CHARACTERIZATION OF THE HYDROLOGY AND WATER QUALITY OF PALUSTRINE WETLANDS AFFECTED BY URBAN STORMWATER

A Report Prepared for the

Puget Sound Wetlands and Stormwater Management Research Program

By

Lorin E. Reinelt
King County Conservation District

Richard R. Horner
King County Resource Planning
University of Washington

King County Resource Planning
707 Smith Tower
506 Second Avenue
Seattle, WA. 98104

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ABSTRACT

The quantity and quality of stormwater entering many palustrine wetlands in the Puget Sound region has changed as a result of rapid development in urbanizing areas. These changes may affect the functions and values of wetlands by impacting soils, plants and animal communities. This report summarizes the results from the hydrology and water quality components of the long-term effects study from April 1988 (start of study) to December 1989. This study is organized on the basis of a control/treatment, before/after (urbanization) experimental design. It is part of the Puget Sound Wetlands and Stormwater Management Research Program.

The hydrology of the wetlands included in this study was highly variable. The range of maximum water level fluctuations for the 19 wetlands was large (0.62 to 4.28 feet), but there was no apparent association with the type of hydrologic system (open water versus flow-through) or outlet conditions. Water level fluctuations on the high end of this range are likely to affect wetland plant and animal communities.

For purposes of the water quality data analysis, the 19 wetlands in the program were classified based on their control/treatment status, degree of existing urbanization and hydrologic system. The control/highly urbanized (CH) and treatment/moderately urbanized (TM) wetlands exhibited the most degraded water quality conditions. On average, these wetland types exhibited the highest values for conductivity, total suspended solids, fecal coliforms and enterococci. A number of differences in wetland water quality were identified based on hydrologic system, but few differences were evident based on treatment status. However, the period for which data are available covers only the baseline condition and the early portion of the development condition for the treatment sites.

Overall, the water quality of the wetlands was characteristic of freshwater systems with similar discharges. The values observed were similar to those found in freshwater lakes and streams in the region. Since water is transient, its greatest effect probably results from accumulation of pollutants in the sediments due to physical settling and chemical reactions. High water level fluctuations likely pose more significant problems to wetland functions because of potential effects on plant succession, habitat and breeding conditions.

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1. INTRODUCTION

1.1 Wetlands in Urbanizing Areas

Wetlands have received increased attention in recent years as a result of continuing wetland losses and impacts, and the realization that wetlands have many important functions and values. Wetlands are recognized as biologically productive ecosystems offering extensive, high-quality habitat for a diverse array of terrestrial and aquatic species, as well as multiple beneficial uses for humans, including flood control, groundwater recharge and water quality treatment. However, as urbanization of natural landscapes occurs, some or all of the functions and values of wetlands may be affected. Some wetlands may be impacted by direct activities such as dredging, filling, draining or outlet modification, while others may be affected by secondary impacts, including increased or decreased quantity and reduced quality of inflow water.

In urbanizing areas, the quantity and quality of stormwater can change significantly as a result of developments in a watershed. Increases in the quantity of stormwater may result from new impervious surfaces (e.g., roads, buildings), installation of storm sewer piping systems, and removal of trees and other vegetation. On the other hand, decreased inflow of water can result from modifications in surface and groundwater flows. The quality of stormwater may decrease due to construction activities, increased automobile traffic, application of fertilizers and pesticides, and domestic animal wastes. For cases where wetlands are the primary receiving water for urban stormwater from new developments, it is hypothesized that the effects of watershed changes will be manifested through changes in the hydrology and water quality of wetlands.

1.2 Puget Sound Wetlands and Stormwater Management Research Program

In response to accelerating development in urbanizing areas, stormwater management problems, and the potential effects of these activities on Puget Sound area wetlands, scientists and managers associated with local, state and federal agencies joined to develop a research program to address these issues. The following general goal was established (King County Resource Planning 1987):

> Determine the effects of urban stormwater discharge on wetlands and, as a corrolary, the effect of wetlands on the quality of urban stormwater. Use the knowledge gained about these effects to develop sound policies and guidelines for effective utilization of wetlands for urban stormwater management and nonpoint source water pollution control.

The first part of this goal is formalized by two components of the research program: (1) a study of the long-term effects of urban stormwater on wetlands, and (2) a study of the water quality benefits to downstream receiving waters as urban stormwater flows through wetlands.

In the long-term effects study, 19 wetlands are being studied over a five- to seven-year period to examine changes in hydrology, water quality, soils, plants and animals (see below). In the water quality benefit study, two wetlands (one urban, one nonurban) are being studied intensively over a two-year period. The quantity and quality of inflow and outflow water, precipitation and groundwater are monitored either continuously or regularly. These data, along with estimates of evapotranspiration from the wetlands, will be used to perform a complete water quantity and quality balance on a seasonal basis.

This report is a summary of results from the hydrology and water quality components of the long-term effects study from April 1988 (start of study) to December 1989. The results from the water quality benefit study will be presented in a separate report.

1.3 Long-term Effects Research Study

The objective of the long-term effects research study is to determine the types, degrees, rates, and significance of ecological change, if any, that accompanies discharge of urban stormwater to freshwater palustrine wetlands. This information might then be used to determine how negative impacts can best be avoided or minimized. Nineteen wetlands throughout King County, Washington are being studied over a five- to seven-year period. The wetlands were chosen primarily based on wetland size, plant communities and known plans for development in the watersheds of half the wetlands. These wetlands, with known plans for watershed development, were paired with similar wetlands expected to experience no development. The complete study includes examination of the hydrology, water quality, soils, plants and animals of these wetlands (King County Resource Planning 1987), however, this report focuses only on a characterization of wetland hydrology and water quality.

