Executive Summary

Cell 4 of STA-1W is a 146 hectare wetland dominated by submerged aquatic vegetation. Historically, this SAV treatment cell has performed well in terms of P removal, exhibiting a settling rate substantially higher than that of other STA-1W Cells. Despite the good P removal performance, there is visual evidence of hydraulic short-circuiting, which has been thought to be impairing treatment performance.

DB Environmental Laboratories, Inc. (DBEL) recently completed a comprehensive tracer study to evaluate Cell 4 hydraulic performance. Data from the Cell 4 study demonstrated suboptimal hydraulic performance and also identified the location of short-circuit pathways, which appear to overlie either unfilled agricultural drainage canals or levee borrow canals.

This report represents a feasibility study in which DBEL investigated the potential for optimizing Cell 4 hydraulic and TP removal performance by making structural modifications to the wetland. Our feasibility analysis incorporates hydraulic modeling to assess the magnitude of short-circuited flow, performance modeling to evaluate the impact of hydraulic improvement on TP removal, and first-order cost analyses of several possible structural modifications that address hydraulic improvements. Our performance modeling used a dynamic tanks-in-series (TIS) approach to simulate existing and improved hydraulic conditions. Prediction trends were validated by comparing results to steady-state TIS solutions and to a steady-state zones of diminished mixing (ZDM) model, a newly formulated internal flow and mixing model.

Based on these analyses, we suggest that the District undertake limited structural efforts to eliminate short-circuit pathways. Our forecast modeling suggests that hydraulic enhancement (reduced short-circuiting) may increase TP mass removal rates. Modeling results also suggests that reductions in TP effluent concentrations due to hydraulic enhancement will be most evident at low hydraulic loading rates (<13 cm/d) and indicate a potential for effluent concentrations less than 14 μg/L. We suggest that stepwise Cell 4 structural modifications will be the most cost-effective and informative hydraulic enhancement approach.

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Introduction

Cell 4 of STA-1W is a wetland dominated by submerged aquatic vegetation (SAV) with a total area of 146 hectares. A stable, diverse SAV community has developed and persisted in Cell 4 since startup in late 1994. Field observations demonstrate that the dominant aquatic macrophyte is *Najas*. *Ceratophyllum* is the next most abundant species, and usually is found near the inflow region. *Potamogeton* is confined to an isolated area along the southwestern levee. Historically, the Cell 4 SAV community has performed well in terms of P removal, exhibiting a settling rate substantially higher than that of the other STA-1W Cells (SFWMD 2000, Walker 1999).

Despite the good P removal performance of Cell 4, there is visual evidence of short-circuiting, which has been thought to be impairing treatment performance (e.g., limiting the minimum achievable effluent P concentration) of the wetland. Beginning in December 1999, DB Environmental Laboratories, Inc. (DBEL) performed a comprehensive tracer study using the fluorescent dye, Rhodamine-WT, to experimentally determine Cell 4 hydraulic performance (DBEL 2000a). Data from the study validated that hydraulic performance in Cell 4 was significantly compromised compared to typical surface flow wetlands (Kadlec and Knight 1996, DBEL 2000a). Additionally, internal sampling within the cell during the tracer study identified the location of short-circuit pathways, which appear to overlie either historic (unfilled) agricultural drainage canals or levee borrow canals.

This report represents a feasibility study in which we investigate the potential for optimizing Cell 4 hydraulic and treatment performance by making structural modifications to the wetland. We include a review of DBEL's tracer study results, historic Cell 4 total phosphorus (TP) treatment performance, and a Cell 4 ground elevation survey. Our feasibility analysis incorporates hydraulic modeling to assess the magnitude of short-circuited flow, TP performance modeling to evaluate the impact of hydraulic improvement on treatment performance, and first-order cost estimation of several possible structural modifications that address hydraulic improvements. In our feasibility assessment, we have placed greater emphasis on potential reductions in TP concentration than on increased mass removals, since the limits of TP reduction in a full scale SAV system is the principal focus for this study.

Background

Review of DBEL's Tracer Study Results

From December 1999 through January 2000, we conducted a tracer study in Cell 4 using the fluorescent dye, Rhodamine-WT (DBEL 2000a). Historically, Cell 4 has received hydraulic loading rates (HLR) approximately three times greater than other STA-1W treatment cells and 5-9 times greater than expected in other STA locations (Table 1). DBEL conducted the tracer study during a period that District water managers projected relatively constant hydraulic characteristics in Cell 4, which are advantageous conditions for data analysis and interpretation. However, it should be noted that Cell 4 inflow during the tracer study was over 30% greater than historic averages (Table 1) and 50% greater than average Cell 4 inflow for the last two years.

Table 1. Summary of tracer study hydraulic conditions

Treatment Area	Condition	HLR (cm/d)	Inflow rate (cfs)	Avg. depth (m)
STA-1W Cell 4	1995 – July 1999	15.4	93	0.61
	July 97- July 99	13.3	80	0.64
	Tracer study	20.5	123	0.74
STA-1W Cells 1, 2, 3	1995 – April 1999	4.1 – 6.6	86-110	0.38-0.76
other STA's (2, 3/4, 5)	projected	1.7 - 3.1	160-800	N/A

On December 16, 1999, dye was introduced into the headwaters of five G254 culverts (A-E). Figure 1 shows the measured tracer response curve of Rhodamine-WT dye at the G256 outlet culverts. The earliest detection of dye at the G256 culverts occurred approximately 16 hours after injection; peak dye concentration was recorded about 48 hours after injection. For comparison purposes, Figure 1 also shows ideal responses that would occur under well-mixed (CSTR) and plug flow (PFR) conditions. Clearly, there are strong similarities in the tracer response curve to that of a CSTR reactor.

Table 2 summarizes key hydraulic parameters that were derived from the tracer response curve. For comparison, Table 2 also shows values typical to other surface flow (SF) wetlands (Kadlec and Knight, 1996). The tanks-in-series (TIS) parameter is a frequently employed metric for hydraulic efficiency. Special cases of the TIS are the single CSTR (N= number of tanks=1) and

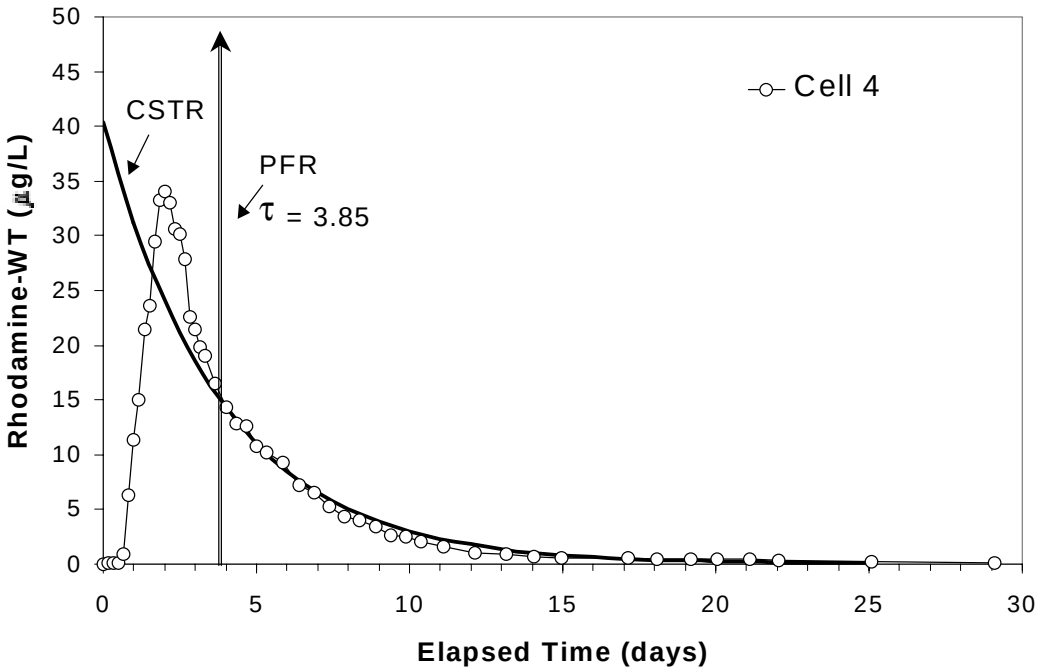

Figure 1. Tracer response curve of Rhodamine-WT dye applied to G254 culverts in Cell 4 on December 16, 1999 and measured subsequently at G256 culverts. Responses to ideal well-mixed (CSTR) and plug flow (PFR) conditions are represented by the exponential decay and vertical (coinciding with the nominal HRT, τ) lines.

the PFR ($N=\infty$). The higher N that a wetland represents, the closer it resembles a PFR. The value of N from the Cell 4 tracer study was N=1.3, which closely resembles a single CSTR and is significantly less than the value of N=3 typically associated with most surface flow wetlands (Kadlec and Knight, 1996). Hydraulic characteristics of a PFR are more conducive to P removal since the average time that inflow water resides in the wetland more closely approximates the HRT. It follows that if the value of N that a wetland represents could be increased, then treatment performance in that wetland should also increase.

Another comparative metric is the Peclet number (Pe), which describes the ratio of tracer transport by bulk flow to the transport by diffusion or dispersion. A comparison of values in Table 2 indicates that Cell 4 transport is dominated by diffusion or dispersion processes ($Pe<1$), whereas transport within other typical SF wetlands is dominated by convective processes ($N>1$). Considering that hydraulic efficiency is thought to be enhanced by bulk flow rather than dispersive or diffusive flow processes, then Cell 4 performs less efficiently than other typical SF wetlands.

