D R A F T

Water Quality Aspects of the Proposed East-Coast Buffer Strip: Evaluation of the C11-West Basin

prepared for

U.S. Department of the Interior
Everglades National Park

by

William W. Walker, Jr., Ph.D.
Environmental Engineer
1127 Lowell Road
Concord MA 01742-5504
Tel 508-369-8061
Fax 508-369-4230
e-mail: wwwalker@shore.net

January 31, 1997

Abstract

A wetland buffer strip has been proposed for construction along the eastern edge of the Everglades to conserve water and to provide additional wetland habitat (CH2MHill, 1996). Potential water-quality impacts would result from diversion of urban and agricultural runoff into the buffer. Existing buffer designs are based largely upon water-supply and hydroperiod targets. Depth regimes differ markedly from those typically found in constructed wetlands designed for water-quality control.

This report develops and demonstrates a model for integrating water-quality concerns with other project objectives and constraints. The phosphorus-balance model used for designing Everglades Stormwater Treatment Areas is coupled with a model for estimating inflow and outflow seepage rates in buffer cells.

The model is used to estimate wetland acreage required to treat discharges from the C11W basin for various sets of design assumptions and objectives. Basin flows, consisting of a mixture of seepage from WCA-3 and runoff from the C11W watershed, are currently discharged into WCA-3A through the S9 pump station. This basin has a high priority from a water-quality perspective because it is one of the few locations along the East Coast where urban/agricultural runoff is currently back-pumped into the Everglades and the discharge is relatively close to Everglades National Park inflow structures.

Historical monitoring data from S9 reveal a strong positive correlation between phosphorus concentration and daily flow. Concentrations range from < 20 ppb at low flows to > 100 pp at high flows. This pattern reflects varying mixtures of seepage and runoff under different flow conditions. Capturing high flows would be an important design objective for a treatment system. With planned watershed development, the flow-weighted-mean phosphorus concentration in the S9 discharge is projected to increase from ~23 ppb (1981-1991) to ~34 ppb. If significant reductions in WCA seepage into C11 are realized with construction of the East Coast Buffer Strip, the concentration would approach 50 ppb.

Treatment area requirements ranging from 201 to 8486 acres are estimated for three water-management scenarios, three wetland prototypes, three target outflow concentrations, and two locations (Tables 7 & 12). Scenarios reflect different levels of seepage reduction, seepage/runoff separation, and discharge to the C11E basin. Wetland prototypes reflect different biological communities with phosphorus settling rates ranging from 10 to 30 m/yr, increasing management requirements, and increasing design uncertainty. Target outflow concentrations of 10, 20, and 30 ppb are considered.

Election of specific design assumptions is beyond the scope of this report. Nominal designs based upon extrapolation of performance data from the Everglades Nutrient Removal Project would require surface areas ranging from 1500 to 3700 acres to achieve a target concentration of 10 ppb, depending upon water management scenario and treatment area location. Scenarios providing reductions in seepage, selective treatment of high flows, and/or treatment of runoff before it is diluted with seepage would have lower total area requirements

than those treating all flows. Because of differences in seepage rates and directions, treatment areas located north of C11W would have higher surface area requirements than areas located south of C11W, particularly for a target concentration of 10 ppb. Given the importance of treating peak flows and existing water-level constraints in the vicinity of the C11W buffer, hydraulic factors may have a large influence on the location and shape of the treatment area.

Designs to achieve concentrations in the 10-30 ppb range with a constructed wetland are extrapolations based upon experience with constructed systems at higher concentrations and upon observed reductions in phosphorus achieved by natural (vs. constructed) communities in impacted regions of the Everglades.   Substantial research is needed to provide a basis for final design and implementation. Such research is currently underway to support Phase II phosphorus-control efforts mandated by and State/Federal Settlement Agreement and the Everglades Forever Act (SFWMD & FDEP, 1996).

Table of Contents

1.0 Introduction 1
2.0 Model Development 2
    2.1 Phosphorus Balance Model 2
    2.2 Buffer Seepage Rates 2
    2.3 Phosphorus Removal 4
3.0 The C11-West Basin 4
    3.1 Watershed and Hydrology 4
    3.2 Historical Water Quality 6
    3.3 Existing Buffer Design 8
4.0 Design Basis for Treatment Areas 9
    4.1 Projection of Future Flows & Phosphorus Loads 10
    4.2 Water Management Scenarios 12
    4.3 Wetland Prototypes 12
    4.4 Target Concentrations 13
5.0 Design Results 14
    5.1 Area Requirements 15
    5.2 Nominal Designs 15
    5.3 Sensitivity Analysis 16
    5.4 Evaluation of Northern Site 17
    5.5 Hydraulic Considerations 18
6.0 Conclusions 19
7.0 References 21

List of Tables

List of Figures

1.0 Introduction

Significant volumes of water are lost from the Everglades Water Conservation Areas (WCA's) and Everglades National Park (ENP) in the form of groundwater flow through and under levees along their eastern boundaries (SFWMD, 1993a). These losses result from a combination of three factors: (1) relatively high water levels in the Everglades, required for purposes of wetland preservation and water storage; (2) relatively low water levels in coastal developed areas, required for drainage and flood protection; and (3) permeability of levees and soils. To reduce these water losses and promote long-term restoration efforts, wetland buffer strips or "Water Preserve Areas" (WPA's) have been proposed for construction along the eastern boundary of the Everglades (CH2MHill, 1996). Maintenance of higher water levels in the WPA's (vs. existing conditions) would flatten regional hydraulic gradients and thereby reduce levee seepage and groundwater flows. Buffer water levels would be maintained by residual seepage and runoff pumped from local drainage canals. Outflows from the buffer would include seepage to regional groundwater, seepage to the Everglades, and surface discharge to the Everglades.

A preliminary design for the buffer strip is described by CH2MHill (1996). The plan includes 27 individual wetland cells (55,319 acres) clustered into 8 regional "Water Management Units " (Figure 1). Cells are designed to function as reservoirs (2,484 acres), marshes (27,038 acres), or groundwater recharge areas (25,797 acres). Reservoir and recharge cells have highly fluctuating water levels with a "working depth" of 4-feet. Marsh cells are designed to provide shallow wetland habitat with seasonal water-level fluctuations similar to those found historically in WCA-3B (maximum water depth of ~1.5 feet in September-November and dry conditions in April and May).

Diversion of urban and agricultural runoff to maintain buffer water levels creates potential regional water-quality impacts. Such impacts would depend upon the quantity and quality of inflows, the extent of treatment provided within the buffer, and the locations and magnitudes of surface and groundwater outflows. Potential impacts of phosphorus are of particular concern. While water-quality improvement has been described as a potential benefit, features required to provide this benefit have not been factored into existing buffer designs, which are based exclusively on water-supply and hydroperiod targets. This is reflected by the fact that depth regimes in cell types described above do not conform to typical design criteria for treatment wetlands (average depth of 2 feet, range 0.5 to 4 feet, Burns & McDonnell, 1994). In areas where existing or projected inflow quality is sufficiently impacted by anthropogenic sources, it is likely that buffer designs will have to be modified to protect water quality in buffer discharge zones (i.e., to meet state and federal water quality standards).

This report develops and demonstrates a methodology which can be used to evaluate and refine buffer designs from a stormwater treatment perspective. A mass-balance model is developed for predicting phosphorus removal and resulting concentrations and loadings in surface and subsurface outflows. The model is applied in a general sense to identify important design features, controlling variables, and data/research needs. Wetland treatment areas for the C11-West basin are subsequently sized using various sets of design assumptions. This rapidly-developing basin has high priority from a water-quality perspective because it is one of the few locations along the East Coast where urban/agricultural runoff is currently back-pumped into the Everglades. There is a need to address water-quality concerns in this basin, regardless of pathways taken in future development of the East Coast Buffer. The methodology developed and demonstrated here provides a framework for factoring water-quality objectives into buffer / treatment area designs for other basins.

2.0 Model Development

2.1 Phosphorus Balance Model

Walker (1995) describes the development and calibration of a model for designing Stormwater Treatment Areas (STA's) to treat runoff from the Everglades Agricultural Area (Burns & McDonnell, 1994). The model consists of coupled water-balance and mass-balance equations describing steady-state flow and phosphorus concentrations in a wetland under sheet-flow conditions (Figure 2, Table 1). A longitudinal profile in flow and P concentration is established from the inflow to the outflow of the treatment area. Seepage is expected to be an important hydrologic component of East Coast buffer areas (CH2MHill, 1994, 1996). Accordingly, the STA design model has been expanded to include terms for inflow and outflow seepage, assumed to be uniformly distributed over the treatment area (Kadlec & Knight, 1996).

Seepage is assumed to leave the buffer water column at the longitudinally-averaged concentration (C_m, Table 1). As the seepage moves through the soil, further reductions in concentration may occur as a result of filtration and other physical/chemical mechanisms operating in the soil matrix. These mechanisms are represented by specifying a maximum value for the exit seepage concentration reaching the WCA and/or the seepage collection canal (C_{smax}). If the average seepage concentration leaving the buffer is less than C_{smax}, the exit concentration is set equal to C_{max}. In this way, regional soils are not allowed to function as a net source of phosphorus; such a situation would not be possible under the steady-state conditions represented by the model. Based upon data from the Everglades Nutrient Removal Project (SFWMD, 1996b) and C11 canal (see below), estimates of maximum seepage concentrations range from 10 to 20 ppb.

2.2 Buffer Seepage Rates

Table 2 summarizes equations for estimating seepage rates, based upon groundwater modeling performed by CH2MHill (1994) for buffer cells east of WCA-3B. The buffer cell is assumed to be aligned in a north/south direction. Seepage rates per mile of buffer length are calculated as a function of buffer width and average water depth. At a depth of 2 feet in the buffer cell (typical design for treatment wetland) and average WCA-3B stage, seepage would move out of the buffer to three locations (Figure 2):

1. To the WCA, west of the buffer.
2. To a seepage collection canal, located immediately east of the buffer, and
3. Under the seepage collection canal to an eastern boundary canal (assumed to represent groundwater recharge).

For shallow buffer depths and/or high WCA elevations, there would be a net seepage from the WCA into the buffer cell. In the schemes evaluated below, collected seepage is assumed to be pumped back to the inflow of the treatment cell. If the collected seepage is found to be of acceptable water quality, discharging it to the WCA (or elsewhere) would tend to improve overall performance of the treatment cell.

The model developed by CH2MHill (1994) represented buffer cells in Dade county east of WCA-3B with an average aquifer transmissivity of 1,216,000 ft^2/day. Based upon regional variations in transmissivity (Figure 3), lower seepage rates are expected in buffer cells further north. An average transmissivity of 800,000 ft^2/day is estimated for C11W buffer cells south of the C11 canal. Seepage coefficients derived from CH2MHill results are multiplied by a scale factor of .66 (= 800 /1216) to reflect local conditions.

Results indicate that total seepage out of the C11W buffer would increase with buffer depth at rates ranging from 10 to 14 cfs/mile/ft for buffer widths between 1500 and 22,500 feet. In comparison, the South Florida Regional Routing Model (Trimble, 1986) employs a levee seepage coefficient of 11 cfs/mile/ft for this region. The coefficient for a buffer cell is expected to be higher than the value for a single levee because seepage from the buffer would occur in two directions (east & west). Although these values appear to be consistent, seepage rates calculated by the model should be considered approximations. Refined estimates based upon hydraulic studies would be needed to support specific treatment cell designs.

The CH2MHill model was derived with a buffer ground elevation of 6.0 feet and WCA-3B water elevation of 6.5 feet (historical average). With future changes in water management (including the buffer strip), WCA-3B stage is expected to increase. Results from Version 2.1 of the South Florida Water Management Model (SFWMM, MacVikar et al., 1983) indicate an increase in average stage from 6.3 feet (Future Base Run) to 7.3 feet (East Cost Buffer / Alternative 5, SFWMD, 1996a). Seepage rates are adjusted for differences in WCA stage using the equation given in Table 2.

Figure 4 shows predicted seepage rates in each direction as a function of buffer depth for a width of 0.5 miles and a WCA-3B stage of 7.3 feet. Corresponding total inflow and total outflow seepage velocities used in the phosphorus balance model (Table 1) are also shown. Net seepage into the buffer would occur at operating depths less than 0.6 feet. For a depth of 2 feet (typical design for treatment wetlands), the model predicts an inflow seepage velocity of 0 m/yr and an outflow seepage velocities of 10.5 m/yr (41% to WCA, 32% to collection canal, and 27% recharge). For a depth of 0.5 feet (typical of wetland cells in the East Coast buffer), the model predicts an inflow seepage rate of 4.5 m/yr from the WCA and an outflow seepage rate of 3.9 m/yr (49% to collection canal and 51% recharge).

2.3 Phosphorus Removal Mechanisms

The predominant mechanisms for phosphorus removal represented by the mass-balance model are:

1. Uptake by wetland plants and subsequent accretion in soils, represented by the settling velocity (K, m/yr)
2. Seepage from the wetland, represented by the outflow seepage velocity (U_o, m/yr)

The outflow seepage velocity calculated above for a treatment cell (10.5 m/yr) is nearly identical to the settling velocity (10.2 m/yr) used for designing STA's (Walker, 1995). Therefore, seepage is expected to be an important phosphorus removal in buffer cells designed for treatment purposes. Phosphorus removal via seepage is not a free lunch, however, because:

1. A portion of the seepage is collected and pumped back into the treatment area.
2. Depending upon location, flow magnitude, and water quality, seepage from the buffer to the WCA or to regional aquifers may have undesirable impacts.
3. Excessive seepage rates may make it difficult to maintain wet conditions in the buffer, a condition which is desirable for controlling peat oxidation and subsequent recycling of stored phosphorus.

STA's have been designed with average inflow hydraulic loads (flow per unit area) ranging from 6-14 m/yr (Burns &McDonnell, 1994). Since these rates are similar to the predicted outflow seepage velocity, treatment cells designed with similar hydraulic loads would have little or no surface discharge. In a treatment cell operating as a retention basin (no surface discharge), the average water depth would adjust so that the outflow seepage rate would equal the net inflow rate (inflow + rainfall - evapotranspiration). Water loads higher then 6-14 m/yr would be needed to maintain water levels in the 0.5-4 foot range desired for treatment.

3.0 The C11-West Basin

3.1 Watershed & Hydrology

The 51,840-acre C11-West basin is located in south central Broward County southwest of Ft. Lauderdale and east of WCA's 3A and 3B (Figure 5). Outflows from the basin occur via the C11 canal and consist a mixture of seepage from WCA-3A & 3B and runoff and groundwater flows from the local watershed. Most of the outflow is pumped west into WCA-3A through the S9 pump station. The remainder is discharged to the C11-East basin through gated culverts at S13A.

The S9 pump station has a capacity of 2,870 cfs, which includes 1,650 cfs (3/4 in/day) for flood control and 1,220 cfs for seepage control (SFWMD, 1995). Flows are released through the S13A gated culvert (capacity 120 cfs) primarily during low-flow periods for water supply and salinity control in the C11-East basin. Monthly flows at S9 and S13A are plotted in Figure 6. In Water Years 1979-1995, the annual average discharge through S9 was 157 kac-ft/yr (range 73 - 219 kac-ft/yr). In WY 1991-1995, when discharge through S13A was also measured, the average flow through S9 was 227 kac-ft/yr and the average flow through S13A was 15 kac-ft/yr.

Most of the canals in the basin are cut into limestone that lies below marl and organic soil layers (Waller, 1978). The porosity of the limestone facilitates rapid movement of water between the aquifer and the canals. The canals intercept levee seepage and groundwater flow from the WCA's, as well as infiltration and surface runoff from the local watershed. Rapid depression and recovery in canal and regional groundwater levels have been observed during and following pumping events at S9, when C11 elevation typically drops from 4 to 0 feet msl (Freiberger, 1973; Waller, 1978). Water quality in the canal is likely to be strongly influenced groundwater inflows and exchanges, which provide both dilution and partial removal (via filtration and other physical/chemical mechanisms) of contaminants typically found in runoff from developed areas (e.g., suspended solids, nutrients, trace metals).

Under current Everglades Restoration activities, the C11W basin has a high priority from a water-quality control perspective because it one of the few locations along the East Coast where urban/agricultural runoff is pumped directly into the Everglades. This practice creates potential water-quality impacts in WCA-3A, particularly near the S9 discharge. Hydraulic features in WCA-3A may facilitate transport of flows discharged from the S9 pump station to ENP Shark Slough inflow structures along Tamiami Trail.

Concerns about development impacts on water quality were expressed in early studies of the basin by the USGS (Freiberger, 1973; Waller, 1978). Waller (1978) reported that C11W watershed was largely undeveloped in the early 1970’s (except for some cattle ranches and citrus groves), but was receiving increasing development pressure. Urban land uses are projected to increase from 46% in 1994 to 79% in 2010 (SFWMD, unpublished GIS data). With future increases in urban runoff (resulting from development) and future decreases in seepage (resulting from construction of the buffer strip), water quality in the C11 canal may deteriorate.

The water-quality impacts of existing and future developments depend upon the extent to which they promote surface runoff (vs. infiltration) into C11 and/or its secondary canals. Impacts are controlled to some extent by onsite BMP’s (e.g., detention basins, retention basins, swales). Such control occurs incidentally, however, because existing stormwater regulations and BMP design criteria (Whalen & McCullum, 1988; SFWMD, 1993b) focus primarily on hydrologic features and are not optimized for water-quality control. For example, the regulations provide an incentive for using dry detention basins (without permanent pools) in place of wet detention basis (with permanent pools). The latter have been shown to provide substantially higher removal efficiencies for phosphorus and other stormwater pollutants (Schueler, 1987; Walker, 1987).

A need for tighter watershed controls is supported by the author's observation of a marked turbidity plume in the C11 canal downstream of lateral inflows (Figure 7). Although this report focuses on "end-of-pipe" treatment strategies, there may be considerable potential for applying water-quality-control measures at strategic locations within the watershed.

3.2 Historical Water Quality

Water quality studies by the USGS (Freiberg, 1973; Waller, 1978) describe conditions in the early 1970's, when the basin was largely undeveloped. Elevated ammonia levels (average 0.38 mg/liter) and depressed dissolved oxygen levels (minimum < 1 mg/liter) were observed upstream and downstream of the S9 pump station during pumping events. These characteristics are typical of canals strongly influenced by groundwater. Nutrient concentrations were "generally low".

Mass-balance calculations summarized by Waller(1978) for October 1973-December 1975 indicate the following flow-weighted-mean concentrations (ppb) at three locations on the C11 Canal (Figure 5):

Location	Ortho-PO4	Inorganic N
S9	5	21
US-27	5	29
Flamingo Road	20	481

Waller attributed the higher concentrations at Flamingo Road to agricultural land use in the eastern portion of the watershed and the lower concentrations at the western stations to less intensive land use and greater influence of groundwater flows.

Total phosphorus concentrations measured by SFWMD at the S9 pump station between 1979 and 1996 are plotted against time and flow in Figure 8. The average concentration for the whole period was 17.8 ± 0.9 ppb. Averages were 14.5 ± 1.8 ppb in 1979-1980, 20.8 ± 1.3 ppb in 1981-1991, and 13.0 ± 0.8 ppb in 1992-1996. Averages were significantly higher in the middle years. Interpretation of this time series is complicated by the fact that concentration is strongly correlated with flow (Figure 8, middle) and high flow events (>750 cfs) were not sampled after 1991 (Figure 8, bottom).