The 19 wetlands were grouped into a variety of categories for examining their hydrology and water quality. These included pre-existing watershed condition (e.g., level of urbanization), expected new development in the watershed, and hydrology of the wetland (Table 1). Secondly, sampling data were grouped by occasion, plant growth season, hydrologic season and all occasions.

The following three categories were established to distinguish pre-existing watershed conditions in terms of percent watershed coverage for the different wetlands: (1) <u>nonurbanized</u> (N) - less

Table 1. Wetland summary information for outlet and hydrologic conditions, sampling location, treatment status, and pre-existing watershed development.

Wetland Name	Acronym	Outlet Condition	Water Level Fluctuation (a)	Dry in Summer?	OW/FT (b)	Sampling Location (c)	C/T (d)	N/M/H (e)
Ames Lake 3	AL3	None	FL	Y	OW	OW	C*	N
Bellevue 3I	B3I	Culvert	SH	N	FT	Out	C	H
Big Bear Creek 24	BBC24	Beaver Dam	SL	N	OW	OW	C*	M
East Lake Sammamish 39	ELS39	Culvert	FH	Y	OW	OW	T	M
East Lake Sammamish 61	ELS61	Int. Stream	FL	N	OW	OW	T	M
East Lake Washington 1	ELW1	Lake	SH	N	FT	FW	T	M
Forbes Creek 1 (f)	FC1	Beaver Dam	S/FH	N	FT	OW	C	H
Harris Creek 13	HC13	Beaver Dam	FL	N	OW	OW	C	N
Jenkins Creek 28	JC28	Int. Stream	SL	Y	FT	FW	T	M
Klahanie East	KE	None	FL	Y	OW	OW	T	N
Lower Cedar River 93	LCR93	None	FH	Y	FT	FW	C	M
Lower Puget Sound 9	LPS9	Catch Basins	FH	Y	FT	FW	C*	M
Middle Green River 36	MGR36	Bulkhead	SL	N	FT	Out	C	N
Patterson Creek 12	PC12	Beaver Dam	FL	N	OW	OW	T	N
Raging River 5	RR5	Beaver Dam	FL	N	OW	OW	C	N
Snoqualmie River 24	SR24	Road	FL	N	OW	OW	C*	N
Soos Creek 4	SC4	Culvert	SL	Y	FT	Out	C	M
Soos Creek 84	SC84	Int. Stream	FL	Y	OW	OW	T	M
Tuck Creek 13	TC13	Culvert	FL	Y	OW	OW	T	N

(a) Water Level Fluctuation (WLF): S = stable base level, F = fluctuating base level, L = low event fluctuation, H = high event fluctuation

(b) OW/FT: OW=Open Water, FT=Flow Thru

(c) Sampling Location: OW=Open Water, Out=Outlet, FW=Flowing Water

(d) C/T: C=Control, T=Treatment, C*=Control Now (will be treatment)

(e) N/M/H: N=Nonurbanized, M=Moderately Urbanized, H=Highly Urbanized

(f) Active beaver and periodic removal of beaver dam by Kirkland public works personnel has resulted in both stable and fluctuating baseflows than 10 percent urban land uses, (2) moderately urbanized (M) - 10 to 39 percent urban land uses, and (3) highly urbanized (H) - greater than or equal to 40 percent urban land uses. Expected change in the watershed, in terms of new development, was the basis for differentiating control (C) sites (i.e., no change or development expected to occur in the wetland watershed) from treatment (T) sites (i.e., change or development expected to occur in the wetland watershed). Currently, eleven of the wetlands are control sites and eight of the wetlands are treatment sites. However, some of the control sites may become treatment sites in the near future if development occurs. Two general categories were designated for the type of wetland hydrologic system: open water (OW) and flow-through (FT) systems. Open water systems contain significant pooled areas with little or no flow gradient. Flow-through systems show evidence of channelization and a significant flow gradient.

2. METHODS AND MATERIALS

2.1 Wetland Hydrology

Hydrology is probably the single most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes (Mitsch and Gosselink, 1986). Water depth, flow patterns, and duration and frequency of flooding influence the biochemistry of the soils and are major factors in the selection of wetland biota. Thus, changes in wetland hydrology may influence significantly the soils, plants and animals of particular wetland systems.

Precipitation, surface water inflow and outflow, groundwater exchange and evapotranspiration are the major factors that influence the hydrology of palustrine wetlands. Outlet conditions, wetland-to-watershed ratios, and wetland morphometry are important also. Water level fluctuation, however, is perhaps the best single indicator of wetland hydrology, because it integrates many of the other factors. Water level fluctuation, type of hydrologic system (OW and FT), outlet conditions, and precipitation are the hydrologic features covered in this report. Future analyses will bring in other factors to a greater extent.

In this research program, wetland water levels are measured instantaneously (using a staff gage) and as a maximum since the last visit (using a crest-stage gage, Figure 1) during each visit to a wetland. Cork dust, sprinkled into the steel pipe of the crest-stage gage, rises with the water and adheres to the inner PVC pipe to mark the maximum water level since the last visit. Generally, staff and crest-stage readings are taken on each sampling occasion, approximately eight times per year. All gages were surveyed to a fixed bench mark at each wetland, so that the readings are consistent, and so gages can be reset in the event of vandalism.

