Integrated Modeling: An Engineering Perspective
How models have integrated science and engineering for Everglades Restoration

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Overview

- Integrate: “to make into a whole by bringing all parts together”

- Model: “a tentative description of a theory or system that accounts for all of its known properties”

- Over the last 25 years of Everglades Restoration, modeling has integrated the key elements of scientific principles into a better understanding of the ecosystem, allowing critical to current and future engineering design and implementation.
Foundation

- Scientific studies provide the basis for the “parts” and “properties”
  - P retention capacity of enriched wetlands
  - Depth regime for sustainable wetland vegetation
  - Concentration regime for sustainable wetland vegetation
  - Vegetative resistance to flow

- Engineering: “the application of science to the betterment of mankind and the environment”
  - Necessary to quantify the desired properties of restoration projects: engineering design criteria)
Nutrient Removal Modeling

- Will not spend much time on hydrologic or hydrodynamic models or digital elevation models for topography
- Instead, will focus on the evolution of nutrient removal models, and how they have improved over time in parallel with scientific understanding and engineering design

### Initial Conceptual Model
- 1989
- Water Column Phosphorus
- Removal = $R \cdot A$
- $R = 1.67 \text{ gm/m}^2\text{/yr}$
- Long-term Sediment Storage

### 2nd Generation Model
- 1992
- Water Column Phosphorus
- Removal = $K \cdot A \cdot C$
- $K = 8 \text{ m/yr}$
- Long-term Sediment Storage

### 3rd Generation Model
- 1993-1999
- Water Column Phosphorus
- Removal = $d(QC)/dA = p \cdot C_p - K \cdot F_w \cdot C$
- $K = 10 \text{ m/yr}$
- Long-term Sediment Storage

### 4th Generation Model
- DMSTA
- 1999-present
- Water Column Phosphorus
- Biomass Phosphorus
- Long-term Sediment Storage

### 5th Generation Model
- P-speciation?
- Concept
- Water Column Phosphorus
- Biomass Phosphorus
- Soil Phosphorus
- Long-term Sediment Storage
The early science

In the 1970s, scientists began observing changes in vegetation communities associated with nutrient enrichment.
Primary nutrient removal principle was a net retention of 1.67 g/m²/yr

Primary hydraulic design criterion was based on observed depth frequencies in Everglades marshes
Combinations of source controls and regional treatment

- Agricultural best management practices, e.g., water retention, fertilizer

- Numerous treatment alternatives evaluated

- Constructed wetlands selected as prototype
1,540 hectares of farmland

Needed engineering design criteria – from science
- Observations from an unharvested cattail marsh in WCA 2A

2 generations of models
- 1st: long-term retention rate = 1.67 g/m²/yr
- 2nd: constant relationship (net settling rate) between nutrient removal and average concentration
  - Lower retention rate (~1 g/m²/yr)
  - Predicted long-term average concentration of 36 ppb
Everglades Nutrient Removal Project

- Consistently reduced phosphorus to <25 ppb with over 80 percent removal

- Recognized need for additional research regarding nutrient removal – constructed two sets of test cells for variety of research
Scientific studies continued to increase our understanding of nutrient removal processes.

