E. Coli TMDLs in Colorado: Finding Solutions

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Susan Strong, City of Fort Collins

Holly Piza, P.E., Mile High Flood District

2019 CASFM Crested Butte, CO
Overview

• What’s the problem with E. coli?
• Regulatory Basics
• Resources for MS4s
• Case Studies:
  • Fort Collins
  • Boulder
What’s the problem with E. coli: 10 Issues

1. Recreating in waters with fecal contamination can make you sick.

2. Over 90 stream segments in Colorado are listed as impaired or on M&E for E. coli.

3. It’s easy to exceed the E. coli stream standard, particularly in the summer.

4. Interpretation of monitoring data can be difficult or inconclusive.

5. We don’t live in a sterile environment—E. coli can originate from both natural and human-related sources. Health risk from sources may vary.
What’s the problem with E. coli: 10 Issues

7. Finding the source(s) can be challenging and expensive.
8. Treating dry and wet weather runoff can be challenging and expensive.
9. In urban areas, there may not be a “silver bullet” that solves the problem.
10. Can the stream standard be consistently attained? If so, how? What are the MS4 permit implications if it’s not?
Regulatory Relationships in Colorado: Standards-TMDLs-Permits

- Basic Standards (Reg. 31)
  - Basin Standards
    - 303(d) List (Reg. 93)
      - Total Maximum Daily Loads (TMDL)
  - Site-specific Standards & Discharger Specific Variance
  - Policies & Listing Methodology

General & Individual Discharge Permits
Colorado Stream Standards

- Fecal indicator bacteria vs. pathogens (e.g., *E. coli* O157:H7)
- EPA 2012 Recreational Water Quality Criteria
- Colorado stream standards
  - Magnitude: 126 cfu/100 mL (primary contact)
  - Duration: 61-day rolling geometric mean
  - Frequency: Geometric mean not allowed to exceed standard
- 303(d) List updated biennially: over 90 segments in Colorado impaired or on M&E list for *E. coli*

<table>
<thead>
<tr>
<th>Colorado Use Classification</th>
<th><em>E. coli</em> (cfu/100 mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class E - Existing Primary Contact</td>
<td>126</td>
</tr>
<tr>
<td>Class P - Potential Primary Contact</td>
<td>205</td>
</tr>
<tr>
<td>Class N - Not Primary Contact</td>
<td>630</td>
</tr>
<tr>
<td>Class U - Undetermined</td>
<td>126</td>
</tr>
</tbody>
</table>
Total Maximum Daily Loads (TMDLs) & Implications for MS4s

\[ \text{TMDL} = \sum \text{WLA} + \sum \text{LA} + \text{MOS} \]

Where:

- **WLA** = the sum of wasteload allocations (point sources such as permitted wastewater and stormwater discharges)
- **LA** = the sum of load allocations (nonpoint sources and background)
- **MOS** = the margin of safety

- WWTPs typically not the source in Colorado
- MS4s likely to have requirements in CDPS permits due to TMDLs
- Nonpoint sources often significant
Table 3. Middle Reach *E. coli* TMDL: allowable loading and pollutant reductions necessary to meet the recreation based *E. coli* standard in Big Dry Creek.

<table>
<thead>
<tr>
<th>Loading Calculations (Giga-cfu/day)</th>
<th>High Flow</th>
<th>Moist Conditions</th>
<th>Mid-Range Flows</th>
<th>Dry Conditions</th>
<th>Low Flow</th>
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</thead>
<tbody>
<tr>
<td>TMDL</td>
<td>423.34</td>
<td>198.56</td>
<td>129.18</td>
<td>73.58</td>
<td>27.94</td>
</tr>
<tr>
<td>MOS (10%)</td>
<td>42.33</td>
<td>19.86</td>
<td>12.92</td>
<td>7.36</td>
<td>2.79</td>
</tr>
<tr>
<td>Allowable Load</td>
<td>381.01</td>
<td>178.71</td>
<td>116.26</td>
<td>66.22</td>
<td>25.14</td>
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<tr>
<td>Existing Load</td>
<td>1119.13</td>
<td>425.48</td>
<td>244.05</td>
<td>114.49</td>
<td>94.98</td>
</tr>
<tr>
<td>Required Reductions</td>
<td><strong>66%</strong></td>
<td><strong>58%</strong></td>
<td><strong>52%</strong></td>
<td><strong>42%</strong></td>
<td><strong>74%</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>WLA</th>
<th></th>
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<tr>
<td>Westminster WWTF</td>
<td>58.24</td>
<td>54.32</td>
<td>51.49</td>
<td>31.97</td>
<td>16.99</td>
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<tr>
<td>Broomfield WWTF</td>
<td>74.20</td>
<td>64.00</td>
<td>57.63</td>
<td>31.58</td>
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<td>MS4s</td>
<td>149.14</td>
<td>36.23</td>
<td>4.29</td>
<td>1.60</td>
<td>1.94</td>
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<tr>
<td>Reserve Capacity</td>
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<td>1.81</td>
<td>0.21</td>
<td>0.08</td>
<td>0.10</td>
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<table>
<thead>
<tr>
<th>LA</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-point Source</td>
<td>91.97</td>
<td>22.34</td>
<td>2.64</td>
<td>0.99</td>
<td>1.19</td>
</tr>
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</table>
Colorado E. coli Toolbox: A Practical Guide for Colorado MS4s

• Introduction
  • Colorado regulations
  • Extent of problem
  • TMDLs
• Finding the sources
• Developing a control strategy
  • Progression of controls
  • Modeling
• Source controls
• Structural BMPs
• Regulatory considerations/site-specific standards
E. coli Fact Sheets on UDFCD.org

- Regulatory Basics
- Microbial Source Tracking
- Stormwater BMP Performance
- Using GIS in Source Investigations

TOOLS FOR MS4s: MICROBIAL SOURCE TRACKING

WHY DOES THE SOURCE OF E. COLI MATTER?

Elevated levels of fecal indicator bacteria (FIB), including E. coli, are one of the most common causes of water quality impairment in surface waters across the United States. While some sources of FIB can be identified through sanitary surveys, sources of FIB in many watersheds remain unknown and thus cannot be effectively controlled through targeted management actions. FIB results alone give no indication of the fecal source (human vs non-human). In addition, the health risk associated with exposure to water containing human waste is much greater than that of most non-human sources. Therefore, identifying the source(s) of fecal contamination in waters with chronically high FIB levels is of critical importance to meet recreational water quality criteria and reduce human health risk.

WHAT IS MICROBIAL SOURCE TRACKING?

Microbial source tracking (MST) uses a set of tools that allow for sources of fecal waste to be distinguished. These tools include conventional methods (e.g., ammonia, CCTV, dye testing) that have been used to identify illicit discharges for the past 20+ years, as well as more recently developed advanced laboratory methods that measure DNA specific to humans and other animals known as "markers" to identify sources. However, MST is more than just a set of tools or methods. MST is a process by which potential waste sources are systematically tested and investigated to identify and locate the origin of fecal bacteria in a contaminated water.
Developing an E. coli Control Strategy

General Themes:
• Find the source(s)
• Address human source first, then other sources
• Address dry weather first, then wet weather
• Implement nonstructural/ source controls, then structural
City of Fort Collins Case Study
<table>
<thead>
<tr>
<th>Segment ID</th>
<th>Stream Segment Description</th>
<th>Season of Impairment</th>
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<tr>
<td>COSPCP11</td>
<td>Cache La Poudre from Shields St. to above Boxelder Creek</td>
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<td>COSPCP12</td>
<td>Cache La Poudre from above Boxelder Creek to South Platte River</td>
<td>May-October</td>
</tr>
<tr>
<td>COSPCP13a</td>
<td>Spring Creek and Fossil Creek (May-October)</td>
<td>May-October</td>
</tr>
<tr>
<td>COSPCP13b</td>
<td>Boxelder Creek from source to confluence with Cache La Poudre</td>
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</table>
Starting Point

• Who is collecting data in your stream?
• Seasonal trends: Winter tends to attain standard; summer tends to exceed.
• Data availability: 5 samples over 61 days often not available
• Any major hot spots?

Table 7. All Sites Recreation Season (2014-2018)

<table>
<thead>
<tr>
<th>Stream</th>
<th>Source</th>
<th>Site</th>
<th>Nbr</th>
<th>Min</th>
<th>Max</th>
<th>Geommean</th>
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<td>18000</td>
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<td>40</td>
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<td>140</td>
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<td>1040</td>
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<td>SC-01</td>
<td>15</td>
<td>1</td>
<td>700</td>
<td>133</td>
</tr>
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</table>
Dry Weather Investigation

- Upload mapped outfalls into Collector App
- How many days to find 150 outfalls?
- Estimating flow rate
- Uploading photos
- Identifying suspect outfalls
- Getting samples to lab on time
- Car or bike or both
Field Challenges
Supplementing E. coli Monitoring With Microbial Source Tracking (HF183)
Collecting GIS Data

- Infrastructure age and maintenance history
- BMP locations
- Ditches
- Septic systems
- Hobby farms, large animal facilities/properties
- Natural areas
- Homeless/transient densities
Housing First Initiative: Addressing Long-Term Homelessness in Fort Collins

The Housing First Initiative (HFI) seeks to produce actionable and accessible community-level data on the issue of homelessness. With that data, we can better identify and implement solutions for people experiencing homelessness.

HFI collects and reports data on persons experiencing homelessness in Fort Collins for six months or longer, piloting solutions through local partnerships and providing intensive case management to transition participants from homelessness to housing. This dashboard does not provide data on all persons experiencing homelessness, but focuses on individuals experiencing chronic and long-term homelessness.

