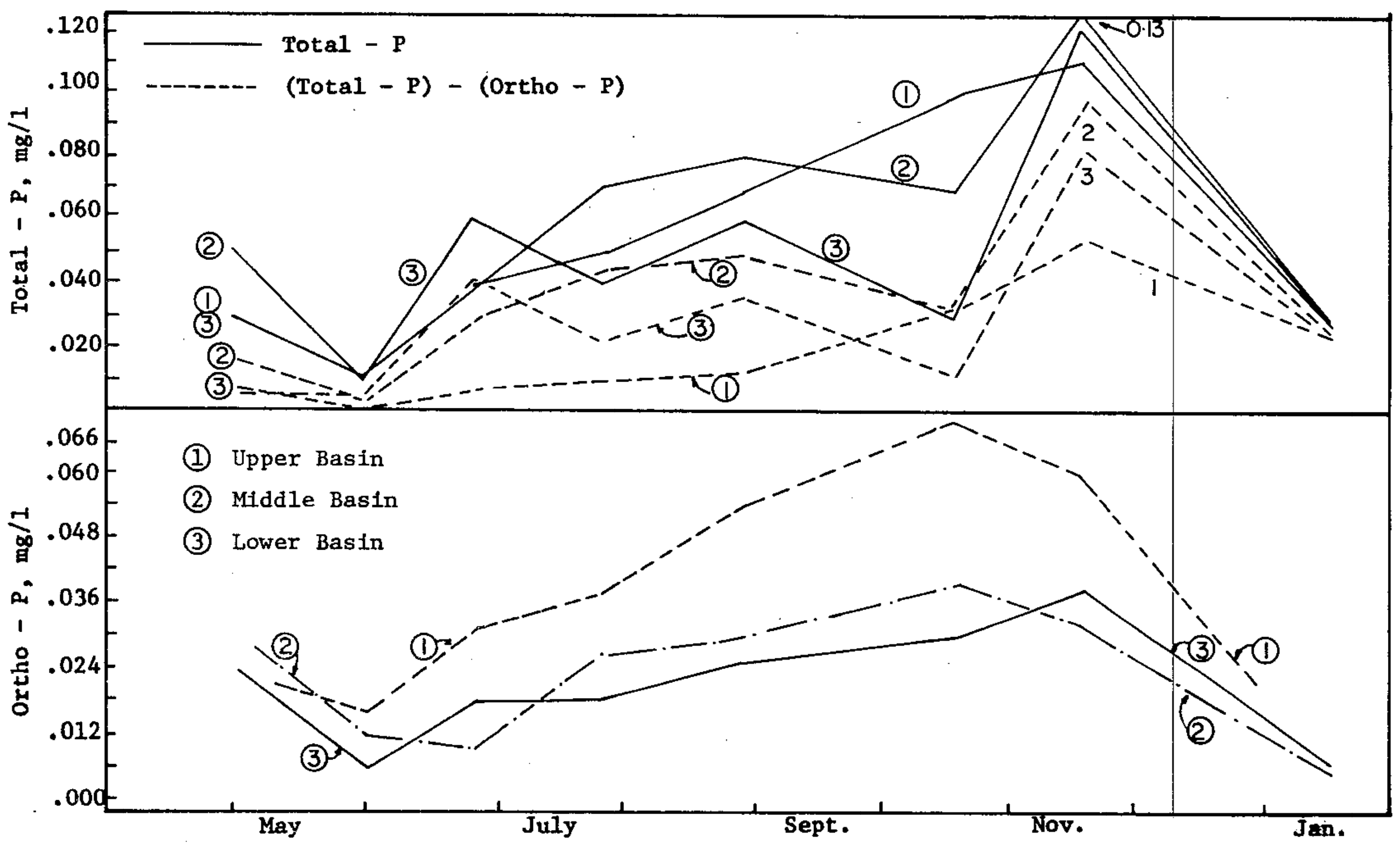

Fig. 75. Ortho and Total Phosphorus, Capitol Lake, 1974-75

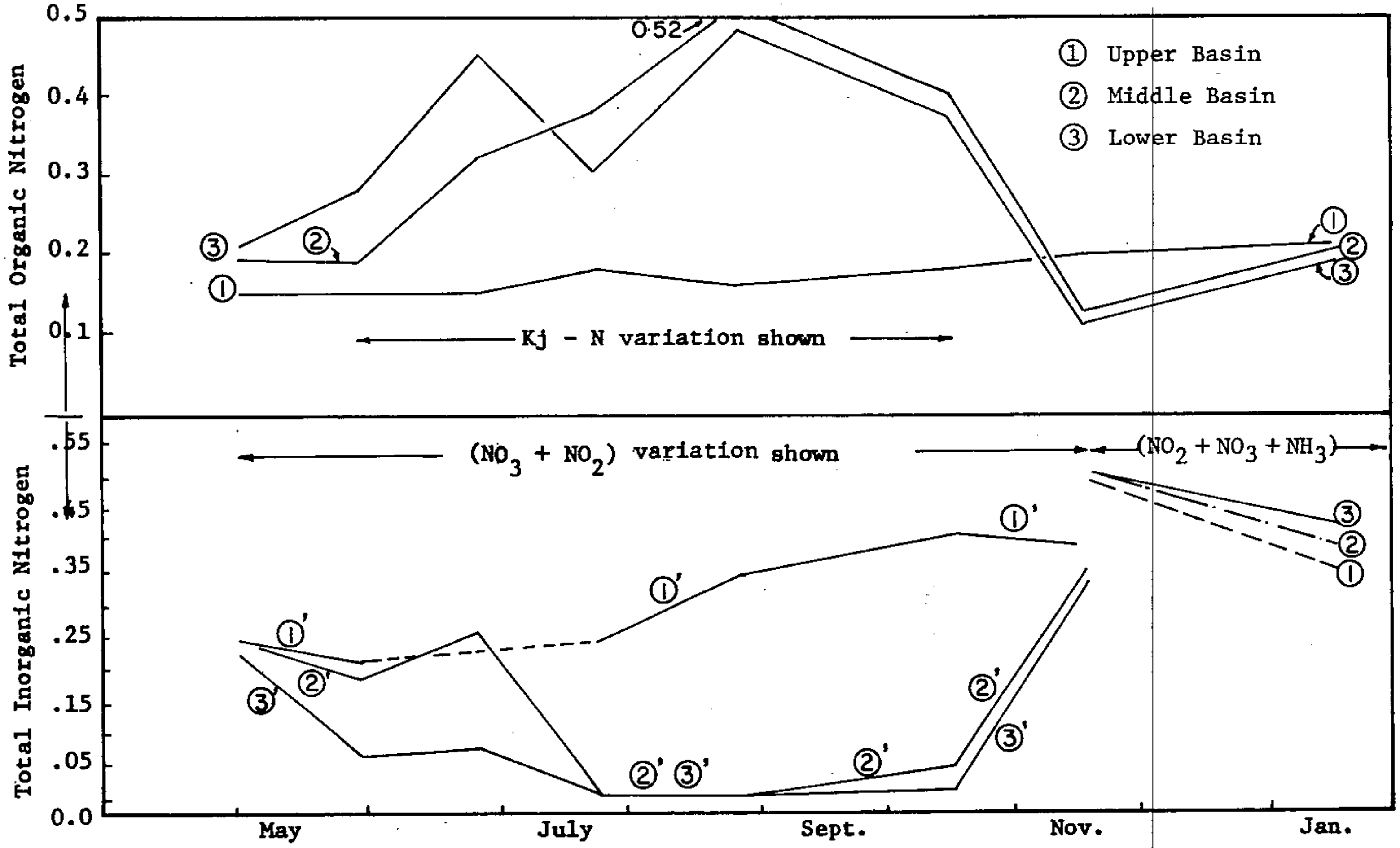

Fig. 76. Organic and Inorganic Nitrogen, Capitol Lake, 1974-75

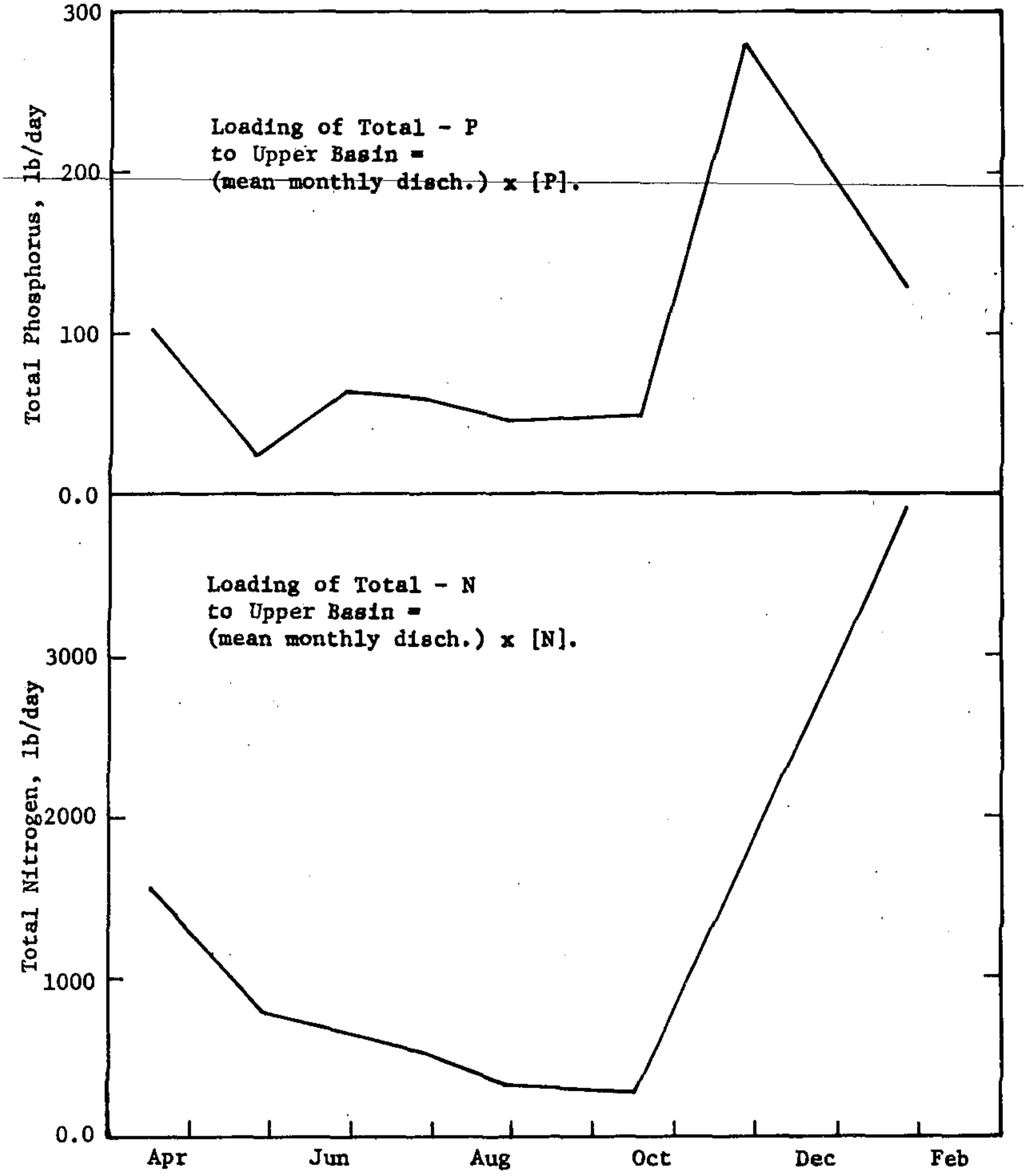

Fig. 77. Loading of Total-N and Total-P to Capitol Lake, 1974-75

in the lake, were observed for indicators of biological metabolism (dissolved oxygen, pH, COD, chlorophyll-A, etc.).

Dissolved oxygen concentrations (Figure 78) were observed to vary relatively little, generally ranging from 9 to 12 mg/l, and always close to or greater than 100 percent saturation. A summary of the average percent of oxygen saturation in the three lake basins from May to October (Table 36) shows a distinct increase from the upper to lower basin.

Table 36

Average Percent D.O. Saturation
Capitol Lake, May-October, 1974

	Percent Saturation
Upper Basin	99
Middle Basin	123
Lower Basin	129

Overall observed COD values also varied little during the growing season, ranging from 3 to 15 mg/l. Again, the increasing trend from the upper to lower basin is evident (Figure 78) and attributable to the general increasing level of biological activity. The significantly higher values observed in November are typical of the surge of dissolved organic material commonly occurring with runoff from rainfall following an extended dry weather period. Observed pH (Figure 79) in the upper basin, indicative of incoming Deschutes River water, varied little between limits of 7.0 and 8.0. Higher pH values, up to a maximum of 9.4, observed in the middle and lower basins are consistent with increased photosynthetic activity during summer months. Estimates of the magnitude of primary productivity, C_{14} uptake and chlorophyll-A concentrations, correspond to the pattern of increasing summer activity established above. Average daily C_{14} uptake rates, calculated according to Vollenweider[35] ranged from barely detectable minimums at the end of the growing season to a maximum of 2767 mg C/m^2/day in the lower basin at the end of June (Figure 80). The average C uptake rate observed over this period was approximately 1200 mg/m^2/day. An estimate of total annual primary productivity (Figure 81) was approximately 250 g C/m^2/year. By comparison

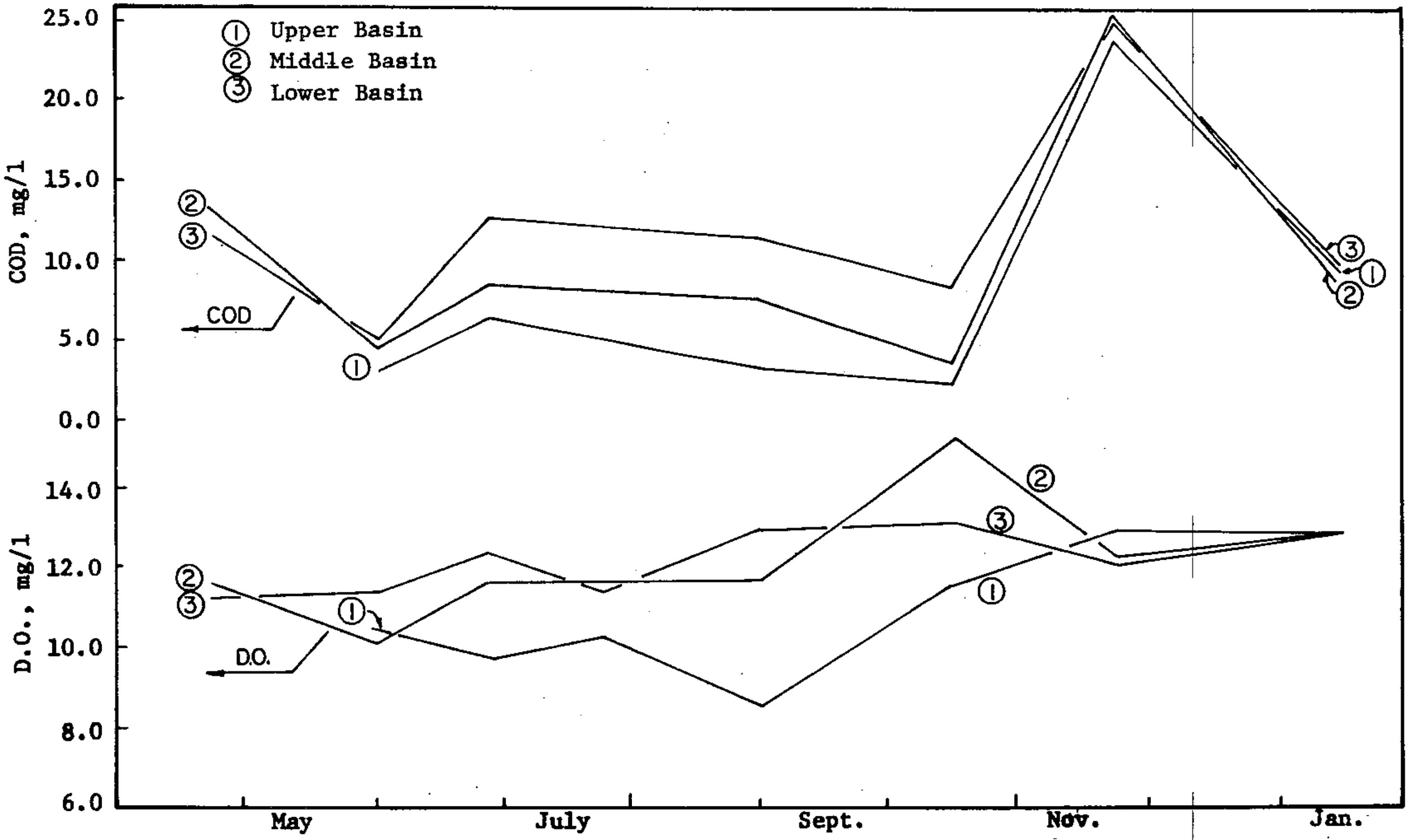

Fig. 78. Dissolved Oxygen and Chemical Oxygen Demand, Capitol Lake, 1974-75

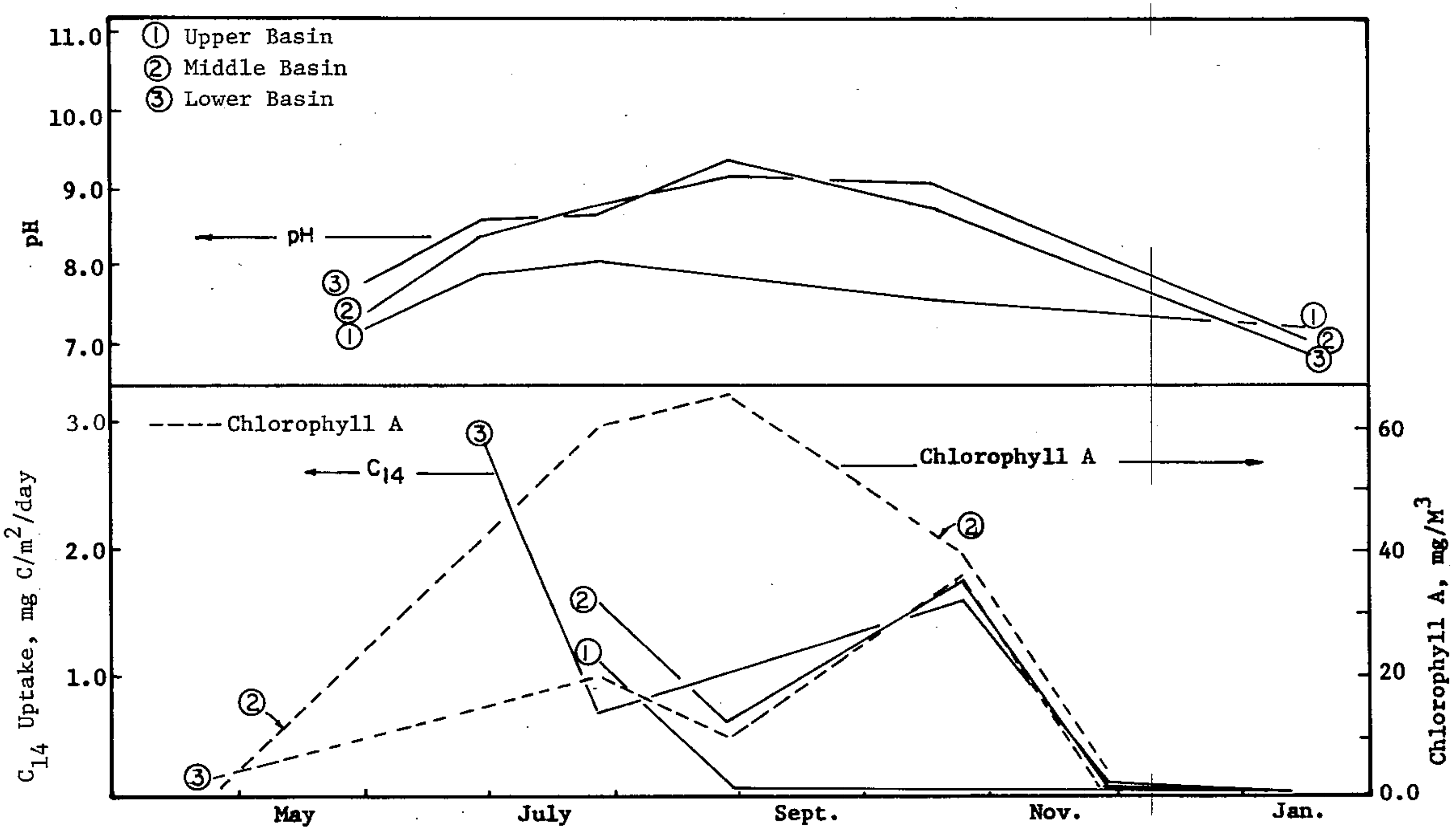

Fig. 79. Primary Productivity and pH, Capitol Lake, 1974-75

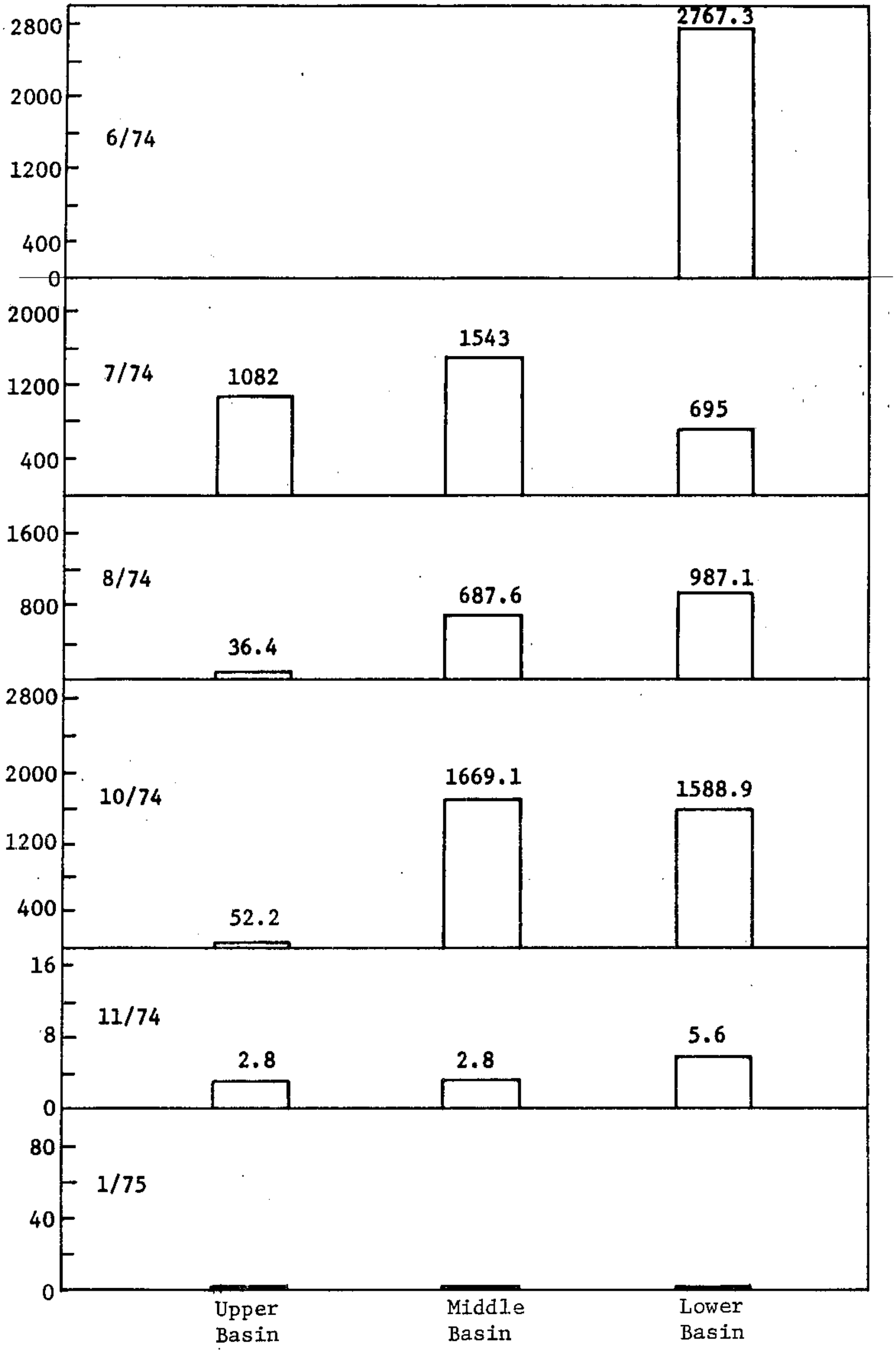

Fig. 80. Primary Productivity, C_{14} Uptake, Capitol Lake, 1974-75

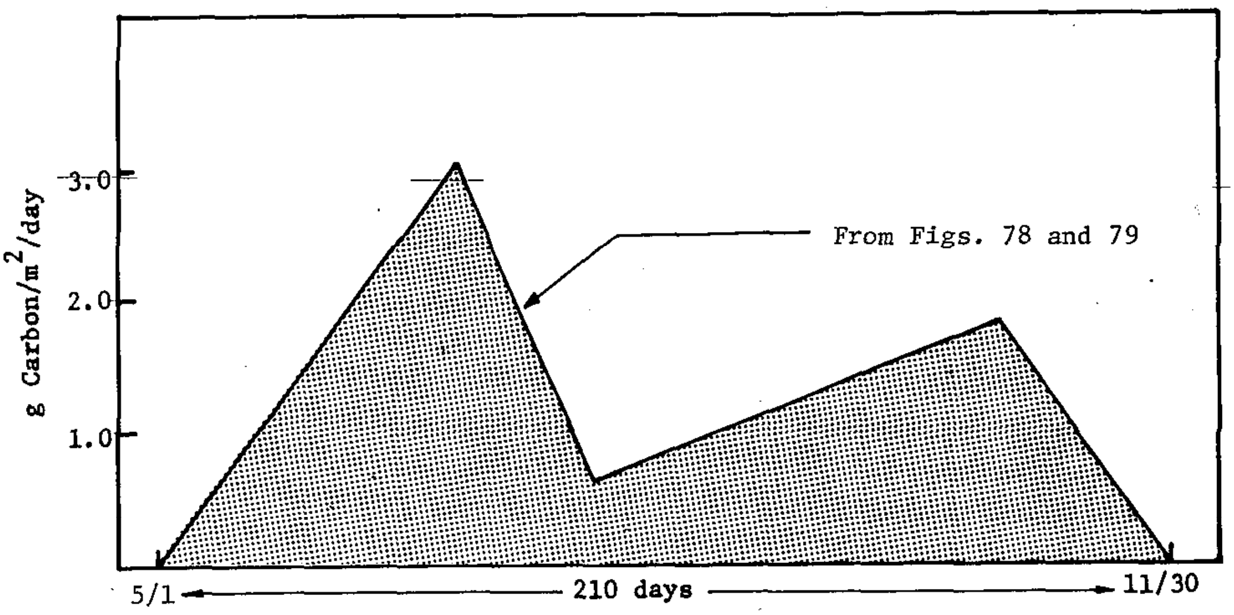

Fig. 81. Estimated Annual Primary Productivity, Capitol Lake, Middle and Lower Basins, May 1 - November 30, 1974

data summarized for a wide range of lakes throughout the world[35] indicate daily and yearly productivity for meso-eutrophic (moderately productive) lakes respectively from 100-400 mg C/m^2-day and from 25-125 g C/m^2-year. Eutrophic (highly productive) lakes have reported ranges >400 mg C/m^2-day and >100 g C/m^2-year. Chlorophyll-A concentrations ranged from minimum values of less than 10 mg/m^3 at both ends of the growing season in April and November to a maximum of 60 mg/m^3 in August. Average chlorophyll-A concentrations observed for the lower and middle basins respectively were approximately 15 and 30 mg/m^3. Vollenweider[35] reports chlorophyll-A ranges for moderately productive lakes, 1-15 mg/m^3, and for highly productive lakes, 5-140 mg/m^3.

Diurnal surveys of metabolic indicators conducted in July and August are summarized in Figures 82 and 83. As can be seen from these figures only minimal variations were observed although the previously discussed trends from basin to basin are again evident. The small variations appear somewhat contradictory to the relatively high productive character of the lake described above. However, the large flow and short detention time in Capitol Lake, particularly when compared to other natural lakes, tend to mask short-term variations.

3. Biological Water Quality Characteristics

a. Phytoplankton

The upper basin algae counts were very low (16 to 274 per ml) during the study period and were dominated almost exclusively by periphytic diatoms (Table 37) characteristic of flowing water. Middle basin counts were moderate (16 to 3828 per ml) and dominated by diatoms. Green algae became more prevalent during July and August. *Aphanizomenon sp.* was found in July but not at nuisance proportions. The lower basin counts were generally the highest of the three basins and contained the highest percentage of green algae. The algae composition of Percival Creek waters are a mixture of periphytic and planktonic algae. The planktonic algae are surviving organisms from Black Lake, the origin of Percival Creek.

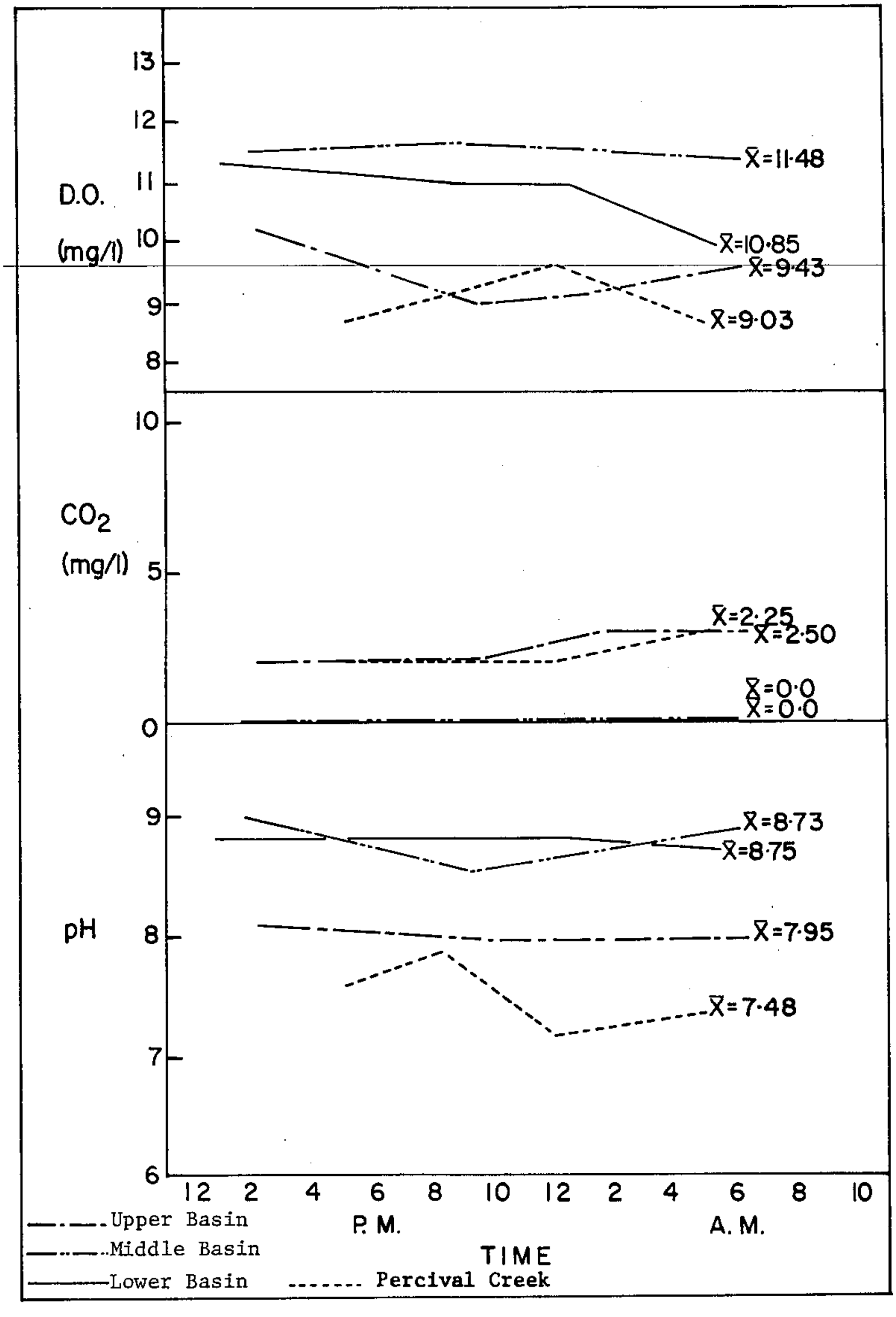

Fig. 82. Diurnal Surveys of Metabolic Indicators, Capitol Lake, July 25-26, 1974

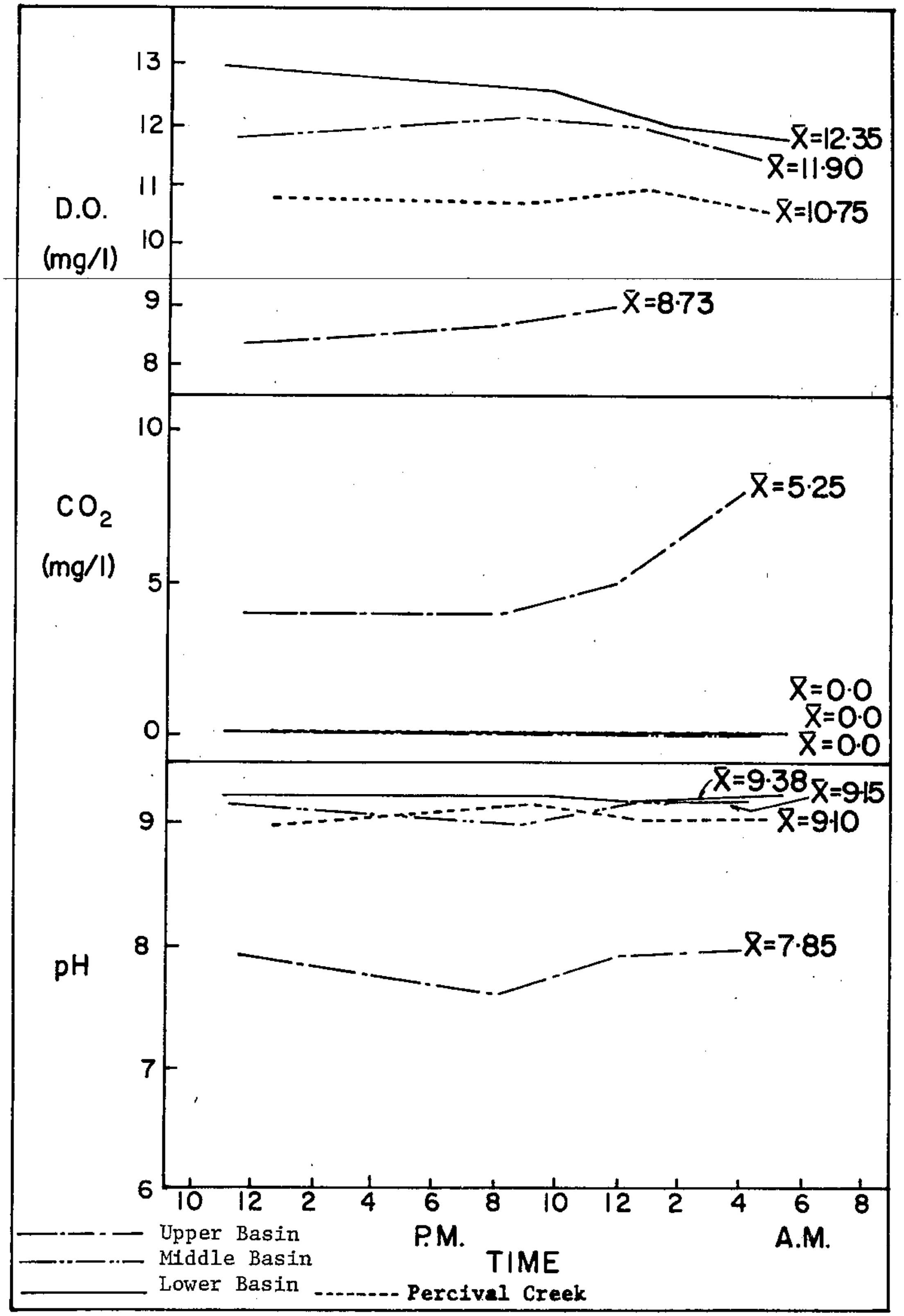

Fig. 83. Diurnal Surveys of Metabolic Indicators, Capitol Lake, August 27-30, 1974

Table 37.

Algae Count Percentages, Capitol Lake, 1974-75

		6-1-74	6-28-74	7-25-74	8-28-74	10-14-74	11-22-74	1-17-75
Lower Basin	Total cells/ml	4196	570	11432	1083	445	17	90
	Diatoms %	91.2	79.5	12.9	51.9	95.7	94.1	100.0
	Greens %	1.1	20.5	87.1	48.1		5.9	
	Blue-greens %	7.7				4.3		
	Others %							
Middle Basin	Total cells/ml	200	97	3828	893	1998	16	56
	Diatoms %	100.0	100.0	25.0	62.4	97.7	100.0	100.0
	Greens %			44.6	37.6	1.9		
	Blue-greens %			30.4		0.4		
	Others %							
Upper Basin	Total cells/ml	242	274	142	164	270	16	90
	Diatoms %	91.3	100.0	100.0	100.0	97.4	100.0	100.0
	Greens %					2.6		
	Blue-greens %	8.7						
	Others %							
Percival Creek	Total cells/ml	316	420	547	1333		103	192
	Diatoms %	84.8	96.6	100.0	77.8		100.0	100.0
	Greens %	2.2	1.7		22.2	----		
	Blue-greens %	13.0						
	Others %		1.7					

Carbon 14 measurements, as discussed previously, were made on six dates as indicated in Figure 84. Summer production rates in the range of 500 to 1000 mg C/m^2/day classify Capitol Lake as eutrophic.[38] Figure 84 also illustrates that production in the middle basin equalled or exceeded that of the lower basin even though algae counts of the lower basin were generally higher. The higher productivity of the middle basin may be due to the higher concentration of soluble nitrogen compared to that of the lower basin.

In July a large amount of floating organic material was observed in the middle basin that was being concentrated by the wind under the I-5 bridge. This material was collected and examined microscopically and found to be Oscillatoria sp. attached to loose organic material.

During June and July, Volvox sp., a macroscopic colonial algae, was observed in the lower basin, especially in areas around the shore. This algae was also noted by Engstrom-Heg[27] at 0.10 colonies per liter. The estimated concentration of Volvox sp. in June, 1974, determined from the zooplankton counts was 398 colonies per liter.

In August, 1974, colonies of Gloeotrichia sp. were observed floating on the surface of the middle basin. Concentrations of Gloeotrichia sp. were heaviest in the upper end of the middle basin and around the boat launch area of the upper basin where it formed a fairly heavy "scum."

b. Zooplankton

Zooplankton counts (Tables 38 and 39) show a dominance of cladocerans consisting of Bosmina sp., Ceriodaphnia sp., and Daphnia sp. Copepod genera present were Cyclops sp. and Diaptomus sp. The highest density of zooplankton occurred on July 25, 1974, and corresponded with high algae production. Dominant rotifers were Asplanchna sp., Polyarthra sp.

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[38] Rodhe, Wilhelm, "Crystallization of Eutrophication Concepts in Northern Europe," Eutrophication: Causes, Consequences, Correctives, National Academy of Sciences, Washington, D.C., 1969.

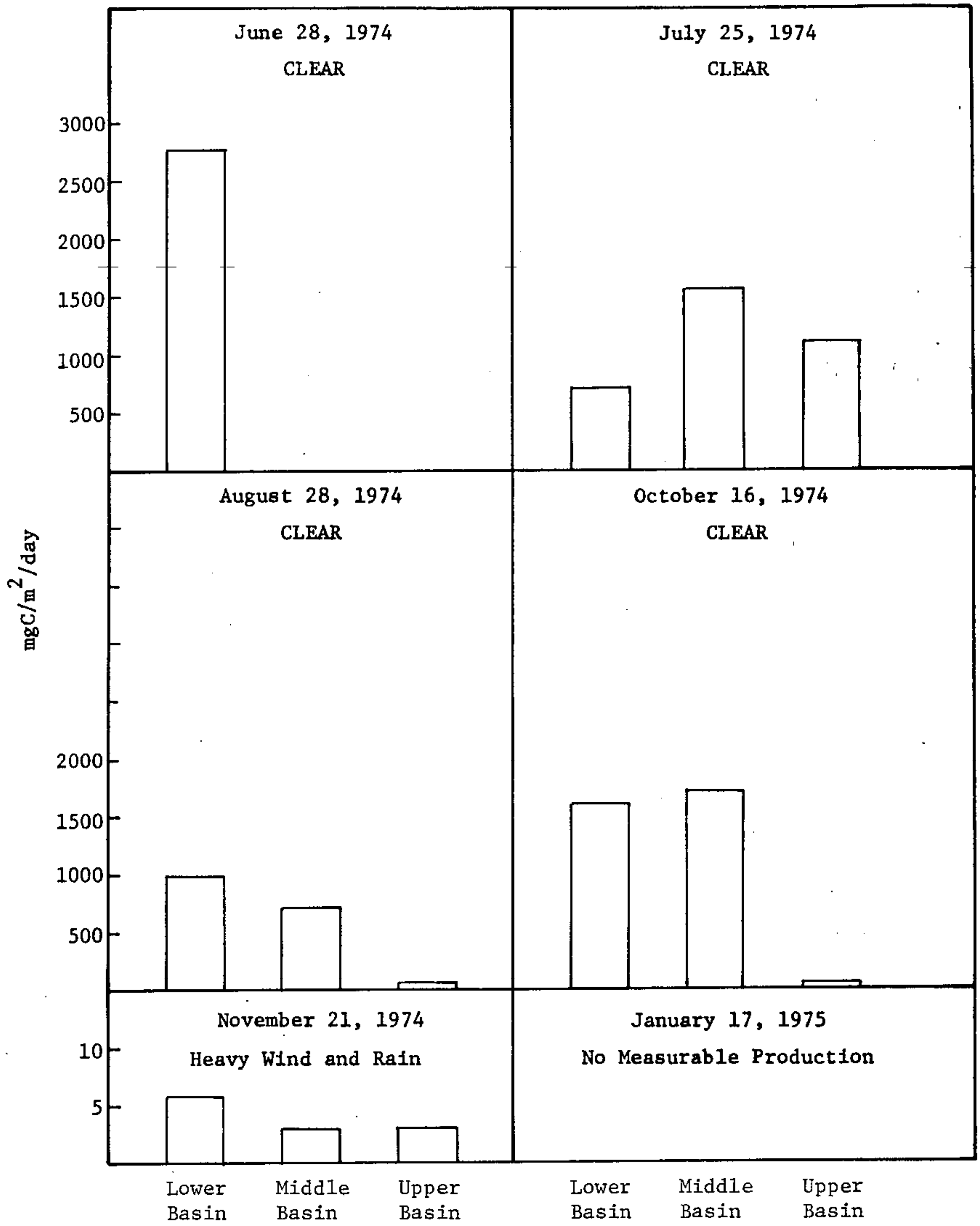

Fig. 84. Algae Productivity (by C^{14}) in Capitol Lake

Table 38.
Capitol Lake Zooplankton Count, Middle Basin, number/liter

	6-28-74	7-25-74	8-28-74	10-16-74	11-22-74
ROTIFERS					
Asplanchna	104	36	171	--	--
Brachionus	4	--	--	3	--
Keratella	2	20	--	--	--
Polyarthra	49	288	--	--	--
Synchaeta	22	59	2	--	--
Trichacerca	1	--	2	--	--
CLADOCERA					
Alonella	19	--	--	--	--
Bosmina	118	40	--	--	1
Ceriodaphnia	--	1	14	--	--
Daphnia	--	8	2	--	--
COPEPODS					
Cyclops	--	1	--	--	--
Diaptomus	1	--	4	--	--
Nauplius (stage)	6	10	--	--	1
Chiromomidae	--	--	--	--	1
Total organisms/liter	326	463	195	3	3

Table 39.
Capitol Lake Zooplankton Count, Lower Basin, number/liter

	6-28-74	7-25-74	8-28-74	10-16-74	11-22-74
ROTIFERS					
Asplanchna	9	71	160	--	--
Brachionus	2	5	--	69	2
Keratella	1	15	--	--	--
Polyarthra	25	218	--	--	1
Synchaeta	9	203	2	--	1
Trichocerca	--	5	1	--	--
Unidentified	84	5	--	--	--
CLADOCERA					
Alonella	--	--	--	--	--
Bosmina	149	41	4	--	--
Ceriodaphnia	--	8	39	--	--
Daphnia	--	112	8	--	--
COPEPODS					
Cyclops	--	--	--	--	--
Diaptomus	--	--	2	--	--
Nauplius (stage)	2	31	--	--	1
Total organisms/liter	281	714	216	69	5

and Synchaeta sp. Most organisms were gone by October even though algae production remained high.

c. Fish

Fishery operations in Capitol Lake have been considerably modified since its beginning in the 1950's. Holding facilities were constructed at the Tumwater Falls fishway and are used to collect eggs from migrating chinook. The holding ponds are converted to rearing ponds after egg stripping operations are completed. The Percival Creek bay is also utilized for chinook rearing from April to June. A recent innovation is the use of Percival Bay in the fall to raise one-year old chinook for early spring release.

