Section 2   Descriptive Ecology of Freshwater Wetlands in the Central Puget Sound Basin

CHAPTER 1   MORPHOLOGY AND HYDROLOGY

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INTRODUCTION

This chapter provides an overview of the morphologic and hydrologic characteristics of palustrine (isolated or depressional freshwater) wetlands and their watersheds in the central Puget Sound Basin. Natural and anthropogenic factors that affect wetland morphology and hydrology are discussed with particular attention to the effects of development (typically, the conversion of forested lands to urban areas) on changing watershed and wetland hydrology. It was concluded that wetland water level fluctuation (WLF) estimates, measured with staff and crest-stage gages, provide a good overall indicator of wetland hydrologic conditions. Analysis methods and materials used in the PSWSMRP are also presented.

Wetlands are ecosystems that develop at the interface of aquatic and terrestrial environments when hydrologic conditions are suitable. 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 filling, draining or outlet modification, while others may be affected by secondary impacts, including increased or decreased quantity and reduced quality of inflow water.

The morphology of a wetland and the wetland's position within the landscape greatly influences its' characteristics. Morphology is used here to describe the wetland's physical shape and form. As a result of a wetland's shape, it may contain significant pooled areas with little or no flow gradient (termed an open-water system), or alternatively, it may show evidence of channelization and contain a significant flow gradient (termed a flow-through system). In some instances, a wetland may also form in a local or closed depression (termed a depressional system).

The outlet condition of a wetland, as defined by the degree of flow constriction, has a direct effect on wetland hydrology and hydroperiod. Finally, a wetland's position in the landscape is also a key factor affecting wetland hydrologic conditions. Palustrine (isolated, freshwater) wetlands usually have relatively small contributing watersheds and often occur in areas with groundwater discharge conditions.

Hydrology is probably the single most important determinant for the establishment and maintenance of specific types of wetlands and wetland processes (Mitsch and Gosselink 1993). Water depth, flow patterns, and the duration and frequency of inundation 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, along with the physical features noted above, are the major factors that influence the hydrology of palustrine wetlands.

PUGET SOUND WETLANDS AND STORMWATER MANAGEMENT RESEARCH PROGRAM

The Puget Sound Wetlands and Stormwater Management Research Program was established to determine the effects of urban stormwater on wetlands and the effect of wetlands on the quality of urban stormwater. There are two primary 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 both studies, the hydrologic and morphologic conditions of the wetlands had a direct effect on observations involving water quality, soils, and the plant and animal communities.

This paper presents hydrologic information gained from a broad overview of the hydrology of 19 wetlands (representing a variety of watershed development conditions) studied from 1988-95, and specific information on the hydrology of two wetlands (one each in an urban and nonurban area) intensively studied from 1988-90 (B3I and PC12, respectively. (Study site locations are shown in Section 1, Figure 1).

WETLANDS IN URBANIZING AREAS

Wetlands have received increased attention in recent years as a result of continuing wetland losses and impacts resulting from new development. In urbanizing areas, the quantity and quality of stormwater can change significantly as a result of land-use conversion 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. 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 of wetlands.

Wetland hydrology is often described in terms of its hydroperiod, the pattern of fluctuating water levels resulting from the balance between water inflows and outflows, topography, subsurface soil, geology, and groundwater conditions (Mitsch and Gosselink, 1986). Wald and Schaefer (1986) referred to seasonal water level changes as the "heartbeat" of Pacific Northwest palustrine systems.

WETLAND HYDROLOGIC FUNCTIONS

Wetlands provide many important hydrologic, ecological, and water quality functions. Specific hydrologic functions include flood protection, groundwater recharge, and streamflow maintenance. Wetlands provide flood protection by holding excess runoff after storms, before slowly releasing it to surface waters. While wetlands may not prevent flooding, they can lower flood peaks by providing detention of storm flows.