Current # of persons experiencing homelessness 6 months or longer in Fort Collins: 434

### Current Population Demographics

<table>
<thead>
<tr>
<th>Length of Time Homeless</th>
<th>Count</th>
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<tbody>
<tr>
<td>0-6 mos</td>
<td>57</td>
</tr>
<tr>
<td>1 year - 1 year</td>
<td>37</td>
</tr>
<tr>
<td>1 year-3 years</td>
<td>150</td>
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<tr>
<td>3 years - 5 years</td>
<td>28</td>
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<tr>
<td>5 years - 10 years</td>
<td>38</td>
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<tr>
<td>10 years+</td>
<td>122</td>
</tr>
<tr>
<td>Unknown</td>
<td>110</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Income Levels at Entry</th>
<th>Count</th>
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</thead>
<tbody>
<tr>
<td>$0</td>
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</tr>
<tr>
<td>$1-499</td>
<td>31</td>
</tr>
<tr>
<td>$500-999</td>
<td>41</td>
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<td>$1000-1499</td>
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<tr>
<td>$1500-1999</td>
<td>12</td>
</tr>
<tr>
<td>$2000+</td>
<td>12</td>
</tr>
</tbody>
</table>

### Participant Demographics (Self-Reported)

#### Gender Distribution

- Male: 170
- Female: 72
- Other: 192

#### Age Distribution

- 0-12mos: 236
- 13-24: 122
- 25-34: 76

#### Race Distribution

- American Indian: 24
- Asian: 36
- Black or African: 42
- Hispanic: 36
- Native Hawaiian: 24

#### Medicaid Distribution

- Enrolled: 236
- Not Enrolled: 122
- Unknown: 76

#### Disability Distribution

- Yes: 184
- No: 188
- Unknown: 62

#### Veteran Distribution

- Yes: 37
- No: 346
- Unknown: 46
- Refused: 16

### Contributing Factors Snapshot (Self-Reported)

- Unable to pay rent/mortgage
- Lost job, couldn't find work
- Relationship problems or family break-up
- Asked to leave
- Mental illness
- Bad credit
- Alcohol/substance abuse problems
- Family member or personal illness
- Abuse or Violence in my home
- Discharged from jail
- Moved to find work
- Legal problems
- Couldn't pay utilities
- Discharged from prison
- Problems with public benefits
- Medical expenses
- Reasons related to my sexual orientation
- Discharged from foster care
City of Boulder Case Study
1993
COB Stormwater Program

2003
MS4 Permitting Phase II (COB)

2004
Boulder Creek is placed on the Impaired Waters (303(d)) List for E.coli

2008
MS4 Permit Update

2011
E.coli TMDL & Implementation Plan for Boulder Creek

2013
Raccoon Study

2016
MS4 Permit Update

2019
City E.coli TMDL Implementation Plan Update
Current Stormwater Quality Program

- Illicit Discharge Program
- TMDL Development
- TMDL Implementation Plan Development
- TMDL Implementation Plan Update
- Slow the Flow Efforts
- “Doo Good” Outreach
- Pet Waste Stations
- Boulder Creek Outfall Surveys
- Storm & Sanitary Efforts
- Stormwater Master Plan Update
- Investigation of Sanitary Mains Under the Creek
- Memo: Raccoons in storm drains
- Raccoon-proofing Pilot
- GI Strategic Plan
- Special Monitoring Studies
- Neonic Sampling
- Macroinvert. Monitoring
- Instream Flow Program
- Bear-proof Trash Enclosure
Doo Good
Pick up dog doo. Protect streams.

Dog doo is more than a nuisance!

IT SPREADS DISEASE
Dog waste contains parasites and bacteria, like E. coli, which account for up to 20% of the pollution in public waterways.

IT HURTS FISH
When dog waste enters streams, nutrients in dog waste can kill small fish and lower oxygen levels.

IT ADDS UP!
Locally, there are 90,000 acres of land receiving 1,000 lbs of doo a day.

Good for Bears
Bad for Bears

Boulder Creek, Colorado
Segment 2b
From 13th Street to the Confluence with South Boulder Creek
Total Maximum Daily Load
Bacteria: 158,000
Infrastructure Investments

1.3 Million Dollars to inspect, clean and line the storm sewer system

2 Million Dollars to line the sanitary system in the University Hill and Downtown areas

3 Sewer Mains TVed under Boulder Creek

0 Cross-Connections Identified to Date
Bear Trash Enclosure Program
What Can You Do?

- Pick up Pet Waste
- Reduce Irrigation Overspray
- Keep Trash from Wildlife
- Report Spills
Monitoring

Boulder Creek E. coli (2016-2018)

SITE
- BC-Eben
- BC-13
- BC-CU
- BC-30
- BC-55

E. coli Geometric (CFU/L/100mL)

0 200 400 600

0 1 2 3 4 5 6 7 8 9 10
TMDL Implementation Plan
Outfall Marine N E.coli Monthly Concentrations

- Flood & Removal of Outlet Grate
- Initial Line Jetting & Outfall Grate Installation
- Reinstallation of Outfall Grate

E.coli (MPN/100 mL)

Date

Conclusions

• E. coli: coming soon to an MS4 permit near you!
• Where to start: Better understand the source(s) during dry weather.
• Expect messy data.
• BMPs can help reduce bacteria—this does not always mean attainment of instream standards at end of pipe though.
• Colorado-based resources are available to develop a better understanding of various aspects of bacteria issues.
• Partners are important—solutions likely extend beyond public works departments.
Questions?

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Development of a New Integrated Decision Support Tool (i-DST)

ELIZABETH GALLO

US-EPA NATIONAL PRIORITIES

https://idst.mines.edu/
Outline

• General Background

• i-DST Background

• Watershed Scale Module

• Front-end Graphical User Interface (GUI)

• Stormwater Control Measure (SCM) and Optimization Simulator

• Test Site: Berkeley Neighborhood Watershed
About me

• 3rd year PhD Candidate at Colorado School of Mines
• Completed my masters in 2017
• Hydrologic Science and Engineering Program
• Civil and Environmental Engineering Department
• Advisor: Terri S. Hogue
Motivation

• Urbanization stresses drainage networks and aquatic ecosystems

Image from Piotr Redlinski for The New York Times
Motivation

• Urbanization stresses drainage networks and aquatic ecosystems

Image from Piotr Redlinski for The New York Times
Solution

Figure: DC Water (https://www.dcwater.com/green-infrastructure)
Research Focus

Stormwater Models

Urban Water Quantity and Quality

Stormwater Infrastructure

Optimal Watershed Scale Plan
### Previous work:

Variability in achieving water quality compliance with SCMs impacts the decision making process when optimizing for a watershed.

### Stormwater management options and decision-making in the urbanized watersheds of Los Angeles, CA.

#### Journal of Sustainable Water in the Built Environment.

### Table: SCM Scenario Analysis

<table>
<thead>
<tr>
<th>Scenario (BMPs)</th>
<th>Volume Capture (m$^3$)</th>
<th>BMP Area (km$^2$)</th>
<th>Peak Flow Reduction</th>
<th>Cost (Billions)</th>
<th>DW Days/yr **</th>
<th>Load Based Exceedances/yr (TMDL Compliance [%])**</th>
<th>WW Days/yr **</th>
<th>Load Based Exceedances/yr (TMDL Compliance [%])**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong> No New</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>259</td>
<td>86 (66.8)</td>
<td>0 (100.0)</td>
<td>0 (100.0)</td>
</tr>
<tr>
<td>BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 All</td>
<td>1,336,766</td>
<td>3.52</td>
<td>43.0%</td>
<td>0.55</td>
<td>336</td>
<td>0 (100.0)</td>
<td>0 (100.0)</td>
<td>0 (100.0)</td>
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<tr>
<td>2 IT</td>
<td>5,094,830</td>
<td>2.02</td>
<td>95.0%</td>
<td>0.70</td>
<td>354</td>
<td>0 (100.0)</td>
<td>0 (100.0)</td>
<td>0 (100.0)</td>
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<tr>
<td>3 DP</td>
<td>3,046,830</td>
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<td>10.0%</td>
<td>0.69</td>
<td>339</td>
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<td>0 (100.0)</td>
<td>0 (100.0)</td>
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<tr>
<td>4 V5+SPP</td>
<td>2,789,910</td>
<td>11.18</td>
<td>65.0%</td>
<td>1.40</td>
<td>340</td>
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<td>0 (100.0)</td>
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<tr>
<td>5 V5+SPP</td>
<td>364,415</td>
<td>1.24</td>
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<td>0.20</td>
<td>278</td>
<td>73 (73.7)</td>
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<td>0 (100.0)</td>
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<td></td>
<td></td>
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<tr>
<td>1 BR</td>
<td>2,901,249</td>
<td>6.42</td>
<td>69.0%</td>
<td>1.51</td>
<td>357</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>1b BR+SPP</td>
<td>2,901,249</td>
<td>6.68</td>
<td>55.7%</td>
<td>1.51</td>
<td>359</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2 V5+SPP</td>
<td>2,901,249</td>
<td>5.54</td>
<td>4.4%</td>
<td>0.71</td>
<td>354</td>
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</tr>
<tr>
<td>2b V5+SPP</td>
<td>2,901,249</td>
<td>7.04</td>
<td>34.0%</td>
<td>0.89</td>
<td>356</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3 V5 +T</td>
<td>2,901,249</td>
<td>5.41</td>
<td>45.4%</td>
<td>0.70</td>
<td>357</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3b V5+T</td>
<td>2,901,249</td>
<td>6.92</td>
<td>55.3%</td>
<td>0.90</td>
<td>358</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Baseline</strong> No New</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>335</td>
<td>307 (89.8)</td>
<td>127 (95.8)</td>
<td>214 (35.7)</td>
</tr>
<tr>
<td>LAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 BR</td>
<td>12,818,268</td>
<td>27.97</td>
<td>47.0%</td>
<td>6.60</td>
<td>358</td>
<td>68 (97.9)</td>
<td>51 (98.4)</td>
<td>18 (95.0)</td>
</tr>
<tr>
<td>1b BR+SPP</td>
<td>12,818,268</td>
<td>15.02</td>
<td>53.0%</td>
<td>6.80</td>
<td>360</td>
<td>71 (97.8)</td>
<td>53 (98.4)</td>
<td>18 (95.0)</td>
</tr>
<tr>
<td>2 V5+SPP</td>
<td>12,818,268</td>
<td>37.30</td>
<td>29.0%</td>
<td>3.80</td>
<td>350</td>
<td>42 (98.0)</td>
<td>67 (95.0)</td>
<td>15 (95.0)</td>
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<tr>
<td>2b V5+SPP</td>
<td>12,818,268</td>
<td>24.86</td>
<td>46.0%</td>
<td>5.20</td>
<td>358</td>
<td>69 (97.9)</td>
<td>52 (98.4)</td>
<td>18 (95.0)</td>
</tr>
<tr>
<td>3 V5 +T</td>
<td>12,818,268</td>
<td>37.30</td>
<td>55.0%</td>
<td>3.80</td>
<td>361</td>
<td>75 (97.7)</td>
<td>57 (98.2)</td>
<td>19 (94.7)</td>
</tr>
<tr>
<td>3b V5+T</td>
<td>12,818,268</td>
<td>24.86</td>
<td>57.0%</td>
<td>5.20</td>
<td>361</td>
<td>75 (97.7)</td>
<td>57 (98.2)</td>
<td>19 (94.7)</td>
</tr>
</tbody>
</table>

* Baseline Scenario is not included in the developed color scale which highlights the performance of BMP scenarios from best to worst for each criteria.

