Emergency Preparation Sessions:

**Session1: Extreme Rainfall Events Along the Front Range of CO**
Baxter Vieux (Vieux), Kevin Steward (UDFCD)

**Session2: Structure-Level Risk Assessment Using 2D Modeling**
Geoff Uhlemann (AECOM)

**Mapping Fluvial Hazard Zones: Developing Guidance, Applications, Pilot**
Stephanie DiBettito (CWCB), Joel Sholtes (USBR), Michael Blazewicz (Round River Design), Katie Jagt (Watershed Science)

**Evacuation Planning for Extreme Events: Failure of Cherry Creek**
Jeffrey Brislawn, Kyle Karsjen (Wood)

**Innovation in Colorado: High Hazard Dam Release – Downstream Floodplain Impacts**
Bill McCormick, Kallie Bauer (CO Division of Water Resources)

**Showcasing the Pilot Boulder County FRIS**
Madeline Kelley (DU), Thuy Patton (CWCB)
Extreme Rainfall Events along the Front Range of Colorado:

How much did we find, and How much did we miss?

Kevin Stewart, P.E., UDFCD Program Manager
Flood Warning & Information Services
On July 26, 2017 news media reported street flooding in Greenwood Village…

- A small stream out of its banks but no notable damages.
- Consistent with evening news reports about street flooding in Greenwood Village…
- **But where was the most extreme rainfall?**
  
  (Hint: Not Greenwood Village!)
Fox Hill Flood
July 26, 2017

Flood damages from >1000 year rain event
Todd Creek
Adams County

- A 8-hour period from
- 8PM (9/11/13) to 4AM (9/12/13)

Rainfall
From: 2013-09-12 20:00:00 PDT
To: 2013-09-13 04:00:00 PDT
Grid No.: 6629

4.5 in 1 hr
> 1000 yr

CASFM 2018 Snowmass at Aspen
Examining Extreme Event Detection

GARR and Gauges over the UDFCD Region
Detecting Extreme Rainfall

- Real-time rainfall is needed for flood alert decisions in support of the Urban Drainage and Flood Control District.
- UDFCD covers 1,608 mi² and parts of 6 counties along the Colorado Front Range
- FCD operates 202 ALERT rain gauges with a mean spacing of 2.6 mi.
- Gauge-adjusted radar rainfall (GARR) is a combination of weather radar and these gauges that fills in between the gauges.
Tools for today’s analysis

- **GARR**
  - Radar spatial patterns at high resolution
  - Rain gauge point measurements
  - Better than either system alone at producing accurate high resolution rainfall everywhere...‘between the gauges’
Return Period

- Defined as: “Average time between events larger than a given threshold”
- Used to categorize precipitation frequency.
- 100-yr event = 1 event in 100 years
NWS NOAA Atlas 14
Precipitation Probabilities

- Statistically at each of the 202 rain gauges there should be:
- One 100yr event occurs on average once every 100 years,
- Any one gauge has a 1% chance any given year
- Over 5 years, one gauge has 4.8% chance of a 100-yr event, Risk=(1-1/T)^n
Since 1991, 30 gauges total (1/yr)
2013-2018, 9 gauges total
GARR Events

<table>
<thead>
<tr>
<th>Year</th>
<th>&gt;100yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>6</td>
</tr>
<tr>
<td>2014</td>
<td>4</td>
</tr>
<tr>
<td>2015</td>
<td>3</td>
</tr>
<tr>
<td>2016</td>
<td>1</td>
</tr>
<tr>
<td>2017</td>
<td>12</td>
</tr>
<tr>
<td>2018</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>26</td>
</tr>
</tbody>
</table>

Average 5.2

- 26 pixel events 5 per year
- 9 gage events, 1 per year
Year | >100yr
--- | ---
2013 | 6

Todd Creek
9/27/2018

Year >100yr
2016 0
Summary

- “Rare” events are not that rare when considering the UDFCD region
- 100-yr events happen frequently
- How much did we find and how much did we miss?

100yr-60min (2013-2018)
9 gage events, 1 per year
26 pixel events, 5 per year
Structure-Level Risk Assessment Using 2D Probabilistic Modeling

CASFM 2018 – Snowmass, CO

Geoff Uhlemann - AECOM
Reasons for a New Approach

Improved Accuracy & Resolution
- To account for uncertainty
- Model future conditions
- >25% NFIP claims are structures outside SFHA (about 60% of losses)
- To capture more extreme events
- Show graduated risk within the 0.2% floodplain
- Include residual and pluvial risk
- Evaluate specific homes
Reasons for a New Approach

Enhanced End Products/Application

- To provide structure-level risk assessment
- To discretize flood insurance
- Communicate location-specific risk
- Evaluate risk behind levees
- CBA & performance-based levee analysis
- Risk-informed decision making process
- Depict total flood risk (fluvial + pluvial)
- Information on wide range of events, esp frequent (2 yr)
- Byproducts are grids for any recurrence interval
Potential NFIP Implications
From Zones to Graduated Risk

- Showing annual exceedance probability (AEP) rather than zones
- Especially useful behind levees
Potential NFIP Implications

*Insurance Premiums*

- Spatially varied insurance premiums (homes, neighborhoods, census blocks, zip codes) based on average annualized loss (AAL) relative to structure value/policy amount
- Can vary behind levees then & account for pluvial
Concept of Probabilistic Modeling Overview

- Monte Carlo distribution & importance sampling
- Fluvial Hydrology
  - Differing flood durations, confidence limits, hydrographs
- Pluvial Hydrology
  - Differing durations, confidence limits, quartiles, hyetographs
- Batch Hydraulics - thousands of runs
  - Differing land cover, breach locations & dimensions
  - All 2D model based – exports max WSEL grids
  - Create AEP grids
- Risk Assessment (at structure level)
  - Extract WSELs from all runs at each structure
  - Damage calcs with varying FFEs
  - AALs
Concept of Probabilistic Modeling
Existing Approach Comparison

1D or 2D Hydraulic Modeling
Concept of Probabilistic Modeling
Random Sampling Methodology

Hydraulics

Loss Calculations (at a single structure)

Hydrology

Damage Curves

Concept behind event sampling
probability
elevation
loss
discharge
loss
elevation
probability
Concept of Probabilistic Modeling

Risk Assessment

- Individual model results plotted out to produce various curves

![Graph showing Flood Elevation Curve and Flood Damage Curve for Building #939043.](image)
Crash Course of Probabilistic Approach
Crash Course of Probabilistic Approach
Fluvial Hydrology

- Rather than selecting the 5 typical discharges along the median line, 300 discharges are randomly sampled between the 5% and 95% confidence limits for a large number of probabilities, from the 50% (2-yr) to the 0.033% (3000-yr) or beyond annual-chance probability

- Applied as inflow hydrograph
  - Vary flood durations & hydrographs
Crash Course of Probabilistic Approach

**Pluvial Flooding**

- Evaluates runoff – applied as excess precip to 2D area
- Major contributor to the residual risk in leveed areas
- Currently not mapped on FIRMs or any of the existing flood products
- Catastrophic models used by private insurance companies capture pluvial hazard
- One reason structures outside the SFHA are flooded
- One cause of repetitive and significant repetitive loss
- Major contributing element in urban flooding
Precipitation values sampled between the 5% and 95% confidence limits for probabilities from the 50% (2-yr) to the 0.033% (3000-yr) or beyond

75 depths for 16 different unique storm duration (6-, 12-, 24-, and 96-hr) vs. temporal distribution (1st, 2nd, 3rd, or 4th quartile) scenarios are analyzed.

From NOAA Atlas 14 Precipitation Frequency Data Server
Crash Course of Probabilistic Approach

Pluvial Hydrology

- Curve Number variation is considered and randomly selected in between +/- one standard deviation
- HEC-HMS generated 1,200 hyetographs that were then used in HEC-RAS to map the excess rainfall on the grid
- But going forward...

**HEC-RAS Version 5.1**

- Will include loss functions
  - Curve Number
  - Green and Ampt
  - Constant and Initial Loss
- Losses will be able to be applied as spatially variable
- Spatially variable rainfall patterns will be included (gridded rainfall data)
- Allows us to take advantage of observed (gage adjusted radar rainfall data) and forecasted data products provided with each grid representing a different temporal pattern
Uncertainty in Manning’s n-values are factored into models – 10 land use layers

<table>
<thead>
<tr>
<th>NLCD Classification</th>
<th>Assigned Manning’s Roughness</th>
<th>Minimum</th>
<th>Normal</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Water</td>
<td></td>
<td>0.025</td>
<td>0.03</td>
<td>0.033</td>
</tr>
<tr>
<td>Developed, Open Space</td>
<td></td>
<td>0.035</td>
<td>0.055</td>
<td>0.095</td>
</tr>
<tr>
<td>Developed, Low Intensity</td>
<td></td>
<td>0.085</td>
<td>0.095</td>
<td>0.11</td>
</tr>
<tr>
<td>Developed, Medium Intensity</td>
<td></td>
<td>0.09</td>
<td>0.115</td>
<td>0.13</td>
</tr>
<tr>
<td>Developed, High Intensity</td>
<td></td>
<td>0.1</td>
<td>0.13</td>
<td>0.16</td>
</tr>
<tr>
<td>Barren Land</td>
<td></td>
<td>0.03</td>
<td>0.033</td>
<td>0.036</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td></td>
<td>0.1</td>
<td>0.12</td>
<td>0.16</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td></td>
<td>0.085</td>
<td>0.115</td>
<td>0.14</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td></td>
<td>0.09</td>
<td>0.115</td>
<td>0.15</td>
</tr>
<tr>
<td>Scrub/Shrub</td>
<td></td>
<td>0.05</td>
<td>0.075</td>
<td>0.09</td>
</tr>
<tr>
<td>Grassland Herbaceous</td>
<td></td>
<td>0.028</td>
<td>0.03</td>
<td>0.035</td>
</tr>
<tr>
<td>Pasture/Hay</td>
<td></td>
<td>0.038</td>
<td>0.045</td>
<td>0.055</td>
</tr>
<tr>
<td>Cultivated Crops</td>
<td></td>
<td>0.035</td>
<td>0.042</td>
<td>0.048</td>
</tr>
<tr>
<td>Woody Wetlands</td>
<td></td>
<td>0.08</td>
<td>0.095</td>
<td>0.12</td>
</tr>
<tr>
<td>Emergent Wetland</td>
<td></td>
<td>0.04</td>
<td>0.065</td>
<td>0.1</td>
</tr>
<tr>
<td>River Channel</td>
<td></td>
<td>0.026</td>
<td>0.028</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Crash Course of Probabilistic Approach

Hydraulics – Simulations

- 2D model scenarios are run in a batch, automated process
- 30 fluvial/land set; 120 pluvial/land set
Probabilistic Approach (Levees)

<table>
<thead>
<tr>
<th>River Elevation (NAVD 88)</th>
<th>System Response Probability (BL2a)</th>
<th>w/ Intervention</th>
<th>w/o Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>415.00</td>
<td>0.0000000377%</td>
<td>0.000000419%</td>
<td></td>
</tr>
<tr>
<td>421.25</td>
<td>0.00000346%</td>
<td>0.0000230%</td>
<td></td>
</tr>
<tr>
<td>427.50</td>
<td>0.108%</td>
<td>0.553%</td>
<td></td>
</tr>
<tr>
<td>432.90</td>
<td>1.50%</td>
<td>7.05%</td>
<td></td>
</tr>
<tr>
<td>440.00</td>
<td>8.32%</td>
<td>37.0%</td>
<td></td>
</tr>
</tbody>
</table>

System Response Curve - BL2a
Results

WSEL, depth, depth * velocity grids
Annual Exceedance Probability (AEP) grids
Damage curves at any structure
Average Annualized Loss (AAL) for any structure or area
Using the results and probabilities from each model run, a probability grid is generated.
Depth-Damage Functions used in Risk Assessments

- Composite Depth-Damage curves for each structure type were used based on available curves from Hazus
Structure-Level Risk

- Detailed Flood Elevation-Probability Curves can be extracted for any structure of interest based on the underlying model results.
Structure-Level Risk

- Flood Damage Curves can be generated, taking into account uncertainties in structure occupancy and first floor elevations (FFE)
Structure-Level Risk

- Average Annualized Losses (AAL) much more accurate – little to no extrapolation required, unlike with typical studies
“Neighborhood” Damage Curves aggregated from structure data can provide insight into expected damages for multiple properties.
Probabilistic approach can consider accredited, breaching, and natural valley levee scenarios (each w/ associated probabilities).

- Natural Valley
  - Annual Exceedance Probability
  - Levee

- Accredited (w/ Levee)
  - Annual Exceedance Probability
  - Levee

AAL: $1,420

AAL: $24
Fluvial (Riverine) Results: Aggregate

<table>
<thead>
<tr>
<th># Structures with Damage</th>
<th>35,197 of 35,236 (99.9%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg. Annualized Loss (AAL)</td>
<td>$4,848,716</td>
</tr>
</tbody>
</table>

Aggregate Flood Damage Curve

Expected Damage ($)

Annual Exceedance Probability

Total Structure Value: $4,432,548,948
Pluvial (Rainfall) Results: Aggregate

# Structures with Damage 21,491 of 35,236 (61%)
Avg. Annualized Loss (AAL) $10,179,415
Combined Fluvial & Pluvial: Aggregate

AAL (Fluvial): $4,848,716

AAL (Pluvial): $10,179,415

Total AAL: $15,028,131
Hot Spot Map of AAL Loss Ratio (Combined Fluvial and Pluvial)

\[
AAL \text{ Loss Ratio} = \frac{AAL}{Structure \text{ Value}}
\]

High AALs were primarily due to pluvial flooding within low-lying topographic areas.
Probabilistic Mapping – Benefits

- More comprehensive analysis of the flood hazard – from the 50% (2-yr) to the 0.033% (3000-yr) annual chance
- More credible analysis of the flood hazard – modeled scenarios consider multiple uncertainties
- Increased confidence in the probability at which a flood would reach a structure’s first floor elevation
- More accurate flood risk and annualized loss estimates
- Improved way to look at risk behind levees
- True multi-frequency grid outputs (WSEL, depth, velocity, and depth * velocity) applications in both pre- and post-disaster environments
- Enhanced outreach and awareness
Next Steps

- Performing additional pilots now
- Methodology and approach being refined based on continued lessons learned
- Development of guidelines and/or best practices (App C)
- Results to inform insurance premium adjustments in areas, particularly behind levees
- Time will tell…
If you have any questions, please visit below!
https://aecom.jobs/

Geoff Uhlemann
geoffrey.uhlemann@aecom.com
303.796.4783
Mapping Fluvial Hazard Zones: Developing Guidance, Applications & the Pilot Mapping Program

Stephanie DiBettito, CFM
Colorado Water Conservation Board

Joel Sholtes, PhD, PE
USBR Sedimentation and River Hydraulics

Michael Blazewicz
Round River Design

Katie Jagt, PE, CFM
Watershed Science + Design, PLLC

September 27, 2018 2:30pm
CASFM Snowmass
Emergency Preparedness
The Fluvial Hazard Zone (FHZ) is the area a stream has occupied in recent history, could occupy, or could physically influence as it stores and transports sediment and debris. The objective of a mapped FHZ is to identify lands most vulnerable to fluvial hazards in the near term.

Estes Park, Larimer County, Colorado
Photo Credit: Town of Estes Park
Planning for erosion hazards is an essential component of effective river corridor management and the prevention of future flood damages.

Nationally, nearly 25% of flood insurance claims come from areas outside of the 100-year floodplain.

In Colorado, the figure is approximate 51% from the 2013 event alone, and 57% cumulatively, since 1978.*

*Only NFIP claims; meaning they came from people with flood insurance.
The Colorado Water Conservation Board (CWCB) is the state coordinating agency for the National Flood Insurance Program (NFIP). **Floodplains are a matter of statewide importance** and the CWCB has been given the authority to prevent flood damages, regulate and designate floodplains, and ensure proper regulation of floodplains. The CWCB has Rules and Regulations for regulatory floodplains that set higher standards for floodplain management for communities in the state.

The Fluvial Hazard Mapping Program will develop and implement a program for mapping fluvial hazard areas, which will help strengthen the CWCB’s role in **preventing flood damages**, regulate and designate floodplains, and ensure proper regulation of floodplains. The CWCB will **provide technical standards**, conduct studies for communities requesting mapping, and provide **regulatory guidance** for communities interested in **voluntarily** adopting map products.
FHZ PROGRAM GOALS

Goal 1. Develop a scientifically defensible set of standards for Colorado.

Goal 2. Implement fluvial hazard mapping throughout Colorado.

Goal 3: Reduce damage from future flood events by increasing awareness of fluvial (river-related) hazards thereby leading to better land use decisions.
STATE PROGRAMS AND TAC

- Vermont River Corridor Planning and Protection Program
  - Mike Kline

- Washington State Channel Migration Zone Program
  - Patricia Olson
  - Tim Abbe

- Montana Channel Migration Easement Program
  - Karin Boyd
  - Tony Thatcher
FLUVIAL HAZARD ZONE MAPPING TIMELINE

2013
- Front Range Flood
- CWCB’s Flood Recovery Master Planning delineates preliminary Channel Migration Zones for Estes Valley and St. Vrain Creek

2014
- CWCB executes Erosion Hazard Mapping Preliminary Study/Proof of Concept

2015
- CWCB executes Fluvial Hazard Zone Pilot Mapping Program

2017
- CWCB Completes Fluvial Hazard Zone Pilot Mapping Program
Erosion is just one of the geomorphic hazards associated with rivers. Simply measuring, modeling, or calculating erosion or bank retreat is insufficient to capture all hazards in a river corridor. Other geomorphic hazards include deposition, avulsion, and fan processes. This program identifies areas susceptible to erosion but also includes areas where these other geomorphic hazards present risk.
GOAL 1. DEVELOP A SCIENTIFICALLY DEFENSIBLE SET OF STANDARDS FOR COLORADO

FHZ PROTOCOL DEVELOPMENT
PHYSIOGRAPHIC, GEOLOGIC, AND HYDROLOGIC CONTEXT
FLUVIAL HAZARD ZONE MAP COMPONENTS

Not Shown:
• Avulsion Zones (AHZ)
• Disconnected Active River Corridor (D-ARC)

Fluvial Hazard Buffer (FHB)
Fan (F)
Active River Corridor (ARC)
Crossing Flag (CF)
Active River Corridor (ARC):
Where the river has occupied in the past or is likely to occupy in the future.

Four Methods to Delineate an ARC:
- **Headwater**: In steep headwater reaches
- **Fluvial Signature**: In streams with steeper slope or streams that are confined and partially confined by their valley walls or terraces
- **Meander Belt-Width**: In low-sloped streams that are unconfined by the valley margin or terraces
- **Urban**: In urbanized and heavily modified stream corridors also assesses the Disconnected-ARC.
The ARC is mapped based on expert identification of the features that compose an active, geomorphic floodplain. We refer to these features as “fluvial signatures” and define them as landforms that are created by the deposition of sediment or erosion of sediment or bedrock. More than 17 of these out-of-channel geomorphic features have been described by Wheaton et al. 2015, and Brierley and Fryirs 2012.
FLUVIAL SIGNATURE METHOD: ARC DELINEATIONS USING AN REM
FLUVIAL SIGNATURE METHOD: FLUVIAL SIGNATURE DATA AND OBSERVATIONS

\[ W_r = \frac{W_{post}}{W_{pre}} \]
FLUVIAL SIGNATURE METHOD: FLUVIAL SIGNATURE DATA AND OBSERVATIONS

\[ W_r = \frac{W_{\text{post}}}{W_{\text{pre}}} \]

Measured width of fluvial disturbance

Approximate arc width

Photo Credit: Civil Air Patrol

Big Thompson Canyon, Larimer County, Colorado
Fluvial Hazard Buffer (FHB):

Regions, such as terraces or hillsides, that extend outward beyond the ARC and may be susceptible to erosion and mass wasting induced by lateral migration, widening, and incision of the river channel.
<table>
<thead>
<tr>
<th>Valley-Channel Confinement</th>
<th>Fluvial Hazard Buffer Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confined and Partially Confined (Vw/Cw &lt; 7)</td>
<td>3.5 Channel Widths</td>
</tr>
<tr>
<td>Unconfined (Vw/Cw &gt; 7) and near valley margin</td>
<td>2 Channel Widths</td>
</tr>
<tr>
<td>Unconfined (Vw/Cw &gt; 7) and far from valley margin</td>
<td>1 Channel Width</td>
</tr>
<tr>
<td>Piedmont Stream with Highly Erodible Valley Margin</td>
<td>0.5 ARC width</td>
</tr>
</tbody>
</table>
HILLSLIDE EROSION – 2013 FRONT RANGE FLOOD
MEASURING HILLSLOPE FAILURE
Avulsion Hazard Zone:
Areas a channel might occupy during a flood event due to a wholesale shift in channel position on the valley floor.
**Fans:**

Fans are triangular-shaped depositional features that generally form where steep transport reaches meet an unconfined, relatively flat river valley and a reduction in sediment and debris transport capacity causes material to deposit.
GO IN THE FIELD!

Estes Park and Telluride, Colorado
Photo Credit: Katie Jagt and Steph DiBettito
FIELD VERIFY—WHY?

Telluride, Colorado
Photo Credit: Katie Jagt
GOAL 2. IMPLEMENT FLUVIAL HAZARD MAPPING THROUGHOUT COLORADO

FHZ PILOT MAPPING PROGRAM
GOAL 3. REDUCE DAMAGE FROM FUTURE FLOOD EVENTS

FHZ REGULATORY GUIDANCE AND EDUCATION
Evacuation Planning for Extreme Events: Failure of the Cherry Creek Dam

Presented by:
Jeffrey Brislawn, CFM / Wood
Kyle Karsjen, Wood

2018 Annual CASFM Conference
Snowmass, CO: “Tackling the Impossible”
Presentation overview

- Project background
- Planning Situation and Probable Maximum Flood Risk
- Planning Process
- Multi-jurisdictional considerations
- Plan Elements
- Summary/Lessons Learned
Project Background
Purpose

• The goal of the Evacuation Plan is to provide a coordinated strategy to evacuate large numbers of persons from an area of high flood risk within the Cherry Creek Dam protected region to an adjoining area of reduced risk prior to, during and after a dam incident or failure.