Figure 9 shows S9 daily flows over the same period. Symbols indicate dates when grab samples were collected. While reasonable sample coverage of peak-flow periods is evident between 1981 and 1991, coverage is relatively poor in the earlier and later portions of the record. Because of this deficiency, concentration data from 1992-1996 may not be representative of recent S9 discharges.

Phosphorus data collected at S9 by the Broward County of Natural Resource Protection (BCDRN) between 1983 and 1996 have also been examined. These data are generally consistent with SFMWD results. Mixing of the two data sets to increase sample intensity is not advised because of a higher detection limit in the BCDRN data (20 vs. 4 ppb).

Given the intermittent nature of pumping events at S9, it is difficult to obtain representative samples for calculation of phosphorus loads or flow-weighted-mean concentrations using a biweekly sampling program. Although the SFWMD historical data provide reasonable perspectives on water quality in the C11 canal, they provide limited information on concentrations and loads being back-pumped into the Everglades, particularly in the past 5 years. Continuous, flow-weighted composite sampling has been initiated recently at S9 to obtain more representative samples in the future.

The flow-weighted-mean phosphorus concentration in the S9 discharge for the 1981-1990 period (when sampled flows were most representative) is estimated at 23 ± 2 ppb. The correlation between concentration and flow and the low frequency distribution of daily flows have been factored into the estimate using the FLUX program (Walker, 1987a). This value may not be representative of existing conditions, however, because of recent watershed development.

The strong correlation between concentration and flow has important implications for design of a treatment system because it suggests that collection and treatment of peak discharges will be very important. This correlation may reflect dominance of runoff from the watershed at high flows and dominance of seepage and infiltrated rainfall at low flows.

Figure 10 shows cumulative frequency distributions for flow and phosphorus load at the S9 pump station. The frequency distribution of daily loads has been developed by fitting a polynomial regression to the historical concentration vs. flow relationship at S9 (Figure 8) and applying the equation to the measured daily flow time series for Water Years 1979-1995. The importance of high flow regimes is illustrated by the fact that flows above 900 cfs occur only 5% if the time, but account for 23% and the total flow volume and 50% of the total load.

The S9 pump station is typically operated to maintain the C11 canal upstream of the pump at an elevation of 4 feet. When elevation exceeds this level, the pump is activated and the canal is drawn down to a minimum elevation of 0 feet. It is possible that this practice contributes to concentration spikes by causing scouring of canal bottom sediments and/or drawing more flow from the eastern portions of the basin as the water level is dropped. The potential for reducing the frequency and severity of concentration spikes by modifying pumping practices within acceptable flood-control constraints should be investigated.

Bechtel & Hill (1996) analyzed SFWMD S9 water quality data for excursions from Florida's Class III water quality standards. Typical of canal waters in this region, dissolved oxygen concentration was below the 5 mg/l criterion in a high percentage (>90%) of the samples. Turbidity exceeded the 30 ntu criterion in 7 out of 255 samples. Free ammonia exceeded the 0.02 mg/liter criterion in 2 out of 246 samples. Total iron exceeded the 1 mg/liter criterion in

1 out of 52 samples. No excursions were observed for heavy metals (Zinc, Cadmium, Copper, and Lead). Because metals have been analyzed less frequently (quarterly since ~1983), SFWMD historical data from S9 includes only 15 samples collected on days in which S9 was operating.

Bechtel & Hill (1996) also report detection frequencies for 16 pesticides obtained from ~70 grab samples collected at S9. Eight pesticides were not detected and four pesticides were detected once. Pesticides detected more than once included 2,4D (5 detections out of 69 samples), Atrazine (13 / 68) , Diuron (5 / 64), and Hexazinone (3 / 5). These compounds and detection frequencies are not a-typical of those found at other inflow points to the Everglades (Bechtel & Hill, 1996). Table 3 lists detected pesticide concentrations at S9, as derived from an updated version of the data base analyzed by Bechtel & Hill.

The presence of pestices is typically traced to agricultural and urban land uses in the basin. The presence of these substances in the C11 canal does not necessarily indicate that they are impacting biological communities in the S9 discharge zone or elsewhere in WCA-3A. The compounds can have widely different fates, toxicities, and analytical resolutions. While there is insufficient information to evaluate the significance of pesticide detections at the present time, further investigation is warranted.

3.3 Existing Buffer Design

In Phase 3B of the East Coast Buffer Feasibility Study (CH2MHill, 1996), Water Management Unit No. 4 was designated for handling flows from the C11W basin (Figure 11). This Unit would consist of one reservoir and six wetland cells located at the western edge of the basin, south of the C11 canal. Cells would be bordered on the west by WCA-3B and on the east by the C11W watershed. Additional buffer cells north of the C11 canal and adjacent to WCA-3A were designated for handling flows from the North New River Canal.

Flows would be diverted from the C11 canal into Cell 12 (832 acres) through a pump station with a capacity of 147 cfs. Cell 12 would be operated as a storage reservoir with a maximum depth of 4 feet. Cell 12 would discharge into Cells 13-18 (2,899 acres), which would be managed as shallow marshes, with average monthly water depths ranging from 0 feet in April-May to ~0.5 feet in July. Marsh depth regimes were designed to mimic WCA-3B and provide desired wetland habitat. The cell configuration and design water-levels also reflect constraints imposed by US-27, which forms the eastern boundary of Cells 12-14, a power station between Cells 12 and 13, and a trailer park between Cells 13 and 14.

The plan was essentially designed to capture flows which were formerly discharged through S13A and pump them into the buffer. Outflows from the buffer would include surface discharge into WCA-3B (47.5 kac-ft/yr) and groundwater recharge (29.3 kac-ft/yr). This plan would not be expected to provide significant water-quality-control benefits for the following reasons:

1. Only ~37% of the total basin flow would be treated. Flows through S9 would be unchanged.
2. Flows above the buffer inflow pump capacity (147 cfs) would be discharged through S9. As indicated in Figure 8, these flows would be likely to contain the highest phosphorus concentrations.
3. Average water depths in buffer marsh cells (0-.5 feet) would be below the desired range for stormwater treatment (0.5 - 4 feet).

These conclusions are consistent with the fact that the plan was not designed for water-quality control purposes.

4.0 Design Basis for Treatment Areas

Preliminary designs for wetland treatment systems to remove phosphorus from the S9 discharge are developed below for a range of assumptions. Despite potential impacts of substances other than phosphorus in the S9 discharge, an initial focus on phosphorus is justified for the following reasons:

1. Phosphorus impacts on the Everglades have been demonstrated and reductions of anthropogenic phosphorus loads have been mandated (e.g., State/Federal Settlement Agreement, 1991; Everglades Forever Act, State of Florida, 1994).
2. Sufficient information is available to support designs with reasonably predictable performance; and
3. Wetland treatment systems designed for phosphorus removal are often effective at removing suspended solids and other runoff contaminants, especially those associated with the particulate fraction, and including pesticides such as atrazine (Kadlec & Knight, 1996). As discussed above, excursions from Class III criteria for turbidity and free ammonia have been observed historically at S9. ENR monitoring data indicate >80% reductions and consistent compliance with Class III criteria in the outflow for both of these parameters.

Alternative design assumptions regarding inflow volumes and loads, basin water management, wetland prototypes, and target outflow concentrations are described below. Corresponding treatment area requirements are described in the next section.

4.1 Projection of Future Flows & Phosphorus Loads

The measured flow-weighted concentration of 23 ppb at S9 between 1981 and 1991 the reflects basin runoff and WCA seepage which occurred during that period. As discussed above, this concentration is not likely to reflect current and future conditions, given recent and projected development of the watershed. Results from Version 2.1 of South Florida Water Management Model (SFWMM) and other data are used below to estimate flows and loads for a developed basin.

The following water-balance and phosphorus-balance equations represent inflows to the C11 canal:

$$Q_{runoff} + Q_{seepage} = Q_{total}$$

$$Q_{runoff}\ C_{runoff} + Q_{seepage}\ C_{seepage} = Q_{total}\ C_{total}$$

The flow terms (Q) are expressed in 1000 acre-ft/yr and the concentration terms (C) are in parts per billion.

The "runoff" term of the water balance represents the sum of surface runoff and rainfall which infiltrates the soil and is eventually collected by primary or secondary canals. This is estimated based upon the difference between average rainfall and average evapotranspiration rates over the 51,840-acre watershed. SFWMM input files and contour maps given by MacVikar (1983) indicate an average rainfall value of ~52 inches/year for the C11W basin. The Lower East Cost Regional Water Supply Plan (SFWMD, 1993a) indicates an average evapotranspiration rate of 25 inches/year over developed areas. This yields an estimate of 27 inches/year or 116.6 kac-ft/yr for Q_{runoff}.

The following table lists average flows from three SFWMM runs in kac-ft/yr:

SFWMM Version 2.1	Current-Base (1988)	Future-Base (2010)	East Coast Buffer (2010)
S9	130.5	144.8	124.5
S13A	67.7	65.3	64.5
Total	198.2	210.1	189.0

These values reflect 1965-1990 climatologic conditions. Future-Base results are used to estimate Q_{total} (210.1 kac-ft/yr). Potential inflow to the treatment area is assumed to equal that which would otherwise be discharged through S9 (144.8 kac-ft/yr). This may be a conservative estimate, based upon comparison with ECB results (124.5 kac-ft/yr, S9 + Buffer Reservoir Inflow). The average measured S9 discharge in Water Years 1979-1995 (157.2 kac-ft/yr) exceeded SFWMM results. Differences may reflect the fact that average rainfall at S9 was about 2.5 inches/year higher in 1979-1995, as compared with 1965-1990.

The difference between Q_{total} and Q_{runoff} (210.1 - 116.6 = 93.5 kac-ft/yr) is assumed to represent seepage from WCA-3A/B into the C11W basin. This result is in good agreement with the sum of levee seepage (47.5 kac-ft/yr) and net groundwater inflows (46.2 kac-ft/yr) across the western boundary of the basin, as derived from SFWMM Future Base results. Net groundwater inflows are estimated based upon the reduction in total groundwater flow occurring within the first 2 miles (59.2 - 12.9 kac-ft/yr). Based upon these results, inflows to the C11 canal would consist of 44% seepage and 56% runoff.

The phosphorus concentration in watershed runoff (C_{runoff}) is assumed to equal the average concentration measured in the C11 canal at the eastern end of the watershed (near S13A) by the Broward County Department of Natural Resource Protection between 1983 and 1996. This concentration (54 ± 13 ppb) is below the 200-500 ppb range typical of urban runoff in South Florida (Whalen and McCullum, 1988). The difference presumably reflects the combined influences of dilution by infiltrated rainfall and phosphorus reductions occurring in onsite retention/detention ponds and other BMP's within the watershed.

The phosphorus concentration in WCA seepage ($C_{seepage}$) is estimated at 10 ppb. This has been derived from samples collected by SFWMD at S9 on days when all of the following conditions are met:

1. No rainfall in previous 7 days at S9 pump station
2. No flow through S9
3. Positive flow through S9XN or S9XS, which release seepage from the north (Levee 37) and south (Levee 33) into C11

Under these conditions, it is assumed that seepage would account for most of the canal water in the vicinity of the S9 pump station.

For phosphorus concentrations of 54 ppb in runoff and 10 ppb in seepage and for a seepage volume fraction of 44%, a flow-weighted-mean concentration of 34 ppb is estimated for the combined inflows to the C11W canal under future conditions. Treatment of all flows which would otherwise be discharged through S9 would require a design inflow 144.8 kac-ft/yr at an average concentration of 34 ppb. Relative to the measured concentration of 23 ppb in 1981-1990, this represents a 48% increase in total concentration. Subtracting a "background" concentration of 10 ppb, a 85% increase in "anthropogenic" phosphorus is indicated.

The above estimates should be refined before developing a detailed design for treating basin flows. The computations rely heavily on the assumed runoff concentration (54 ppb), which has a relatively high standard error (13 ppb). Better estimates of runoff concentrations and loads could be developed from (1) future direct measurements of flow and phosphorus concentrations in secondary canals and groundwater; and (2) a more detailed watershed modeling effort, which would predict surface runoff and groundwater flows and loads from each contributing area. Existing hydrologic models of the basin (PBS&J, 1989) may provide a starting point for such analyses.

4.2 Water Management Scenarios

Inflow volumes and concentrations may be influenced by future changes in water management. For example, construction of the East Coast Buffer strip would be expected to decrease groundwater inflows to the basin. Results from the SFWMM ECB run indicate that levee seepage and groundwater flows from the WCA's would be reduced from 93.7 kac-ft/yr to < 32 kac-ft/yr. This would have the effect of reducing the volume and increasing the concentration to be treated. In addition, flows through S13A may be lower than those predicted by SFWMM. In Water Years 1992-1995 measured flows accounted for <1 to

13% of the C11W canal outflow. Corresponding percentages derived from SFWMM flows are 31% (Future-Base) and 34% (ECB).

Three water management scenarios have been devised to reflect a range of alternatives:

1. Future Base. Treat all flows which would otherwise occur through S9, based upon SFWMM Future Base. (Flow = 144.8 kac-ft/yr, Load = 8,920 kg/yr, Concentration = 34 ppb)
2. EC Buffer. WCA inflow seepage reduced from 93.7 to 20 kac-ft/yr. Flow through S13A derived from SFWMM ECB. (Flow = 72.1 kac-ft/yr, Load = 4233 kg/yr, Concentration = 48 ppb)
3. EC Buffer without S13A Discharge. WCA inflow seepage reduced from 93.7 to 20 kac-ft/yr. S13A flow set to zero. Extreme case of water conservation. (Flow = 136.6 kac-ft/yr, Load = 8022 kg/yr, Concentration = 48 ppb)

Water and mass balances for each scenario are summarized in Table 4.

Even if reductions in WCA seepage were not realized, treatment volumes and loads similar to Scenarios 2 & 3 might be achieved by selectively treating high flows and discharging low flows (generally containing lower phosphorus concentrations) through S9. Discharging 50 kac-ft/yr through S9 under low-flow conditions at a concentration of 10 ppb would have the same effect on treatment requirements as reducing WCA inflow seepage by 50 kac-ft/yr.

4.3 Wetland Prototypes

The most important design assumption for sizing a treatment area is the selection of a value for the phosphorus settling rate. Table 5 describes four wetland prototypes corresponding to the following range in settling rates:

Prototype	Setting Rate (m/yr)
STA	10.2
ENR	20
WCA-2A/South	30
Periphyton STA	60

This list reflects decreasing land requirements but increasing levels of uncertainty, design risk, and probable maintenance costs. It also reflects a gradient in dominant vegetation types and mechanisms from a macrophyte / peat-based community to a periphyton / marl-based or peat-based community. Based upon observations made in laboratory microcosms and natural communities (e.g., Everglades transects), periphyton-based communities may have a greater chance of achieving target outflow concentrations below 10 ppb. Substantial research is needed, however, to develop an adequate basis for predicting the feasibility, longevity, and maintenance requirements of a Periphyton-based treatment system (PSTA) (Kadlec & Walker, 1996).

Although experience with macrophyte/peat based treatment systems does not include concentrations below 20-30 ppb, the lower concentration limit of such systems is unknown. If sufficient area is provided, it is possible that the downstream ends of macrophyte-based areas would "evolve" (with or without intervention) into periphyton-based communities which would be capable of achieving very low P concentrations. This evolution would depend upon threshold effects, antecedent conditions, hydrologic conditions, and time scale in ways which are not yet understood, but are the subject of ongoing research (SFWMD & FDEP, 1996).

In the following section, treatment areas are sized using settling rates of 10.2, 20, and 30 m/yr. Although a Periphyton STA might be operated at very high settling rates under certain conditions, it is anticipated that such a design would involve considerable redundancy (extra area) to allow periodic maintenance (Kadlec & Walker, 1996). In this case, the effective settling rate might decrease to 30 m/yr or lower. The 30 m/yr rate (estimated from phosphorus gradients in the central and southern portions of WCA-2A) is intend to reflect the PSTA concept.

4.4 Target Phosphorus Concentrations

The target outflow concentration is another key design variable. Target concentrations of 30, 20, and 10 ppb are considered. Concentrations of 20-30 ppb are at the lower limit of demonstrated technology (e.g., operating wetland treatment systems). Regardless of the performance assumption (settling rate), designs to achieve 10 ppb are extrapolations of the model and engineering experience. Although the design model reproduces observed phosphorus gradients in natural communities down to levels below 10 ppb (Walker, 1995;1996), concentrations in this range have not been consistently observed in constructed systems.

The average outflow concentration from the Everglades Nutrient Removal project after 29 months of operation (August 1994-November 1996, 23 ppb) is near the lower limit of demonstrated technology. There is some risk that the low outflow concentration and high apparent settling rate (~20 m/yr) are inflated by startup phenomena and/or un-quantified outflow seepage rates. Although vegetation patterns are still evolving in the ENR, there is no evidence of a net decline in phosphorus removal efficiency over the 29-month operating period. Boney Marsh, a treatment wetland located in the floodplain of the Kissimee River, achieved a similar average outflow concentration (21 ppb) over an 11-year period with an average inflow concentration of 50 ppb and settling rate of 13 m/yr (Kadlec & Newman, 1992).

It is assumed that each target concentration would be applied to the surface discharge from the treatment area. The model also predicts concentrations and loads in seepage from the treatment area to the adjacent WCA. A maximum seepage concentration of 20 ppb is assumed. This assumption may be conservative (too high), based upon the fact that concentrations at S9 are typically around 10 ppb under low-flow conditions, when canal waters are comprised primary of seepage (Figure 8). Although area estimates are derived based upon surface outflow concentration, resulting concentrations and loads in the combined surface and seepage discharges to the WCA are also presented.

5.0 Design Results

Wetland surface areas required to treat discharges from the C11-W basin are estimated below for various water-management scenarios and design assumptions. Treatment areas are initially assumed to be located adjacent to WCA-3B in the vicinity of Water Management Unit 4 (Figures 1 & 11). Cell surface areas and depths represented in the existing buffer plan (CH2MHill, 1996) are not taken as constraints. An alternative location adjacent to WCA-3A in WMU 3 is examined. Hydraulic factors, which may have a large influence on actual design dimensions and locations, are discussed in the next section.

Iterative application of the model (Table 1) permits estimation of the treatment area required to meet a target outflow concentration, given estimates of inflow volume, inflow load, and other model input variables. Figure 12 illustrates the formulation of water and phosphorus balances for the basin and treatment area. Alternative water management scenarios, wetland prototypes, and target concentrations are developed in the previous section. Values and bases for the remaining model input variables are listed in Table 6.

Figure 13 plots water-balance and phosphorus-balance terms against treatment area for water management scenario 1 and a settling rate of 20 m/yr. Surface and seepage flows to the WCA are shown, along with other primary input and output terms of the wetland water and phosphorus budgets. As the treatment area increases from 500 to 5000 acres, surface outflow decreases and seepage outflow increases. They are of equal magnitude at an area of ~2500 acres. Retention of all flows (zero surface discharge) would require ~6000 acres at this operating depth (2 feet).

Surface outflow concentrations decrease from 30 ppb at 500 acres to 7 ppb at 5000 acres. The average concentration in the total discharge to the WCA (surface + seepage) tracks the surface discharge concentration between 500 and 2500 acres, but levels off at 16 ppb with further increases in area. This response reflects the increasing importance of seepage and the assumed maximum seepage concentration of 20 ppb.

5.1 Area Requirements vs. Design Assumptions

Table 7 lists areas required to achieve target concentrations of 30, 20, and 10 ppb for each water management scenario and wetland prototype. Over the range of assumed settling rates, area requirements for achieving a 10 ppb outflow concentration range from 1717 to 4713 acres for scenario 1, 1029 to 2357 acres for scenario 2, and 1949 to 4467 acres for scenario 3. Surface outflow concentrations are plotted against surface area and wetland prototype for each water management scenario in Figures 14-16.