** DW and WW Days/year equals the total possible dry and wet weather exceedances with an exception to LAR Dry weather Cu and Pb. Multiply the DW Days/yr by 9 (TMDL Locations) to get the total possible exceedances for LAR Cu and Pb.

*** TMDL Compliance represents the percentage of days that which the TMDL will be met e.g. WW TMDL Compliance = WW Days/yr - Exceedance/yr + WW Days/yr * 100.
Previous work:
Variability in achieving water quality compliance with SCMs impacts the decision making process when optimizing for a watershed.

<table>
<thead>
<tr>
<th></th>
<th>BC</th>
<th>DC</th>
<th>LAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Quality</td>
<td>Least Degraded</td>
<td>Most Degraded</td>
<td>Variable</td>
</tr>
<tr>
<td>Eliminate TMDLs with SCMs?</td>
<td>Yes</td>
<td>No</td>
<td>Variable</td>
</tr>
<tr>
<td>Available SCM Options</td>
<td>Any</td>
<td>Treat and Release Only</td>
<td>Treat and release in more urbanized areas</td>
</tr>
<tr>
<td>Available Ancillary Benefits to Consider</td>
<td>All</td>
<td>Restricted to above options</td>
<td>Restricted in urban areas</td>
</tr>
</tbody>
</table>
Current work:

Stormwater practitioners lack a comprehensive decision support tool that incorporates both green and grey infrastructure, life cycle costs and environmental assessment, and co-benefits.
Today's Topic

i-DST Tool Background

Watershed Tool Background

Updates to Front-end GUI

Updates to EPA-SUSTAIN Code

Test Site Modeling Example
i-DST Project Goals

• Develop an integrated, scalable, decision support tool (called i-DST) for grey, green, and hybrid infrastructure

• **Planning-level** tool – suitable for project prioritization (not design)

• Components:
  • Hydrology, water quality
  • BMP optimization and uncertainty estimation
  • Life cycle cost assessment (LCCA)
  • Life cycle assessment (LCA)
  • Quantification of co-benefits

Conceptual model of tool components and the flow of information between them.
Science Advisory Board (SAB)

• Have a board of 21 urban water experts to help us:
  • Identify tool needs
  • Identify novel grey/green infrastructure techniques to include
  • Connect us with datasets
  • Provide feedback on the tool

• NGOs
• Consultants
• City/county governments
• Federal agencies
• Academics
# Science Advisory Board (SAB)

<table>
<thead>
<tr>
<th>Member</th>
<th>Organization</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Janet Clements</td>
<td>Corona Environmental Consulting</td>
<td>CO</td>
</tr>
<tr>
<td>Darren Mollendor</td>
<td>City of Denver</td>
<td>CO</td>
</tr>
<tr>
<td>Holly Piza</td>
<td>Denver Urban Drainage and Flood Control District</td>
<td>CO</td>
</tr>
<tr>
<td>Tracey Pond</td>
<td>City of Golden</td>
<td>CO</td>
</tr>
<tr>
<td>Scott Struck</td>
<td>Geosyntec Consultants</td>
<td>CO</td>
</tr>
<tr>
<td>Jeffrey Williams</td>
<td>City of Denver</td>
<td>CO</td>
</tr>
<tr>
<td>Colin Bell</td>
<td>City and County of Denver: Green Infrastructure Program</td>
<td>CO</td>
</tr>
</tbody>
</table>
Scalable

- Tool will be developed at:
  - Watershed level (i-DST)
  - Individual site scale (i-DST-SB)
Scalable

- Tool will be developed at:
  - Watershed level (i-DST)
  - Individual site scale (i-DST-SB)
Legend:

- Input Data Group
- Tool Module
- Optional Utility

Optional Utility

Legend:

- Input Data Set
- Default values available

Hydrologic Scenario Builder (Qt)

- Define hydrologic connectivity
- Set optimization scenarios

Distributed SCM LCC/LCCA Module (Excel)

- Establish location
- Define types of SCMs
- Quantify Escalation factors

Gray Infrastructure LCC/LCCA Module (Excel)

- Cost and energy per volume of wastewater treated
- Basic details on existing wastewater facilities

i-DST-SUSTAIN (.exe)

- Simulate SCM processes
- Optimize distribution (number and type) of SCMs based on life cycle cost and hydrologic/water quality criteria

Post-processor (Qt)

- Assess co-benefits SCM solutions
- Use multiple decision criteria analysis to interpret optimization output
- Display/visualize results

Optional Workflow

Mandatory Workflow

Modeled or Observed Time Series

- Flow
- Water quality mass or concentrations

Time series format utility (Qt)

BMP treatment calibration utility (Excel/SUSTAIN)

SCMs Scenarios

- Optional: Cost, Performance, Design of SCMs
- Optimization Objectives

Gray System Information

- Optional: Wastewater plant information and operation costs/energy

Tool Module

- Inputs, parameters, or notes

Optional Utility

Optional: Cost, Performance, Design of SCMs

Optimization Objectives
**SCMs Scenarios**
- Optional: Cost, Performance, Design of SCMs

**Optimization Objectives**
- Cost, Performance, Design of SCMs

**Hydrologic Scenario Builder (Qt)**
- Define hydrologic connectivity
- Set optimization scenarios
  - SCM geometry, hydrology, water quality
  - 1st order distributed SCM LCC/LCCA
  - 1st order gray infrastructure LCC/LCCA

**Modeled or Observed Time Series**
- Flow
- Water quality mass or concentrations

**i-DST-SUSTAIN (.exe)**
- Simulate SCM processes
- Optimize distribution (number and type) of SCMs based on life cycle cost and hydrologic/water quality criteria

**Post-processor (Qt)**
- Assess co-benefits SCM solutions
- Use multiple decision criteria analysis to interpret optimization output
- Display/visualize results

**Scenario Builder**

**BMP Simulation + Optimization**

**Visualization**

**Model Output**

<table>
<thead>
<tr>
<th>Time Series</th>
<th>Value</th>
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<tbody>
<tr>
<td>1/1</td>
<td>0.5</td>
</tr>
<tr>
<td>1/2</td>
<td>0.7</td>
</tr>
<tr>
<td>1/3</td>
<td>0.6</td>
</tr>
<tr>
<td>1/4</td>
<td>0.5</td>
</tr>
<tr>
<td>1/5</td>
<td>0.4</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
</tr>
</tbody>
</table>
EPA SUSTAIN Features

*Also water quality treatment*

\[
\text{Cost} = a + b \cdot (\text{Length})^c + d \cdot (\text{Area})^e + f \cdot (\text{Volume})^g
\]

**Built In* Evaluation Factors:**
- Peak Discharge
- Annual Average Volume
- Exceeding Frequency
- Annual Average Load
- Annual Average Concentration
- Maximum Days Average Concentration
Today's Topic

Time Series

1/1 0.5
1/2 0.7
1/3 0.6
1/4 0.5
1/5 0.4
...
...

Scenario Builder

BMP Simulation + Optimization

Model Output

Updates to Front-end GUI

Updates to EPA-SUSTAIN Code

Test Site Modeling Example

i-DST Tool Background

Watershed Tool Background

Updates to EPA-SUSTAIN Code

Test Site Modeling Example

Model Output

Scenario Builder

BMP Simulation + Optimization

Visualization
Scenario Builder

Arc GIS 9.3
• Outdated
• Often Crashes

Excel VBA (Opti-Tool)

QT/C++

Image: Lee J., Riverson J.
Scenario Builder

Arc GIS 9.3

Excel VBA (Opti-Tool)
- EPA Region 1 Tool
- TetraTech
- GUI to build input files

QT/C++
Scenario Builder

Arc GIS 9.3

Excel VBA (Opti-Tool)

QT/C++

- Easier and faster
- Less error prone
- More control
- Portability
Updates to SUSTAIN

1. Hybrid-Grey Infrastructure

Available SCM Types in SUSTAIN
- Green Roof
- Bio-retention
- Infiltration Trench
- Vegetated Swale
- Dry Pond
- Wet Pond
- Buffer Strip
- Porous Pavement
- Porous Pavement
- Rain Barrel
- Cistern
## Updates to SUSTAIN

1. Hybrid-Grey Infrastructure

<table>
<thead>
<tr>
<th>Available SCM Types in SUSTAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Roof</td>
</tr>
<tr>
<td>Bio-retention</td>
</tr>
<tr>
<td>Infiltration Trench</td>
</tr>
<tr>
<td>Vegetated Swale</td>
</tr>
<tr>
<td>Dry Pond</td>
</tr>
<tr>
<td>Wet Pond</td>
</tr>
<tr>
<td>Buffer Strip</td>
</tr>
<tr>
<td>Porous Pavement</td>
</tr>
<tr>
<td>Rain Barrel</td>
</tr>
<tr>
<td>Underground Detention*</td>
</tr>
<tr>
<td>Underground Infiltration*</td>
</tr>
<tr>
<td>Underground Gravel Bed</td>
</tr>
<tr>
<td>Above Ground Storage</td>
</tr>
</tbody>
</table>

* Simulated as a pipe or a ‘box’

SCM figures: StormTrap and Contech

### Underground Detention

![Underground Detention](image1)

### Underground Infiltration

![Underground Infiltration](image2)

### Underground Pipes

![Underground Pipes](image3)
Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs

1. Bypass when reach max SCM volume capacity
Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs

1. Bypass when reach max SCM volume capacity

- Underground SCM
- Above ground SCM
- Pre SCM Implementation
Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs

2. Accurate stage-surface area-volume relationship for pipes
Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs

2. Accurate stage-surface area-volume relationship for pipes
Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs
3. BMP decay rate calibration tool

Inputs
• Precip time series
• Storm event SCM volumes, influent, and effluent data

Output
• Calibrated k or k-C* values
Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs
3. BMP decay rate calibration tool
4. More evaluation factors

<table>
<thead>
<tr>
<th>Water Quantity Benefits</th>
</tr>
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<tbody>
<tr>
<td>Average Annual Flow Volume</td>
</tr>
<tr>
<td>Flow Exceedance Frequency</td>
</tr>
<tr>
<td>Flow Duration Curve</td>
</tr>
<tr>
<td>Peak Discharge Flow</td>
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</table>

<table>
<thead>
<tr>
<th>Water Quality Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Annual Load</td>
</tr>
<tr>
<td>Average Annual Concentration</td>
</tr>
<tr>
<td>Days above X Concentration</td>
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</table>
## Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs
3. BMP decay rate calibration tool
4. More evaluation factors

<table>
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<tr>
<td>Peak Discharge Flow</td>
</tr>
<tr>
<td><strong>Seasonal Average Flow Volume</strong></td>
</tr>
<tr>
<td><strong>Average Annual Groundwater Recharge</strong></td>
</tr>
<tr>
<td><strong>Seasonal Average Groundwater Recharge</strong></td>
</tr>
<tr>
<td><strong>Average Annual Evapotranspiration</strong></td>
</tr>
<tr>
<td><strong>Seasonal Average Evapotranspiration</strong></td>
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<tr>
<td><strong>New Peak Discharge Flow Calculations</strong></td>
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<table>
<thead>
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</thead>
<tbody>
<tr>
<td>Average Annual Load</td>
</tr>
<tr>
<td>Average Annual Concentration</td>
</tr>
<tr>
<td>Days above X Concentration</td>
</tr>
<tr>
<td><strong>Seasonal Average Load</strong></td>
</tr>
<tr>
<td><strong>Seasonal Average Concentration</strong></td>
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</tbody>
</table>
Updates to SUSTAIN

1. Hybrid-Grey Infrastructure
2. Simulation of Underground SCMs
3. BMP decay rate calibration tool
4. More evaluation factors
5. Life Cycle costs utilized in the Optimizer
Test Site: Berkeley Neighborhood Watershed

- 1,035 acres
- 53% impervious
- 15% of total area covered by future infil-redevelopment
- Concern of increase in surface water runoff

High Resolution Modeling of Infil Development Impact on Stormwater Dynamics in Denver, CO. *Journal of Sustainable Water in the Built Environment*. Panos et al. 2019
What is the optimal suite and number of SCMs to reduce infill-redevelopment runoff back to pre-redevelopment flow?

- Scenario 1: +1.2% imp
- Scenario 2: +4.7% imp
- Scenario 3: +8.1% imp

**High Resolution Modeling of Infill Development Impact on Stormwater Dynamics in Denver, CO. Journal of Sustainable Water in the Built Environment.** Panos et al. 2019
What is the optimal suite and number of SCMs to reduce infil-redevelopment runoff back to pre-redevelopment flow?

High Resolution Modeling of Infil Development Impact on Stormwater Dynamics in Denver, CO. *Journal of Sustainable Water in the Built Environment*. Panos et al. 2019
High Resolution Modeling of Infil Development Impact on Stormwater Dynamics in Denver, CO. *Journal of Sustainable Water in the Built Environment*. Panos et al. 2019

Timeseries

1. Baseline/current flow
2. Scenario 1: +1.2% imp
3. Scenario 2: +4.7% imp
4. Scenario 3: +8.1% imp

What is the optimal suite and number of SCMs to reduce infil-redevelopment runoff back to pre-redevelopment flow?
Workflow and Model Routing
Workflow and Model Routing
Workflow and Model Routing
Workflow and Model Routing

Aggregate BMP

Outlet

\[ i = \# \text{ of iterations} \]
Workflow and Model Routing

Aggregate BMP

$n_i$

Outlet

i = # of iterations
Workflow and Model Routing

i = # of iterations

Summary evaluation factor for i iterations

Aggregate BMP

Outlet

i

Non Redeveloped

Redeveloped
What is a pareto curve?

- Plotting cost vs evaluation factor during the optimization
- Evolutionary search technique
- Solve nonlinear, single or multi-objective, complex problems
- Find the optimal solution

![Diagram showing Scatter Search and NSGAII (Non-dominated Sorting Genetic Algorithm II)]
Pareto Curve Example

<table>
<thead>
<tr>
<th></th>
<th>Porous Pavement Units</th>
<th>Bio-retention Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min number of SCMs</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Max number of SCMs</td>
<td>60</td>
<td>33</td>
</tr>
<tr>
<td>Iteration 1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Iteration 2</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Iteration 3</td>
<td>20</td>
<td>29</td>
</tr>
</tbody>
</table>
SCMs in the Berkeley Neighborhood model

<table>
<thead>
<tr>
<th>SCMs</th>
<th>Los Angeles Capital Cost/ft(^3)</th>
<th>Area on Surface [ft(^2)]</th>
<th>Surface Storage Volume [ft(^3)]</th>
<th>Total Storage Volume [ft(^3)]</th>
<th>Maximum units to be optimized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-retention</td>
<td>14.60</td>
<td>100</td>
<td>100</td>
<td>306</td>
<td>1300</td>
</tr>
<tr>
<td>Vegetated Swale</td>
<td>10.07</td>
<td>32</td>
<td>50</td>
<td>82</td>
<td>2600</td>
</tr>
<tr>
<td>Underground Infiltration</td>
<td>10.34</td>
<td>0</td>
<td>100</td>
<td>253</td>
<td>1300</td>
</tr>
<tr>
<td>Porous Pavement</td>
<td>15.69</td>
<td>100</td>
<td>100</td>
<td>204</td>
<td>1300</td>
</tr>
</tbody>
</table>
Optimization Set up

Individual SCM Comparison

• 4 pareto curves
• Optimize each SCM separately
• Routing 100% of infil-redevelopment to the SCM
• Evaluation factors:
  • average annual flow volume
  • groundwater recharge potential

Full optimization

• 1 pareto curve
• Optimize all SCMs simultaneously
• Routing 25% of infil-redevelopment to each SCM type
• Evaluation factors:
  • average annual flow volume
  • groundwater recharge potential
Results: Individual Optimizations
Individual SCM Comparison

- 4 optimization curves
- Optimize each SCM separately
- Routing 100% of infiltration to the SCM
Underground infiltration reaches baseline conditions at the cheapest capital cost.
Tradeoff between cost and volume capacity

![Graph showing the tradeoff between cost and volume capacity for different methods. The x-axis represents cost, and the y-axis represents average annual flow volume (AAFV) in cubic feet. The graphs compare costs for Bio-Retention, Vegetated Swale, Underground Infiltration, Porous Pavement, and Pre-Redevelopment AAFV. Each method has a distinct curve.]
I argue that when comparing individual SCM pareto frontiers, displaying capture volume on the x-axis is efficient for planning level decisions.
I argue that when comparing individual SCM pareto frontiers, displaying capture volume on the x-axis is efficient for planning level decisions.
What about other benefits??
Water Quantity Benefits

Average Annual Flow Volume
Flow Exceedance Frequency
Flow Duration Curve
Peak Discharge Flow

Seasonal Average Flow Volume
Average Annual Groundwater Recharge
Seasonal Average Groundwater Recharge
Average Annual Evapotranspiration
Seasonal Average Evapotranspiration
New Peak Discharge Flow Calculations

Water Quality Benefits

Average Annual Load
Average Annual Concentration
Days above X Concentration

Seasonal Average Load
Seasonal Average Concentration

15+ pareto curve plots is a lot to look at and almost impossible to compare.
Can we summarize multiple evaluation factors in only one plot?

Example from Los Angeles modeling efforts

\[
\text{Benefit Score}_{j,i} = \left[ \frac{\text{Benefit value}_{j,i} - \min[\text{Benefit Value}_i]}{\max[\text{Benefit Value}_i] - \min[\text{Benefit Value}_i]} \right] \times \text{Ranking}
\]

\[
\text{Overall Score}_{j,i} = \frac{\sum_m \text{Benefit Score}_{j,i}}{\sum \text{rankings}}
\]

\(j = \text{BMP Type}\)
\(i = \text{Treatment Volume}\)
\(m = \text{Evaluation factor}\)
Can we summarize multiple evaluation factors in only one plot?