In other words:
1. There are a lot of people in the inundation area
2. There is a lot of water coming
3. How do our communities work together to get people out efficiently and effectively?
Watershed and Planning Area

- Cherry Creek Dam completed in 1950
- Managed in conjunction with Chatfield and Bear Creek dams to mitigate flood risk in the Denver area.
- 2017 Army Corps of Engineers Water Control Plan Modification and Dam Safety Modification study identified concerns and mitigation options
Cherry Creek Dam and Reservoir – Perspective View

Source: Army Corps of Engineers
Perspective View Towards Denver
Planning Situation and Probable Maximum Flood Risk
Probable Maximum Precipitation and Flood

- 24.7” in 72 hrs in watershed upstream of Dam
- The PMF produces uncontrolled drainage flooding peak flows of 27,000 cfs at the Cherry Creek gage and 109,000 cfs at the South Platte River at Denver stream gage.
- It would take 40 days to empty the flood water stored in the reservoir and the spillway would flow for about 8 days.
- Assumed that the weather forecast would allow a warning and planning time of approximately 24-72 hours.
Probable Maximum Flood Risk

**Cherry Creek Dam**
Probable Maximum Flood

**CHERRY CREEK DAM - SIGNIFICANT POOL ELEVATIONS**

- **Top of Dam Elevation (5,644.4 feet)**
- **2013 Boulder Flood Elevation (5,630.8 feet)**
- **Spillway Flows Elevation (5,610.6 feet)**
- **June 1973 Record Elevation (5,565.8 feet)**
- **Normal Pool Elevation (5,550 feet)**
- **100 Year Flood Elevation (5,562 feet)**
- **Projected overtopping in PMF* (5,647.6 feet)**

**During PMF*, time from start of spillway flows to overtopping = 4 hours**

**Elevation area under consideration for release triggers (apprx. 5,570 - 5,600 feet)**
20 - 50 feet above normal pool

**Downtown Denver**

- Begins flooding
- 3 hours from overtopping
- Peak flood height
- 4 hours from overtopping

**Operational Releases**

---

* Probable Maximum Flood (Maximum conceivable flooding conditions during an extremely rare rain event.)

** This estimate places rainfall from the 2013 Boulder Flood over the Cherry Creek Basin. Downstream conditions in Denver would have prevented releases from Cherry Creek Dam’s gated outlets. Water would have flowed through the spillway.
Consequence Impact Areas

- In-Pool Area
- Downstream of Spillway
- Downstream of Dam

Source: Army Corps of Engineers
Regional Inundation

Controlled Release (Blue) and Failure (Pink)

FEMA Flood Hazard Areas
Consequences/Planning Situation

- Population at Risk: approximately 300,000 in the inundation area
- Critical facilities, bridges and other infrastructure
- 25,000 buildings impacted
- Hospitals, nursing homes, schools
Planning Process
Evacuation Planning Committee and Working Groups

Developed with input from subject matter experts, stakeholders and local emergency managers

- **Steering Committee**
  - Arapahoe County Emergency Management
  - City and County of Denver Emergency Management
  - City of Aurora Emergency Management
  - Adams County Emergency Management

- **Evacuation Planning Team (EPT)**
  - Regional stakeholders and subject matter experts
    - Army Corps of Engineers
    - Urban Drainage and Flood Control District
    - CO Division of Homeland Security and Emergency Management
    - Regional Transportation District
    - CDOT
    - Colorado State Patrol
Planning Process and Timeline

- Two large group Evacuation Planning Team meetings
  - Kickoff (April 12, 2017)
  - Plan Rollout (October 2017)
- Two working group sessions
  - 2 half-day sessions for each working group in May/June and August
- Monthly coordination calls and additional meetings with Steering Committee
- Initial Draft provided to Steering Committee October 10th, 2017
Planning Process

Planning Considerations from the 2017 Oroville Dam Incident Used to Inform Plan

- Notifications, evacuation warnings and orders
- Transportation of Evacuees
- Shelters and Shelter Operations
- Security of the Evacuated Area
- Diversion, Inundation, and Debris
- Decision support and decision-making
- Intergovernmental Relations and Coordination
Evacuation Zones

• Zones for internal management of incident
• Determined Early on for planning purposes
• In- Pool Area (1)
• Downstream of Spillway (2)
• Downstream of Dam (3-7)
Dam Failure Flood Evacuation Zones and “Island”

- “Island” blue area on map between spillway and Cherry Creek/S Platte may need to be evacuated
  - 324,914 residents
  - Reduced flood risk, but potentially isolated from services should a failure occur
Multi-Jurisdictional Considerations
Multi-Jurisdictional Considerations

Multi-Agency Coordination

- Denver EOC
  - Field Ops
  - Dept Ops
- Adams County EOC
  - Field Ops
  - Dept Ops
- Aurora EOC
  - Field Ops
  - Dept Ops
- Arapahoe County EOC
  - Field Ops
  - Dept Ops
- State EOC
- Federal RRCC

A presentation by Wood.
Evacuation Plan Crosswalk with Local Emergency Operations Plans

Coordination with existing planning mechanisms and emergency procedures

<table>
<thead>
<tr>
<th>Evacuation Components/Annexes</th>
<th>Relevant Emergency Support Function</th>
<th>Relevant Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Plan</td>
<td>• Emergency Management</td>
<td>• Direction and Control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Evacuation</td>
</tr>
<tr>
<td>Communications and Warning</td>
<td>• Communications</td>
<td>• Communications and Warning</td>
</tr>
<tr>
<td></td>
<td>• External Affairs</td>
<td>• Emergency Public Information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Evacuation</td>
</tr>
<tr>
<td>Transportation</td>
<td>• Transportation</td>
<td>• Transportation and Resources</td>
</tr>
<tr>
<td></td>
<td>• Public Works and Engineering</td>
<td>• Evacuation</td>
</tr>
<tr>
<td></td>
<td>• Public Safety and Security</td>
<td></td>
</tr>
<tr>
<td>Access and Functional Needs</td>
<td>• Mass Care</td>
<td>• Sheltering and Mass Care</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Evacuation</td>
</tr>
<tr>
<td>Animal Protection</td>
<td>• Agriculture and Natural Resources</td>
<td>• Sheltering and Mass Care</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Evacuation</td>
</tr>
<tr>
<td>Reunion and Reunification</td>
<td>• Mass Care</td>
<td>• Sheltering and Mass Care</td>
</tr>
</tbody>
</table>

A presentation by Wood.
Plan Elements
Base Plan - Overview

- Situation/overview of hazard
- Relationship to existing plans
- Concept of operations
- Direction, Control and Coordination
- Multi-Agency Coordination System
- Evacuation Decision Making and Authorities
- Roles and Responsibilities
- Plan maintenance and exercising recommendations
## Tiered Activation Stages

<table>
<thead>
<tr>
<th>Evacuation Plan – Stages and Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stage 1 Evacuation</strong> – Controlled release flooding on Cherry Creek, spillway flooding and uncontrolled drainage flooding; the dam is still structurally sound and functioning</td>
</tr>
<tr>
<td>Evacuation Area: Evacuation zones should be evacuated depending on projected release flows with priority on Zones 3, 4, 5, 6 and 7; Spillway flows will necessitate evacuation of Zones 1 and 2</td>
</tr>
<tr>
<td><strong>Phase 1:</strong> Evacuation Watch: immediate preparation for a full-scale evacuation.</td>
</tr>
<tr>
<td><strong>Phase 2:</strong> Evacuation Warning: evacuate</td>
</tr>
<tr>
<td><strong>Stage 2 Evacuation</strong> – Potential Dam Failure Situation</td>
</tr>
<tr>
<td>Evacuation Area: All evacuation zones should be evacuated with priority on Zones 1, 2, 3, 4, and 5; Evacuation of Denver in areas ringed by I-25, I-225 and I-270 as second priority.</td>
</tr>
<tr>
<td><strong>Phase 1:</strong> Evacuation Watch</td>
</tr>
<tr>
<td><strong>Phase 2:</strong> Evacuation Warning</td>
</tr>
<tr>
<td><strong>Stage 3</strong> – Dam Failure</td>
</tr>
<tr>
<td>Evacuation Area: Continued evacuation of all inundation zones excluding the Interstate Ring</td>
</tr>
<tr>
<td>Preparedness/Blue Sky Activities: Building partnerships, exercise, training, personal preparedness</td>
</tr>
</tbody>
</table>
Functional Annexes

- Focused on specific areas of the response requiring jurisdictional coordination
  - Transportation
  - Communications and Warning
  - Access and Functional Needs
  - Family Reunification and Re-entry
  - Animal Protection
- Developed with input from working groups
- Functional considerations as communities execute the response based on jurisdictional response plans
  - Watch vs. Warning phase considerations
- Annexes do not supersede jurisdictional operations
Communications and Warning

Key Elements

• Joint Information Centers (JICs) – Local jurisdictions
• Multi-jurisdictional/multi-agency coordination on communication through Joint Information System (JIS)
  – Unified decisions regarding:
    • What messages will be released – Watch vs Warning
    • When the messages will be released
    • Sample message text edits
    • Coordinated messaging

Lead PIO/Multi-Agency Coordination Flow Chart

Jurisdictional PIO Activated

Lead PIO represents Jurisdiction to collaborate on multi-agency decisions

Lead PIO implements multi-agency decisions under jurisdictional framework
Communications and Warning

Messaging Dissemination Channels and Tools

- IPAWS
- Wireless Emergency Alerts (WEA)
- Wireless Communications
- Radio
- Variable Message Signs
- Television broadcast and message scrolls
- NOAA WX radio
- UDFCD Alert
- Social Media
- Sample Message Templates
- Sample Evacuation Order
Social Vulnerability Considerations

Non English Speaking Populations

Households without Vehicle Access
Transportation Annex

<table>
<thead>
<tr>
<th>Zone number and name</th>
<th>Boundaries/Description</th>
<th>Primary Jurisdictions Involved</th>
<th>Primary Transportation Options</th>
<th>Flood Arrival Time (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1 Reservoir pool</td>
<td>Reservoir pool area- areas adjacent to reservoir and State Park</td>
<td>Arapahoe, Aurora, Greenwood Village, Cherry Creek State Park</td>
<td>Motor vehicle</td>
<td>0-1</td>
</tr>
<tr>
<td>Zone 2a Spillway South</td>
<td>West Tollgate Creek to Colfax Blvd</td>
<td>Arapahoe, Aurora</td>
<td>Motor vehicle RTD - bus</td>
<td>0-1</td>
</tr>
<tr>
<td>Zone 2b Spillway North</td>
<td>West Tollgate Creek from Colfax Blvd, junction with Sand Creek to confluence of South Platte River</td>
<td>Aurora, Adams, Denver, Commerce City</td>
<td>Motor vehicle RTD - bus</td>
<td>1-2</td>
</tr>
<tr>
<td>Zone 3 Arapahoe-Glendale</td>
<td>Cherry Creek Dam to South Colorado Boulevard</td>
<td>Arapahoe, Denver, Glendale</td>
<td>Motor vehicle Foot RTD - bus</td>
<td>1-2</td>
</tr>
<tr>
<td>Zone 4 Denver South</td>
<td>South Colorado Boulevard to W Colfax Ave</td>
<td>Denver</td>
<td>Motor vehicle Foot RTD – bus and light rail</td>
<td>2-3</td>
</tr>
<tr>
<td>Zone 5 Denver Downtown</td>
<td>W Colfax Ave to I-70</td>
<td>Denver</td>
<td>Motor vehicle Foot RTD – bus and light rail, Amtrak</td>
<td>3-4</td>
</tr>
<tr>
<td>Zone 6 Commerce City</td>
<td>I-70 to I-76</td>
<td>Denver, Adams, Commerce City</td>
<td>Motor vehicle RTD - bus</td>
<td>4-5</td>
</tr>
<tr>
<td>Zone 7 Adams County</td>
<td>I-76 to the E 168th Avenue (Adams-Weld County line)</td>
<td>Adams, Brighton</td>
<td>Motor vehicle RTD - bus</td>
<td>5.5</td>
</tr>
</tbody>
</table>
Transportation Appendix

• Supporting maps and statistics
• Interstate Ring ‘Mega Zone’
  – I 25
  – I 225
  – I 270
Evacuation Routes

• Regional Routes and Barricades
  – I 25
  – I 225
  – I 270

• Detailed maps with critical facilities for each zone for emergency managers

• Simple messages for the public that vary based on watch vs warning
Summary / Lessons Learned
Summary / Lessons Learned

• Consequence analysis spurred action and informed planning process
• Emergency managers want to plan for controlled release scenarios, not just dam failure
• Communities want autonomy but recognize the value of working together in a common framework
• Coordination and cross referencing existing jurisdictional plans and procedures key in a multi-jurisdictional effort.
• Drawing the line between evacuation of dangerous areas versus isolated areas
• Overall scope of regional mass evacuation would require additional planning e.g. regional mass care, regional mass evacuation
• Continuity of operations would be challenging due to widespread impacts
Acknowledgements
Acknowledgements

Thanks to everyone that contributed to this effort!

• Arapahoe County
• Denver City and County
• Aurora
• Adams County
• US Army Corps of Engineers
• Working group and Evacuation Planning Team members
• Wood project team
Questions?
Jeff Brislawn
jeff.brislawn@woodplc.com
Innovation in Colorado:
High Hazard Dam Release - Downstream Floodplain Impacts Database and Tools

Bill McCormick, P.E., P.G.
Kallie Bauer, P.E., CFM
Outline

• Why we did this project
• How we did this project
• How the project turned out
• What we Learned
• Where we go from here
Colorado Dam Safety Mission

• Prevent loss of life and property damage from dam failures

• Maximize Safe storage of water

• Technical liaison between dam owners and emergency and floodplain managers
1750ish Program Dams

Dams concentrated in populated areas

425 High Hazard Dams
Spillway Flows
9/20/13
Outlet Releases - Dillon Dam
DISCHARGE CURVE-OUTLET WORKS

2 - 4'-0" x 5'-0" HIGH PRESSURE GATES
1 - 2'-3" x 2'-3" HIGH PRESSURE GATE
Outlet Releases - EAP Activations
2015 - Eleven Mile Canyon Dam
Outlet channel

Spillway channel
Eleven Mile Inundation Map

**Access Road Tunnels**
- 2.0 Miles Downstream of Eleven Mile Canyon Dam
- Maximum Flow Rate (cfs) = 838,745
- Maximum Water Surface Elevation (ft) = 8,410
- Maximum Stage (ft) = 53
- Wave Arrival Time (hr:min) = 0:18
- Time to Peak Flood Stage (hr:min) = 2:50

**Cove Campground**
- 1.2 Miles Downstream of Eleven Mile Canyon Dam
- Maximum Flow Rate (cfs) = 839,724
- Maximum Water Surface Elevation (ft) = 8,479
- Maximum Stage (ft) = 59
- Wave Arrival Time (hr:min) = 0:15
- Time to Peak Flood Stage (hr:min) = 2:50

**Reservoir Campground**
- 0.5 Miles Downstream of Eleven Mile Canyon Dam
- Maximum Flow Rate (cfs) = 840,952
- Maximum Water Surface Elevation (ft) = 8,528
- Maximum Stage (ft) = 45
- Wave Arrival Time (hr:min) = 0:15
- Time to Peak Flood Stage (hr:min) = 2:50

Eleven Mile Canyon Dam
- 0.1 Miles Downstream of Eleven Mile Canyon Dam
- Maximum Flow Rate (cfs) = 844,178
- Maximum Water Surface Elevation (ft) = 8,539
- Maximum Stage (ft) = 54
- Wave Arrival Time (hr:min) = 0:12
- Time to Peak Flood Stage (hr:min) = 2:45

Notes: The base map is the latest USGS Quadrangle maps as of January 2007 and the StreetMap USA database from ESRI, Redlands, CA. Aerial Photography is from the USGS/SCS Douglas, Jefferson and Teller County is dated November of 2005 and Pari County is dated February of 2007.

The flood inundation information shown is based on a computer simulated failure.
Project to highlight the Gap?

• $95,000 project, Funded by NDSP States Grants ($45K) and Colorado Water Conservation Board grant ($50k)
• Created a High Hazard Dam Release - Downstream Floodplain Impacts Database and Ranking Tool
• “Controlled Releases” only
• Safe Channel Capacity Comparisons
• Promote and share information, database and tools with floodplain and emergency managers
Ranked Dams - Statewide
Aug 2017 - Barker and Addicks Dams

- Flood control dams built in 1940
- Water surface in reservoir rising at ½ ft per hour
- Record high elevation
- Outlets opened, releasing 4,000 cfs each
Neighborhoods around Barker and Addicks Reservoir
What Did We Learn?

• Colorado in 2013 and 2015, Texas 2017 show dams operating as designed but still cause dangerous flooding downstream

• Dam Emergency Action Plans have maps for dam failure inundation - of no use in operational release flooding scenarios
Why should Floodplain Managers care about Dams

- Not all dams provide flood control
- FEMA maps don’t show spillway flows or outlet releases
- Dam releases impact floodplain management
1. Use Existing Information
2. Be versatile
3. Be updatable
4. Provide easy access to information
DWR Dam Safety Jurisdictional Dam Database
Colorado High Hazard Dams Release Database
CO High Hazard Dams Release Database – General Information

**General Information**
- Dam Name
- Dam ID
- NID ID
- Latitude
- Longitude
- County
- Stream
- CO Database Drainage Area

**Outlet Works**
- Outlet Capacity
- Outlet Description

**Dam**
- Total Maximum Controlled Discharge
- Type
- Off Channel
- PAR
- Social Vulnerability
- Distance to Downstream Town
- Height
- Length
- Dam Safety Engineer
- Owner Type
- Owner

**Spillways**
- Controlled Capacity
- Total Capacity

**Streamflow Statistics at Dam**
- Drainage Area
- Elevation
- Basin Slope
- EL7500
- Precip
- 16HR100YR
- PK2
- PK5
- PK10
- PK25
- PK50
- PK100
- PK200
- PK500

**Links! Sorting! Views!**
## CO High Hazard Dams Release Database – Initial Ranking

<table>
<thead>
<tr>
<th>Dam Name</th>
<th>Total Max.</th>
<th>Dam and/or Main Channel Drainage Area (ft²)</th>
<th>Q100/Total Max. Controlled Discharge</th>
<th>Rating 1</th>
<th>Rating 2</th>
<th>Rating 3</th>
<th>Rating 4</th>
<th>Rating 5</th>
<th>Total Score</th>
<th>Composite Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIUET HESS</td>
<td>1242.7</td>
<td>10.52</td>
<td>0.00847</td>
<td>30</td>
<td>1.36799</td>
<td>0.1</td>
<td>0.06739</td>
<td>85</td>
<td>0.00080</td>
<td>11</td>
</tr>
<tr>
<td>MAPLE GROVE</td>
<td>13467.0</td>
<td>10.40</td>
<td>0.00077</td>
<td>4</td>
<td>0.17593</td>
<td>3</td>
<td>0.17731</td>
<td>174</td>
<td>0.00007</td>
<td>76</td>
</tr>
<tr>
<td>BEAR CREEK</td>
<td>2000.0</td>
<td>255.67</td>
<td>0.11384</td>
<td>142</td>
<td>1.56500</td>
<td>65</td>
<td>0.01363</td>
<td>13</td>
<td>0.00050</td>
<td>25</td>
</tr>
<tr>
<td>SHAFFIELD</td>
<td>8300.0</td>
<td>3020.77</td>
<td>0.16035</td>
<td>171</td>
<td>1.63855</td>
<td>67</td>
<td>0.07234</td>
<td>90</td>
<td>0.00012</td>
<td>5</td>
</tr>
<tr>
<td>EGGERT &amp; HILLCREST</td>
<td>385.6</td>
<td>1.52</td>
<td>0.00184</td>
<td>15</td>
<td>0.16049</td>
<td>37</td>
<td>0.06072</td>
<td>75</td>
<td>0.00060</td>
<td>91</td>
</tr>
<tr>
<td>CELLY ROAD DETENTION</td>
<td>650.0</td>
<td>10.65</td>
<td>0.01543</td>
<td>52</td>
<td>6.15942</td>
<td>127</td>
<td>0.07083</td>
<td>88</td>
<td>0.00145</td>
<td>61</td>
</tr>
<tr>
<td>JLUNN</td>
<td>420.0</td>
<td>48.25</td>
<td>0.11497</td>
<td>140</td>
<td>2.47619</td>
<td>86</td>
<td>0.00125</td>
<td>17</td>
<td>0.00238</td>
<td>87</td>
</tr>
<tr>
<td>ITANDELEY LAKE</td>
<td>760.0</td>
<td>15.95</td>
<td>0.02292</td>
<td>69</td>
<td>5.55714</td>
<td>122</td>
<td>0.07125</td>
<td>89</td>
<td>0.00143</td>
<td>60</td>
</tr>
<tr>
<td>TALSTON</td>
<td>650.0</td>
<td>46.41</td>
<td>0.07119</td>
<td>119</td>
<td>1.35882</td>
<td>51</td>
<td>0.02852</td>
<td>29</td>
<td>0.00154</td>
<td>62</td>
</tr>
<tr>
<td>RINIAOD</td>
<td>5600.0</td>
<td>671.88</td>
<td>0.12226</td>
<td>143</td>
<td>2.79182</td>
<td>98</td>
<td>0.03338</td>
<td>46</td>
<td>0.00018</td>
<td>10</td>
</tr>
<tr>
<td>SOUTH PLATE RESERVOIR</td>
<td>150.0</td>
<td>0.30</td>
<td>0.00276</td>
<td>10</td>
<td>2.48102</td>
<td>87</td>
<td>0.02993</td>
<td>26</td>
<td>0.00009</td>
<td>180</td>
</tr>
<tr>
<td>MONTGOMERY</td>
<td>1248.0</td>
<td>7.84</td>
<td>0.00631</td>
<td>24</td>
<td>0.25744</td>
<td>8</td>
<td>0.04840</td>
<td>57</td>
<td>0.00080</td>
<td>87</td>
</tr>
<tr>
<td>CHERRY CREEK</td>
<td>8100.0</td>
<td>385.87</td>
<td>0.04761</td>
<td>104</td>
<td>1.80247</td>
<td>71</td>
<td>0.25933</td>
<td>219</td>
<td>0.00012</td>
<td>5</td>
</tr>
<tr>
<td>MALMONT 'A'</td>
<td>210.0</td>
<td>1.52</td>
<td>0.00721</td>
<td>27</td>
<td>1.95238</td>
<td>75</td>
<td>0.06072</td>
<td>75</td>
<td>0.00076</td>
<td>121</td>
</tr>
<tr>
<td>LINTERO</td>
<td>1800.0</td>
<td>150.91</td>
<td>0.10806</td>
<td>138</td>
<td>0.82778</td>
<td>27</td>
<td>0.174</td>
<td>0.03311</td>
<td>45</td>
<td>0.00056</td>
</tr>
<tr>
<td>LOWER CABIN CREEK</td>
<td>549.0</td>
<td>12.85</td>
<td>0.02486</td>
<td>75</td>
<td>0.57013</td>
<td>18</td>
<td>0.142</td>
<td>0.02843</td>
<td>26</td>
<td>0.00182</td>
</tr>
<tr>
<td>ROLLY</td>
<td>195.0</td>
<td>2.05</td>
<td>0.01050</td>
<td>43</td>
<td>0.69231</td>
<td>124</td>
<td>0.07923</td>
<td>97</td>
<td>0.00513</td>
<td>126</td>
</tr>
<tr>
<td>NILON</td>
<td>4800.0</td>
<td>334.09</td>
<td>0.07599</td>
<td>122</td>
<td>0.85691</td>
<td>28</td>
<td>0.82414</td>
<td>236</td>
<td>0.00029</td>
<td>12</td>
</tr>
<tr>
<td>CLEAR CREEK</td>
<td>2145.0</td>
<td>68.77</td>
<td>0.03206</td>
<td>88</td>
<td>0.58275</td>
<td>19</td>
<td>0.2976</td>
<td>39</td>
<td>0.00047</td>
<td>23</td>
</tr>
<tr>
<td>LOUTDER - NORTH</td>
<td>940.0</td>
<td>11.60</td>
<td>0.01234</td>
<td>45</td>
<td>4.85106</td>
<td>114</td>
<td>1.074</td>
<td>0.17822</td>
<td>175</td>
<td>0.00106</td>
</tr>
<tr>
<td>CHAMBERS LAKE</td>
<td>1700.0</td>
<td>31.93</td>
<td>0.01878</td>
<td>56</td>
<td>0.66747</td>
<td>21</td>
<td>0.430</td>
<td>357</td>
<td>0.00211</td>
<td>27</td>
</tr>
</tbody>
</table>
Ranking Dams

What makes a “risky” dam?