Area requirements depend strongly on the assumed scenario and prototype. Area should not be interpreted as relative indicator of overall cost because of each scenario and prototype would involve different capital and operating costs. The lower area requirements for scenario 2 primarily reflect the lower volume treated (~50% of that treated under scenario 1). Reductions in volume and treatment area similar to or greater than those represented in Scenario 2 could be achieved by combinations of the following:

1. Reductions in seepage from WCA-3 into C11 resulting from construction of the buffer strip;
2. Selective treatment of higher flows at S9; and
3. Location of one or more treatment sites upstream in the watershed, where surface runoff could be captured and treated before it is diluted by seepage.

The last measure would be equivalent to promoting application of onsite BMP's.

Scenario 3 has the highest area requirements because it assumes that no flows are discharged to the C11 East basin through S13A. Based upon comparison of S13A flows predicted by the SFWMM Future-Base and East Cost Buffer runs (65.3 vs. 64.3 kac-ft/yr), zero discharge through S13A may not be realistic. This scenario is intended to reflect an extreme case of water conservation.

5.2 Nominal Designs

Recommendation of a specific design basis (especially, unique values for settling rate and target concentration) is beyond the scope of this report. Results are presented above for various sets of design assumptions. To demonstrate the methodology and to provide a starting point for discussion, "nominal designs" based upon a settling rate of 20 m/yr and target concentration of 10 ppb are evaluated in greater detail below. Essentially, these designs extrapolate the settling rate measured in the ENR project over a concentration range of 120 to 23 ppb down to 10 ppb. Results (in terms of surface area) are similar to those obtained with a settling rate of 10 m/yr and target of 20 ppb. Designs to achieve concentrations in this range are extrapolations of current information and substantial research would be needed to provide a basis for final design and implementation.

Nominal designs would involve areas of 2500, 1460, and 2760 acres, for water management scenarios 1, 2, & 3, respectively. Water and mass balance for these designs are listed in Tables 8, 9, and 10, respectively. These areas can be compared with the total area of Water Management Unit 4 (3336 acres, Cells 12-18, Figures 1& 11). Areas required to achieve 20 ppb with the same settling rate are 46 to 59% of those required to achieve 10 ppb.

Table 11 shows the performance of nominal designs for each scenario as a function of the "actual" settling rate (i.e., that which actually occurs after the project is constructed). This demonstrates sensitivity of performance to errors in the design assumption. Performance is measured by outflow concentration and load reduction for surface and total discharges to the

WCA. For example, if a settling rate of 10 m/yr were realized instead of the design rate of 20 m/yr, the outflow concentration for scenario 1 would be 18 ppb instead of 10 ppb and the surface load reduction would be 69% instead of 83%.

5.3 Sensitivity Analysis

Figure 17 illustrates the sensitivity of predicted outflow concentration to variations in model input variables for scenario 1. Sensitivity is expressed as the change in predicted concentration resulting from a 10% increase in each input variable. Sensitivity rankings are summarized as follows:

High:	Surface Area, Settling Rate, Runoff Volume
Medium:	Depth, Transmissivity, Width, S13A Flow, WCA Seepage, Runoff Conc
Low:	Rainfall, ET, Rainfall ET Conc., Seepage Conc., Seepage Recycle

The importance of wetland performance (and management) is illustrated by sensitivity to settling rate. The equal importance of watershed/water management is illustrated by sensitivity to runoff volume, runoff concentration, S13A flow, and WCA seepage. It is apparent that a unique focus on a treatment wetland to achieve low discharge concentration would not be sufficient.

Sensitivity to depth reflects the dependence of seepage rate on water surface elevation, as illustrated in Figure 4. The analysis indicates a ~0.5 ppb decrease in outflow concentration for each 10% increase in depth (from 2 to 2.2 feet). This result does not reflect possible sensitivity of phosphorus uptake (settling rate) to depth.

Historical monitoring data from the S10 inflow zone of WCA-2A suggests that yearly average settling rates are approximately proportional to mean depth over a depth range of 0 to 3 feet (Walker, 1996). Shallower depths are correlated with increased frequency of dry out, peat oxidation, and phosphorus recycling. At depths exceeding the average design range (average 2 feet, maximum 4 feet), performance may decline because of light limitation and/or loss of rooted macrophytes.

While operating the treatment wetland at a greater depth would promote phosphorus removal via seepage, it may have a negative impact on uptake. Avoidance of severe dryout and prolonged high water levels are thought to be important in macrophyte-based wetlands. The tolerances and optimal operating depths have not been precisely defined, however. For example, even though an average depth of 2 feet has been assumed for design purposes, values of 1 or 3 feet could provide similar (or better) performance. This is the subject of ongoing research directed at identifying the limits of STA technology (SFWMD & FDEP, 1996).

5.4 Evaluation of Northern Site

The above results assume a treatment location south of C11 in the vicinity of Water Management Unit 4 (Figures 1 & 11), with a surface discharge into WCA-3B. Diverting the

S9 discharge into this region would constitute a major water-management decision, since it would move C11W basin outflows from WCA-3A to WCA-3B. As discussed below, hydraulic constraints may preclude diversion of high flows into Water Management Unit 4 (at least as it is currently conceived). Acreage estimates for a location north of C11 (Water Management Unit 3, adjacent to WCA-3A) are listed in Table 12. The following changes to model input variables have been made to reflect the new location: WCA elevation from 7.27 to 9.42 ft, treatment area width from 0.5 to 1 mile, and transmissivity from 800,000 to 600,000 ft^2/day. Regional contour maps (Waller, 1978) suggest that average ground elevation in the central and southern portions of WMU-3 is similar to that found in WMU-4 (~ 6 feet).

Figure 18 shows acreage required to achieve targets of 10 and 20 ppb for each location and wetland prototype. Area requirements for the northern location are higher than those derived above for the southern location, particularly for a target concentration of 10 ppb. This primary reflects a change in seepage rate and direction resulting from the change in WCA elevation from 7.23 ft (WCA-3B) to 9.42 feet (WCA-3A). For a water elevation of 8 feet in the treatment area at both locations, seepage towards the WCA at the southern location would be reversed at the northern location. Total seepage velocities would change from 0 m/yr inflow and 10.5 m/yr outflow at the southern location to 3.3 m/yr inflow and 2.5 m/yr outflow at the northern location.

Nominal design areas for a northern location are 3310, 1950, and 3700 acres for water management scenarios 1, 2, and 3, respectively. These compare with a total area of 4094 acres in Water Management Unit 3 (Cells 9-11, Figure 11).

5.5 Hydraulic Considerations

The above analysis evaluates treatment area requirements from the standpoint of phosphorus assimilative capacity. Hydraulic constraints would also be very important to consider in designing a treatment system for the basin. The strong correlation between concentration and flow at the S9 pump station (Figure 8) suggests that it would be important to capture and treat peak flows. Based upon SFWMM simulations (Future Base, 1965-1990), peak flows would be characterized by a maximum daily flow of 2880 cfs (S9 pump capacity) and a maximum 7-day average flow of 1685 cfs.

Under the Phase 3B buffer design for C11W (CH2MHill, 1996), diversions into the buffer would be limited by pump capacity (147 cfs) and by wetland depth / hydroperiod targets. This strategy would be not be appropriate for a treatment system because peak flows containing the highest phosphorus concentrations (> 100 ppb, Figure 8) would not be captured.

Given the importance of treating high flows, the inflow pump capacity for the treatment area would be determined by flood-control requirements for the basin. If no additional storage can be developed in the watershed, the required capacity would be similar to that of the existing S9 pump station. A lower pump capacity and peak inflow rate would be desirable because of cost considerations and because of limitations in wetland hydraulic capacity discussed below.

Wetland hydraulic capacity would be determined by water depth, width, land slope, and vegetation density (Kadlec & Knight, 1996). Figure 19 shows estimated flow capacity as a function of inlet water depth for 2500-acre treatment area adjacent to WCA-3B (nominal design for water management scenario 1). This is an idealized representation of buffer Cells 12-16 (Figure 11) as one continuous flow path with an average width of 0.5 miles. Flow capacities are calculated for low, medium, high estimates of vegetation resistance using equation 9-44 from Kadlec & Knight (1996).

The outlet weir depth is set at 2 feet (target depth for treatment system). A ground slope of 0 is assumed. A regional contour map (SFWMD, 1981) suggests that 0.00005 would be an upper bound estimate of the actual ground slope (north to south) in this area. With this ground slope, the calculated inlet water depths would be approximately 0.5 feet below those shown in Figure 19 at high flows.

In order to transport the peak historical S9 discharge (~ 3000 cfs), the inlet water depth would have to be 6 to 9 feet; this corresponds to a head loss of between 4 and 7 feet between the wetland inflow and outflow. If the inlet water depth were constrained to a maximum of 6 feet, the maximum hydraulic capacity would range from 600 to 2900 cfs. The Phase 3B buffer design applied a maximum depth constraint of 4 feet for Cell 12, based upon potential impacts on the US-27 roadbed. With a 4-foot constraint on inlet depth, maximum transport capacity would range from 120 to 600 cfs. Such a design would be unable to handle flows containing the highest phosphorus concentrations (Figure 8).

The relatively high predicted head losses through the wetland reflect the long and narrow shape of the treatment area (length / width = 16). Higher hydraulic capacity could be achieved by increasing the flow path width. Figure 20 shows results for a width of 1 mile. This system would have a length/width ratio of 4, which is a more typical design for wetland treatment systems (Kadlec & Knight, 1996). Estimates of inlet depth range from 4 to 6 feet for a flow of 3000 cfs. With a 4-foot constraint on the inlet depth, maximum transport capacity would range from 500 to 2,400 cfs.

It appears unlikely that narrow portions of the proposed C11W buffer strip (particularly, Cells 12 & 13, Figure 11) would provide adequate hydraulic capacity for treating peak flows. Widening these areas or diverting flows to other sections of the buffer strip (Cells 9-11, 14-18) would probably be necessary. Existing basin features in the vicinity of the C11W buffer strip (e.g., US-27, power substation, Trailer Park) may place constraints on wetland water levels and transport capacity. More detailed engineering studies would be needed to find practical ways of providing the required treatment areas and water levels, given the topography and other constraints. Multiple sites, including regional treatment of discharges from secondary canals, should be investigated.

6.0 Conclusions

1. The methodology developed and demonstrated above provides a framework for factoring water-quality objectives into buffer / treatment area designs for C11W and other basins along the East Coast Buffer Strip.

2. Historical monitoring data from S9 reveal a strong positive correlation between phosphorus concentration and daily flow. Concentrations range from < 20 ppb at low flows to > 100 pp at high flows. This pattern reflects varying mixtures of seepage and runoff under different flow conditions. Because of this correlation, the ability to capture high flows would be an important design objective for a treatment system.

3. Excursions from Class III water quality criteria for turbidity and free ammonia have occurred historically at S9. Based upon ENR performance data, a wetland treatment system would be expected to provide >80% reductions in both of these parameters.

4. A variety of pesticides (Atrazine, Hexazinone, Diuron, 2,4-D) have been detected historically at S9 at frequencies and concentrations which are not a-typical of those found at other inflow points to the WCA's. Further studies are needed to evaluate their significance and probable fate in a wetland treatment system.

5. With planned watershed development, the flow-weighted-mean phosphorus concentration in the S9 discharge is projected to increase from ~23 ppb (1981-1991) to ~34 ppb. If significant reductions in WCA seepage into C11 are realized with construction of the East Coast Buffer Strip, the concentration could approach 50 ppb.

6. Wetland treatment area requirements ranging from 201 to 8486 acres are estimated for three water management scenarios, three wetland prototypes, three target phosphorus concentrations, and two general locations (Tables 7 & 12). Broader public discussions and evaluations are necessary to select an appropriate design basis.

7. Nominal (not to be confused with recommended) designs are based upon extrapolation of performance data from the Everglades Nutrient Removal Project (settling rate = 20 m/yr) and an assumed target concentration of 10 ppb.

8. For a location adjacent to WCA-3B, nominal area requirements range from 1460 to 2760 acres, depending on water management scenario. This range can be compared with the total surface area of 3336 acres in the Water Management Unit 4 of the proposed East Coast Buffer Strip.

9. For an alternative location adjacent to WCA-3A, nominal area requirements range from 2000 to 3700 acres. This range can be compared with the total surface area of 4094 acres in Water Management Unit 3. The effects of location on treatment area requirements are attributed to differences in seepage rates and directions.

10. Water management scenarios providing reductions in seepage, selective treatment of high flows, and/or treatment of runoff before it is diluted with seepage would have

lower total area requirements than those treating all flows. Promoting BMP's in the watershed could also reduce treatment acreage.

11. Given the importance of treating peak flows and existing water-level constraints in the vicinity of the C11W buffer, hydraulic factors may have a large influence on the location and shape of the treatment area.

Designs to achieve concentrations in the 10-30 ppb range with a constructed wetland are extrapolations based upon experience with constructed systems at higher concentrations and upon observed reductions in phosphorus achieved by natural (vs. constructed) communities in impacted regions of the Everglades. Substantial research is needed to provide a basis for final design and implementation. Such research is currently underway to support Phase II phosphorus-control efforts mandated by and State/Federal Settlement Agreement and the Everglades Forever Act (SFWMD & FDEP, 1996).

7.0 References

Burns & McDonnell, Inc., “Everglades Protection Project, Conceptual Design”, report to South Florida Water Management District, February 1994.

CH2MHill, Inc., “Seepage Analysis”, in “Analysis of Water Supply Potential for Area B, the Everglades Buffer Strip, and the Hillsboro Basin: Phase 3Aa - East Coast Buffer Concept Preliminary Feasibility Study”, prepared for South Florida Water Management District, Contract C-4123-A2, June 1994.

CH2MHill Inc., “Analysis of Water Supply Potential for Area B, the Everglades Buffer Strip, and the Hillsboro Basin: Phase 3b, East Cost Buffer Study”, prepared for South Florida Water Management District, Contract C-4123-A3, March 1996.

Freiberger, H.J., “Effects of Backpumping from South New River Canalat Pump Station S-9 on Quality of Water in Water-Conservation Area 3, Broward County, Florida”, U.S. Geological Survey, Open File Report 73026, 1973.

Kadlec, R.H. and S. Newman, “Phosphorus Removal in Wetland Treatment Areas, Principles and Data”, Everglades Protection Stormwater Treatment Area Design Support, South Florida Water Management District, 1992.

Kadlec, R.H. and R. L. Knight, Treatment Wetlands, Lewis Publishers, 1996.

Kadlec, R.H. and W.W. Walker, “Perspectives on the Periphyton STA Idea”, prepared for U.S. Department of the Interior, Draft, December 26, 1996.

MacVikar, T.K., T. VanLent, & A. Castro, “South Florida Water Management Model, Documentation Report”, South Florida Water Management District, Technical Publication 84-3, December 1983.

MacVikar, T.K., “Rainfall Averages and Selected Extremes for Central and South Florida”, South Florida Water Management District, Technical Publication 83-2, March 1983.

Post, Buckley, Schuh, & Jernigan, Inc., “Water Management study Report, Western C-11 Basin”, prepared for South Florida Water Management District, June 1989.

Schueler, T.R., “Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMP’s”, Metropolitan Washington Council of Governments, July 1987.

South Florida Water Management District, “Water Management Study of the Western C-11 Canal Basin”, Resource Control Department, October 1981.

South Florida Water Management District,” Lower East Coast Regional Water Supply Plan”, Planning Department, Draft, March 1993a.

South Florida Water Management District, “Management and Storage of Surface Waters, Permit Information Manual, Volume IV”, Surface Water Management Division, June 1993b.

South Florida Water Management District, “Permit Application for District Structures Discharging Into, Within, or From the Everglades Protection Area and Are Not Included in the Everglades Construction Project”, submitted to Florida Department of Environmental Protection, Revision December 22, 1995.

South Florida Water Management District, "Lower East Coast Regional Water Supply Plan, Options Design Documentation for Alternative No. 5, East Coast Buffer C-9", Planning Department, Lower East Coast Planning Division, March 1996a.

South Florida Water Management District, “Everglades Nutrient Removal Project, 1995 Monitoring Report”, submitted to Florida Department of Environmental Protection, March 1996b.

South Florida Water Management District and Florida Department of Environmental Protection, “Everglades Program Implementation, Program Management Plan”, Revision 2, November 14, 1996c.

Trimble, P., “South Florida Regional Routing Model”, South Florida Water Management District, Technical Publication 86-3, June 1986.

Walker, W.W., “Empirical Methods for Predicting Eutrophication in Impoundments, Report 4, Applications Manual”, prepared for Office of the Chief, U.S. Army Corps of Engineers, Report E-81-9, USAE Waterways Experiment Station, Vicksburg, Mississippi July 1987.

Walker, W.W.,, “Phosphorus Removal by Urban Runoff Detention Basins”, Lake and Reservoir Management, Volume 3, pp. 314-325, 1987.

Walker, W.W., “Design Basis for Everglades Stormwater Treatment Areas”, Water Resources Bulletin, Vol. 31, No. 4, pp. 671-685, August 1995.

Walker, W.W., “Phosphorus Settling Rates in Northern & Southern Regions of WCA-2A”, presentation before Everglades Technical Advisory Committee, October 1996.

Waller, B.G., “Effects of Land Use and Water Management on Water Quality in the Western South New River Canal Basin, Southeast Florida, 1974-1975”, U.S. Geological Survey, Water-Resources Investigations, Report 78-30, prepared in cooperation with South Florida Water Management District, March 1978.

Whalen, P. J. and M.G. Cullum, “An Assessment of Urban Land Use / Stormwater Runoff Quality Relationships and Treatment Efficiencies of Selected Stormwater Management Systems”, Technical Report 88-9, South Florida Water Management District, July 1988.

