Constructed Wetlands for Wastewater Treatment: A Planning & Design Analysis for San Francisco

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I will briefly describe my background that led me to constructed wetlands as a masters thesis topic, and will provide an introduction to what exactly 'constructed wetlands for wastewater treatment' are. I will draw upon my own experiences visiting projects in California and in Thailand this summer, and can briefly describe some ideas I have drawn up for wetland systems in Los Angeles, Portugal, Taiwan, and San Francisco. From my recent trip to Thailand this summer to study constructed wetlands systems, I gained an important new perspective on how planners and designers must help integrate this engineering-based technology into the built environment in ways that the local community both supports and benefits from. My upcoming challenge will be to create a convincing proposal for a constructed wetland system along the southeastern waterfront of San Francisco, to mitigate wintertime overflows of untreated sewage into the San Francisco Bay.
Overview

- My background
- What are constructed wetlands anyway?
- Case studies - CA, Thailand
- Lessons learned from Thailand
- Design Ideas - CA, Portugal, Taiwan
- My thesis challenge: San Francisco CSO treatment
What led me here?

ＢＡ. in Biology, Williams College (2002)
- Ecology thesis
- Biomimicry Guild
  - nature as design teacher
- Green building work, LEED consulting
- Urban & environmental planning

My passion: elegant, efficient, & synergistic systems!
What are constructed wetlands anyway?

**What:** Decentralized, low-energy, low-cost systems to improve water quality

**How:** Rely on natural wetland function - plants and microorganisms uptake & break down wastewater nutrients, anaerobic & aerobic

**Why:** Provide multiple benefits - habitat, water quality, recreation, education, aesthetic/amenity value, water security & reuse, CO2 reductions
Conventional vs Natural TS

Less energy and infrastructure...

...But requires more space and time
The Treatment Phases

**Primary Treatment** = grit removal, settling

**Secondary Treatment**
- remove bacteria/pathogens, nutrients, organic compounds, metals (end of Federal requirement)

**Tertiary Treatment** = extra polishing for discharge, re-use applications
Similar Processes...

Activated sludge = Oxidation pond
- Oxygen pumped into water to foster microorganisms
- Shallow, relies on wind, sometimes aerators; open water fosters algae that produce oxygen for microbes

Trickling filter = Root zone action
- Large surface area for biofilm to develop, absorb more organic matter both aerobically and anaerobically
- Aerobic ‘rhizosphere’ creates similar conditions for bacteria to break down organic matter both aerobically (nitrification) and anaerobically (denitrification)
Secondary Treatment CWTS

Sub-Surface Flow (SF) wetlands
- 1-3ft depth, smaller

Free Water Surface (FWS) wetlands
- 4-18” depth, habitat
Tertiary Polishing CWTS

Further removes nutrients, organic matter, & suspended solids; can be wildlife & recreation amenity.
Case Studies: CA & Thailand
Case Study: Arcata Marsh (CA)

- Municipal wastewater treatment
- 19,000 residents
- 2.3 mgd
- 85 acres, plus recreation
Case Study: Ubolratana (Thailand)

- Community & market wastewater
- 660 residents
- 8,000 gpd (300m³/day)
- 4.9 acres
Case Study: Phayao (Thailand)

- Fish processing wastewater treatment
- 10 fish producers
- 2,600 gpd (10m3/day)
- 0.15 acres
Phayao Lessons Learned

- Community participation in design and O/M is critical!
- Engineers seeking landscape architecture collaboration

