Dynamic Model for
Stormwater Treatment Areas
Features & Potential CERP Applications

W. Walker & R. Kadlec

CERP Water Quality Team Meeting
South Florida Water Management District
October 10, 2003

Slides will be posted at wwwalker.net/dmsta

DMSTA Website - *wwwalker.net/dmsta*

Related Report :

TECHNOLOGY REVIEW
OF
PERIPHYTON STORMWATER TREATMENT

R. H. Kadlec and W. W. Walker

August 8, 2003

posted at: wwwalker.net/dmsta

Topics

- DMSTA Applications
- Model Concept & Evolution
- Features
- Limitations
- Future Directions
- Demonstration
- Potential CERP Applications

DMSTA Applications

- Design & Optimization of Treatment Facilities
- Integrating Treatment Research & Monitoring Data
- Interpreting "Real-Time" STA Performance Data
- Identifying Data Gaps (Research, Monitoring)
- Design & Evaluation of CERP Alternatives
- Feedback to Adaptive Process for Achieving Long-term Water Quality Objectives

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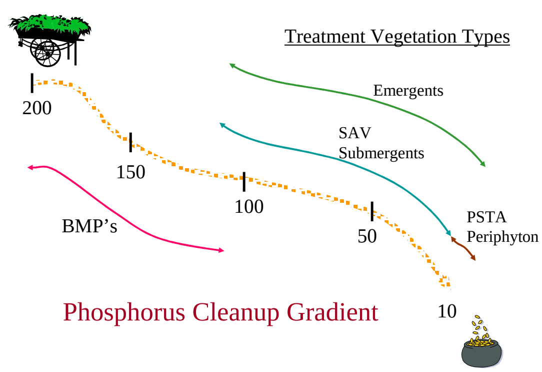
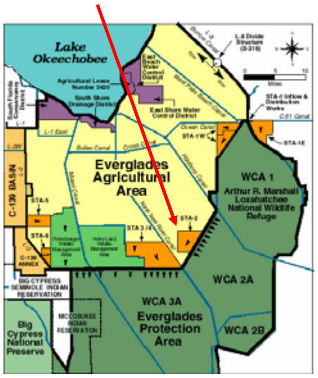
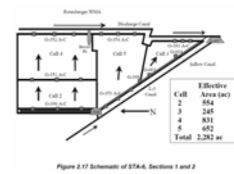
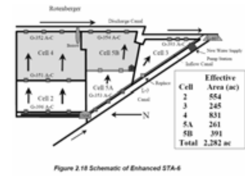


ECP Stormwater Treatment Areas



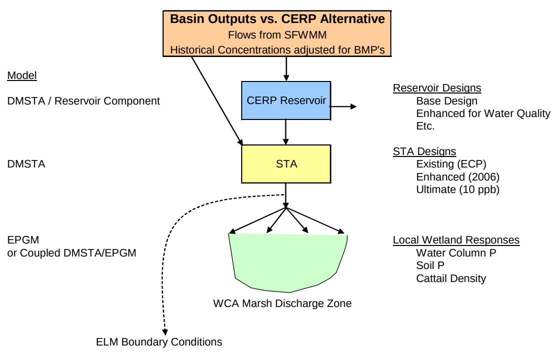


Initial STA Design
Developed in1994



Enhanced STA Design
Developed in 2002

Potential CERP Applications



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Evolution of P Balance Models for Everglades Applications

- STA Design Model (1994)
- Everglades P Gradient Model (1997)
- DMSTA (2000)
- DMSTA / EPGM Hybrid (200X?)

Phosphorus Balance Models

- Engineering-Oriented
- Limited Input Data & Calibration Requirements
- Calibrated & Tested vs. Regional Datasets
  - Natural Wetlands
  - Stormwater Treatment Areas
  - Experimental Platforms
- Applicability Limited to Data Boundaries
- Uncertainty Evaluated
- Spreadsheet Platform with User Interface

