CASFM 2017 PRESENTATIONS

Bookmarked Tracts:
1. Emergency Preparation & Risk Management (Wednesday)
2. Green Infrastructure & Stormwater Quality (Wednesday)
3. Stream Restoration (Wednesday)
4. Planning for Hazards Luncheon (Wednesday)
5. Floodplain Management (Thursday)
6. Professional Development (Thursday)
7. Stormwater Management & Master Planning (Thursday)
8. Technical Modeling (Thursday)
Developing a Holistic Flood Risk Information System (FRIS) for Colorado
<table>
<thead>
<tr>
<th>Topic Section</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5 Flood Risk Assessment and Communication</td>
<td><strong>Recommendation 14:</strong> FEMA, and its mapping partners including the private sector, should transition to a flood risk assessment focus that is structure specific. Where data are available, FEMA and its partners should contribute information and expertise consistent with their interests, capabilities, and resources towards this new focus.</td>
</tr>
<tr>
<td></td>
<td>a) A necessary prerequisite for accurate flood risk assessments is detailed flood hazard identification, which must also be performed to advance mitigation strategies and support loss estimations for insurance rating purposes.</td>
</tr>
<tr>
<td></td>
<td>b) FEMA should initiate dialogue with risk assessment stakeholders to identify potential structure-specific risk assessment products, displays, standards, and data management protocols that meet user needs.</td>
</tr>
<tr>
<td></td>
<td>c) FEMA and its partners should develop guidelines, best practices, and approaches to implementing structure-specific risk assessments.</td>
</tr>
</tbody>
</table>
Figure 4-11: North Carolina’s FRIS provides risk information at the structure level.
Your Flood Risk Information System

An online system to access and share flood information for your Boulder County community. This pilot project will allow the sharing of flood information for all stakeholders in the hopes of increasing the entire community's flood risk knowledge.
My Focus

Application Geographic Information Science (GIS) in flood risk communication

Developing a Flood Risk Information System for the stakeholders of Boulder County as proof of concept for all of Colorado’s communities
Phase I: Quantitative Data

Phase II: Focus Groups

Phase III: FRIS Web App

Figure 4.11: North Carolina's FRIS provides risk information at the structure level.
Phase I

1. Structure-Specific
2. Additional Quantitative Data
Input Data

1. National Flood Hazard Layer (NFHL)
   - Cross-section lines shown on the FIRM.
   - Flood insurance risk zones (SFHA) on the FIRM.

2. Building footprints dataset (Boulder County)
Interpolation Methods

**Triangular Irregular Networks (TIN)**
Vector surface constructed by triangulating a set of points.

**Natural Neighbor**
Thiessen polygons are created from known input points. New polygons are created for unknown locations. The value of point is based on the percent overlaps.

Jing, L. (University of Denver)
Interpolation Methods

**Inverse Distance Weighted (IDW)**

Weighted average of points in the neighborhood of the point you are trying to estimate.

**Topo to Raster**

A discretized *thin plate spline* technique designed for the creation of hydrologically correct digital elevation models (DEMs).
### Efficiency

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>R2</th>
<th>RMSE</th>
<th>ME</th>
<th>MRE</th>
<th>Min</th>
<th>Max</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaN</td>
<td>0.999862985</td>
<td>6.01324194</td>
<td>2.515059445</td>
<td>0.001797514</td>
<td>4931.82</td>
<td>8277.13</td>
<td>3345.31</td>
</tr>
<tr>
<td>TIN</td>
<td>0.999853035</td>
<td>6.23070737</td>
<td>2.528123994</td>
<td>0.00186245</td>
<td>4931.319336</td>
<td>8276.754883</td>
<td>3345.435547</td>
</tr>
<tr>
<td>IDW 1</td>
<td>0.999499809</td>
<td>11.46153501</td>
<td>6.819498018</td>
<td>0.003429544</td>
<td>4932.4</td>
<td>8274.4</td>
<td>3342</td>
</tr>
<tr>
<td>IDW 2</td>
<td>0.99950909</td>
<td>11.35462801</td>
<td>6.655693527</td>
<td>0.003397555</td>
<td>4932.4</td>
<td>8274.4</td>
<td>3342</td>
</tr>
<tr>
<td>IDW 3</td>
<td>0.999499843</td>
<td>11.46120864</td>
<td>6.819445178</td>
<td>0.003429446</td>
<td>4932.4</td>
<td>8274.4</td>
<td>3342</td>
</tr>
<tr>
<td>IDW 4</td>
<td>0.999509438</td>
<td>11.35043946</td>
<td>6.645733157</td>
<td>0.003396301</td>
<td>4932.4</td>
<td>8274.4</td>
<td>3342</td>
</tr>
<tr>
<td>IDW 5</td>
<td>0.999499841</td>
<td>11.46129721</td>
<td>6.821730515</td>
<td>0.003429473</td>
<td>4932.4</td>
<td>8274.4</td>
<td>3342</td>
</tr>
<tr>
<td>IDW 6</td>
<td>0.999509534</td>
<td>11.34922432</td>
<td>6.643923382</td>
<td>0.003395938</td>
<td>4932.4</td>
<td>8274.4</td>
<td>3342</td>
</tr>
<tr>
<td>Topo to Raster 1</td>
<td>0.999829388</td>
<td>6.745967886</td>
<td>2.79996037</td>
<td>0.001986381</td>
<td>4880.51</td>
<td>8276.62</td>
<td>3396.11</td>
</tr>
<tr>
<td>Topo to Raster 2</td>
<td>0.999814958</td>
<td>7.038668788</td>
<td>2.824861295</td>
<td>0.00206544</td>
<td>4868.24</td>
<td>8276.07</td>
<td>3407.83</td>
</tr>
<tr>
<td>Topo to Raster 3</td>
<td>0.999831562</td>
<td>6.694244101</td>
<td>2.844266843</td>
<td>0.001975152</td>
<td>4887.04</td>
<td>8276.27</td>
<td>3389.23</td>
</tr>
<tr>
<td>Topo to Raster 4</td>
<td>0.999831998</td>
<td>6.677125476</td>
<td>2.770951123</td>
<td>0.001963803</td>
<td>4875.92</td>
<td>8276.02</td>
<td>3400.1</td>
</tr>
</tbody>
</table>

### Error

R\(^2\) coefficient of determination

RMSE root mean square error

ME mean error (absolute)

MRE mean relative error

Min, Max, Range
Continued Work & Outcomes

- Explore the efficiency and error of more outputs
- Explore custom formula for pixel calculation
- Join base flood elevation of “best” raster to building footprint data
- Make data available on FRIS
Phase I

1. Structure-Specific
2. Additional Quantitative Data
Phase II
Methods
Analysis
Outcomes
Focus Groups

**Group 1**
Members/employees of the local government or organizations that operate in Boulder County

**Group 2**
Residents (homeowners and renters) of Boulder County
Pre-Survey
  Background information
  Flooding knowledge/experience
  Technology use

Guided Group Discussion
  Static verses Dynamic Maps
  Structure-Specific Data
  Local Knowledge
  Other Data

Post-Survey
  Discussion Reflection
Analysis
• Reviewing Pre- and Post-Survey responses for trends
• Transcribe, code, analyze discussion audio recordings for theme emergence

Outcomes
• Incorporate feedback into the final FRIS
• Process incorporated into FRIS Implementation Plan
Preliminary Outcomes – Structure-Specific Data

100% of government/organization employees thought structure level flood risk information was very to extremely useful for homeowners.

“I do like the idea of making a more interactive flood information site… My only concern is if [the information] could impact homeowners negatively.”
– homeowner
100% of government/organization employees thought local information was *moderately to extremely useful*.

“I think personal/local knowledge is really powerful in gathering stories and connecting people to this FRIS data” - homeowner
Preliminary Outcomes – Other Data for FRIS

Focus Group 1
• Definitions of flood terms
• Links to flood warning information

Focus Group 2
• Understanding inundation calculations and error
• Links to local organizations
Phase I

1. Structure-Specific
2. Additional
Phase III
FRIS creation
Welcome to the Sussex County ArcGIS Online Collaboration Resource

The Collaboration Resource is a cloud-based content management system for the County’s data, maps, and applications for use by local, county, and state agencies as well as the public. This site provides public access to many online business or information focused applications and data as well providing a collaborative environment for organizations in need of geospatial tools and data for the maintenance of spatial data.
The river flooding hazard is rated High for this location.

This year you have a 12% chance of flooding. Over the next 15 years you have a 84% chance. Over the next 30 years you have a 90% chance.

<table>
<thead>
<tr>
<th>Annual Chance of Flood</th>
<th>Depth Above Finished Floor (in feet)</th>
<th>Damage</th>
<th>Building Losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>1.4</td>
<td>18%</td>
<td>$45,190</td>
</tr>
<tr>
<td>4%</td>
<td>2.6</td>
<td>28%</td>
<td>$67,242</td>
</tr>
<tr>
<td>2%</td>
<td>2.8</td>
<td>28%</td>
<td>$71,372</td>
</tr>
<tr>
<td>1%</td>
<td>3.2</td>
<td>29%</td>
<td>$74,547</td>
</tr>
<tr>
<td>0.2%</td>
<td>3.9</td>
<td>32%</td>
<td>$81,671</td>
</tr>
</tbody>
</table>

Figure 4-11: North Carolina’s FRIS provides risk information at the structure level
Challenges

• Varying data sources and timelines
• Draft dataset still in progress
• Focus group participation
• Narrowing FRIS elements for 2-yr master’s project
Final Outcomes

Keep an eye out for...

Phase I: Quantitative Data

Phase II: Focus Groups

Phase III: FRIS Web App
Final Outcomes

- Completed proof-of-concept **FRIS** for Boulder County

- **GIS Implementation Plan** available for download (from FRIS) for replication by other communities
Special Thanks To:

Dr. Hillary B. Hamann, Dr. E. Eric Boschmann, & Dr. Jing Li from the University of Denver

The University of Denver's Geography and the Environment Department - Laurance C. Herold Fund

The GIS in the Rockies 2017 Scholarship Award

Thuy Patton & Carolyn Fritz of the CWCB

Erin Cooper, David Haynes, & Dave Watson of Boulder County

Julia Bailey, Terri Fead, & Shea Thomas of UDFCD
References


Dewberry Consultants, LLC. 2015. Reducing losses through higher regulatory standards & best practices and cost-effective strategies report. FEMA.


FEMA. 2016. Standards for flood risk analysis and mapping.


Myers, M. D. 1997. Qualitative research in information systems. MIS Quarterly 21 (2) (Jun 1,): 241-2. www.qual.auckland.ac.nz


Risk Evaluation of Smaller Levee Systems

A Prototype

Mark E. Baker, P.E. – NPS Dam and Levee Safety Officer
Kayla Ranney, C.F.M. – HDR Water Resources EIT
### Multi-Attribute Consequences Matrix

<table>
<thead>
<tr>
<th>Impact Levels</th>
<th>Public Health and Life Loss</th>
<th>Natural Resources (Park Purpose)</th>
<th>Cultural/Historical Resources (Park Purpose)</th>
<th>Park Visitation (Park Purpose)</th>
<th>Repair Cost</th>
<th>Non-park Infrastructure and Utilities</th>
<th>Park Infrastructure</th>
<th>Political &amp; Reputation Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>II</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>III</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>IV</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Very Low</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

The figure above illustrates a multi-attribute consequences matrix. Each cell represents the level of impact for a specific category along the impact levels. The matrix helps in assessing and prioritizing the consequences associated with various attributes.
Dam & Levee Safety Program - Inventory

30 Levees
(includes sea walls, dikes, diversion structures, & canals)
MWR – Tall Grass Prairie Levee at Strong City, Kansas
Gulf Islands National Lakeshore, FL Fort Pickens, Seawall
Fort Pickens flooding due to Hurricane Ivan, 2004
Bandelier National Monument
2011 Las Conchas Fire
Bandelier National Monument
Examples of Levees - Temporary Structures

Jersey barriers and sandbags
Bandelier National Monument, NM
Interim Levee Safety Guidelines Framework

- Research levee authorities/policy/guidelines
- Levee Size Classification
- Levee Hazard Potential Classification
- Levee Inventory Request
- Levee Inspection/Examination template
- Risk screening methodology/template
- Pilot examination and risk screening of 7 systems
Approach to building NPS Levee Safety Program

- Consistent with WRRDA 2014 provisions for National Levee Safety Program
- USACE levee safety guidance and tools to the extent practicable
- True to NPS mission
Strategies:
- Do several levees in a batches
- Park’s participation is key
- Appreciate how busy they are
- Screen first (conserve program resources)
- Help them understand and assess the many consequences
- Expert elicitation
- Ratchet up on only the higher risks
Joint NPS/USACE small levees pilot

- 7 systems
- 3 joint risk screenings
- USACE processes (LST, LSOG, LSAC) and NPS pilot tools
- NLD inventory input
Risk Screening Process

- Research available data
- Site Examination
- Analysis and report development
  - Hydrology and Hydraulics
  - Geotechnical Analysis
  - Seismic Loading
- Workshop
- Finalize Report
Hydrology and Hydraulics Analysis

Risk = \( f(\text{Hazard}, \text{Performance}, \text{Consequences}) \)

1. Hazard = Hydrologic Loading
Hydrology and Hydraulics Analysis

\[ \text{Risk} = f(\text{Hazard, Performance, Consequences}) \]

2. Levee performance based on loading conditions

Risk = $f(\text{Hazard, Performance, Consequences})$

Hazard and performance is probability of failure (y-axis)
Risk = \( f(\text{Hazard, Performance, Consequences}) \)

3. Consequences of levee failure evaluated

Potential Failure Modes

- Breach prior to overtopping
- Breach due to overtopping
- Overtopping without breach
- Malfunction of levee component (e.g. closure structure cannot close)
Approach

• Intended to support general flood risk level of study
• Appropriate analysis detail based on perceived level risk
• Collaboration with USACE
Review of Previous Studies and Historical Flooding

- Documentation of previous flooding events (NPS, USGS, NOAA, FEMA, etc.)
Hydrology and Hydraulics Analysis

Review of Previous Studies and Historical Flooding

- Documentation of previous flooding events (NPS, USGS, NOAA, FEMA, etc.)
- Photographs of past flooding
Review of Previous Studies and Historical Flooding

- Documentation of previous flooding events (NPS, USGS, NOAA, FEMA, etc.)
- Photographs of past flooding
- High water marks
- Anecdotal information
- Historical aerial imagery
Hydrology and Hydraulics Analysis

Hydrology

- USGS Regression Equations
Hydrology and Hydraulics Analysis

**Hydrology**

- USGS Regression Equations
- FEMA Flood Insurance Studies
- Other previous studies

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
Flooding Source and Location & Drainage Area (sq. miles) & 10-Percent & 2-Percent & 1-Percent & 0.2-Percent \\
\hline
MARIPOSA CREEK (continued) & 5.02 & * & * & 1,960 & * \\
At Fourmile Street crossing & & & & & \\
Approximately 2,400 feet downstream of Highway 49 & 4.02 & * & * & 1,640 & * \\
\hline
MERCEDES RIVER & 418.6 & * & * & 36,000 & * \\
At Forcita Road & & & & & \\
\hline
SOUTH FORK MERCEDES RIVER & 91.9 & * & * & 23,000 & * \\
Near Wawona & & & & & \\
\hline
\end{tabular}
\caption{Summary of Discharges - continued}
\end{table}

*Data not available*
Hydrology and Hydraulics Analysis

**Hydrology**
- Post-wildfire conditions
- Sediment-loaded flow


http://www.water.ca.gov/floodsafe/ca-flood-preparedness/fpw-day2.cfm
Hydraulics

Coastal sites

<table>
<thead>
<tr>
<th>Flooding Source</th>
<th>Stillwater Elevation</th>
<th>Base Flood Elevation (Feet NAVD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GULF OF MEXICO</td>
<td>4.0</td>
<td>VE 11-16</td>
</tr>
<tr>
<td>Transects 1-17</td>
<td>6.8 10.5 11.0</td>
<td>AE 8-12</td>
</tr>
</tbody>
</table>
Hydrology and Hydraulics Analysis

Hydraulics
Riverine sites

1D Model

2D Model
Hydrology and Hydraulics Analysis

Coastal Seawall: Fort Pickens Seawall
Coastal Seawall: Fort Pickens Seawall

Loading: FEMA stillwater flood elevations – 50 to 100-year event overtops the seawall

Performance:
- 1926 Hurricane – overtopping, flood damage to buildings, no loss of life
- Hurricane Ivan (2004) – overtopping, reservoir inside of wall for several days, damage to historical buildings, no loss of life

Consequences: Damage to historical resources

PFM driver of risk: Overtopping without breach

Resulting Risk: Moderate
Riverine Levee: El Portal Residence Area

Levee
Riverine Levee: El Portal Residence Area

Levee

- **Hydrology**
  - Regional regression equations

- **Hydraulics**
  - 2D model due complex flow pattern
  - Topographic data with sufficient resolution available for model development
Riverine Levee: El Portal Residence Area

Levee

Loading: Flows up to 100-year event could be contained

Performance:
• Levee has the possibility of overtopping between the 100 and 200-year events
• Velocities along the waterside levee toe were found to be high

Consequences: Flood events larger than the 100-year event could lead to flooding the egress route, while the El Portal Trailer Village remains dry.

PFM driver of risk: Breach due to overtopping

Resulting Risk: Moderate
Riverine Levee: El Portal Residence Area

Levee
Conclusions

- Guidelines were a prototype – more changes will be needed for future risk screening.
- NPS risk screening contributed to USACE future National Levee Risk Screening Guidelines.
- Risk screening allows NPS to better understand the risk associated with their levees and take targeted actions to mitigate unacceptable risks.
Questions?

Mark. E. Baker, P.E.
NPS Dam & Levee Safety Officer
mark_e_baker@nps.gov
Flood Risks from Spillways

BIA Safety of Dams (SOD) Program

- Over 900 dams on 42 Federally-recognized Indian reservations
- 138 are classified as probable life loss (high-hazard potential)
- 25% of DOI’s high-hazard potential dam inventory
Flood Risks from Spillways

Coolidge Dam - San Carlos Reservation
Flood Risks from Spillways

Headgate Rock Dam - Colorado River Indian Tribes
Flood Risks from Spillways

Red Lake Dam - Navajo Reservation
Flood Risks from Spillways

Elgo Dam – San Carlos Reservation
Flood Risks from Spillways

Water Tank Dam - San Felipe Reservation
Flood Risks from Spillways
Flood Risks from Spillways

Dams are a significant part of the water resources infrastructure and trust assets of many Reservations and Tribes.

**BIA Program Dams - Primary Use**

- Recreation: 32%
- Irrigation: 33%
- Flood Control: 18%
- Fire Protection/Stock Pond: 11%
- Water Supply: 5%
- Conservation: 1%

Dams are a significant part of the water resources infrastructure and trust assets of many Reservations and Tribes.
Flood Risks from Spillways

Risk-Informed Decision Making and Prioritization

- Risk Informed Dam Safety Decisions and Rehabilitation Prioritization
- \( f-N \) charts utilized to depict probabilities and consequences associated with dam failures
Flood Risks from Spillways

Risks Associated with Spillway Operation in Accordance with Design Intent
Flood Risks from Spillways

Lack of Floodplain Management ≠ Lack of Flood Risk

- Flooding is the most common and destructive natural disaster in the U.S.
- 37 of 566 Federally Recognized Tribes (7 percent) participate in NFIP
- Most tribal lands remain unmapped
- Tribal communities may be unaware of their flood risk, even in high risk areas
Floodplain management is a responsibility of BIA Division of Water and Power.

It is BIA SOD Program policy to encourage floodplain management below dams and along reservoir shorelines.
Flood Risks from Spillways

Number of Major Flood Disaster Declarations by County and U.S. Indian Reservation (1980 – 2005)

- None
- 1
- 2 - 5
- 6 - 10
- More than 10

Indian Reservation
Flood Risks from Spillways

Denver, 1850’s

Photo: Colorado History Museum
Flood Risks from Spillways

Warning Time
- Fatalities very low > 90 Min

Warning Message
- Detailed Information
- Precise Details
- Good Understanding of the Flood Severity
EWS MapView

350 sites, 3200 sensors, 3600 rules
MOST COMMON MONTH AMONG TOP 10 DAILY PRECIPITATION TOTALS, PRISM 1981-2015

Courtesy of USGS [Dettinger, 2016]
Partnerships

Local Tribes

National Monitoring Center

Bureau of Indian Affairs

ONERAIN

DAM SAFETY, SECURITY, & EMERGENCY MANAGEMENT
NMC Call Center

NATIONAL MONITORING CENTER

The NMC is located on the Flathead Indian Reservation in Ronan, Montana.

The NMC is staffed 24 hours per day, seven days a week, by personnel from the Confederated Salish and Kootenai Tribes of the Flathead Nation.
EWS Data Dashboards

Storm Prediction Center

Weather Links (click image)

Snotel
- St Lawrence Alt (above Washakie)
- Hobbs Park

Webcam north of Riverton

Webcam in Lander

Washakie Upstream

Washakie Dam

Washakie Downstream

DAM SAFETY, SECURITY, & EMERGENCY MANAGEMENT
Example EWS Data
Flood Risks from Spillways

138 Dams = 58 EAPS

- Planning Meetings
- Exercises

Results:
Improved tools to communicate risks below dams
Flood Risks from Spillways

PMF Dam Failure Inundation Maps

- Each EAP typically has had a PMF Dam Failure Inundation Map
Flood Risks from Spillways

BIA Safety of Dams Mission

“to reduce the potential loss of human life and property damage caused by dam failure by making BIA dams as safe as practically possible.”

Were our EAPs adequately reflecting our mission?
Or putting us at greater liability?
Flood Risks from Spillways

FEMA 64, July 2013
Suggests Response Levels

- High flow
- Non-failure
- Potential failure
- Imminent failure

BIA SOD Handbook, revised 2014

- Response Level 1
- Response Level 2
- Response Level 3
Flood Risks from Spillways

EAP Response Levels  →  Integrity of the Dam

Normal Flooding  ≠  Dam Safety Emergency

BIA has created new tools:

- Rate of Rise Graphs
- Site Plan Maps
- Watershed Maps
- Rainfall Maps
- Spillway Discharge Curves
- Flood Animations
- Non-Dam-Failure Inundation Maps

To provide better information to aid tribes with flood planning efforts.
Flood Risks from Spillways

Rate of Rise Graphs

- Rainfall driven
- Provide advanced warning time
- Other PFMs may exist!

Image credit: damfailures.org http://damfailures.org/lessons-learned
Flood Risks from Spillways

Dam Familiarization – Site Plan Maps/Watershed Maps

Indian Lake Dam – Umatilla
Tat Momolikot Dam – Tohono O’odham
Flood Risks from Spillways

Frequency Storm Rainfall Maps

Ray Lake & Washakie Dams – Wind River

San Francisco & Water Tank Dams – San Felipe
Flood Risks from Spillways

PMP Rainfall Maps

Eagle Creek No.1, Silver Lake, & Mescalero Dams – Mescalero

Ray Lake & Washakie Dams – Wind River
Flood Risks from Spillways

NOAA Atlas 14 100-Yr 24-Hr

NOAA Atlas 14 1,000-Yr 24-Hr

HMR 55A 24-Hr General Storm PMP

HMR 55A 1-Hr Local Storm PMP
Flood Risks from Spillways

- NOAA Atlas 14 100-Yr 24-Hr
- NOAA Atlas 14 1,000-Yr 24-Hr
- HMR 55A 24-Hr General Storm PMP
- HMR 55A 1-Hr Local Storm PMP
Flood Risks from Spillways

Spillway Discharge Curves

[Graph showing spillway discharge curves with key points:
- Top of Dam = 2462.0 feet
- Auxiliary Spillway Crest = 2459.0 feet
- Service Spillway Crest = 2454.0 feet
- Threshold Description (e.g., Rd 5 Culvert Capacity) = 37 cfs]
Many different types of spillways at BIA facilities:

- Uncontrolled (passive) vs Controlled
- Broad-crested, sharp-crested, ogee weirs, and morning-glory inlets
- Culverts, Open Channels
- Discharge curves generated from best available data
Flood Risks from Spillways

Spillway Discharge Curves

Coolidge Dam, AZ
Flood Risks from Spillways

Spillway Discharge Curves

Coolidge Dam - Spillway Stage-Discharge Curve

Spillway Discharge Associated with Response Level Zone at Zero Rate of Rise

Top of Dam = 2536.0 feet

Approximate Low Chord Spillway Deck = 2523.0 feet

Maximum Recorded Reservoir Surface = 2521.7 feet

Approximate Safe Channel Capacity = 2516.4 feet

Spillway Crest = 2511.5 feet

Estimated Combined Spillway Discharge (cubic feet per second)

Thousands

Coolidge Dam, AZ
Flood Risks from Spillways

Flood Inundation Animations
<table>
<thead>
<tr>
<th>Flood Event</th>
<th>Peak Flowrate</th>
<th>Total Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-Yr Flood</td>
<td>13,600 cfs</td>
<td>14,400 ac-ft</td>
</tr>
<tr>
<td>Sunny-Day Dam Failure</td>
<td>30,600 cfs</td>
<td>1,730 ac-ft</td>
</tr>
<tr>
<td>Combined Spillway Capacity Flood</td>
<td>58,000 cfs</td>
<td>---</td>
</tr>
<tr>
<td>PMF Dam Failure</td>
<td>225,300 cfs</td>
<td>142,600 ac-ft</td>
</tr>
</tbody>
</table>
## Flood Risks from Spillways

<table>
<thead>
<tr>
<th>Flood Event</th>
<th>Peak Flowrate</th>
<th>Total Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-Yr Flood</td>
<td>13,600 cfs</td>
<td>14,400 ac-ft</td>
</tr>
<tr>
<td>Sunny-Day Dam Failure</td>
<td>30,600 cfs</td>
<td>1,730 ac-ft</td>
</tr>
<tr>
<td>Combined Spillway Capacity Flood</td>
<td>58,000 cfs</td>
<td>---</td>
</tr>
<tr>
<td>PMF Dam Failure</td>
<td>225,300 cfs</td>
<td>142,600 ac-ft</td>
</tr>
</tbody>
</table>
Flood Risks from Spillways

Flooding Risks Associated with Designed Spillway Operation
Flood Risks from Spillways

Flooding Risks Associated with Designed Spillway Operation
Flood Risks from Spillways

Flooding Risks Associated with Designed Spillway Operation
Flood Risks from Spillways

Flooding Risks Associated with Designed Spillway Operation
Questions?

Rinda Tisdale, MEP, CEM
Emergency Management Coordinator
Rinda.Tisdale@bia.gov

Matthew Young, PE, CFM
Dam Safety Engineer
Matthew.Young@bia.gov

Lee Mauney, PE, CFM
Dam Safety Engineer
Lee.Mauney@bia.gov
MODELING, MITIGATION & REGULATION OF MUD AND DEBRIS HAZARDS IN ASPEN, COLORADO

APRIL LONG, P.E. – CITY OF ASPEN
ANDREW EARLES, PHD, PE – WRIGHT WATER ENGINEERS, INC.
DAI THOMAS, PHD, PE – TETRA TECH – RIVER, COASTAL AND ENGINEERING GROUP – FORT COLLINS
CATHERINE BERG, P.E. – PITKIN COUNTY

20TH SEPTEMBER 2017
CITY OF ASPEN
&
ASPEN MOUNTAIN
PROJECT APPROACH

I. Geology & Historic Mudflows
II. Hydrology
III. Developing Hazard Rating System
IV. Mudflow & Mudflood Modeling
V. Depth & Hazard Mapping
VI. Estimates of Representative Damages
VII. Mitigation Measures
COMPLEX GEOLOGY

Castle Creek Fault Zone

Approximate outline of drainage basin on Aspen Mountain, above the City of Aspen.

Legend:
- Alluvial Fans; subject to sediment deposition during mud floods, mudflows, and debris flows.
- Landslides; areas that slid in the past and may be prone to future movement.
- Rockfall Areas; areas on or below cliffs that are prone to future rockfall.
- Potentially Unstable Slopes; areas potentially prone to future land sliding.
HISTORIC EVENTS & ACTIVITIES

• September 1919
  – Cloudburst
  – “yellow clay mud from the mountain”

• August 1964
  – 1.13 inches in 1 hour
  – Pioneer Gulch up to 5’ of mud

• June 1984
  – Strawpile Landslide
HYDROLOGY

Nearby Studies for Mudflow & Mudflood Unit Rate of Runoff Comparisons

<table>
<thead>
<tr>
<th>Study</th>
<th>Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspen (previous study)</td>
<td>WRC</td>
</tr>
<tr>
<td>Aspen (NOAA Atlas 14 Update)</td>
<td>WWE</td>
</tr>
<tr>
<td>Milton Creek</td>
<td>USGS</td>
</tr>
<tr>
<td>Breckenridge</td>
<td>Tetra Tech</td>
</tr>
<tr>
<td>Glenwood Springs</td>
<td>USACE</td>
</tr>
</tbody>
</table>

![Graph showing the number of days with snowfall, mixed snow and rain, and rain over 1" from 1935-2015, along with average snow water equivalent at Schofield SNOTEL Site.](image)
MUDFLOW CHARACTERISTICS

![Graph showing mudflow characteristics. The graph illustrates the relationship between concentration by volume and concentration by weight, as well as the flow over time. The labels include 'Water Flow', 'Mud Flood', 'Mud Flow', and 'Landslide'. The concentration by volume (C_V) is plotted against concentration by weight (C_W). The flow over time is also shown with different lines representing 'Flow', 'Bulked Flow', and 'Sed. Conc.'.
TYPICAL MUDFLOW CHARACTERISTICS IN ASPEN AREA

• Saturated Soil Conditions

• Sediment

• Rainfall (10 to 25-Year Event)
OVERVIEW OF MODELING

- Develop new mudflow flow (FLO-2D) model
  - 2-Hour, 2-, 25-, and 100-Year Rainfall Events
  - Depth andExtent of Flooding
  - Hazard Mapping
  - Wildfire Analysis
  - Mitigation
  - Economic Analysis
  - Develop New Guidelines
NEW FLO-2D MODEL

- 20-foot Grid Size
- 165,214 Elements
- Based on LiDAR mapping from City
### MANNING’S N ROUGHNESS

<table>
<thead>
<tr>
<th>Land Use</th>
<th>n-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban/Structures</td>
<td>0.04</td>
</tr>
<tr>
<td>Roads/Streets</td>
<td>0.02</td>
</tr>
<tr>
<td>Mine Tailing</td>
<td>0.40</td>
</tr>
<tr>
<td>Grassland/Ski Runs</td>
<td>0.20</td>
</tr>
<tr>
<td>Light Forest</td>
<td>0.30</td>
</tr>
<tr>
<td>Medium Forest</td>
<td>0.35</td>
</tr>
<tr>
<td>Dense Forest</td>
<td>0.40</td>
</tr>
</tbody>
</table>
## Horton parameters

<table>
<thead>
<tr>
<th>HSG</th>
<th>Initial Rate (in/hr)</th>
<th>Final Rate (in/hr)</th>
<th>Decay Coeff (s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5</td>
<td>1</td>
<td>0.0007</td>
</tr>
<tr>
<td>B</td>
<td>4.5</td>
<td>0.6</td>
<td>0.0018</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>0.5</td>
<td>0.0018</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>0.5</td>
<td>0.0018</td>
</tr>
</tbody>
</table>
RAINFALL

2-hour duration, front loaded storm
Derived from NOAA Atlas 14 hourly point precipitation depth

<table>
<thead>
<tr>
<th>Recurrence Interval (years)</th>
<th>Rainfall (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.47</td>
</tr>
<tr>
<td>5</td>
<td>0.64</td>
</tr>
<tr>
<td>10</td>
<td>0.77</td>
</tr>
<tr>
<td>25</td>
<td>0.95</td>
</tr>
<tr>
<td>50</td>
<td>1.09</td>
</tr>
<tr>
<td>100</td>
<td>1.23</td>
</tr>
</tbody>
</table>

![Graph showing rainfall depth over time for different recurrence intervals.](image-url)
WATER AND SEDIMENT HYDROGRAPH

![Water and Sediment Hydrograph](image-url)
MODEL OUTPUT
MAPPING

Depths and Velocities

Example 25-year Mudflow
MAPPING

Flood Hazard Index

Example 100-year Mudflood

<table>
<thead>
<tr>
<th>FHI</th>
<th>Max Depth ($D_{max}$) (ft)</th>
<th>AND/OR</th>
<th>$D_{max} \times V_{max}$ (ft$^2$/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>$D \geq 3.3$</td>
<td>OR</td>
<td>$vh \geq 3.3$</td>
</tr>
<tr>
<td>M</td>
<td>$0.7 \leq D &lt; 3.3$</td>
<td>AND</td>
<td>$0.7 \leq vh &lt; 3.3$</td>
</tr>
<tr>
<td>L</td>
<td>$0.7 \leq D &lt; 3.3$</td>
<td>AND</td>
<td>$vh &lt; 0.7$</td>
</tr>
</tbody>
</table>
## COST ESTIMATES

<table>
<thead>
<tr>
<th>Location</th>
<th>Mud Depth</th>
<th>Days of cleanup</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streets</td>
<td></td>
<td></td>
<td>&gt;$300,000</td>
</tr>
<tr>
<td>Sewer Lines</td>
<td></td>
<td></td>
<td>&gt;$380,000</td>
</tr>
<tr>
<td>Residential</td>
<td>6’</td>
<td>11</td>
<td>&gt;$800,000</td>
</tr>
<tr>
<td>Hotel</td>
<td>3’</td>
<td>50</td>
<td>&gt;$4.5M</td>
</tr>
<tr>
<td>Commercial</td>
<td>3’</td>
<td>3</td>
<td>$165,000</td>
</tr>
</tbody>
</table>
MITIGATION ALTERNATIVES

- Reduce Sediment Supply
- Routing to Parks as Storage Areas
- On Mountain Mitigation
- Floodproofing
- Warning System
Vulnerable Sites in Aspen

A few inches of curb overtopping = Feet of Mud!
POSSIBLE CHANGES TO REGULATIONS

- Adjust zoning areas
- 25-year (55% concentration)
- 100-year (20% concentration)

- Increase depth tolerance up to 0.5 feet
  - Only on ground previously inundated
  - Make reasonable effort to not increase.

