MONITORING A WETLAND WASTEWATER TREATMENT SYSTEM AT CANNON BEACH, OREGON

by

Kenneth T.Franklin

A RESEARCH PAPER

submitted to

THE DEPARTMENT OF GEOGRAPHY

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

April 1987

Directed by
Dr. Robert E. Frenkel

ACKNOWLEDGEMENTS

First and foremost thanks go to Bob Frenkel. From conception through completion of the project, his exacting standards and unflagging support (both in the office and in the field) enabled the author to complete what at times seemed an impossible task.

Research was supported in part by the Environmental Protection Agency, Region 10 under Grant No. X-000328-01-0. This paper would never have been completed without the help and support of the Oregon Division of State Lands, especially Ken Bierly and Joyce Wescott.

Field work was made possible with the volunteer assistance of Irv Jones, Neal Maine, Ed Johnson, Dan Elek, and the indomitable super subaquatic crew of GGS 539. Special thanks to Doug O'Neil who devised a unique method of collecting *Daphnia*. Thoughtful criticism and advice were provided by Ralph Rogers, Don Thompson, Dave Bella, and Keith Muckleston. Thanks to Liz Frenkel for providing an efficient courier service. Last but not least, special thanks to Jean Franklin for editorial and technical assistance as well as moral support.

ABSTRACT

Since 1984, the city of Cannon Beach has used a 7 ha, two-cell red alder/twinberry/slough sedge palustrine wetland to treat chlorinated effluent from a four-cell aerated/facultative lagoon system. For three years effluent has met summer wastewater discharge limitations (10 mg/L BOD_5 and 10 mg/L TSS). Field research in 1986 concerned vegetation ecology, hydrology, and water quality to develop monitoring procedures for improved wastewater wetland management. After three years operation, a complex pattern of vegetative flooding stress is observed. Nested frequency plots (155, 50 x 50 cm within 100 x 100 cm) provide baseline data for vegetation trend assessment. Average 1986 wetland influent and effluent flow rates were .40 and .06 MGD respectively. An independent water budget estimate suggests ground water infiltration is at least 65-85% of the water loss. BOD_5 and TSS influent concentrations are reduced approximately by 40% and 85% respectively. Predictions are made for successional trends as a function of hydroperiod and microtopography.

CONTENTS

INTRODUCTION

Wetlands have been, and continue to be, subject to all sorts of abuses by humans: they are filled, drained, and used to collect inadvertent discharges of polluted water. Through a combination of clearing, draining, and flood control projects, 30-50% of the original wetland area of the continental U.S. has been lost (Office of Technology Assessment 1984). Since the 1970's there has been greater public recognition that wetlands deserve protection, as they often provide valuable ecological services, or functions, to the human population and to the biosphere as a whole (Mitsch and Gosselink 1986). These functions include cleansing polluted waters (Godfrey et al. 1985, Nichols 1983), preventing floods (Novitzki 1979, Verry and Boelter 1979), protecting shorelines (Knutson et al. 1981), and providing important habitats for flora and fauna (Williams and Dodd 1979, Odum et al. 1984).

The recognition that wetlands can improve water quality under certain situations has called attention to the planned use of both natural and artificial wetland treatment systems as cost-effective alternatives for upgrading sewage treatment facilities and treating urban and agricultural runoff. Several reviews and conferences that have dealt with the potential and limitations of wetland treatment systems include Hammer and Kadlec (1983), the U.S. Environmental Protection Agency (1983), the U.S. Environmental Protection Agency and U.S. Fish & Wildlife Service (1984), and Godfrey et al. (1985). While there are hundreds of wetland treatment facilities of various sizes and designs located in the southeastern and midwestern part of the U.S., comparatively few exist in the Pacific Northwest.

The City of Cannon Beach, on the northern Oregon coast, is among the first municipalities in the Pacific Northwest to use a natural wetland in combination with conventional technology to treat domestic wastewater. A seven hectare red alder/slough sedge/ twinberry palustrine wetland, divided into two cells in series, treats chlorinated effluent from a four-cell aerated/facultative lagoon system (Figure 1). Operation began June, 1984.

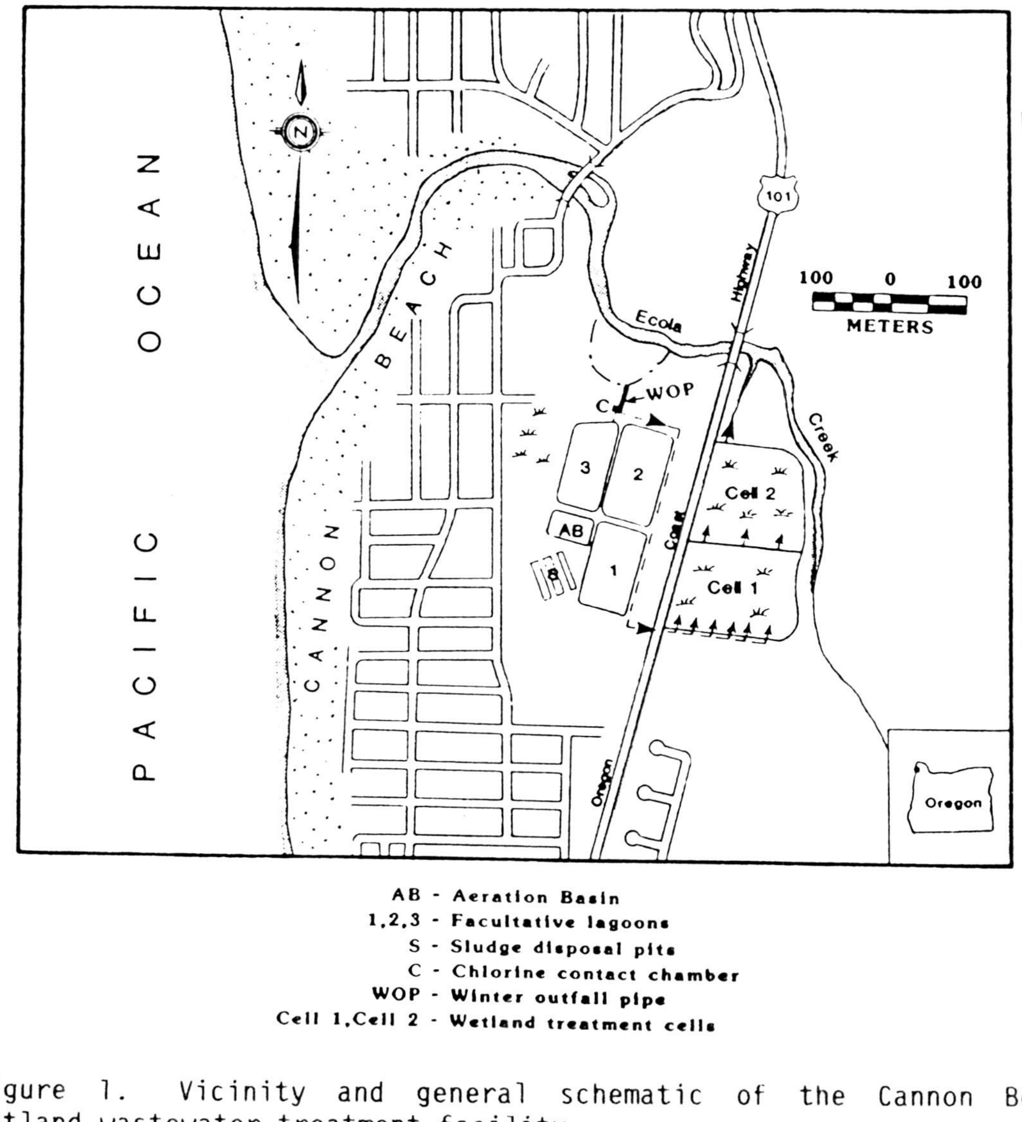


Figure 1. Vicinity and general schematic of the Cannon Beach wetland wastewater treatment facility.

Wetland treatment occurs May 1 through November 1 to meet the more stringent summer wastewater discharge standards established by the Oregon Department of Environmental Quality (ODEQ) (Table 1). These limitations are 10 mg/l BOD_5 (five-day biochemical oxygen demand) and 10 mg/l TSS (total suspended solids), hereinafter referred to as 10/10 limitations.

Table 1. Ecola Creek discharge requirements (KCM 1981).

	Monthly Average Effluent Concentrations (mg/l)	
Period	BOD_5	TSS
Pre-project (before 6/1/84)		
9/20 - 5/19	30	50
5/20 - 9/19[a]	--	--
Present (after 6/1/84)		
11/1 - 5/31[b]	30	50
5/1 - 10/31[c]	10	10

[a] Wastewater held in lagoons in summer; discharge allowed only with ODEQ written permission.

[b] Direct discharge of lagoon sewage effluent into Ecola Creek.

[c] Discharge of lagoon sewage effluent into Ecola Creek via wetland

During the 1970's, the existing three-cell, five hectare lagoon treatment system was approaching its design capacity. Required to hold sewage in the lagoons May-September by ODEQ, the city was being forced into upgrading its sewage facilities because the lagoon's storage capacity was projected to be inadequate for summer holding (KCM 1981, Thompson and Minor 1986). The problem was caused by a large influx of tourists in summer, when the permanent population of 1200 swells to as much as ten times that number at the height of the visitor season.

ODEQ's concern was for the potential public health problems associated with low summertime creek flows and high effluent discharges. The concern was that the creek would receive effluent and polluted waters would pose a hazard to the large numbers of tourists on the beach. Over a period of nearly eight years (1975-1982) several alternative proposals for upgrading the treatment system were considered and negotiated between the City's Sewer Advisory Board, state and federal resource and regulatory agencies.

Treatment alternatives ranged from conventional technologies such as chemical treatment, a package activated sludge plant and slow sand filtration to an aquaculture system, and an artificial marsh treatment system (Thompson and Minor 1986). By 1980, the city favored treatment by the artificial marsh, but the concept met with disapproval by some state and federal agencies, which cited issues of land use regulation and excessive wildlife habitat alteration (KCM 1981, Thompson and Minor 1986). In 1982, after intense negotiation, the present, and least expensive scheme -- a natural wetlands wastewater treatment system combined with improvements to the existing lagoons -- was adopted by the City Council and approved by all appropriate agencies.

WETLAND WASTEWATER TREATMENT SYSTEM

Setting

The wetland, located in Clatsop County adjacent to the Oregon Coast Highway (U.S 101), is composed of several different vegetation cover types resulting from historical patterns of land use (Figure 2). The eastern portion of the treatment cells are dominated by a Sitka spruce (*Picea sitchensis*) and red alder (*Alnus rubra*) overstory, a remnant of a once extensive Sitka spruce forest. The understory includes red elderberry (*Sambucus racemosa*), sword fern (*Polystichum munitum*) and other typical coastal species. The largest trees are located in this area (some Sitka spruce are over five feet in diameter).

Tree cover is less dense towards the western portion of the cells, a consequence of logging and highway construction. In low areas, treeless patches and stagnant pools are dominated by slough

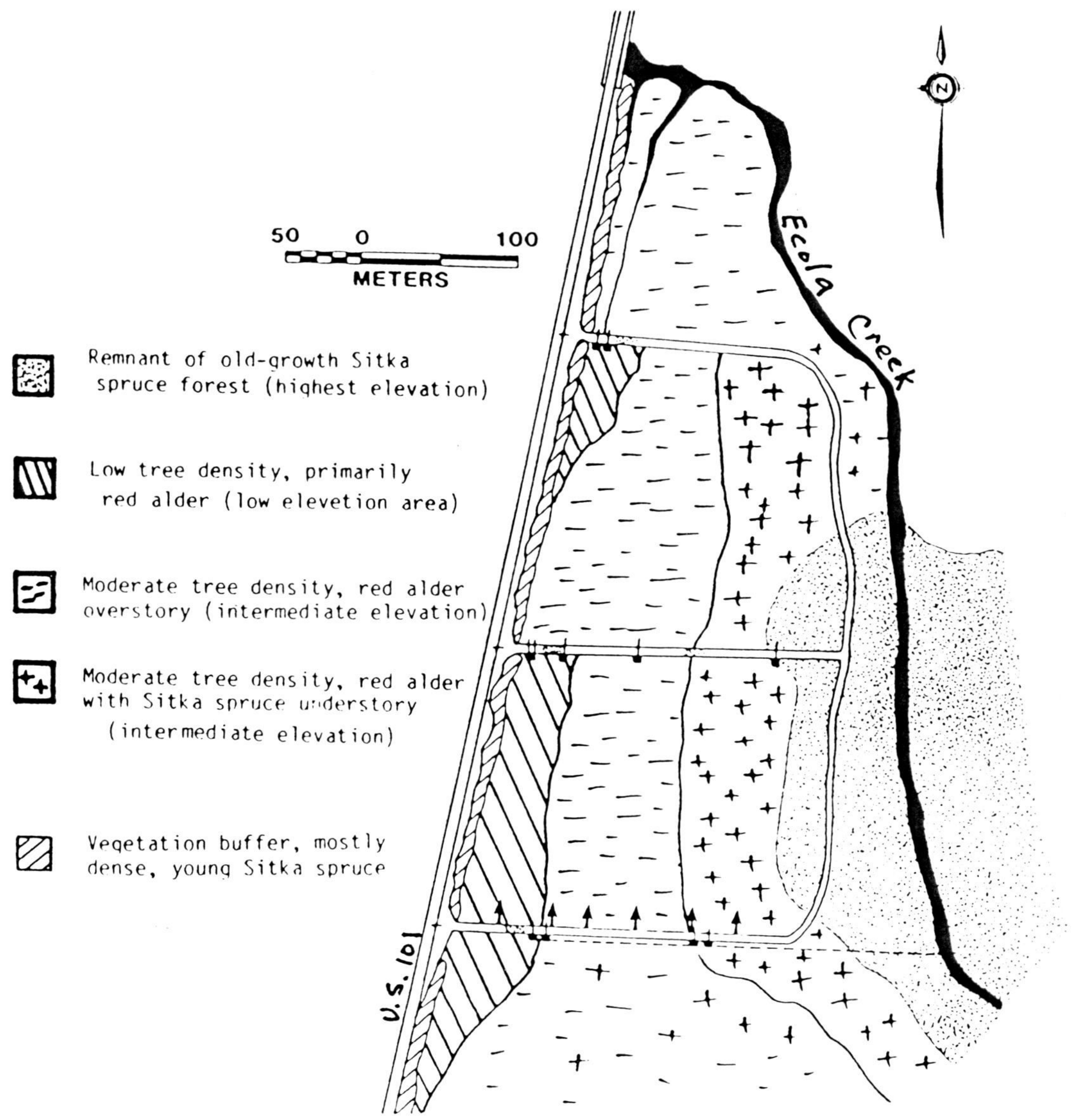


Figure 2. Vegetation cover types in the wastewater wetland in 1986.

sedge (Carex obnupta), skunk cabbage (Lysichitum americanum), and twinberry (Lonicera involucrata). The dominant understory species throughout the wetland is slough sedge.

Present flooding of the treatment cells with secondary effluent has so far had a minor influence on wetland vegetation composition and structure compared to historical direct and indirect anthropogenic disturbances. These include (1) historic filling of land for the town of Cannon Beach which restricted drainage of the wetland area; (2) clearcut logging in the 20th century, most recently in the mid-1950s; and (3) construction of Highway 101 which severed the previous wetland configuration and altered the hydrology.

The nearest climatological station is in the city of Seaside, eight miles to the north. Average annual precipitation (essentially all rainfall) is approximately 70-80 inches, about 75% of which falls during November-March. Summer months can have periods of relatively dry weather, but fog is very common and probably reduces evapotranspiration rates compared to more inland locations.

Two soil types are mapped by the Soil Conservation Service (1982) in the wetland: Nehalem silt loam and the Coquille-Clatsop complex. Nehalem silt loam is found in the areas of higher elevation near the creek, a natural levee. This is a well-drained to moderately well-drained soil formed in the mixed alluvium of the Ecola Creek floodplain. No surface sewage lagoon effluent is in contact with these soils. The Coquille-Clatsop complex is the dominant soil type in the treatment cells; these are poorly-drained soils composed of a very dark grayish brown silt loam surface layer (33 cm thick), underlain by a dark grayish brown silty clay loam and silty clay to 150 cm. Four bore holes were drilled for a foundation study by Kelly/Strazer Associates (1983) indicating the wetland soils "consist predominantly of soft organic silts with peat layers which occasionally grade to medium stiff below about 4 feet".

Design

The primary objective of the treatment system is to meet the 10/10 limitations as shown in Table 1. A secondary objective is to minimize disturbance of wildlife habitat, a habitat of importance especially for winter elk herds. During the winter a herd of Roosevelt elk, averaging 18-20 animals, wanders over the lower Ecola Creek watershed, including the project area (KCM 1981).

The treatment cells are simple in design; the clay-lined, partially rip-rapped, dikes forming the cell boundaries take advantage of the highway barrier to the west and the natural levee of Ecola Creek to the east (Figure 3). During construction, structural disturbance to the swamp was limited to occasional tree removal and placement of fill material for the dikes. A six-port discharge header on the south dike, producing a small stream of discharged wastewater localized at each pipe orifice, allows some spatial control over effluent dispersal. Hydraulic control is also

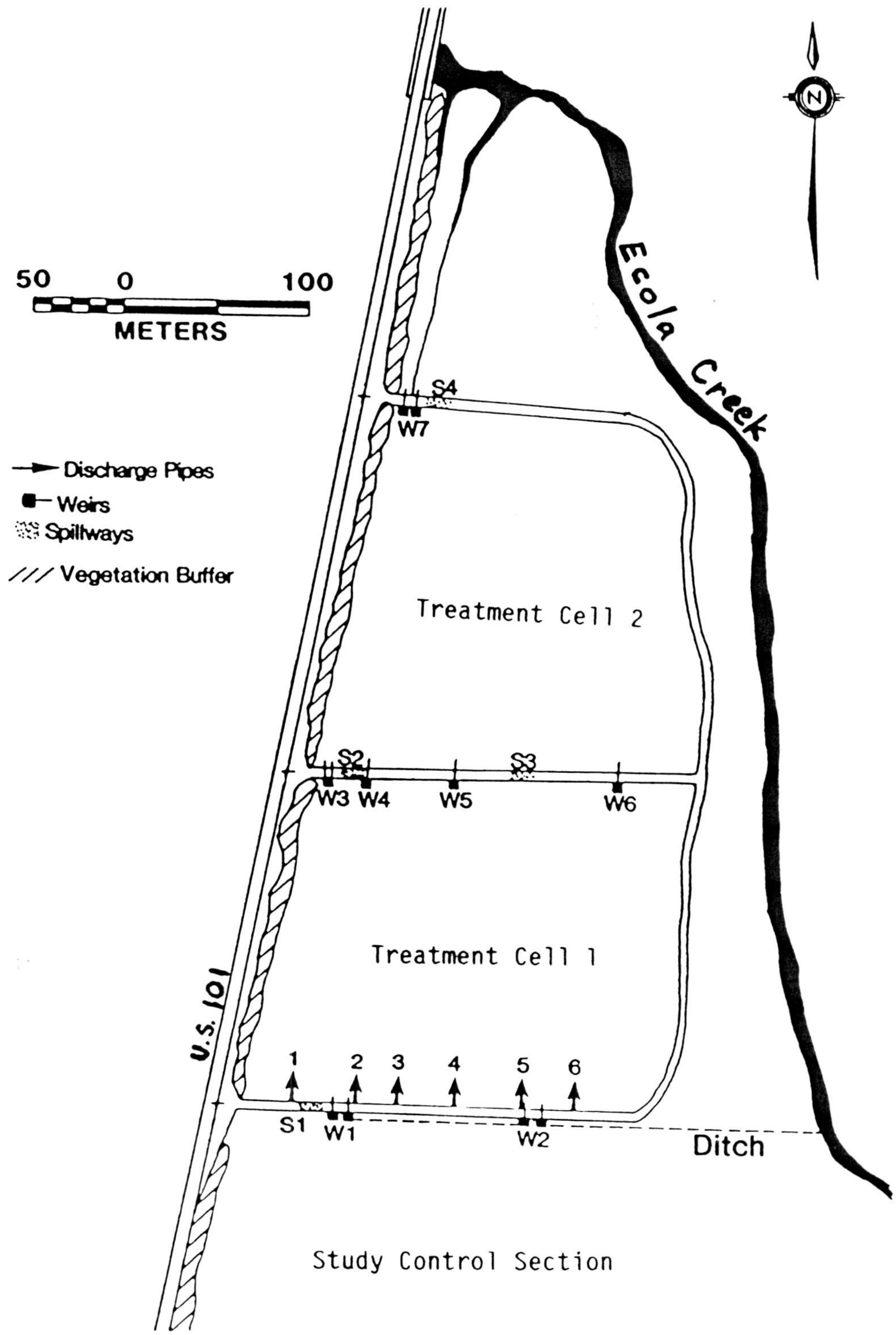


Figure 3. Schematic representation of the wetland treatment cells. Discharge pipes and weirs are not drawn to scale.

obtained by four weirs in the middle dike. For the 1986 operational season, weirs 3 and 4 were closed to discharge; weir 5 was set at a level that allowed overflow, and weir 6 had very infrequent overflow due to its higher elevational position. Weir levels are not currently calibrated to wetland water levels and the operational hydroperiod.