Table 2. Summary of Cell 4 key hydraulic parameters

Parameter	Cell 4	Values typical of surface-flow wetlands*
Nominal HRT, τ (days)	3.85	varies
Measured HRT, τ_a (days)	4.7	varies
Dimensionless variance σ_Θ^2, (days^2)	0.78	0.13-0.4
Tanks-in-series, N	1.3	2-8 (typically 3)
Dispersion Number, D	1.25	0.07-0.33
Peclet number, Pe	0.80	3 - 14

*Kadlec and Knight (1996)

In addition to measuring dye concentrations at the G256 outlet structure, we also measured TP concentrations at 26 internal stations in Cell 4 along 5 transects (DBEL 2000a). Internal sampling was conducted at 3, 7, 27, 51, 99 and 149 hours after tracer injection. Figure 2 shows the time series of Rhodamine-WT dye through Cell 4. At 7 hours after injection, short-circuiting

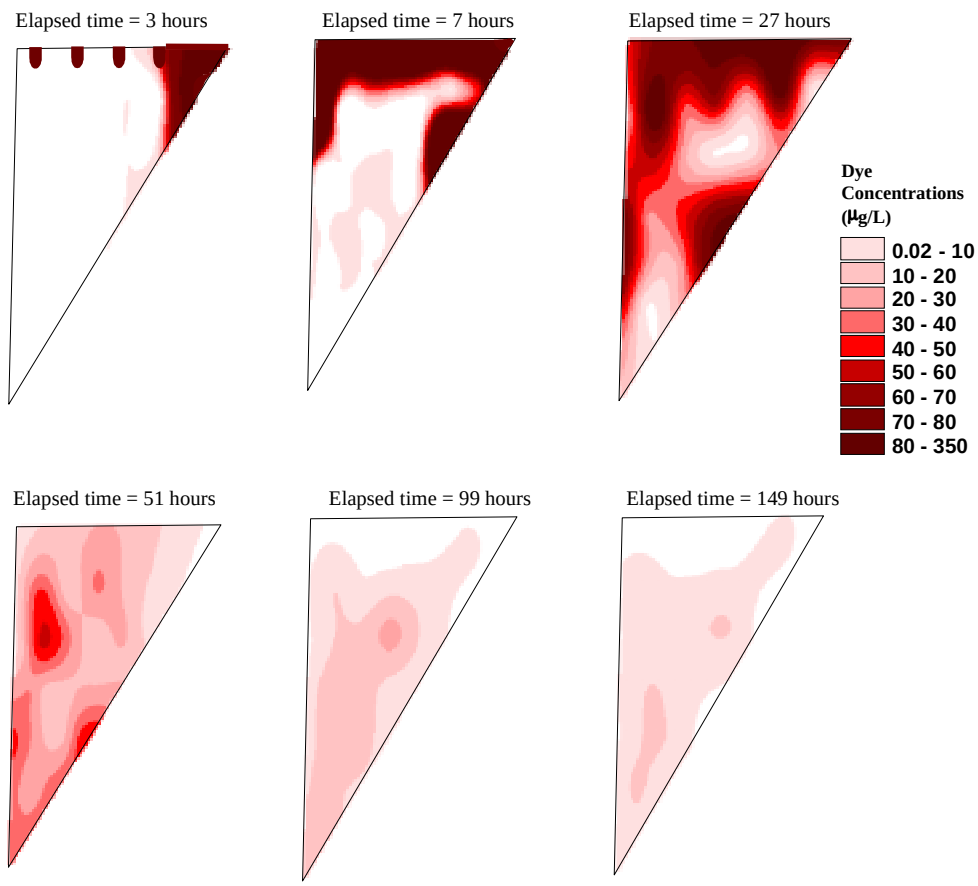

Figure 2. Time series showing the progression of the Rhodamine-WT dye through Cell 4. Dye was introduced into influent at five evenly spaced culverts (G254 A-E) along the northern (top) boundary of the cell. Effluent leaves through a five culvert structure (G256) located at the southern (bottom) tip of the cell.

pathways are clearly evident in the northern half of Cell 4. Similarly, short-circuit pathways are evident in the southern half of Cell 4 at 27 and 51 hours after injection.

The short-circuiting pathways tend to route waters with high TP concentration directly to Cell 4 outflow, thus bypassing SAV treatment areas. This is depicted in Figure 3, which shows plots of internal TP concentrations collected at two intervals during the Cell 4 tracer study. TP concentrations measured along the northeast and most of the western perimeter are nearly as high as those measured at G254 inflow stations. These findings confirm the identified short-circuit-pathways and also demonstrate the effect of these short-circuits on treatment performance.

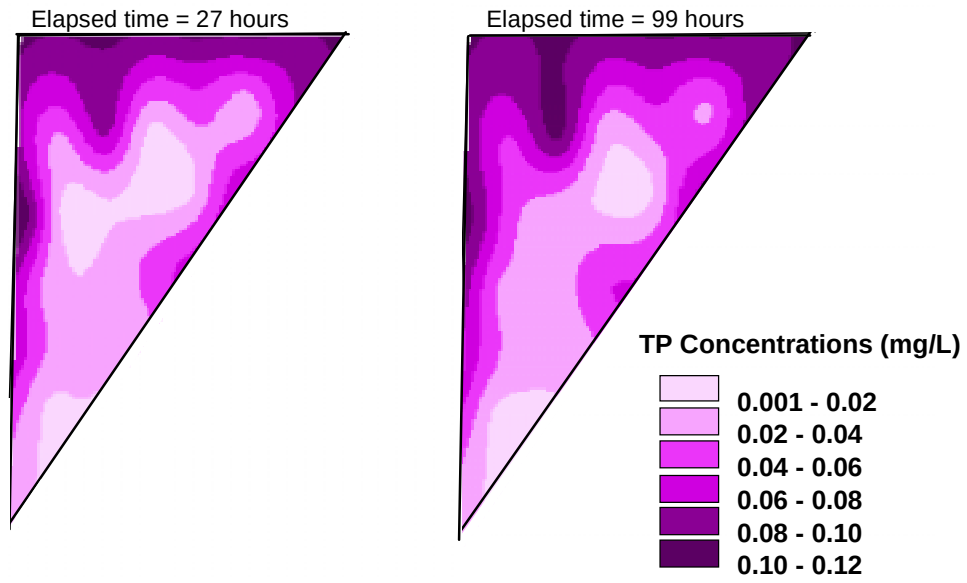

Figure 3. The distribution of total phosphorus concentrations (mg/L) within Cell 4 at 27 and 99 hours following tracer injection**.** Influent enters through five culverts (G254 A-E) evenly spaced along the northern (top) boundary of the cell. Effluent leaves through a five culvert structure (G256) located at the southern (bottom) tip of the cell.

Summary of Cell 4 Ground Elevation Survey in Short-Circuit Pathways

The apparent location of the short-circuiting pathways coincides with the location of pre-existing agricultural or levee borrow canals that were not plugged or filled when Cell 4 was constructed in the early 1990s. We performed a limited sounding of the perimeter and interior channels to determine their approximate depths (± 1 ft. accuracy) and also used available survey data from the District. These findings are summarized in Figure 4. As indicated, the deepest zones are approximately 4' deeper than average Cell 4 ground elevations and are located in the northeast and southwest perimeters, the G254 inflow distribution canal, and the lateral C-7 canal.

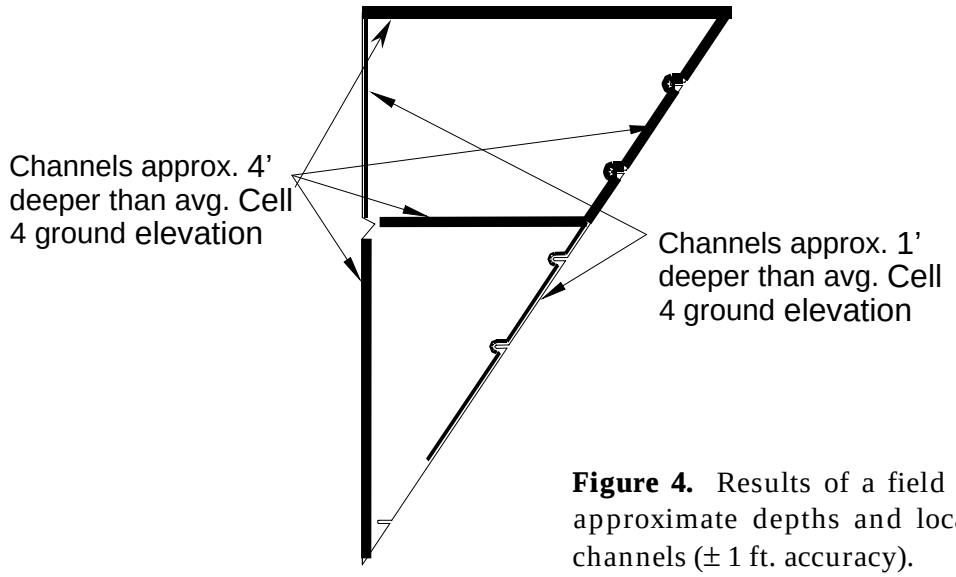

Figure 4. Results of a field survey indicating the approximate depths and locations of short-circuit channels (± 1 ft. accuracy).

Review of Cell 4 Historical TP Treatment Performance

To assist with this feasibility analysis, we performed a review of historic Cell 4 performance data (DBEL 2000b). Figure 5 shows a time history of influent and effluent total phosphorus (TP) concentrations measured at the G254 and G256 structures, respectively, during the period from 1995 through July 1999. All samples were collected by the District and represent weekly composites of three-times daily sampling. During the first 3 years of operation, Cell 4 exhibited seasonally dependent performance that resulted in high effluent concentrations during winter

months. However, after this startup period and since mid-1997, Cell 4 performance has steadily improved.