• Ability to release “large” discharges relative to drainage area
• Large spillways
• Proximity to population

Ranking Relationships

• Drainage area/Total Maximum Controlled Discharge
• Q100/Total Maximum Controlled Discharge
• Distance to Downstream Town
• Q100/Total Spillway Capacity
• 1/Total Maximum Controlled Discharge
• 1/Total Spillway Capacity
Downstream Consequences

• The “first” habitable structures (at least one)
• The “first” road/railroad (at least one)
# CO High Hazard Dams Release Database

## Potential Downstream Impacts Ranking

<table>
<thead>
<tr>
<th>Dam Name</th>
<th>Dam ID</th>
<th>NID ID</th>
<th>kmz</th>
<th>Controlled Capacity (cfs)</th>
<th>Outlet Capacity (cfs)</th>
<th>Total Max. Controlled Discharge (cfs)</th>
<th>Dam and/or Main Channel Drainage Area (m²)</th>
<th>Initial Ranking</th>
<th>Dam Not Considered by Total</th>
<th>Consequence Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUTTER HESS</td>
<td>080040</td>
<td>CC092469</td>
<td>Google Earth</td>
<td>640</td>
<td>13467.0</td>
<td>13242.7</td>
<td>10.52</td>
<td>1</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>MAPLE GROVE</td>
<td>070219</td>
<td>CC000203</td>
<td>Google Earth</td>
<td>13361.0</td>
<td>13467.0</td>
<td>13242.7</td>
<td>10.52</td>
<td>2</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>CHATFIELD</td>
<td>080324</td>
<td>CC01281</td>
<td>Google Earth</td>
<td>8300.0</td>
<td>8300.0</td>
<td>8300.0</td>
<td>3020.77</td>
<td>4</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>LEGGETT &amp; HILLCREST</td>
<td>060131</td>
<td>CC00232</td>
<td>Google Earth</td>
<td>385.0</td>
<td>385.0</td>
<td>385.0</td>
<td>1.52</td>
<td>5</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>KELLY ROAD DETENTION</td>
<td>060209</td>
<td>CC00345</td>
<td>Google Earth</td>
<td>690.0</td>
<td>690.0</td>
<td>690.0</td>
<td>10.65</td>
<td>6</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>MUNN</td>
<td>070302</td>
<td>CC00980</td>
<td>Google Earth</td>
<td>420.0</td>
<td>420.0</td>
<td>420.0</td>
<td>48.29</td>
<td>7</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>STANLEY LAKE</td>
<td>080226</td>
<td>CC00101</td>
<td>Google Earth</td>
<td>700.0</td>
<td>700.0</td>
<td>700.0</td>
<td>15.93</td>
<td>8</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>RALSTON</td>
<td>070224</td>
<td>CC00205</td>
<td>Google Earth</td>
<td>650.0</td>
<td>650.0</td>
<td>650.0</td>
<td>46.41</td>
<td>9</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>TRINIDAD</td>
<td>190122</td>
<td>CC00050</td>
<td>Google Earth</td>
<td>5500.0</td>
<td>5500.0</td>
<td>5500.0</td>
<td>671.86</td>
<td>10</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>SOUTH PLATTE RESERVOIR</td>
<td>080446</td>
<td>CC02858</td>
<td>Google Earth</td>
<td>0.0</td>
<td>110.0</td>
<td>110.0</td>
<td>0.30</td>
<td>11</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>MONTGOMERY</td>
<td>230134</td>
<td>CC00312</td>
<td>Google Earth</td>
<td>1243.0</td>
<td>1243.0</td>
<td>1243.0</td>
<td>7.84</td>
<td>12</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>CHERRY CREEK</td>
<td>090116</td>
<td>CC01260</td>
<td>Google Earth</td>
<td>0100.0</td>
<td>0100.0</td>
<td>0100.0</td>
<td>305.67</td>
<td>13</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>VALMONT 'A'</td>
<td>060221</td>
<td>CC00256</td>
<td>Google Earth</td>
<td>230.0</td>
<td>230.0</td>
<td>230.0</td>
<td>1.52</td>
<td>14</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>ANTERO</td>
<td>230102</td>
<td>CC00351</td>
<td>Google Earth</td>
<td>1800.0</td>
<td>1800.0</td>
<td>1800.0</td>
<td>190.91</td>
<td>15</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>LOWER CABIN CREEK</td>
<td>070110</td>
<td>CC00240</td>
<td>Google Earth</td>
<td>549.0</td>
<td>549.0</td>
<td>549.0</td>
<td>13.65</td>
<td>16</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>HOLLY</td>
<td>080335</td>
<td>CC02214</td>
<td>Google Earth</td>
<td>195.0</td>
<td>195.0</td>
<td>195.0</td>
<td>2.05</td>
<td>17</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>DILLON</td>
<td>360104</td>
<td>CC00875</td>
<td>Google Earth</td>
<td>4400.0</td>
<td>4400.0</td>
<td>4400.0</td>
<td>334.09</td>
<td>18</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>CLEAR CREEK</td>
<td>110102</td>
<td>CC01434</td>
<td>Google Earth</td>
<td>1500</td>
<td>1500</td>
<td>1500</td>
<td>68.77</td>
<td>19</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>BOULDER - NORTH</td>
<td>060104</td>
<td>CC00215</td>
<td>Google Earth</td>
<td>940.0</td>
<td>940.0</td>
<td>940.0</td>
<td>11.60</td>
<td>20</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>CHAMBERS LAKE</td>
<td>030115</td>
<td>CC00127</td>
<td>Google Earth</td>
<td>1700.0</td>
<td>1700.0</td>
<td>1700.0</td>
<td>31.93</td>
<td>21</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>ENGLEWOOD</td>
<td>080221</td>
<td>CC00300</td>
<td>Google Earth</td>
<td>250.0</td>
<td>250.0</td>
<td>250.0</td>
<td>9.39</td>
<td>22</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>LEYDEN</td>
<td>070209</td>
<td>CC01216</td>
<td>Google Earth</td>
<td>193.0</td>
<td>193.0</td>
<td>193.0</td>
<td>8.87</td>
<td>23</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>TROUT CREEK</td>
<td>110233</td>
<td>CC02813</td>
<td>Google Earth</td>
<td>304.0</td>
<td>304.0</td>
<td>304.0</td>
<td>60.84</td>
<td>24</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>EXPOSITION PARK</td>
<td>020648</td>
<td>CC02816</td>
<td>Google Earth</td>
<td>109.0</td>
<td>109.0</td>
<td>109.0</td>
<td>5.00</td>
<td>25</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
<tr>
<td>GROSS</td>
<td>060221</td>
<td>CC00247</td>
<td>Google Earth</td>
<td>1385.0</td>
<td>1385.0</td>
<td>1385.0</td>
<td>92.96</td>
<td>26</td>
<td>Google Earth</td>
<td>Google Earth</td>
</tr>
</tbody>
</table>
CO High Hazard Dams Release Database – FEMA
Hydraulic Analysis

More than 20 completed

Safe Channel Capacity – just before impacts
Video Instruction

Colorado High Hazard Dams
Video 2 Data Sources
Example - Fossil Creek Dam
<table>
<thead>
<tr>
<th>Hydraulic Analysis Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dam Name</strong></td>
</tr>
<tr>
<td><strong>Dam ID</strong></td>
</tr>
<tr>
<td><strong>Safe Channel Capacity (cfs)</strong></td>
</tr>
<tr>
<td><strong>Discharge Qcont (cfs)</strong></td>
</tr>
</tbody>
</table>

**Safe Channel Capacity Mapping in Google Earth**

<table>
<thead>
<tr>
<th>Reference Flow 1 (cfs)</th>
<th>616</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference Flow 1 Frequency and Source</td>
<td>2-year (SS)</td>
</tr>
<tr>
<td>Reference Flow 2 (cfs)</td>
<td>3450</td>
</tr>
<tr>
<td>Reference Flow 2 Frequency and Source</td>
<td>10-year (SS)</td>
</tr>
</tbody>
</table>

**Hydraulic Analysis Findings**

The safe channel capacity of the reach downstream of Fossil Creek Dam is estimated to be 616 cfs. The maximum controlled discharge is 393 cfs. For comparison, the 2-year peak discharge estimated by StreamStats is 516 cfs; the 10-year peak discharge estimated by StreamStats is 3450 cfs. The downstream impact area is rural. The first impacted roads downstream of the dam are South County Road 5, South County Road 3, and County Road 32 East. The roads may be overtopped at a peak discharge of approximately 616 cfs. The first impacted structure downstream of the dam is located at the end of Watson Drive. The residential house may be flooded at a peak discharge of approximately 616 cfs.
Fossil Creek Dam - Inundation Map

South County Road 5
Peak Discharge = 96,719 cfs
Volume of Flood Wave = 13,899 ac-ft
Time of Peak Flood Wave = 0.17 hours

State Highway
Peak Discharge = 
Volume of Flood Wave = 
Time of Peak Flood Wave = 

Interstate 25
Peak Discharge = 116,780 cfs
Volume of Flood Wave = 14,907 ac-ft
Time of Peak Flood Wave = 0.01 hours
Message for Floodplain Managers

• We know the Risk exists
• Flooding can happen downstream of a dam because of operations
• Know what you don’t know
  • Database can sort by county
  • Information for all high hazard dams
• You might be surprised by the number of dams that can impact your floodplains
• Work together to manage floodplains below dams
Next Steps

- Sharing the database
- Pilot study with Fort Collins:
  - Map outlet flows
  - Analyze data
  - guidelines
Questions?
SHOWCASING THE PILOT BOULDER COUNTY FLOOD RISK INFORMATION SYSTEM (FRIS)

HOLISTIC FLOOD RISK COMMUNICATION
COLORADO’S 5-YEAR FLOOD ANNIVERSARY

DATE: Monday, September 10, 2018
TIME: 10:00AM-11:30AM
LOCATION: Bohn Park
199 2nd Avenue Lyons, CO 80540

When the rains of September 2013 poured down on Colorado and caused flooding, the town of Lyons was severely impacted. Today, however, Lyons is flourishing.
Please join Gov. Hickenlooper and leaders from across the state in commemorating Colorado’s 5-year anniversary of the 2013 floods, and in celebrating the resilience of Colorado communities.

5 years later, Colorado communities continue to rebuild after devastating floods
Five year anniversary of catastrophic floods

BY: Russell Haythorn
POSTED: 6:46 PM, Sep 10, 2018
UPDATED: 7:01 PM, Sep 10, 2018
TAG: colorado flooding anniversary | 2013 floods | floods in colorado | 5 year anniversary | 5 year anniversary of floods
BOCO FRIS

Tags
BOCO FRIS

1. Understanding and Exploring Your Flood Risk Information System
Web Mapping Application
An online system to access and share flood information for your Boulder County community.

2. Calculate Your Base Flood Risk
Web Mapping Application

3. Local’s Knowledge
Web Mapping Application

4. Add Your Flood Knowledge
Web Mapping Application

Building Info

<table>
<thead>
<tr>
<th>Structure Type</th>
<th>One Story No Basement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessed Building Value</td>
<td></td>
</tr>
<tr>
<td>Flood Depth (ft)</td>
<td></td>
</tr>
<tr>
<td>Damage Percent (decimal)</td>
<td></td>
</tr>
<tr>
<td>Calculate Cost Estimate</td>
<td></td>
</tr>
</tbody>
</table>
Geographer and focused on the application of geographic information science and remote sensing to the and science communication. Interested in mixed methods and Participatory GIS

BA in Environmental Studies/GIS Certificate
University of Pittsburgh - 2014
MS in Geographic Information Science
University of Denver – 2018
PhD Geography Student
University of Arizona - current
Flood risk communication is complicated

FIGURE 9.1. Levels of Hazard Evaluation and Risk Assessment
Flood risk communication is complicated


FIGURE 9.1. Levels of Hazard Evaluation and Risk Assessment

Risk = \text{Flood probability} \times \text{Exposure} \times \text{Vulnerability}
Flood risk communication is complicated

Flood risk communication is complicated.
Flood risk communication is complicated

More detailed information
Case Study Location
Top-down, one-way flow of information
Two-way flow of information

Meyer’s et. al (2012)
My Project

- Investigated the application of Geographic Information Science (GIS) to flood risk communication through a pilot project in Boulder County, Colorado

- Explored stakeholders’ preferences in flood risk communication

- Proposed novel products and data layers
Proof-of-concept
New communication tool
Flood Risk Information System
Theoretical framework
Structure-specific data
Public Data

- Geodatabase Dataset Layer Description:
  - FEMA NFHL
  - S_XS Cross-section lines
  - S_Wtr_Ln Stream Centerlines
  - S_Fld_Haz_Ar Flood Hazard Areas (SFHA Polygons)
  - Boulder County's Geospatial Open Data BuildingFootprints Structure/House Polygons
Natural Neighbor

Triangular Irregular Networks (TIN)

Topo to Raster

Inverse Distance Weighted (IDW)
Parameters
Power (P)
Number of points/search radius (N)
Point input (Pt)
Line input (Ln)
Polygon input (Py)
<table>
<thead>
<tr>
<th>Output</th>
<th>Goodness of Fit</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R²</td>
<td>RMSE</td>
</tr>
<tr>
<td>Validation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaN</td>
<td>0.9999</td>
<td>6.013</td>
</tr>
<tr>
<td>TIN</td>
<td>0.9999</td>
<td>6.231</td>
</tr>
<tr>
<td>IDW 3</td>
<td>0.9995</td>
<td>11.462</td>
</tr>
<tr>
<td>IDW 4</td>
<td>0.9995</td>
<td>11.355</td>
</tr>
<tr>
<td>IDW 5</td>
<td>0.9995</td>
<td>11.461</td>
</tr>
<tr>
<td>IDW 6</td>
<td>0.9995</td>
<td>11.350</td>
</tr>
<tr>
<td>IDW 7</td>
<td>0.9995</td>
<td>11.461</td>
</tr>
<tr>
<td>IDW 8</td>
<td>0.9995</td>
<td>11.349</td>
</tr>
<tr>
<td>TPS 9</td>
<td>0.9998</td>
<td>6.746</td>
</tr>
<tr>
<td>TPS 10</td>
<td>0.9998</td>
<td>7.039</td>
</tr>
<tr>
<td>TPS 11</td>
<td>0.9998</td>
<td>6.694</td>
</tr>
<tr>
<td>TPS 12</td>
<td>0.9998</td>
<td>6.677</td>
</tr>
<tr>
<td>Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaN</td>
<td>0.9999</td>
<td>6.260</td>
</tr>
</tbody>
</table>
Coordinate System: NAD 1983 UTM Zone 13N
Projection: Transverse Mercator
Datum: North American 1983
Geometric Classification (10 classes)

Base Flood Water Surface Elevation
NaN Interpolation (ft)
- 4,241 - 4,894
- 4,895 - 5,082
- 5,083 - 5,137
- 5,138 - 5,153
- 5,154 - 5,158
- 5,159 - 5,173
- 5,174 - 5,228
- 5,229 - 5,417
- 5,418 - 6,070
- 6,071 - 8,322
### Table 2

**Structure Two or More Stories, With Basement**

<table>
<thead>
<tr>
<th>Depth</th>
<th>Mean of Damage</th>
<th>Standard Deviation of Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>-8</td>
<td>1.7%</td>
<td>2.70</td>
</tr>
<tr>
<td>-7</td>
<td>1.7%</td>
<td>2.70</td>
</tr>
<tr>
<td>-6</td>
<td>1.9%</td>
<td>2.11</td>
</tr>
<tr>
<td>-5</td>
<td>2.9%</td>
<td>1.80</td>
</tr>
<tr>
<td>-4</td>
<td>4.7%</td>
<td>1.66</td>
</tr>
<tr>
<td>-3</td>
<td>7.2%</td>
<td>1.56</td>
</tr>
<tr>
<td>-2</td>
<td>10.2%</td>
<td>1.47</td>
</tr>
<tr>
<td>-1</td>
<td>13.9%</td>
<td>1.37</td>
</tr>
<tr>
<td>0</td>
<td>17.9%</td>
<td>1.32</td>
</tr>
<tr>
<td>1</td>
<td>22.3%</td>
<td>1.35</td>
</tr>
<tr>
<td>2</td>
<td>27.0%</td>
<td>1.50</td>
</tr>
<tr>
<td>3</td>
<td>31.9%</td>
<td>1.75</td>
</tr>
<tr>
<td>4</td>
<td>36.9%</td>
<td>2.04</td>
</tr>
<tr>
<td>5</td>
<td>41.9%</td>
<td>2.34</td>
</tr>
<tr>
<td>6</td>
<td>46.9%</td>
<td>2.63</td>
</tr>
<tr>
<td>7</td>
<td>51.8%</td>
<td>2.89</td>
</tr>
<tr>
<td>8</td>
<td>56.4%</td>
<td>3.13</td>
</tr>
<tr>
<td>9</td>
<td>60.8%</td>
<td>3.38</td>
</tr>
<tr>
<td>10</td>
<td>64.8%</td>
<td>3.71</td>
</tr>
<tr>
<td>11</td>
<td>68.4%</td>
<td>4.22</td>
</tr>
<tr>
<td>12</td>
<td>71.4%</td>
<td>5.02</td>
</tr>
<tr>
<td>13</td>
<td>73.7%</td>
<td>5.19</td>
</tr>
<tr>
<td>14</td>
<td>75.4%</td>
<td>7.79</td>
</tr>
<tr>
<td>15</td>
<td>76.4%</td>
<td>9.84</td>
</tr>
<tr>
<td>16</td>
<td>76.4%</td>
<td>12.36</td>
</tr>
</tbody>
</table>

---

**5 ft Flood Depth**

**$80,0000 Damage**

**3 ft Flood Depth**

**$40,0000 Damage**

US Army Corps Eng (EGM) 04-01 2003
Local Knowledge
Local Knowledge
Focus Groups:
- **Community Planners:** members/employees of the local, state, federal, or private organizations

- **Community Members:** homeowners and renters in Boulder County

Event Tasks:
- Pre-survey
- Guided Group Discussion
- Post-survey

<table>
<thead>
<tr>
<th></th>
<th>Community Members</th>
<th>n=8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Year Born</td>
<td></td>
<td>1957</td>
</tr>
<tr>
<td>Hispanic</td>
<td></td>
<td>100% - No</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td>100% - White</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td>5 Female : 3 Male</td>
</tr>
<tr>
<td>Residence</td>
<td></td>
<td>100 % - Own Home</td>
</tr>
<tr>
<td>Time at current residence</td>
<td></td>
<td>(\leq 1) yr one: 2-4 yr two: 5-9 yr one: (\geq 10) four</td>
</tr>
<tr>
<td>Current primary residence in a flood zone</td>
<td>Response:</td>
<td>1 Unsure: 4 No: 3 Yes</td>
</tr>
<tr>
<td></td>
<td>Reality:</td>
<td>2 No : 6 Yes</td>
</tr>
<tr>
<td>Have you experienced a flooding event</td>
<td></td>
<td>100 % - Yes, personally</td>
</tr>
</tbody>
</table>
Focus Groups:

- **Community Planners:** members/employees of the local, state, federal, or private organizations

- **Community Members:** homeowners and renters in Boulder County

Event Tasks:
- Pre-survey
- Guided Group Discussion
- Post-survey

<table>
<thead>
<tr>
<th>Community Planners</th>
<th>n=8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization Type</td>
<td></td>
</tr>
<tr>
<td>LOCAL</td>
<td>5</td>
</tr>
<tr>
<td>STATE</td>
<td>1</td>
</tr>
<tr>
<td>FEDERAL</td>
<td>1</td>
</tr>
<tr>
<td>PRIVATE</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Community Members</th>
<th>n=8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Year Born</td>
<td>1957</td>
</tr>
<tr>
<td>Hispanic</td>
<td>100% - No</td>
</tr>
<tr>
<td>Race</td>
<td>100% - White</td>
</tr>
<tr>
<td>Gender</td>
<td>5 Female : 3 Male</td>
</tr>
<tr>
<td>Residence</td>
<td>100 % - Own Home</td>
</tr>
<tr>
<td>Theme</td>
<td>FG1</td>
</tr>
<tr>
<td>---------------------------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>Web map has more data/basemap provides context</td>
<td>7</td>
</tr>
<tr>
<td>Web map is interactive</td>
<td>4</td>
</tr>
<tr>
<td>Web map has color</td>
<td>1</td>
</tr>
<tr>
<td>Web map starts conversation</td>
<td>2</td>
</tr>
<tr>
<td>Web map is simple/understandable</td>
<td>1</td>
</tr>
<tr>
<td>Web map is more accessible</td>
<td>-</td>
</tr>
<tr>
<td>Static map is simple/understandable</td>
<td>4</td>
</tr>
<tr>
<td>Static map is more accessible</td>
<td>1</td>
</tr>
<tr>
<td>Static map has more data</td>
<td>2</td>
</tr>
<tr>
<td>Static map is more trustworthy</td>
<td>1</td>
</tr>
</tbody>
</table>
What are the pros and cons of structure-specific data?