Wetlands that are connected to groundwater or aquifers provide important recharge waters. Wetlands retain water, allowing time for surface waters to infiltrate into soils and replenish groundwater. During periods of low streamflow, the slow discharge of groundwater maintains instream flows. The connection of wetlands with streamflows and groundwater make them essential in the proper functioning of the hydrologic cycle.

HYDROLOGY OF PALUSTRINE WETLANDS

The hydrology of palustrine wetlands is governed by the following components: precipitation, evapotranspiration, surface inflow, surface outflow, groundwater exchange, and change in wetland storage (Figure 1-1). In a hydrologic balance, these components are represented by the following equation (Reinelt et al., 1993):

$$P + I +/- G +/- \quad S = ET + O \qquad (1)$$

where P = precipitation; I = surface inflow; G = groundwater exchange, S = change in wetland storage, ET = evapotranspiration; and O = surface outflow.

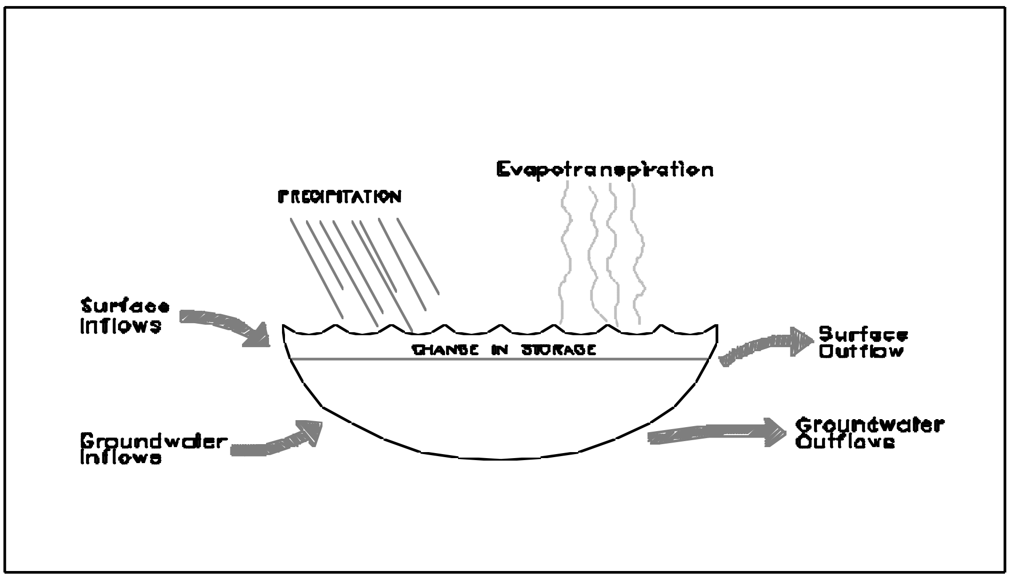

Figure 1-1. Wetland water budget components

Precipitation

Precipitation is determined by regional climate and topography. Approximately 75 percent of the total annual rainfall occurs from October to March during a well-defined wet season in the Puget Sound region. Generally, annual precipitation totals across central Puget Sound increase further east with increasing elevation. Rainfall tends to be more uniform geographically during the wet season, and more variable and intense during short dry-season cloud bursts.

Surface Inflows

Surface inflows result from runoff generation in the wetland's watershed. The quantity of surface inflows are determined by watershed land characteristics such as cover (e.g., impervious surface, forest), soils, and slope, as well as the wetland-to-watershed ratios. The rate of water delivery to the wetland is also affected by the predominant flow type in the watershed (e.g., overland or sheet flow, subsurface flow or interflow, concentrated flow). Generally, as a watershed becomes more developed, with more constructed storm drainage systems, the more rapid the hydrologic response in the watershed.

