SESSION 1

Stormwater Management: RDAs—a New Acronym to Learn

Paul Hindman, UDFCD

ABSTRACT:

At the federal government level the topic of stormwater has been and still is high on the list for the President, Congress, and many federal agencies. Recently the American Rivers, the Conservation Law Foundation and the Natural Resources Defense Council have zeroed in on an existing clause in the Clean Water Act that allows for Residual Designation Authorities or RDA's. The Environmental Protection Agency (EPA) has test driven his approach in Regions 1, 3, and 9. Colorado is in Region 8 but I'm sure RDA's are coming our way,

This presentation will provide a description of what a RDA is and how they are now being implemented. Also discussed will be the response from APWA, NAFSMA, NCL, NACo, and USCM highlighting the issue of another layer of stormwater regulations.

RDA's-a New Acronym to Learn

By: Paul A. Hindman, Executive Director

Reader’s Digest Association

Real Diaper Association

real Diaper association

Resource Development Administration

Really Dumb Actions

Reader's Digest Association

Real Diaper Association

real Diaper association

Resource Development Administration

Really Dumb Actions

Reader’s Digest Association

Real Diaper Association

Resource Development Administration

Really Dumb Actions

Reader's Digest Association

Real Diaper Association

real Diaper association

Resource Development Administration

Really Dumb Actions

Regional Discharge Act

Reader's Digest Association

Real Diaper Association

real Diaper association

Resource Development Administration

Really Dumb Actions

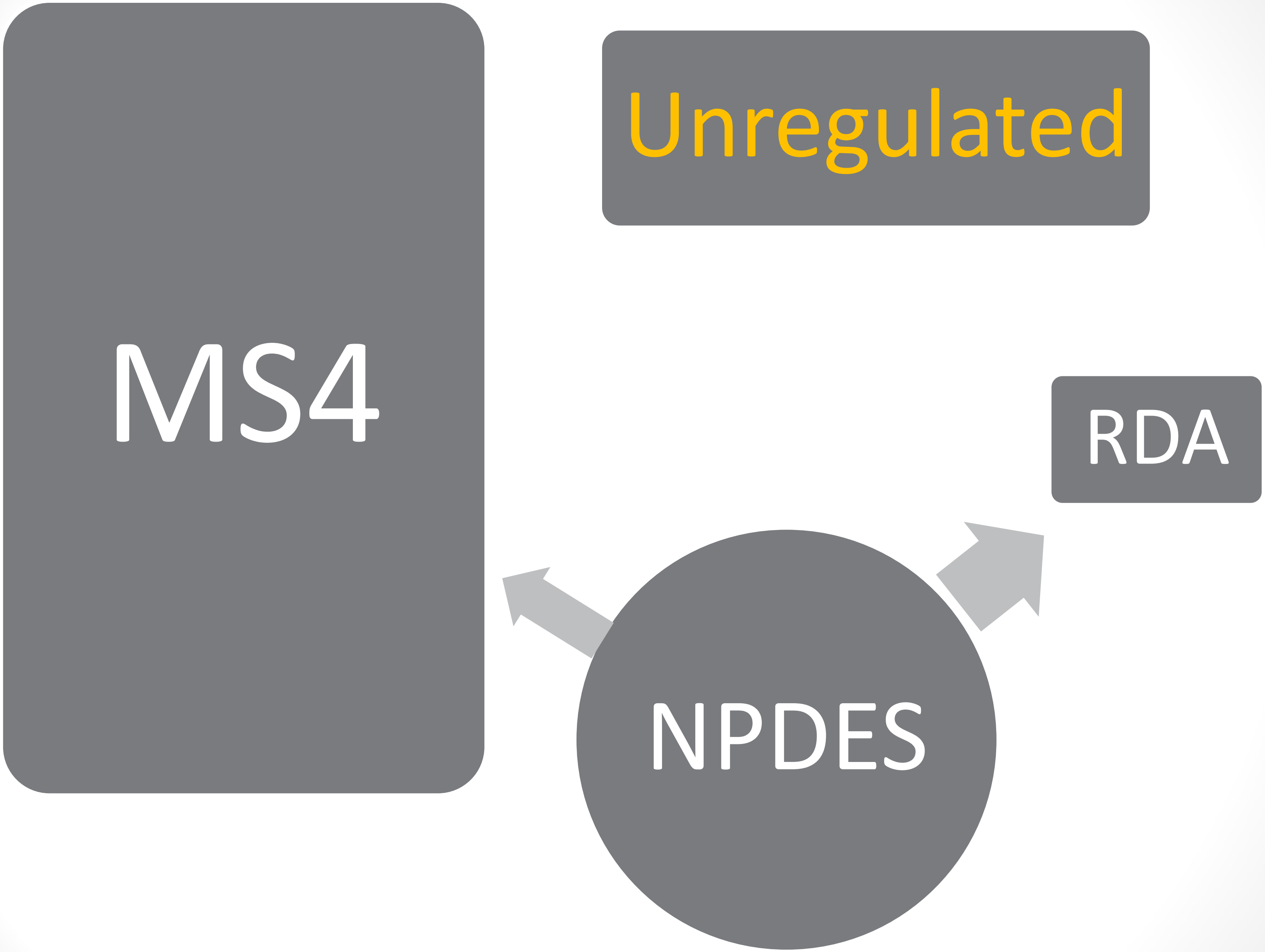
Regional Discharge Act

Residual Designation Authority (RDA)

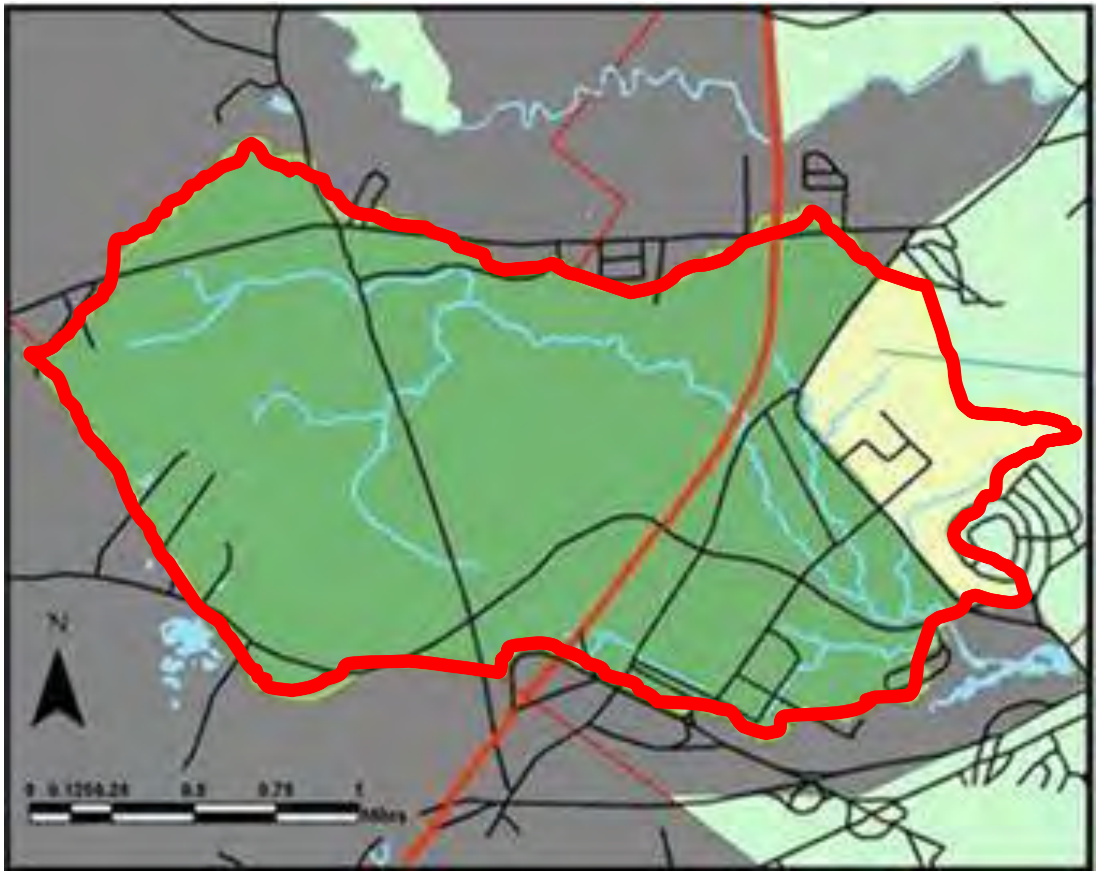
- Separate stormwater permit
- Commercial and Industrial