The number of species of fish in Capitol Lake probably has not changed since 1955 but the yearly rotenone treatment of Percival Bay prior to chinook stocking may have changed the abundance somewhat.

d. Benthic Organisms

Benthic samples (Table 40) show differences in numbers and composition of benthos between the lower and middle basins. The June 28, 1974, sample indicates marine polychetes dominant in both the lower and middle basins. This sampling was conducted immediately after the salt water flushing of the lake and these organisms probably migrated in with the salt water. The distinct separation of the two polychetes in the lower and middle basins may reflect their degree of mobility or their degree of salinity preference. The polychete Nereis sp. is much larger and appears much more mobile. These polychetes are brackish organisms and their survival in Capitol Lake until January is surprising. The October sampling again showed a distinct difference between the lower and middle basins with the ostracod Typhlocypis sp. dominant in the middle basin and the amphipod Corophium sp. dominant in the lower basin. Chronomid larvae which were absent or present at low densities during the June and October sampling were dominant in both the lower and middle basins in January.

Table 40. Benthic Organisms of Capitol Lake, Washington (Organisms per m^2)

	MIDDLE BASIN						LOWER BASIN					
	6-28-74		10-16-74		1-17-75		6-28-74		10-16-74		1-17-75	
	$\#/m^2$*	$\#/ft^2$	$\#/m^2$	$\#/ft^2$	$\#/m^2$	$\#/ft^2$	$\#/m^2$	$\#/ft^2$	$\#/m^2$	$\#/ft^2$	$\#/m^2$	$\#/ft^2$
Hydrozoa												
Unidentified											43	(4)
Plychaeta												
Ampharetidae							1376	(128)	129	(12)	43	(4)
Nereidae												
Nereis	215	(20)	258	(24)					86	(8)		
Oligochaeta												
Enchytraeidae											43	(4)
Unidentified					129	(12)						
Insecta												
Chironomidae	86	(8)			258	(24)	86	(8)			215	(20)
Tipulidae	344	(32)										
Crustacea												
Ostracoda												
Typhlocypris			860	(80)	43	(4)						
Amphipoda												
Corophium							43	(4)	3784	(352)		
Microprotopus			43	(4)								
Arachnida												
Hydracarina			43	(4)								
Total	645	(60)	1204	(112)	430	(40)	1505	(140)	3999	(372)	344	(32)

* $m^2 = 10.76\ ft^2$

$\#/m^2 x0.9294 = \#/ft^2$

e. Aquatic Macrophytes

The following species of aquatic macrophytes were identified in Capitol Lake from a general survey in August, 1974: *Potamogeton pectinatus*, *Potamogeton crispus*, *Potamogeton foliosus*, *Elodea canadensis*, *Lemna gibba*, and *Typha latifolia*. The distribution of these macrophytes is given in Figure 85.

The dominant submergent species of the lower and middle basin was *P. pectinatus* which grew heaviest along the west shores of these basins. This species was also found at lower densities throughout the southern arm of Percival Cove, along the eastern margin of the upper basin, and in spots along the eastern margins of the lower and middle basins.

The dominant submergent macrophyte of both upper basin and Percival Cove is *Elodea canadensis*, although *P. pectinatus* occurs in significant numbers in both areas and *P. foliosus* is a significant member of the upper basin vegetation. Underwater observations in one shallow portion of the middle basin (Figure 85) indicated very sparse growths of *E. canadensis*.

Potamogeton crispus was observed at one location on the northwest side of the middle basin but is not regarded as a significant member of the aquatic flora of Capitol Lake.

Typha latifolia (cattail) is a significant and abundant shoreline plant along the margins of the lake shore. *T. latifolia* occurs extensively on the small islands in the upper basin, along the western margins of the upper and middle basins, and around Percival cove. *T. latifolia* also inhabits a small portion of the shoreline on the east side of the lower basin.

Lemna gibba, a small floating leaved species, was observed growing among the *T. latifolia* stands.

A general observation is that the macrophytes in Capitol Lake were restricted to the shallow margins of Capitol Lake and were not dense

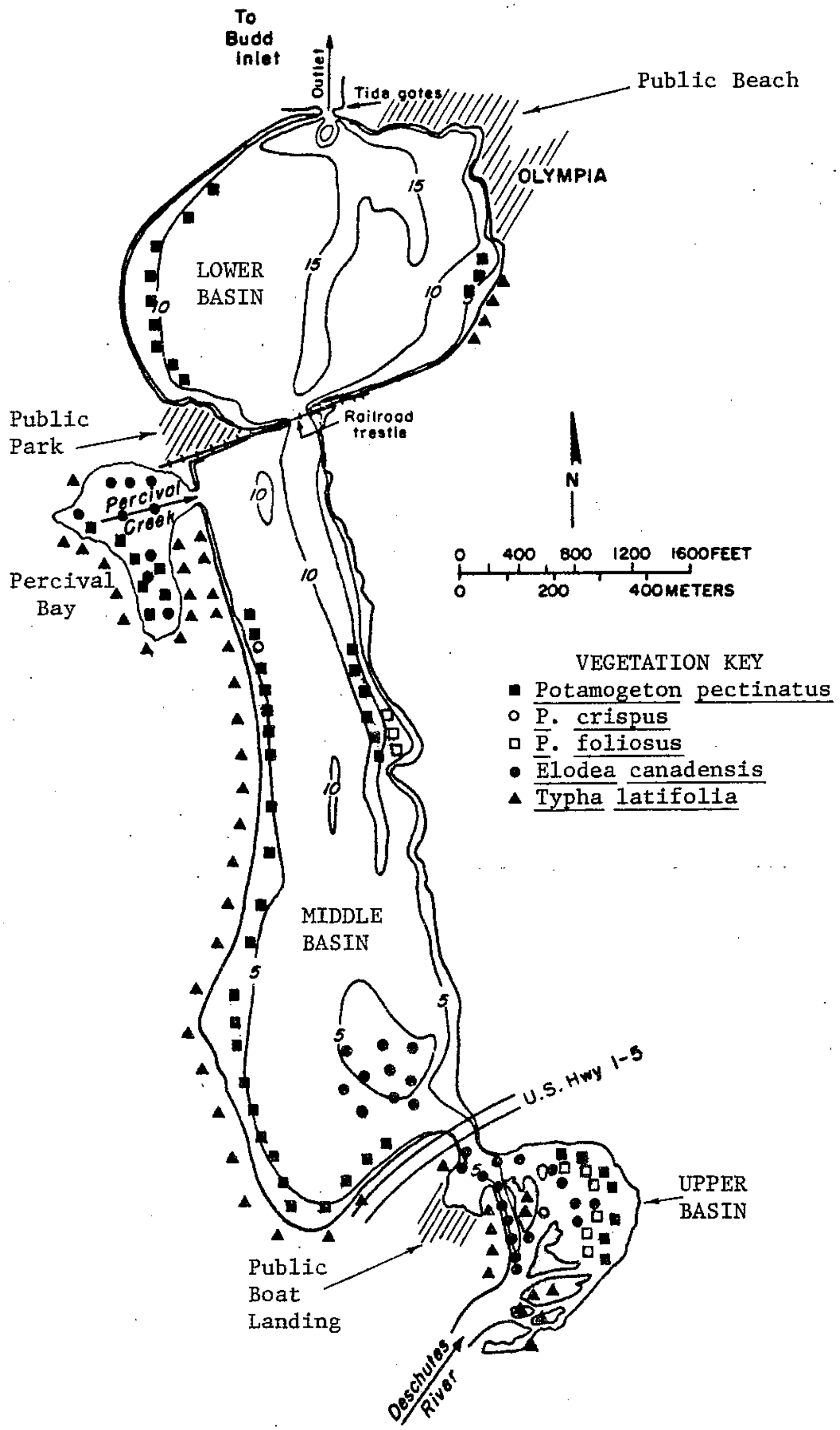

Fig. 85. Distribution of Aquatic Macrophytes on Capitol Lake

enough to interfere with recreation activities. P. pectinatus which is common in the lower and middle basins is salt resistant[39] and is apparently able to survive the annual salt water flushing. Light limitation and sedimentation apparently limit its distribution to the margins of the basins. Although limited observations on the distribution of Elodea canadensis were made, the observation that it was never collected in the dredge samples in the lower or middle basins indicate a very limited range. E. canadensis is probably controlled by the salt water flushing and occurs mainly in the upper basin and Percival Cove which are not affected by the salt water flushing.

f. Bacteriological Quality

Bacteriological sampling in Capitol Lake and the Deschutes River during the 1974-75 study period was conducted by the Thurston-Mason County Health Department, the Washington Department of Ecology, and the U.S. Geological Survey. Data from the above sources are summarized in Table 41 with sampling sites as shown in Figure 86.

Fecal coliform counts, generally the most reliable indicator of sewage pollution,[40] ranged from 4 to 130/100 ml in the Deschutes River (October 1974-February 1975), and from 1 to 400/100 ml in Capitol Lake (February 1974-August 1974). Average counts from February to August were 112.3/100 ml in the upper basin, 56.6/100 ml in the middle basin, and 15.8/100 ml in the lower basin. A generally improving trend in bacteriological quality is indicated as water flows from inlet through to the lower basin. Although data are very limited, quality in the swim area was observed to be generally good with counts consistently below the 200/100 ml maximum level recommended[41] for body contact recreation.

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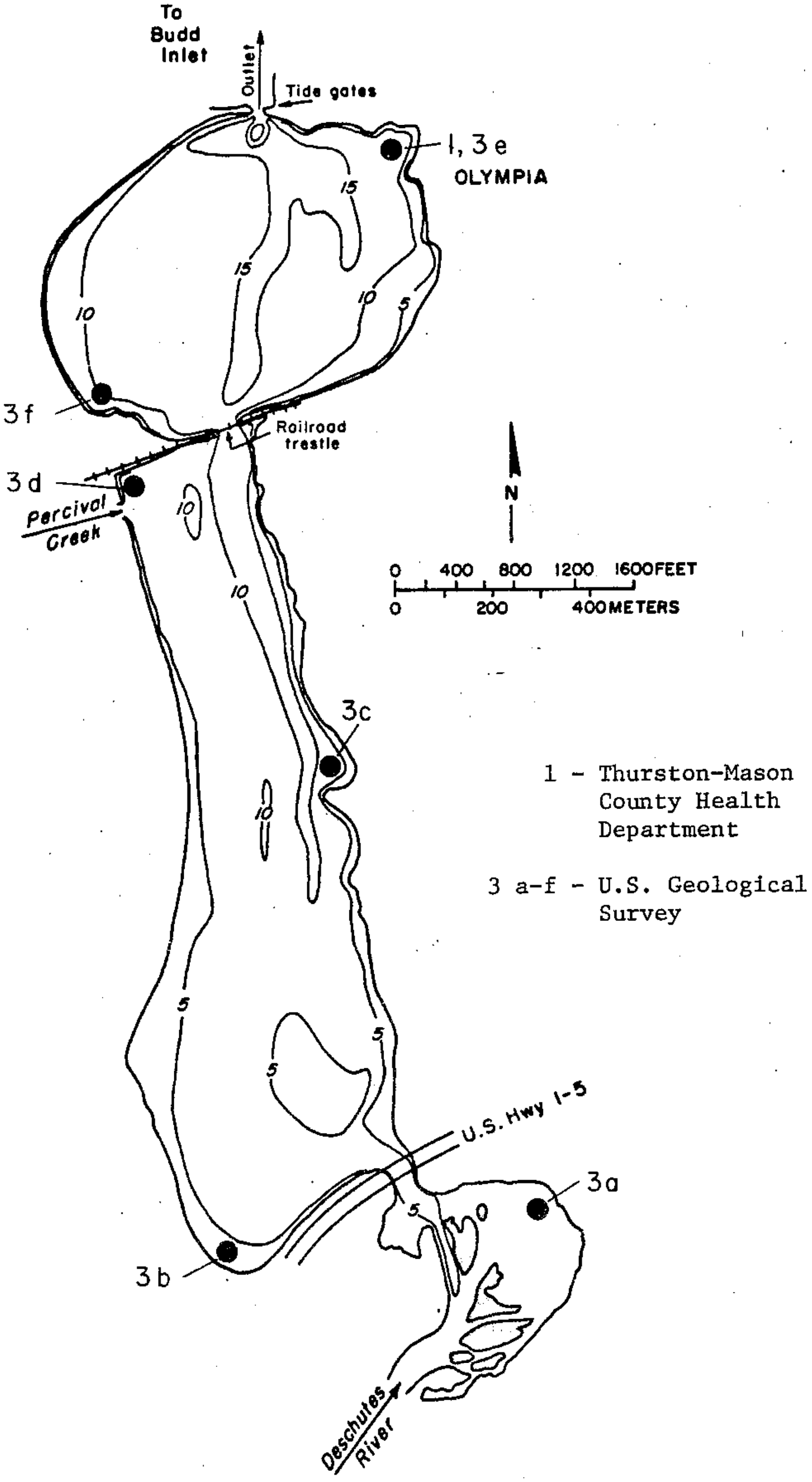
[39] Sculthorpe, C. D., The Biology of Aquatic Vascular Plants, St. Martin's Press, 1967.

[40] Geldreich, E. E., et al., "Type Distribution of Coliform Bacteria in the Feces of Warm-Blooded Animals," Journal of the Water Pollution Control Federation, Vol. 34, 1962.

[41] Geldreich, E. E., "Applying Bacteriological Parameters to Recreational Water Quality," Journal of the American Water Works Association, Vol. 62, No. 2, 1970.



1 - Thurston-Mason County Health Department

3 a-f - U.S. Geological Survey

Fig. 86. Bacteriological Sampling Location Map

Table 41.

Bacteriological Quality, Capitol Lake and the Deschutes River, 1974-75

	10/74		11/74		12/74		1/75		2/75	
	T.C.*	F.C.*	T.C.	F.C.	T.C.	F.C.	T.C.	F.C.	T.C.	F.C.
Deschutes River near Olympia[2]	1190	130	125	5	1550	25	2100	4	110	35

Capitol Lake[3]	2/74	4/74	6/74	7/74	8/74
	F.C.	F.C.	F.C.	F.C.	F.C.
Upper Basin, a	14	90	~325	--	20
Middle Basin, b	2	12	16	--	~400
Middle Basin, c	8	36	8	--	1
Middle Basin, d	6	164	25	--	1
Lower Basin Swim Area	18	43[1] (T.C.) 41[3]	25	150[1] (T.C.)	12
Lower Basin, f	7	20	3	--	1

*T.C. - Total Coliform/100 ml; F.C. - Fecal Coliform/100 ml.

[1] Thurston-Mason County Health Department, unpublished data, 1974-75, T.C.

[2] Washington Department of Ecology, unpublished STORET data, 1974-75.

[3] U.S. Geological Survey, unpublished data, 1974-75.

4. Bottom Sediment Composition

Bottom sediment core samples were collected from each of the three basins of Capitol Lake to establish the general character of lake bottom material. Core samples were analyzed for oxidation reduction potential (ORP), pH, total phosphorus (total-P), Kjeldahl nitrogen (Kj-N), nitrate nitrogen (NO_3-N), and chemical oxygen demand (COD). Data from the core analyses are summarized in Figures 87, 88 and 89.

Observed values of ORP were relatively high and positive for all cores, and varied little throughout the depth of the cores (up to 56 cm). This and the presence of NO_3-N at all depths suggests the presence of aerobic conditions at significant depths below the water-sediment interface. It should be pointed out that the ORP and other measurements were not conducted in situ; rather the measurements were made in the laboratory several days after collection and storage of the cores at 4°C.

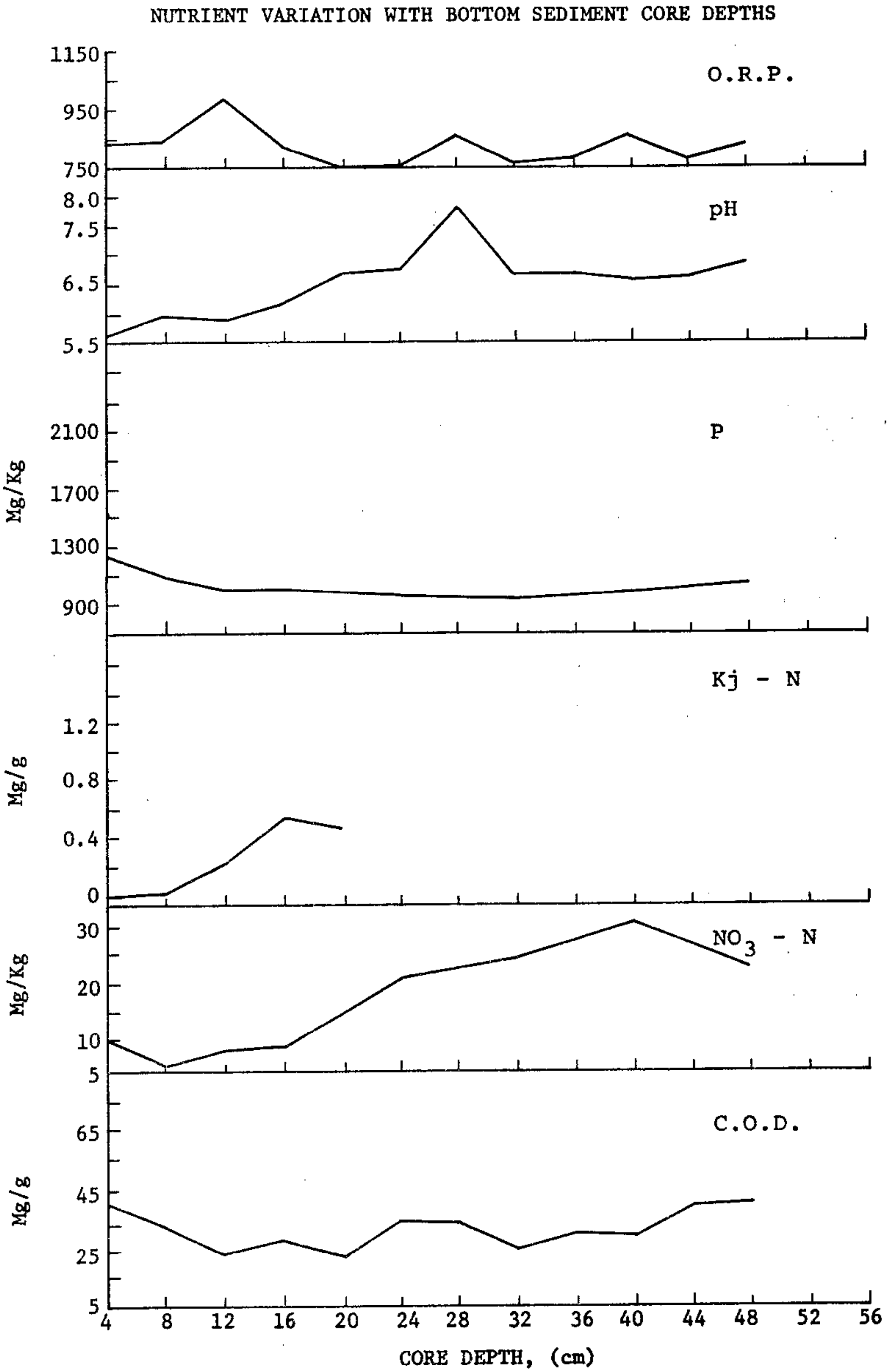


Fig. 87. Bottom Sediment Composition, Capitol Lake, Upper Basin

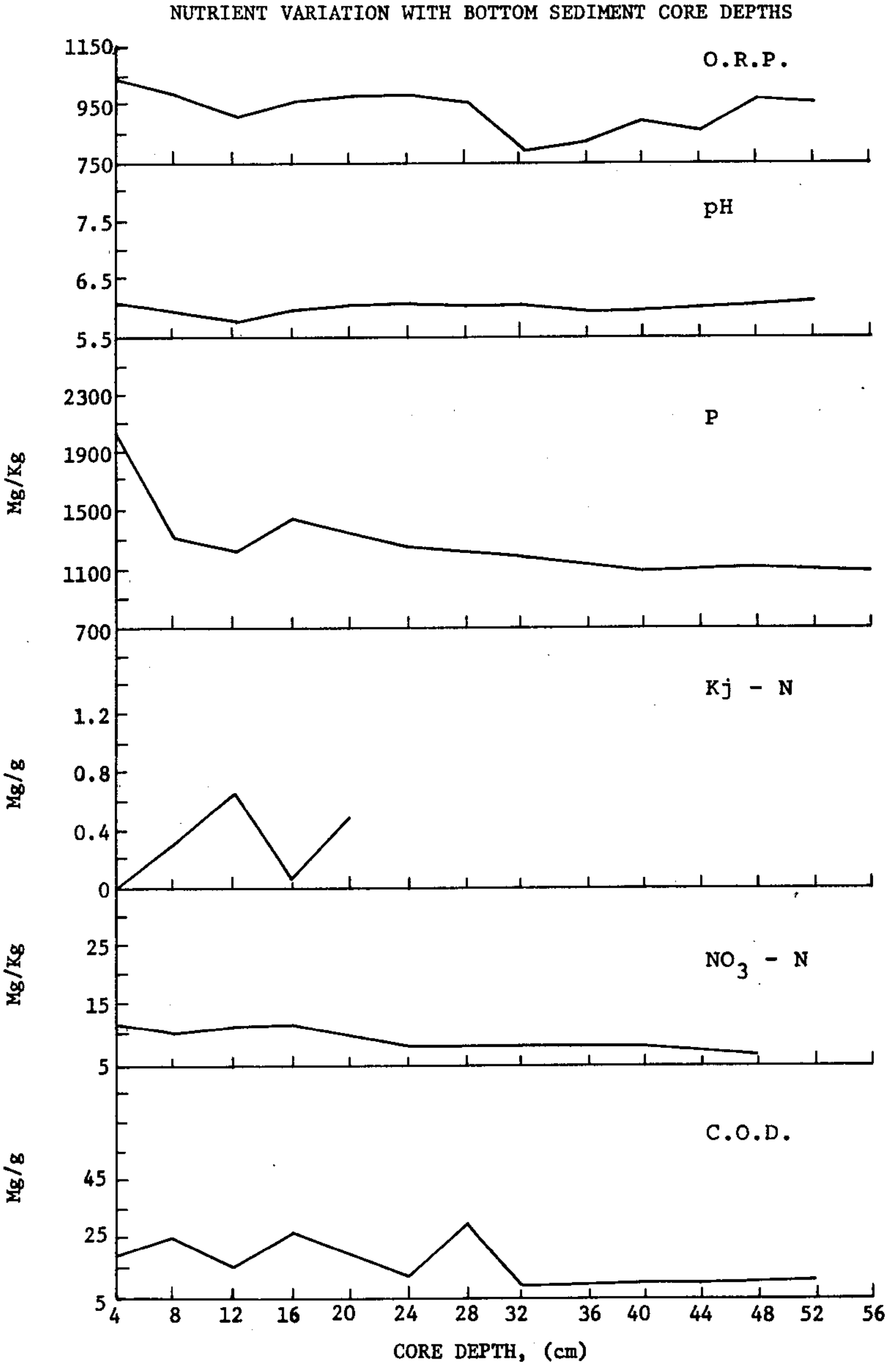


Fig. 88. Bottom Sediment Composition, Capitol Lake, Middle Basin

NUTRIENT VARIATION WITH BOTTOM SEDIMENT CORE DEPTHS

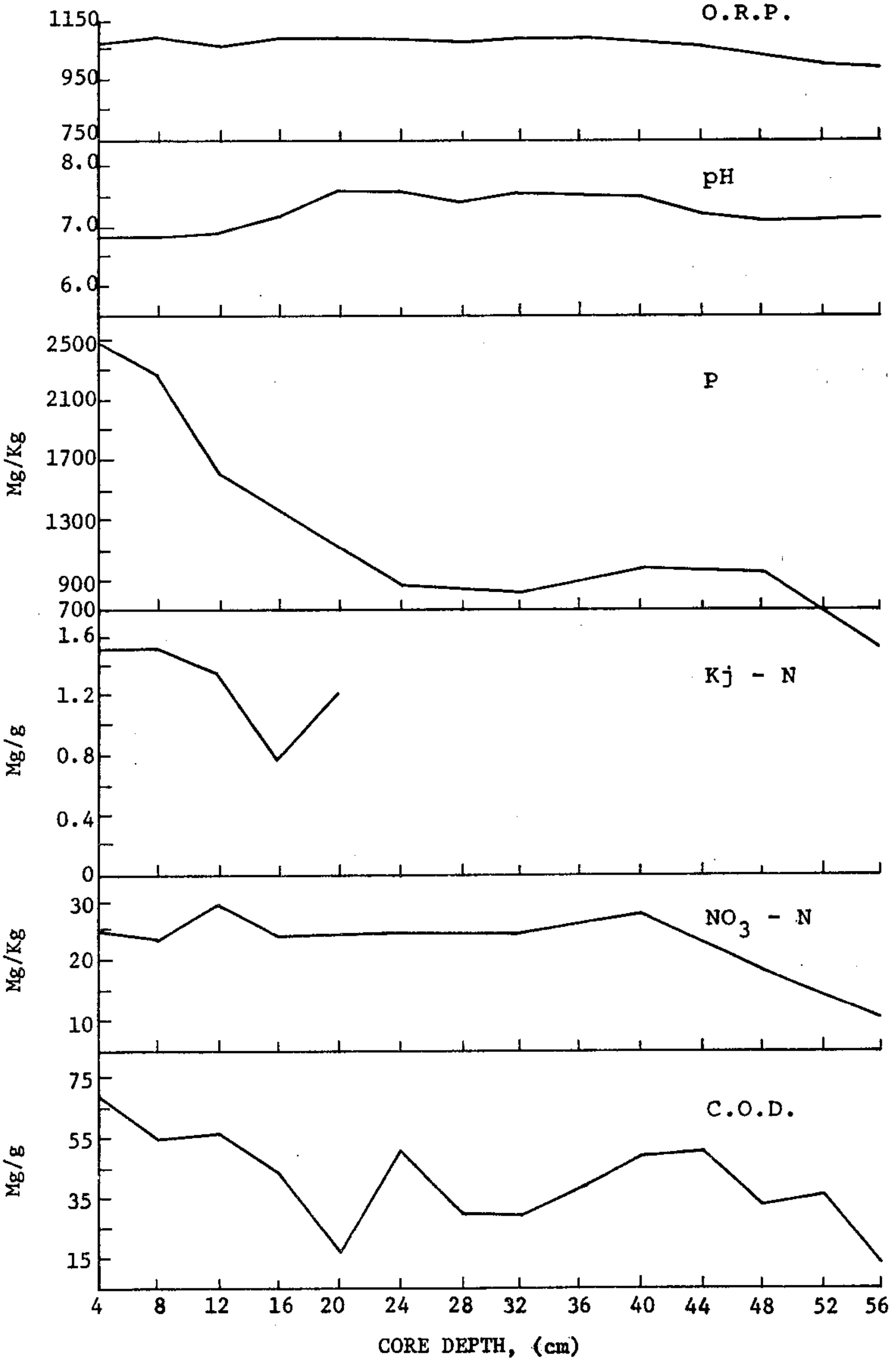


Fig. 89. Bottom Sediment Composition, Capitol Lake, Lower Basin

Measurements of pH showed little variation over the depth of the cores except for the upper basin where a gradual trend was observed from 5.5 at the surface to 7.0 at a depth of 48 cm. The lower pH in this core suggests the possibility of anaerobic activity in the upper sediment layers.

Measurements of nutrient and organic composition were observed to vary somewhat over the depth of the cores taken but without any clearly definable trends. This was particularly the case in cores from the middle and upper basins. In the lower basin COD, total-P, and NO_3-N were observed to decrease steadily with increasing depth.

D. Discussion

Capitol Lake has had a very brief existance therefore little documentation of water quality problems occurring during this period is available. Bacteriological records (Table 41)[32] indicate that the lake received significant sewage pollution during its early existance. Records show, however, that steady improvement in bacteriological quality was made through the 1950's. Conditions observed since the early 1960's have usually been adequate to meet public health requirements for safe water contact recreation use of the lake. Unpublished reports of the Washington Department of Fisheries between 1968 and 1971 indicate that aquatic weed growth in the lake reached nuisance proportions during that period, perhaps beginning as early as 1966-67. Various techniques for controlling weed growth were investigated.[26] Following testing and evaluation of available control procedures, a program of periodic draining and back flushing with salt water was concluded to be the most practical.[26] This management program has been carried out from 1968 to present (1975). Lack of recurrence of the weed growth in nuisance proportions has been interpreted as evidence of the effectiveness of this procedure.[26] The only other documented water quality problems have been short term in nature such as a chemical spill.[24] Such problems have been dealt with by draining the lake (discharging lake contents to Budd Inlet) and refilling with fresh water.

While water quality problems in the lake have appeared to be limited, the emergence of the weed problem is suggestive of broader potential problems. The weed growth itself and associated potential problems are of major concern because of their adverse effects on major lake uses. The purpose of the subsequent discussion is to evaluate water quality and potential problems in light of data summarized in the preceding sections of this report.

1. Chemical Water Quality

a. Chemical Constituents and Significance

Chemical constituents in the Capitol Lake - Deschutes River system are among the primary determining factors of overall water quality. With the objective of protecting water quality for all beneficial uses (water supply, wildlife habitat, general recreation and aesthetic enjoyment, and fish production) the Class A water quality standard (Table 24) has included specific criteria for pH, dissolved oxygen, total dissolved gas. In addition, a general criterion is included requiring that aesthetic quality be protected by excluding substances that offend human senses of sight, smell, taste, and touch. In the absence of sewage pollution and colored or malodorous industrial wastes, substances of major concern are those that might impair aesthetic quality by stimulation of aquatic weed and algae growth. The major plant nutrients, nitrogen and phosphorus, are commonly considered to be the chemicals of greatest significance. In the absence of gross pollution these substances may also have an indirect controlling effect on pH, D.O., and total dissolved gases, because of their influence on the aquatic plant community.

Nitrogen and phosphorus concentrations in the Capitol Lake - Deschutes River system must be evaluated both for their effect on conditions in the lake and in light of the prevailing natural condition which is basically that of a river with an artificial impoundment at its downstream terminus. Nitrogen and phosphorus concentrations observed in Capitol Lake during this study are summarized in Table 42. Observed values were consistent with previously observed nitrogen and phosphorus concentrations (Figures 64 and 65).

Table 42.

Nitrogen and Phosphorus in Capitol Lake, 1974-75

Capitol Lake	Inorganic-N (mg/l)			Total-N (mg/l)			Total-P (mg/l)		
Basin	min	max	mean	min	max	mean	min	max	mean
Upper	0.04	0.53	0.35	0.15	0.71	0.47	0.01	0.11	0.06
Middle	0.04	0.52	0.27	0.35	0.64	0.48	0.01	0.13	0.06
Lower	0.04	0.54	0.22	0.30	0.62	0.47	0.01	0.12	0.06

The data shown in Table 43 from a recent study of some Washington lakes[42] provide some local perspective to the Capitol Lake observations. Table 43 summarizes nitrogen and phosphorus concentrations observed in 18 Washington lakes from February to November, 1971. The lakes have been divided into groups on the basis of residence time (average volume divided by average annual surface-water outflow); six of the lakes having residence times less than 0.5 years; twelve greater than 0.5 years. Residence times ranged from 0.06 years to 2.2 years with an average of 1.1 years compared to an average residence time of 2.7 days for Capitol Lake. Comparison of values in Tables 42 and 43 shows the nitrogen and phosphorus concentrations observed in Capitol Lake to be in the same range as those of several other lakes in the region.

Table 43.

Nitrogen and Phosphorus Concentrations in 18* Washington Lakes

Residence Time (years)	Inorganic-N (mg/l)	Ortho-P (mg/l)	Total-P (mg/l)
(1) ≤ 0.5	0.44	0.011	0.021
(2) ≥ 0.5	0.29	0.015	0.027
Overall Average	0.34	0.014	0.025

*(1) Black, Long, Ohop, Steilacoom, Hancock, Samish (West Arm)

(2) Wildcat, Kitsap, Silver, Tanwax, Clear, Harts, Wilderness, Pipe, Cavanaugh, Samish (East Arm), Newman, Walupt

Based on analysis of nutrient data from numerous lakes throughout the world,[35] nutritional status classifications have been summarized in Table 44.[42] Using this classification scheme it can be seen that Capitol Lake would be expected to be moderately productive (meso-eutrophic) based on inorganic nitrogen since productivity appears to be nitrogen limited. Evidence of nitrogen as opposed to phosphorus limitation is provided in Figures 75 and 76. Here, total inorganic nitrogen concentrations can be seen to be reduced to less than 0.01 mg/l in the middle and lower basins during the peak of the growing season,

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[42] Bortleson, G. C., _et al_., "Data on Selected Lakes in Washington, Part III," Washington Department of Ecology, _Water Supply Bulletin 42_, 1974.

Table 44.

Lake Nutritional Status by Nitrogen and Phosphorus Concentration[43]

Nutritional Status	Inorganic-N (mg/l)	Ortho-P (mg/l)	Total-P (mg/l)
ogliotrophic	<0.2	<0.001	<0.005
oglio-mesotrophic	0.2 - 0.3	0.001 - 0.005	0.005 - 0.01
meso-eutrophic	0.3 - 0.65	0.005 - 0.02	0.01 - 0.03
eutrophic	>0.65	>0.02	>0.03

while at the same time observed ortho-P concentrations averaged 0.03 mg/l. Available nitrogen was essentially exhausted while significant concentrations of phosphorus remained. Calculation of a nitrogen to phosphorus ratio from total annual N and P loadings to Capitol Lake gives N:P = 9.42. This indicates the total supplies of nitrogen and phosphorus to be well balanced and does not suggest possible phosphorus limitation.

Evaluation of specific surface loading of nitrogen and phosphorus in Capitol Lake provides further perspective for evaluating existing and potential nutrient related problems. Surface loading of nutrients, commonly expressed in units of g/m^2 of lake surface per year, is of major significance because of the dependence of plant growth on surface area for light availability. Evaluation of data from lakes throughout Europe and North America[35] has led to general surface loading criteria for evaluation of lake nutrient status. Criteria summarized in Table 45 indicate permissible and dangerous loading levels suggested for maintaining essentially static productivity conditions. Calculated values of specific surface loadings of total-N and total-P for Capitol Lake are given in Table 46. Also included in this table are comparative data on several North American lakes.[35] Comparing data from Capitol Lake with suggested surface loadings (Table 45),

Table 45.

Suggested N and P Surface Loading Levels

Mean Depth up to	*Permissible Loading Up to:*		*Dangerous Loading in Excess of:*	
	Total-N (g/m^2-yr)	Total-P (g/m^2-yr)	Total-N (g/m^2-yr)	Total-P (g/m^2-yr)
5m	1.0	0.07	2.0	0.13
10m	1.5	0.10	3.0	0.20
50m	4.0	0.25	8.0	0.50
100m	6.0	0.40	12.0	0.80

Table 46.

N and P Specific Surface Loadings
Capitol Lake 1974-75 and North American Lakes

Location	Date (yr)	Specific Surface Loading (g/m^2-yr) Total-N	Total-P	Surface Area (RM^2)	Mean Depth (m)	Residence Time (yrs)	Trophic Status
Capitol Lake	*74-75*	*307.6*	*34.8*	*1.13*	*2.4*	*0.007*	---
L. Washington	57	31.4	1.34	87.6	33.0	3.2	eutrophic
L. Mendota	42-44	3.1	0.17	39.4	12.0	12.0	eutrophic
L. Menona	42-44	---	2.14	14.0	7.8	1.2	eutrophic
L. Waubesa	42-44	---	(9.93)**	8.3	4.8	0.3	eutrophic
L. Kegonsa	42-44	---	(6.64)**	12.7	4.6	0.35	eutrophic
Moses Lake	63-64	7.0	0.9	27.5	5.6	---	eutrophic
L. Sebasticook	64-65	6.7	0.21	17.4	6.0	---	eutrophic
Lake Tahoe	61-62	0.23	0.04	497.0	303.0	700.0	oligotrophic
Geist Res.	63-64	(49.5)*	3.10	7.3	---	---	eutrophic

*Inorganic-N

**Soluble-P

and with data on other lakes (Table 46), two important points are evident. First, surface loadings of nitrogen and phosphorus to Capitol Lake are extremely high. Observed loadings of both nitrogen and phosphorus were approximately 100 times greater than suggested dangerous levels and 10 to 100 times greater than levels observed in several highly productive lakes. The important point is that the residence time of Capitol Lake is very much shorter than that of typical lakes reported in the literature. The average residence time of 16 lakes considered by Vollenweider[35] was 4.3 years; the average residence time of the 18 Washington lakes surveyed by Bortleson[42] was 1.1 years. While the very heavy surface nutrient loadings provide the potential for massive blooms, the very short mean residence times provides a flushing action that helps minimize the development of such blooms. The conditions under which heaviest algae growth should be expected is that of lowest flow or longest residence time in late summer, particularly when accompanied by warm, clear weather. Under these conditions with excess available phosphorus remaining in the middle and upper basins (as indicated by Figure 75) significant potential for nitrogen fixing blue-green algal blooms exists.

The importance of the very short residence time of Capitol Lake to minimization of nutrient build-up, particularly through sedimentation and accumulation in bottom sediments, is illustrated by the nutrient budget. An overall budget for both total-N and total-P was formulated by summing the product of flow rate and nitrogen or phosphorus concentration in the lake influent and effluent. Details are given in Appendix D (Table D8) and results are summarized in Table 47.

Table 47.
Total-N and Total-P Budget, Capitol Lake, 4/74-3/75

	Total-N (kg)	Total-P (kg)
Deschutes River, in	348,500	37,000
Percival Creek, in	45,800	2,500
Total, in	394,400	39,500
Total, out	376,500	45,200
Retention, percent	4.5	-15.0

Deschutes River influent measurements are those taken at the upstream end of the upper basin. Measurements of nitrogen and phosphorus concentrations made in the lower basin were used as effluent concentrations. On this basis retention calculations may be slightly conservative. Overall, the nutrient budget should be considered as approximate since the single monthly concentrations were used as monthly averages. Nevertheless, considering only the general magnitude of nitrogen and phosphorus retention percentages, it is apparent that nutrient retention is very slight. By comparison, the range and nutrient retention values for 16 lakes in Europe and North America[35] are summarized in Table 48. A recent study[43] of the phosphorus budget in a Canadian lake with a relatively low residence time (22 days) has emphasized the importance of the high degree of flushing to minimizing the effect of high nutrient loading.

Table 48.

Nutrient Retention in European and North American Lakes[35]

	Range	Mean
Retention of Total-N, percent	12-90	54
Retention of Total-P, percent	0-93	49

Nutrient characteristics of the Deschutes River system provide an important perspective for evaluating conditions in Capitol Lake. This aspect cannot be overlooked because of the unalterable natural riverine characteristic of the lake system. Concentrations of nitrate-N and orthophosphate-P observed in this study are compared to reported concentrations for 19 rivers tributary to Puget Sound (Table 49). Values summarized for the Deschutes River at both upstream and downstream stations are somewhat higher than the average but well within the range of concentrations found in comparable local rivers.

A broader perspective of nutrient concentrations in the Deschutes River may be gained by considering the total-N and total-P production of the

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[43] Dillon, P. J., "The Phosphorus Budget of Cameron Lake, Ontario: The Importance of Flushing Rate to the Degree of Entrophy of Lakes," Limnology and Oceanography, Vol. 20, No. 1, January, 1975.

Table 49.

Nitrogen and Phosphorus: Range and Mean for Puget Sound Tributaries[20]

	NO_3, mg/l, (N,mg/l)			PO_4, mg/l, (P,mg/l)		
River, Location	Max	Min	Mean	Max	Min	Mean
Nooksack at Deming^{U}	1.0	0.0	0.4	0.21	0.0	0.02
Nooksack at Ferndale^{D}	2.5	0.1	0.8	0.05	0.0	0.00
Skagit at Marblemount^{U}	1.1	0.0	0.3	0.08	0.0	0.01
Skagit at Mt. Vernon^{D}	1.5	0.0	0.4	0.07	0.0	0.02
Sauk at Darrington^{U}	0.9	0.0	0.2	0.08	0.0	0.02
Baker at Concrete^{U}	0.5	0.1	0.3	0.03	0.0	0.01
Samish at Burlington^{D}	4.7	0.7	2.2	0.09	0.0	0.03
Stillaguamish, S. F., Granite Falls^{U}	0.7	0.0	0.3	0.11	0.0	0.02
Stillaguamish, N. F. at Arlington^{D}	1.0	0.1	0.6	0.04	0.0	0.02
Stillaguamish at Sylvana^{D}	2.0	0.0	0.6	0.10	0.0	0.02
Skykomish at Gold Bar^{U}	0.6	0.0	0.3	0.06	0.0	0.01
Sultan at Sultan^{D}	0.8	0.1	0.4	0.07	0.0	0.01
Snoqualmie at Snoq.^{U}	1.8	0.0	0.5	0.12	0.0	0.02
Snoqualmie at Carnation^{D}	0.9	0.5	0.7	--	--	--
Tolt at Carnation^{D}	1.0	0.1	0.4	0.03	0.0	0.01
Snohomish at Snoh.^{D}	2.6	0.0	0.7	0.12	0.0	0.02
Green at Palmer^{U}	0.9	0.0	0.2	0.06	0.0	0.02
Green at Auburn^{D}	1.9	0.0	0.7	0.13	0.0	0.03
Green at Tukwila^{D}	4.5	0.4	2.0	0.83	0.05	0.21
Puyallup at Orting^{U}	1.6	0.0	0.3	0.14	0.0	0.03
Puyallup at Puyallup^{D}	2.0	0.1	0.7	0.13	0.01	0.05
White at Greenwater^{U}	0.9	0.3	0.61	--	--	--
White at Sumner^{D}	3.3	0.0	0.7	0.28	0.02	0.09
Nisqually at McKenna^{U}	0.9	0.0	0.3	0.19	0.0	0.04
Snokomish at Potlatch^{D}	0.7	0.0	0.2	0.06	0.0	0.03
Elwha at Port Angeles^{D}	0.3	0.0	0.1	0.11	0.0	0.02
Dungeness at Squim^{D}	0.6	0.0	0.2	0.06	0.0	0.01
Duckabush at Brinnon^{D}	0.4	0.0	0.1	0.07	0.0	0.01
Deschutes at Rainier^{U}	0.7	0.1	0.4	0.13	0.0	0.05
Deschutes at Tumwater	1.6	0.6	1.1	0.12	0.0	0.07
Capitol Lake Inlet (WSU, 1974-5)	2.4	0.0	0.84	0.21	0.06	0.12
Average of Upstream Sites	0.97	0.04	0.34	0.11	0.0	0.023
	(.22)	(.02)	(.08)	(.04)		(.01)
Average of Downstream Sites	1.44	0.1	0.53	0.096	0.002	0.027
	(.33)	(.02)	(.12)	(.03)		(.01)
Average of Urban Sites	4.6	0.55	2.1	0.46	0.025	0.12
	(1.04)	(.12)	(0.47)	(.15)		(.04)
Capitol Lake Inlet (WSU, 74-75)	(.41)	(0.0)	(0.28)	(.07)	(.02)	(.04)

total drainage basin. Nitrogen and phosphorus production rates (in kg/ha-yr) for the Deschutes basin can be calculated, as for the nutrient budget, as the product of nutrient concentration and flow rate divided by the total drainage area tributary to the point of calculation (Tumwater Falls). Nutrient production values calculated from current observations are summarized in Table 50. Also given in this table are nutrient production values typical of very similar land areas in Wisconsin and southern Ontario.[44] Comparison of values given in Table 50 indicates that nutrient production of the Deschutes River basin may be considered well within a normal range, or even relatively low. This observation is of considerable significance when considering possible need for managing nutrient inputs to Capitol Lake.