Groundwater

The role and influence of groundwater on wetland hydrology are highly variable. The exchange of water between the wetland and groundwater is governed by the relative elevations of surface water in the wetland and surrounding groundwater, as well as soil permeability, local geology and topography. Numerous studies have discussed the importance of groundwater in maintaining wetland hydrology (Winter, 1988, Surowiec, 1989, Mitsch and Gosselink, 1986). Wetlands can be discharge or recharge zones for groundwater, or both depending on the time of year. The palustrine wetlands studied in this research are predominantly groundwater discharge zones (i.e., water discharges from groundwater to the wetland).

Groundwater flow to wetlands can be quantitatively estimated using Darcy's Law, an empirical law governing groundwater flow:

$$Q = K * (dH/dL) * A \qquad (2)$$

where K = hydraulic conductivity, dH/dL = the hydraulic or piezometric gradient and A = cross-sectional area or control surface across which groundwater flows.

In the detailed study of two wetlands, shallow and deep piezometers were installed at both wetlands to estimate the horizontal and vertical components, respectively, of groundwater flow to the wetlands.

Change in Wetland Storage

Wetland storage changes seasonally and in response to storm events. The water storage can be estimated as the mean water depth of the wetland multiplied by the areal extent of the wetland (Mitsch and Gosselink, 1986). Seasonal changes in wetland storage are attributable to the local patterns of precipitation and evapotranspiration.

Duever (1988) asserted that the prime factor controlling seasonal fluctuation is drainage basin topography and that wetland water levels generally coincide with regional groundwater levels. Surowiec (1989) noted that steep slopes adjacent to a wetland can also lead to increased groundwater inputs, particularly on a seasonal basis.

Event changes in wetland storage result from increased surface or ground water inputs associated with precipitation. Reinelt and Horner (1990), Azous (1991), and Taylor (1993) referred to this as water level fluctuation, and estimated it for an occasion i as the difference between a crest-stage measurement (peak water level since the previous sampling occasion) and the instantaneous staff-gage measurement.

Evapotranspiration

Evapotranspiration (ET) consists of water that evaporates from wetland water or soils combined with the water that passes through vascular plants that is transpired to the atmosphere. Solar radiation, temperature, wind speed and vapor pressure are the main factors influencing evaporation rates (Linsley et al., 1982).

The ratio of ET to evaporation varies widely depending on vegetation type and site conditions. Reported ET ratios vary between 0.67 and 1.9 (Dolan et al., 1984; Boyd, 1987; Koerselman and Beltman, 1988). Generally, emergent wetland vegetation transpires more than woody vegetation; however, factors such as plant density also effect transpiration rates. Evapotranspiration is greatest from May to August (exceeding 100 mm per month) and least from November to March.

Surface Outflow

Surface outflows are affected by all the hydrologic factors noted above. For wetlands with relatively large watersheds, outflows are often comparable in magnitude to inflows. The physical features that affect surface outflows include outlet conditions, wetland-to-watershed ratios, and wetland morphometry.

RESEARCH METHODS AND WETLAND DESCRIPTORS

Many of the methods and materials used for morphologic, hydrologic, and watershed data collection were previously reported in PSWSMRP papers (Reinelt and Horner, 1990; 1991; Taylor, 1993). This paper provides a summary of the methods, with additional information on data processing and analysis.

Wetland Morphology

Three different measures of wetland morphology that influence the hydrology and hydroperiod of wetlands were defined by Reinelt and Horner (1990): wetland shape/type (open water, flow through, depressional), outlet condition, and wetland-to-watershed ratio. Wetlands were classified as open-water systems if significant open water pools were present and surface water velocities were predominantly low (less than 5.0 cm/s). Wetlands were classified as flow-through systems if there was evidence of channelization and significant water velocities. All depressional wetlands are also open water wetlands.