List of Tables

1 STA Design Equations Modified to Account for Infiltration & Exfiltration

2 Estimation of Inflow and Outflow Seepage Rages for Buffer Cells

3 Pesticides Detected at S9 Pump Station

4 Water & Phosphorus Balances on C11W Canal for Three Water-Management Scenarios

5 Prototypes for Treatment Wetland Design

6 Model Input Values

7 Treatment Area Requirements for Locations Adjacent to WCA-3B

8 Water & Mass Balances for Nominal Design - Scenario 1

9 Water & Mass Balances for Nominal Design - Scenario 2

10 Water & Mass Balances for Nominal Design - Scenario 3

11 Performance Sensitivity to Settling Rate

12 Treatment Area Requirements for Locations Adjacent to WCA-3A

Table 1
STA Design Equations Modified to Account Infiltration and Exfiltration

Variable Definitions:

P	=	Rainfall (m/yr)
E	=	Evapotranspiration Rate (m/yr)
Q_x	=	External Inflow Volume (million m^3/yr)
C_x	=	External Inflow Concentration (ppb)
C_i	=	Total Inflow Concentration (ppb)
C_p	=	Rainfall Phosphorus Concentration (ppb)
K_e	=	Effective Settling Rate (m/yr)
F_w	=	Fraction of Days with Water Elevation Above Ground Surface
U_o	=	Infiltration Rate (outflow) (m/yr)
C_s	=	Concentration in Exfiltration (ppb)
U_s	=	Exfiltration Rate (Inflow Seepage) (m/yr)
A	=	Wetland Surface Area ($km^{2)}$
C_m	=	Average Concentration within STA (ppb)
C_b	=	Background Concentration (ppb)
f_r	=	Seepage Recycle, as Fraction of Total Seepage Out of STA (-)
Q_r	=	Seepage Recycle Flow (million m^3/yr)
C_r	=	Seepage Recycle Concentration (ppb)
C_{rmax}	=	Maximum Seepage Recycle Concentration (ppb)

Water Balance:

$$d\,Q / d\,A \quad = \quad b \; = \; P - E + U_s - U_o$$

boundary condition: $Q = Q_x + Q_r$ @ $A = 0$ (inflow to wetland)

$$Q_o = Q_x + Q_r + b\,A$$

Phosphorus Balance:

$$d\,(QC) / dA = P\,C_p + U_s C_s - K_e\,F_w\,C - U_o\,C$$

boundary condition: $QC = Q_x C_x + Q_r C_r$ @ $A = 0$

$$C_i = (Q_x C_x + Q_r C_r) / (Q_x + Q_r)$$

$$C_o = C_b + (C_i - C_b)(Q_o / Q_i)^{(-r/b)}$$

$$r = P - E + U_s + F_w K_e$$

$$C_b = (P\,C_p + U_s C_s) / r$$

Seepage Recycle:

$$Q_r = f_r\,U_o\,A$$

$$C_m = (Q_i C_i + U_s C_s A + P\,C_p A - Q_o C_o) / (K_e + U_o)\,A$$
$$C_r = \text{Minimum}\,(C_m, C_{rmax})$$

Table 2
Estimation of Inflow and Outflow Seepage Rates for Buffer Cells

Variable Definitions:

Q_i	=	Seepage from Buffer to Location I (cfs)
B_i	=	Seepage Coefficient for Flows to Location I (cfs/mile/ft of head)
E_i	=	Average Water Surface Elevation at Location I (feet)
E_o	=	Average Ground Elevation in Buffer (feet)
Z	=	Mean Water Depth in Buffer Cell (feet)
L	=	Buffer Length (North-South Dimension) (miles)
W	=	Buffer Width (East-West Dimension) (feet)

Seepage Rate from Buffer to Location I, (cfs):

$$Q_i = B_i \; L \; (E_o + Z - E_i)$$

where,

I = 1 From Buffer to WCA, Located Immediately to the West of Cell
I = 2 From Buffer to Seepage Collection Canal, Located to the East of Cell
I = 3 From Buffer to Eastern Boundary Canal (Assumed to Represent Recharge)

Total Seepage Into & Out of Buffer (cfs):

$$Q_s = -\mathrm{Min}(Q_1,0) - \mathrm{Min}(Q_2,0) - \mathrm{Min}(Q_3,0)$$

$$Q_o = \mathrm{Max}(Q_1,0) + \mathrm{Max}(Q_2,0) + \mathrm{Max}(Q_3,0)$$

Seepage Velocities Into & Out of Buffer (m/yr):

$$U_s = 1822 \; Q_s / W \; L$$

$$U_o = 1822 \; Q_o / W \; L$$

Seepage Coefficients, B_i (cfs/mile/ft) & Elevations, E_i, (ft):

Width (feet)	1500	22400	-
Variable	B_i	B_i	E_i
To WCA-3B	12.76	16.65	6.5
To Seepage Collection Canal	2.06	3.42	4.5
To East (Recharge)	1.22	1.94	3.0
Buffer Ground Surface			6.0

Derived from CH2MHill(1994), Section 4, Seepage Analysis, Table 4-2, for areas adjacent to WCA-3B; average transmissivity = 1,216,000 ft^2/day.

Coefficients (B_i) for a given buffer width are interpolated from values in the above table and then multiplied by the ratio (T / 1,216,000), where:

T = local transmissivity (ft^2/day) ~ 800,000 ft^2/day for C11 West buffer (Figure 3)

Pesticides Detected at S9 Pump Station

Date	Compound	Value	Units	Medium	Daily Flow (cfs)
10/04/89	2,4-D	2240	ug/kg	Sediment	0
10/04/89	2,4,5-T	1290	ug/kg	Sediment	0
10/04/89	2,4,5-TP	170	ug/kg	Sediment	0
04/19/76	DDE	0.7	ug/kg	Sediment	-
10/27/87	PARAQUAT	1200	ug/kg	Sediment	0
02/11/92	PHORATE	175.82	ug/kg	Sediment	0
02/06/91	TRIFLURALIN	9.96	ug/kg	Sediment	403
07/31/91	2,4-D	0.545	ug/l	Water	503
02/11/92	2,4-D	0.034	ug/l	Water	0
06/30/93	2,4-D	7.2	ug/l	Water	0
07/31/91	2,4,5-TP	0.014	ug/l	Water	503
03/29/95	AMETRYN	0.013	ug/l	Water	0
01/24/96	AMETRYN	0.012	ug/l	Water	0
04/08/92	ATRAZINE	0.036	ug/l	Water	0
06/03/92	ATRAZINE	0.26	ug/l	Water	0
06/03/92	ATRAZINE	0.24	ug/l	Water	0
07/29/92	ATRAZINE	0.059	ug/l	Water	447
03/17/93	ATRAZINE	0.051	ug/l	Water	477
12/07/94	ATRAZINE	0.13	ug/l	Water	887
03/29/95	ATRAZINE	0.021	ug/l	Water	0
06/07/95	ATRAZINE	0.11	ug/l	Water	502
08/09/95	ATRAZINE	0.12	ug/l	Water	496
10/11/95	ATRAZINE	0.09	ug/l	Water	577
04/17/96	ATRAZINE	0.0021	ug/l	Water	0
01/24/90	BROMACIL	0.21	ug/l	Water	0
01/24/90	CHLOROTHALONIL	0.012	ug/l	Water	0
06/08/89	DIURON	7.9	ug/l	Water	0
11/04/92	DIURON	0.43	ug/l	Water	573
06/07/95	DIURON	0.4	ug/l	Water	502
06/07/95	HEXAZINONE	0.024	ug/l	Water	502
08/09/95	HEXAZINONE	0.024	ug/l	Water	496
10/11/95	HEXAZINONE	0.022	ug/l	Water	577
04/17/96	HEXAZINONE	0.025	ug/l	Water	0
07/25/96	HEXAZINONE	0.023	ug/l	Water	0
08/09/95	TRIFLURALIN	0.033	ug/l	Water	496

Source: SFWMD Pesticide Monitoring Program
Detected values out of 3551 water-column analyses and 1627 sediment analyses
Period of record: April 1976 - Oct 1996

Water & Phosphorus Balances on C11W Canal for Three Water-Management Scenarios

Scenario	1			2			3		
S13A Discharge	SFWMM-Future Base			SFWMM-ECB			None		
WCA Seepage	SFWMM-Future Base			Reduced by Buffer*			Reduced by Buffer*		
Variable	Flow	Load	Conc	Flow	Load	Conc	Flow	Load	Conc
Units	kac-ft/yr	kg/yr	ppb	kac-ft/yr	kg/yr	ppb	kac-ft/yr	kg/yr	ppb
Inflows to C11W Canal									
C11W Watershed	116.6	7775	54	116.6	7775	54	116.6	7775	54
Seepage from WCA	93.5	1154	10	20.0	247	10	20.0	247	10
Total Flow	210.1	8929	34	136.6	8022	48	136.6	8022	48
Outflows from C11W Canal									
S13A	65.3	2776	34	64.5	3789	48	0.0	0	
Inflow to Treatment Area	144.8	6153	34	72.1	4233	48	136.6	8022	48
Total	210.1	8929	34	136.6	8022	48	136.6	8022	48

* Seepage Controlled by Buffer Strip and/or Separated from Other Basin Inflows and Discharged Through S9

Table 5

Prototypes for Wetland Treatment Design

Prototype	Description
STA Design	Design Basis for Stormwater Treatment Areas, Everglades Construction Project
	Macrophyte Dominated
	Operating Depth Average ~ 2 ft, Range ~ .5 - 4 ft
	Settling Rate ~ 10.2 m/yr, 90% Conf. Interval ~ 8.9 to 11.6 m/yr (Walker, 1995)
	Estimated from 26-Year Peat Accretion in S10 Inflow Zone of WCA-2A
	Similar Rates Observed in Constructed Wetland Treatment Systems
	Annual Rates of 8-20 m/yr Inferred from WCA-2A Water Col. When Water Depths 1-3 ft
	Longterm P Storage in Accreted Peat
	Relatively Stable Community
	Relatively Low Maintenance Requirements
	Performance Hindered by Dry Out
	Design Risk Relatively Low; Performance Reproduced In Other Constructed Systems
	Not Demonstrated in Constructed Systems below ~20 ppb
ENRP	Everglades Nutrient Removal Project, 29 Months of Operation, STA Prototype
	Macrophyte Dominated with Open Water Areas
	Operating Depth Range ~ 1 to 3 ft
	Settling Rate ~ 20 m/yr, Range of 12-Month Averages ~ 15 to 25 m/yr
	Estimated from Water Column Mass Balance
	Average Outflow Conc = 23 ppb, Monthly Means 10 - 40 ppb
	Rate Possibly Influenced by Unquantified SeepageTerms & Startup Phenomena
	Performance Hindered by Dry Out
	Design Risk Moderate; ENR Rate Uncommon in Other Treatment Systems
	Not Demonstrated in Constructed Systems below ~20 ppb
2A-South	Everglades Marsh 5-10 km South of S10's in WCA-2A
	Mixed Macrophyte/Slough/Periphyton Community
	Settling Rate ~ 30 m/yr (Walker, 1996)
	Estimated from Water-Column P Concentration Gradients, 16 years
	Rate Possibly Inflated by Seepage and Community Transition Phenomena
	Concentration Range ~70 to <10 ppb
	Constructability & Longevity of Biological Community Unknown
	Performance Less Sensitive to Dry Out
	High Risk Level; Not a Demonstrated Technology
	Potential for Achieving P Concentration < 10 ppb
PSTA	Periphyton-Based Stormwater Treatment Area
	Periphyton Mat with Sparse Macrophytes
	Settling Rate ~ 60 m/yr (Kadlec & Walker, 1996)
	Estimated from Short-Term Dosing Experiments in WCA-2A, ENP, Laboratory
	Longterm P Storage in Marl, Possibly Requiring Periodic Harvesting and/or Dry-Out
	Community Likely to be Displaced by Macrophytes When Subject to Nutrient Loading
	Likely to Require Soil Removal Prior to Construction & Intensive Periodic Maintenance
	Redundancy (Extra Area) Needed in Design to Allow Maintenance Activities
	Shallow Depth Required to Avoid Light Limitation and Maintain High Productivity
	Performance Possibly Enhanced by Periodic Dry Out
	Relatively High Maintenance Requirements
	Highest Risk Level; Not a Demonstrated Technology; No Experience
	Potential for Achieving P Concentration < 10 ppb

Model Input Values

Category	Variable	Units	Value	Comments
Design	Wetland Surface Area	acres	Various	Set by Design
	Buffer Mean Depth	feet	2	Set by Design
	Buffer Width	feet	2640	Set by Design
	Seepage Canal Recycle	%	100%	Set by Design
	Buffer Hydroperiod	%	100%	Percent of Time Water Depth > 0 ft; Set by Design
Wetland Protype	P Settling Rate	m/yr	10.2	STA Design Basis (Walker, 1995)
		m/yr	20	ENR Performance
		m/yr	30	WCA-2A South / ENR
Atmospheric	Buffer Rainfall	in/yr	47.0	SFWMM, Vicinity of C11W Buffer
	Buffer ET	in/yr	58.7	SFWMM, Potential ET
	Rainfall P Conc (Bulk)	ppb	30	SFWMD data from ENR Atmospheric Collector
Seepage	Buffer Base Elevation	ft	6.0	Vicinity of C11W Buffer
	WCA Stage	ft	7.27	SFWMM ECB, WCA-3B
	Seepage Canal Control Elev	ft	4.5	CH2MHill (1996)
	Eastern Canal Control Elev	ft	3.0	CH2MHill (1996)
	Local Transmissivity	ft2/day	800000	Regional Measurements, Figure ?
	Max Buffer Outflow Seepage Conc	ppb	20	Assumed; Conservative for C11W Canal
Watershed	Watershed Area	acres	51840	CH2MHill(1996)
	Watershed Rainfall	in/yr	52.0	SFWMM, McVikar (1983), Average for Watershed
	Watershed ET	in/yr	25.0	SFWMM Average for Developed Watersheds
	Runoff Conc	ppb	54	BCDNRP, C11 Station Near S13A
	Conc in Seepage from WCA	ppb	10	calibrated to S9 @ Low Flow

Treatment Area Requirements for Locations Adjacent to WCA-3B

Wetland Prototype	Settling Rate m/yr	Target Outflow Conc (ppb) 30	20	10
Water Management Scenario 1				
STA	10.2	584	2185	4313
ENR	20	300	1153	2491
WCA2A-South	30	201	778	1717
Water Management Scenario 2				
STA	10.2	868	1528	2357
ENR	20	470	857	1456
WCA2A-South	30	321	591	1029
Water Management Scenario 3				
STA	10.2	1646	2895	4467
ENR	20	891	1625	2758
WCA2A-South	30	608	1121	1949

Treatment Areas in Acres

Water & Phosphorus Balances for Nominal Design

Water Management Scenario: 1

Input Variable	**Value**	**Units**
Treatment Area	2500	acres
Width	2640	feet
Length	41250	feet
Operating Depth	2.0	feet
Seepage Recycle	100%	percent of collected
Transmissivity	800000	ft2/day
Rainfall	47.0	in/yr
ET	58.7	in/yr
Rainfall P Conc	30	ppb
P Settling Rate	20	m/yr
WCA Stage	7.3	feet
Buffer Ground Elev	6.0	feet

Mass Balance - C11W	**Flow kac-ft/yr**	**Load kg/yr**	**Conc ppb**
C11W Runoff	116.6	7775	54
C11W Seepage In from WCA	93.5	1154	10
Total Inflow	210.1	8929	34
S9 Outflow	0.0	0	0
S13A W->E	65.3	2776	34
Buffer Pump In	144.8	6153	34
Total Outflow	210.1	8929	34

				Unit Area Fluxes		
Mass Balance - Buffer	**Flow kac-ft/yr**	**Load kg/yr**	**Conc ppb**	**Flow in/day**	**Flow m/yr**	**Load g/m2-yr**
Buffer Pump In	144.8	6153	34	1.90	17.7	0.608
Buffer Recycled Seepage	27.8	686	20	0.37	3.4	0.068
Buffer External Inflow	172.6	6839	32	2.27	21.0	0.676
Buffer Seepage In from WCA	0.0	0	0	0.00	0.0	0.000
Buffer Rainfall	9.8	363	30	0.13	1.2	0.036
Buffer Total Inflow	182.4	7201	32	2.40	22.2	0.711
Buffer ET	12.2	0	0	0.16	1.5	0.000
Buffer Total Seepage Out	86.4	2131	20	1.14	10.5	0.210
Buffer Recharge	23.4	576	20	0.31	2.8	0.057
Buffer Seepage to WCA	35.3	869	20	0.46	4.3	0.086
Buffer Pump Out	83.7	1028	10	1.10	10.2	0.102
Buffer Marsh Uptake		4042				0.399

Discharges to WCA's	**Flow kac-ft/yr**	**Load kg/yr**	**Conc ppb**
S9 Outflow	0.0	0	0
Buffer Pump Out	83.7	1028	10
Total Surface Inflow	83.7	1028	10
Buffer Seepage to WCA	35.3	869	20
Total Discharge to WCA	119.0	1898	13

Water & Phosphorus Balances for Nominal Design

Water Management Scenario: **2**

Input Variable	**Value**	**Units**
Treatment Area	1460	acres
Width	2640	feet
Length	24090	feet
Operating Depth	2.0	feet
Seepage Recycle	100%	percent of collected
Transmissivity	800000	ft2/day
Rainfall	47.0	in/yr
ET	58.7	in/yr
Rainfall P Conc	30	ppb
P Settling Rate	20	m/yr
WCA Stage	7.3	feet
Buffer Ground Elev	6.0	feet

Mass Balance - C11W	**Flow kac-ft/yr**	**Load kg/yr**	**Conc ppb**
C11W Runoff	116.6	7775	54
C11W Seepage In from WCA	20.0	247	10
Total Inflow	136.6	8022	48
S9 Outflow	0.0	0	0
S13A W->E	64.5	3789	48
Buffer Pump In	72.1	4233	48
Total Outflow	136.6	8022	48

				Unit Area Fluxes		
Mass Balance - Buffer	**Flow kac-ft/yr**	**Load kg/yr**	**Conc ppb**	**Flow in/day**	**Flow m/yr**	**Load g/m2-yr**
Buffer Pump In	72.1	4233	48	1.62	15.1	0.716
Buffer Recycled Seepage	16.2	401	20	0.37	3.4	0.068
Buffer External Inflow	88.3	4634	42	1.99	18.4	0.784
Buffer Seepage In from WCA	0.0	0	0	0.00	0.0	0.000
Buffer Rainfall	5.7	212	30	0.13	1.2	0.036
Buffer Total Inflow	94.1	4846	42	2.12	19.6	0.820
Buffer ET	7.1	0	0	0.16	1.5	0.000
Buffer Total Seepage Out	50.5	1518	24	1.14	10.5	0.257
Buffer Recharge	13.6	337	20	0.31	2.8	0.057
Buffer Seepage to WCA	20.6	508	20	0.46	4.3	0.086
Buffer Pump Out	36.4	448	10	0.82	7.6	0.076
Buffer Marsh Uptake		2880				0.487

Discharges to WCA's	**Flow kac-ft/yr**	**Load kg/yr**	**Conc ppb**
S9 Outflow	0.0	0	0
Buffer Pump Out	36.4	448	10
Total Surface Inflow	36.4	448	10
Buffer Seepage to WCA	20.6	508	20
Total Discharge to WCA	57.0	956	14

Water & Phosphorus Balances for Nominal Design

Water Management Scenario: 3

Input Variable	Value	Units
Treatment Area	2760	acres
Width	2640	feet
Length	45540	feet
Operating Depth	2.0	feet
Seepage Recycle	100%	percent of collected
Transmissivity	800000	ft2/day
Rainfall	47.0	in/yr
ET	58.7	in/yr
Rainfall P Conc	30	ppb
P Settling Rate	20	m/yr
WCA Stage	7.3	feet
Buffer Ground Elev	6.0	feet

Mass Balance - C11W	Flow kac-ft/yr	Load kg/yr	Conc ppb
C11W Runoff	116.6	7775	54
C11W Seepage In from WCA	20.0	247	10
Total Inflow	136.6	8022	48
S9 Outflow	0.0	0	0
S13A W->E	0.0	0	0
Buffer Pump In	136.6	8022	48
Total Outflow	136.6	8022	48

				Unit Area Fluxes		
Mass Balance - Buffer	Flow kac-ft/yr	Load kg/yr	Conc ppb	Flow in/day	Flow m/yr	Load g/m2-yr
Buffer Pump In	136.6	8022	48	1.63	15.1	0.718
Buffer Recycled Seepage	30.7	758	20	0.37	3.4	0.068
Buffer External Inflow	167.3	8780	43	1.99	18.5	0.786
Buffer Seepage In from WCA	0.0	0	0	0.00	0.0	0.000
Buffer Rainfall	10.8	400	30	0.13	1.2	0.036
Buffer Total Inflow	178.2	9180	42	2.12	19.7	0.822
Buffer ET	13.5	0	0	0.16	1.5	0.000
Buffer Total Seepage Out	95.4	2874	24	1.14	10.5	0.257
Buffer Recharge	25.8	637	20	0.31	2.8	0.057
Buffer Seepage to WCA	38.9	961	20	0.46	4.3	0.086
Buffer Pump Out	69.2	854	10	0.82	7.6	0.076
Buffer Marsh Uptake		5452				0.488

Discharges to WCA's	Flow kac-ft/yr	Load kg/yr	Conc ppb
S9 Outflow	0.0	0	0
Buffer Pump Out	69.2	854	10
Total Surface Inflow	69.2	854	10
Buffer Seepage to WCA	38.9	961	20
Total Discharge to WCA	108.2	1815	14

Performance Sensitivity to Settling Rate

Wetland Prototype	Actual P Setting Rate m/yr	Discharges to WCA: Surface Discharge Flow kac-ft/yr	Surface Discharge Load kg/yr	Surface Discharge Conc ppb	Surface Discharge Load Reduc.	Total Discharge Flow kac-ft/yr	Total Discharge Load kg/yr	Total Discharge Conc ppb	Total Discharge Load Reduc.
Water Management Scenario 1			**Design Area =**		**2500**	**acres**			
STA	10.2	83.7	1894	18	69%	119.0	2765	19	55%
ENR	20	83.7	1028	10	83%	119.0	1898	13	69%
WCA2A-South	30	83.7	555	5	91%	119.0	1245	8	80%
Water Management Scenario 2			**Design Area =**		**1460**	**acres**			
STA	10.2	36.4	942	21	78%	57.0	1450	21	66%
ENR	20	36.4	448	10	89%	57.0	956	14	77%
WCA2A-South	30	36.4	218	5	95%	57.0	707	10	83%
Water Management Scenario 3			**Design Area =**		**2760**	**acres**			
STA	10.2	69.2	1793	21	78%	108.2	2754	21	66%
ENR	20	69.2	854	10	89%	108.2	1815	14	77%
WCA2A-South	30	69.2	416	5	95%	108.2	1343	10	83%

Nominal designs sized to meet 10 ppb with ENR settling rate (20 m/yr).
Total discharge includes groundwater seepage to WCA at a maximum concentration of 20 ppb.