Mass Balance Equation

Storage Increase = Inputs - Outputs - Net Removal

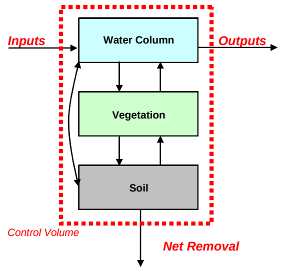
= 0 at Steady-State

Inputs
- Structure Inflows
- Seepage Inflows
- Atmospheric Deposition

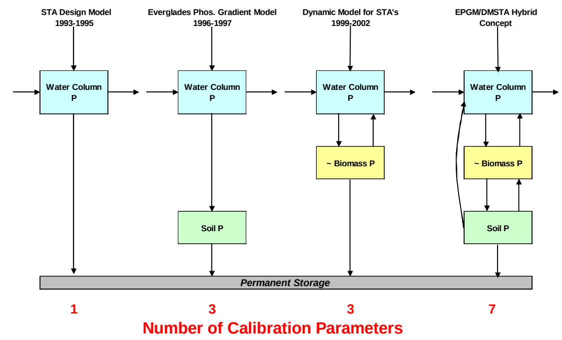
Outputs
- Structure Outflows
- Seepage Outflows

Net Removal
- Burial (Soil Accretion)

Storage
- Water Column
- Vegetation
- Soils



Phosphorus Balance Models for Everglades Applications

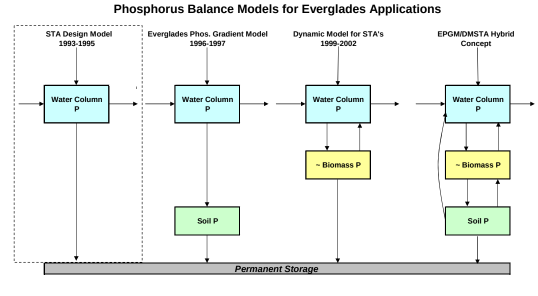


Phosphorus Mass Balance Models Developed for Everglades Applications

W. W. Walker & R.H. Kadlec for U.S. Department of the Interior

Model	STADM	EPGM	DMSTA	HYBRID
Description	STA Design Model	Everglades Phos. Gradient Model	Dynamic Model for STA's	EPGM/DMSTA Hybrid
Development Dates	1993-1995	1996-1997	1999-2002	Concept
Primary Purposes	Design of Phase I Stormwater Treatment Areas	Impacts of STA Discharges on WCA's	Design of Enhanced Stormwater Treatment Areas - All EPA Basins	Same as EPGM/DMSTA + WCA Recovery + CERP Applications
Applic. to Natural Wetlands	WCA-2A	WCA's	WCA-2A; C111	Everglades
Dynamic Time Scale	Steady State	Years	Days --> Years	Days--> Years
Computational Platform	Any Spreadsheet	Lotus or Excel	Excel / Visual Basic	Excel / Visual Basic
Wetland Trajectory	Steady State	Enrichment	Enrichment	Enrichment or Recovery
Spatial Configuration	Gradient (Plug Flow)	Gradient (Plug Flow)	1-Dim. Branched (Cells in Series, Parallel)	General 1-D Branched or Linked to Existing Hydro Models (NSM Output)
Model Coefficients	1	3	3	7
Calibration Basis	WCA-2A, Treatment Wetlands	WCA-2A	~70 Platforms: Tmt Wetlands, Test Cells, Mesocosms	EPGM/DMSTA; Updated to Include Threshold Research, EPA REMAP; ENP & USGS Research

Phosphorus Balance Models for Everglades Applications



STA Design Model

Net Removal / Area = K x TP Conc

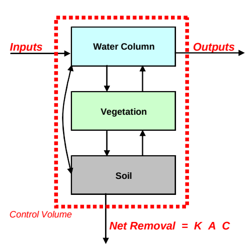
K ~ 10 m/yr

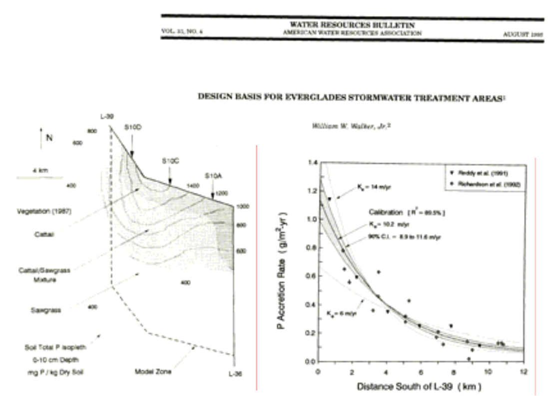
Inputs
- Structure Inflows
- Seepage Inflows
- Atmospheric Deposition