Outlet conditions were defined by level of constriction (Reinelt and Horner, 1991; Taylor, 1993) as high (e.g., undersized culvert, closed depression, confined beaver dam), or low to moderate (e.g., overland flow to stream, oversized culvert, broad bulkhead or beaver dam). The wetland-to-watershed ratio was determined by the wetland and contributing watershed areas. Watershed areas were delineated based on USGS quadrangle map contours and wetland areas were obtained from the King County Wetlands Inventory (1992). The hydroperiod of wetlands with low wetland-to-watershed ratios (less than 0.05) tends to be dominated by surface inflows, whereas wetlands with higher ratios are more influenced by regional groundwater conditions.

Watershed Characteristics

Changes in land use ultimately affect wetlands receiving water from an urbanizing drainage basin. Different land uses have unique combinations of factors that directly affect watershed hydrology, such as imperviousness and vegetative cover. By collecting information about drainage basin land use, it is possible to link wetland hydroperiod characteristics to specific land uses, as well as general changes associated with urban development.

A geographic information system (GIS) was developed to manage land use data for the watersheds of the study wetlands, and to facilitate quantitative and graphical analysis of land-use patterns. Land-use classifications, based on a national standard (Anderson, 1976), were determined from 1989 aerial photographs and subsequently digitized into Arc/Info (Reinelt et al., 1991). For each study site, the GIS contained information about total watershed and wetland area, and the area and percent of watershed area for each land use type (e.g., urban, agriculture, forest).

Watershed Imperviousness

The literature consistently identifies hydrologic effects of urbanization with increased impervious areas within the watershed (Schueler, 1994). Impervious area increases within a watershed reduce evaporation and infiltration, and as a result of forest clearing for urban conversion also result in a loss of vegetative storage and decreased transpiration (Lazaro, 1979).

Imperviousness was estimated from aerial photos and empirical relationships between land uses and percent impervious cover (Table 1-1, Gluck and McCuen, 1975; Alley and Veenhuis, 1983; KCSWM, 1990). This estimation technique was found to produce results consistent with values used in Puget Sound lowland hydrologic models (PEI, 1990; SCS, 1982). Effective impervious areas (impervious surfaces connected to a storm drainage system) were also estimated according to a formula reported by Alley and Veenhuis (1983) based on drainage basins in the Denver area:

$$EIA = 0.15\ TIA^{1.41} \qquad (R^2 = 0.98, \text{standard error} = 7.5\%) \quad (3)$$

where EIA and TIA = percent effective and total impervious area, respectively.

Table 1-1. Impervious and effective impervious areas associated with land uses.

CODE	NATIONAL STANDARD	IA%	EIA%	Reference
111	Low Density SFR (<1 unit/acre)	<15	4	a
112	Med. Density SFR (1-3 unit/acre)	20	10	a
113	High Density SFR (3-7 units/acre)	40	25	a
114	Mobile Homes	70	60	b
115	Low Density MFR (>7 units/acre)	80	72	b
120	Commercial (general)	90	85	b
121	Retail sales and services	80	72	b
123	Offices and professional services	75	66	b
124	Hotels and Motels	75	66	c
131	Light Industrial	60	48	d
132	Heavy Industrial	80	72	c
144	Freeway Right-of-way	100	99	b
151	Energy Facilities	80	72	c
152	Water Supply Facilities	80	72	c
155	Utility Right-of-way	5	1.5	c
160	Community Facilities (general)	75	66	c
161	Educational Facilities	40	27	b
162	Religious Facilities	70	60	c
171	Golf Courses	20	10	b
172	Parks	5	1.5	b
190	Open Land (general)	2	1	c
192	Land being developed	50	37	c
193	Open space - designated	2	1	c
200	Agricultural Land	5	1.5	c
300	Grassland	2	0	c
400-430	Forest Lands	2	0	c
440	Clearcut areas	5	0	c

REFERENCES:

a. King County Surface Water Management (1990)
b. PEI (1990)
c. Estimate based on similar land uses
d. Alley and Veenhuis (1983)

WATERSHED SOILS

The Soil Conservation Service (SCS) Soil Survey for King County (Snyder et al., 1973) was used to evaluate the drainage characteristics of the soils in each of the 19 drainage basins. Two soil parameters were reviewed to determine which would be an appropriate index of the soil hydrologic characteristics relevant to the analysis: permeability and general drainage characteristics.