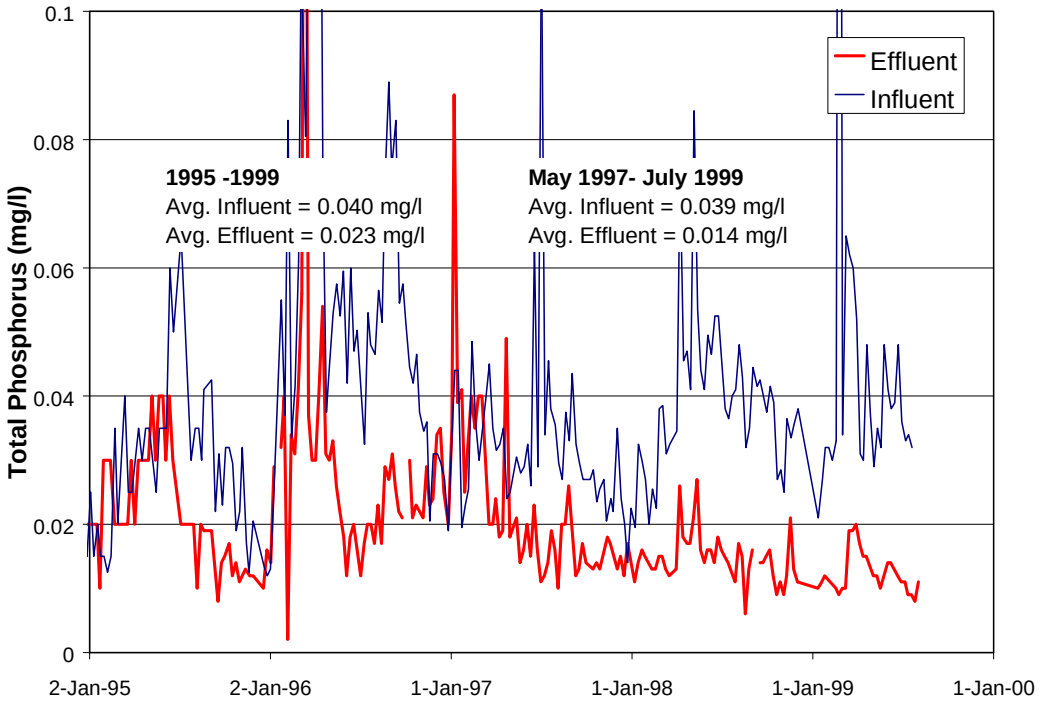

Figure 5. Time history of Cell 4 influent and effluent TP concentrations.

Table 3 summarizes Cell 4 TP removal performance on an annual basis in terms of effluent concentrations, mass removal rates, removal rate constant (k), and treatment efficiency (mass removed / mass loaded). Cell 4 exhibits a general trend toward improved performance over time: average effluent concentrations have been decreasing, while treatment efficiency has been increasing. Mass removal rates and removal rate constants remain elevated compared to that predicted for other STA-1W treatment cells (SFWMD 2000). For the first half of 1999 (full year's data not available at time of study), the Cell 4 effluent concentration averaged 12 µg / L.

Table 3. Summary of Cell 4 TP removal performance

Year	**Effluent TP** (µg / L)	**Mass removal rate** (g / m² / yr)	**P settling rate, k*** (m / yr)	**Treatment Efficiency** (%)
1995	21	0.7	28	26
1996	29	1.7	49	31
1997	21	0.7	26	30
1998	14	1.2	44	70
1999 (through July)	12	1.2	43	65

* annual average of daily calculated settling rate

Rationale for Improving Cell 4 Hydraulic Performance

For this feasibility study, we employed two modeling approaches to investigate the magnitude and treatment ramifications of short-circuiting pathways in Cell 4. The first approach employs a 1-D hydraulic analysis to assess flow distributions through the Cell 4 cross-section. The second approach employs a dynamic simulation model that couples a TP removal model with a tanks-in-series hydraulic model to assess the impact of enhanced hydraulic performance on effluent TP concentrations.

1-D Hydraulic Modeling

To assess flow distributions across the Cell 4 cross-section, the upper reach of Cell 4 was modeled with HEC-RAS. HEC-RAS is an analysis tool developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corp of Engineers and includes modeling capabilities for open-channel hydraulic conveyance. The goal of the analysis was to approximate flow distributions between east and west deep zones and the central SAV areas. We performed limited field soundings to approximate the depth and width of short-circuit pathways relative to the SAV pathway; we estimate our survey had a ± 1 ft. accuracy. The model was run with water depth and flow conditions close to those found during the tracer study. The value of Manning's "n" for SAV-dominated areas was set to n=0.6, based on an average Cell 4 depth of 0.74 m (Kadlec, 1999a). The value of Manning's "n" for the open-water canal areas was set to 0.07 based on field observations that the channels most resemble "a natural stream, sluggish reaches, weedy, deep pools" (Chow, 1959). The analysis was conducted at the tracer study flow condition of 125 cfs.

Table 4 summarizes significant findings from the HEC-RAS analysis. In this analysis, the short-circuit canals represented approximately 8% of the northern reach cross-section area. However, the model predicted that the borrow canals convey approximately 50% of the total flow. If the SAV Manning's "n" were 0.8 instead of 0.6, net conveyance through the channels was predicted to be 58% of total flow. If Manning's "n" through the channels were 0.3 instead of 0.07, net conveyance decreased to 18% of total flow. Modeling results would also be quite sensitive to the ground elevation profile used to define borrow canal dimensions. Since our ground

elevation had limited accuracy and since Manning's n is not accurately known, the modeling results (Table 4) should be interpreted as estimates and not design values.

Table 4. Summary of HEC-RAS analysis for northern reach of Cell 4. Results are estimates, subject to possible inaccuracies in our ground elevation survey (±1 ft) and the assigned values for of Manning's n

	West Channel (n=0.07)	**SAV area** (n=0.6)	**East channel** (n=0.07)
% of cross-sectional area	3%	92%	5%
% of hydraulic conveyance	20%	49%	31%

Performance Modeling

There are several possible modeling approaches, including both dynamic and steady-state models, that could be used for estimating the impact of hydraulic improvement on Cell 4 TP effluent concentrations. Dynamic models offer the advantage of more accurate prediction in event-driven wetlands (Kadlec, 1999b), but at the cost of increased computational intensity. Some options for dynamic models (listed in order of increasing computation intensity) include:

- Dynamic simulation model coupling a removal model with a tanks-in-series (TIS) hydraulic model. This approach is an extension of hydraulic modeling approaches that have typically been applied to conventional chemical reactors.
- Dynamic network modeling using a non-ideal (partial mixing) flow model with first-order removal kinetics. This wetland model has recently been developed by Werner and Kadlec (2000) and is termed the "zones of diminished mixing" (ZDM) model. It employs Monte Carlo simulation and in its current form requires a computer workstation.
- Two-dimensional hydrodynamic modeling coupled with a water quality model such as is being developed by Hydroqual (1998) for the ENR.

We have chosen the TIS removal model for estimating the impact of improved hydraulic performance on Cell 4 TP removal, as it has the most appropriate level of detail for this feasibility study. We also applied two steady-state models (a TIS model and a ZDM model) to reinforce findings from the dynamic model. In interpreting modeling results, we placed greater emphasis on potential reductions in TP concentration than on increased mass removals, since

the limits of TP concentration reductions in a full scale SAV system is the principal focus for this study.

For the TIS-based analysis, we applied the following methodology:

1. A single CSTR (N=1) TP removal model was calibrated to 2.2 years of the most recently available Cell 4 performance data (May 1997 through July 1999) to produce the same mean effluent concentration as was measured in Cell 4 during that time and to minimize a prediction error function. Our tracer study results (N=1.3) confirm the appropriateness of a single CSTR model to simulate Cell 4 "existing" conditions.
2. The model (described in more detail below) is a first-order removal model that includes a recycle pathway to account for C* effects. This model architecture was originally proposed and developed by Dr. Bill Walker (Walker 1999), a DOI consultant working on Everglades restoration issues.
3. The calibrated model was extended to a TIS model, whereby the Cell 4 treatment area was modeled with between 2 and 4 CSTRs in series. These conditions (N=2-4) represent what might reasonably be expected of Cell 4 hydraulic performance after implementing structural modifications to eliminate short-circuit pathways. This analysis predicted the potential Cell 4 performance that would have been realized over the last 2.2 years if Cell 4 hydraulics were characterized as "typical", instead of short-circuited.
4. Lastly, the calibrated model was exercised using scaled input files (2x flow, ½x flow, 2x flow + 2x concentration) to predict Cell 4 performance under potential future loading scenarios. The model was run with values of N=1-4, assessing the performance of both an "existing" and "enhanced" Cell 4 to these scenarios.

Model Calibration

Figure 6 shows a diagram of the model that we used to simulate TP removal in Cell 4. The model maintains both a dynamic Cell 4 water balance and a dynamic phosphorus mass balance. Water balance flows are shown around the Cell 4 boundary in Figure 6 and include rain and G254 inflows, and evapotranspiration (ET), seepage, and G256 outflows.

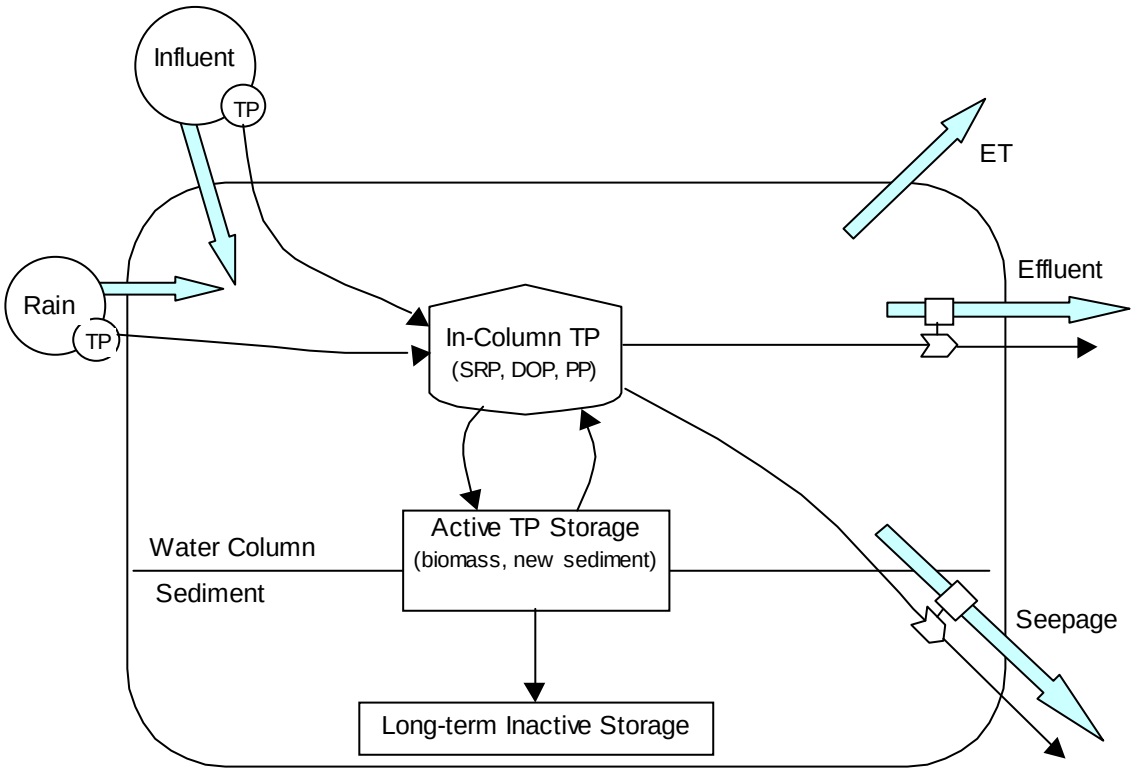

Figure 6. Diagram of TP treatment model showing first-order removal from water column with recycle flux from "active storage" compartment.