Outputs
- Structure Outflows
- Seepage Outflows

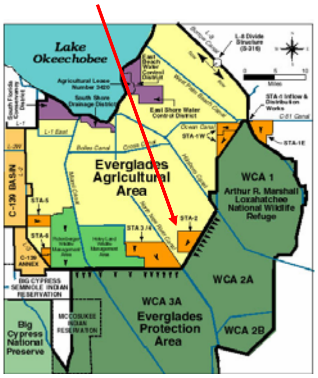
Net Removal
- Burial (Soil Accretion)

Storage
- Water Column
- Vegetation
- Soils



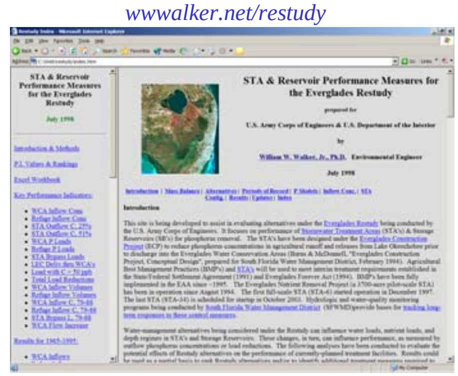


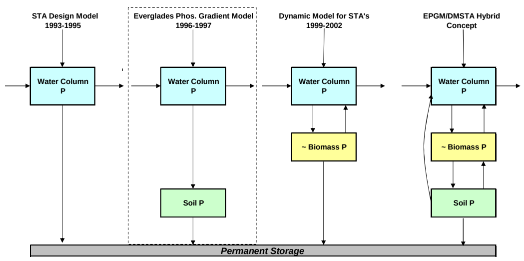
ECP Stormwater Treatment Areas



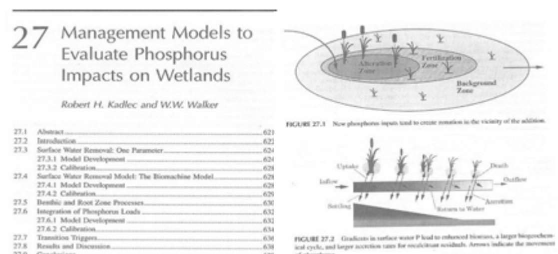
STA Design Model Application to CERP (1997-98)

wwwalker.net/restudy



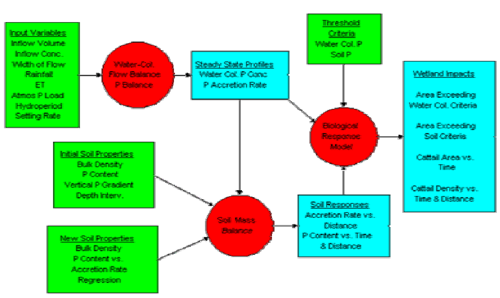


Everglades P Gradient Model - 1997



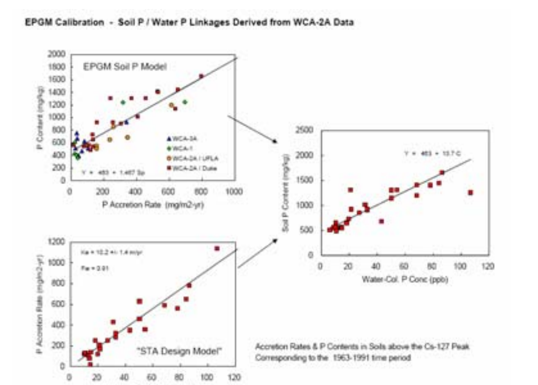
Kadlec, R.H. & W.W. Walker, "Management Models to Evaluate Phosphorus Impacts on Wetlands", Phosphorus Biogeochemistry in Subtropical Ecosystems, K.R. Reddy, G.A. O'Connor, & C.L. Schelske, eds., Lewis Publishers, 1999.

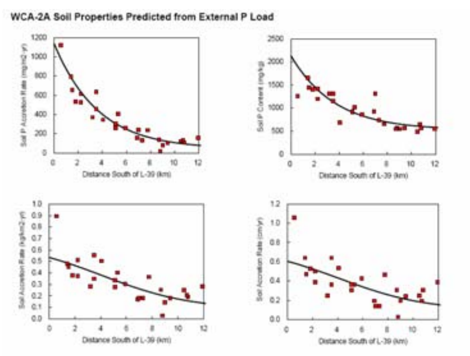
Everglades Phosphorus Gradient Model

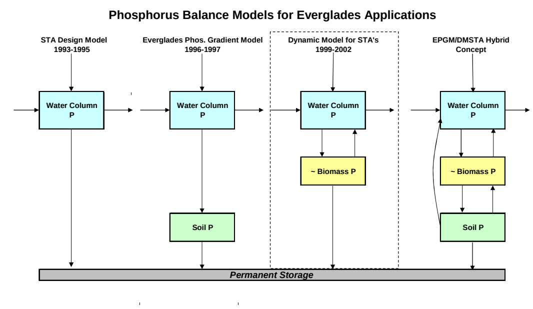


Primary Application:
Simulating Impacts of STA Discharges on Downstream WCA Marshes.