Table 50.

Total-N and Total-P Production of River Drainage Basins[44]

	Total-N (kg/ha-yr)	Total-P (kg/ha-yr)
Deschutes River at Capitol Lake	8.3	0.9
Deschutes River, Dept. of Fisheries 1969-70	1.3 (NO_3 only)	0.3 (PO_4 only)
Hynes[44] (20° slope)	34.0	1.6
Hynes[44] (8° slope)	16.0	0.45

Chemical parameters of importance other than the plant nutrients include: pH, D.O., salinity, and dissolved organics. The consistently low values of COD, chlorides, and conductivity (summarized in Table 33 and Figures 73 and 78) indicate the generally high quality and pollution-free nature of the Deschutes River - Capitol Lake system. In the absence of significant pollution from domestic or industrial waste discharges, pH and D.O. are affected primarily by natural cycles of growth and respiration of the algae-plant and bacterial communities. Values of pH and D.O. as summarized in Tables 33 and 35 and Figures 73, 78, 82 and 84, can be seen to respond to these biological

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[44] Hynes, H.B.H., <u>The Ecology of Running Waters</u>, University of Toronto Press, 1972.

influences during the spring-fall growing period. During periods of maximum productivity biological activity was great enough to raise pH and D.O. levels above limits specified for Class A waters (Tables 23-24). In light of the foregoing evaluation of nutrient conditions, these pH and D.O. effects are seen as a natural product of the physical and chemical environment. Such conditions may be anticipated as long as the lake exists at the mouth of the river.

A dissolved oxygen model was not developed for Capitol Lake as originally planned. This decision was made following the diurnal studies (Figures 78 and 79) which indicated, along with general water quality patterns, that such a model would be of negligible value to overall water quality assessment.

b. Bottom Sediment

The chemical composition of bottom sediments provides information for evaluating interval lake processes and conditions and for comparison to other aquatic systems. Total-P concentrations in the three basins of Capitol Lake ranged from 530 to 2500 mg/kg. In the upper basin, concentrations varied little with depth averaging about 1100 mg/kg over the entire depth.

In the middle basin core a decrease from 2000 to 1300 mg/kg was observed in the upper 8 cm, but the P-content remained essentially constant at 1200-1300 mg/kg through the remaining depth of the core. Total-P content of the lower basin was observed to decline gradually over the depth of the core from 2500 mg/kg at the surface to 530 mg/kg at the 52-56 cm depth. A Percival Cove sediment sample had a total-P content of 1073 mg/kg (Table 51).

Table 51.

Bottom Sediment Composition, Percival Cove

Depth cm	Moisture %	Total-P mg/kg	Kj-N mg/g	COD mg/g
0-10	30.2	1073.3	8.0	62.2

By comparison, O'Neal and Sceva[36] have reported total-P content of sediments from "lightly and heavily" polluted coastal estuaries ranging from 240 to 950 mg/kg and from 590 to 2500 mg/kg, respectively. It should be noted that total-P is not a consistent indicator of bottom sediment quality and must be considered in combination with corresponding nitrogen and organic carbon measurements.

Kjeldahl-N content of sediment samples from the main lake basins ranged from 0.0 to 1.6 mg/g in the surface 10 cm layer. Levels observed in the upper and middle basins ranged from 0.0 to 0.7 mg/g and did not show a consistent pattern of variation with depth. In the lower basin, Kj-N levels were observed to range from 1.6 to 0.9 mg/g, decreasing with increasing depth over the upper 20 cm.

Chemical oxygen demand (COD) of sediments in the three main lake basins ranged from 6.0 to 70 mg/g. Percival Cove sediment (Table 51) had an average COD of 62 mg/g in the upper 10 cm. The upper basin sediment was observed to have essential COD content averaging about 30 mg/g over the 52 cm core depth. The middle basin sediment also had a relatively uniform COD content averaging approximately 12 to 15 mg/g over the 52 cm depth. Sediment from the lower basin was observed to have a COD content decreasing steadily with depth from 60 to 70 mg/g at the surface to 20 to 30 mg/g at the maximum depth.

A comparison of phosphorus, nitrogen and organic carbon content of the Capitol Lake bottom sediment samples with published data on similar components in a range of clean to polluted sediments is given in Table 52. Comparing values presented in the table for organic carbon and nitrogen, the sediments appear to be clean to lightly polluted. The C:N ratios in the upper and middle basins appear high which is indicative of organic pollution.[45] In this case, however, significant quantities of organic debris such as wood chips were observed in the two respective cores which undoubtedly accounts for the higher ratios. The very low C:N ratio observed in Percival Cove might possibly be attributable to the fish rearing activities concentrated there resulting in accumulation of highly nitrogenous waste material.

Table 52.

Capitol Lake Bottom Sediment Comparison

Sediment Location Description	Total-P mg/g (mean) range	Organic Kj-N mg/g (mean) range	Organic-C mg/g (mean) range	C:N (mean) range
Upper Basin	(1.1) 0.93 - 1.26	(0.24) 0.00 - 0.56	(11.70) 8.20 - 14.9	(48.7)
Middle Basin	(1.2) 1.10 - 2.03	(0.28) 0.00 - 0.62	(6.33) 3.60 - 12.0	(22.6)
Lower Basin	(1.3) 0.58 - 2.49	(1.30) 0.80 - 1.56	(15.10) 5.40 - 25.5	(11.6)
Percival Cove	1.07	8.0	23.3	2.9
● lightly polluted[36]	(0.58) 0.24 - 0.95	(0.55) 0.01 - 1.31	(7.8) 1.10 - 18.0	(14.2)
● heavily polluted[36]	(1.06) 0.59 - 2.55	(2.64) 5.80 - 6.80	(66.4) 14.6 - 148.1	(25.2)
● Lake Tahoe[46]	---	(2.21) 0.06 - 16.6	(26.6) 0.06 - 198.0	(11.9) 4.2 - 28.4
● sand, silt, clay, loam[47]	---	0.20 - 1.00	4.0 - 21.0	---
● stable, organic origin[47]	---	1.00 - 2.00	20.0 - 50.0	---
● decaying organic, fresh[47]	---	7.00 - 50.0	50.0 - 400.0	---
● surface runoff sediments[45]	0.14 - 0.77	0.22 - 4.05	1.1 - 22.2	7.0 - 11.0

[45] Hendricks, A. C., and Silvey, J.K.G., "Nutrient Ratio Variation in Reservoir Sediments," Journal of the Water Pollution Control Federation, Vol. 45, No. 3, March, 1973.

[46] Ballinger, D. C., and McKee, G. D., "Chemical Characterization of Bottom Sediment," Journal of the Water Pollution Control Federation, Vol. 43, No. 2, February, 1971.

[47] McGauhey, P. H., et al., "Comprehensive Study on Protection of Water Resources of Lake Tahoe Basin," Lake Tahoe Area Council, June, 1963.

In drawing conclusions from the bottom sediment analyses summarized herein, the limited extent of the data as authorized within the scope of this study cannot be overemphasized. Should other than general inferences be dependent on these data, more detailed studies of sediment composition may be advisable. With this in mind, conclusions concerning various aspects of lake sediment management can be drawn and recommendations developed.

A program of remedial and maintenance dredging is being considered as detailed by Byrne.[3] The object of this program is to restore full usefulness of Capitol Lake where uses have been impaired or precluded by sediment accumulation. The optimum renovation program will be the one capable of achieving the project objective while incurring minimum monetary and environmental cost. Decisions required in program design include where and how deep to dredge and how may monetary and environmental costs be minimized. Decisions on these matters may depend largely on bottom sediment composition and related water quality interactions. However, no dredging has been proposed for the lower basin and dredging decisions for the upper basin will depend primarily on physical requirements for sediment removal facilities and aesthetic considerations. Thus, this discussion is directed to requirements for the middle basin.

Water quality considerations important to establishing the depth and location of dredging include sediment nutrient content relationships, potential effects on algae and aquatic weed growth, and potential effects on natural fish food habitat. Nitrogen, phosphorus, and organic contents of sediment in the middle basin were found to be essentially independent of sediment depth over the 52 to 56 cm sampled. This information thus provides no basis for establishing a dredging depth. Again the limitation of the limited sampling is recognized. However, an assumption of uniform composition of sediment deposited from the Deschutes River input appears to be justified. This assumption would not be considered justified specifically in areas as Percival Cove where intensive fish rearing activities including food distribution are conducted.

Aquatic weed growth observed in the middle basin (Figure 85) was limited almost exclusively to areas shallower than 5 to 6 feet. This seems to imply that dredging of shallow areas, recognizing the need for maintaining bank stability, to a depth uniformly greater than 6 feet would seem to be adequate. However, light penetration observations throughout the growing season of this study (Figure 72) indicated adequate light availability for weed growth at depths up to 4 to 5 meters. Thus, it appears that other factors including the practice of salt water flushing are important to limiting more extensive weed growth. Maintenance of the regular salt water flushing program[26] appears to be essential to minimizing weed propagation if combined with minimal dredging in the middle basin.

Potential effects of dredging on natural fish food habitat and production are of concern because approximately 10 percent of total fish food used in the Department of Fisheries fish rearing is estimated to be of natural origin.[48] To protect natural habitat areas the Department of Fisheries wishes to minimize loss of existing shallow areas and areas containing soft clay-mud bottom material. A minimal dredging program as suggested above appears to be compatible with fisheries concerns.

Increasing the volume of the lake by dredging is expected to have some effect on water quality that cannot be estimated quantitatively. Quantitative prediction would require development of an algal growth model that was not possible within the scope of this study. However, the overall pattern of nitrogen and phosphorus variation through the total lake (as discussed previously in this section) permits some qualitative speculation. Peak growing season inorganic nitrogen concentrations have been observed (Figures 64 and 76) to be reduced to extremely low levels in the middle and lower basins. At the same time significant concentrations of dissolved phosphorus have been observed (Figures 65 and 75). This combination of conditions favors the growth of blue-green algae that can obtain nitrogen from the air allowing continued growth to the extent of available phosphorus. To some extent

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[48] R. Noble, Washington Dept. of Fisheries, Personal Communication, 1975.

(as illustrated by the data in Figures 64, 65, 75 and 76) these conditions exist at the present time. The effect of dredging in the upper and middle basins will be to increase the net retention time in the lake. This will provide additional time for increased algal crop development as long as nutrient, light, and temperature conditions remain favorable. Planned dredging is estimated (Figure 29) to increase the total lake volume from 2214 acre-ft to 2780 acre-ft. At the 20-year low flow of 74 cfs, this will increase the mean residence time in the lake from 15 days to 19 days. Thus approximately four additional days will be available for continued algal growth under adverse low flow condition. A realistic interpretation of this effect would be simply as an amplification of adverse low flow conditions by a factor of 1.26 (2780 acre-ft/2214 acre-ft). Given the existence of the lake at the mouth of the river, adverse algal growth must be accepted as an occurrence that may likely accompany the low flow periods which are favorable to algae growth.

2. Biological Quality

a. Bacteria

Historical and current bacteriological quality records for Capitol Lake are summarized in Tables 29 and 41 and Table D1 (Appendix D). Of primary concern for maintenance of recreational utility of the lake is whether or not lake water meets recommended bacteriological quality standards during the summer recreation season. The State of Washington Class A water quality standard (Table 24) applied to Capitol Lake, specifies that total coliform organisms shall not exceed median values of 240 colonies per 100 ml with less than 20 percent of the samples exceeding 1000/100 ml when associated with any fecal source. Bacteriological samples taken during this study indicate considerable variability between sampling dates and sampling stations (as noted in the preceding discussion, section C.3.f.). As indicated, the limited data available for the lower basin and swim area show an average fecal coliform count of 15.8/100 ml during the February-August period. Total coliform measurements taken at the swim area in April and August were 43 and 150/100 ml. While these data indicate generally acceptable bacteriological quality the limited number of analyses does not permit statistical analysis and firm conclusions to be made. Keeping the limited data in mind, additional observations are as follows.

Fecal coliform counts during the summer in the southwest corner of the lower basin were consistently lower than in the swim area. The observed differences in February and April may be attributable to differences in circulation/sedimentation patterns at the respective locations. It is likely that bathing activity at the swim area accounts for at least a portion of the observed differences in the June and August samples. Hydraulic model studies (Chapter V) illustrated the fact that the swim area location has poor circulation. This type of condition has been shown elsewhere[49] to contribute to accumulation or slow die off of coliform organisms. Assuming continued input of coliform source materials from intermittent and undefined sources, improvement of bacteriological quality in the swim area could be achieved by improving circulation. This could be accomplished, for example, by pumping water from the main channel in the center of the basin to the swim area. Operation of such a system would be necessary only during periods of swimming activity. Efforts to locate and, if possible, eliminate coliform source inputs may also prove fruitful in improving lake bacteriological quality.

b. Phytoplankton

The upper basin algae counts were very low during the study period and were dominated almost exclusively by periphytic diatoms characteristic of flowing waters. The middle basin counts were moderate and also dominated by diatoms. Green and blue-green algae became more prevalent during July and August. The lower basin counts were generally the

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[49] Johnstone, D. L., and Bailey, G. C., "Comparative Water Quality in Constructed Embayments and Main Channel--Biological, Chemical, Physical and Esthetic Aspects," Department of Civil and Environmental Engineering, Washington State University, Pullman, February, 1974.

highest of the three areas and contained the greatest percentage of green algae. Algae counts were not considered high enough at any station to be considered a nuisance.

Algae productivity measured by C_{14} is consistently higher at the middle basin station (Figure 84). The algae in the middle basin respond to the relatively quiescent conditions and abundant nutrient supply. As the algae are moved to the lower basin, productivity continues to be high but may be limited somewhat by reduced nutrient levels (Figure 90). Additional conditions observed in Capitol Lake during 1974 that are not reflected in the algae counts are as follows.

During the July sampling, large amounts of loose organic material were observed (Figure 91) in the middle basin that were being blown upstream by the wind and concentrating under the I-5 bridge. This material was examined microscopically and found to be Oscillatoria sp. attached to very loose organic material. During June and July, Volvox sp., a macroscopic colonial algae, was observed in the lower basin, especially in areas around the shore. Estimate of Volvox in June was 398 colonies per liter. Engstrom-Heg[27] also noted a Volvox "bloom" at 0.10 colonies per liter. Heavy densities of Gloeotrichia sp., a colonial blue-green were also observed in August floating on the surface. Concentrations of Gloeotrichia sp. were heaviest in the south end of the middle basin and around the boat land area near the I-5 bridge (Figure 92).

With the heavy concentrations of nutrients flowing into Capitol Lake, it appears that the only thing saving it from troublesome algae problems is the short retention time. It is anticiapted that the lake restoration project will increase retention time slightly but probably not enough to affect algae levels.

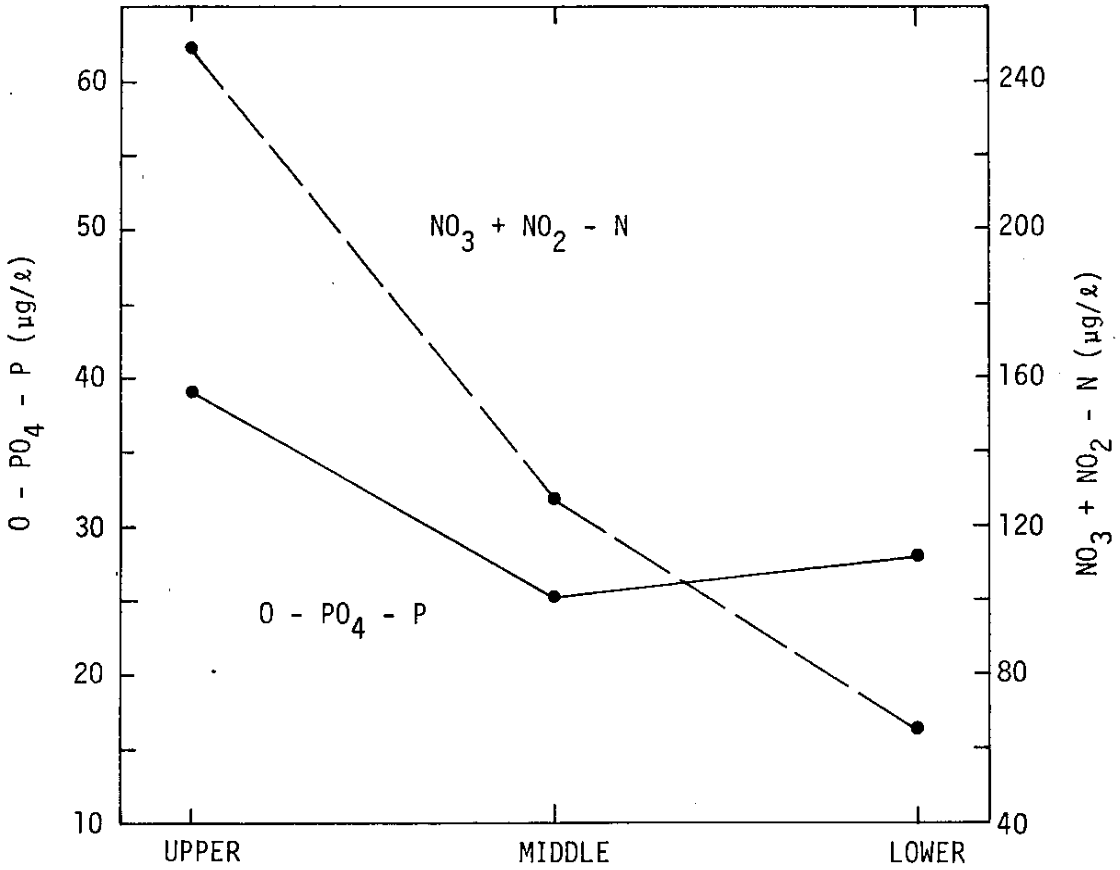

Fig. 90. Mean Concentrations of Soluble Nutrients in Capitol Lake from the Upper Basin Inlet to the Lower Basin from April to October, 1974

c. Zooplankton

Zooplankton counts (Tables 38 and 39) show a dominance of cladocerans consisting of *Bosmina sp.*, *Ceriodaphnia sp.*, and *Daphnia sp.* Copepod genera present were *Cyclops sp.* and *Diaptomus sp.* The highest density of zooplankton was observed in the July 25, 1974, sampling. Engstrom-Heg reported peak densities for the summer and fall of 1955 on July 18, August 18, and September 12. Data from the current study is in agreement with data from the Department of Fisheries (1955) showing very low counts in October. Observed low counts in November and January are due to high runoff and turbidity during this period.

A numerical comparison of observed zooplankton counts with comparable sampling dates of the 1955 study (Table 53) indicates much greater density of zooplankton during 1974. Some of this difference, however, is probably due to difference in sampling methods. Engstrom-Heg used oblique tows with a Clarke-Bumpus sampler fitted with a #0 (0.569 mm mesh) net. Current sampling was done in the top 2 m using a Van Dorn sampler as a trap and filtering through a #20 (0.05 mm mesh) net. Assuming that the zooplankton were only in the top 2 m and that the current sampling method was 100 percent more efficient, there still appears to have been a real increase in zooplankton numbers since 1955.

Zooplankton composition appears to have remained stable since 1955 except that <u>Epischura</u> <u>sp</u>., the dominant copepod in 1955, was not observed in the current study.

Zooplankton numbers may increase slightly and show earlier season peaks after the lake restoration measures are completed but composition will probably remain the same.

Table 53.

A Comparison of Zooplankton Counts for 1955 and 1974 (in number/l)[27]

Date 1955	Cladocera	Copepods	Date 1974	Cladocera	Copepods
		LOWER BASIN			
6/28	4.3	0.64	6/28	149	2
7/18	6.1	2.7	7/25	161	31
8/30	0.2	0.8	8/28	51	2
10/20	2.1	0.2	10/16	0	0
		MIDDLE BASIN			
6/28	1.8	0.1	6/28	137	7
7/18	0.1	1.3	7/25	49	11
8/30	0.3	6.1	8/28	16	4
10/20	0.4	0.1	10/16	0	0

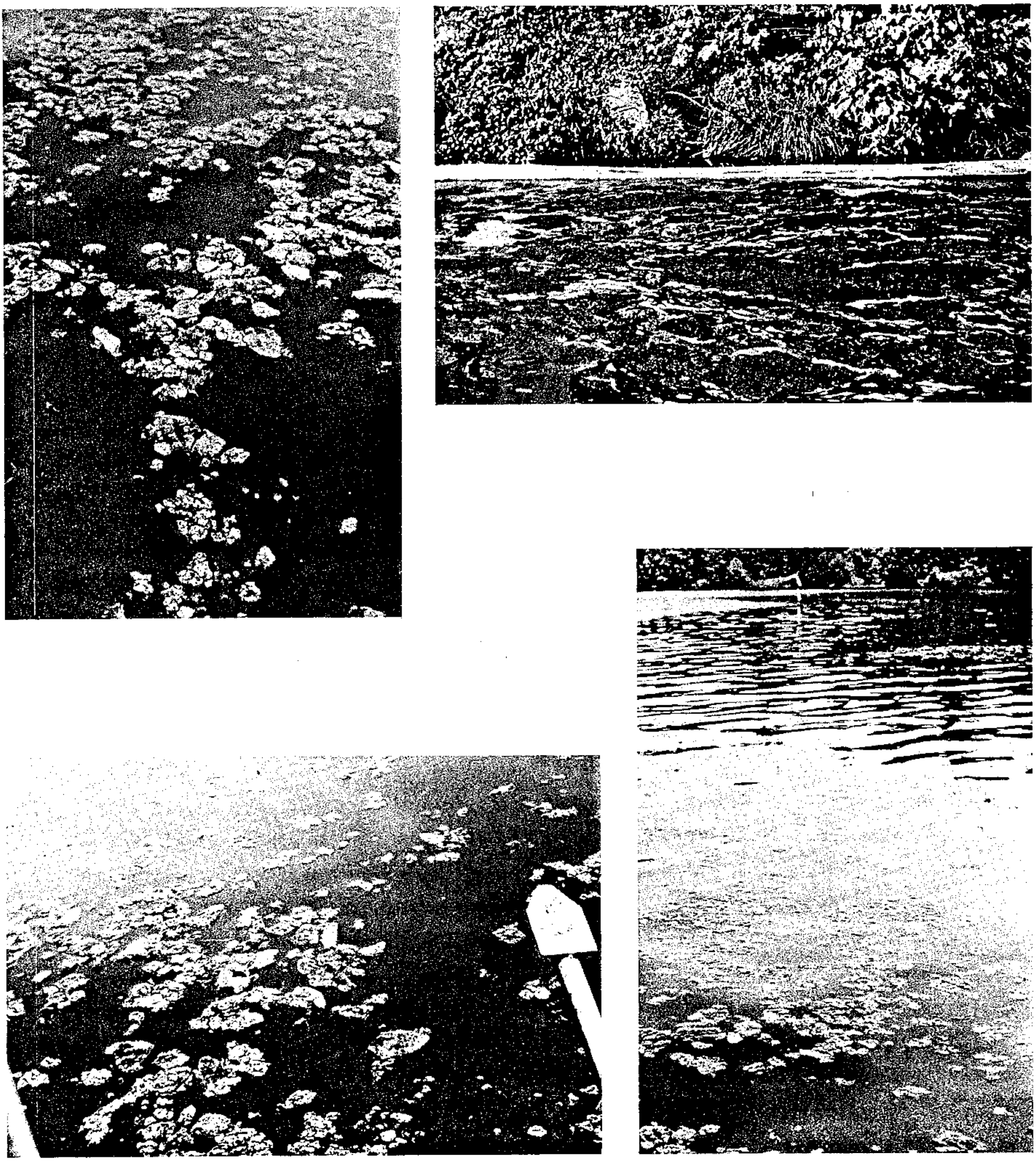

Figure 91. Algae (Oscillatoria Mats)

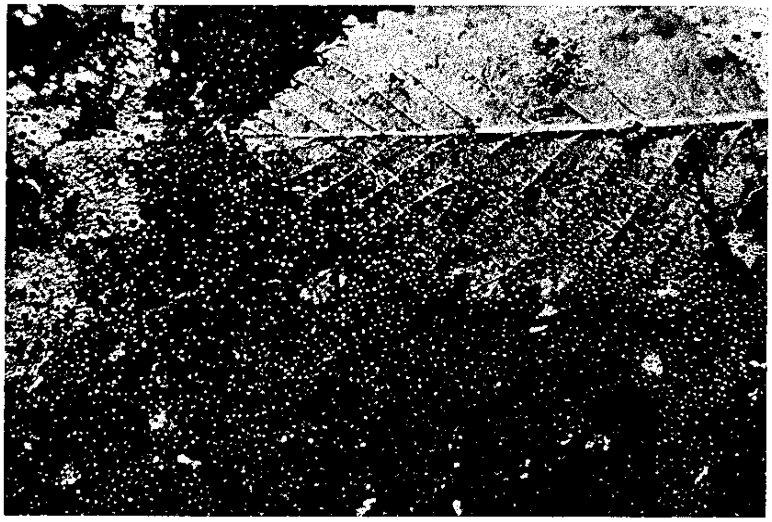

Figure 92. Algae (Gloeotrichia)

d. Benthos

Observations of the benthic organisms of Capitol Lake during 1974-75 indicate a greater diversity (Table 40) than found by Engstrom-Heg.[27] Although chinonomid larvae were abundant, ostracods, amphipods, and marine polychates were found to be equally abundant. The abundance of all organisms varied seasonally and by station. No samples were taken at the south station because of the rock and gravel substrate, but there are probably some lotic-type organisms (mayflies, caddisflies) at this station.

Stomach analysis of fish by Engstrom-Heg indicated that polychates were present in 1955 even though none were detected from his bottom samples. The two polychates found were generally separated with Ampharetidae in the lower basin and Nereis sp. in the middle basin. A few Ampharetidae were found in the lower basin in January indicating there is some carryover from one year's salt-water flush to the next. Whether the polychates, ostracods and amphipods constitute a significant portion of the chinook diet depends on whether or not the fish will adapt to bottom feeding. It may be that the preference of chinook for surface feeding and the annual salt water flushing have increased the mortality of the chironomids so that they are not as competitive ecologically. More probable is the fact that the ostracods and amphipods are slower to colonize than the chironomids and have become established in the period since 1955.

The proposed lake restoration project is not expected to shift benthic composition since all types of bottom organisms should benefit from a more stable lake bottom. Total numbers will probably increase after the project.

e. Fishing Rearing Operations

The objective of the Capitol Lake chinook rearing program is to produce smolt (migratory) size fingerlings from unfed (just hatched) to 30-day fed fry in a 4-month period (March to June). Recently instituted was an experimental program to raise yearling chinook from October to the following March.

Fish are reared in two areas around Capitol Lake. Percival Cove is utilized as a rearing area by closing off the narrow section between the inlet and the bridge. The two holding ponds near the fishway built for holding adults were converted to rearing ponds with some structural modification. Each of these ponds is 90 ft long, 20 ft wide, and has a volume of 8000 ft^3 at a depth of 4.5 ft.

Rearing operations begin in March or April with the delivery of unfed to 30-day fed fry to the Capitol Lake rearing areas from area hatcheries. These fish are fed until the holding capacity of the rearing areas is reached. At this time some fish are released to Capitol Lake. By early June all the fish have been released to the lake and the gates are opened to release the fish to Budd Inlet. No fish hatchery are reared in July and August, then in September through November Percival Cove is again stocked but with larger yearling chinook. These fish are reared through the winter and released in March prior to restocking with the unfed fry. The lake system also supports a natural population of salmon and trout varying by species and number from year to year. The Washington Department of Game releases 20,000-30,000 cutthroat and steelhead in the Capitol Lake - Deschutes River system each year.

The combined release from the Percival Cove and Deschutes ponds to Capitol Lake is about 190,000 pounds. Natural salmon produced in the system is estimated by the Department of Fisheries to be 15,000-20,000 pounds per year. The number of pounds released to the ocean is not directly measurable but regular estimates are made by the Department of Fisheries. Since the rearing capacity of the Deschutes ponds is 16,000 pounds and Percival Cove is 50,000-100,000 pounds, it is necessary to release fish to Capitol Lake periodically during the March to June rearing season. The rate of growth and survival of the fish released to Capitol Lake is not easily measured but reliable estimates are obtainable from the Department of Fisheries.

Percival Cove is again stocked in the fall with yearling chinook and these are released the following March with a spring drawdown. The rearing capacity of the Percival Cove is much greater during the winter due to lower temperature and higher dissolved oxygen and greater flows. Therefore it is not necessary to release fish periodically to the lake. The release for the winter operation is estimated at 110,000 pounds, representing a net gain of 70,000 pounds.

Generally, fish as tertiary consumers at the top of the food chain pyramid, are the receivers of water quality. In a rearing and feeding operation, however, where food does not limit density, the fish have an influence on their environment. One of the factors limiting the capacity of Percival Cove is oxygen limitation. Reports by Finn[23,24] indicate that oxygen within the schools of fish are several parts per million lower than the surrounding water. Nutrient addition from unused food and fecal material may create rich amounts of natural food, but an imbalance or nutrient overloading may be occurring in Percival Cove and heavy algal growths interfere with fish respiration.

The fish rearing program generally takes place during the least critical months for water quality. Nutrient addition and oxygen depletion would be most critical during July, August, and September, with low flows and high temperatures. To determine the effect of the rearing operation on the lake water quality, it would be necessary to measure the nutrient input and output of Percival Cove. Although some work indicates only a slight increase in soluble nutrients to obtain an accurate picture, it is necessary to measure total nutrient quantities including soluble and organic fractions. The loss of soluble nutrients in the Percival Cove area should show results similar to the pattern observed between the upper and lower basins of the main lake. Heavy algae blooms noted by the Department of Fisheries[23,24,25] are an indication of heavy nutrient addition.

f. Summary and Comparison with Past Studies

Biological parameters indicate Capitol Lake is eutrophic but does not exhibit many common symptoms because of its unique natural characteristics and management procedures. Without the low residence time and periodic salt water flushing it appears that Capitol Lake would experience severe algae and macrophyte problems assuming the nutrient concentrations remain at their present levels. Compared to 1955 conditions,[27] Capitol Lake appears to be supporting more biological activity. Shifts in some species have also become apparent.

Chlorophyll observations from the current and past studies are too infrequent and variable to permit direct comparison. However, the early Department of Fisheries study[27] did not note any heavy algae growths except for the _Spirogyra sp_. and _Volvox sp_. as previously noted. Current Volvox counts were higher though--this may be due to normal variation. Volvox commonly appears where nitrogen concentrations are high.

Zooplankton standing crop as an indication of primary production was comparable for 1955 and 1974 although methods differed somewhat. The comparison of zooplankton numbers for similar sampling dates is given in Table 53. It appears that cladoceran numbers have increased substantially, however biomass may be the same for the two periods if the mean size has shifted to smaller organisms. Composition has remained the same except that the copepod genus _Epischura_ was not found in the 1974 sampling.

Benthic organism composition appears to have changed considerably from an almost 100 percent dominance by chironomid larvae to a composition of polychates (marine), amphipods, ostracods and dipteran larvae. It might be expected that dipteran larvae would be first to colonize a new impoundment because of their mobility. Engstrom-Heg[27] reported a standing crop of 159 lb/acre (17.8 g/m^2) of chironomid larvae. Wet weight of samples from current observation (Table 52) indicates a mean standing crop of 19.0 g/m^2.

The planned restoration project will probably have the most substantial effect on the benthic portion of the biological community. With reduced deposition of coarse sediments, food material will be more readily available and smothering of young larva should be reduced. This should result in an increased standing crop of benthic organisms.

Primary production will probably not be affected by the project since retention time will not be increased to any significant extent.

Table 54.
Benthic Weight (Preserved Samples)

Sample Location	Date	Sample Weight (g)	Standing Crop (g/m^2)
Lower Basin	6/28	0.357	15.4
Middle Basin	6/28	1.733	74.6
Lower Basin	10/16	0.207	8.9
Middle Basin	10/16	0.295	12.7
Lower Basin	1/17	0.04	1.7
Middle Basin	1/17	0.02	0.9

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APPENDICES

APPENDIX A

TO CHAPTER III

APPENDIX A. HYDROLOGIC ANALYSIS AND DATA

INTRODUCTION

This appendix to Chapter III, Hydrology of Capitol Lake and Its Drainage Basin, contains technical details, graphs and data which support the material presented in Chapter III. The material in Appendix A is arranged in three parts with brief explanatory text, figures and tables.

1. Deschutes River Basin

The relationship between average daily streamflows at the Olympia and Rainier stream gages on the Deschutes River is presented in Figure A1. There is a variability of about ±16%, but the equation

$$\text{QADO*} = 4.6(\text{QADR})^{0.82} \qquad \text{(A1)}$$

gives a good representation of long-term average flows. A sample of the data from the gaging station at Olympia (1952-54, 1958-64) is included in Table A1.

The average daily flows for the discontinued gaging station at Olympia were estimated for the period of water years 1955-57 and 1965-73 using Equation A1. The daily flow values are presented in Tables A2 through A13 in chronological sequence.

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*QADO - discharge, average daily at Olympia
QADR - discharge, average daily at Rainier

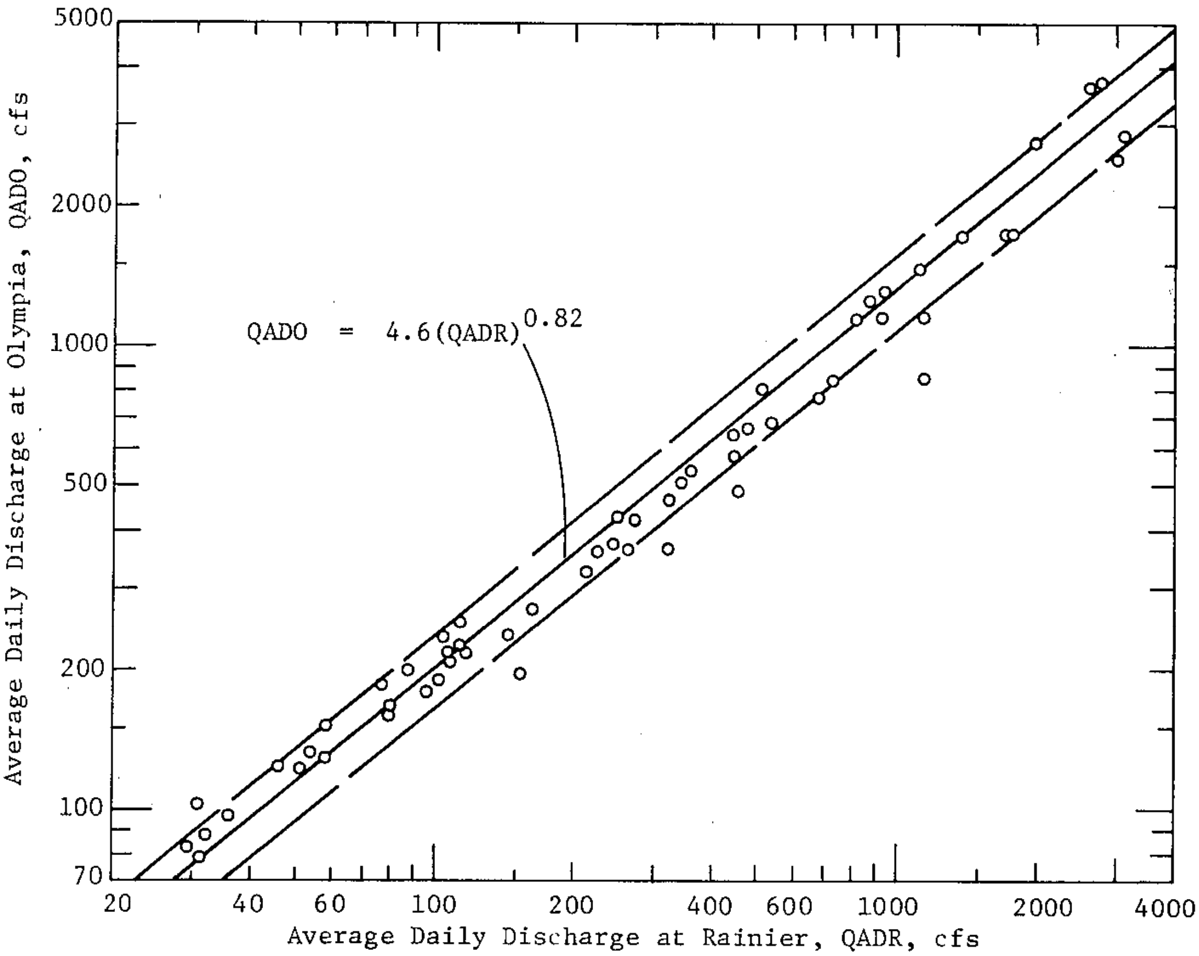


Fig. A1. Relationship Between Average Daily Flow of the Deschutes River at Olympia to the Flow at the Rainier Stream Gaging Station; Sample of Data from Period of Record 1951-54 and 1958-63

Table A1.

Monthly Mean Discharge of Deschutes River at Olympia Gage 120800, cfs, 1952-54, 58-64

Water Year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1952	247	419	620	466	713	376	328	244	146	115	92	81	3847
1953	77	86	242	1308	794	424	304	277	211	136	106	94	4059
1954	196	357	893	1015	1246	583	604	262	246	162	118	115	5797
1958	129	226	658	732	780	408	497	217	155	109	87	84	4082
1959	130	709	630	990	579	517	489	346	207	137	106	152	4992
1960	238	554	581	419	799	626	676	423	212	148	127	116	4919
1961	170	919	451	792	1302	981	486	433	202	147	117	115	6120
1962	163	286	612	423	303	377	382	309	177	116	101	98	3342
1963	195	709	743	465	707	404	616	333	182	147	123	125	4749
1964	177	651	436	1305	741	581	379	274	230	130	115	96	5115
Mean	172	492	587	792	796	528	476	312	197	138	109	108	4702

Mean Average Annual Flow = 391 cfs

Long Term Annual Flow = 405 cfs

(Extrapolated from Rainier Gaging Station Records through 1973).

Tables A2 - A13, extrapolated.

Flows 1955-73 based on Fig. A1.