Figure 4 shows the generalized water dispersal pattern for the 1986 operational season. The channelization pattern and total area of inundation is of course a function of influent flow rates. Several primary channels carry higher velocity flows in the eastern section of the cells and slower velocity within deeper water areas in the lower elevational western section of the cells.

A ditch located outside of cell 1, adjacent to the south dike, is connected to Ecola Creek, allowing flushing by creek waters and sheet flow from the control section during heavy rains (Figure 3). This design helps maintain pre-project hydrologic conditions during the winter season. Spillways are also located in the dikes to help discharge high water flows. Two weirs at the north end of cell 2 allow discharge of effluent to Ecola Creek along a natural channel. During the winter, tidal influence extends to this channel causing some backflow into cell 2 (Elek, personal communication 1987). A current meter that measures average daily flow rates is located at this discharge structure.

An approximate 10 m wide vegetation buffer, primarily a dense stand of young Sitka spruce, is located along the western boundary

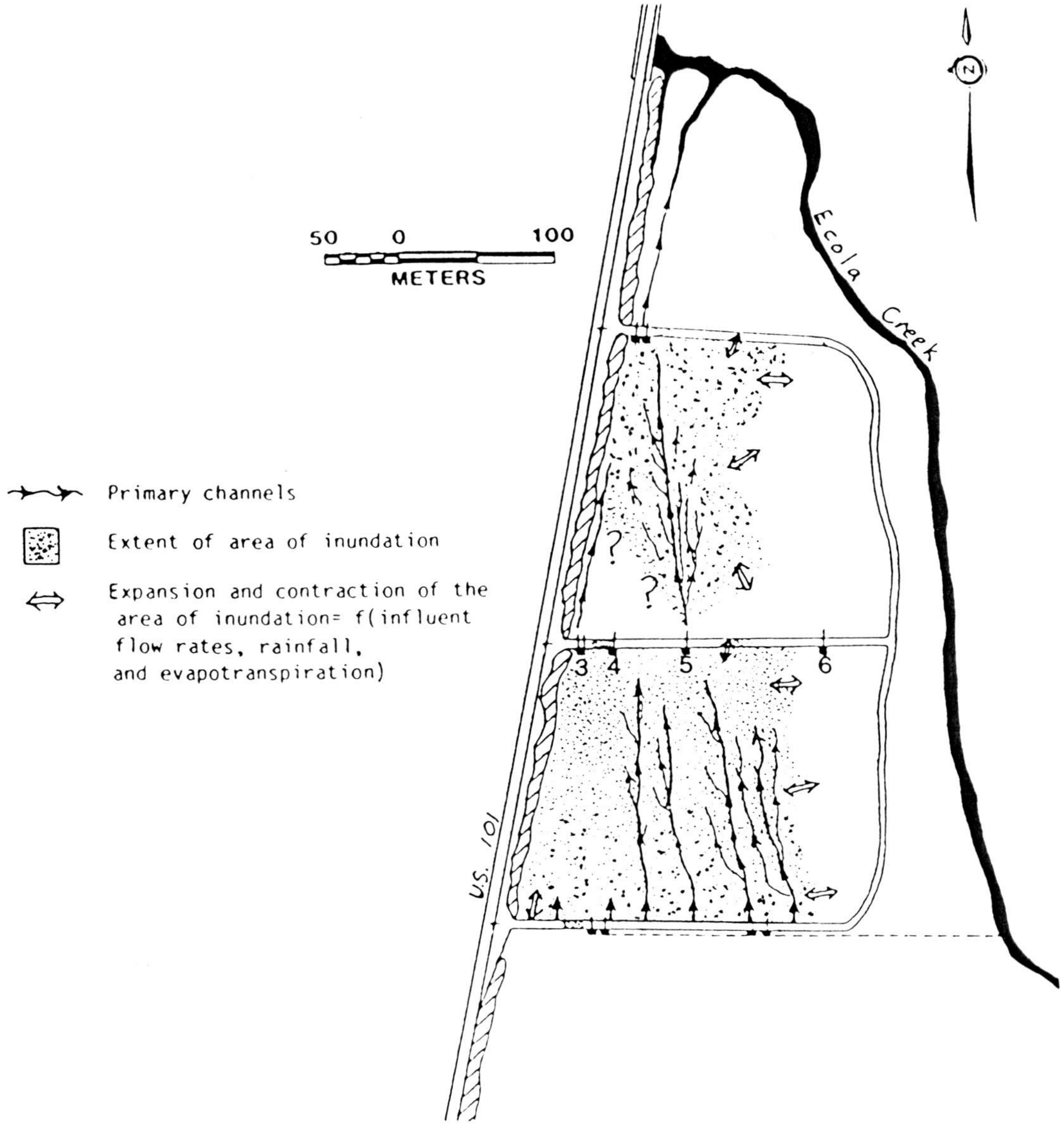


Figure 4. Generalized diagram of channelization and water dispersal for the treatment cells in 1986. Weirs 3 and 4 closed to overflow. Data is based on staff gauge observations on September 14-15 with the mean influent flow rate equal to 0.310 MGD.

of the treatment cells and provides an effective noise and visual buffer from heavy highway traffic. Fencing has been limited to chainlink gates at the dike entrances to the highway, allowing passage of curious pedestrians, fisherman, deer, and other animals.

RESEARCH OBJECTIVES

An important Section 404 Corps of Engineers permit condition for the Cannon Beach project is the following: "A biological monitoring plan will be devised to document the effects of the system's operation on floral assemblage. From the data collected, a management plan will follow which allows for optimal water level maintenance to promote desirable/beneficial vegetation assemblages within the treatment facility" (Corps of Engineers 1983). The precursor to this permit condition involves the need for data to help make informed decisions on future proposals to use wetlands for tertiary treatment. In the absence of data and background, approval of the Cannon Beach project was based on a need for a data base and experience for wetland wastewater treatment in the Pacific Northwest.

Treatment plant operators currently monitor BOD_5, TSS, chlorine residual, and fecal coliform on a bi-weekly basis for facultative lagoon and wetland influent and effluent; hydrological monitoring is limited to automatic recordings of lagoon and wetland influent and effluent flow rates. Despite capital costs of over $1.5 million for the project, no funds were allocated for any biological monitoring. Although a requirement of the Corps of Engineers' permit conditions, the only biological monitoring conducted prior to 1986 was a volunteer effort by Corps of Engineers (COE), Oregon Department of Fish & Wildlife (ODFW), and U.S. Fish & Wildlife (USFWS) staff to establish a baseline survey for vegetation trend assessment just prior to system operation (Rogers 1984).

A research program reported upon here, funded by the Environmental Protection Agency, Region 10, conducted April through September, 1986 sought to repeat the 1984 vegetation survey and develop additional ecological and hydrological monitoring methods for improved wastewater wetland management. Because of the uncertainty associated with funding future monitoring efforts, inexpensive yet effective monitoring procedures are desired.

Three objectives of the research study addressed the following questions: (1) how have water and to a lesser extent nutrient additions since 1984 affected vegetation composition and structure?; (2) is the hydrological system operating as predicted and how might it vary as the wastewater wetland ages?, and; (3) how is the facility functioning with respect to improved wastewater treatment? These questions will each be dealt with separately in the following sections of the paper.

VEGETATION ECOLOGY

Introduction

The primary disturbance associated with effluent discharge into the wetland is plant flooding stress. Frequent winter flooding and occasional flooding during the growing season is normal for the site. An estimated hydroperiod for the site (Figure 5), however, shows flooding now occurs during the growing season, the period during which plants are most susceptible to metabolic stress associated with anaerobiosis in flooded soils (Bedinger 1979, Gill 1970). The operational hydroperiod is determined by influent flow rates and weather conditions (Figures 6 and 7).

The degree of flooding stress imposed upon the plant community is a complex phenomena dependent on multiple factors. For example, Van der Valk (1981) describes a model based on the interaction of plant life history traits -- life span, propagule longevity, and propagule establishment requirements -- and the timing of water drawdowns and flooding events; the operational hydroperiod places selection pressure on those species capable of reproducing and growing in the new conditions. At the Cannon Beach site, however, little autecological data exists for even the dominant species, prohibiting the construction of such a model (except perhaps for red alder). As shown by the profiles of Transects C and D (Figure 8) and the water dispersal pattern (Figure 4), predicting flooding stress and subsequent successional change is

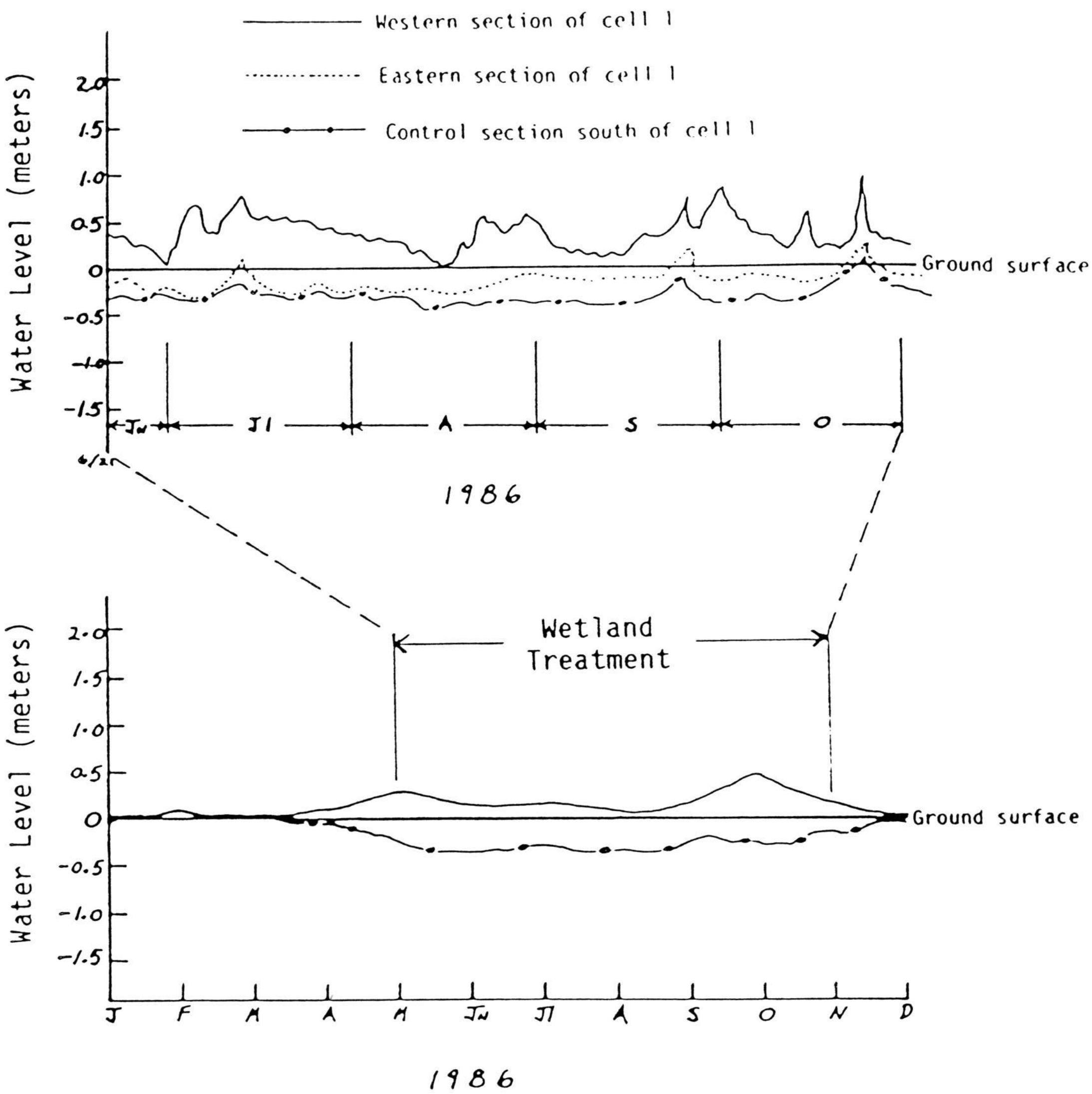


Figure 5. Estimated hydroperiods for the Cannon Beach wastewater wetland. Upper diagram provides details during late spring through early fall; lower diagram is generalized for the year.

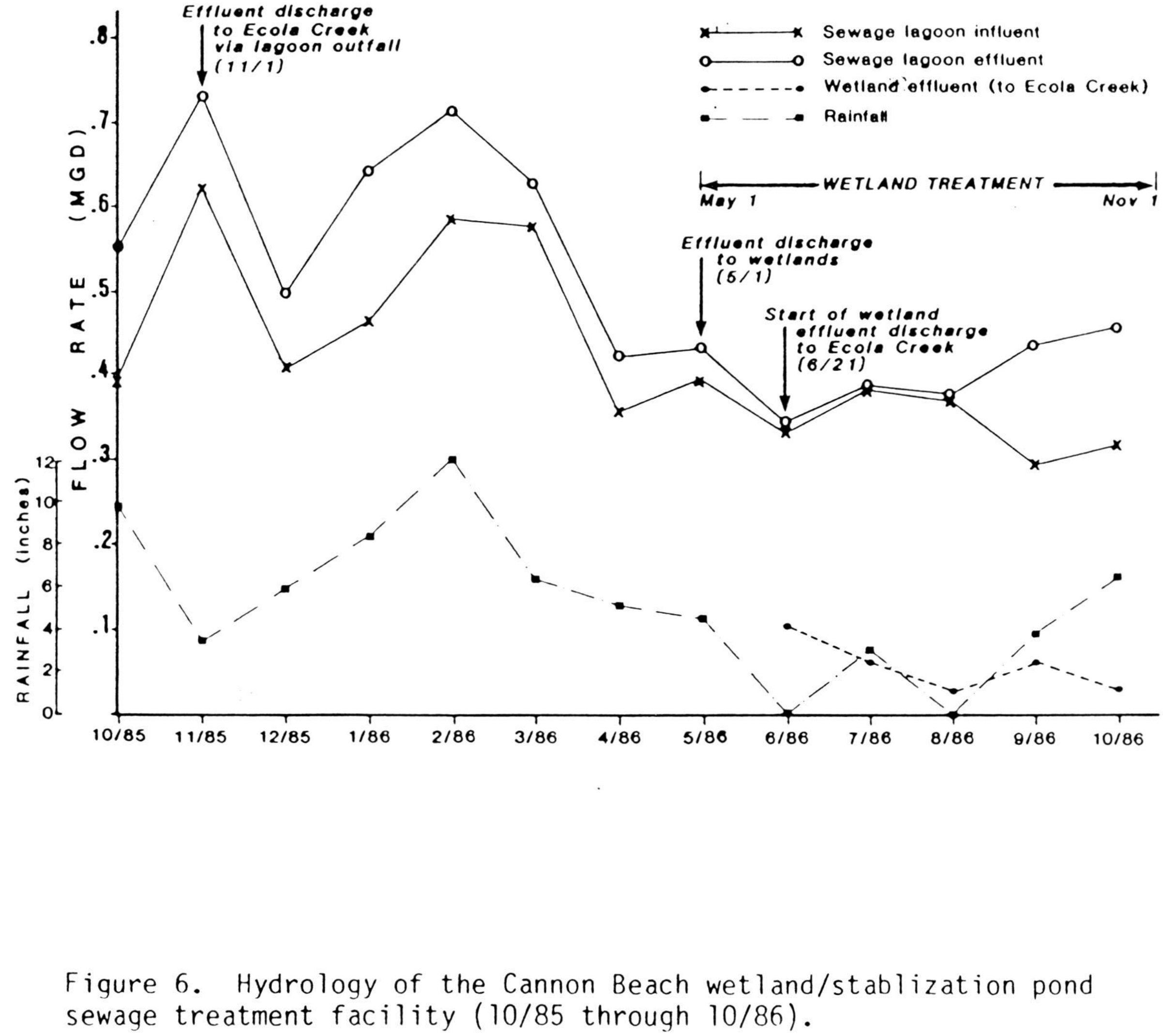


Figure 6. Hydrology of the Cannon Beach wetland/stablization pond sewage treatment facility (10/85 through 10/86).

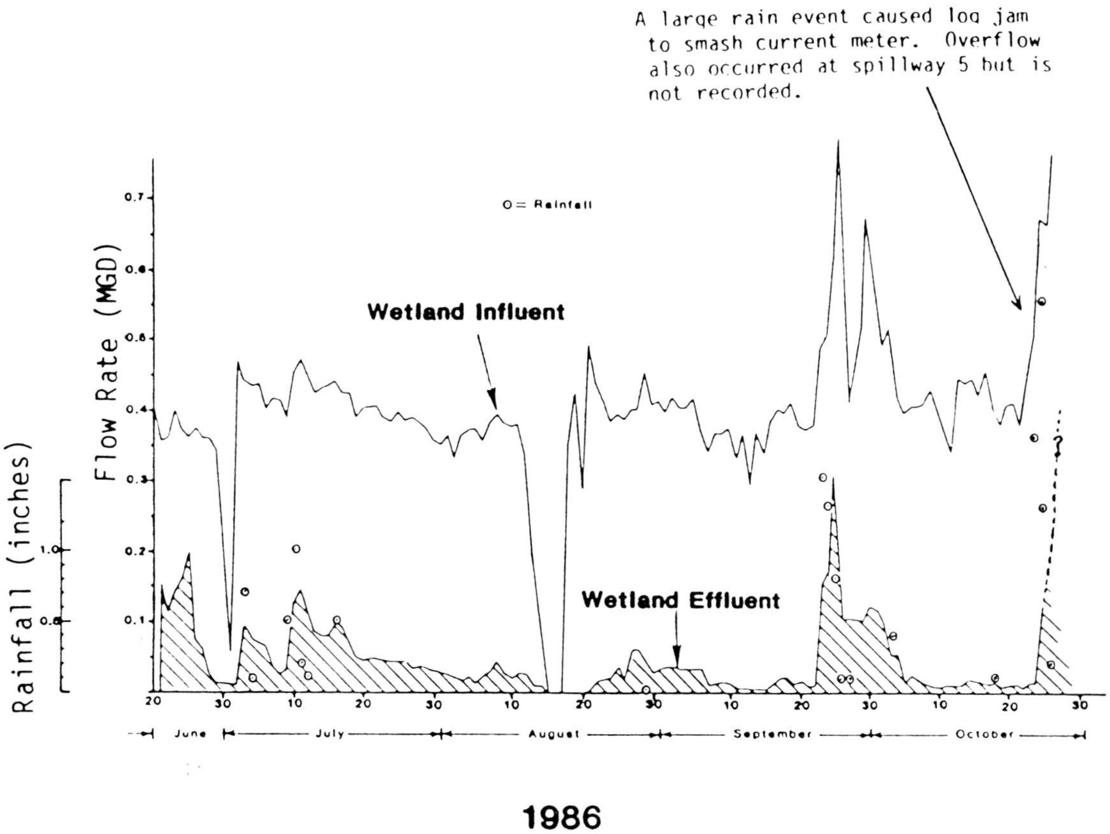


Figure 7. Wetland influent and effluent flow rates and rainfall for the 1986 operational season. Rainfall is recorded at the Cannon Beach City Hall.

a complex spatial and temporal problem given different operational hydroperiods throughout the treatment cells.

During the growing season, vegetation plays a role in renovation of the sewage lagoon effluent by nutrient uptake (temporary and long-term), serving as attachment sites for microbes, acting as physical filters for suspended solids, and reducing solar radiation by the canopy cover, which in turn reduces algal productivity. Determining a mass balance for BOD, TSS, and various nutrients for the Cannon Beach treatment cells is a very complex and difficult undertaking far beyond the scope of the present research study. Despite the important role of the soil and microbial community in pollutant removal and transformation, ecological monitoring described in this report is limited to the assessment of vegetation change induced by treatment operation. How biotic fluctuations caused by flooding will influence pollutant removal and transformation can only be assessed by future studies.

In the following section two methods of vegetation sampling and analysis for trend assessment are described: (1) Rogers (1984) sampling procedure conducted in 1984 and repeated in 1986 (hereinafter called the permanent plot method); and (2) a procedure using nested frequency quadrats conducted in 1986.