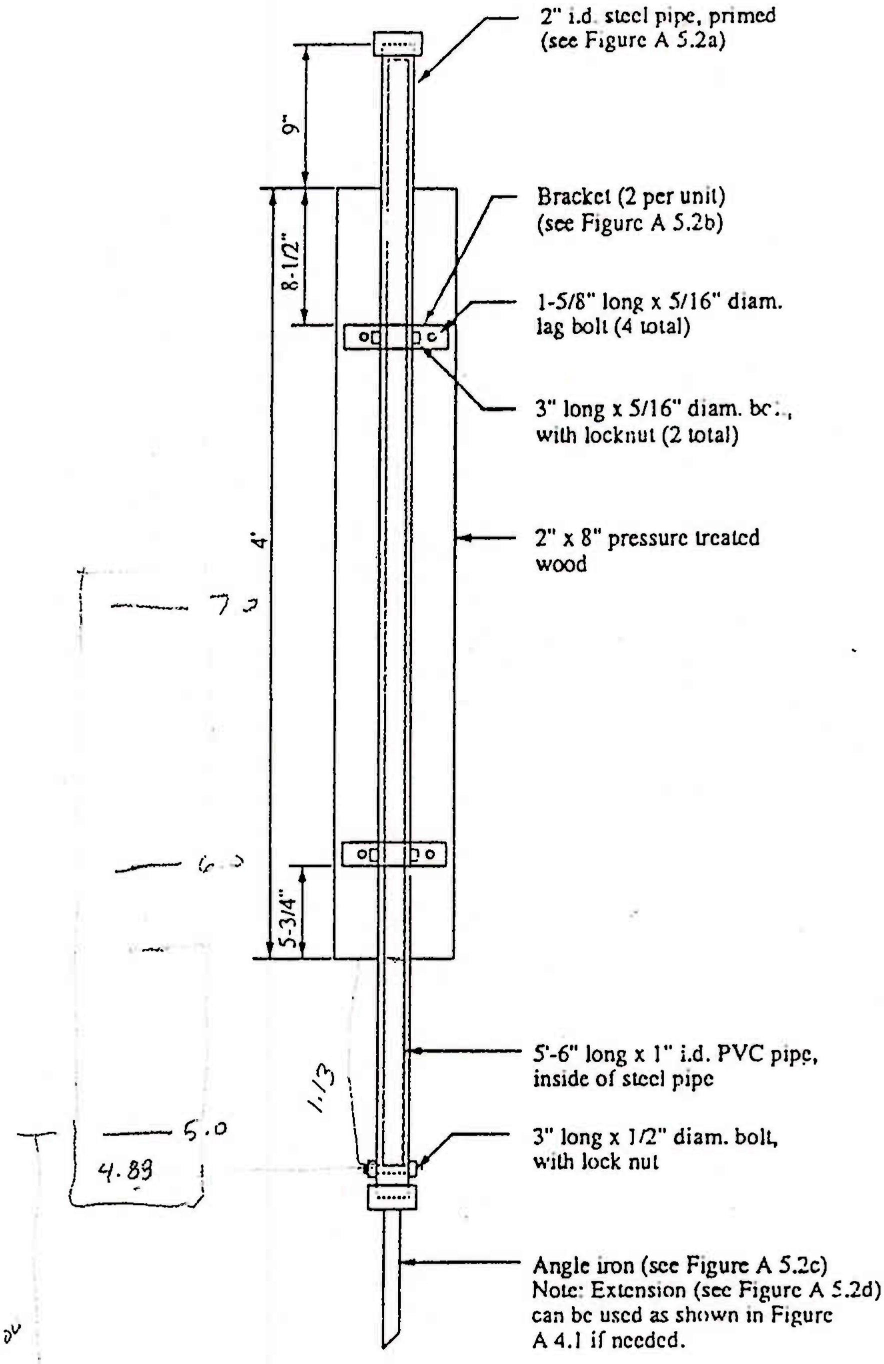

Figure 1. Crest-stage gage

As noted above, two types of hydrologic systems are common in the palustrine wetlands of this study. The open water systems contain significant pooled areas and possess little or no flow gradient, while the flow-through systems are often channelized and possess a significant flow gradient. These hydrologic distinctions are particularly useful when examining water quality variables such as temperature, dissolved oxygen (DO) and chlorophyll a that may be influenced significantly by the type of water system.

Outlet conditions also play an important role in the control of wetland water levels and hydrology. In particular, outlet constrictions may prevent or reduce outflows from a wetland either seasonally or all year. Beaver dams and culverts are the most common outlet conditions that restrict outflow, but constructed bulkheads and weirs function in a similar manner. Many wetlands have no obvious outlet constriction and discharge in sheet flow directly to a stream. Finally, some wetlands have no outlet, and therefore, water is lost exclusively through groundwater recharge and evapotranspiration. Table 1 identifies the type of outlet condition for each wetland.

There are many official precipitation stations throughout King County where daily and hourly precipitation records are available. Daily precipitation data from stations nearest to the wetlands of this study were obtained from King County Surface Water Management Division to contribute to the hydrologic picture of the wetlands. Figure 2 shows the locations of these stations.

2.2 Wetland Water Quality

Water samples were collected on seven occasions during 1988 (May - November) and eight occasions during 1989 (February - December). Sampling was stratified so that more samples were collected during the wet (November - February) and dry (July - September) seasons and fewer samples were collected during the "shoulder" seasons. The distribution of sampling dates is shown in Figure 3. At the beginning of the study in May 1988, 14 wetlands were included in the water quality sampling program. Five wetlands were added in the beginning of 1989 for a total of 19 wetlands (Figure 2). On some occasions during the dry season of both years, between one and nine wetlands were completely dry; thus, no water samples were collected then at those wetlands.