The phosphorus model aggregates wetland P-removal processes with fluxes between three internal P storage compartments: TP in the water column, active TP storage, and long-term inactive TP storage. TP in the water column represents combined PP, DOP, and SRP species. TP enters the Cell 4 water column in concert with rain and influent flows and also via the recycle pathway from “active TP storage”. TP leaves the water column in concert with effluent and seepage flows and with first-order removal to the “active TP storage” compartment. “Active TP storage” represents P stored from short-term removal mechanisms such as biomass uptake and new sediment formation including both mineral (calcium-bound) and organic components. A fraction of the modeled “active TP storage” is recycled to the water column, accounting for wetland processes such as desiccation, decomposition, dissolution, desorption. The recycle flux is, in essence, a dynamic C* flux. An additional fraction of “active TP storage” is buried to long-

term inactive storage; this is the only pathway by which TP is permanently removed from the system.

We programmed the model with Visual BASIC using an Excel spreadsheet for input and output files. Input files to the model consisted of District-collected flow, stage, and influent TP data. Influent TP data were collected by the District in autosamplers three times per day, seven days per week and composited to weekly samples. Output files from the program included simulated values of model fluxes, storages, and effluent TP concentration. The differential equations (Table 5) that were used to define changes to 'water', 'in-column TP' and 'active TP' storages were written as finite difference equations and simulated on a daily time step.

Table 5. Summary of simulation model differential equations

Storage	Differential Equation
Water (depth)	$\frac{d(depth)}{dt} = G254_{in} + Rain - G256_{out} - Seepage - ET$ where $G256_{out} = A*(depth - B)$
In-column TP	$\frac{d(TP_{in-column})}{dt} = G254_{in} * [TP]_{in} + Rain * [TP]_{rain} - G256_{out} * [TP]_{CSTR} - Seepage * [TP]_{CSTR} - K_{short-term} * [TP]_{CSTR} + K_{turnover} * \Phi * TP_{sediment}$
Active TP storage	$\frac{d(TP_{active\ sed})}{dt} = K_{short-term} * [TP]_{CSTR} - K_{turnover} * \Phi * TP_{sediment} - K_{turnover} * (1-\Phi) * TP_{sediment}$

(see Table 6 for variable definitions)

The model was calibrated in two steps. First, the water balance coefficients (A and B in Table 6) were determined to best match historic depth (stage) and G256 flow data. District-measured flow and stage data were available for the period of January 1995 through July 1999. District-estimated values for ET and seepage flows were also available for the same period. Calibration was done using trial and error to minimize the coefficient of variation (V) between historic and predicted flows and stage. Calibration values are given in Table 6 and the resulting value for V for both flow and stage was approximately 20%. The mean depth predicted for the 4.6-year simulation period was 0.60 m, which compared favorably to the 0.61 m historic mean. When

G254 inflows were halved or doubled in the model input series, mean depth was predicted at 0.52 m and 0.80 m respectively.

Table 6. Summary of model coefficients and calibration values

Coefficient	Description	Calibration Value
A B	G256 outflow coefficient G256 outflow offset	0.98 / day 0.47 m
$K_{short\text{-}term}$	first-order removal coefficient from in-column to short-term active TP storage	153 m / yr
$K_{turnover}$	average turnover time of aggregated active TP storage compartment	2 / yr
Φ	fraction of active TP storage that is recycled back to in-column storage	0.55

After calibrating water balance coefficients, phosphorus removal coefficients (Table 6) were calibrated to 2.2 years of Cell 4 data, May 1997 through July 1999, which were the two most recent years of data available at the time of this analysis. During these two years, Cell 4 did not exhibit the seasonal variations in performance that were evident in years prior, which may have been due to "start-up phenomena". Hence, the two years of data used for this analysis may be more indicative of what is expected to be Cell 4's long-term performance. Model coefficients were determined with a trial and error approach that led to a near minimal root mean square (RMS) error between daily simulated and measured effluent TP concentrations. Note that the short-term removal constant, $k_{short\text{-}term}$, is specific to this model and cannot be directly compared to the Cell 4 TP settling rate (Table 3).

Simulation effluent TP concentrations from the calibrated model are shown in Figure 7. The mean value of simulated TP effluent for the period of interest was 14 µg / L and the RMS error in simulation was approximately 4 µg / L, giving a coefficient of variation (V) of approximately 30%. From a qualitative perspective, the calibrated model also tended to match dynamic trends (ups and downs) in the measured TP effluent concentrations (Figure 7).

TP removal predictions were most sensitive to the coefficient values of $K_{short\text{-}term}$ and M. Doubling or halving the calibration values of either of these parameters resulted in an approximately ±40% variations in mean TP prediction. On the other hand, predictions were

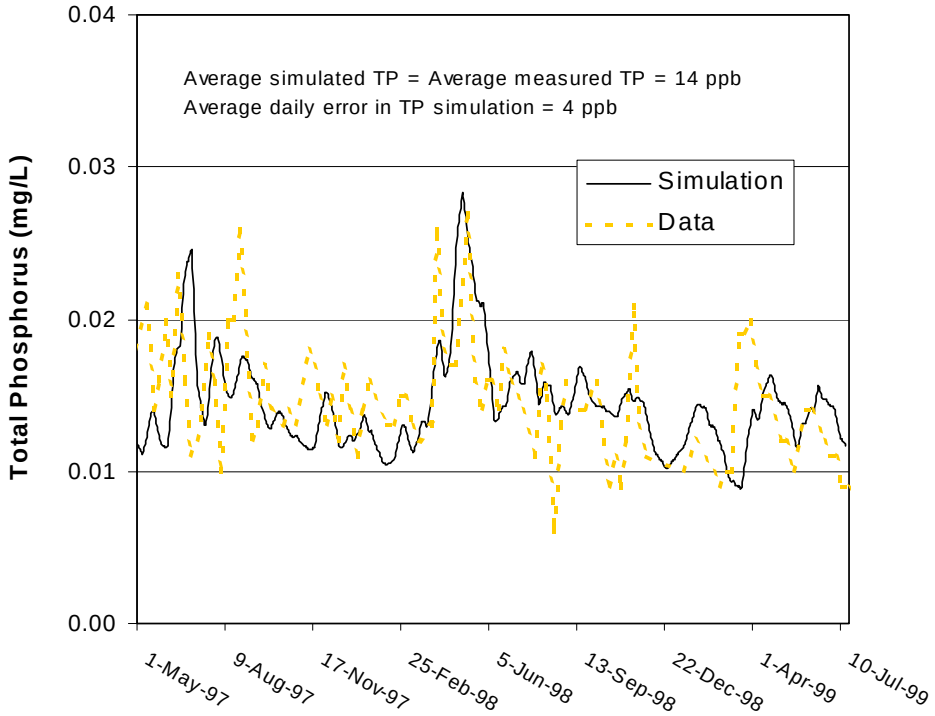

Figure 7. Comparisons of measured and simulated Cell 4 effluent TP concentrations. Measured TP concentrations are weekly composites of 3x daily samples. Simulated data were smoothed with a 14-day rolling average of daily simulated concentrations.

relatively insensitive to the value of $K_{turnover}$. Halving or doubling the selected value of $K_{turnover}$ resulted in only 3% change in the predicted TP effluent concentration. Subsequently, the value of 2/yr was selected as a "sensible" value for the annual turnover of the active storage compartment, which in this model aggregates both biomass and newly deposited sediment.

Model Predictions for "Existing" and "Enhanced" Conditions

The simulation model was used to generate a matrix of Cell 4 performance predictions for a range of externally applied loads and internal hydraulic conditions. Four loading scenarios were investigated, which are summarized in Table 7. For analysis purposes, internal hydraulic conditions were categorized as either "existing" or "enhanced". "Existing" refers to the current condition with short circuit pathways. "Enhanced" refers to a hypothetical Cell 4 condition in which hydraulic performance is not dominated by short-circuit pathways. "Enhanced" conditions could result from any of the four concepts presented for structurally modifying Cell

4 presented in the next section. However, it is important to note that the modeling analysis presented here is not intended to represent specific structural modifications, but instead simply analyzes the relationship between TP removal and hydraulic performance.

Table 7. Summary of simulation model loading scenarios

Loading Scenario	**Influent Flow Rate** (cfs)	**HLR** (cm / d)	**Avg. Influent TP Concentration** (µg / L)
Historic (5 / 97 – 7 / 99)	77	12.8	36
2x Historic Flow	154	25.6	36
2x Flow, 2x Conc.	154	25.6	72
½x Historic Flow	39	6.4	36

"Enhanced" conditions were modeled by extending the calibrated model to a TIS model. Figure 8 shows a diagram of the TIS model for N=3, whereby each CSTR incorporates the calibrated TP removal model. The number of tanks-in-series used in a wetland model is inversely proportional to the amount of dispersion and mixing represented in the model. TP removal in a wetland would be optimal under conditions of no dispersion and mixing (i.e., plug flow), which implies that every parcel of water would be resident in the wetland for the exact same amount of time. Most wetlands are hydraulically represented with between 2 and 4 TIS (Kadlec and Knight 1996). We feel that it is reasonable to assume that Cell 4 hydraulic behavior will be more typical after the major short-circuits have been plugged, hence we have used a range N = 2-4 to represent "enhanced" Cell 4 conditions. For our comparison, the "enhanced" wetland modeled with N = 2-4 suggests less dispersion and mixing than in the "existing" wetland modeled with N=1, and hence better conditions for TP removal.