<table>
<thead>
<tr>
<th>Theme</th>
<th>FG1</th>
<th>FG2</th>
<th>Total</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provides more detailed risk info</td>
<td>7</td>
<td>4</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>Starts engagement</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Simple/clear</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Information is confusing</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Provides too much info</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Information not useful</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>A more general tool preferred</td>
<td>-</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>
What are the pros and cons of incorporating local knowledge?

<table>
<thead>
<tr>
<th>Local Knowledge</th>
<th>FG1</th>
<th>FG2</th>
<th>Total</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helpful format</td>
<td>3</td>
<td>11</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>Allows for contribution</td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Useful for mapping/other efforts</td>
<td>5</td>
<td>-</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Impacts people quickly</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Starts engagement</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Provides too much information</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Information purpose is confusing</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Dislike data management requirement</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
What are the pros and cons of incorporating local knowledge?

<table>
<thead>
<tr>
<th>Local Knowledge</th>
<th>FG1</th>
<th>FG2</th>
<th>Total</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Helpful format</strong></td>
<td>3</td>
<td>11</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td><strong>Allows for contribution</strong></td>
<td>5</td>
<td>1</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td><strong>Useful for mapping/other efforts</strong></td>
<td>5</td>
<td>-</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td><strong>Impacts people quickly</strong></td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>Starts engagement</strong></td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
What additional information or data would you like included in the FRIS?

<table>
<thead>
<tr>
<th>Other Data/Information For FRIS</th>
<th>FG1</th>
<th>FG2</th>
<th>Total</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background, statistics, and information on flooding</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Action information for during an event</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Live flood data and warnings</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Information for other types of local hazards</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Information to protect/improve home</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Characteristic of community relating to flooding and communication</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Outreach information</td>
<td>-</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Local insurance information</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 9: Project prioritization matrix evaluating benefits and challenges (Esri 2018)
<table>
<thead>
<tr>
<th>App Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRIS App</td>
<td>An App of Apps. Organizes and displays other four applications</td>
</tr>
<tr>
<td>Understand Your Flood Risk Information System</td>
<td>A story map that provides background information on flooding and Boulder County</td>
</tr>
<tr>
<td>Calculate Your Base Flood Risk</td>
<td>Provides users with depth and cost estimates for structures</td>
</tr>
<tr>
<td>Local's Knowledge</td>
<td>Displays VGI and NFHL layers together</td>
</tr>
<tr>
<td>Add Your Flood Knowledge</td>
<td>Allows users to actively contribute to VGI layer</td>
</tr>
</tbody>
</table>

ArcGIS Online
Building Footprints

- Configurable Apps
- App Templates
- App Builders
- Widgets Components
- SDKs
- APIs

Easier, quicker, coarse-grained, more black box, less coding.

More effort, more time, fine-grained, more control, more coding.
https://tinyurl.com/FRIS-CASFM
Understanding and Exploring Your Flood Risk Information System

An online system to access and share flood information for your Boulder County community. This pilot project allows the sharing of flood information for community stakeholders. Our hope is to increase the entire community’s flood risk knowledge so appropriate, preventive action can be taken.
Online Community Flood Risk Products and Data

Electronic survey
5 questions
77 responses
65 different communities
Does your community have flood risk information available online?

- Yes: 45
- No: 29
- I don't know: 14
Does the community's website have an interactive, dynamic WebApp or WebMap?

N= 45
(45 responded ‘Yes’ to online FRI)

16

29

Yes  No
Does the WebApp or WebMap have the following? (Select all that apply)

N= 27
(29 responded ‘Yes’ to online web map)

- Flood Zones (i.e. 1% AEP inundation area) 25
- Cross sections and/or base flood elevations lines 14
- Building Footprints 14
- Topographic Data (i.e. contours) 13

(29 responded ‘Yes’ to online web map)
Discussion

• Set out to create a proof-of concept tool that promotes communication specifically the exchange of flood risk information.

• Limitations included, the FRIS was a successful proof-of-concept project that addresses the main gaps accentuated by government reports, academic literature, and the community feedback.

• FRIS products are not “one size fits all” or static.
Future

• Incorporate new NFHL as it becomes effective

• Explore improvements for structure specific tool

• More focus groups to increase participants representation of the community

• Product testing, implementation, improvement

• Use FRIS to advocate for more/new data (especially non-regulatory)
The University of Denver Geography and the Environment Department
DR. HILLARY B. HAMANN, DR. JING LI, DR. E. ERIC BOSCHMANN

Colorado Water and Conservation Board
THUY PATTON, STEPHANIE DIBETITTO, CAROLYN KEMP

Boulder County
ERIN COOPER, DAVE WATSON

The Urban Drainage and Flood Control District
TERRI FEAD, MORGAN LYNCH, KEVIN STEWART

The Army Corps of Engineers
PATRICK NOWAK
Funded by

Laurance C. Herold Fund

2017 GIS in the Rockies Scholarship


Burningham, Kate, Jane Fielding, and Diana Thrush. 2008. ‘It'll never happen to me’: understanding public awareness of local flood risk. *Disasters* 32, no. 2 (June 1,) : 216-238.


Questions?
CASFM 2018 Annual Conference

**Floodplain Management Sessions:**

**Session 1:** Local Choices and How They Can Impact the National Flood Insurance Program  
Traci Sears (Montana DNRC)

**Session 2:** Hyper Hydrology: A Holistic View of Colorado Hydrology  
Chris Ide (Wood), Joshua Hill (Wood)

**Making The Most Of It:** Leveraging The CHAMP Study For Other Uses  
Erin Cooper (Boulder County), Olivia Cecil (Boulder County), Kevin Doyle (Michael Baker Intl.)
LOCAL CHOICES
And How They Can Impact the National Flood Insurance Program

September 26, 2018
AN AGREEMENT

FEDERAL GOVERNMENT makes subsidized flood insurance available within the community

LOCAL COMMUNITIES adopt and enforce floodplain regulations that meet FEMA requirements (VOLUNTARY)
June 17, 1950 Flood of Alkali and Antelope Creeks

Ed S. Bacon bunkhouse

on Milwaukee tracks

Rich and Sue Knudsen
Box 179
Harlowton, MT 59526

MTDNRC
PO Box 201601
Helena, MT 59602-1601

Dear [Name],

Here are copies of the letters my aunt wrote to her aunt and uncle following the flood of 6/17/1950, here in Harlowton. The pictures are of her parents' property, a mile and a half north of town on the Old Gap Road. The house was moved to Harlow and we now live in it. My son and I still own the property north of town. According to her brother and Dad, the wall of water 9 feet high at the barn came down Alkali Creek to start with as 9 cars derailed with the 460-space.

Our son has added to the bunkhouse and now lives in it. After the flood, it was moved to higher ground.

Hope you might find a use for these.

Happy Thanksgiving to all of your crew!

Rich and Sue Knudsen

RECEIVED
NOV 18 2017
D.N.R.C
'Neighborhood should have not been built': Homeowners file lawsuit against developer after flooding issues

Bloomberg Businessweek
August 31, 2017, 3:09 AM MDT

Harvey Wasn’t Just Bad Weather. It Was Bad City Planning

Houston exulted in sprawling, hands-off growth. That’s no way to prepare for natural catastrophes.
Example Permit Application Request - Background Information

- Tongue River residential home
  - Pre-FIRM – built in 1972
  - Mapped into floodplain in 2010 with new study
  - Since 2010 – entire home is located in AE Zone Floodway

- In 2017, the homeowner submits floodplain application to:
  - Add an addition to the house – one bedroom and additional bathroom
  - Proposed elevation of addition same as existing house

- Permit was denied because:
  - Existing code allows no new structures in floodway
  - Existing code requires New construction or substantial improvement of any residential structure ...... lowest level of floor is at two feet above the base flood elevation

The existing residential structure is one foot below the Base Flood Elevation (BFE)
Proposed variances from must show the following:

- Good and Sufficient cause is shown
- An exceptional hardship to the applicant exists
- The variance provides the minimum necessary action to afford relief
- The variance will not increase flood heights, cause additional threats to public safety, cause extraordinary public expense, create nuisances, cause fraud or victimization of the public, or conflict with local laws or ordinances.
- If a variance is granted, the community must maintain a record of all variances
- Variances are for floodplain management purposes only and could significantly affect insurance premium rates on affected structures.

BEST ADVICE TO DECISION MAKING BOARDS – DON’T GRANT THESE VARIANCES UNLESS ABSOLUTELY NECESSARY
Mitigation and Recovery

- Keys to Recovery Success
  - Act quickly
  - Actively plan
  - Engage the community
  - Develop partnerships, networks and effective coordination strategies

- Systematic and inclusive
- Leadership and unity of effort
- Pre-disaster & post-disaster recovery planning
Basic Enforcement Process

• Right to inspection (inspection of work in progress)
• Stop work order
• Revocation of permit
• Right to periodic inspection
• Violations to be corrected
• Actions in event of failure to take corrective actions
• Order to take corrective actions
• Appeal
• Failure to comply
• Section 1316
How is Section 1316 used?

• Intended for use primarily as a backup for local enforcement actions (i.e., if a community could not force compliance through the enforcement mechanisms in its regulations, it could use Section 1316 as additional leverage)

• Not intended merely as a mechanism to remove bad risks from the policy base

• Section 1316 will only be implemented in instances where States or communities submit declarations specifically for that purpose.
No Adverse Impact

Managing principle focused on the impact on others

- Protects property rights—ensures action of any property owner does not adversely impact the property rights of others
- Leads to reduced flood losses while promoting better stewardship and community mitigation efforts
- Prevention of harm is treated different legally than making the community a better place—tougher to challenge in court
Thank you!

- **Traci Sears**  
  (406) 444-6654  
  tsears@mt.gov
Hyper Hydrology: A Holistic View of Colorado Hydrology

Through the Colorado Hazard Mapping Program

woodplc.com
Outline

• CHAMP III Overview
• Colorado’s Hydrologic Regions
• Hydrology Methods
• Hydrologic Region Specifics

THANK YOU!
CHAMP III
Colorado Hazard Mapping Program – Phase III
Modernized vs. Unmodernized
Modernized vs. Unmodernized
Phase III Goals

- Modernize 12 counties
  - LiDAR / IFSAR with Bathymetry
  - Survey
  - Hydrology
  - Hydraulics
  - Floodplain Mapping

- Digitize 12 counties
Phase III Scope

- Digital Conversion
- New Floodplain Mapping

- **A**: 863.5 miles
- **AE**: 112.0 miles
Colorado’s Hydrologic Regions
Colorado Hydrologic Regions

Plains Regions
Paleoflood Investigations to Improve Peak-Streamflow Regional-Regression Equations for Natural Streamflow in Eastern Colorado, 2015
USGS SIR 2016-5099

West Regions
Regional Regression Equations for Estimation of Natural Streamflow Statistics in Colorado, 2009
USGS SIR 2009-5136
Hydrology Methods
Bulletin 17C Gage Analysis

USGS and DWR
Peak Flows
Hydrologic Modeling

HEC-HMS
- SCS Type II Rainfall Distributions
- Atlas 14 Rainfall Totals
- TR-55 Curve Number
- Wood Tools
  - Basin Delineation
  - Time of Concentration
Regression Equations
Rain-on-Grid

- HEC-RAS 5.0.5
  - HMS Parameters
  - Input Hydrographs
Rain-on-Grid
Hydrologic Region Specifics
Southwest Region

Peak Streamflow Regression Equation

\[ Q_{100} = 10^{2.91} A^{0.59} (A - 7500)^{-0.35} \]

Drainage Area

Percentage of A above 7,500 feet (plus 1)

Challenges:

- Regression was overestimating peak flows for low-lying areas.
- HEC-HMS models were overestimating runoff for high-elevation basins.
The peak flow is overestimated when there is a small percentage of drainage area above 7,500 ft.
Southwest Region

The peak flow is overestimated when there is a small percentage of drainage area above 7,500 ft.

Used Utah regression equations for low-lying areas near Colorado-Utah border.

\[
PK100 = 115,000 \times DRNAREA^{0.393} \times (ELEV/1,000)^{-2.58}
\]

- Drainage Area
- Average Basin Elevation
Southwest Region

Bulletin 17C

HEC-HMS

HEC-HMS > 3x Bulletin 17C
Southwest Region

Rainfall

Land Use

Initial Abstraction
Southwest Region

Rainfall

Applied Aerial Reduction Factor (ARF)

ARF=0.75

Land Use

Modified Land Use Classifications/Curve Numbers

Barren Land → Pinyon-Juniper

Initial Abstraction

Increased Initial Abstraction Ratio in High-Elevation Basins

0.2 (Default) → 0.3-0.4


22 A presentation by Wood.
IC1  Land use - Rock is not a CN 98
    Ide, Christopher, 9/20/2018

IC2  Initial Abstraction - Porus rock as well.
    Ide, Christopher, 9/20/2018
Northwest Region

Peak Streamflow Regression Equation

\[ Q_{100} = 10^{0.93} A^{0.74} A_{7500}^{0.81} P^{1.65} \]

Challenges:
- Unable to calibrate HEC-HMS models using regression due to overestimation of peak flows for low-lying areas.
- Lack of nearby stream gage data to calibrate HEC-HMS models.
Northwest Region

Compared StreamStats drainage basin parameter outputs to HEC-HMS inputs

- Precipitation
- Time of Concentration
- Curve Number
Mountain Region

Peak Streamflow Regression Equation

\[ Q_{100} = 10^{-0.46} A^{0.75} S^{0.14} P^{1.35} \]

Challenges:
- HEC-HMS models were overestimating runoff for high-elevation basins.
Plains Region

Peak Streamflow Regression Equation

\[ Q_{0.01} = 10.0654 \times 40.403 \times C^{0.593} \]

**Challenges:**
- Regression peak flows are highly dependent of the percentage of clay in the basin. Can produce highly variable and sometimes unreasonable results.
Plains Region

For smaller basins, higher percentages of clay can drastically increase peak flows.

Small amounts of clay produce unreasonably low peak flows.
Regression results were highly variable and often did not produce reasonable results.

Verified HEC-HMS results using Kansas and Nebraska regression equations, StreamStats parameter comparisons, and other studies conducted in the area.

Plains Region

- Frenchman Creek (A=235 mi²)
- Unnamed Stream (A=16 mi²)
Rio Grande Region

Peak Streamflow Regression Equation
\[ Q_{100} = 10^{-0.19} A^{0.87} P^{1.17} \]

- Drainage Area
- Mean Annual Precipitation

Challenges:
- HEC-HMS models were overestimating runoff for high-elevation basins.
- Difficult to model hydraulics in flat areas.
Rio Grande Region
Rio Grande Region

Modified high-elevation basin parameters
Rio Grande Region
Rio Grande Region

Inflow Hydrographs

Runoff Hyetographs
Summary
Summary – Southwest Region

Challenges:
• Regression was overestimating peak flows for low-lying areas.
• HEC-HMS models were overestimating runoff for high-elevation basins.

Solutions
• Used neighboring state regression equations (when appropriate).
• Modified HEC-HMS input parameters for high-elevation basins and calibrated to downstream stream gages.
Summary – Northwest Region

Challenges:
- Unable to calibrate HEC-HMS models using regression due to overestimation of peak flows for low-lying areas.
- Lack of nearby stream gage data to calibrate HEC-HMS models.

Solutions
- Compared StreamStats drainage basin parameter outputs for HEC-HMS calibration.
Summary – Mountain Region

Challenges:
• HEC-HMS models were overestimating runoff for high-elevation basins.

Solutions
• Modified HEC-HMS input parameters for high-elevation basins and calibrated to similar, nearby stream gage basins.
Summary – Plains Region

Challenges:
• Regression peak flows are highly dependent of the percentage of clay in the basin. Can produce highly variable and sometimes unreasonable results.

Solutions
• Use regression equations with caution when the percentage of clay is on either end of the allowable range.
• Use neighboring state regression equations (when appropriate) and StreamStats drainage basin parameter outputs for HEC-HMS calibration.
Summary – Rio Grande Region

Challenges:
• HEC-HMS models were overestimating runoff for high-elevation basins.
• Difficult to model hydraulics in flat areas.

Solutions
• Modified HEC-HMS input parameters for high-elevation basins and calibrated to similar, nearby stream gage basins.
• Modeled hydrology/hydraulics for streams in the flat San Luis Valley using 2-D methodologies.
### Summary

<table>
<thead>
<tr>
<th>Hydrologic Region</th>
<th>Challenges</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southwest</td>
<td>Regression was overestimating peak flows for low-lying areas. HEC-HMS models were overestimating runoff for high-elevation basins.</td>
<td>Used neighboring state regression equations (when appropriate). Modified HEC-HMS input parameters for high-elevation basins and calibrated to downstream stream gages.</td>
</tr>
<tr>
<td>Northwest</td>
<td>Unable to calibrate HEC-HMS models using regression due to overestimation of peak flows for low-lying areas. Lack of nearby stream gage data to calibrate HEC-HMS models.</td>
<td>Compared StreamStats drainage basin parameter outputs for HEC-HMS calibration.</td>
</tr>
<tr>
<td>Mountain</td>
<td>HEC-HMS models were overestimating runoff for high-elevation basins.</td>
<td>Modified HEC-HMS input parameters for high-elevation basins and calibrated to similar, nearby stream gage basins.</td>
</tr>
<tr>
<td>Plains</td>
<td>Regression peak flows are highly dependent of the percentage of clay in the basin. Can produce highly variable and sometimes unreasonable results.</td>
<td>Use regression equations with caution when the percentage of clay is on either end of the allowable range. Use neighboring state regression equations (when appropriate) and StreamStats drainage basin parameter outputs for HEC-HMS calibration.</td>
</tr>
<tr>
<td>Rio Grande</td>
<td>HEC-HMS models were overestimating runoff for high-elevation basins. Difficult to model hydraulics in flat areas.</td>
<td>Modified HEC-HMS input parameters for high-elevation basins and calibrated to similar, nearby stream gage basins. Modeled hydrology/hydraulics for streams in the flat San Luis Valley using 2-D methodologies.</td>
</tr>
</tbody>
</table>
MAKING THE MOST OF IT: Leveraging The CHAMP Study For Other Uses

Erin Cooper, Boulder County
Olivia Cecil, Boulder County
Kevin Doyle, Michael Baker Intl.
CHAMP & Boulder County

- 2015 – Senate Bill 15-245 funds Colorado Hazard Mapping Program (CHAMP)
- 270 miles of CHAMP study area are within Boulder County
Benefits from CHAMP study

- Improving county processes
- Enhancing local understanding of flood risk through improved communication
- New & innovative ways to put the flood study to use
Putting CHAMP to Use

Some of the ways Boulder County has leveraged the CHAMP study:

1. Best Available Information
2. Planning & Permitting
3. FEMA CRS Credits
4. LiDAR LOMAs
5. Overtopping
   • Depth & Velocity Grids
   • Capacity
6. Evacuation Priorities
1. Best Available Information

Extensive outreach & early guidance on revised predictions for flood risk – powerful information to help property owners understand the coming changes.

Boulder County “FO District” = FEMA Floodplain + Boulder County Floodplain
1. Best Available Information

Floodplain maps now show two flood studies as one regulatory tool

FEMA Regulatory Floodplain

Boulder County Floodplain

Floodplain Overlay District

FEMA Floodplain

FEMA Floodway

CHAMP Floodplain

CHAMP Floodway

Composite Floodplain

Composite Floodway
2. Permitting Decisions using BFEs

- New structures built above CHAMP BFE
- Permitting approved/denied based on CHAMP flood risk zones (Floodplain Overlay District)
2. Permitting Decisions – comparing to CHAMP vs. Effective

No-rise & CLOMR/LOMR analyses compared to CHAMP vs compared to effective
3. FEMA Community Rating System

- Credit for early regulation to the CHAMP study
  - New Study credit
  - Floodway Standard
- Community discounts on flood insurance premiums

410 FLOOD HAZARD MAPPING

The OBJECTIVE of this activity is to improve the quality of the mapping that is used to identify and regulate development at risk from flood hazards.
What else can we do with all this data
What other groups could use the data

- Floodplain Department
- OEM
- Transportation
- Land Use Planning
- Public Health
4. LiDAR LOMAs
4. LiDAR LOMAs

Boulder County Successes:
- 10+ LiDAR LOMAs approved for residents
- Residents are eligible for a flood insurance reimbursement

Data included in LOMA submittal:
- Annotated FIRM, FIRMette
- CHAMP FIS profile with BFE shown
- LiDAR Final Accuracy Report
- Topographic Map
- Subdivision Plat Map
- CHAMP Phase I data for reach
- Memo to FEMA from Boulder County
5 & 6. Overtopping and Evacuation

Lower Recurrence Intervals added to HMS models
5 & 6. Overtopping and Evacuation

Additional Products
created with existing 10, 25, and 50 year flow data
5 & 6. Overtopping and Evacuation

Vulnerable Roads & Bridge Spatial Files

Bridge Capacity Spatial Files
Closing

- Applying CHAMP data and products to the benefit of existing County processes, plans, and programs.
- Developing new ways to put flood study data to work to benefit the County & residents and build Resilience.
- “Standing on the Shoulders of Giants”
Thank you!