Table A2. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1955

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	93	134	373	1488	640	438	1359	402	340	235	139	91
2	93	126	349	1057	537	398	1161	390	312	225	139	91
3	93	127	312	782	466	363	873	383	309	211	134	91
4	97	136	292	644	423	343	701	380	319	197	128	87
5	93	153	283	566	409	316	607	380	330	188	125	87
6	93	209	388	493	409	312	566	388	330	191	121	87
7	93	193	517	442	913	303	610	390	333	182	121	87
8	198	171	446	451	2701	330	684	413	346	172	116	87
9	114	186	390	549	1402	366	993	398	376	211	112	87
10	106	209	398	493	914	537	1215	376	376	216	110	87
11	197	235	366	442	718	747	1034	413	346	201	110	87
12	304	246	417	409	603	864	1445	525	312	188	108	87
13	224	243	829	470	529	725	1477	478	283	172	110	93
14	184	445	693	493	470	570	1025	648	251	167	108	150
15	157	541	939	470	435	493	803	599	232	159	104	125
16	143	875	747	509	405	442	701	513	216	155	102	313
17	143	1096	578	557	376	409	631	462	211	150	102	225
18	139	1277	486	509	353	388	570	455	212	141	102	164
19	243	1769	431	438	333	376	525	529	207	136	102	136
20	445	1267	395	402	319	359	497	545	201	134	101	125
21	399	791	373	376	306	359	497	466	197	101	117	---
22	328	578	380	366	300	787	529	402	201	125	99	112
23	283	462	466	388	289	763	635	376	241	125	95	110
24	246	395	906	416	335	648	623	340	212	125	95	104
25	217	521	794	497	346	561	549	319	197	123	95	104
26	194	614	586	470	335	533	553	335	197	136	95	102
27	181	684	478	427	325	525	557	349	207	172	93	108
28	167	590	446	402	402	603	501	325	222	150	93	125
29	153	489	693	388	---	1241	458	333	212	141	93	112
30	146	423	1099	376	---	1125	420	388	204	141	91	108
31	141	---	1980	435	---	1048	---	376	---	145	91	---
Mean:	181	506	574	523	571	557	760	422	264	165	108	116
Total:	5617	15187	17791	16205	15993	17272	22799	13076	7932	5115	3351	3372

Water Year Total: 143710; Mean: 395

Table A3. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1956

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	104	701	1250	651	474	889	997	354	228	159	109	85
2	102	875	1062	697	458	1338	828	325	222	152	112	87
3	102	1645	889	1593	438	1488	722	310	219	143	159	85
4	119	1707	763	2255	431	1290	668	303	228	139	121	85
5	257	1381	697	2197	438	911	631	295	225	139	108	85
6	191	922	742	1980	446	709	582	288	225	146	104	83
7	172	706	1030	1583	451	775	599	280	244	137	102	83
8	403	586	974	1175	462	974	590	265	244	134	101	85
9	1370	505	1020	965	442	766	566	257	286	132	101	85
10	1270	505	856	840	423	631	570	257	309	128	99	91
11	701	470	1980	778	435	561	635	265	346	127	97	97
12	478	423	3758	725	640	513	644	257	286	127	97	95
13	380	388	1509	787	635	489	655	249	254	121	97	89
14	322	353	1052	782	553	462	684	233	235	121	95	85
15	280	312	856	1177	482	455	672	233	241	119	95	85
16	251	319	759	1624	423	466	599	225	232	117	97	85
17	232	309	664	1477	420	497	545	225	235	112	95	83
18	216	376	610	1197	402	553	497	217	219	110	91	83
19	204	1520	852	1020	402	684	505	217	235	110	91	83
20	191	1025	2932	1030	431	701	590	217	257	110	89	83
21	182	771	3113	931	486	879	626	217	241	110	89	85
22	172	631	3310	873	497	1311	548	217	225	108	89	83
23	167	607	2342	1057	455	2361	508	217	211	106	87	83
24	172	1086	1541	1075	455	2129	481	217	201	106	89	81
25	516	2757	1348	885	501	1990	440	217	191	104	87	81
26	799	2197	1324	766	497	1799	426	217	182	102	110	83
27	607	2255	1259	677	478	1223	398	217	176	102	108	89
28	574	1488	997	619	729	965	383	217	171	101	97	87
29	827	1183	836	586	974	1043	383	216	164	101	91	85
30	1139	1107	734	549	---	1089	383	219	160	101	89	95
31	877	---	660	509	---	1223	---	228	---	101	87	---
Mean:	432	970	1346	1066	495	1005	578	247	230	120	99	86
Total:	13377	29110	41719	33060	14358	31164	17355	7671	6892	3725	3075	2574

Water Year Total: 204080; Mean: 558

Table A4. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1957

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
1	95	549	179	354	426	836	759	309	194
2	89	438	172	369	426	747	631	289	188
3	85	359	188	354	280	655	549	269	179
4	85	333	346	340	325	590	521	254	172
5	85	322	280	310	426	864	635	244	172
6	85	322	238	280	513	1020	603	235	212
7	85	300	219	303	489	1940	525	232	191
8	85	269	219	303	474	1551	466	238	172
9	85	247	1121	310	791	1748	427	241	164
10	89	228	2352	325	697	1498	409	247	159
11	112	216	1498	467	689	1179	390	228	160
12	93	204	1272	561	574	965	388	219	179
13	91	216	1034	453	521	864	405	219	188
14	89	204	944	398	513	771	409	216	263
15	104	201	799	369	501	828	664	204	225
16	194	254	901	340	455	811	603	191	201
17	207	1105	778	310	423	759	489	188	179
18	388	713	1105	295	413	660	438	260	171
19	289	505	873	280	423	590	402	263	164
20	307	402	739	265	423	623	376	244	155
21	623	343	689	249	380	664	349	238	146
22	425	306	639	233	363	623	335	413	146
23	505	277	613	208	1263	570	325	493	137
24	370	257	600	184	3408	582	370	395	134
25	363	235	561	176	2673	570	343	333	128
26	474	225	494	167	2673	517	325	289	128
27	486	219	453	150	1551	474	306	260	132
28	380	204	412	150	1075	446	300	241	127
29	322	194	383	150	---	466	306	222	123
30	446	188	369	150	---	486	319	212	119
31	545	---	354	325	---	759	---	201	---
Mean:	248	328	672	294	827	828	446	261	167
Total:	7691	9835	20824	9128	23168	25656	13367	8087	5008

Table A5. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1965

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	227	112	2342	565	1235	908	225	286	167	108	91	75
2	166	139	2089	1185	958	714	227	269	166	108	91	75
3	143	150	1239	967	800	626	216	255	157	108	91	75
4	128	644	843	693	719	521	209	269	152	106	91	73
5	117	525	650	623	831	467	204	286	150	104	91	73
6	112	354	553	827	1172	426	197	266	146	102	91	73
7	106	272	478	707	856	400	197	249	143	99	106	71
8	106	227	474	592	839	385	196	243	141	99	114	71
9	132	212	513	525	805	370	207	230	141	99	99	71
10	162	196	501	517	697	539	212	222	139	102	93	71
11	125	233	497	533	619	343	201	216	139	106	97	71
12	116	236	458	509	592	333	193	212	139	106	102	73
13	106	252	453	481	711	318	193	204	136	104	128	73
14	108	227	474	541	749	307	196	197	136	97	116	75
15	153	204	513	788	658	292	193	197	139	95	99	91
16	207	188	426	995	600	278	201	243	132	93	93	97
17	188	179	369	920	577	272	209	243	130	95	91	91
18	162	176	354	810	561	258	201	225	128	95	87	81
19	146	167	347	788	553	252	372	222	123	95	97	77
20	132	166	343	771	521	246	1109	272	121	93	123	75
21	125	166	479	810	485	243	873	272	117	97	106	73
22	116	167	2701	762	478	246	654	252	117	97	97	73
23	112	260	3257	855	431	243	521	240	116	95	93	73
24	108	2148	1707	1424	403	230	442	225	116	93	93	71
25	108	1583	1265	1023	385	227	403	209	116	91	91	71
26	104	1322	1676	873	389	230	366	207	114	85	97	69
27	99	873	1635	2409	1413	227	328	193	112	91	93	69
28	97	619	1096	1748	1127	222	303	181	108	93	83	69
29	97	658	835	1970	---	230	283	181	106	91	81	67
30	99	1413	702	2148	---	219	286	179	108	91	79	67
31	104	---	600	1850	---	212	---	174	---	91	77	---
Mean:	129	469	964	974	720	342	321	230	132	98	96	74
Total:	4011	14068	29869	30209	20164	10604	9617	7119	3955	3029	2981	2234

Water Year Total: 137860; Mean: 378

Table A6. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1966

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	64	77	228	449	586	566	640	236	155	145	91	75
2	64	77	363	928	494	466	586	240	176	157	89	75
3	64	104	337	626	433	420	518	261	166	278	89	75
4	69	370	590	542	400	386	466	288	157	288	89	73
5	89	304	486	1183	433	400	441	316	150	228	89	73
6	132	258	389	2617	605	466	449	375	145	199	87	71
7	114	202	554	1728	558	542	474	341	148	177	85	71
8	91	171	654	1850	502	888	478	291	148	166	85	71
9	85	155	486	1370	482	2849	458	278	145	155	87	69
10	81	148	393	952	466	1707	449	265	157	145	87	73
11	77	181	322	856	486	1043	631	246	171	141	87	99
12	73	164	274	895	570	783	1055	230	167	136	83	99
13	75	150	246	1139	482	822	800	222	155	130	83	83
14	104	145	225	1728	441	1092	659	222	148	127	85	79
15	249	141	207	1280	400	1237	586	216	141	125	83	83
16	176	130	194	917	379	1204	534	230	137	123	83	79
17	132	123	184	723	356	882	482	222	136	117	83	81
18	114	121	176	605	337	843	428	207	130	114	81	119
19	116	240	167	530	322	1157	389	199	128	112	79	106
20	130	291	166	474	344	1032	386	197	125	108	77	87
21	116	319	181	433	368	915	363	202	123	106	77	79
22	104	640	171	400	368	783	337	204	130	104	77	77
23	97	498	166	379	379	718	322	191	121	102	77	81
24	91	349	285	363	368	718	322	184	121	102	77	83
25	87	274	274	337	360	724	295	176	116	110	77	81
26	83	246	230	319	356	802	288	177	114	104	79	91
27	81	445	838	330	416	849	278	177	114	101	83	91
28	83	379	1717	349	664	780	265	171	214	97	91	81
29	83	291	1270	574	---	716	252	166	186	95	83	77
30	79	249	772	701	---	706	243	157	153	93	81	77
31	79	---	534	697	---	704	---	155	---	91	79	---
Mean:	99	241	422	848	441	877	462	227	146	138	83	82
Total:	3082	7242	13079	26274	12355	27200	13874	7042	4377	4276	2583	2459

Water Year Total: 123843; Mean: 339

Table A7. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1967

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	75	145	1214	750	939	490	449	319	199	128	95	79
2	77	137	1466	675	835	465	407	304	199	125	93	87
3	77	130	1338	785	745	428	386	294	199	121	89	91
4	73	125	1970	986	701	393	382	286	191	117	89	89
5	73	125	1551	1018	657	367	389	278	182	116	89	87
6	71	134	1191	831	593	348	363	282	177	114	89	87
7	71	125	1156	742	542	334	356	294	172	112	95	85
8	75	117	804	733	506	334	349	312	167	112	97	81
9	77	112	613	684	473	482	360	319	162	112	91	81
10	75	112	693	622	445	486	352	295	157	108	91	93
11	71	108	1005	814	428	445	334	278	155	106	91	130
12	75	211	1779	802	415	404	322	272	152	104	89	110
13	93	315	3610	1078	896	386	407	255	148	102	85	85
14	95	914	2284	1163	830	370	449	246	145	101	83	77
15	81	1316	1252	1027	728	742	398	243	141	101	81	75
16	77	793	911	1059	666	943	386	263	139	99	81	71
17	75	586	759	856	706	957	382	295	136	97	81	69
18	73	445	675	711	882	939	466	292	134	97	81	67
19	73	369	645	2000	728	810	558	286	130	99	79	67
20	255	328	856	3086	612	745	482	280	132	104	77	64
21	376	294	728	1769	546	714	428	286	159	106	79	67
22	481	261	609	1172	498	1036	433	277	398	101	79	67
23	508	236	538	920	461	1655	398	254	261	99	81	69
24	350	219	514	776	432	1291	368	233	201	99	83	69
25	258	247	605	675	411	990	363	216	174	99	83	69
26	214	307	618	693	393	810	386	202	159	101	83	67
27	212	337	546	1322	374	689	393	197	150	99	83	69
28	191	403	494	2598	393	609	382	197	143	99	81	69
29	172	347	527	1920	---	558	352	212	137	97	79	73
30	169	1131	530	1748	---	522	337	233	134	97	77	85
31	155	---	490	1163	---	490	---	219	---	95	79	---
Mean:	155	348	1031	1135	601	653	394	265	171	105	85	79
Total:	4798	10429	31971	35178	16835	20232	11817	8219	5133	3267	2633	2379

Water Year Total: 152891; Mean: 419

Table A8. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1968

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	128	327	363	373	409	412	545	292	291	148	99	181
2	171	282	1243	359	1256	385	505	268	1434	145	99	171
3	251	255	1624	333	2217	359	468	254	956	141	99	155
4	252	233	1370	315	2822	347	431	247	595	137	99	143
5	164	225	1221	300	1467	385	460	254	459	134	99	136
6	145	211	846	282	913	389	452	251	380	132	97	130
7	136	202	683	278	701	359	420	244	334	128	97	125
8	125	204	557	292	604	340	393	238	303	127	93	123
9	119	437	493	1166	549	310	366	230	278	125	93	119
10	114	929	525	1211	501	297	347	224	258	125	91	117
11	174	915	723	688	464	286	333	217	247	123	89	116
12	228	554	596	577	428	400	315	214	236	130	87	117
13	236	420	497	1156	396	431	297	211	224	130	89	114
14	370	363	431	1161	369	396	307	204	216	127	99	130
15	261	341	389	1216	344	744	513	197	204	130	106	209
16	204	301	359	1156	330	1413	485	191	194	127	102	222
17	176	274	340	913	333	1018	416	186	188	121	101	199
18	160	258	322	723	758	706	373	182	182	119	101	431
19	179	243	304	727	2040	561	347	182	181	119	132	398
20	159	228	282	908	1445	485	325	220	177	123	130	313
21	311	216	275	1186	1291	431	330	211	171	117	117	255
22	441	207	416	870	1049	393	310	194	177	116	110	220
23	462	199	616	674	1110	373	315	188	176	116	127	201
24	368	204	635	584	1049	393	307	196	169	112	283	184
25	518	204	639	517	787	452	297	197	160	110	254	171
26	445	194	665	473	635	501	292	199	155	110	349	160
27	494	186	596	424	553	800	282	188	155	106	304	153
28	1150	186	525	389	493	1738	272	184	157	104	410	146
29	663	301	464	366	448	1110	272	181	166	102	319	141
30	466	360	412	359	---	770	282	172	155	101	241	136
31	368	---	378	373	---	623	---	167	---	101	199	---
Mean:	304	315	606	656	888	568	369	212	299	122	152	181
Total:	9438	9459	18789	20349	25761	17607	11057	6583	8978	3786	4715	5416

Water Year Total: 141938; Mean: 388

Table A9. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1969

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	132	298	557	1348	280	360	645	383	298	164	104	83
2	130	324	474	1100	280	363	840	369	261	157	104	83
3	127	474	1090	918	398	390	740	354	238	155	102	81
4	136	403	2040	938	523	419	626	340	220	157	102	81
5	141	341	1299	1520	655	542	595	325	209	241	106	83
6	150	298	956	1707	512	674	548	315	201	212	106	81
7	162	269	725	2109	437	588	494	318	197	186	102	81
8	145	298	979	1326	1402	514	452	347	189	171	101	81
9	137	704	1294	1032	1880	455	424	385	181	149	99	81
10	209	520	1930	969	1171	413	416	388	176	153	99	79
11	271	1477	1738	934	2010	382	398	370	172	153	97	77
12	341	1593	1160	732	1530	357	507	343	169	150	95	77
13	496	946	874	644	1001	340	462	322	166	143	97	77
14	453	674	744	599	783	328	437	303	160	139	95	79
15	626	550	656	556	684	330	393	280	155	134	93	77
16	619	467	644	524	725	383	365	260	150	130	93	79
17	464	409	583	498	697	1191	378	246	146	128	93	91
18	402	395	587	453	627	1244	573	244	145	125	91	169
19	349	378	554	426	587	976	668	307	141	123	91	243
20	385	366	498	398	546	763	692	309	141	119	91	289
21	370	389	455	369	510	631	581	266	139	119	89	179
22	378	946	428	354	481	586	514	251	153	117	87	157
23	346	851	490	325	462	577	542	243	194	116	87	278
24	310	655	1172	318	437	525	517	241	243	114	85	274
25	285	534	1001	310	413	482	453	228	201	112	85	216
26	261	463	730	310	392	481	398	224	199	110	87	193
27	240	451	623	295	375	554	369	212	204	110	91	169
28	224	437	538	288	363	561	398	225	202	108	91	160
29	246	549	467	280	---	546	426	246	188	108	87	150
30	341	678	414	280	---	577	412	486	176	106	85	174
31	344	---	683	295	---	655	---	366	---	104	83	---
Mean:	297	571	851	715	720	554	505	306	187	139	94	134
Total:	9220	17137	26383	22155	20161	17187	15163	9496	5614	4823	2918	4022

Water Year Total: 153779; Mean: 421

Table A10. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1970

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	328	130	166	362	1064	347	244	354	172	110	85	75
2	375	127	160	337	880	340	244	347	164	110	91	77
3	313	125	160	322	749	333	330	352	160	104	91	85
4	252	582	199	307	648	315	330	344	159	95	85	104
5	212	1080	184	286	588	300	241	325	155	97	85	112
6	186	735	181	272	557	347	304	304	153	93	81	102
7	172	683	189	261	541	770	354	282	150	87	81	139
8	392	505	193	257	529	612	310	275	148	87	85	128
9	673	393	211	268	513	501	497	300	150	85	81	102
10	483	330	211	268	489	435	969	322	159	85	77	91
11	356	289	600	247	452	396	665	315	150	83	73	83
12	288	257	1738	244	424	385	533	330	143	81	69	77
13	243	233	1156	485	400	424	448	322	145	81	69	73
14	216	220	1477	2868	373	608	393	297	143	81	69	71
15	194	211	979	1603	557	697	352	276	143	79	69	67
16	179	214	701	974	1880	627	325	265	143	81	71	67
17	169	202	656	1095	1583	584	300	247	139	83	71	69
18	159	189	604	1520	1327	517	286	241	134	83	71	87
19	152	181	592	1830	965	460	322	230	132	83	69	141
20	145	181	573	1676	744	420	304	220	128	85	67	117
21	141	227	706	1402	631	385	286	214	127	87	69	95
22	136	207	1121	1300	565	354	275	211	119	85	67	93
23	132	211	2304	1562	513	337	268	206	112	87	62	137
24	132	247	1424	1321	468	330	444	196	112	87	64	112
25	132	230	908	1830	431	307	665	193	110	91	67	95
26	127	214	706	1789	405	292	604	186	110	99	69	85
27	130	202	584	2294	385	282	521	181	110	104	69	81
28	155	189	513	1434	366	275	440	181	108	104	73	79
29	150	181	460	1008	---	265	396	184	108	95	71	77
30	139	176	416	800	---	257	369	193	110	91	69	75
31	134	---	396	787	---	247	---	177	---	87	71	---
Mean:	226	298	660	1000	680	411	401	260	137	90	74	93
Total:	6995	8951	20468	31009	19027	12749	12019	8070	4096	2790	2291	2796

Water Year Total: 131261; Mean: 360

Table A11. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1971

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	73	127	366	1095	929	447	939	337	252	222	117	117
2	73	119	344	781	815	452	780	367	244	212	116	212
3	73	116	366	627	710	581	657	406	232	197	112	191
4	71	110	369	539	648	535	585	422	225	189	110	148
5	75	112	950	487	582	472	549	393	219	186	110	132
6	81	134	3601	439	526	435	567	354	216	191	108	145
7	77	128	3895	411	488	948	554	329	228	182	106	130
8	75	224	1840	560	456	999	698	344	238	174	106	121
9	77	300	1095	1326	443	701	1413	344	222	182	104	117
10	87	272	920	1487	576	943	1696	317	219	189	102	116
11	81	304	1337	990	653	1799	1199	310	222	204	101	116
12	75	464	976	751	622	2342	943	358	216	197	101	117
13	73	412	741	651	636	1445	766	427	222	186	101	108
14	73	307	645	567	662	1109	662	410	263	177	101	104
15	71	254	839	1850	1212	948	603	344	238	174	101	102
16	71	369	1634	2050	1194	771	554	501	219	169	99	101
17	71	382	1391	1748	872	662	539	558	206	164	95	99
18	85	416	882	1380	731	581	501	422	209	150	93	95
19	145	362	657	2532	662	530	456	389	238	155	93	95
20	189	310	585	1850	581	492	435	393	238	155	93	93
21	307	282	517	1228	521	460	414	354	222	153	95	93
22	333	241	464	1001	484	509	389	325	216	150	110	93
23	541	247	418	1540	452	711	380	317	225	148	112	91
24	541	1324	384	2245	627	1154	358	322	219	145	101	99
25	366	982	358	3354	761	905	351	344	473	143	93	106
26	278	569	340	3618	627	1027	367	347	414	141	93	123
27	220	529	329	2049	563	1091	354	329	325	130	91	119
28	186	448	447	1326	497	938	371	314	280	112	91	137
29	116	354	1013	1050	---	1031	354	307	255	112	91	255
30	150	330	2197	167	---	1634	336	287	232	116	89	201
31	137	---	2167	990	---	1261	---	258	---	116	95	---
Mean:	159	351	1034	1338	661	900	625	362	248	165	101	126
Total:	4921	10528	32067	41489	18530	27913	18770	11229	7427	5121	3130	3776

Water Year Total: 184901; Mean: 507

Table A12. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1972

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	169	502	550	357	468	1645	439	505	209	148	104	83
2	150	449	474	372	435	1561	443	456	201	143	108	83
3	141	359	412	357	410	1337	414	427	191	143	108	79
4	132	527	395	337	393	1082	380	414	191	139	104	77
5	128	498	770	325	389	2849	558	410	194	139	102	77
6	127	390	1098	322	501	3265	1017	419	191	139	102	77
7	123	373	727	343	829	1676	1031	398	189	150	101	79
8	121	373	582	424	934	1190	1054	380	189	139	101	85
9	119	352	1233	701	901	994	827	352	186	145	97	102
10	116	482	918	644	721	1256	716	328	191	155	95	104
11	110	594	651	2313	662	1498	639	310	204	153	93	95
12	110	766	697	1614	990	1686	746	303	194	150	93	87
13	110	714	586	955	1748	1860	706	325	186	171	93	85
14	121	558	974	706	1194	1370	621	340	179	172	91	83
15	132	498	667	582	1212	1068	581	325	182	155	95	83
16	121	458	523	523	1990	920	549	318	177	145	110	83
17	116	399	603	578	1717	848	509	318	172	139	132	83
18	112	354	651	701	1910	795	464	318	166	132	132	83
19	439	318	558	2226	1370	756	431	292	160	128	108	97
20	626	288	518	4194	1212	662	414	272	159	128	102	127
21	390	271	894	4637	985	603	530	277	159	123	102	325
22	303	255	1080	2390	839	621	545	283	155	121	108	292
23	292	246	1016	1820	721	645	497	269	155	116	101	295
24	258	518	837	1381	648	645	484	260	174	116	94	236
25	233	727	727	1145	585	645	572	238	197	116	93	191
26	288	804	648	925	535	585	558	228	169	116	91	164
27	295	735	530	771	1665	539	517	225	164	114	91	150
28	258	796	458	663	2895	501	706	232	159	110	91	137
29	233	846	407	591	3059	464	693	238	153	110	87	128
30	227	683	369	540	---	435	581	232	150	108	85	121
31	240	---	366	505	---	410	---	216	---	108	83	---
Mean:	206	504	675	1095	1097	1110	607	320	178	135	100	126
Total:	6390	15133	20939	33942	31818	34411	18222	9908	5346	4171	3098	3791

Water Year Total: 187169; Mean: 511

Table A13. Predicted Discharges of Deschutes River at Discontinued Olympia Gage (800) Site Based on Correlation with Daily Flows at Rainier Gage (790), WY 1973

Day	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	116	108	189	581	340	585	232	177	169	177	87	73
2	114	146	288	558	332	701	225	174	164	166	87	71
3	108	150	292	497	310	540	216	174	159	155	83	71
4	108	243	249	439	302	447	209	177	153	148	83	69
5	104	325	216	401	284	393	204	172	145	143	83	69
6	102	244	196	358	269	351	201	179	145	143	89	69
7	101	272	179	332	258	322	194	169	153	137	89	73
8	101	340	171	299	252	295	191	194	145	132	83	73
9	101	331	160	279	247	277	186	272	139	127	83	69
10	102	512	153	284	255	393	182	288	132	123	81	67
11	97	368	146	295	317	476	179	252	128	121	79	67
12	95	274	143	810	310	431	177	225	137	116	79	67
13	95	228	139	1850	292	401	174	216	153	114	79	67
14	93	197	134	1686	272	354	172	209	137	110	77	67
15	91	176	130	1158	266	325	169	197	137	108	77	67
16	91	162	430	1163	252	325	216	189	153	104	79	64
17	87	150	926	948	280	363	325	177	258	102	79	64
18	85	146	1210	781	336	347	347	172	252	102	77	67
19	87	159	1434	701	325	476	385	169	216	101	77	75
20	87	150	1042	621	299	497	337	166	191	101	75	159
21	91	141	2438	630	280	452	295	160	174	101	73	225
22	91	134	2236	554	266	397	272	155	160	99	73	150
23	91	132	1676	484	252	347	263	159	155	99	73	155
24	91	132	1920	600	241	322	252	359	153	99	77	148
25	91	152	1274	751	272	302	238	393	197	95	77	172
26	95	301	1840	590	329	284	222	310	288	93	73	139
27	95	261	2313	492	414	276	209	258	272	91	73	121
28	127	243	1614	439	393	266	201	228	235	91	71	110
29	136	230	1050	397	---	247	191	209	209	91	75	102
30	117	206	815	376	---	241	186	191	191	89	75	99
31	108	---	675	376	---	238	---	179	---	87	75	---
Mean:	100	220	828	636	294	376	228	211	176	115	79	96
Total:	3098	6613	25678	19730	8245	11671	6850	6549	5300	3565	2441	2889

Water Year Total: 102629; Mean: 281

2. Percival Creek Basin

The Percival Creek hydrologic analysis depended heavily on gaging station records in other nearby basins such as Skookum, Goldsborough and Woodland Creeks. Various steps were involved in making preliminary flow predictions and then verifying or modifying those predictions. For example, Table A14 was used to differentiate between periods of high and low average annual flow (QAA) in comparing estimates of (QAA) for Percival Creek.

The precipitation records at Shelton, Elma and Olympia (Table 10, Chap. III) had a common period between 1952 and 1958 which was selected as the base period because it provided both the maximum range of extreme values and a seven-year average flow close to the long-term average flow.

Tables A15 and A16 were information basic to the determination of long-term average monthly and annual flows in Percival Creek as well as the variability which can be expected in those flows.

The summary of monthly flows and average percentages of annual flows in each month is presented in Table A17 for Skookum, Goldsborough and Woodland Creeks. Based on the monthly distribution of annual flow of Goldsborough and Woodland Creeks, the monthly flow distribution for Percival Creek was estimated. The variability in these average monthly flows can be estimated by referring to Table A16 for Goldsborough Creek. Table A17 is the basis for Figure 22 in Section B2 of Chapter III.

The flood flows in Percival Creek were predicted on the basis of the relationships between low, average and flood flows at the gages on Goldsborough and Woodland Creeks. Other streams were considered and their flows are summarized in Table A18 and are plotted in Figure A2. The graphical relationships in Figure A2 are:

Table A14.

Sliding Five-Year Average Annual Streamflow Woodland Creek (120810), A = 24.6 sq mi

WATER YEAR	QAA (cfs)	5-YEAR AVERAGE	10-YEAR AVERAGE	20-YEAR AVERAGE
1950	36.8			
1951	41.7			
1952	19.1	29.2 (1.09)*		
1953	17.5			
1954	30.9		27.79 (1.03)	
1955	20.7			
1956	43.9			
1957	25.1	26.38 (0.98)		
1958	18.5			
1959	23.7			
1960	26.6			26.87
1961	37.0			
1962	20.0	27.86 (1.04)		
1963	25.6			Percival Cr. QAA = 30 cfs
1964	30.1			
1965	23.9		25.95 (0.97)	
1966	18.5			
1967	24.4	24.04 (0.89)		
1968	22.5			
1969	30.9			
TOTAL	537.4			
AVERAGE	26.87			

*Ratio of short-term to long-term average.

Table A15. Total Monthly Discharge of Woodland Creek (120810) and Monthly Means

Water	Total Monthly Flows in cfs-days												
year	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEAR TOTAL
1950	407	509	751	1574	1715	2606	1798	1239	918	767	637	521	13442
1951	544	707	1383	2085	2859	2391	1540	1191	910	664	516	431	15220
1952	528	558	826	830	885	751	601	554	477	397	316	283	7004
1953	287	281	298	813	1146	818	650	564	473	388	345	326	6387
1954	349	565	974	1613	1648	1558	1182	939	768	664	569	468	11296
1955	452	622	763	744	779	873	832	702	541	460	439	366	7570
1956	462	886	2121	2869	1823	2115	1567	1199	971	820	670	566	16069
1957	611	618	930	813	873	1386	1050	807	604	565	488	411	9154
1958	416	387	515	790	883	933	795	632	469	361	281	275	6735
1959	302	545	802	1176	1158	1082	917	-	-	-	-	-	5982
1960	-	466	830	846	1283	1202	1186	992	724	580	531	458	9097
1961	478	827	986	1222	1831	2482	1610	1415	878	704	590	498	13521
1962	511	599	848	889	696	817	732	630	466	384	367	344	7283
1963	361	666	981	952	1166	1094	1166	891	659	524	453	392	9302
1964	443	748	870	1747	1674	1484	1073	877	698	557	468	380	11019
1965	395	432	884	1209	1315	1112	931	816	560	377	356	352	8379
1966	322	361	515	973	657	990	764	634	478	392	322	332	6740
1967	304	349	944	1432	1249	1179	955	753	561	462	360	347	8894
1968	411	387	563	844	1157	1133	935	765	604	500	475	444	8218
1969	499	687	1273	1744	1637	1291	1038	901	672	586	492	457	11277
Monthly Mean	14	19	29	41	47	44	36	28	22	17	15	13	Average cfs 27
Percent of Yr.	4.3	5.7	9.2	12.8	13.5	13.9	10.9	8.8	6.7	5.4	4.6	4.1	% 100

Table A16. Average Monthly Discharge of Goldsborough Creek (120765) in cfs

WATER YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
1951	-	-	-	-	-	-	-	-	-	24	20	23	---
1952	70	108	172	155	186	104	71	51	35	24	23	18	1017
1953	19	25	100	376	324	122	92	77	47	29	23	24	1258
1954	45	144	265	283	396	205	175	59	46	35	27	28	1707
1955	49	217	156	159	162	156	175	67	40	35	27	24	1266
1956	110	290	351	367	167	321	150	63	54	33	26	23	195
1957	87	92	196	96	171	227	116	64	41	30	26	21	1165
1958	34	70	180	223	245	120	124	58	36	23	20	20	1153
1959	36	177	218	313	174	138	184	152	59	34	24	31	1540
1960	47	211	238	212	326	174	188	108	60	33	30	26	1652
1961	37	168	138	252	519	382	128	89	48	33	24	24	1841
1962	44	97	159	128	92	130	98	79	42	28	28	24	949
1963	58	233	201	176	170	126	150	80	41	35	28	26	1324
1964	64	269	182	398	197	203	91	57	48	33	29	23	1593
1965	30	106	194	241	265	115	98	83	41	27	24	22	1246
1966	32	91	113	291	125	226	84	46	33	29	21	23	1113
1967	42	82	305	330	280	220	127	638	39	28	21	21	1558
1968	95	103	209	366	363	249	150	68	58	32	33	37	1763
1969	70	128	198	208	174	137	137	64	41	29	22	33	1240
1970	39	64	142	231	155	130	137	62	34	26	21	28	1069
Mean of Month	53	141	196	253	236	183	130	73	44	30	25	25	cfs

19 Years Average Annual Flow = 116 cfs

Table A17.

Summary of Predicted Mean Monthly Precipitation and Streamflows--Percival Creek Basin at Capitol Lake

BASED ON (Gage No.)	UNITS	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	AVERAGE
Skookum Cr. 12-780														
Precipitation	in.	7.4	8.6	11.1	12.1	7.3	6.8	4.0	1.3	2.0	0.9	1.2	1.7	64.4
Flow SC	cfs	24.0	74.0	125.0	141.0	117.0	78.0	56.0	18.0	9.0	4.0	3.0	3.0	54.0
% of Total Flow	%	3.7	11.4	19.3	21.8	18.0	12.0	8.6	2.8	1.4	0.6	0.5	0.5	100.0
Predicted Flow PC	cfs	16.3	50.4	85.2	96.1	79.7	53.2	38.2	12.3	6.1	2.7	2.0	2.0	34.0
Goldsborough Cr. 12-765														
Precipitation	in.	7.4	8.6	11.1	12.1	7.3	6.8	4.0	1.3	2.0	0.9	1.2	1.7	64.4
Flow GC	cfs	59.0	135.0	202.0	237.0	236.0	179.0	129.0	63.0	43.0	30.0	25.0	22.0	113.0
% of Total Flow	%	4.3	9.9	14.9	17.4	17.4	13.2	9.5	4.6	3.2	2.2	1.8	1.6	100.0
Predicted Flow PC	cfs	14.6	33.3	49.8	58.4	58.2	44.1	31.8	15.5	10.6	7.4	6.2	5.4	30.0
Woodland Cr. 12-810														
Precipitation	in.	5.0	7.7	8.4	8.4	5.8	5.0	3.0	1.6	1.4	0.7	1.0	2.1	50.0
Flow WC	cfs	13.7	18.6	29.1	40.6	47.2	44.0	35.5	28.0	21.8	17.2	14.7	13.4	27.0
% of Total Flow	%	4.2	5.7	9.0	12.5	14.6	13.6	11.0	8.7	6.7	5.3	4.5	4.1	100.0
Predicted Flow PC	cfs	9.1	12.5	19.4	27.1	31.5	29.4	23.7	18.7	14.5	11.4	9.8	8.9	18.0
Percival Creek*														
Precipitation	in.	6.0	7.9	9.2	9.9	6.3	5.6	3.4	1.4	1.6	0.8	1.1	1.8	55.0
% of Total Flow	%	4.3	7.8	12.0	15.0	16.0	13.4	10.2	6.7	5.0	3.7	3.1	2.8	100.0
Flow Percival Creek	cfs	15.4	29.7	45.1	55.7	58.4	47.9	36.1	22.3	16.4	12.3	10.4	9.4	30.0

*Flow based on average of Goldsborough and Woodland Creeks.

Table A18.

Relationships Between Low, Average and Flood Flows Used to Predict Percival Creek Floods

Station (Number)	QAA	Q7L2	QF2	$QF2^2$ $\times 10^5$	QF50	$QF50^2$ $\times 10^5$	$Q7L2 \times QF2^2$ $\times 10^5$	$Q7L2 \times QF50^2$ $\times 10^5$
Goldsborough Creek (0765)	116.0	20.0	924	8.54	1680	28.22	170.8	564.5
Woodland Cr. (0810)	29.6	13.0	91	0.08	213	0.45	1.1	5.9
Dewatto Cr. (0685)	68.0	13.0	1080	11.66	2490	62.00	151.6	806.0
Huge Creek (0735)	11.5	3.6	130	0.17	508	2.58	0.6	9.3
Chambers Cr. (0915)	112.0	32.0	322	1.04	837	7.00	33.2	224.2

FOR PERCIVAL CREEK

Equations from Fig. A2: $(QF2)^2(Q7L2) = 3.0(QAA)^{3.25}$; $Q7L2 = 8.4$ cfs; $QAA = 30$ cfs

$$\therefore QF2 = \left[\frac{3.0(QAA)^{3.25}}{Q7L2}\right]^{0.5} = \left[\frac{3.0(30)3.75}{(8.4)}\right]^{0.5} = 150 \text{ cfs}$$

$$(QF50)^2(Q7L2) = 12.5(QAA)^{3.25}$$

$$\therefore QF50 = \left[\frac{12.5(QAA)^{3.25}}{Q7L2}\right]^{0.5} = \left[\frac{12.5}{3.0}\right]^{0.5}(150) = 307 \text{ cfs}$$

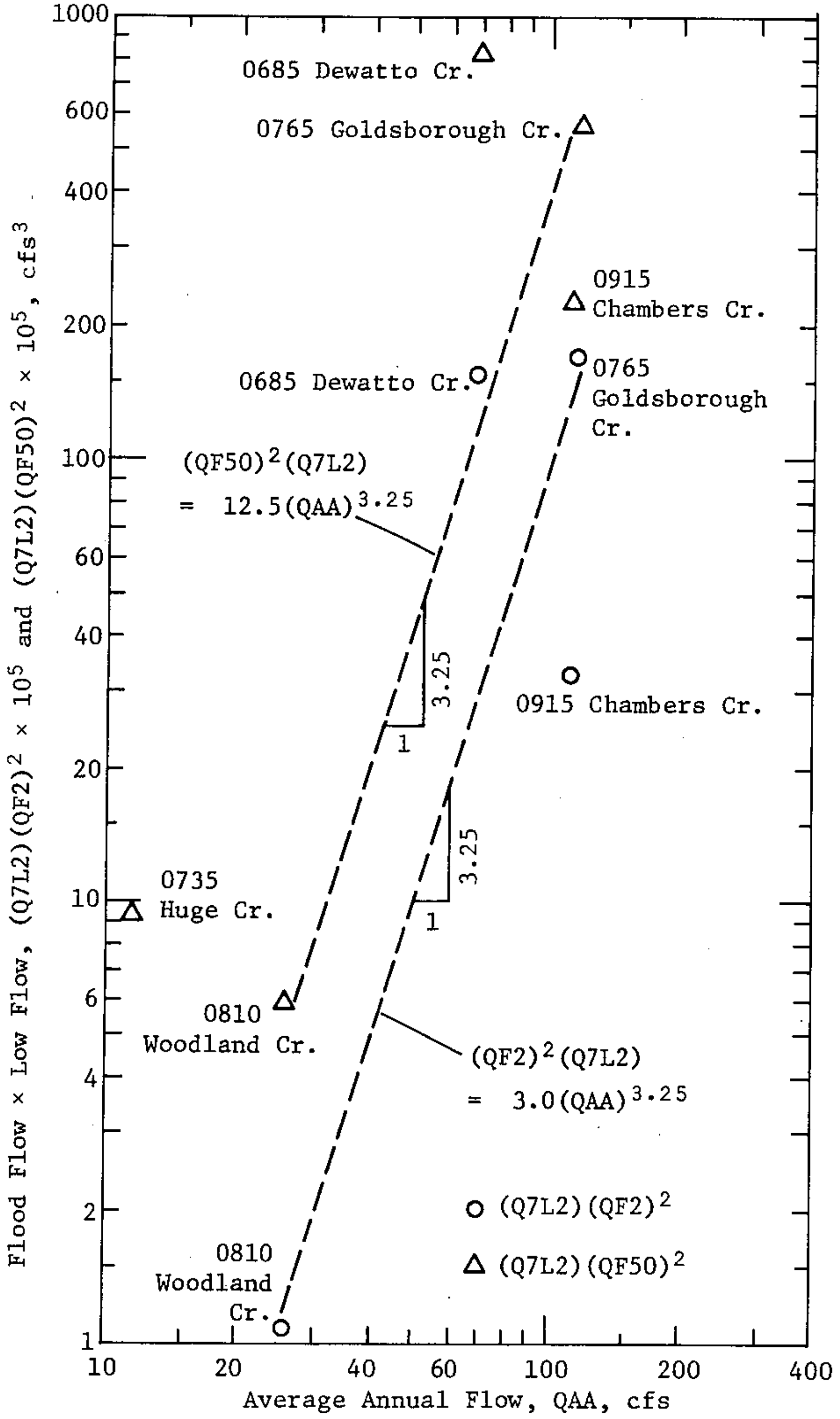


Fig. A2. Relationships Between Low, Average and Flood Flows Used to Predict 2-Year and 50-Year Peak Floods in Percival Creek at Its Confluence with Percival Cove and Capitol Lake; Basin Drainage Area = 13 sq mi

$$(QF2)^2(Q7L2) = 3.0(QAA)^{3.25} \tag{A2}$$

and

$$(QF50)^2(Q7L2) = 12.5(QAA)^{3.25} \tag{A3}$$

The 2-year and 50-year peak flood flows of 150 and 307 cfs, respectively, (see Figure 29, Flood Frequency Curve, Chapter III) were determined using these equations.

The complete set of miscellaneous measurements made at five stations in the Percival Creek basin is presented in Table A19 (refer to Table 14 in Chapter III). Using the values in Table 14, a series of correlations against gaged flows was developed to extend the records for verification of low-flow estimates and for determination of flow distribution among the subbasins as shown in Fig. A3.

3. Physical Characteristics and Hydrology of Capitol Lake

a. Data for Analysis of Inflow-Outflow Relations During Sample Period

The data which were derived from lake level records at gage number 3 are presented for the sample period in November, 1974, in Table A20. The rate of change of flow into and out of Capitol Lake was derived from the slope of the same lake level charts and the estimated rate of flow into the lake from the Deschutes River. The inflow-outflow data are presented in Table A21.

b. Tide Gate Operational Procedures

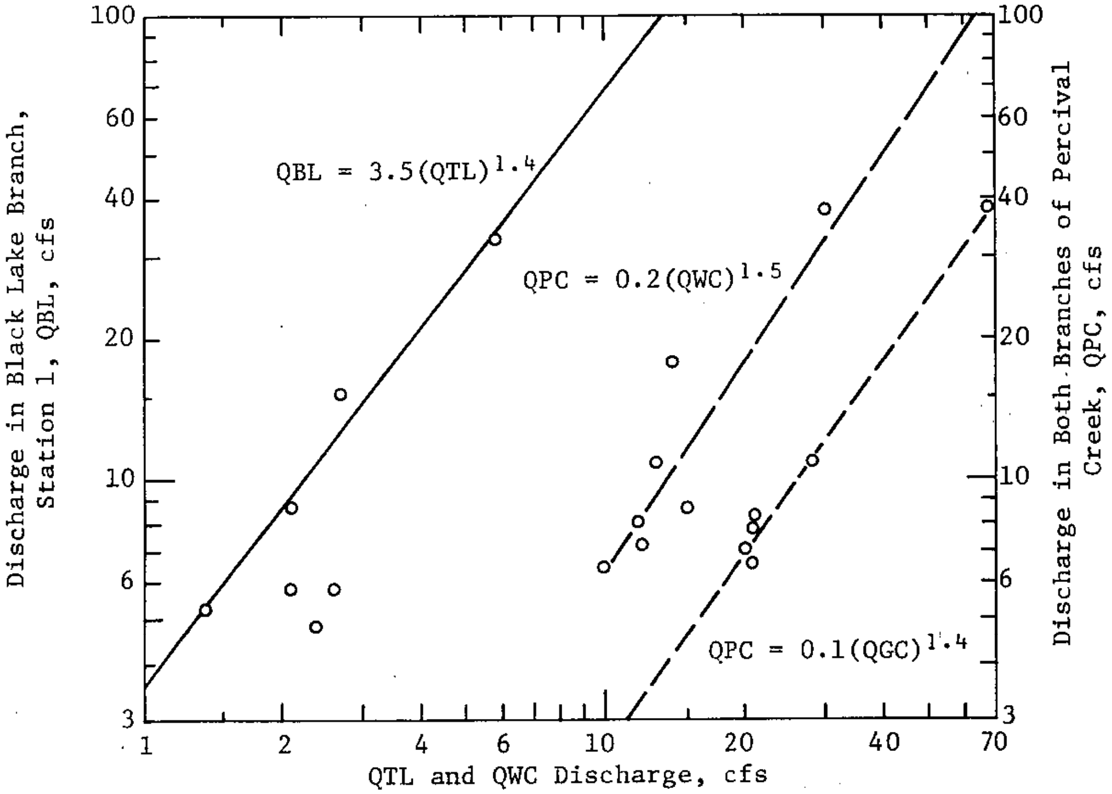
The water level in Capitol Lake is controlled within limits by operation of the gates in the gate house. The automatic control system opens and closes these gates. The Deschutes River supplies the major portion of the fresh water inflow to the lake. The automatic control system operates to exclude salt water from the lake and to keep the lake level approximately constant regardless of the fresh water inflow (mean lake level is -3.5 ft Olympia datum; 6.29 ft msl).

Table A19.

Miscellaneous Streamflow Measurements in Percival Creek

Date	Station 1	Station 2	Station 2A	Station 2B	Station 3
	Black Lake Branch at Mottman Rd	Percival Creek at Mottman Rd	Black Lake Branch 100' Above Mouth	Black Lake Branch at Lake Outlet	Percival Creek at Percival Cove 0.2 mi. upstream
8/15/48				6.39	
7/6/49		10.6		10.8	
8/1/49		8.57		8.30	
8/15/49		7.54			
9/6/49		5.53		4.95	
9/30/49		6.69		6.90	
5/17/63	33.4	5.73			
7/9/65	8.89	2.08			
9/24/65	5.85	2.02			
8/16/66	5.28	1.42			
8/11/67	4.96	2.43			
9/9/68	15.6	2.62			
8/14/69	5.98	2.64			
5/7/70	25.0	5.21			
8/14/70	4.93	1.57			
9/2/70					6.32
9/14/70		1.59	7.98		
2/23/71	62.6				
5/12/71	29.2	5.57			
5/20/71	28.9				
7/7/71	19.5				
9/20/71	6.90				

Location of Station 1	SW¼SE¼ Sec. 21, T.18 N., R.2 W., 100 ft upstream from mouth 1.5 mi southwest of State Capitol
Location of Station 2	South line of SE¼SE¼ Sec. 21, T.18 N., R.2 W., at Mottman Rd Crossing, 1.5 mi southwest of State Capitol
Location of Station 2A	SE¼SE¼ Sec. 21, T.18 N., R.2 W., 100 ft upstream from mouth 1.5 mi southwest of State Capitol
Location of Station 2B	NE¼NW¼ Sec. 32, T.18 N., R.2 W., at Black Lake Road crossing at NE end of Black Lake, 3 mi west of Tumwater
Location of Station 3	SE¼NW¼ Sec. 22, T.18 N., R.2 W., 0.2 mi upstream from mouth, 0.5 mi west of State Capitol



NOTES:

QTL - discharge in the Trosper Lake Branch of Percival Creek at miscellaneous Gaging Station No. 2.

QWC - discharge in Woodland Creek at Station No. 120810.

QBL - discharge in the Black Lake Branch of Percival Creek at miscellaneous Gaging Station No. 1.

QPC - Percival Creek total discharge at the junction of Black Lake and Trosper Lake Branches.

QGC - discharge in Goldsborough Creek at Station No. 120765.

All discharges are on the same days as recorded in Table 14.

Fig. A3. Discharge Relationships Between the Black Lake and Trosper Lake Branches of Percival Creek, Woodland Creek, and Goldsborough Creek Based on Same Day Measurements Between 1963 and 1969. (Refer to Table 14)

Table A20. Change in Water Surface Elevation of Capitol Lake - Gage at Powerhouse.

Refer to Fig. 30.

Time	Day in 1974						
hr-min	11-16	11-17	11-18	11-19	11-20	11-21	11-22
0000		0	0	0	0	-2	0
0030	0	+1	-1	+1	0	-1	-1
0100	0	0	0	+2	-1	0	-2
0130	0	0	0	0	+1	0	-1
0200	0	0	-1	0	+1	0	0
0230	0	0	0	0	+2	0	-1
0300	0	0	+1	0	+1	0	0
0330	0	0	0	0	0	0	-1
0400	0	+1	0	0	+1	0	-1
0430	0	0	0	0	0	0	0
0500	0	0	+1	-1	0	0	+1
0530	0	0	-1	0	0	+2	0
0600	+1	0	-1	0	0	+1	0
0630	0	-1	0	+1	0	+1	0
0700	+1	0	+1	+1	0	+1	+1
0730	+2	+1	+2	+1	+1	+1	+1
0800	+2	+2	+1	0	+1	+1	+1
0830	+3	+4	+2	+2	0	+2	0
0900	+1	+2	+3	+2	+2	+2	+1
0930	-2	+1	+3	+4	+4	+4	0
1000	-5	+1	+2	+5	+5	+10	+1
1030	-3	-4	+2	+4	+7	+14	+1
1100	0	-2	-5	-2	+6	+16	+2
1130	0	-4	-4	-7	+4	+14	+2
1200	0	0	-5	-6	-7	+7	+2
1230	-1	0	-1	-2	-12	-10	0
1300	0	-1	+1	-2	-7	-19	-2
1330	0	0	0	0	-3	-20	-3
1400	+1	0	0	-1	-2	-13	-2
1430	0	0	+1	-1	0	-4	-2
1500	0	0	-1	0	0	-2	-2
1530	0	0	0	0	-1	-1	-1
1600	0	0	0	0	0	-1	-1
1630	+1	+1	0	0	0	0	-1
1700	0	+1	0	0	+1	0	0
1730	+1	-1	+1	+1	0	0	0
1800	0	0	0	0	0	0	0
1830	+1	0	+1	0	0	0	0
1900	0	+1	+1	0	0	0	0
1930	0	+1	+1	0	0	+1	0
2000	0	-1	0	+1	+3	0	0
2030	0	0	0	0	0	+1	0
2100	-1	0	0	0	+1	0	0
2130	-1	-1	-1	-1	+1	+1	0
2200	-1	0	-1	0	0	0	+1
2230	0	+1	-1	-1	0	0	+1
2300	-1	0	-1	0	0	-1	+1
2330	0	+1	-1	-1	-1	0	0
2400							

Units are millimeters from lake level strip chart records.