Treatment Area Requirements for Locations Adjacent to WCA-3A

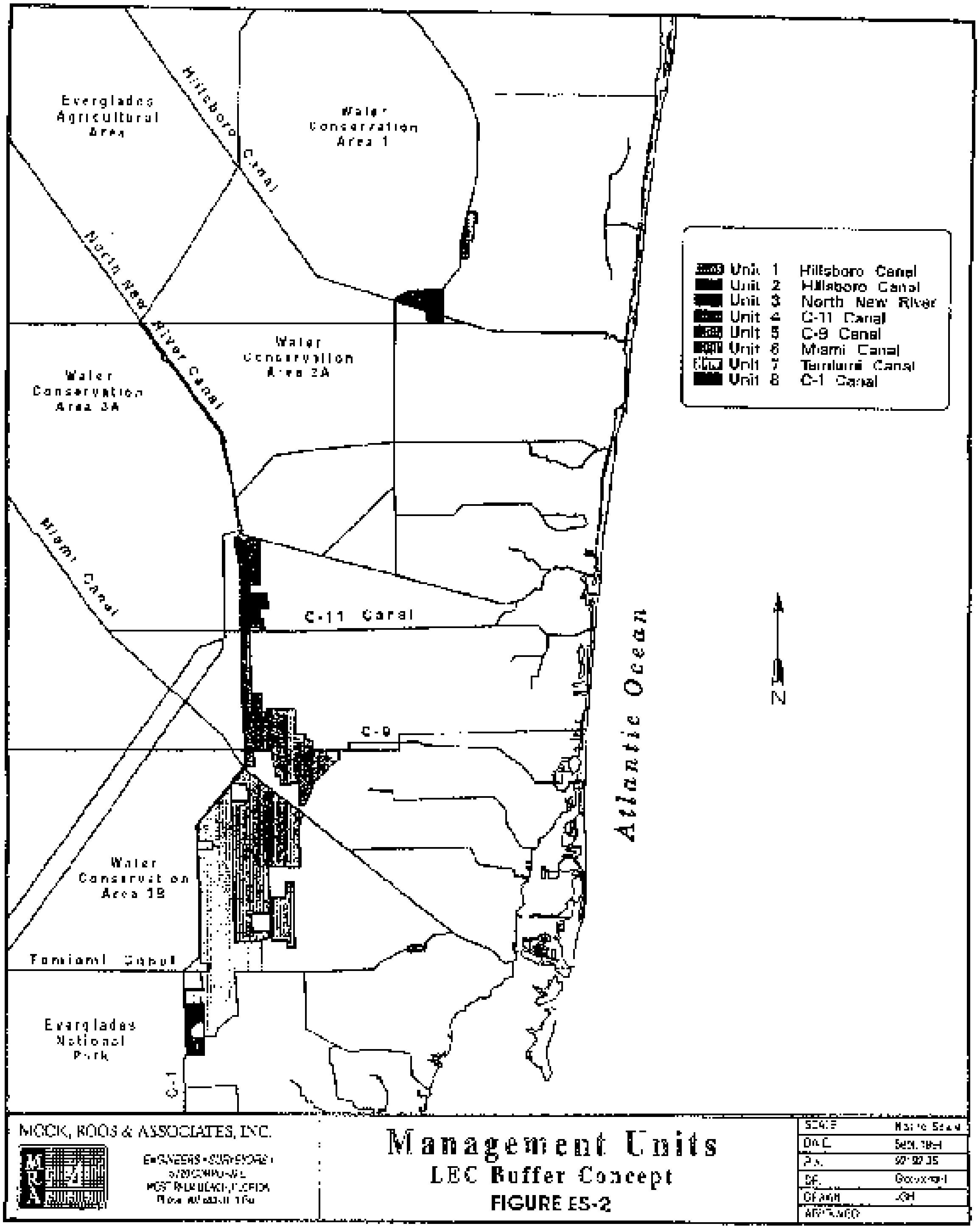
Wetland Prototype	Settling Rate m/yr	Target Outflow Conc (ppb) 30	20	10
Water Management Scenario 1				
STA	10.2	534	2352	7153
ENR	20	287	1199	3111
WCA2A-South	30	195	798	1978
Water Management Scenario 2				
STA	10.2	890	1861	4478
ENR	20	478	950	1943
WCA2A-South	30	325	634	1238
Water Management Scenario 3				
STA	10.2	1687	3527	8486
ENR	20	906	1800	3683
WCA2A-South	30	616	1201	2345

Treatment Areas in Acres

List of Figures

1 Water Management Units
2 Buffer Cell Schematic
3 Transmissivity Variations along the East Coast Buffer Strip
4 Seepage Rates vs. Buffer Water Depth
5 C11-West Basin
6 Monthly Flows at S9 & S13A
7 Turbidity Plume in C11 Canal
8 S9 Phosphorus Concentrations vs. Time & Flow
9 Daily Flows & Sampling Events at S9, 1979-1996
10 Cumulative Frequency Distributions of S9 Daily Flow & Phosphorus Load
11 Buffer Cells in C11W Vicinity
12 Schematic for C11 Mass-Balance Calculations
13 Water & Mass-Balance Terms vs. Surface Area
14 Outflow Concentration vs. Area & Settling Rate - Scenario 1
15 Outflow Concentration vs. Area & Settling Rate - Scenario 2
16 Outflow Concentration vs. Area & Settling Rate - Scenario 3
17 Performance Sensitivity to Model Input Values
18 Treatment Area Requirements vs. Prototype, Scenario, & Location
19 Hydraulic Capacity of Treatment Area, Width = 0.5 Miles
20 Hydraulic Capacity of Treatment Area, Width = 1 Mile

Figure 1



CH2MHill(1996)

Buffer Cell Schematic

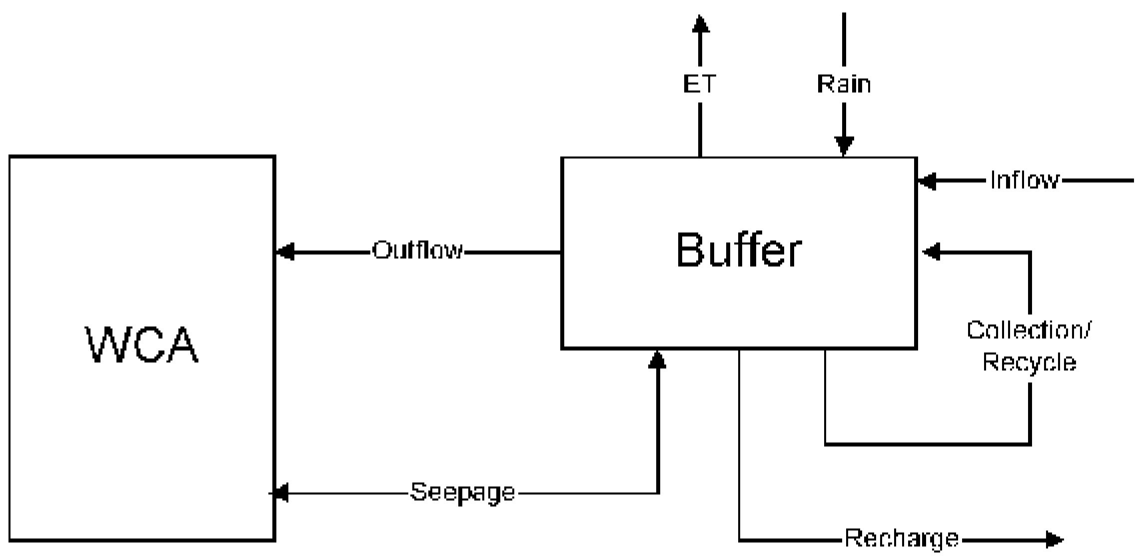
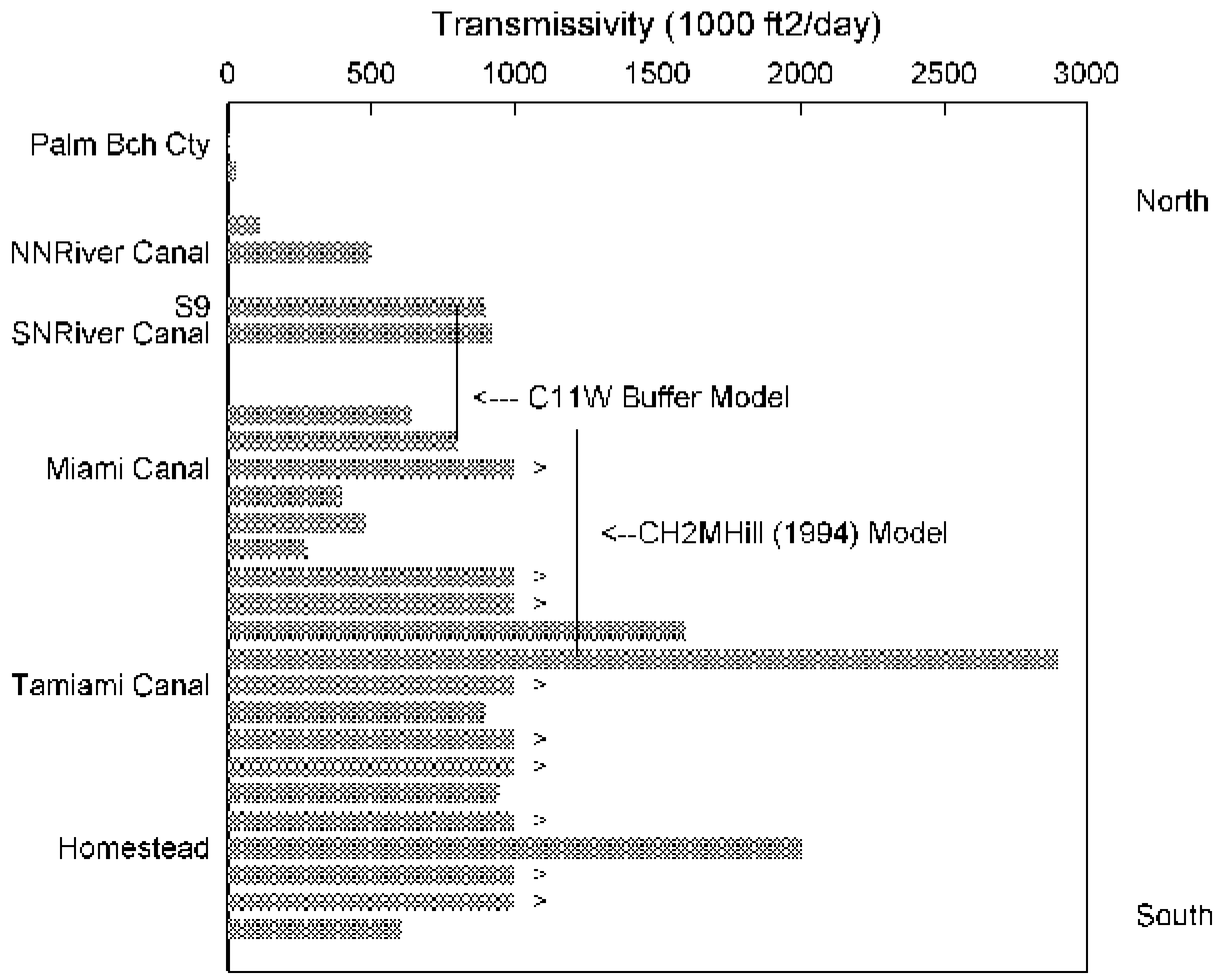


Figure 2

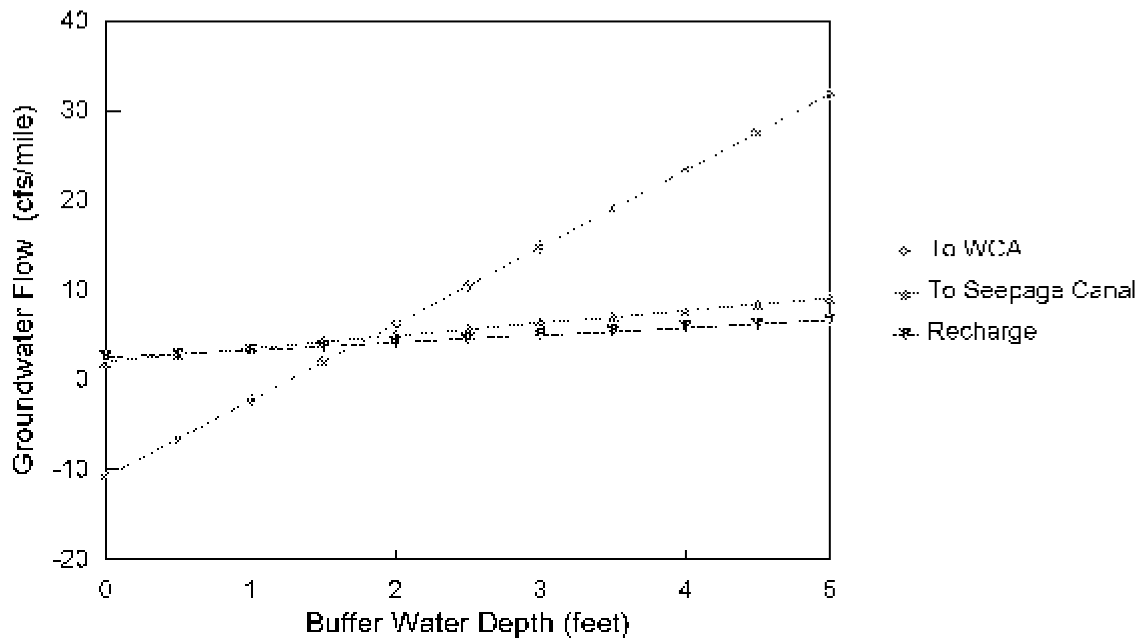
Figure 3

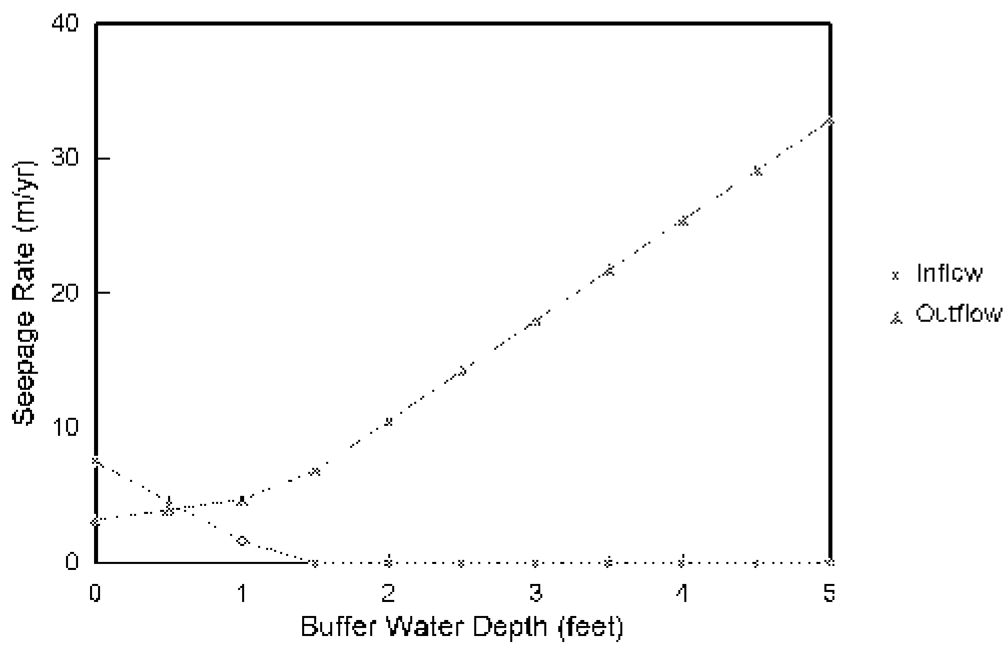
Transmissivity Variations Along East Coast Buffer Strip



Transmissivity measurements along eastern edge of Water Conservation Areas & ENP
From USGS Hydrogeology Maps for Broward & Dade Counties
> symbol means greater than indicated value