Boulder County

Erin Cooper, CFM
escooper@bouldercounty.org

Olivia Cecil, EIT
ocecil@bouldercounty.org

Michael Baker International

Kevin Doyle, PE
kdoyle@mbakerintl.com
Green Infrastructure Sessions:

Session 1: Quantifying Volume Reduction in Grass Buffers and Swales
Andrew Earles (Wright Water Engineers), Derek Rapp (Peak Stormwater), Jim Wulliman and Sara Johnson (Muller Engineering), Holly Piza (UDFCD)

Session 2: Navigating the New Jersey & Washington State Stormwater Programs as Models for Approving Manufactured Treatment Devices
Mark B. Miller (AquaShield, Inc.)

Permaculture and Low Impact Development (LID)
Patrick Padden (Padden Permaculture)

Comprehensive Watershed Planning: Prioritize, Target and Implement Multipurpose Projects
Darren Beck (HR Green, Inc.)

Developing a Comprehensive Stormwater Infrastructure Master Plan
Drew Beck (Matrix Design Group)

Strategic Planning for Green Infrastructure in Boulder
Candice Owen (City of Boulder)
QUANTIFYING VOLUME REDUCTION IN GRASS BUFFERS AND SWALES

Andrew Earles, Wright Water Engineers
Derek Rapp, Peak Stormwater
Jim Wulliman and Sara Johnson, Muller Engineering
Holly Piza, UDFCD

CASFM 2018
4-Step Process

- Reduce Runoff LID/MDCIA
- Treat & Slowly Release WQCV
- Stabilize Stream Channel
- Protected Receiving Water
- Source Controls
New MS4 Design Standard

(C) Runoff Reduction Standard

- Directly Connected Impervious Area (DCIA)
- Unconnected Impervious Area (UIA)
- Receiving Pervious Area (RPA)
- Separate Pervious Area (SPA)

Total Runoff Volume ≤ 40% WQCV
Infiltration

- **Infiltration Research**
  - Pitt and Lantrip, 2000
  - Colorado Field Studies

- Soil
- Vegetation

---

*Infiltration Through Disturbed Urban Soils*

Robert Pitt and Janice Lantrip

Prior research by Xie (1997) examined soil cores from paved and roofed surfaces in urban areas and showed infiltration rates at these surfaces were the same as on highway pavements and found that very little water was infiltrated. During earlier research, it was observed that urban soils did not behave as indicated by some earlier experiments conducted by the Colorado Division of Water Resources (CDWR) in Colorado. In Table 1.1, Xie measured highly variable infiltration rates. However, A and M hydrologic groups had an initial rate about 15 to 20 times higher than the initial rate of about 2.5 to 3 inches per hour. Infiltration rates generally ranged from 0 to 20 inches per hour. Areas that experienced extreme rainfall, high runoff, and advection such as the highest infiltration rates. It was hypothesized that most of the observed variations in infiltration rates were due to the following factors:

In attempts to explain the variations, different factors were considered in the following case.
Infiltration Rates
(Pitt and Lantrip, 2000)

Sandy Soils
Infiltration (iph)

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed non-compacted</td>
<td>39</td>
<td>15</td>
</tr>
<tr>
<td>Observed compacted</td>
<td>15</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Clayey Soils
Infiltration (iph)

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed dry non-compacted</td>
<td>18</td>
<td>6.6</td>
</tr>
<tr>
<td>Observed dry compacted and saturated</td>
<td>3.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Published</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.05</td>
</tr>
</tbody>
</table>
Central Colorado Field Studies

- Douglas County/SEMSWA
- 4 Sites (2012-2015)
  - Residential
  - Park
  - Commercial
  - SEMSWA Office Swale
- Soil types
  - Sandy Loam
  - Clay Loam
- Sheet flow infiltration

SEMSWA office swale
Central Colorado Field Studies

Sheet flow infiltrated vs time

Assumed minimum infiltration capacity

Infiltration, inches

Time, min

Orth, Heritage 1, Salera, SEMSWA swale
Central Colorado Field Studies

Sheet flow infiltration rate vs time

Infiltration rate, Inches per hour (iph)

Time, min

Orth
Heritage 1
Solara swale
SEMSWA swale
## Two Ends of the Soil Spectrum

<table>
<thead>
<tr>
<th>Property</th>
<th>Sandy</th>
<th>Clayey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage rate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Aeration</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Water holding capacity</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Organic content</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Ability to store plant nutrients</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Adsorption of pollutants</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>
Topsoil: “Searching for the Sweet Spot”

“SWEET SPOT”
Vegetation Studies

Test Number

First Plant Growth

Infiltration Rate (in/hr)

Time
Variables Considered

- Total Area
- Hydrologic Soil Group/ Horton Infiltration Parameters
- Ratio of UIA to RPA
- Overland Slope
- Depression Storage
Rainfall

- Water Quality Capture Volume (WQCV) for Denver = 0.6 inches of rainfall
- 0.6 inches depth distributed over 2 hours using CUHP temporal distribution
- Analyzed range from 0.25 to 0.95 inches
Largest impacts

- Soil Type
- UIA:RPA ratio
  (imperviousness)
Runoff vs. Subarea Imperviousness (C/D Soils) for Varying Rainfall Depths

\[ y = 7 \times 10^{-5}x^2 + 0.0015x \]
\[ Q = C_0 + C_1 (0.95 - P_2) + C_2 (\text{Area}) + C_3 (L:W) + C_4 (\text{Slope}) + C_5 (\text{Imp}) + C_6 (\text{Imp}^2) \quad \text{Equation 1} \]

Where:
- \( Q \) = Runoff (inches)
- \( P_2 \) = 2-hour WQCV Rainfall Depth (inches)
- \( \text{Area} \) = total subarea, sum of UIA and RPA (acres)
- \( L:W \) = Ratio of total flow length to catchment width
- \( \text{Slope} \) = average overland slope (%)
- \( \text{Imp} \) = subarea imperviousness (%) calculated as \( \frac{\text{UIA}}{\text{(UIA+RPA)}} \) * 100
- \( C_x \) = coefficients determined through regression analysis

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Constant ( C_0 )</th>
<th>Rainfall (in) ( C_1 )</th>
<th>Area (ac) ( C_2 )</th>
<th>L:W ( C_3 )</th>
<th>Slope (%) ( C_4 )</th>
<th>%Imp ( C_5 )</th>
<th>%Imp(^2) ( C_6 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.81E-01</td>
<td>-7.79E-01</td>
<td>-1.45E-02</td>
<td>-1.93E-03</td>
<td>7.03E-04</td>
<td>-2.49E-02</td>
<td>2.64E-04</td>
</tr>
<tr>
<td>B</td>
<td>-7.77E-02</td>
<td>-9.25E-01</td>
<td>-1.07E-02</td>
<td>-1.45E-03</td>
<td>5.02E-04</td>
<td>-1.36E-04</td>
<td>9.24E-05</td>
</tr>
<tr>
<td>C/D</td>
<td>-1.13E-02</td>
<td>-8.99E-01</td>
<td>-1.17E-02</td>
<td>-1.57E-03</td>
<td>5.45E-04</td>
<td>3.55E-03</td>
<td>4.64E-05</td>
</tr>
</tbody>
</table>
Equation vs. SWMM Runoff
Recommended Constraints

- $0.25 \text{ inches} < \text{Precipitation} < 0.95 \text{ inches}$
- $0.025 \text{ acres} < \text{Area} < 2.0 \text{ acres}$
- $0.0625 < \text{L:W ratio} < 16.0$
- $0.5\% < \text{Slope} < 33\%$
Quantifying Runoff Reduction

- Intro to UD-BMP - Runoff Reduction
- Examples
Quantifying Runoff Reduction
Intro to UD BMP – Runoff Reduction

- **Inputs**
  - **Site Information**
    - Area Type and how much of each
      - UIA/RPA
      - DCIA
      - SPA
    - Soils
    - HSG A, B, C/D (%)
    - Average Slope of RPA
    - Interface width (Area Type UIA:RPA only)
Quantifying Runoff Reduction
Intro to UD BMP – Runoff Reduction

- Runoff Output/Results
  - Total Area
  - L/W Ratio
  - UIA/Area
  - Runoff (from UIA:RPA pair)
    - Depth
    - Volume
    - Reduction (Infiltration into RPA+ Depression Storage)
Quantifying Runoff Reduction
Intro to UD BMP – Runoff Reduction

- WQCV Output/Results
  - *Calculated WQCV based on impervious area only*
  - WQCV Reduction (as volume and as %)
  - Untreated WQCV

<table>
<thead>
<tr>
<th>CALCULATED WQCV RESULTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area ID</td>
</tr>
<tr>
<td>---------</td>
</tr>
</tbody>
</table>
Quantifying Runoff Reduction

- Regional Trail 10 ft wide x 100 ft long
  - B Soils

### Calculated Runoff Results

<table>
<thead>
<tr>
<th>Area ID</th>
<th>Trail 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>UIA:RPA Area (ft²)</td>
<td>1,500</td>
</tr>
<tr>
<td>L/W Ratio</td>
<td>0.15</td>
</tr>
<tr>
<td>UIA/Area</td>
<td>0.6667</td>
</tr>
</tbody>
</table>

| Runoff (in) | 0.00 |
| Runoff (ft³) | 0 |
| Runoff Reduction (ft³) | 42 |

### Calculated WQCV Results

<table>
<thead>
<tr>
<th>Area ID</th>
<th>Trail 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>WQCV (ft³)</td>
<td>42</td>
</tr>
<tr>
<td>WQCV Reduction (ft³)</td>
<td>42</td>
</tr>
<tr>
<td>WQCV Reduction (%)</td>
<td>100%</td>
</tr>
<tr>
<td>Untreated WQCV (ft³)</td>
<td>0</td>
</tr>
</tbody>
</table>
Quantifying Runoff Reduction

- Regional Trail 10 ft wide x 100 ft long
  - C\D Soils – 852 ft²
Quantifying Runoff Reduction

- Regional Trail 10 ft wide x 100 ft long
  - B Soils – RPA 5 feet wide along the 100 ft trail
  - C/D Soils – RPA 8.5 feet wide along the 100 ft trail
Quantifying Runoff Reduction

- Parking Lot 7,000 ft\(^2\)
  - B Soils – RPA = 3,500 ft\(^2\)
  - C/D Soils – RPA = 5,910 ft\(^2\)
Verifying Soil Type
Run-on ratio
When you need a level spreader (?)
Defining the RPA
Slotted Curb

SECTION A

SLOTTED CURB
Sediment Pad at Swale Entry
More Information Available

www.UDFCD.org

- Technical Memorandum, Determination of Runoff Reduction Method Equations (UIA to RPA) based on Multivariable SWMM Analysis, Piza and Rapp 2018
- Criteria Manual, Volume 3, Fact Sheet T-0
- UD-BMP (Excel Based Tool for calculating runoff)
- Flood Control District Youtube video for using UD-BMP
Coming soon

Topsoil Management Guidance
Thank You
A bunch of stormwater Quality programs
Underground BMPs

To evaluate performance of an underground proprietary BMP, data should be provided to the local jurisdiction to demonstrate that anticipated BMP performance will be comparable to that of surface-based BMPs such as extended detention basins, constructed wetland basins, sand filter basins, or retention ponds. Underground BMPs approved for stand-alone treatment should be capable, on an annual basis, of producing effluent quality with a median TSS concentration of no more than 50 mg/L. This level of treatment is comparable to the long-term effluent median concentrations from the International Stormwater BMP Database for surface-based BMPs.

Data collected to substantiate performance of proprietary BMPs should meet the following criteria:

1. Testing must consist of field data (not laboratory data) collected in compliance with the criteria in Table UG-1. Laboratory studies and/or vendor-supplied studies without third party involvement or verification should not be considered. The Technology Acceptance Reciprocity Partnership (TARP) Protocol for Stormwater Best Management Practice Demonstrations may provide additional useful information on development of a monitoring program for evaluation of underground BMPs. Information on the TARP program can be found in several locations on the internet, including http://www.dep.state.pa.us/dep/deputate/pde/tech/services/arp. For ongoing field testing guidelines from the American Society of Civil Engineers Urban Water Resources Research Council (ASCE UWRRC) Task Committee Developing Guidelines for Certification of Manufactured Stormwater BMPs (Yousif et al. 2009) may also be applicable in the future.

2. Data collected in environments similar to the Colorado Front Range (i.e., semi-arid with freezing and thawing in the winter) are preferable. This is particularly important for flow-based devices where differences in rainfall intensity and duration may affect performance.

3. Data should be collected and analyzed in accordance with the guidance provided in Urban Stormwater BMP Performance Adjudging (Girvan and WWE 2009; available online at www.bmpdatabase.org). When reviewing performance data, it is important to recognize that the use of percent removal may be more reflective of how "dirty" the influent water is rather than how well the BMP is actually performing (Jensen et al. 2008). Instead, look at effluent concentrations for a range of influent concentrations. The device should have performance data that demonstrate the ability to meet a median TSS effluent concentration of approximately 30 mg/L or lower on an annual basis.

4. Data should be collected or verified by independent third parties in accordance with good Quality Assurance/Quality Control (QA/QC) procedures.

Many studies have been conducted over the past decade to document the performance of underground BMPs. Sources of data that may be used to support using a proprietary BMP include the following:

- International Stormwater BMP Database (www.bmpdatabase.org).
- University of Massachusetts Amherst Stormwater Technologies Clearinghouse (www.masspol.net).
Then in mid-2016...

- Proposes a National program to evaluate products and practices.
- Draws upon New Jersey & Washington State stormwater programs for MTD evaluations.

From WERF 2016
Let’s look at 2 stormwater programs as models for approving (evaluating) Manufactured Treatment Devices (MTDs)…

Lab testing protocol

Field testing protocol
A Spirited Debate: Lab vs. Field Testing

- **Lab testing** provides repeatable and defensible results under controlled conditions to allow for side by side comparisons of MTD performance testing.
- **Field testing** is a logical progression from lab testing and provides long term, real world results under random storm conditions under which an MTD would be expected to encounter.
Two Step Process for NJDEP “Certification”

**Step 1**: NJCAT “Verification”

- [njcat.org](http://www.njcat.org)

**Step 2**: NJDEP “Certification” (if eligible)

- [njstormwater.org/treatment.html](http://www.njstormwater.org/treatment.html)
NJCAT Verification vs. NJDEP Certification

- **NJCAT Verification** provides independent documentation of a protocol-based performance claim for an MTD in either a lab and/or field test setting.

- **NJDEP Certification** allows an eligible MTD to be specified within New Jersey under conditions specific to state stormwater rules.

We’ll talk about eligibility later.....
NJDEP Lists MTD Certifications @ www.njstormwater.org/treatment.html

Links to NJDEP Certifications

Link to NJCAT Verification Database
Technology Verification

The Energy and Environmental Technology Verification (EETV) Act at N.J.S.A. 13D:1-134 et seq., establishes the guidelines for a verification and certification process to approve the use of innovative energy and environmental technologies that benefit the environment and economy of New Jersey. The New Jersey Legislature found that, in establishing the technology verification and certification program, it is in the public's interest to encourage the commercial development and use of new technology-based environmental and energy related products, services and systems that reduce and prevent environmental pollution and promote energy conservation in the most cost-effective and environmentally efficient manner in the State.

Highlights

Although innovative environmental and energy technologies often consume fewer natural resources than traditional methods, they encounter numerous technical, financial and regulatory impediments. Over the years, NJCAT has broken down many of the barriers, but there are still daunting challenges facing innovative technologies.

Stormwater Treatment Systems

Stormwater Management Technologies in particular are difficult to evaluate. Pollutant removal performance depends upon many factors, e.g., influent particulate size distribution, influent pollutant concentration (loading), stormwater flow rate, sump design and capacity, and maintenance. NJCAT involvement and activities over the past decade in identifying and evaluating a number of pre-manufactured stormwater treatment devices has created the knowledge and experience base necessary to effectively and confidently assess anticipated sediment removal performance.

The New Jersey Stormwater rules (35 N.J.R. 154) clearly establish that manufactured stormwater
### NJCAT MTD Verifications @
www.njcat.org/verification-process/technology-verification-database.html

#### Lab Verifications

<table>
<thead>
<tr>
<th>Company</th>
<th>Product</th>
<th>Verification Date</th>
<th>Link to Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>AquaShield Inc.</td>
<td>Aqua-Fillter</td>
<td>December 2005</td>
<td>Download</td>
</tr>
<tr>
<td>AquaShield Inc.</td>
<td>Aqua-Swirl</td>
<td>December 2005</td>
<td>Download</td>
</tr>
<tr>
<td>BaySaver Technologies</td>
<td>BaySaver Enhanced Media Cartridge</td>
<td>November 2018</td>
<td>Download</td>
</tr>
<tr>
<td>Bo Clean Environmental Services</td>
<td>Kraken Membrane Filtration System</td>
<td>April 2018</td>
<td>Download</td>
</tr>
</tbody>
</table>

#### Field Verifications per TARP or NJDEP 2009

#### Lab Verifications open for Public Comment
Ever heard of TARP? Well, it is no longer applicable to NJDEP.

The Technology Acceptance Reciprocity Partnership

Protocol for
Stormwater Best Management Practice Demonstrations

Endorsed by California, Massachusetts, Maryland, New Jersey, Pennsylvania, and Virginia

Final Protocol 8/01 Updated: 7/03

There was no TARP Tier I

Original NJDEP Certification Process

- NJCAT Lab Verification, no standard protocol
- NJDEP Issued “Conditional Interim Certification”
- TARP Tier II Field Test
- NJCAT Field Verification Report
- NJDEP Final Certification

Find a field test site + QAPP
New Jersey Lab Testing Protocols for HDSs and Filters

New Jersey Department of Environmental Protection
Laboratory Protocol to Assess Total Suspended Solids Removal by a Hydrodynamic Sedimentation Manufactured Treatment Device

January 25, 2013

http://www.njstormwater.org/treatment.html
Stormwater Manufactured Treatment Device Protocols and Guidance Documents

- NJDEP MTD Process - January 25, 2013, pdf, 70kb
- NJCAT MTD Process - January 25, 2013, pdf, 182 kb
- HDS Protocol - January 25, 2013, pdf 350 kb
- Filter Protocol - January 25, 2013, pdf, 290kb
- Funding of MTDs by the New Jersey Environmental Infrastructure Financing Program, pdf 112kb
- Transition for Manufactured Treatment Devices July 15, 2011, pdf, 29kb
- Interim Process for Certification of Manufactured Treatment Devices - Posted 4/23/09, pdf 72kb
Procedure for Obtaining Verification of a Stormwater Manufactured Treatment Device from New Jersey Corporation for Advanced Technology

For use in accordance with the Stormwater Management Rules, N.J.A.C. 7:8

January 25, 2013
NJCAT Verification + NJDEP Certification Process

1. Vendor Submits Application to NJCAT Exec. Dir.
   - NJCAT Exec. Dir. Approves Application
   - Vendor Prepares QAPP
   - NJCAT Exec. Dir. Approves QAPP

2. Modify lab setup and/or test methods if needed
   - Laboratory Testing
   - Vendor + NJCAT Exec. Dir. prepares Verification Report
   - 30 Day Public Comment Period for Verification if seeking NJDEP Certification. Posted on NJCAT Website
   - Resolve Any Public Comments

3. All Comments Resolved
   - NJCAT Board
   - Final Verification Report Posted on NJCAT Website
   - Submit Verification Report + Maintenance Manual to NJDEP
   - Verifications ineligible for NJDEP Certification posted on NJCAT website, no Public Comment Period
   - NJDEP Certification Letter Posted
Example NJDEP Certification Letter

(NJDEP Limits:
HDSs to 50% annual TSS
Filters to 80% annual TSS
Regardless of whether the NJCAT Verification is for a greater annual TSS removal efficiency percentage.)
If following NJDEP as a model for local approval...

Require only NJCAT Verification?

Then which Verification?
- 2013 Lab + MTDs Ineligible for Certification
- CIC Lab (Certifications expired)
- NJDEP 2009 Field (Certifications expired)
- TARP Tier II Field (Certifications expired)

OR...

Require NJDEP Certification per 2013 Protocol?

“Level Playing Field”, all hold Final Certification
Consider 4 fundamental aspects of the NJDEP/NJCAT MTD Process

1. NJDEP Certification is specific to New Jersey stormwater rules. An MTD must hold NJDEP Certification in order to be specified in New Jersey.

2. NJDEP Certification does not necessarily carry a higher level of technical scrutiny beyond that of an NJCAT Verification. However, NJDEP reviews maintenance manuals, NJCAT does not. NJDEP Certifications includes Maintenance Manual as part of Cert. Letter.

3. Not all NJCAT Verifications for an MTD are eligible for NJDEP Certification when there is a deviation from the protocol. This has significant ramifications for MTD sizing outside of NJ.