Residual Designation Authority

(not covered by MS4)


Unregulated
MS4
RDA
NPDES

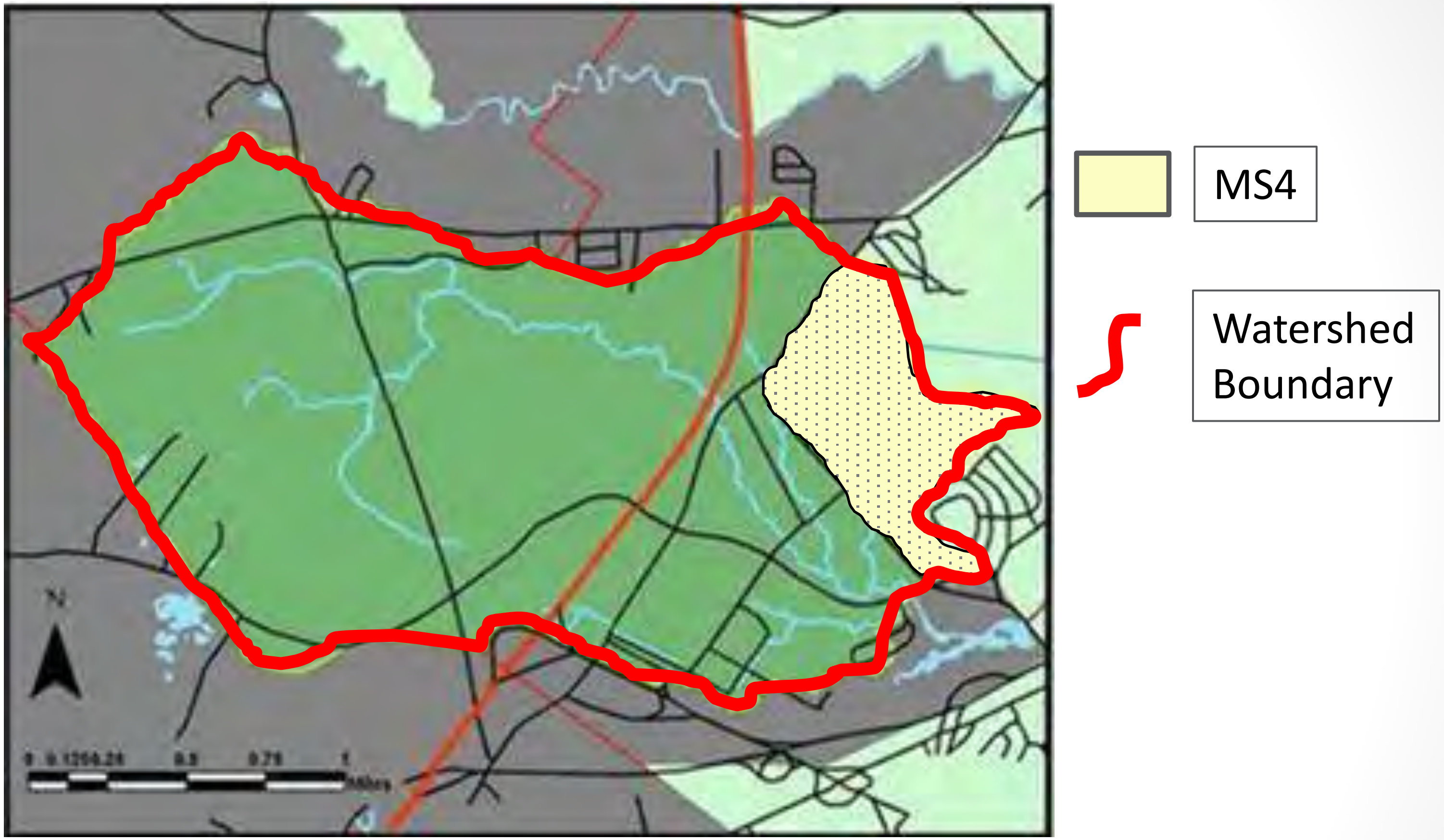
- 1987-Clean Water Act amendments include stormwater
- 2008-First RDA