Example from Los Angeles modeling efforts
Aggregate Benefits: Prioritize Equally

Aggregate Benefits: Prioritize AAL

- Vegetated Swale
- Bio-Retention
- Dry Pond
- Infiltration Trench
- Underground Detention
- Underground Infiltration
- CMP Detention
- Porous Pavement

Cost (Billions)

AAFV+AA+GWIRP

Total SCM Volume Capacity [cubic feet] \times 10^4
Results: Full Optimization
Full optimization

• 1 optimization curve
• Optimize all SCMs simultaneously
• Routing 25% of infill redevelopment to each SCM type
1000 Solutions across a range of AAFV and Costs
30 best solutions reach the AAFV target at the cheapest cost
Best solutions favor 1) bio-retention
Best solutions favor 1) bio-retention and 2) underground infiltration.
Future work and further analysis on two best solutions

Two best solutions:
- Cheapest Cost
- Smallest total capture volume required to reach baseline flow conditions
- One solution that favors bio-retention
- One solution that favors underground infiltration

Which is the optimal solution??
Future work and further analysis on two best solutions

<table>
<thead>
<tr>
<th>Stormwater Capture Outputs</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant SCM type</td>
<td>Bio-retention</td>
<td>Underground Infiltration</td>
</tr>
<tr>
<td>Cost</td>
<td>179,450</td>
<td>176,910</td>
</tr>
<tr>
<td>AAFV $ \times \cdot 10^7$ [ft$^3$]</td>
<td>2.1652</td>
<td>2.1665</td>
</tr>
</tbody>
</table>

Very similar cost and average annual flow volume..
Future work and further analysis on two best solutions

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<td>2.1665</td>
</tr>
<tr>
<td>Greener vs Greyer</td>
<td>Greener</td>
<td>Greyer</td>
</tr>
<tr>
<td>Volume Capture Required [ft^3]</td>
<td>32,333</td>
<td>32,589</td>
</tr>
<tr>
<td>Surface Area Required [ft^2]</td>
<td>9,928</td>
<td>7,491</td>
</tr>
<tr>
<td>GWRP*10^7 [ft^3]</td>
<td>0.2348</td>
<td>0.2335</td>
</tr>
</tbody>
</table>
Future work and further analysis on two best solutions

<table>
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<td>0.2348</td>
<td>0.2335</td>
</tr>
<tr>
<td>Stormwater Capture Score</td>
<td>66.6</td>
<td>33.3</td>
</tr>
</tbody>
</table>

**Notes:**
- The graphs and tables compare the two best solutions (1 and 2) based on various stormwater capture outputs.
- The dominant SCM types are Bio-retention and Underground Infiltration.
- The cost for solution 1 is 179,450, and for solution 2 is 176,910.
- The AAFV in 10^7 ft^3 for solution 1 is 2.1652, and for solution 2 is 2.1665.
- Solution 1 is considered Greener than solution 2 in terms of volume capture required and surface area required.
- Solution 1 has a Stormwater Capture Score of 66.6, while solution 2 has a score of 33.3.

**Legend:**
- Vegetated Swale
- Bio-retention
- Porous Pavement
- Underground Infiltration

**Color Scale:**
- Color scale indicating preference from higher to lower preference option.
Life cycle costs and co-benefits may be the tipping point between SCM solutions.
Co-benefit Selection Process for i-DST

1. **Full suite of co-benefits**
   - **Strength of link in the literature**
     - **Strong**
     - **Weak**

2. **Can be measured using existing i-DST outputs?**
   - **Yes**
   - **No**

3. **Can be related to existing i-DST outputs?**
   - **Yes**
   - **No**

4. **Compile for static educational component**

5. **Include co-benefit in i-DST**
Future work and further analysis on two best solutions

**“Greener” bio-retention Solution**

<table>
<thead>
<tr>
<th>Score</th>
<th>Stormwater Capture/LCC</th>
<th>Life Cycle Analysis</th>
<th>Co-benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Score</strong></td>
<td>66.6</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

**“Greyer” Underground Infiltration Solution**

<table>
<thead>
<tr>
<th>Score</th>
<th>Stormwater Capture/LCC</th>
<th>Life Cycle Analysis</th>
<th>Co-benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Score</strong></td>
<td>33.3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Thank you! Questions?

Email: emgallo@mines.edu
Email: idst@mines.edu
Website: https://idst.mines.edu/
Follow us: @iDST_Team

If you are interested in attending future workshops or beta testing the tool send us an email!!

idst@mines.edu
Matrix of all Optimization Controls

<table>
<thead>
<tr>
<th>Optimization Search Algorithm Controls</th>
<th>Target Evaluation: X-X% Reduction</th>
<th>10 - 90%</th>
<th>60-70%</th>
<th>64 - 65%</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMIP Units to capture X-X% of 85th</td>
<td>1 - 125%</td>
<td>75 - 125%</td>
<td>1 - 125%</td>
<td>75 - 125%</td>
</tr>
<tr>
<td>NSGA II</td>
<td><a href="#">Diagram</a></td>
<td><a href="#">Diagram</a></td>
<td><a href="#">Diagram</a></td>
<td><a href="#">Diagram</a></td>
</tr>
<tr>
<td>Cost Minimization</td>
<td><a href="#">Diagram</a></td>
<td><a href="#">Diagram</a></td>
<td><a href="#">Diagram</a></td>
<td><a href="#">Diagram</a></td>
</tr>
<tr>
<td>Scatter Search</td>
<td><a href="#">Diagram</a></td>
<td><a href="#">Diagram</a></td>
<td><a href="#">Diagram</a></td>
<td><a href="#">Diagram</a></td>
</tr>
<tr>
<td>Cost Minimization</td>
<td><a href="#">Diagram</a></td>
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</tr>
</tbody>
</table>
Integrating LID into Municipal Design Criteria – A Colorado MS4 Perspective

CITY OF BOULDER
DESIGN AND CONSTRUCTION STANDARDS

CHAPTER 7
STORMWATER DESIGN
Effective: June 20, 2019

CASFM
September 25th, 2019

Kevin Koryto, Stormwater Quality Engineer
City of Boulder
Why talk about stormwater quality design criteria?
Background

Water Quality Design Standards Included in MS4 Phase II Revised Permit:

1. Water Quality Capture Volume
   - Treat runoff volume for 80\textsuperscript{th} percentile, 0.6-in event

2. Pollutant Removal
   - 30 mg/L TSS effluent concentration

3. Runoff Reduction
   - Infiltrate 60\% of the WQCV
Boulder’s Design Criteria

The MS4 permit has new design standards…

YEAH, IF YOU COULD JUST GO AHEAD AND IMPLEMENT THAT

THAT WOULD BE GREAT
Boulder’s Design Criteria

Boulder Design and Construction Standards (DCS)
- Establishes technical requirements for infrastructure design & review
- Companion document to Boulder Revised Code (BRC)
- Not a manual, references external guidance documents
- First major revision in 20 years

CITY OF BOULDER
DESIGN AND CONSTRUCTION STANDARDS

CHAPTER 7
STORM WATER DESIGN
Effective: November 16, 2000

CITY OF BOULDER
DESIGN AND CONSTRUCTION STANDARDS

CHAPTER 7
STORMWATER DESIGN
Effective: June 20, 2019
Boulder’s Design Criteria

- **Implementation Timeline**

  **Creation**
  - Feb – Dec 2018
    - DCS Revisions
    - Code Revisions
    - Stakeholder Input
    - Technical Review
    - Legal Review

  **Adoption**
  - Jan – Jun 2019
    - Advisory Board Review
    - Planning Board Review
    - City Council
    - Final Revisions
    - Development Review Process Integration

  **Implementation**
  - Jul – Dec 2019
    - Outreach & Training
    - Process Implementation
    - Tracking Implementation

  **Continuation**
  - 2020 and Beyond
    - Monitoring & Evaluation
    - Feedback & Process Revision

*MS4 Permit Deadline: July 1, 2019*
The three elements of stormwater quality design criteria:

<table>
<thead>
<tr>
<th>1. Implementation Threshold</th>
<th><strong>When</strong> does stormwater quality have to be designed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Design Standard</td>
<td><strong>What</strong> is the metric for an adequate design?</td>
</tr>
<tr>
<td>3. Design Process</td>
<td><strong>How</strong> are stormwater quality facilities designed?</td>
</tr>
</tbody>
</table>
# Stormwater Quality Thresholds

<table>
<thead>
<tr>
<th>Authority</th>
<th>Regulation</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal, EPA</td>
<td>Clean Water Act: NPDES Phase II Stormwater Final Rule (2003)</td>
<td>Implement permanent stormwater controls when more than 1 acre of land is disturbed</td>
</tr>
<tr>
<td>State, CDPHE</td>
<td>MS4 Permits</td>
<td>Replicate</td>
</tr>
<tr>
<td>Local</td>
<td>Local Ordinance</td>
<td>Replicate or go stricter</td>
</tr>
</tbody>
</table>

**Boulder’s Previous Requirement:** For less than 1 acre, city “may” require

*Does the 1-acre threshold make sense for our community?*

*What about in built-out communities where redevelopment is predominant?*
Stormwater Quality Thresholds

- Survey of 34 community stormwater programs
- 2/3 of communities have a threshold lower than 1 acre
- Increased impervious area and other conditions, also commonly used
Stormwater Quality Thresholds

Boulder’s Approach

- Maintain 1-acre threshold
- Demonstration of LID required for all sites, including < 1 ac
- Collect development data to support future evaluation and revision

Low Impact Development (LID) Checklist

<table>
<thead>
<tr>
<th>LID techniques, as defined below shall be implemented for all new development and redevelopment</th>
</tr>
</thead>
<tbody>
<tr>
<td>LID techniques have been investigated and implemented to the maximum extent practical for this site.</td>
</tr>
<tr>
<td>□ Yes □ No</td>
</tr>
</tbody>
</table>

**Conserve Existing Amenities:** Planning efforts shall account for and, where practicable, preserve or restore existing site features that naturally retain stormwater on site, including vegetated areas, high infiltrating soils, and natural surface drainage patterns, such as meadows and trees.

**Minimize Impacts:** Planning efforts shall account for and minimize, where practicable, land disturbance, impervious surface addition, and soil compaction. This may include removing unnecessary impervious areas, minimizing driveway and sidewalk widths, and sequencing construction to minimize compacted areas.