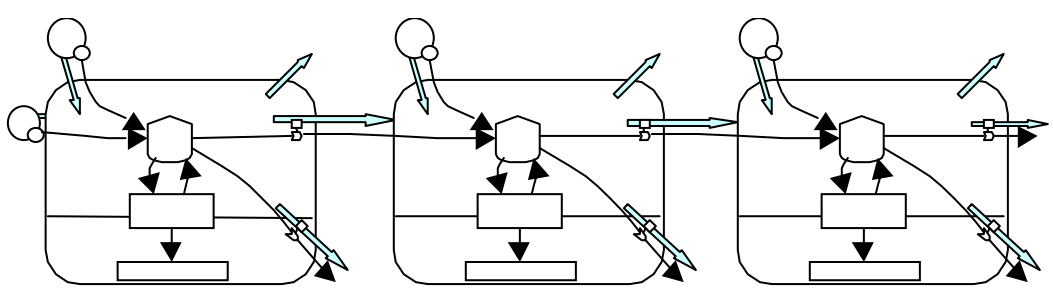

Figure 8. Diagram of TIS model used to evaluate impact of improved hydraulic performance on TP removal (N = 3).

Results of simulation modeling are summarized in Figure 9 and in Table 8. The values of TP effluent concentration expressed in Table 8 are the same values as plotted in Figure 9. Simulation results are based on the assumption that biological and chemical conditions within Cell 4 remain similar to those of the period of data anlaysis. It is important to note that the percent improvements suggested in Table 8 are of the same magnitude as the daily RMS error between the calibration model and measured data, which limits the strength of our findings.

For all loading conditions, modeling results suggest that treatment effectiveness as given by the TP settling rate, k, might increase by approximately 10-15% with hydraulic improvement (Table 8). However, the impact of hydraulic improvement on effluent TP concentrations varies depending upon loading conditions. Under historic loading conditions of the last 2.2 years, modeling results predict that effluent TP concentrations might range from 10-12 μg/L, as opposed to the measured 14 μg/L, a potential reduction of between 14-29% in effluent TP concentration due to hydraulic enhancement. With higher influent loadings (154 cfs + 36 μg/L, 154 cfs + 72 μg/L), modeling results suggest that effluent concentrations (20-40 μg/L) might increase above the measured average in the last two years (14 μg/L). Additionally, the impact of hydraulic improvement on concentration reduction diminishes as TP loading to Cell 4 increases; modeling results suggest effluent concentration might only be reduced by an additional 10-15% due to hydraulic improvement at higher loadings (Table 8). Conversely, at lower loading rates (6.4 cm/d), simulation results suggest a potential for TP effluent concentrations less than 10 μg/L. For reference, even though an HLR of 6.4 cm/d is approximately one-half of historic Cell 4 loading, it is still three times greater than projected mean HLR's for other STA's (Table 1), indicating the potential for increased performance in SAV-based STA cells.

The results presented above are based on dynamic TIS simulations with a calibrated TP removal model. We also applied two steady-state models to reinforce findings from dynamic simulation modeling. The first alternate model is the steady-state 'chemical reactions in TIS' model given by Kadlec and Knight (1996):

$$\frac{C_o}{C_i} = \left[1 + \frac{k_{CSTR}}{Nq}\right]^{-N}$$

where C_o = mean effluent concentration (μg/L)

C_I = mean influent concentration (μg/L)

k_{CSTR} = CSTR settling rate (m/yr)

N = number of tanks-in-series

q = hydraulic loading rate (m/yr)

Table 8. Summary of simulated effluent TP concentrations and settling rates. "Existing" condition refers to Cell 4 as-is with significant short-circuits (modeled with N=1). "Enhanced" refers to a hypothetical Cell 4 condition in which short-circuiting has been reduced. The range of values presented for "enhanced" conditions resulted from simulations conducted for a range of TIS from N = 2-4. Therefore, results are estimates and not design values.

Loading Scenario	Cell 4 Data	Simulated TP Effluent Concentration (μg/L)			Simulated TP Settling Rate, k (m/yr)		
		Existing Condition	Enhanced Condition	% Improved	Existing Condition	Enhanced Condition	% Improved
½x Historic Flow		9	4 – 6	33-56%	19	21-22	11-16%
Historic (5/97 – 7/99)	14	14	10 –12	14-29%	31	34-35	10-13%
2x Historic Flow		20	17 – 18	10-15%	45	49-52	9-16%
2x Flow, 2x Conc.		40	34 – 36	10-15%	45	49-52	9-16%

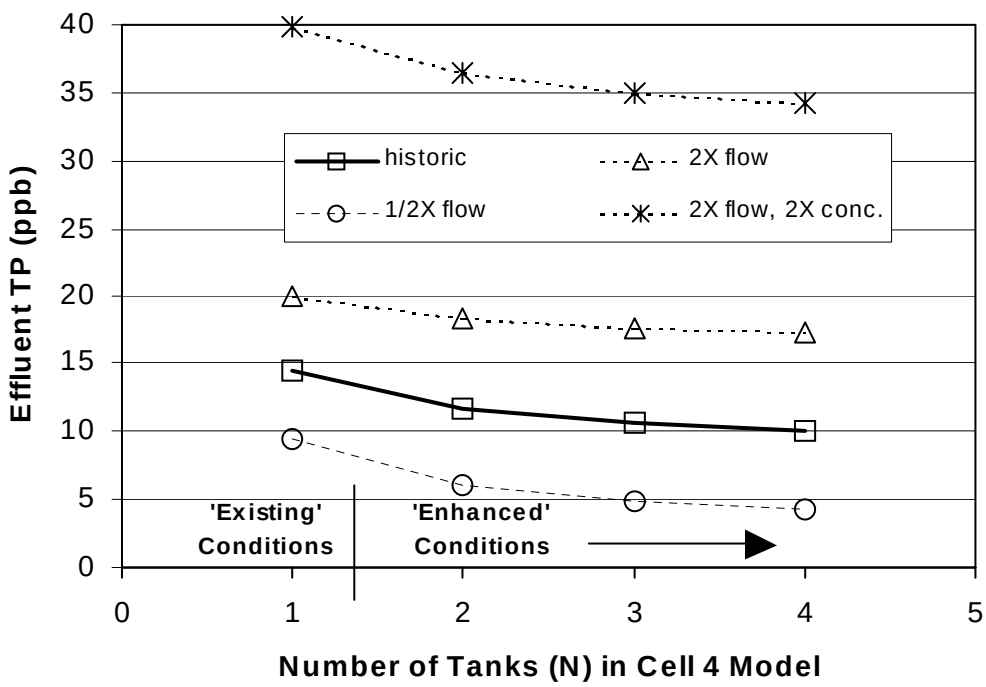

Figure 9. Simulation model results indicating improved TP removal with improved hydraulic performance.

For the historic 2.2 year data set that was used to calibrate the dynamic model, the known values for these parameters were C_o = 14 µg/L, C_i = 36 µg/L, and q = 47 m/yr. For comparison to the dynamic TIS model, the steady-state settling rate was calibrated using N=1 for Cell 4's "existing" condition; the calibration value was k_{CSTR}=70 m/yr. As indicated in Table 9, the steady-state model produces nearly identical results to the dynamic simulation model. In all cases (N = 2-4), results were similar within 10%, thus corroborating findings from the dynamic TIS model.

The second model that we used to reinforce the dynamic TIS findings was the steady-state solution to the ZDM model given by Werner and Kadlec (2000) as:

$$\frac{C_o}{C_i} = (e^{Tz-T-x+\frac{x^2}{Tz+x}})(1-0.13e^{-0.076Pe})$$

where z = fraction of total wetland area that comprises zones of diminished mixing (ZDMs)

x = ratio of cross-flow into ZDMs compared to flow in main channels

Pe = Peclet number in main flow channel

T = Damkohler number = k_{ZDM}/q

k_{ZDM} = settling rate in ZDM model (m/yr).

As z is decreased in the model, the fraction of zones excluded from the main flow channel are decreased. As x is increased, the excluded zones interact more with the main flow path. Werner (pers. comm., April 2000) has calibrated ZDM model coefficients to the RTD from our Cell 4 tracer study, arriving at calibration values of z = 0.39, x = 1.06, and Pe = 11.7. Using these values and average Cell 4 conditions from the 2.2 year data set, the rate constant calibrated to k_{ZDM} = 45 m/year. Note that the value of this rate constant is specific to this model and cannot be compared to the Cell 4 TP settling rate (Table 3).

As indicated in Table 9, the agreement between dynamic TIS and steady-state ZDM model predictions for the "existing" Cell 4 condition under a range of loading conditions was also good. The steady-state ZDM model also reinforced the relationships between loading, hydraulic performance and TP removal that were identified with TIS simulation model (Figure

9). We did not apply the ZDM model to "enhanced" conditions because of uncertainties in estimating ZDM model parameters for future Cell 4 conditions (pers. comm., Werner, April 2000)

Table 9. Comparison of simulation results from three modeling techniques. For comparative purposes, "enhanced" conditions are represented in this table with TIS modeling results using N=3, rather than a range of N = 2-4 as in the remainder of the report.

Load Condition	**Simulated Effluent TP (µg/L)**					
	"Existing" Conditions			**"Enhanced" Conditions**		
	Dynamic CSTR (N=1)	**Steady-state CSTR (N=1)**	**Steady-state ZDM**	**Dynamic TIS (N=3)**	**Steady-state TIS (N=3)**	**Steady-state ZDM**
½x Historic Flow	9	9	7	5	5	N / A
Historic	14	14	14	11	11	N / A
2x Historic Flow	20	21	22	18	18	N / A
2x Flow, 2x Conc.	40	41	43	35	37	N / A

Cell 4 Enhancement Options to Improve Hydraulic Performance

We investigated four options for altering flow patterns in Cell 4, which included:

1. Plugging short-circuiting channels
2. Filling short-circuiting channels
3. Blocking flow from entering short circuiting channels
4. Constructing an internal levee to compartmentalize Cell 4 and redistribute flow.

The goal of the first three options is to enhance Cell 4 hydraulic performance by diverting flow from the deep perimeter channels to the central vegetated areas. Our presumption is that if any of these three options were undertaken, Cell 4 hydraulics would better compare to other "typical" wetlands (Kadlec and Knight 1996) and could hence be modeled with an increased number of tanks-in-series. The goal of the fourth option is to improve hydraulic performance in Cell 4 by collecting flow in the northern half and redistributing it to the southern half, which by definition increases the number of tanks-in-series (N>1). This approach does not directly address the short-circuit borrow canals, but has been suggested as a means for optimizing hydraulic performance in large STA cells.