Soil permeability, is measured as a range of infiltration rates, the units of which are distance/time. Soil permeability for the majority of the soils found in the watersheds was in the range of 2.0 - 6.3 inches/hour. The drainage class is a more general description of the soil characteristics such as “Moderately well-drained” or “Somewhat excessively drained.” Many soils in the Pacific Northwest (e.g. Alderwood series) are underlain by glacial till, a hardpan layer that limits the ultimate depth of percolation and plays an important role in routing subsurface flow. Drainage class was therefore thought to be a better estimator of the hydrologic role of the watershed soils than permeability because it represents the effects of the multiple soil horizons characterized as a particular soil type; an infiltration rate is based on the top soil layer.

For this study, a watershed soils index (WSI) was calculated as an area weighted mean of soil drainage classes found in the study basins. Each of six drainage classes described by the SCS was assigned a number that ranged from 1 to 6, with lower numbers representing poorly drained soils (Table 1-2). The range of the WSI corresponded with the SCS Hydrologic Soil groups, which are used in the Curve Number method of runoff estimation. The WSI was preferred for the analysis because it describes soil drainage to a finer level than the hydrologic soil group.

Table 1-2. Soil drainage classes and watershed soils index (WSI).

Drainage Class	WSI	SCS Hyd. Group (1)	Examples
Very poorly drained	1	(D)	(Muck)
Poorly drained	2	D	Norma, Bellingham
Somewhat poorly drained	3	(D)	(Oridia, Renton)
Moderately well drained	4	C	Alderwood, Kitsap
Well drained	5	B, C	Ragnar, Beausite
Somewhat excessively drained	6	A	Everett, Indianola

(1) Parenthesis indicates soils that were not found in any of the wetland watersheds.

WETLAND HYDROLOGY

Wetland Water Level Measurements and Fluctuation

Water level measurements in wetlands can be made using a variety of gages or instruments. Readings can be either instantaneous, continuous, or representative of a peak or base level since the last site visit. In the PSWSMRP, we utilized staff and crest stage gages to record instantaneous water levels and peak occasion water levels, respectively, during each site visit. At two wetlands (Bellevue 3I and Patterson Creek 12), continuous water levels were recorded over a two-year period (1988-90) using automatic data recorders. Gages were placed in open water areas or areas of channelized flow where water level measurements could be attained throughout most of the year.

The crest-stage and staff gage data were used to estimate wetland water level fluctuation. To estimate the water level fluctuation at a wetland site, two factors were considered: (1) the water level prior to the storm event, hereafter referred to as the base water level, and (2) the water level change resulting from the event. Four methods of calculating water level fluctuation were investigated in a preliminary analysis before choosing a preferred method to use in the analysis (Azous 1991, Taylor, 1993). The methods differed primarily in how the base water level prior to the stormwater influx was estimated. The fluctuation was then calculated as the difference between the maximum and base water levels. The selected method used the midpoint of the sampling interval to estimate the base water level:

$$WLF_i = C_i - 0.5(S_i + S_{i-1}) \qquad (4)$$

where WLF_i , C_i , and S_i = the water level fluctuation, crest level, and base level, respectively for sampling occasion i, and S_{i-1} = the base level for occasion i-1.

The water level fluctuation data were used in three ways during the analysis. The data from each sampling occasion were used when evaluating the relationship between precipitation and water level fluctuation. Mean and maximum study period WLF values were used when assessing the effects of land use and wetland characteristics on the wetland hydroperiod.

Seasonal Fluctuation in Wetland Water Levels

Seasonal fluctuation in wetland water levels is probably the most important factor governing wetland development and functioning in the Pacific Northwest (Wald and Schaefer, 1986). A quantitative measure of seasonal WLF was developed based on an examination of the hydroperiod plots for the study wetlands.