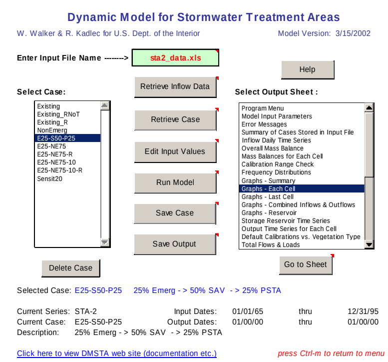
Reference:
W.W. Walker & R.H. Kadlec, "A Model for Simulating Phosphorus Concentrations in Waters & Soils Downstream of Everglades Stormwater Treatment Areas", prepared for U.S. Department of the Interior, August 1996. http://www.wwwalker.net/epgm



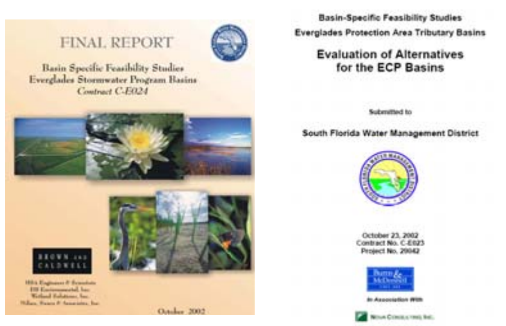




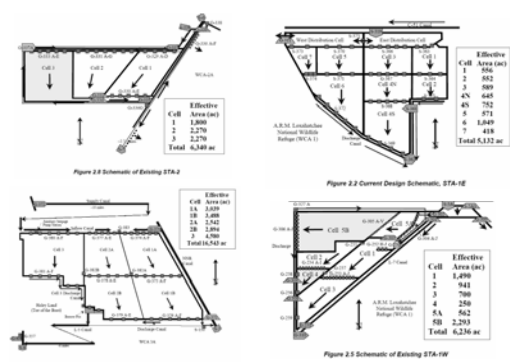
~70 Platforms Used for DMSTA Calibration & Testing



Model Applications by SFWMD Consultants
Basin-Specific Feasibility Studies

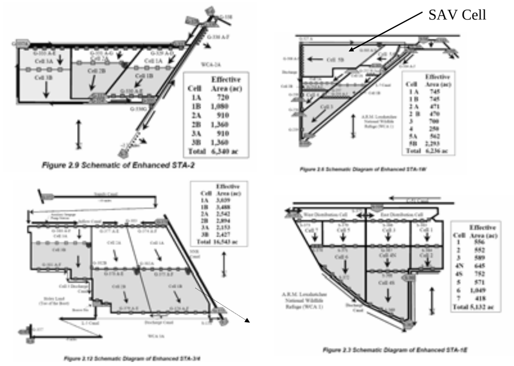


Initial ECP STA Designs (30-50 ppb)



Enhanced STA Designs (?10-15 ppb?)

Benefits of Vegetation & Hydraulic Improvements forecasted by DMSTA



Topics

- DMSTA Applications
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- **Features**
- Limitations
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- Demonstration
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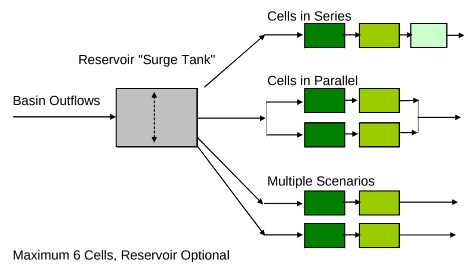
DMSTA Features

- Treatment Cells in Series and/or Parallel
- Hydrology and Hydraulics
  - Water budget, stage-discharge,seepage
  - Tanks-in-series flow pattern
- Dynamic Phosphorus Cycling
  - Water column storage
  - Solid (biomass, sorption) storage
  - Uptake, recycle, permanent burial