Seepage Rates vs. Buffer Water Depth

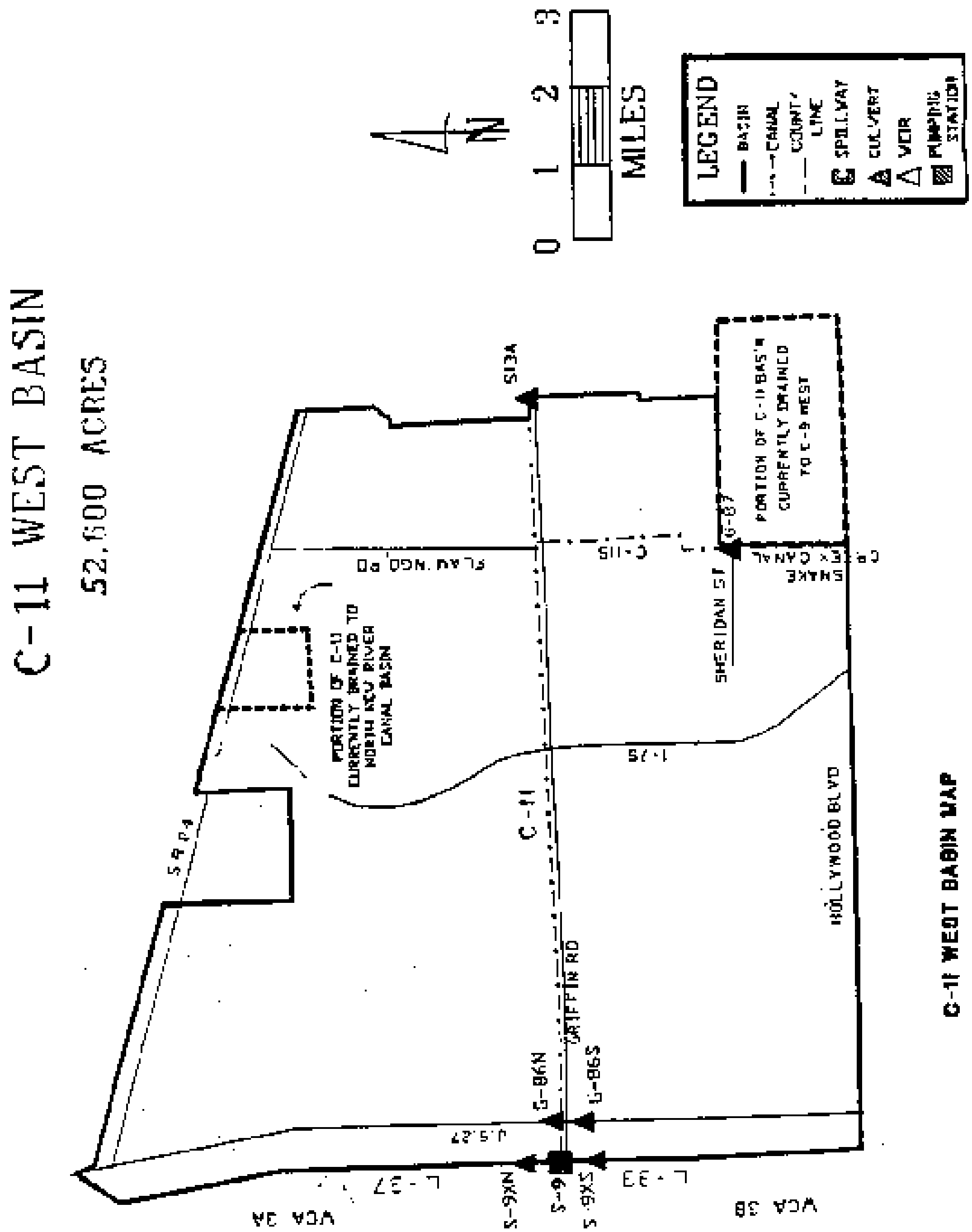




WCA Stage	7.27	feet
Buffer Ground Elev	6.00	feet
Buffer Width	2640	feet

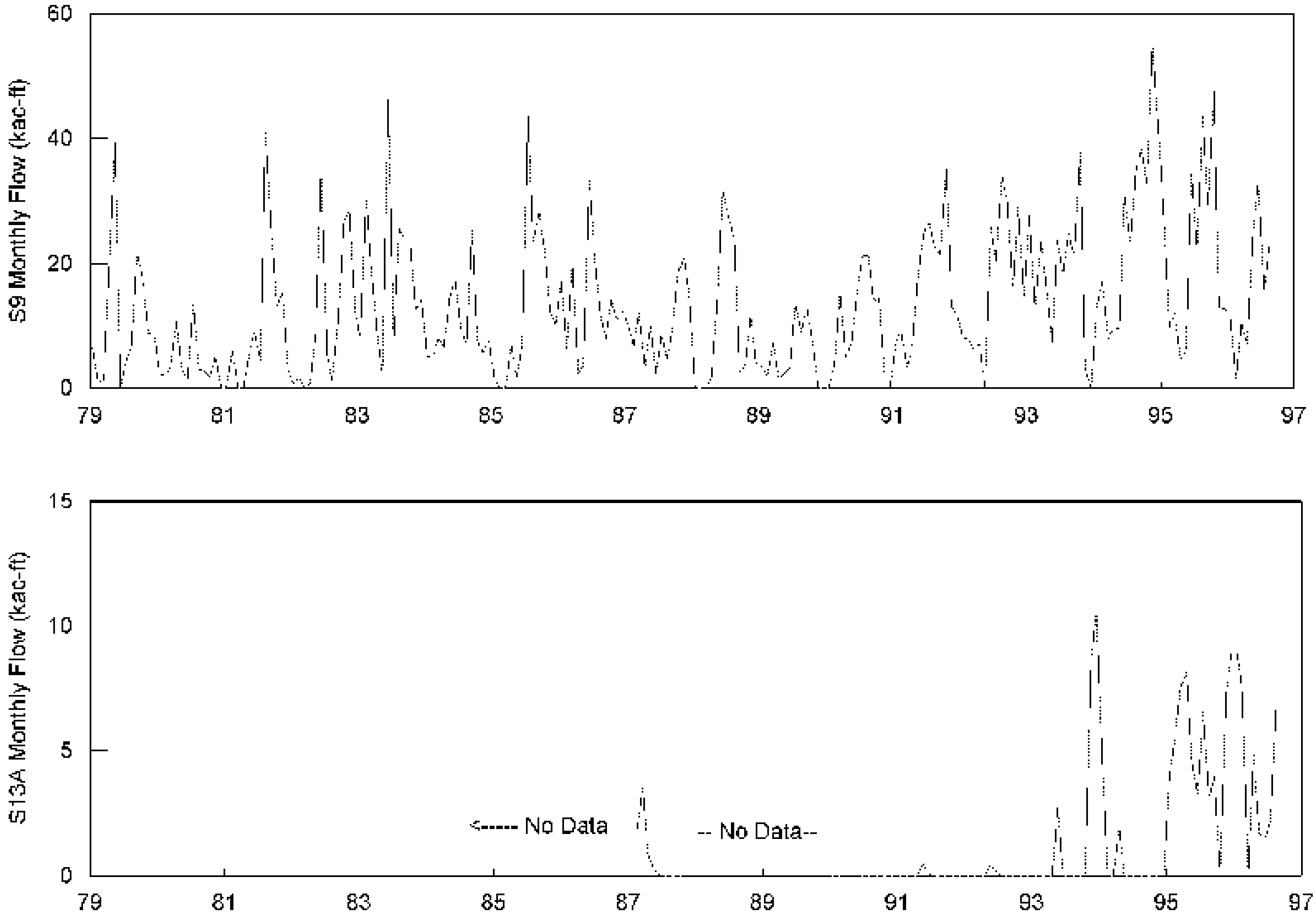
Figure 5

SFWMD (1995)

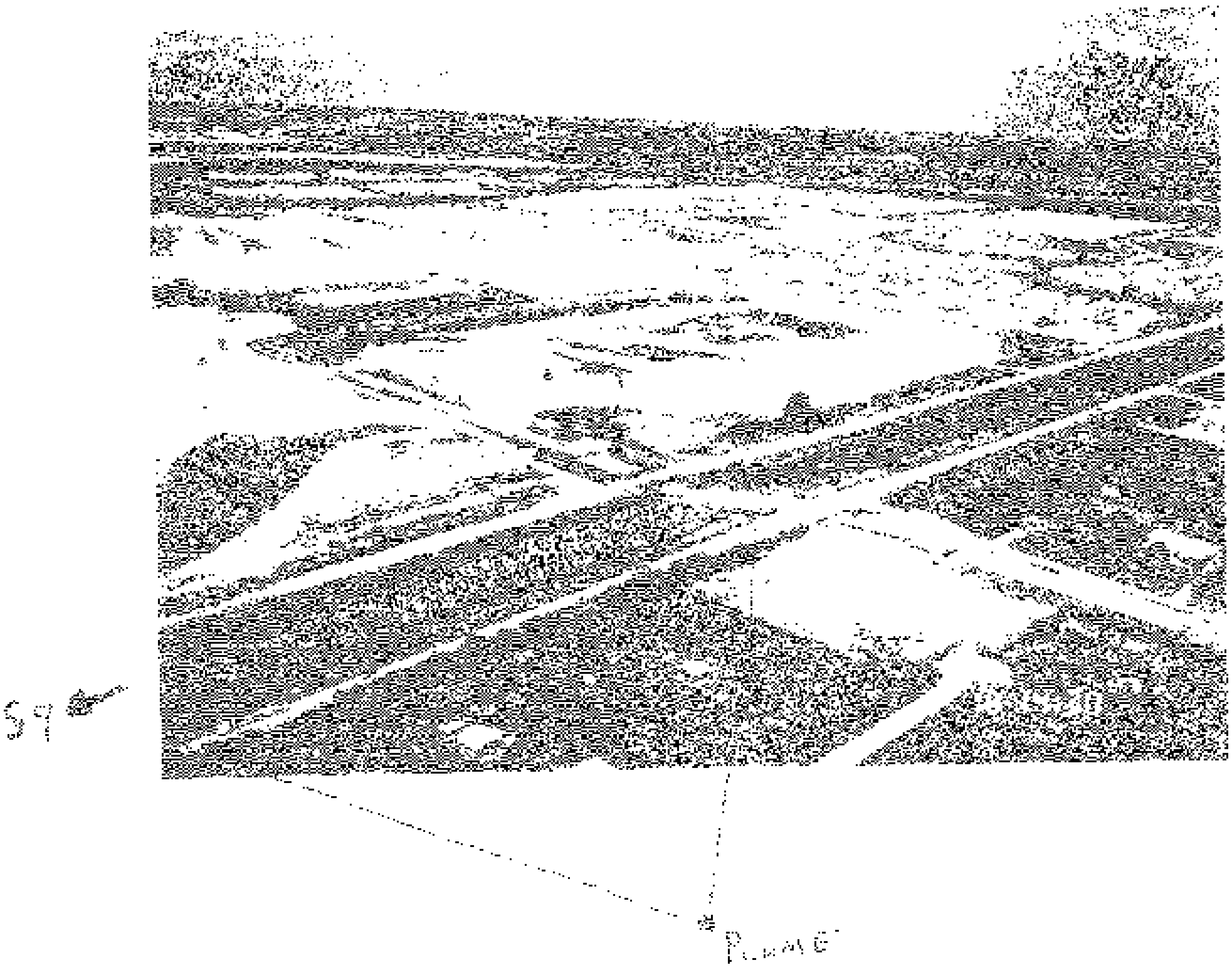


C-11 WEST BASIN MAP

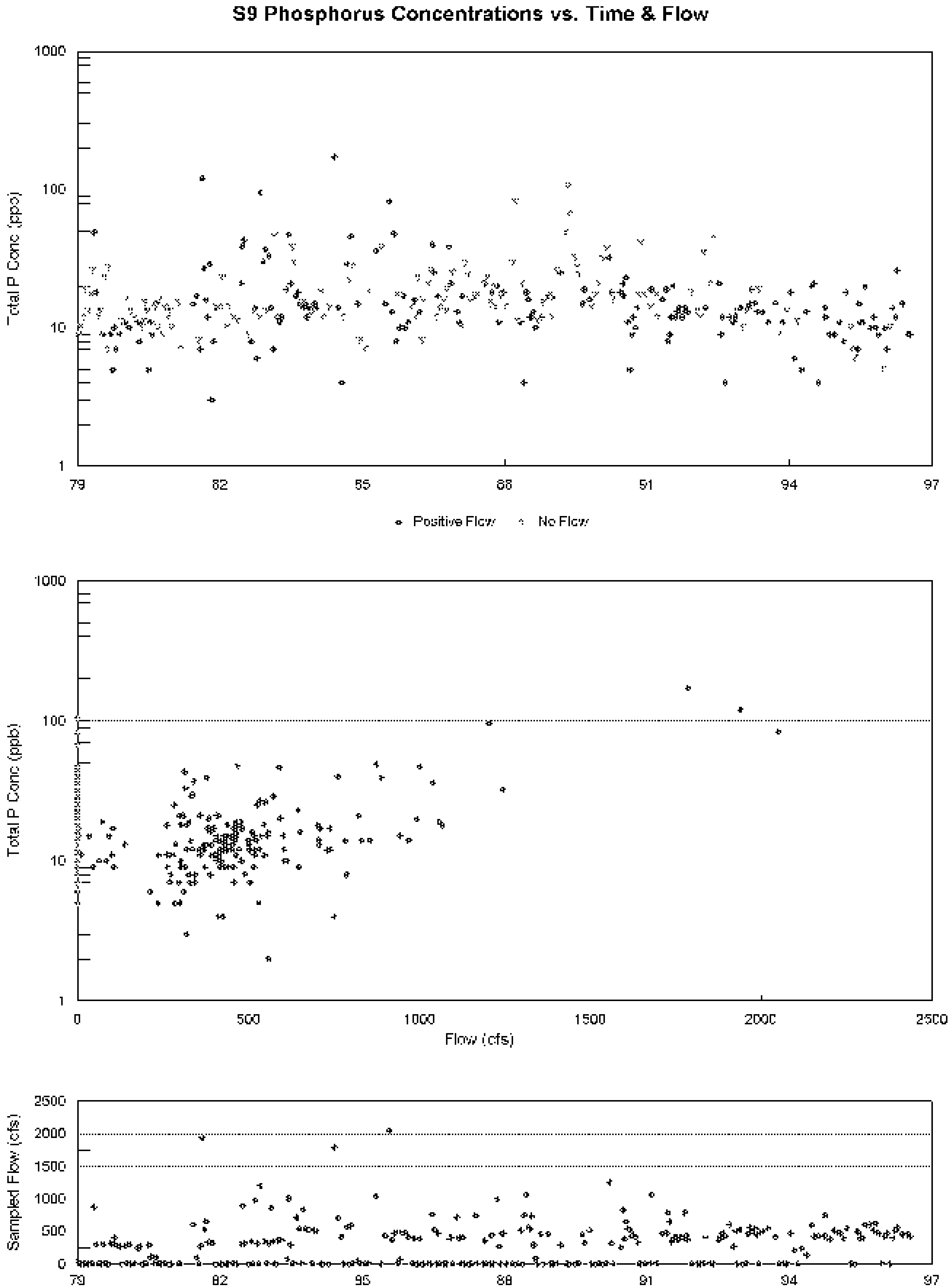
Monthly Flows at S9 & S13A



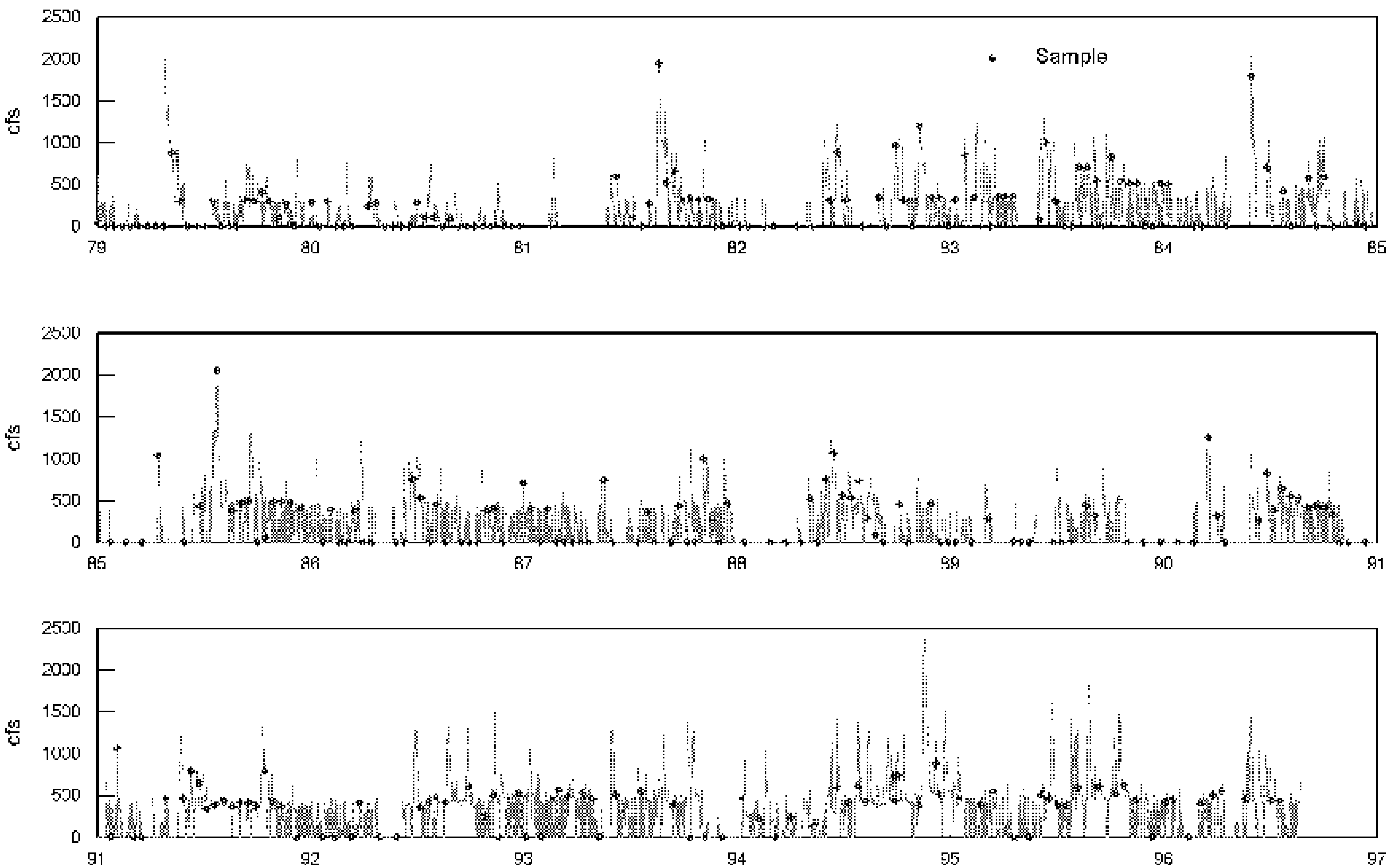
Turbidity Plume in C11 Canal



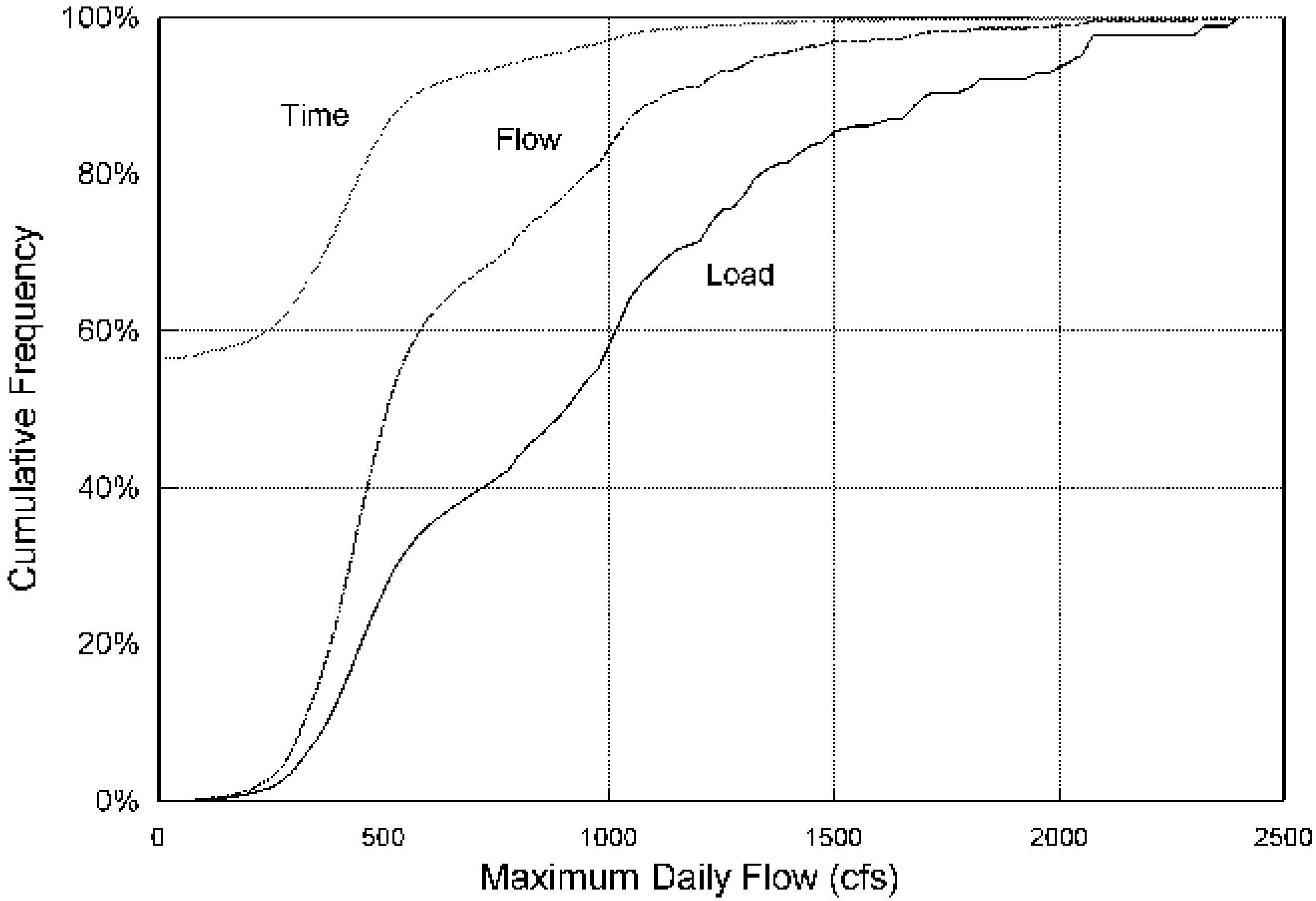
Figure


S9 Phosphorus Concentrations vs. Time & Flow
Total P Conc (ppb)
1000
100
10
1
79
82
85
88
91
94
97
Positive Flow
No Flow
Total P Conc (ppb)
1000
100
10
1
0
500
1000
1500
2000
2500
Flow (cfs)
Sampled Flow (cfs)
2500
2000
1500
1000
500
0
79
82
85
88
91
94
97