May and October are months when the water level changes dramatically in those sites that undergo large seasonal fluctuations. Noting this, the dry season water level was estimated as the mean of staff gage measurements collected during the months June through September. Similarly, the wet season water level was estimated as the mean of staff gage measurements collected between November and May. Approximately equal sample sizes were used to calculate each of the seasonal mean water levels. The mean seasonal difference in water levels was calculated as the difference in these seasonal mean water levels. The data from the early study period (April 1988 - April 1991) were used to calculate seasonal WLFs.

A second measure of the seasonal WLF is the range of water levels observed. The water depth range was calculated as the difference between the study period maximum and minimum water levels. This measure, used with the mean seasonal water level difference described above, provided a picture of the wetland hydroperiod suitable for analysis, because both typical and extreme events were addressed.

Length of Summer Dry Period

The length of the summer dry period (as defined by the absence of surface water) was also analyzed; however, this dry period estimate was subject to the following limitations: (1) Estimating the length of the dry period was affected by the flow characteristics and topography within the wetland; that in turn determined which areas dry first. Because gages were placed in the wetland areas thought to be the last to dry out during the summer, a water level of 3 cm or less constituted “dry” in this analysis. (2) The exact length of the dry period was uncertain, because of the frequency of site visits. The approximate monthly sampling interval during the summer months did not allow for the determination of the date the water level reached “zero.” To compensate for this uncertainty, the transition from “wet” to “dry” (or vice versa) was assumed to occur at the midpoint of the sampling interval.

RESULTS AND THE CONCEPTUAL MODEL

Descriptive results of the morphologic and hydrologic analysis of the study wetlands are shown in Table 1-3. The various water level fluctuation patterns observed in the wetlands and a conceptual model relating wetland and watershed characteristics to wetland hydroperiod are also presented below.

Table 1-3. Wetland and watershed morphologic and hydrologic characteristics.

Wetland	Outlet Condition	Outlet Constriction	WLF Type	Dry in Summer?	System Type	% TIA 1989	% TIA 1995
AL3	None	high	FL	Y	OW/D	4	4
B3I	Culvert	high	SH	N	FT	55	55
BBC24	Beaver dam	low	SL	N	OW	3	11
ELS39	Culvert	high	FH	Y	OW	25	25
ELS61	Stream	low	FL	N	OW	5	11
ELW1	Lake	low	SH	N	FT	20	20
FC1	Beaver dam	moderate	S/FH	N	FT	31	31
HC13	Beaver dam	high	FL	N	OW	4	4
JC28	Stream	low	SL	Y	FT	20	21
LCR93	None	high	FH	Y	FT	6	6
LPS9	Drain inlet	high	FH	Y	FT	22	22
MGR36	Stream	low	SL	N	FT	3	3
NFIC12	None	high	FL	Y	OW/D	2	40
PC12	Beaver dam	high	FL	N	OW	5	7
RR5	Beaver dam	low	FL	N	OW	3	3
SR24	Road	low	FL	N	OW	2	2
SC4	Culvert	low	SL	Y	FT	12	12
SC84	Stream	low	FL	Y	OW	19	17
TC13	Drain inlet	moderate	FL	Y	OW	2	2

WATER LEVEL FLUCTUATION PATTERNS

Based on the water level fluctuation analysis, wetlands were classified into four distinguishable types of hydroperiods (Figure 1-2): (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 were defined quantitatively using a threshold of 20 cm. Wetlands with a base water level range less than or greater than 20 cm were considered stable or fluctuating, respectively. Similarly, wetlands with event fluctuations less than or greater than 20 cm were considered low or high, respectively. Figure 1-2 shows the WLF pattern for the 19 study wetlands.