**Table 1. List of Alternative Treatment Technologies Investigated By The District.**

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1. Chemical Treatment/In-Canal Sedimentation</td>
<td>1. Chemical Treatment/High-Rate Sedimentation</td>
</tr>
<tr>
<td>2. Limerock Treatment</td>
<td>2. Chemical Treatment/Dissolved Air Flotation/Filtration</td>
</tr>
<tr>
<td>3. Sedimentation in Limestone Borrows</td>
<td>3. Chemical Treatment/Adsorption Clarification/Filtration</td>
</tr>
<tr>
<td>4. Percolation Ponds</td>
<td>4. Chemical Treatment/High Rate Magnetic Filtration</td>
</tr>
<tr>
<td>8. Algal Filtration</td>
<td>8. Chemical Treatment/Microfiltration</td>
</tr>
<tr>
<td>10. Ozone Treatment*</td>
<td>10. Low Intensity Chemical Dosing of STAs</td>
</tr>
<tr>
<td>11. Sediment Dredging</td>
<td>11. Submerged Vegetation/Limerock</td>
</tr>
<tr>
<td>12. Wetlands (STAs)</td>
<td>12. Dolimitic Limerock/Fixed Film Bioreactor</td>
</tr>
<tr>
<td>13. Managed Wetlands</td>
<td>13. Periphyton STAs</td>
</tr>
<tr>
<td>14. Chemical Treatment/Direct Filtration</td>
<td>14. Chemical Treatment/High-Rate Two-Stage Filtration</td>
</tr>
<tr>
<td>15. Barge Treatment*</td>
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<tr>
<td>16. Overland Flow</td>
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*Dropped during preliminary evaluation
Multiple objectives:

Nutrient reduction,

Water supply,

Hydropattern restoration,

Reduce freshwater discharges to estuaries
Stormwater Treatment Areas

STAs are constructed wetlands that remove and store nutrients through plant growth and the accumulation of dead plant material in a layer of peat.
Emergent Vegetation - optimal performance: 15-20 ppb

Submerged Aquatic Vegetation (SAV) optimal performance: 10-15 ppb

Periphyton-based Stormwater Treatment Area (PSTA): optimal performance 10-15 ppb
Design of STAs

- Improved science and model – focused on determining area to achieve interim target of 50 ppb
- Still simple but in parallel with science for treatment wetlands with low concentrations
  - Steady state, long-term average annual,
  - Estimate of net settling rate (K) increased from 8 to 10 m/yr
- Enhancements
  - Influence of dryout (wetting factor)
  - Influence of atmospheric deposition
## Summary of STA Sizes

<table>
<thead>
<tr>
<th>STA</th>
<th>Inflow ha-m/yr</th>
<th>Inflow Load Mtons/yr</th>
<th>Size ha</th>
<th>Removal Mtons/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>STA-1E</td>
<td>15,417</td>
<td>29</td>
<td>2,166</td>
<td>23</td>
</tr>
<tr>
<td>STA-1W</td>
<td>17,637</td>
<td>38</td>
<td>2,700</td>
<td>31</td>
</tr>
<tr>
<td>STA-2</td>
<td>21,584</td>
<td>34</td>
<td>2,603</td>
<td>25</td>
</tr>
<tr>
<td>STA-3/4</td>
<td>74,001</td>
<td>87</td>
<td>6,672</td>
<td>53</td>
</tr>
<tr>
<td>STA-5</td>
<td>9,620</td>
<td>25</td>
<td>1,667</td>
<td>21</td>
</tr>
<tr>
<td>STA-6</td>
<td>6,660</td>
<td>13</td>
<td>923</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>144,919</strong></td>
<td><strong>226</strong></td>
<td><strong>16,732</strong></td>
<td><strong>163</strong></td>
</tr>
</tbody>
</table>
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STA-1W – 2,700 ha
STA-2 – 2,603 ha
Stormwater Treatment Area 3/4

is the world’s largest constructed wetland:

over 6,700 ha of former agricultural land.

Over 400 metric tons of phosphorus removed
STA-3/4 inflow pump – 115 m³/sec
3-m diameter blades; 30 km of reinforced steel bar
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**STAs are performing well**

Averaging 19 ppb outflow

Over 80 percent load reduction

[Graphs showing STA Phosphorus Concentrations and Removal over years]
Everglades marshes are receiving significantly less nutrients

10-yr average annual TP loads to WCA-1 reduced by 74%
(96% in last year)

10-yr average TP concentrations reduced by 60%
Long-Term Water Quality Solutions

- 2nd round of enhancements:
  - Expansion of BMPs (esp. urban basins)
  - Expansion of STAs – Additional 7,700-ha
  - Enhancement of STAs
    - Continue strong science-based program to optimize performance
  - Synchronization with CERP projects

- ADAPTIVE MANAGEMENT
Primary enhancement to reduce TP discharges is to increase treatment area, e.g., 3,563-ha expansion of STA-2.

