Plant Ecology of Green Infrastructure for Urban Water Sustainability

Guest Lecture for Urban Water Sustainability
Brandon Winfrey
Postdoc, UCLA
Dec 1, 2015
What are some examples?

What do they do?

How do they work?
Stormwater Biofilters and Constructed Wetlands
Hereford Road Raingarden

Little Stringybark Creek

Overflow Pit

Inflow Pit

Runoff Collection

Loamy Sand

Sand and Fine Gravel

Gravel

Constructed Wetland Example
Elmer Ave. Green Street Project, Los Angeles, CA (photos: http://watershedhealth.org/)
Typical Stormwater Runoff Water Quality

**TABLE 1** Typical Concentrations of Constituents in Stormwater Runoff in Southern California and Southeast Australia

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Unit</th>
<th>Southern California</th>
<th>Southeast Australia</th>
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<tbody>
<tr>
<td>Total suspended solids</td>
<td>mg/L</td>
<td>30–70</td>
<td>40–150</td>
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<tr>
<td>Total nitrogen</td>
<td>mg/L</td>
<td>2–10</td>
<td>1–3</td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>mg/L</td>
<td>0.2–0.9</td>
<td>0.1–0.4</td>
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<tr>
<td>Cadmium</td>
<td>μg/L</td>
<td>2–5</td>
<td>4–5</td>
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<tr>
<td>Copper</td>
<td>μg/L</td>
<td>8–100</td>
<td>10–60</td>
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<tr>
<td>Lead</td>
<td>μg/L</td>
<td>2–30</td>
<td>10–140</td>
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<td>Zinc</td>
<td>μg/L</td>
<td>80–500</td>
<td>100–300</td>
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<tr>
<td>E. coli</td>
<td>MPN/100 mL</td>
<td>360–1800</td>
<td>600–31,000</td>
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*Data from Refs 14–17.
**Data from Refs 5, 11, 18, and 19.

Typical Domestic Raw Sewage Water Quality (Metcalf & Eddy, 2003)

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<tr>
<th>Constituent</th>
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<th>Low</th>
<th>Medium</th>
<th>High</th>
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<td>mg/L</td>
<td>120</td>
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<td>400</td>
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<tr>
<td>TN</td>
<td>mg/L</td>
<td>20</td>
<td>40</td>
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<tr>
<td>TP</td>
<td>mg/L</td>
<td>4</td>
<td>7</td>
<td>14</td>
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<tr>
<td>Fecal Coliform</td>
<td>#/100 mL</td>
<td>$10^3$ - $10^5$</td>
<td>$10^4$ - $10^6$</td>
<td>$10^5$ - $10^8$</td>
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</table>
FIGURE 3 | Distribution of antecedent dry days for Melbourne and Los Angeles. Inset: Distributions of antecedent dry days for Melbourne and Los Angeles during Driest and Wettest Years. Data for 1994–2013: Melbourne\(^9\) and Los Angeles.\(^{10}\) (Ambrose and Winfrey, 2015)
Hereford Road Biofilter in Mt. Evelyn, VIC, AU:

- Infiltrating/Drained
- Standalone system
- 7 plant species
Ballona Creek Biofilter in Culver City, CA, US:

- Infiltrating
- Standalone system
- 9 plant species
KEY DIFFERENCES BETWEEN BIOFILTERS IN SOUTHEAST AUSTRALIA AND SOUTHERN CALIFORNIA

- Climatic differences dictate vegetation choice and hydraulic design.
- Setting - curb cutout vs standalone.
- Drainage type - underdrain vs infiltration
- Filter media - multilayered vs uniform (and largely unknown filter media in US)
Biofilters as Ecosystems

• What is an ecosystem?

• What type of ecosystem(s) might biofilters mimic?
Biofilters as Ecosystems

- Organisms interacting with environment
  - Multiple pathways of interaction resulting in processes that:
    - Improve water quality
    - Store water during rain events
    - Provide aesthetic and cultural benefits

- Vernal Pools
  - Seasonal hydroperiod
Plants Adapted for Wet Conditions
Light

Photosynthesis

Respiration (in light and dark)

CO₂ → H₂O → O₂

H₂O
Oxygen flows through water ~10,000 times slower than through air.

Plants produce more Ethylene at Low \( O_2 \).

\( C_2H_4 \) can:
- Stimulate senescence
- Slow plant growth
- Induce seed germination
- Induce root hair growth
- Induce adventitious root growth
Morphological Adaptations - Roots

- Adventitious Roots
  - Provide more surface area for gas and nutrient exchange
  - Roots form at shallow soil depths from stem to be closer to water surface

**Figure 4.6**
Adventitious roots of spikerush (*Eleocharis cellulosa*) produced after four months of flooding.

Morphological Adaptations - Roots
Morphological and Physiological Adaptations

- **Aerenchyma Tissue**
  - Allows gas exchange between stems and roots
  - Roots can extrude air while inundated
  - Common in cattail and other rushes.
Plants Adapted for Dry Conditions
Morphological and Physiological Adaptations- Stomata

- **Morphological**
  - Shape of stomata- sunken in pits to trap moist air
  - Fewer
  - Leaf curling
  - Open less

- **Physiological**
  - When open less, must compensate biochemically

Carbon dioxide enters, while water and oxygen exit, through a leaf's stomata.
Growth represented by increase in tree diameter.

Graphs show periods of slowed growth during dry periods for deciduous and evergreen species.