- No depth increase on land not inundated under existing conditions
BENEFITS OF STUDY

• Improved mapping and hazard classification system

• Model will be available to:
  • Developers
  • Engineers

• Substantial decrease in analysis cost for redevelopment

• Easier for City to review

• City to keep track of model changes
ACKNOWLEDGEMENTS

Expert Advisors, Reviewers & Co-authors

Jim O’Brien, PhD, PE - FLO-2D
Bob Kirkham, PG – Consulting Geologist
Mike Horvath, P.E., City of Aspen

Cooperating Partner

Aspen Skiing Company
Presentation Overview

1. Goals and Guiding Principles
2. Planning Area
3. Elements of the Study
4. Technical Analyses
5. Actionable List of Projects
6. Plan Development
7. Implementation

Team Members
Goals and Guiding Principles

- Provide a framework that promotes a resilient Monument Creek Watershed
  - Health, safety, and welfare of the public
  - Healthy ecosystems & T&E protection
  - Sustainable, self-maintaining
  - Cost-effective

- Stakeholder identified Core Values
  - Safety
  - Resiliency
  - Constructability
  - Environment
  - Community
  - Schedule

Goals and Guiding Principles

- Objectives
  - Identify areas of concern
  - Update technical foundation
  - Define a comprehensive, holistic restoration Master Plan
  - Actionable list of projects
  - Provide conceptual design for high priority projects
Planning Area

- Drainage Area: 237 sq mi
- Elevation Range: 6,000ft – 9,727ft
- Primary Tributary to Fountain Creek
- Diversity of Terrain and Vegetation
- Complex Climate
- Communities
  - City of Colorado Springs
  - Monument
  - Palmer Lake
  - Black Forest
  - Other El Paso County

Elements of the Study

- Technical Analyses
  - Data Collection
  - Environmental
  - Hydrology
  - Hydraulics
  - Geomorphology
- Public Involvement
  - Stakeholder
  - Community
- Alternatives Analysis
- Project Prioritization
- Plan Development

Plan Contents

1. Executive Summary
2. Conceptual Plan Mapbooks
3. Final Project List
4. General Stewardship Recommendations
5. Conceptual Design Toolbox
6. Project Implementation Guidelines
7. Plan Development
Project Identification

- More than 250 projects were identified via technical analyses, stakeholder input, and community involvement.
- Identified projects categorized by primary objectives:
  1. Immediate Action Items
  2. Stream and Channel Restoration
  3. Detention and Water Quality Facilities
  4. Flood Risk Reduction
  5. Local Erosion
  6. Riparian Buffer Restoration
  7. Trails and Open Space
  8. Aquatic and Terrestrial Habitat
  9. Programmed Capital Improvements Projects

Alternatives Analysis

- Evaluated Alternatives by Category
- Immediate, High, Moderate, and Low Rankings
- Reduce 200+ projects to 42 High and Immediate Projects

Prioritization

- Evaluated all of the High and Immediate Ranking Projects
- Stakeholder input on evaluation criteria
- Immediate, High, Moderate, and Low Priorities Assigned
Actionable List of Projects

- 42 Prioritized, High and Immediate Ranking Projects
Projects Summary

- Actionable List of 42 Prioritized, High and Immediate Ranking Projects
  - Variety of Issues and Alternatives Represented
    - Immediate Action (3)
    - Stream and Channel Restoration (11)
    - Detention and Water Quality Facilities (9)
    - Flood Risk Reduction (5)
    - Local Erosion (7)
    - Riparian Buffer Restoration (3)
    - Trails and Open Space (4)
    - Costs Range from $112,000 to $5,181,000

- Immediate Action Projects
  - Failed Wingwall and Erosion Issues near I-25
  - 3 Projects
  - Costs Range from $112,000 to $648,000
  - Separate from the list of prioritized, high ranking projects

- Stream and Channel Restoration Projects
  - 11 Projects
  - Costs Range from $158,000 to $2,475,000
  - Natural Channel and Small Drop Structure Design Approaches
Projects Summary

- Detention and Water Quality Facilities
  - 9 Projects
  - Costs Range from $743,000 to $5,181,000
  - Recommended Retrofit and New Full Spectrum Facilities

Projects Summary

- Flood Risk Reduction Projects
  - 5 Projects
  - Costs Range from $277,000 to $2,555,000
  - Recommended Culvert and Bridge Replacements

Projects Summary

- Local Erosion Projects
  - 7 Projects
  - Costs Range from $178,000 to $1,354,000
  - Stabilize Headcutting
Projects Summary

• Riparian Buffer Restoration Projects
  – 3 Projects
  – Costs Range from $182,000 to $1,309,000
  – Establish Vegetation Through the Riparian Corridor

Projects Summary

• Trails and Open Space Projects
  – 4 Projects
  – Costs Range from $511,000 to $1,748,000
  – Promote Access, Visibility, and Recreation Through Trails and Open Space

General Recommendations

• Continue post-fire mitigation efforts
• Conserve and protect wildlands
• Manage forests for the mitigation of wildfire
• Conserve riparian buffer zones
• Maintain and prevent encroachment upon the 100-year floodplain
• Value the watershed and its creeks and streams as assets/resources
General Recommendations

- Development and redevelopment should incorporate LID to reduce runoff volume & restore hydrology
- Planning and design should be done in accordance with DCM documents
- Stream flows and release rates published as a part of this report should be adopted

General Stewardship Recommendations

- City and District Drainage Criteria Manual
- USACE Watershed Management Plan
- Fountain Creek Vision Task Force
- District Policy Evaluation Report
- Resource Management
  - Upper Monument Creek Landscape Restoration Initiative
  - Corridor Restoration Master Plan
- Access, Visibility, and Education

Conceptual Design Toolbox

<table>
<thead>
<tr>
<th>Project Area</th>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank Stabilization</td>
<td>Needed 600 FT</td>
<td>No. of Rock Vanes Design (1-ft) 4 EA, Total Vane Length 320 FT, Boulders in Vane 110 EA, No. of 3-ft Drops 0 EA, Total Grouted Boulder Area 0 SF, Concept Design Slope 0.50%, Cut 40 CY, Fill 420 CY, Net -380 CY, Drop Structures Total Area 0 SY, Grouted Boulder (1 Boulder Thick) 0 CY, Vegetation Area 5300 SF</td>
</tr>
</tbody>
</table>
Plan Accomplishments

- Problem identification
- Updated technical information
  - Hydraulics, Hydrology, and Geomorphology
- Comprehensive project development
- Actionable list of projects
- Mapbooks
- Conceptual designs
- Enduring stakeholder collaborative

Plan Implementation

- Monument Branch Phase I
Plan Implementation
• Monument Creek at Pikeview

Plan Implementation
• Black Forest Creek Restoration

Plan Implementation
• Palmer Lake LOMR
Plan Implementation

- Colorado Springs Stormwater Infrastructure Master Plan

Thank You
Summary of Maximum Flooding During 2013 near Arboles, Colorado, With a Comparison to Maximum Flooding for Small Basins in Southwestern Colorado

Robert D. Jarrett, Ph.D.
Lakewood, Colorado

28th Annual CASFM Conference
Communication Meets Leadership: The Future of Water

Breckenridge, Colorado
September 20, 2017

Study for
- Archuleta County
- Anthony Melonakis

Contact: paleoflood@comcast.net
Storm of July 10, 2013; Maximum recorded = 0.30 inches in Archuleta County

Andrews Drive Tributary
Arboles, Colorado

Substantial Property and Infrastructure Damages

OVERARCHING PROBLEM: Limited Rainfall and Flood Data in Smaller Basins Below About 7,500 ft in Southwestern Colorado
Presentation Overview

- Introduction
- Overview of 2013 Flood Season
- Critical-Depth Method for Peak Discharges
  - July 10, 2013 Flood
  - Maximum Paleoflood
- Define the Rainfall-Runoff Footprint
- Determine Flood Frequency
- Additional Hazard Awareness
- Concluding Remarks
No Rainfall or Streamflow Data for July 10, 2013

Study Objectives for Archuleta County Officials

- Determine The Magnitude and Frequency of the Flood
- Provide a Better Flood History for SW Colorado
- Improve the Understanding of Flood Hazards
Waldo Burn Area, Colorado Springs
Four Major Flash Floods in July and August 2013

• US Hwy 24, Colorado Springs

• Waldo Canyon - Aug 10, 2013

0.5 to 1 inch of rain < 1 hour
True wall-of-water floods
1 person killed

2013 rainfall frequencies about 5-10 yrs; record floods
September 8-17, 2013 Storm Rainfall

Up to 20 inches in 7 days
Selected 2013 Flood Discharges

Documented 144 Peak Discharges Throughout Northern Colorado Front Range Streams

Source: Map by Kevin Stewart, UDFCD
Ice-Dam Failure Flooding
3-5 ft high wall-of-water flooding

December 10, 2013

Clear Creek nr Golden
San Miguel River nr Placerville

Localized floods (e.g., 7/10/13) often go unnoticed

Source: Channel 7 News; Denverchannel.com
Presentation Overview

- Introduction
- Overview of 2013 Flood Season
- Critical-Depth Method for Peak Discharges
  - July 10, 2013 Flood
  - Maximum Paleoflood
- Define the Rainfall-Runoff Footprint
- Determine Flood Frequency
- Additional Hazard Awareness
- Concluding Remarks
Validation of Manning’s n-Values for Streams in Colorado

“Determination of roughness coefficients for streams in Colorado,”
U.S. Geological Survey Water Resources Investigations 85-4004, R Jarrett

Study results: Manning’s n rapidly varies with flow depth

(Methods: Jarrett, 1985)
Critical-Depth Sites For Discharge

• Flow-over-road

• Weir/flumes

• Drops

• Waterfalls

Excellent controls for stage-discharge relations (or rating curves)
Critical-Depth Method for Peak Discharges

Evaluated CD method for large floods at 40 gaged sites in western US rivers

Stream slope \( \geq 0.01 \text{ ft/ft} \)

Arkansas River nr Buena Vista

Long reaches of near critical flow; Froude No. \( \sim 1 \) (Jarrett, 1984)

Thus, discharge is a function of channel geometry not roughness!!!
Lack of straight reaches mountain streams

\[ Q = V_c \times A \]

Cross sections

\[ N_{xs} = 2-4 \]

~Straight, uniform sub-reaches

Subdivided XS as needed

\[ Q = V_c \times A \]
\[ V_c = (g \times D)^{0.5} \]

Qp is average all XSs

Q is independent of n value; key is reach and cross section selection

Sabino Canyon, AZ, flood of 1999
Validation of critical-depth method

For critical flow, velocity and discharge are a function of channel shape

\[
\log(Q_{\text{site}}) = 0.03 + 0.986 \log(Q_{\text{gage}})
\]

(source: Jarrett & England, 2002)
Attributes of a Flood Reach for Peak Discharge Estimation

1. Stream slope greater than ~ 0.01 ft/ft
2. Relatively straight channel (~50 ft)
3. Relatively uniform width
4. Reach is stable
5. Evaluate channel change
6. Minimal obstructions (debris, boulders, trees)
7. Good high-water marks
Presentation Overview

• Introduction
• Overview of 2013 Flood Season
• Critical-Depth Method for Peak Discharges
  • July 10, 2013 Flood
  • Maximum Paleoflood
• Define the Rainfall-Runoff Footprint
• Determine Flood Frequency
• Additional Hazard Awareness
• Concluding Remarks
Paleoflood Hydrology

Study of sediment and botanical evidence of past floods to help better understand flood hazards

Crooked River, CA

Flood sediments

River meanders

Botanical evidence

1976 flood scar - Big Thompson River at Drake
Types and locations of PaleoStage Indicators (PSIs)

- Rock alcove with sequences of slack-water deposits
- Flood stage
- Erosional scar
- Scar on tree
- Gravel bar
- Low-water channel

- Escalante River, UT – an ideal paleoflood site of “alcove” slack-water deposits

- Lefthand Creek near Boulder, Colorado: 1 hour after May 1995, flood peak
What is the relation of flood deposits and flood height?

1995 to 2000 -- studied over 192 stream sites with recent large floods
PSI-HWM comparison for 192 flooded rivers indicated maximum height of fresh deposits of flood sediments - approximately equal maximum flood height or high-water marks.
Average recurrence interval ~75 years for all sites

Conclusion

PSI = HWM for $S < 0.03$ ft/ft

PSI > HWM for $S > 0.03$ ft/ft
The types of sites where sediments are deposited (PSIs)

1) locations of rapid energy dissipation where sediments are deposited e.g., tributary junctions, decreased gradient, channel-width expansions or increased flow depth
2) locations along the sides of valleys in wide, expanding reaches
3) ponded areas upstream from channel contractions
4) the inside of bends
5) overbank areas on the outside of bends

(source: Jarrett and England, 2002; Yanosky and Jarrett, 2002)
Bonneville Glacial Lake Outburst Flood ~15,000 years ago

Snake River, ID

Flood depth more than 450 ft,
Flood discharge ~36 million ft$^3$/s

Note: preservation of paleostage indicators for 10’s of thousands of years
Presentation Overview

- Introduction
- Overview of 2013 Flood Season
- Critical-Depth Method for Peak Discharges
  - July 10, 2013 Flood
  - Maximum Paleoflood
- Define the Rainfall-Runoff Footprint
- Determine Flood Frequency
- Additional Hazard Awareness
- Concluding Remarks
Study Area
Arboles, Colorado
July 10, 2013 Storm

Regional Study Area (approx.)

Southwest Colorado Basins; DA <40 mi², <7,500 ft
Andrews Drive Tributary, Arboles

Location of Most Property & Infrastructure Damages 7/10/13
<table>
<thead>
<tr>
<th>Semi-arid climate</th>
<th>Mean basin elevation of 6,730 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean annual precipitation of about 14 in</td>
<td>Pinon pine forest</td>
</tr>
<tr>
<td>Drainage area of 0.78 mi²</td>
<td>Large areas of exposed bedrock</td>
</tr>
<tr>
<td>Elevation of about 6,140 ft</td>
<td>Poorly drained (“D”) soils</td>
</tr>
<tr>
<td>Mean basin slope of 36 percent</td>
<td>Very low infiltration rates</td>
</tr>
</tbody>
</table>
Andrews Drive Tributary (0.78 mi²)

July 10, 2013
Flood deposits

(source: Archuleta County)
7/10/13 Flood Sites in Andrews Drive Tributary

Site numbers 4-7
Andrews Drive Tributary (site 5)

Older Flood boulders (PSI)

July 10, 2013 High-water line

Upstream View of Channel at Cross Section 5
Need to assess channel stability in alluvial channels

Small brush on channel bed
Water Flood, Hyper-concentrated Flow, or Debris Flow?

Determined by clast orientation (imbrication)

7/10/13 was a hyper-concentrated flow

Typical High-Water Marks – July 10, 2013
HWMs of organic debris
Andrews Drive Tributary

Note: Top of flood boulder deposits (new PSIs) = 7/10/13 HWMs
Non-Inundation Surfaces (NISs) are the lack of flood erosional or depositional features and are as important as PSIs in determining upper discharge bounds.
Site 5. Andrews Drive Tributary
Critical-Depth Computations

<table>
<thead>
<tr>
<th>Station ft</th>
<th>Depth ft</th>
<th>Comments</th>
<th>Qmax = +1.5 ft (large boulders on left bank) cfs</th>
<th>Qnis = +1 ft above Qmax boulders</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>G fine drift</td>
<td>0.0 1.5 top large, very weathered boulders</td>
<td>0.0 2.5</td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
<td></td>
<td>4.0 1.9</td>
<td>4.0 2.9</td>
</tr>
<tr>
<td>8</td>
<td>0.7</td>
<td></td>
<td>8.0 2.2</td>
<td>8.0 3.2</td>
</tr>
<tr>
<td>12</td>
<td>1.9</td>
<td></td>
<td>12.0 3.4</td>
<td>12.0 4.4</td>
</tr>
<tr>
<td>16</td>
<td>3.3</td>
<td></td>
<td>16.0 4.8</td>
<td>16.0 5.8</td>
</tr>
<tr>
<td>20</td>
<td>3.4</td>
<td></td>
<td>20.0 4.9</td>
<td>20.0 5.9</td>
</tr>
<tr>
<td>24</td>
<td>3.5</td>
<td></td>
<td>24.0 5.0</td>
<td>24.0 6.0</td>
</tr>
<tr>
<td>28</td>
<td>3.5</td>
<td></td>
<td>28.0 5.0</td>
<td>28.0 6.0</td>
</tr>
<tr>
<td>32</td>
<td>2.8</td>
<td></td>
<td>32.0 4.3</td>
<td>32.0 5.3</td>
</tr>
<tr>
<td>36</td>
<td>1.1</td>
<td></td>
<td>36.0 2.6</td>
<td>36.0 3.6</td>
</tr>
<tr>
<td>40</td>
<td>0.4</td>
<td></td>
<td>40.0 1.9</td>
<td>40.0 2.9</td>
</tr>
<tr>
<td>44</td>
<td>0</td>
<td>F-P fine drift, wash line</td>
<td>44.0 1.5 (level tag line)</td>
<td>44.0 2.5</td>
</tr>
<tr>
<td>48</td>
<td></td>
<td></td>
<td>48.0 1 ft abv top of boulders</td>
<td></td>
</tr>
</tbody>
</table>

Dave = 1.9 ft
Dave = 3.2 ft

Q_{2013} = 44 ft x 1.9 ft x Vc (7.8 ft) 650 cfs
Q_{max} = 44 ft x 3.2 ft x Vc (10.2 ft/s) 1440 cfs
Q_{nis} = 52 ft x 3.7 ft x Vc (3.7 ft x 32.2 ft/s)^2/s^0.5 = 2,100 cfs

XS5: Q_{2013} = 650 cfs  Q_{max} = 1,440 cfs  Q_{nis} = 2,100 cfs
Site 5. Andrews Drive Tributary, Arboles

Andrews Drive Tributary peak discharges are the average of sites 4-7.
Presentation Overview

• Introduction

• Overview of 2013 Flood Season

• Critical-Depth Method for Peak Discharges
  • July 10, 2013 Flood
  • Maximum Paleoflood

• Define the Rainfall-Runoff Footprint

• Determine Flood Frequency

• Additional Hazard Awareness

• Concluding Remarks
Select Sites to Identify 7/20/13 Maximum Flooding and Rainfall-Runoff Footprint
## 2013 Flood - 13 Stream Sites near Arboles

<table>
<thead>
<tr>
<th>Site Number</th>
<th>Stream and Location</th>
<th>GPS Elevation (ft)</th>
<th>Slope (ft/ft)</th>
<th>Latitude (-107.48)</th>
<th>Longitude (approx)</th>
<th>Area (mi²)</th>
<th>MBE (ft)</th>
<th>MBSlope (%)</th>
<th>DA&gt;7500 ft (%)</th>
<th>Qmax (cfs)</th>
<th>Qmin (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sambrito Creek at CR 988 near Arboles</td>
<td>6253</td>
<td>0.01</td>
<td>37.031</td>
<td>-107.48</td>
<td>13.8</td>
<td>7230</td>
<td>23.6</td>
<td>35.7</td>
<td>470</td>
<td>1120</td>
</tr>
<tr>
<td>2</td>
<td>Left Bank tributary (sec 1/12) to CR 973 near Arboles</td>
<td>6358</td>
<td>0.02</td>
<td>37.039</td>
<td>-107.45</td>
<td>1.02</td>
<td>6730</td>
<td>15.8</td>
<td>0.86</td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>Right bank tributary (sec 5) near CO 151 to Piedra River near Arboles</td>
<td>6138</td>
<td>0.02</td>
<td>37.045</td>
<td>-107.42</td>
<td>1.59</td>
<td>6590</td>
<td>23</td>
<td>4.91</td>
<td>270</td>
<td>410</td>
</tr>
<tr>
<td>4</td>
<td>Andrew Drive tributary near Arboles</td>
<td>0.025</td>
<td>37.045</td>
<td>-107.42</td>
<td>590</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Andrew Drive tributary near Arboles</td>
<td>0.0</td>
<td>37.041</td>
<td>-107.4</td>
<td>650</td>
<td>1440</td>
<td>2100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Andrew Drive tributary near Arboles</td>
<td>0.02</td>
<td>37.043</td>
<td>-107.4</td>
<td>830</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Andrew Drive tributary near Arboles</td>
<td>0.02</td>
<td>37.043</td>
<td>-107.4</td>
<td>690</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ave 4 to 7</td>
<td>Andrew Drive tributary near Arboles (average of sites 4 through 7)</td>
<td>6141</td>
<td>0.02</td>
<td>37.041</td>
<td>-107.4</td>
<td>0.78</td>
<td>6730</td>
<td>36.4</td>
<td>6.94</td>
<td>690</td>
<td>1440</td>
</tr>
<tr>
<td>8</td>
<td>Right bank tributary (sec 23) near CR 500 to San Juan River at Carracas</td>
<td>6227</td>
<td>0.01</td>
<td>37.01</td>
<td>-107.26</td>
<td>1.53</td>
<td>6520</td>
<td>21.9</td>
<td>0</td>
<td>80</td>
<td>320</td>
</tr>
<tr>
<td>9</td>
<td>Right bank tributary (sec 16) near CR500 to San Juan River near Carracas</td>
<td>6131</td>
<td>0.025</td>
<td>37.014</td>
<td>-107.29</td>
<td>0.41</td>
<td>6700</td>
<td>33.5</td>
<td>0</td>
<td>10</td>
<td>880</td>
</tr>
<tr>
<td>10</td>
<td>Sandoval Canyon (sec 13) near CR 500 near Carracas</td>
<td>6112</td>
<td>0.025</td>
<td>37.024</td>
<td>-107.34</td>
<td>1.71</td>
<td>7300</td>
<td>28.5</td>
<td>37.6</td>
<td>180</td>
<td>1480</td>
</tr>
<tr>
<td>11</td>
<td>Right bank tributary (sec 14) near CR 500 near Arboles</td>
<td>6120</td>
<td>0.05</td>
<td>37.024</td>
<td>-107.36</td>
<td>1.09</td>
<td>6980</td>
<td>41.1</td>
<td>18.6</td>
<td>380</td>
<td>1050</td>
</tr>
<tr>
<td>12</td>
<td>Right bank tributary (sec 10) near CR500 to San Juan River near Arboles</td>
<td>6131</td>
<td>0.015</td>
<td>37.027</td>
<td>-107.38</td>
<td>1.55</td>
<td>7150</td>
<td>30.5</td>
<td>32.1</td>
<td>240</td>
<td>890</td>
</tr>
<tr>
<td>13</td>
<td>Left bank tributary (sec 33) near CR500 to Piedra River near Arboles</td>
<td>6134</td>
<td>0.02</td>
<td>37.058</td>
<td>-107.41</td>
<td>1.08</td>
<td>6960</td>
<td>29.9</td>
<td>11.3</td>
<td>220</td>
<td>500</td>
</tr>
<tr>
<td>14</td>
<td>Right bank tributary (sec 32) to site 15 near CO Hwy 151 to Piedra River near Arboles</td>
<td>6137</td>
<td>0.015</td>
<td>37.055</td>
<td>-107.42</td>
<td>0.35</td>
<td>6330</td>
<td>21.4</td>
<td>0</td>
<td>40</td>
<td>380</td>
</tr>
<tr>
<td>15</td>
<td>Left bank tributary (sec 32) near CO Hwy 151 to Piedra River near Arboles</td>
<td>6136</td>
<td>0.02</td>
<td>37.055</td>
<td>-107.42</td>
<td>1.14</td>
<td>6810</td>
<td>28.9</td>
<td>8.13</td>
<td>80</td>
<td>710</td>
</tr>
<tr>
<td>16</td>
<td>Left bank tributary (sec 34) near CR 500 to Piedra River near Arboles</td>
<td>6125</td>
<td>0.025</td>
<td>37.045</td>
<td>-107.4</td>
<td>0.33</td>
<td>6440</td>
<td>25.1</td>
<td>0</td>
<td>3</td>
<td>410</td>
</tr>
</tbody>
</table>

(source of basin characteristics: https://streamstats.usgs.gov/ss/)

7/10/13 is largest flood (per unit discharge) in SW Colorado based on Pruess and others, 1998.
Estimated using unit discharge (Q/DA) at the 13 Sites

(Method: Jarrett, 1990, 2001)
Presentation Overview

• Introduction
• Overview of 2013 Flood Season
• Critical-Depth Method for Peak Discharges
  • July 10, 2013 Flood
  • Maximum Paleoflood
• Define the Rainfall-Runoff Footprint
• Determine Flood Frequency
• Additional Hazard Awareness
• Concluding Remarks
Flood-Frequency Estimates - StreamStats
Andrews Drive Tributary (& 12 other Sites)

Flow Statistics Ungaged Site Report
Date: Wed Feb 3, 2016 5:38:35 PM GMT-7
Study Area: Colorado
NAD 1983 Latitude: 37.0407 (37 02 26)
NAD 1983 Longitude: -107.402 (-107 24 08)
Drainage Area: 0.78 mi²

Peak-Flows Basin Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Regression Equation Valid Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drainage Area (square miles)</td>
<td>0.78 (below min value 1)</td>
<td>Min: 1, Max: 4390</td>
</tr>
<tr>
<td>Percent above 7500 ft (percent)</td>
<td>6.94</td>
<td>Min: 0, Max: 99</td>
</tr>
</tbody>
</table>

Warning: Some parameters are outside the suggested range. Estimates will be extrapolations with unknown errors.

Peak-Flows Statistics

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
<th>Unit</th>
<th>Prediction Error (percent)</th>
<th>Equivalent years of record</th>
<th>90-Percent Prediction Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>PK2</td>
<td>32.4</td>
<td>ft³/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK5</td>
<td>78</td>
<td>ft³/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK10</td>
<td>122</td>
<td>ft³/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK25</td>
<td>201</td>
<td>ft³/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK50</td>
<td>273</td>
<td>ft³/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK100</td>
<td>354</td>
<td>ft³/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK200</td>
<td>450</td>
<td>ft³/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PK500</td>
<td>626</td>
<td>ft³/s</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(source: https://water.usgs.gov/osw/streamstats/)
Flood-Frequency Estimates for Andrews Drive Tributary

FF estimates by Davis Consulting Services (used Rational Method in 2008)
## Flood-Frequency Estimates (all 13 study sites)

<table>
<thead>
<tr>
<th>Site Number</th>
<th>Stream and Location</th>
<th>Q2</th>
<th>Q10</th>
<th>Q25</th>
<th>Q50</th>
<th>Q100</th>
<th>Q500</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sambrito Creek at CR 988 near Arboles</td>
<td>175</td>
<td>496</td>
<td>744</td>
<td>940</td>
<td>1160</td>
<td>1820</td>
</tr>
<tr>
<td>2</td>
<td>Left Bank tributary (sec 1/12) to CR 973 near Arboles</td>
<td>44</td>
<td>201</td>
<td>349</td>
<td>495</td>
<td>670</td>
<td>1290</td>
</tr>
<tr>
<td>3</td>
<td>Right bank tributary (sec 5) near CO 151 to Piedra River near Arboles</td>
<td>53</td>
<td>202</td>
<td>333</td>
<td>454</td>
<td>595</td>
<td>1060</td>
</tr>
<tr>
<td>4</td>
<td>Andrew Drive tributary near Arboles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Andrew Drive tributary near Arboles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Andrew Drive tributary near Arboles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Andrew Drive tributary near Arboles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ave 4 to 7</td>
<td>Andrew Drive tributary near Arboles (average of sites 4 through 7)</td>
<td>32</td>
<td>122</td>
<td>201</td>
<td>273</td>
<td>354</td>
<td>626</td>
</tr>
<tr>
<td>8</td>
<td>Right bank tributary (sec 23) near CR 500 to San Juan River at Carra</td>
<td>61</td>
<td>297</td>
<td>526</td>
<td>757</td>
<td>1040</td>
<td>2080</td>
</tr>
<tr>
<td>9</td>
<td>Right bank tributary (sec 16) near CR 500 to San Juan River near Carli</td>
<td>26</td>
<td>133</td>
<td>239</td>
<td>348</td>
<td>480</td>
<td>967</td>
</tr>
<tr>
<td>10</td>
<td>Sandoval Canyon (sec 13) near CR 500 near Carracas</td>
<td>200</td>
<td>559</td>
<td>834</td>
<td>1050</td>
<td>1300</td>
<td>2020</td>
</tr>
<tr>
<td>11</td>
<td>Right bank tributary (sec 14) near CR 500 near Arboles</td>
<td>37</td>
<td>122</td>
<td>192</td>
<td>254</td>
<td>320</td>
<td>534</td>
</tr>
<tr>
<td>12</td>
<td>Right bank tributary (sec 10) near CR 500 to San Juan River near Arboles</td>
<td>44</td>
<td>134</td>
<td>206</td>
<td>267</td>
<td>332</td>
<td>534</td>
</tr>
<tr>
<td>13</td>
<td>Left bank tributary (sec 33) near CR 500 to Piedra River near Arboles</td>
<td>38</td>
<td>135</td>
<td>217</td>
<td>290</td>
<td>372</td>
<td>637</td>
</tr>
<tr>
<td>14</td>
<td>Right bank tributary (sec 32) to site 15 near CO Hwy 151 to Piedra F</td>
<td>24</td>
<td>121</td>
<td>217</td>
<td>317</td>
<td>438</td>
<td>882</td>
</tr>
<tr>
<td>15</td>
<td>Left bank tributary (sec 32) near CO Hwy 151 to Piedra River near A</td>
<td>41</td>
<td>149</td>
<td>243</td>
<td>328</td>
<td>423</td>
<td>739</td>
</tr>
<tr>
<td>16</td>
<td>Left bank tributary (sec 4) near CR 500 to Piedra River near Arboles</td>
<td>23</td>
<td>116</td>
<td>209</td>
<td>306</td>
<td>423</td>
<td>853</td>
</tr>
</tbody>
</table>
Regional Study Area is Southwest Colorado below 7,500 ft; DA < 40 mi²

Presentation Overview

• Introduction
• Overview of 2013 Flood Season
• Critical-Depth Method for Peak Discharges
  • July 10, 2013 Flood
  • Maximum Paleoflood
• Define the Rainfall-Runoff Footprint
• Determine Flood Frequency
• Additional Hazard Awareness
• Concluding Remarks
• Riverine flooding is limited to a channel and its associated floodplain. As flow depth and discharges increase, incrementally more area is subject to flooding.

• On alluvial fans, water can migrate to alternative courses or channels depending on debris blocking a channel.
Riverine Flooding (with defined channel and floodplain) vs Alluvial Fan Flooding in the Study Area
Concluding Remarks

- July 10, 2013 is the Largest Flood (basis of unit discharge) in Southwestern Colorado

- 7/12/13 Flood Recurrence Interval was about 650 years

- Recognition of Alluvial Fan Flood Potential

- Results Provide Archuleta County Officials Means to Assess Flood Risk

- Methodology Can Be Used In Other Basins (slopes > 0.01 ft/ft)
  - Applicable to Many/Most Streams in Colorado

- Methodology is Extremely Cost Effective – one person
  - Fieldwork – 1.5 Days
  - Analyses – 7 Days

Thanks again – Archuleta County & Anthony Melonakis
Methods References


Davis Engineering Service, 2008, Drainage study for Andrews Lane culvert, prepared for Archuleta County, Colorado, December 02, 2008, Pagosa Springs, Colorado, 4p., and Appendices A-D.


Contact: paleoflood@comcast.net
Methods References


Local Adoption and Use of Best Available Floodplain Information: Boulder County Lessons Learned

CASFM 2017 Annual Conference
September 21, 2017
Stephanie DiBetitto, Community Assistance Program Manager, CWCB
Harry A. Katz, Floodplain Specialist, Boulder County
September 2013 Flood Changed Physical Floodplains

- Hazard areas changed
- Rebuilding relies heavily on predictive floodplain mapping
- Effective floodplain map delineations not as accurate as desirable
New channels

Pre-flood channel

Post-flood channel
Effective Floodplain issues
Updating the Floodplain Maps

Colorado Water Conservation Board’s (CWCB)
Colorado Hazard Mapping Program (“CHAMP”)
CHAMP Study Reaches
CHAMP Reaches in Boulder County
CHAMP creates Phase I draft maps

Public Outreach & Technical Review

CHAMP Phase I maps to FEMA

FEMA Preliminary Maps

Appeals Period

FEMA Effective FIRMs
Direct Program Benefits

**Programmatic Benefits**
- Comprehensive State Hazard Mapping Program
- Floodplain Mapping
  - State and Local Priorities vs. FEMA driven
  - Large footprint - faster FEMA map updates
  - Leverage more FEMA funding through CTP Program
  - State-led program with FEMA compliant products
  - Integration with State Risk MAP Program

**Data Benefits**
- Updated information for local planning & decision making
- Proactive data sharing and collaboration
- Availability of multi-hazard data
Best Available Information

• What is best available information?
  – Tool for community to reduce flood risk

• Why is this information important for CO communities?
  – Represents the most suitable flood hazard information for performing community planning, engineering, development review, permitting, and emergency management functions, and helps communities become more hazard-resilient by working towards the following floodplain management goals

• Use of most restrictive information recommended
Roles and Responsibilities

Federal Role (FEMA, NFIP)
• Floodplain mapping *lead*
• Floodplain management
• Flood insurance

State Role (CWCB, CHAMP)
• Floodplain mapping – *as FEMA partner*
• Community assistance

Local Role (Boulder County)
• Floodplain mapping *participant*
• Floodplain regulation & outreach

Ultimate Goal:
*Protect Life, Health, & Safety*
Boulder County Floodplain

**September 2016** – Land Use Code floodplain regulations (4-400) amended to include a regulatory ‘Boulder County Floodplain’ and also:

- Created a process for adoption of best available floodplain data onto maps of predicted extent of 100-year floodplain
- Eliminated the need for the county to wait for FEMA to produce Flood Insurance Rate Maps (FIRMs) before updating maps with better data
- Furthered the county’s ability to protect health, safety, & welfare of residents and visitors
The Floodplain Overlay ("FO") District

Boulder County "FO District" = FEMA Floodplain + Boulder County Floodplain

The purpose of adopting a Boulder County Floodplain is to facilitate use of the best available data for the County to establish floodplain boundaries... (4-403 FO District Defined; Official Map)
Current Regulatory Floodplain

Proposed Boulder County Floodplain

Proposed Floodplain Overlay District

FEMA Floodplain

BoCo Floodway

CHAMP Floodplain

CHAMP Floodway

Composite Floodplain

Composite Floodway
Current Regulatory Floodplain

- FEMA Floodplain
- BoCo Floodway
Proposed Boulder County Floodplain

- CHAMP Floodplain
- CHAMP Floodway
Proposed Floodplain Overlay District

- Composite Floodplain
- Composite Floodway
Common Questions

• What happens when FEMA maps are effective but are narrower than current FO District?
  – The County has the authority according to [the Code] to regulate to a more conservative map if it deems such regulation appropriate
• Why is the CHAMP data being called the Boulder County Floodplain?
Lessons Learned

• GIS requirements
• Public use vs regulatory use
• Best Available Information and Insurance
• Stream restoration projects
Lessons Learned – GIS Requirements

Current Regulatory Floodplain

Proposed Boulder County Floodplain

Proposed Floodplain Overlay District
Lessons Learned – Public vs Regulatory Use

Current Regulatory Floodplain

Proposed Boulder County Floodplain

Proposed Floodplain Overlay District
Lessons Learned – Insurance

- Utilizing more conservative data can:
  - reduce future insurance rates
  - provide additional flood protection
- Helps residents understand impact of new maps on future insurance rates
Lessons Learned – Stream Restoration Projects

• Several large scale stream restoration projects on going in Boulder County

• How do maps get updated when they are not yet effective?
  – Requires coordination with FEMA
  – LOMR to CHAMP data
Boulder County Floodplain Information


Boulder County Floodplain Remapping information: www.bocofloodplainremapping.com

Boulder County Floodplain Management Website: www.bouldercounty.org/property/flood/pages/default.aspx
2D Large Scale Base Level Engineering in South Dakota

Brian Murphy, PE, CFM
Why are we here?