Watershed Boundary

Long Creek Watershed

Maine

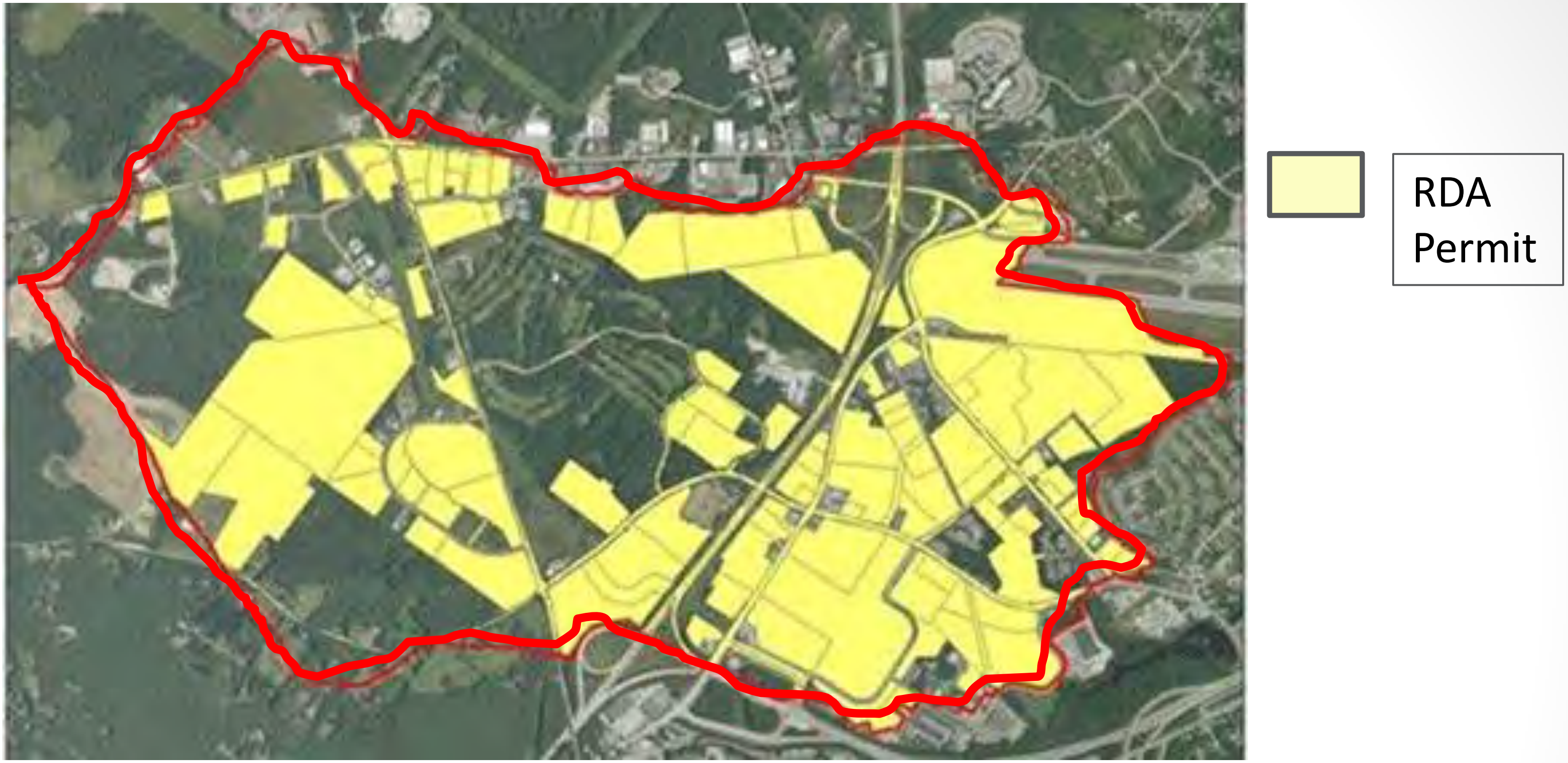


Long Creek Watershed

Maine

Long Creek Watershed

Maine



Long Creek Watershed

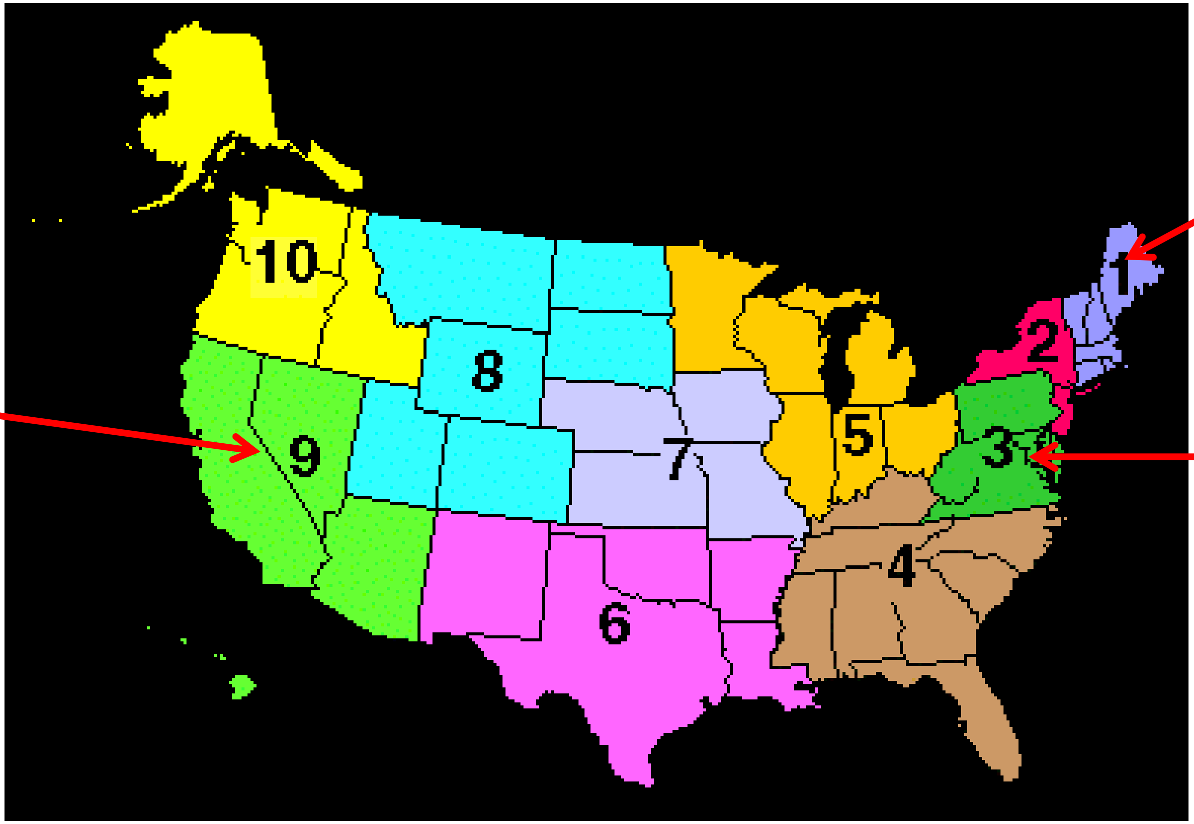
Maine

- Lone Creek Watershed Management District. 3.45 sq. mile area; $1.45 million; 5-Yr. budget
- $3000 per land owner per year
- General consensus is that it worked.

Long Creek Watershed

Maine

July, 2013



February, 2014

However

Evaluating Potential for Hazardous Sediments in Stormwater Quality Control Facilities

Holly Piza, UDFCD
Eliot Wong, Wright Water Engineers

ABSTRACT:

Urban stormwater quality treatment facilities are designed to maximize the removal of sediment and other solids. Such solids have an affinity for a host of pollutants commonly found in urban runoff, such as heavy metals, solvents and other chemicals. The disposal of these pollutants may be regulated under federal law by the Resource Conservation and Recovery Act (RCRA) and under the companion Colorado state law, Colo. Rev. Stat. § 25-15-301 *et seq.* These laws define the compounds regulated as hazardous wastes, and the circumstances in which those compounds are regulated.

Accumulated sediments must periodically be removed to assure proper facility function. If the sediment is classified as a hazardous waste due to the presence of certain regulated pollutants, special (and often expensive) treatment and/or disposal requirements may be applicable.

This paper (1) describes circumstances under which stormwater BMP sediments can be classified as hazardous wastes; (2) briefly addresses major legal and regulatory considerations and initially assesses how this issue is being addressed in other locations; (3) presents sediment chemistry data for ten representative BMPs in the UDFCD region, including an evaluation of whether or not the sediments in these BMPs could be classified as hazardous wastes; and (4) provides recommendations for managing this potential issue.