In general, outflow TP decreases as loading rate decreases.
4th Generation Design Model
- Used for design of enhancements

- Evolution of models continued
  - Dynamic Model for STAs (DMSTA)
- Increases ability to simulate individual phosphorus sources & sinks
- Allows dynamic simulation compared to original design model, which was based on long-term average annual values
- Calibrated from actual performance of STAs
  - Vegetation types
  - Greater interaction with sediments
  - Refined representation of internal hydraulics
Dynamic Model for Stormwater Treatment Areas
(Drs. Bill Walker and Bob Kadlec)

DMSTA2 Phosphorus Cycling Model

One CSTR at Steady-State
Unit Area Storage & Fluxes
Concs in mg/m3
Fluxes in mg/m2-yr
Storage in mg/m2

Water Column
Mass = M
Conc = C = M / Z

Biomass P Storage
S

State Variables:
M  Water Column P Storage  mg/m²
S  Temporary P Storage in Biota, etc.  mg/m²
Z  Water Column Mean Depth  m

F_C  Conc Multiplier
F_Z  Depth Multiplier
K_1  S  C
K_2  S^2
K_3  S

www.walker.net/dmsta/index.htm
State/federal regulatory agencies and courts - additional science and engineering necessary to achieve water quality goals

Need additional enhancements to models, as processes other than loading rate (area) dominate at low concentrations

Figure 2. Comparison of simulated and actual relationship between phosphorus loading rate and outflow TP concentration.

Comparison of Simulated and Actual Relationship Between PLR and Outflow Concentration
Actual STA Data Within PLR boundary of simulations (1.2 g/m²/yr) and <50 ppb outflow

No statistically significant relationship for actual STA performance, even if two high values are excluded

y = 4.9143x + 8.2642
R² = 0.2662
Slope is significant at 95%
Present models address total phosphorus – which responds differently than component P species

- Concentrations tend to flatten out midway through treatment cell
- Species-dependent net settling rate - may partially explain insensitivity of outflow concentration to P loading rate
Periphyton-based STA Demonstration Project

- 45 ha in size
- Removed ~0.5 m of organic substrate to minimize P flux from soil
- Exposed the limestone caprock
- Cost ~ 3 times typical STA
- Designed to receive full-scale flows and loads
- Modular design for replication in other cells
Other factors include
- dryout
- rewetting
- sediment flux, and
- phosphorus speciation

Expanding the research of PSTA process

Developing specific nutrient removal model

While performance has been very good (~10 ppb), still don’t understand the science sufficiently to replicate in other STAs.
Future enhancements

- Science and engineering focus is on sustaining good performance and
  - How to replicate and sustain good performance of PSTA
    - Necessary to remove organic soil, or are there less expensive alternatives?
    - Specific roles of periphyton and other vegetation
    - Influence of hydraulic pulsing
  - Another generation of models needed to account for other processes, including
    - P release following dryout
    - P flux from various types of sediment
    - Speciation of P
Summary

- Over the last 25 years of Everglades Restoration, modeling has integrated the key elements of scientific principles into a better understanding of the ecosystem.
  - Allowed quantification of scientific principles necessary to establish relevant engineering design criteria
  - Used in evaluation of alternatives and sensitivity analyses
  - Assisted in design of treatment facilities
  - Helped give structure to further scientific research

- Confident that continued adaptive implementation of focused scientific studies and of the integration of these observations through enhanced models will allow engineers to design, construct and operate more effective treatment wetlands
Questions before coming to Florida (small wave capital of the world)?

For More Information:

- [www.sfwmd.gov](http://www.sfwmd.gov)
- Everglades Restoration
- South Florida Environmental Report
  - Summary of all available data
- [www.garygoforth.net](http://www.garygoforth.net)