Sampling consisted of grab samples taken at the first location possible in the following hierarchy (open water, outlet, downstream of inlet). All sample bottles were prepared in accordance with U.S. EPA (1983) specifications. The laboratory analysis methods, including preservation chemicals and analytical instruments used, are shown in Table 2. Most laboratory analyses were performed by the Municipality of Metropolitan Seattle (Metro) during 1988 and Aquatic Research Incorporated during

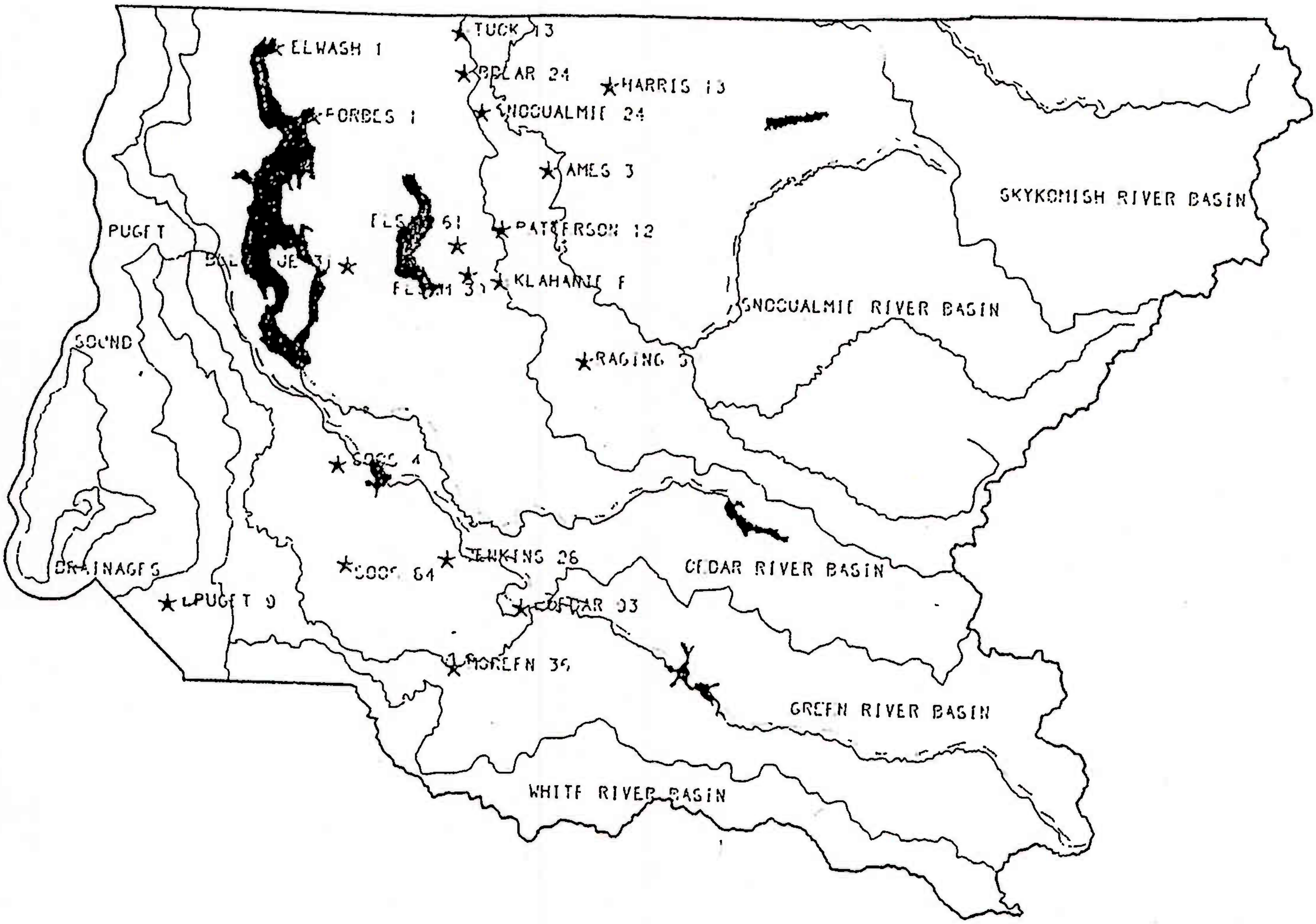

Figure 2. GIS map of King County showing wetland sites (*)

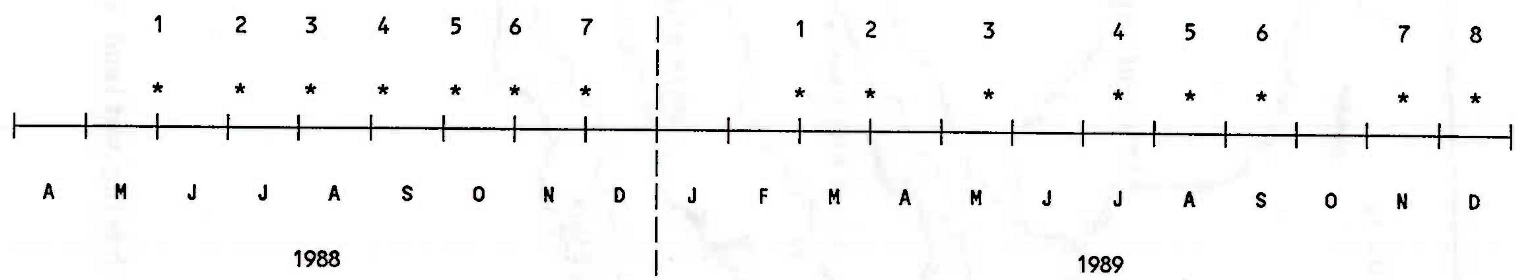

Figure 3.. Time Line of Sampling Occasions (numbers and asterisks indicate approximate time of sampling occasions during 1988 and 1989).