Consider these areas...
New Risk Assessment Methodology

- Large Scale Automated Engineering (LSAE) with regulatory upgrades to Base Level Engineering (BLE)
- 2 Dimensional modeling (HEC-RAS 5.0.1)
- Rain on Grid
- Base Flood Elevations (BFEs) are available for multiple return periods as water surface elevations grids
- Resulting floodplains meet FEMA G&S for Approximate-level studies (Zone A – ready)
- Enhanced products to facilitate better decisions at the community level.
Overview

• 2D LSBLE Defined
• South Dakota Project Background
• Technical Approach
• Calibration and Results
• Challenges and Key Takeaways
• Benefits to the Risk MAP program
What is 2D LSAE?

• Terminology Note:
  – Large Scale Automated Engineering (LSAE) is now referred to as Large Scale Base Level Engineering (LSBLE)

• 2D LSBLE
  – Rain-on-Grid hydrology
  – Two-dimensional (2D) hydraulic models covering large basins
  – Floodplain results for every drainage covered by model grid cell mesh

• Requires high resolution terrain data
• Scalable products
South Dakota 2D LSBLE Application

- Perform 2D LSBLE for 27 eastern South Dakota Counties
- Increase and enhance the flood risk products in South Dakota

Flood damage in Brown County, S.D. in Apr. 2011
Image: South Dakota Public Broadcasting

Flooding on the James River in S.D. in Mar. 2011
Image: Mitchell Republic
Project Scope

- Hydrologic and hydraulic modeling
  - 10% through 0.2% annual chance exceedance (ACE) events

<table>
<thead>
<tr>
<th>Annual Chance Exceedance</th>
<th>H&amp;H Modeling</th>
<th>Floodplain Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>✔️</td>
<td>--</td>
</tr>
<tr>
<td>4%</td>
<td>✔️</td>
<td>--</td>
</tr>
<tr>
<td>2%</td>
<td>✔️</td>
<td>--</td>
</tr>
<tr>
<td>1%-minus</td>
<td>✔️</td>
<td>--</td>
</tr>
<tr>
<td>1%-plus</td>
<td>✔️</td>
<td>--</td>
</tr>
<tr>
<td>1%</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>0.20%</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>
Technical Workflow

- Terrain Data Development
- Model Area Delineation
- Hydrology Development
- Hydraulic Considerations
- Calibration
Conceptual Overview
Terrain Data Overview

• High resolution 1-meter LiDAR available for entire project area (except half of Clark County)

Non-model backed Zone A’s on 10m DEM

2D HEC-RAS 5.0.1 on high-res LiDAR
Model Area Delineation

- Main considerations for model areas:
  1. **SIZE**: Max model area ~ 1,300 sq mi
  2. **DRAINAGE**: Account for all contributing basin area (Rain-on-Grid + external inflows)
  3. **DATA**: Leverage gage data for inflows and calibration

- 26 total model areas
Hydrology Components

Rain-on-Grid
- Developed for each model area
- Applied in HEC-RAS to generate runoff from 2D model area

Upstream Basin Contributions
- Inflow hydrograph required for upstream basins not accounted for by Rain-on-Grid
Rain-on-Grid

- No losses in HEC-RAS 5.0
- Simple HMS model to develop excess precipitation hyetograph
- SCS CN Method
  - NOAA Atlas 14 precip raster
  - NRCS Soils + National Land Cover Data (NLCD) = Average CN
Upstream Basin Contributions

• External inflow options:
  1. Unit hydrograph approach where gage data available
  2. Flow transfer from upstream 2D LSBLE model
  3. Simple HMS runoff model
Hydraulic Considerations

HEC-RAS 5.0 Inputs
- Manning’s n
- Boundary Conditions
- Computational Parameters

Breaklines Offsets
- Flow impediments
- Structures and crossings
**HEC-RAS 5.0 Hydraulic Parameters**

- **Grid cell mesh**
  - 200-foot nominal cell size

- **Manning’s n**
  - NLCD 2011 spatial coverage

- **Boundary Conditions**
  - Upstream: Inflow hydrographs
  - Downstream: Normal depth

- **Computational options**
  - Diffusion Wave Equation
  - 30-second timestep

*Decrease Run Time: Increase Accuracy & Stability*

(Cell Size, Timestep)
Model Calibration

- USGS gage data (period of record >20 years) to develop discharge targets
- Adjusted Curve Numbers and/or hydrograph timing
- 33 total calibration gages
Base Level Engineering Deliverables

- Hydrologic Calculations for multiple events
  - 10%, 4%, 2%, 1% and 0.2% water surface elevations

- HEC-RAS Hydraulic modeling for these events
  - Modeling for multiple return periods including the 10%, 4%, 2%, 1% and 0.2% profiles!
Depth Results
Water Surface Elevation Results
Velocity Results
Velocity Results

Risk communication (three feet of swiftly flowing water is more dangerous than five feet of standing water)
2D LSBLE Challenges

- Data limitations
- Structures
- Model run times → 12 to 120 hours
- File sizes → Single model ~ 20 to 100 GB
- Total deliverable → ~7 TB!
Key Takeaways

• 2D LSBLE methodology provides efficient, accurate option for floodplain hazard identification
• There are still engineering challenges
• Process will continue to evolve and improve
Benefits to the Risk MAP Program

• Delivering high-quality risk data
  – Coordinated Needs Management Strategy (CNMS)
  – New, Validated, or Updated Engineering (NVUE)

• Increasing awareness of flood risk
  – Percent of local officials aware of flood risk affecting their communities
Benefits to the Risk MAP Program

• Promoting community mitigation action
  – Percent of population acting on community planned mitigation strategies
• Building towards Technical Mapping Advisory Council (TMAC) recommendations
  – Structure-based risk and flood frequency determination
  – Database driven, digital display environment
• Reduce risk to lives and property
There are three main options for communities to consider:

**Option #1:** NEW assessments of the existing floodplains

**Option #2:** Which areas need to be upgraded to detailed study?

**Option #3:** Utilize this information as best available data to base decisions off of for development and planning.
Best Available Data Use

• Uses
  – Where no effective special flood hazard area (SFHA) exists
  – Where there is an effective Zone A

• Cannot Use
  – Effective AE
  – If alternate sources have more detailed data/information
    • e.g. storm water master plan, bridge design
Other uses of 2d LSBLE BAI

• Update State/Local Mitigation Plan
• Emergency Response
• Evacuation Planning
• Critical Facilities in or near flood hazard area
• Residential/Commercial Development Planning
• Hazard Mitigation Grant Program
Project Acknowledgments

FEMA Region 8 Staff

Terrain Data Sources:

• USGS National Elevation Dataset
• South Dakota Department of Environment and Natural Resources
Questions?
Comments?
The Challenges of Updating Regulatory Hydrology and Floodplain Mapping – A Case Study of Estes Park, Colorado

Andrew Earles, Ph.D., P.E. and Shannon Tillack, P.E.
Wright Water Engineers, Inc.

Kevin Houck, P.E.
Colorado Water Conservation Board

Tina Kurtz
Town of Estes Park

Isaac Allen, El
AECOM
Presenters

• Andrew Earles, Ph.D., P.E. – Wright Water Engineers (WWE)

• Kevin Houck, P.E. – Colorado Water Conservation Board

• Shannon Tillack, P.E. – WWE

• Tina Kurtz – Floodplain Administrator/Environmental Planner, Town of Estes Park

• Isaac Allen, EI - AECOM
<table>
<thead>
<tr>
<th>Location</th>
<th>Drainage Area (mi²)</th>
<th>1% AEP (100-year)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FR at Confluence with Big Thompson</td>
<td>39.9</td>
<td>680</td>
<td>1,860</td>
</tr>
<tr>
<td>FR at Estes Park Corporate Limits</td>
<td>37.3</td>
<td>680</td>
<td>1,740</td>
</tr>
<tr>
<td>FR at Upstream Detailed Study Limit</td>
<td>37.3</td>
<td>680</td>
<td>1,740</td>
</tr>
<tr>
<td>UBT at Lake Estes</td>
<td>137.5</td>
<td>2,180</td>
<td>3,010</td>
</tr>
<tr>
<td>UBT at St. Vrain Avenue</td>
<td>136.9</td>
<td>2,180</td>
<td>3,010</td>
</tr>
<tr>
<td>UBT at Confluence with FR</td>
<td>87.1</td>
<td>1,460</td>
<td>2,170</td>
</tr>
<tr>
<td>UBT at Crags Drive</td>
<td>87.0</td>
<td>1,460</td>
<td>2,170</td>
</tr>
<tr>
<td>BCC at Confluence with Big Thompson</td>
<td>10.0</td>
<td>230</td>
<td>310</td>
</tr>
<tr>
<td>BCC at Estes Park Corporate Limits</td>
<td>9.3</td>
<td>210</td>
<td>290</td>
</tr>
<tr>
<td>DG at Confluence with UBT</td>
<td>6.3</td>
<td>2,750</td>
<td>715</td>
</tr>
</tbody>
</table>
Colorado Flood Hazard Mapping Program
Senate Bill 15-245

An Act

Passed by General Assembly based on recommendations by Colorado Resiliency and Recovery Office and Floodplain Management Subcommittee

- Updates flood maps for entire northern flood affected area
- Also maps advisory erosion zones and debris flow zones
- Funds available July 1, 2015
- Work complete June 30, 2018
Why Senate Bill 15-245

- Outdated hydrology
  - Updated understanding of rainfall
  - Additional 30-40 years of stream gauge record
- 2013 flood changed flooding characteristics
- Preliminary analyses suggested flood risk underportrayed in many areas
- Recovery should proceed according to current, updated data
Note: A new HEC-HMS rainfall/runoff model was created for BT-15. For BT-16, a revised version of the Big Thompson River Phase 1 CDOT/CWCB Post Flood HEC-HMS model was used.

Note: BT-14 (Dry Creek) will use effective data from the "Hydrology Report for Dry Creek Floodplain" prepared for the City of Loveland.

Note: New HEC-HMS rainfall/runoff models were created for BT-17 through BT-23.

Note: The South Platte upstream of the St. Vrain Creek confluence and downstream of the Big Thompson River confluence will be studied at a later stage of CHAMP.

Hydrology Sources and Methods
COLORADO HAZARD MAPPING PROGRAM PHASE 1
Mapping Process

- Update hydrology
- Gather updated terrain data
- Survey river infrastructure as needed
- Prepare hydraulic model to determine flood elevations
- Overlay flood elevations on to terrain map to produce floodplain boundaries
Technical Challenges
16 individuals contributed as advisers, peer reviewers, and commenters:

- Town of Estes Park
- Estes Valley Watershed Coalition
- Colorado Water Conservation Board
- FEMA
- University of Colorado Denver
  independent peer reviewer
- Bob Jarrett – Retired USGS
- AECOM
- Van Horn Engineering
- David Bauer – Floodplain Contractor
  for Town
- Derek Rapp – Technical Consulting
  CDOT
Was the September 2013 storm an outlier event?

The State Climatologist says:

“This was an extreme and infrequent event, but it was not unexpected. The Colorado Front Range is uniquely positioned to occasionally be pounded by flood-producing storms. When you look at past history and at future possibilities, storms like this can and will happen again.”

– Nolan Doesken
Why the 2013 flood should be considered

- The flood actually happened
- There is no physical or statistical reason it can’t happen again
- It does not meet any meteorological or statistical criteria to be considered an outlier
- It was a data-rich event that allows for a high level of calibration not normally available
<table>
<thead>
<tr>
<th>Watershed</th>
<th>No. of Peak Flow Estimates Used During Calibration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper Big Thompson River</td>
<td>7</td>
</tr>
<tr>
<td>Fall River</td>
<td>3</td>
</tr>
<tr>
<td>Black Canyon Creek</td>
<td>1</td>
</tr>
<tr>
<td>Dry Gulch</td>
<td>1</td>
</tr>
</tbody>
</table>
NOAA Atlas 14 vs. SCS Type II Rainfall Distributions

Comparison of SCS Type II & NOAA Atlas 14 Precipitation Distributions, Incremental

Incremental Distribution vs. Hour

- SCS Type II
- NOAA Atlas 14
Town of Estes Park
Flood Mitigation Strategies
<table>
<thead>
<tr>
<th>Current Town Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Fish Creek infrastructure project</td>
</tr>
<tr>
<td>• Fall river channel restoration by historic hydroplant</td>
</tr>
<tr>
<td>• Moraine Ave Bridge replacement</td>
</tr>
<tr>
<td>• Army Corps of Engineers Silver Jackets floodproofing study</td>
</tr>
<tr>
<td>• Stormwater master plan &amp; stormwater utility feasibility study</td>
</tr>
<tr>
<td>• Downtown plan</td>
</tr>
<tr>
<td>• Federal/state/local partnerships</td>
</tr>
</tbody>
</table>
Potential Future Town / Community Mitigation Activities

- Stormwater infrastructure
- Bridge and river channel capacity enlargement
- Floodplain master plan
- Flood mitigation studies and projects
- Streamgage installations
- Community Rating System participation
- Continue federal/state/local partnerships
Mitigation Activities for Landowners / Business Owners

• Stay informed and involved
• Floodproofing/building techniques
• Flood insurance
• Helping find and implement solutions to challenges
Status of Map Updates
Challenges

• Increased flows likely to produce wider floodplains out of channels
• Obtaining adequate detail of ground surface in Town with high density of buildings
Hydraulic Modeling

1-D Models
- Common HEC-RAS Steady Flow Analysis
- Structure data incorporated
- Channel adjustments made based on survey data
- DS boundary conditions from 2D model results

Boundary Conditions
- Inflow boundaries set based on peak flows from Wright Water Engineers analysis
- Individual steady-state, peak flow scenarios run for Big Thompson, Fall River, and Black Canyon Creek
- Inflow discharges for peak scenarios set based on hydrograph timing required to meet WWE recommended outflows at Estes Visitors Center
- Outflow boundary set based on water level at Olympus Dam

Methods

Challenges of Updating Regulatory Hydrology and Floodplain Mapping
Floodplain Mapping

- Challenges of Updating DFIRM with 2D Model Results
  1. Revise floodplain based on contours where buildings block flooding
  2. Regulatory floodway to be calculated from 2D model
     - No previous guidance in FEMA standards – Worked with FEMA to develop approach
     - Floodways to be completed after hydraulics are approved by FEMA

![Diagram of Floodplain Mapping](image)

Methods

Challenges of Updating Regulatory Hydrology and Floodplain Mapping
Approach to Outreach

- Due to increase in floodplain extents, outreach is critical
  - Early and often – keep representatives from the Town informed throughout the process
  - Provide opportunities for input prior to FEMA regulatory process
  - Routine progress updates through project website/meetings
- Data sharing and coordination with other ongoing efforts
  - Avoid redundancy and conflicting results
  - Ensure best-available data is included in updated hydraulics and floodplain mapping products
Approach to Outreach (cont’d)

Outreach/Coordination

Challenges of Updating Regulatory Hydrology and Floodplain Mapping
Alternatives for Conveying Flood Risk

- FEMA FIRMs can be difficult to digest for non-technical audiences
- Virtual and augmented reality and other innovative approaches to outreach may offer easier ways to present flood risk
  - Ex. Infraworks visualization software

[Map Image]

https://goo.gl/c8eo1d
Other Ongoing Efforts

- **USACE Analysis**
  - Structure based analysis
- **Upper Big Thompson Watershed Masterplan**
  - Mitigation opportunities and plans for resiliency
  - Stream health and restoration
- **Storm Water Masterplan**
- **Construction/Reconstruction Activities**
  - The Loop
- List is not inclusive of all efforts in and around the Town!
### CHAMP Progress Meetings

- Estes Park Hydrology Review Meeting
- Estes Flood Risk Review Meeting
- Preliminary Results - Community Comment Period

### CHAMP Newsletters

- Resilience Meeting
- Preliminary FIRM Creation and FEMA QC
- Preliminary FIRM Release
- CCO Meeting

### Federal Register Publication

- Federal Register Publication and 90 day appeal period
- Appeal resolution
- Final QC (assume no revised preliminary)
- Letter of Final Determination
- Compliance Period
- Effective FIRM release

---

**Continued Coordination**

![Timeline Chart]

- **CHAMP Risk MAP**
- **Outreach/Coordination**
- **Challenges of Updating Regulatory Hydrology and Floodplain Mapping**

---

**CHAMP Risk MAP**

<table>
<thead>
<tr>
<th>Event</th>
<th>Timeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAMP Progress Meetings</td>
<td>October 2016 to April 2017</td>
</tr>
<tr>
<td>Estes Park Hydrology Review Meeting</td>
<td>August 2017 to June 2018</td>
</tr>
<tr>
<td>Estes Flood Risk Review Meeting</td>
<td>July 2018 to November 2018</td>
</tr>
<tr>
<td>Preliminary Results - Community Comment Period</td>
<td>December 2018</td>
</tr>
<tr>
<td>CHAMP Newsletters</td>
<td>December 2018</td>
</tr>
<tr>
<td>Resilience Meeting</td>
<td>December 2018</td>
</tr>
<tr>
<td>Preliminary FIRM Creation and FEMA QC</td>
<td>March 2019</td>
</tr>
<tr>
<td>Preliminary FIRM Release</td>
<td>March 2019</td>
</tr>
<tr>
<td>CCO Meeting</td>
<td>March 2019</td>
</tr>
<tr>
<td>Federal Register Publication and 90 day appeal period</td>
<td>April 2019</td>
</tr>
<tr>
<td>Appeal resolution</td>
<td>April 2019</td>
</tr>
<tr>
<td>Final QC (assume no revised preliminary)</td>
<td>April 2019</td>
</tr>
<tr>
<td>Letter of Final Determination</td>
<td>April 2019</td>
</tr>
<tr>
<td>Compliance Period</td>
<td>April 2019</td>
</tr>
<tr>
<td>Effective FIRM release</td>
<td>April 2019</td>
</tr>
</tbody>
</table>
QUESTIONS?
Design Verification of Micropool at EDB 502L

Saman Mehdi, EI – Jacobs Engineering
Jeremy Deischer, EI – ICON Engineering

CASFM Conference 2017
Breckenridge, CO
Extended Detention Basin

- Similar to a detention basin used for flood control.
  - Uses a much smaller outlet that extends the emptying time.
  - Designed to promote the process of sedimentation.
  - Provides necessary Water Quality Capture Volume (WQCV).
Micropool

- Man-made wetland
  - Permanent pool at base of Detention Basin
- Reduces clogs in well-screen
- Controls buoyant debris and sediment from re-suspension

Detention Basin Outlet Design, Dr. Guo
Micropool (cont’d)

- Controls mosquito population
  - Shallow waters attract mosquitos
  - Pond life feeds on mosquito larvae
Micropool (cont’d)

- Pollutant removal
- Aids in keeping cost of Extended Detention Basin (EDB) maintenance low
- Improves water quality downstream of the system
Micropool (cont’d)

- Sedimentation
  - Removes entrained solids and other debris
  - Aids in efficiency of hydraulic systems

- Micropool allows for even more sedimentation to occur due to its added depth to the system.
Purpose

- Begin the implementation of a more in depth guideline for the design of micropools.
- Take into consideration size and density of particles within the EDB.
Project Site
Project Site
Project Site
Previous Analysis

- Drainage Report by Harris Kocher Smith
- Masters Report by Jeremy Deischer and Elisabeth Miller
  - Verified parameters used by HKS
Micropool

Condition of Clear Screen

Condition of Clogged Screen

*Figure provided by Dr. Guo*
Micropool Syphon Effect

Once the upper portion of the well-screen is clogged, the area between the well-screen and perforated plate begin to act as a syphon to pump water through the system.

*Figure provided by Dr. Guo*
UDFCD recommends that a micropool be:
- 2.5 feet in depth
- Have a surface area of at least 10 square feet
- Consist of a concrete base
  - Prevents accidental clogging from riprap
Micropool Design Parameters

- WQCV Discharge
- Surcharge Depth
- Surface Area
- Evaporation Rate
- Inter-event Time
- Sediment Dead Storage
WQCV Design Flow

- Consider Depth of Pond when full (prior to overtopping)
- Determine flow rate at specified depth
- From Miller and Deischer Report:
  - WS Elevation prior to overtopping: 5300.96 feet
  - Design Flow: 0.40 cfs
Surcharge Depth

- (4) 1” holes in submerged perforated plate
- 4” on center spacing
- Surcharged Depth = 1.0 ft.
Design Parameters

- $A = \frac{Q}{V}$
  - Design flow rate divided by velocity to freeze the particle floating within the pool

- Float Velocity:
  - Particle Size
  - Drag Coefficient
Design Parameters (cont’d)

- Drag Coefficient
  - Reynolds Number < 1:
    - \( C_d = \frac{24}{Re} \)
  - 1 < Reynolds Number < 10^4:
    - \( C_d = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34 \)
  - Reynolds Number > 10^4:
    - \( C_d = 0.4 \)
Design Parameters (cont’d)

- **Forces:**
  - **Body Force:** $F_g$
  - **Drag Force:** $F_d$
  - **Buoyancy Force:** $F_b$
Substituting the force equations in Newton’s Second Law, we can derive the equation for Terminal (or Float) Velocity:

\[ v = \sqrt{\frac{4gD}{3C_d}} (1 - S) \]

- Particle Size
- Specific Gravity
- Drag Coefficient
Particle Size and Density Analysis

- Collect samples from screen
  - Particle Size
  - Particle Density
Particle Size

- Sieve Analysis
# Gradation Analysis

<table>
<thead>
<tr>
<th>Sieve #</th>
<th>Sieve Size (mm)</th>
<th>Mass of each sieve (g)</th>
<th>Mass of each sieve + retained soil (g)</th>
<th>Mass of soil retained (g)</th>
<th>Percentage on each Sieve (Rn)</th>
<th>Cumulative Percent Retained (sum Rn)</th>
<th>% Finer (100-SumRn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4.75</td>
<td>508.80</td>
<td>515.20</td>
<td>6.40</td>
<td>34.59</td>
<td>34.59</td>
<td>65.41</td>
</tr>
<tr>
<td>10</td>
<td>2.00</td>
<td>677.40</td>
<td>682.80</td>
<td>5.40</td>
<td>29.19</td>
<td>63.78</td>
<td>36.22</td>
</tr>
<tr>
<td>20</td>
<td>0.83</td>
<td>430.80</td>
<td>433.50</td>
<td>2.70</td>
<td>14.59</td>
<td>78.38</td>
<td>21.62</td>
</tr>
<tr>
<td>40</td>
<td>0.43</td>
<td>342.30</td>
<td>343.30</td>
<td>1.00</td>
<td>5.41</td>
<td>83.78</td>
<td>16.22</td>
</tr>
<tr>
<td>60</td>
<td>0.25</td>
<td>336.70</td>
<td>337.30</td>
<td>0.60</td>
<td>3.24</td>
<td>87.03</td>
<td>12.97</td>
</tr>
<tr>
<td>100</td>
<td>0.15</td>
<td>328.20</td>
<td>329.70</td>
<td>1.50</td>
<td>8.11</td>
<td>95.14</td>
<td>4.86</td>
</tr>
<tr>
<td>200</td>
<td>0.08</td>
<td>303.50</td>
<td>303.90</td>
<td>0.40</td>
<td>2.16</td>
<td>97.30</td>
<td>2.70</td>
</tr>
<tr>
<td>Pan</td>
<td></td>
<td>369.10</td>
<td>369.60</td>
<td>0.50</td>
<td>2.70</td>
<td>100.00</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total: 18.5</td>
<td>100.00</td>
<td></td>
</tr>
</tbody>
</table>
Gradation Analysis

Particles D15 will pass through the well screen 
D15 ~ 0.40 mm
Particle Density

- Particle Density calculated to determine specific gravity
- Specific Gravity = 0.83
### Design of Micro Pool for Detention Basin

<table>
<thead>
<tr>
<th>Design</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment Area</td>
<td>4.90</td>
</tr>
<tr>
<td>Imperviousness %</td>
<td>76.40</td>
</tr>
<tr>
<td>Drain Time</td>
<td>72.00</td>
</tr>
<tr>
<td>Volume</td>
<td>0.24</td>
</tr>
<tr>
<td>Design Flow Rate</td>
<td>0.40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design of Micro Pool</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Float Specific Gravity</td>
<td>0.83</td>
</tr>
<tr>
<td>Elevation at Basin Bottom</td>
<td>5297.70</td>
</tr>
<tr>
<td>Surface water elevation</td>
<td>5301.00</td>
</tr>
<tr>
<td>Size of Float Particle</td>
<td>0.40</td>
</tr>
<tr>
<td>Water Viscosity</td>
<td>0.00000012</td>
</tr>
</tbody>
</table>

#### Floating Velocity

<table>
<thead>
<tr>
<th>Float Size</th>
<th>Reynolds No.</th>
<th>Drag Coeff</th>
<th>Float Velocity</th>
<th>Diff in Re</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>Guess</td>
<td></td>
<td>m/s</td>
<td>Check</td>
</tr>
<tr>
<td>0.400</td>
<td>3.240</td>
<td>9.414</td>
<td>0.010</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Float Velocity for particle: $V_s = 0.032$ ft/sec
Summary of Results

- $Q = 0.4 \text{ cfs}$
- $V = 0.032 \text{ ft/sec}$
- $A = 12.45 \text{ sq ft}$
Evaporation / Inter-event Time

- Evaporation assumed 0.35 in/day
- Inter-event time assumed 7 days
- Total depth evaporated 2.45 inches
Sediment Dead Storage

- 1 ft
  - Conservative depth below invert value to allow for the settling and storage of sediment.
### Geometry of Micro Pool

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Flow Rate</td>
<td>Qo = 0.40 cfs</td>
</tr>
<tr>
<td>Surcharge Depth</td>
<td>Ds = 1.00 ft</td>
</tr>
<tr>
<td>Surface Area</td>
<td>As = 12.45 sq ft</td>
</tr>
<tr>
<td>Evaporation Rate</td>
<td>E = 0.35 in/day</td>
</tr>
<tr>
<td>Interevent Time</td>
<td>Inter Time = 7.00 days</td>
</tr>
<tr>
<td>Sediment Dead Storage</td>
<td>Dsed = 1.00 ft</td>
</tr>
<tr>
<td>Depth for Micro Pool</td>
<td>Ys = 2.20 ft</td>
</tr>
</tbody>
</table>
Design Verification

Steel well-screen (or equal)

Tw=5300.98

1/4" Stainless steel perforated flow control plate

WQCV Level EL 5300.65

Top micro pool W.S.

Bottom of micro pool 5295.03

Section A-A
Table of UDFCD recommendation, as-built conditions, design calculations

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>UDFCD Rec.</th>
<th>Design Calc.</th>
<th>As-Built</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Area (sq. ft.)</td>
<td>10</td>
<td>12.45</td>
<td>72</td>
</tr>
<tr>
<td>Micropool Depth (ft.)</td>
<td>2.5</td>
<td>2.2</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Conclusions / Recommendations

- As-Built Condition of the Micropool at EDB 502L has been sufficiently built with design criteria set forth in this presentation.
- If calculated micro-pool depth < 2 ft., use default 2.5 ft.
- No immediate improvements recommended to EDB 502L
Further Investigation

- More extensive collection of samples from the micropool area and surrounding basins
- Design verification of micropool in surrounding areas to check for consistency and efficiency.
- Further research into assumed evaporation rate
FOR MORE INFORMATION

James.Guo@UCDenver.edu
WWW.UCDENVER.EDU/~Jguo -- Website
WWW.UDFCD.ORG -- Free Software
WWW.URBANWATERSHEDS.ORG -- Training Classes

Porous Pavements in UC-Denver Campus
Thank you
Please take your seat. You will not have time to read the paper during next 30 min.
MS4 TMLD Framework

- 2009 Added to Phase I MS4 Permit
- Dry Weather Discharge (>5gpm)
- Storm Basin Maintenance / Investigation Strategy
- San Storm Intersections and Parallel Lining
- Inlet placards on 90%
- General goals of 126 cfu/100ml
- Start with 10 now 6 active basins
## E.Coli Mitigation Operational Costs

<table>
<thead>
<tr>
<th>Priority Basin</th>
<th>E.Coli GeoMean</th>
<th>Removal Petition</th>
<th>2006 – 2016*</th>
<th>Acreage or % Total Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>N42W</td>
<td>Yes</td>
<td>131</td>
<td>2017/E.coli &lt; 126</td>
<td>$590,818</td>
</tr>
<tr>
<td>N69E</td>
<td>Yes</td>
<td>266</td>
<td>2016/ &lt;5 gpm</td>
<td>$282,298</td>
</tr>
<tr>
<td>N201W</td>
<td>Removed</td>
<td>Removed</td>
<td>NA</td>
<td>$66,750</td>
</tr>
<tr>
<td>N211W</td>
<td>Removed</td>
<td>Removed</td>
<td>NA</td>
<td>$17,696</td>
</tr>
<tr>
<td>N221W</td>
<td>Yes</td>
<td>1638</td>
<td>TBD</td>
<td>$845,984</td>
</tr>
<tr>
<td>N311WC</td>
<td>Yes</td>
<td>1339</td>
<td>TBD</td>
<td>$1,401,949</td>
</tr>
<tr>
<td>N411E</td>
<td>Yes</td>
<td>873</td>
<td>TBD</td>
<td>$2,098,211</td>
</tr>
<tr>
<td>N433E</td>
<td>Yes</td>
<td>897</td>
<td>TBD</td>
<td>$2,475,393</td>
</tr>
<tr>
<td>N453E/N452E</td>
<td>Removed</td>
<td>Removed</td>
<td>NA</td>
<td>$370</td>
</tr>
<tr>
<td>S191W A/B</td>
<td>Yes</td>
<td>143</td>
<td>2016/E.coli &lt; 126</td>
<td>$427,031</td>
</tr>
</tbody>
</table>

**Total To Aug 2016:** $8,206,501
Consecutive 12 Sample Mean Result

N-311-W

Geometric Mean E. coli in CFU/100 ml

12 Sample GM Ecoli
12 Sample Mean Load
Wasteload Allocation
We were stuck. We had to make sense of it. We had to put our thinking hat on.
<table>
<thead>
<tr>
<th>Dry Weather Pilot Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration Gallery</td>
</tr>
<tr>
<td>Ultra Violet (UV) Disinfection</td>
</tr>
<tr>
<td>Path Shield Engineered Up Flow Media</td>
</tr>
<tr>
<td>DNA Source Identification</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Bio Char sand filtration</td>
</tr>
<tr>
<td>Potable water drip application</td>
</tr>
<tr>
<td>Percarbonate</td>
</tr>
<tr>
<td>Dry weather discharge to Sanitary</td>
</tr>
<tr>
<td>Pilot tests (under way with focus on lifecycle cost)</td>
</tr>
</tbody>
</table>
I can do a lot with a stick and duct tape.

Infiltration Gallery
Path Shield Engineered
Up Flow Media
Ultra Violet Treatment Pilot Study

Now we need to taste it!!!!

We need a couple of people

But who?????
when a man loves what he does he will……
I just pass governorship 101
Darren was so inspirational I did too...... Micky
A few minutes later.........
Sampling for Bio Char pilot project
Pop-up Park
How many truck load?
What is the smallest opening that you can get thru?

• We need to cutoff easy access!!!!
No More Easy Access

NOT ON MY WATCH
Source Tracking DOGs?
DO or DO NOT .... There is NO TRY...

Whaaaat

SNIFF THIS!!!!!
Canine Source Tracking

• First study Water Environment Research Foundation (WERF) 2010/14

• The final research report found: The canines were 100% accurate on sites/samples where the lab results did not find any human waste indicators.

• One canine was 100% accurate and the other was 86% accurate (when factoring for a scent volume phenomena) where the lab results found at least 1 human waste indicator.
Canine Source Tracking

• Adding canine scent tracking to the source tracking toolbox.

• The major advantages include real time results, the ability to test a high number of sites per day, and low cost per sample.

• ECS canine source tracking is a useful approach for prioritizing sampling sites for which DNA-based and other expensive laboratory tests can then confirm and quantify the human waste contamination.
Canine Field Work Over the course of Three field days:

- Screened/Sniff 5 miles of Storm Drain.
- 2 Priority Basins had been tested 13 sites that were sampled for water testing.
- 32 manholes were tested for canine responses but not sampled.
Stormwater Quality vs. Space

Presented by:

Chad Cantrell, P.E., CFM
Cody Gratny, P.E.
LEARNING OBJECTIVES

1. WQ toolbox for challenging sites
2. Sample case studies of urban BMPs
3. Lessons learned
To limit disruption of natural hydrology by reducing impervious cover, increasing on-site infiltration, reducing or eliminating pollution from stormwater runoff and eliminating contaminants.
STANDARD BMPs

- Preferred water quality treatment
- Long track record
- Mostly above ground
- Easier to maintain and verify functionality
- May not always fit with development
INITIAL APPROACH

• BMP Selection Process
  • Design team buy-in
  • Integration with other features
  • Site constraints
  • Review agency acceptance of BMP
  • Long-term maintenance
  • Install cost vs lifecycle cost
• How do we evaluate the 80% TSS removal for non-standard BMPs?