In the discussion and costing analysis below, each of these options was investigated as a stand-alone solution. Ultimately, hybrid combinations or partial implementations may represent the most cost-effective solution; one possible combination is suggested in the final section of this report. All cost estimates are intended as first-order estimates only.

Plugging Short-Circuiting Canals

Figure 10 shows a conceptual diagram of plugging short-circuit channels to deter flow from entering them. We suggest adding plugs along the length of the north-south borrow canals in addition to plugging the east and west ends of the G254 distribution canal. Fill material would be used to construct dikes extending from perimeter levees outward, blocking flow in the deep zone borrow canals and on the ends of the G254 distribution canals. The District has used this technique to plug historic agricultural canals along the southern perimeter of STA-1W Cell 5 and in other ENR locations.

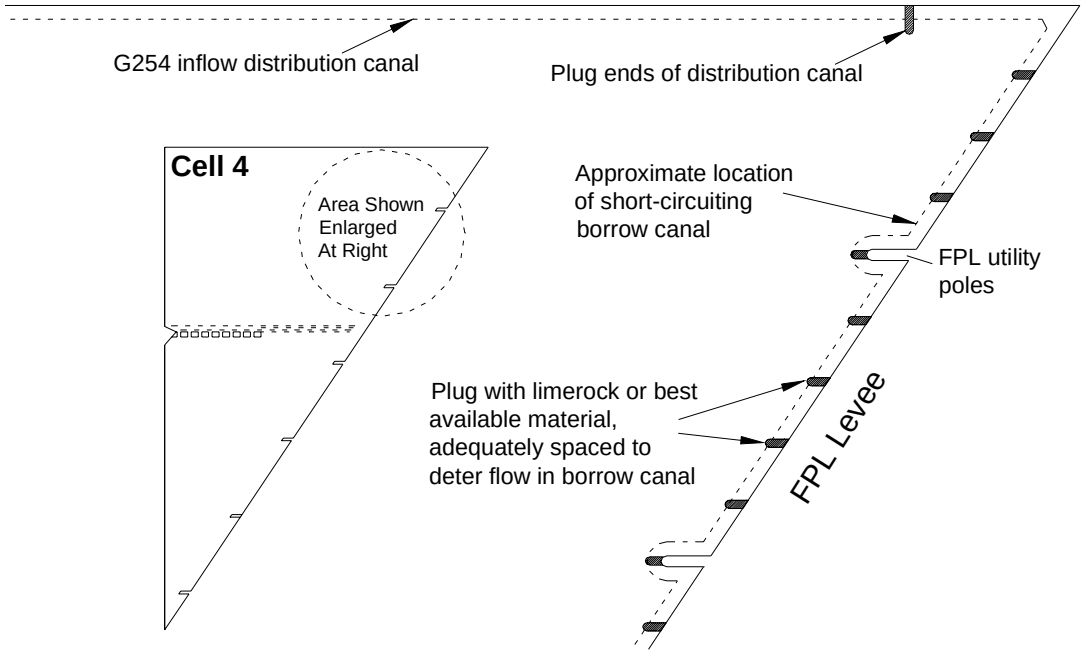

Figure 10. Option #1: plugging short-circuiting channels at intervals adequate to reduce conveyance. The diagram shows only the north-east corner of Cell 4. However in this option, plugs would be placed along the entire north-south length of perimeter borrow canals.

As an additional measure, we also suggest cutting short deep zones in the direction of flow immediately in front of G254 inflow culverts. This would encourage flow to enter the central SAV areas of the cell, rather than being routed into the perimeter deep zones.

Optimal plug-spacing in the borrow canals is the critical design variable, as the plugs must be spaced frequently enough to effectively decrease canal conveyance. In order to decrease canal conveyance, the net flow resistance imposed by the plugs must exceed the flow resistance exhibited by SAV vegetation in the central portions of Cell 4. The District employed a 2-D hydraulic analysis to determine the plug spacing used in the "fix" of Cell 5 hydraulics; the determined spacing was approximately ¼-mile along the several mile long levee. For reference, the FPL utility poles on the eastern levee in Cell 4 are spaced at approximately ¼-mile intervals.

As a preliminary assessment, we applied a 1-D hydraulic analysis, using HEC-RAS, to investigate the impact of plug spacing on borrow canal conveyance. The analysis used the same model that was applied (above) to estimate percent conveyance through the perimeter channels

compared to vegetated areas. The model simulated plugs by blocking flow in the perimeter channels at increments of 600', 400', and 200'. Results of the model are summarized in Table 10 The model suggests that as plug spacing is decreased from 600' to 200', deep channel conveyance decreased from 50% to 40% of total. It is important to note that our engineers believe that the 1-D model underestimates the impact of canal spacing; we expect that a 2-D analysis would reveal larger acceptable spacings. However, the 1-D model also suggests that plug spacing will need to be significantly more frequent than the ¼-mile spacing that was used in Cell 5. For detailed design purposes, we recommend that a comprehensive 2-D analysis be performed.

Table 10. Summary of 1-D HEC-RAS analysis for plug spacing. Results are estimates and not design values.

Plug spacing	% Conveyance of Total Flow			% Improvement to SAV contact area
	West channel n = 0.07	SAV area n = 0.6	East channel n = 0.07	
none	20%	49%	31%	-
600' oc	19%	52%	29%	6%
400' oc	18%	54%	28%	11%
200' oc	15%	60%	25%	22%

Plug spacing directly influences cost. Table 11 summarizes estimated costs for plugging Cell 4's perimeter canals as a function of plug spacing and fill material. Appendix A summarizes assumptions and calculation tables that were used in arriving at these estimates.

Table 11. Summary of cost estimates for plugging perimeter canals

Plug spacing	Estimated fill volume (cubic yards)	Cost w/ onsite materials & contractors	Cost w/ imported mat'ls & offsite contractors
1320' (¼-mile)	2500	$7,300	$24,800
600'	6000	$17,500	$59,600
400'	9000	$26,200	$89,400
200'	19000	$54,400	$185,600

Filling Short-Circuiting Canals

A second option for diverting flow from deep short-circuiting channels would be to fill the channels to the average Cell 4 ground elevation and inoculate these areas with SAV. Once vegetated, there would be no greater tendency for water to flow through these areas than through the central portion of the cell. As shown in Figure 11, one option as a source for fill material is to dredge lateral deep zones across Cell 4 perpendicular to the direction of flow. Lateral deep zones are sometimes employed in treatment wetlands as a means of redistributing flow (Kadlec and Knight, 1996). Alternate approaches would be to use available on-site (within STA-1W) fill material or to import fill from off-site.

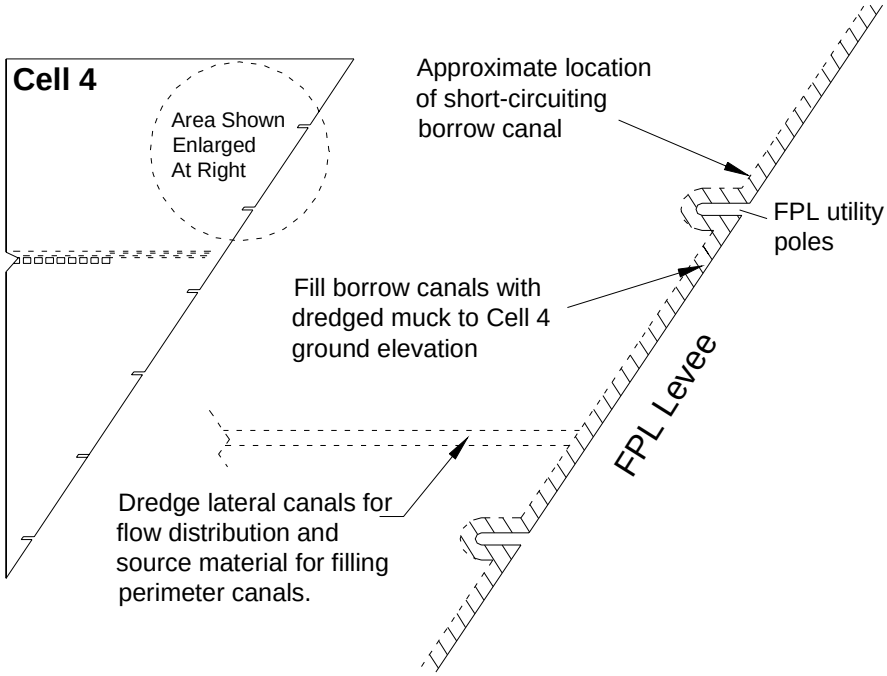

Figure 11. Option #2: filling short-circuiting channels to the Cell 4 ground elevation. The diagram shows only the north-east corner of Cell 4. However in this option, the entire north-south length of the borrow canals would be filled.

Cost estimates for filling deep zones along the Cell 4 perimeter are shown in Table 12. Assumptions and calculation tables that were used in arriving at these cost estimates are summarized in Appendix A. Note that the estimated fill volume required is over 64,000 yd^3. If

the proposed lateral deep zones were 3' deep and 40' wide, over 14,000 linear feet of lateral canal would be required. Given the triangular plan view of Cell 4, approximately 8 lateral zones would be required. As this is an excessive number of redistribution zones, it would be preferable to use an alternate fill material (limerock or marl) that might be available on the STA-1W site for this option.

Table 12. Summary of cost estimates for filling deep channels

Option	Fill Volume (yd^3)	Estimated Cost
dredging lateral deep zones and filling	64,300	$215,000
alternate fill (on-site)	64,300	$192,000

Blocking Flow from Entering Short-Circuiting Canals

A third option for diverting flow from short-circuiting deep channels would be to block flow from entering the channels altogether. Figure 12 illustrates examples of blocking flow by using a narrow berm constructed between FPL poles. An alternate approach for blocking flow would be to use heavy gage silt barriers (turbidity curtains), but these materials may not have the adequate longevity considering reptile and other disturbances; they would also degrade over time due to UV light. Cost estimates are given in Table 13, with details reserved for Appendix A.