Options for Managing Phayao Constructed Wetlands Facility
August 6, 2007

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<thead>
<tr>
<th>Option</th>
<th>Description</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>1. No Change</td>
<td>Existing conditions, one user monopolizes system, other users must negotiate</td>
<td>Least discussion/effort required</td>
<td>Small problems remain, one user monopolizes system, inefficient O/M or system, foundation money wasted, other users lose, long-term environmental damage, many conflicts will occur between all users</td>
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<td>with system operator</td>
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<td>2. System Rental</td>
<td>Specific user rents system from government</td>
<td>Most efficient O/M of system, government gets revenue</td>
<td>Local &amp; government opposition, other users still have small problem, renter might not share</td>
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<td>3. Collection Trucks</td>
<td>Collection trucks bring other users' wastewater, pay one user for O/M*</td>
<td>Other users can work from home, everyone shares system resources, no more smells at home, most cost-effective,</td>
<td>Other users must pay, one user must operate/maintain system for others, operator might discriminate unfairly</td>
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*O/M: Operation and Maintenance
Design ideas I’ve had so far

- Mare Island, Vallejo, CA - Arcata-style municipal treatment wetlands
- Los Angeles, CA - living machine for urban parks
- Bombarral, Portugal - urban runoff treatment in rural agricultural towns
- Beimen, Taiwan - saline environment wetlands to clean habitat ponds
Mare Island Treatment Wetland (CA)
Living Machine for LA Urban Park Restrooms

Living Machine Specifications
Serves picnic barbecue area, playing fields & courts, and outdoor classroom. Design flow of 2,400 gpd treats wastewater of up to 450 visitors/day (e.g. soccer tournaments, concerts). 5,600 ft2 greenhouse houses anaerobic digesters, aerated vegetation tanks, clarifiers, treatment marshes, and chlorine contact basins. Treated water is recycled in toilets and irrigation system. *

Anaerobic digestion: 2 anaerobic digester tanks (37.85 m3, 10,000 gal each), 10 day residence, acid-forming and methane-producing bacteria break down carbon molecules and produce methane. Methane cogeneration powers the Living Machine circulation and aeration pumps, supplemented by solar panels on-site.

Aerated Vegetated Tanks: 2 parallel sets of 5 aerated vegetation tanks (5,000 gal each), 5-7hr residence, plants convert ammonium and organic nitrogen to nitrates. Floating plant palette: duckweed (Lemma minor), azolla (Azolla filiculoides), water hyacinth (Pistia stratiotes), and parrot’s feather (Myriophyllum aquatum).

Clarifiers: 2 clarifier settling tanks (500 gal each), 1 day residence, effluent settles, sludge is solar-power pumped back to anaerobic digester, tea is pumped into marshes.

Treatment Marshes: 2 shallow vegetated marshes (30x30’ each), 4 day residence, lined with crushed limestone, sequesters inorganic nitrogen and reduces BOD/TSS. Open water fosters Gambusia affinis for mosquito control. Emergent vegetation palette: Iris versicolor, Colocasia esculenta, Typha latifolia, Canna americanalis, Cyperus alternifolius, Cyperus haspan, and Ludwigia repens. Mosquitoes are controlled by eliminating stagnant open water.

Chlorine Contact Tank: 1 chlorine contact tank (500 gal), 1hr residence time, de-chlorinated with sulfur dioxide before returning to Visitor’s Center toilets for re-use.

*System based on IslandWood School, Bainbridge Island, WA (2002). Assumptions: 1.6gal/flush toilets, 1.7gpm faucets, 2 flushes/visitor, 1 min washing/visitor.
Rural Portugal - urban storm-sewer runoff treatment
Spoonbill Habitat Ponds, Taiwan

**Treatment Marshes**: 2 shallow vegetated marshes (85m3 each), 4 day residence, crushed limestone liming, sequestrates inorganic nitrogen, reduces BOD/TSS. Open water fosters *Culex annulipes* for mosquito control. Emergent vegetation palette: Iris versicolor, *Cocculus esculentus*, *Typha latifolia*, *Ganna americanus*, *Cyperus alternifolius*, *Cyperus houanen*, and *Ludwiga repens*. Mosquitoes are controlled by eliminating stagnant open water.

**Chlorine Contact Tank**: 1 chlorine contact tank (20 m³), 1 hr residence, de-chlorinated with sulfur dioxide before returning to Visitor's Center toilets for reuse.