• Owners typically do not want to engage in infield monitoring data

• Manufacturer and test data from UDFCD, NJCAT and GULD

• Treatment trains
CASE STUDY 1

Welton Place

Location: Denver
Size: 2.3 Ac
WQ Vol: 2,650 CF
100-yr Vol: 8,300 CF
WQ Area: 3,800 SF
Install Year: 2007

LEGEND
- Purple: ROOF DETENTION W/ WQ IN BASIN B
- Orange: WQ AND DETENTION IN BASIN B
- Green: WQ AND DETENTION AREA
- Blue: WQ AND DETENTION BY OTHERS
CASE STUDY 1

Welton Place

BMPs Used:
• Rain Garden (PLD)
• Rooftop Detention
• 54-inch Corrugated Aluminum Pipe Underground Detention
CASE STUDY 1

Welton Place

Lessons Learned

• Utility coordination
• Shoring with zero lot lines
• Access manholes
• Sand based sod
• Maintenance

10 Years Later
CASE STUDY 2

Chaffee & Shoshone Residences

Location: Denver
Size: 2.1 Ac

Pond A
WQ Vol: 1,463 CF
100-yr Vol: 7,880 CF
WQ Area: 1,525 SF

Pond B
WQ Vol: 500 CF
100-yr Vol: 3,550 CF
WQ Area: 1,000 SF

Install Year: 2011/2012
CASE STUDY 2
Chaffee & Shoshone Residences

BMPs Used:
- Extended Detention Basin
- Rooftop Detention
- Rain Garden (PLD)
CASE STUDY 2

Chaffee & Shoshone Residences

Lessons Learned

• Financial planning and phasing
• Water tolerant plantings
• Design team coordination
• Design outlets vs installed outlets
• Verify performance curve w/ manufacturer

Charlie says, “Check your roof outlets”
CASE STUDY 3
The Province
Location: Boulder
Size: 3.0 Ac
WQ Vol: 3,940 CF
WQ Area: 3,978 SF
Install Year: 2013
CASE STUDY 3

The Province

BMPs Used:
• Green Roof
• Rain Garden (PLD)
• Permeable Pavers
CASE STUDY 3

The Province

Lessons Learned

• No one is sure who’s scope is a green roof
• Permeability vs. adjacent historic structures
• No infrastructure = complicated storm design
• Integration requires constant coordination
• Leave slack in the liner to accommodate settlement
CASE STUDY 4

Dairy Block

Location: Denver
Size: 1.6 Ac
WQ Flow: 5.0 CFS
100-yr Vol: 10,300 CF
WQ Area: 180 SF
Install Year: 2017
CASE STUDY 4
Dairy Block

BMPs Used:
• Rooftop Detention
• Underground Detention
• Underground WQ
• Permeable Pavers
Lessons Learned

• Complex coordination w/ design team

• Detention structures under buildings

• Hydraulic modeling and routing for multiple BMPs

• Zero lot line construction w/ historic structure
CASE STUDY 5

DPS West, Manual, and JFK Football Fields

Location: Denver
Size: 3.3 Ac
WQ Vol: 2,150 CF
100-yr Vol: 16,030 CF
WQ Area: 78,660 SF
Install Year: 2010
CASE STUDY 5
DPS West, Manual, and JFK Football Fields

BMPs Used:
- Gravel subgrade and trench allowing infiltration
- Permeable pavers
CASE STUDY 5
DPS West, Manual, and JFK Football Fields

Lessons Learned
• Constructability of drainage trench
• Leveling course over drainage trench
• Correct rock gradation
• Overflow drains
• Permeable paver hatch pattern
• Long term monitoring
• Tc close to natural field
CASE STUDY 6

APS Vista Peak Campus

Location: Aurora
Size: 100 Ac
WQ Vol: 1.7 Ac-Ft
100-yr Vol: 11.2 Ac-ft
WQ Area: 5.3 Ac
Install Year: 2009

BMPs Used:
• Constructed wetlands basins
CASE STUDY 6

APS Vista Peak Campus

Lessons Learned

• Armoring of forebays
• Island stability
• Low flow path
• Sufficient inflow for master planned areas
• Water rights
• Biology students
• Maintained ecosystem
• Frogs breathe through their skin
CLOSING THOUGHTS

- Multiple functions
- Team ownership
- Be flexible with design options
- Treatment train for non-standard BMPs
- Work with manufacturers
- Long term maintenance costs
- Excavators are not for temporary bracing
Background

- 2008 review of chemicals used in City operations
- Snow and Ice Control Review:
  - Streets implementing BMPs for operations
    - Colorado
    - Nationwide
  - Pacific Northwest Snowfighters product standards
- Recommendations included
  - Enhanced training program for operators
  - Environmental Management System (EMS)
  - Ongoing water quality monitoring program
Fort Collins Snow & Ice Control

- **Goals**
  - Safe and drivable roads
  - Meet EMS goals

- **Anti-icing**
  - 24-48 hrs. pre-event
  - Weakens bond
  - Salt brine

- **Deicing**
  - Prior to plowing
  - Hot spots/ice spots
  - Deicing materials
Master Snow Removal Plan

- Route prioritization
- Technology
  - Several forecasting sources
  - Road weather information system
  - Automated Vehicle Location (AVL) System
- Materials used
## Anti-icing & Deicing Materials

<table>
<thead>
<tr>
<th>Deicing Material</th>
<th>Cl⁻ Content¹</th>
<th>Cl⁻ Content²</th>
</tr>
</thead>
<tbody>
<tr>
<td>APEX Meltdown</td>
<td>224,500 mg/L</td>
<td>342,927 mg/L</td>
</tr>
<tr>
<td>NexGen Torch</td>
<td>215,500 mg/L</td>
<td>-</td>
</tr>
<tr>
<td>Salt Brine</td>
<td>135,000 mg/L</td>
<td>353,583 mg/L</td>
</tr>
<tr>
<td>Rock Salt</td>
<td>612,000 mg/kg</td>
<td>303,420 mg/kg</td>
</tr>
</tbody>
</table>

¹ Materials were analyzed by Stewart Environmental Consultants, LLC

² Materials were analyzed at CSU Soil and Water Laboratory
Water Quality Concerns

- EPA ambient water quality criteria
  - Maximum concentration = 860 mg/L
  - Continuous concentration = 230 mg/L

- Colorado
  - No standard for aquatic life protection
  - Drinking water source 30-day average = 250 mg/L
Water Quality Concerns

- Lewis 1999 performed median lethal concentrations (LC50) analysis for 3 Colorado aquatic species

<table>
<thead>
<tr>
<th>Species</th>
<th>24-hr LC50 Dilution</th>
<th>24-hr LC50 Cl(^-) (mg/L)</th>
<th>48-hr LC50 Dilution</th>
<th>48-hr LC50 Cl(^-) (mg/L)</th>
<th>96-hr LC50 Dilution</th>
<th>96-hr LC50 Cl(^-) (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreal Toad</td>
<td>2.2%</td>
<td>4620</td>
<td>1.8%</td>
<td>3780</td>
<td>0.32%</td>
<td>672</td>
</tr>
<tr>
<td>Rainbow Trout</td>
<td>2.5%</td>
<td>5250</td>
<td>1.8%</td>
<td>3780</td>
<td>1.4%</td>
<td>2940</td>
</tr>
<tr>
<td>Ceriodaphnia</td>
<td>0.26%</td>
<td>546</td>
<td>0.19%</td>
<td>399</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes: Deicing material used in testing had Cl\(^-\) concentration = 210,000 mg/L

Goals of the Study

1. Evaluate the amount of chlorides applied
2. Analyze changes in baseflow concentrations
3. Determine the effects of deicing materials on urban stream quality
4. Determine optimal application rates
Project Approach - Study Area

Spring Creek Watershed
- Area: ~12 sq. miles
- Developed Area: 73.9%
- 2011 NLCD Imperviousness: 26.4%
- Winter Flow Rates: 2-20 cfs

Monitoring Locations
- Drake
- Center
- College
- Timberline
Project Approach - Applied Chlorides

- **Automated Vehicle Location Data (AVL)**
  - Location, time, and the type (liquid/solid) and amount of deicing materials applied

- **ArcGIS analysis**
  - Aggregate the amount of deicing materials applied in each subwatershed for each event

### Event Deicing Material

<table>
<thead>
<tr>
<th>Event Start Date</th>
<th>Deicing Material</th>
<th>Chloride Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Granular (lbs)</td>
<td>Liquid (gallons)</td>
</tr>
<tr>
<td>Drake</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/7/2016</td>
<td>64,232</td>
<td>4,428</td>
</tr>
<tr>
<td>2/1/2016</td>
<td>38,028</td>
<td>6,624</td>
</tr>
<tr>
<td>3/17/2016</td>
<td>10,839</td>
<td>1,087</td>
</tr>
<tr>
<td>3/23/2016</td>
<td>9,508</td>
<td>483</td>
</tr>
<tr>
<td>1/3/2017</td>
<td>64,232</td>
<td>5,547</td>
</tr>
<tr>
<td>1/11/2017</td>
<td>8,695</td>
<td>2,028</td>
</tr>
<tr>
<td>1/16/2017</td>
<td>5,773</td>
<td>802</td>
</tr>
<tr>
<td>1/24/2017</td>
<td>4,906</td>
<td>905</td>
</tr>
<tr>
<td>2/1/2017</td>
<td>19,219</td>
<td>1,720</td>
</tr>
<tr>
<td>2/23/2017</td>
<td>5,824</td>
<td>371</td>
</tr>
</tbody>
</table>
Project Approach - In-stream Chlorides

- **In-stream Monitoring**
  - Continuous Monitoring (In-Situ WaterTroll 9500)
    - Pressure (Depth): To determine flow
    - Conductivity: To determine chloride concentration
  - Grab Samples
    - Analyzed chloride concentrations
  - Specific Conductivity and Chloride Relationship
Project Approach - Flowrate

In-stream Flowrate

- Continuous stream depth using pressure sensor
- Correction factors using manual depth measurements
- Surveyed cross-sections and slopes for each location
- eRAMS cross-section tool was used to determine the flow rate based on Manning’s Equation
Project Approach - Event Loads

**In-stream Chloride Loads**

- Baseflow Separation
  - Event loads
  - Removed noise in pressure sensor
  - Runoff Flow = Total Flow – Baseline Flow

- Event Load = Runoff Volume * Event Cl⁻ Concentration

- Load calculations began when Cl⁻ levels and were elevated and ended when concentrations returned to baseline
Results - Amount Of Chlorides Applied

2017 Annual Amount of Chlorides Applied per Sub-watershed

<table>
<thead>
<tr>
<th>Location</th>
<th>Chlorides Applied (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drake</td>
<td>90,927</td>
</tr>
<tr>
<td>Center</td>
<td>127,953</td>
</tr>
<tr>
<td>College</td>
<td>107,337</td>
</tr>
<tr>
<td>Timberline</td>
<td>240,466</td>
</tr>
</tbody>
</table>
Results - Amount Of Chlorides Applied
Results - Amount Of Chlorides Applied

2017 Annual Cumulative Amount of Chlorides Applied per Sub-watershed

<table>
<thead>
<tr>
<th>Location</th>
<th>Chlorides Applied (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drake</td>
<td>90,927</td>
</tr>
<tr>
<td>Center</td>
<td>218,880</td>
</tr>
<tr>
<td>College</td>
<td>326,217</td>
</tr>
<tr>
<td>Timberline</td>
<td>566,683</td>
</tr>
</tbody>
</table>
Results - Amount of Chlorides Delivered

2017 Annual Amount of Chlorides Applied and Delivered per Sub-watershed

<table>
<thead>
<tr>
<th>Sub-watershed</th>
<th>Chlorides Applied (lbs)</th>
<th>Chlorides Delivered (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drake</td>
<td>90,927</td>
<td>47,483</td>
</tr>
<tr>
<td>Center</td>
<td>218,880</td>
<td>43,561</td>
</tr>
<tr>
<td>College</td>
<td>326,217</td>
<td>34,405</td>
</tr>
<tr>
<td>Timberline</td>
<td>566,683</td>
<td>65,706</td>
</tr>
</tbody>
</table>
Results - Chloride Concentrations

Drake Chloride Concentrations
1/23/2017 - 1/25/2017

Chloride Concentration (mg/L) vs. Precipitation (in)

Precipitation:
- 0.01 in on 1/23/2017
- 0.06 in on 1/24/2017
- 0.01 in on 1/25/2017

Chloride Concentration:
- Low levels before and after precipitation events
- Peak concentration on 1/25/2017

Graph shows changes in chloride concentration over time with corresponding precipitation levels.
Results - Chloride Concentrations

- Criteria Maximum Concentration (CMC): 1-hr 860 mg/L
- Criterion Continuous Concentration (CCC): 4-hr 230 mg/L
- Median Lethal Concentration (LC50)

<table>
<thead>
<tr>
<th>Event Start Date</th>
<th>Mass Cl⁻ Applied (lbs)</th>
<th>Maximum Average Cl⁻ Concentration (mg/L)</th>
<th>Criteria Exceeded?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1-hr</td>
<td>24-hr</td>
</tr>
<tr>
<td>Drake</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/3/2017</td>
<td>51,228</td>
<td>2,350</td>
<td>893</td>
</tr>
<tr>
<td>1/11/2017</td>
<td>14,935</td>
<td>2,423</td>
<td>656</td>
</tr>
<tr>
<td>1/24/2017</td>
<td>49,470</td>
<td>1,564</td>
<td>538</td>
</tr>
<tr>
<td>2/1/2017</td>
<td>15,457</td>
<td>884</td>
<td>353</td>
</tr>
<tr>
<td>2/23/2017</td>
<td>4,361</td>
<td>479</td>
<td>100</td>
</tr>
<tr>
<td>2017 Total</td>
<td>90,927</td>
<td>2,423</td>
<td>893</td>
</tr>
</tbody>
</table>
Results - Baseline Chloride Concentrations

<table>
<thead>
<tr>
<th>Location</th>
<th>2012 Baseline</th>
<th>2017 Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drake</td>
<td>62.6</td>
<td>82.2</td>
</tr>
<tr>
<td>Center</td>
<td>57.1</td>
<td>69.6</td>
</tr>
<tr>
<td>College</td>
<td>63.1</td>
<td>80.5</td>
</tr>
<tr>
<td>Timberline</td>
<td>63.1</td>
<td>83.9</td>
</tr>
</tbody>
</table>
Improving the Study - Streets

RDO Data Collection
- Type of liquid deicing agent
- Application rates (pounds per lane mile)

Protocol
- When to select quantities and types of deicing agents

Performance Metrics
- Identify performance metrics for road safety
Improving the Study - Sampling

Improve Sampling Plan

• Dual storm sampling

Sample Collection Timing

• First sample: 3-10 hours from the beginning of the storm
• Second sample: 20-24 hours from the beginning of the storm
• Sample times should be sooner with higher temperature storms

Solids/Groundwater

• Soil and groundwater analysis for chloride contribution to system
• Storm sewer solids analysis for chlorides contribution to system
Improving the Study - Data Collection

Pressure Transducer
  • Add a second cross section with a pressure transducer
  • Increase redundancy and confidence of flow measurements for the study

Service Conductivity Sensor
  • Reduce sensor bias

Develop Manuals
  • Installation & Calibration
  • Sampling & Surveying
  • Data Analysis
Conclusions

• Chloride concentrations increase during winter runoff events and exceed EPA recommendations
• Only a portion of applied chlorides are delivered as runoff during winter event
• Baseline concentrations appear to have increased since the 2012 study
• Study improvements will allow for recommendations to be made regarding application rates without compromising road safety
Thank you.

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

- **Contact:** Susan Strong
  - 970.416.2325
  - sstrong@fegov.com
Low Impact Development Retrofit after 20 years
AT A BOULDER, CO OFFICE BUILDING

Colorado Association of State Floodplain Managers
2017 Annual Conference, Breckenridge CO
September 20, 2017
1989: Land and Water (LAW) Fund is established
1992: LAW Fund purchases office building at Baseline and Broadway, Boulder, Colorado
2003: LAW Fund changes name to Western Resource Advocates
SITE DESCRIPTION

- 0.65 acre
- 75% directly connected impervious area
- Gently sloping
- Expansive clay soils mixed with sandy layers
LAND USE

A new, improved no-parking zone

Land and Water Fund of the Rockies plans a kinder landscape.

By CRAIG ROBERTS

Circulation Director/Editor

The plan is one of 20 that won an award from the WaterSmart Forum on Nonpoint Source Pollution.

“We wanted to be in a place where we walked out talk,” Green said.

Nonpoint source pollution is a growing problem in the United States.

Point source pollution mainly comes from factories and sewage treatment plants. Nonpoint source pollution is harder to nail down. It comes from smaller businesses that aren’t as large as large factories and from residential chemical pollution. Sampling our engines in the sewage and running samples of rainwater.

It’s very small. We’re looking at wastewater plants in the suburban landscape.

“New source it costs virtually nothing. We’ve done studies on all of these plants to see what we can measure.”

The purchase of water, drought, and a good water management system is hard to find. Green said there’s no point for the project in the areas of next year.

Environmental Center of the Rockies Demonstration Project—Urban Storm Runoff

HISTORICAL BACKGROUND

In 1990, the National Geographic Society, The Conservation Fund, and the U.S. Geological Survey launched an ambitious effort to make the American public aware of freshwater’s value and the need to identify solutions to problems threatening the nation’s freshwater resources.

As part of that campaign, the National Forum on Nonpoint Source Pollution was created. The Forum focused on developing and implementing specific actions that could take to eliminate nonpoint source (NPS) pollution. The Forum addressed this critical issue by identifying and demonstrating innovative, nonregulatory remedies for this pervasive water quality problem. Consisting of national leaders representing public, private, and nonprofit organizations, the Forum sought solutions that would balance the nation’s economic and environmental needs.

Since passage of the Clean Water Act in 1972, many “point” sources of pollution from factories and sewage treatment plants have been successfully controlled. However, NPS pollution is now the nation’s chief threat to water quality. NPS pollution comes from many diffuse sources and is brought about as rainwater and snowmelt wash off the land into streams, lakes, coastal estuaries, and marshes, or seeps into groundwater. As this runoff moves across plowed fields, city streets, or suburban backyards, it picks up soil particles, pesticides, fertilizers, animal wastes, and other pollutants such as road salt and crankcase oil. It is estimated to account for over half of our nation’s water pollution and has harmful effects on drinking water supplies, recreation, fisheries, and wildlife.

The Forum’s goal is to develop, implement, and communicate to the public, remedies for NPS pollution based on market incentives, voluntary initiatives, and education was turned into 25 innovative demonstration projects spread across the face of our nation. Three of those projects are located in Colorado: Adopting Orphan Sites for Credit (Coors Brewing Company); Westerly Creek Restoration Project (Stapleton International Airport redevelopment); and Urban Stormwater Control Project (the Land and Water Fund of the Rockies).
ADVISORY GROUP:

• Denver landscape architect Joan Hirschman
• Wenk Associates
• City of Boulder
• Professor Gilbert White
• Wright Water Engineers, Inc.
The Urban *Stormwater Control* Project:

- Onsite water management and conservation
- Use of native and drought tolerant plants
- Multiple use of site elements
- Encourage the use of multiple modes of site access
Original Structural Stormwater Retrofits:

- Biofiltration/infiltration swale
- Biofiltration buffer
- Biofiltration planters
- Water Storage check dams
Original Landscape Retrofits:

- Low water use garden
- Riparian and upland landscape edges
- Shade and parking buffer
1998: Melissa Figurski from University of Florida, Dept. of Civil Engineering in cooperation with the University of Colorado

Would planned native installations be adequately supported by natural precipitation?

RESULTS: Annual irrigation demands would be reduced, not fully negated
Site Water Balance

1999: Wright Water Engineers

How effective are the new LID stormwater control facilities using data from 1999 calendar year?

RESULTS:
- Surface runoff discharged from site on two days during the calendar year
- Remaining water infiltrated into soil and left site via evapotranspiration
Project Assessment

Stormwater Management

Site Use

and

Aesthetics
Original Structural Stormwater Retrofits:

- Biofiltration/infiltration swale
- Water Storage check dams
- Biofiltration buffer
- Biofiltration planters
Parking Area Landscape Buffer
Western Biofiltration Planters
Western Biofiltration Planters

(1998)

(2017)
Water Storage Check Dams

(2017)

(2017)
North and East Building Landscape Buffer

(2000)

(2008)

(2017)
North and East Building Landscape Buffer

(2000)

(2017)

(2017)
SUMMARY: Final Suggestions for Future Projects...

1. LID should be robust and redundant to be highly effective for hydrology and water quality
2. The success of the ECR’s retrofit project due to building occupant’s participation, but anticipate change over time
3. Consider site context – landscape must be both aesthetically pleasing and functional
4. The cost of ongoing maintenance should be anticipated when considering cost of construction
5. Practice adaptive management
6. Prepare a multi-year management plan, including:
   - Original landscape architecture plans
   - List of recommended species
   - Area specific maintenance protocols
   - Recommended annual schedule and budget
7. Hire a landscape maintenance contractor who is an expert in LID landscapes
References


Heaney, James, Dave Sample and Len Wright (No Date). Urban Storm Runoff: Preliminary Research Results, Environmental Center of the Rockies, Demonstration Project – Urban Storm Runoff. Boulder Area Sustainability Information Network (BASIN).


Case Studies

• Case Study 1:
  ▫ Woodbury Drive Reconstruction, Woodbury, MN

• Case Study 2:
  ▫ Neighborhood Green Initiatives, Hinsdale, IL

• Case Study 3:
  ▫ Linear Roadway BMPs throughout St. Louis, MO
Case Study 1:
Woodbury Drive Reconstruction:
Delivering a Low Impact Roadway with Alternative Stormwater System
CSAH 19 (Woodbury Drive), Woodbury, MN

Project Limits

BMP Locations
Regulatory Goals

- South Washington Watershed District (SWWD) & City of Woodbury
  - Water Quality
  - Volume Reduction
  - Rate Control
Regulatory Goal 1: Water Quality

- Reduce post development TP load by 60% to Bailey Lake
- Achieve Colby Lake’s target standard maximum allowable unit load of 0.34 lbs. TP/ac/yr
Regulatory Goal 2: Volume Reduction

- Infiltrate either the first $\frac{1}{2}$ -inch of runoff over the entire site or the first inch of runoff over the site’s new impervious.
- $\frac{1}{2}$ - inch of runoff over entire site (1.84 ac-ft).
Regulatory Goal 3: Peak Elevations

- Maintain 2 and 100-yr peak inflow rates
- Maintain 10-yr flood levels (maximum of 1 foot allowed with additional analysis)
- Maintain FEMA Zone A 100-yr flood levels (maximum of \( \frac{1}{2} \) foot allowable with additional analysis)
BMP Options

Preliminary
• Iron Enhanced Sand Filter Berm
• Infiltration Trenches

Final
• Offsite Stormwater Reuse Systems

[Map showing BMP options with markers for Berm and Trench]
Eagle Valley Treatment Area

Runoff from approximately 415 acres (hatched area) treated by Eagle Valley Reuse System.
Eagle Valley Reuse System
# Eagle Valley Golf Course

<table>
<thead>
<tr>
<th>Existing</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigates 60 acres</td>
<td>Irrigate 60 acres</td>
</tr>
<tr>
<td>Pumps 30 million gal/yr from aquifer</td>
<td>Pump 7.5 million gal/yr from aquifer (25%)</td>
</tr>
<tr>
<td></td>
<td>Pump 22.5 million gal/yr from stormwater pond</td>
</tr>
<tr>
<td></td>
<td>Achieve TP unit loading of 0.12 lbs/ac/yr.</td>
</tr>
<tr>
<td></td>
<td>Route water through babbling brook feature when irrigation is not needed</td>
</tr>
</tbody>
</table>
Prestwick Treatment Area

Runoff from approximately 134 acres (hatched area) treated by Reuse System
Prestwick Reuse System
Prestwick Golf Course

<table>
<thead>
<tr>
<th>Existing</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Irrigates 75 acres</td>
<td>• Irrigate 75 acres</td>
</tr>
<tr>
<td>• Pumps 35 million gal/yr from aquifer</td>
<td>• Pump 17.5 million gal/yr from aquifer (50%)</td>
</tr>
<tr>
<td></td>
<td>• Pump 17.5 million gal/yr from stormwater pond</td>
</tr>
<tr>
<td></td>
<td>• Exceed required TP removal of 11.7 lbs/yr by 32.1 lbs/yr</td>
</tr>
<tr>
<td></td>
<td>• Refill interior amenity ponds</td>
</tr>
</tbody>
</table>
Results

- Regulatory
  - Achieved or exceeded all water quality, volume reduction and peak elevation goals
  - Water reuse project selected for Legacy Grant and SWWD contributed matching funds
Eagle Valley Construction Photos

Photos courtesy of Water in Motion
Eagle Valley Construction Photos
Prestwick Construction Photos
Case Study 2: Neighborhood Drainage Improvements: Using Green Initiatives: The Woodlands – Village of Hinsdale, IL
Project Location
Three Phases

PHASE 1

PHASE 2

PHASE 3
Existing Conditions
Existing Conditions
Previous Studies

**• September 2008 Drainage Study**
- Reconstruct roadways with curb and gutter
- Traditional storm sewer conveyance
- Large storm sewers with underground detention required
- **2008 Cost estimate for improvements - $24.4 Million**

**• December 2009 Feasibility Study**
- Focused on “green initiatives”
- Combination of rain gardens, bio-swales, underground storage were utilized
- **Projected costs for improvements - $15.0 Million**
Goals and Objectives

- Minimize Tree impacts
- Maintain Subdivision Characteristics
- Minimize increase in impervious area
- Stay within ROW
- Minimize Storm Sewers
- Maximize BMP’s for infiltration and storage
- Minimum 10-year storm with no surcharge
- Convey 100-year overland without damage to structures
Design Approach

- Identify flooding locations
- **Delineate sub-watershed areas (approx. 1 – 2 acres max.)**
- Develop flow path and correlate to flooding locations
- **Develop concept BMP’s (type and location)**
- Verify suitability for infiltration using soil borings
- Review conveyance path
- **Series of staff meetings and public meetings**
- Finalize concept BMP’s
- Develop a XP-SWMM model
- Finalize stormwater management plan and design
Objective: Address flooding utilizing green initiatives
Model Set-up

Build the Model
## North System - Results

<table>
<thead>
<tr>
<th>Event</th>
<th>Peak Flow Without BMPs</th>
<th>Peak Flow With BMPs</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-year 2-hour</td>
<td>69.85 cfs</td>
<td>23.45 cfs</td>
<td>66%</td>
</tr>
<tr>
<td>10-year 2-hour</td>
<td>35.25 cfs</td>
<td>15.87 cfs</td>
<td>55%</td>
</tr>
</tbody>
</table>

Measurement Point
South System - Results

<table>
<thead>
<tr>
<th>Event</th>
<th>Peak Flow Without BMPs</th>
<th>Peak Flow With BMPs</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-year 2-hour</td>
<td>44.04 cfs</td>
<td>15.67 cfs</td>
<td>65%</td>
</tr>
<tr>
<td>10-year 2-hour</td>
<td>22.98 cfs</td>
<td>9.47 cfs</td>
<td>58%</td>
</tr>
</tbody>
</table>
Underground storage were perforated to promote infiltration into the native soils to the greatest extent possible.
Some rain gardens were placed over the underground storage units
Landscape Options

Non-Natives
- Spirea
- Daylilies
- Perennial Fountain Grass

Turf grass
- 2” - 4” deep roots

Non-native shrubs
- 1’ - 3’ deep roots

Natives
- Prairie Dropseed
- Black-eyed Susan
- Common Ninebark

Native Plants

- Buffalo Grass
Managing Expectations

BE CAREFUL WITH THE LANDSCAPE DESIGN
Many people think native plants look weedy...
Mix of Non-Native Plants

Picture is Worth a Thousand Words

DESIGN INTENT—Create defined and organized “edges” with non-native plants and the bottom with native plants
Key Elements of Rain Garden

SOIL MIXTURE
30% sand, 30% compost and 40% topsoil

NATIVE PLANT MIX (Plugs planted in the bottom of all rain gardens)

<table>
<thead>
<tr>
<th>COMMON NAME</th>
<th>BOTANICAL</th>
<th>PERCENTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodding Wild Onion (Allium cernum)</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Blue Flag Iris (Iris virginica)</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Common Fox Sedge (Carex stipata)</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Foxglove (Penstemon digitalis)</td>
<td>25%</td>
<td></td>
</tr>
</tbody>
</table>
Oversight and review through every step of construction is critical!

Phase 1 Completion – June 2013
Phase 1 Completion – June 2013
- Short term and long term maintenance is critical for long term success
- Qualified professionals should be maintaining these landscapes
Check dams were utilized in areas with slope to slow the water down and promote infiltration.
- Utilized lower profile plants in the front yards of homes
- If possible in your project, use smaller inlet structures
Summer 2014

Before...

After...
All Three Phases Now Complete

The Woodlands project has received awards from:

- APWA Project of the Year
- ACEC Special Achievement
- APWA Sustainability Project Award
Case Study 3: Converting Constraints to Opportunities:  
The Application of LID/BMP Site Development Techniques to Linear Roadway Projects in St. Louis, MO

Special Thanks to our Clients:
Green Street Concepts
Green Street Concepts
International Plaza Drive

City of St. Ann, MO

**Pre-Construction:**
- 1,330 linear feet
- Collector road
- Major entry to City

**Project Goals:**
- Road diet
- Multi-modal needs served by bike lanes and ADA compliant sidewalks
- WQv met with natural BMPs
International Plaza Drive

Construction
International Plaza Drive
International Plaza Drive
Thank you!

Contact Information

Ajay Jain, P.E., CFM
Phone: 815.759.8331
Cell: 815.509.8302
Email: ajain@hrgreen.com

HR GREEN, INC.
Learn more at HRGreen.com
PLANNING FOR HAZARDS
Land Use Solutions for Colorado

Colorado Association of Stormwater and Floodplain Managers
September 20, 2017
Background

- 2012-13 federally-declared fires and floods devastated many Colorado communities

- Planning for Hazards guide project initiated by Department of Local Affairs to:
  - Inform impacted local governments’ long-term recovery efforts
  - Help communities proactively plan to reduce risks by:
    - Identifying their risk to hazards
    - Selecting and implementing land use strategies to make communities safer

- Clarion Associates hired to develop the guide with input from Advisory Committee; University of Colorado Denver maintaining website

- Funded with CDBG-DR Resilience Planning grant

- Guide and website published in March, 2016
Planning for Hazards
General Principles
General Principles

Avoidance

*The most effective way to protect development from hazards is simply to prohibit development in known hazard areas.*

But that's not always possible........
General Principles

• Prevent development in hazardous areas
• Direct future growth to safer areas
• Strengthen existing regulations and development in hazardous areas
Consider Community Context

- Size and geographic location
- Technical, administrative, and financial capacity
- Community goals and political will
Consider the Interrelatedness of Hazards

For example:

- Drought $\rightarrow$ Fire
- Lightning $\rightarrow$ Fire
- Fire $\rightarrow$ Flooding
- Fire $\rightarrow$ Debris Flow
- Flooding $\rightarrow$ Soil Hazards
Planning for Hazards – A Collaborative Approach

- Land use planners
- Emergency managers
- Elected and appointed officials
- Public works officials
- Community advocates
- Business owners
- Developers
- Citizens
Outline:

• Introduction and Summary
• Planning Framework
• Hazard Identification and Risk Assessment
• Planning Tools and Strategies
  • Model Code Language
• Moving Forward
• Appendix – Hazards in Colorado
The Hazards Lineup

Avalanche
Drought
Earthquake
Extreme Heat
Flood
Hazardous Material Release
Landslide, Mud/Debris Flow, and Rockfall
Severe Winter Storm
Soil Hazards
Wildfire
Wind Hazards
Planning Tool Profiles

* New Tool Profiles Include:
  - Resiliency Plan
  - Capital Improvement Plan
Tool Profiles

Subdivision and Site Design Standards

How it Works

Subdivision and site design standards are used by communities to regulate how parcels of land are divided into developable lots, and how those lots are subsequently designed and laid out through the development process. Subdivision typically includes the creation of a sketch plan (showing basic lot layout and provisions for public infrastructure), and subsequent creation of a more detailed preliminary plat (indicating building footprints and specific measurements), and then culminating in a final plat that creates the new lots. Abbreviated procedures are typically established for minor subdivisions that involve the creation of just a handful of lots.

Site design standards are related and define the basic parameters for development on individual lots, including maximum or minimum lot size, how buildings are situated on a lot, traffic and circulation patterns, pedestrian connectivity, preservation of open areas, and avoidance of hazardous areas.

Communities increasingly consider hazard mitigation when adopting site layout standards. For example, applicants are required to avoid mapped hazard areas (like floodplains) in new development or to develop strategies to mitigate the hazard risk.

Implementation

As communities grow, they should identify where new growth should be concentrated through long-range planning mechanisms, such as the comprehensive planning process. There can be pressure to locate new development in areas that are known to be at risk from hazards. Communities must balance competing interests when reviewing proposed development. For example, the need for additional workforce housing in a community should be balanced against the desire to protect natural areas, view corridors, and natural hazard areas, as well as the safety and welfare of future inhabitants of the development. Communities are challenged with keeping development out of harm’s way while allowing individuals to develop land consistent with stated policies. Communities can often find middle ground through subdivision standards that allow for new subdivisions to be approved when they meet conditions to mitigate hazards, such as water cisterns for wildfire protection, slope stabilization for landslide and rockfall, and keeping buildable lots out of the floodplain. Additional incentives and regulations can be explored such as cluster subdivisions, density bonuses, and Transfer of Development Rights (TDRs), each of which are good tools for promoting avoidance of hazards. Each of these is discussed in separate planning tool profiles.

According to APA’s Zoning Practice issue on Safe Growth Audits (Godschalk, 2009), communities should ask themselves the following questions related to their subdivision regulations:

1. Do the subdivision regulations restrict the subdivision of land within or adjacent to natural hazard areas?
2. Do the regulations provide for conservation subdivisions or cluster subdivisions in order to conserve environmental resources?
3. Do the regulations allow density transfers where hazard areas exist?

As with zoning codes, adoption of subdivision ordinances or site layout standards requires approval by the governing body (City Council, Board of Trustees, or County Commissioners).

Where It’s Been Done

Pagosa Springs adopted sensitive area protection standards for subdivisions and for redevelopment of existing areas in its Land Use and Development Code (2015). The standards generally address the following issues:

- **Slopes.** Slopes greater than 30 percent, or are otherwise unstable or subject to hazards, are not allowed to be platted or developed for residential uses without mitigation controls in place.
- **Natural Features.** Subdivisions or development shall protect waterways, vegetation, and rocks and other natural features or vistas.
- **Areas of Special Flood Hazard.** Mapped flood hazard areas identify areas where subdivisions shall not be approved without evidence that it is not in a flood hazard or meets other flood damage protection regulations to the satisfaction of the floodplain administrator.
- **Geologic Hazard Areas.** Subdivisions and site plans must meet mitigation conditions prior to approval in mapped geologic hazard areas in the Town as the information becomes available, including provisions to prevent danger to human life or property.
- **Wildfire Hazard Areas.** Applicants for subdivisions or other development must provide evidence from a professional forester that the proposal meets several conditions, including adequate roads for emergency services and criteria for wildfire areas published by the Colorado State Forest Service.
- **Perimeter Fencing.** Limits the height to protect migration of elk and deer.
- **Riparian Setbacks.** To promote and preserve the quality of the river ecology, aesthetic, and recreation.

In addition to these standards, approval criteria for major subdivisions also address areas that may involve soil or topographical conditions that present hazards.
Model Code Language

- Integrating Risk Reduction into Comprehensive Plans
- Climate Plan
- Community Wildfire Protection Plan (CWPP)
- Hazard Mitigation Plan
- Parks and Open Space Plan
- Pre-Disaster Planning
- Community Rating System
  - Development Agreements
  - Transfer of Development Rights
  - Density Bonuses
  - 1041 Regulations
  - Cluster Subdivisions

- Land Acquisition
  - Overlay Zoning
  - Stream Buffers and Setbacks
  - Low-Impact Development and Stormwater Management BMPs
  - Site-Specific Assessments
  - Subdivision and Site Layout Standards
  - Use-Specific Standards

- Building Code
- Critical Infrastructure Protection
- WUI Code
  - Application Submittal Requirements
  - Post-Disaster Building Moratorium
Model Code Language

- Language to be tailored for local governments (in blue)
- Based on several best practices throughout Colorado and the nation
- Includes commentary for further explanation (in margin)
Appendix - Hazards in Colorado

- Expanded information related to the hazards profiled in the guide. Each hazard includes:
  - Description of the hazard
  - Hazard risk in Colorado
  - Related hazards
  - Available data sources
  - Summary of applicable planning tools and strategies
Planning for Hazards Website
Purpose of the Guide

Learn how the Hazard Mitigation Guide can help your community address risks and integrate hazard mitigation into policies, regulations, and standards.

Intro
This guide provides detailed, Colorado-specific information about how to assess a community’s risk level to hazards and how to implement several land use planning tools and strategies for reducing a community’s risk.

Read the Guide
To explore this guide or specific chapters in the traditional format, Page-by-Page from start to finish, look for the purple Table of Contents on the top right and the previous/next buttons on the bottom of each page.
Goals of the Website

- Accommodate different user experiences
- Offer user-friendly interface
- Make it easy to access information from the printed guide
- Bring the document to life through enriched media
- Dynamic with new content over time

Janelle - student
Jim - planner
Gina – elected official
Wildfire

On This Page
- Description
- Wildfire in Colorado
- Related Hazards
- Available Data Sources
- Assessing the Risk of Wildfire

Description
The Colorado Natural Hazards Mitigation Plan defines a \textit{wildfire} as an unplanned, unwanted \textit{wildland fire}, including unauthorized human-caused fires, escaped wildland fire use events, escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out\cite{36}. Wildland fire occurs when vegetation, or "fuel," such as grass, leaf litter, trees, or shrubs, is exposed to an ignition source and the conditions for combustion are met, resulting in fire growth and spread through adjacent vegetation.