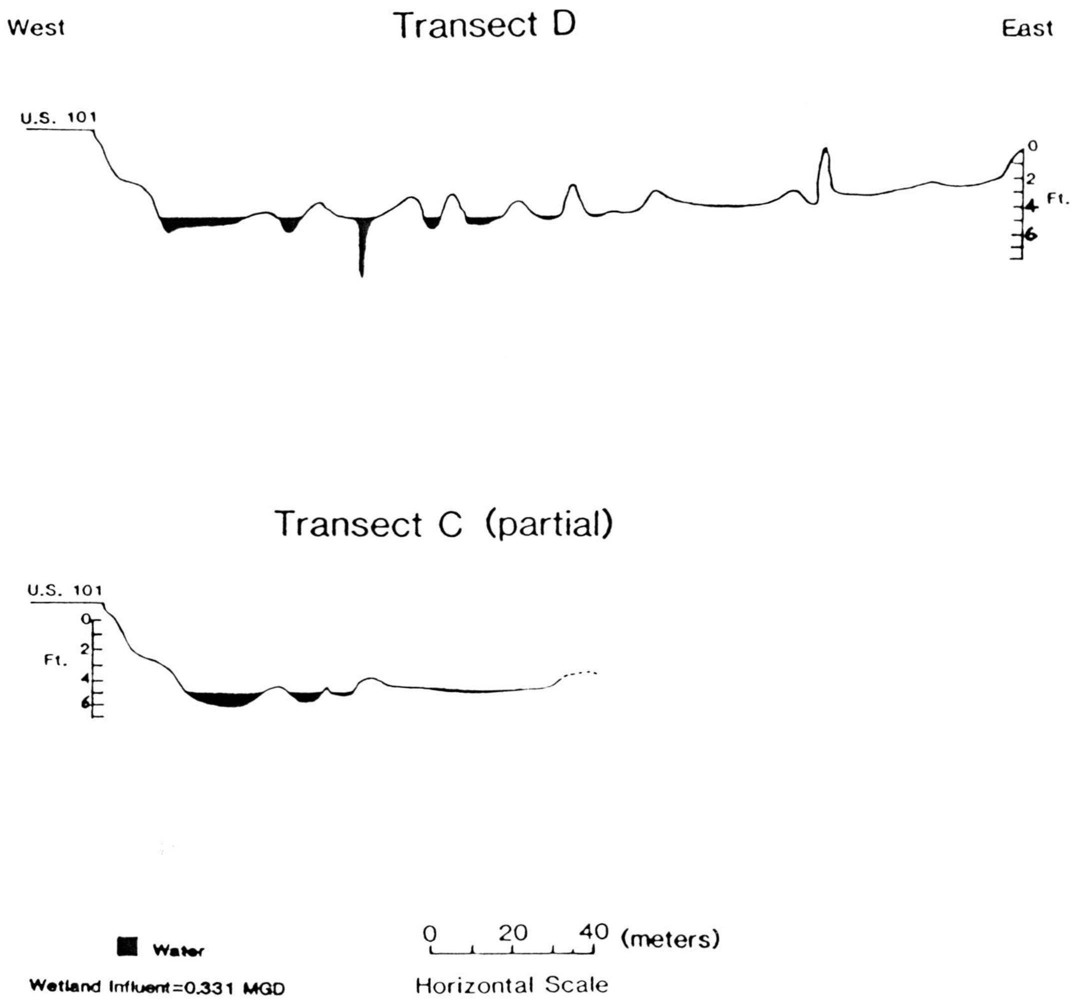


Figure 8. Topographic profiles for transects D and C (partial).

1984/1986 VEGETATION SURVEY COMPARISONS

Methods and Materials

A volunteer group of COE, ODFW, and USFWS staff established a baseline vegetation survey May 31 and June 1, 1984 by using a method of estimating herbaceous and shrub cover along a stratified series of transects (Rogers 1984) (Figure 9). At each transect point shown in Figure 9, a one square meter herbaceous plot was randomly located within 10 meters of the transect point and marked by two 1/2 inch X 2 m PVC pipes stuck in the soil. A total of 22 herbaceous plots were sampled along six transects. A 1 m x 10 m shrub plot was also centered at right angles to the transect at each transect point, without any markings (22 total). For each herbaceous and shrub plot, species were identified and their percent cover (rooted and not rooted within the plot) estimated to the nearest 5%. Percent cover was also estimated for bare ground and standing water.

In addition to the herb and shrub plots, tree sampling belt transects were established along transects A, C, and F. In a band five meters north and south of the transect line all trees greater than 10 cm in diameter were recorded by species and diameter. Trees were numbered serially eastward along the transects with 1 in. X 3 in. aluminum foil tags secured with galvanized nails.

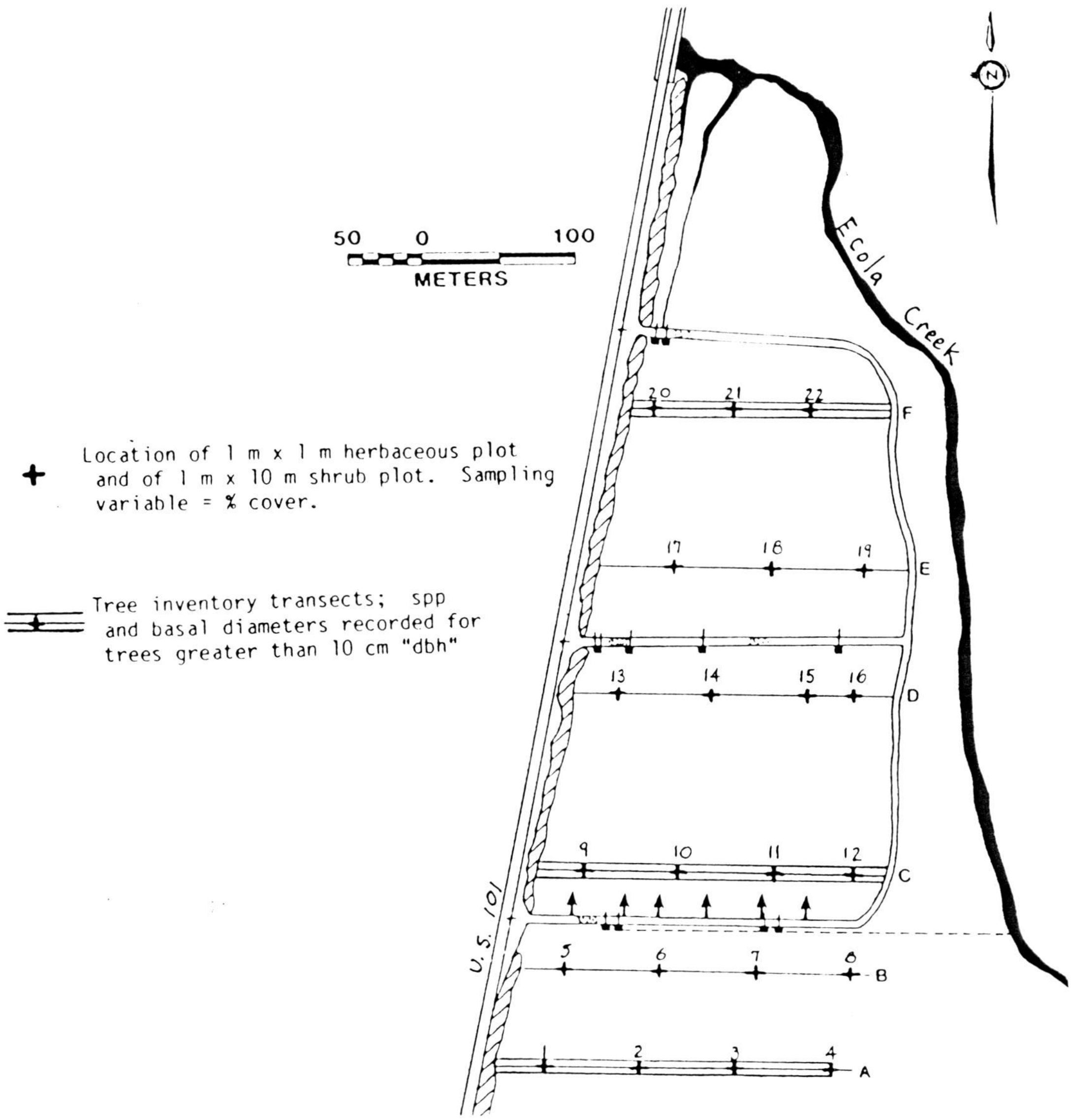


Figure 9. Permanent plot sampling design (Rogers 1984).

Results and Discussion

Herbs and Shrubs

Given the nature of the method, statistical significance of changes from 1984 to 1986 could not be calculated. Therefore, assuming changes of at least 10% are "significant", the key results depicted in Figures 10 and 11 are as follows:

(1) All three ferns (Athyrium filix-femina, Adiantum pedatum, and Polystichum munitum) show no "significant" changes in 1986 relative to 1984 for cell 1 (ca. 4%). A reduction in the abundance of these species, however, is expected in the areas of channelization and deeper water (Figure 4). In cell 2, however, P. munitum increased by ca. 10% with A. filix-femina and A. pedatum showing no "significant" changes.

(2) A pre-project prediction concerning Carex obnupta was that it would likely survive summertime flooding (Demgen, 1983). This appears to be the case for three years operation. Figure 10 indicates essentially no reduction in C. obnupta coverage in cell 1 for 1986 relative to 1984. Cell 2 shows a 20% increase in C. obnupta cover.

(3) From Figure 11, none of the shrubs show a "significant" change, except in cell 2 where Lonicera involucrata has 28%

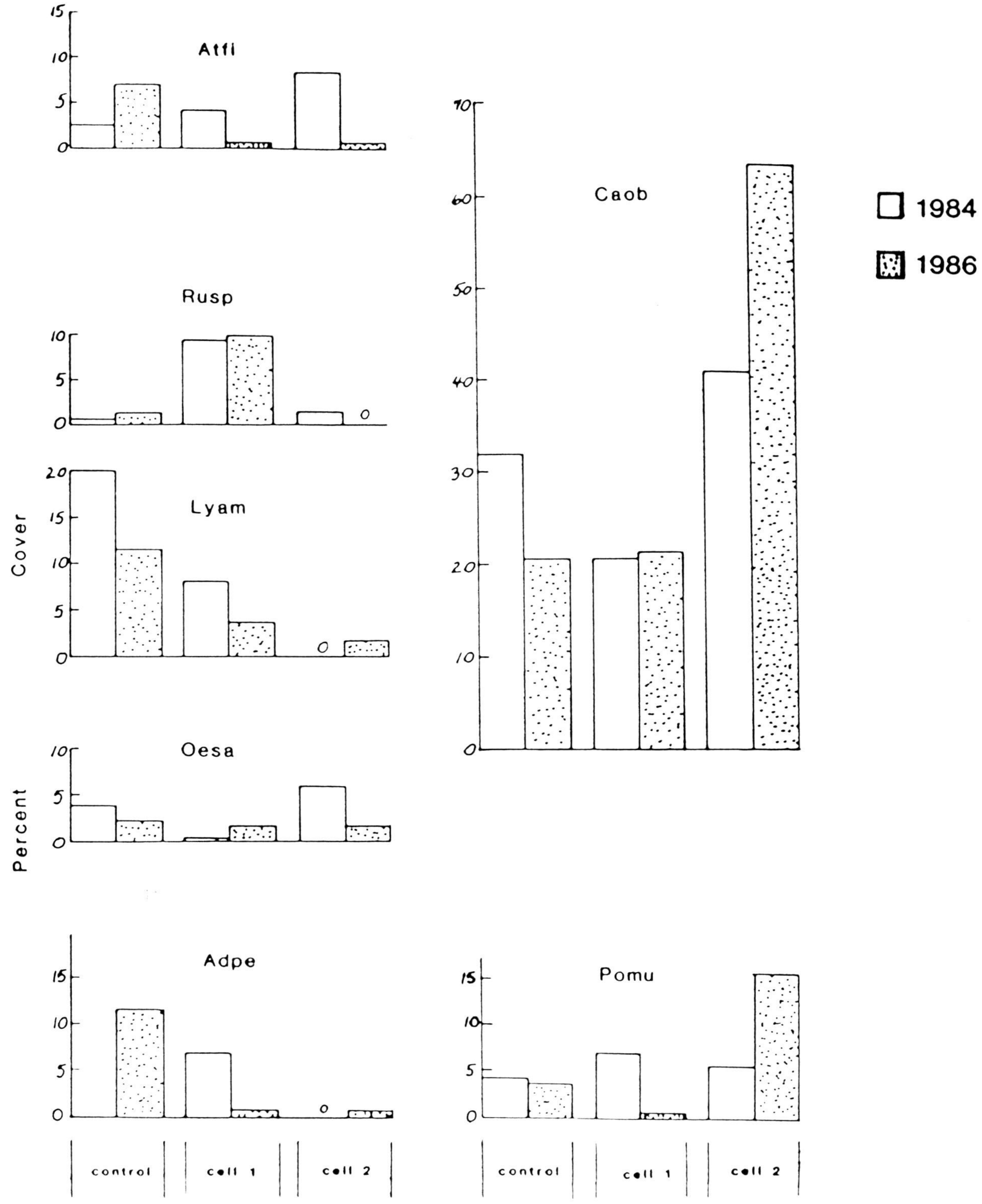


Figure 10. Herbaceous sampling results for dominant species using the permanent plot method, 1984 vs. 1986. Species acronyms are given in Appendix C.

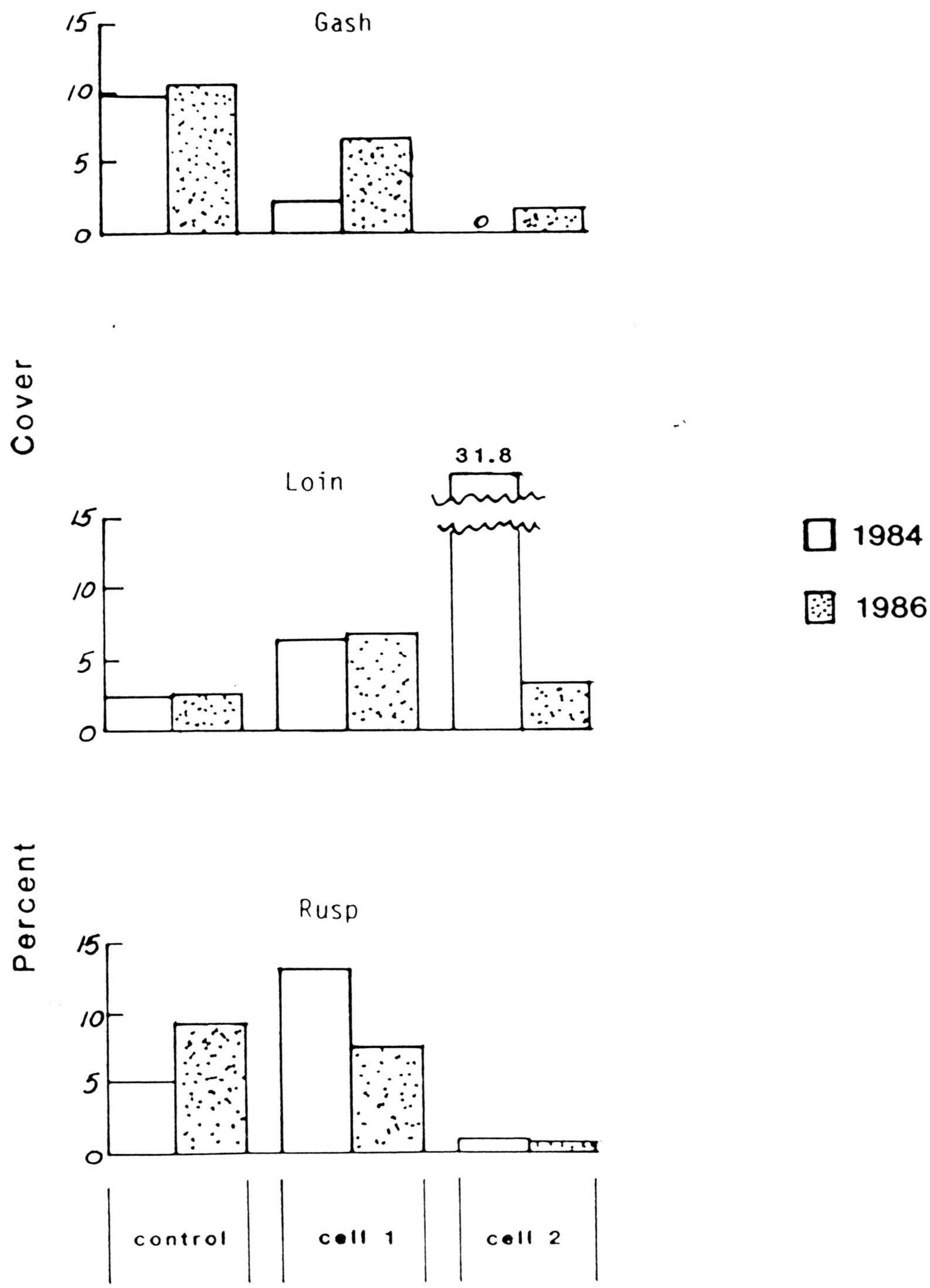


Figure 11. Shrub sampling results for dominant species using the permanent plot method, 1984 vs. 1986. Species acronyms are given in Appendix C.

less cover in 1986 than 1984. Qualitative observations in 1986 confirm a higher degree of flooding stress (defoliated branches) in the western section of cell 2 than elsewhere in the wetland.

One must be very cautious when interpreting the results depicted in Figures 10 and 11 for herbaceous and shrub changes since 1984, for the following reasons:

(1) Different survey crews were involved (1984 vs. 1986) and there was no calibration of cover estimates within and between survey crews. Subjectivity is greatly increased when different survey crews are involved, especially combined with the cold and very wet weather conditions of April 26, 1986.

(2) Sampling for herbaceous and shrub cover occurred May 30, 1984 vs. April 26, 1986; phenological differences are probable but not assessed.

(3) Precise relocation of plots was difficult and time consuming despite staking. Shrub plots were not staked, leading to imprecise cover estimates. Transect points, marked by light blue paint on trees, were sometimes difficult to relocate.

(4) Estimating percent cover of shrubs in plots greater than one square meter can be highly inaccurate. This was especially true for multiple stemmed shrub and vine species, such as *R. spectabilis* and *L. involucrata*;

(5) Except for estimating cover on an overall treatment cell basis the number of sample plots and their spatial location is inadequate to sample the microhabitat complexity and total acreage involved. For increased accuracy and resolution, more sample plots are required (e.g., comparing changes west to east, lower elevation areas to higher elevations, etc.).

(6) Whether a plant was rooted or non-rooted within a sampling plot was not specified at the outset. Lack of this information resulted in considerable uncertainty in cover estimates, especially for *A. rubra* and shrub species.

Trees

A new baseline data set was collected June-July 1986 and is listed and described in Appendix A. Unfortunately, during the original tree transect survey of 1984, care was not taken to standardize the vertical position of diameter measurements; therefore, no meaningful comparison of basal growth can be made between the 1986 and 1984 measurements. According to Rogers (personal communication) diameters were measured at "eye height";

however, this height varies with the height of the investigator and, particularly, the side of the tree at which the measurement is taken. This height can vary from a few inches to four feet or more.

From the 1986 data set importance values are derived for each tree species and are shown in Table 2A. The importance value is the sum of relative frequency and relative dominance for each species and allows a comparison of overstory sructure and composition for the control and treatment cell sections of the wetland. Transect A (control) is more similar to transect F for Alnus rubra and Picea sitchensis than to transect C. The difference is accounted for by a larger importance value for P. sitchensis along transect C (because of a larger mean basal area) and the presence of Pyrus fusca along transects C and F and not along A. The essential point is that there are differences in canopy structure and composition for the control and treatment cell sections that impart different, and difficult to assess, influences on successional change in each respective section of the wetland -- exclusive of wastewater flooding disturbance. Table 2C also shows results of double-sampling the tree transects in 1986 in order to provide descriptive statistical information when the survey is repeated.

An additional problem with this method is the assumption that basal growth accurately assesses flooding stress and can predict survival of trees; basal diameter growth can stop yet the trees may continue to survive. Studies by Mitsch and Rust (1984) indicate a

Table 2. Tree transect survey results for 1986. See Appendix A for data list and Appendix C for species acronyms.

A. Relative Frequency (RF), Relative Dominance (RD), and Importance Value (IV) for tree transects.

	Transect A			Transect C			Transect F		
	RF	RD	IV	RF	RD	IV	RF	RD	IV
Alru	88.4	85.9	114.3	76.0	69.1	145.1	84.1	91.6	175.7
Pisi	11.6	14.1	25.7	14.0	28.6	42.6	8.7	4.6	13.3
Pyfu	0.0	0.0	0.0	10.0	2.3	12.3	7.2	3.8	11.0

RF = (frequency of given spp)(sum of frequencies of all spp)$^{-1}$ x 100
RD = (sum of basal area of given spp)(sum of basal area of all spp)$^{-1}$ x 100
IV = RF + RD

B. Basal Areas (BA) for the tree transects. Sampling areas: Transect A = 0.218 ha, Transect C = 0.203 ha, and Transect F = 0.170 ha.