**TREATMENT WETLANDS**

**Design flow (3)**: 8,705 m³/day (2-3 mg/d), reduces fish/spoonbill fecal coliform and suspended solids. Provides sustainable technology education for tourists, creates varied habitats, serves as research laboratory for nearby NT University students, and filters Chigu lagoon tidal waters.

**Oxidation pond**: 129,800 m³ (32 ac), 2-3 day residence, 1.2 m depth, solar-powered fountains and algae oxygenate water to oxidize biodegradable organic matter.

**Treatment pond**: 30,150 m³ (7.4 ac), 2 day residence, 1.2 m depth, dense salt-tolerant vegetation (*Typha angustifolia*, *mangroves*, *Kandelia candel*, *Avicennia marina*, and *Lumnitzera racemosa*) (7). Mangroves have proven effective at sequestering nutrients and heavy metals from wastewaters prevalent in Asia. (3)

**Enhancement marshes**: 1.9 204,500 m³ (50 ac), 9 day residence, 1.2 m depth, varied local vegetation (*Paspalum vaginatum*, *Scirpus paucicastrum*, *Sarcocornia reduibora*, *Chenopodium album*, *Zostera marina*, *Phragmites communis*, and *Phlebus inflexa* (7)), protected habitat islands for local birds, interpretive signs, and educational signage. *Aquaculture in Marsh 3*: oyster farming panels, carp and tilapia, and mildfish, grouper, and mullet for export as fish fry (1). Mosquitoes are controlled by eliminating stagnant open water.
My Master’s Thesis

Assess feasibility of constructed wetlands for urban areas like San Francisco (geographic, financial, regulatory)

Design a prototypical wetland to treat combined sewer overflow discharges in Yosemite Slough
San Francisco’s Challenge

Wintertime combined sewer overflows into Bay & ocean - minimally treated wastewater enters Bay up to 10 times per year!
San Francisco’s Challenge

“Seventy-one percent of the collection system is over 65 years old and one-third of all sewers are more than 100 years old. As the “normal” life expectancy of sewer pipes is 50-100 years, a proactive repair and replacement program is essential in all future programs.”

“Sewer replacement costs for 70 miles of undersized sewers in backlog as of 2003 was estimated to cost $143 million or approximately $2 million per mile.”

(SF PUC Sewer Separation Technical Memorandum, May 2006)
Yosemite Slough, San Francisco
Demonstration CSD* Wetland idea

* CSD = Combined Sewer Discharge
Yosemite Slough Site = Vacant City Land
Demonstration CSD Wetland idea
Yosemite Slough = Between Hunters Point and Candlestick Demonstration CSD Wetland idea.
Yosemite Slough Demonstration CSD Wetland idea

Proposed design sketch for constructed wetland (top right) and restored natural wetlands.
Yosemite Slough, San Francisco
Demonstration CSD Wetland idea

Proposed size: 5 acres
Capacity: 3.3 million gallons storage & tertiary treatment
Cost: $4 mill capital cost, $100K/yr O&M

Benefits:
- Increase Yosemite watershed storage by 28%
- Reduce CSOs by 46%
- Habitat buffer for Yosemite Slough Restoration
- Provide education & open space amenity
Challenges

• Economic: high land costs in urban areas
• Perceptions: fear of new and ‘untested’ technology (engineers, urban residents)
• Regulatory: water re-use restrictions, access

Opportunities

• Economic: rising cost of maintenance, CO2 emissions
• Ecological: habitat for endangered species, migratory birds
• Mutual benefit: buffers storm surges/flood risk to humans, buffers urban runoff pollution risk to water quality
• Urban amenity: provides recreation, education, aesthetic amenity (marriages in the marsh!)
What’s Next?

- Chapter writing - fall semester
- Designs & details - spring semester
- Current hot topics I’m researching
  - Basic natural treatment system engineering (CE113)
  - Sea level rise question - built-in adaptability?
  - Water re-use potential - regulations?
  - Constructed wetland inventory & toolkit
Questions?