**Minimize Directly Connected Impervious Areas (MDCIA):** Planning efforts shall account for and minimize impervious areas, such as rooftops and pavement, that directly drain to the stormwater utility system or a local stream without prior stormwater control. This may include using or integrating receiving pervious areas into the site landscape, such as vegetated swales and buffers. Where practicable, site drainage patterns shall be designed to promote sheet flow to vegetated area and roof downspouts shall be disconnected from direct discharge to the storm sewer. Receiving pervious areas shall be designed to slow run-off and promote infiltration.
### Design Standards

<table>
<thead>
<tr>
<th>Authority</th>
<th>Regulation</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>State, CDPHE</td>
<td>MS4 Permits</td>
<td>Establishes base design standards</td>
</tr>
<tr>
<td>Local</td>
<td>Local Ordinance</td>
<td>Replicate, select from, or go stricter</td>
</tr>
</tbody>
</table>

#### Design Standard Approaches:

- **Pollutant Removal Requirement**
  - Capture volume (*WQCV*)
  - Effluent concentration limit
  - Percent removal
  - Load reduction

- **Retention Requirement**
  - **Volume infiltrated** or reused
  - Match pre-development hydrograph

---

**NYC (2017) Survey of 34 Municipalities:**

- 56% Require both pollutant removal and retention
- 33% Have only a retention requirement
- 11% Have only a pollutant removal requirement
Design Standards

MS4 Permit Design Standards:

1. Water Quality Capture Volume
   - Treat runoff volume for 80th percentile, 0.6-in event

2. Pollutant Removal
   - 30 mg/L TSS effluent concentration

3. Runoff Reduction
   - Infiltrate 60% of the WQCV

For TSS Load Reduction: 60% infiltrated ≈ WQCV
Retention Design Standard Comparison

Colorado’s Phase II Permit Retention Requirement:

0.36 in = 60% of 0.6 in (roughly not accounting for WQCV calc)

National Survey (NYC, 2017):

1.0 in = Median retention requirement

NYC (2017) Survey of 34 Municipalities:

- 0.3 inches minimum
- 1.0 inches median
- 1.25 inches maximum

Colorado
### Design Process

<table>
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<tr>
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<tbody>
<tr>
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</tr>
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<td>State, CDPHE</td>
<td>MS4 Permits</td>
<td>Review requirement</td>
</tr>
<tr>
<td>Local</td>
<td>Local Ordinance</td>
<td>Open ended</td>
</tr>
</tbody>
</table>

### Local Criteria Building Blocks

- **Local Design Criteria**  
  [Boulder DCS]
  - Requires Standards & Methods
  - Implements Process

- **MS4 Permit**  
  [CO Phase II]
  - Design Standards
  - Recordkeeping/Review Requirements

- **Regional Manual**  
  [UDFCD Vol. 3]
  - Technical Methods & Sizing Criteria
  - Implementation Guidance
## Boulder’s Design Process Objectives

<table>
<thead>
<tr>
<th>Objective</th>
<th>Driver</th>
</tr>
</thead>
</table>
| **1. Meet Permit Requirements** | **Colorado Phase II MS4 Permit**  
CDPS GENERAL PERMIT CORO09000  
STORMWATER DISCHARGES ASSOCIATED WITH  
MUNICAL SEPARATE STORM SEWER SYSTEMS (MS4s)  
EFFECTIVE JULY 1, 2016 |
| **2. Promote Infiltration with GI/LID** | **Bacteria primary pollutant of concern**  
*E. coli* TMDL Implementation Plan  
City of Boulder |
| **3. Guide effective designs** | **Lessons learned from design and maintenance failures** |
**Boulder Design Standard Hierarchy**

**Boulder Specified Design Approach**

**Tier 1 – Runoff Reduction**
- **Full Infiltration**
  - Ex.: Bioretention without underdrain

**Tier 2 – WQCV**
- **Partial Infiltration/Filtration**
  - Ex.: Bioretention with underdrain
- **No Infiltration**
  - Ex.: Bioretention with underdrain and liner

**Tier 3 – Pollutant Removal**
- **Alternative Design**
  - Ex.: Media Filter

**Infiltration Conditions**

- **HSG A/B and No Risk**
- **HSG C/D and No Risk**
- **Identified Infiltration Risk**
- **Site Specific Constraint**
Evaluating Infiltration

Selection Process

<table>
<thead>
<tr>
<th>Treatment Approach</th>
<th>Step 1. Feasibility Screening</th>
<th>Step 2. Field Test Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Infiltration (Runoff Reduction)</td>
<td>HSG A or B, No soil, groundwater, or geological risk factors.</td>
<td>Required, Infiltration rate tested at ≥ 1 in/hr OR For RPAs topsoil texture analysis</td>
</tr>
<tr>
<td>Partial Infiltration (WQCV)</td>
<td>HSG C or D, No soil, groundwater, or geological risk factors.</td>
<td>Optional, Infiltration rate tested at &lt; 1 in/hr OR For RPAs topsoil texture analysis</td>
</tr>
<tr>
<td>No Infiltration (WQCV)</td>
<td>Lined system required due to risk factors.</td>
<td>N/A</td>
</tr>
<tr>
<td>Alternative Design (Pollutant Removal/Constrained Site)</td>
<td>Proof of physical site constraints/risk factor preventing other design.</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Boulder Infiltration Conditions

- HSG used only as a first look
- Differentiated soil conditions
  - HSG A: 16%
  - HSG B: 44%
  - HSG C: 28%
  - HSG D: 12%
- Boulder Creek Drainage: 80% HSG A/B
### 4. Full Infiltration – Runoff Reduction Criteria

Runoff Reduction Design Standard: SCMs are selected, designed, and constructed to infiltrate into the ground where site geology permits, evaporate, or evaportranspire a quantity of water equal to 80% of what the WQCV would be if all impervious area for the applicable development site discharged without infiltration.

None of the applicable development area may be excluded when using the Runoff Reduction Standard.

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Preliminary infiltration feasibility screening has been</td>
<td></td>
<td></td>
</tr>
<tr>
<td>documented in the drainage report with a rational conclusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for full infiltration.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. The Runoff Reduction Design Standard has been met for the</td>
<td></td>
<td></td>
</tr>
<tr>
<td>treatment area.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Required sizing criteria for full infiltration has been</td>
<td></td>
<td></td>
</tr>
<tr>
<td>achieved and documented in the drainage report.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Field infiltration test requirements have been met and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>documented in the drainage report.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SCM Name</th>
<th>SCM Type</th>
<th>Drainage Area (ac)</th>
<th>WQ Event Runoff Volume (ft³)</th>
<th>WQ Event Infiltrated Volume (ft³)</th>
<th>Percent Infiltrated (%)</th>
<th>Detention Storage (yes/no)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

**Treatment Area Not Rout ed to SCM:**

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>0%</th>
<th>N/A</th>
</tr>
</thead>
</table>

**Total:**

---

*Refer to D.C.S. Section 7.16(D)(1) for full infiltration treatment approach criteria.

*SCM Name shall match drainage report and plan designation. Attach additional table if more than three SCMs are planned.

*SCM Type shall match USDCM Volume 3, Treatment BMP Factsheet nomenclature.*
Building Blocks

Building a green infrastructure (GI) program

- City GI Program
- GI Pilots, Guidance and Tools
- Stormwater Design Criteria
- Stormwater Permit Compliance
Acknowledgements

Heather Williams
Mary Halley

Holly Piza

Jeff Arthur
Amanda Bevis
Pieter Beyer
Emily Halvorson
Elizabeth Judd
Kevin Koryto

Scott Kuhna
Brett Linenfelser
Candice Owen
Hella Pannewigh
Jessica Pault-Altiase
Edward Stafford
Thank You!

References:

https://bouldercolorado.gov/plan-develop/design-construction-standards

Innovative and Integrated Stormwater Management, Search: “NYC Stormwater Report”

Contacts:

Kevin Koryto
Stormwater Quality Engineer
KorytoK@BoulderColorado.gov

Candice Owen
Stormwater Quality Supervisor
OwenC@BoulderColorado.gov
Beneficial Use of Water Treatment Residuals as a Bioretention Media Amendment for Phosphorus Removal

2019 CASFM Annual Conference
September 24-27, 2019

• Basil Hamdan, P.E., CFM – City of Fort Collins - Utilities
• Tyler Dell – Colorado State University –
  Colorado Stormwater Center
What are Water Treatment Residuals (WTRs)?
What are WTRs?

• The flocculating agent of water treatment
• Fort Collins Utilities uses Aluminum Sulfate $\text{Al}_2(\text{SO}_4)_3$
• Delivered as a liquid
• Stored in large tanks and added to the water
What are WTRs?

• Calculated, added, monitored for the source water
• Causes flocculation
• Removed in the sediment from water treatment residuals
What are WTRs?

• Sediment containing the aluminum sulfate as well as particles removed from water treatment needs to be managed (full-time position)
  1. Dewatering
  2. On-site Management
  3. Landfill Issues (Costs + Life Cycle)
Fort Collins Zero Waste Initiative
Meanwhile Back At The Ranch...

- Stormwater nutrients and current practices
- Regulation 85
- Lead pipes and phosphate
- COFC Climate Action Plan
- Innovate Fort Collins
- Colorado State University – Stormwater Center - COFC Collaboration
- CSU- City Sustainability Network

Phosphorus Concentrations

- TP Influent
- TP Effluent
- Dissolved P Influent
- Dissolved P Effluent

With Modification | Without Modification
---|---
Concentrations (mg/L) | 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Fort Collins Water Treatment Plant produces over 1,000 tons of WTRs/yr

Larimer County Landfill originally scheduled to be closed within 5-10 years

Regulation 85 sets new TMDLs for streams and phosphorus

Current stormwater practices export phosphorus
We want to use WTRs as a media amendment to reduce waste and treat phosphorus.
WTR Column Study

• Wanted to test the concept and mixing strategy
• 4 different configurations
  • Top Applied – 0.5”
  • Top Applied – 1.0”
  • Bottom Applied – 1.0”
  • Mixed Application – 1.0”
<table>
<thead>
<tr>
<th>Year</th>
<th># of Sig Events (&gt; 0.1 in)</th>
<th>Water Volume ft$^3$</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total Precip</td>
<td>Sig. Event Precip</td>
<td>Total Estimated Runoff</td>
</tr>
<tr>
<td>2007</td>
<td>21</td>
<td>104,280</td>
<td>83,490</td>
<td>66,165</td>
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<tr>
<td>2008</td>
<td>22</td>
<td>110,220</td>
<td>98,670</td>
<td>80,520</td>
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<tr>
<td>2009</td>
<td>41</td>
<td>173,333</td>
<td>155,760</td>
<td>121,935</td>
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<tr>
<td>2010</td>
<td>28</td>
<td>115,253</td>
<td>101,805</td>
<td>78,705</td>
</tr>
<tr>
<td>2011</td>
<td>32</td>
<td>143,633</td>
<td>127,958</td>
<td>101,558</td>
</tr>
<tr>
<td>2012</td>
<td>18</td>
<td>72,765</td>
<td>59,483</td>
<td>44,633</td>
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<tr>
<td>2013</td>
<td>33</td>
<td>143,055</td>
<td>127,793</td>
<td>100,568</td>
</tr>
<tr>
<td>2014</td>
<td>33</td>
<td>131,753</td>
<td>107,828</td>
<td>80,273</td>
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<tr>
<td>2015</td>
<td>38</td>
<td>155,595</td>
<td>134,558</td>
<td>103,208</td>
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<tr>
<td>2016</td>
<td>27</td>
<td>93,473</td>
<td>75,983</td>
<td>53,708</td>
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<tr>
<td>2017</td>
<td>36</td>
<td>139,343</td>
<td>117,398</td>
<td>88,110</td>
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<tr>
<td>Average</td>
<td>30</td>
<td>125,700</td>
<td>108,248</td>
<td>83,580</td>
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</tbody>
</table>
Based on previous rain gage analysis