Wildland fires are either ignited by lightning or by some consequence of human activity. In Colorado, lightning accounts for only 17 percent of wildfires, with human ignitions accounting for the remainder\cite{37}. Human causes vary and can include escaped debris pile burning, campfires, fireworks, construction sparks, downed transmission lines, and arson.

Wildland fires can occur during any time of year. Although there are frequent references to a "fire season," ignitions are a result of the ability of fuels to support combustion. In addition to an ignition source, the fuel type, amount of fuel, distribution pattern, and moisture content—coupled with weather and topography—will determine the conditions for combustion and resulting fire behavior. Fire behavior "outputs" include intensity,
Overlay zoning is used by communities to apply area-specific standards and/or conditions to a zoning district (such as residential or mixed-use) that determines the types of uses permitted, the dimensional requirements, and sometimes additional district-specific standards. An overlay district (or overlay zone) is an additional layer of standards that apply to all areas within a defined overlay boundary, regardless of the underlying base zoning district. For example, an area with single-family homes that is zoned R-1 might also be within a hillside overlay zone. In this example, the permitted uses might allow construction of a single-family home according to the R-1 standards, but also might apply additional requirements for hillside stability.
Video Interviews & Library of Resources

- Enriched media content
- Real life examples of planning for hazards
- Description of tools
- Collection of relevant videos external to guide & site
Moving Forward/ Next Steps
Putting the Guide into Action

- The Center for Sustainable Urbanism at the University of Colorado Denver is updating the website.

- Developed facilitator and participant workbooks and supporting materials to convene a six work-session process to plan for hazards.

- Pilot project underway with 2 pilot communities to test process.

- Developing FEMA workshop with support from DHSEM.

- New tools and model code language being added to site.
<table>
<thead>
<tr>
<th>Critical Facilities, Infrastructure, and Assets</th>
<th>Examples</th>
<th>Our Community</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Reservoirs, water treatment plants, water supply facilities</td>
<td></td>
</tr>
<tr>
<td>Emergency Services</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas/Electric</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Healthcare and Public Health</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Banking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government Facilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Gas/Power</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear Waste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical Plants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defense &amp; Security</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Critical Manufacturing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural Assets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultural Assets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic Assets</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Thank You for your Support!

- Thank you CASFM for granting this project the funds to continue hosting our [www.planningforhazards.com](http://www.planningforhazards.com) website for the next two years
- Your support is critical as we secure a long-term funding strategy for updating and expanding this project
Community Engagement – Virtual Reality to Relay Races
Sandra Bratlie, PE, CFM & Heidi Hansen, PE, CFM
Just the Facts!
Confused?
Outreach
• Promotes Awareness
• Doing something for your community

Engagement
• Promotes Learning
• Doing something with your community
Outreach

- Annual Brochure
- Bus Benches
- Flood Awareness Week Posters, Brochures & Banners
- Event Booths
The Limits of Outreach
**swag**
/swag/

**noun**

1. stands for Stuff We All Get; typically, free merchandise distributed when attending an expo or trade show.  
   *Look at all of this SWAG!*

2. an alternative term for pirate’s treasure; like booty.  
   *Me holds are burstin’ with swag.*
Wheel of Floodplains

“It is not the answer that enlightens, but the question.”
– Eugène Ionesco
Flood Safety Relay
1997 Spring Creek Flood – 20 Years

Follow the Flood

Follow the Flood

http://www.uwyo.edu/ogden/fortcollins/data_shed.html
Remembrance Ceremony

City produced video: https://youtu.be/i9D3lWN1edI

Flood Education Day
FEMA Immersed VR Experience

FEMA Immersed VR Experience

FEMA Immersed Highlights:
• Explore the damage in a flooded neighborhood
• Witness the challenges of an evacuation
• Lead a stranded teacher to safety at a flooded school
• Experience mitigation decisions being made
• Discover which preparations can lead to positive results.
Early VR Experiences

1800’s

1980’s
DIY Virtual Reality
City of Fort Collins VR Photos:
https://www.flickr.com/photos/fortcollinsgov/albums/72157684776543734/with/36305643132/
Flood Control
Walking and Bike Tours
Use this link to access
Follow the Flood

Self Guided Tours
Full Tour in 3 Minutes!
Engineering Meets Sales: Cultivating Likeability

EMILY C. MURPHY, CPSM, MA
DIRECTOR OF MARKETING AND CLIENT RELATIONS
CALIBRE ENGINEERING, INC
The Seller-Doer Model

- Increase in the S-D model
- 84% of Eng. firms use S-D model
- 4% of firms focus on existing clients; vast majority on existing and new

The Seller-Doer Model

- People do business with people they like

Compelling People. Kohut & Neffinger, 2014
“What It Takes to Win in Any Market.” Lea & Rossi, 2009
How Do I Increase My Likeability?
1. Be Warm

“7 Body Language Tricks to Make Anyone Like You.” Zhang, 2014
“Do These 5 Emotionally Intelligent Things Within 5 Minutes of Meeting Someone.” Deutschendorf 2017
“Can You Make Yourself More Likeable?” Powlowski, 2017
“Enhance Your Social Value Manifold.” Pherwani, 2017

Compelling People. Kohut & Neffinger, 2014
“The Dynamics of Warmth and Competence Judgments.” Cuddy Glick and Beninger, 2011
360 Degrees of Influence. Monarth, 2012
The Science of Influence. Hogan, 2011
1. Be Warm

Penn Gildersleeve, Retired
1. Be Warm

Morgan Lynch, UDFCD
1. Be Warm

- Be curious, ask questions
- Be enthusiastic
- Find shared connections
- Smile
- Eye contact
- Nod
- Turn toward the person; mirror the other person
- Approach them as an old friend
- Be familiar
- Hold a warm drink

Compelling People. Kohut & Neffinger, 2014
“The Dynamics of Warmth and Competence Judgments.” Cuddy Glick and Beninger, 2011
360 Degrees of Influence. Monarth, 2012
The Science of Influence. Hogan, 2011
2. Be Strong/Competent

*Compelling People.* Kohut & Neffinger, 2014
“The Dynamics of Warmth and Competence Judgments.” Cuddy Glick and Beninger, 2011
*360 Degrees of Influence.* Monarth, 2012
“7 Body Language Tricks to Make Anyone Like You.” Zhang, 2014
“Can You Make Yourself More Likeable?” Powlowski, 2017
2. Be Strong/Competent

Sarah Young, Aurora Water
2. Be Strong/Competent

Dr. Andrew Earles, Wright Water Engineers
2. Be Strong/Competent

- Clarity of expression, avoid vagueness
- Present tense, emotionally resonant language
- Avoid filler/weak phrases
- Speak with excitement
- Speak clearly, loudly
- Be confident in yourself
- Make yourself at home
- Stand straight and tall
- Limit fidgeting
- Stick to strengths
- Connection between behavior and character
- 2 minute Strength poses
- Halo effect

Compelling People. Kohut & Neffinger, 2014
“The Dynamics of Warmth and Competence Judgments.” Cuddy Glick and Beninger, 2011
360 Degrees of Influence. Monarth, 2012
“7 Body Language Tricks to Make Anyone Like You.” Zhang, 2014
3. Be Self-Aware

360 Degrees of Influence. Monarth, 2012
The Science of Influence. Hogan, 2011
“Can You Make Yourself More Likeable?” Powlowski, 2017
3. Be Self-Aware
3. Be Self-Aware

- Increase your self-reflection
- Listen
- Increase your situational awareness
4. Be Helpful & Valuable

Compelling People. Kohut & Neffinger, 2014
360 Degrees of Influence. Monarth, 2012
The Science of Influence. Hogan, 2011
"Can You Make Yourself More Likeable?" Powlowski, 2017
4. Be Helpful & Valuable
4. Be Helpful & Valuable

- Do favors
- Share advice
- Share connections
- Share information
5. Be Authentic

Compelling People. Kohut & Neffinger, 2014
360 Degrees of Influence. Monarth, 2012
“Can You Make Yourself More Likeable?” Powlowski, 2017
5. Be Authentic
5. Be Authentic
5. Be Authentic
5. Be Authentic

- Harness what is likeable about you
- Be aware of your strengths and mood
- Cultivate relationships that you want to make
- Engage in situations that you want to engage in
- You can conjure authentic comfort
- Align your interior and exterior
- It’s ok to be nervous or uncomfortable
- Be vulnerable and acknowledge your weaknesses
Cultivating Likeability

1. Be Warm
2. Be Strong/Competent
3. Be Self Aware
4. Be Helpful & Valuable
5. Be Authentic
The point is not to like everyone or have everyone like you.

It’s about genuine connections.

EMILY C. MURPHY, CPSM, MA
CALIBRE ENGINEERING, INC
303-730-0434
EMURPHY@CALIBRE-ENGINEERING.COM
Resources


EVERYTHING IS AWESOME!

When you’re Part of the Design-Build Team
Take-aways
- Generally a bad time for a presentation
- Attention span peaks when presenter alludes to impending happy hour
DESIGN BUILD IS...

- Project delivery method
- Single Point of Responsibility
PROS & CONS

Pros
- Faster Delivery
- Cost Savings
- Innovation

Cons
- Less Control
- Unfamiliar
- Less Competition
BEST PRACTICES

Partnering

Short List 3 Teams

Co-locate
PAST DESIGN-BUILD PROJECTS WITHIN DENVER

- Central Park BLVD over I-70
- Peoria
- US 6 @ I-25 with CDOT
- Emily Griffith Campus
PAST DESIGN-BUILD PROJECTS WITHIN DENVER

- Central Park BLVD over I-70
- Peoria
- US 6 @ I-25 with CDOT
- Emily Griffith Campus
PRELIMINARY DESIGN WORK

- Montclair & Park Hill drainage basin
- 100-yr design flow
PLATTE TO PARK HILL – PROJECT FRAMEWORK

- 3 Projects
- Two DB Teams
- Schedule
CITY PARK GOLF COURSE

Design Build Advantages:
- Time Frame
- Known Constraints
- Clear Objective

Project Challenges:
- Public and political Input
- Many stakeholders

Project Awarded to Saunders
CITY PARK GOLF COURSE
TECHNICAL REQUIREMENTS

- 100-yr Storm detention
  - 227 ac-ft
  - 8hr max detention time
  - No adverse effects to Golf in storm events
  - Integrated in Golf Course

- Urban Drainage Maintenance
- Eligibility
- Water Quality
- Trash Vaults
39TH AVE GREENWAY & PARK HILL

Design Build Advantages:

- Time Frame
- One point of contact for city
- Opportunity for innovation in design

Design Build Challenges:

- Public and political Input
- Lot of unknowns = risk
- Storm Water design build
39TH AVE & PARK HILL
TECHNICAL REQUIREMENTS

• Open Capture & Convey 100-yr stormwater runoff event
  • 3,600 cfs to Globeville Landing Outfall
• No adverse impacts to park/trail during the 5-yr and 10-yr storm event

• Urban Drainage maintenance Eligibility
• Water Quality Channel
• Trash Vaults
WHERE ARE WE IN THE PROCESS

- Three Short listed Bidders
  - Kiewit
  - Jacobs
  - Wenk
  - Enginuity
- Kraemer North America
  - AECOM
  - RNL
  - StudioCPG
  - Merrick
- SEMA
  - FHU
  - DHM Design
  - ICON Engineering

- Notice to Proceed Expected
  November 2017
QUESTIONS?

DBIA.org for more info
https://www.denvergov.org/content/denvergov/en/platte-to-park-hill.html
The Redevelopment of Original Aurora: Where Stormwater & Urban Planning Meet

Jon Villines, EIT, CFM – Aurora Water
Ben Murphy, PE – Calibre Engineering
CASFM Conference, Breckenridge, CO
Thursday, September 21, 2017
What is Original Aurora?

- Oldest part of Aurora, NW corner of City, Colfax, Montview, & Havana arterial spines
- Infill/redevelopment incentive area, major developments including:
  - Stanley Marketplace
  - Stapleton Aurora
  - Fitzsimons Medical Campus/VA Hospital
  - R-Line Light Rail Corridor
  - Colfax Arts District
  - 15+ other redevelopment projects in the works
Why Original Aurora?

• Proximity to Denver, Lowry, central Aurora, DIA, Fitzsimons, R-Line, Interstates, and more
• Affordable single family, multi-family, institutional, and commercial real estate
• Tax incentives and municipal redevelopment initiatives surrounding Stanley Marketplace
• General trend of urban infill redevelopment and movement of regional center eastward
Stormwater Management

- No WQ or detention existing
- Proximity to Westerly and Sand Creeks
- What do we require of redevelopment?
  - WQ treatment required per MS4
  - City code requires detention to pre-development flows, could waive (w/study) or regional pond
- UDFCD master plans cover part of area, gaps in H&H due to local storm sewer
Original Aurora SW Master Plan

• Detailed H&H of existing local storm sewer including 2D flow split modeling
• Analysis of how redevelopment will impact imperviousness, runoff, and water quality
• Alternatives analysis for on-site and sub-regional WQ BMPs, LID, etc.
• Identify options for regional detention and water quality
• Develop standards for allowable LID BMPs
How Does Original Aurora’s Approach Differ from Traditional Master Planning?

**Traditional Approach**

- Analyze H&H
- Identify Flooding, Current and Future
- Analyze Alternative Solutions
- Recommend Flood Hazard Projects

**Original Aurora Approach**

- Analyze Development Impact to H&H
- Identify “Exemption Projects”
- Evaluate Cost and Impact of Exemption Projects
- Recommend Exemption Projects
- Recommend Low Impact Development
Hydrology & Hydraulics

Traditional Street Grid
What is an Exemption Project?

• A project that allows potential redevelopments to move forward without the need to construct onsite WQ or Detention facilities.

• A project that creates offsite WQ or Detention facilities that offset the impacts created by the redevelopment parcels.

• Example Exemption Projects Include:
  – Sub-regional Water Quality and Detention Ponds
  – In-Street Water Quality and Detention Ponds
  – Low Impact Development Techniques
Rain Gardens
Rain Gardens
Permeable Pavements
Permeable Pavements
Green Alleys
Green Pedestrian Muse
Next Steps and Deliverables

• Work still underway on analyzing alternatives and exemption projects.
• 2D Modeling Across All of Original Aurora.
• We are currently in the middle of running our hydraulic analysis A project that allows potential redevelopments to move forward without the need to construct onsite WQ or Detention facilities.
• Original Aurora Master Study Report
• Development Guidelines for Original Aurora
  – Low Impact Development Requirements
Questions?

Jon Villines, EIT, CFM – Aurora Water
Ben Murphy, PE – Calibre Engineering
CASFM Conference, Breckenridge, CO
Thursday, September 21, 2017
DEVELOPING A STORMWATER CAPITAL PRIORITY MATRIX

J. DAVID VAN DELLEN, P.E.
CASTLE ROCK WATER
FACING THE CHALLENGE

Castle Rock, Douglas County
- South of Denver, outside Urdan Drainage District
- Current growth over 3,000 residents annually
- Approximately 65,000 population
- 900 Feet vertical elevation change within 33 sq. miles

Long-term Capital Plan
- 71 Miles of major drainageway and 43% complete
- $88 million remaining in stream stabilization
- 5-year capital plan budget of $12 million
**CAPITAL PRIORITY MATRIX**

**DEVELOPING AN APPROACH**

<table>
<thead>
<tr>
<th>Prioritization by Watershed</th>
<th>Pros – Efficient project administration</th>
<th>Cons – Nominal flexibility to address problem areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 19 major drainageways</td>
<td></td>
<td>– Potentially higher costs if over improved</td>
</tr>
<tr>
<td>- Average of 3.7 miles per drainage or $3.8 million</td>
<td></td>
<td>– High impact to natural system</td>
</tr>
<tr>
<td>- Complete less than half a drainageway per year</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prioritization by Reach</th>
<th>Pros – Addresses more problem areas consecutively</th>
<th>Cons – Promotes polarizing effect on system</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Average Reach Length 0.4 miles</td>
<td></td>
<td>– Still implementing full suite of improvements</td>
</tr>
<tr>
<td>- At $1.2 million per mile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Complete an average of 4 Reaches per year</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Prioritization by Feature</th>
<th>Pros – Targets specific problem areas as needed</th>
<th>Cons – Harder to administer</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 815 Features identified</td>
<td></td>
<td>– Maximum flexibility</td>
</tr>
<tr>
<td>- Average cost per Feature $108,600</td>
<td></td>
<td>– Higher mobilization costs long-term</td>
</tr>
<tr>
<td>- Complete an average of 18.5 Features per year</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**SELECTED APPROACH**

Formerly Adopted through Drainageway Master Plans
Priority 1 Improvements – Known existing risks; funded through existing customer base rates
Priority 2 Improvements – Anticipated risks due to development; funded through development impact fees
Priority 3 Improvements – Anticipated low risk; joint funded rates and fees

Priority by Feature, scheduled by Reach and Watershed
- All 815 Features receive a priority score.
- Capital projects cluster priorities over multi-reach spans for efficiency in design, permitting and construction

---

Example: Trail project drives need for adjacent stream stabilization. Funding only allows for Priority 1 Improvements to protect transportation and utility crossings and bank stabilization near trail. (Plan by Enginuity)
GOALS AND GUIDELINES OF PRIORITY MATRIX

- Defensible approach for selecting capital priorities
- Selection process based on risk and benefit
- Align with CRW Mission to balance fiscal, environmental and social responsibilities
- Consistent distribution of rate required revenue over time

- Framework for criteria selection based on seven Guiding Principles for Stormwater Enterprise
  - Protect life and Property; reduce hazardous conditions
  - Involve the public in decision making
  - Enhance Water Quality and mitigate impacts to waterways
  - Preserve flood storage capacity
  - Ensure effective long-term maintenance
  - Coordinate with other infrastructure needs in community
  - Balance revenue and expenses

- Feature scoring based on a point system

### Priority Matrix Scoring System

<table>
<thead>
<tr>
<th>Category</th>
<th>Score 1</th>
<th>Score 2</th>
<th>Score 3</th>
<th>Score 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous Conditions – Flow Rate</td>
<td>&lt; 1,000 CFS</td>
<td>1,000 – 2,000 CFS</td>
<td>2,000 – 6,000 CFS</td>
<td>&gt; 6,000 CFS</td>
</tr>
<tr>
<td>Hazardous Conditions – Proximity to Infrastructure</td>
<td>None</td>
<td>Adjacent</td>
<td>Within/Crossing</td>
<td>Both Adj. and Xing</td>
</tr>
<tr>
<td>Water Quality Impact – Slope Ratio</td>
<td>&lt; 1.5</td>
<td>1.5-2.0</td>
<td>2.0-2.5</td>
<td>&gt; 2.5</td>
</tr>
<tr>
<td>Water Quality Impact – Channel Velocity</td>
<td>&lt; 5 FPS</td>
<td>5-8 FPS</td>
<td>8-11 FPS</td>
<td>&gt; 11 FPS</td>
</tr>
<tr>
<td>Protecting Storage Capacity – Channel Geometry</td>
<td>&lt; 0.03</td>
<td>0.03-0.06</td>
<td>0.06-0.22</td>
<td>&gt; 0.22</td>
</tr>
<tr>
<td>Effective O&amp;M - % Watershed Build-out</td>
<td>&lt; 15%</td>
<td>15-30%</td>
<td>30-45%</td>
<td>&gt; 45%</td>
</tr>
<tr>
<td>Coordination of Infra. Needs – Project Year</td>
<td>Beyond 2031</td>
<td>2026-2030</td>
<td>2021-2025</td>
<td>2016-2020</td>
</tr>
<tr>
<td>Feature Score Subtotal*</td>
<td>7</td>
<td>14</td>
<td>21</td>
<td>28</td>
</tr>
</tbody>
</table>
PRINCIPLE 1 – PROTECT PEOPLE AND PROPERTY
BY REDUCING HAZARDOUS CONDITIONS

Hazardous Conditions measured by:

- Magnitude of Flooding using 100-year flow rate
  1 – 0 to 1,000 CFS
  2 – 1,000 to 2,000 CFS
  3 – 2,000 to 6,000 CFS
  4 – Greater than 6,000 CFS

- Proximity to Structures and Infrastructure
  1 - None
  2 - Adjacent
  3 - Crossing/Within
  4 - Both
PRINCIPLE 3 – PROTECT WATER QUALITY AND MITIGATE IMPACTS TO RECEIVING WATERS

Water Quality Impacts measured by a stream’s potential for erosion:

- Ratio between existing and stable slope
  1 – Less than 2.0
  2 – 2.0 to 3.0
  3 – 3.0 to 4.0
  4 – greater than 4.0

- Actual channel velocity relative to permissible velocity
  1 – Less than 5 FPS (Max permissible V for poor soils)
  2 – 5 to 8 FPS (Max permissible V for good soils)
  3 – 8 to 11 FPS (Above permissible velocity range)
  4 – Greater than 11 FPS (Far above permissible range)
PRINCIPLE 4 – PROTECT STORAGE CAPACITY IN FLOODPLAIN

Measure floodplain storage capacity based on channel geometry. UDFCD provides guidance on optimal terracing of a floodplain to promote storage capacity and minimize velocities:

- Channel geometry based on width to depth ratio (W/D)
  1 – Greater than 36
  2 – 16 to 36
  3 – 6 to 16
  4 – Less than 6

Scenario 1: Degraded, Incised Channel
W/D = 6

Scenario 2: Active Channel Filled to Reconnect Floodplain
W/D = 16

Scenario 3: Wider and shallower floodplain terrace
W/D = 36

Figure 8-10 Impact of channel geometry on velocity (USDCM Volume 1)
PRINCIPLE 5 – PROVIDE FOR EFFECTIVE
OPERATION AND MAINTENANCE

Maintenance burden on a system can be measured by the degree of upstream development which can cause excessive erosion and/or sedimentation. According to Center for Watershed Protection, threshold imperviousness of 10% associated with onset of stream ecology impacts.

-Percent watershed build-out
  1-Less than 15%
  2-15 to 30%
  3-30% to 45%
  4-Greater than 45%

<table>
<thead>
<tr>
<th>Effective Operation and Maintenance – Percent Watershed Build-Out</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower Limit</strong></td>
</tr>
<tr>
<td><strong>35% Imp. Watershed</strong></td>
</tr>
<tr>
<td>35%x15%= 5% Imp</td>
</tr>
<tr>
<td>35%x30%= 10% Imp</td>
</tr>
<tr>
<td>35%x45%= 15% Imp</td>
</tr>
<tr>
<td>&gt;15% Imp</td>
</tr>
<tr>
<td><strong>% Watershed Build-out</strong></td>
</tr>
<tr>
<td>Less than 15% Build-out</td>
</tr>
<tr>
<td>15-30% Build-out</td>
</tr>
<tr>
<td>30-45% Build-out</td>
</tr>
<tr>
<td>Greater than 45% Build-out</td>
</tr>
</tbody>
</table>
CAPITAL PRIORITY MATRIX

PRINCIPLE 6 – COORDINATE INFRASTRUCTURE NEEDS

Inter-department and inter-agency infrastructure needs scored based on project year for trails, utilities, roadways or private development:

- Stakeholder Project Year
  1 – Greater than 15 years
  2 – 10 to 15 years
  3 – 5 to 10 years
  4 – 0 to 5 years

Drop Structure installed to protect new trail underpass at railroad crossing
PRINCIPLE 2 – INVOLVE THE PUBLIC IN THE DECISION MAKING PROCESS

Drainageway Master Plans incorporated public input in the selection of Priority 1, 2 and 3 Improvements. Once a priority score is calculated based on the other six principles, a Priority factor is applied as follows:

- Priority Factor
  - Priority 1 Improvements PS = 1.5
  - Priority 2 Improvements PS = 1.0
  - Priority 3 Improvements PS = 0.8

This ensures existing risks identified from field reconnaissance or public input take precedence with or without growth in the community.

Failing drop structure reported by resident
PRINCIPLE 7 – OPERATE AS A BUSINESS
BALANCING REVENUES AND EXPENSES

- Budgets are set based on community tolerance including customer rates and development impact fees.
- Rates and Fees are calculated annually based on capital plans and adopted by council.
- Debt services are allowable as needed.
- Capital plans are identified based on statistical ranking.
- Priority matrix is adaptable based on available budget and need.

Example: East Plum Creek
90th Percentile Improvements; $1.5 million (5-year CIP)
80th Percentile Improvements; $1.4 million (6-10 year CIP)
SUMMARY AND CONCLUSION

- Priority scoring by feature provides for the most flexibility in planning
- Priority scoring system balances fiscal, environmental and social responsibilities
- Projects should consider prioritized improvements spanning multiple stream reaches to consolidate design, permitting and construction
- A priority matrix should be reviewed and updated regularly to keep in step with development, economic factors and community vision
“Do you know your outfall.. from a hole in the ground?”

A presentation by:

Paul Thomas
Jesse Clark
Chris Kroeger
Why should we be concerned about drainage infrastructure design?

We have made lots of progress:

• Drop Structures
• Streams/waterways
• Water quality facilities
Introduction

Contextual impacts of common elements are often not considered

- Inlets
- Culvert outlets
- Run-downs
- Trickle channels
The quality of our built environment matters! Poorly implemented infrastructure can contribute to a sense of sterility—or blight.
Who cares? (More people than you think.)

- The younger and Millennial generations appreciate, and are drawn to quality...
  ...and they are voting with their feet!

  Cities with a perceived high quality of urban life are thriving.

- A poorly conceived infrastructure project can actually turn into a long-term liability for urban growth.
There is a “new” paradigm for how we build our cities (that’s actually really old!)

- Investment to create high quality, livable communities
- Aesthetics, experience, and environment all matter
- No more “throw-away” solutions.

We should be focused on infrastructure that we are proud of, that lasts, and that inspires future generations.
HAVE WE LOST THE IDEA THAT DRAINAGE INFRASTRUCTURE SHOULD BE BEAUTIFUL AND DURABLE – MULTIFUNCTIONAL AND COMMUNITY DRIVEN?
“Better” infrastructure

- Sound Engineering
- Addresses Safety
- Enhances Environmental
- Employs New Technology
- Better Construction Methods
- Provides “Added” Value?
“Better” infrastructure

- Sound Engineering
- Addresses Safety
- Enhances Environmental
- Employs New Technology
- Better Construction Methods
- Provides **ESSENTIAL** Value
Multi-functionality - beyond just drainage

- Water quality
- Habitat
- Education
- Recreation
Providing ESSENTIAL Value Means

Multi-functionality - beyond just drainage

- Water quality
- Habitat
- Education
- Recreation
Multi-functionality - beyond just drainage

• Water quality
• Habitat
• Education
• Recreation
Providing ESSENTIAL Value Means

Multi-functionality - beyond just drainage
• Water quality
• Habitat
• Education
• Recreation
Providing ESSENTIAL Value Means

Multi-functionality - beyond just drainage

• Water quality
• Habitat
• Education
• Recreation

• Place-making
Questions to ask for place-making

- Will anyone **see it**?
- (How) could people "**experience**" it? (i.e. touch it, sit by it, kids, etc.)
- What is/will be its **context**?
- Could it **inspire or teach** something?
- How will it be **maintained**?
Case Studies

Bayaud Park

Sloan's Lake Marina

River North Outfall

City Center Park

Lowry Outfall
Case Studies

Bayaud Park Drainage Inlets

Lowry Southwest Neighborhood
Case Studies

Bayaud Park Drainage Inlets

Minimizing impact of large culvert inlet in park
Case Studies

Bayaud Park Drainage Inlets

Designing drainage inlet that provides seating

CASFM ANNUAL CONFERENCE 2017
Case Studies

Sloan’s Lake Marina Water Quality Outfall

WQ Forebay Garden

CASFM ANNUAL CONFERENCE 2017
Case Studies

Sloan’s Lake Marin Water Quality Outfall

Sculptural and interactive outlet “forebay” after construction
Case Studies

Sloan’s Lake Water Quality Outfall

After establishment

CASFM ANNUAL CONFERENCE 2017
Sloan’s Lake Water Quality Outfall

Providing an “interactive storm water experience” for park visitors
Case Studies

Lowry Town Center Outfall at Great Lawn Park
Lowry Town Center Outfall at Great Lawn Park

Outfall location in visually sensitive area
Lowry Town Center Outfall at Great Lawn Park

...and iconic setting
Lowry Town Center Outfall at Great Lawn Park

...while discharging efficiently.

CASFM ANNUAL CONFERENCE 2017
Case Studies

Lowry Town Center Outfall at Great Lawn Park

Outfall designed as interactive crossing feature
Case Studies

Lowry Town Center Outfall at Great Lawn Park
Aurora City Center Park Outfall and Pond
Case Studies

Aurora City Center Park Outfall and Pond

Undersized storm drainage
Case Studies

Aurora City Center Park Outfall and Pond

Another, bigger pipe... That outfalls into the park
Aurora City Center Park Outfall and Pond

Another, bigger pipe...
That outfalls into the park
Case Studies

Aurora City Center Park Outfall and Pond

• Simple ideas. Simple solutions.
Case Studies

Aurora City Center Park Outfall and Pond

Simple ideas. Simple solutions.
Case Studies

Aurora City Center Park Outfall and Pond
Case Studies

River North Storm Outfall
Case Studies

River North Storm Outfall

The Outfall Site
The "traditional" approach

River North Storm Outfall
Case Studies

River North Storm Outfall

The Future of “Ri-No”
Case Studies

River North Storm Outfall

Enhance Context?
We imagined a place... that did “the work”...
Case Studies

River North Storm Outfall

...provides an experience - and sets an example...
Case Studies

River North Storm Outfall

...and that uses “urban drool” to enhance the feature.
Case Studies

River North Storm Outfall

…and that uses “urban drool” to enhance the feature.
Case Studies

River North Storm Outfall
Case Studies

River North Storm Outfall
An Engineer's Perspective

Everything is Harmonious and Fantastic!
Stereotypical mindset of an engineer:

- Like to manage risk
- Struggle to find comfort in the unknown
- Not many of us know how to think in terms of possibility
What’s the risk of a stereotypical engineering mindset?

3 major project fronts

• Consultant
• Owner
• Review process

Normal project challenges → barriers
An Engineer’s Perspective

How can engineers support getting to the fantastic land of harmony and innovation?
An Engineer’s Perspective

What can we (engineers) do?

• Recognize barriers, don’t be constrained by them
• Collaboration
• Provide time for the Vision Process
• Consider non-traditional design and construction delivery methods

• UDFCD project partners
• Design-build
• Construction Management/General Contractor (CM/GC)
What it takes to create superior infrastructure

THE 3 C’S

• Creativity
  • Vision – understand opportunities and fulfill a vision
  • The right people – client, consultants, reviewers
Conclusion

What it takes to create superior infrastructure

THE 3 C’S

• Creativity
  • Vision – understand opportunities and fulfill a vision
  • The right people – client, consultants, reviewers

• Courage
  • Try new things
  • Challenge status quo
  • Accept some risk
What it takes to create superior infrastructure

THE 3 C’S

• Creativity
  • Vision – understand opportunities and fulfill a vision
  • The right people – client, consultants, reviewers

• Courage
  • Try new things
  • Challenge status quo
  • Accept some risk

• Commitment
  • Potentially higher cost = higher value
  • Exceptional design takes time
  • Let it “live” - and be willing to adapt / adjust
Conclusion

What it takes to create superior infrastructure

THE 3 C’S

• **Creativity**
  • Vision – understand opportunities and fulfill a vision
  • The right people – client, consultants, reviewers

• **Courage**
  • Try new things
  • Challenge status quo
  • Accept some risk

• **Commitment**
  • Potentially higher cost = higher value
  • Exceptional design takes time
  • Let it “live” - and be willing to adapt / adjust
Enhances the context

Works towards a vision

Improves quality of life

Supports economic development

Celebrates engineering

Sustainable and durable

Generates community pride
Putting “One Water” into Stormwater Education

Donny Roush
Darren Mollendor

2017 Annual Conference, Colorado Association of Stormwater and Floodplain Managers
One Water means...

- ...an integrated planning and implementation approach to managing finite water resources for long-term resilience and reliability, meeting both community and ecosystem needs. (Water Research Foundation, 2017)

- Rocky Mountain Water (July 2017)
One Water means...

- One World One Water sculpture (2012)
- One Well: The Story of Water on Earth (2007)
Denver’s stormwater education & outreach

- Stormwater permits (MS4s) require public outreach and education
- Convergence in 2012 of Urban Waters Federal Partnership, Denver 2020 Sustainability Plan, and Next Generation Science Standards
- STEM education helps accomplish municipal objectives
- Keep It Clean – Neighborhood Environmental Trios
What is a kick net?
What is KIC – NET?

Keep It Clean – Neighborhood Environmental Trios
KIC-NET in Denver & Albuquerque

CO: 29 schools (including 4 in Lakewood), 131 educators, ~2,000 students, 88% FRL, 92% children of color

NM: 10 schools, 26 educators, 754 students, 78% FRL, 91% children of color
What are the outputs?

• Toolkit creation
  • 152-page activity guide with 30+ place-based lessons (2nd Edition, CO + NM versions)
  • Correlations to Next Generation Science Standards, Common Core State Standards, and Guidelines for Excellence in Environmental Education
  • stream monitoring equipment and references

• Instructional partnership: Professional Development, Lesson-planning, Co-facilitation, & Culminating Activities

• Evaluation
  • quantitative: pre-test/post-test participant surveys (n = 213 for 2014; 58 for 2016)
  • qualitative: interviews using Most Significant Change Technique (n = 9 for 2014; 11 for 2016)
What are the outcomes?

- 65% of pre/post survey items showed statistically significant gains in watershed stewardship attributes
- Qualitative themes: “increased academic engagement/achievement,” “sense of empowerment” & “conservation behaviors”
- 84 student-led environmental action projects, such as...
From 2017, so far...
One Water as a teachable concept

South Platte River Expedition

- 6 years of support to Expeditionary Learning Schools doing year-long study of Denver’s river – continues at Odyssey
- Expanded and rewritten by Expeditionary Learning Education for 3rd grade as “The Role of Freshwater around the World”
- Adopted by DPS as district-level 3rd grade module
- In use for 3rd grade at Centennial, Samuels, and Tollgate
- Uses One Well as the unit’s anchor text
One Water as a teachable concept

Learning targets

• I can explain the importance and role of components of Denver’s water system(s), such as the South Platte River, Roberts Tunnel, Antero Reservoir, Cheesman Dam, and small scale green infrastructure facilities.

• I can integrate resources from Denver Water and Denver Public Works into my lessons in 2017-18.
Thanks for & to...