	Basal Area (m^2/ha)					
	Transect A	N	Transect C	N	Transect F	N
Alru	21.9	61	11.0	38	16.5	50
Pisi	3.6	8	4.6	7	0.8	6
Pyfu	0.0	0	0.4	5	0.7	5

C. Resampling results in 1986 to determine a statistical confidence.

	Transect A	Transect C	Transect F
N	26	10	14
d(cm)	0.019	0.040	0.214
σ	$\pm$0.017	$\pm$0.035	$\pm$0.190

d = mean difference between sampling values.

σ = standard deviation based on $\sigma = \frac{\sqrt{\pi}d}{2}$; note when resampling: 95% C.I. of a single measurement, x, is x $\pm$ 1.74d.

complex nonlinear relationship between growth and flooding stress and such a nonlinear relationship should be accounted for when this baseline data set is resampled and analyzed.

Flooding stress, consisting of defoliated trees, sparsely leaved tress, and some dead trees, is observed in 1986 for red alder and twinberry in deeper water towards the western section of the treatment cells and adjacent to the dikes where water ponds (Figure 12). Determining the extent and stablity of the observed flooding stress is a complex spatial and temporal problem highly dependent on the operational hydroperiod which has not yet been recorded. Observations along the dikes appear to indicate ca. 25% of the treatment cell area is under significant stress after three years operation (Figure 12). But as Figure 13 also indicates, high hummocks within the wetland contain trees of relatively good vigor, complicating any prediction.

1986 MONITORING METHODS

Introduction

In response to the problems discovered with the permanent plot method for sampling herbaceous vegetation, a method was developed using nested frequency quadrats following a similar approach by Hironaka (1985) and Smith et al. (1986) in rangeland vegetation. The use of species frequency as a variable in vegetation sampling is a common and well-established method for

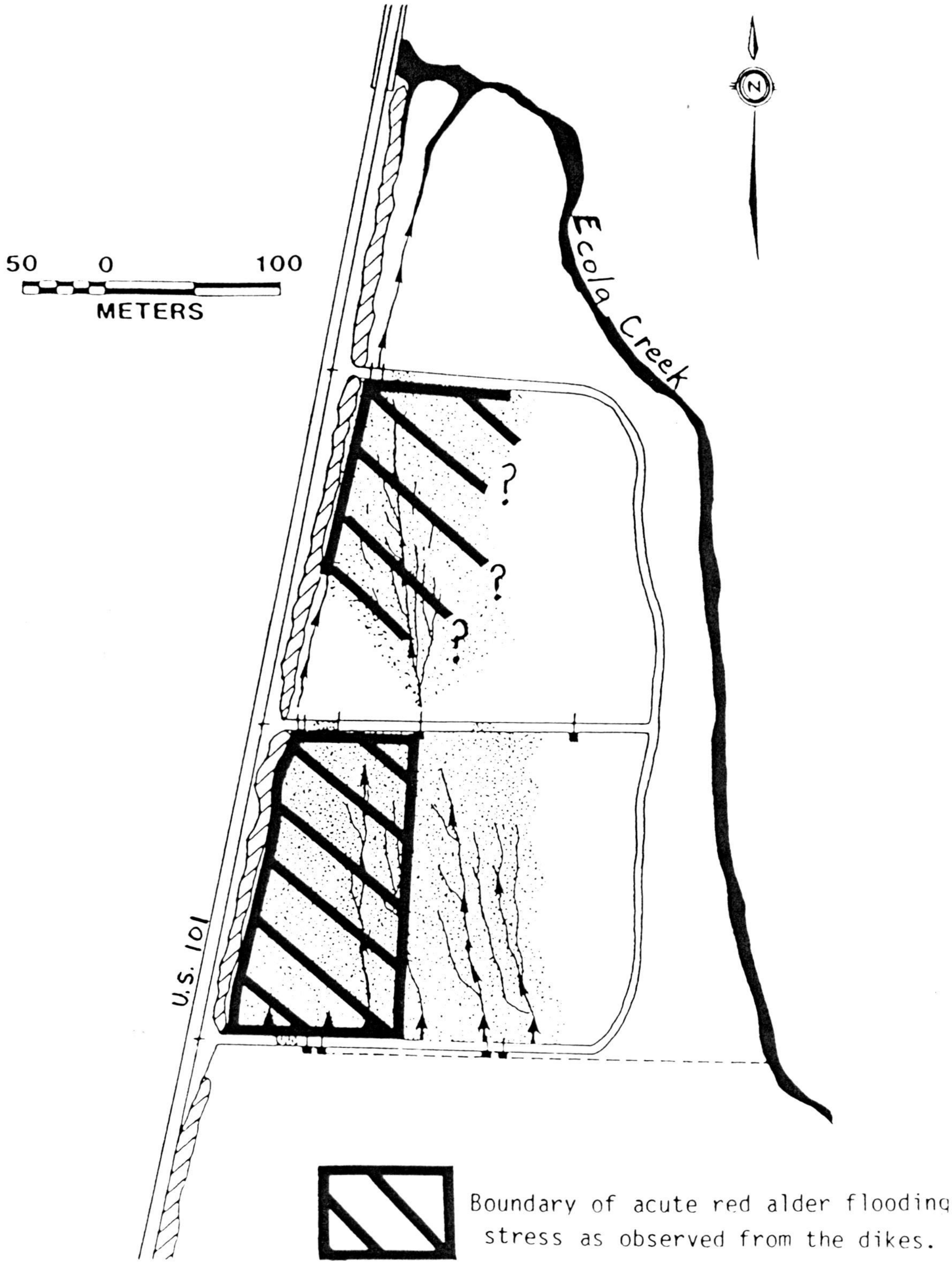


Figure 12. Generalized boundary of acute red alder flooding stress observed from the wetland boundary dikes, 1986. Stressed red alder consisted of defoliated trees, sparsely leaved trees, and some dead trees.

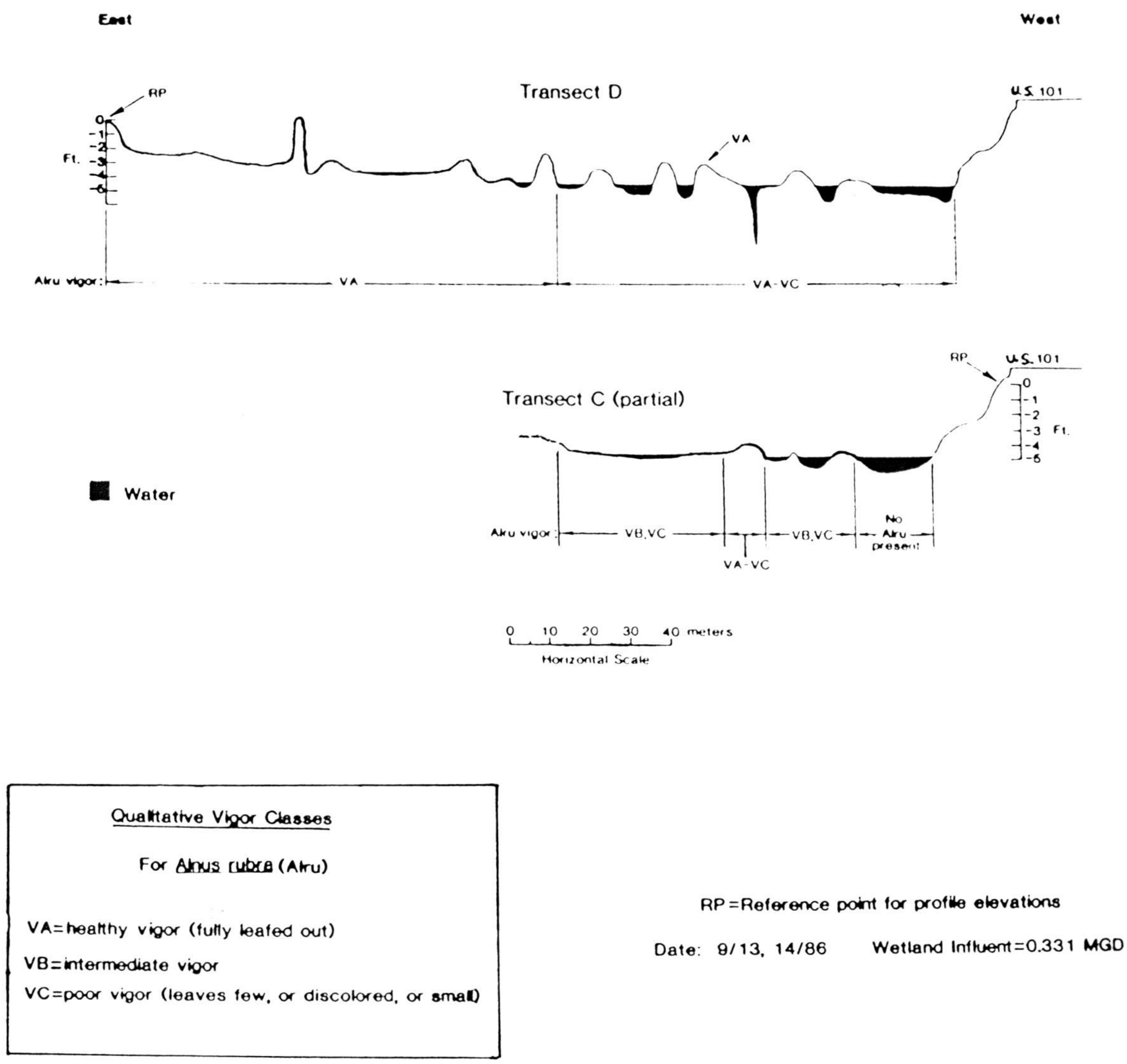


Figure 13. Qualitative vigor zones for red alder along transects D and C (partial). Note that hummocks within the acute zone of flooding stress (Figure 12 -- determined by observations made solely from the dikes) contain trees of healthy vigor.

sampling herbaceous vegetation in rangeland and other vegetation types.

Frequency is the number of times a species is recorded in a set of plots or points and is usually expressed as a percent. Interpretation of frequency does present problems, however. Frequency depends on plot size and shape as well as the spatial distribution of species in the sample area. When plants are not dispersed in a regular or random pattern, frequency has no fixed relationship to density, abundance or cover (Mueller-Dombois and Ellenberg 1974). On the other hand, frequency data is easily collected and is objective (either a plant is or is not in a plot). Nested frequency methods establish a set of different plot sizes such that in any resampling the same plot size is used in reassessment of the trend for a given species.

Nested frequency sampling has not been utilized extensively in wetland environments. The method is based on the presence or absence of a species in a nested series of quadrats. For vegetation trend analyses, nested frequency is considered to have greater objectivity, repeatablity, and rapidity of use than repeat cover or yield methods (Hironaka 1985, Smith et al. 1986). The results are also more stable relative to seasonality than cover methods. One of the major attractions of nested frequency for trend assessment is that it does not require relocation of transects or plots. It essentially assesses the entire stand of vegetation and therefore can establish trend for the stand. A fixed plot method, on the other hand, can only assess trend for the plot.

Because species frequency varies as a function of quadrat size, the use of nested quadrats increases the probability of choosing an appropriate quadrat size (Hironaka 1985). Frequency values alone, however, do not allow for spatial pattern description, nor for accurate assessment of cover or biomass, and therefore cover estimates often accompany frequency measurements.

Methods and Materials

For convenience and to evenly distribute a sampling network throughout the wetland, nested frequency plots were taken along seven belt transects of indeterminate width. Ideally, nested plots would be randomly located throughout the wetland, but statistically random location would have been impossible. Theoretically, in vegetation reassessment, relocation of transects and plots is not required. However, because of the heterogeneity of the vegetation in cells 1 and 2, approximate transect relocation would be highly desirable in reassessment.

Transects A through F generally corresponded with Rogers (1984) transect locations (Figure 14). Transect G was added to more completely sample cell 1. Two transects were established in the control area and cell 2, and three in cell 1. Nested frequency sampling was accomplished along all transects in a "semi-random" manner.

After local trial two plot sizes were chosen: a 50 cm x 50 cm nested within a 100 cm x 100 cm plot. Four types of data were

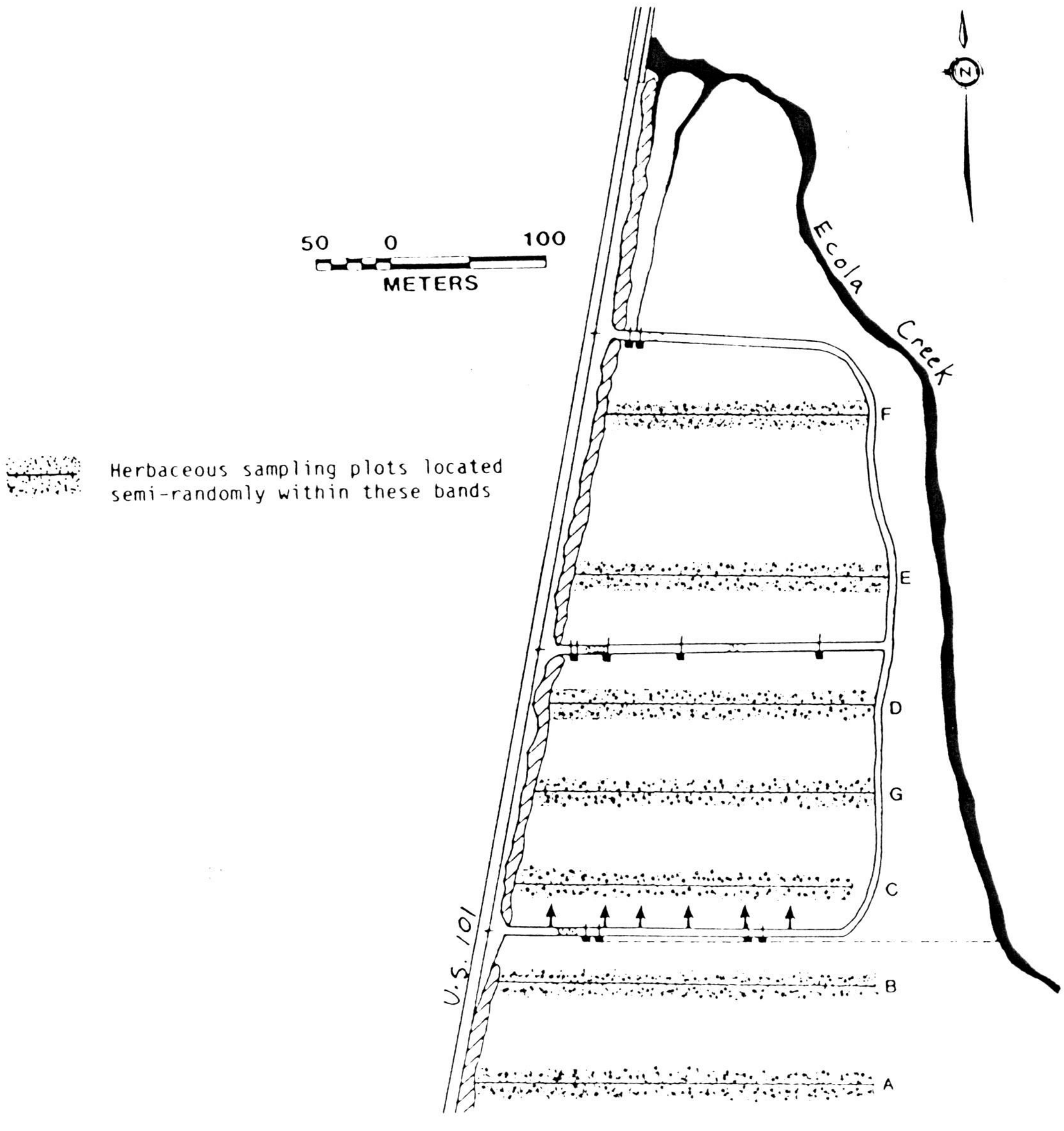


Figure 14. Nested frequency/microenvironmental sampling method (1986). Sampling transects A-C and D-F corresspond to the permanent plot method. Transect G was added in 1986.

collected at each plot: frequency, cover, water depth, and a qualitative aquatic index used to gain some qualitative measure of wetland character and degree of inundation. The plots were made in the field by using four 1.5 m x 3/4 inch PVC pipes as a frame (the pipes doubling as walking sticks -- an important consideration in extremely difficult terrain and given the necessity of minimizing hand-held objects). A starting point was located at either end of the transect and a magnetic bearing of 73 or 253 degrees gave the general heading.

At approximately 10 m intervals along the transect one team member would stand with either a telescopic stadia rod or two connected PVC pipes (total length of 3 meters) and await the bearing and distance of the next plot location which was called out by the other team member. The distance and direction was chosen by using a random number table photocopied onto a 3x5 index card. Distances varied from 0 to 9 meters and random bearings were selected from a 180 degree "forward pointing" semicircle, i.e., no backtracking. Once the angle and distance coordinates were chosen, the plot was established with the PVC extensions each marked at 50 cm intervals. Recorded separately at each 50 cm x 50 cm and 100 cm x 100 cm plot location were species presence or absence and an estimate of the percent cover in the 100 x 100 cm plot based on the Braun-Blanquet scale (less than 5%, 5-25%, 25-50%, 50-75%, greater than 75%).

A qualitative aquatic index value was recorded at each 100 cm x 100 cm plot location. Figure 15 schematically illustrates the classification used to assign aquatic index values. This index was: aquatic (A)= greater than 50% plot area saturated or inundated; intermediate aquatic (IA)= 25-50% plot area saturated or inundated; and upland or non-aquatic (NA)= less than 25% of plot area saturated or inundated. The purpose of this index was to gain some qualitative measure of wetland character and degree of inundation. When a plot was inundated, the water depth was recorded. Aquatic index values are of course a function of influent flow rates and weather conditions.

Results and Discussion

Spatial heterogeneity in plant cover for the treatment cells and the control is revealed by results of the nested frequency sampling survey (Tables 3 - 6). For example, A. filix-femina and C. obnupta have relatively low frequencies along transect C relative to the other transects (Table 3). There is also a distinct difference in frequency values for A. filix-femina on an east vs. west basis for cells 1 and 2 relative to the control (Table 6). The data suggest the adverse effects of the operational hydroperiod in the western section of cells 1 and 2 on this fern. However, for C. obnupta the east vs. west difference in frequency values is not apparant. For C. obnupta these spatial differences imply that (1) wastewater flooding has had a greater impact adjacent to the

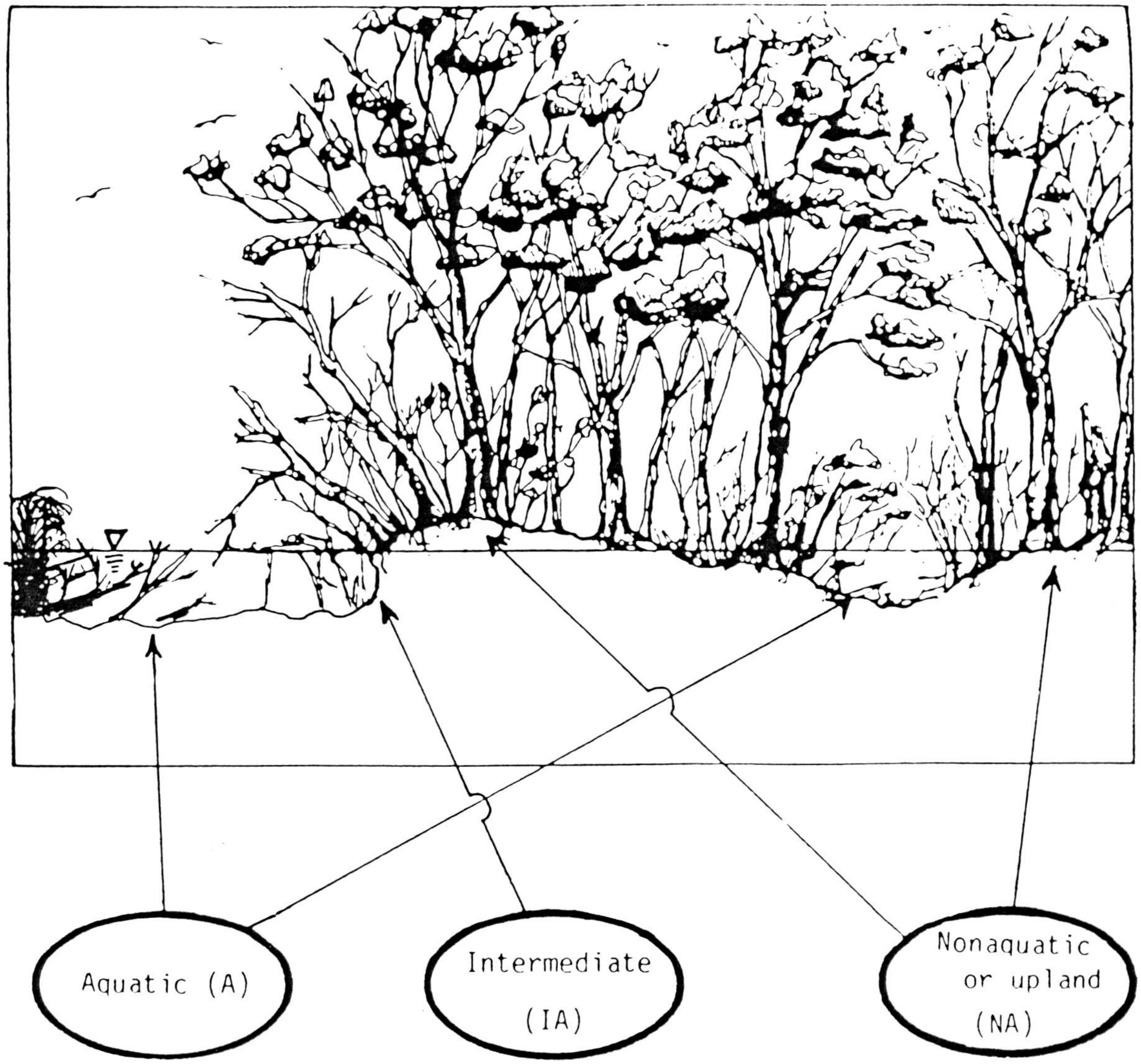


Figure 15. Structural classification of the microenvironment associated with each nested frequency sampling plot.