Table A20. Continued.

Time	Day in 1974						
hr-min	11-23	11-24	11-25	11-26	11-27	11-28	11-29
0000	0	0	0	0	0	0	0
0030	0	+1	+1	+1	0	0	0
0100	0	0	0	+1	0	0	-1
0130	0	0	0	0	0	0	0
0200	0	0	+1	+1	0	0	0
0230	0	0	+1	0	+1	+1	0
0300	-1	-1	0	+1	+1	0	0
0330	-2	0	0	0	+1	0	+1
0400	0	-1	-1	0	0	+1	+1
0430	0	-1	-1	0	+1	+1	0
0500	0	0	-2	-1	0	+1	+2
0530	0	0	-1	-2	-1	+1	+4
0600	0	0	0	-1	-2	0	+3
0630	0	0	0	-1	-1	-2	+1
0700	0	+1	0	0	-2	-2	-3
0730	0	+1	0	0	0	-2	-5
0800	+2	+1	0	0	-1	-1	-2
0830	+1	0	0	0	0	0	-2
0900	+1	+1	0	0	0	-1	-1
0930	0	+1	+1	-11	0	0	0
1000	+1	0	0	0	-1	0	-1
1030	0	+1	+1	+7	+1	0	0
1100	+1	+1	+1	+5	0	0	0
1130	+2	+1	0	0	+1	+1	0
1200	+2	+3	+1	+1	+1	0	0
1230	+2	+5	+1	+1	+1	+1	0
1300	+1	+9	+2	+1	0	+1	0
1330	-2	+4	+2	+1	+1	+1	0
1400	-3	-3	+1	+1	+1	0	+1
1430	-3	-9	0	+2	+1	+1	+1
1500	-3	-8	-3	0	+1	+1	+2
1530	-2	-4	-3	-1	+1	+1	+1
1600	0	-3	-3	-4	0	+1	+2
1630	0	-2	-1	-2	-3	0	+3
1700	0	0	0	0	-3	-2	0
1730	0	-1	-1	-2	-2	-2	-3
1800	0	-1	0	-1	0	-3	-3
1830	0	0	0	0	-1	0	-2
1900	0	-1	0	0	0	-1	-2
1930	0	+1	+1	0	0	0	0
2000	0	0	0	-1	0	-1	0
2030	0	0	0	+1	+1	+1	-1
2100	0	-1	0	+1	0	+1	0
2130	+1	+1	0	0	+1	+1	+1
2200	0	0	0	+1	0	+1	+1
2230	+1	0	0	+1	+1	0	+1
2300	0	+1	0	0	0	0	0
2330	0	+1	0	0	0	0	0
2400			0	0	0	0	+1

Units are millimeters from lake level strip chart records.

Table A21. Flow Into and Out of Capitol Lake Based on Volume Change in Lake Level.

Refer to Fig. 30.

Time hr-min	Day in 1974						
	11-16	11-17	11-18	11-19	11-20	11-21	11-22
0000	-	-	-	-	-	-	-
0030	0	+119	-119	+119	0	-119	-119
0100	0	0	0	+238	-119	0	-238
0130	0	0	0	0	+119	0	-119
0200	0	0	+119	0	+119	0	0
0230	0	0	0	0	+238	0	-119
0300	0	0	+119	0	+119	0	0
0330	0	0	0	0	0	0	-119
0400	0	+119	0	0	+119	0	-119
0430	0	0	0	0	0	0	0
0500	0	0	+119	-119	0	0	+119
0530	0	0	-119	0	0	+238	0
0600	+119	0	-119	0	0	+119	0
0630	0	-119	0	+119	0	+119	0
0700	+119	0	+119	+119	0	+119	+119
0730	+238	+119	+238	+119	+119	+119	+119
0800	+238	+238	+119	0	+119	+119	+119
0830	+357	+476	+238	+238	0	+238	0
0900	+119	+238	+357	+238	+238	+238	+119
0930	-238	+119	+357	+476	+476	+476	0
1000	-595	+119	+238	+595	+595	+1190	+119
1030	-357	-476	+238	+476	+833	+1666	+119
1100	0	-238	-595	-238	+714	+1904	+238
1130	0	-476	-476	-833	+476	+1666	+238
1200	0	0	-595	-714	-833	+833	+238
1230	-119	0	-119	-238	-1428	-1190	0
1300	0	-119	+119	-238	-833	-2261	-238
1330	0	0	0	0	-357	-2380	-357
1400	+119	0	0	-119	-238	-1547	-238
1430	0	0	+119	-119	0	-476	-238
1500	0	0	-119	0	0	-238	-238
1530	0	0	0	0	-119	-119	-119
1600	0	0	0	0	0	-119	-119
1630	+119	+119	0	0	0	0	-119
1700	0	+119	0	0	+119	0	0
1730	+119	-119	+119	+119	0	0	0
1800	0	0	0	0	0	0	0
1830	+119	0	+119	0	0	0	0
1900	0	+119	+119	0	0	0	0
1930	0	+119	+119	0	0	+119	0
2000	0	-119	0	+119	+357	0	0
2030	0	0	0	0	0	+119	0
2100	-119	0	0	0	+119	0	0
2130	-119	-119	-119	-119	+119	+119	0
2200	-119	0	-119	0	0	0	+119
2230	0	+119	-119	-119	0	0	+119
2300	-119	0	-119	0	0	-119	+119
2330	0	+119	-119	-119	-119	0	0
2400	0	0	0	0	-238	0	0

Units are cubic feet per second.

Table A21. Continued.

Time hr-min	Day in 1974						
	11-23	11-24	11-25	11-26	11-27	11-28	11-29
0000	-	-	-	-	-	-	-
0030	0	+119	+119	+119	0	0	0
0100	0	0	0	+119	0	0	-119
0130	0	0	0	0	0	0	0
0200	0	0	+119	+119	0	0	0
0230	0	0	+119	0	+119	+119	0
0300	-119	-119	0	+119	+119	0	0
0330	-238	0	0	0	+119	0	+119
0400	0	-119	-119	0	0	+119	+119
0430	0	-119	-119	0	+119	+119	0
0500	0	0	-238	-119	0	+119	+238
0530	0	0	-119	-238	-119	+119	+476
0600	0	0	0	-119	-238	0	+357
0630	0	0	0	-119	-119	-238	+119
0700	0	+119	0	0	-238	-238	-357
0730	0	+119	0	0	0	-238	-595
0800	+238	+119	0	0	-119	-119	-238
0830	+119	0	0	0	0	0	-238
0900	+119	+119	0	0	0	-119	-119
0930	0	+119	+119	-1309	0	0	0
1000	+119	0	0	0	-119	0	-119
1030	0	+119	+119	+833	+119	0	0
1100	+119	+119	+119	+595	0	0	0
1130	+238	+119	0	0	+119	+119	0
1200	+238	+357	+119	+119	+119	0	0
1230	+238	+595	+119	+119	+119	+119	0
1300	+119	+1071	+238	+119	0	+119	0
1330	-238	+476	+238	+119	+119	+119	0
1400	-357	-357	+119	+119	+119	0	+119
1430	-357	-1071	0	+238	+119	+119	+119
1500	-357	-952	-357	0	+119	+119	+238
1530	-238	-476	-357	-119	+119	+119	+119
1600	0	-357	-357	-476	0	+119	+238
1630	0	-238	-119	-238	-357	0	+357
1700	0	0	0	0	-357	-238	0
1730	0	-119	-119	-238	-238	-238	-357
1800	0	-119	0	-119	0	-357	-357
1830	0	0	0	0	-119	0	-238
1900	0	-119	0	0	0	-119	-238
1930	0	+119	+119	0	0	0	0
2000	0	0	0	-119	0	-119	0
2030	0	0	0	+119	+119	+119	-119
2100	0	-119	0	+119	0	+119	0
2130	+119	+119	0	0	+119	+119	+119
2200	0	0	0	+119	0	+119	+119
2230	+119	0	0	+119	+119	0	+119
2300	0	+119	0	0	0	0	0
2330	0	+119	0	0	0	0	0
2400	0	0	0	0	0	0	+119

Units are cubic feet per second.

Two gates are used, each with its own set of controls. Both gates open 18 ft on the arc and each control is designed to operate the gate over its entire opening due to a 6-inch change in the lake level. The east gate (24 ft wide) is normally closed at -4 ft and open at -3.5 ft, and the west gate (36 ft wide) is normally closed at -3.5 ft and open at -3.0 ft. These elevations are referenced to City of Olympia datum (+9.79 ft msl). For every water level within the 6-inch range from fully closed to fully open, there will be a definite gate opening. A sensitivity of 1/32 inch is used so that for each 1/32 inch of water level change the gate opening changes approximately one inch. If successive changes are in opposite directions then a water level change of more than 1/32 inch is required to cause gate movement. Normal setting is for 3 or 4 successive movements in one direction before movement can be reversed. This feature eliminates hunting due to small wind waves generated in the control float well.

The gates will neither open nor remain open if the tide in Budd Inlet raises the salt water elevation higher than 2 inches below the lake water level. As with the gate controls there are provisions to prevent hunting due to small wave-generated salt water level changes. Options available are:

1) the "normal" lake level can be changes and is changed from time to time;
2) manual over-rides are available to open and close the gates as required; and
3) the sensitivity and hunting controls can be changed.

Observed variances include salt water intrusion when some obstruction prevented gate seating, and when the fishway gates were open during fish runs. The lake level is not "normal" during construction, fish release, cleaning Percival Creek fish rearing area, and during some lake recreation activities. The highest observed (historical) tide water level is approximately "0" Olympia datum, or 9.79 ft msl.

APPENDIX B

TO CHAPTER IV

APPENDIX B

SEDIMENTATION STUDIES

1. Introduction

The sediment transport study of the Deschutes and Nisqually River basin conducted between November 1971 and June 1973 by the Geological Survey was of timely value to the Capitol Lake sediment study.[14] Suspended sediment data taken near LaGrande, Rainier, and Olympia have been compiled to provide good correlations of suspended sediment in the Deschutes River as a function of river flow. Figure B1 illustrates the location of Capitol Lake and the gaging stations in relation to the Deschutes and Nisqually River basins. It has been found also that the bed load transport of the Deschutes River (larger particles, i.e., gravel) is only about 10 percent or less of the suspended sediment transport. Most of the sediment is of small grain size and is generated in the upper, steeper portions of the Deschutes River basin. Extensions of the U.S. Geological Survey report have been developed between suspended sediment load, basin geomorphic parameters, annual precipitation, and streamflow so that a year-to-year estimate of Deschutes River sediment load entering Capitol Lake can be made in the future. Assuming that the natural sediment characteristics of Percival Creek basin are similar to those of the Deschutes River, Percival Creek would prove only about one-quarter of one percent of the annual sediment to Capitol Lake over a period of years.

Another major emphasis in this study was on the dredging and maintenance of the Upper Lake so that it will serve as an efficient sedimentation basin for the rest of Capitol Lake. Very fine material will, of course, continue in suspension into the middle and lower basins, and into Budd Inlet, during periods of high discharge in the Deschutes River. These flood flows occur only for a very small percentage of the time. Also, with proper initial dredging of particular areas in the upper basin where sediment tends to accumulate, and with establishment of a maintenance system to remove and dispose of accumulated sediment from year to year, Capitol Lake can be restored to more

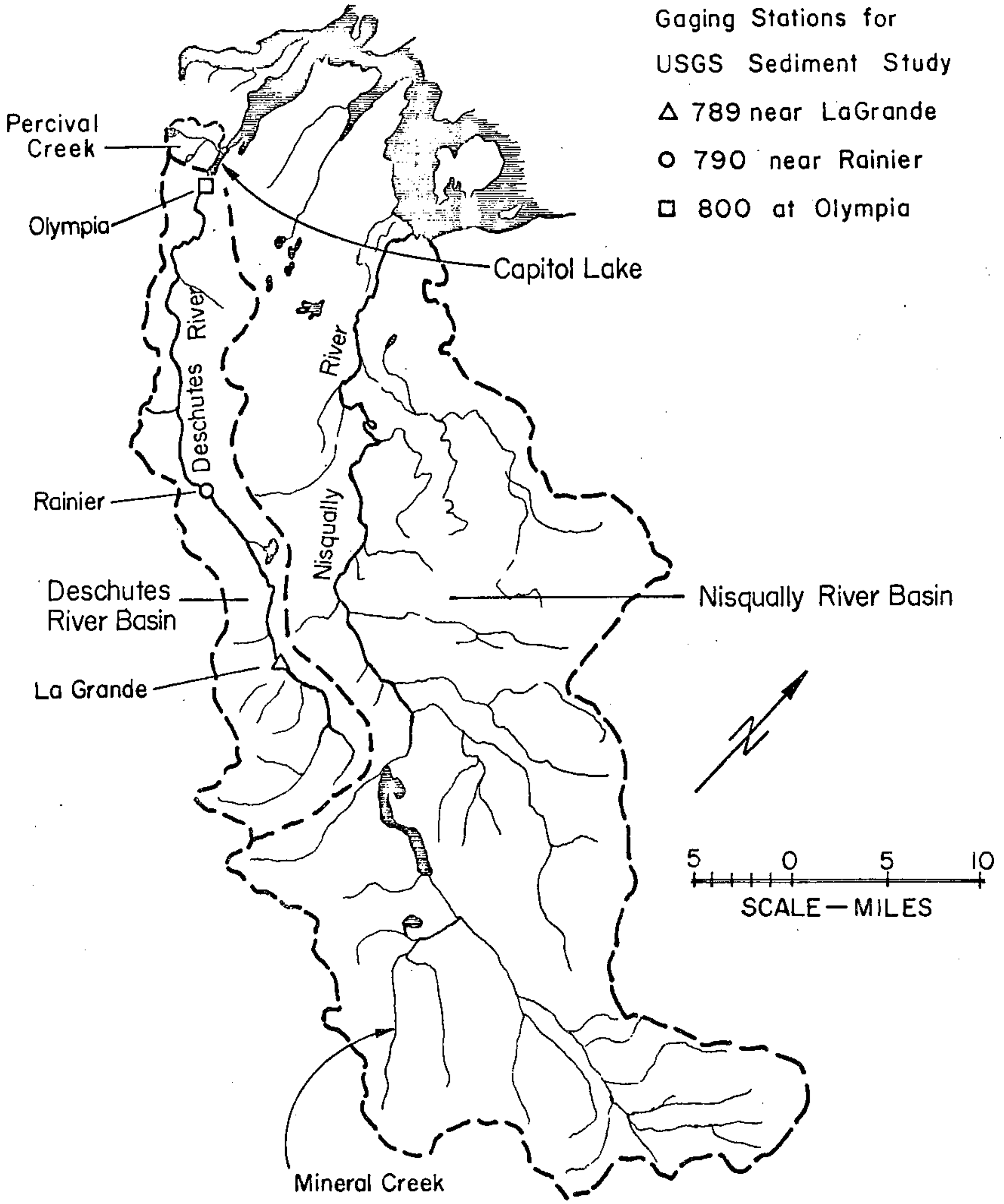


Fig. B1. Capitol Lake Drainage Basin and Sediment Study Gaging Stations in the Deschutes River Basin; Nisqually River Basin Included to Show Location of Mineral Creek manageable conditions and maintained to serve the purposes for which it is currently used without redredging the entire lake. Maintenance systems for removing the yearly sediment accumulation in certain portions of the upper basin, and in the vicinity of the I-5 bridge, have been analyzed, and are discussed in detail in Section 4 of this Appendix. Following the concepts presented by the consultant for utilization of the upper basin as a sedimentation basin and maintained substantially in its current natural state, several systems have been considered for removing sediment.[3] The systems would all feed into a materials handling facility on the southeast shore of the upper lake. Water would drain from the stockpile into a clarification chamber and the clear water is returned to the Deschutes River. The accumulated dredgings can be removed according to the original plans developed by the consultant, as updated according to the results of this study, and as finalized in the project design in 1975-76.

2. Hydrology of Deschutes River Affecting Sediment Transport

Detailed hydrologic analyses of the Deschutes River Basin have been presented in Chapter III of this report. Therefore, only those hydrologic aspects which have direct bearing on the sediment problem will be repeated or introduced in this section.

Portions of Table 2 from Chapter II are repeated here as Table B1 to reemphasize the importance of drainage basin characteristics in analyzing streamflows and thus the sediment transport characteristics of the stream in question.

To improve predictive capability of sediment loads in the Deschutes River, the average suspended concentration graphs of the Deschutes River near LaGrande, Rainier, and Olympia were analyzed in terms of river basin geomorphic parameters, and averages of precipitation and streamflow. The three gaging stations average suspended sediment concentration (QS), shown in Figure B2, are related to the concurrent instantaneous river discharge (QI) at those stations. The measurements upon which these average graphs were based show variabilities ranging between 25 and 50

Table B1.

River Basin Parameters of Deschutes River, Washington

Gage Station (No.)	L1 (mi)	LT (mi)	Upper Elev. (ft)	Gage Elev. (ft)	Relief H (mi)	Basin Area, A (sq mi)
LaGrande (12078902)	38.6 $\Sigma=38.6$	61.5 $\Sigma=61.5$	549	0.38	0.38	56.2
Rainier (12079000)	11.2 $\Sigma=49.8$	24.1 $\Sigma=85.6$	2550	350	0.42	89.8
Olympia (12080000)	8.9 $\Sigma=58.7$	29.1 $\Sigma=114.7$	2550	95	0.47	160.0

<u>Nomenclature</u>: L1 = length of first-order (unbranched perennial streams);

LT = total length of perennial streams;

Upper Elevation = highest average contour around headwaters;

H = Relief--difference in elevation between headwaters and gage (or outlet, for ungaged basin); and

A = drainage area defined by topographic divide above gaging station or basin outlet.

percent between LaGrande and Olympia. But the average rating curves reproduced in Figure B2 should be indicative of long-term average conditions. The three equations for the rating curves in Figure B2 and the values of suspended river discharges of 1000 through 7000 cfs are presented in Table B2.

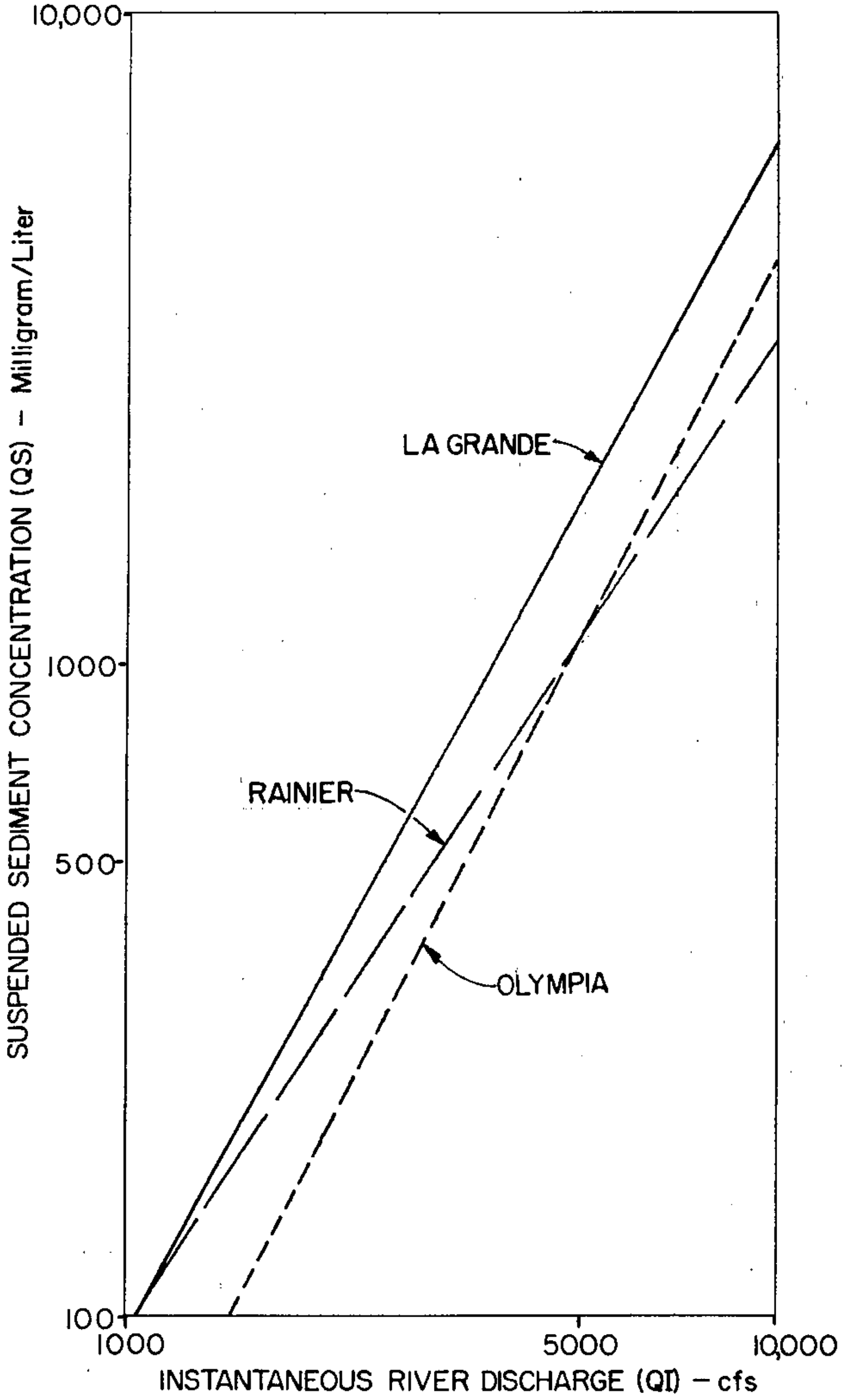


Figure B2. Relation of Instantaneous Suspended-Sediment Concentration to Concurrent Water Discharge for Deschutes River Basin at LaGrande, Rainier, and Olympia (Graphs from Figs. 6, 7, and 8 in Reference 11)

Table B2. Suspended Sediment Concentration and Discharges at Three Stations in the Deschutes River Basin

Station	QS (mg/liter)	QI (cfs)						
		1000	2000	3000	4000	5000	6000	7000
LaGrande	$QS = 0.00034(QI)^{1.83}$	105.4	374	785	1374	1999	2788	3719
Rainier	$QS = 0.02(QI)^{1.55}$	89.7	274	492	788	1080	1436	1828
Olympia	$QS = 0.000082(QI)^{1.93}$	49.4	187	411	742	1102	1564	2112

The suspended sediment concentrations were then plotted for each station at the river discharge values between 1000 and 7000 cfs against a "river parameter" as shown in Figure B3. The estimated bed load transported by the Deschutes River amounts to only about 10 percent of the suspended load.(11) The river parameter combines first-order stream length (L1), total stream length (LT), basin relief (H), and drainage area (A) at each station. The suspended sediment concentration at Rainier is lower than the concentration at Olympia at high discharges; but the reverse is true for lower discharges. Referring back to Figure B2, this relationship is seen to be the result of the different slopes on the suspended sediment rating curves at Rainier and Olympia. The two rating curves cross at a river discharge of about 5500 cfs and from that discharge the concentration of suspended sediment is larger at Olympia than Rainier. The largest river discharges experienced at the two stations prior to the USGS study were 6650 cfs at Olympia in 1964, and 5620 cfs at Rainier in 1955. The LaGrande gage has only been maintained since the Geological Survey suspended sediment study began in 1971.(11) About 85 percent of the sediment is transported by river discharges greater than 1000 cfs which occur only about 8 percent of the time.

Considering the slopes (n) of the dashed lines in Figure B3, each representing an instantaneous river discharge, then each line can be written in equation forms as:

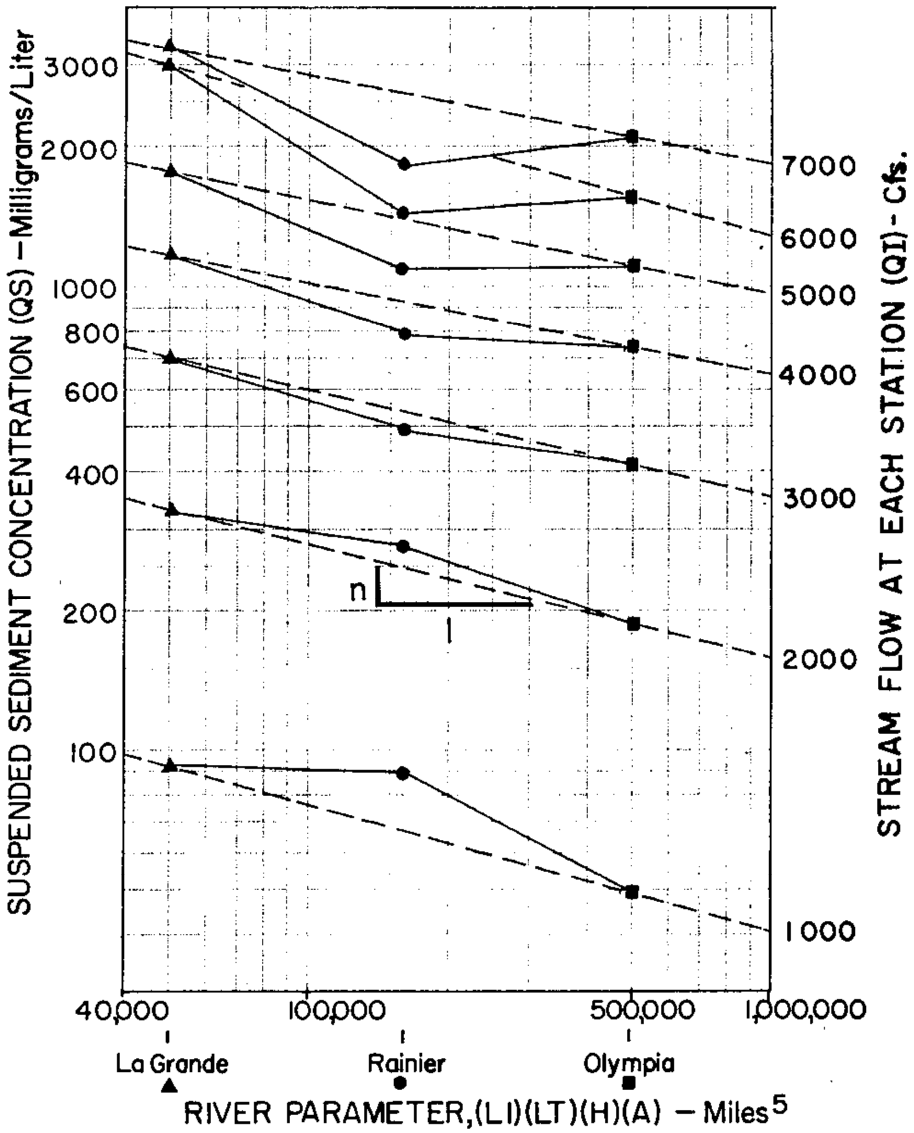


Figure B3. The Suspended-Sediment Concentration Discharge Related to the River Parameter (First-Order Stream Length, Total River Length Elevation Relief, and Basin Area) for the 3 Stations in the Deschutes River Basin

$$QS = C[(L1)(LT)(H)(A)]^{-n}\Big|_{1000}^{7000} \qquad (B1)$$

Or, using the abbreviation (RP) for the river parameter [(L1)(LT)(H)(A)], Eq. (B1) can be written for each river discharge as

$$QS = C/(RP)^{n} \qquad (B2)$$

Using the relationship in Figure B2 and Eq. (2) from Chapter III of $(LT) = 0.21(P \cdot A)^{0.70}$, this can be substituted into Eq. (B2) to relate sediment loads to annual precipitation. Also, Eq. (1) of $QAA = 0.052(P \cdot A)$ could be inserted to relate sediment load to average annual flow.

The coefficient (C) in Eq. (B2) varies as a function of the instantaneous discharge and so do the slopes of each of the dashed discharge lines (n) in Figure B3. The relationships between the coefficient (C), the slopes of the graphs (n) and river discharge (QI) are shown in Figures B4 and B5. The slopes of the lines in Figure B3, as displayed in Figure B5, decrease with discharge. This indicates that as river discharges get larger there is less variation in sediment concentration between the upper and lower portions of the Deschutes River basin.

3. Calculation of Annual Sediment Loads

Using the relationships in Figure B2 between suspended sediment (QS) and instantaneous river discharge (QI), sediment load estimates were made for the average flow-duration curve near Olympia (Figure 14 in Chapter III), and for water years* 1961, 1962 and 1963. Also, the sediment load was calculated for the storm between January 16 and February 5, 1964, when the maximum flood of record occurred at Olympia (Figure 20). Results of these calculations are summarized in Table B3.

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*Water year: Oct. 1 to Sept. 30 of following year denoted by calendar year number in which January occurs.

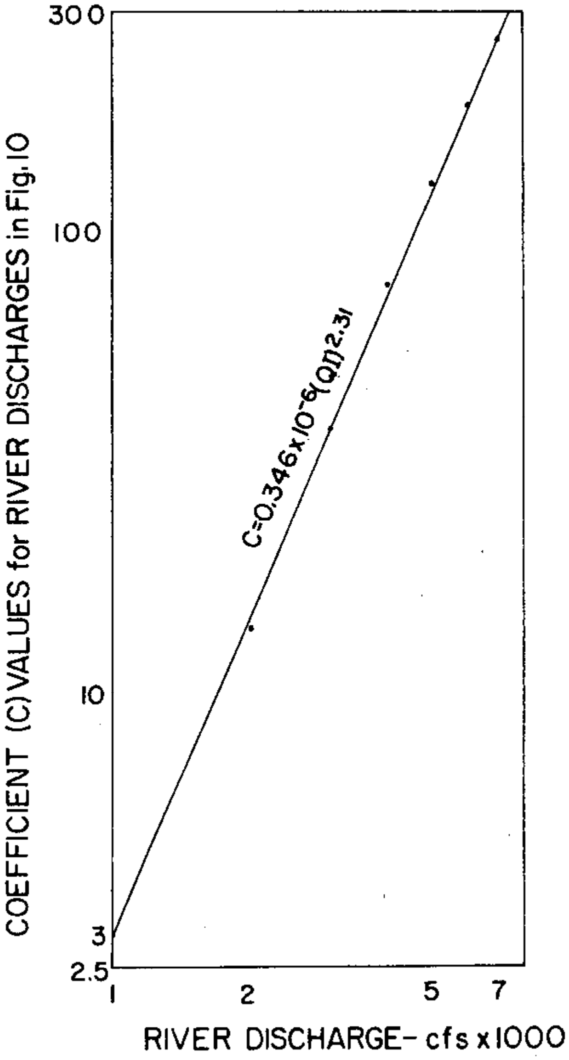

Figure B4. Coefficients for Each River Discharge Equation in Fig. B3.

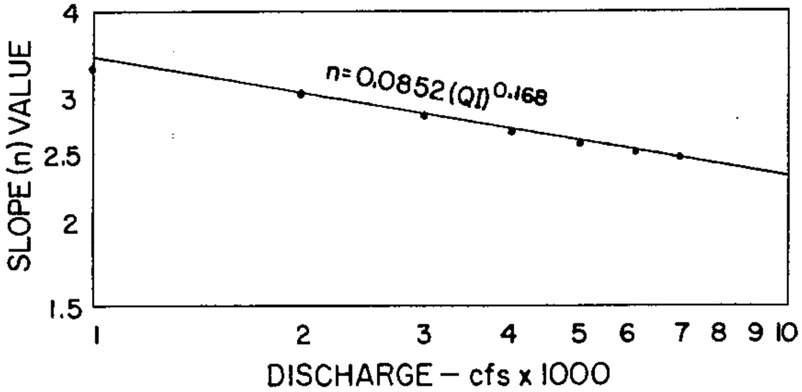

Figure B5. Slopes of River Discharge Lines (n) in Fig. B3 Related to Discharge

Table B3. Calculated Sediment Discharges of Deschutes River at Olympia

Time Period	Suspended Sediment (tons)	Estimated Total Sediment Load* (tons)
1961	28,400	31,240
1962	3,760	4,136
1963	21,600	23,760
Jan. 16-Feb. 5, 1964	26,200	28,820
Average Value**	29,600	32,560

*Based on estimated bed load equal to 10 percent of suspended load.

**Based on duration curve in Figures 17 and 20, Chapter III.

The average value of 32,560 tons per year would be about 30 percent higher than the 25,000 tons estimated in reference 11. Without knowing the in-place weight of the sediment deposited in the lake, a conversion from tons per year to cubic feet per year could be made only for assumed values of in-place specific weight. Therefore, four samples of deposition were taken as part of this study at locations shown in Figure B6. The analysis of these sediment samples is presented in Table B4.

Table B4. Wet Density of Deposited Sediment

Sample No.	Wet Volume (cc)	Wet Weight (grams)	Dry Weight (grams)	Wet Density gram/(cc)	Wet Density ton/(cu yd)
1	1203	1924	1200	1.59	1.34
2	261	417	260	1.60	1.35
3	591	1027	709	1.74	1.47
4	220	354	196	1.57	1.32
Averages	569	930	591	1.63	1.37

Dry Density: 1.04 gm/cc, 1.24 tons/cu yd

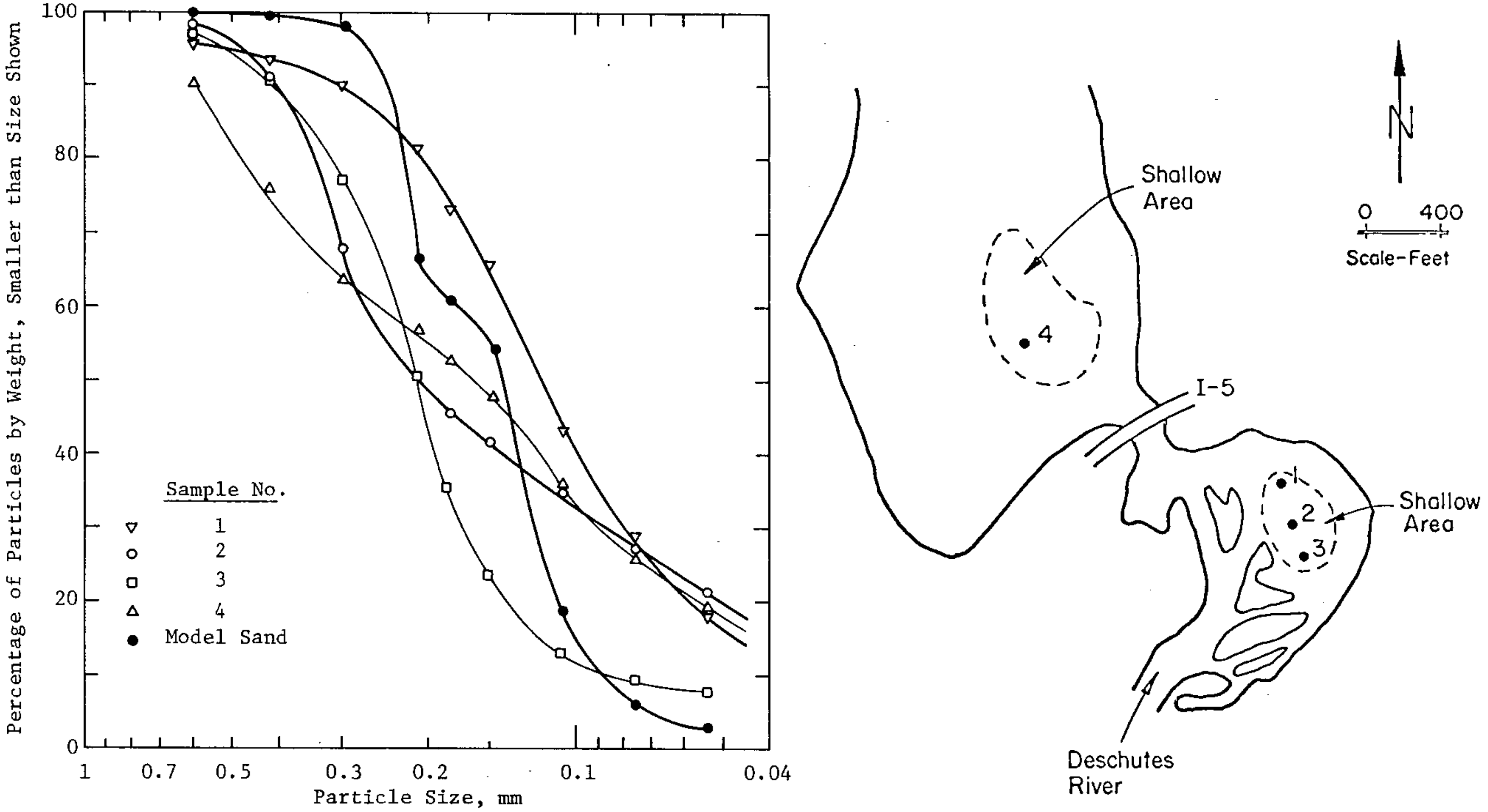

Figure B6. Size Distribution of Sediment Samples in Capitol Lake Taken on July 25, 1974, and the Sand Used in the Lake Model; Location of Samples in Upper and Middle Lakes

Based on the average submerged weight of the largest sediment sample, the average annual sediment discharge of 32,560 tons per year would be equivalent to 23,766 cubic yards per year. An analysis of variability of this load can be made by noting the variation in annual sediment tonnage in Table B3. For dry weight conditions, the average sediment load of 32,560 tons per year would be equal to about 26,260 cubic yards.

4. Alternatives for Maintenance of the Lake

Many alternative methods for the maintenance and initial dredging of Capitol Lake have been addressed in the report used as reference 3, "Engineering Investigation for Rehabilitation of Capitol Lake, Olympia, Washington" dated April, 1973. This report was prepared by Patrick J. Byrne and Associates of Olympia, and it provided an excellent basis upon which more detailed analysis and research were conducted on the various alternatives. Some of the proposals from the 1973 report have been given more detailed consideration as described in the following sections.

For the maintenance dredging of the upper lake, there are three main alternatives considered, and each one of them can have some modifications.

Alternative 1: The same as the periodic dredging part of proposal No. 2 in the consultant's report.(3) Briefly, an Upper Lake sump near the middle of the Upper Lake will be dredged once every two years to remove a total of 40,000 cubic yards each time. The dredging work would be contracted. It has been estimated that 50 percent of the sediment would pass into the Middle Basin.(3) The middle basin sump located north of the I-5 bridge would need to be redredged once every 20 to 30 years. The east half of the Upper Basin would be closed off allowing silt removal operations to be conducted without adding turbidity to the lake water. There would be permanent bed sills, gates and sheet piling to facilitate the temporary closure and maintain channel alignments and island shapes.

Alternative 2: A permanent piping system would be laid under the areas in the Upper Lake sump where sediment tends to accumulate. The size of the pipe would be six inches and there are six separate pipes, each connecting to slurry pumps. This arrangement of piping is shown in Figure B7. One end of the pipe is open for dredging. The pipe opening is laid at 30 feet below the present bottom of the lake at elev. -40. It will dredge out a 30-foot deep cone. Laboratory pumping tests on fine sand, comparable to the material found in the Upper Lake, have determined the angle of repose is 32°. The radius of the cone can be determined from the angle of repose and the depth is to be equal to 48 feet. The volume of each cone is 2,800 cubic yards. With six cones, the total volume is 17,150 cubic yards. To remove the yearly sediment accumulation of 40,000 cubic yards, the pumping system should be operated three times a year. If six slurry pumps are pumping at the same time, about three days of pumping are required to complete the dredging. Some sediment will still pass on to the middle basin but at a much reduced rate. It is estimated that the Middle Lake sump north of the I-5 bridge will need dredging once every 30 to 40 years.

At the dredging inlet there are water jets to help loosen the sediment (as shown in Figure B8). One of the jets will be placed below the pipe and directed downward which will cause a pocket below the pipe inlet for the accumulation of rocks. The few large rocks in the area are deposited upstream or in the deeper existing channel close to the east bank of the Upper Lake. The flow in the dredge lines can be reversed by using the auxiliary high head pump which supplies the small jet lines. The advantage of this system is that the dredging operation will be relative simple and the manpower requirement for this operation is small. It can be handled by the State maintenance crew. The environmental impact is small. It is a clean and quiet

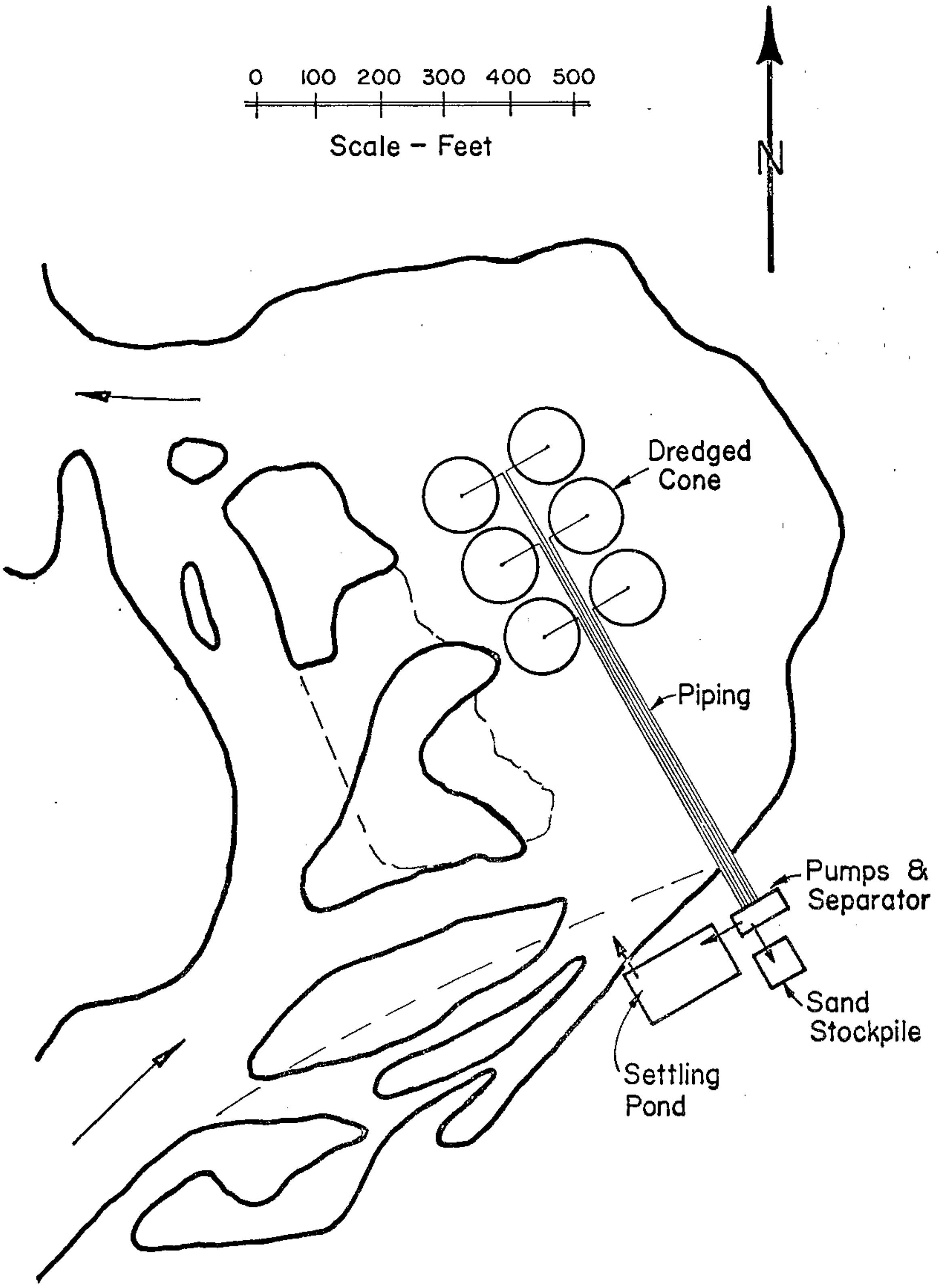

Figure B7. Dredging System for Maintenance (Alternative No. 2)

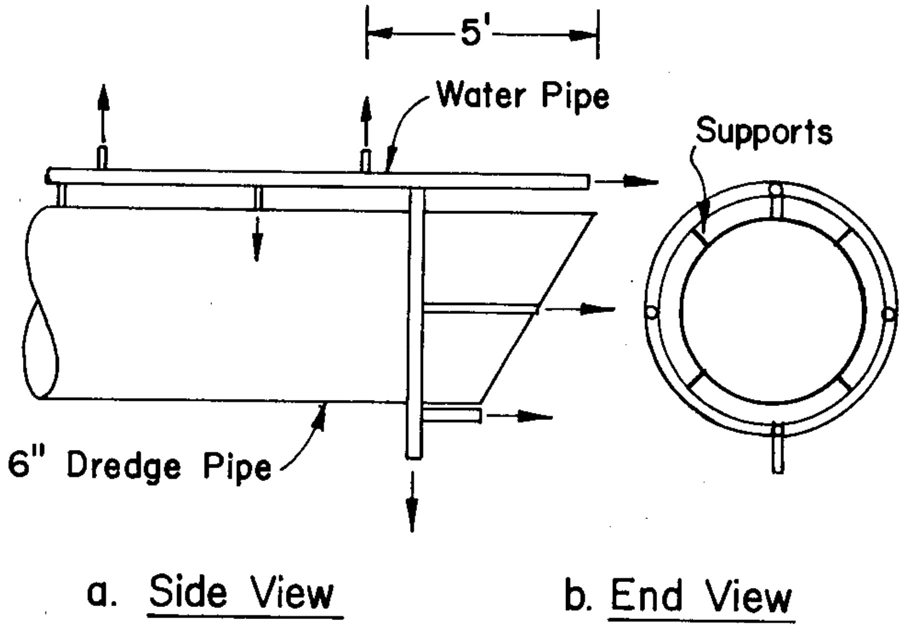

Figure B8. Inlet Jets for Alternative No. 2 Dredging System

dredging operation and will not increase the turbidity in the lake. After the discussion with the State fishery personnel, it is felt that a deeper suction dredge will not be detrimental to fish. The installation cost of this system has not been estimated. (<u>This alternative was later discarded due to its inflexibility to dredge other parts of the Lake</u>.)