Table 2. Laboratory Analysis Specifications

Variable	Method	Equipment	Preservation
Temperature	Thermometer	--	None
Dissolved Oxygen	Azide modification of Winkler Method	--	None
pH	Potentiometric	Beckman	None
Conductivity	Wheatstone bridge-type meter	Amber Science, Inc. Model 604	4 C refrigeration
Alkalinity	Titrimetrix	Jenco pH Meter Model 6071	4 C refrigeration
TSS	Gravimetric	Mettler Type H 80 Analytical Balance	4 C refrigeration
Chlorophyll a	Spectrophotometric	IBM UV/VIS Model 9410	4 C refrigeration
Ammonia-Nitrogen	Automated phenate	Alpkem RFA Model 300	4 C refrigeration
Nitrate+Nitrite-Nitrogen	Automated Cd Reduction	Alpkem RFA Model 300	4 C refrigeration
Soluble Reactive Phosphorus	Automated Heteropoly Blue after filtration	Alpkem RFA Model 300	4 C refrigeration
Total Phosphorus	Automated Heteropoly Blue after persulfate digestion	Alpkem RFA Model 300	4 C refrigeration
Fecal Coliforms	Membrane Filter	--	4 C refrigeration
Enterococci	Membrane Filter	--	4 C refrigeration
Metals			
(Cd, Cu, Pb)	Graphite Furnace Atomic Adsorption (GFAA)	Perkin-Elmer Model 3030	Nitric Acid to pH <2
(Zn)	Inductively Coupled Plasma (ICP)	Jarrell-Ash Model 61	Nitric Acid to pH <2

1989. Ecova and the Pacific Northwest Environmental Laboratory (PNEL) performed the metal analyses.

The wetland water quality data collected during 1988 and 1989 were grouped in a variety of different ways to perform statistical analyses and examine trends. The data were grouped by occasion (e.g., each occasion, each season, all occasions), by each or all wetlands, and by categories (e.g., control versus treatment, open water versus flow-through system). The water quality data analysis plan is shown in Table 3 and the results of the analyses are presented in Appendix A.

Seasons were determined based on literature guidance and expert judgment relative to expected plant uptake or release of dissolved substances in the Pacific Northwest. For the period of study, the following five seasons, dates, and classifications were used:

Season 1 (03/01 - 05/15): early growing season (some uptake)
Season 2 (05/16 - 08/15): intermediate (high uptake)
Season 3 (08/16 - 09/30): decline (maybe some release)
Season 4 (10/01 - 11/15): decay (high release)
Season 5 (11/16 - 02/28): dormant

Five categories were established for column two of Table 3 based on treatment status and pre-existing level of watershed development. The five categories are: control/nonurbanized (CN), control/moderately urbanized (CM), control/highly urbanized (CH), treatment/nonurbanized (TN), and treatment/moderately urbanized (TM). No wetlands fit a treatment/highly urbanized category.

The Student's t-test was used in the analysis of water quality data to compare the difference between two population means (e.g., treatment versus control wetlands, open-water versus flow-through hydrologic systems). The test assumes that both populations possess a normal probability distribution and that their variances are equal. A pooled estimator of the variance is used in the t-test to pool the information from both samples. The t-statistic is computed by the following equation:

$$t = \frac{Y_1 - Y_2}{s(1/n_1 + 1/n_2)^{0.5}}$$

where Y_1, Y_2 = estimates of the population means
s = square root of the pooled estimator of the variance
n_1, n_2 = number of measurements from samples 1 and 2

Once the t-statistic is computed, it is compared with a critical value taken from a table of t-statistics. A chosen level of significance (e.g., 0.05), combined with the degrees of freedom (d.f. = $n_1 + n_2 - 2$), is used to determine the critical value of t. If the computed t is greater than the critical value of t,

Table 3. Water quality data analysis plan

	Wetland	Five Categories	Control/ Treatment	Open Water/ Flow-through
Each Wetland Each Occasion	A1.1 (raw data)	X	X	X
Each Wetland Each Season	A2.1	A2.2 (see A5.2)	A2.3 (see A5.3)	A2.4 (see A5.4)
Each Wetland All Occasions	A3.1	A3.2	A3.3	A3.4
All Wetlands Each Occasion	A4.1	A4.2	A4.3	A4.4
All Wetlands Each Season	A5.1	A5.2	A5.3	A5.4

then there is a significant difference between the two means at the selected significance level.

Geometric means (GMs) were used instead of arithmetic means when examining the bacterial data (fecal coliforms (FC) and enterococci) to allow for comparisons with state water quality standards stated in terms of GMs. The GM is computed by taking the logarithm of individual data values, computing their mean and taking the antilog. The logarithm values, however, were used for the Student's t-test.

3. RESULTS AND DISCUSSION

3.1 Wetland Hydrology

Water level fluctuations for the 19 wetlands generally fit into one of four basic patterns: (1) stable base water level with low event fluctuations (SL), (2) stable base water level with high event fluctuations (SH), (3) fluctuating base water level with low event fluctuations (FL), and (4) fluctuating base water level with high event fluctuations (FH). The four patterns are defined quantitatively for the palustrine wetlands in this research program according to Table 4. Examples of the four patterns are shown in Figures 4 thru 7. Plots of the base water level and water level fluctuation for all wetlands are shown in Appendix B.

Water depth and water level fluctuation varied widely for the 19 wetlands. Mean instantaneous and crest water depths were computed for all occasions, wet and dry seasons (Table 5). Mean instantaneous water depths varied from 0.17 to 2.44 feet, and mean crest depths varied from 0.52 to 3.08 feet for the 19 wetlands. Complete statistics (n, range, mean, standard deviation (SD) and coefficient of variation (CV) = SD/mean) for the "all occasions" data are given in Appendix C1. During the wet season, the ranges were 0.31 to 3.13 feet and 0.53 to 3.33 feet, respectively. During the dry season, the ranges were 0.06 to 2.11 feet and 0.51 to 2.86 feet, respectively.