Table 3. Frequency along each transect of dominant plant species in nested 50 cm x 50 cm and 100 cm x 100 cm plots. A species that occurs in the 50 cm x 50 cm plot automatically also occurs in the 100 cm x 100 cm plot. Species acronyms are given in Appendix C.

		Frequency (%) in 50 cm x 50 cm plot							100 cm x 100 cm plot						
		Transect							Transect						
Species	Life Form	A	B	C	G	D	E	F	A	B	C	G	D	E	F
Atfi	fern	26	26	13	41	29	24	38	50	61	23	71	50	53	50
Pomu	fern	23	9	7	12	21	18	6	27	30	13	18	29	18	16
Caob	sedge	50	52	17	65	50	76	88	68	70	23	82	79	88	100
Lemi	aquatic	0	0	7	24	36	0	6	0	0	7	24	36	0	6
Loin	shrub	9	4	7	0	7	12	3	23	4	7	18	29	18	13
Lyam	herb	27	22	13	0	7	0	0	64	48	23	6	7	6	3
Oesa	herb	36	35	23	6	29	18	22	73	52	47	18	36	29	28
Rusp	shrub	18	9	13	29	43	18	9	32	30	23	47	43	35	9

Table 4. Frequency by cell of dominant plant species in nested 50 cm x 50 cm and 100 cm x 100 cm plots. Species acronyms are given in Appendix C.

	Frequency (%) in 50 cm x 50 cm plot			100 cm x 100 cm plot		
Species	Control Transects A & B	Cell 1 Transects C, G, & D	Cell 2 Transects E & F	Control Transects A & B	Cell 1 Transects C, G, & D	Cell 2 Transects E & F
Atfi	24	25	33	56	39	78
Pomu	16	11	10	29	18	16
Caob	51	38	84	69	52	96
Lemi	0	18	4	0	18	4
Loin	7	5	6	11	15	14
Lyam	24	8	0	56	15	4
Oesa	36	20	20	62	36	29
Rusp	13	25	12	31	34	18

Table 5. Comparison of percent cover values: Permanent Plot Method (PP) (1986) vs. 1986 Nested Frequency (NF) Sampling Method. Species acronyms are given in Appendix C.

	Control		Cell 1		Cell 2	
Species	% Cover PP Method	% Cover NF Plots	% Cover PP Method	% Cover NF Plots	% Cover PP Method	% Cover NF Plots
Atfi	6.9	3.1	0.7	4.6	0.8	4.1
Caob	20.6	19.5	21.4	22.0	63.3	55.7
Lemi	0.0	0.0	0.0	8.3	0.0	1.3
Loin	4.0	0.3	1.0	2.2	5.5	4.5
Lyam	11.6	9.6	3.6	2.3	1.7	0.10
Oesa	2.3	2.1	1.6	2.3	1.7	1.0
Pomu	4.0	3.2	1.0	3.0	23.0	2.4
Rusp	1.3	4.5	9.7	10.0	0.0	1.7

Table 6. 1986 frequency results of dominant plant species separated on an east vs. west basis. The number to the left of the slash is the frequency in the 50 cm x 50 cm plot size, and the number to the right of the slash is the frequency in the 100 cm x 100 cm plot size.

	Frequency in 50cm x 50cm plot size (%)/Frequency in 1m x 1m plot size (%)					
	Control		Cell 1		Cell 2	
Species	East 1/2 N=22	West 1/2 N=23	East 1/2 N=31	West 1/2 N=30	East 1/2 N=24	West 1/2 N=25
Atfi	27/59	22/52	26/58	23/30	54/79	12/24
Caob	64/73	39/65	45/58	29/47	92/96	76/96
Lemi	0/0	0/0	3/3	33/33	0/0	0/8
Loin	0/5	13/22	6/20	3/10	0/0	12/28
Lyam	32/68	17/43	10/20	6/10	0/8	0/0
Oesa	50/73	22/52	26/53	13/20	38/54	4/4
Pomu	14/27	17/30	16/23	7/13	17/25	4/8
Rusp	5/27	22/35	29/32	20/37	21/25	4/12

Table 7. 1986 aquatic index/rooting environment frequencies. Cell 2 data is incomplete for the aquatic index and is omitted. Results are based on N = 45, control; N = 61, cell 1; and, N = 49, cell 2.

	Frequency (%)					
	Aquatic Index			Rooting Environment		
Location	NA	IA	A	rooted in log/upland	rooted in muck	N
Control	22	55	22	44	56	45
Cell 1	12	31	57	36	67	61
Cell 2	--	--	--	19	81	49

NA= nonaquatic or upland; sample plot less than 25% inundated
IA= intermediate; sample plot 25-50% inundated
A= aquatic; sample plot greater than 50% inundated

Table 8. Dominant species frequencies in the three aquatic index classes.

		Frequency (%)					
		Cell 1			Control		
Species	Life Form	A	IA	NA	A	IA	NA
Atfi	fern	25	58	8	16	48	36
Caob	sedge	41	41	18	21	62	17
Lemi	aquatic	82	12	0	0	0	0
Loin	shrub	22	56	22	33	50	17
Lyam	herb	67	33	0	28	60	12
Oesa	herb	18	50	32	21	58	21
Pomu	fern	0	54	46	0	38	62
Rusp	shrub	14	57	29	7	64	29

discharge header than elsewhere in the wetland, or (2) _C_. _obnupta_ had a lower frequency along transect C prior to the 1984 initiation of effluent discharge into the wetland. Figure 10 (permanent plot method) lends support to the second hypothesis, indicating _C_. _obnupta_ had a lower cover in cell 1 relative to the control and cell 2 prior to the initial discharge of wastewater (though not shown, transects C and D were approximately the same in _C_. _obnupta_ cover for 1984, ca. 20%)

Another distinct spatial pattern is found for _Lemna minor_. It is a floating aquatic, absent from the control section, but present in areas of deeper water. Note the increase in frequency values in cell 1 from the discharge header (transect C) to the middle dike (transect D). In cell 2 it is absent along transect D and is present along transect F (Table 3). Among the factors that determine the distribution of this species are water availablity, dissolved nutrient supply and canopy cover (shading). It is expected that this species will increase in cover as the canopy thins out (reduction in red alder density via flooding stress). Explaining the distribution of _L_. _minor_ and then attempting to predict future change is further complicated by the presence of dabbling ducks. Ducks, which feed on _L_. _minor_ and influence its cover locally, were found in the western sections of the treatment cells throughout the summer of 1986.

Prior to sampling in 1986, _Oenanthe sarmentosa_, the water parsley, was predicted to have a higher frequency in cell 1 relative to the control. This prediction was based on the observation of O. sarmentosa growing in large floating mats in the highly enriched aeration basin, east of U.S. 101, which receives the incoming raw sewage. Table 4 shows this prediction has not yet been borne out; the frequency value of O. sarmentosa for cell 1 is approximately half of the control value. There is also a distinct east vs. west difference shown in Table 6 -- frequency values are greater in the higher and less frequently inundated eastern section of the control and cells 1 and 2. Cover data yields a somewhat different pattern: Figure 10 shows O. sarmentosa cover to be initially less in cell 1 relative to the control and cell 2 for 1984 and the cover values for O. sarmentosa calculated from the nested frequency data indicate nearly equal cover values in 1986. The cover data indicates an increase in O. sarmentosa for cell 1 relative to the control (the small values for cover, however, make this interpretation difficult to defend).

Surprising results are shown in Table 5, where the permanent plot method is compared to the nested frequency method for percent cover of the dominant plant species. Percent cover values for C. obnupta (control and cell 1), L. involucrata (cells 1 and 2), L. americanum (control and cell 1), O. sarmentosa (control and cell 1), P. munitum (control), and R. spectabilis (cell 1) are extremely close for both methods. Sampling occured nearly three months later with the nested frequency method and the survey was conducted by several different individuals than the permanent plot survey crew of

April 26, 1986. The problem with the permanent plot method, however, is the small sample size that, although quite consistent with the nested frequency method on an overall basis, is much too small to make spatial separations in the data for reliable description and trend assessment (Table 6).

Tables 7 and 8 show results of the aquatic index. Data were incomplete for cell 2 and are therefore omitted. It is not surprising that cell 1 has a larger frequency for A (aquatic) than in the control given summer flooding in cell 1 for three years. Of more importance, however, is the relation of the aquatic index to dominant species shown in Table 8. For example, species with relatively lower frequencies in the aquatic zone (A) -- Athyrium filix-femina (Atfi), Lonicera involucrata (Loin), Polystichum munitum (Pomu), and Rubus spectabilis (Rusp) -- are likely to be adversely affected by an increased hydroperiod relative to the current operational hydroperiod. Note that Carex obnupta and Lysichitum americanum have larger frequency values for the aquatic zone in cell 1 relative to the control, indicating possible expansion into these areas. Future studies should assess this observation.

Table 7 also shows the frequency of the rooting environment (either rooted in muck, or rooted in a log or on an upland hummock) for the treatment cells and control based on 155 nested frequency plots. The data indicate more upland area and woody debris in the control than in the two treatment cells. Cell 2 has substantially more 'muck area' than the control and cell 1. This spatial difference in substrate influences the type of species that can survive and colonize a given area of the wetland under selection pressure of different operational hydroperiods. Spatial variablity in the substrate (and thus plant cover) and quantity of woody debris may also influence settling and resuspension rates of suspended solids throughout the wetland.

Recommendations for Resampling

The nested frequency method described herein is a relatively rapid means of sampling vegetation under the very difficult conditions of the Cannon Beach wetland. For a two person team, one can expect to sample ca. 10 plots per hour given the method described. Sampling should occur just after the peak of the growing season (August - September) and should be coordinated with the treatment plant operators so that wetland influent is shut-off at least five to seven days prior to sampling. It is recommended that collapsible but convenient quadrat frames be used rather than the PVC pipes. However, the importance of minimizing hand-held objects should not be underestimated.

There is no need when resampling to establish flagging on transects A through F. A hand-held sighting compass is sufficient to maintain the desired bearing. The use of a telescopic stadia rod for establishing each quadrat location (as described in the methods section) is highly recommended.

After resampling the wetland using the nested frequency method, an Analysis of Variance Test can be used to determine (1) if there are significant differences between the species means for a given plot size and (2) if more than two years data are available, establish the basis for performing the least significant differences (LSD) test.

A warning for any future researchers that repeat the vegetation sampling methods described in this report: interpret the results with care. Because so little autecological information is available for the species located in the Cannon Beach area (under normal conditions much less being flooded with secondary effluent) one can draw erroneous conclusions from changes in plant cover and frequencies. For example, the operational hydroperiod and enriched wastewater not only affects species physiologically by reducing oxygen availablity to the roots, but can also transport propagules not usually transported by water during the summer (as in the control). Neither the permanent plot method nor the nested frequency sampling method will yield any information on the significance of this phenomenon. Other complications include the effects of relatively dry and early spring weather (e.g., 1987) that enables some plant species to establish significant growth prior to wastewater discharge compared to wetter and colder springtimes -- how does this affect plant survival, reproduction, and ultimately plant distribution and succession?

WATER BUDGET ESTIMATE

Introduction

Hydrology is perhaps the key determinant influencing the type of wetland found in a given area (Mitsch and Gosselink 1986). The water regime is also of prime importance in determining pollutant inputs and outputs of a wetland. Therefore, understanding site-specific hydrological characteristics of the Cannon Beach wetland is necessary to make informed management decisions as the wetland wastewater treatment system ages and in the event of undesirable changes in water quality and wildlife habitat. For example, a key relationship for the site would be the area of inundation as a function of the operational hydroperiod (water depth, frequency and amplitude of flooding, and duration of flooding), which is directly related to the influent flow rates. These data could be used to control, in a more systematic fashion than present, the desired wetland plant and animal community (i.e., fewer or more trees, greater production of Daphnia sp. and other invertebrates, etc.) while still maintaining necessary wastewater treatment.

Channelization and water dispersal and their relationship to vegetation change in the treatment cells have been discussed in the previous section. These hydrologic and biotic interactions also influence pollutant removal, transformation, and transport processes in the wetland.

Seasonal and summer operational variablity in the quantities and rates of wetland water inflows and outflows determine the storage status of the wetland. To infer pollutant inflows and outflows from the water budget requires precise knowledge of water budget components. This section considers a simple mathematical model to estimate the water budget for the treatment cells.

Methods

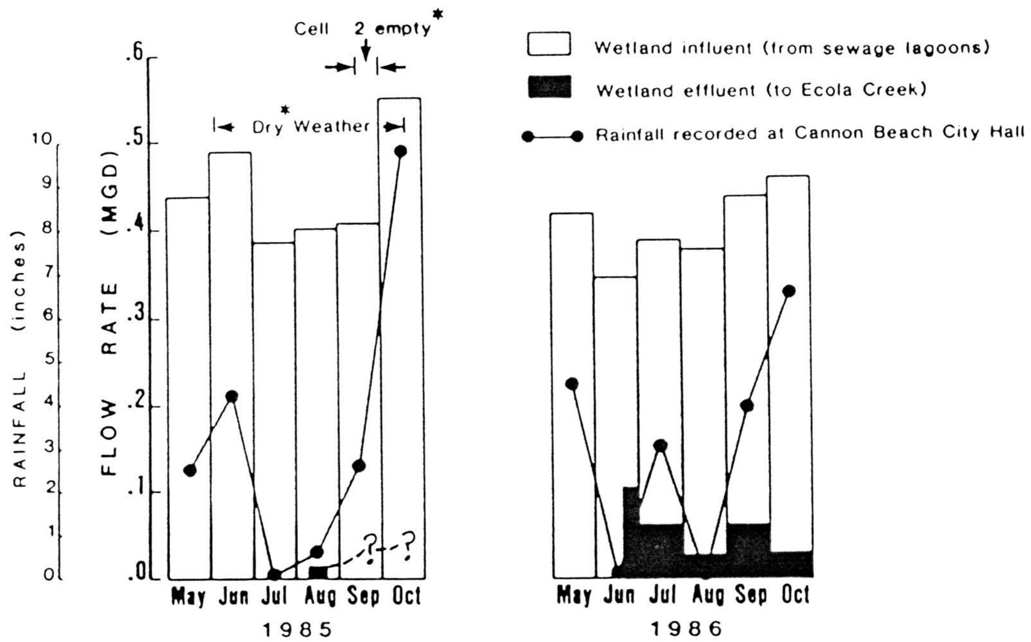
The data collected for the water budget model are derived from Cannon Beach water quality monitoring reports, literature reviews, and limited field work. The only original data are water depth measurements obtained by staff gauge observations.

Lack of funding prevented application of more sophisticated techniques of study, but an attempt is made to demonstrate the utility of simple, inexpensive methods of studying wetland hydrology.

Water Budget Model

Figure 16 shows measured hydrologic characteristics of the Cannon Beach wastewater wetland for summer operation during 1985 and 1986. Two striking characteristics of Figure 16 are (1) the significant water loss in the wetland, and (2), the earlier start of effluent discharge into Ecola Creek for 1986 (51 days) relative to that in 1985 (101 days). These two chacteristics are investigated by a simple mathematical model conceptually depicted in Figure 17.

The fundamental concept used to calculate the water budget is a water mass balance for the wetland water sheet; in words, the

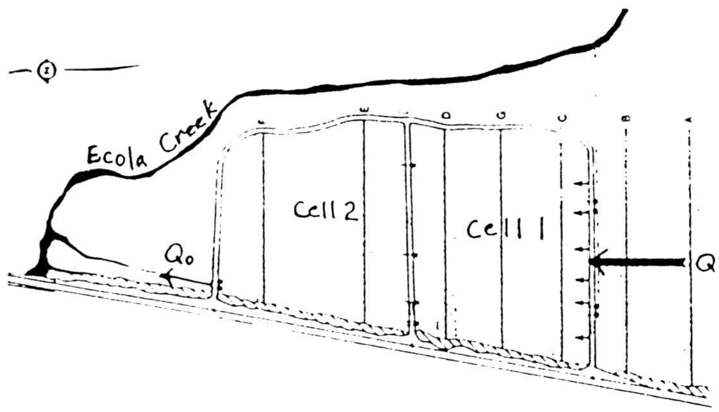


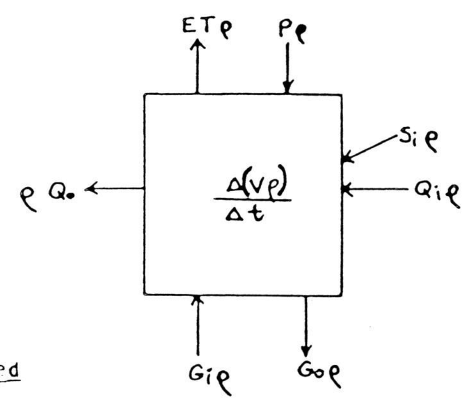
*Plant operator notes.

Wetland effluent flow rate for 1985 is not measured by stream gauge but is an estimate by the treatment plant operator.

Figure 16. Hydrology of the Cannon Beach wastewater wetland -- 1985 vs. 1986.

(Time rate of change of water mass in the wetland water sheet) =
(rate of water input into wetland) - (rate of water output out of wetland)





The units of each component are mass/time

Parameters

Measured	Estimated	
	•	V= volume of water storage in wetland
	•	ΔV= change in V over the balance period
•		Q_i= wetland influent flow rate
•		Q_o= wetland effluent flow rate
•		P= precipitation rate
	•	S_i= surface inflow rate (excluding Q_i)
	•	G_i= ground water inflow rate
	•	G_o= ground water outflow rate
	•	ET= evapotranspiration rate
		ρ = density of water

Figure 17. A conceptual model of the water budget for the Cannon Beach wastewater wetland.

concept is (time rate of change of water mass within the water sheet)= (rate of water input into wetland) - (rate of water output out of wetland). Mathematically, the relationship is expressed by the following equation

$$(\Delta V)/\Delta t = (Q_i \rho + P\rho + S_i \rho + G_i \rho) + (ET\rho + G_o \rho + Q_o \rho)$$

Each term in equation 1 is defined in Figure 17. The density term, ρ, is common to each term in equation 1 and cancels out resulting in the following equation

$$\Delta V/\Delta t = (Q_i + P + S_i + G_i) + (ET + G_o + Q_o)$$

Also, $\Delta V = \Delta L\ A(L)$ where ΔL is the average water level in the treatment cells and A(L) is the area of inundation as a function of L.

As a first order approximation assume surface inflows excluding the wastewater influent (S_i) and ground water inflows (G_i) are negligible for the balance period. Heavy rainfall is infrequent during the summer and this assumption appears valid. In addition, if the effluent flow rate (Q_o) is the same at the beginning and end of the balance period, assume $\Delta L = 0$, thus $\Delta V = 0$. Under these assumptions equation 2 reduces to

$$0 = Q_i + P - ET - G_o - Q_o \qquad (3)$$

Measured quantities for equation 2 are Q_i, P, and Q_o. If an evapotranspiration rate (ET) is assumed then the ground water outflow rate can be estimated as the residual of equation 3:

$$G_o = Q_i + P - ET - Q_o \quad (4)$$

Figure 18 shows the balance period used for this model from July 16 to October 2, 1986; effluent flow rates (Q_o) are 0.098 and 0.099 MGD respectively and influent flow rates are 0.441 and 0.486 MGD respectively.