<u>Alternative 3</u>: The State would purchase a "Mud Cat" type of dredging machine. This machine would be used to remove sediment accumulation on the east side of the Upper Lake and elsewhere as needed. The capacity of the machine is 800 cubic yards per day. To remove 40,000 cubic yards of yearly accumulation takes 50 days. With additional pipes and a booster pump, the shallow area north of the I-5 bridge can be dredged. This machine which needs two operators could be operated by State maintenance personnel, and it could be used to do maintenance dredging elsewhere in Capitol Lake and in other lakes. A place to park, store, and maintain the dredge must be provided.

5. Disposal of Dredged Material

The cost of disposal is substantial and will increase in the future after the nearby disposal sites are filled. If the dredge spoil is separated into sand and mud, the possibility of recycling this material is enhanced. A separation facility and stockpile area could be located near the southeastern shore of the upper basin. The dredged spoil would go through a screen separator* to separate sand and larger material as shown in Figure B9. These materials will be dropped on a conveyor belt to a stockpile area. The remaining material and water will flow to a settling pond. Small amounts of suitable chemicals will be added to promote settling of the mud. The clear water will be skimmed off the surface and returned to the lake by an overflow weir and conduit as shown in Figure B10. Once the material is separated into sand and mud, it should be possible to find a company or a governmental agency willing to remove it for a fee which will reduce the disposal cost.

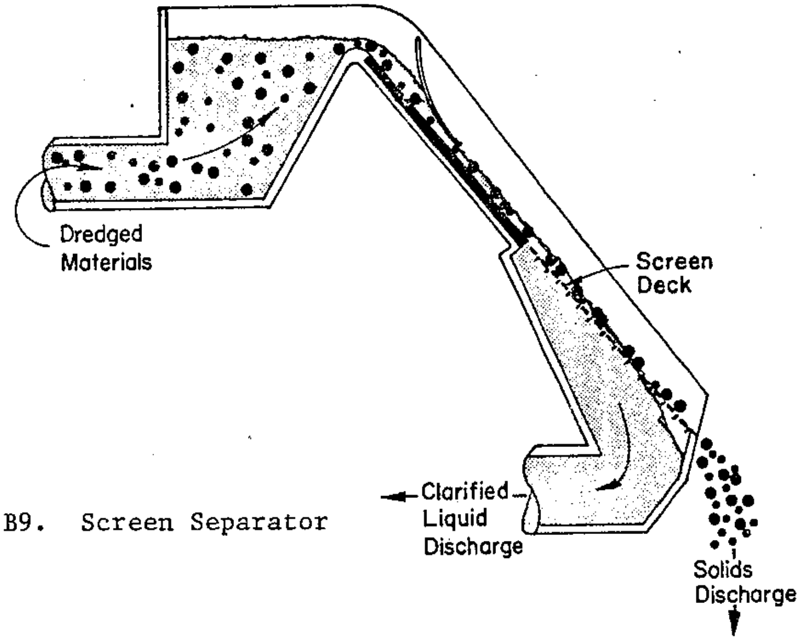

Fig. B9. Screen Separator

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*Such as Gross-Flow Sieve by Kason Corp., 231 Johnson Ave., Newark, N.J. 07108 or Hydrasieve Screens by Bauer Bros. Co., Springfield, Ohio 45501. Hydrocyclone can also be used at a higher cost.

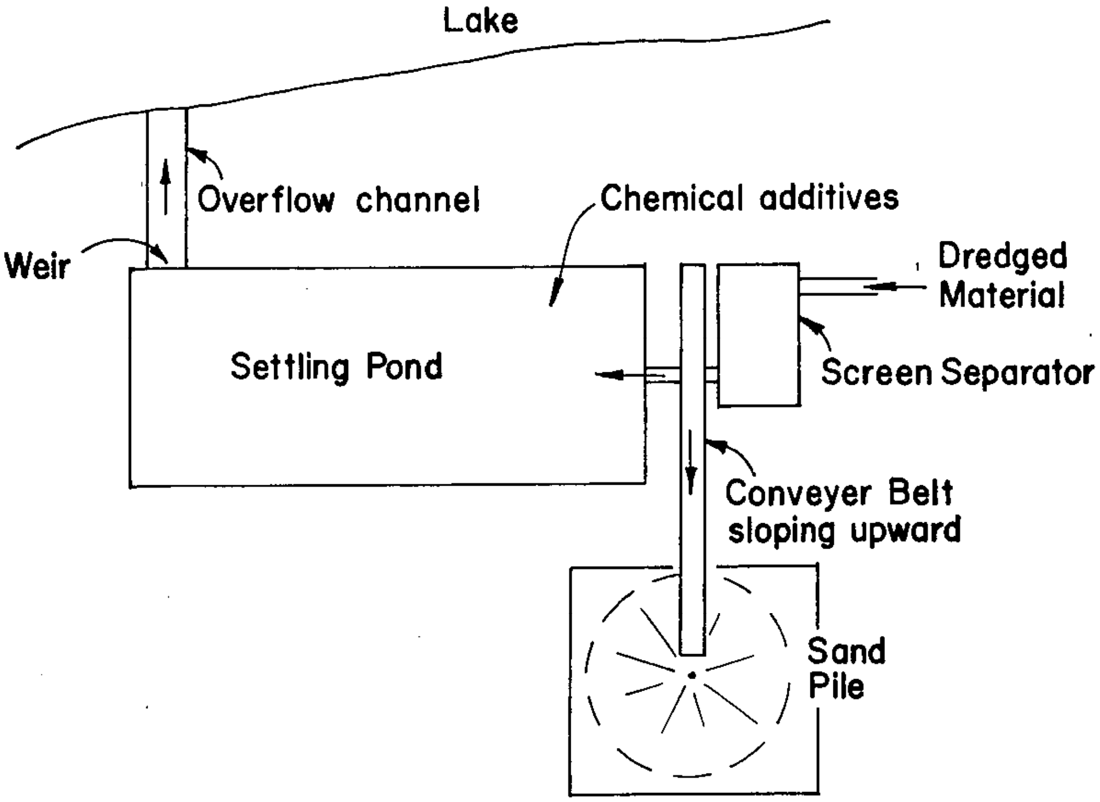


Figure B10. Treatment Facility for Dredged Materials

6. Preliminary Recommendations as of September 1974

a. Initial Dredging

1. Initial dredging should be done by a private contractor, not by State personnel, because of the magnitude of the job.

2. The lower (or north) basin between the railroad and the dam should not be dredged. The lower basin has reached an equilibrium condition and the existing condition does not interfere with its use. Net sediment accumulation is very small in this basin.

3. The middle basin should be dredged according to the initial dredge plan for the middle basin in the consultant's report.[3]

   (a) The shallow area north of the I-5 bridge should be removed and dredged to elev. -20 feet.

   (b) Remove the shallow area near the east shore of the middle basin and dredge to the 1951 condition in this area.

   (c) Remove the shallow area near the west shore.

   (d) Dredge other shallow problem areas in the Middle Basin.

   (e) The southwest corner is a stagnate flow area and will be difficult to maintain. It should be filled to create a park area. A portion of the dredged spoil can be deposited here after riprap is used to close off the corner (see Fig. B11).

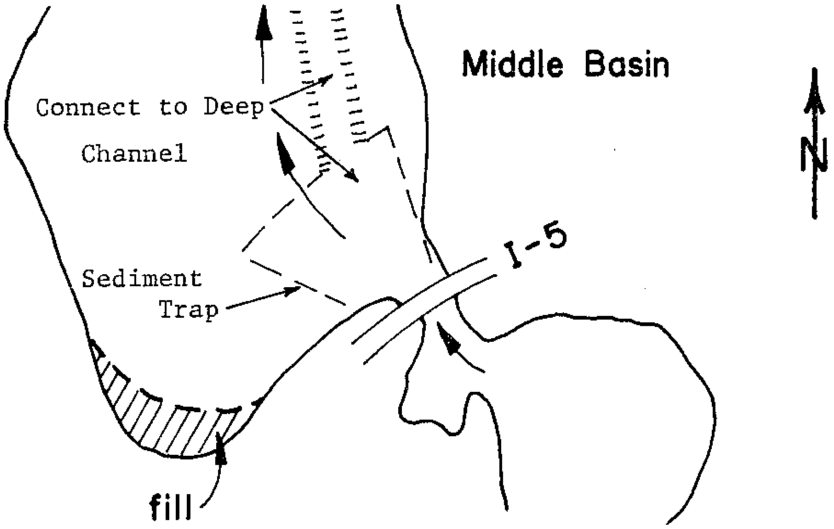


Figure B11. The Southwest Corner of the Middle Basin

4. The Upper Lake will not be "initially" dredged except concurrently to carry out the maintenance dredging outlined below.

b. Maintenance Dredging

1. Maintenance dredging should be done by a State crew.

2. Alternative 3 is recommended.

3. Even though the Upper Lake will trap a large amount of sediment, some material will move into and through the Middle Lake. Therefore, it can be anticipated that the Middle Lake will have to be dredged on a maintenance schedule, or according to the initial dredging plan once every 30 or 40 years.

c. Spoil Treatment

Treatment facilities should be provided near the upper basin.

APPENDIX C

TO CHAPTER V

APPENDIX C

HYDRAULIC MODEL STUDY DETAILS

SUMMARY

Because the hydraulic model studies were conducted in two phases on sedimentation and water quality flow characteristics, the material in this appendix is presented in the same order. Detailed information on the model study portions of the Upper Lake sediment trap investigation are presented first. Other aspects of the Upper Lake sedimentation study, such as suggested means for handling dredged materials and material sizes, are presented in Appendix B. Finally, supplemental data in graphical form is presented on flood routing, travel times and flow patterns with and without the fills in the southwest part of the Middle Lake.

1. Hydraulic Model Studies and Associated Information on the Use of Upper Capitol Lake as a Sediment Trap

The sediment model was a replica of the upper basin and the southern portion of the middle basin. Delmonte sand was used to form the bottom of the basins while the shorelines and islands were formed by solid materials. This sand which is finely crushed silicon rocks passing a 70-mesh screen was manufactured under controlled conditions and is very clean and light in color, making it ideal for use in model studies where visual observation is important. The size distribution of Delmonte sand is nearly the same as that of the average lake bottom sediment as shown in Figure B12, Appendix B.

The sand was used as a bed load in the model to confirm the location of deposition areas in the upper basin of the prototype. Although this hydraulic model cannot be used to duplicate the suspended sediment transport characteristics of the Deschutes River, the model does duplicate the areal extent of long-term sediment deposition patterns in the upper basin and downstream of the I-5 highway bridge. For large water bodies with slow-velocity areas, the long-term areal deposition of both suspended and bed load sediments will be about the same. This has been confirmed for the upper basin of Capitol Lake by the hydraulic model studies.

The model was distorted having a horizontal length scale of 1 (model) : 200 (prototype), and a vertical scale of 1:20. The distortion ratio of 1 horizontal to 10 vertical is a common and acceptable distortion ratio for this type of model study. Based on the Froude Model Law, the relationships between the model and the prototype are:

	Model	:	Prototype
Velocity ratio	1	:	4.47
Discharge ratio	1	:	17,880
Volume ratio	1	:	800,000
Time ratio	1	:	44.7

These tests were conducted in the hydraulic sediment model of Upper Capitol Lake to evaluate the following conditions:

(a) The division of Deschutes River streamflow under 1970 topographic conditions for a range of flows.
(b) The deposition pattern of sediment transported by the Deschutes River for the same 1970 topographic conditions and range of flows.
(c) Comparison of the results of the tests conducted under condition No. 2 with the existing topography in order to verify model operation.
(d) Modifications to the islands and shoreline under 1974 topographic conditions to improve the efficiency of sediment deposition and subsequent maintenance dredging.

a. Water Flow Tests

Initially the model was shaped according to a 1970 contour map. The flow patterns in the upper basin were determined for several clear water inflow discharges. The flow pattern or streamlines were obtained by observing and recording the path of small floats placed one by one in the Deschutes River channel. The width of the river channel in the model at the float starting point was ten inches. Most floats were placed at one-inch intervals which represent ten percent of the total flow between any two adjacent streamlines. Figures C1, C2 and C3 show the streamlines for discharges of 1000, 3000 and 6000 cfs in the prototype, respectively.

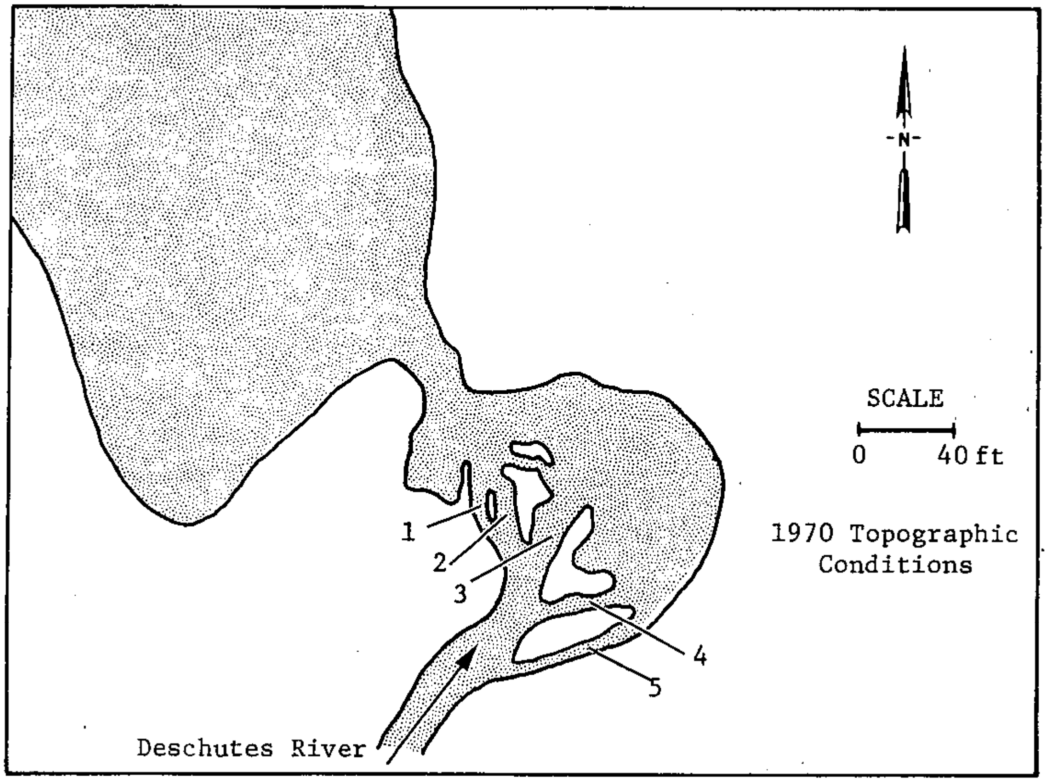
There were five separate flow channels formed by the islands in the upper basin as of 1970. The distribution of flow through each channel was determined from the measured streamlines. The results are tabulated in Table C1.

b. Sediment Flow Tests

Delmonte sand was added to the inflow through a metering device. After a four-hour discharge at 3000 cfs and 0.2 percent concentration of sand by weight, the sediment deposition areas for the 1970 model conditions were recorded as shown in Figure C4. The total volume of sand added to the water during this test was three cubic feet which is equivalent to 88,000 cubic yards in the prototype through the conversion volume ratio of 1:800,000. The average sediment discharge in the Deschutes River is about 35,000 to 40,000 cubic yards per year.

Figure C5 shows the upper basin as of June, 1974, based on aerial photographs. Comparing Figures C4 and C5, it is noted that the 1974 condition in Figure C5 can be predicated from the sediment deposition pattern as recorded for the model test in Figure C4. For instance, Channel 1 in 1970 which disappeared by 1974 resulted from sediment being deposited in Channel 1 as shown in Figure C4. Islands B and C in 1970 were combined into a larger island by 1974, and the near closure of Channel 5 in 1974 has been duplicated in the hydraulic model.

Similar tests were run at a discharge of 6000 cfs and 0.2 percent sand concentration for 1970 conditions in the model. The results were essentially the same as shown in Figure C4. This confirms that the hydraulic model predicts the flow and sediment deposit pattern in the upper basin.



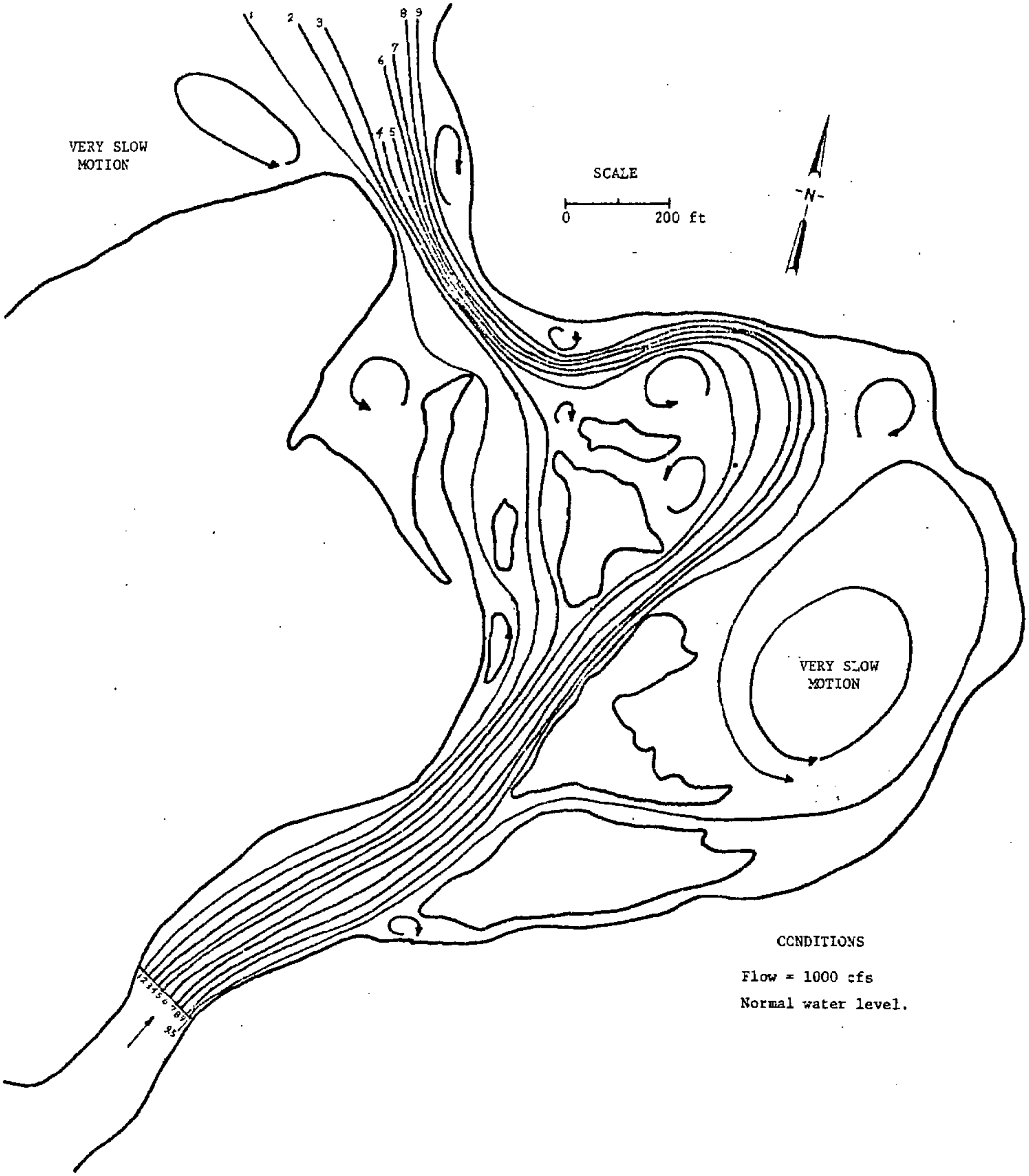
SKETCH OF CHANNEL LOCATIONS FOR TABLE C1

Table C1.

Distribution of Flow in the Upper Basin Channels of Capitol Lake

LAKE SURFACE LEVEL	At Normal Level, Elev. -3.5' (Olympia Datum)			At 2' Above Normal Level Elev. -1.5' (1.2" in model)*	
TOTAL FLOW, cfs	500	1000	3000	3000	6000
CHANNEL NUMBER	(percent of total flow in each channel)				
1	5	10	10	10	10
2	40	35	40	35	35
3	55	50	35	40	35
4	0	5	10	10	15
5	0	0	5	5	5

*1.2" above normal level in model

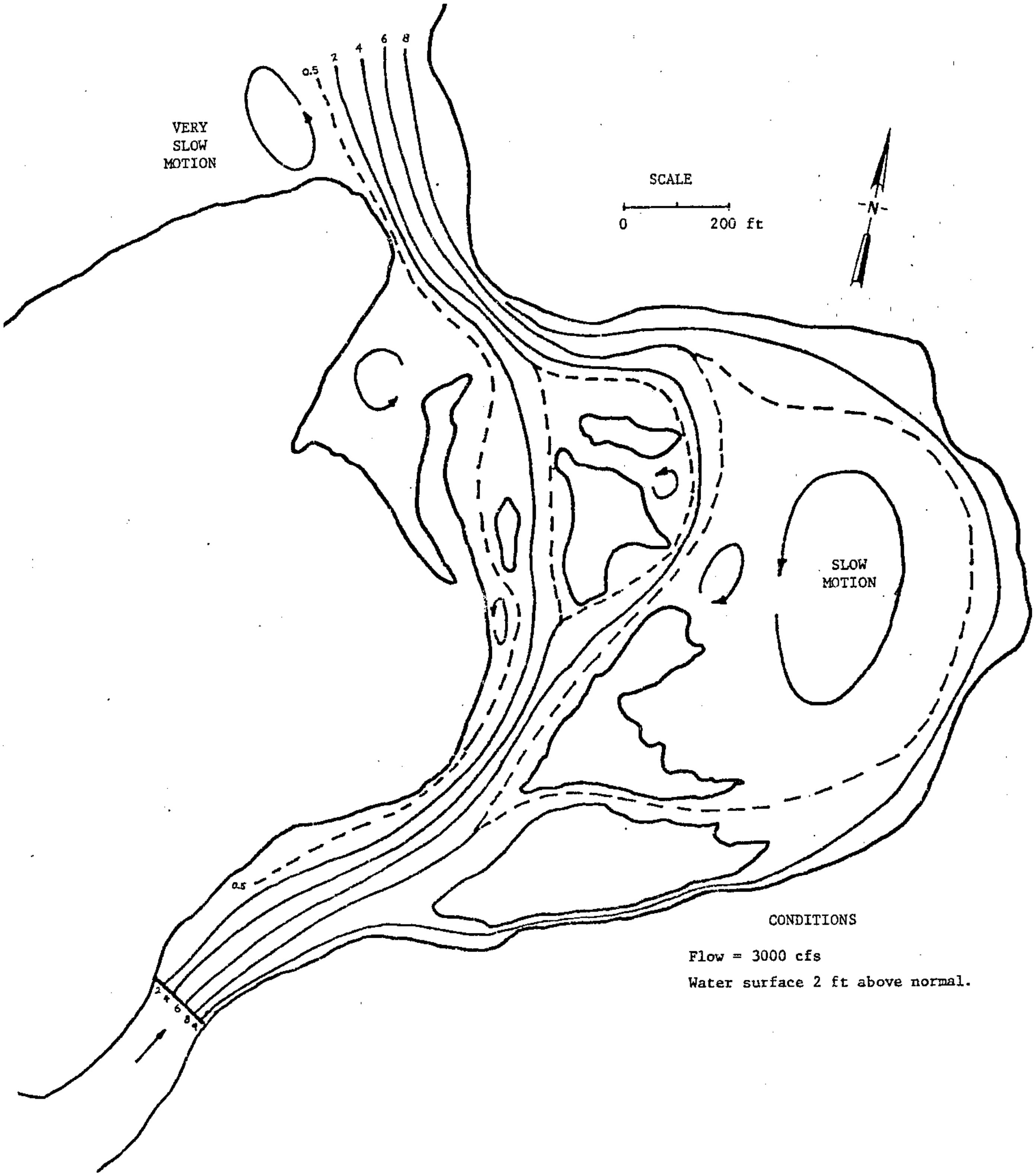


CONDITIONS

Flow = 1000 cfs

Normal water level.

Fig. C1. Streamlines for 1000 cfs River Discharge, Capitol Lake, Washington



CONDITIONS

Flow = 3000 cfs

Water surface 2 ft above normal.

Fig. C2. Streamlines for 3000 cfs River Discharge, Capitol Lake, Washington

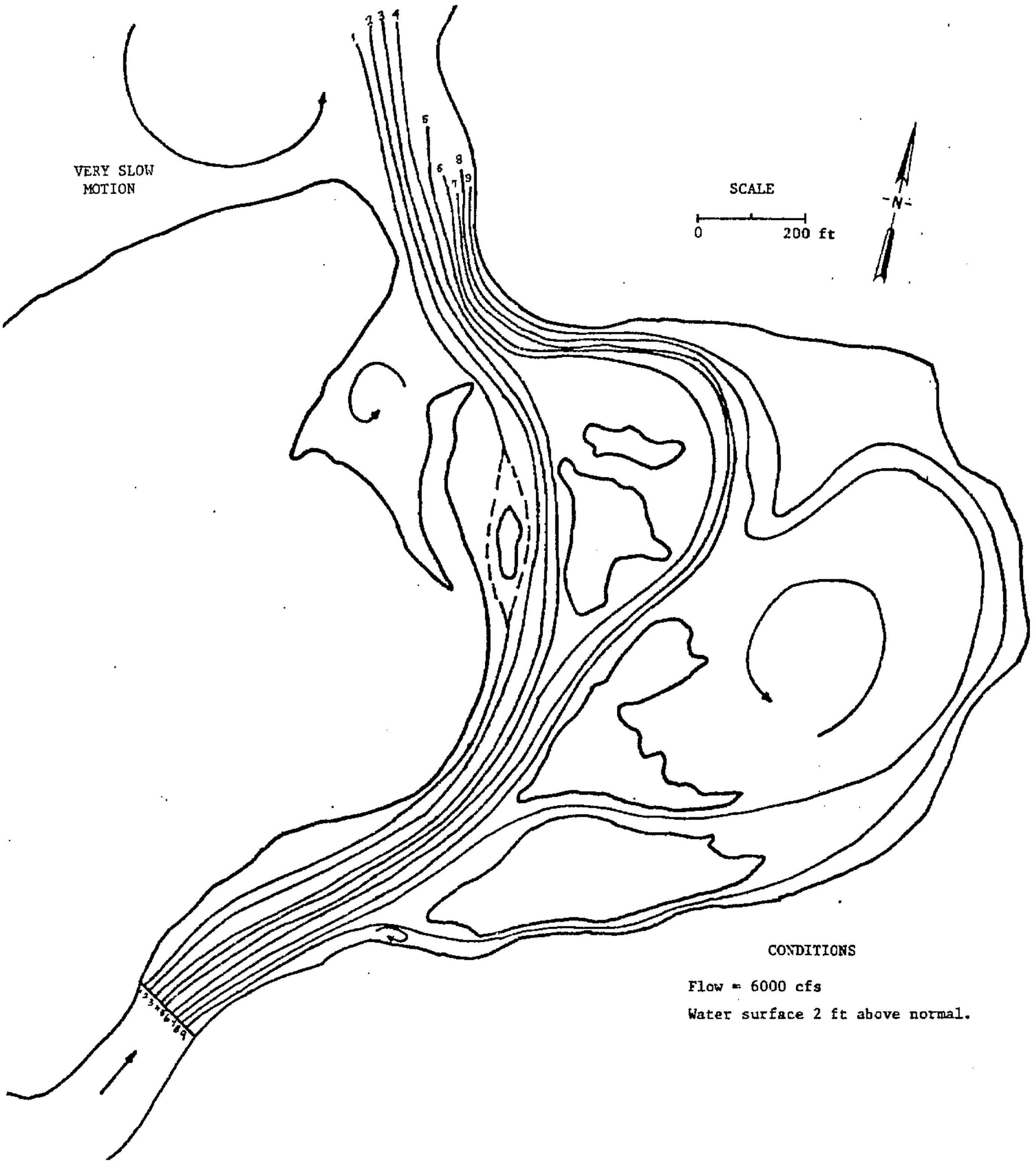


Fig. C3. Streamlines for 6000 cfs River Discharge, Capitol Lake, Washington

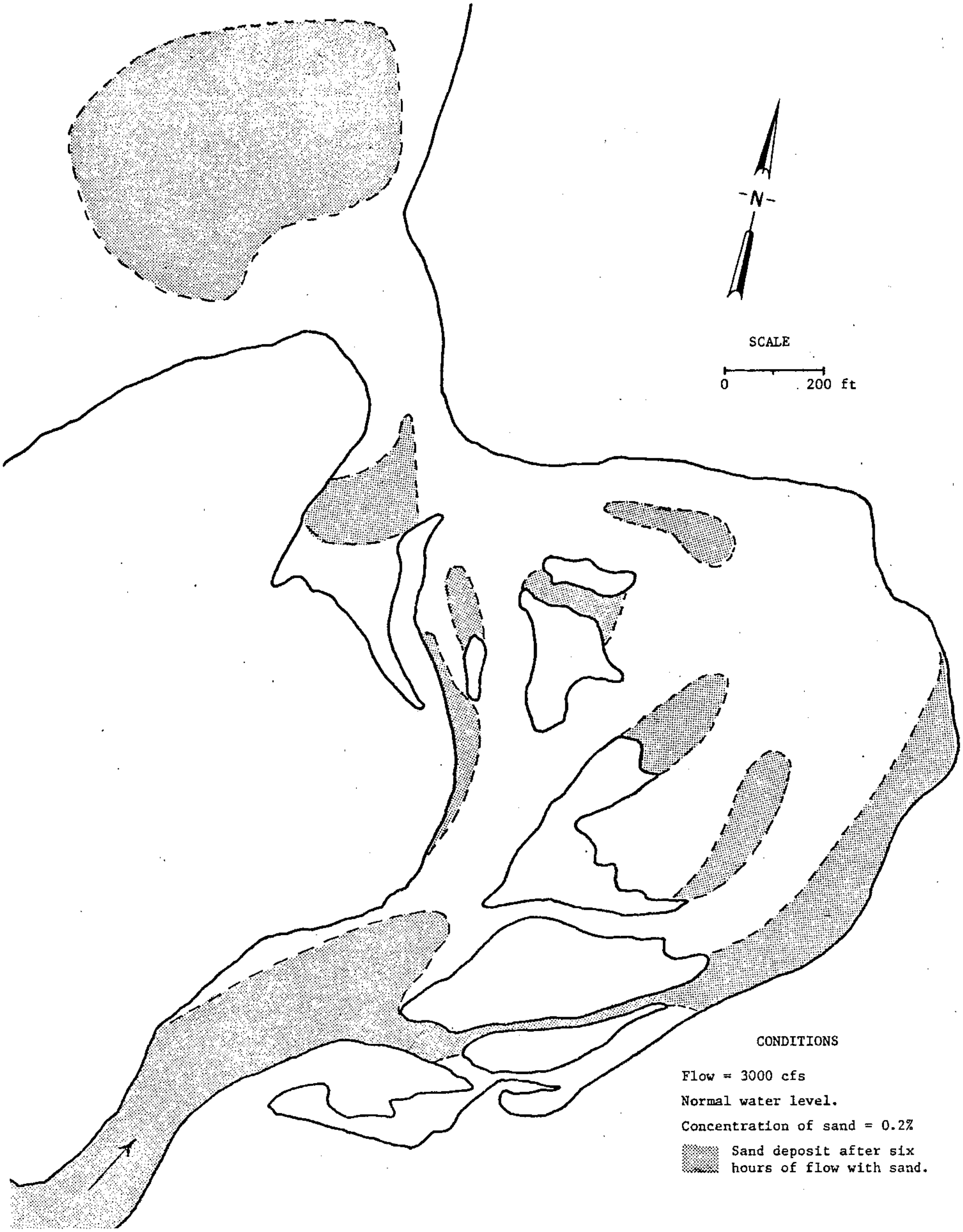


Fig. C4. Sediment Deposit Pattern in 1970 Model, Capitol Lake, Washington

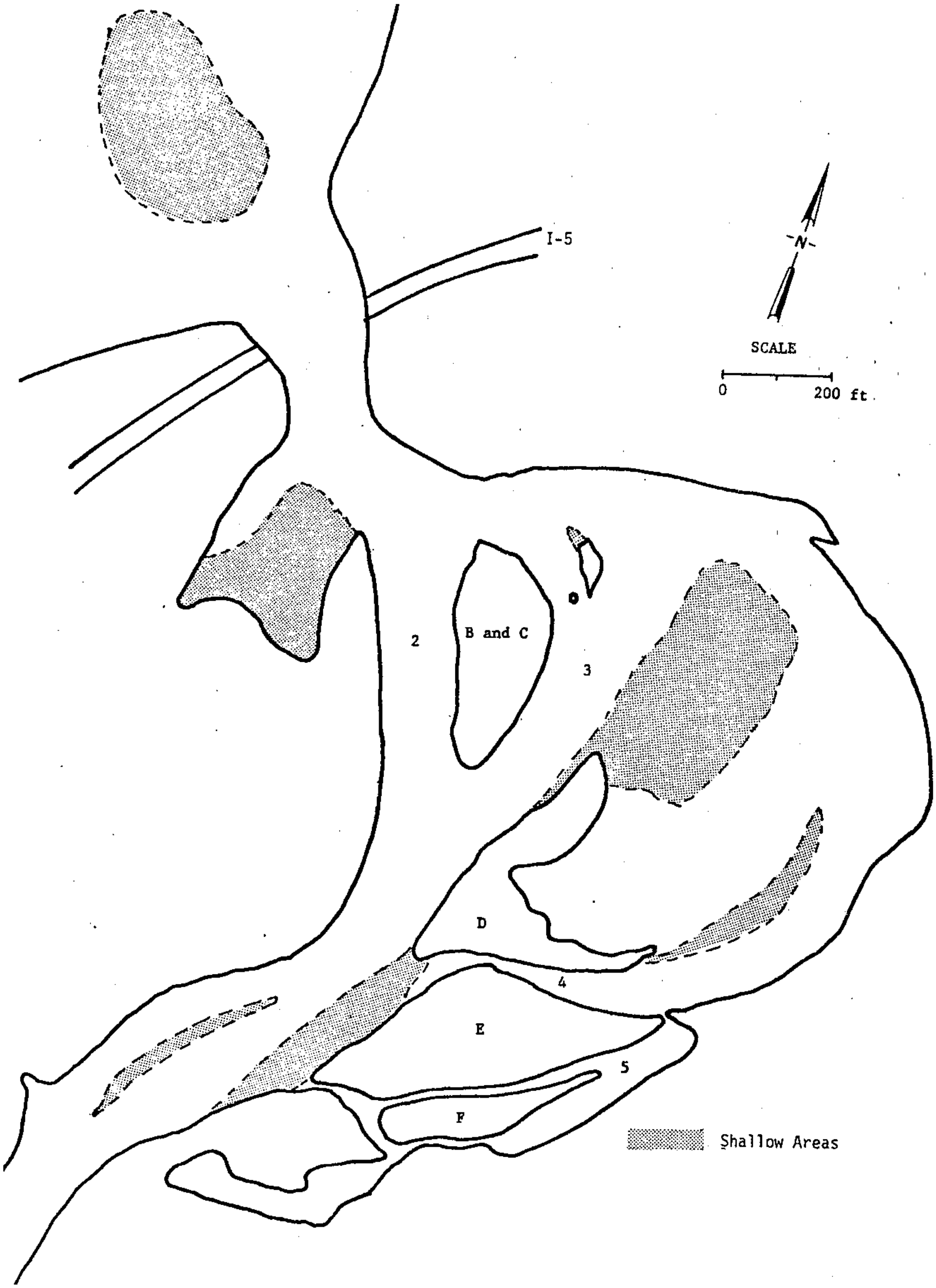


Fig. C5. 1974 Upper Basin of Capitol Lake, Olympia, Washington

c. Channel Modifications in the Upper Basin

Many alternative methods for the maintenance of Capitol Lake have been addressed in the report by Patrick J. Byrne and Associates.[3] One of the conclusions of that report was that part of the upper basin should be used as a sediment basin. Based on this conclusion and the results of the hydraulic model studies already discussed, three alternatives for removal of sand from the basin were considered. The present Upper Lake is no longer an effective sedimentation basin, hence certain channel modifications are necessary to make the various alternatives more effective.

Channel Modification No. 1: This is the same as the channel modification required in proposal No. 2 of the consultant's report,[3] or Alternative 1 in the preliminary report.[4] The detailed configuration is shown in Figure C6 which is copied from Plates II-323 and 324 of the consultant's report.[3] There would be permanent bed sills, gates and sheet piling for channel modifications necessary to divert flow to the east side of the upper basin during flood flows and to facilitate the temporary closure of the east sediment basin during dredging operations to avoid adding turbidity to other parts of the lake.

In the preliminary report[4] (see also Appendix B, Part 1 of this report), Alternative 2 uses a permanent piping system for dredging and Alternative 3 uses a "Mud Cat" dredging machine. Both Alternatives 2 and 3 are clean operations which will not increase turbidity of the lake. For a clean operation, temporary closure of the basin during dredging would not be necessary using these two dredging methods.

Channel Modification No. 2: Figure C7 is a modification of the 1974 map (Fig. C5) except island D and a portion of island E have been removed. The flow and sediment deposition patterns are shown. Even at high flows, 30 percent of the flow bypasses the eastern sedimentation basin and flows directly into the middle basin of Capitol Lake through the I-5 bridge opening. The flow and sedimentation patterns in the vicinity of the larger island have a tendency to shift from time to time.

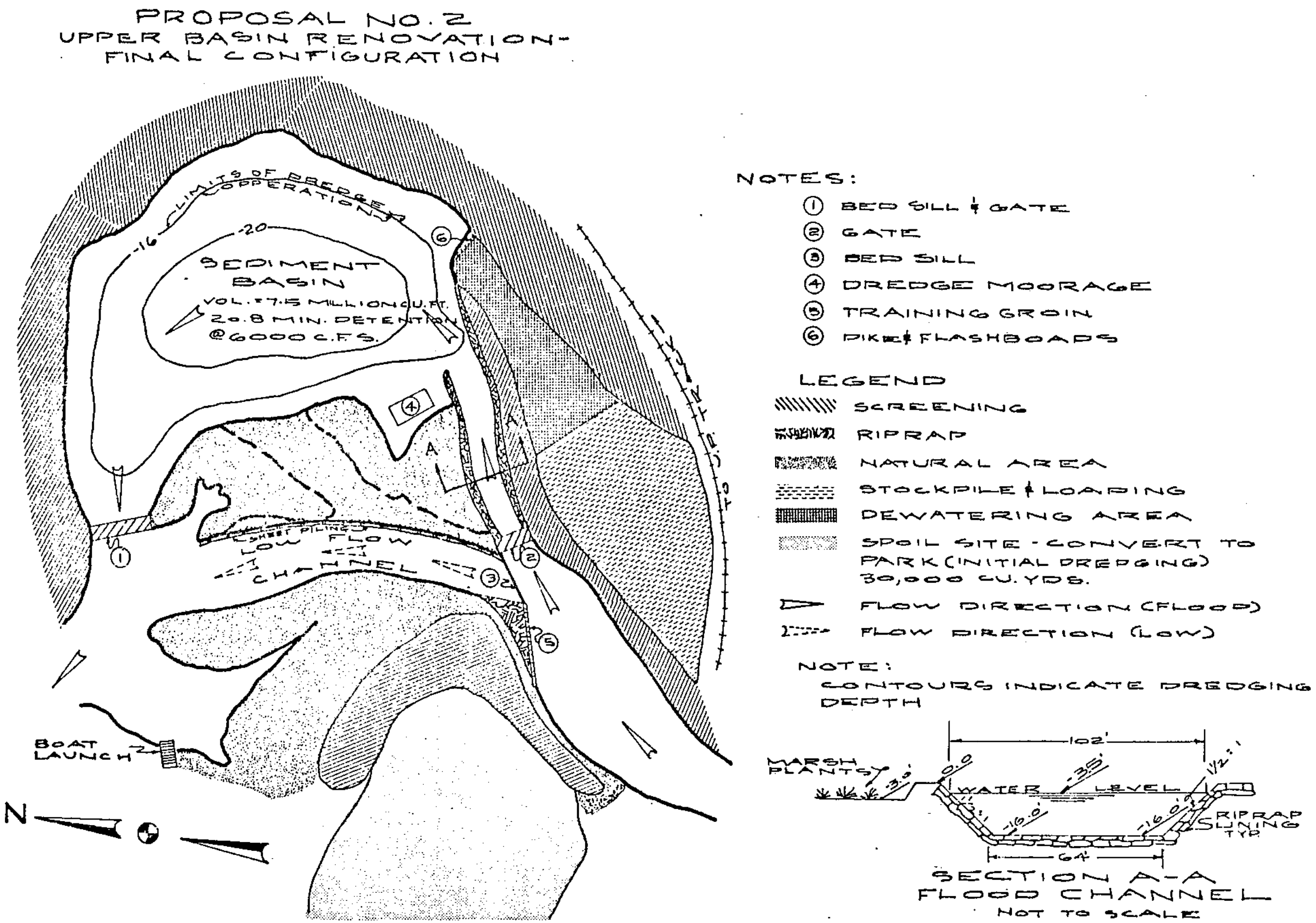


Fig. C6. Proposed Channel Modification No. 1 (This figure is copied from Plate II-323, 324 of the "Engineering Investigation for Rehabilitation of Capitol Lake," Vol. II, by P. J. Byrne, April, 1973.)