STEMWORKS Certified

CAEE
Best New Program Award 2014

NACo 2016 Achievement Award Winner

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lakewood

SHOEMAKER

DENVER PARKS & RECREATION

DENVER ENVIRONMENTAL HEALTH

EARTH FORCE

U.S. FISH & WILDLIFE SERVICE

NATIONAL WILDLIFE REFUGE SYSTEM

CITY OF ALBUQUERQUE

FRIENDS OF VALLE DE ORO

National Wildlife Refuge

DENVER PUBLIC WORKS
WOODBRIAR PARK
Catalyst for the Transformation of Integrated Stormwater Management & Community Recreation
1. PROJECT INTRODUCTION

2. FOUR CATALYSTS FOR TRANSFORMATION
   • COLLABORATION
   • EDUCATION
   • INSPIRATION
   • INNOVATION

3. PROCUREMENT

4. QUESTIONS?
Woodbriar Park: Catalyst for the Transformation of Integrated Stormwater Management & Community Recreation

2017 Annual CASFM Conference

REGIONAL CONTEXT
Woodbriar Basin Area

- Basin is approximately 2,416 acres
- Basin consists of medium to low density single and multi-family housing
- Large, still developing commercial area at the southern end of the basin
- Flows from south of the park area currently collect in the northeast corner of the park
EXISTING CONDITIONS
NEIGHBORHOOD FLOODING

Woodbriar Park: Catalyst for the Transformation of Integrated Stormwater Management & Community Recreation

2017 Annual CASFM Conference
1. **Reduce frequency and severity of neighborhood flooding**
2. **Enhance community recreation opportunities**
3. **Incorporate native plant material**
4. **Reduce water consumption for irrigation**
5. **Preserve & protect mature trees**
6. **Maintain views into and around the park**
1. PROJECT INTRODUCTION

2. FOUR CATALYSTS FOR TRANSFORMATION
   - COLLABORATION
   - EDUCATION
   - INSPIRATION
   - INNOVATION

3. PROCUREMENT

4. QUESTIONS?
Woodbriar Park: Catalyst for the Transformation of Integrated Stormwater Management & Community Recreation

2017 Annual CASFM Conference

COMMUNITY OUTREACH STRATEGIES

COLLABORATION

DINOSAUR BREEDING FACILITY COMING TO YOUR NEIGHBORHOOD

W O O D B R I A R P A R K

RENOWNATION

OH. THAT'S NOT WHAT YOU WANT IN YOUR NEIGHBORHOOD PARK? TELL US WHAT YOU DO WANT. COME TO OUR OPEN HOUSE.

APRIL 27TH BETWEEN 4-7 PM PICNIC SHELTER AT WOODBRIAR PARK EVERYONE IS INVITED!

Take the survey. You could win a prize!

Complete the park survey: greeleygov.com/Woodbriar
1. **PROJECT INTRODUCTION**

2. **FOUR CATALYSTS FOR TRANSFORMATION**
   - **COLLABORATION**
   - **EDUCATION**
   - **INSPIRATION**
   - **INNOVATION**

3. **PROCUREMENT**

4. **QUESTIONS?**
**Parks & Open Lands Master Plan**

**Community Awareness**

**Education**

**Park Enhancements**

While new parks will be an important focus during the next 10 years, it is also essential to continue to implement standards in maintaining and updating Greeley’s existing parks. Community feedback indicated that the Parks Division does a good job maintaining parks and that there is a willingness of park staff to listen to and respond to resident concerns as they arise. When public meeting participants were asked what the focus of future investment should be, maintaining and improving existing parks was the second highest priority with support from almost 40% of participants. Some of the more specific improvements people support include:

- Increasing the amount of natural areas, plants and trees within parks and along streets
- Adding more amenities and variety of recreation opportunities
- Serving those with special needs or disabilities
- Providing for a diverse combination of activities to serve all age groups

*Figure 12: Priorities for Existing Parks*

<table>
<thead>
<tr>
<th>What do you think should be a priority to address in Greeley’s existing parks? (Keypad Polling Session #1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve bike and pedestrian connections to parks</td>
</tr>
<tr>
<td>Expand the amount of natural areas, plants, and trees within parks</td>
</tr>
<tr>
<td>Add more amenities and variety of recreation opportunities</td>
</tr>
<tr>
<td>Replace aged equipment or facilities</td>
</tr>
<tr>
<td>Enforce park rules</td>
</tr>
<tr>
<td>Add more parking spaces</td>
</tr>
<tr>
<td>Provide space for programmed events and activities</td>
</tr>
<tr>
<td>Other</td>
</tr>
<tr>
<td>Improve maintenance</td>
</tr>
<tr>
<td>Parks are fine as they are</td>
</tr>
</tbody>
</table>

**Did you know Woodbriar Park consumed 3,530,000 gallons of water for irrigation in 2016?**

That's enough water to provide 107 households with water for 1 year!!

...or you could fill 5 Olympic-sized swimming pools!!!

OR it would be like leaving your faucet running for 13.4 years!!
**Groundcovers**

**Education**

- **Native/Xeric Grasses**
  - Fine Fescue (Mowed and Unmowed)
  - Blue Grama (Unmowed)

- **Turf Grasses**
  - Kentucky Bluegrass (Irrigated and Mowed)
  - Wheatgrass (Mowed and Unmowed)
  - Naturalized Grass Mix (3 Mow Heights)
  - Naturalized Grass Mix (Unmowed)
  - Mixed Prairie Grasses (Unmowed)
1. **PROJECT INTRODUCTION**

2. **FOUR CATALYSTS FOR TRANSFORMATION**
   - COLLABORATION
   - EDUCATION
   - INSPIRATION
   - INNOVATION

3. **PROCUREMENT**

4. **QUESTIONS?**
ON-SITE “COMMUNITY PREFERENCE” OPEN HOUSE
Community Preference - Play

Woodbriar Park: Catalyst for the Transformation of Integrated Stormwater Management & Community Recreation
2017 Annual CASFM Conference
INSPIRATION

COMMUNITY PREFERENCE - ARTS & EDUCATION

Woodbriar Park: Catalyst for the Transformation of Integrated Stormwater Management & Community Recreation

2017 Annual CASFM Conference
COMMUNITY PREFERENCE - CHARACTER

IMAGES OF INSPIRATION
(VERY) INITIAL PROPOSAL CONCEPTS

CRAZY IDEA #1: “ADAPTIVE REUSE(S)”

CRAZY IDEA #2: “THE ACTIVATED BATH TUB”

EXISTING CONDITION
COMMUNITY PREFERENCE SUMMARY

<table>
<thead>
<tr>
<th>KEY POINTS</th>
<th>OPTION 1</th>
<th>OPTION 2</th>
<th>OPTION 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Relocates shelter and play area to northwest corner of park and within existing trees.</td>
<td>• Relocates shelter and play area to north edge of park, closest to 18th St., and within existing trees.</td>
<td>• Relocates shelter to west side of park and play area to northwest corner of park.</td>
<td></td>
</tr>
<tr>
<td>• Extends Cottonwood Creek furthest west into the park.</td>
<td>• Minimizes extension of Cottonwood Creek into the park.</td>
<td>• Minimizes extension of Cottonwood Creek into the park.</td>
<td></td>
</tr>
<tr>
<td>• Creates terraced lawns between play area and practice field.</td>
<td>• Creates terraced lawns between play area and practice field.</td>
<td>• Maximizes practice field area within detention pond.</td>
<td></td>
</tr>
<tr>
<td>• Provides a small amphitheater near the play area.</td>
<td>• Provides densely-vegetated riparian corridor along creek.</td>
<td>• Creates terraced lawns between shelter and practice field.</td>
<td></td>
</tr>
<tr>
<td>• Spreads detention area furthest across park.</td>
<td>• Concentrates detention area in center of park</td>
<td>• Provides flat, passive use area near creek.</td>
<td></td>
</tr>
<tr>
<td>• Approx. 29 potential tree removals</td>
<td>• Approx. 26 potential tree removals</td>
<td>• Approx. 31 potential tree removals</td>
<td></td>
</tr>
</tbody>
</table>
1. PROJECT INTRODUCTION

2. FOUR CATALYSTS FOR TRANSFORMATION
   • COLLABORATION
   • EDUCATION
   • INSPIRATION
   • INNOVATION

3. PROCUREMENT

4. QUESTIONS?
Woodbriar Park: Catalyst for the Transformation of Integrated Stormwater Management & Community Recreation

2017 Annual CASFM Conference

PUBLIC ART
Woodbriar Park: Catalyst for the Transformation of Integrated Stormwater Management & Community Recreation

2017 Annual CASFM Conference
1. PROJECT INTRODUCTION

2. FOUR CATALYSTS FOR TRANSFORMATION
   • COLLABORATION
   • EDUCATION
   • INSPIRATION
   • INNOVATION

3. PROCUREMENT

4. QUESTIONS?
CONTRACTOR SELECTION UPDATE

- We had nine contractors submit qualifications packages
- Six contractors were deemed qualified to propose
- Proposals will include approach, schedule and ball-park pricing
- Plan to have a contractor on the team by the end of October
QUESTIONS? ....
Outline

• Provide a brief overview
• Review methodology and key findings
• Present general recommendations
• Discuss monitoring parameters and the ‘learning by doing’ process
• Questions, discussion
Outline

• **Provide a brief overview**
• Review methodology and key findings
• Present general recommendations
• Discuss monitoring parameters and the ‘learning by doing’ process
• Questions, discussion
Timeline

• Phase 1: Assess existing information, develop approach

Phase 2: Implementation (field work, analysis, documentation)

Phase 3a: Additional field work, channel assessments

Phase 3b: Prioritize reaches based on existing conditions, Assess potential future conditions, and develop restorative concepts

Monitoring: Spawning habitat, channel flow and flushing responses

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 3a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase 3b</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Stream Management Plan

Identify target flows that will benefit and protect stream health, recreation and other water user needs while maintaining water supply requirements. Identify reaches that would benefit from flow enhancements, coordinated water operations and physical restoration.
Study Reach

- 80 River miles including:
  - Colorado River
    - Willow Creek
    - Williams Fork
    - Blue River
    - Muddy Creek
  - Fraser River
    - Jim Creek
    - Vasquez Creek
    - Ranch Creek
    - St. Louis Creek
Scope of Work

1. Develop and recommend environmental flow regimes (self sustaining fish populations)
2. Address flow requirements for local water users
3. Integrate environmental flow regimes and water user needs for final flow recommendations
4. Assess future flow regimes and compare to the recommended flows
5. Identify potential restoration opportunities utilizing both flow-management techniques and physical-based approaches
Outline

• Provide a brief overview
• **Review methodology and key findings**
• Present general recommendations
• Discuss monitoring parameters and the ‘learning by doing’ process
• Questions, discussion
Stream Health: Indicators

- Environmental flows for support of fish species and life stages
  - Stream temperatures
  - Water quality
  - Habitat health
  - Riparian health and stability
Surface Water Temperature

• Reviewed existing available data
• Chronic temps based on State standards $17^\circ C$ (Tier I), and $18.2^\circ C$ (Tier II), 7 day rolling average ($MWAT$)
• Daily Maximum $21.2^\circ C$ and $23.8^\circ C$ for Tier I and II respectively ($DM$)
Colorado River Water Temperatures, 7-day rolling average
Summer 2007

Date
7/1
7/11
7/21
7/31
8/10
8/20
8/30
9/9
9/19
9/29
10/9

Temp (deg C)
25
20
15
10
5
0

Above Windy Gap
Below Windy Gap
Chimney Rock
Hot Sulpher Springs
Lone Buck
CR3
Parshall
Kids Pond
KB Ditch
Kremmling
18.2 MWAT
**Surface Water Temperature**

- **Key Findings**: most segments are within State standards most of the time with the general exception of July and August when:
  - Colorado River from Windy Gap to Williams Fork exceed state stds for the MWAT
  - Ranch Creek daily temperatures frequently exceed the state stds for the DM
Surface Water Temperature,

• Recommendations
  – Expand continuous monitoring, combine with air and flow measurements at same location
  – Where possible, release flows from reservoirs to address high water temperatures
  – Investigate segments that may benefit from restoration such as reconstruction of low flow channel, installation of pools, increase cover.
Water Quality of Streams

- Parameters
  - Dissolved Oxygen
  - pH (F6/F7) (may be related to algae)
  - Turbidity
  - Nitrates
  - Phosphorus
  - Ammonia
  - Manganese
  - Iron
  - Copper (F6-F10 on 303(d) list for monitoring and evaluation)
  - Hardness
- Algae (filamentous, didymo)
Water Quality of Streams

- Generally found most samples taken after mid 1990’s (following WWTP upgrades) within standards except:
  - pH and Copper-upper Fraser
  - Union Pacific Moffat Tunnel discharge
  - Algae (filamentous, didymo) (observed)
Water Quality of Streams

- Recommendation
  - Continue to monitor sites
    - Monitor sites with high pH and Copper
    - Monitor Union Pacific Moffat Tunnel discharge
    - Algae (filamentous, didymo): address with flow and temperature recommendations
Habitat Health

Aquatic Habitat
   – Species- browns, rainbows, brooks
   – Life stages- adult, juvenile, spawning/incubation

• Winter survival
• Develop target flow recommendations for summer (April-September) and winter (October-March)
• Flushing flows-spawning gravel mobilization
• Flows to mobilize riffle material
METHODS TO ASSESS HABITAT HEALTH

- Foot, float & fly surveys
- Detailed instream flow surveys
- Habitat assessments
- Channel stability evaluation
- Riffle stability evaluations
- Spawning surveys and core sampling
- Barrier surveys
PHABSIM and IHA

Physical HABitat SIMulation

FISRWG 1998
Example of Phabsim Output
Reaches with PHABSIM Sites

• Fraser River and tribs
  – Mainstem Fraser River
    • F3, F6 and F9
  – Ranch Creek
    • Upper and Lower
  – St Louis Creek
  – Vasquez Creek

• Colorado River and tribs
  – Mainstem Colorado River
    • CR3, CR4, CR 5, CR6, CR7
  – Williams Fork
  – Muddy Creek
  – Blue River (4 sites)
  – Willow Creek
Colorado River Below Windy Gap-CR4

- Environmental Flows
  - Target Flow Range for winter and summer
  - Minimum flushing flow for fine sediments

Available?
Hydrographs from Existing Gage Data
Colorado River at HSS USGS 9034250
Flows Equal or Exceeded, Water Years 1986-

Min winter flow recommendations
Min summer flow recommendations
Key Findings-Aquatic Habitat (relative to existing conditions)

- Adult trout habitat in short supply in comparison to juvenile.
- **Trout spawning is occurring system-wide.**
- Late summer flows typically lower than target ranges on most reaches, especially portions of Fraser, Ranch Creek, Colorado River below Granby Reservoir, Colorado River below Windy Gap.
- **Flows below Williams Fork & Green Mountain dams generally meet or exceed target ranges but rapid flow changes problematic.**
Key Findings-Aquatic Habitat (relative to existing conditions)

- Localized fine sediment issues system-wide, but most severe in upper Fraser, Muddy Creek and CR4.
- Flushig flows too infrequent on some reaches (CR below Granby, CR below Windy Gap; Upper Fraser, Ranch Ck)
- Winter flows are low and infrequently meet target ranges, but not necessarily due to diversions.
- Fish passage hampered by variety of control structures throughout system.
Outline

- Provide a brief overview
- Review methodology and key findings
- Present general recommendations
- Discuss monitoring parameters and the ‘learning by doing’ process
- Questions, discussion
Focus for Recommendations

- Flows and flow regime for support of stream health and aquatic habitat,
- Conditions for local water users including diverters and recreational uses,
- Water temperatures,
- Excessive sediment deposition, and
- Presence of algae.

- Flow enhancements
- Physical restoration
Enhancement Proposal

Enhancements to improve existing conditions (voluntary measures)
1. Stream flow/water supply management-potentially adds water to streams
2. Water quality: contribute funds to waste water facilities
3. Contribute to stream restoration
4. Cooperative measures (operations)

Enhancements are voluntary. If successful, the enhancements should provide habitat benefits and improve existing conditions
Volume Needed to Meet Target Flows
In August and September

Stream flow/water supply
Time Series Analysis

Instream physical habitat at a given time and place calculated as a function of streamflow.
Example 1
Apply all available water to enhance flows in August and September

**GRANBY RESERVOIR**

BASE FLOWS PLUS
+ 80 cfs

+ 8 cfs
88 cfs

CR3

Fraser River
+1000 ac.ft

CR4

Williams Fork
+1000 ac.ft

CR5

KB Ditch

CR6

KREMMLING

**BASE FLOWS**

+ 5412 ac-ft 10825 Water
+ 2000 ac-ft MP Firm
+ 700 ac-ft MP Pump
+ 1500 ac-ft County Pump

9612 ac-ft Total
Physical Restoration—general list

• Channel restoration (reduce excessively wide channels; increase depth)
• Increase aquatic structure—provide refuge for fisheries under stressful flow conditions
• Enhance fish passage around man-made barriers
• Improve connectivity of river and spawning areas
• Implement BMPs/reduce sediment
• Consider ramping guidelines for flow releases out of reservoirs

(See SMP)
Specific Recommendations (below Windy Gap)

1. Apply enhancement flows
   - Option 1: augment late summer low flows
   - Option 2: increase flushing flows

2. Consider by-passing Windy Gap (Connectivity Channel)
   - Reduce petri-dish effect of reservoir
   - Enhance fish passage
   - Improve sediment transport

3. Construct in-stream habitat features
   - Provide cover and pools
   - Narrow channel

4. Inspect and replace headgates
   - Reduces in-stream disturbances to create push-up dams
   - Enhance fish passage
<table>
<thead>
<tr>
<th>Reach ID</th>
<th>Reach Description</th>
<th>Restoration Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>CR4</td>
<td>Colorado River Windy Gap to Williams Fork</td>
<td>Highly impacted reach; recommendations include both enhancements and physical restoration</td>
</tr>
<tr>
<td>F2</td>
<td>Fraser River DW Diversion to WPWSC intake</td>
<td>Flow enhancements, sediment basin and passage of spawning gravels recommended for this reach</td>
</tr>
<tr>
<td>CR3</td>
<td>Colorado River Granby Reservoir to Windy Gap</td>
<td>Previous and ongoing restoration is extensive. Additional study is recommended. Flow enhancements for CR4 will improve CR3</td>
</tr>
<tr>
<td>F-RC2</td>
<td>Fraser River Trib Ranch Creek ds of gage to confluence</td>
<td>F-RC2 benefits from flow enhancements recommended for F-RC1</td>
</tr>
<tr>
<td>F-RC1</td>
<td>Fraser River Trib Ranch Creek to ds of gage</td>
<td>Investigate culvert capacities downstream to accommodate increased flushing flows</td>
</tr>
<tr>
<td>F3</td>
<td>Fraser River WPWSC intake to Town of WP</td>
<td>Recommendations in F2 will provide benefits in F3</td>
</tr>
<tr>
<td>MC2</td>
<td>Muddy Creek Woford to Colorado River</td>
<td>Allow stream to stabilize before developing restoration recommendations</td>
</tr>
<tr>
<td>F4</td>
<td>Fraser River Town of WP to Town of Fraser</td>
<td>Recommendations in F2 will provide benefits in F4</td>
</tr>
<tr>
<td>CR1</td>
<td>Colorado River North Fork to Shadow Mountain</td>
<td>Additional study required in conjunction with Red Top diversion changes</td>
</tr>
<tr>
<td>CR5</td>
<td>Colorado River Williams Fork to KB Ditch</td>
<td>Recommend additional study to address grade control structures</td>
</tr>
<tr>
<td>CR6</td>
<td>Colorado River KB Ditch to Blue River Confluence</td>
<td>CRS5 benefits from flow enhancements in CR4</td>
</tr>
<tr>
<td>F6</td>
<td>Fraser River Fraser CWWTP to Ranch Creek</td>
<td>Partner on existing projects</td>
</tr>
<tr>
<td>F7</td>
<td>Fraser River Ranch Creek to mouth of Canyon</td>
<td>Consider public access and trail enhancements</td>
</tr>
<tr>
<td>F8</td>
<td>Fraser River Canyon</td>
<td>Consider public access</td>
</tr>
<tr>
<td>F9</td>
<td>Fraser River Canyon to Granby</td>
<td>Partner on existing projects</td>
</tr>
<tr>
<td>BR</td>
<td>Blue River Green Mountain to Colorado River</td>
<td>Develop ramping and flow management strategies to support spawning</td>
</tr>
<tr>
<td>CR7</td>
<td>Colorado River Blue River to County line</td>
<td>Maintain target flows and support recommendations from Wild and Scenic alternative</td>
</tr>
<tr>
<td>F5</td>
<td>Fraser River Town of Fraser to Fraser CWWTP</td>
<td></td>
</tr>
<tr>
<td>F10</td>
<td>Fraser River Granby to Colorado River at Windy Gap</td>
<td></td>
</tr>
<tr>
<td>F-SL</td>
<td>Fraser River Trib St. Louis Creek</td>
<td>Support efforts to restore native cutthroat populations</td>
</tr>
<tr>
<td>F1</td>
<td>Fraser River J540 to DW Diversion</td>
<td>Monitor for and address low DO levels</td>
</tr>
<tr>
<td>WR</td>
<td>Williams Fork Below reservoir to Colorado River</td>
<td></td>
</tr>
<tr>
<td>F-VC</td>
<td>Fraser River Trib Vasquez Creek</td>
<td></td>
</tr>
<tr>
<td>F-JC</td>
<td>Fraser River Trib Jim Creek</td>
<td>No recommendations made at this time</td>
</tr>
<tr>
<td>WC</td>
<td>Willow Creek Reservoir to Colorado River</td>
<td>No recommendations made at this time</td>
</tr>
<tr>
<td>ME</td>
<td>Muddy Creek Inflow to Woford</td>
<td>No recommendations made at this time</td>
</tr>
<tr>
<td>F-TC</td>
<td>Fraser River Trib Tenmile Creek</td>
<td>No recommendations made at this time</td>
</tr>
<tr>
<td>CR2</td>
<td>Colorado River Shadow Mountain to Granby Reservoirs</td>
<td>No recommendations made at this time</td>
</tr>
<tr>
<td>TG</td>
<td>Colorado River Hwy 40 to confluence</td>
<td>No recommendations made at this time</td>
</tr>
<tr>
<td>RE</td>
<td>Colorado Trib City Rd 33 to confluence</td>
<td>No recommendations made at this time</td>
</tr>
</tbody>
</table>
Report
Grand County website (water resources management)
Stream Management Plan

• Executive Summary
  – Objectives and Key Findings
  – Restoration Overview
  – Learning by Doing

• Reaches Summaries
  – Reach Description
  – Flow Recommendations
  – Study Results
  – Restoration Opportunities

• Appendices
  – Methods
  – Review of Temperature Data
  – Review of Water Quality Data
  – Water Users and Recreation
  – Survey Data
  – Restoration Measures
Monitoring Parameters-SMP

- Stream flows
- Intergravel fine sediment concentrations
- Fish population and diversity
- Benthic macro invertebrates
- Riffle (RSI) and channel conditions
- Sediment below detention basin

Reporting now includes all above parameters
‘Learning by doing’ includes the monitoring, evaluation and adjustment of restoration and flow enhancements for the purpose of meeting pre-established goals.

1. Monitoring - requires long-term commitment to data collection and tracking
2. Evaluation - requires clearly defined goals, standards and techniques
3. Adjustment - required if goals and standards are not being met
Learning by doing

The Learning By Doing Cooperative Effort (LBD)

- strives to maintain, restore or enhance the aquatic environment in Grand County
- partnership comprised of East and West Slope water stakeholders
- includes a Management Committee and a Technical Advisory committee
Questions, discussion
North Douglas Creek Restoration and Post-Fire Mitigation

Presented by:

Adam Copper, P.E., City of Colorado Springs
Thomas Donahue, E.I., Matrix Design Group, Inc.
Jason Messamer, P.E., Matrix Design Group, Inc.
Presentation Overview

1. 2012 Waldo Canyon Fire
2. Emergency Response & WARSSS Study
3. Matrix Phase 1
4. Matrix Phase 2
5. City Emergency Measures
6. Matrix Phase 3
2012 Waldo Canyon Fire

Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3
Douglas/Camp Ridge
2012 Waldo Canyon Fire
Burn Scar
Watershed Impacts

Legend
- Camp Creek
- Douglas Creek
- Fountain Creek
- Monument Creek
- Burn Perimeter

Matrix Design Group
AN EMPLOYEE-OWNED COMPANY

COLORADO SPRINGS
Emergency Funding Sources
North Douglas Sediment Basins

WARSSSS Study
Watershed Assessment of River Stability and Sediment Supply (WARSSS Study)

Waldo Canyon Fire Watershed Assessment: The WARSSS Results

April 5th, 2013
Dave Rosgen, Brandon Rosgen, Sumner Collins – Wildland Hydrology
Jim Nankervis – Blue Mountain Consultants
Kyle Wright – U.S. Forest Service

The Waldo Canyon Fire Master Plan for Watershed Restoration & Sediment Reduction

April 26th, 2013
Dave Rosgen, Brandon Rosgen, Sumner Collins – Wildland Hydrology
Jim Nankervis – Blue Mountain Consultants
### WARSSSS Results

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Hydrologic Processes</th>
<th>Hillslope Processes</th>
<th>Roads and Trails</th>
<th>Channel Processes</th>
<th>Total Introduced Sediment (tons/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Yield (acre-ft/yr)</td>
<td>Flow-Related Sediment (tons/yr)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-Fire</td>
<td>Post-Fire</td>
<td>Pre-Fire</td>
<td>Post-Fire</td>
<td>Pre-Fire</td>
</tr>
<tr>
<td>Camp Creek</td>
<td>2,115</td>
<td>3,702</td>
<td>71</td>
<td>16,897</td>
<td>4,193</td>
</tr>
<tr>
<td>Douglas Creek</td>
<td>1,511</td>
<td>2,156</td>
<td>47</td>
<td>7,834</td>
<td>4,057</td>
</tr>
<tr>
<td>Fountain Creek</td>
<td>2,500</td>
<td>4,822</td>
<td>90</td>
<td>25,075</td>
<td>7,303</td>
</tr>
<tr>
<td>West Monument Creek</td>
<td>2,747</td>
<td>4,035</td>
<td>104</td>
<td>7,489</td>
<td>2,532</td>
</tr>
<tr>
<td>Totals</td>
<td>8,873</td>
<td>14,715</td>
<td>312</td>
<td>57,295</td>
<td>18,085</td>
</tr>
</tbody>
</table>

#### Sub-Basin Rankings

<table>
<thead>
<tr>
<th>Sub-Basin</th>
<th>Overall Rank</th>
<th>Sub-Basin Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC-007</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>DC-001</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>DC-006</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>DC-004</td>
<td>17</td>
<td>4</td>
</tr>
<tr>
<td>DC-F02</td>
<td>21</td>
<td>5</td>
</tr>
<tr>
<td>DC-F09</td>
<td>44</td>
<td>6</td>
</tr>
<tr>
<td>DC-005</td>
<td>51</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sub-Basin</th>
<th>Overall Rank</th>
<th>Sub-Basin Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>FC-002</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>FC-010</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>FC-004</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>FC-007</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>FC-011</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>FC-005</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>FC-009</td>
<td>15</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sub-Basin</th>
<th>Overall Rank</th>
<th>Sub-Basin Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC-010</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>MC-007</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>MC-008</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>MC-013</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>MC-015</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td>MC-017</td>
<td>26</td>
<td>6</td>
</tr>
<tr>
<td>MC-001</td>
<td>36</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sub-Basin</th>
<th>Overall Rank</th>
<th>Sub-Basin Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC-007</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>CC-017</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>CC-001</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>CC-F08</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>CC-014</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>CC-019</td>
<td>22</td>
<td>6</td>
</tr>
<tr>
<td>CC-015</td>
<td>24</td>
<td>7</td>
</tr>
</tbody>
</table>
Emergency Response

Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3

Matrix Design Group
An Employee-Owned Company

Colorado Springs
Emergency Response

Background

Emergency Response

Phase 1

Phase 2

City Emergency Measures

Phase 3
June Events 2013 - Basins Begin to Infill
September 2013 Events

~ 7.2 inches of rainfall
  (September 10th)

~ 600 cfs/sq-mi estimated flow

Expected Bankfull Discharge
~ 3.7 cfs/sq-mi
(160 times greater)
Sediment Deposition

Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3
Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3

COS Exigent Funding Awarded
Phase 1 Design Goals

1. Construct Large Sediment Basin
2. Encourage Natural Alluvial Fan
3. Transition to Single Threaded Channel
Construction Begins
Construction Begins

Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3

Matrix Design Group
An Employee-Owned Company

COLORADO SPRINGS
Construction Begins
Construction Begins

Let’s Rock.
Step-Pool Construction

Background

Emergency Response

Phase 1

Phase 2

City Emergency Measures

Phase 3

Matrix

DESIGN GROUP
AN EMPLOYEE-OWNED COMPANY

COLORADO SPRINGS
Step-Pool Construction

Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3
Transition to Single Thread Channel Completed
Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3

Sediment Basin Completed

Matrix Design Group
An Employee-Owned Company

COLORADO SPRINGS
Cross-Vane Construction

Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3
Completed Cross-Vanes
Performance

July 13, 2014 – The debris basin in North Douglas is complete
Performance

July 17, 2014 – After two back-to-back thunderstorms
Performance

May 12, 2015 – Debris Basin. Approx. 4.5 inches between 7th to 9th
Performance

White stakes

May 20, 2015
Performance

Location rock wall

May 26, 2015. Aggradation above rock wall
Performance

Looking East

Debris Basin

Top of rock wall

May 26, 2015.
Emergency Measures

Debris basin emptied, damage to sill
Damage to some cross vanes
Channel migration
Site changes including
• Excavated borrow pit
• Channel in Alluvial Fan
Emergency Measures
Phase 3

- Continuation of Previous Phase Design
- Convert borrow-pit to sediment basin
- Restore alluvial fan
- Cross Vane Repairs
- EWP/DEF Funding
- Design/Build
Upper Section

Background

Emergency Response

Phase 1

Phase 2

City Emergency Measures

Phase 3

Matrix Design Group
A Employee-Owned Company

COLORADO SPRINGS
Sediment Basin

ROCK STEP ELEVATION
N.T.S.

ROCK STEP SECTION
N.T.S.
Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3

Sediment Basin

PHREATIC SURFACE

FACTOR OF SAFETY

COARSE SAND
Phi Angle = 45 degrees
Cohesion = 0
Total Unit Weight = 135 pcf

Project No: D17-J-031
Date: February 20, 2017
Drawn by: BTM
Reviewed by: WIB

VIVID Engineering Group, Inc.
1035 Elton Drive
Colorado Springs, Colorado 80905
719-846-4556

Global Slope Stability Analysis Results
Proposed N. Douglas Creek Improvements
Sw of Algonquin Drive and Potez Way
Colorado Springs, Colorado
Background

Emergency Response

Phase 1

Phase 2

City Emergency Measures

Phase 3

Boulder Wall

Matrix Design Group
An Employee-Owned Company

Colorado Springs

4/ 6/2017
Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3

Boulder Wall

Matrix Design Group
An Employee-Owned Company

COLORADO SPRINGS

4/10/2017
Boulder Wall
Riprap Sill
Concrete Crossing

Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3
Cross Vane
Substantial Completion
Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3

Substantial Completion

Matrix Design Group
An Employee-Owned Company

COLORADO SPRINGS
Substantial Completion
Substantial Completion

We done??

Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3
Substantial Completion
Substantial Completion

Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3

Matrix Design Group
An Employee-Owned Company

Colorado Springs
Project Reception

Background

Emergency Response

Phase 1

Phase 2

City Emergency Measures

Phase 3
Project Reception
Project Reception

Background
Emergency Response
Phase 1
Phase 2
City Emergency Measures
Phase 3
Project Reception

Pretty Neat.
Upstream Sediment
Questions?
The Good, Bad, and the Ugly of Implementing a Short Time-Frame Plant Materials Program for Flood Recovery

Randy Mandel, Vice President, Technical Services, Great Ecology / Revegetation Lead, CWCB Emergency Watershed Protection Program
Sara Copp Franz, Associate Ecologist, Great Ecology / Revegetation Specialist, CWCB Emergency Watershed Program
2013 Colorado Front Range Floods

Photo courtesy of R. Mandel
The 2013 Front Range Flood occurred from September 9 to September 15, 2013.

The heavy rain caused catastrophic damage over nearly 200 miles, affecting 17 counties.

The Colorado Emergency Watershed Protection (EWP) Program was created to fund the implementation of emergency recovery measures to address hazards to life and property for flood-affected areas.
2013 Colorado Front Range Floods

- Phase 2 of the program is funded and administered by the USDA Natural Resources Conservation Service (NRCS) and managed by the Colorado Water Conservation Board (CWCB) with a budget of $63.2 million and a project time-period from Spring 2016 to Spring 2018.

- To provide the necessary plant materials for revegetation, a portion of this funding is being used to create an ecotypic revegetation program.
Ecotypic Plant Materials

- **Ecotypic**: local native, site-specific ecotype.
- **Ecotype**: a genetically distinct geographic variety, population, or race within a species which is adapted to specific environmental conditions.
- **Native**: a species that occurs naturally in a particular site as determined by living (biotic) and non-living (abiotic) factors and was not introduced by human activities.
Ecotypic Plant Materials

Photo courtesy of R. Mandel
Ecotypic Plant Materials

Ecotypic plant materials are important because these plants:

- Have improved site adaptability;
- Improve water conservation;
- Are less likely to become invasive;
- Co-evolved with local site conditions such as hydrology and biophysiology, therefore tend to have greater resiliency to stress;
- Tend to be more aesthetically aligned (display sense of place);
- May be required by law, policy, or covenant;
- Tend to impart long-term improved economics through reduced maintenance and irrigation costs.
Restoration Requirements

- Extremely short project period: 24 months total.
- Plant materials required for approximately 74 projects.
- Necessary plant materials include seed, cuttings, and container stock.
- Cuttings and container stock were increased from ecotypic sources.
- Collection from within watershed sources prioritized.
Due to the lengthy increase period required (circa 5 to 7 years), ecotypic seed could not be increased in the necessary amounts. As such, seed was obtained from local providers with its genetic source of origin being as close to the project as possible. All included species were confirmed on both county and site-specific level as occurring in a given watershed. Occurrence confirmed by (1) floristic review; (2) onsite confirmation; (3) Colorado DNR CWCB restoration matrix; (4) peer review.
Species were grouped by hydrologic and elevational preference.