For the measured values of Q_i, P, and Q_o the units of volume/time are converted to cm/time by the following formula:

$$(X gal/day)(3.069 \times 10^{-6} ac\text{-}ft/gal)(12 in/ft)(2.54 cm/in)/15\ ac$$
$$= Y\ cm/day$$

From Figure 18, total values for Q_i, P, and Q_o for the balance period are:

Q_i= 188.8 cm added to the wetland

P= 17.8 cm measured by a local rain gauge

Q_o= 19.9 cm lost from the wetland by surface outflows

Given the aforementioned assumptions, all that is needed to estimate ground water outflows (G_o) is an assumed mean ET rate for the treatment cells over the balance period. Unfortunately no

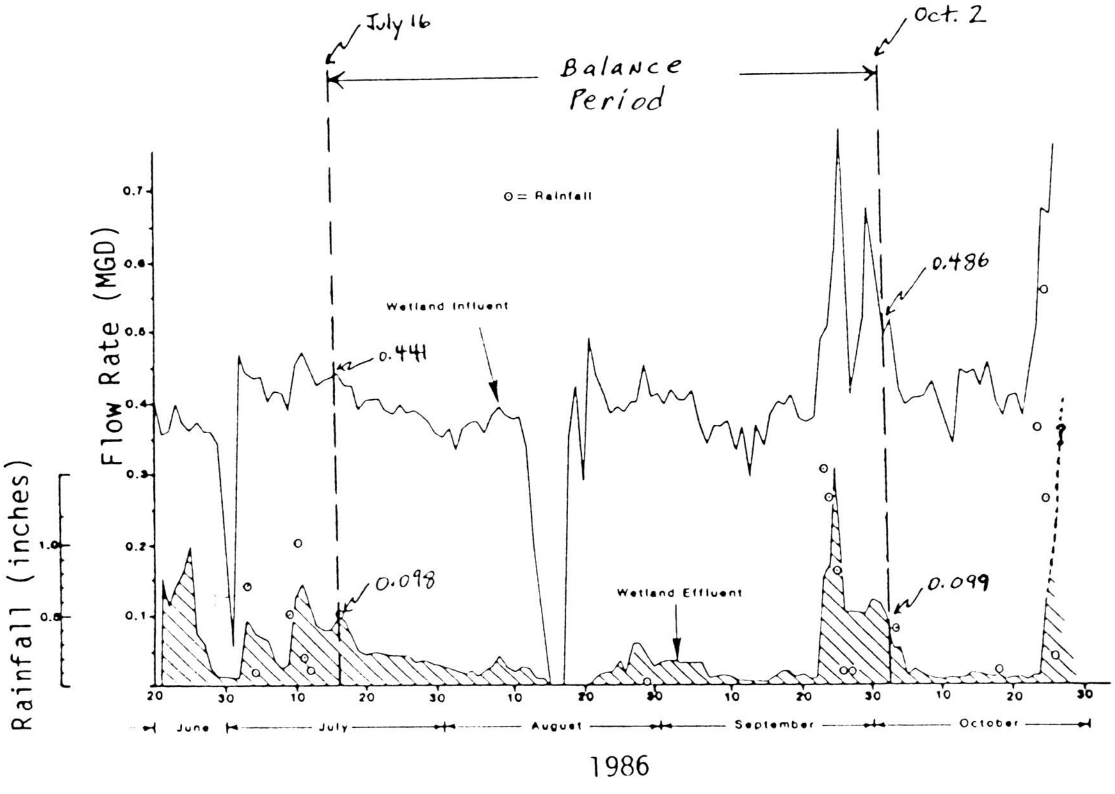


Figure 18. The balance period used to estimate the water budget for the Cannon Beach wastewater wetland.

direct evapotranspiration measurements are available for Oregon coastal zone swamp forests. In the absence of direct measurements pan evaporation data from the Astoria experiment station (Table 9) are used. Pan evaporation rates for Astoria are likely to be a poor surrogate for evapotranspiration at the wastewater wetland because the evaporation pan is more a giant slow response thermometer than an index of actual evapotranspiration rates over heterogenous stands of vegetation (William P. Lowry, personal communication 1987). However, pan evaporation data can be used to estimate a range of possible ET values to test the model's sensitivity to assumed ET rates (Figure 19).

Table 9. Astoria pan evaporation data (Astoria Experiment Station 1963-1972).

	Astoria Pan Evaporation Rate				
	Rate	$Rate_{max}$	Rate	No. of	Total
Month	cm/month	cm/month	cm/day	# days	cm
July	12.0 1.4	13.4	0.43	16	6.9
Aug	10.6 1.3	11.9	0.38	31	11.9
Sept	7.6 1.4	9.0	0.30	30	9.0
Oct	4.4 0.9	5.3	0.17	2	0.3
					Total= 28.1 cm

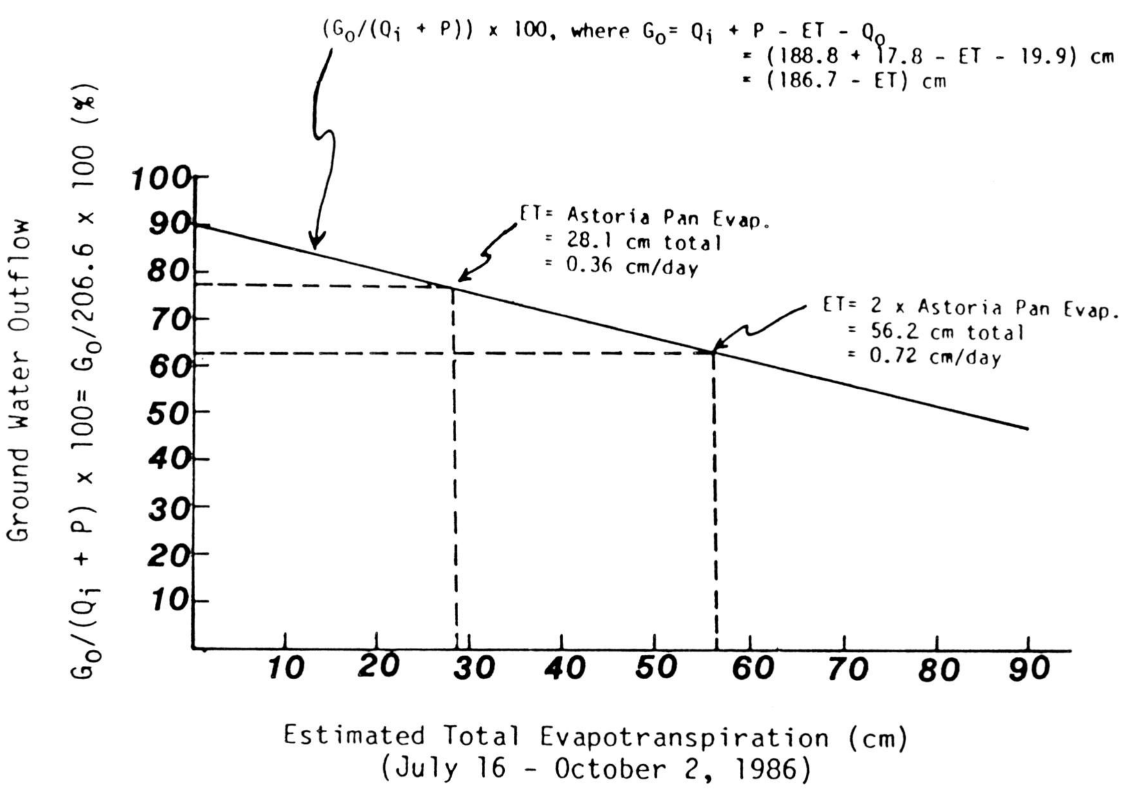


Figure 19. An estimate of ground water outflows (G_0) expressed as a percentage of total water inputs into the Cannon Beach wastewater wetland ($G_0/(Q_i + P) \times 100$) for the balance period of July 16 to October 2, 1986.

Figure 19 graphs estimated ground water outflows as a function of total estimated evapotranspiration for the balance period. Note that the calculated ground water outflow is relatively insensitive to large variations in assumed evapotranspiration values. For example, given an estimated ET= 28.1 cm (0.36 cm/day), which is the Astoria pan evaporation rate, G_o= 77% of Q_i + P. Even with a value double the Astoria pan evaporation rate, ET= 56.2 cm (0.72 cm/day), G_o is still 63% of Q_i + P. This latter value of ET is highly unlikely given that the maximum possible ET rate for any forest is 0.6 cm/day (Waring and Schlesinger 1985). With the generally foggy conditions at Cannon Beach during the summer the ET value of 28.1 cm may even be too high, but only direct site measurements will lay the question to rest. A hypothetical curve is also shown in Figure 17 where Q_o= 150 cm; in this case proportional change in G_o is greater as a function of ET than the actual curve and its magnitude is only 10-20% Q_i + P.

Discussion

Calculating components of a wetland water budget as a residual of a mass balance equation, such as equation 1, may lead to significant errors; the component that is derived may contain an unknown error which may be larger than the value of the component itself (Solokov and Chapman 1974). For long-term, regional studies the storage term, ΔV, can be considered equal to zero, however, for relatively short balance periods (e.g., a few months) and smaller areas, ΔV is generally not equal to zero and even more precise data is needed for the storage term (Solokov and Chapman 1974, Dooge 1975).

How valid is the assumption for the Cannon Beach site that ΔV equals zero for the balance period? Effluent flow rates for the beginning and end of the balance period are essentially identical (a difference of 0.001 MGD or 0.006 cm/day). The total amount of water added to the wetland 5 days prior to July 16 ($Q_i + P$, with $S_i=G_i=0$) equals 13.8 cm and the total amount of water added to the wetland 5 days prior to October 1 ($Q_i + P$, with $S_i=G_i=0$) equals 16.2 cm, only a 15% difference. Thus, the assumption that the water level had an approximate net change of zero ($\Delta L=0$) for the balance period appears reasonable.

The literature offers conflicting information regarding the magnitude of evaporation from open water relative to evapotranspiration from wetland vegetation. In a forested pond cypress dome in Florida, Heimburg (1984) reported swamp evapotranspiration as 80% of pan evaporation during the dry season (spring and fall) and as low as 60% of pan evaporation during the wet season (summer). Eisenlohr (1966) found 10% lower evapotranspiration from vegetated prairie potholes than from non-vegetated potholes in North Dakota. However, Hall et al. (1972) estimated, through measurements and calculations, that a stand of vegetation in a small New Hampshire wetland lost 80% more water than did the open water in the wetland.

Because of the conflicting measurements and difficulty of directly measuring evapotranspiration from wetlands Linacre (1976) concluded that neither the presence of wetland vegetation nor the type of vegetation had major influences on evaporation rates, at least during the active growing season. Another complication is that the red alder in the western portion of the cells undergoing flooding stress have reduced transpirational rates relative to the unstressed red alder and large Sitka spruce in the eastern portion of the cells.

If the initial assumption that $\Delta V = 0$ over the balance period is valid, then the water budget model indicates ground water outflows account for 65-85% of the total water input into the wetland treatment cells for the balance period of July 16 through October 2, 1986 (Figure 19). A large proportion of the water loss via G_0 likely flows laterally east towards Ecola Creek. Lateral flow is probably impeded by the highway barrier west of the treatment cells. Only a more detailed study using shallow wells will be able to determine this aspect of the water budget more precisely.

Why wetland effluent (Q_0) starts so much earlier and at a greater magnitude in 1986 relative to 1985 is difficult to answer given so little measured data. If the operator's notes are correct one would at first assume that ET is much greater in 1985 vs. 1986 because of the dry weather noted. However, the previous analysis suggests G_o is the primary sink for wetland water inputs (Q_i + P). The various possiblities that may account for this difference include:

1. The G_o rate was greater in 1985 than 1986, with ET rates about the same for both time periods or perhaps ground water storage capacity is becoming saturated.

2. Both G_o and ET were greater in 1985 relative to 1986.

3. The water budget model in this paper is incorrect with G_o smaller than estimated and ET the most significant sink for water in the wetland (thus ET was much greater in 1985 than 1986).

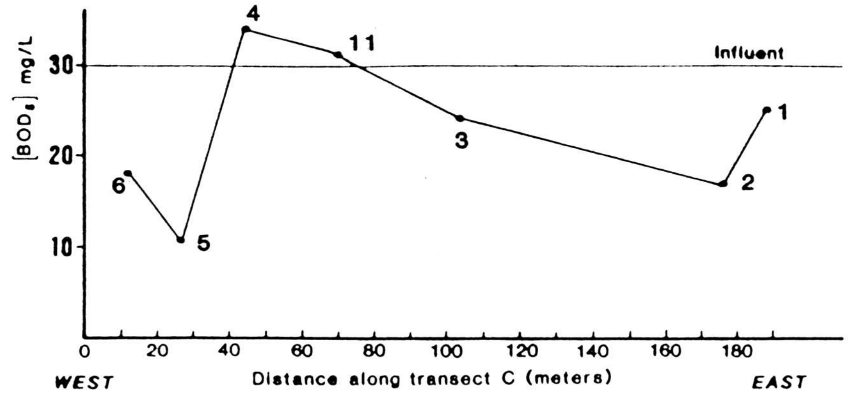
4. The treatment plant operator was incorrect in his estimate of both Q_o timing and magnitude.

Whichever the case may be, the consumption of water by ET + G_o in the wetland for 1986 is substantial. The implications of the significant water consumption in the wetland via ET + G_o are discussed in the next section.

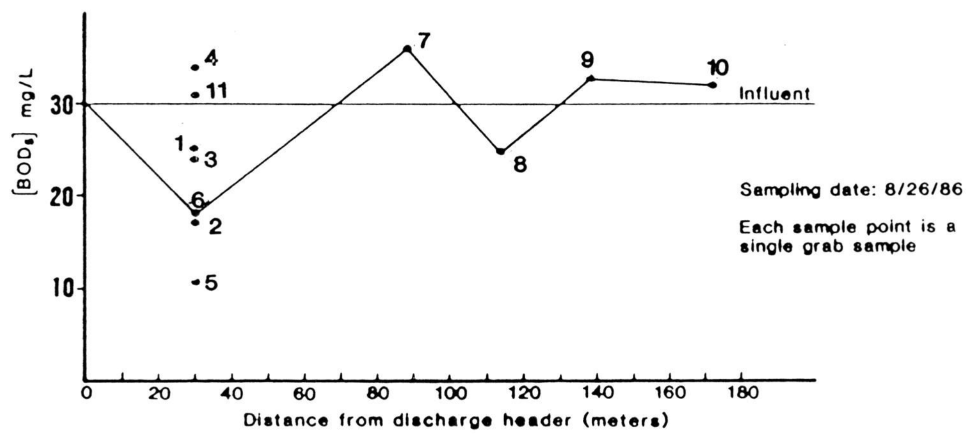
WATER QUALITY

Materials which enter and leave the wetland treatment cells are associated with solids, dissolved in water, or are gases. Total inputs and outputs of these materials are dependent on the dynamics of the hydrologic regime (Kadlec 1985). For example, large flow rates mean higher flow velocities, more aeration and greater resuspension rates of settable and suspended solids in different sections of the wetland. Figures 20 and 21 display BOD_5 and suspended solids data taken along two approximately perpendicular transects in cell 1. The water is deeper in the western section of cell 1 and with large amounts of woody debris appears to flow more slowly in this section than in the middle and eastern section of cell 1, which has more clearly defined channels. Variable flow rates are the norm for the treatment cells, but even with a constant influent flow rate extremely small gradients throughout the wetland can cause spatial variations in flow velocities resulting in complex spatial variablity in settling and resuspension rates of algal detritus, flocculent material, plant litter, and inorganic substances. Seasonal variations in ambient temperature and the hydrologic regime (hydroperiod and water budget) not only directly affect wetland physical and chemical treatment processes but influence the vegetation cover and subsequent litter production, the decomposer and invertebrate community, and avifauna and mammalian

(A)



(B)



Sample locations:

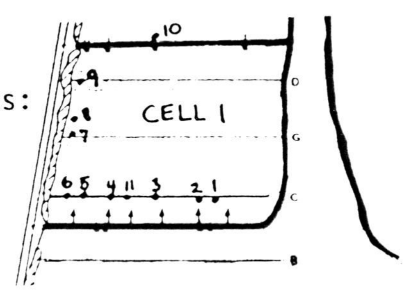


Figure 20. Spatial variation of five-day biochemical oxygen demand (BOD_5) in cell 1. (A) Grab samples taken along transect C. (B) Grab samples taken along a transect perpendicular to (A).

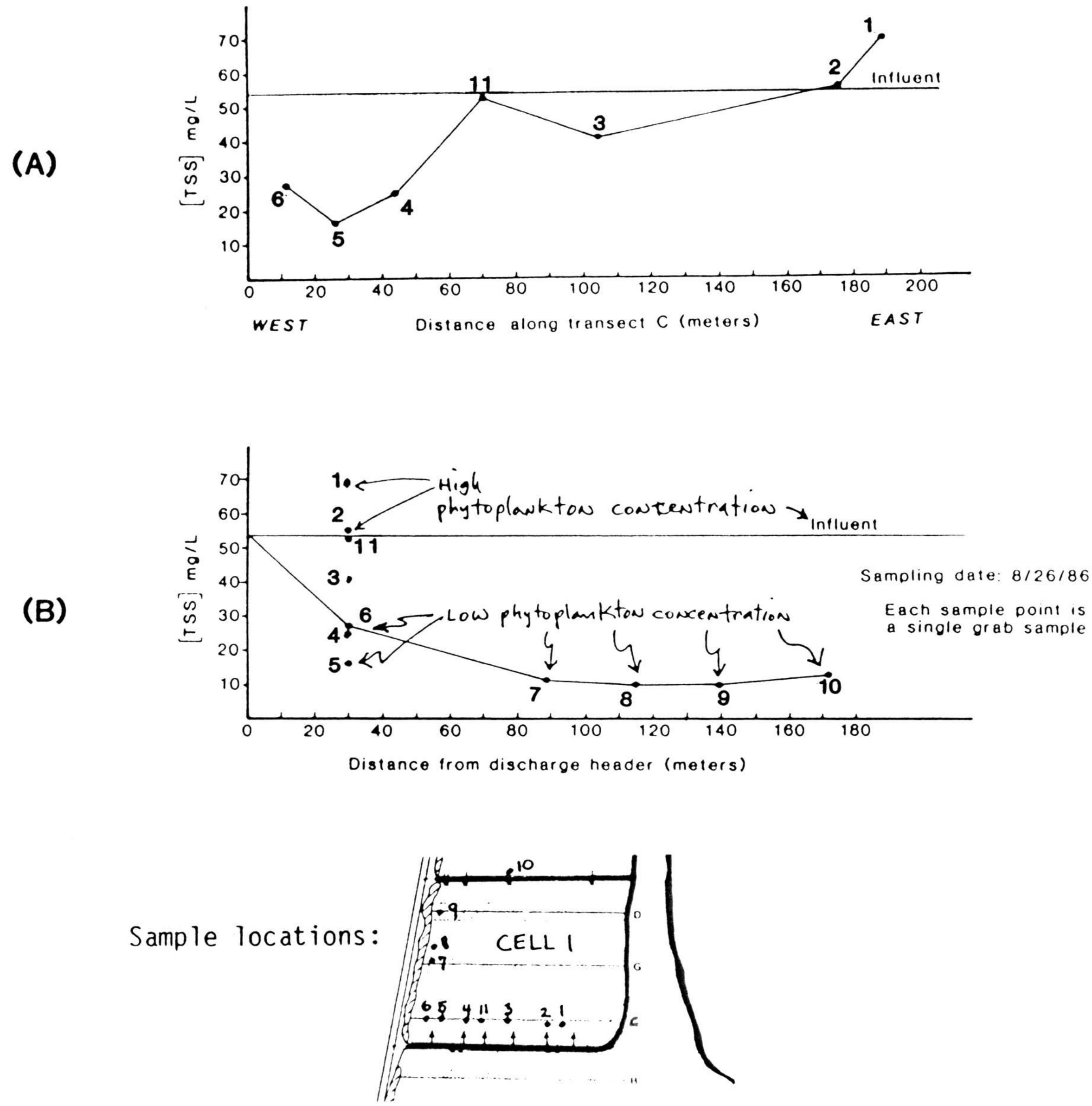


Figure 21. Spatial variation of total suspended solids (TSS) in cell 1. (A) Grab samples taken along transect C. (B) Grab samples taken along a transect perpendicular to (A).

activity; all of these factors can strongly influence total inputs and outputs of waterborne substances (Kadlec 1985, Guntenspergen and Stearns 1985).

Complex spatial variations were observed for Daphnia sp. and copepod population densities throughout the wetland during the summer of 1986. Daphnia feed on phytoplankton and have been found to clarify wastewaters in experimental treatment systems (Dinges 1976) but can also stimulate growth and productivity of some algae species (Porter 1976). The Daphnia ranged from white to deep red in color, indicating different dissolved oxygen concentrations throughout the wetland (Dinges 1976). The importance of phytoplankton grazing by invertebrates in suspended solids reduction as compared to physical settling processes for the Cannon Beach wetland is not assessed.

The Cannon Beach wastewater wetland treatment system has consistently met the 10/10 limitations for three years operation (Figure 22 and 23). Because of the significant water loss via G_o + ET the wetland has been a very effective particulate filter given loading rates of BOD and TSS of the past three years operation. Figures 24 and 25 show BOD and TSS loading rates of the wetland and Ecola Creek for 1986.