4. An NJCAT Verification can be issued for an MTD technology that is not recognized by NJDEP to be eligible for Certification. This has significant ramifications for MTD technology approval outside of NJ.
Let’s look closer at NJCAT/NJDEP Aspects #3 & #4

**#3: Deviation from Protocol - Sizing:** An MTD test follows the protocol but uses a coarser PSD. An NJCAT Verification could still be obtained but that test would **not be eligible** for NJDEP Certification since the test purposefully deviated from the protocol to obtain a more favorable performance result. If an agency outside of NJ accepts NJCAT verifications only, then this test would allow for MTD sizing to be more favorable (smaller MTD) compared to those MTDs that tested to the protocol using the finer specified PSD (larger MTD). **Could this lead to undersizing?**

**#4: Ineligible Technology for Certification:** The NJCAT Application will identify whether an MTD technology is accepted by NJDEP, and whether the proposed MTD test will be eligible for NJDEP Certification. For example, NJDEP considers underground infiltration structures (inclusive of fabric) not to be filtration MTDs and not eligible for Certification. However, NJCAT can issue a Verification for that technology as a pretreatment device but not NJDEP eligible. Agencies outside of New Jersey can then make their determination whether (a) that technology is an MTD, or (b) to allow the Verification (and sizing) for pretreatment and/or filtration.
“TAPE” is Ecology’s process for approving emerging & proprietary technologies (MTDs)

Current TAPE is August 2011, Revised Version in progress

How hard could it be to get some field samples? Well, 73 pages worth.
Select WDOE/TAPE slides taken from presentation at Washington State Municipal Stormwater Conference, May 17, 2017, Carla Milesi, WSC
Emerging stormwater treatment technologies (TAPE)

Stormwater treatment technologies are reviewed and certified by the Washington state Technology Assessment Protocol - Ecology — better known as the TAPE program.

Submitting treatment technologies for review

Vendors, designers, and manufacturers who wish to have their treatment technologies reviewed should follow these three steps:

1. Follow the TAPE process

Refer to the TAPE process overview for everything you need to know about how we evaluate your technology.

2. Prepare your technology
2. Prepare your technology

Refer to the [2011 TAPE guidance manual](#) as you prepare your technology for review and certification.

3. Send in your application

The [application form](#) and fee must be submitted both as a hard copy and digitally to:

TAPE Program  
Washington State Department of Ecology  
Cashiering  
PO Box 47611  
Olympia, WA 98504-7696

Email: [douglas.howie@ecy.wa.gov](mailto:douglas.howie@ecy.wa.gov)

We also review chemical technologies

We also accept applications to the Chemical Technology Assessment Protocol – Ecology (C-TAPE) program. See the [construction site chemical technology guidance](#) for more information.
Approved technologies

The following table lists the devices that have received a designation through the TAPE process.

In addition to our certification, local jurisdiction approval is required (and not guaranteed) for installation of treatment technologies we have evaluated and given a use designation.

<table>
<thead>
<tr>
<th>Manufactures</th>
<th>Device Name</th>
<th>Treatment Type</th>
<th>Use Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AquaShield, Inc.</td>
<td>Aqua-Filter System, Aqua-Blend C Filter Media</td>
<td>Basic Treatment</td>
<td>Pilot Level</td>
</tr>
<tr>
<td>AquaShield, Inc.</td>
<td>Aqua-Filter System, Coarse Perlite Filter Media</td>
<td>Basic Treatment</td>
<td>Cond Level</td>
</tr>
<tr>
<td>BaySaver Technologies, Inc.</td>
<td>BayFilter w/ BFC Media</td>
<td>Basic Treatment</td>
<td>General Level</td>
</tr>
<tr>
<td>BaySaver Technologies, Inc.</td>
<td>BayFilter w/EMC Media</td>
<td>Basic Treatment</td>
<td>General Level</td>
</tr>
<tr>
<td>BaySaver Technologies, Inc.</td>
<td>BayFilter w/GAC Media</td>
<td>Basic Treatment</td>
<td>Pilot Level</td>
</tr>
</tbody>
</table>
Example GULD for Pretreatment (50% TSS per storm)

(Page 1 of 5)
## TAPE Use Level Designations

<table>
<thead>
<tr>
<th>Use Level Designation</th>
<th>Minimum Data</th>
<th>Months (justified extensions allowed)</th>
<th>Max. # of Installations in WA</th>
<th>Field Testing Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot (PULD)</td>
<td>Lab data</td>
<td>30</td>
<td>5, Unlimited for Retrofits</td>
<td>All installation sites to be monitored. At least 1 indicative of or in Pacific NW</td>
</tr>
<tr>
<td>Conditional (CULD)</td>
<td>Field data, lab data may supplement</td>
<td>30</td>
<td>10, Unlimited for Retrofits</td>
<td>1 site indicative of or in Pacific NW</td>
</tr>
<tr>
<td>General (GULD)</td>
<td>Field data, lab data may supplement</td>
<td>Unlimited</td>
<td>Unlimited</td>
<td>None</td>
</tr>
</tbody>
</table>
Requirements for New/Redevelopment

- Treatment Facilities
  - Pretreatment (Total Suspended Solids)
  - Basic (Total Suspended Solids)
  - Enhanced (Dissolved Copper and Zinc)
  - Phosphorus (Total Phosphorus)
  - Oil (motor oil fraction of Total Petroleum Hydrocarbons)
TAPE Approval Timeline

~ 3 years, $250K

1. Submit App
2. Receive P/CULD
3. Find Potential Field Site
4. Pick Site
5. Evaluate Site
6. Prepare QAPP
7. QAPP Approved
8. Field Evaluation
9. Prepare TER
10. Receive GULD
11. BER Review
<table>
<thead>
<tr>
<th>Performance Goal</th>
<th>Influent Range</th>
<th>Criteria</th>
<th>Required Water Quality Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic Treatment</strong></td>
<td>20-100 mg/L TSS</td>
<td>Effluent goal ≤ 20 mg/L TSS &lt;sup&gt;a&lt;/sup&gt;</td>
<td>TSS</td>
</tr>
<tr>
<td></td>
<td>100-200 mg/L TSS</td>
<td>≥ 80% TSS removal &lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt; 200 mg/L TSS</td>
<td>&gt; 80% TSS removal &lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><strong>Dissolved Metals Treatment</strong></td>
<td>Dissolved copper 0.005 – 0.02 mg/L</td>
<td>Must meet basic treatment goal and better than basic treatment currently defined as &gt; 30% dissolved copper removal &lt;sup&gt;b,d&lt;/sup&gt;</td>
<td>TSS, hardness, total and dissolved Cu and Zn</td>
</tr>
<tr>
<td></td>
<td>Dissolved zinc 0.02 – 0.3 mg/L</td>
<td>Must meet basic treatment goal and better than basic treatment currently defined as &gt; 60% dissolved zinc removal &lt;sup&gt;b,d&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td><strong>Phosphorus Treatment</strong></td>
<td>Total phosphorus (TP) 0.1 to 0.5 mg/L</td>
<td>Must meet basic treatment goal and exhibit ≥ 50% TP removal &lt;sup&gt;b&lt;/sup&gt;</td>
<td>TSS, TP, orthophosphate</td>
</tr>
<tr>
<td><strong>Oil Treatment</strong></td>
<td>Total petroleum hydrocarbons (TPH) &gt; 10 mg/L &lt;sup&gt;e&lt;/sup&gt;</td>
<td>1) No ongoing or recurring visible sheen in effluent 2) Daily average effluent TPH concentration &lt; 10 mg/L &lt;sup&gt;a,e&lt;/sup&gt; 3) Maximum effluent TPH concentration of 15 mg/L &lt;sup&gt;a,e&lt;/sup&gt; for a discrete (grab) sample</td>
<td>NWTPH-Dx, visible sheen</td>
</tr>
<tr>
<td><strong>Pretreatment</strong></td>
<td>50-100 mg/L TSS</td>
<td>Effluent goal ≤ 50 mg/L TSS &lt;sup&gt;a&lt;/sup&gt;</td>
<td>TSS</td>
</tr>
<tr>
<td></td>
<td>≥ 100 mg/L TSS</td>
<td>&gt; 50% TSS removal &lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>
Both the NJDEP/NJCAT & Ecology MTD approval processes provide robust performance testing programs to serve as models to assist other state/local regulators to evaluate MTD performance claims with greater confidence.

MTD testing presents many challenges in the field and lab. Understanding the limitations of both is critical for any performance evaluation.

The NJDEP/NJCAT lab-based approach allows for side-by-side comparison of MTD performance claims.

Ecology’s field-based approach provides long term, real-world performance and functionality to support MTD performance claims based on initial laboratory testing.

NJDEP MTD certifications are specific to New Jersey to allow for MTD sales in New Jersey. Just because an MTD may hold NJCAT Verification, that verification may not be eligible for NJDEP Certification. Has significant marketplace implications outside of NJ.

And in conclusion...
It’s all about good clean water...

Tennessee River, Chattanooga
Thank you.

Mark Miller      mmiller@aquashieldinc.com
2733 Kanasita Drive, Suite 111
Chattanooga, Tennessee 37343
888-344-9044
www.AquaShieldInc.com
Permaculture and Low Impact Development (LID)

By Patrick Padden
CASFM Annual Conference
September 27, 2018

PADDEN PERMACULTURE
Ecological Landscape Design and Build
970-999-4306
Permaculture is a combination of sustainable site design, energy smart technology, edible landscaping, and innovative water management practices.
PERMACULTURE

Bill Mollison’s *Permaculture One*
Established Pattern
Front Range Cities, Colorado
A landscape on the wasteful path to scarcity. Rain, runoff, and topsoil are quickly drained off the landscape to the street where the sediment-laden water contributes to downstream flooding and contamination. The landscape is dependent upon municipal/well water irrigation and imported fertilizer.
A landscape on the stewardship path to abundance. Rain, runoff, leaf drop, and topsoil are harvested and utilized with the landscape contributing to flood control and enhanced water quality. The system is self-irrigating with rain and self-fertilizing with harvested organic matter.
Xeriscape Projects

Xeriscape is not one particular style or look – it's the creation of a healthy, attractive landscape that conserves water.

Xeriscape

• Provides a diversity of seasonal colors and textures
• Lowers outdoor water use 30-50 percent
• Reduces yard maintenance
Perennial Polycultures
I group plants together in a way that mimics natural ecosystems, but I select species that are especially productive for humans.

Plant List
- Toka Plum
- Stanley Plum
- Golden Raspberry
- Blackberry
- Strawberry
- Lead Plant (Nitrogen Fixer)
- Comfrey (Dynamic Accumulator for soil fertility)
- Goji Berry
- Western Sand Cherry
- Black and Red Currant
- Culinary Herbs
- Alliums and Citronella for Insect repellent

Rainwater
Harvesting Patios
I always design an infiltration basin around the perimeter of my patios. This feature allows runoff to passively irrigate useful plants.

Downspout Incorporation
The runoff from downspouts is often an under valued resource in conventional landscape designs, but is always integrated in a Padden Permaculture Design.
Greywater Harvesting Laundry Machine
Brad Lancaster Design
Tucson, Arizona
Edible Landscaping

Landscapes designed with permaculture in mind will often incorporate groupings of fruits and veggies, usually perennial varieties to make the most efficient use of space.
Fruit Tree Guild
Grow more ~ Work less

theresiencyinstitute.net
Harvesting Street Runoff
People’s Food Co-op
Portland, Oregon
Permaculture Sites Around the World
Permaculture is a global movement that is providing solutions to many of the world’s social and ecological challenges.
Permaculture Design Certificate (PDC)

July 20—Aug. 1, 2019
Sunrise Ranch, Colorado

11 day permaculture course
- permaculture design process
- rainwater harvesting and earthworks
- natural building and appropriate technology
- regenerative tools and techniques
- permaculture gardening and food forestry
- animals, soils, compost
PADDEN PERMACULTURE

Ecological Landscape Design and Build

970-999-4306
grow food, not lawns.
Comprehensive Watershed Planning: Prioritize, Target and Implement Multipurpose Projects
Introduction

- PART 1
  - What is 1W1P?
  - How it came to be
  - Planning funding
  - Operation of plan
  - Implementation funding

- PART 2
  - Case study
PART ONE – 1W1P OVERVIEW
What is 1W1P?

- Aligns local water planning towards watershed-based implementation
- 63 HUC8 (~700 mi²)
- Comprehensive
- Formal agreements
- No new governing agency
Actions

Targeted

Strategies

Issues

Values

- Assemblage of all locally-relevant plans, programs and studies
- Statement of existing watershed status
- Unified agreement on priority values
- Vision of long-term management goals by value
- Selection of 10-year management targets
- Identification of implementation actions
- Prioritization of actions based on ability to meet multiple goals
- Prioritized, targeted and measurable goals
What is 1W1P?

Part of MN’s 10-yr management cycle

1. Monitoring
2. Issues and stressors
3. WRAPS
4. 1W1P
5. Voluntary implementation
How it came to be

LGWR 2011

Pilot Watersheds 2014

Statewide 2025

Legislation 2012

Program Adoption 2016
Planning funding

Nov 2008 voters approved CWF to:

- Protect drinking water sources
- Protect, enhance, and restore lakes, rivers, streams, and groundwater
- Protect, enhance, and restore wetlands, prairies, forests, and fish, game, and wildlife habitat
- Support parks and trails
- Preserve arts and cultural heritage
## Operation of plan development

<table>
<thead>
<tr>
<th>Planning Groups</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Policy Committee</strong></td>
<td>Local plan authorities purposed with making final decisions about plan content and regarding expenditure of planning funds. Final owner and operator.</td>
</tr>
<tr>
<td><strong>Advisory Committee</strong></td>
<td>Various local, State, Federal, Tribal and NGO technical members. Makes recommendations on plan content and implementation to the Policy Committee.</td>
</tr>
<tr>
<td><strong>Work Planning Group / Steering Committee</strong></td>
<td>A small group of local staff, BWSR Board Conservationist, and consultants for the purposes of logistical and process decision-making in the plan development process.</td>
</tr>
</tbody>
</table>
Plan partners

- Municipalities/Townships
- Counties
- Soil and Waters Conservation Districts
- Watershed Districts
- Flood Management Authorities
- State BWSR, DNR, DOT, DOH, etc.
- USFS, USACE, USFWS
- Tribal Government
- NGOs and Public
Planning process

Formal agreements, initiation

Assemble/review existing plans and studies

Establish planning zones (=/< 3)

Prioritize issues

Assemble implementation programs and procedures

Develop implementation plan

Establish measurable goals

Prioritize resources

Internal review

External review

Approval

Adopt plan

Implement, evaluate, update
Plan content

- Executive summary
- Land and Water narrative
- Priority resources and issues
- Measurable goals
- Targeted implementation schedule
- Plan implementation programs
- Plan administration and coordination
# Operation of plan implementation

<table>
<thead>
<tr>
<th>Type of Governance Agreement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memorandum of Agreement (MOA)</td>
<td>An agreement between multiple parties; method of formally recognizing a partnership; specifies mutually-accepted expectations and guidelines</td>
</tr>
<tr>
<td>Joint Powers Agreement (JPA)</td>
<td>Agreement to jointly deliver a service or a product</td>
</tr>
<tr>
<td>Joint Powers Board (JPB)</td>
<td>Type of JPA that specifically establishes a new entity or board that operates autonomously from the members. Risk is transferred to this entity.</td>
</tr>
<tr>
<td>Watershed District (WD)</td>
<td>Formal local unit of government, defined by hydrologic boundary and formed by a local petition process</td>
</tr>
</tbody>
</table>
Implementation funding

- Watershed-based funding
- $4,875,000 Y1
- $4,875,000 Y2
- 10% non-State match (cash or in-kind)
- Eligible activities
Case study – Leech Lake River 1W1P

- 1,335 mi²
- 3 counties
- Leech Lake Bank of Ojibwe
- 277 river miles
- 750 lakes (166,374 acres)
- Northern Lakes and Forest Ecoregion
- Largely forested
- 46% privately held land
- Some of most pristine lands in MN
## Case study – Leech lake River 1W1P

<table>
<thead>
<tr>
<th>Planning Groups</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Policy Committee</strong></td>
<td>Cass Environmental Services Dept, Cass SWCD, Hubbard County, Hubbard SWCD</td>
</tr>
<tr>
<td><strong>Advisory Committee</strong></td>
<td>Cities, Chamber of Commerce, Counties, The Nature Conservancy, USACE, MNDNR, USFS</td>
</tr>
<tr>
<td><strong>Work Planning Group / Steering Committee</strong></td>
<td>Cass and Hubbard SWCD Administrators, BWSR BC, Leech Lake Band of Ojibwe, Leech Lake Area Watershed Foundation, Consultants</td>
</tr>
</tbody>
</table>
Case study – Leech Lake River 1W1P

Natural Resources
Case study – Leech Lake River 1W1P

Climate and Risk

Climate-change
Case study – Leech Lake River 1W1P

Leadership
Case study – Leech Lake River 1W1P

Quality of Life
Case study – Leech Lake River 1W1P

1. High Quality Lakes
2. Recreational Lakes
3. Impoundments
4. Impaired Lakes
5. High Value/Priority Rivers and Streams
6. Declining, Impaired and Channelized Rivers and Streams
7. Wetlands
8. Groundwater
9. Upland Resources – Forests
10. Upland Resources – Habitat
11. Upland Resources - Working lands
12. Upland Resources - Cities and towns
Case study – Leech Lake River 1W1P

Priorities:

1. High Quality Lakes
2. Recreational Lakes
3. Impoundments
4. Impaired lakes
5. High Value Rivers
6. Impaired/Declining Rivers
7. Wetlands
8. Groundwater
9. Forests
10. Habitat
11. Working lands
12. Cities and towns

Goal Attainment Level:

- Maintain
- Improve
- Enhance
- Protect
Case study – Leech Lake River 1W1P

Level 1
- Metric scoring

Level 2
- Natural Values Ranking

Level 3
- Aggregate Ranking
### Case study – Leech Lake River 1W1P

<table>
<thead>
<tr>
<th>HIGH QUALITY LAKES METRICS</th>
<th>SCORING</th>
<th>DATA SETS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coldwater Habitat Presence</td>
<td>Yes = 1, No = 0.01</td>
<td>WRAPS</td>
</tr>
<tr>
<td>P-Sensitivity Lake Presence</td>
<td>0.33, 0.66 and 1.0; high, higher highest</td>
<td>State 2108 data</td>
</tr>
<tr>
<td>WQ Trend</td>
<td>Close to threshold = 1</td>
<td>State 2017 data</td>
</tr>
<tr>
<td></td>
<td>Declining trend = 0.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No data = 0.33; rising = 0.01</td>
<td></td>
</tr>
<tr>
<td>Forest</td>
<td>Composite score above mean = 1 (X=99.08; range = 15 – 175)</td>
<td>Forests of the Future data</td>
</tr>
<tr>
<td>Terrestrial Biodiversity</td>
<td>Yes = 1, No = 0.01</td>
<td>State MCBS Biodiversity data</td>
</tr>
<tr>
<td>WRAPS Priority Lake</td>
<td>Yes = 1, No = 0.01</td>
<td>WRAPS</td>
</tr>
<tr>
<td>Lakes of Biological Significance</td>
<td>Outstanding =1</td>
<td>WRAPS</td>
</tr>
<tr>
<td></td>
<td>High = 0.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate = 0.33</td>
<td></td>
</tr>
<tr>
<td>Wild Rice Lake</td>
<td>High = 1 (local = high and/or DNR List = high)</td>
<td>State Top 350 lakes and Local Preference data</td>
</tr>
</tbody>
</table>
Case study – Leech Lake River 1W1P
Case study – Leech Lake River 1W1P
Case study – Leech Lake River 1W1P
## CASFM | One Watershed, One Plan

### Case study – Leech ake River 1W1P

<table>
<thead>
<tr>
<th>Resource</th>
<th>Management Strategy</th>
</tr>
</thead>
</table>
| Cities and Townships         | 1. Urban stormwater management for City of Laporte (particular attention to highway runoff)  
                                2. Update stormwater management.  
                                3. Stormwater management plan for future development including land development and Stormwater ordinance updates. |
| Groundwater                  | 1. Update ground water plan with Geologic Atlas and shallow well data.  
                                2. Targeted well-monitoring.  
                                3. SSTS Management (inventory, functional assessment) for Garfield Lake  
| Kabekona River               | 1. SSTS Management (inventory, functional assessment, regulatory)  
                                2. River corridor regulation  
                                3. Wild Rice easements  
                                4. Riparian easements and acquisitions  
                                5. Riparian conservation and stewardship  
                                6. Stormwater water quality and temperature stormwater BMPs  
                                7. Culvert hydraulic, hydrologic, sediment transport and fish barrier inventory and assessment priority.  
                                8. Pasture management. |
PART THREE – LOCAL EXAMPLE
COLORADO WATER PLAN
“Productive economy, vibrant and sustainable cities, productive agriculture, strong environment, robust recreational industry”

Social, Economic and Environmental Values for Vision to shape mission of plan.
MANAGEMENT GROUPS
- Federal Agencies
  - USACE
  - USFS
  - USFWS
  - NRCS
- State of Colorado
  - CO Water Cons. Board
  - CO Watershed Assembly
  - DNR
  - DOT
  - DOA
- Local drainage authorities
  - Urban Drainage and Flood Control District
- Counties
- Conservation Districts
- Municipalities/Townships
- NGO’s
  - The Greenway Foundation
  - Trout Unlimited

EXAMPLE PLANS
- Colorado Water Plan
- Statewide Water Supply Initiative
- Basin Improvement Plans
- Stream Management Plans
- Watershed Protection Plans
- ...several others
LOCAL POLICY COMMITTEE & PLAN OWNER/OPERATOR

- Urban Drainage and Flood Control District
- Conservation Districts
- Colorado Watershed Assembly

STEERING COMMITTEE

- The Greenway Foundation
- USACE
- USFS
- USFWS
- NRCS
- DNR
- Co Water Cons. Board.
- DOT
- DOA
- Municipalities/Townships
- Trout Unlimited
CASFM | One Watershed, One Plan