Treatment Cell Configurations



Reservoir Component

Reservoir Functions:
- Reduce peak inflows to STA
- Improve STA performance
- Reduce STA outflow spikes & marsh impacts
- Remove P

Input Specifications:
- Ratio maximum to mean STA inflow
- Maximum reservoir volume constraint
- Outflow rules
  - Empty ASAP or
  - Fixed hydraulic residence time (V/Q)
- 2^{nd} Order P Removal Rate

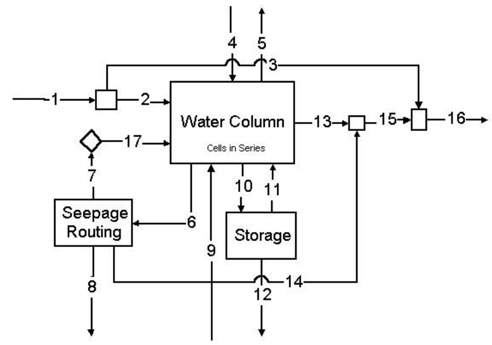
Wetland Design Information

- Surface area
- Mean width
- Outflow control depth. (Weir setting for example)
- Community type. (Triggers selection of P-removal parameters)
- Hydraulic efficiency (Number of Tanks in Series)
- Depth triggering bypass
- Inflow triggering bypass
- Outflow pump capacity
- Out-seepage feed-back fraction
- Out-seepage feed-forward fraction
- Out-seepage concentration

Driving Variables

- Daily time series of water inflows
- Daily time series of inflow concentrations
- Daily time series of rainfall
- Daily time series of evapotranspiration
- Atmospheric deposition (wet, dry)
- In-seep supply elevation
- In-seep rate coefficient
- Seepage water inflow concentration
- Out-seep receiving elevation
- Out-seep rate coefficient

DMSTA Flow Net



Water Balance & Hydraulics

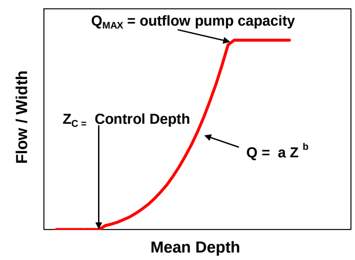
Water mass balance, level pool:

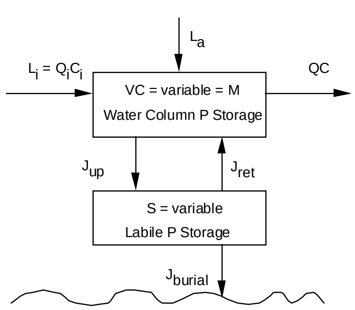
$$A\frac{dh}{dt} = Q_i + A\cdot(P - ET) - Q_o \pm I$$

Stage-discharge relation:

$$Q_o / W = ah^b$$

Depth / Discharge Relationship





Phosphorus Cycling and Removal

Phosphorus Movement & Storage

$$J_{up} = F_z K_1 CS$$

$$J_{ret} = K_2 S^2$$

$$J_{burial} = K_3 S$$

$$\frac{\partial S}{\partial t} = F_z K_1 CS - K_2 S^2 - K_3 S$$

Phosphorus Removal Parameters

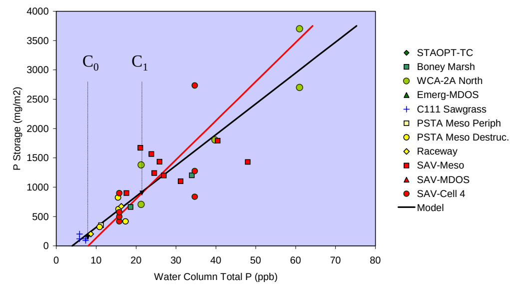
Three primary parameters:

1. Community turnover rate, or biogeochemical cycling rate, K_s.
2. Lowest attainable P concentration, C_o .
3. Community P storage potential, measured as the water concentration C_1 at which the community stores 1000 mgP/m^2.

Three secondary parameters:

4. The depth dependence maximum, Z_{max}.
5. The community transition midpoint, S_M.
6. The community transition bandwidth, S_B.