- Fort Collins experiences an average of 30 runoff producing storms/year
- The average depth contained by the rain garden from those storms is 6.2”
- The 95th confidence interval 7.0”
- The average dissolved phosphorus EMC from the parking lot is approximately 0.228 mg/L
Performance of WTR Columns

• Bottom application performed the best followed closely by mixed

• The top applied did provide some removal but not much

• Application rates of top application did not impact performance
  • Time of exposure
  • Picking up pollutants from media beneath

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>Average Reduction</th>
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<tr>
<td>Mixed 1&quot;</td>
<td>71.9%</td>
</tr>
<tr>
<td>Top Applied 1&quot;</td>
<td>19.0%</td>
</tr>
<tr>
<td>Top Applied 0.5&quot;</td>
<td>19.3%</td>
</tr>
<tr>
<td>Bottom Applied 1&quot;</td>
<td>77.1%</td>
</tr>
</tbody>
</table>
WTR Pilot Project: 700 Wood Street
Site Background

Rain Garden (Bioretention)
- Installed in 2012
- 2.25 acre parking lot
- Rain Garden Area: 1,900 ft²
- Rain Garden Volume: 1,400 ft³
Stormwater Monitoring

Monitored site since 2013
Pilot Project Application

- Used a top application of approximately 0.5”
  - This should handle at least 10 years of phosphorus loading
- Installed sampling equipment to capture influent and effluent water quality samples
  - Looking primarily for dissolved P, aluminum, and potential radioactive particulate from the WTRs
- Collected a sample on 9/8/2019, results should be in soon...
Conclusions

• Mixed application appears to be the optimal application that would yield the least amount of risk
• Continuation of column study for 30 rainfall years
• Expansion to additional types of technologies
  • Wetlands
  • Extended Detention Basins
• Elimination/re-use of Fort Collins water treatment residuals waste
Thank you!

- **Contact: Tyler Dell**
  - 970.491.8015
  - Tyler.Dell@colostate.edu
  - StormwaterCenter.colostate.edu

- **Contact: Basil Hamdan**
  - 970.224.6035
  - bhamdan@fcgov.com
SUBWATERSHED WATER QUALITY BMP RETROFIT ANALYSIS
Process Overview

- Target
- Measure
- Prioritize
Process Overview

Municipal Challenges

- Staffing resources
- Implementation funding
- Water quality/TMDL
- Fully built landscape
Process Overview

Solutions

• Optimized BMP targeting
• Optimized BMPs by location
• Measurable, defensible outcomes
Process Overview

Benefits

- Comprehensive planning
- Apples-to-apples vetting
- CIP planning
- NPDES reporting support
- Powerful grant writing
Process Overview

1. Desktop
2. Field
3. Modeling
4. Valuation
5. Implementation Plan
Process Overview

Desktop Analysis: potential retrofit location screening

- Outfalls
- Pond mod's
- Open space
- Parking lots
- Rural
- Residential
- Urban
- Underground
- Base WQ Model
Process Overview

Field Analysis: site validation and data collection

- Confirm data
- Site constraint identification
- BMP alternatives identification
- Spot invert survey
- Infiltration testing
- Base model update
Process Overview

Treatment Analysis

- Subwatershed WQ modeling of alternatives
- 30-year, continuous modeling
- Incremental treatment (%) sizing runs
- TP, TKN, TSS, CU, PB, ZN, Hydrocarbons
- Water balance
- Treatment train effects
- WQ effects by outfall
Process Overview

Value Analysis

- Apples-to-apples comparison of alternatives
- 30-year Present Day Values (PDV)
- PDV / 30-year treatment = value
- Incremental cost analysis
- Triple Bottom Line analysis by subwatershed
- Alternative ranking by subwatershed
- Comprehensive mapping and database development
Potential Locations

- Existing pond modification potential
- Above roadway culverts
- Below stormwater outfalls
- Within the conveyance system
- Transportation right of ways
- Large parking lots
- Hotspot operations
- Small parking lots
- Residential streets/blocks
- Open space/pervious areas for disconnecting pervious areas
- Large rooftops
- Underground treatment
BMP-Function Groups

- Extended Detention (Full Spectrum)
- Stormwater Wetlands
- Infiltration
- Bioretention
- Filtration
- Swales
- Stormwater Harvesting
- Chemical Reaction
## BMP Groups by Location

<table>
<thead>
<tr>
<th>Location</th>
<th>Stormwater Treatment Option (BMP)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extended Detention</td>
</tr>
<tr>
<td>Existing pond modification</td>
<td>•</td>
</tr>
<tr>
<td>Above roadway culverts</td>
<td>•</td>
</tr>
<tr>
<td>Below stormwater outfalls</td>
<td>•</td>
</tr>
<tr>
<td>Within the conveyance system</td>
<td>▲</td>
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<tr>
<td>Transportation right of ways</td>
<td>•</td>
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<tr>
<td>Large parking lots</td>
<td>•</td>
</tr>
<tr>
<td>Hotspot operations</td>
<td>○</td>
</tr>
<tr>
<td>Small parking lots</td>
<td>○</td>
</tr>
<tr>
<td>Residential streets/blocks</td>
<td>○</td>
</tr>
<tr>
<td>Open space</td>
<td>○</td>
</tr>
<tr>
<td>Urban hardscape</td>
<td>○</td>
</tr>
<tr>
<td>Large rooftops</td>
<td>○</td>
</tr>
<tr>
<td>Underground treatment</td>
<td>▲</td>
</tr>
</tbody>
</table>

- • = Preferred stormwater treatment option
- ▲ = Feasible in some circumstances
- ○ = Seldom used for the retrofit
- X = Not recommended under any circumstances

Source: Center for Watershed Protection
Total Phosphorus Yield by Land Use and Soils

lbs/ac/yr
<table>
<thead>
<tr>
<th>Term</th>
<th>Flow ac-ft</th>
<th>Load lbs</th>
<th>Conc ppm</th>
<th>Flow cfs</th>
<th>Load lbs/yr</th>
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</thead>
<tbody>
<tr>
<td>01 watershed inflows</td>
<td>167.9</td>
<td>52198.9</td>
<td>114.4</td>
<td>0.3</td>
<td>62306.0</td>
</tr>
<tr>
<td>03 infiltrate</td>
<td>54.8</td>
<td>4209.8</td>
<td>28.3</td>
<td>0.1</td>
<td>5024.9</td>
</tr>
<tr>
<td>04 exfiltrate</td>
<td>54.8</td>
<td>0.0</td>
<td></td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>05 filtered</td>
<td>0.0</td>
<td>4209.8</td>
<td></td>
<td>0.0</td>
<td>5024.9</td>
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<tr>
<td>06 normal outlet</td>
<td>91.6</td>
<td>15222.7</td>
<td>61.1</td>
<td>0.2</td>
<td>18170.2</td>
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<tr>
<td>07 spillway outlet</td>
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<td>3677.3</td>
<td>62.8</td>
<td>0.0</td>
<td>4389.3</td>
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<tr>
<td>08 sedimen + decay</td>
<td>0.0</td>
<td>29087.4</td>
<td></td>
<td>0.0</td>
<td>34719.5</td>
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<tr>
<td>09 total inflow</td>
<td>167.9</td>
<td>52198.9</td>
<td>114.4</td>
<td>0.3</td>
<td>62306.0</td>
</tr>
<tr>
<td>10 surface outflow</td>
<td>113.2</td>
<td>18900.0</td>
<td>61.4</td>
<td>0.2</td>
<td>22559.5</td>
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<tr>
<td>11 groundw outflow</td>
<td>54.8</td>
<td>0.0</td>
<td></td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>12 total outflow</td>
<td>167.9</td>
<td>18900.0</td>
<td>41.4</td>
<td>0.3</td>
<td>22559.5</td>
</tr>
<tr>
<td>13 total trapped</td>
<td>0.0</td>
<td>33297.2</td>
<td></td>
<td>0.0</td>
<td>39744.5</td>
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<tr>
<td>14 storage increase</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td>0.0</td>
<td>0.1</td>
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<tr>
<td>15 mass balance check</td>
<td>0.0</td>
<td>1.6</td>
<td></td>
<td>0.0</td>
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<tr>
<td>Load Reduction %</td>
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<td>63.8</td>
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<tr>
<td>Mass Balance Error %</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Incremental Cost of Treatment

![Graph showing incremental cost of treatment vs. percent subwatershed TP-load reduction. The x-axis represents the percent subwatershed TP-load reduction, ranging from 10 to 100. The y-axis represents the cost per LB-TP removed, ranging from $100 to $1,000,000. The graph includes several data points indicating the relationship between cost and reduction percentage.](image-url)
# Within Subwatershed Value by Strategy