- Actions
  - Targeted
    - Strategies
      - Issues
        - Values
          - Colorado Water Plan
          - Basin Improvement Plans
          - Stream Management Plans
          - Watershed Protection Plans
          - Statewide Water Supply Initiative
          - Local drainage authorities (e.g., Urban Drainage and Flood Control District, Denver area)
          - Federal Agencies
          - NGO/Special interest Groups
            - Greenway Foundation
            - Trout Unlimited
Values

- Social
- Economic
- Environment
Values

Social

Economic

Environment

Quality of life, way of life

Hunting, fishing, recreation

Water supply

Etc.
Values

- Social
- Economic
- Environment

Vibrant sustainable cities
Sustainable agriculture
Conservation development
Flood risk mgmt
Etc.
Values
- Social
- Economic
- Environment
  - Water quality
  - Habitat
  - Etc.
• Synthesis of existing information.
• Based on right project, right location, right costs

Prioritized, targeted and measurable local 10-yr implementation plan
Contact Information

Shawn Tracy, Water Resource Project Manager
651.659.7747
stracy@hrgreen.com

One Watershed, One Plan
http://www.bwsr.state.mn.us/planning/1W1P/index.html
Developing a Comprehensive Stormwater Infrastructure Master Plan

Drew Beck, PE, CFM
Tim Biolchini, PE
Richard Mulledy, PE

September 27, 2018
Outline

- Background
- Goals
- Approach
- Database and Web Application
- Takeaways
Project Goals

- GIS-based web application for CIP planning
- Existing infrastructure gaps
- CIP prioritization and budgeting tool
- Create a Stormwater Channel Assessment Program framework
- BMP tracking system
Colorado Springs Utilities
Operations & Maintenance
Development Review
Fountain Creek Watershed
Flood Control & Greenway District
CIP Delivery
Parks & Open Space
GIS and IT
Benchmarking

- City of Aurora
- City & County of Denver
- Urban Drainage & Flood Control District

- Project Definitions
- Sub-Projects
- Prioritization
- Querying
- Cut Sheets
- Work Flow
- Cost Index
- Editability
- Accessibility
Over 258 mi of open channel

- 37 major drainage basins
- 63 mi improved/195 unimproved
- 1,260 grade control structures
- 800+ existing BMPs

GIS data
- Tablet data collection
- Geolocated photos
Parameters collected:

- Location - GPS
- Improvement type
- Condition
  - Tier 1
  - Tier 2
- Height
- Vegetation
Tier 1 – Infrastructure Condition

- Health/safety/flooding
- Channel stability
- Utility risks
- Road/bridge/structure risk
- Criteria – headcuts, unstable banks, severe floodplain disconnect, undermined drop structures

Tier 2 – Corridor Function

- Recreation
- Habitat/riparian function
- Aesthetics
- Criteria – geomorphic floodplain connection, vegetation quality and connection, bedrock

Data Collection – Field Review
Tier 1 – Infrastructure Condition: Examples

- Good (green) – healthy stream corridor; sustainable [35%/67%]
- Fair (yellow) – some instability but no adjacent risks; at risk in large flood; maintenance [50%/28%]
- Poor (orange) – instability with adjacent risks; could need a CIP [10%/4%]
- Critical (red) – needs immediate attention; imminent risk [<5%/<1%]
Tier 2 – Corridor Value: Examples

- Good (green) – healthy stream corridor; high aesthetic and habitat value [30%/48%]
- Fair (yellow) – some impaired habitat but mostly functioning [45%/35%]
- Poor (orange) – disconnected floodplain, sparse vegetation [20%/16%]
- Critical (red) – minimal habitat value [<5%/<1%]
Field Assessment

Examples

Tier 1 – Good

Tier 2 - Poor
Over 400 documents

- Plans/Reports
- IGA Projects
- Needs Assessment
- Databases
- Spreadsheets
- Hand written notes
- Individual staff knowledge

GIS data
Over 462 Potential Projects

- 326 Channel projects
- 55 Detention projects
- 81 Storm drain projects
# Project Organization: Inventory Spreadsheet

<table>
<thead>
<tr>
<th>No.</th>
<th>ID</th>
<th>Cost Table (SIMP ID) (NEW)</th>
<th>Attribute Only (SIMP ID) (New)</th>
<th>IGID (NEW)</th>
<th>Improvement Name</th>
<th>Location (Street Names)</th>
<th>Drainageway</th>
<th>Category</th>
<th>Description</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Cost Subtotal</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-0</td>
<td></td>
<td></td>
<td></td>
<td>Sand Creek DBPS - Detention Basin Cost Estimate</td>
<td>Sand Creek Basins</td>
<td></td>
<td>0 - Project summary</td>
<td>-</td>
<td>LS</td>
<td>1</td>
<td>$$$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1-1</td>
<td>SC-C6</td>
<td></td>
<td></td>
<td>Sand Creek DBPS</td>
<td>Lower Sand Creek</td>
<td>Sand Creek</td>
<td>X - Channel - Grade Control</td>
<td>Grade control</td>
<td>EA</td>
<td>6</td>
<td>$27,000</td>
<td>$162,000</td>
<td>Constructed</td>
</tr>
<tr>
<td>1</td>
<td>1-2</td>
<td>SC-C6</td>
<td></td>
<td></td>
<td>Sand Creek DBPS</td>
<td>Lower Sand Creek</td>
<td>Sand Creek</td>
<td>X - Channel - Lining Sel linings (1 side)</td>
<td>LF</td>
<td>350</td>
<td>$127</td>
<td>$44,450</td>
<td>Not constructed</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1-3</td>
<td>EFSC-C8</td>
<td></td>
<td></td>
<td>Sand Creek DBPS</td>
<td>East Fork Sand Creek Tributaries</td>
<td>East Fork Sand Creek</td>
<td>X - Channel - Lining Selective riprap lining</td>
<td>LF</td>
<td>5700</td>
<td>$85</td>
<td>$484,500</td>
<td>Not constructed</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1-4</td>
<td>EFSC-D1</td>
<td></td>
<td></td>
<td>Sand Creek DBPS</td>
<td>Constitution Ave and East Fork Sand Creek</td>
<td>East Fork Sand Creek</td>
<td>X - Detention</td>
<td>Public regional 100-year detention with water quality (278 AF)</td>
<td>AC-FT</td>
<td>278</td>
<td>$10,000</td>
<td>$2,795,000</td>
<td>Not constructed</td>
</tr>
<tr>
<td>1</td>
<td>1-5</td>
<td>EFSC-D1</td>
<td></td>
<td></td>
<td>Sand Creek DBPS</td>
<td>Constitution Ave and East Fork Sand Creek</td>
<td>East Fork Sand Creek</td>
<td>X - Detention</td>
<td>Land acquisition</td>
<td>AC</td>
<td>26.9</td>
<td>$15,900</td>
<td>$427,710</td>
<td>Not constructed</td>
</tr>
<tr>
<td>1</td>
<td>1-6</td>
<td>EBSC-B160</td>
<td></td>
<td></td>
<td>Sand Creek DBPS - Roadway Culvert Crossing Cost Estimate</td>
<td>Bridlespur Road</td>
<td>East Bierstadt Creek</td>
<td>X - Culvert</td>
<td>2-8Hx10'W CBC</td>
<td>LF</td>
<td>160</td>
<td>$750.00</td>
<td>$120,000</td>
<td>Not constructed</td>
</tr>
<tr>
<td>1</td>
<td>1-7</td>
<td>EBSC-B47A</td>
<td></td>
<td></td>
<td>Sand Creek DBPS - East Fork Sand Creek Bridge Crossing Cost Estimate</td>
<td>Unnamed Roadway</td>
<td>East Bierstadt Creek</td>
<td>X - Bridge / Full span 8-10'Hx14'W CBC</td>
<td>LF</td>
<td>250</td>
<td>$1,250.00</td>
<td>$312,500</td>
<td>Not constructed</td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**

- **Summary of costs by document.**
- **Project Improvements identified in the reviewed document.**
- **Steps in inventory spreadsheet to define project organization.**
Middle Tributary
MT-D2
Detention

Project Description:
Middle Tributary Detention Retrofit Upstream of USAFA Property Boundary

Cost Analysis:

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Cost Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion control blanket</td>
<td>BY</td>
<td>10,385</td>
<td>8.00</td>
<td>$82,780</td>
</tr>
<tr>
<td>Grouted 7” dia boulder rundown</td>
<td>BY</td>
<td>108</td>
<td>216.00</td>
<td>$23,414</td>
</tr>
<tr>
<td>Outlet structure trash rack, screen and railing</td>
<td>LF</td>
<td>375</td>
<td>44.00</td>
<td>$16,500</td>
</tr>
<tr>
<td>6” concrete channel (9’ thick, 6’ deep)</td>
<td>LF</td>
<td>700</td>
<td>9.00</td>
<td>$6,300</td>
</tr>
<tr>
<td>Access road (12” wide, 8’ class B gravel)</td>
<td>LF</td>
<td>50</td>
<td>91.00</td>
<td>$4,550</td>
</tr>
<tr>
<td>Outlet pipe, RCP</td>
<td>CY</td>
<td>1</td>
<td>1,230.00</td>
<td>$1,230.00</td>
</tr>
<tr>
<td>Outlet pipe protection - FEB w/ riprap</td>
<td>CY</td>
<td>1</td>
<td>1,230.00</td>
<td>$1,230.00</td>
</tr>
<tr>
<td>Concrete crest wall, 12” thick</td>
<td>CY</td>
<td>59</td>
<td>502.55</td>
<td>$29,466.5</td>
</tr>
<tr>
<td>Emergency spillway (Type M riprap)</td>
<td>CY</td>
<td>990</td>
<td>75.95</td>
<td>$75,210</td>
</tr>
<tr>
<td>Excavation (haul)</td>
<td>CY</td>
<td>5,796</td>
<td>30.00</td>
<td>$173,980</td>
</tr>
<tr>
<td>Excavation embankment (onsite)</td>
<td>CY</td>
<td>901</td>
<td>14.01</td>
<td>$12,619</td>
</tr>
<tr>
<td>Forebay riprap (Type L) w/ bedding</td>
<td>CY</td>
<td>114</td>
<td>69.86</td>
<td>$7,929.6</td>
</tr>
<tr>
<td>Infill forebay (6’ conc. Bottom)</td>
<td>CY</td>
<td>448</td>
<td>259.57</td>
<td>$113,434.8</td>
</tr>
<tr>
<td>Outlet structure - 6” walls</td>
<td>CY</td>
<td>4</td>
<td>722.00</td>
<td>$2,888.0</td>
</tr>
<tr>
<td>Place topsoil</td>
<td>CY</td>
<td>4,571</td>
<td>12.00</td>
<td>$54,853</td>
</tr>
<tr>
<td>Mulchtop soil</td>
<td>CY</td>
<td>4,571</td>
<td>10.00</td>
<td>$45,711</td>
</tr>
<tr>
<td>Mulch</td>
<td>AC</td>
<td>9</td>
<td>556.56</td>
<td>$5,009.0</td>
</tr>
<tr>
<td>Seeding, native</td>
<td>AC</td>
<td>9</td>
<td>585.56</td>
<td>$5,270.0</td>
</tr>
<tr>
<td>Contingency</td>
<td>%</td>
<td>20</td>
<td>7,192.00</td>
<td>$1,438,000</td>
</tr>
<tr>
<td>Design / Engineering</td>
<td>%</td>
<td>15</td>
<td>7,133.33</td>
<td>$107,000</td>
</tr>
</tbody>
</table>

Total: $962,850

Potential Partnership:
Prioritization

Planning
- Drainage Basin Planning Studies
- Existing Infrastructure Needs Assessment

Condition

Capacity
## Planning Prioritization

### Technical (60%)

<table>
<thead>
<tr>
<th>Drainage Basin</th>
<th>DBPS Published Date</th>
<th>Age of DBPS</th>
<th>Design Standard</th>
<th>Degree of Future Development</th>
<th>Existing Regional Detention</th>
<th>Future Regional Detention</th>
<th>Potential Natural Stream Preservation/Restoration Opportunities</th>
<th>Closed Basin</th>
<th>City-Input (based on economic, social and political climate at the time of ranking)</th>
<th>Weighted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Canyon</td>
<td>2/1/1980</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>63</td>
</tr>
<tr>
<td>Black Squirrel Creek</td>
<td>1/1/1989</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>61</td>
</tr>
<tr>
<td>North Douglas Creek</td>
<td>3/1/1981</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>South Douglas Creek</td>
<td>3/1/1981</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Mesa</td>
<td>3/1/1986</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Sand Creek (including Upper Sand Creek)</td>
<td>3/1/1996</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>Camp Creek</td>
<td>10/1/1964</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>56</td>
</tr>
<tr>
<td>Westside</td>
<td>10/1/1975</td>
<td>0</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Peterson Field (Sand Creek)</td>
<td>8/1/1984</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>55</td>
<td></td>
</tr>
</tbody>
</table>

### Score Range

- Technical (60%): 0-3, 0-4, 0-3, 0-3, 0-3, 0-1, 0-1, 0-5
- Situational Awareness (40%): 0-100
- Weighted Score: 0-100

### Scaling Multiplier

- 5, 5, 12, 1, 1, 10, 6, 5

### Table Entries

- **Black Canyon**: DBPS Published Date 2/1/1980, Age of DBPS 1, Design Standard 3, Degree of Future Development 2, Existing Regional Detention 3, Future Regional Detention 1, Potential Natural Stream Preservation/Restoration Opportunities 1, Closed Basin 1, City-Input (based on economic, social and political climate at the time of ranking) 1, Weighted Score 63.
- **Black Squirrel Creek**: DBPS Published Date 1/1/1989, Age of DBPS 2, Design Standard 3, Degree of Future Development 3, Existing Regional Detention 1, Future Regional Detention 1, Potential Natural Stream Preservation/Restoration Opportunities 0, Closed Basin 1, City-Input (based on economic, social and political climate at the time of ranking) 1, Weighted Score 61.
- **North Douglas Creek**: DBPS Published Date 3/1/1981, Age of DBPS 1, Design Standard 4, Degree of Future Development 2, Existing Regional Detention 3, Future Regional Detention 2, Potential Natural Stream Preservation/Restoration Opportunities 0, Closed Basin 1, City-Input (based on economic, social and political climate at the time of ranking) 57.
- **South Douglas Creek**: DBPS Published Date 3/1/1981, Age of DBPS 1, Design Standard 4, Degree of Future Development 2, Existing Regional Detention 3, Future Regional Detention 2, Potential Natural Stream Preservation/Restoration Opportunities 0, Closed Basin 1, City-Input (based on economic, social and political climate at the time of ranking) 57.
- **Mesa**: DBPS Published Date 3/1/1986, Age of DBPS 1, Design Standard 4, Degree of Future Development 2, Existing Regional Detention 2, Future Regional Detention 1, Potential Natural Stream Preservation/Restoration Opportunities 0, Closed Basin 1, City-Input (based on economic, social and political climate at the time of ranking) 57.
- **Sand Creek (including Upper Sand Creek)**: DBPS Published Date 3/1/1996, Age of DBPS 3, Design Standard 2, Degree of Future Development 3, Existing Regional Detention 1, Future Regional Detention 3, Potential Natural Stream Preservation/Restoration Opportunities 0, Closed Basin 1, City-Input (based on economic, social and political climate at the time of ranking) 57.
- **Camp Creek**: DBPS Published Date 10/1/1964, Age of DBPS 0, Design Standard 4, Degree of Future Development 1, Existing Regional Detention 3, Future Regional Detention 1, Potential Natural Stream Preservation/Restoration Opportunities 1, Closed Basin 1, City-Input (based on economic, social and political climate at the time of ranking) 1, Weighted Score 56.
- **Westside**: DBPS Published Date 10/1/1975, Age of DBPS 0, Design Standard 4, Degree of Future Development 1, Existing Regional Detention 2, Future Regional Detention 1, Potential Natural Stream Preservation/Restoration Opportunities 1, Closed Basin 1, City-Input (based on economic, social and political climate at the time of ranking) 1, Weighted Score 55.
- **Peterson Field (Sand Creek)**: DBPS Published Date 8/1/1984, Age of DBPS 1, Design Standard 4, Degree of Future Development 1, Existing Regional Detention 3, Future Regional Detention 1, Potential Natural Stream Preservation/Restoration Opportunities 1, Closed Basin 1, City-Input (based on economic, social and political climate at the time of ranking) 1, Weighted Score 55.
Project Prioritization

DCM Principles

- Regional implications
- Infrastructure integration
- Land allocation
- Runoff mitigation
- Multi-purpose
- Natural systems
- Downstream impacts
- Maintenance
- Flood hazard
- Legal/permit obligations

Technical criteria

- Channels
- Detention
- Storm drains

Decision Matrix
## Technical Criteria - Channels

<table>
<thead>
<tr>
<th>Channel Technical Criteria</th>
<th>DCM Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 1 Score (Infrastructure condition)</td>
<td>Downstream Impacts</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
</tr>
<tr>
<td></td>
<td>Flood Hazard</td>
</tr>
<tr>
<td>Tier 2 Score (Corridor function)</td>
<td>Multi-Purpose Preservation</td>
</tr>
<tr>
<td>Bank Risk</td>
<td>Infrastructure Integration</td>
</tr>
<tr>
<td></td>
<td>Downstream Impacts</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
</tr>
<tr>
<td>Bank Height</td>
<td></td>
</tr>
<tr>
<td>Improvement type (if any)</td>
<td></td>
</tr>
<tr>
<td>K-Factor score (susceptibility to erosion)</td>
<td></td>
</tr>
<tr>
<td>303(d) impairments</td>
<td>Downstream Impacts</td>
</tr>
<tr>
<td>Adjacent utilities, institutions, and facilities</td>
<td>Legal/Permit</td>
</tr>
<tr>
<td></td>
<td>Infrastructure Integration</td>
</tr>
</tbody>
</table>
## Technical Criteria - Detention

<table>
<thead>
<tr>
<th>Detention Technical Criteria</th>
<th>DCM Principles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location in watershed</td>
<td>Runoff Mitigation</td>
</tr>
<tr>
<td></td>
<td>Downstream Impacts</td>
</tr>
<tr>
<td></td>
<td>Flood Hazard</td>
</tr>
<tr>
<td>Closed basins &amp; Parcel ownership</td>
<td>Land Allocation</td>
</tr>
<tr>
<td>Proposed detention pond volume</td>
<td>Runoff Mitigation</td>
</tr>
<tr>
<td></td>
<td>Downstream Impacts</td>
</tr>
<tr>
<td></td>
<td>Flood Hazard</td>
</tr>
<tr>
<td>Underlying Hydrologic Soil Group</td>
<td>Preservation</td>
</tr>
<tr>
<td></td>
<td>Natural Systems</td>
</tr>
<tr>
<td>Maximizing BMP treatment area within the City</td>
<td>Preservation</td>
</tr>
<tr>
<td></td>
<td>Multi-Purpose</td>
</tr>
<tr>
<td></td>
<td>Downstream Impacts</td>
</tr>
<tr>
<td>Provide protection for people as permanent and recreational users?</td>
<td>Protect or improve habitat, water quality, and geomorphology?</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
<td>----------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Infrastructure Integration, Flood Mitigation, Flood Hazard, Downstream Impacts, Multi-Purpose</strong></td>
<td><strong>Preservation</strong></td>
</tr>
<tr>
<td>Permanent user protection?</td>
<td>Protects or improves water quality?</td>
</tr>
<tr>
<td>Applicable justifications:</td>
<td>Applicable justifications:</td>
</tr>
<tr>
<td>Neighborhood access</td>
<td>Trail users</td>
</tr>
<tr>
<td>Heavily traveled road</td>
<td>Golf course users</td>
</tr>
<tr>
<td>Other (specify)</td>
<td>Other (specify)</td>
</tr>
<tr>
<td>Recreational user protection?</td>
<td>Protects or improves habitat?</td>
</tr>
<tr>
<td>Applicable justifications:</td>
<td>Applicable justifications:</td>
</tr>
<tr>
<td>Neighborhood access</td>
<td>Trail users</td>
</tr>
<tr>
<td>Heavily traveled road</td>
<td>Golf course users</td>
</tr>
<tr>
<td>Other (specify)</td>
<td>Other (specify)</td>
</tr>
<tr>
<td>Protect or improve water quality?</td>
<td>Treats WQCV</td>
</tr>
<tr>
<td>Protect or improve habitat?</td>
<td>Stabilizes highly erodible banks/channels</td>
</tr>
<tr>
<td>Protects or improve geomorphology?</td>
<td>Natural channel preservation/design</td>
</tr>
<tr>
<td>Protects or improve geomorphology?</td>
<td>Other (specify)</td>
</tr>
<tr>
<td>Meets MS4 requirements and brings existing system up to compliance?</td>
<td>Meets MS4 requirements and the existing system is already in compliance?</td>
</tr>
<tr>
<td>Create infrastructure investments that are high value and reasonable to construct?</td>
<td>Improve downstream conditions?</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Infrastructure Integration, Land Allocation, Maintenance</td>
<td>Downstream Impacts, Flood Hazard</td>
</tr>
<tr>
<td>Applicable justifications: Low maintenance needs, Low cost, high return, Moderate to high cost, but foundational, Closed basin, Land acquisition, Other (specify)</td>
<td>Applicable justifications: Improves downstream channel, Reduces downstream flooding, Other (specify)</td>
</tr>
</tbody>
</table>

**Technical Score**

**Decision Score**

**Priority Rank**
Takeaways

- Evolution is painful
- Deferred maintenance is not the sum of its parts
- Leverage existing data
- Listen to users
- Communicate
City Project Manager – Tim Biolchini
Engineering Stormwater Division Manager – Richard Mulledy
Stormwater Capital Programs Manager – Brian Kelley
Strategic Planning for Green Infrastructure in Boulder

Candice Owen, P.E.