Calibration of Biomass P Storage Parameters C_0 & C_1



DMSTA Vegetation Types

Emergent

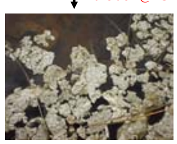
K ~ 10-15 m/yr

Non-Emergent "NEWS"

Submersed Aquatic Vegetation "SAV"

K ~ 30-60 m/yr

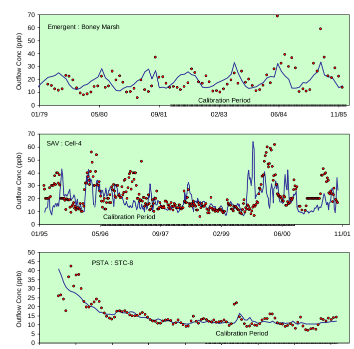
Transition @ 15-20 ppb



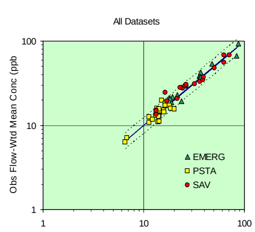
Periphyton / "PSTA"

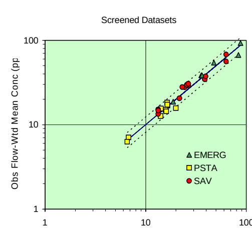
K ~ 20-30 m/yr

Calibration to Prototype Datasets



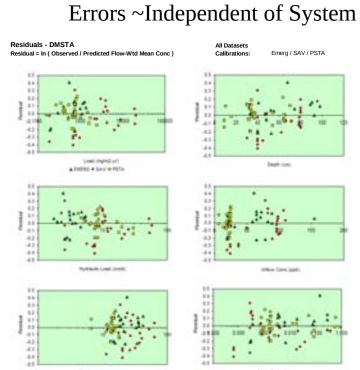
DMSTA Testing vs. Independent Datasets





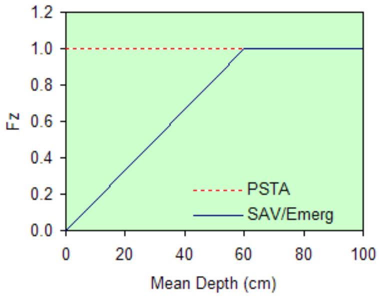
Datasets represent experimental mesocosms, test cell, full-scale treatment cells, & natural wetlands.
Screen datasets have at least 1 full year of data.

DMSTA Testing: Residuals Analysis Errors ~Independent of System Variables

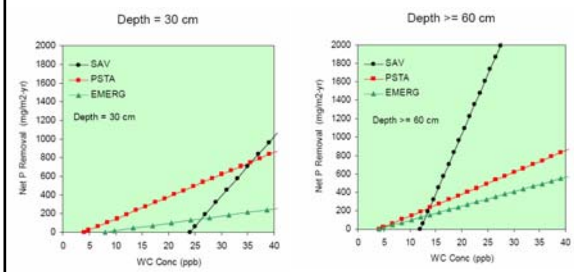


- •P Load
- •Hydraulic Load
- •Depth
- •Inflow P Conc
- •Predicted P Conc
- •Velocity
- •Area
- •Length/Width
- •Dataset Duration
- •Max/Mean Flow
- •Biomass P Storage
- •Hydraulic Efficiency
- •etc

P Uptake Rate vs. Depth



Net P Removal Rates vs. Water Col P, Vegetation Type, & Water Depth Steady-Flow System



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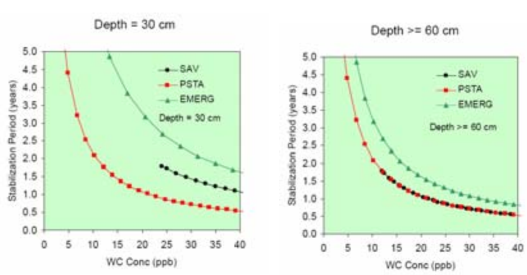
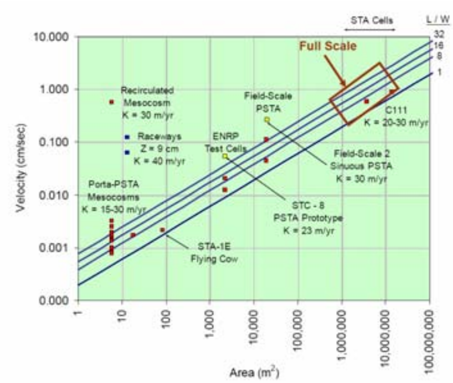
DMSTA Limitations

- Developed & Calibrated for Total P Only
- Adaptable to Other WQ Components with First-Order Kinetics & Calibration Data
- Applicability Limited by Dataset Boundaries
- Standard Error ~20% of Predicted Average Outflow P
- Limited Spatial Scale & Duration of Calibration Datasets
- Implicit Factors (Calcium, P speciation, Velocity, etc.)
- Further Calibrations (Reservoirs, Hydrilla, Hyacinth, etc).
- Reservoir Model (Hydraulics, P Uptake)
- Vegetation Types ASSUMED not PREDICTED !!
- Uncertainty Associated with Large-Scale Vegetation Mgt.