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Install Cost</th>
<th>Annual O&amp;M</th>
<th>D.A. Load(^1) ((\text{TP-LB/YR})^2)</th>
<th>TP Removed ((% / \text{YR})^2)</th>
<th>TP Removed ((\text{LB/YR})^2)</th>
<th>30-Year Treatment Value (($/\text{LB/YR})^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeable Parking(^3)</td>
<td>$140,400</td>
<td>$200</td>
<td>10.6</td>
<td>78</td>
<td>9.8</td>
<td>$14,347</td>
</tr>
<tr>
<td>Stormwater Planters(^4)</td>
<td>$45,745</td>
<td>$250</td>
<td>10.6</td>
<td>45</td>
<td>4.8</td>
<td>$9,582</td>
</tr>
<tr>
<td>Sub-sidewalk Storage(^5)</td>
<td>$195,000</td>
<td>$250</td>
<td>10.6</td>
<td>42</td>
<td>4.4</td>
<td>$44,375</td>
</tr>
<tr>
<td>Raingardens(^2)</td>
<td>$15,000</td>
<td>$250</td>
<td>8.3</td>
<td>34</td>
<td>2.8</td>
<td>$5,446</td>
</tr>
<tr>
<td>Stormwater Planter Boxes(^3)</td>
<td>$42,000</td>
<td>$250</td>
<td>4.2</td>
<td>56</td>
<td>2.3</td>
<td>$18,370</td>
</tr>
<tr>
<td>Infiltration Trench(^4)</td>
<td>$2,500</td>
<td>$0</td>
<td>2.1</td>
<td>79</td>
<td>1.3</td>
<td>$1,923</td>
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<tr>
<td>H169 Detention(^5)</td>
<td>$135,000</td>
<td>$750</td>
<td>13.4</td>
<td>59</td>
<td>7.5</td>
<td>$8,500</td>
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<tr>
<td>Extended Detention(^2)</td>
<td>$225,000</td>
<td>$750</td>
<td>67</td>
<td>46</td>
<td>31</td>
<td>$2,299</td>
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</tbody>
</table>
# Between Subwatershed Value by Strategy

<table>
<thead>
<tr>
<th>Subwatershed</th>
<th>BMP</th>
<th>Install Cost</th>
<th>TP lb/yr</th>
<th>30-yr TP value</th>
<th>Manage Stormwater</th>
<th>Surface WQ</th>
<th>Enhance Public Space</th>
<th>Infrastr. Integration</th>
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<td>7</td>
<td>Infiltration Trench</td>
<td>$2,500</td>
<td>1.3</td>
<td>$1,923</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
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<tr>
<td>6</td>
<td>Extended Detention</td>
<td>$105,000</td>
<td>46</td>
<td>$2,299</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>$4,181</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>13</td>
<td>Raingardens</td>
<td>$9,000</td>
<td>2.1</td>
<td>$4,406</td>
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<td>Y</td>
<td>Y</td>
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<td>$5,446</td>
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<td>Y</td>
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<td>Y</td>
<td>Y</td>
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<tr>
<td>7</td>
<td>H169 Detention</td>
<td>$63,000</td>
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<td>$8,500</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>1</td>
<td>Stormwater Planters</td>
<td>$45,745</td>
<td>4.8</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
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<td>Stormwater Planters</td>
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<td>Y</td>
<td>Y</td>
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<td>Y</td>
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<td>Permeable Paving</td>
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<td>Y</td>
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<td>Y</td>
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<tr>
<td>7</td>
<td>Stormwater Planters</td>
<td>$42,000</td>
<td>2.3</td>
<td>$18,370</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>1</td>
<td>Sub-Sidewalk Storage</td>
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<td>4.4</td>
<td>$44,375</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
</tbody>
</table>
Contact Information

Shawn Tracy
763.248.0134
stracy@hrgreen.com

Greg Panza
720.602.4939
gpanza@hrgreen.com
Reimagining a Denver Landmark
City Park Golf Course

CASFM
September 25, 2019
Background

15.25 SQUARE MILE COLLECTION AREA

NO NATURAL DRAINAGE WAY

DENSE URBAN FABRIC

AGING AND UNDERSIZED PIPES

= SIGNIFICANT FLOODING CHALLENGES
Background

PLATTE TO PARK HILL

- Upgraded City Park Golf Course
- New Globeville Landing Outfall Park
- New 39th Ave Greenway
- Cole Neighborhood
- Clayton Neighborhood
- Park Hill Golf Course
- Downtown Denver
- South Platte River
- City Park

Projected 100-Year Storm Flood
A Community Approach

AN ENGAGED CITY

THE CLIENT
City & County of Denver
Mayor's Office
Public Works
Public Recreation
Community Planning and Development

EXPERTISE
Landscape Architects
Urban Designers
Planners

KEY PARTNERS
Colorado Department of Transportation
Urban Drainage & Flood Control District
Regional Transportation District
US Army Corps of Engineers

To date, there have been

250+ Public and stakeholder meetings

PUBLIC MEETINGS

1. Public & Community Meetings
2. Design Workgroups
3. Small Groups & 1-on-1 Meetings

IDENTIFICATION OF ALTERNATIVES
Fall 2015

ANALYSIS & FEASIBILITY
Winter 2015

PREFERRED ALTERNATIVES
Spring 2016

PRELIMINARY DESIGN
Summer 2016

FINAL DESIGN AND CONSTRUCTION
Start Fall 2016

STRATEGIES FOR PUBLIC ENGAGEMENT

STRATEGY

1. Public & Community Meetings
2. Design Workgroups
3. Small Groups & 1-on-1 Meetings

STAKEHOLDER

Government Agencies
Media
Schools
Special Interest Groups
Local Leaders
Industry Experts
Business Owners
Property Owners
Neighborhood Residents
Non-English Speakers
General Public

Platte to Park Hill – City Park Golf Course
Community Goals

HERITAGE TREES

UNPARALLELED VIEWS

99%
Of high priority trees preserved

54%
Of significant stands preserved

Matrix
City and County of Denver
Constraints

- Groundwater
- Earthwork/Soil Suitability
- Hydrology
- Embankment
- Golf
- Trees
- Views
- Historic
- Schedule
Platte to Park Hill – City Park Golf Course

Preliminary design

Downstream Key Design Points
Franklin_100yr = 3,615 cfs
High St_100-yr = 3,886 cfs
Williams St_100-yr (Open channel) = 2,708 cfs

CPGC Detention
Qin_100yr = 4,398 cfs
Qout_100-yr = 3,861 cfs
WSEL_100yr = 5248
Volume_100-yr = 215.9 AF

Qin_10yr = 825 cfs
Qout_10-yr = 419 cfs
WSEL_10yr = 5241
Volume_10-yr = 73.2 AF
Why Design Build?

- Schedule
- Innovation
- One point of Contact
Technical requirements

- 100-yr Storm detention
  - $Q_{\text{max}} = 3,275 \text{ cfs (227 ac-ft)}$
  - 8 hr max detention time
  - No adverse effects to golf in storm events
  - Integrated into golf course

- 10-yr storm impacts
  - Mile High Flood District Maintenance Eligibility
  - Water Quality – residence time
  - Trash Vaults - offline
Final Design

- Design Overview
- Designing to the TR's
- Unique Design Features
- Construction Phasing
- 2D Model
- Lessons Learned
Design Build Team
Design Overview
Meeting the Technical Requirements

<table>
<thead>
<tr>
<th>CPGC SWMM Model Comparison Table</th>
<th>Return Period</th>
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<tbody>
<tr>
<td></td>
<td>WQ</td>
</tr>
<tr>
<td></td>
<td>10-Year</td>
</tr>
<tr>
<td></td>
<td>100-Year</td>
</tr>
<tr>
<td>Qin (cfs)</td>
<td>411</td>
</tr>
<tr>
<td>Qout (cfs)</td>
<td>294</td>
</tr>
<tr>
<td>Volume (ac-ft)</td>
<td>21</td>
</tr>
<tr>
<td>WSEL (ft)</td>
<td>-</td>
</tr>
</tbody>
</table>

### Design

| Qin (cfs)                        | 411          | 825          | 4398          |
| Qout (cfs)                       | 276          | 410          | 3724          |
| Volume (ac-ft)                   | 23.9         | 76.9         | 213.5         |
| WSEL (ft)                        | 5239.1       | 5243.6       | 5251.0        |

### RFP Criteria Comparison

| **Non-Jurisdictional Dam Surface Area** ** (acres) | 20 | 14.2 |
| **Non-Jurisdictional Dam Volume Above Natural Grade** ** (acre-ft) | 100 | 8.4 |
| **Non-Jurisdictional Dam Berm Height** ** (ft) | 10.0 | 0.6 |
| **Maximum Embankment Slope** ** (h:v) | 4:1 | 4:1 |
| **Max Wetland Channel Length** ** (ft) | 2000 | 2018 |
| **Max Wetland Channel Slope** ** (%) | 0.3% - 0.7% | 0.3% |
| **Max Wetland Channel Velocity (Normal Depth)** ** (ft/s) | 3.5 | 3.5 |
| **Residence Time** ** (min) | 7:10 | 9.6 |
| **Maximum Forebay Depth** ** (ft) | 4.0 | 3.0 |
| **Minimum Forebay Depth** ** (ft) | 3.0 | 3.0 |
| **Forebay Sediment Depth** ** (ft) | 1.5 | 1.5 |
| **Forebay Footprint** ** (acres) | 1.0 | 1.2 |

### Notes:

1. **Contours shown are one foot interval. Existing topography shown was provided by Saunders Construction Company.**

2. **Hydrologic analysis is based on the two basins drainage plan SWMM modeling provided by Matrix Design Group on September 28, 2017. The SWMM modeling provided by Matrix is the basis for RFP addendum 3 and was adapted from the MattUSDWMM model with corrections by Enginuity. Proposed pond analysis is outlined in the City Park Golf Course – Regional Detention Pond Final Drainage Report, by Martin/Martin, Inc., dated February 12, 2018.**

3. **The addendum 3, section 12.2.4.11, area specific drainage requirements that identify playable golf facility criteria, are summarized as follows:**

   3.1. **No ponding greater than 6 hours or adverse impacts shall occur during the 10-year or 100-year recurrence interval storm events, on any non-green playable golf facilities (fairways, tee boxes, bunkers, chipping area, putting practice area, cart paths, golf cart bridges, first tee facilities, etc.). Adverse impacts are defined as erosion, damage to turf, washing away of material, or any other damage that would require more than minimal maintenance. Considerations to determine adverse impacts should include depth of water, velocity of flow, and type of facility being inundated.**

   3.2. **Greens shall not be inundated during the 10-year nor the 100-year event.**

4. **Groundwater surface elevations are based on data from the Interim Draft Geotechnical Investigation Report, City Park Investigation, by Yeh and Associates, Inc. January 11, 2017.**
Trash Vault
Trash Vault Diversion
Construction Phasing
Lessons learned

- Trash Grate diversion
  - Maximize grate area
- Neighboring projects
- Balancing stakeholder goals
  - Communication
- Phasing