Water level fluctuation was determined by examining low and high water levels. The maximum water level fluctuation (WLF) was calculated according to the following equation:

$$WLF_{max} = C_{max} - I_{min}$$

where C_{max} = maximum crest water depth
I_{min} = minimum instantaneous water depth

The range of maximum water level fluctuations for the 19 wetlands was from 0.62 to 4.28 feet (Table 6, Figure 8). During the wet season (October - March), the maximum fluctuation varied from 0.45 to 3.68 feet, and during the dry season (April - September), values varied from 0.54 to 3.88 (Figure 9). It is important to

Table 4. Criteria for classification of wetlands by base water level and relative event fluctuations.

Type (a)	Base Water Level (Annual Fluctuation)	Relative Event Fluctuations
SL	< 0.75 ft.	< 0.75 ft.
SH	< 0.75 ft.	> 0.75 ft.
FL	> 0.75 ft.	< 0.75 ft.
FH	> 0.75 ft.	> 0.75 ft.

(a) S = stable base level, F = fluctuating base level,
L = low event fluctuation, H = high event fluctuation

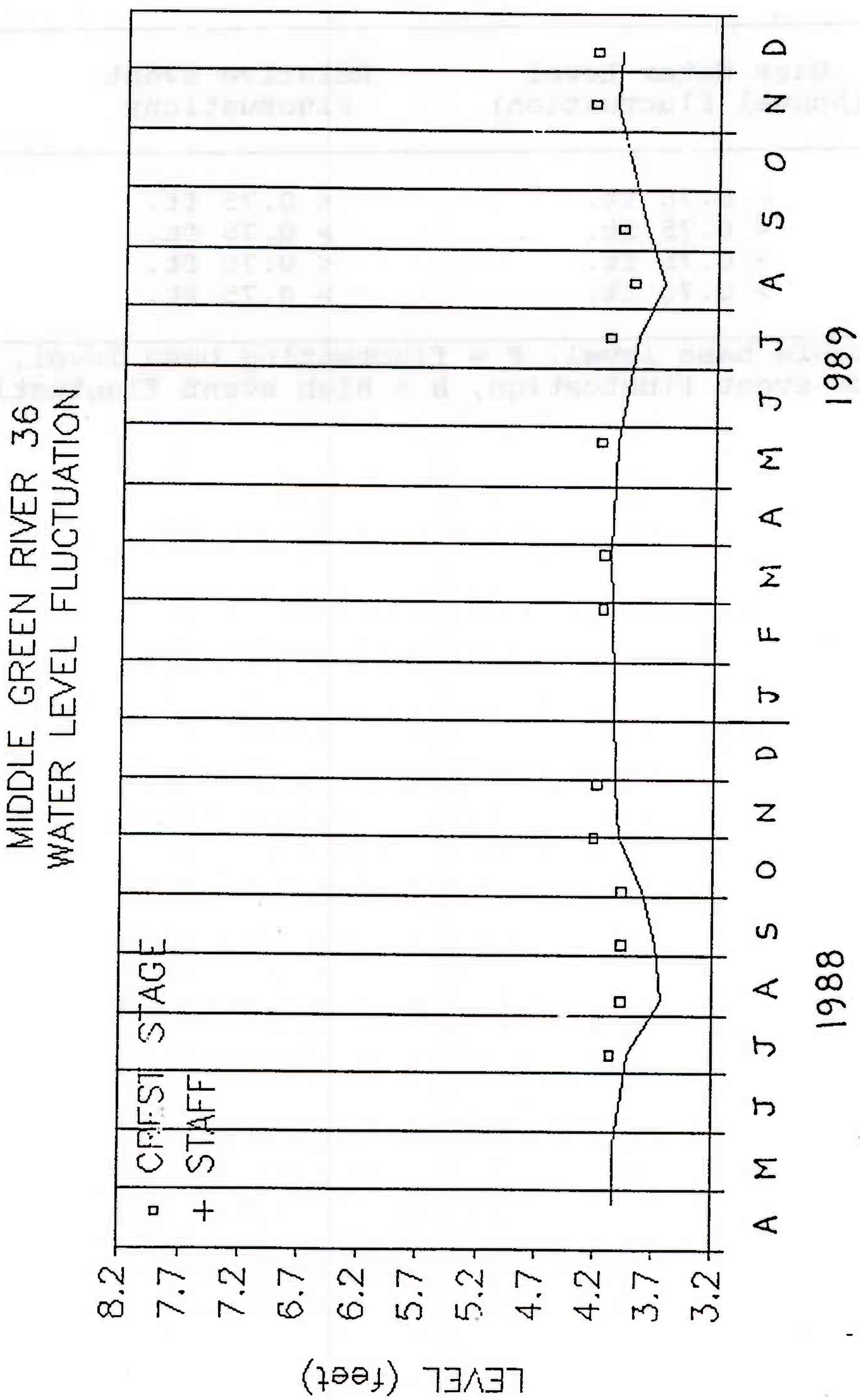

Figure 4. Plot of wetland with stable base water level and low event fluctuation (SL)