Stabilization Period vs. Water Col P Vegetation Type, & Water Depth



Limitations Associated with Platform Size



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DMSTA Long-Term Workplan

- Track STA Performance
- Track Treatment Research Platforms
- Track Natural Areas
- Enhance Model Platform / Interface
- Enhance Hydraulic Features
- Enhance Reservoir Model
- Enhance P Cycling Model
- Model for Enrichment & Recovery of Natural Areas
- Develop New Model Releases for Use in Design

Potential Enhancements to P Cycling Model

- Velocity effects on P uptake
- Inlet P speciation
- Live vs. dead biomass storage
- Calcium
- Soil and/or Floc Compartments
- Startup Simulation
- Vegetation changes driven by system variables (loads, soil P, water column P, depth, etc)
- Other, as identified in STA tracking & research

Potential Enhancements to Hydraulic Features

- Increase number of treatment cells (now 6)
- Increase flexibility for cell-to-cell routing
- Add seepage modeling options (cross-talk?)
- Add stage/discharge modeling options
- Allow user-specified water balances
- Variable bottom topography
- Other, as identified by model users

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Potential Water Quality Benefits of Reservoirs

- Reduce peak inflows to STA
  - Improve STA performance
  - Protect STA vegetation
- Remove P
- Reduce STA outflow spikes & marsh impacts
- Increase Operational Flexibility

Integrated Alternative – SFWMD Long-Term Conceptual Plan

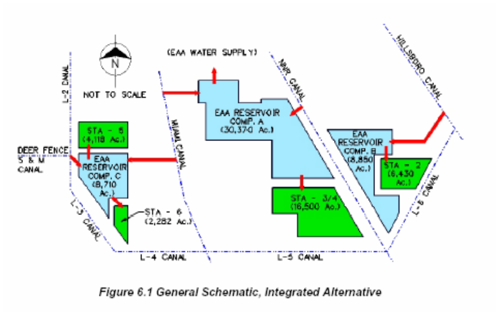
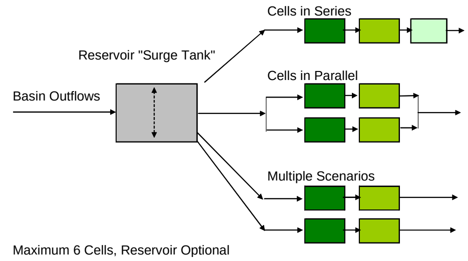


Figure 6.1 General Schematic, Integrated Alternative

Treatment Cell Configurations

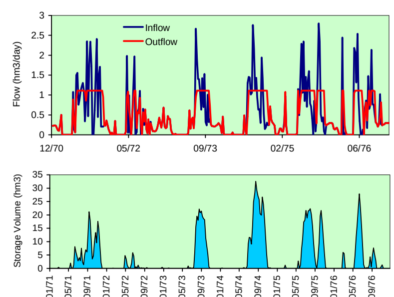


DMSTA Reservoir Component

Input Specifications
- Ratio maximum to mean STA inflow
- Maximum reservoir volume constraint
- Outflow rules
  - Empty ASAP or
  - Fixed hydraulic residence time (V/Q)
- 2nd Order P Removal Rate

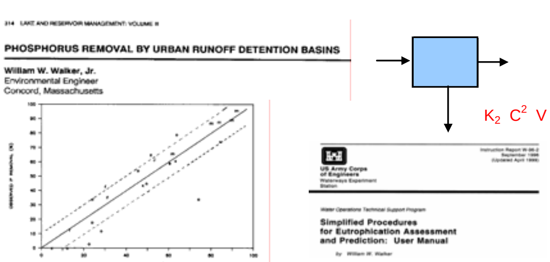
Needed for CERP Applications
- More Hydraulic Options
- Calibration of P Removal Model