Daily Flows & Sampling Events at S9, 1979-1996



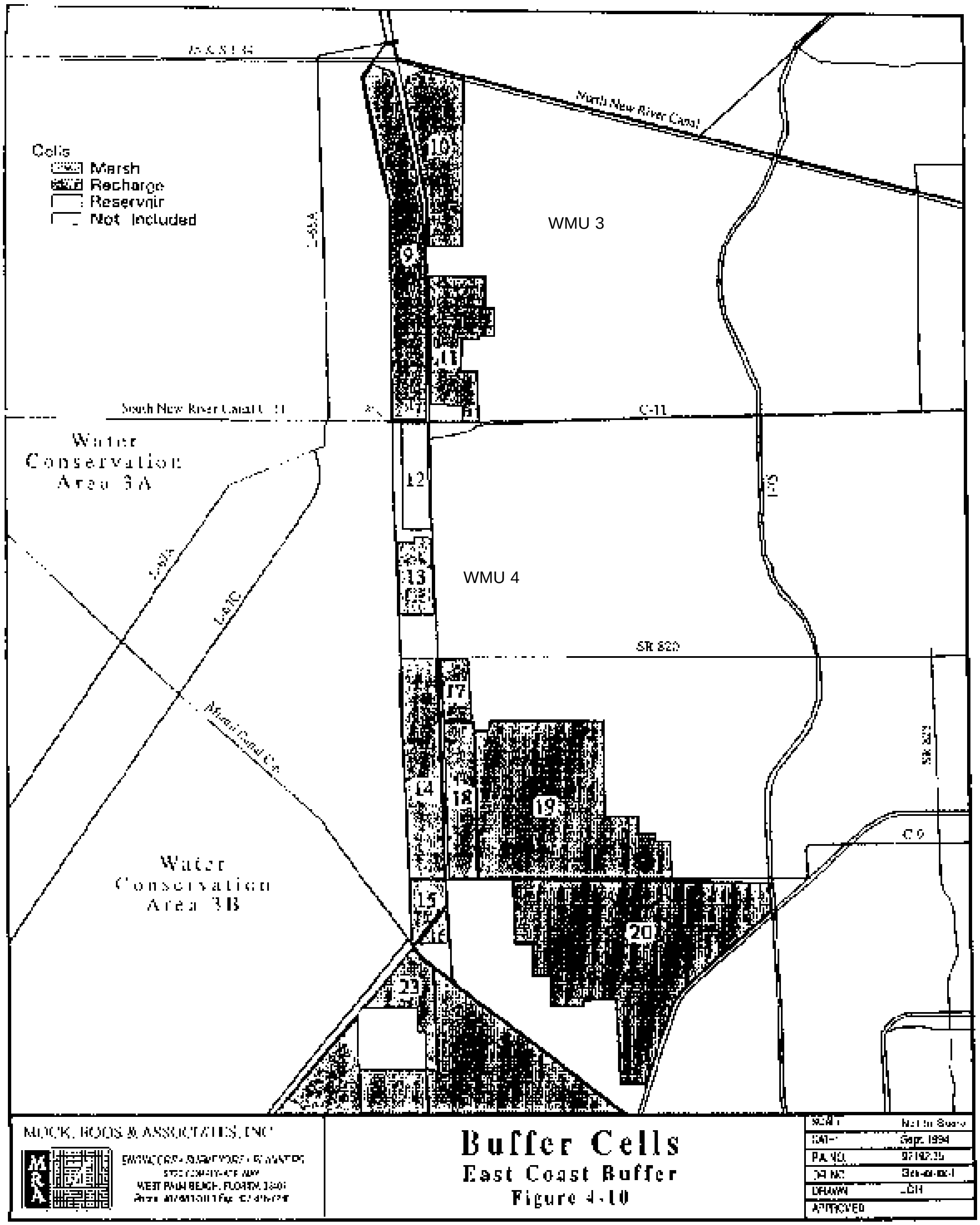
Cumulative Frequency Distributions of S9 Daily Flow & Phosphorus Load



Days	Percent of Days with Flow < Indicated Flow
Flow	Percent of Total Flow Volume Occuring at Flows < Indicated Flow
Load	Percent of Total P Load Occuring at Flows < Indicated Flow

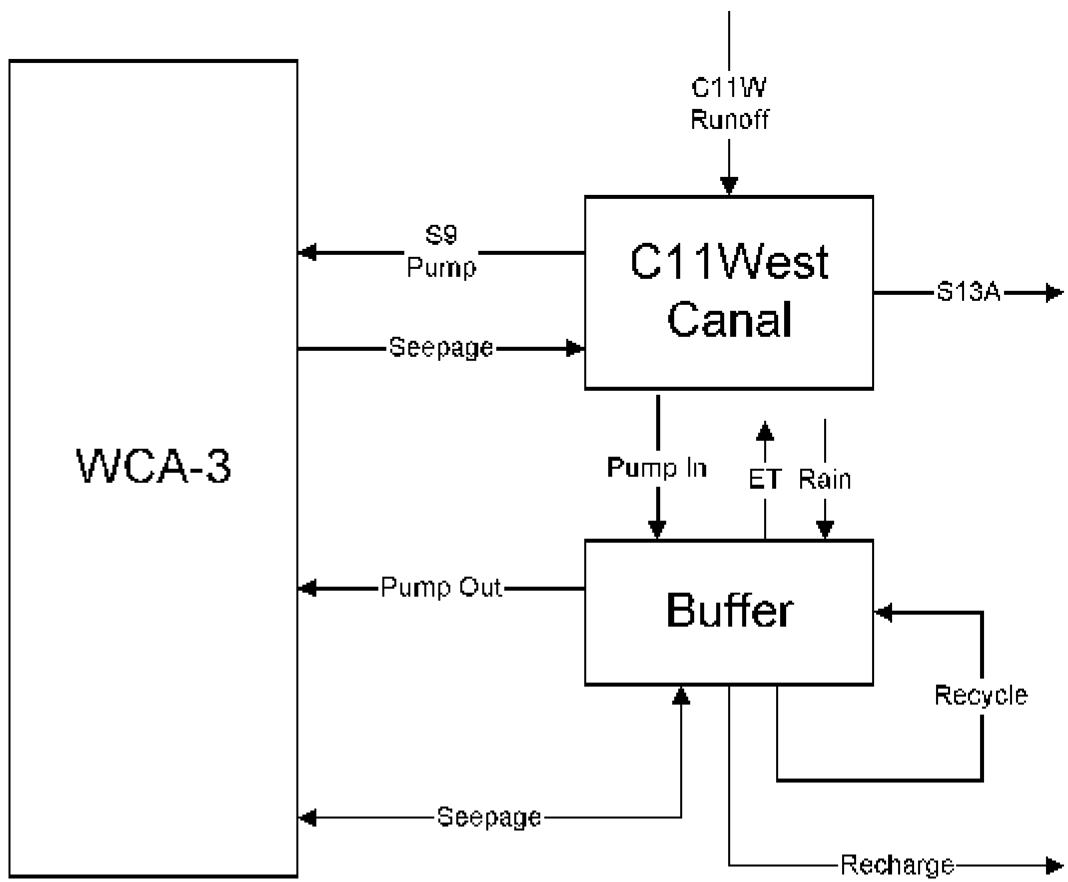
Measured Daily Flows at S9. Water Years 1979-1995
Load Curve Calculated from Polynomial Regression Relating Concentration to Flow

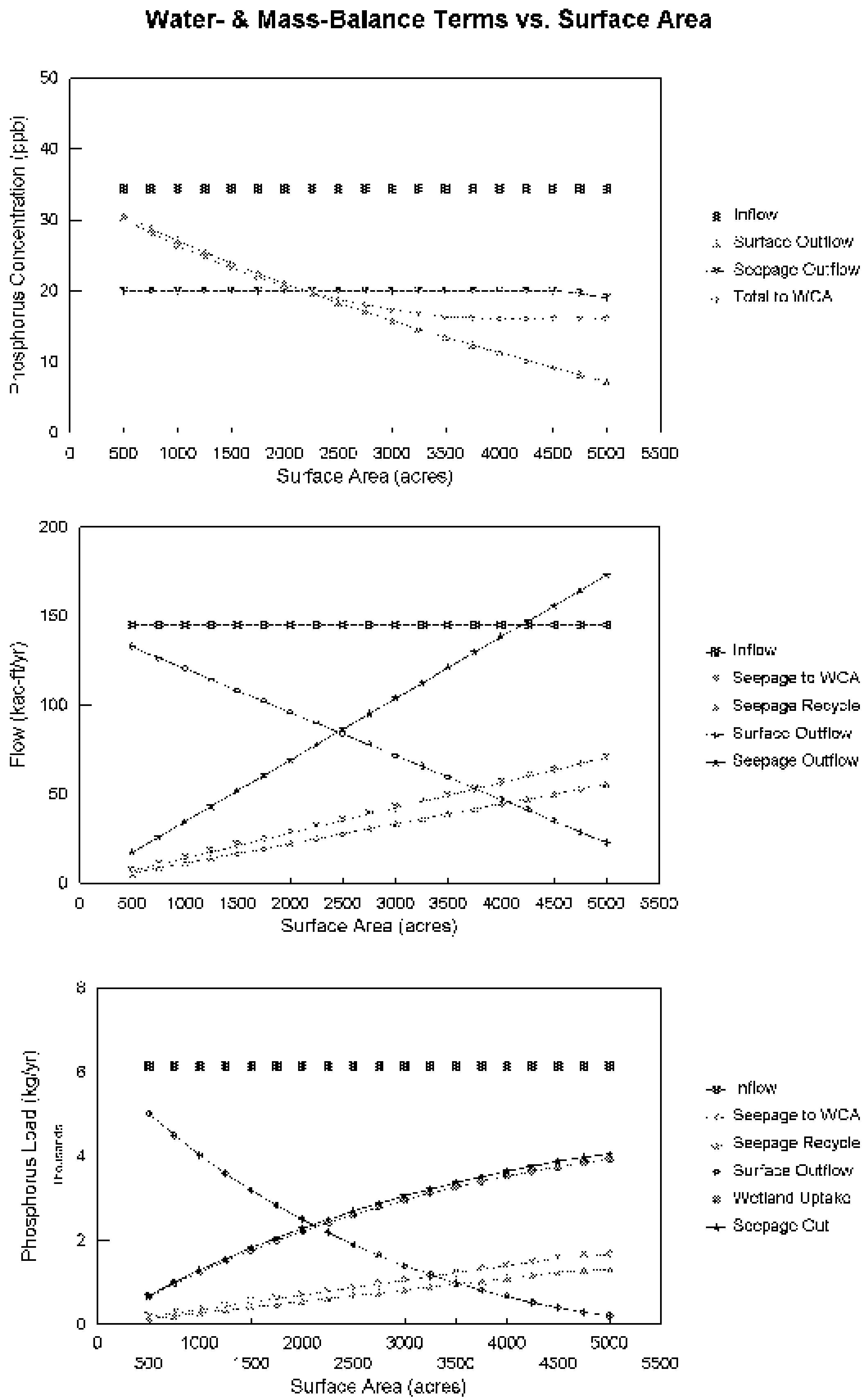
Figure 1



Ref: CH2MHill (1996)