For the purposes of restoration design, a total of five distinct ecological zones were recognized:

- **Zone 1**: Wetland (0 - 1 ft above low-flow water surface, 70 – 100% wet annually);
- **Zone 2**: Riparian (1 - 3 ft above low-flow water surface, bankful, 40 – 70% wet annually);
- **Zone 3**: Transitional (2 – 4 ft above low-flow water surface; 100 yr flood elevational 40% wet annually to bankful height);
- **Zone 4**: Upland (4+ ft above low-flow water surface);
- **Zone 5**: Overbank or swale.
<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Percent of Mix</th>
<th>Material Type</th>
<th>Container Size</th>
<th>Plant Spacing</th>
<th>Number of Plants</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Salix drummondiana</em></td>
<td>Drummond’s willow</td>
<td>5</td>
<td>cutting</td>
<td>48-inch cutting</td>
<td>6-foot spacing</td>
<td>11</td>
</tr>
<tr>
<td><em>Salix drummondiana</em></td>
<td>Drummond’s willow</td>
<td>5</td>
<td>container</td>
<td>D-60</td>
<td>6-foot spacing</td>
<td>11</td>
</tr>
<tr>
<td><em>Salix exigua</em></td>
<td>narrowleaf willow</td>
<td>10</td>
<td>cutting</td>
<td>48-inch cutting</td>
<td>6-foot spacing</td>
<td>21</td>
</tr>
<tr>
<td><em>Salix geyeriana</em></td>
<td>Geyer’s willow</td>
<td>7.5</td>
<td>cutting</td>
<td>48-inch cutting</td>
<td>6-foot spacing</td>
<td>16</td>
</tr>
<tr>
<td><em>Salix geyeriana</em></td>
<td>Geyer’s willow</td>
<td>5</td>
<td>container</td>
<td>D-60</td>
<td>6-foot spacing</td>
<td>11</td>
</tr>
<tr>
<td><em>Salix timorata</em></td>
<td>bluestem willow</td>
<td>5</td>
<td>cutting</td>
<td>48-inch cutting</td>
<td>6-foot spacing</td>
<td>11</td>
</tr>
<tr>
<td><em>Salix timorata</em></td>
<td>bluestem willow</td>
<td>5</td>
<td>container</td>
<td>D-60</td>
<td>6-foot spacing</td>
<td>11</td>
</tr>
<tr>
<td><em>Salix lasiandra sap. caudata</em></td>
<td>whiplash willow</td>
<td>5</td>
<td>cutting</td>
<td>48-inch cutting</td>
<td>6-foot spacing</td>
<td>11</td>
</tr>
<tr>
<td><em>Salix lasiandra sap. caudata</em></td>
<td>whiplash willow</td>
<td>5</td>
<td>container</td>
<td>D-60</td>
<td>6-foot spacing</td>
<td>6</td>
</tr>
<tr>
<td><em>Salix monticola</em></td>
<td>Rocky Mountain willow</td>
<td>7.5</td>
<td>cutting</td>
<td>48-inch cutting</td>
<td>6-foot spacing</td>
<td>16</td>
</tr>
<tr>
<td><em>Salix monticola</em></td>
<td>Rocky Mountain willow</td>
<td>5</td>
<td>container</td>
<td>D-60</td>
<td>6-foot spacing</td>
<td>11</td>
</tr>
<tr>
<td><em>Salix ulugifolia</em></td>
<td>strapleaf willow</td>
<td>7.5</td>
<td>cutting</td>
<td>48-inch cutting</td>
<td>6-foot spacing</td>
<td>16</td>
</tr>
<tr>
<td><strong>Graminoids</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Carex nebrascensis</em></td>
<td>Nebraska sedge</td>
<td>5</td>
<td>container</td>
<td>10 cubic inch</td>
<td>4-foot spacing</td>
<td>11</td>
</tr>
<tr>
<td><em>Carex pellita</em></td>
<td>woolly sedge</td>
<td>5</td>
<td>container</td>
<td>10 cubic inch</td>
<td>4-foot spacing</td>
<td>11</td>
</tr>
<tr>
<td><em>Carex utriculata</em></td>
<td>Beaked sedge</td>
<td>4</td>
<td>container</td>
<td>10 cubic inch</td>
<td>4-foot spacing</td>
<td>9</td>
</tr>
<tr>
<td><em>Eleocharis palustris</em></td>
<td>creeping spikerush</td>
<td>4</td>
<td>container</td>
<td>10 cubic inch</td>
<td>4-foot spacing</td>
<td>9</td>
</tr>
<tr>
<td><em>Glyceria striata</em></td>
<td>fowl managrass</td>
<td>4</td>
<td>container</td>
<td>10 cubic inch</td>
<td>4-foot spacing</td>
<td>9</td>
</tr>
<tr>
<td><em>Juncus arcticus sap. litoralis</em></td>
<td>mountain rush</td>
<td>4</td>
<td>container</td>
<td>10 cubic inch</td>
<td>4-foot spacing</td>
<td>9</td>
</tr>
<tr>
<td><em>Juncus longistylius</em></td>
<td>longstyled rush</td>
<td>4</td>
<td>container</td>
<td>10 cubic inch</td>
<td>4-foot spacing</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td>219</td>
</tr>
</tbody>
</table>
## Zone 2: Seed

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Percent of mix</th>
<th>Seeds/sq ft</th>
<th>Pure Live Seed (PLS) Weight</th>
<th>PLS lb Required per Ac</th>
<th>PLS lbs Required Per Project Area</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forb Species</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asclepias incarnata</td>
<td>swamp milkweed</td>
<td>2.5</td>
<td>3.75</td>
<td>68.100</td>
<td>2.40</td>
<td>1.20</td>
</tr>
<tr>
<td>Geum macrophyllum</td>
<td>largeleaf avena</td>
<td>2.5</td>
<td>3.75</td>
<td>793.353</td>
<td>0.21</td>
<td>0.10</td>
</tr>
<tr>
<td>Mimulus guttatus</td>
<td>common monkeyflower</td>
<td>2.5</td>
<td>3.75</td>
<td>4,200,000</td>
<td>0.04</td>
<td>0.10</td>
</tr>
<tr>
<td>Mertensia ciliata</td>
<td>alpine bluebells</td>
<td>2.5</td>
<td>3.75</td>
<td>1,000,000</td>
<td>0.16</td>
<td>0.10</td>
</tr>
<tr>
<td>Verbena hastata</td>
<td>blue verbena</td>
<td>2.5</td>
<td>3.75</td>
<td>1,792.800</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td><strong>Graminoids</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calamagrostis canadensis</td>
<td>bluejoint reedgrass</td>
<td>5</td>
<td>7.5</td>
<td>4,114,584</td>
<td>0.08</td>
<td>0.10</td>
</tr>
<tr>
<td>Deschampsia caespitosa</td>
<td>tufted hairgrass</td>
<td>15</td>
<td>22.5</td>
<td>1,812,500</td>
<td>0.54</td>
<td>0.27</td>
</tr>
<tr>
<td>Glyceria striata</td>
<td>fowl manna grass</td>
<td>10</td>
<td>15</td>
<td>170,000</td>
<td>3.84</td>
<td>1.93</td>
</tr>
<tr>
<td>Juncus arcticus spp. littoralis</td>
<td>mountain rush</td>
<td>15</td>
<td>22.5</td>
<td>6,950,000</td>
<td>0.14</td>
<td>0.10</td>
</tr>
<tr>
<td>Juncus torreyi</td>
<td>Torrey rush</td>
<td>10</td>
<td>15</td>
<td>12,150,000</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Nasella virdula</td>
<td>green needlegrass</td>
<td>7.5</td>
<td>11.25</td>
<td>152,117</td>
<td>3.22</td>
<td>1.62</td>
</tr>
<tr>
<td>Poa alpina</td>
<td>alpine bluegrass</td>
<td>5</td>
<td>7.5</td>
<td>1,069,921</td>
<td>0.31</td>
<td>0.15</td>
</tr>
<tr>
<td>Poa palustris</td>
<td>fowl bluegrass</td>
<td>20</td>
<td>30</td>
<td>2,078,000</td>
<td>0.63</td>
<td>0.32</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>100</td>
<td>150</td>
<td>11.71</td>
<td>6.19</td>
<td></td>
</tr>
</tbody>
</table>
Plant Materials Harvest

- Required pre-identification of collection areas to determine population size, species richness, accessibility, and timing.
- All plant materials were harvested under permit.
  - Permitting requires time, therefore begin early;
  - Agencies have variable response to permitting requests;
  - State lands were primary source of material, with private lands and federal lands providing a reduced number of materials.
- Crews were primarily organized through the Colorado State Forest Service, with support provided through Watershed Coalitions, Volunteer Groups; and Great Ecology.
Plant Materials Harvest

Photo courtesy of R. Mandel
Plant Materials Harvest

- All harvest was carried out in a sustainable manner:
  - No more than 15% of the available propagules (seed or cuttings) were collected from a given area.
  - No more than 30% of the available propagules were collected from a given plant.
  - All collection areas were chosen based on their ecological ability to withstand to collection (ecological resiliency).
Ecotypic Plant Materials

Photo courtesy of R. Mandel
Plant Materials Harvest

- Seed for container production was primarily harvested during 2016.
- Cuttings primarily harvested during 2017 to help ensure viability.
- The majority of the collected seed, plants, and cuttings were maintained through CSFS.
- Harvested seed was cleaned, tested for purity and germinability, then subjected to pretreatment (scarification) to break dormancy.
  - Most native seed from temperate regions has dormancy requirements.
  - Dormancy helps assist native populations to not ‘over-invest’ their genetic materials all at once to minimize exposure to uncertain and/or rapidly changing environmental conditions.
Plant Materials Harvest

- Seed purity is huge as even a small percentage of non-target material can result in long-term failure and/or requirement for costly cultural practices.
  - e.g. Grand Teton National Park – *Carex feta*
  - Seed needs to periodically be re-tested to note changes in germinability over time.
  - Most woody species have 10 yrs or so of longevity; most grasses have 3 to 5 yrs; forbs vary greatly by species.
  - Tetrazolium (Tz) testing can be used in place of germination tests to provide short turnaround information on seed viability.
Plant Materials Harvest

- Production of native plants from seed requires time.
  - Pretreatment can take from 0 to 120+ days. Some species up to multiple years and requiring specialized conditions (e.g. fumation, scarification, etc.)

- Once pretreatment has completed, growth period requirements vary by species and container size.
  - Graminoids in 10 ci, 12 – 14 weeks;
  - Forbs in 10 ci 14 – 16 weeks;
  - Woody plants in D40s: 24 weeks;
  - Woody plants in D60s: 36 weeks.
Plant Materials Harvest

- As such, project revegetation planning needed to work proactively backwards from necessary plant numbers and project timeframes.
- Additionally, requisite species numbers were very susceptible to change through design alterations or altering project timing.
  - Changes in area or treatment affected hydrologic zone and bank height.
  - Changes due to funding or politics to delay projects by months, strongly impacting readiness and plant materials allocation.
The harvest of woody cuttings proved challenging due to:

- Availability of certain species due to out-competition by introduced species (e.g. *Salix fragilis*) and/or insufficient numbers to provide sustainable collection;
- Existence of monocultures (e.g. *Salix exigua*) in many potential harvest areas;
- Lack of available collection personnel with proper training for species ID; and
- Permitting challenges.
Ecotypic Plant Materials

Photo courtesy of R. Mandel
Ecotypic Plant Materials

Photo courtesy of R. Mandel
Plant Materials Storage

- Most seed was stored professionally off-site, therefore long-term storage was largely a non-issue.
- Most cuttings were site-collected then transported to CSFS for storage in their cold-storage facility.
- To be viable, cuttings should be harvested during dormancy periods (approximately November to April).
- Maximum storage period is normally 60 days; under 45 days being preferred.
Due to the short timeframe for EWP and the variable timing of project implementation, many harvested cuttings required much longer storage periods. In some cases, over 100 days of storage was required. Required viability testing through examination. Verification of living tissue through a combination of bending, testing, and scratching proved invaluable.
Ecotypic Plant Materials

Photo courtesy of R. Mandel
Implementation

- All and all, given the limitations of time, budget, and labor, EWP implementation has been a huge success thus far.
- In total, the approximately 74 projects incorporates 41 miles of riparian restoration and includes approximately 218 acres across 14 watersheds and five counties.
- A total of 70 species are included. 66% woody; 6% herbaceous; 29% graminoid (grasses and grasslikes).
- A total of 60,588 cuttings; 143,090 large containers (D40/D60); and 83,290 plugs are projected to be utilized by spring of 2018.
- Approximately 986 lbs of native seed is projected to be seeded by spring of 2018.
Implementation

Photo courtesy of R. Mandel
Implementation

The greatest challenges to date have been:

- Timing and budget (always too tight and never enough);
- Irrigation (plants like water);
- Noxious and/or invasive species (limited budgets for control; water nexus);
- Availability for some key species and need for cultural studies to improve production capabilities;
- Availability of trained installation crews with consistent attention to planting detail;
- Long-term monitoring and its funding.
Questions?

Randy Mandel
Vice President, Technical Services
Great Ecology
rmandel@greatecology.com

Sara Copp Franz
Associate Ecologist
Great Ecology
scoppyfranz@greatecology.com
Using Ecological Functions Approach to Measure Stream Restoration Goals

September 20, 2017

Moneka Worah
ERO Resources Corporation
mworah@eroresources.com
Floodplain Functions
How do you measure ecological functions?

**Area Determination**
- Pre-stream length and sinuosity = Post-stream length and sinuosity
- Pre-wetland/riparian acreage = Post-wetland/riparian acreage

**Functional Assessment**
- Measure specific attributes/parameters
  - Give values for each function
  - Must be repeatable and consistent
Project Background

- EIS and ROD completed in 2014

- Three Integrated Terrestrial Resources
  - Birds, Wetlands, and Preble’s meadow jumping mouse (Preble’s)

- “Systems” Mitigation Approach
Systems Approach Development

Research Existing Models

- Habitat Evaluation Procedure (HEP)
- Habitat Suitability Index (HSI)
- Habitat Equivalency Analysis (HEA)
- Montana Wetland Functional Assessment
- Functional Assessment of Colorado Wetlands (FACWet)
Ecological Functional Assessment (EFA) Model

Model Criteria

• Capture overlap of resources
• Transferable to potential off-site mitigation areas

 Desired Outcome

• Create “common currency” for impacts on birds, wetlands, and Preble’s
Develop Project-Specific Model

- Field mapping of vegetation polygons
- Gather site-specific metrics for each resource within polygon
- Assign Ecological Functional Index (EFI) values
- Calculate impacts as Ecological Functional Units (EFUs)
- Evaluate on-site and off-site mitigation opportunities
Mapping and collection of polygon-specific habitat attributes
Chatfield Vegetation Baseline Mapping
Convened a group of biological experts

Identified “ecological functions” and assigned index values to vegetation communities

Flow Chart of the EFU Approach

On-Site Resource Mapping

Bird Habitat Mapping

Preble’s Habitat Mapping

Wetland Habitat Mapping

Map habitat polygons for each resource/establish baseline for maximum inundation levels

Complete field assessment and data forms

Define and assign an EFI value for each resource

Calculate Debits and Credits

Debits
Calculate the Chatfield reallocation impacts for maximum reservoir elevation and convert to EFUs

Credits
Calculate baseline EFUs for on-site mitigation areas

Calculate habitat degradation since 2011

Calculate predicted degradation

Review mitigation EFU estimates

EFU lift

EFU protection
Chatfield Bird Baseline (BEFI) Mapping along Plum Creek
Chatfield Wetlands
Baseline (WEFI)
Mapping along Plum Creek
Chatfield Preble’s Baseline (PEFI) Mapping along Plum Creek
EFI = Ecological Function Index  
EFU = Ecological Function Unit

EFI values for 3 resources

Bird
4

Preble’s
6

Wetland
2

Combined overlap is sum of EFI

Bird
10

Preble’s
6

Wetland
8

EFI + WEFI + PEFI = Combined EFI (CEFI)

CEFI x Acres = EFU

12 at 2 acres = 24 EFUs

• BEFI + WEFI + PEFI = Combined EFI (CEFI)
• CEFI x Acres = EFU
Credit (Mitigation) Analysis
- On-site enhancement
- Off-site preservation and/or enhancement

Debit (Impact) Analysis
- Impacted EFUs

Flow Chart of the EFU Approach

On-Site Resource Mapping
- Bird Habitat Mapping
- Preble’s Habitat Mapping
- Wetland Habitat Mapping

Map habitat polygons for each resource/establish baseline for maximum inundation levels

Complete field assessment and data forms

Define and assign an EFI value for each resource

Calculate Debits and Credits

Debits
- Calculate the Chatfield reallocation impacts for maximum reservoir elevation and convert to EFUs

Credits
- Calculate baseline EFUs for on-site mitigation areas

Calculate habitat degradation since 2011
Calculate predicted degradation
Review mitigation EFU estimates

EFU lift
EFU protection
### On-Site and Off-Site Ecological Functional Units

<table>
<thead>
<tr>
<th>Impact Activity</th>
<th>Impacted EFUs</th>
<th>Residual EFUs</th>
<th>On-site EFUs</th>
<th>Off-site EFUs</th>
<th>Total Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluctuation (below 5444)</td>
<td>775</td>
<td>0</td>
<td>85</td>
<td>690</td>
<td>775</td>
</tr>
<tr>
<td>Recreation Facility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent Impact above 5444</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>796</td>
<td>0</td>
<td>85</td>
<td>711</td>
<td>796</td>
</tr>
</tbody>
</table>

### 2016 Baseline Estimate

<table>
<thead>
<tr>
<th>Impact Activity</th>
<th>Impacted EFUs</th>
<th>Residual EFUs</th>
<th>On-site EFUs</th>
<th>Off-site EFUs</th>
<th>Total Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluctuation (below 5444)</td>
<td>657</td>
<td>264</td>
<td>370</td>
<td>23</td>
<td>657</td>
</tr>
<tr>
<td>Recreation Facility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent Impact above 5444</td>
<td>35</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>692</td>
<td>264</td>
<td>370</td>
<td>58</td>
<td>692</td>
</tr>
</tbody>
</table>
Flow Chart of the EFU Approach

On-Site Resource Mapping

Bird Habitat Mapping

Preble’s Habitat Mapping

Wetland Habitat Mapping

Map habitat polygons for each resource/establish baseline for maximum inundation levels

Complete field assessment and data forms

Define and assign an EFI value for each resource

Calculate Debits and Credits

Debits
Calculate the Chatfield reallocation impacts for maximum reservoir elevation and convert to EFUs

Credits
Calculate baseline EFUs for on-site mitigation areas

Calculate habitat degradation since 2011

Calculate predicted degradation

Review mitigation EFU estimates

EFU lift

EFU protection

Adapt Model for Plum Creek Habitat Degradation
Plum Creek Degradation

- Headcut migration
- Loss of connectivity
- Changes in vegetation communities
- Woody species mortality
- Weed colonization

<table>
<thead>
<tr>
<th>Dates</th>
<th>Distance of Headcut Movement (ft)</th>
<th>Average Distance (ft/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 2010 – March 2011</td>
<td>166</td>
<td>221</td>
</tr>
<tr>
<td>March 2011 – October 2013</td>
<td>420</td>
<td>163</td>
</tr>
<tr>
<td>October 2013 – October 2014</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>October 2014 – October 2015</td>
<td>650</td>
<td>650</td>
</tr>
<tr>
<td>Total</td>
<td>1291</td>
<td>242</td>
</tr>
</tbody>
</table>
Plum Creek Degradation

June 6, 2016

April 24, 2016

June 6, 2017

June 6, 2017

Calculate Habitat Degradation
Plum Creek Degradation of EFIs and EFUs

Example of wetland conversion to weedy upland

Example of willow scrub-shrub wetland conversion to upland

Calculate Habitat Degradation
Flow Chart of the EFU Approach

On-Site Resource Mapping

- Bird Habitat Mapping
- Preble’s Habitat Mapping
- Wetland Habitat Mapping

Map habitat polygons for each resource/establish baseline for maximum inundation levels

Complete field assessment and data forms

Define and assign an EFI value for each resource

Calculate Debits and Credits

Debits:
Calculate the Chatfield reallocation impacts for maximum reservoir elevation and convert to EFUs

Credits:
Calculate baseline EFUs for on-site mitigation areas

Calculate habitat degradation since 2011

Calculate predicted degradation

Review mitigation EFU estimates

EFU lift

EFU protection
Preservation Concept Adapted from Clayton Ridenour/Corps.

Habitat quality due to headcutting

- Present
- 10 Years
- 20 Years
- 30 Years

- Low Quality
- High Quality

- Observed
- Existing Condition
- Projected

- Future without Protection
- Future with Basic Protection
- Future with Moderate Protection
- Future with Extensive Protection

Calculate Predicted Degradation
Lift was calculated as the difference between the reduced EFUs of the future **without** mitigation within a 10-year planning horizon and the predicted increase of EFUs for a future **with** mitigation and includes both protection of existing habitat and habitat enhancement.
Chatfield Preble’s Baseline (CEFI) Mapping along Plum Creek
Adaptive Management Plan

- Assess
- Design
- Implement
- Monitor
- Evaluate
- Adjust
Cherry Creek Dam Safety Modification Study

Used “Chatfield EFA Model” for two target significant ecological resources - wetlands and Preble’s:

• Evaluated baseline conditions
• Evaluated potential impacts
Cherry Creek Dam Safety Modification Study

- Identify mitigation alternatives that incorporate the complementary habitat requirements to take place based on function, not ratios or acres
EFA Adaptations: Incorporate Other Target Resources

- **Aquatic Habitat**
  - Stream Quantification Tool
    - Function-based framework for stream assessments and restoration projects

- **Habitat Suitability Index (HSI)**
  - For known aquatic species within a study area
  - Rated on a 0.0 to 1.0 scale
Overview of EFA Model

- Adaptable
- Applicable for various projects and resources
- Ability to make improved mitigation decisions
- Allows a standard unit for evaluating impacts on overlapping resources
- Measures debits and credits
- Ensures that resources are fully replaced through time
- Can be combined with cost data to measure mitigation alternative effectiveness in terms of cost per units gained
Questions?
Encouraging St. Vrain Resiliency through the USACE Section 205 Program in Longmont

2017 Annual CASFM Conference

Jordan Williams, CFM
Monica Bortolini, PE, CFM
Agenda

- Resilient St. Vrain
- Section 205 Overview
- Feasibility Study
- Next Steps
- Lessons Learned
- Questions
Resilient St. Vrain

- Developed after Longmont experienced catastrophic flooding in September 2013
- Extensive multi-year project to fully restore the St. Vrain Greenway trails and improve the St. Vrain Creek channel to protect people and property from future flooding
Regulatory, Existing Conditions, Post Project
Upcoming Resilient St. Vrain Projects:
Section 205 Study Area
Section 205 Overview

- How are we studying this?*
  - Section 205 of the 1948 Flood Control Act, as amended
  - Letter of request received from City of Longmont (February 5, 2014)

- What is Section 205? *
  - Authorizes the Corps of Engineers to construct projects (structural or nonstructural) to reduce damages caused by flooding.
  - Projects must be technically feasible, beneficial to the public, economically viable, and environmentally acceptable.

- Objective*
  - Identify if potential exists to develop flood risk management solutions that are technically feasible, economically viable, beneficial to the public, and environmentally acceptable.

- Longmont’s Goals
  - Identify a project that meets the vision of RSVP, Section 205 requirements, and maximizes federal dollars available

*content from Public Meeting in City of Longmont
Feasibility Study- Phase I

- Built upon the existing Resilient St. Vrain documentation to further define the existing conditions and future conditions without project improvements including:
  - Hydrologic Evaluation
  - Hydraulic and Sediment Transport Evaluation
  - Flood Risk and Floodplain Management Evaluation
  - Geotechnical and Structural evaluations
  - Phase I Environmental Site Assessment
  - Cultural Resources Evaluation
  - Economics Evaluation
  - Environmental Evaluation
## Hydrologic Modeling

<table>
<thead>
<tr>
<th>Location</th>
<th>2-yr</th>
<th>5-yr</th>
<th>10-yr</th>
<th>25-yr</th>
<th>50-yr</th>
<th>100-yr</th>
<th>200-yr</th>
<th>500-yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lykins Gulch Confluence (St. Vrain Creek at Golden Ponds)</td>
<td>1,180</td>
<td>1,970</td>
<td>2,700</td>
<td>5,750</td>
<td>9,290</td>
<td>14,500</td>
<td>21,100</td>
<td>31,900</td>
</tr>
<tr>
<td>St. Vrain Creek at BNSF Railroad Bridge</td>
<td>1,520</td>
<td>2,590</td>
<td>3,520</td>
<td>6,020</td>
<td>9,730</td>
<td>15,200</td>
<td>22,300</td>
<td>33,600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>10-yr</th>
<th>50-yr</th>
<th>100-yr</th>
<th>500-yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lykins Gulch Confluence (St. Vrain Creek at Golden Ponds)</td>
<td>3,690</td>
<td>7,610</td>
<td>10,160</td>
<td>20,500</td>
</tr>
<tr>
<td>St. Vrain Creek at BNSF Railroad Bridge</td>
<td>4,110</td>
<td>8,240</td>
<td>10,580</td>
<td>21,200</td>
</tr>
</tbody>
</table>
Hydraulic Modeling
### Existing Bridge Capacities

<table>
<thead>
<tr>
<th>Bridge Name</th>
<th>Design Year</th>
<th>Flowrate (CFS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunset Street</td>
<td>2015</td>
<td>14,381</td>
</tr>
<tr>
<td>Boston Avenue</td>
<td>1989</td>
<td>10,160</td>
</tr>
<tr>
<td>Main Street</td>
<td>2015</td>
<td>16,251</td>
</tr>
<tr>
<td>S. Pratt Parkway</td>
<td>2017</td>
<td>15,200</td>
</tr>
</tbody>
</table>

- Hover Street ~ 50 yr
- BNSF Bridge ~ 25 yr
Izaak Walton Split – Main Channel
Channel Stability Evaluation
Flood Risk and Floodplain Management

Risk = f [(Probability of Flooding) x (Consequences)]
Economics Evaluation

- Considers the benefits and costs of all flood risk management alternatives over a 50-year period.

- The estimated equivalent annual damages over the life of the project will be calculated based on a number of factors including the depth of flooding at each structure.
Alternatives Workshop

- Facilitated by USACE

- Identify objectives, constraints, and potential management measures

- Brought together USACE, City, and contractor staff

- Took a fresh look at the study area to identify potential measures
Alternatives Workshop – Potential Measures

Channel improvement

Elevation

Detention

Bridge improvement

Wet Floodproofing

Levee
Alternatives Workshop

<table>
<thead>
<tr>
<th>Reach #1 Potential Measure</th>
<th>Criteria for Alternatives (refer to Criteria for Measures tab for an index of criteria 1 to 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Replace Boston Street Bridge</td>
<td>1</td>
</tr>
<tr>
<td>Increase channel capacity</td>
<td>1</td>
</tr>
<tr>
<td>Benching</td>
<td>1</td>
</tr>
<tr>
<td>Grade control structures</td>
<td>1</td>
</tr>
<tr>
<td>Floodproof/elevate</td>
<td>0</td>
</tr>
<tr>
<td>Relocate or buy-out (e.g., leave a floodplains)</td>
<td>0</td>
</tr>
<tr>
<td>Culvert (at grade or below grade)</td>
<td>0</td>
</tr>
<tr>
<td>Levee/Floodwalls</td>
<td>0</td>
</tr>
<tr>
<td>Split flow channel</td>
<td>-1</td>
</tr>
<tr>
<td>Detention/retention</td>
<td>-1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reach #2 Potential Measure</th>
<th>Criteria for Alternatives (refer to Criteria for Measures tab for an index of criteria 1 to 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Grade control</td>
<td>0</td>
</tr>
<tr>
<td>Floodproofing/elevation</td>
<td>-1</td>
</tr>
<tr>
<td>Add a structure at Hover Street</td>
<td>0</td>
</tr>
<tr>
<td>Replace Hover Street Bridge*</td>
<td>-1</td>
</tr>
<tr>
<td>Culvert (at grade or below grade)</td>
<td>0</td>
</tr>
<tr>
<td>Culvert (at grade or below grade)**</td>
<td>0</td>
</tr>
<tr>
<td>Split flow channel</td>
<td>-1</td>
</tr>
<tr>
<td>Texas crossing (naturally let the water over top a road)</td>
<td>-1</td>
</tr>
<tr>
<td>Levee/Floodwalls</td>
<td>-1</td>
</tr>
</tbody>
</table>

*qualitative assessment, score doesn’t necessarily indicate priority
Next Steps

- **Estimated 36 Months**

  - **2016**
    - Estimate Existing and Future Without Project Conditions
    - Scoping meeting

  - **2017**
    - Formulate Alternative Plans
    - Corps and Sponsor develop alternatives together

  - **2018**
    - Evaluate/Compare Plans; Select Recommended Plan; Develop Draft Report
    - Public involvement meetings

  - Finalize Feasibility Report and Environmental Assessment
    - Public, state and agency review of draft final report
Lessons Learned and Longmont’s Point of View

- Data and analysis from one study will not always transfer seamlessly to another
- Economic analysis is a useful tool in evaluating risk and potential projects
- USACE has unique criteria for evaluating projects
- Helpful to bring so many experts to the table
Acknowledgements:
Questions?
Rebuilding roads and creeks together:

overcoming barriers to successful integration of natural environment rehabilitation with reconstruction of the built environment
Hydrographs of Boulder Creek during September 2013 flood

Provisional data from USGS and Colorado DWR; prepared by Sheila Murphy, USGS
2013 Flood - Gold Run
2013 Flood – Embankment Failure
James Canyon – Embankment Failure
Lefthand Canyon Drive - Debris Flow
Lefthand Canyon Drive - Debris Flow
Lower Lefthand - Scour
James Canyon - Scour
Lefthand Canyon – Culvert Failure
What Now?
Step 1 – Emergency Repairs
Step 1 – Emergency Repairs: 1-Lane Goat Road
Step 2 – Emergency Winter Road
Step 3 – Emergency Safety & Paving
Step 4 – Final Design
Watershed Recovery

Emergency Response → Immediate Debris Removal & Bank Stabilization → Watershed Master Plans → Creek Projects
Stream Restoration - 30% Design + Field Fit
Opportunities & Challenges: Construction Funding Coordination

- Optimized use of grants
  - Reduced costly structures
- Spatial Challenges
  - Who pays?
- Timing Challenges:
  - EWP deadline 12/2017
  - Road deadline late 2018
Opportunities & Challenges: 30% Stream Design

- Allowed flexibility to respond to a healing stream during construction
- Developed to pass off to stream restoration contractor as design-build
  - Road contractors not equipped for this process
- Uncertainty around LOMR
Opportunities & Challenges: Design Optimization

- Reduce erosion & sedimentation at road-creek interface:
  - Crossings
  - Flood Conveyance
  - Erosion Control & Sediment Transport
Opportunities & Challenges: Design Optimization

- Optimize stream for sediment transport & flood control
FEMA rules are meant for what?

- What are the assumptions of the NFIP regulations?
  - Effective floodplain maps reflect reality
  - 100% design plans submitted
  - Stable landscape
October 2013: Rush, rush, rush
Spring 2014: Compare to what?
Spring 2014: Compare to what?
Winter 2014: With these maps?
2015, 2016: No rise? CLOMR?
2016, 2017: Permitting road/stream together
2017 and looking ahead
Questions?
Lessons Learned

- Coordinate stream and road design closely
- Coordinate with floodplain managers closely and regularly
  - Were new flows adopted?
  - Evolving guidance: Compare to pre-flood conditions? Existing conditions?
- No-rise vs CLOMR: Just expect to get the CLOMR
- Experienced field-fit experts are crucial to project success
- Won’t know until you know - survey and remodel as construction continues
- There are pros and cons to 30% stream design
2D Modeling as the Tool of Choice: Hydraulic Analysis of Lower Main Street Bridge in Jamestown

Anthony Alvarado, PE, CFM
James Hitchman, PE
Jennifer Aieta, PE

CASFM Conference
Breckenridge, Colorado
September 2017
Overview

- 2013 Flood Damage in Jamestown
- Lower Main Street Bridge
- Now vs Then in 2D Modeling
- Benefits of 2D vs 1D Modeling
- Summary
Why 2D Modeling?

• Multi-directional flow
• Simulate the bridge debris blockage
• Analysis of potential alternatives
  – New bridge
  – Fuse plug
  – Additional span
  – Raise the bridge deck
  – New bridge location
Challenges?
Welcome to the Colorado GeoData Cache

You can find large geographic data (e.g., LiDAR, imagery) and other data here. It started with data collected after the catastrophic flooding in 2013 and will grow to hold other data collected within the state.

Please register. We'd like to know about who is using this site:

Sign up

Otherwise, don't just sit there. Start getting your data!

Sign in
Existing Conditions: 100-Year Flow (No Debris)
Existing Conditions: 100-Year Flow (Blocked Bridge)
Evaluating Alternatives: Increased Freeboard

Freeboard:
100-Year = 0 FT
50-Year = 0 FT
10-Year = 2.4’
Evaluating Alternatives: Increased Freeboard

Freeboard:
100-Year = 2.2 FT
50-Year = 2.9 FT
10-Year = 5.0’
More benefits of 2D: Accurate Input into the BCA
More benefits of 2D: Public Communication
More benefits of 2D: Public Communication
Public Communication
Summary

• 2D Modeling
THANK YOU!

Anthony Alvarado, PE, CFM
970.797.3501 (direct)
970.412.2545 (mobile)
alvaradoa@ayresassociates.com
Smooth Transition
Adjusting Manning’s n values for 2D modeling

Andrew Friend, P.E., and Mark McBroom, P.E.
## Table 3-1 Manning’s 'n' Values

<table>
<thead>
<tr>
<th>Type of Channel and Description</th>
<th>Minimum</th>
<th>Normal</th>
<th>Maximum</th>
</tr>
</thead>
</table>
## A. Natural Streams

1. Main Channels
   - a. Clean, straight, full, no riffs or deep pools
   - b. Same as above, but more stones and weeds
   - c. Clean, winding, some pools and shoals
   - d. Same as above, but some weeds and stones
   - e. Same as above, lower stages, more ineffective slopes and sections
   - f. Same as "d" but more stones
   - g. Sluggish reaches, weedy, deep pools
   - h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush

2. Flood Plains

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Normal</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.025</td>
<td>0.030</td>
<td>0.033</td>
</tr>
<tr>
<td>0.030</td>
<td>0.035</td>
<td>0.040</td>
</tr>
<tr>
<td>0.033</td>
<td>0.040</td>
<td>0.045</td>
</tr>
<tr>
<td>0.035</td>
<td>0.045</td>
<td>0.050</td>
</tr>
<tr>
<td>0.040</td>
<td>0.048</td>
<td>0.055</td>
</tr>
<tr>
<td>0.045</td>
<td>0.050</td>
<td>0.060</td>
</tr>
<tr>
<td>0.050</td>
<td>0.070</td>
<td>0.080</td>
</tr>
<tr>
<td>0.070</td>
<td>0.100</td>
<td>0.150</td>
</tr>
</tbody>
</table>
Cowan [1956] and Chow [1959]

\[ n = (n_0 + n_1 + n_2 + n_3 + n_4) \, m \]
Cowan [1956] and Chow [1959]

\[ n = (n_0 + n_1 + n_2 + n_3 + n_4) \cdot m \]

- Base material: (0.020 – 0.028)
- Channel variations: (0.00-0.015)
- Vegetation: (0.005-0.100)
- Cross section irregularity: (0.00-0.02)
- Obstructions: (0.00-0.06)
- Degree of meandering: (1.0-1.3)
Cowan [1956] and Chow [1959]

\[ n = (n_0 + n_1 + n_2 + n_3 + n_4) m \]

- **base material** (0.020 – 0.028)
- **channel variations** (0.00-0.015)
- **vegetation** (0.005-0.100)
- **cross section irregularity** (0.00-0.02)
- **obstructions** (0.00-0.06)
- **degree of meandering** (1.0-1.3)
Losses between Cross Sections
Cross Section Irregularities

\[ n = (n_0 + n_1 + n_2 + n_3 + n_4) \text{ m} \]
Obstructions

\[ n = (n_0 + n_1 + n_2 + n_3 + n_4) \ m \]
Meandering

\[ n = (n_0 + n_1 + n_2 + n_3 + n_4)^m \]
A 1D model uses the Manning’s n term to *implicitly* model more than just “roughness” – it also captures energy lost due to lateral flow and complex flow paths.