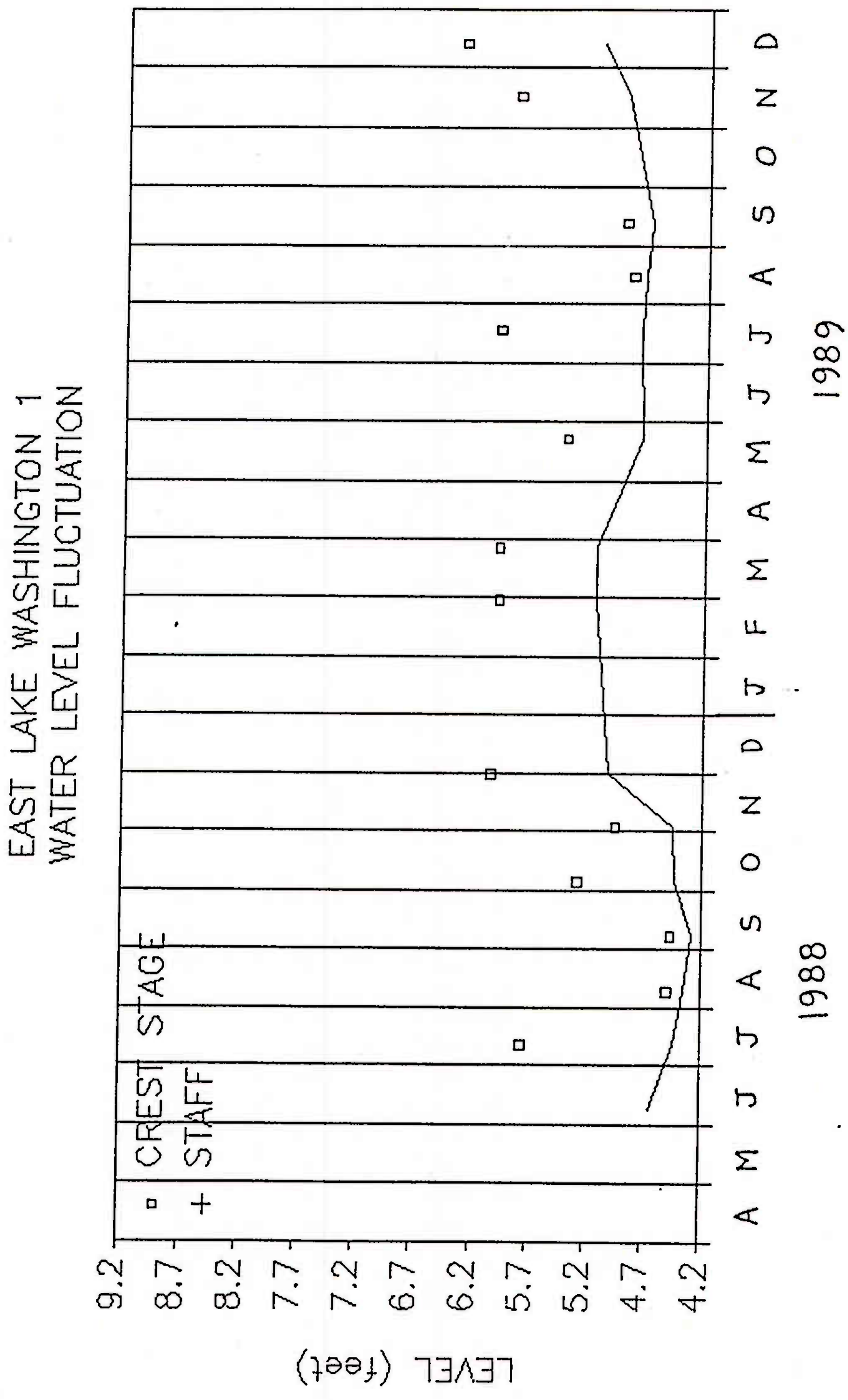

Figure 5. Plot of wetland with stable base water level and high event fluctuatuion (SH)