Cannon Beach operators report 'removal efficiencies' for BOD and TSS to ODEQ. Removal efficiencies are calculated by comparing effluent concentrations and total loading (concentration x flow rate) of BOD and TSS to that of the influent. These water quality

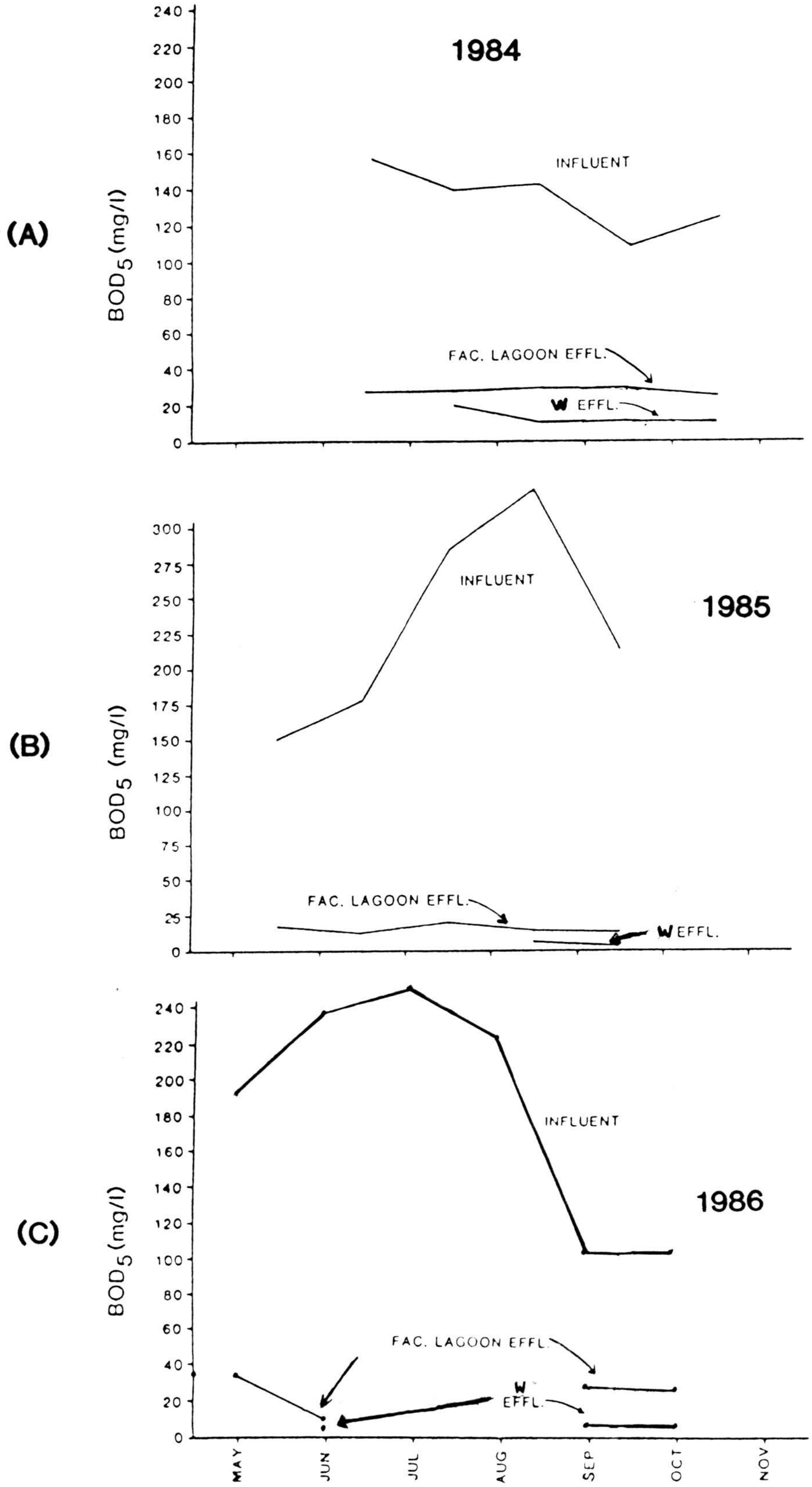


Figure 22. Mean monthly biochemical oxygen demand data for the Cannon Beach wastewater treatment system -- 1984 - 1986. Sampling frequency is approximately biweekly. (Cannon Beach monitoring reports and Thompson and Minor 1986). Data is incomplete for 1986.

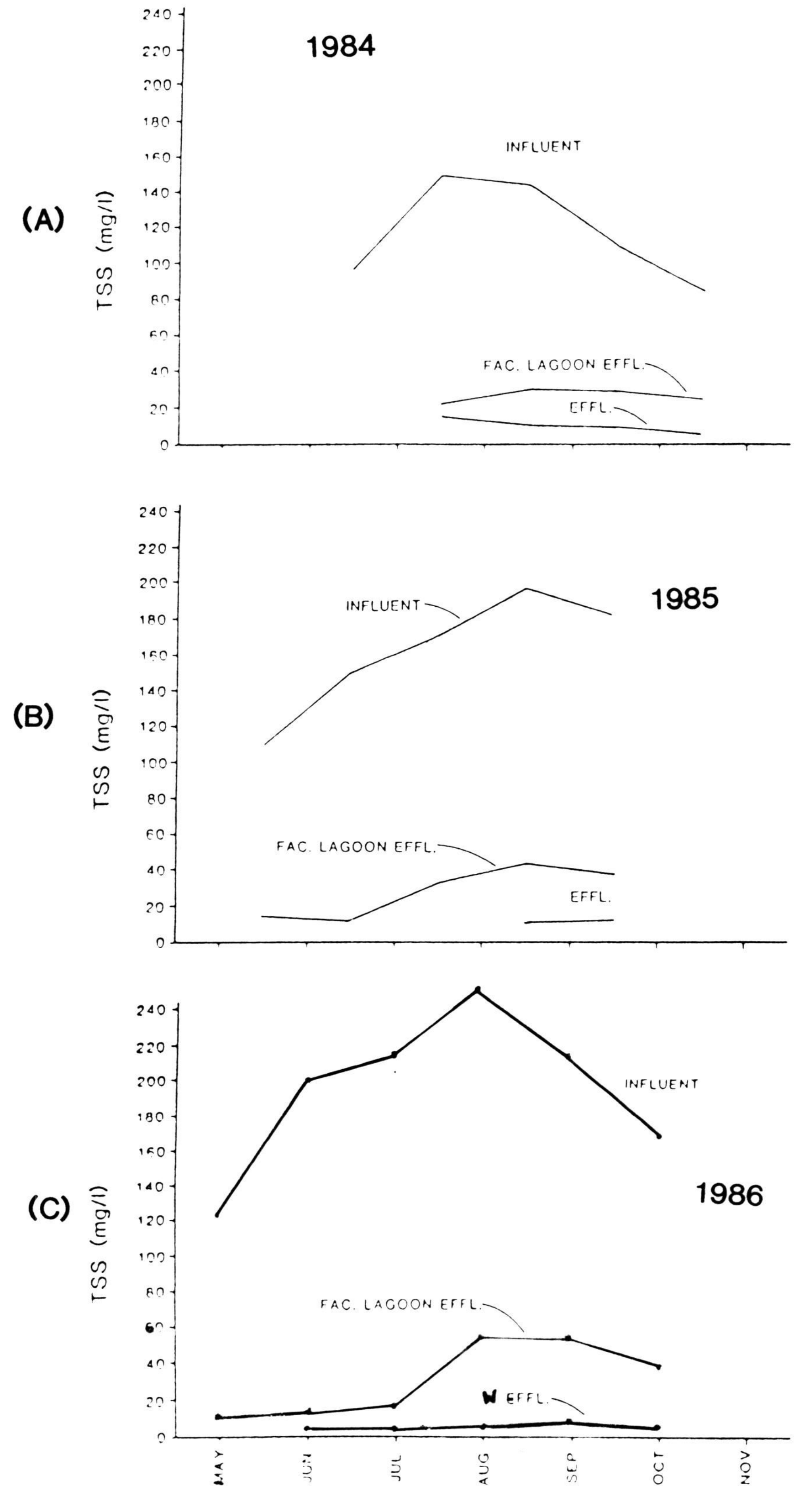


Figure 23. Mean monthly total suspended solids data for the Cannon Beach wastewater treatment system -- 1984 - 1986. Sampling frequency is approximately biweekly. (Cannon Beach monitoring reports and Thompson and Minor 1986). Data is incomplete for 1986.

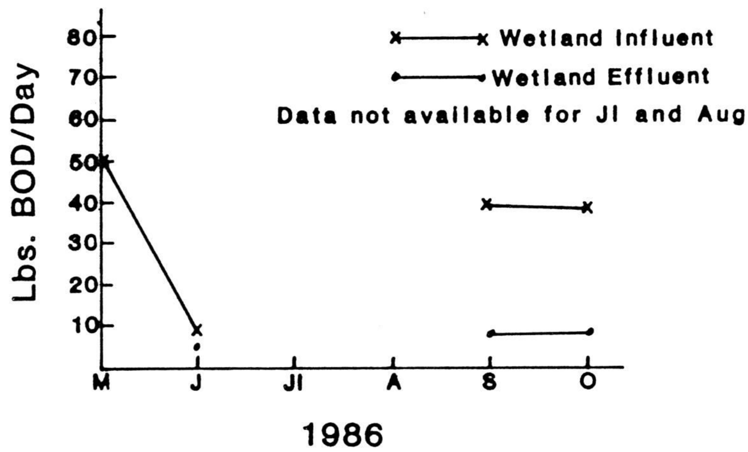


Figure 24. Mean monthly biochemical oxygen demand loaading rates for the wetland treatment cells and Ecola Creek -- 1986. Data is not available for July and August.

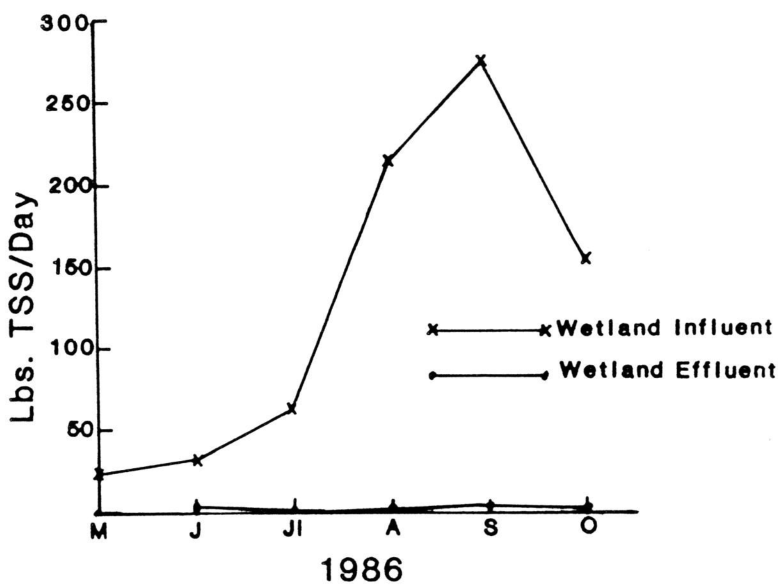


Figure 25. Mean monthly total suspended solids loading rates for the wetland treatment cells and Ecola Creek -- 1986.

constituents are measured from composite grab samples taken on the same day. The term 'removal efficiency' as reported can be highly misleading. Comparing outflow concentrations to inflow concentrations without accounting for the time lag of advective transport of these materials through the wetland can lead to erroneous conclusions, especially if determining nutrient or fecal coliform 'removal efficiencies'.

Because of time and funding constraints nutrient sampling for the 1986 operational season is limited to two sampling periods for phosphorus (Figure 26). The data is so limited as to prevent drawing conclusions about phosphorus 'removal efficiencies'. Samples were unfiltered and not representative of the 'undisturbed' wetland water sheet. It is very difficult to obtain representative water samples in the wetland without stirring up detritus and muck, so future phosphorus sampling should focus on filtered samples and dissolved phosphorus species. Phosphorus removal tends to be poor in bogs with low soil mineral content and removal tends to be highest in mineral soils in terrestrial environments (greater than 90% removal) (Richardson 1985). No soil chemical analyses have been conducted on Coquille soils, but the Cannon Beach wetland is probably intermediate in the soil inorganic-organic matter spectrum. Ecola Creek is not considered nutrient sensitive because of its proximity to the ocean.

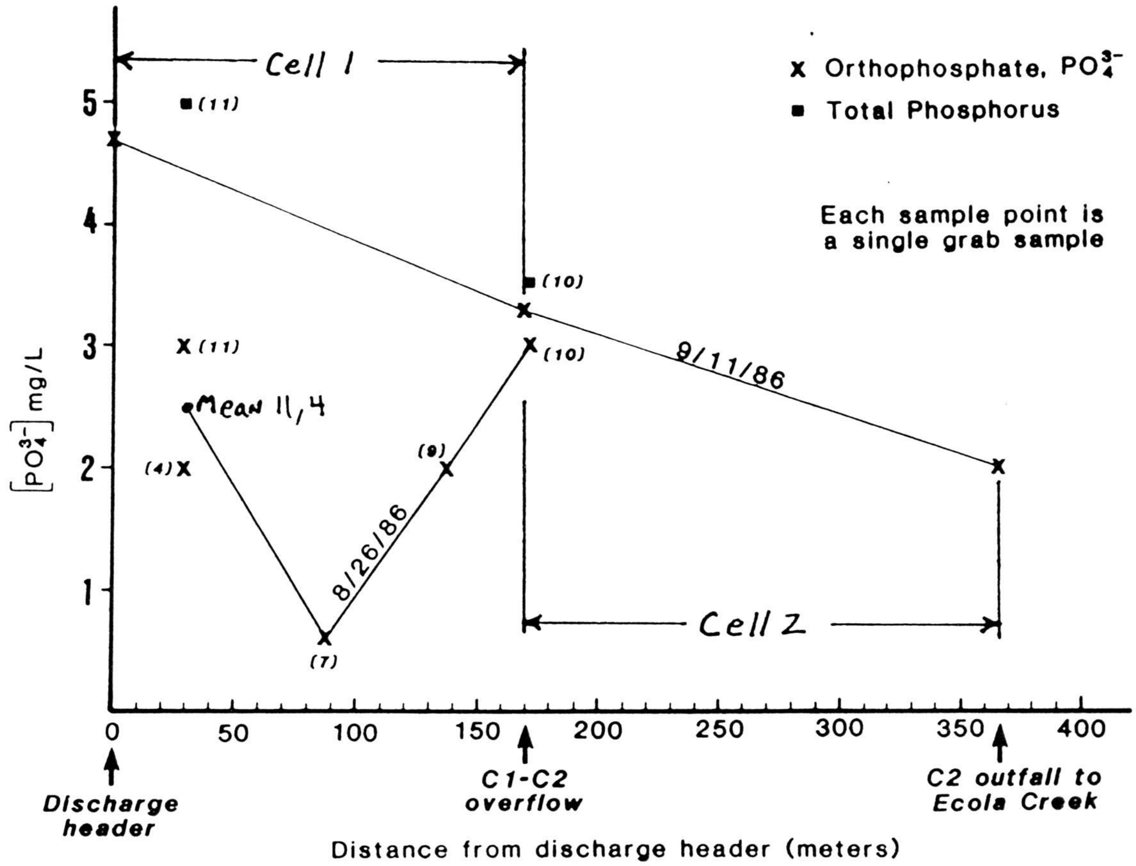


Figure 26. Orthophosphate and total phosphorus data for the wetland treatment cells -- 1986. Laboratory analysis conducted at the Cannon Beach wastewater treatment plant using a Hach test kit (Model # PO-24).

SUMMARY AND CONCLUSIONS

The City of Cannon Beach uses a seven hectare red alder/ slough sedge/twinberry palustrine wetland, divided into two cells in series, to treat chlorinated effluent from a four-cell aerated/ facultative lagoon sewage treatment system. Operation began June, 1984. The system has proven to be an effective means of meeting summer wastewater discharge limitations (10 mg/l BOD_5 and 10 mg/l TSS).

The primary purpose for biological monitoring, established by special conditions of the Corps of Engineers 404 permit, is to provide data to assist evaluation of future wetland treatment system proposals in the region. Research will also permit development of monitoring procedures for improved wastewater wetland management. A vegetation sampling scheme (referred to as the permanent plot method) was devised and baseline data collection performed in 1984 by staff of the Corps of Engineers, Oregon Department of Fish & Wildlife, and the U.S. Fish & Wildlife Service. This vegetation survey was repeated in 1986. Results indicate herbaceous and shrub vegetation changes since 1984 are relatively minor, however, a decrease in herbaceous cover has occurred in channelized and deeply flooded areas, especially towards the western section of the treatment cells (the western section is at a lower elevation relative to the eastern section and thus has deeper water levels for given influent flow rates). The data also indicate an increase in slough sedge cover in the eastern section of cell 2 which has shallow water levels (3-10 cm) and frequent drawdowns.

A complex pattern of flooding stress, consisting of defoliated trees, sparsely leaved trees, and some dead trees, is observed in 1986 for red alder, and to a lesser extent twinberry, in deeper water towards the western section of the treatment cells and adjacent to the dikes where water ponds. The hummocky topography complicates prediction of the extent and stability of flooding stress because high hummocks in the western section of the cells contain trees and shrubs of relatively good vigor. Prediction is further complicated by red alder being blown over in storms and subsequently surviving by adventitious rooting and apical dominance shifting to former branches.

Field research conducted April through September 1986 developed a method of herbaceous vegetation sampling using the nested frequency method; one hundred fifty-five nested frequency sampling plots (50 cm x 50 cm nested within 1 m x 1 m) yield a baseline data set for future vegetation trend analyses. An excellent agreement was found for percent cover of herbaceous and shrub vegetation as determined by the nested frequency method (155 plots) and the permanent plot method (22 herbaceous plots and 22 shrub plots). The nested frequency method, however, yields substantially more plots per man hour and thus more sampling resolution per man hour than the permanent plot method.

For 1986, wetland influent and effluent flow rates were 0.40 and 0.038 MGD respectively. An independent water budget estimate suggests ground water infiltration is at least 65-85% of the water loss.

For three years the Cannon Beach system has met ODEQ water quality discharge standards (10/10 limitations). BOD_5 and TSS wetland influent concentrations were reduced by 40% and 85% respectively. Phytoplankton constitute the bulk of the suspended solids discharged into the wetland. Within thirty to forty meters into the first treatment cell the concentration of phytoplankton is greatly reduced; the suspended solids in the wetland water sheet are therafter predominantly composed of plant detritus and humic materials. Settling and resuspension rates of suspended solids vary in a complex manner throughout the treatment cells. The relative importance of physical settling, physical filtration by vegetation and woody debris, invertebrate grazing, and reduced solar radiation by the canopy cover to phytoplankton removal is not quantitatively assessed by this study.

The loss of tree species is not likely to adversly affect water quality treatment, especially for BOD and suspended solids. Bacterial metabolism is the primary removal mechanism for BOD and colloidal solids; sedimentation is the primary removal mechanism for settable solids (Tchobanoglous and Culp 1980). Longer term retention of nutrients by trees may diminish in a portion of the cells with extensive tree death, but the effect on overall nutrient removal and transformation will probably be minimal.

As the treatment system ages passerine bird habitat will decrease in the western section of the cells as the tree density decreases, but waterfowl habitat will increase. Slough sedge cover is likely to remain relatively stable and perhaps increase in shallow portions of the cells.

Monitoring needs to be improved and coordinated with management decisions. For example, how should dike vegetation be maintained? Given the ability to manipulate water levels and the dispersal pattern how should these be varied and for what purpose?

Monitoring Recommendations

Two levels of monitoring are described in this section. The first level is least expensive and the minimum recommended level of monitoring. The second level is more costly, but also yields more information. Achieving the first level does not mean that the second level should not also periodically be reached -- many components of the second level require a single effort followed by less demanding measurements. Monitoring recommendations are limited to the wetland treatment operation of the Cannon Beach wastewater treatment facility.

Level 1

1. Plant operators should:
   a. Maintain a wetlands observation record that includes: a record of any changes made in

discharge header wastewater distribution and weir levels (i.e., type of change, reasons for change, date of change); and a record of weather conditions.

b. Measure the hydroperiod at three water sampling stations located in the western portion of the treatment cells on a bi-weekly basis while taking required water samples. Either a stationary staff gauge or a mobile measuring rod could be used, with an emphasis on a repeatable and consistent method.

c. Determine the area of inundation as a function of influent flow rates to gain some understanding of the operating range of the system.

2. It is highly recommended that the nested frequency sampling method be repeated every two years; the survey should be repeated during August-September. A greater number of sample plots per man hour can be obtained with the nested frequency method than for the permanent plot method resulting in greater sampling resolution per man hour.