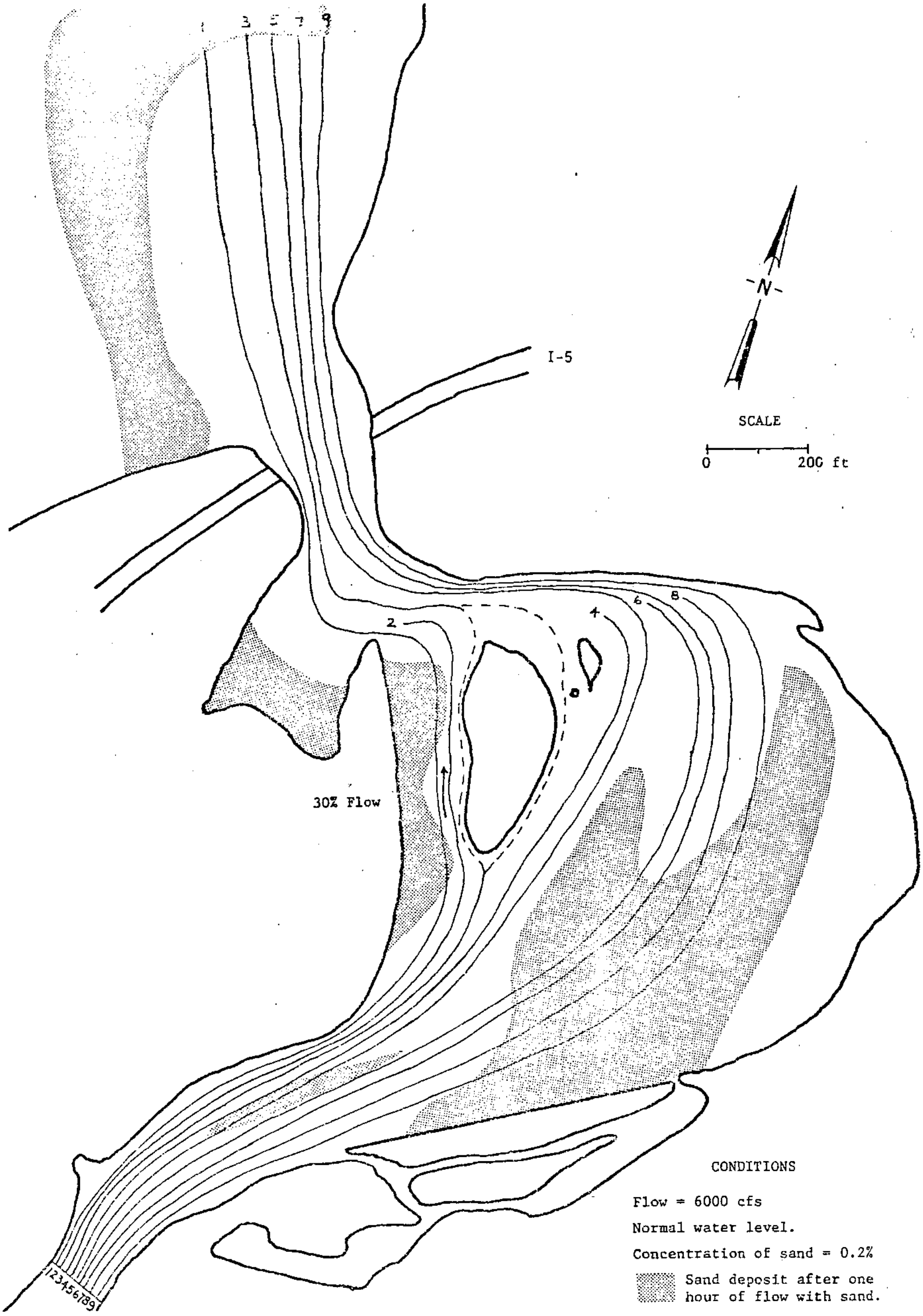


Fig. C7. Channel Modification No. 2, Capitol Lake, Olympia, Washington

Channel Modification No. 3--Figure C8: This is the same as Figure C7 with the addition of a flow training groin. *The flow through the channel at the west side is now only about four percent of the total flow, and this channel will be filled by sediment during high flows through natural accretion, thus serving as an additional sediment trap.*

Channel Modification No. 4--Figure C9: This is the same as Figure C7 except that there has been partial removal of an island instead of the complete removal. Also, it is similar to Channel Modification No. 1 without gates, bed sill, and sheet piling. The flow and sediment patterns are stable. The flow through the channel at the west side is only four percent of the total. This west side channel will tend to be filled by sediment in the future by natural accretion during each high flow cycle.

Channel Modification No. 5--Figure C10: This modification is very similar to the consultant's preliminary proposal No. 2 shown in Figure C6 except that:

(1) the south channel should be about 225 ft wide along the south bank of the island;

(2) the upstream channel would flair from the narrowest section just below the falls to a width of about 200 ft at the downstream end of the training groin; and

(3) no control structures would be required if clean maintenance dredging is used.

(4) Wire basket riprap (gabion) would be used for the training groin and to protect the modified island as shown in Figure C10.

Tests were made also with the middle of the east side basin dredged to an initial model depth of 6 inches (10 ft deep in prototype below the average present bed elevation). Most of the sand in the flow settled in the dredged hole during the model test. Results of these tests are shown in Figures C10A and C10B for two larger flows. In the preliminary report, three alternatives of maintenance dredging were discussed.[4] In Alternative 1, the dredging would be done in the middle of the sedimentation basin. For Alternative 2, a permanent piping system would be utilized

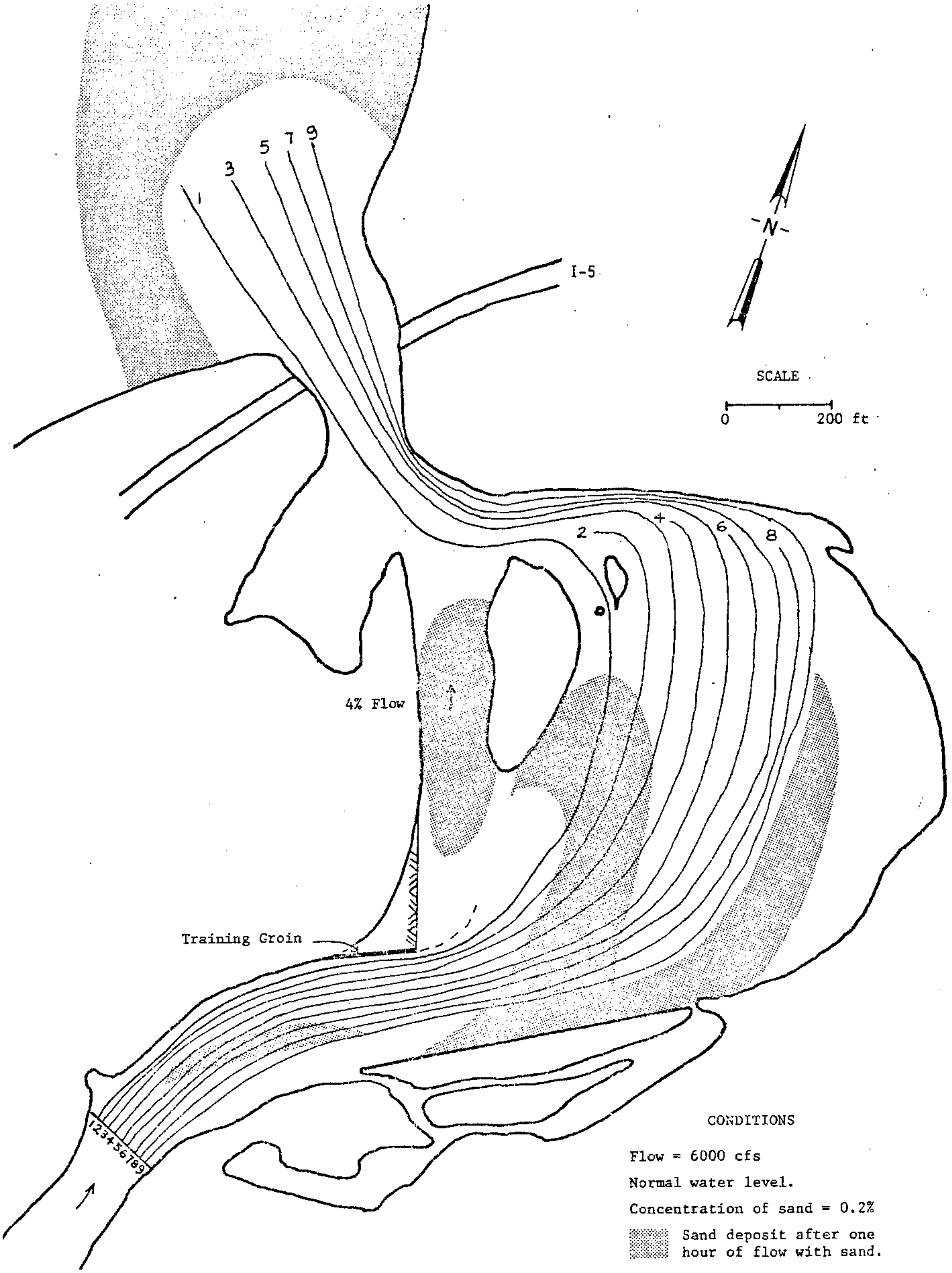
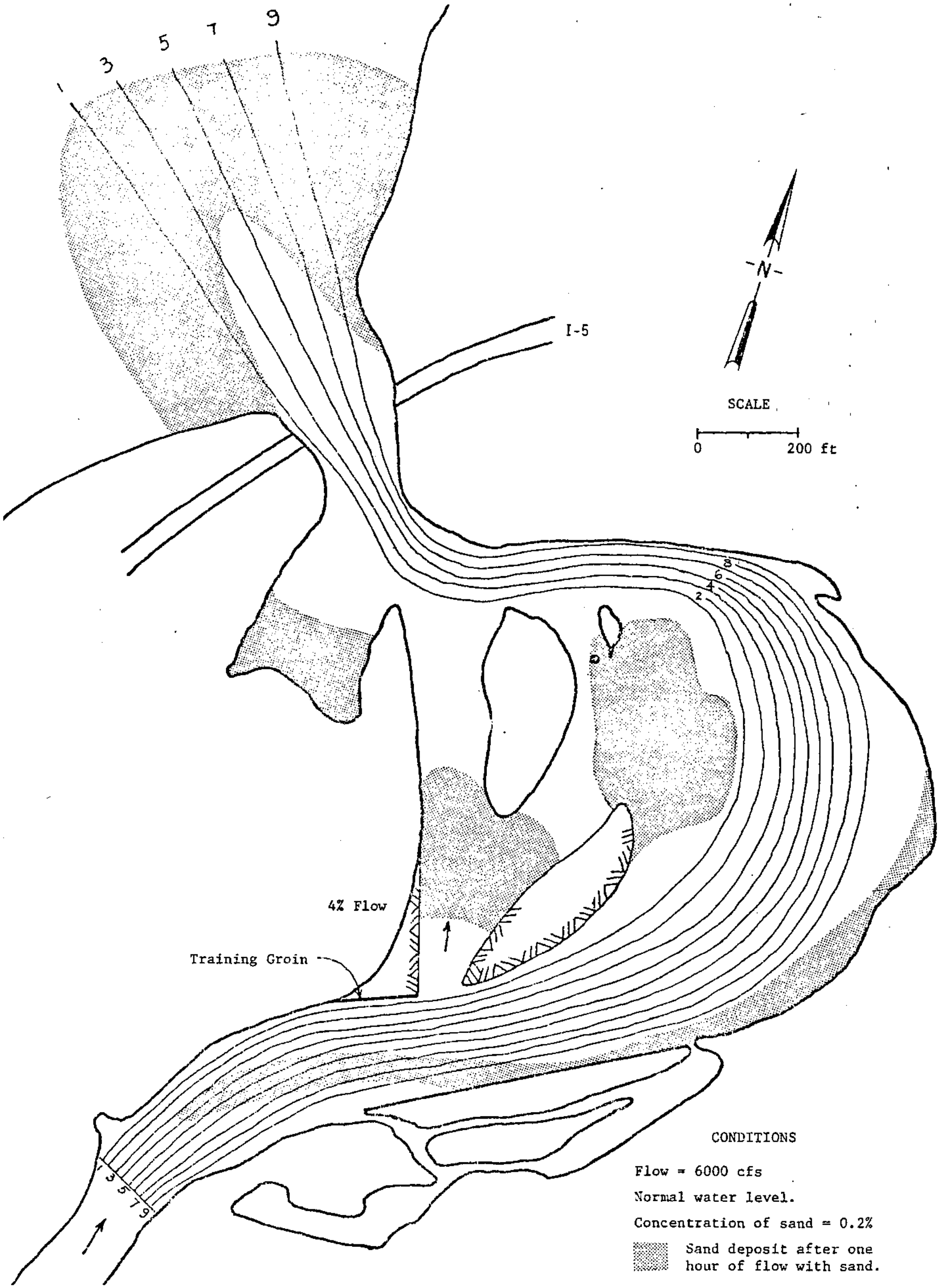


Fig. C8. Channel Modification No. 3, Capitol Lake, Olympia, Washington



CONDITIONS

Flow = 6000 cfs

Normal water level.

Concentration of sand = 0.2%

▨ Sand deposit after one hour of flow with sand.

Fig. C9. Channel Modification No. 4, Capitol Lake, Olympia, Washington

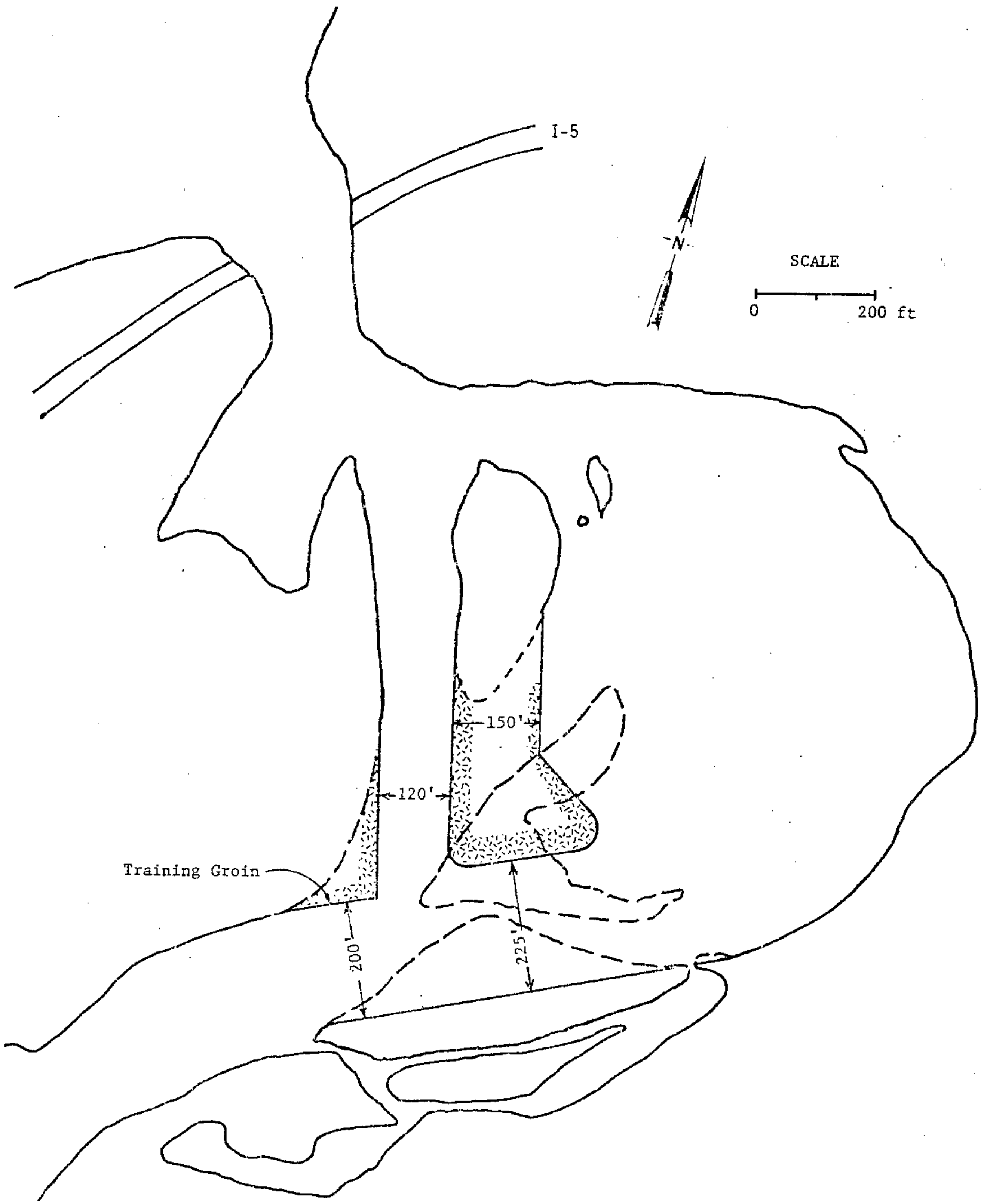


Fig. C10. Channel Modification No. 5, Capitol Lake, Olympia, Washington

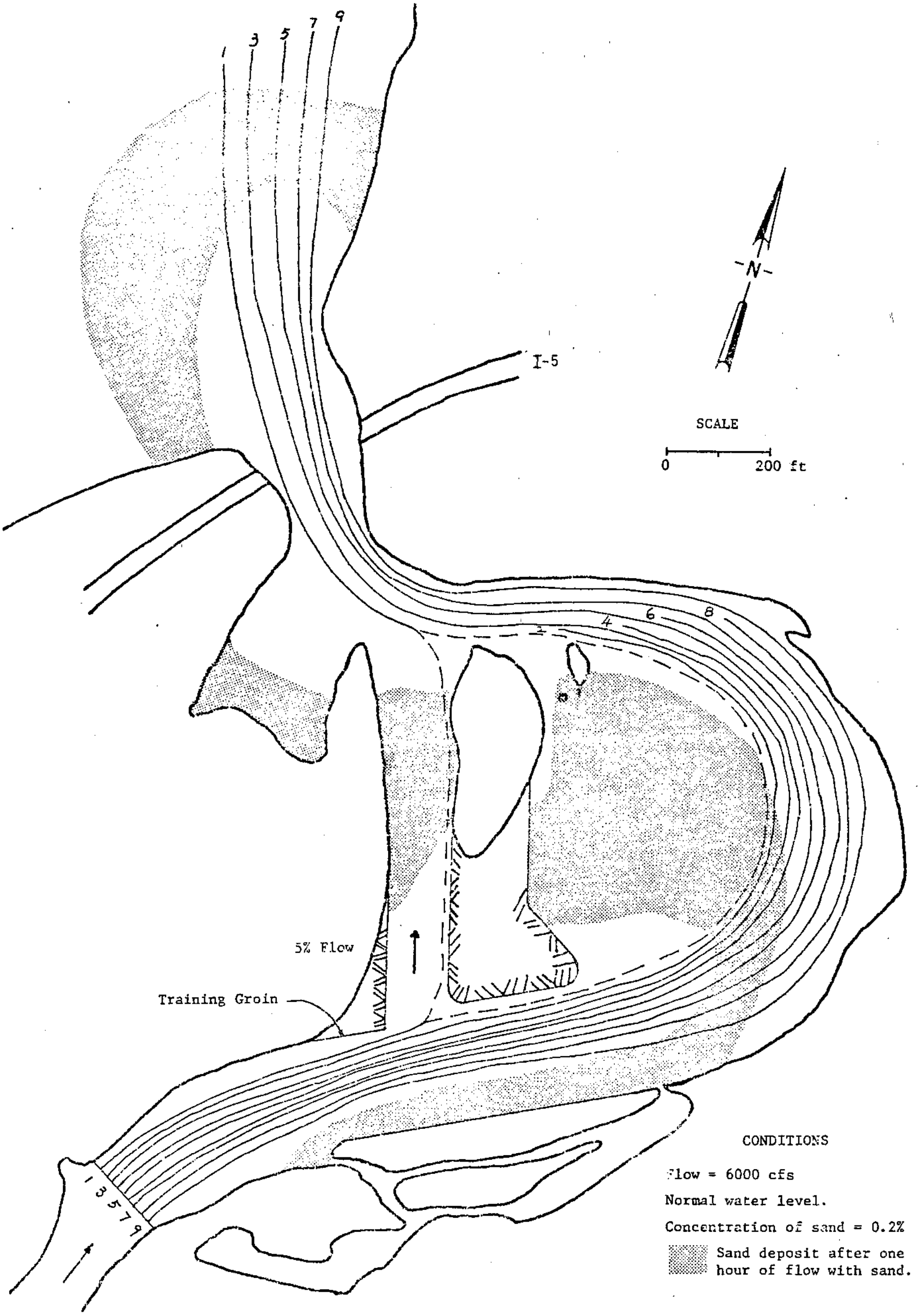
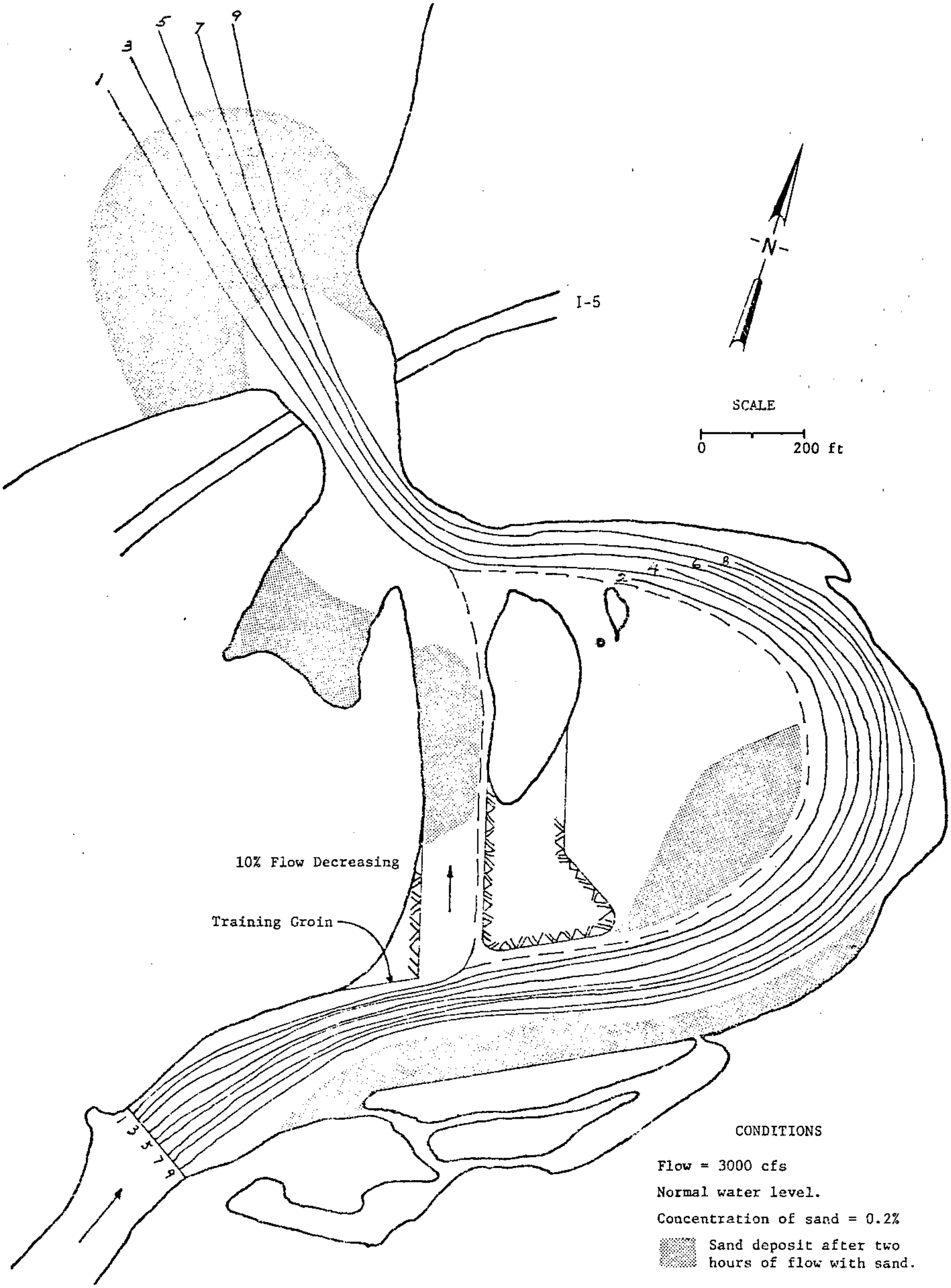


Fig. C10A. Channel Modification No. 5, Capitol Lake, Olympia, Washington



CONDITIONS

Flow = 3000 cfs

Normal water level.

Concentration of sand = 0.2%

▨ Sand deposit after two hours of flow with sand.

Fig. C10B. Channel Modification No. 5, Capitol Lake, Olympia, Washington for maintenance dredging. The location of the piping system is shown in Figure C11. The orientation and location could be changed slightly without reduction in sediment trapping efficiency. For Alternative 3, sediment removal would be done by a "Mud Cat" type of dredging machine and this method is recommended. A pie-shaped area as shown in Figure C11 would be dredged and this shape would be compatible with dredge operation and the accumulation of sediment.

Also shown in Figure C11 is an option for moving the main channel a short distance to the south of Channel Modification No. 5. The advantages of this suggested option are:

(1) the northern and central islands (B, C and D in Figure 6 of Supplement No. 1) would be joined with dredged fill, and otherwise would be relatively undisturbed;

(2) most of the excavation for the improved channel would be from Island E;

(3) the material from Island E would be a short haul from the low area to the east, west and south of Island F;

(4) this low area would be filled above anticipated flood levels to provide protection for the maintenance dredging materials handling facilities;

(5) the southwestern tip of Island D might have to be trimmed and protected with riprap (or gabions), but the southeast tip would be allowed to adjust its shape naturally; and

(6) the tip of the training groin would be moved about 50 ft to the south to improve flow conditions past the south end of Island D.

d. Conclusions

(1) If a clean maintenance dredging operation is used, Channel Modification No. 5 should be used.

(2) For a dredging process which will increase the turbidity of lake water (not using a Mud Cat or fixed-pipe dredging system), Channel Modification No. 1 (Figure C6) could be used. The sheet piling in

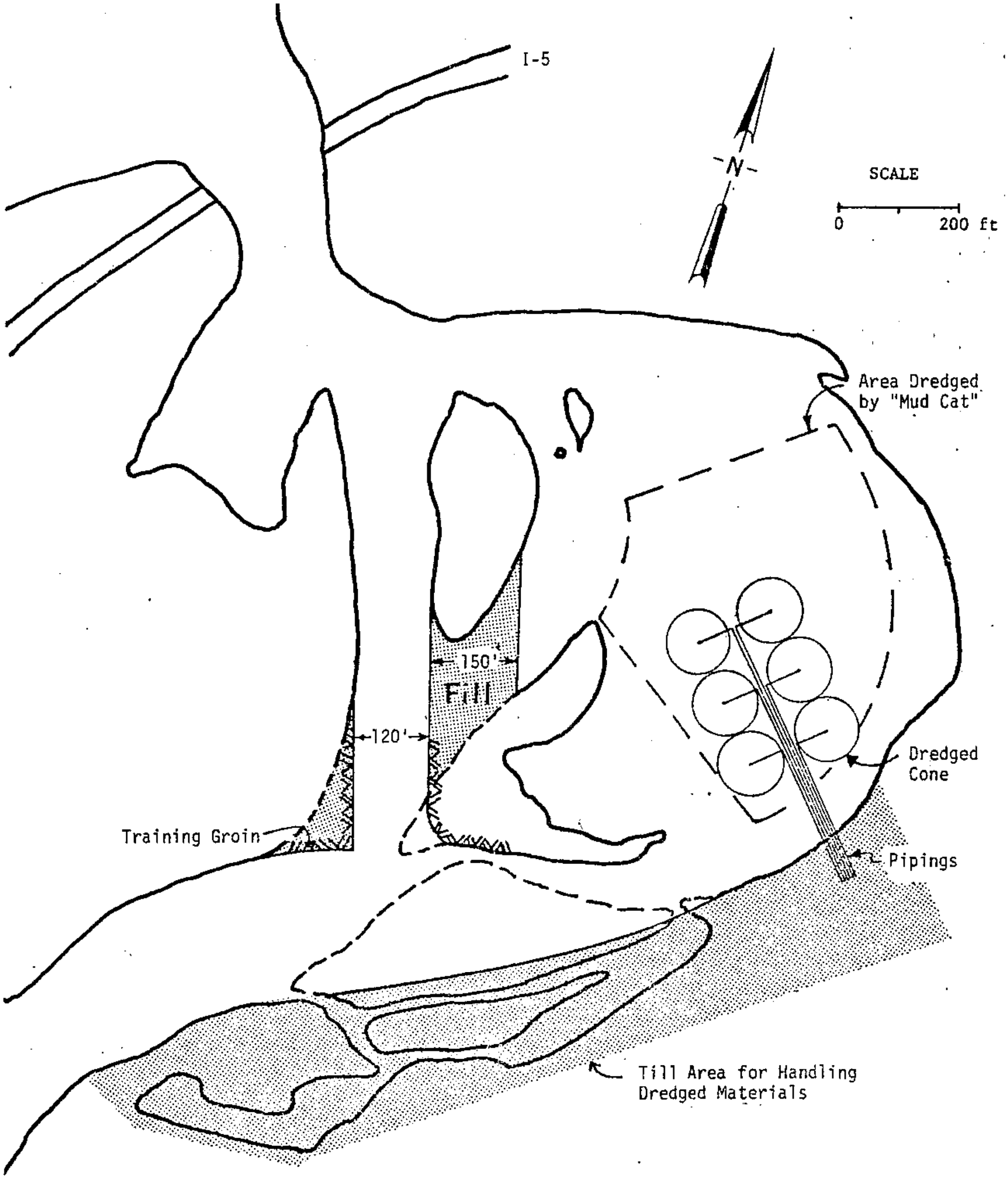


Fig. C11. Location of Dredge and Fill Areas and Optional Channel Alternative No. 5

Figure C6 is not necessary. Other methods of reducing silt dispersion during initial dredging operation can be incorporated into the final design at less expense than Modification No. 1 in Figure C6.

(3) The combination of various features of the modifications tested, the consultant's proposal No. 2 (Figure C6), and the hydraulic principles for effective sediment removal led to the following aggregate recommendation.....that Channel Modification No. 5 will:

a) require a minimum amount of bank protection along the south edge of the island and at the training groin;

b) cause sediment to accumulate in the inside of the bend (behind the island) as the flow moves around the east and north sides of the upper lake;

c) will cause sediment accumulation along the south bank of the main channel opposite the island;

d) will cause sediment accumulation in the secondary channel beside the new island north of the training groin;

e) require no control structures; and

f) will operate in as near a natural condition as possible.

2. Hydraulic Model Flow Pattern and Dye Tests--Supplemental Information to Chapter V

The results of the flood flow-lake elevation tests are shown in Figure C12 and indicate a sharp rise in lake level elevation above Deschutes River discharges of 2700 cfs, unless the gates are capable of removing the effects of this discharge rapidly. The elevations shown in Figure C12 are the levels at which the lake will stabilize when the flow is steady for more time than the values shown on the time scale.

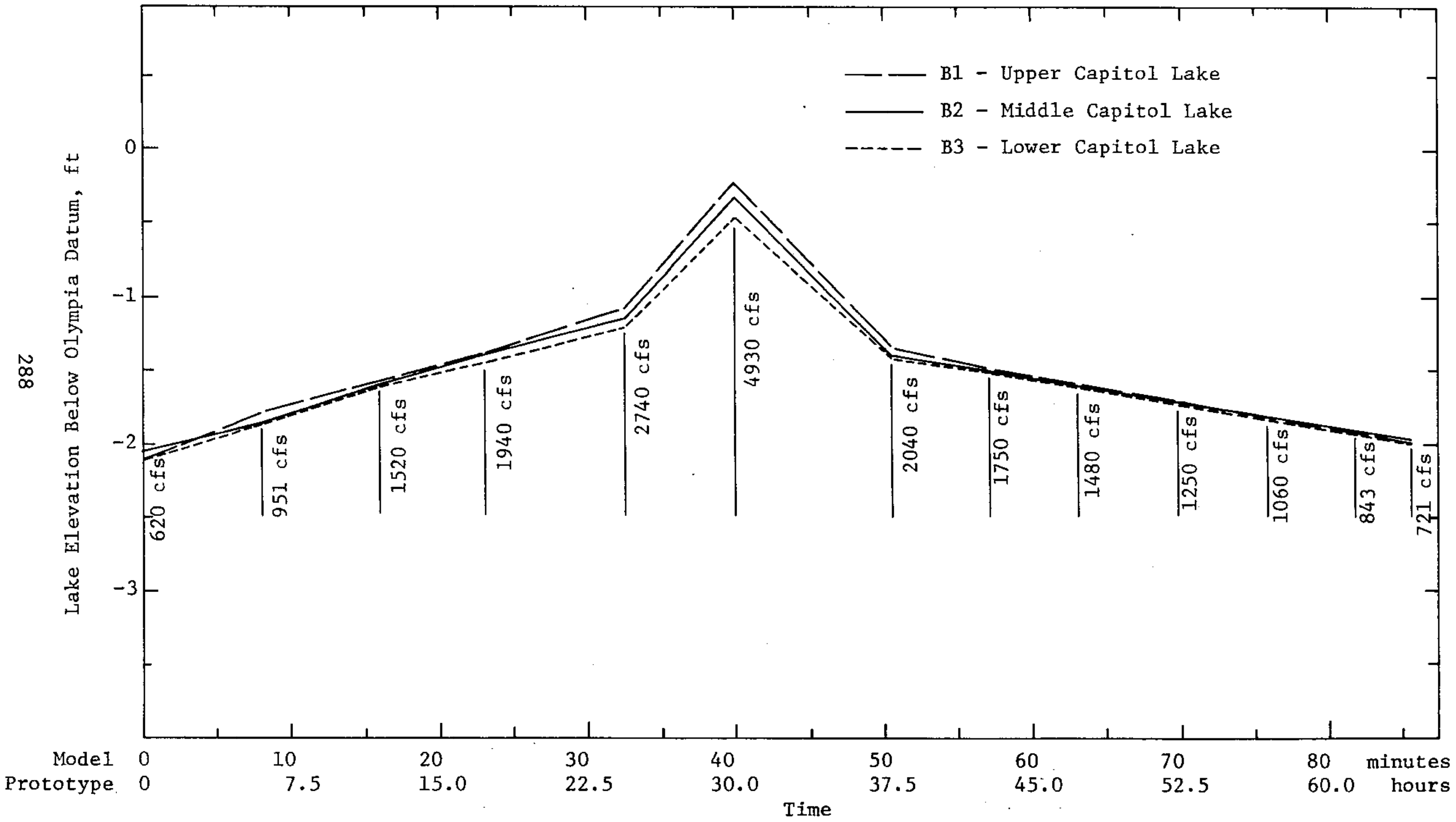


Fig. C12. Stabilized Lake Level for Simulated Hydrograph, January 15 - February 10, 1964

The times that it takes for flows of various sizes to travel from the Deschutes River falls to the 5th Avenue dam are shown in Figure C13.

The effects of fills A1 and B in the southwest corner of the Middle Lake can be seen by comparing Figure C14 (no fill) with Figure C15 (fill A1) and Figure C16 (fills A1 and B). The additional stagnant area caused by fill B and shown in Figure C16 is the one which was demonstrated in the photograph (Figure 44b) in Part 4a of Chapter V.

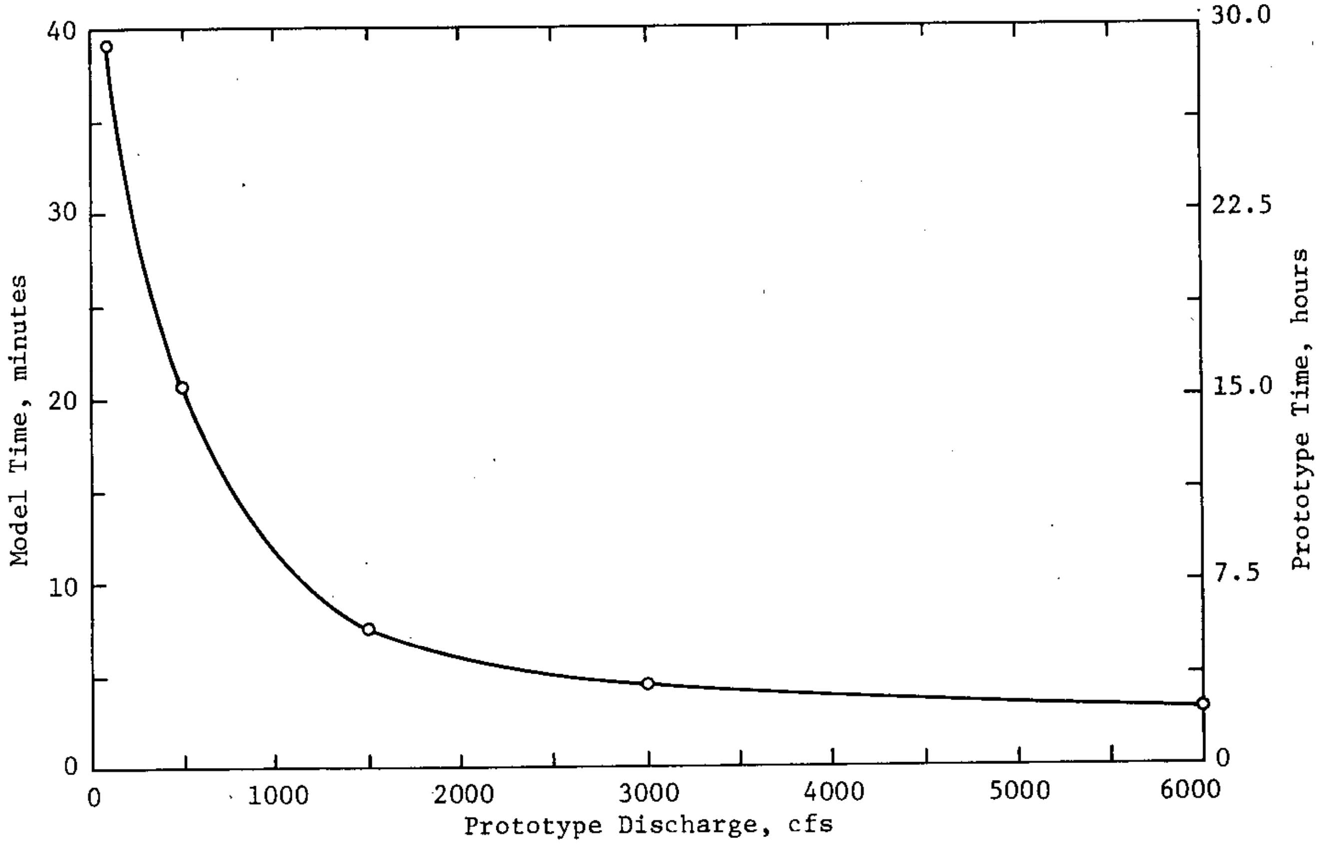


Fig. C13. Travel Time Related to Prototype Constant Discharge from Inlet to Outlet of Total Lake

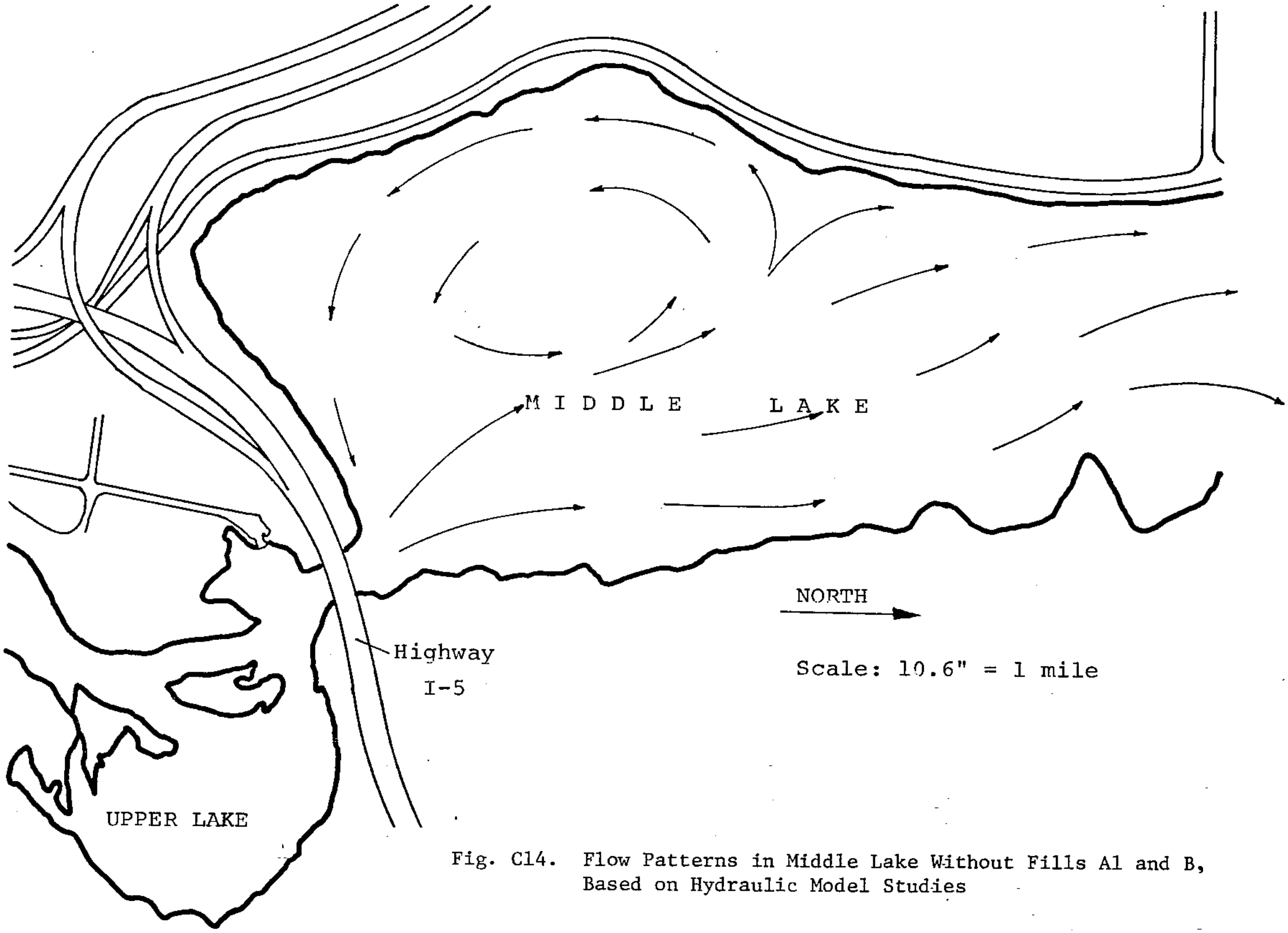


Fig. C14. Flow Patterns in Middle Lake Without Fills A1 and B, Based on Hydraulic Model Studies