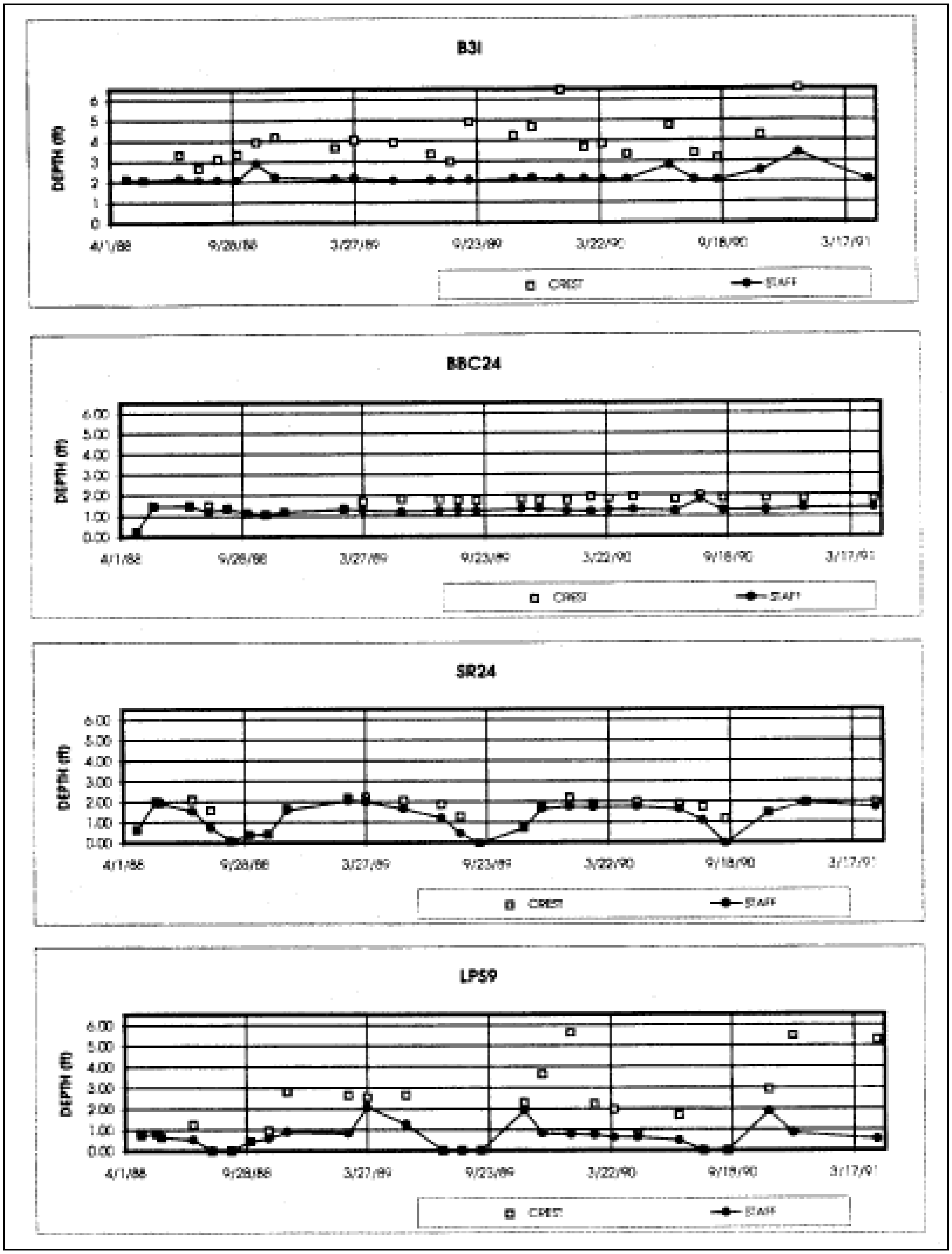

Figure 1-2. Four Water Level Fluctuation Patterns

CONCEPTUAL MODEL OF INFLUENCES ON WETLAND HYDROPERIOD

A conceptual model was developed by Taylor (1993) to characterize the relationships between watershed and wetland morphological characteristics and wetland hydroperiod (Figure 1-3). This model was used as a basis to examine, through application of a multivariate regression model, which wetland and watershed hydrologic processes, and factors governing these processes, had the greatest influence on wetland hydroperiod. Results from this analysis are presented in Section 3 of this report.