Ecophysiological Adaptations- Seasonal Growth

Curled leaves of mulefat
Morphological Adaptations- Roots

*Carex sp.*

Roots

Extensive, shallow

Ready to take up lots of water
Role of Plants in Water Quality Improvement
**Plant Uptake**

**Water Contains N and P**

- Through uptake of water, nutrients assimilated in plant biomass

- Forms are oxidized and reduced N species and phosphate

- Varies widely in amount of uptake
Oxidized rhizosphere:

Coupled oxic/anoxic transformations
FIGURE 4.3
A cross section of the root of the swamp tree, green ash (*Fraxinus pennsylvanica*), growing in a soil medium. The oxidized iron rhizosphere is clearly identified by the orange (iron oxide) color surrounding the root. Photo by Bill Good.
• Slower Water Velocity
• Increases removal of suspended solids
• Plants slow down water flow, allow for settling and prevent resuspension

Removal via Settling affected by Water Velocity
Other Roles of Plants

- Habitat for Biofilm Growth
  - Most microbe-mediated processes occur in and near biofilm

- Provide insulation in winter

- Aesthetics
Read et al. 2008 and Read et al. 2010

- Evaluated 20 plant species in column study for water quality improvement (2008) and evaluated plant growth and traits (2010)
  - Identified 2-3 species best at N and P reduction.
  - Long roots, root mass, root depth found to be correlated to best N and P removal.
  - Carex sp. combined root traits and high growth rate, resulting in highest nutrient removal.

Bratieres et al. 2008 and Hatt et al. 2009

- Bratieres: large-scale column study, evaluated plant species and filter media effects on water quality
  - Plant results similar to Read studies
  - Found filter media with added C resulted in P leaching

- Hatt evaluated several operating stormwater biofilters
  - Found health of plant community important for maintaining high hydraulic conductivity and nutrient removal
  - Nitrogen removal could be enhanced by reducing extremes of wet and dry periods (saturated zone)

http://www.monash.edu.au/fawb/
Le Coustemer et al. 2012

- Evaluated several plant species for effect on maintaining hydraulic conductivity over time.
  - Larger roots result in higher conductivity
  - Carex sp. good at WQ improvement
  - Melaleuca sp. good at maintaining hydraulics
  - Case for multi-species planting

Fig. 3 — Change in K with time for the Carex (dark grey) and Melaleuca (light grey) systems (mean shown by dotted line and 95% CI shown by shaded band).
Biofilter Plant Species- What attributes are we looking for?
Final Exam Question

What plant traits/adaptations make a good biofilter plant?
Final Exam Question

What plant traits/adaptations make a good biofilter plant?

- Adapted to dry and wet conditions
- Native
- Large root system with fine roots
- Medium growth rate
- Aesthetic
- DEPENDS ON GOALS!
Ecology in stormwater biofilters

• Plant surveys and mycorrhizal colonization of biofilter plant roots in Southern California and Australia
Various-aged biofilters in Melbourne, Sydney, and Perth sampled.

**Average site species richness:** ~5.6

**Mostly native, facultative wetland, drought-adapted species**

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**30 species**

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**24 species**

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**19 species**
Plant Surveys and Root Characteristics

• Total root length increases with age

• Species richness decreases with increasing age

• Root length longest in driest city, Perth
Presence of Mycorrhizae

• Some biofilter plant roots colonized by mycorrhiza
  – species previously documented as non-mycorrhizal
  – Implications for enhanced nutrient removal

<table>
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<tr>
<th>Plant Species</th>
<th>City</th>
<th>Percent Colonization</th>
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<td>Juncus flavidus</td>
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Column Studies- Monash University and UCLA
• Plants matured for 20 weeks
• Measured WQ every 6 weeks
How does management affect biofilter function?

• Two species of high-performing and common biofilter plants evaluated in columns at Monash University – pruned and harvested vs. non-pruned.
Monash Harvest Column Study

All treatments significantly and substantially (>90%) removed TN and TP from inflow and, initially, significantly better nitrate removal than control (UN)
Nitrogen over 10 Week Regrowth Period

More nitrogen removed via harvest than was retained in column during regrowth period.

Does this improve N removal?
Average Total Nitrogen Outflow Concentrations in March and April

Total Nitrogen inflow = 2.1 mg N/L

80-90% reduction in TN
Average Nitrate Outflow Concentrations in March and April

Nitrate inflow = 0.967 mg N/L

80-90% reduction in NO3-N
UCLA Biofilter Plant Column Study

• Identified 5 species commonly used in biofilters with specific characteristics
  – Long roots, fast growth, aesthetic, drought tolerant, and CA native

• Growing single plants in columns
  – Stormwater simulation trials

• Alter watering regime and design

• Measure nutrient and metal removal

• Measure plant growth and flow rates
• Identified 5 species commonly used in biofilters with specific characteristics – Long roots, fast growth, aesthetic, drought tolerant, and California native

• Growing single plants in columns – Stormwater simulation trials
• Alter watering regime and design
• Measure nutrient and metal removal
• Measure plant growth and flow rates
First letter of treatment is species
Second letter of treatment is design/watering
Averages in blue

Nitrate Inflow = 1.87 mg L\(^{-1}\) NO\(_3\) – N
First letter of treatment is species
Second letter of treatment is design/watering
Averages in blue

Nitrate Inflow = 1.87 mg L^{-1} NO_3 \text{-- N}
Preliminary Results

• **Species effects**

• **Planted vs. Unplanted**
  – Surprisingly, only 3 planted treatments outperformed unplanted columns for nitrate removal

• **Saturated vs. No Saturated Zone**
  – Significant effects on nitrate removal for one species

• **Dry vs. Typical Rainfall**
  – One species removed nitrate better when watered less!
Conclusions

• Ecology is important!
• Plant species traits affect function
• Plant species management affects function
• Many studies at lab and field scales need to be done
Thanks for your attention.

Email: bwinfrey@ucla.edu