Reservoir Simulation



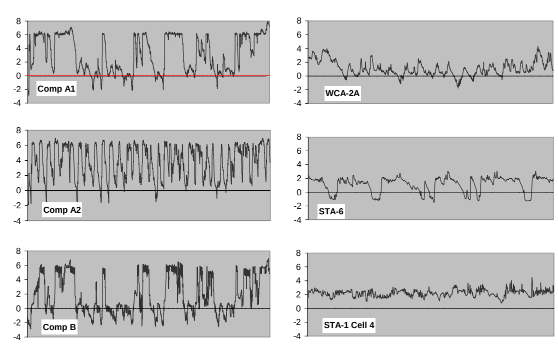
DMSTA Reservoir P Model

Data from Corps Reservoirs & Urban Runoff Detention Ponds

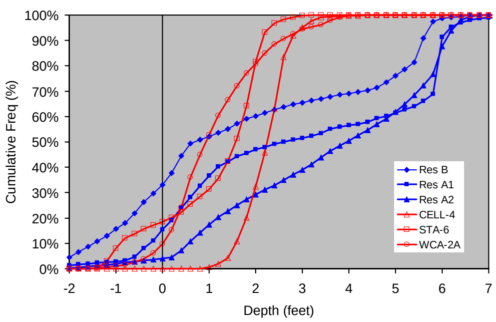


Daily Water Depths (ft)

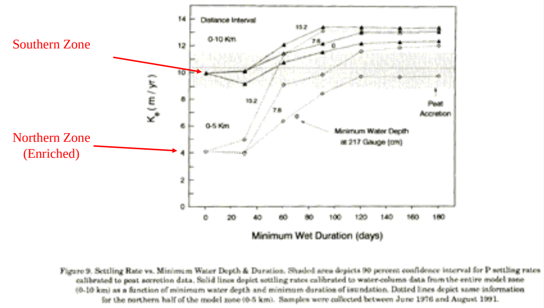
CERP Reservoirs **DMSTA Datasets**



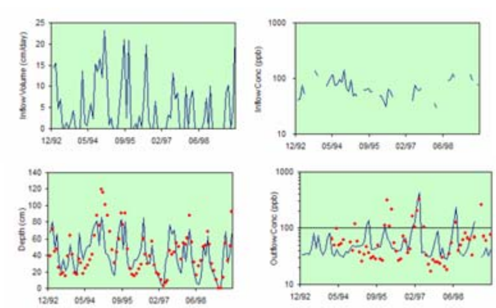
Depth Frequency Distributions
DMSTA Datasets vs. CERP Reservoirs



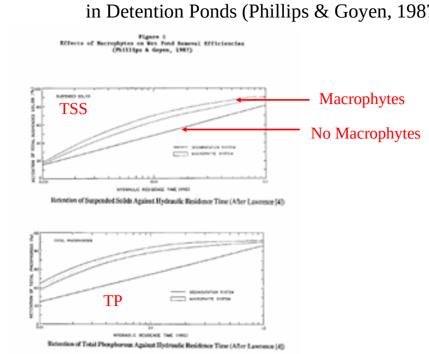
Effect of Dryout on P Removal Rate
WCA-2A (Walker, 1995)
STA Design Model Calibration to Water Col. Data



DMSTA Simulation of Northern WCA-2A



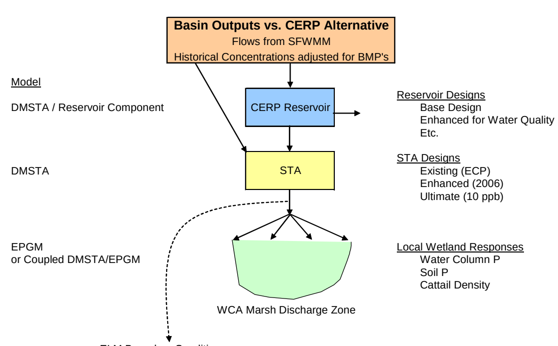
Effect of Macrophytes on TSS & TP Removal
in Detention Ponds (Phillips & Goyen, 1987)



P Removal in Reservoirs Key Questions

- Forecasted inflow & depth regimes?
- What will grow there?
- How will it perform?
- Can P uptake be "Optimized" ?
  - Facility design
  - Startup / soil preparation / seeding
  - Depth /Outflow regulation
  - Vegetation Management (Herbicides etc)
- Tradeoffs with other functions/benefits?

Potential CERP Applications



Framework for DMSTA Application to CERP Update