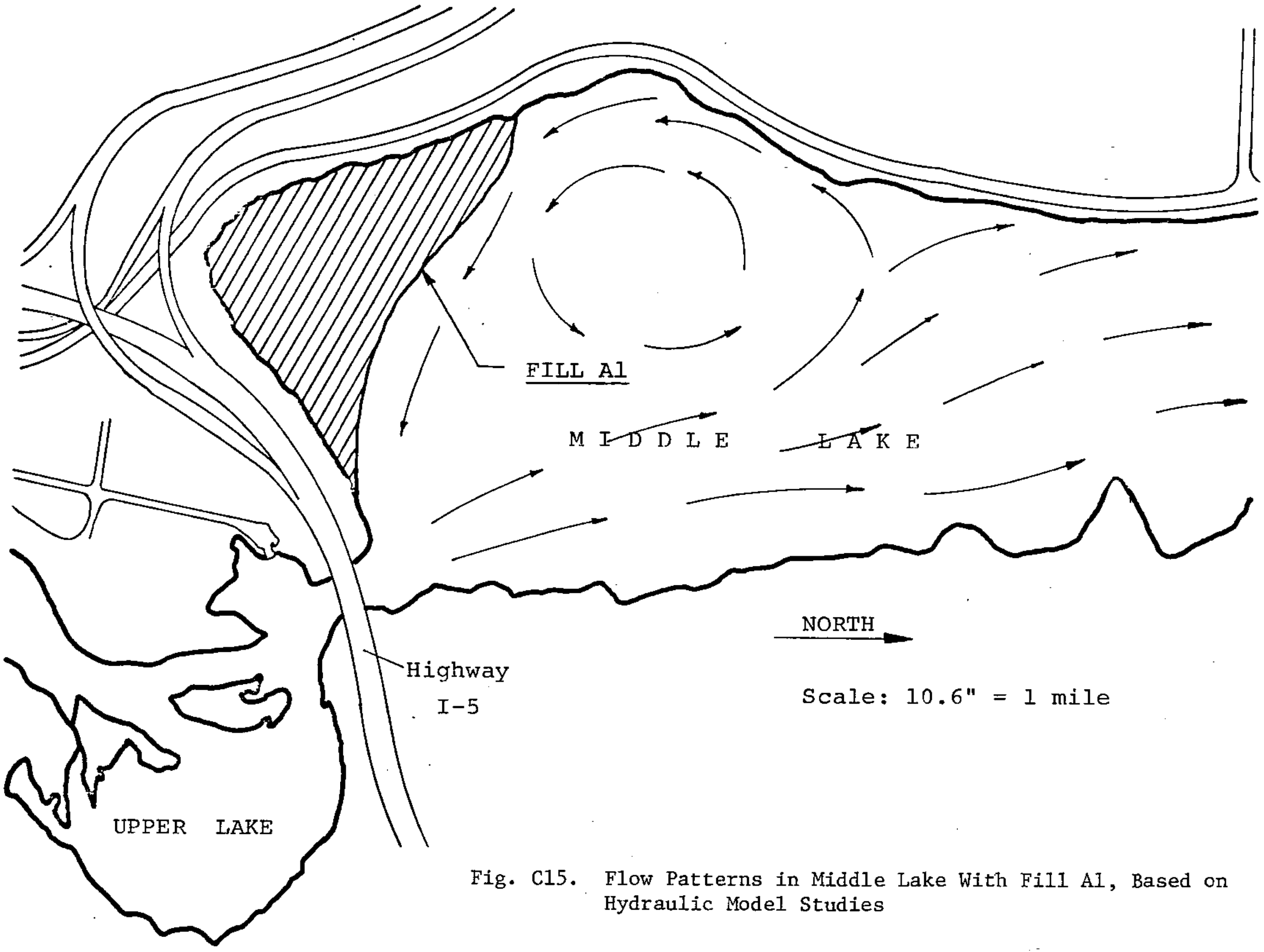


Fig. C15. Flow Patterns in Middle Lake With Fill A1, Based on Hydraulic Model Studies

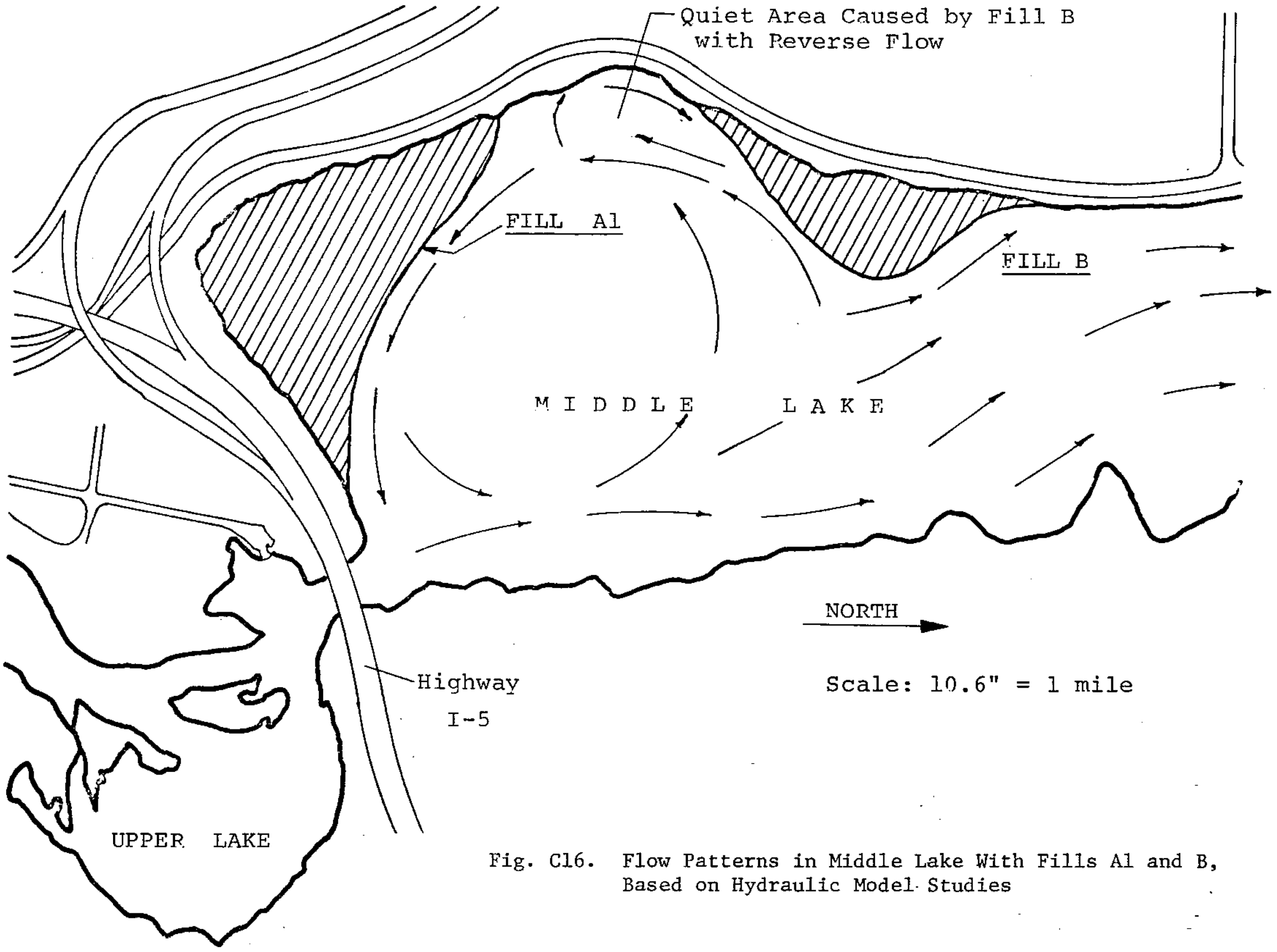


Fig. C16. Flow Patterns in Middle Lake With Fills A1 and B, Based on Hydraulic Model Studies

APPENDIX D

TO CHAPTER VI

Table D1.

Bacteriological Data, Thurston-Mason County Health Dept.

Site	Results		Date
South of railroad track	5/5 10 ml. tubes pos.		9/7/50
Old brewery	5/5 10 ml. tubes pos.		9/7/50
West side of lake	5/5 10 ml. tubes pos.		9/7/50
End of Legion Way	5/5 10 ml. tubes pos.		9/7/50
Opposite old brewery	62 per 100 ml.		6/20/51
Outlet gate	70 per 100 ml.		6/20/51
1953 to 1957 - See Enclosure			
Swim area near Tumwater	>16 MPN*		6/18/63
Across from Elks Club	93		9/10/63
Deep end off dock	23		7/7/64
End of dock	240		5/22/64
Next to shore	43		5/22/64
Next to shore	1,100		6/23/64
Off float - 100' from shore	3.6		6/30/64
40' from shore	43		6/30/64
Wading area	43		7/7/64
Wading area (after Lakefair weekend)	11,000+		7/14/64
Swimming lanes off float	11,000+		7/14/64
Wading end	460		7/28/64
Deep end	42.0		7/28/64
Capitol Lake park	23		8/24/64
Wading area	93		4/30/65
End of dock	240		4/30/65
Trestle	46,000	Earthquake Breaks Sewer	4/30/65
End of dock	110,000		5/4/65
Wading area	>110,000		5/4/65
Trestle	110,000		5/4/65
Wading area	210		5/14/65
Dock	240		5/14/65
Trestle	1,100		5/14/65
Trestle	240		5/21/75
Dock	75		5/21/65

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*MPN (Most Probable Number) is used for remainder of table.

Table D1. (continued)

Site	Results	Date
Wading area	43	5/21/65
End of dock	9.1	6/28/65
Wading area	23	6/28/65
Swimming area	43	7/20/65
Swimming area	240	7/27/65
Wading area	43	7/27/65
Wading area	20	8/3/65
Swimming area	43	5/31/66
Wading area	240	7/19/66
Swimming area	1,200	7/19/66
Swimming area	43	7/26/66
Wading area	1,100	7/26/66
Deep area	460	8/2/66
Wading area	4,600	8/2/66
Deep area	7,500	8/8/67
Half-way out	430	8/15/67
Swimming area	2,300	8/1/67
Wading area	2,300	8/8/67
Wading area	2,300	8/22/67
Deep area	430	8/22/67
Swimming area	9,300	9/5/67
Trestle	43	9/26/67
South end near freeway	930	9/26/67
Deep end	93	9/26/67
Wading area	75	9/26/67
Deep end	23	9/19/67
Near freeway	4,300	9/19/67
Wading area	430	9/19/67
Trestle	430	9/19/67
Trestle	4,300	10/3/67
Wading area	2,300	10/3/67
Deep end	2,300	10/3/67
Deep end	430	10/10/67

Table D1. (continued)

Site	Results	Date
Boat ramp	9,300	10/10/67
Trestle	930	10/10/67
Wading area	2,300	10/10/67
Trestle	2,300	10/24/67
Long swimming dock	2,400	10/24/67
Wading area	430	10/24/67
Boat ramp	4,300	10/24/67
Wading area	430	12/12/67
Long swimming dock	430	12/12/67
Trestle	2,300	12/12/67
Boat ramp south of freeway	2,300	12/12/67
Trestle	430	5/28/68
Public access area	>2,300	5/28/68
Wading area	930	5/28/68
Long swimming dock	43	5/28/68
Swim area	23	6/18/68
Nearer to gate	430	6/18/68
Swimming dock	240	7/2/68
Wading area	240	7/2/68
Wading	23	7/9/68
Long dock	43	7/9/68
Long dock	93	7/6/68
Wading area	93	7/16/68
Swimming area	7.3	7/23/68
Wading area	3.6	7/23/68
Wading area	240	7/30/68
Long dock	>2,300	7/30/68
Wading area	240	8/6/68
Long dock	430	8/6/68
Long dock	2,300	8/13/68
Wading area	930	8/13/68
Long dock	23	8/20/68
Wading area	9.1	8/20/68

Table Dl. (continued)

Site	Results	Date
Swim area	2,300	8/27/68
West side, 2 mi. - south end of beach	2,300	8/27/68
Wading area	930	8/27/68
Wading area	43	9/3/68
Long dock	150	9/3/68
Near gate	240	4/22/69
Trestle	240	4/22/69
Trestle	930	4/29/69
Gate	240	4/29/69
Wading area	930	6/17/69
Deep end	930	6/17/69
Deep end	240	6/24/69
Wading area	93	6/24/69
Wading area	93	7/1/69
Long dock	150	7/1/69
Wading area	210	7/8/69
Deep end	43	7/8/69
Wading area	23	7/29/69
Long dock	9.1	7/29/69
Wading area	21	8/12/69
Long dock	15	8/12/69
Long dock	21	6/30/70
Wading area	11	6/30/70
Swimming area	150	8/1/72
Swimming area	23	7/1/74
Swimming dock	43	4/30/74

Table D2. Budd Inlet Sediment Composition[36]

BOTTOM SAMPLE NO. 1440

Station Location: Olympia, Washington. Bay on east side of dock area.

Latitude: 47° 03' 20" N   **Longitude:** 122° 53' 58" W

Sampling Date: 3-12-69

PARTICLE SIZE DISTRIBUTION

Gravel (+6 mesh)	2%
Sand	40%
Silt and Clay (-200 mesh)	58%

Coefficient of Uniformity: 8

CHEMICAL CHARACTERISTICS (DRY WT.)

Parameter	Unit	Value
Volatile Solids	%	12.3
Chemical Oxygen Demand (COD)	g/kg	12.8
Initial Oxygen Demand (IDOD)	g/kg	1.78
Oxidation-Reduction Potential	millivolts	-0.13
Sulfides	g/kg	1.01
Total Phosphorus	g/kg	0.68
Kjeldahl Nitrogen	g/kg	2.94
Ammonia Nitrogen	g/kg	
Grease and Oil	g/kg	2.56

BOTTOM SAMPLE NO. 1439

Station Location: Olympia, Washington. South end of Inner Harbor.

Latitude: 47° 03' 00" N   **Longitude:** 122° 54' 16" W

Sampling Date: 3-12-69

PARTICLE SIZE DISTRIBUTION

Gravel (+6 mesh)	0%
Sand	9%
Silt and Clay (-200 mesh)	91%

Coefficient of Uniformity: 4

CHEMICAL CHARACTERISTICS (DRY WT.)

Parameter	Unit	Value
Volatile Solids	%	10.9
Chemical Oxygen Demand (COD)	g/kg	100
Initial Oxygen Demand (IDOD)	g/kg	1.83
Oxidation-Reduction Potential	millivolts	-0.11
Sulfides	g/kg	1.21
Total Phosphorus	g/kg	1.09
Kjeldahl Nitrogen	g/kg	3.12
Ammonia Nitrogen	g/kg	
Grease and Oil	g/kg	3.19

Table D3.

Experimental Procedures and Analytical Methods

A. Water Sample Preservation and Analyses

Subsurface samples were taken for laboratory analysis, transported in ice-filled coolers and stored at 4°C until analyzed. In addition, samples designated for nutrient analysis (P and N) were fixed with one ml chloroform per liter. Analysis for nutrients generally was completed within seven to ten days and inert elements (Cl^-, SO_4, etc.) within 24 days. The following physical and chemical methods were used for water analysis:

Alkalinity - measured in situ with methyl orange indicator, phenolphthalein indicator and 0.02 N H_2SO_4 titrant (ASPH, 1971).

Ammonia Nitrogen - automated colorimetric method using a phenatehypochlorite reagent and read at a wavelength of 630 nm. This method is modified from Technicon Industrial Method 98-70W (Technicon, 1971) by omitting prusside reagent.*

Carbon Dioxide - measured in situ by titrimetric method using .02 N NaOH (ASPH, 1971).

Chemical Oxygen Demand - automated colorimetric method using a potassium dichromate-sulfuric acid digestion mixture. Technicon Industrial Method 137-71W (Technicon, 1972). Some samples also were run by manual methods (ASPH, 1971) and the automated results were adjusted to the manual methods by the resulting regression formula.

Chloride - mercuric nitrate titration (ASPH, 1971) modified for low chloride concentration.

Dissolved Oxygen - measured in situ by the azide modification of the Winkler method (ASPH, 1971).

Kjeldahl Nitrogen - automated method using selenium dioxide, perchloric acid-90% sulfuric acid digestion mixture. The resulting ammonia is determined with phenate, hypochlorite, nitroprusside at a wavelength of 630 nm. Modified from Technicon Industrial Method 145-71A (Technicon, 1972) by omitting manganese and the dilution manifold.

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*In all automated procedures listed in this section, minor modifications have been made (tubing size, air filters, etc.) to meet our standards of accuracy. Major modifications from referenced procedures are noted and described in this section.

Table D3. (continued)

Light Penetration - measured with a standard 20cm (8-in.) Secchi disk and a submarine photometer (Gemware).

Nitrate and Nitrite Nitrogen - automated colorimetric method using a cadmium-copper reducing column to reduce nitrate to nitrite. The nitrite reacts with sulfanilamide and N-1-naphthylethylenediamine hydrochloride to form a reddish-purple azodye which is read at a wavelength of 520 nm. Technicon Industrial Method 100-70W (Technicon, 1972).

Nitrite - same method as "Nitrate and Nitrite" except reducing column is omitted.

Orthophosphate - automated colorimetric method with ascorbic acid-antimony reagent and read at a wavelength of 880 nm. Technicon Industrial Method 155-71W (Technicon, 1972).

pH - measured <u>in situ</u> with Leeds and Northrup Model 7417 meter.

Specific Conductance - measured <u>in situ</u> with Chemtrix Model 70 conductivity meter.

Sulfate - automated colorimetric method using methylthymol blue reagent and read at a wavelength of 460 nm. This procedure is modified from Technicon Industrial Method 113-71W (Technicon, 1972) by adding a cation exchange column and changing sample and dilution tubes to accommodate a 0-40 mg/l range.

Suspended Solids (volatile and non-volatile) - filtered with Whatman glass fiber C filters, dried at 105°C and volatilized at 550°C (ASPH, 1971).

Temperature - measured <u>in situ</u> with mercury-filled thermometer (Taylor).

Total Phosphate - automated method using vanadium-perchloric acid-45% sulfuric acid digestion mixture to convert organic phosphate to orthophosphate. The orthophosphate then is determined colorimetrically with ascorbic acid reagent at a wavelength of 880 nm. Technicon Industrial Method 188-72W (Technicon, 1972).

Turbidity - Hach Model 2100A turbidity meter.

B. Sediment Analyses

Sediment cores were taken at four sites (Fig. 2) in June 1974 with a Ewing-type piston corer mounted on a pontoon barge. The cores were collected in cellulose acetate liners 1.83 m (6 ft) long and of 3.5cm

(1.4-in.) inner diameter. The cores were transported to the WSU laboratory on ice and dry ice in a styrofoam-lined box. In the laboratory the cores were extruded from the liners, cut into 3- or 4cm sections and analyzed for pH and oxidation-reduction potential. The sections then were dried at 105°C, weighed and analyzed for chemical oxygen demand (COD), total phosphate, Kjeldahl nitrogen and nitrate nitrogen. Kjeldahl nitrogen was analyzed by manual methods (ASPH, 1971), nitrate nitrogen with a specific ion electrode (Orion). Samples for total phosphate were digested manually and then analyzed for orthophosphate by an automated method (see above).

C. Phytoplankton Productivity

Phytoplankton productivity was measured by counts, carbon fixation and chlorophyll-A.

Water samples for algae counts were concentrated from 500 ml to 10 ml with a Foerst centrifuge. One ml of the concentrate was placed in a Sedgewick-Rafter counting chamber and the algae in 10 fields (delineated by a Whipple disk) were counted at 160 magnifications. At low algae concentrations a strip count was used. This procedure is outlined in detail in Standard Methods (APHA, 1971). Unknown algae were identified at 320 and 800 magnifications with toxonomic keys by Prescott (1962) and Patrick (1966). Algae counts are expressed as cells per ml of original sample.

Carbon-14 uptake measurements were made at each sampling station during the summer (June-August), fall (October, November) and winter (January). Water collected from 0.5- and 1.5m depths was placed in light and dark 250ml bottles. Five microcuries ^{14}C as $NaH^{14}CO_3$ were added to the bottles. The bottles were suspended horizontally from buoys at 0.5m depths for a four-hour midday incubation period. After incubation, a portion (25 to 100 ml) was filtered with .45μm membrane filters, and the filters then were rinsed with distilled water. The filters were glued to planchets and placed in a desiccator. The radioactivity of the filters was measured on an ultra-thin window proportional detector (Picker Nuclear

Table D3. (continued)

Instruments). The efficiency of this counter and the absolute activity of ^{14}C inoculant were measured using liquid scintillation.

Chlorophyll-A concentrations were measured by procedures given in Standard Methods (ASPH, 1971) using membrane filters (Millipore AAW .45 micron) and acetone extraction.

D. Zooplankton Measurements

Zooplankton samples were collected by filtering lake water through a #10 or #20 plankton net and bucket. The samples were preserved with a formalin-alcohol-glycerine preservative.

E. Benthic Organisms

Benthic organisms were collected with a 15.24- by 15.24cm (6- x 6-in.) Eckman dredge. Dredge samples were sieved with a 30-mesh sieve. The number of organisms was multiplied by 43 and reported as numbers per square meter.

Explanations for Table D4.

(1) Temperature, degrees Celcius

(2) Dissolved oxygen, mg/l

(3) pH

(4) Free carbon dioxide, mg/l

(5) Alkalinity (CO_3^- + HCO_3^-), mg/l as $CaCO_3$

(6) Specific conductance, µmhos/cm

(7) Nitrate and nitrite nitrogen, mg/l as N

(8) Nitrite nitrogen, mg/l as N

(9) Ammonia nitrogen, mg/l as N

(10) Kjeldahl nitrogen, mg/l as N

(11) Total nitrogen (NO_3 + NO_2 + Kj-N), mg/l as N

(12) Ortho-phosphate, mg/l as P

(13) Total phosphate, mg/l as P

(14) Suspended solids, mg/l

(15) Volatile suspended solids, mg/l

(16) Chemical oxygen demand, mg/l

(17) Biochemical oxygen demand, mg/l, 5 days @ 20 C

(18) Turbidity, formazin turbidity units

(19) Chloride, mg/l

(20) Sulfate, mg/l

(21) Secchi disk, m, by submarine photometer

Table D4. Compiled Field Data

Sampling Station	Date	(1) Temp	(2) D.O.	(3) pH	(4) CO_2	(5) Alk		(6) Cond	(7) NO_3+NO_2-N	(8) NO_2-N	(9) NH_3-N	(10) Kj-N	(11) Total N	(12) O-PO_4-P	(13) Total PO_4-P	(14) SS	(15) VSS	(16) COD	(17) BOD	(18) Turb	(19) Cl^-	(20) SO_4	(21) Secchi Disk
						$CO_3^=$	HCO_3^-																
Upper Basin	4/27-4/30								0.260	0.004	0.036	0.19		0.022	0.030						0.004	4.0	
Deschutes River at Waldrick Rd.									0.156	0.003	0.033	0.16		0.021	0.033						0.003	3.0	
Middle Basin	4/27-4/30								0.260	0.005	0.056	0.25		0.033	0.050						0.005	4.8	
Lower Basin	4/27-4/30								0.230	0.004	0.040	0.25		0.033	0.030						0.004	6.7	
Percival Creek	4/27-4/30								0.200	0.003	0.062	0.36		0.014	0.030						0.003	4.4	

Sampling Station	Date	(1) Temp	(2) D.O.	(3) pH	(4) CO_2	(5) Alk		(6) Cond	(7) NO_3+NO_2-N	(8) NO_2-N	(9) NH_3-N	(10) Kj-N	(11) Total N	(12) O-PO_4-P	(13) Total PO_4-P	(14) SS	(15) VSS	(16) COD	(17) BOD	(18) Turb	(19) Cl^-	(20) SO_4	(21) Secchi Disk
						$CO_3^=$	HCO_3^-																
Upper Basin	5/31-6/1	15.0°C	10.4	7.4	6		40	105	0.225			0.15	0.375	0.018	0.01	10.6	0.6	3.0		0.97	6.0		
Middle Basin	5/31-6/1	16.0°C	10.0	7.4	7		40	110	0.196	0.004		0.19	0.386	0.013	0.01					1.00	7.0		2.5+
Lower Basin	5/31-6/1	16.0°C	11.7	7.8	1		42	120	0.070	0.006		0.28	0.350	0.005	0.01	10.3	9.0	5.0		1.10	11.0		2.0
Bottom*		15.0°C	10.8	7.5	5		39	130	0.135	0.004		0.28		0.007	0.01	12.9	4.9	4.9		1.40	11.5		
Percival Creek	5/31-6/1	16.5°C	9.1	7.2	8		28	82	0.075	0.004		0.37	0.445	0.010	0.01	11.5	4.8	1.0		0.90	3.5		

*Bottom readings are taken at 4 meters depth.

Sampling Station	Date	(1) Temp	(2) D.O.	(3) pH	(4) CO_2	(5) Alk		(6) Cond	(7) NO_3+NO_2-N	(8) NO_2-N	(9) NH_3-N	(10) Kj-N	(11) Total N	(12) O-PO_4-P	(13) Total PO_4-P	(14) SS	(15) VSS	(16) COD	(17) BOD	(18) Turb	(19) Cl^-	(20) SO_4	(21) Secchi Disk
						$CO_3^=$	HCO_3^-																
Upper Basin	6/27-6/28	15.5°C	9.6	7.9	3		43	92	< 0.003	< 0.001		0.15	0.04	0.032	0.04	5.5	0	6.4	1.1	3.0	6.75		
Middle Basin	6/27-6/28	16.0°C	11.6	8.4	0	2	41	103	0.260	< 0.002		0.32	0.04	0.010	0.04	10.0	4.0	8.5	2.1	2.2	9.50		2.0
Lower Basin	6/27-6/28	18.0°C	12.3	8.6	0	8	36	114	0.081	< 0.001		0.45	0.06	0.018	0.06	12.3	2.7	12.7	2.8	1.2	13.00		1.0
Percival Creek	6/27-6/28	17.0°C	8.6	7.7	5		33		0.070	< 0.001		0.29	0.05	0.017	0.05	9.0	3.5	14.3	0.9	2.2	4.50		

Table D4. Compiled Field Data (continued)

Sampling Station	Date	(1) Temp	(2) D.O.	(3) pH	(4) CO_2	(5) Alk $CO_3^=$	(5) Alk HCO_3^-	(6) Cond	(7) NO_3+NO_2-N	(8) NO_2-N	(9) NH_3-N	(10) Kj-N	(11) Total N	(12) O-PO_4-P	(13) Total PO_4-P	(14) SS	(15) VSS	(16) COD	(17) BOD	(18) Turb	(19) Cl^-	(20) SO_4	(21) Secchi Disk
Upper Basin	7/23-7/25	18.0°C	10.1	8.1	2		44	125	0.250	0.004		0.18	0.430	0.040	0.05				0.85	1.7	7.25		
Middle Basin	7/23-7/25	20.0°C	11.5	8.9	0	10	32	115	< 0.003	< 0.003		0.38	0.383	0.028	0.07				2.50	3.0	7.50		1.3
2 m depth		19.0°C	10.4	8.7	0	2	40	120															
Lower Basin	7/23-7/25	20.0°C	11.4	8.8	0	6	35	110	< 0.003	0.003		0.30	0.303	0.018	0.04				1.65	2.1	8.00		1.4
(Bottom) 2 m depth		19.0°C		8.5	0	8	34	110	0.005	< 0.003		0.33		0.022	0.04								
Percival Creek	7/23-7/25	19.0°C	8.7	7.6	2		30	80	0.070	< 0.003		0.26	0.330	0.018	0.03				0.40	1.8	3.50		

Sampling Station	Date	(1) Temp	(2) D.O.	(3) pH	(4) CO_2	(5) Alk $CO_3^=$	(5) Alk HCO_3^-	(6) Cond	(7) NO_3+NO_2-N	(8) NO_2-N	(9) NH_3-N	(10) Kj-N	(11) Total N	(12) O-PO_4-P	(13) Total PO_4-P	(14) SS	(15) VSS	(16) COD	(17) BOD	(18) Turb	(19) Cl^-	(20) SO_4	(21) Secchi Disk
Upper Basin	8/27-8/30	17.0°C	8.4	7.9	4	0	50	135	0.350	0.004		0.16	0.510	0.057	0.07	1.4	-7.0	3.4		0.76	7.50		1.25
Middle Basin	8/27-8/30	23.0°C	11.8	9.2	0	18	31	150	0.002	< 0.002		0.52	0.522	0.030	0.08	10.6	-1.4	7.9		1.20	8.25		1.10
2 m depth		22.0°C	11.6		0	16	32																
Lower Basin	8/27-8/30	24.0°C	12.9	9.4	0	32	29	162	0.002	< 0.002		0.48	0.482	0.024	0.06	5.2	-3.4	11.5		1.10	10.00		1.30
4 m depth		20.0°C	7.7	8.5	7	0	53	156															
Percival Creek	8/27-8/30	23.0°C	10.8	9.0	0		30	145	0.031	< 0.002		0.49	0.521	0.025	0.06		2.0	12.6		1.40	8.00		

Sampling Station	Date	(1) Temp	(2) D.O.	(3) pH	(4) CO_2	(5) Alk $CO_3^=$	(5) Alk HCO_3^-	(6) Cond	(7) NO_3+NO_2-N	(8) NO_2-N	(9) NH_3-N	(10) Kj-N	(11) Total N	(12) O-PO_4-P	(13) Total PO_4-P	(14) SS	(15) VSS	(16) COD	(17) BOD	(18) Turb	(19) Cl^-	(20) SO_4	(21) Secchi Disk
Upper Basin	10/16-10/17	14.0°C	11.5	7.6	12	0	48	65	0.410	< 0.002		0.18	0.590	0.067	0.10	7.9	-0.1	2.2		1.2	10.75		2.5
Middle Basin	10/16-10/17	12.0°C	15.2	9.1	0	18	31	105	0.050	0.004		0.40	0.450	0.038	0.07	8.2	-3.8	3.8		2.8	25.00		1.3
Lower Basin	10/16-10/17	14.0°C	12.6	8.8	0	14	38	230	0.015	< 0.002		0.37	0.385	0.029	0.03	6.0	-5.5	8.7		2.7	79.50		1.5
4 m depth		13.0°C			0	20	29	210	0.045	0.005		0.34		0.025	0.06		-2.3	7.0		2.7	69.00		
Percival Creek	10/16-10/17	9.0°C	13.1	8.8	10	0	47	52	0.300	0.002		0.10	0.400	0.023	0.03	10.1	4.0	1.4		1.5	4.00		

Table D4. Compiled Field Data (continued)

Sampling Station	Date	(1) Temp	(2) D.O.	(3) pH	(4) CO_2	(5) Alk $CO_3^=$	(5) Alk HCO_3^-	(6) Cond	(7) NO_3+NO_2-N	(8) NO_2-N	(9) NH_3-N	(10) Kj-N	(11) Total N	(12) O-PO_4-P	(13) Total PO_4-P	(14) SS	(15) VSS	(16) COD	(17) BOD	(18) Turb	(19) Cl^-	(20) SO_4	(21) Secchi Disk
Upper Basin	11/20-11/21	7.0°C	12.9		4		23	50.94	0.39		0.120	0.32	0.71	0.057	0.11	132.5		24.0		72.0			0.2-0.3
Middle Basin	11/20-11/21	7.0°C	12.2		5		25	52.82	0.36		0.155	0.28	0.64	0.033	0.13	110.4		26.0		72.5			0.2
Lower Basin	11/20-11/21	7.0°C	12.0		5		25	254.60	0.34		0.160	0.27	0.61	0.038	0.12	68.0		25.6		53.0			0.2
Percival Creek	11/20-11/21	7.5°C	11.1		5		28	82.49	0.54		0.120	0.57	1.11	0.012	0.05	120.0		25.2		3.9			

Sampling Station	Date	(1) Temp	(2) D.O.	(3) pH	(4) CO_2	(5) Alk $CO_3^=$	(5) Alk HCO_3^-	(6) Cond	(7) NO_3+NO_2-N	(8) NO_2-N	(9) NH_3-N	(10) Kj-N	(11) Total N	(12) O-PO_4-P	(13) Total PO_4-P	(14) SS	(15) VSS	(16) COD	(17) BOD	(18) Turb	(19) Cl^-	(20) SO_4	(21) Secchi Disk
Upper Basin	1/14-1/17	40.0°F	12.8	7.2	4	0	23	54	0.315		0.040	0.25	0.565	0.005	0.030	55.0	14.3	9.6			3.50		
Deschutes River at Waldrick Rd.		4.4°C							0.289		0.057	0.16	0.449	0.110	0.035	78.7	16.5	10.3			4.25		
Middle Basin	1/14-1/17	4.4°C	12.8	7.1	5	0	27	62	0.350		0.040	0.25	0.600	0.005	0.030	57.5	16.9	8.7			4.00		
Runoff*								83	0.035		0.052	0.37		0.006	0.030	68.6	14.3	13.0			7.75		
Lower Basin	1/14-1/17	33.0°F	12.8	6.9	4	0	26	62	0.384		0.045	0.24	0.624	0.006	0.030	51.9	16.4	9.8			5.00		
4 m depth		0.5°C						60	0.381		0.074	0.24		0.008	0.040	51.4	16.8	10.3			4.50		
Percival Creek	1/14-1/17	39.0°F	12.1	7.1	6	0	23	63	0.245		0.045	0.38	0.625	0.004	0.020		10.8	19.1			4.00		
Black Lake Outlet		3.8°C						60	0.185		0.045	0.32		0.006	0.020		12.1	17.9			3.50		

*Runoff entering mid basin.

Table D5a.

Water Quality Data, Capitol Lake, Diurnal Study, July 25-26, 1974

Station	Time	Temp °C	CO_2 mg/ℓ	CO_3^- Alk mg $CaCO_3$/ℓ	HCO_3^- Alk mg $CaCO_3$/ℓ	D.O. mg/ℓ	pH	Conductivity µmhos/cm
Upper Basin	4:30 PM	17	2	0	45	8.9	7.9	115
	1:30 AM	16	3	0	44	9.1	7.9	119
	6:25	15	3	0	42	9.6	7.9	117
Middle Basin	9:00 PM	20	0	6	34	11.6	8.5	122
	1:00 AM	20	0	10	31	11.5	8.7	115
	6:00	20	0	8	35	11.3	8.8	105
Lower Basin (outlet)	8:45 PM	20	0	10	30	11.0	8.8	108
	12:30	20	0	10	31	11.0	8.8	95
	5:30 AM	19	0	4	35	10.0	8.6	78
Percival Creek	8:20	20	2	0	34	9.1	7.8	98
	12:00 PM	19	2	0	35	9.6	7.2	92
	5:00 AM	17.5	3	0	38	8.7	7.3	87

Table D5b.

Water Quality Data, Capitol Lake, Diurnal Study, August 27-30, 1974

Station	Time	Temp °C	CO_2 mg/ℓ	CO_3^- Alk mg $CaCO_3$/ℓ	HCO_3^- Alk mg $CaCO_3$/ℓ	D.O. mg/ℓ	pH	Conductivity µmhos/cm
Upper Basin	8:10	20	4	0	54	8.7	7.6	142
	12:00	18	5	0	56	9.0	7.9	134
	4:00	16	8	0	49	8.8	8.0	127
Middle Basin	8:43	23	0	16	33	12.2	9.0	162
	12:24	22	0	14	33	12.1	9.2	150
	4:20	21	0	14	36	11.5	9.2	142
Lower Basin	9:45 PM	23	0	24	29	12.6	9.4	160
	1:30 AM	22	0	24	31	12.1	9.3	147
	5:10	20	0	30	22	11.8	9.4	146
Percival Creek	9:00	22	0	14	32	10.7	9.2	146
	12:45	21	0	12	28	10.9	9.1	137
	4:45	20	0	12	28	10.6	9.1	137

Table D6a. Analysis of Lake Sediment Cores of Capitol Lake Upper Basin, Core II

Depth (cm)	pH	ORP (mv)	Total-P (mg/kg)	NO_3 (mg/kg)	H_2O (%)	Kj-N (mg/g)	COD (mg/g)
0-4	5.65	845	1266.7	10.4	69.8	0.0	39.3
4-8	6.	850	1106.7	6.2	70.2	0.0	32.3
8-12	5.9	770	980	7.	74.5	0.22	24.2
12-16	6.2	845	980	9.6	76.1	0.56	27.4
16-20	6.7	750			75.7	0.44	21.9
20-24	6.75	750	953.3	20.9	72.6		34.0
24-28	7.8	870			71.5		33.6
28-32	6.7	760	933.3	24.4	74.4		24.8
32-36	6.68	815			74.2		30.4
36-40	6.55	870	960	30.	75.2		29.3
40-44	6.55	815			74.		39.3
44-48	6.8	840	1026.7	22.5	69.3		39.8

REMARKS: Grey fairly uniform throughout sandy clay.

Table D6b. Analysis of Lake Sediment Cores of Capitol Lake Lower Basin, Core I

Depth (cm)	pH	ORP (mv)	Total-P (mg/kg)	NO_3 (mg/kg)	H_2O (%)	Kj-N (mg/g)	COD (mg/g)
0-4	6.8	1070	2493.3	25.	56.8	1.56	68.1
4-8	6.8	1090	2280	23.	58.6	1.56	55.4
8-12	6.9	1060	1580	29.	61.3	1.36	56.3
12-16	7.3	1100		24.	70.6	0.80	43.7
16-20	7.6	1110			69.4	1.24	16.0
20-24	7.6	1110	873.3	24.8	71.9		49.9
24-28	7.4	1070			75.4		31.5*
28-32	7.6	1110	780	24.8	78.2		29.5*
32-36	7.5	1110			74.5		38.7*
36-40	7.5	1080	946.7	27.5	72.6		47.6
40-44	7.35	1050			69.8		50.5
44-48	7.2	1030	926.7	18.	71.4		34.3
48-52	7.25	1020			75.6		35.1
52-56	7.15	1000	580	10.	80.3		14.4

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*Considerable shell fragments and coarse material.

REMARKS: Black silted top - 8 AM, going from sandy silt to silty sand at bottom, large amounts of shell fragments throughout the core.

Table D6c. Analysis of Lake Sediment Cores of Capitol Lake Middle Basin, Core II

Depth (cm)	pH	ORP (mv)	Total-P (mg/kg)	NO_3 (mg/kg)	H_2O (%)	Kj-N (mg/g)	COD (mg/g)
0-4	6.1	1040	2033.3	11	77.3	0.0	21.3
4-8	6.05	980	1326.7	10.5	77.6	0.28	25.5
8-12	5.8	935	1246.7	11.5	79.8	0.62	15.5
12-16	6.0	960	1466.7	12.1	75.4	0.06	27.5
16-20	6.1	980			79.1	0.44	
20-24	6.15	1020	1273.3	8.2	77.7		14.2
24-28	6.05	970			76.1		31.9
28-32	6.1	815	1200	8.3	81.		9.6
32-36	6.0	840			81.2		10.1
36-40	6.0	895	1100	8.2	80.2		10.3
40-44	6.1	860			73.3		9.8
44-48	6.1	970	1133.3	7.3	79.7		11.0
48-52	6.2	960	1106.7		78.		13.0

REMARKS: Grey-black sand throughout, more fines toward top.

Table D7.

ALGAE COUNTS IN NUMBER PER MILLILITER AT CAPITOL LAKE

Upper Basin

	6/1/74	6/28/74	7/25/74	8/28/74	10/14/74	11/22/74	1/17/75
DIATOMS							
Achnanthes			22				
Asterionella			2				
Cocconeis			10	14	21		
Cyclotella	7	7	5		21		
Cymbella		219	32	41	14	6	
Diatoma					21	1	
Fragilaria	14						
Gomphonema	14	7	25	27	7		21
Hannea	7		2				
Melosira	21				21		48
Navicula	41	14	7	55	110	4	21
Nitzschia			17	27	14		
Rhoicosphenia						1	
Synedra	117	27	20		34	4	
GREEN ALGAE							
Staurastrum					7		
BLUE-GREEN ALGAE							
Oscillatoria	21						
Total cells/ml	242	274	142	164	270	16	90

Table D7.

ALGAE COUNTS IN NUMBER PER MILLILITER AT CAPITOL LAKE (Cont.)

Middle Basin

	6/1/74	6/28/74	7/25/74	8/28/74	10/14/74	11/22/74	1/17/75
DIATOMS							
Asterionella		41	445	21			
Ceratoneis	7						
Cocconeis					29	1	14
Cyclotella	27	7	34	158	1490	1	7
Cymbella	21	21			10	1	
Diatoma					10	4	
Fragilaria			410	261			
Gomphonema	7					1	
Gyrosigma					10		
Melosira		7	68	7	20	8	14
Navicula	69	7		7	294		14
Nitzschia	21						7
Pinnularia	21						
Rhoicosphenia					20		
Synedra	27			103	69		
Tabellaria		14					
GREEN ALGAE							
Pandorina			68				
Scenedesmus				329	39		
Staurastrum				7			
Tribonema			1641				
BLUE-GREEN ALGAE							
Aphanizomenon			1162				
Total cells/ml	200	97	3828	893	1998	16	56

Table D7.

ALGAE COUNTS IN NUMBER PER MILLILITER AT CAPITOL LAKE (Cont.)

Lower Basin

	6/1/74	6/28/74	7/25/74	8/28/74	10/14/74	11/22/74	1/17/75
DIATOMS							
Achnanthes						2	
Asterionella	219	213	384	7			7
Cocconeis	14					1	
Cyclotella	3450				281	1	
Cymbella		7			7		
Diatoma						1	
Fragilaria		185	1096	350			41
Gomphonema						1	7
Gyrosigma							7
Hannea						1	
Melosira	34	41		130	110	4	
Navicula	34				21	1	14
Nitzschia							14
Synedra	75	7		75	7	4	
GREEN ALGAE							
Ankistrodesmus	14						
Coccoid green				233			
Pandorina		110	27				
Pediastrum				7			
Scenedesmus				274		1	
Selenastrum	27						
Staurastrum	7						
Synura				7			
Tribonema			9925				
BLUE-GREEN ALGAE							
Aphanizomenon	322				19		
Total cells/ml	4196	570	11432	1083	445	17	90

Table D7.

ALGAE COUNTS IN NUMBER PER MILLILITER AT CAPITOL LAKE (Cont.)

Percival Creek

	6/1/74	6/28/74	7/25/74	8/28/74	10/14/74	11/22/74	1/17/75
DIATOMS							
Achnanthes						7	
Asterionella	172	110		25			
Cocconeis		34	411	49			
Cyclotella	14	14	68	395		14	27
Cymbella							14
Fragilaria		158					75
Gomphonema	27			25			
Melosira	27	76		395		75	69
Navicula						7	
Stephanodisus		7					
Synedra	21			148			
Tabellaria	7	7	68				
GREEN ALGAE							
Dictyosphaerium		7					
Pandorina	7						
Scenedesmus				148			
Synura				25			
Unknown coccoid				123			
BLUE-GREEN ALGAE							
Aphanizomenon	41						
Total cells/ml	316	420	547	1333		103	192

Table D8. Nutrient Budget, Capitol Lake, Washington

Date (1974-75)	4/27	5/31	6/30	7/25	8/27	Sept*	10/16	11/21	Dec*	1/17	Feb*	Mar*
<u>INPUT</u>												
Upper Basin												
Flow, cfs	313	223	128	146	79	63	81	2197	1911	1624	596	643
Concentration												
Total-P, mg/l	0.031	0.010	0.040	0.050	0.067	0.096	0.100	0.107	0.070	0.033	0.030	0.030
Total-N, mg/l	0.450	0.375	0.154	0.430	0.410	0.500	0.590	0.710	0.638	0.565	0.530	0.490
P-input, kg/day	24	5	13	18	13	15	20	575	327	132.4	43.8	47.2
N-input, kg/day	345	205	48	154	79	77	117	3818	2984	2246	773	771
Percival Creek												
Flow, cfs	24	11	5	3	1	4.5	8	215	201	188	60	64
Concentration												
Total-P, mg/l	0.026	0.006	0.046	0.026	0.060	0.047	0.033	0.046	0.046	0.045	0.037	0.032
Total-N, mg/l	0.560	0.442	0.291	0.267	0.493	0.487	0.480	1.090	0.858	0.625	0.600	0.580
P-input, kg/day	1.5	0.2	0.6	0.2	0.1	0.5	0.6	24.0	23.0	21.0	5.4	5.0
N-input, kg/day	33	12	4	2	1	5	9	573	422	288	88	91
<u>OUTPUT</u>												
Lower Basin												
Flow, cfs	337	234	133	149	80	67.5	89	2412	2112	1812	656	707
Concentration												
Total-P, mg/l	0.033	0.087	0.057	0.043	0.056	0.043	0.030	0.123	0.078	0.032	0.030	0.030
Total-N, mg/l	0.480	0.350	0.530	0.310	0.483	0.434	0.385	0.610	0.618	0.625	0.580	0.530
P-output, kg/day	27	50	19	16	11	7	7	726	403	142	48.2	51.9
N-output, kg/day	396	200	173	113	95	72	84	3601	3194	2772	931	917
BALANCE: Input-Output												
Net P, kg/day	-1	-45	-5	+2	-2	+9	+14	-127	-53	+11.4	+1.0	+0.3
Net N, kg/day	-18	+17	+121	+43	-15	+10	+42	+790	+212	-238	-70	-55

*Concentration values estimated.