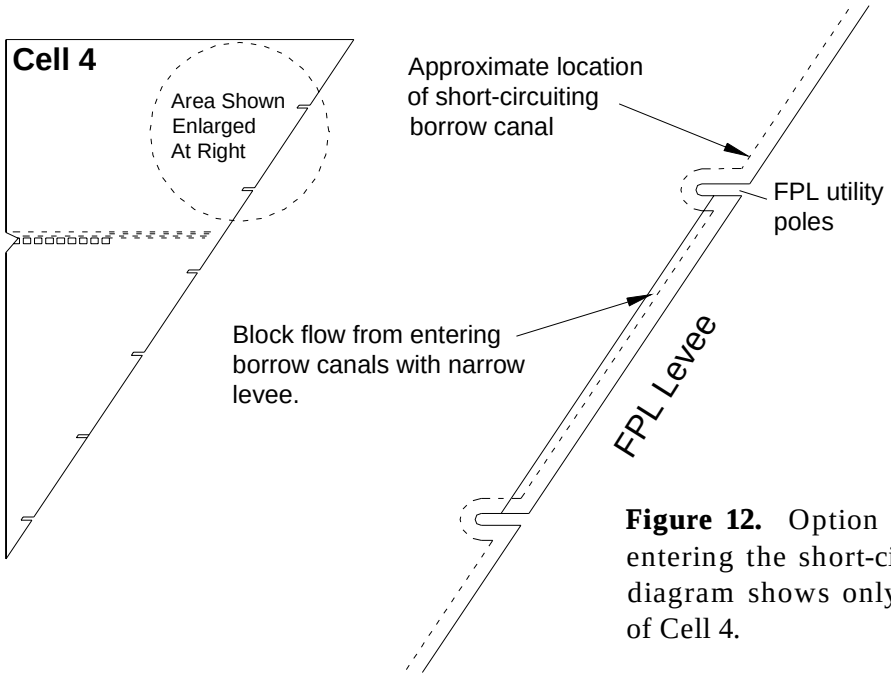

Figure 12. Option #3: blocking flow from entering the short-circuiting channels. The diagram shows only the north-east portion of Cell 4.

Table 13. Summary of cost estimates for blocking flow into deep channels

Option	Required Materials	Estimated Cost
narrow levee	42,000 yd^3	$125,000
silt curtain	15,000 linear feet	$116,000

Constructing an Internal Levee

The last option that was investigated as a stand-alone solution would be to complete construction of an internal lateral berm that will be partially constructed with C-7 canal enhancements (to be completed Spring 2000). As shown in Figure 13, the District will be creating the western half of an east-west berm with the spoil from widening the C-7 canal. The half-berm has been designed to provide several flow-through pathways toward the center portion of Cell 4. We suggest to the District to consider entirely blocking north-south flow through the berm along the western-most edge of the spoil pile, thus deterring flow from entering the short-circuit channel along the southwestern levee. In addition, the berm would be extended until it reached the eastern levee (Figure 13).

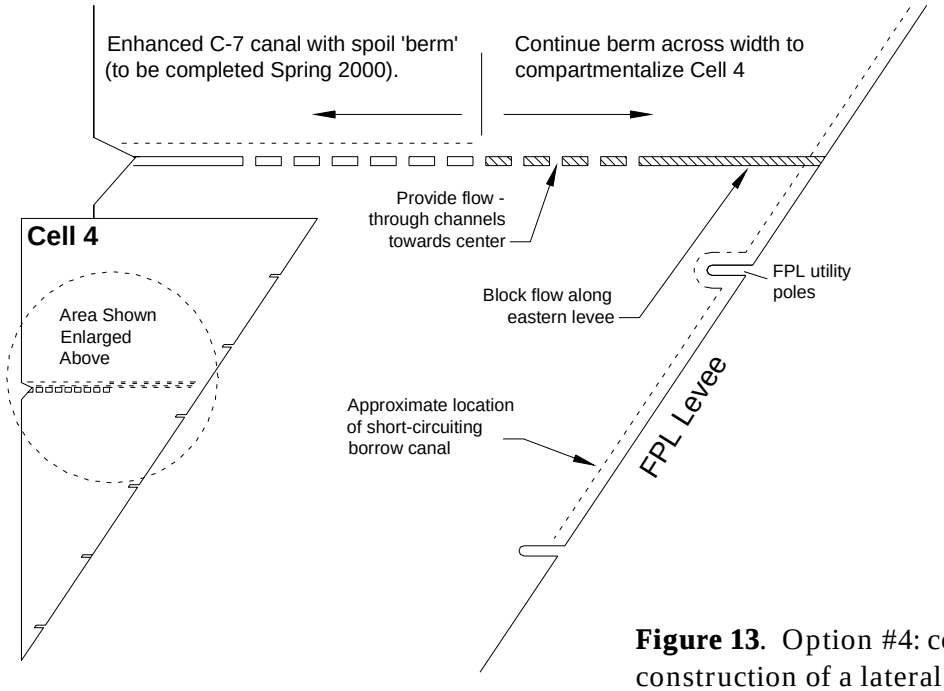

Figure 13. Option #4: completing construction of a lateral berm to divide Cell 4 into two series-connected compartments.

Table 14 summarizes cost estimates for completing a mirror image of the District's half-berm that would effectively divide Cell 4 into two series-connected compartments. As with the filling option (above), there are two options for source material: dredged muck from within Cell 4 from the creation of lateral deep zones or external on-site fill such as limerock that might be available in STA-1W. The fill volume required is approximately 10,000 yd^3. If the proposed lateral deep borrow zones were 3' deep and 40' wide, 7500 linear feet of lateral canal would be required, which would create approximately 3 lateral deep zones across Cell 4.

Table 14. Summary of cost estimates for completing lateral berm

Option	Fill Volume (yd^3)	Estimated Cost
dredge deep zones	10,000	$51,000
alternate on-site fill	10,000	$39,000

Summary

The above discussions and analyses of our tracer study, performance modeling, and cost estimation for hydraulic enhancements are summarized as follows:

- Our tracer study identified impaired hydraulic performance in Cell 4, as well as the location of likely short-circuiting pathways. The short-circuiting pathways are located in residual, unfilled agricultural drainage or levee canals, and tend to accelerate the flow of untreated waters to Cell 4 outflow structures.
- At the current loading rates (13 cm/day or 80 cfs inflow), Cell 4 performance has been very good. Since mid-1997, Cell 4 effluent TP concentrations have averaged 14 μg/L, mass removal rates have averaged 1.14 g-P/m^2/yr, and removal efficiency has averaged over 60%. Since mid-1997, Cell 4 has not exhibited the seasonal variations in performance that were evident in years prior.
- Our 1-D hydraulic analysis indicated that deep channels may convey a substantial portion of Cell 4 flow, far in excess of the 10% net cross-sectional area that they occupy (in the north reach).
- Our performance modeling indicates that hydraulic improvement could increase TP mass removal rates in Cell 4, but the impact on effluent TP concentration would depend upon hydraulic loading rate (HLR). At high HLRs (>13 cm/day or 80 cfs inflow), effluent concentrations would increase above historic averages, with only marginal incremental impact from hydraulic improvement. However, the model suggests that at low HLRs (<13 cm/day), Cell 4 effluent TP concentrations could possibly decrease below 10 μg/L with hydraulic improvement.
- As stand alone options, plugging the short-circuit channels (if on-site materials are available) or completing the lateral berm associated with the C-7 canal would be the most cost effective alternatives for enhancing Cell 4 hydraulics. The cost of plugging would be dependent upon the spacing frequency, which has not yet been accurately determined, but would range from $7,300 to $54,400 (1320'-200' spacings) using on-site (STA-1W) materials. If materials must be imported from off-site, cost more than doubles. As stand-alone options, filling the channels or blocking flow from entering the channels would cost at least twice that estimated for plugging or constructing a berm.

- The cost basis for structural alterations based on loading scenario and cost per mass phosphorus removed per year ($/kg-P/yr) is summarized in Table 15. For this analysis, mass of phosphorus removed was calculated as the difference between simulated TP effluent concentration for N=1 ("existing") and N=3 ("enhanced") models, multiplied by annual flow rate (m^3/yr). For the "plugging channels" option, a plug spacing of 400' was used in this comparison. On a mass removal basis, plugging the channels is the most effective option, followed by completing the lateral berm.

Table 15. Summary of mass removal and cost estimates for hydraulic enhancement options

		Historic Flows	**2X Flow**	**½X Flow**	**2X Flow 2X Conc.**
Mass	Additional TP removed due to enhancement (kg-P/yr)	255	331	155	662
Cost ($/kg-P/yr)	Plugging channels. 400' spacing, on-site materials	103	79	169	40
	Plugging channels. 400' spacing, off-site materials	350	270	577	135
	Filling channels, on-site mat'ls	751	579	1235	289
	Blocking channels, on-site mat'ls	490	378	756	189
	Completing berm, on-site mat'ls	200	154	308	77

Recommendations

As a first phase in the design process, our modeling suggests the feasibility of increasing TP removal in Cell 4 by improving its hydraulic performance. However, the predicted reductions were modest and most evident at very low loading conditions (½x historic average). Based on these findings, we recommend that the District undertake efforts to improve Cell 4 hydraulics, but these structural efforts should be limited in scope.

Based on available data, however, we cannot offer a specific recommendation as to which modification option should be pursued, as there is insufficient information to develop an optimal design. We believe that each of the four structural modification options investigated above has the potential to lead to "enhanced" conditions. Three of the options (plugging, filling, and blocking deep zones) focus on eliminating the impact of the residual canals on overall Cell 4 hydraulics. Our presumption is that if any of these 3 options are undertaken, Cell 4 hydraulics will better compare to other "typical" wetlands as defined by Kadlec and Knight (1996). The fourth option (compartmentalizing Cell 4) improves hydraulic performance by collecting and mixing flow from the northern half and redistributing it to the southern half. From an economic perspective, plugging the channels is most cost-effective of our four suggested options. However from a technical perspective, there are no previously published experimental results that confirm the relative merits of the four options. Additionally, the TIS modeling does not have adequate resolution to discern between specific modification approaches - it simply suggests the benefit of improved hydraulics. A conservative design approach would for call for a detailed topographic survey of Cell 4, followed by high resolution 2-D hydraulic and water quality modeling for each modification option. The problem with this approach is that it would, in all likelihood, cost as much as the modifications themselves, effectively doubling the cost of the entire project.