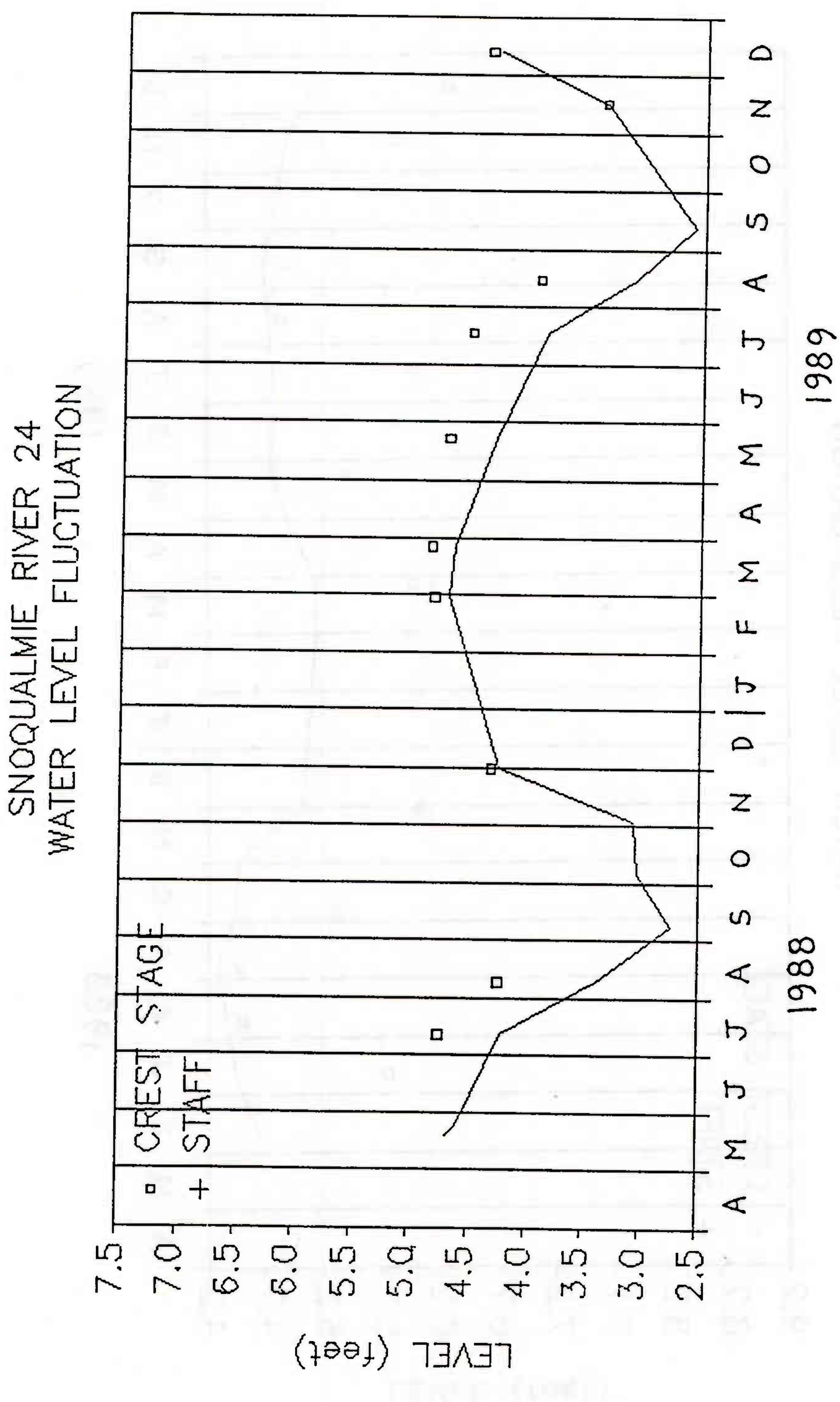

Figure 6. Plot of wetland with fluctuating base water level and low event fluctuation (FL)

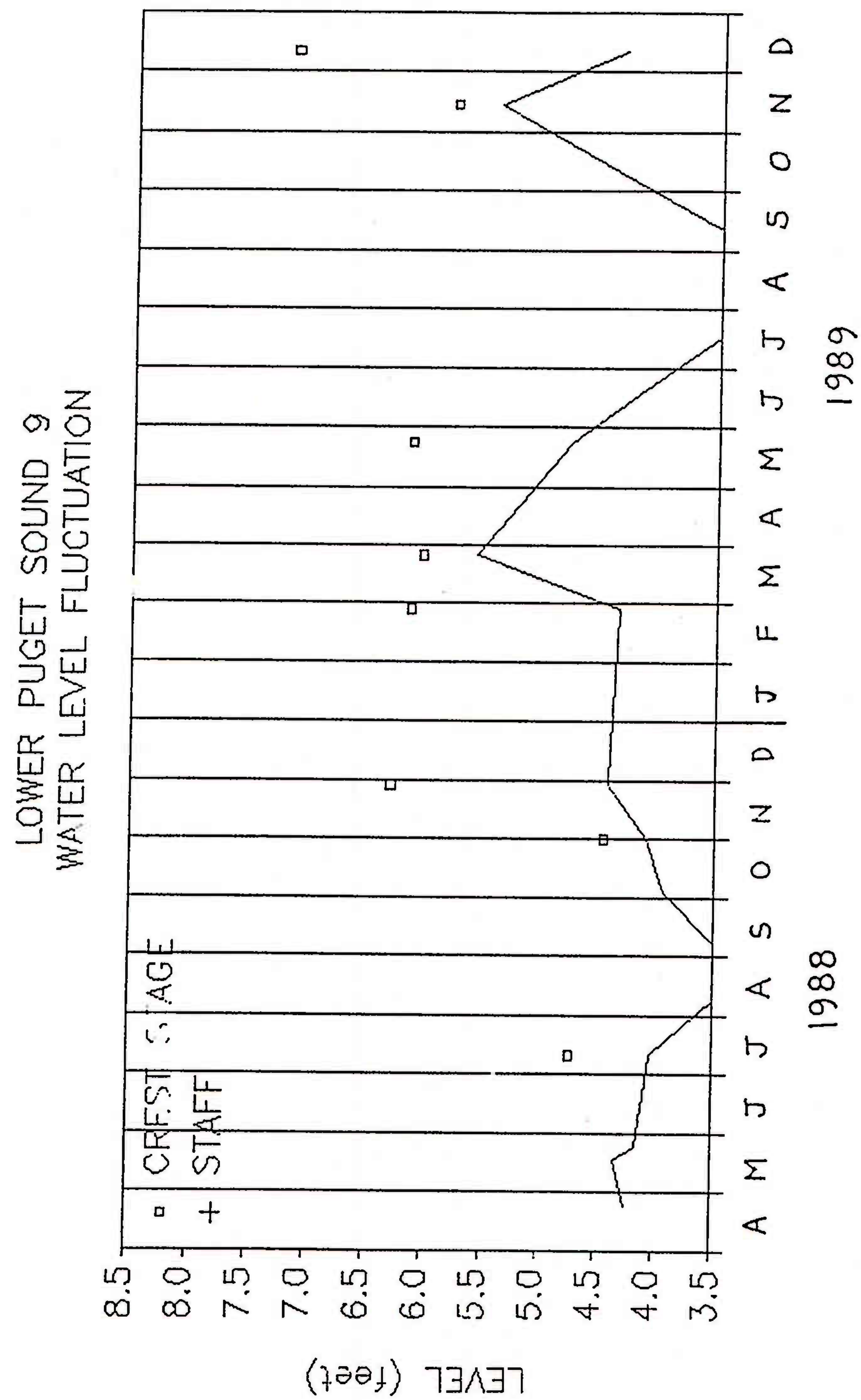

Figure 7. Plot of wetland with fluctuating base water level and high event fluctuation (FH)