September 27, 2018
Overview

• Background
• Project Components
  – Stakeholder Group
  – Process and Policy
  – Prioritization and Pilots
• Next Steps
Shifting Paradigms...
The GI Way of Thinking

Gray infrastructure:
• Use basins, pipes & ditches to **remove** pollutants from stormwater where it collects

Green infrastructure:
• Use **soil** and vegetation to manage **rainwater** close to where it falls

Source: Tompkins County NY (Bioswale)
Shifting Paradigms...
The GI Way of Thinking

Soil & Vegetation are now Infrastructure

At the pre-design stage:
LID Opportunities

During design & construction:
BMP Design Elements

After construction:
BMP Maintenance Elements
Background: Stormwater in Boulder

- Boulder is mostly infill on marginally draining urban soils
- Many sites are dense and space is very valuable
- Approval process for changing criteria is challenging
- New MS4 permit requirements posed challenges
How do we do this in Boulder?

• What are we required to do?
  – *MS4 permit requirements*

• What can we do?
  – *Understand ability to infiltrate*

• What should we do?
  – *Set by stakeholder group*
Project Goals

- MS4 Permit Compliance
- Build a Green Infrastructure Program that promotes GI on both Private and Public Projects

- GI Program
- Pilots, Guidance and Tools
- Post-Construction requirements
- Permit Compliance
Project Design

Internal Stakeholder Process

Support decisions made throughout the project and provide critical feedback through 5 meetings

GI Process & Policy

MS4 Permit Compliance and inclusion of GI in city development requirements

Prioritization & Pilots

5 conceptual designs for GI projects and tools to repeat prioritization and GI installation types
STAKEHOLDER GROUP PROCESS
VISION
What do YOU envision for the final outcome of this project?

CRITICAL SUCCESS FACTORS
What must this project and process accomplish in order for you to think it has been successful?
Making policy & process changes

**Assess**
- Opportunities
- Problems
- Needs

**Gather Input**

**Set Goals**
- Combine like inputs
- Set priorities

**Identify Strategies**
- Align needs with opportunities
- Build tactics

**Employ Tactics**
- Educate
- Change policies
- Change processes

**Analyze**
- Combine like inputs
- Set priorities

**Agree**
- Align needs with opportunities
- Build tactics

**Act**

Project Vision & Critical Success Factors
Resulting Policies

- Prioritization factors for pilot projects
- MEP of LID for <1 acre development
- Do as much GI as practicable on city projects
POLICY AND PROCESS
Code and Design Standards Revisions

Technical Report

The technical report shall provide a description of and developed rainfall conditions, approximate the water quality and erosion control measures, storm sewers, proposed storm water utility improvements of study data sources, methods and findings, and is

(1) Background. Provide a written statement development that includes the following:
   a) Site location, including legal description, characteristics, identifying land use, networks and storm water systems in the surrounding area.
   b) Site description, including the total ground cover, wetlands, ground water systems.

(2) Development Proposal. Provide a general development, including land use, density, water planning concepts.

(3) Existing Condition Hydraulics. Provide:
   a) Land cover, denoting by type all to landscaped areas, designated open areas, parks, or similar land uses, and urban areas.
   b) Natural features, including stream courses, springs, sinkholes, rock outcrops.
   c) Floodplains and floodways, known shallow-basins, and clay lenses.
   d) Natural soil identified by coring, TX-4, and urban topography or fill.
   e) Unsaturated hydrology, and treated: Arid areas, where infiltration of storm water is utilized.
   f) Areas where infiltration of storm water is utilized.
   g) Areas of cultural, historic, or archeological State Historic Preservation Office.

Existing Storm Water Basins and Drainage Systems:

(a) Outline drainage patterns and their
(b) Outline drainage patterns, existing
(c) Previous drainage studies for the area

7.16 Storm Water Quality Measure Maintenance

(A) Required

The Director of Public Works may require the inspection of storm water quality measures after their installation to confirm their conformance with the approved final storm water report plan and the record drawings for the applicable development site, and to evaluate if the storm water quality measures in the larger storm water system facilities of the property are clean, free of sediment and debris, and in full operational condition. The Director of Public Works may order corrective actions before construction closure will be approved.

7.16 Storm Water Quality Measure Maintenance

(A) Required

1. The project owner shall be responsible for maintaining permanent storm water quality measures. Maintenance shall be as recommended by the BMP Inspection and Maintenance Field Guide published by the Colorado Stormwater Center (preferred), the CDIPCD Drainage Manual, the Denver Urban Drainage Guidelines, or other regionally-appropriate source of maintenance guidance and shall be performed such that all function and operation of the measure as designed and are preserved.

2. The use of storm water quality measures for materials stockpiles, parking, and storage of equipment, construction materials, waste, or pollutants in prohibited.

3. The area that discharges to a green infrastructure practices shall be fully stabilized with permanent vegetation with no areas of bare soil or erosion to prevent the discharge of sediment to, and clogging of, the practice. The area shall at all times be kept clean to prevent the discharge of sediment and pollutants to the practice. Use of the area for construction or maintenance staging, materials stockpiles, or washing, storage of equipment, waste, or pollutants in prohibited.

4. Green infrastructure practices should be protected from soil compaction. Controls should be established to prevent erosion by equipment and vehicles, and foot traffic unrelated to their maintenance.
Code and Design Standards Revisions

- Permit required
- Stakeholder Input
- Necessary Clean-up

Policy Revisions
Policy & Process Questions

• What does MS4 compliance and GI look like in Boulder?
• What happens <1 acre?
• How can we best integrate with capital projects throughout the city to install GI?
• How do we create better, clearer policy and back that up with assisting documents and guidance?
MS4 Post-Construction Requirements

- Runoff Reduction
- Water Quality Capture Volume
- Pollutant Removal
- MS4 Post-Construction Requirements
MOUs for Permit Compliance

City of Boulder, CO

DRAFT POLICIES
STANDARD OPERATING PROCEDURE

for the Design and Construction of Stormwater Quality BMPs In Public Projects

City departments responsible for the design, subject to penalties and enforcement action, must abide by the policies and procedures outlined below.

II. WAQS, P&D, and City Project Managers must undergo training every five years. The preferred course is Design and Review training offered by GWQI. Certification documentation for all training must be submitted to the City Project Manager.

II. In the event that GWQI training is not available, the City Project Manager must be responsible for identifying other suitable training.

2. PROCESS

Figure 1 illustrates the general process for implementing BMPs. It starts at the time a City project is approved and follows the project through construction. Further sections that follow.

Figure 1. General Process for BMP Design

1. Project Planning
Determine City project applicability to BMP requirements

Why? The City of Boulder requires stormwater quality BMPs for certain projects.

2. Project Design
WQES or P&D reviews the design and approves BMPs.

Why? Prevents the City from implementing unsuitable BMPs.

3. REQUIRED DOCUMENTATION

Table 5. Construction Stage Documentation

<table>
<thead>
<tr>
<th>Department Responsible</th>
<th>Required Documentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stormwater BMP as-built plans, prepared in accordance with BRC Title 11, Chapter 5 and the DCS.</td>
<td></td>
</tr>
<tr>
<td>1. Documentation of construction inspections and final inspection, including corrective action reporting to the responsible department/contractor.</td>
<td></td>
</tr>
<tr>
<td>2. Create and maintain data for City BMP tracking.</td>
<td></td>
</tr>
</tbody>
</table>

GLOSSARY

Applicable City project: An applicable City project is subject to the water quality improvement requirements in Boulder Revised Code, Title 21, Chapter 5. Stormwater and Flood Management (GWQI).

Best Management Practice (BMP): For purposes of this document only, a BMP is a single, engineered, structural control that is designed and constructed to address water and sediment quality concerns.
Supporting Documents

- Compliance “Packet”
  - Checklists
- Example GI projects
- MEP LID Guidance
PILOT PROJECTS
Project Components

• Unique GI
  – Based on GIS analysis and prioritization
• CIP project opportunities
• Planning for future use of capital funds
GI Potential Capital Projects - Compiling the List

1 - Define Projects
2 - Assign weighting factor importance to site suitability categories
3 - Assign numerical ranking to detailed evaluation criteria for each project
4 - Review project raw score and weighted total for project prioritization
5 - Sort the list by the weighted total to list in order of prioritization
# Green Infrastructure Potential Projects - Evaluation

## Table X: Boulder Priority Ranking

<table>
<thead>
<tr>
<th>Overall Priority Ranking</th>
<th>Weighted Total</th>
<th>Project ID</th>
<th>Proposed Project</th>
<th>Proposed CIP Description</th>
<th>CIP Project Cost</th>
<th>GI - Stormwater Est Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>74.5</td>
<td>7</td>
<td>Sumac &amp; 19th Street (Wonderland Creek) Neighborhood Drainage Improvements</td>
<td>PavDrain &amp; Hybrid drainage swale w/ bioretention cells &amp; staged stormwater intakes + risers</td>
<td>$748,200</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>74</td>
<td>11</td>
<td>Valmont City Park Development</td>
<td>Integrated SW mgnt w/ hybrid swale in landscape; bioretention; PCCP paver &amp; storage in parking; educational signage</td>
<td>$5,000,000</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>66.5</td>
<td>18</td>
<td>CU South Planned Open Space</td>
<td>Passive GI and regional storage</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>62</td>
<td>9</td>
<td>Twomile Canyon Creek 1 Runoff Collection &amp; Conveyance</td>
<td>Kalmia &amp; Jupiter improvements PavDrain Shoulder &amp; Bioswale with sub-surface conveyance and capacity improvements to creek/road crossing</td>
<td>$1,000,000</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>60.5</td>
<td>1</td>
<td>North Boulder Library Site Based GI</td>
<td>Integrated SW mgnt w/ hybrid swale in landscape; PCCP paver &amp; storage in parking; educational signage</td>
<td>$5,000,000</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>60.5</td>
<td>2</td>
<td>New Fire Station Site Based GI</td>
<td>Integrated SW mgnt w/ hybrid swale in landscape; PCCP paver &amp; storage in parking; educational signage</td>
<td>$12,500,000</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>59</td>
<td>3</td>
<td>Alpine &amp; Balsam Area Plan Streetscape / Landscape</td>
<td>Permeable Pavement, Stormwater Planters, PavDrain Shoulder, Focal Point w/ Focal Planters</td>
<td>$1,000,000</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>58</td>
<td>13</td>
<td>30th &amp; Colorado Bike/Ped Underpass</td>
<td>Inform plan with concept roadway corridor GI - PCCP parking. FocalPoint, Bioretention planters</td>
<td>$5,900,000</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>56</td>
<td>16</td>
<td>Elmer's Twomile Creek 2 - New and Replacement Storm Sewer</td>
<td>Integrated stormwater management mix of GI bioretention swale, infiltration trenches w/storm collection system</td>
<td>$3,874,000</td>
<td></td>
</tr>
</tbody>
</table>
Unique GI Projects
NEXT STEPS
Next Steps

• Two more Stakeholder Meetings
• Finalize Pilot Projects – Format
• Path forward with funding for GI projects
• Incorporate Code and policy changes
• Finalize compliance tools
Candice Owen
owenc@bouldercolorado.gov

THANK YOU!
5 Stakeholder Meetings

- What is our vision for this program?
- What level of stormwater management is enough?
- How do we incorporate these concepts in city projects and on private development?
CASFM 2018 Annual Conference

Professional Development Sessions:

Session 1: The Truth About Motivation & Team Building
Emily C. Villines (Calibre Engineering, Inc.)

Session 2: Wonderland Creek Construction Lessons Learned
Kurt Bauer & Robby Glenn (City of Boulder, Public Works)
The Truth About Motivation & Team Building

Emily C. Villines, MA, CPSM
Calibre Engineering, Inc.
evillines@calibre-engineering.com
13-30% of staff actively engaged

Strong corporate culture = 500% more revenue growth than an average company

Strong corporate culture = 765%+ net income over 10 years
High Functioning Group Dynamics: People have to feel safe in and connected to the group

- Purposefully invest in exchanges
- Acknowledge individual value
- Actively practice an open forum of communication
- Leadership puts the team’s interest ahead of everything (and everyone) else
High Functioning Group Dynamics:
People have to trust each other

- Trust comes from vulnerability
  - Leaders have to be vulnerable first
  - Use vulnerable language
- Eliminate hierarchy
  - Do the hard stuff together
  - Fight authority bias
  - Discuss issues without leaders
- Encourage a spirit of curiosity
  - Support open communication
  - Give staff a platform
  - Ask without intent to answer
  - Explore together without trying to win
High Functioning Group Dynamics: People have to be driven by a common, clarified purpose

- Develop purpose together
- Create beacons, language, priorities, and catch phrases
- Assign advocates
- Link to present and future
What motivates us?
The fun of mastering a challenge.

We need...
- Creativity at work
- Opportunities for quality and continual improvement
- Genuine achievement
- Opportunity to increase competence
- New and engaging intellectual challenges

Work needs to...
- Create situations for progression
- Offer opportunities for learning and improvement
- Encourage experimentation
- Encourage time devoted to enjoyable work
What motivates us?  
Having control

We need a work environment in which...

• Goals are clear
• Feedback is immediate
• We are able to focus on output (our work) instead of input (our hours)
• We are able to create new domains for ourselves and processes for our work
• We are given the freedom to make decisions and manage our work
What motivates us?
Working for a bigger purpose

- Establish a purpose
- Give to charity or non-profit causes related to work
- Take time to do non-commissioned work related to what you love

Find purpose. The means will follow.

Mahatma Gandhi
Resources

• Coyle, Daniel. The Culture Code: The Secrets of Highly Successful Groups.
• McGregor, Lindsay & Doshi, Neel. How to Motivate Frontline Employees.
• Pink, Daniel. The Surprising Truth About What Motivates Us.
• Sackstein, Starr. Educators' Powerful Role in Motivation and Engagement.
• Subat, Alex. Tips on Enhancing and Tracking Employee Motivation.
• Thompson, Sonia. 3 Science Backed Ways to Improve Your Performance.
• Zvada, Emmanuel. Management Blunders that Kill Employee Morale and Motivation.

Image Credits

• Creativebusinessresources.com
• Rd.com
• Cbc.ca
• Istockphoto.com
• Ciotalknetwork.com
• Healthworkscollective.com
• Carolyntate.co
• Patientsafenetwork.com
• Refreshleadership.com
• Fr.depositphotos.com
• Aleanjourney.com
• Chintanjain.com
• Iconfinder.com
• Quotefancy.com
• Entrepreneur.com
WONDERLAND CREEK PROJECT

- Nine years in the making
- 100-year channel improvements
- 450 dwelling units no longer in 100-year floodplain
- Missing Multi-use path link
2013 Flood Event
PROJECT COMPLEXITY

- BNSF Railroad
- Boulder White Rock Ditch
- Fully urbanized area
- Numerous utilities
FINANCES

- $20.3 million original bid
- $22 million final construction cost
- $8 million design + Construction Services
- $30 million total project cost
FUNDING SOURCES

- Federal Funding: $5.7 million (19%)
- UDFCD: $4.8 million (16%)
- City of Boulder: $19.5 million (65%)

Percentage of project using outside funds: 35%
CONSTRUCTION TIMELINE

- January 2016 construction begins
- Original Contract length 2 years
- Substantially complete June 23rd 2018 (6-month delay)
- Final Acceptance deadline October 31st, 2018
KEY LESSONS LEARNED

1. Consider consequences of grant administration

2. Utilize contractor and internal staff in design

3. Establish city-private utilities relationship
HOW MANY FULL-TIME ONSITE INSPECTORS?

(a) One
(b) Two
(c) Three
(d) Four
1. The consequences of federal funding
CDOT FORMS

- Form 205 – Sublet Application
- Form 266 – Inspectors Progress Report
- Form 832 – Trainee Status and Evaluation Report
- Form 838 – On the Job Trainee/Apprentice Record
- Form 1391 – Contractors Annual EEO Report
- Form 1415 – Anticipated DBE Participation Plan
- Form 1418 – Monthly payment summary
- Form 1419 – DBE Participation Report
- Form 90 – Contract Modification Order (CMO) – 48 change orders on project
MINOR CONTRACT REVISIONS

- Incorporate MCR’s into bid tab.
  - 5-10% of project cost
  - Accounts for small changes
  - Can be combined into one CMO
  - Approx. 50% of our CMO could have been MCR’s
CONSTRUCTION MANAGEMENT

CDOT FUNDING:

- Design engineer cannot be primary construction manager

- Project Delivery Method selection
  - Design/bid/build
  - Construction Manager/General Contractor
  - Design/Build
HUD VS. CDOT

- Davis Bacon FHWA and HUD forms are different
  - Verify prevailing wages
- Every payroll can be audited
- Underestimated administrative time
HUD & CDOT

- Expect full-time employee to administer paperwork

- ~10% of funds will likely go to administration of grant (just city)
2. CONTRACTOR AND INTERNAL REVIEW IN DESIGN
HOW MANY HOURS OF TRAFFIC CONTROL FLAGGING ARE REQUIRED FOR A PROJECT OF THIS SCALE?

(a) 5,000
(b) 10,000
(c) 20,000
(d) 30,000

Total Cost = $580,000
CONSTRUCTABILITY REVIEW

Consider CM/GC option or 3rd party contractor review

- Constructability
- Phasing
CONSTRUCTABILITY REVIEW

Consider CM/GC option or 3rd party contractor review

- Ensure Specs address complex phasing
- Consider liquidated damages
PRIVATE UTILITY CONFLICTS

3. Establish and maintain city-private utilities relationship
COORDINATION

- Include private utilities in design
- Relocation design: 4 to 6 months
- Pothole (Include in bid documents)
- Meet as frequently as needed
CONSTRUCTION

- Designated utility coordinator
- Utility relocates are contractor’s responsibility
- Be involved with observation
- Be ready for unknown utilities
PROJECT COMMUNICATIONS

- Build rapport with community during design
- Identify businesses w/critical needs
- Inform public of progress & milestones
- Over deliver under promise
KEY LESSONS LEARNED

1. Consider consequences of grant administration
2. Utilize contractor and internal staff in design
3. Establish city-private utilities relationship
QUESTIONS?
BACKUP SLIDES
CONSTRUCTION STAFF AND ROLES

Are all aspects of the project covered?
INSPECTORS

Construction Manager

Assistant Construction Manager

Missing Areas

- Inadequate field staffing
- Experience with stream work
- Water Utility (pipe) inspection
- Clarity on decision making authority
EXECUTION PLAN

- Project Execution Plan (PEP)
- Role responsibilities
- Resource allocation
- Organization chart
POTHOLING

- Pothole during design
- Verify tie-ins, material, elevations, and diameters
- Don’t assume as-builts are correct
- Bill SB 18-167
APPROXIMATE PERCENTAGE OF TIME SPENT BY CONSTRUCTION MANAGER ON CDOT PAPERWORK?

(a) Twenty
(b) Forty
(c) Sixty
(d) Eighty
CONCLUSIONS

- Ensure all aspects of project are covered by CM team
- Verify requirements for federal funding and associated implications
- Perform a constructability review
- Coordinate as early and as often as you can with Private Utilities
- Have a construction team that can flex with whatever may happen
CASFM 2018 Annual Conference

Stream Restoration Sessions:

Session1: When Engineers Go Wild!
Richard Borchardt & Barb Chongtoua (UDFCD)

Session2: Urban Stream Design – How We Got to Now
Mary Powell (Corvus Environmental), Dave Skuodas (UDFCD)

Action & Reaction: Approaches for Understanding Sedimentation & Erosion
Matthew Johnson & Brinton Swift (HDR)

The Gunnison River and Riparian Habitat Rehabilitation Project Local Partnerships at Work
Dan Brauch & Steve Westbay (City of Gunnison)

Drone Based Riprap Imaging and Gradation Measurement
LeAndra Nelson (Kiewit Engineering Group)
When Engineers Go Wild!

CASFM Annual Seminar
September 27, 2018
Richard Borchardt, The Flood Control District, Project Manager
Barb Chongtoua, The Flood Control District, Project Manager
Wild about Cherry Creek
Wild about Cherry Creek
Wild about Cherry Creek

Photo Courtesy of Molly Trujillo
Wild about Streams
Have you ever wondered.......
......what events shaped you?
War
Wild about Active Channels
Wild about Active Channels

LAOS
Wild about Active Channels

US
Failures
Have you ever wondered.......
......what events shaped streams?
Water
Sediment
Terrain
Wild about Active Channels
The stream is living history of these events
Stream will change if one factor changes
The channel is coming apart.

Another reach improved.

1994 1999 2000 2001 2002

Improvements in upstream reaches completed.

Improvements in upstream reaches completed.

Development starting to occur in the basin.

Downstream reaches near Santa Fe experiencing soil deposition due to upstream soil movement.
The channel is coming apart.

Another reach improved.

1994

1999

2000

2001

2002

Improvements in upstream reaches completed.

Development starting to occur in the basin.

Downstream reaches near Santa Fe experiencing soil deposition due to upstream soil movement.

Improvements in upstream reaches completed.
Be wild
Push beyond conventional bounds
Q2 = 130 CFS
Q100 = 660 CFS
Oake Gulch
South Newlin Gulch
Harvard Gulch
Montbello Channels
After
Before
Dad Clark
After
Water
Sediment
Terrain
Wild about Sediment Transport

Cherry Creek at Eco Park

Sand Bar

Sand Deposit on Overbanks

Photo Courtesy of Muller Engineering
Wild about Sediment Transport

Cherry Creek at Eco Park

Terrain

Sediment

Water

\[ Q_s \cdot D_{50} \propto Q_w \cdot S \]
Wild about Sediment Transport
Wild about Sediment Transport

Cherry Creek at Eco Park
Wild about Sediment Transport
Wild about Sediment Transport
Wild about Sediment Transport
Wild about Sediment Transport and Storage

Photo Courtesy of Muller Engineering
Wild about Sediment Transport and Storage

Photo Courtesy of Muller Engineering

04/31/2008

5/30/13

Photo Courtesy of Muller Engineering
Wild about Sediment Transport and Storage
Wild about Sediment Transport and Storage

Bank of Cherry Creek

9/6/13

Sediment Storage

5/10/18
Wild about Sediment Transport

Wild about Sediment Transport and Storage
Wild about Maintenance

3/5/18

5/24/2018
Wild about Maintenance

11/21/14

6/6/18
Wild about the Future
When Engineers Go Wild!

Richard Borchardt, The Flood Control District, Project Manager
Barb Chongtoua, The Flood Control District, Project Manager