3. At minimum, the permanent plot sampling method should be repeated every two years. The influent should be shutoff for a one week period during the vegetation

sampling survey. This survey need not take place in the same year as the nested frequency sampling. Researchers should integrate hydroperiod information with vegetation survey data and draw inferences with caution.

4. Repeat the tree survey for basal diameter in the summer of 1989 and thereafter at 3 year intervals. Observations should be made on tree vigor for each tagged tree as well as generally throughout the wetland.

Level 2

1. Level 1 monitoring in addition to a detailed topographic survey. The topographic survey would best be carried out when the wetland was not flooded, such as immediately after the October shut-off date.

2. Develop a simple mathematical model to determine the area of inundation as a function of the water level, A(L), and the water level, L, as a function of influent flow rates, rainfall and weather conditions, $L=f(Q_i, P, ET)$. Experiments should be conducted to determine A(L) and L variability with changes in water dispersal via the discharge pipes and weirs.

3. A network of shallow wells can be placed at dike perimeters to investigate ground water recharge.

4. Monitor nitrogen and phosphorus on at least a bi-weekly basis for wetland influent and effluent. Caution should be exercised, however, when reporting 'removal efficiencies' because dissolved materials may be carried out via ground water infiltration -- this is not the same type of 'removal' as consumption at solid interfaces.

Management Recommendations

It is unlikely that wetland BOD and TSS loading of Ecola Creek through wetland discharge will exceed ODEQ limitations in the near future. If limitations are exceeded on a consistent basis then operators will probably need to lower mean water levels and decrease the water turnover rate by manipulating the dispersal pattern and weir levels to acheive maximum contact of wastewater with soils. A last, and highly unlikely, alternative should this occur would be to make the flow more tortuous by damming up some of the main channels with soil material and establishing *Carex obnupta* or other emergent species.

A willingness to experiment based on clearly defined objectives, monitor changes, and incorporate observations into management is a sound approach to managing Oregon's first wastewater wetland treatment system.

LITERATURE CITED

Bedinger, B. 1979. Relation between forest species and flooding, p. 427-435, In Wetland functions and values: The state of our understanding. Greeson, P.E., J.R. Clark, and J.E. Clark (eds). American Water Resource Association, Minneapolis, Minnesota.

Corps of Engineers. 1983. Permit reference no. 071-OYA-4-004772. Portland District Army Corps of Engineers, Regulatory Branch.

Demgen, F. 1982. Site visit report - Cannon Beach 12-13-82. On file at the Cannon Beach wastewater treatment plant office.

Dinges, R. 1976. A proposed integrated biological wastewater treatment system, p. 225-230, In Biological control of water pollution. J. Tourbier and R.W. Pierson (eds.). Univ. of Pennnsylvania, Philadelphia.

Dooge, J. 1975. The water balance of bogs and fens, p. 233-271, In Hydrology of marsh-ridden areas. Proceedings of the Minsk Symposium. The Unesco Press, Paris.

Eisenlohr, Jr., W.S. 1975. Hydrology of marshy ponds on the Coteau Du Missouri, p. 305-311, In Hydrology of marsh-ridden areas. Proceedings of the Minsk Symposium. The UNESCO Press, Paris.

Gill, C.J. 1970. The flooding tolerance of woody species--A review. Forestry Abstracts 31: 671-688.

Godfrey, P.J., E.R. Kaynor, S. Pelczarski, and J. Benforado (eds.). 1985. Ecological considerations in wetland treatment of municipal wastewaters. Van Nostrand Reinhold Co., New York.

Guntenspergen, G.R. and F. Stearns. 1985. Ecological perspectives on wetland systems, p. 69-95, In Ecological considerations in wetland treatment of municipal wastewaters. Godfrey, P.J. et al. (eds). Van Nostrand Reinhold Co., New York.

Hall, F.R., R.J Rutherford, and G.L. Byers. 1972. The influence of a New England wetland on water quantity and quality. New Hampshire Water Resource Center Research Report 4. Univ. of New Hampshire, Durham.

Hammer, D.E., and R.H. Kadlec. 1983. Design principles for wetland treatment systems. U.S. Environmental Protection Agency Report EPA-600/2-83-026. Ada, Oklahoma.

Heimburg, K. 1984. Hydrology of north-central Florida cypress domes, p. 72-82, In Cypress swamps. K.C. Ewel and H.T. Odum (eds). Univ. of Florida Press, Gainsville.

Hironaka, M. 1985. Frequency approaches to monitor rangeland vegetation, p. 84-86, In Proceedings 38th Annual Meeting of the Society for Range Management. Salt Lake City, Utah, February 11-15, 1985.

Hitchcock, C.L. and A. Cronquist. 1973. Flora of the Pacific Northwest. Univ. of Washington Press, Seattle, WA.

Kadlec, R.H. 1985. Aging phenomena in wastewater wetlands, p. 338-345, In Ecological considerations in wetland treatment of municipal wastewaters. Godfrey, P.J. et al. (eds.). Van Nostrand Reinhold Co., New York.

Kelly/Strazer Associates. 1983. Geotechnical investigation and report, proposed wetlands/marsh treatment area and related facilities, City of Cannon Beach. Kelly/Strazer Associates, Geotechnical Consultants, Portland, OR.

Knutson, P., et al. 1981. National survey of planted salt marshes: (vegetative stabilization and wave stress). Wetlands 1: 129-157.

Kramer, Chin & Mayo, Inc. 1981. Facilities plan addendum no. 2: Development & evaluation of wetlands/marsh wastewater treatment system - City of Cannon Beach. Kramer, Chin & Mayo, Inc. Salem, Oregon.

Linacre, E. 1976. Swamps, p. 329-347, In Vegetation and the atmosphere, vol. 2, Case Studies. J.L. Monteith, ed. Academic Press, London.

Mitsch, W.J. and J.G. Gosselink. 1986. Wetlands. Van Nostrand Reinhold Co., New York.

Mitsch, W.J. and W.G. Rust. 1984. Tree growth responses to flooding in a bottomland forest in northeastern Illinois. Forest Science 30: 499-510.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York. p. 62

Nichols, D.S. 1983. Capacity of natural wetlands to remove nutrients from wastewater. J. Water Pollution Control Federation 55: 495-505.

Odum, W.E., Smith III, T.J., Hoover, J.K., and C.C. McIvor. 1984 The ecology of tidal freshwater marshes of the United States east coast: A community profile. U.S. Fish and Wildlife Service. FWS/OBS-87/17. Washington D.C.

Office of Technology Assessment. 1984. Wetlands: Their use and regulation. U.S. Congress OTA-O-206, Washington D.C.

Porter, K.G. 1979. Enhancement of algal growth and productivity by grazing zooplankton. Science 192: 1332-1334.

Richardson, C.J. 1985. Mechanisms controlling phosphorus retention capacity in freshwater wetlands. Science 228: 1424-1427.

Rogers, R.T. 1984. Field report: Biological monitoring plan, Cannon Beach wetland sewage treatment facility. On file at the Portland District Army Corps of Engineers Regulatory Branch office, Portland, Oregon.

Smith, S.D., Bunting, S.C., and M. Hironaka. 1986. Sensitivity of frequency plots for detecting vegetation change. Northwest Science 60: 279-286.

Soil Conservation Service. 1982. Soil interpretation records for the Coquille-Clatsop Complex and the Nehalem Silt Loam, unpublished.

Tchobanoglous, G. and G.L. Culp. 1980. Wetland systems for wastewater treatment: An engineering assessment, p. 13-42, In Aquaculture Systems for wastewater treatment: An engineering assessment. EPA 430/9-80-007, U.S. EPA, Washington, D.C.

Thompson, D. and J. Minor. 1986. Wetlands/marsh treatment system improves lagoon effluent quality. Presented at the 52nd Annual Pacific Northwest Pollution Control Association.

U.S. Environmental Protection Agency. 1983. Freshwater wetlands for wastewater management:Environmental impact statement - Phase 1 report. EPA 904/9-83-107, U.S. EPA Region IV. Atlanta, Georgia.

U.S. Environmental Protection Agency and the U.S. Fish and Wildlife Service. 1984. The ecological impacts of wastewater on wetlands. EPA-905/3-84-002, U.S. EPA Region V. Chicago, Illinois.

Van der Valk, A.G. 1981. Succession in wetlands: A Gleasonian approach. Ecology 62: 688-696.

Verry, E.S. and D.H. Boelter. 1979. Peatland hydrology, p. 389-402, In Wetland functions and values: The state of our understanding. P.E. Greeson, J.R. Clark, and J.E. Clark (eds.). American Water Resource Association, Minneapolis, Minnesota.

Waring, R.H. and W.H. Schlesinger. 1985. Hydrology of forest ecosystems, In Forest ecosystems: Concepts and management. Academic Press, Inc.

Williams, J.D. and C.K. Dodd, Jr. 1979. Importance of wetlands to endangered and threatened species, In Wetland functions and values: The state of our understanding. P.E. Greeson, J.R. Clark, and J.E. Clark, eds. American Water Resource Association, Minneapolis, Minnesota.

APPENDIX A

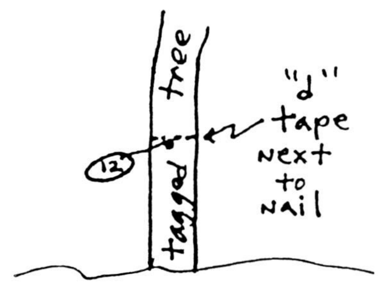
Tree Transect Data

Transect A

Genus/spp	Tag #	Diam (cm)	Notes
Alru	1	18.1	next to 101
"	2	13.3	↑ vegetation buffer
"	3	19.1	
"	4	11.5	
"	5	14.7	
"	6	16.3	
"	7	16.3	
"	8	17.2	
"	9	22.6	
"	10	12.5	
"	11	10.8	
"	12	—	
"	13	15.1	
Pisi	14	28.6	
Pisi	15	11.2	
Alru	16	35.9	
Pisi	17	15.8	
Alru	18	24.9	
"	19	17.3	
"	20	20.1	↓
"	21	25.1	wetland ↓
"	22	15.0	
"	23	29.2	
"	24	25.4	
Pisi	25	70.9	
Alru	26	24.8	
Alru	27	11.0	
Pisi	28	15.8	
Alru	29	27.3	
Pisi	30	23.2	
Alru	31	25.0	
Pisi	32	28.3	
Alru	33	33.8	
"	34	21.2	
"	35	14.1	
"	36	23.4	
"	37	28.2	
"	38	19.2	
	39	16.0	
Pisi	40	26.7	
Alru	41	31.9	
Pisi	42	29.9	
Pisi	43	24.3	
Alru	44	29.1	

Genus/spp	Tag #	Diam (cm)	Notes
Alru	45	31.3	
"	46	20.5	
"	47	27.3	
"	48	27.5	
"	49	25.9	
"	50	30.0	
"	51	23.0	
"	52	47.0	
"	53	—	
"	54	—	
"	55	16.0	
"	56	22.1	
"	57	—	dead
"	58	11.3	
"	59	41.4	
"	60	37.5	
"	61	38.6	
"	62	21.9	
"	63	16.4	
"	64	43.4	
"	65	10.7	
"	66	26.1	
"	67	10.4	
"	68	24.5	
"	69	26.5	
"	70	26.7	
"	71	16.5	
"	72	47.8	
"	73	18.0	
"	74	26.5	
"	75	22.6	
"	76	56.6	
"	77	55.3	
"	78	50.7	
"	79	29.9	
"	80	21.8	
Pisi	81	26.2	
Pisi	82	36.0	
Alru	83	—	
"	84	51.0	
"	85	46.0	
"	86	37.8	
"	87	38.4	
"	88	21.2	

Location of diameter measurements:



See Appendix C for spp acronyms

Transect A (cont'd)

Genus/spp	Tag #	Diam (cm)	Notes
—	82	—	can't find
Alru	83	51.0	
"	84	46.0	
"	85	37.8	
"	86	38.4	
"	87	21.2	
"	88	42.1	
"	89	32.0	
Pisi	90	19.6	
Alru	91	22.2	

Genus/spp	Tag #	Diam (cm)	Notes

Transect C

Genus/spp	Tag #	Diam (cm)	Notes
Pisi	1	13.2	Next to 101
"	2	14.2	↑ VEGETATION BUFFER
"	3	14.2	
"	4	14.2	
"	5	14.7	
"	6	23.4	
"	7	11.9	
"	8	19.6	
Alru	9	34.3	
Pisi	10	14.5	
Alru	11	21.3	
Alru	12	25.9	
Pisi	13	10.4	
"	14	10.7	
"	15	11.2	
"	16	13.5	
"	17	12.2	
Alru	18	28.4	
Alru	19	30.2	↓
"	19a	—	Wetland ↓
"	19b	—	
"	19c	—	
"	20	15.0	
"	21	20.8	
"	22	12.4	
"	22a	—	
—	23	—	can't find
Alru	24	16.3	
"	25	13.7	
"	26	26.7	
"	27	—	
"	28	14.7	
"	29	18.8	
"	30	26.7	
"	31	22.6	
"	32	30.2	
Pyfu	33	11.7	
Pyfu	34	8.1	
Alru	35	27.7	
Alru	36	30.0	
Pyfu	37	10.4	
Alru	38	33.5	
Alru	39	39.4	
Alru	40	21.3	

Genus/spp	Tag #	Diam (cm)	Notes
Pisi	41	18.0	
Alru	42	47.6	
Alru	43	14.9	
Pisi	44	28.2	
Alru	45	18.8	
Alru	46	26.7	
Pisi	47	72.0	
Alru	48	42.2	
Alru	49	30.0	
Alru	50	36.1	
Pisi	51	14.0	
Alru	52	17.8	
Pyfu	53	12.0	
Pyfu	54	22.0	
Pisi	55	66.0	
Alru	56	15.0	
Alru	57	22.3	
"	58	28.2	
"	59	26.9	
"	60	—	
"	61	15.8	
"	62	31.8	
Pisi	63	20.9	
Alru	64	35.0	
"	65	39.8	
"	66	41.2	
"	67	27.2	dead
"	68	—	dead
"	69	22.1	
"	70	28.7	
Pisi	71	21.8	
Alru	72	22.8	
Alru	73	22.4	
Pisi	74	—	can't find
Alru	AA	24.6	Near #45-55.
"	AB	34.8	
"	AC	38.9	
"	AD	23.4	
"	AE	20.3	
"	AF	24.8	

Transect F

Genus/spp	Tag #	Diam (cm)	Notes
Pisi	1	15.5	Next to 101
"	2	17.9	vegetation buffer
"	3	25.1	
"	4	34.2	
"	5	40.9	
"	6	14.9	
Alru	7	11.2	
Alru	8	35.5	
Pyfu	9	—	wetland
Pyfu	10	13.0	
Alru	11	15.9	
Alru	12	17.9	
Alru	13	12.2	
Pyfu	14	28.1	
Pyfu	15	15.6	
Pisi	AA	20.8	
Alru	16	16.9	
"	17	33.9	
"	18	16.4	
"	19	21.2	
"	20	21.4	
"	21	23.9	
"	22	32.8	
"	23	35.2	
"	24	27.2	
"	25	31.7	
Pyfu	26	9.6	
Alru	27	—	can't find
"	28	23.2	
"	29	15.2	
"	30	15.5	
"	31	20.0	
"	32	18.3	
"	33	10.4	
Pisi	34	11.7	
Alru	35	25.9	
Pisi	36	15.0	
Alru	37	23.4	
"	38	15.2	
"	39	24.4	
"	40	25.3	
Pisi	41	11.4	
Alru	42	16.5	
Alru	43	26.9	

Genus/spp	Tag #	Diam (cm)	Notes
Alru	44	20.8	
Pyfu	45	14.2	
Alru	46	30.7	
"	47	29.5	
"	48	20.1	
"	49	20.3	
Pisi	50	21.1	
Alru	51	26.2	
"	52	30.3	
"	53	15.5	
"	54	22.6	
"	55	18.0	
"	56	18.0	
"	57	33.5	
"	58	25.1	
"	59	33.0	
"	60	30.5	
"	61	—	can't find
"	62	20.3	
Pisi	63	20.6	
Alru	64	34.3	
"	65	26.2	
"	66	15.5	
"	67	22.9	
"	68	27.6	
"	69	32.2	
"	70	27.2	
"	71	36.1	
"	72	27.3	
"	73	33.5	
"	74	32.5	
"	75	33.0	
"	76	16.0	
"	77	30.7	
"	78	25.4	
"	79	14.8	Next to east dike

APPENDIX B

Nested Frequency Method Notes

A partial field data sheet is provided to help the next survey crew. Example calculations are also shown below. Refer to the 1986 Monitoring Methods section -- Methods and Materials (p.33) -- for details concerning field methods.

Location: Transect A

WEST — EAST

Plot #	1	2	3	4	5	6	7	8	9
AQI	NA	A	IA	IA	NA	A	A	IA	NA
SPP									
Oesa	+2	-1			-2	+1			-1
Gash			0+5					0+1	+1
Pomu		0-2			0+1			0+1	+2
Atfi			0-2	+1	-1	+1			-1
:									
:									
:									
h(cm)	0	0	0	0	0	1.0	0	0	0

KEY

Rooted within quadrat, in muck:
- \+ presence in 50cm x 50cm plot, presence in 1m x 1 m plot
- \- absence in 50cm x 50cm plot, presence in 1m x 1m plot

Rooted within quadrat, on log or upland hummock:
- 0+ presence in 50cm x 50cm plot
- 0- absence in 50cm x 50cm plot, presence in $1m^2$ plot

AQI = Aquatic Index:
- A - aquatic, 50% plot inundated
- IA - intermediate, 25-50% plot inundated
- NA - upland or nonaquatic, 25% plot inundated

Numbers following +, -, or 0+, 0- are cover classes:
- 1 = $< 5\%$
- 2 = $5\% < x < 25\%$
- 3 = $25\% < x < 50\%$
- 4 = $50\% < x < 75\%$
- 5 = $> 75\%$

h = depth of water relative to ground surface

Example frequency calculation:

Oesa: frequency in $.25m^2$ = 2/9 x 100 = 22%

frequency in $1.0m^2$ = 5/9 x 100 = 55%

Example aquatic index/spp frequency calculation:

Atfi: NA = 2/5 x 100 = 40%
IA = 2/5 x 100 = 40%
A = 1/5 x 100 = 20%

APPENDIX C

Species acronym list for the Cannon Beach wastewater wetland, 1986. Taxonomy is based on Hitchcock and Cronquist (1973).

	Scientific Name	Common Name
Acci	Acer circinatum	vine maple
Adpe	Adiantum pedatum	maidenhair fern
Alru	Alnus rubra	red alder
Atfi	Athyrium filix-femina	lady fern
Blsp	Blechnum spicant	deer fern
Cal sp.	Calichtriche sp.	water-starwort
Cade	Carex deweyana	sedge
Caob	Carex obnupta	slough sedge
Car sp.	Cardamine sp.	bitter cress
Cial	Circaea alpina	enchanter's nightshade
Ep sp.	Epilobium sp.	willow weed
Erar	Erechtites arguta	fireweed
Gash	Gaultheria shallon	salal
Gatr	Gallium trifidum	bedstraw
Hy sp.	Hydrophyllum sp.	waterleaf
Lemi	Lemna minor	duckweed
Loin	Lonicera involucrata	twinberry
Lyam	Lysichitum americanum	skunk cabbage
Madi	Maianthemum dilatatum	false lily-of-the-valley
Mefe	Menziesia ferruginea	fool's huckleberry
Mo sp.	Montia sibirica	candy flower
Oesa	Oenanthe sarmentosa	water parsley
Chgl	Chrysosplenium glechomaefolium	golden carpet
Oxor	Oxalis oreganum	wood sorrel
Tome	Tolmiea menziesii	youth-on-age
Pisi	Picea sitchensis	Sitka spruce
Povu	Polypodium vulgare	licorice fern
Pomu	Polystichum munitum	sword fern
Pyfu	Pyrus fusca	wild crabapple
Rumex sp.	Rumex sp.	dock
Rupa	Rubus parviflorus	thimble berry
Rusp	Rubus spectabilis	salmon berry
Ruur	Rubus ursinus	pacific blackberry
Saca	Sambucus callicarpa	red elderberry
Seja	Senecio jacobaea	groundsel
Stco	Stachys cooleyae	hedge nettle
Tiun	Tiarella unifoliata	coolwort
Vapa	Vaccinium parvifolium	huckleberry
Vigi	Vicia gigantea	giant vetch

APPENDIX C

Species located within the wastewater wetland boundaries but not occuring in the nested frequency/permanent plot sampling survey:

Scmi	_Scirpus microcarpus_	small-fruit bullrush
Juef	_Juncus effusus_	soft rush
Tyla	_Typha latifolia_	cattail
Ve sp.	_Veronica_ sp.	speedwell
Poam	_Polygonum amphibium_	water smartweed
Pohy	_Polygonum hydropiper_	smartweed