A 2D model represents this energy loss due to lateral flow and more complex flow paths *explicitly*. 
What Manning’s n values should be used for 2D models?

(it’s not in the HEC-RAS manual)
Experiment Details

- Reaches were modeled three times
  - HEC-RAS 1D
  - SRH 2D
  - HEC-RAS 2D (Saint Venant) (aka “Full Momentum” setting)
- Reaches without hydraulic structures were chosen
Four Case Studies

- Bozeman Creek
- Walker River
- Fourmile Creek
- Weir Gulch
Walker River

- Lyon County, NV
- Larger River, bigger flows (Q100 = 6000 cfs)
- Desert/plain, flat slope very broad floodplain, unpredictable flow paths
Bozeman Creek

- Gallatin County, MT
- Smaller stream, lower flows (Q100 = 777 cfs)
- Moderate slope, transitions from heavily wooded area to agricultural areas
Fourmile Creek

- Boulder County, CO
- Very steep mountain canyon with $Q_{100} = 2799$ cfs
Weir Gulch

- Lakewood, CO
- Small, urbanized watershed (Q100 = 1388 cfs)
- Moderate slope, grassy “greenbelt” floodplain area
Study Details

- 1-percent-annual-chance event
- Each of the 1D and 2D models was created and run with a baseline Manning’s n value
- First, we made a comparison between each of the 2D models and the 1D model results using identical n values
- Second, Manning’s n values were adjusted at each cross section in the HEC-RAS 1D model until the water surface elevation matched the 2D model
Results - WSE

Average WSE Difference Compared to 1D Model, same n

<table>
<thead>
<tr>
<th>Location</th>
<th>SRH 2D</th>
<th>HEC-RAS 2D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walker River</td>
<td></td>
<td>Average = +0.41</td>
</tr>
<tr>
<td>Bozeman Creek</td>
<td></td>
<td>Average = +0.23</td>
</tr>
<tr>
<td>Weir Gulch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fourmile Creek</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The diagram illustrates the average WSE differences for SRH 2D and HEC-RAS 2D models. The average WSE difference for SRH 2D is +0.23 feet, and for HEC-RAS 2D, it is +0.41 feet.
SRH 2D vs HEC-RAS 2D

SRH 2D

HEC-RAS 2D
Results - n

Average Increase in 1D n Required to Create Equal WSE

<table>
<thead>
<tr>
<th>Creek</th>
<th>SRH 2D</th>
<th>HEC-RAS 2D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walker River</td>
<td></td>
<td>Average = 24%</td>
</tr>
<tr>
<td>Bozeman Creek</td>
<td></td>
<td>Average = 16%</td>
</tr>
<tr>
<td>Fourmile Creek</td>
<td></td>
<td>Average = 16%</td>
</tr>
<tr>
<td>Weir Gulch</td>
<td></td>
<td>Average = 16%</td>
</tr>
</tbody>
</table>

Adjustment to n

Walker River
Bozeman Creek
Fourmile Creek
Weir Gulch
Theoretical reality check

Average Increase in 1D n Required to Create Equal WSE

<table>
<thead>
<tr>
<th></th>
<th>SRH 2D</th>
<th>HEC-RAS 2D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walker River</td>
<td>16%</td>
<td>Average = 24%</td>
</tr>
<tr>
<td>Bozeman Creek</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>Fourmile Creek</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Weir Gulch</td>
<td>20%</td>
<td></td>
</tr>
</tbody>
</table>

Average = 16%

Average = 24%
Range of Adjustments

Average Increase in 1D n Required to Create Equal WSE - SRH 2D

- Walker River: 37%
- Bozeman Creek: 15%
- Fourmile Creek: 10%
- Weir Gulch: 1%

Average = 16%

Average Increase in 1D n Required to Create Equal WSE - HEC-RAS 2D

- Walker River: 45%
- Bozeman Creek: 24%
- Fourmile Creek: 14%
- Weir Gulch: 14%

Average = 24%
Complex Flow Path Comparison

Walker River

Weir Gulch
Range of Adjustments

Average Increase in 1D n Required to Create Equal WSE

SRH 2D

Walker River: 37%
Bozeman Creek: 15%
Fourmile Creek: 10%
Weir Gulch: 1%

Average Increase in 1D n Required to Create Equal WSE

HEC-RAS 2D

Walker River: 45%
Bozeman Creek: 24%
Fourmile Creek: 14%
Weir Gulch: 14%
**Recommendation**

When adjusting Manning’s n values for the creation of a 2D model, DECREASE Manning’s n values (compared to comparable 1D values) by...

<table>
<thead>
<tr>
<th>2D Model</th>
<th>Simple Flow Paths</th>
<th>Moderate (Default)</th>
<th>Complex Flow Paths</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRH 2D</td>
<td>0% - 10%</td>
<td>10% - 20%</td>
<td>20% - 40%</td>
</tr>
<tr>
<td>HEC-RAS 2D</td>
<td>0% - 15%</td>
<td>15% - 30%</td>
<td>30% - 50%</td>
</tr>
</tbody>
</table>
Tool of Choice
Wisconsin River
**Calibration Table**

<table>
<thead>
<tr>
<th>Type</th>
<th>Date/Time</th>
<th>Flow</th>
<th>Measured/Observed</th>
<th>Model</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured WSE (NWS Gage)</td>
<td>9/28/10 1:30 PM</td>
<td>65,000</td>
<td>795.38'</td>
<td>795.51'</td>
<td>0.13'</td>
</tr>
<tr>
<td></td>
<td>9/29/10 1:30 AM</td>
<td>60,000</td>
<td>794.88'</td>
<td>795.00'</td>
<td>0.12'</td>
</tr>
<tr>
<td></td>
<td>9/29/10 7:45 AM</td>
<td>55,100</td>
<td>794.38'</td>
<td>794.46'</td>
<td>0.08'</td>
</tr>
<tr>
<td></td>
<td>9/29/10 1:20 PM</td>
<td>49,000</td>
<td>793.77'</td>
<td>793.80'</td>
<td>0.03'</td>
</tr>
<tr>
<td></td>
<td>9/29/10 5:30 PM</td>
<td>45,000</td>
<td>793.38'</td>
<td>793.28'</td>
<td>-0.1'</td>
</tr>
<tr>
<td>Observed WSE</td>
<td>Peak*</td>
<td>67,500</td>
<td>795.38'</td>
<td>794.9'</td>
<td>= 0.1'</td>
</tr>
<tr>
<td></td>
<td>9/29/10 7:48 AM</td>
<td>55,100</td>
<td>4.9 ft/s</td>
<td>5.17 ft/s</td>
<td>0.27 ft/s</td>
</tr>
</tbody>
</table>

*The 65,000 cfs model results were used to compare against the peak high water mark elevation.*
<table>
<thead>
<tr>
<th>Type</th>
<th>Date/Time</th>
<th>Flow</th>
<th>Measured/Observed</th>
<th>Model</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured WSE (NWS Gage)</td>
<td>9/28/10 1:30 PM</td>
<td>65,000</td>
<td>795.38'</td>
<td>795.51'</td>
<td>0.13'</td>
</tr>
<tr>
<td></td>
<td>9/29/10 1:30 AM</td>
<td>60,000</td>
<td>794.88'</td>
<td>795.00'</td>
<td>0.12'</td>
</tr>
<tr>
<td></td>
<td>9/29/10 7:45 AM</td>
<td>55,100</td>
<td>794.38'</td>
<td>794.46'</td>
<td>0.08'</td>
</tr>
<tr>
<td></td>
<td>9/29/10 1:20 PM</td>
<td>49,000</td>
<td>793.77'</td>
<td>793.80'</td>
<td>0.03'</td>
</tr>
<tr>
<td></td>
<td>9/29/10 5:30 PM</td>
<td>45,000</td>
<td>793.38'</td>
<td>793.28'</td>
<td>-0.1'</td>
</tr>
<tr>
<td>Observed WSE</td>
<td>Peak*</td>
<td>67,500</td>
<td>795'+</td>
<td>794.9'</td>
<td>≈ -0.1'</td>
</tr>
<tr>
<td></td>
<td>9/29/10 1:20 PM</td>
<td>49,000</td>
<td>786.7'+</td>
<td>786.6'</td>
<td>≈ -0.1'</td>
</tr>
<tr>
<td>Measured Velocity</td>
<td>9/29/10 7:48 AM</td>
<td>55,100</td>
<td>4.9 ft/s</td>
<td>5.17 ft/s</td>
<td>0.27 ft/s</td>
</tr>
</tbody>
</table>

*The 65,000 cfs model results were used to compare against the peak high water mark elevation.
Rio Grande
Bar 3

Existing Conditions Inundation Depth Plots

The 2D model, based on 2010 topographic data, shows Bar 3 beginning to inundate around 4000 cfs and is fully inundated at 7000 cfs.

Depth, ft

2000 cfs  3000 cfs  4000 cfs  5400 cfs  7000 cfs
Bar 3
Acres of Rio Grande silvery minnow habitat at various discharges

- Project Conditions
- Existing Conditions

Discharge (cfs) vs. Silvery Minnow Habitat (acres)

Discharge values range from 2000 to 7000 cfs.

The graph shows a comparison between project conditions and existing conditions for silvery minnow habitat at various discharges.
Bar 3
Frequency-Dependent Availability of Silvery Minnow Habitat

![Graph showing the frequency-dependent availability of Silvery Minnow habitat under Project Conditions and Existing Conditions. The graph plots discharge (cfs) on the x-axis and Silvery Minnow Habitat (acre-days/year) on the y-axis. The Project Conditions line peaks at a higher habitat availability compared to the Existing Conditions line.]

Inset image of a Silvery Minnow.
<table>
<thead>
<tr>
<th>Boundary Category</th>
<th>Boundary Type</th>
<th>Permissible Shear Stress (lb/sq ft)</th>
<th>Permissible Velocity (ft/sec)</th>
<th>Citation(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Soils</strong></td>
<td>Fine colloidal sand</td>
<td>0.02 - 0.03</td>
<td>1.5</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Sandy loam (noncolloidal)</td>
<td>0.03 - 0.04</td>
<td>1.75</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Alluvial silt (noncolloidal)</td>
<td>0.045 - 0.05</td>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Silty loam (noncolloidal)</td>
<td>0.045 - 0.05</td>
<td>1.75 - 2.25</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Firm loam</td>
<td>0.075</td>
<td>2.5</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Fine gravels</td>
<td>0.075</td>
<td>2.5</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Stiff clay</td>
<td>0.26</td>
<td>3 - 4.5</td>
<td>A, F</td>
</tr>
<tr>
<td></td>
<td>Alluvial silt (colloidal)</td>
<td>0.26</td>
<td>3.75</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Graded loam to cobbles</td>
<td>0.38</td>
<td>3.75</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Graded silts to cobbles</td>
<td>0.43</td>
<td>4</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>Shales and hardpan</td>
<td>0.67</td>
<td>6</td>
<td>A</td>
</tr>
<tr>
<td><strong>Gravel/Cobble</strong></td>
<td>1-in.</td>
<td>0.33</td>
<td>2.5 - 5</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>2-4-in.</td>
<td>0.67</td>
<td>3 - 6</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>6-in.</td>
<td>2.0</td>
<td>4 - 7.5</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>12-in.</td>
<td>4.0</td>
<td>6.5 - 12</td>
<td>A</td>
</tr>
<tr>
<td><strong>Vegetation</strong></td>
<td>Class A turf</td>
<td>3.7</td>
<td>6 - 8</td>
<td>E, N</td>
</tr>
<tr>
<td></td>
<td>Class B turf</td>
<td>2.1</td>
<td>4 - 7</td>
<td>E, N</td>
</tr>
<tr>
<td></td>
<td>Class C turf</td>
<td>1.0</td>
<td>3.5</td>
<td>E, N</td>
</tr>
<tr>
<td></td>
<td>Long native grasses</td>
<td>1.2 - 1.7</td>
<td>4 - 6</td>
<td>G, H, L, N</td>
</tr>
<tr>
<td></td>
<td>Short native and bunch grass</td>
<td>0.7 - 0.95</td>
<td>3 - 4</td>
<td>G, H, L, N</td>
</tr>
<tr>
<td></td>
<td>Reed plantings</td>
<td>0.1-0.6</td>
<td>N/A</td>
<td>E, N</td>
</tr>
<tr>
<td></td>
<td>Hardwood tree plantings</td>
<td>0.41-2.5</td>
<td>N/A</td>
<td>E, N</td>
</tr>
<tr>
<td><strong>Temporary Degradable RECPs</strong></td>
<td>Jute net</td>
<td>0.45</td>
<td>1 - 2.5</td>
<td>E, H, M</td>
</tr>
<tr>
<td></td>
<td>Straw with net</td>
<td>1.5 - 1.65</td>
<td>1 - 3</td>
<td>E, H, M</td>
</tr>
<tr>
<td></td>
<td>Coconut fiber with net</td>
<td>2.25</td>
<td>3 - 4</td>
<td>E, M</td>
</tr>
<tr>
<td></td>
<td>fiberglass roving</td>
<td>2.00</td>
<td>2.5 - 7</td>
<td>E, H, M</td>
</tr>
<tr>
<td><strong>Non-Degradable RECPs</strong></td>
<td>Unvegetated</td>
<td>3.00</td>
<td>5 - 7</td>
<td>E, G, M</td>
</tr>
<tr>
<td></td>
<td>Partially established</td>
<td>4.0 - 6.0</td>
<td>7.5 - 15</td>
<td>E, G, M</td>
</tr>
<tr>
<td></td>
<td>Fully vegetated</td>
<td>8.00</td>
<td>8 - 21</td>
<td>F, L M</td>
</tr>
<tr>
<td><strong>Firnags</strong></td>
<td>6 - in. df</td>
<td>2.5</td>
<td>5 - 10</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>9 - in. df</td>
<td>3.8</td>
<td>7 - 11</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>12 - in. df</td>
<td>5.1</td>
<td>10 - 13</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>18 - in. df</td>
<td>7.6</td>
<td>12 - 16</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>24 - in. df</td>
<td>10.1</td>
<td>14 - 18</td>
<td>E</td>
</tr>
<tr>
<td><strong>Soil Bioengineering</strong></td>
<td>Wattles</td>
<td>0.2 - 1.0</td>
<td>3</td>
<td>C, I, J, N</td>
</tr>
<tr>
<td></td>
<td>Reed fascine</td>
<td>0.8-1.25</td>
<td>5</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>Coir roll</td>
<td>3 - 5</td>
<td>8</td>
<td>E, M, N</td>
</tr>
<tr>
<td></td>
<td>Vegetated coir mat</td>
<td>4 - 8</td>
<td>9.5</td>
<td>E, M, N</td>
</tr>
<tr>
<td></td>
<td>Live brush mattress (initial)</td>
<td>0.4 - 4.1</td>
<td>4</td>
<td>B, E, I</td>
</tr>
<tr>
<td></td>
<td>Live brush mattress (grown)</td>
<td>3.90-8.2</td>
<td>12</td>
<td>B, C, E, I, N</td>
</tr>
<tr>
<td></td>
<td>Brush layering (initial/grown)</td>
<td>0.4 - 6.25</td>
<td>12</td>
<td>E, I, N</td>
</tr>
<tr>
<td></td>
<td>Live fascine</td>
<td>1.25-3.10</td>
<td>6 - 8</td>
<td>C, E, I, J</td>
</tr>
<tr>
<td></td>
<td>Live willow stakes</td>
<td>2.10-3.10</td>
<td>3 - 10</td>
<td>E, N, O</td>
</tr>
<tr>
<td><strong>Hard Surfacing</strong></td>
<td>Gabion</td>
<td>10</td>
<td>14 - 19</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>12.5</td>
<td>&gt;18</td>
<td>H</td>
</tr>
</tbody>
</table>

* Ranges of values generally reflect multiple sources of data or different testing conditions.


ERDC TN-EMRRP SR-29
Predicting In-Stream Habitat Improvements with 2D Hydraulic Modeling: A Case Study from the North St. Vrain

Michael Baker International
Flood Recovery Goals

- Protect Life and Property
- Establish Geomorphic Stability
- Support Recovery of Ecosystem Processes

Predicting In-Stream Habitat Improvements with 2D Modeling
Predicting In-Stream Habitat Improvements with 2D Modeling

Conceptual Model

Surveying

Surface Creation

Hydrology and Hydraulics

Analysis and Conclusions
Conceptual Model

Support the Life History of the Target Species

www.wildtrout.org
Support the Life History of the Target Species

Wetland / Floodplain Connectivity

Backwater Areas

Channel Diversity

Structural Diversity

Naturally Sustained Features

Pool Habitat

Riffles and Gravel Bars

Sediment Continuity / Bank Stability

Predicting In-Stream Habitat Improvements with 2D Modeling
Support the Life History of the Target Species

Wetland / Floodplain Connectivity

Riffles and Gravel Bars

Sediment Continuity / Bank Stability

Backwater Areas

Natural Sustained Features

Channel Diversity

Structural Diversity

Pool Habitat

Eggs
Eggs, 2-3mm in diameter, hatch in alevins in a few months, depending on temperature.

Parr
Fry and parr are territorial and solitary. They need plenty of cover in the river from stones, weed and trailing bankside plants, and shallows water that is not too fast flowing. Only around 5% of young trout survive their first year of life.

Alevins
Alevins stay in the gravel, living off the yolk sac. Then they emerge as fry, set up territories and grow into parr.

Adults
Adult trout have a territory that gives them a good supply of food and a place to hide from predators; preferring deeper pools. In water they migrate, perhaps miles upstream to spawn. Brown trout live up to 5-20 years.
Predicting In-Stream Habitat Improvements with 2D Modeling

Conceptual Model

Surveying

Surface Creation

Hydrology and Hydraulics

Analysis and Conclusions
Predicting In-Stream Habitat Improvements with 2D Modeling

Accurate and Dense Survey

- RTK-GPS, 3 cm accuracy
- In Stream – Thalweg, Toe of Bank, Top of Bank
- Cross Sections, Side Channels, Water Surface
- 3700 points in total over 2.5 miles
Predicting In-Stream Habitat Improvements with 2D Modeling

Conceptual Model

Surveying

Surface Creation

Hydrology and Hydraulics

Analysis and Conclusions

Predicting In-Stream Habitat Improvements with 2D Modeling

Conceptual Model

Surveying

Surface Creation

Hydrology and Hydraulics

Analysis and Conclusions
Predicting In-Stream Habitat Improvements with 2D Modeling

Existing Surface Development

Blend of LiDAR and Survey

LiDAR for Floodplains

Survey for Channel Bathymetry and Features
Predicting In-Stream Habitat Improvements with 2D Modeling

Proposed Surface Development

BREAKLINE software – Mike Geenan, Green Watershed Restoration

Grade in Bankfull Cross Sections

Grade in Pool Cross Sections
Predicting In-Stream Habitat Improvements with 2D Modeling

Conceptual Model
Surveying
Surface Creation
Hydrology and Hydraulics
Analysis and Conclusions
Hydrology

- Effective Flood Insurance Study Flow Rates
- Estimates of Bankfull Flow
- Estimates of Environmental Flows
Recurrence Interval

CFS

Baseflows – Drought Refuge

Bankfull – Spawning, Backwater Refuges

Flood Refuges
Chose 2d Hydraulic Modeling

- Complex Floodplains
- Risk to Life and Property
- Superior Results vs. 1D models
- SRH-2d Modeling
Predicting In-Stream Habitat Improvements with 2D Modeling
Predicting In-Stream Habitat Improvements with 2D Modeling

Conceptual Model

Surveying

Surface Creation

Hydrology and Hydraulics

Analysis and Conclusions

9/25/2017
Habitat Modeling

- Conceptual Model with Parameters
- GIS Analysis
- 2d Hydraulic Results

Habitat Suitability
GIS Workflow

- Transform 2D hydraulic results from CSV into grids
- Estimate suitability ranges for velocity & depth*
- Query the Grids
- Automation

*Rearing Habitat: Depth < 1ft; Velocity < 0.82 ft/s
Pool Habitat: Depth > 2ft; Velocity < 0.5 ft/s
"I SPEND A LOT OF TIME ON THIS TASK. I SHOULD WRITE A PROGRAM AUTOMATING IT!"

**THEORY:**
- Writing Code
- Work on Original Task
- Automation Takes Over
- Free Time

**REALITY:**
- Writing Code
- Debugging
- Ongoing Development
- No Time for Original Task Anymore
- Rethinking
Predicting In-Stream Habitat Improvements with 2D Modeling
Results
Predicting In-Stream Habitat Improvements with 2D Modeling
Predicting In-Stream Habitat Improvements with 2D Modeling

BANKFULL

- Proposed Bankfull Rearing
- Existing Bankfull Rearing
Predicting In-Stream Habitat Improvements with 2D Modeling
10 YEAR

- Purple: 10yr Increased Floodplain Connectivity
- Yellow: 10yr Decreased Floodplain Connectivity
Predicting In-Stream Habitat Improvements with 2D Modeling

<table>
<thead>
<tr>
<th>Flows</th>
<th>Current</th>
<th>Proposed</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Inundated Area (m²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base flow (41 cfs)</td>
<td>46254</td>
<td>38644</td>
<td>-16%</td>
</tr>
<tr>
<td>Bankfull (350 cfs)</td>
<td>74440</td>
<td>75883</td>
<td>2%</td>
</tr>
<tr>
<td>10 yr flood (1123 cfs)</td>
<td>106333</td>
<td>123082</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>Rearing Habitat (m²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base flow (41 cfs)</td>
<td>2081</td>
<td>2762</td>
<td>33%</td>
</tr>
<tr>
<td>Bankfull (350 cfs)</td>
<td>3333</td>
<td>3047</td>
<td>-9%</td>
</tr>
<tr>
<td>10 yr flood (1123 cfs)</td>
<td>4308</td>
<td>10024</td>
<td>133%</td>
</tr>
<tr>
<td></td>
<td>Pool Habitat (m²)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base flow (41 cfs)</td>
<td>Next Time!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bankfull (350 cfs)</td>
<td>Next Time!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 yr flood (1123 cfs)</td>
<td>Next Time!</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

- It takes a team
- It takes some skills
- There’s actionable insights to be had
- Complexity is hard to model
- There’s more to be done!
Project Sponsors and Partners

- HUD Community Development Block Grant – Disaster Recovery, Project # CDBG-DR-P16-020
Questions?
Educating a 1D Dynamic SWMM Model using FLO-2D: A Case Study of the Old Town Drainage Basin in Fort Collins

Beck Anderson, City of Fort Collins
Jeremy Deischer, EI, ICON Engineering
Overview

- Project Background
- Project Scope
- EPA SWMM Model Elements
- FLO-2D – Steady and Unsteady State
- Calibration Process
- Next Steps
Old Town Basin

- North-Central Ft. Collins
- Established in 1800s
- Fully Developed Basin
- 1600+ Tributary Acres
- 8 Major Watersheds
- CSU Campus
- Flooding Potential
Flooding History

- Flooding Events
- Major Capital Projects Constructed
  - Howes, Locust, Oak, Willow
- Future Capital Projects
Flooding History

1992

2017

1992

2017
Need for Update

- New Software /Modeling Techniques Available
- Updated Terrain Data
- Floodplain Update
- Selected Plan
- Upcoming Capital Projects
Previous Analysis

- MODSWMM
  - Kinematic Wave Model
- Created in 2003
- Last Updated in 2005
- City Regulated Floodplain (> 200 cfs)

- Back in 2005...
  - Hurricane Katrina
  - Lance wins #7
  - Star Wars III
  - #1 Grossing Movie
  - #1 Selling Phone
Project Scope

- Verify Basin Boundaries
- Convert to EPA SWMM
  - Dynamic Wave
  - Storm Drain / Surface Flow
- Detention Basins
  - Storage – Discharge to Elevation - Discharge
- Account for Storm Drains ≥ 24 in
Trans-Basin Flows

Canal Importation Basin

CSU Study

Educating a 1D Dynamic SWMM Model using FLO-2D: A Case Study of the Old Town Drainage Basin in Fort Collins
EPA SWMM Model - Conduits

- Rain-on-grid FLO-2D provide an overview of overall drainage paths
- Identified flow splits at street intersections
- Storm Drains limited to 24-in and greater for model stability
EPA SWMM Model - Conduits

- Surface flow conduits sampled from DEM
- Calibration links extend beyond right-of-way
- Conveyance conduits within right-of-way
EPA SWMM Model - Conduits

Intersection Transect  Conduit Transect
### EPA SWMM Model – Conduits

#### Element Name: XX_Y###_ZZ_D

<table>
<thead>
<tr>
<th>XX</th>
<th>Outfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG</td>
<td>Magnolia</td>
</tr>
<tr>
<td>OK</td>
<td>Oak</td>
</tr>
<tr>
<td>CW</td>
<td>Campus West</td>
</tr>
<tr>
<td>HW</td>
<td>Howes</td>
</tr>
<tr>
<td>LC</td>
<td>Locust</td>
</tr>
<tr>
<td>LM</td>
<td>Lemay</td>
</tr>
<tr>
<td>MM</td>
<td>Mulberry/Myrtle</td>
</tr>
<tr>
<td>WL</td>
<td>Willow</td>
</tr>
<tr>
<td>SC</td>
<td>Spring Creek</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Y</th>
<th>Element Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Basin</td>
</tr>
<tr>
<td>J</td>
<td>Junction</td>
</tr>
<tr>
<td>O</td>
<td>Outfall</td>
</tr>
<tr>
<td>L</td>
<td>Link, Conveyance</td>
</tr>
<tr>
<td></td>
<td>Element</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>###</th>
<th>Identification Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Identification numbers generally increase in upstream direction.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ZZ</th>
<th>Link Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF</td>
<td>Surface Flow</td>
</tr>
<tr>
<td>P</td>
<td>Pipe</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>D</th>
<th>Link Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>North</td>
</tr>
<tr>
<td>S</td>
<td>South</td>
</tr>
<tr>
<td>E</td>
<td>East</td>
</tr>
<tr>
<td>W</td>
<td>West</td>
</tr>
</tbody>
</table>
FLO-2D Surface Flow Diversions

- 57 Intersections
- 1 Detention Area
FLO-2D

- Physical process model that routes rainfall-runoff
- Volume Conversation Model
- Computes overland flow in 8-directions
FLO-2D Steady State Model

- Range of steady state inflows
- FLO-2D output target flows for SWMM
FLO-2D Steady State Model
Calibrating Intersection Links

- Inlet offsets adjusted until 100-yr flow within 10%

<table>
<thead>
<tr>
<th>Diversion Number</th>
<th>XS ID (FLO2D)</th>
<th>Location</th>
<th>Intersection Target Inflow (cfs)</th>
<th>Intersection Outflow (cfs)</th>
<th>FLO2D Rating Curve (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Intersection 5-Cherry St. / N Whitcomb St. - 5 ft Cells</td>
<td>0</td>
<td>20</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Intersection Target Inflow (cfs)</td>
<td>0.0</td>
<td>19.1</td>
<td>44.1</td>
<td>86.3</td>
</tr>
<tr>
<td></td>
<td>Intersection Outflow (cfs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Flow E on Cherry</td>
<td>0.0</td>
<td>14.2</td>
<td>32.8</td>
<td>60.4</td>
</tr>
<tr>
<td>7</td>
<td>Flow S on Whitcomb</td>
<td>0.0</td>
<td>4.9</td>
<td>11.3</td>
<td>25.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface Outflow Link Name</th>
<th>Link Flow Results (cfs)</th>
<th>Target Flow</th>
<th>Percent Error (based on total flow)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100-yr</td>
<td>10-yr</td>
<td>2-yr</td>
</tr>
<tr>
<td>TOTAL OUTFLOW</td>
<td>199.9</td>
<td>73.5</td>
<td>29.3</td>
</tr>
<tr>
<td>HW_L330_SF_E</td>
<td>122.6</td>
<td>49.8</td>
<td>20.5</td>
</tr>
<tr>
<td>HW_L330_SF_S</td>
<td>77.2</td>
<td>23.7</td>
<td>8.8</td>
</tr>
</tbody>
</table>

\[ f_x = \text{FORECAST(M121, INDEX(D122:K122,1, MATCH(M121,D121:K121,1)):INDEX(D122:K122,1, MATCH(M121,D121:K121,1)+1), INDEX(D121:K121,1, MATCH(M121,D121:K121,1)):INDEX(D121:K121,1, MATCH(M121,D121:K121,1)+1)) } \]
College Ave. / Mulberry St.

- Significant ponding behind roadway crowns
- Ponding noted in area as far back as 1960s.
Educating a 1D Dynamic SWMM Model using FLO-2D: A Case Study of the Old Town Drainage Basin in Fort Collins
Previous Analysis

- 5 separate outlets
- Weir segment analyzed by Flowmaster
Educating a 1D Dynamic SWMM Model using FLO-2D: A Case Study of the Old Town Drainage Basin in Fort Collins
College Ave. / Mulberry St. Pond
### FLO-2D Results

<table>
<thead>
<tr>
<th>Location</th>
<th>XS ID (FLO2D)</th>
<th>Surface Outflow</th>
<th>SWMM Model Results</th>
<th>Target Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Link Flow Results (cfs)</td>
<td>Percent of Total Outflow</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>100-yr</td>
<td>10-yr</td>
<td>2-yr</td>
</tr>
<tr>
<td>N on Mason St.</td>
<td>XS24</td>
<td>MG_L180_SF_N</td>
<td>257.93</td>
<td>39.7</td>
</tr>
<tr>
<td>N on College Ave.</td>
<td>XS6</td>
<td>MG_L055_SF_N</td>
<td>100.25</td>
<td>14.4</td>
</tr>
<tr>
<td>E on Magnolia St.</td>
<td>XS7</td>
<td>MG_L055_SF_E</td>
<td>36.82</td>
<td>0.5</td>
</tr>
<tr>
<td>E on Mulberry St.</td>
<td></td>
<td>MG_L130_SF_E</td>
<td>227.28</td>
<td>35.0</td>
</tr>
<tr>
<td>E on Myrtle St.</td>
<td></td>
<td>MG_L604_SF_E1</td>
<td>157.43</td>
<td>44.5</td>
</tr>
<tr>
<td><strong>TOTAL FLOW</strong></td>
<td></td>
<td></td>
<td>779.7</td>
<td>133.6</td>
</tr>
</tbody>
</table>
But wait! Just when you thought you were finished...
Surface Depression Storage

- Must be filled before flow is exchanged with a neighbor grid element
- Typical
  - $0.004 \text{ ft.} < \text{TOL} < 0.1 \text{ ft.}$
- Urban Rec: 0.004 ft.
- Previous version used 0.1-ft no matter what was entered
## FLO-2D Results

### Table B-4: College & Mulberry and Mason & Mulberry Ponds (P604 - P605) Calibration Results

<table>
<thead>
<tr>
<th>Location</th>
<th>XS ID (FLO2D)</th>
<th>Surface Outflow Link Name</th>
<th>SWMM Model Results</th>
<th>FLO2D Model Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Link Flow Results (cfs)</td>
<td>Percent of Total Outflow</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100-yr</td>
<td>100-yr</td>
</tr>
<tr>
<td>N on Mason St.</td>
<td>XS24</td>
<td>MG_L180_SF_N</td>
<td>122.75</td>
<td>13%</td>
</tr>
<tr>
<td>N on College Ave.</td>
<td>XS6</td>
<td>MG_L055_SF_N</td>
<td>146.19</td>
<td>16%</td>
</tr>
<tr>
<td>E on Magnolia St.</td>
<td>XS7</td>
<td>MG_L055_SF_E</td>
<td>49.84</td>
<td>5%</td>
</tr>
<tr>
<td>E on Mulberry St.</td>
<td>-</td>
<td>MG_L130_SF_E</td>
<td>284.66</td>
<td>31%</td>
</tr>
<tr>
<td>E on Myrtle St.</td>
<td>-</td>
<td>MG_L604_SF_E1</td>
<td>329.35</td>
<td>35%</td>
</tr>
<tr>
<td><strong>TOTAL FLOW</strong></td>
<td></td>
<td></td>
<td><strong>932.8</strong></td>
<td></td>
</tr>
</tbody>
</table>
EPA SWMM Model

- 3 Design Storms
  - 2-, 10-, & 100-year
- 187 Subcatchments
- 393 Junctions
- 7 Storage Units
- 592 Conduits
Next Steps

- Potential Inundation Areas
- Review and adjust previous Selected Plan of Improvements
- Updating Regulatory Floodways within City right-of-way
- Upcoming Capital Projects
  - Mulberry St. / Riverside Avenue
  - Magnolia St. Outfall
Thank you

- Questions?
Selecting the Right Model

Josh Hollon & Brinton Swift
Importance of Model Selection

- **Project Management**
  - Appropriate use of available budget
  - Schedule management

- **Data Needs**
  - Input
  - Output

- **Risks**
  - Hydraulics represent huge risks
  - Lack of detail may not identify risks
  - Simplifications can overestimate risk
  - Wrong analysis can be more costly
Importance of Model Selection

- Finding the right tool
  - Leverage the tools capabilities
  - Proprietary vs Open Source
  - Future Users

- Available Programs
  - Not an endorsement or recommendation

- Comments/Improvements
  - Email us
Normal Depth

- Irregular Geometry
- Unsteady Flow
- Hydraulic losses
- Backwater Impacts
- Structures
- Spatially varied H&H
- Spatial flow change
• Irrigation channels
• Roadside ditches
• Curb & gutters
• Gutter pans
• Sidewalk chases
- Simple input
- Simple output
Culvert

- Multiple, non-uniform openings
- Disconnected culverts
- Unsteady Flow
- Unknown downstream WSEL
- Need more than simple upstream/downstream hydraulic result
- Single Barrel
- Multiple Barrel
- Standard culvert shape
- Simplistic Overtopping
• Simple Input
• Simple Output
1D Steady State

- Natural or constructed flood storage
- Unsteady flow
- Diverging flow paths
- Varied WSEL at bridges/culverts
- Flow redirection
- Rapidly varied flow
- Need for sediment transport results
- Channels with varying vegetation/roughness
- Multiple channel reaches
- Bridges
- Culverts
- Parallel Floodplains
- Wide range of applications
  - Bridge analysis
  - Scour analysis
  - Channel design
  - FEMA Permitting
  - Simple prismatic channels
  - Complex channel section geometry
1D Unsteady State

- Braided Streams
- Diverging flow paths
- Varied WSE at bridges/culverts
- Highly skewed bridges
- **Flood routing (Volume!)**
  - Floodplain storage
  - Looped hydrograph
  - Split flow timing
- **Storm durations**
- **Sediment transport**
- **Tides or Reservoir operations**
- More complex analysis
  - Hydrographs
  - Computational stability
  - Model run times
- More output data
  - Animated WSE
  - Durations of flow
  - Volumes of flow
- More experience needed
2D

- Vertical velocity distribution
- Complex hydraulic losses
- Vertical sediment profiles
- Need dynamic hydraulic loads on structures
- Split flow paths
  - Bridges
  - Braided systems
  - Complex floodplains
- Non-uniform WSE
- Highly skewed bridges
- Floodplain storage
• More spatial detail
  • More terrain data
• Great for visualizations
  • Easy to understand
• Informative for 1D models
• Requires experience
• More dimensions doesn’t mean more expensive!
Questions

- Josh Hollon, 303.323.9853
  Josh.Hollon@HDRInc.com

- Brinton Swift, 303.318.6312
  Brinton.Swift@HDRInc.com