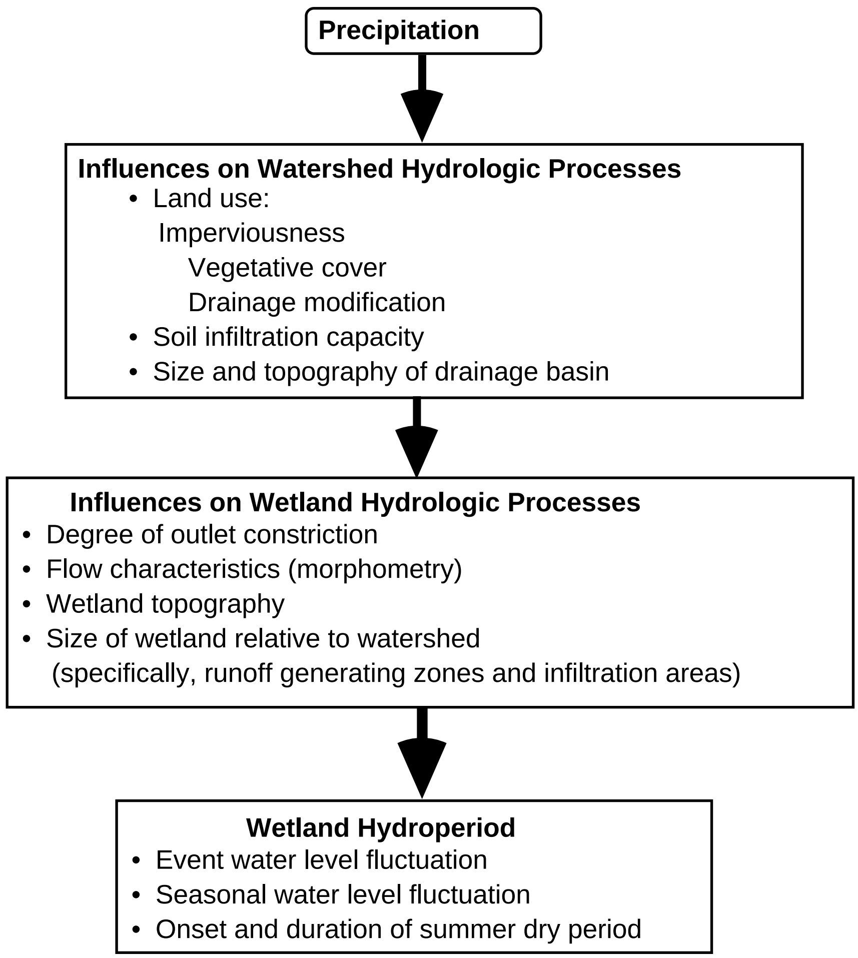

Figure 1-3. Conceptual model of influences on wetland hydroperiod.

CONCLUSIONS

There are many descriptive measures of the morphologic and hydrologic characteristics of freshwater wetlands in the central Puget Sound basin. This paper summarized those that were examined and utilized by the PSWSMRP. The physical shape or type of wetland (e.g., open water, flow-through), the wetland's position within the landscape (particularly as related to the wetland-to-watershed ratio), and the degree of outlet constriction were presented as key wetland characteristics affecting hydroperiods. The imperviousness, land cover, and soils of the watershed were also found to be important characteristics affecting surface runoff and wetland hydrology.

The quantity of stormwater entering many wetlands in the central 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 the hydrology, which in turn may affect the plant and animal communities. If the relationships between watershed and wetland changes and their impacts on wetland hydroperiod can be characterized and documented, it may be possible to mitigate these effects through improved watershed controls or development regulations.

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