Schematic for C11-W Mass-Balance Calculations

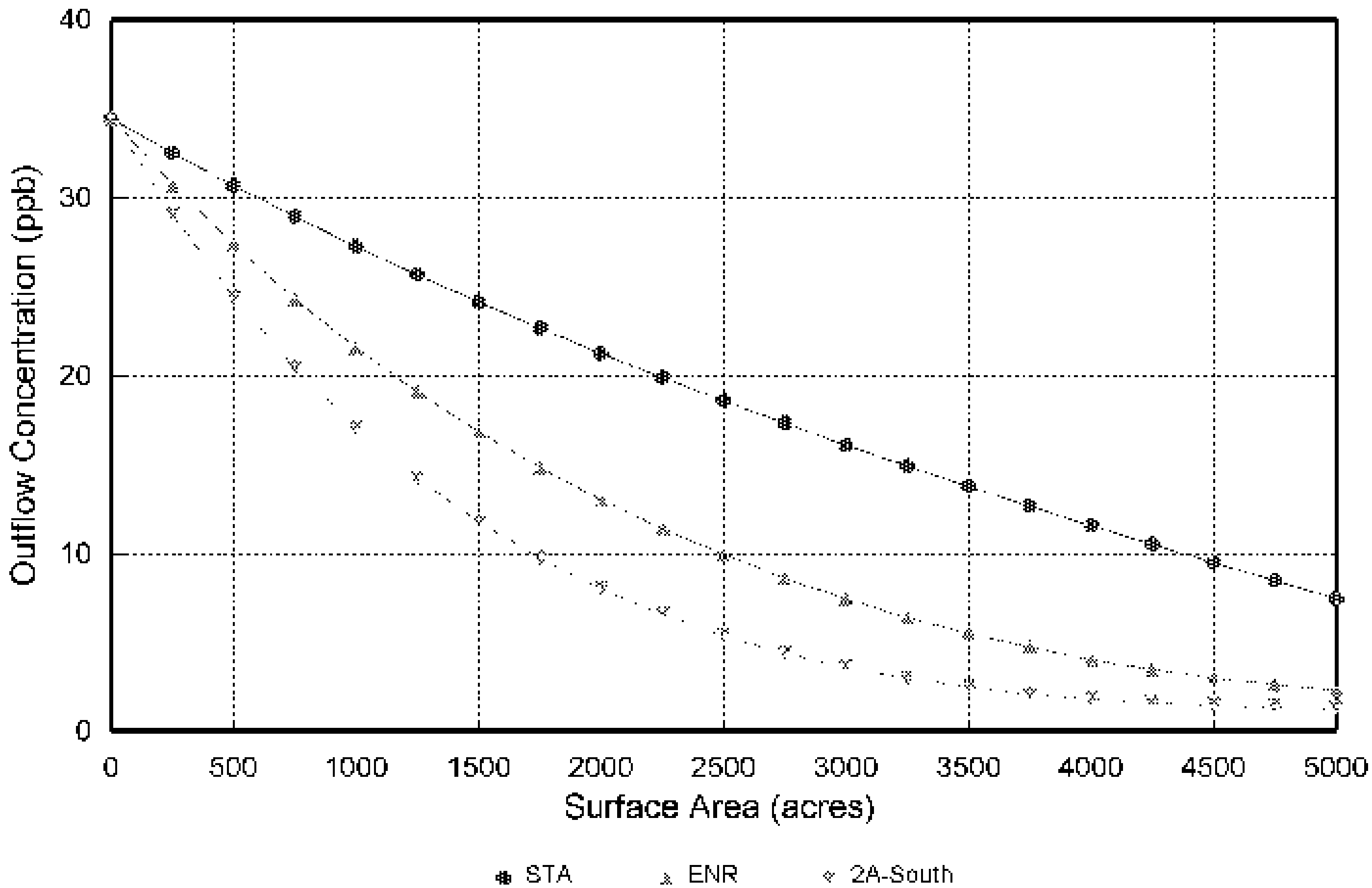




Water Management Scenario 1
Settling Rate = 10.2 m/yr

Outflow Concentration vs. Area & Settling Rate

Water Management Scenario: **1**

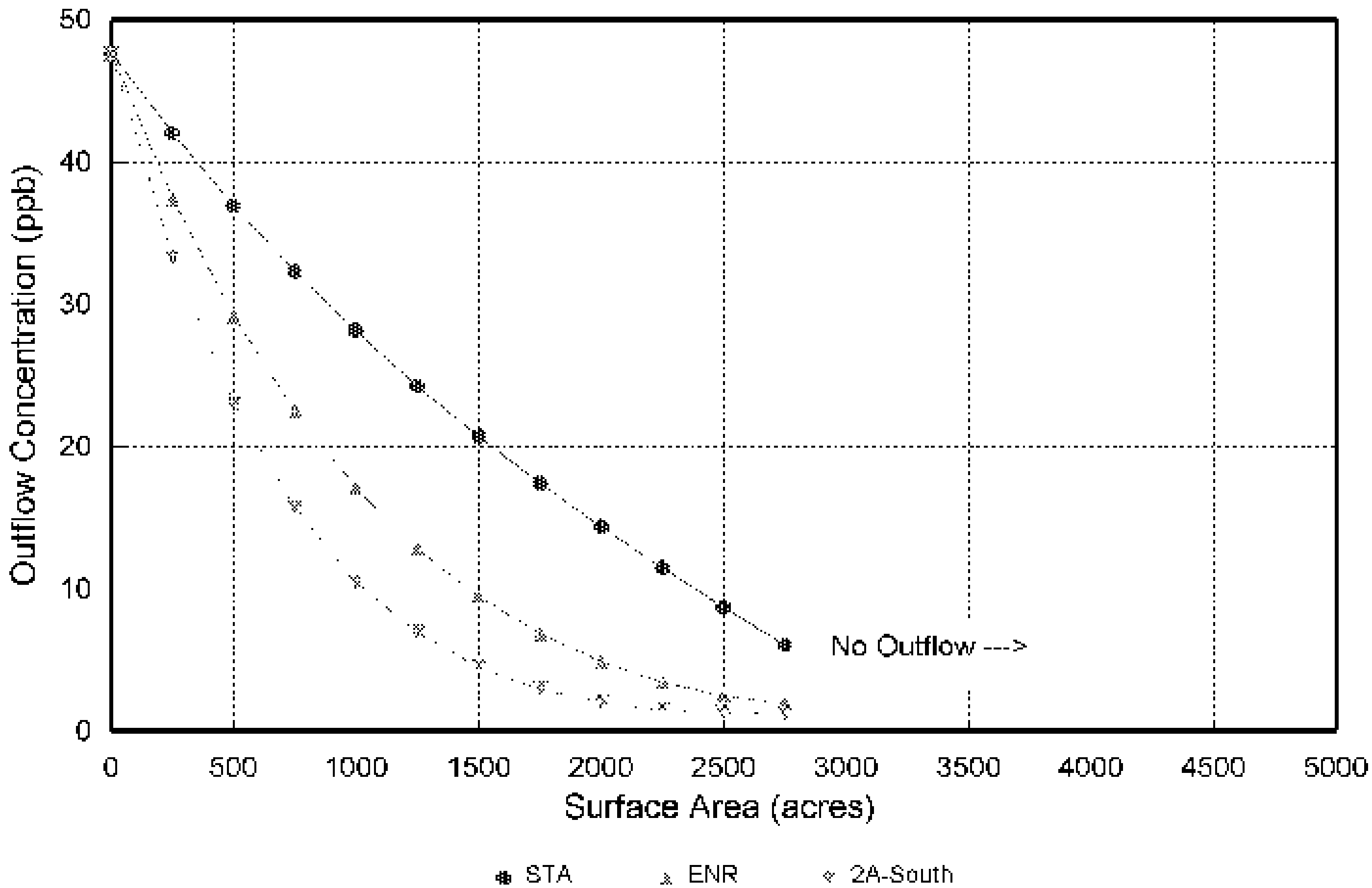


Design Basis	Settling Rate (m/yr)
STA	10.2
ENR	20.0
WCA-2A South	30.0

Treatment Area Inflow		
Flow	144.8	kac-ft/yr
Load	6153	kg/yr
Conc	34	ppb

Outflow Concentration vs. Area & Settling Rate

Water Management Scenario: **2**

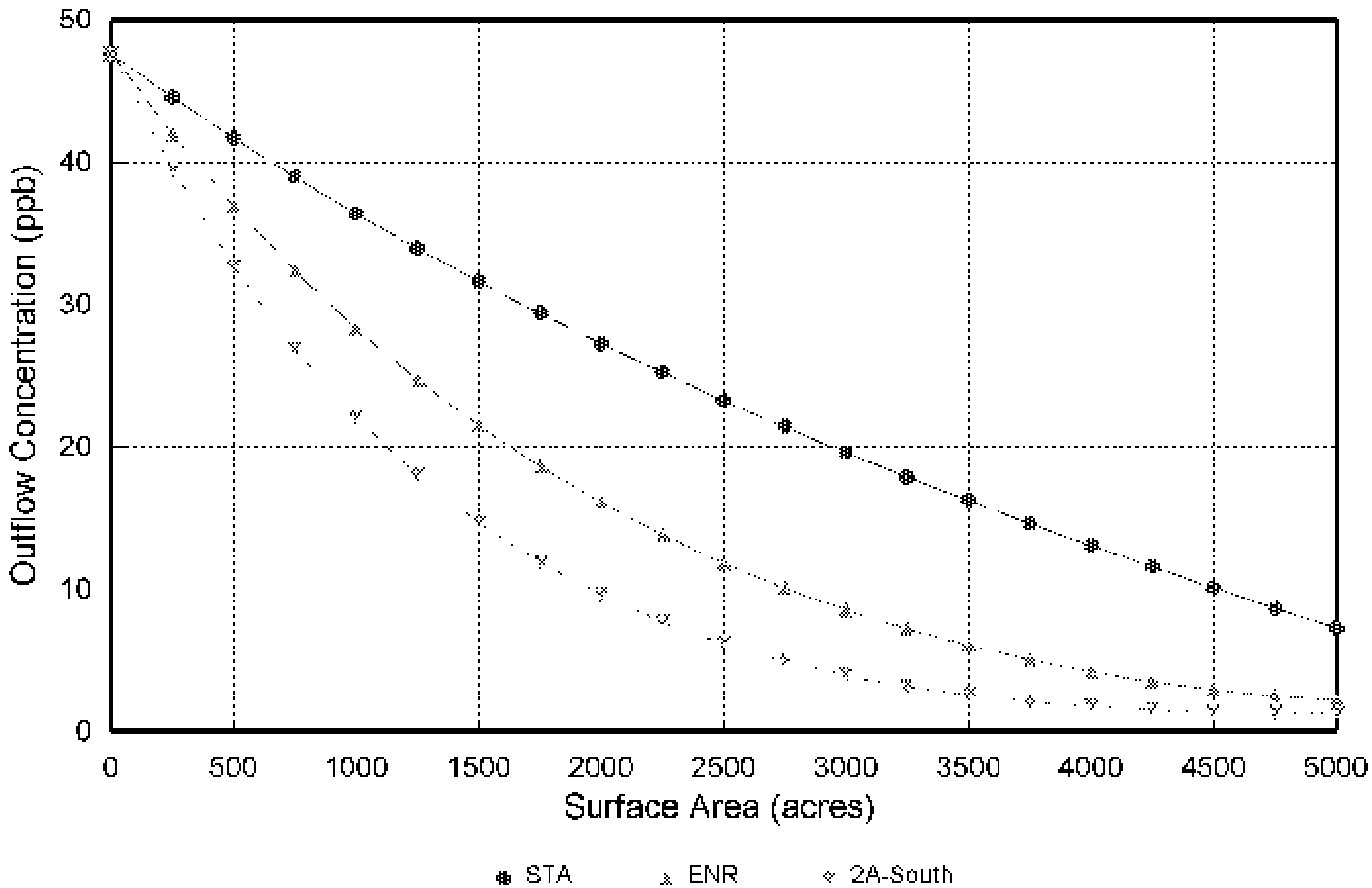


Design Basis	**Settling Rate (m/yr)**
STA	10.2
ENR	20.0
WCA-2A South	30.0

Treatment Area Inflow		
Flow	72.1	kac-ft/yr
Load	4233	kg/yr
Conc	48	ppb

Outflow Concentration vs. Area & Settling Rate

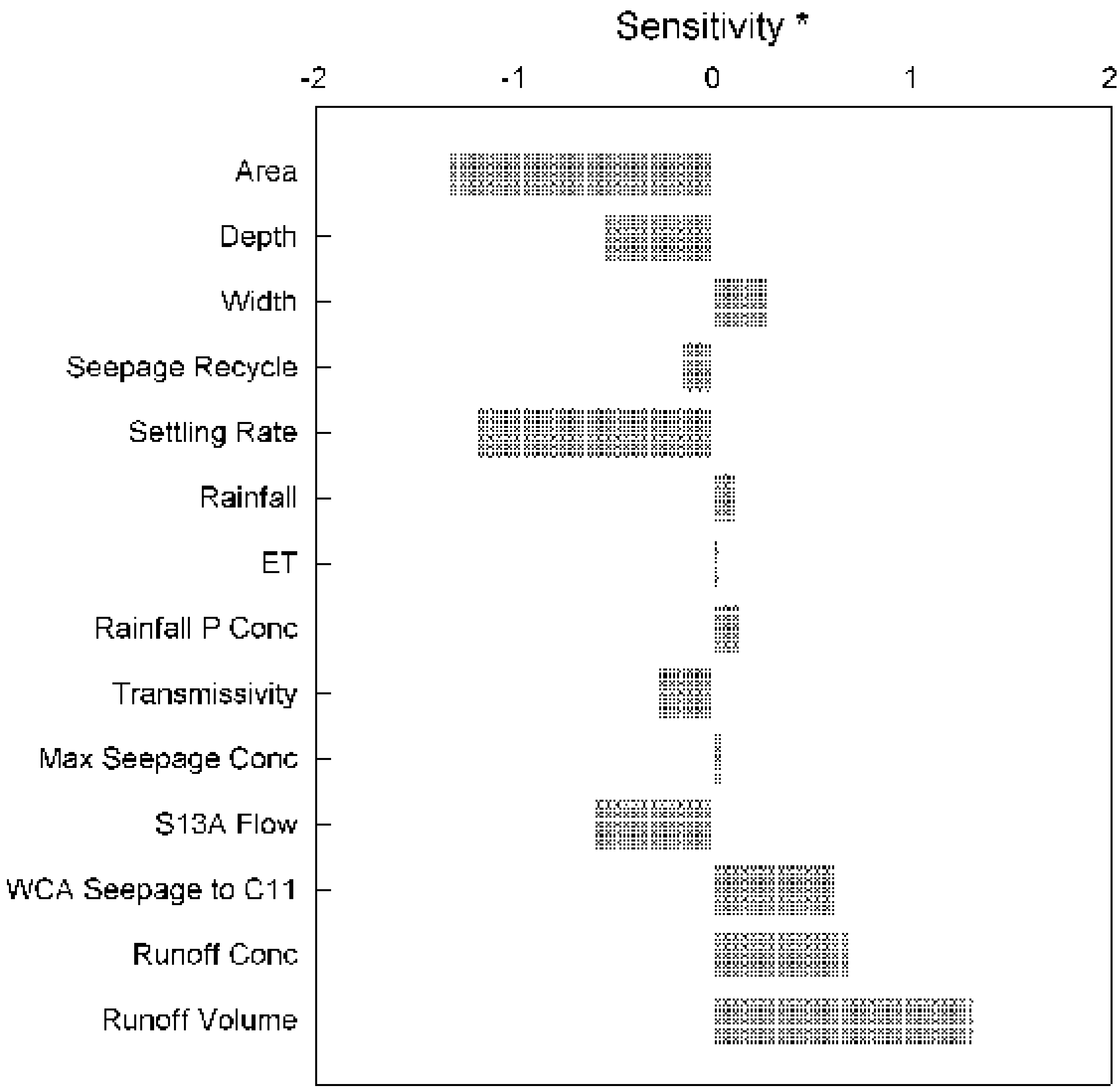
Water Management Scenario: **3**



Design Basis	Settling Rate (m/yr)
STA	10.2
ENR	20.0
WCA-2A South	30.0

Treatment Area Inflow		
Flow	136.6	kac-ft/yr
Load	8022	kg/yr
Conc	48	ppb

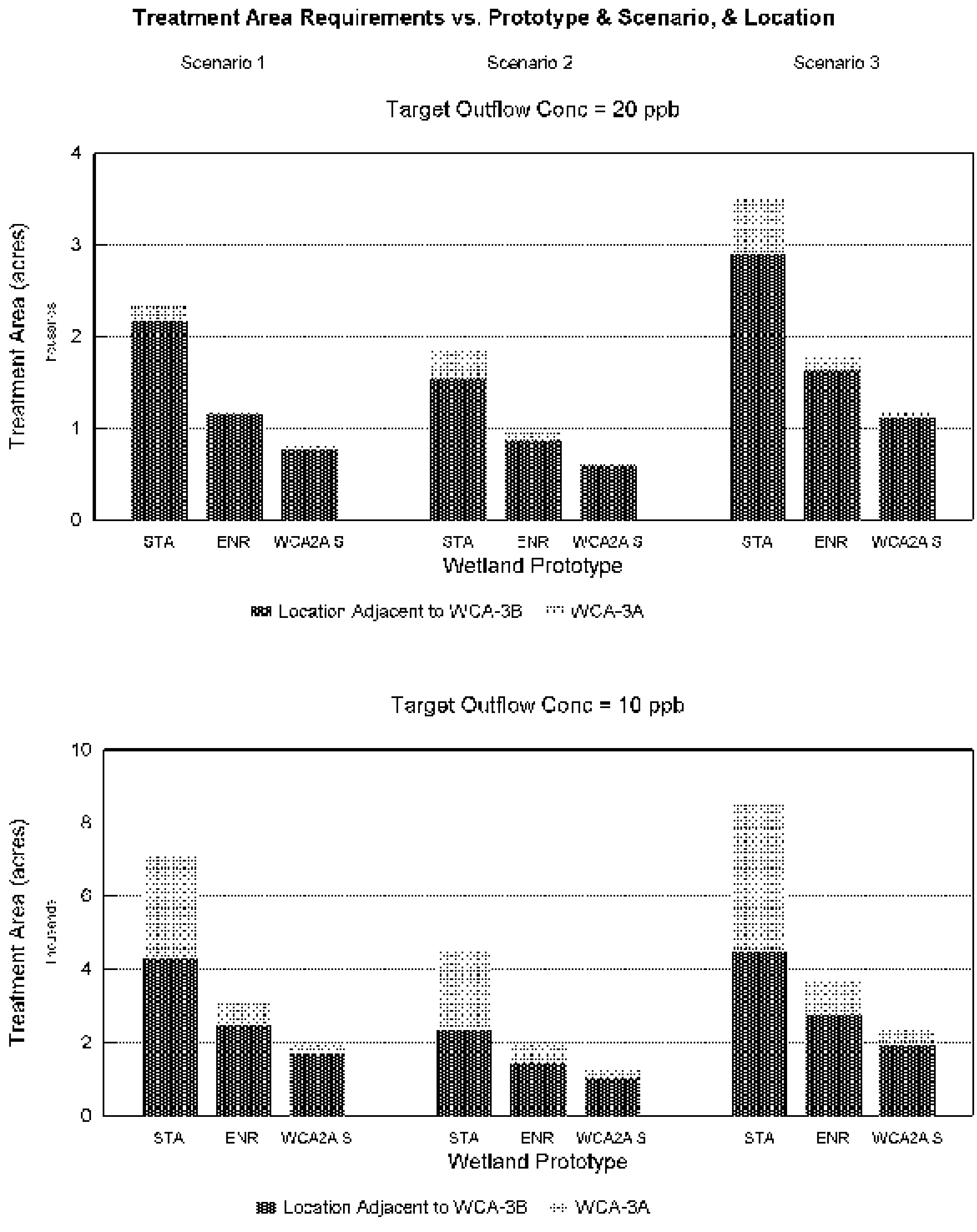
Performance Sensitivity to Model Input Values



* Increase in Predicted Outflow Conc (ppb) resulting from a 10% increase in each Input Variable

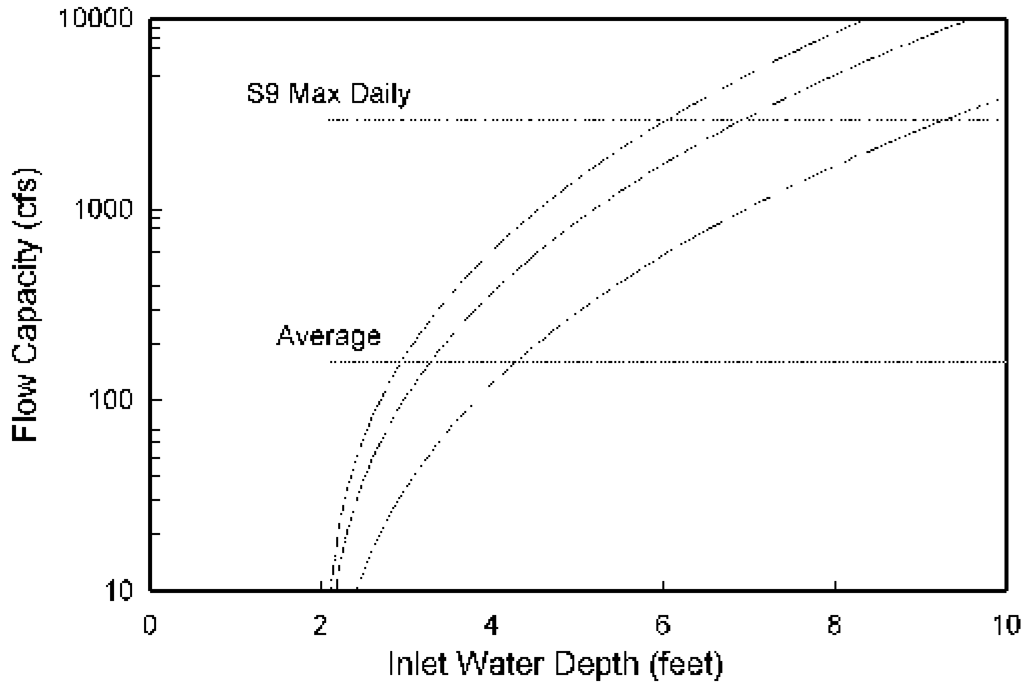
Water Management Scenario	1	
Treatment Area	2500	acres
Settling Rate	20	m/yr
Outflow Concentration	10	ppb

Figure 1



Wetland Prototype:	STA	ENR	WCA2A-South
Settling Rate (myr):	10 2	20	30

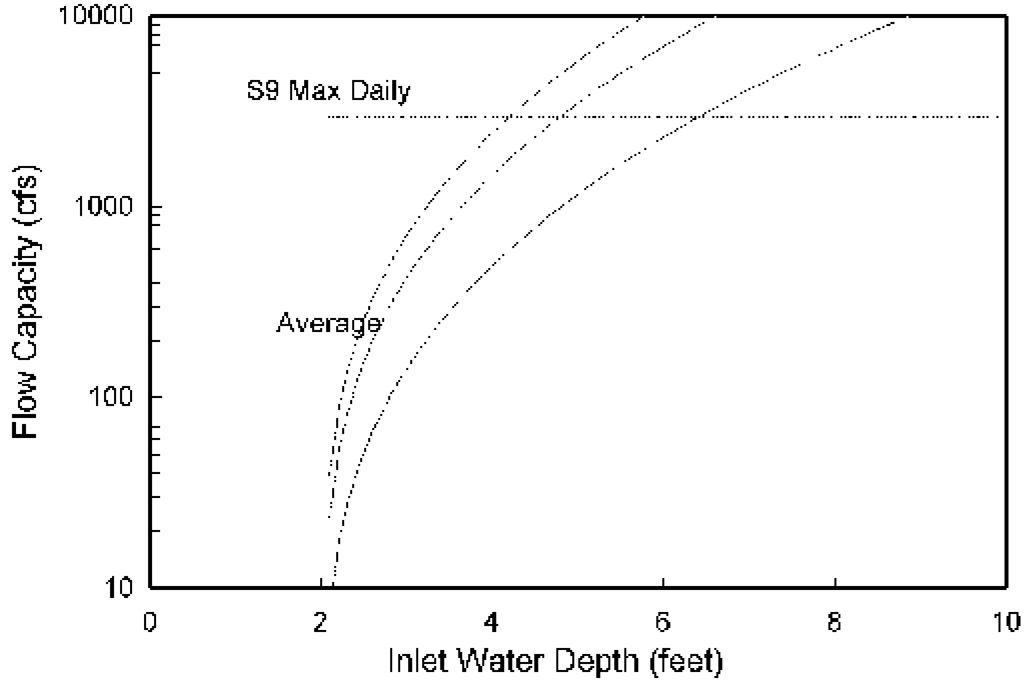
Hydraulic Capacity of Treatment Area
Width = 0.5 Miles



Marsh Parameters		
Surface Area	2500	acres
Width	2640	ft
Length	41250	ft
Outlet Weir Depth	2	ft
Ground Slope	0	

Reference: Kadlec & Knight (1996), Equation 9-44
Low, Medium, & High Vegetation Resistance (a = 5 , 3, 1 x 10^7)

Hydraulic Capacity of Treatment Area
Width = 1 Mile



Marsh Parameters		
Surface Area	2500	acres
Width	5280	ft
Length	20625	ft
Outlet Weir Depth	2	ft
Ground Slope	0	

Reference: Kadlec & Knight (1996), Equation 9-44
Low, Medium, & High Vegetation Resistance (a = 5 , 3, 1 x 10^7)