In lieu of a specific recommendation, we offer a suggestion for the District's consideration. We suggest an empirical stepwise approach that would be both cost effective and instrumental in providing design data to District engineers for optimizing hydraulic performance in other large STA's. The project could proceed as follows:

1. Perform a limited "fix" in Cell 4 by plugging the east and west ends of the inflow distribution canal and by plugging borrow canals along the east and west levees. This is shown as Step 1 in Figure 14 and represents only one of many other limited fix solutions that could be considered. In the borrow canals, plug spacing could vary from tightly-spaced plugs in the north to widely-spaced plugs in the south to effectively manage cost (approximately halving cost estimates for 400' spacing in Table 11). The net effect should dramatically reduce hydraulic short-circuiting. As suggested by modeling results (Table 8), the impact of hydraulic improvement on improved TP removal would be most evident at low hydraulic loading rates.
2. Document the impact of the plugs with a 2nd dye tracer study and internal sampling.

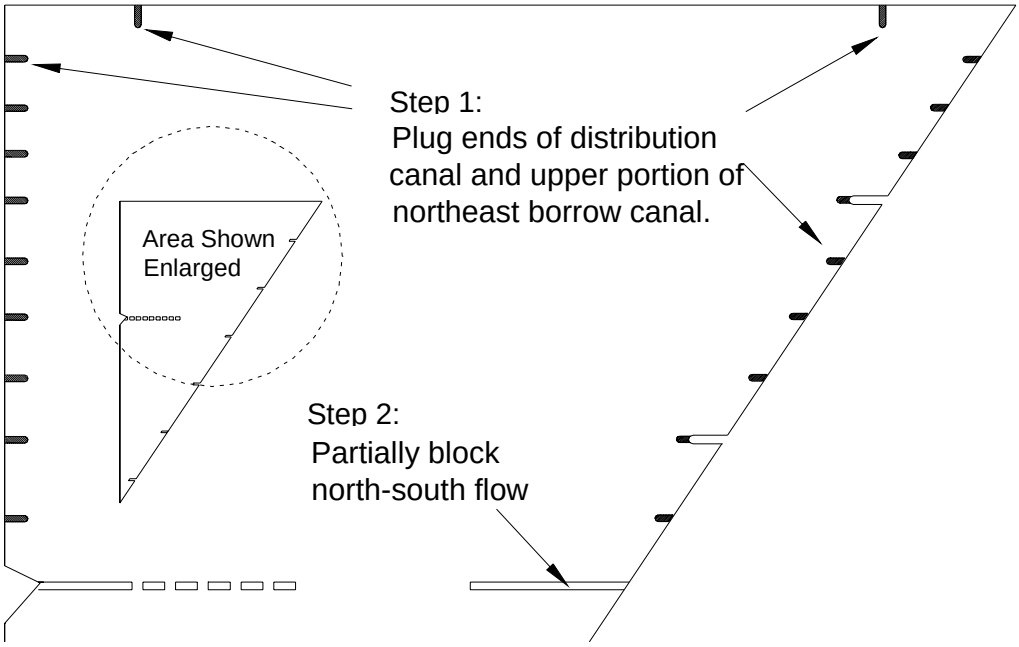

Figure 14. DBEL recommends that the District undertakes a "fix" of Cell 4 with limited scope. One possible suggestion is a stepwise plan, in which the borrow canals would be plugged in the first step and the cell would be compartmentalized in the second step. The plugs shown above have a spacing of approximately 250' in the northern part of the cell, with spacing increasing to 650' near the C-7 canal. The could be a cost effective way to address the most crucial issue of preventing G254 inflow from directly entering the short-circuit channels. The suggested stepwise evaluation provides District engineers with more extensive design data for the large STA cells. The step could be reversed, to better couple these modifications with the District's other on-site construction activities.

3. Compartmentalize Cell 4 by completing the C-7 berm across the width of the cell (Step 2 in Figure 14). Compartmentalization may be a useful means for optimizing hydraulic performance of the large STA cells. This step could be reversed with Step 1 to better couple these modifications with the District's other on-site construction activities.
4. Document the impact of compartmentalization with a 3rd dye tracer study and internal TP sampling.

This stepwise approach would provide the District engineers with crucial design data in two areas: maximum P-removal potential of SAV-dominated Cell 4 and hydraulic design optimization for large STA's.

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Appendix A

Cost Estimate For Plugging Perimeter Channels

Plug Sizing

Length of Plugs (ft) =	50
Width of Plugs @ top (ft) =	15
Slope of sides (width/hieght) =	2.5

Canal Sizes

zone	length (ft)	avg. gnd. elevation	avg. depth (ft)	avg width (ft)	
north-west	2700	8.7'	3	50	"north" = north of C-7 canal
south-west	4210	5.7'	6	50	"south" = south of C-7
north-east	3250	5.7'	6	50	depth = avg. stage - gnd. elev.
south-east	5070	8.7'	3	50	avg. stage = 11.7'

Fill Volume

zone	spacing = # plugs	1320 volume (yd^3)	spacing = # plugs	600 volume (yd^3)	spacing = # plugs	400 volume (yd^3)	spacing = # plugs	200 volume (yd^3)
north-west	2	308	4	616	6	924	13	2001
south-west	3	1128	7	2633	10	3762	21	7899
north-east	2	752	5	1881	8	3009	16	6019
south-east	3	462	8	1231	12	1847	25	3848
TOTAL	10	2650	24	6361	36	9541	75	19767

assumes: no settling due to placement on limerock substrate (scoured canal bottoms)
top of plugs 6" above average Cell 4 stage

Plug Costs

On-site mat'ls and contractors

Item	Cost	Units	1320'	600'	400'	200'
mat'ls & services	$2.50	yd^3	$6,625	$15,903	$23,853	$49,418
contingency (10%)			$663	$1,590	$2,385	$4,942
TOTAL			$7,288	$17,493	$26,238	$54,359

Offsite mat'ls and contractors

Item	Cost	Units	1320'	600'	400'	200'
mat'ls (delivered)	$5.50	yd^3	$14,575	$34,986	$52,476	$108,719
dozer*	$800.00	plug	$8,000	$19,200	$28,800	$60,000
subtotal			$22,575	$54,186	$81,276	$168,719
contingency (10%)			$2,258	$5,419	$8,128	$16,872
TOTAL			$24,833	$59,604	$89,403	$185,590

*assumes 1 day dozer time per plug @$800/day

Cost Estimate For Filling Perimeter Channels

Canal Sizes

zone	length (ft)	avg. depth (ft)	avg width (ft)
north-west	2700	3	50
south-west	4210	6	50
north-east	3250	6	50
south-east	5070	3	50

"north" = north of C-7 canal
"south" = south of C-7
depth = avg. stage - ground

Fill Volume

zone	volume (yd^3)
north-west	5000
south-west	31185
north-east	24074
south-east	9389
TOTAL	69648

assumes: muck filled to Cell 4 ground elevation (~9.66') with no settling
average Cell 4 water depth = 2'
does not take into account tapered side walls on bottom of canals

Fill Costs

Dredge deep zones in Cell 4 and use spoil for berm

Item	Cost	Units	req'd	complete fill	1/2 intermittent fill
barges	$10,500	total	2	$21,000	$21,000
dredge muck	$1.25	/yd^3	69648	$87,060	$43,530
fill muck	$1.25	/yd^3	69648	$87,060	$43,530
subtotal				$195,120	$108,060
contingency (10%)				$19,512	$10,806
TOTAL				$214,632	$118,866

*barge costs includes estimates for mobilization, assembly, disassembly, + 1 month rental

On-site mat'ls and contractors

Item	Cost	Units	req'd	complete fill	1/2 intermittent fill
mat'ls & services	$2.50	/yd^3	69648	$174,120	$87,060
contingency (10%)				$17,412.00	$8,706
TOTAL				$191,532	$95,766

Cost Estimate For Blocking Flow into Perimeter Channels

Canal Sizes

zone	length (ft)	avg. depth (ft)	avg width (ft)
north-west	2700	3	50
south-west	4210	6	50
north-east	3250	6	50
south-east	5070	3	50

"north" = north of C-7 canal
"south" = south of C-7
depth = avg. stage - ground

Linear feet to Block = 15230

Costs

Silt barriers

item	cost	units	req'd	complete block	1/2 block
silt barrier	$6.50	/ft	15230	98,995	49,498
installation	$50	/hr	120	6,000	3,000
subtotal				$104,995	$52,498
contingency (10%)				$10,500	$5,250
TOTAL				$115,495	$57,747

Narrow levee w/ on-site mat'ls and contractors

Item	Cost	Units	req'd	complete fill	1/2 intermittent fill
barge	$10,500	total	1	$10,500	$10,500
matl's & services	$2.50	/yd^3	41177	$102,944	$51,472
subtotal				$113,444	$61,972
contingency (10%)				$11,344	$6,197
TOTAL				$124,788	$68,169

assumptions:

berm constructed from barge floating in borrow canal: mat'l loaded to barge then dumped into position
barge costs includes estimates for mobilization, assembly, disassembly, + 1 month rental
berm assumed to be 5' wide at top w/ 2.5:1 sides and 4.5' deep (3' water + 1.5' settling).

Cost Estimate For Completing Lateral Berm Along C-7 Canal

Fill Volume (yd^3) = 10,000

assumes: muck berm is approximately 1200' long * 75' wide * 3' tall
does not take into account grade on sides of berm

Fill Costs

Dredge deep zones in Cell 4 and use spoil for berm

Item	Cost	Units	req'd	berm
barges	$10,500	total	2	$21,000
dredge muck	$1.25	/yd^3	10000	$12,500
fill muck	$1.25	/yd^3	10000	$12,500
subtotal				$46,000
contingency (10%)				$4,600
TOTAL				$50,600

*barge costs includes estimates for mobilization, assembly, disassembly, + 1 month rental

On-site (STA-1W) fill

Item	Cost	Units	req'd	berm
barges	$10,500	total	1	$10,500
mat'ls & services	$2.50	/yd^3	10000	$25,000
subtotal				$35,500
contingency (10%)				$3,550
TOTAL				$39,050