Potential for Hazardous Sediments in Stormwater Quality Treatment Facilities

Holly Piza, P.E., Urban Drainage & Flood Control District

Eliot Wong, P.E., Wright Water Engineers

2014 UDFCD Annual Seminar April 15,2014

Agenda

Project Importance
Project Approach
Cost of testing/cost of disposal
Beneficial Uses
What Does it all Mean?

Section 9: Solid Waste Impoundments (Regulations pertaining to Solid Waste Sites and Facilities 6 CCR 1007-2)

Who's Responsible?

What should we test?

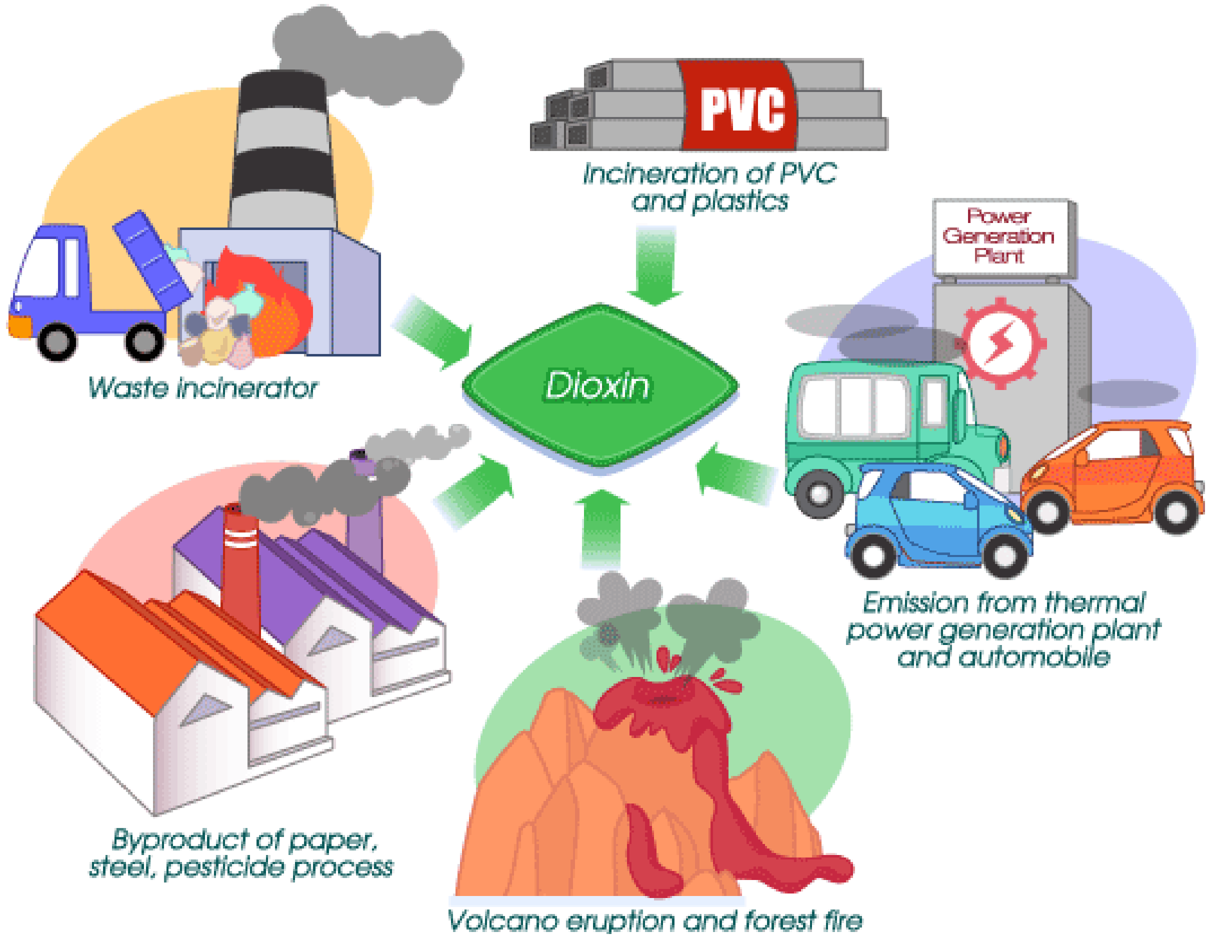
PCBs…

(polychlorinated
biphenyl)

PCBs…

Hudson River, 2009

Dioxin…

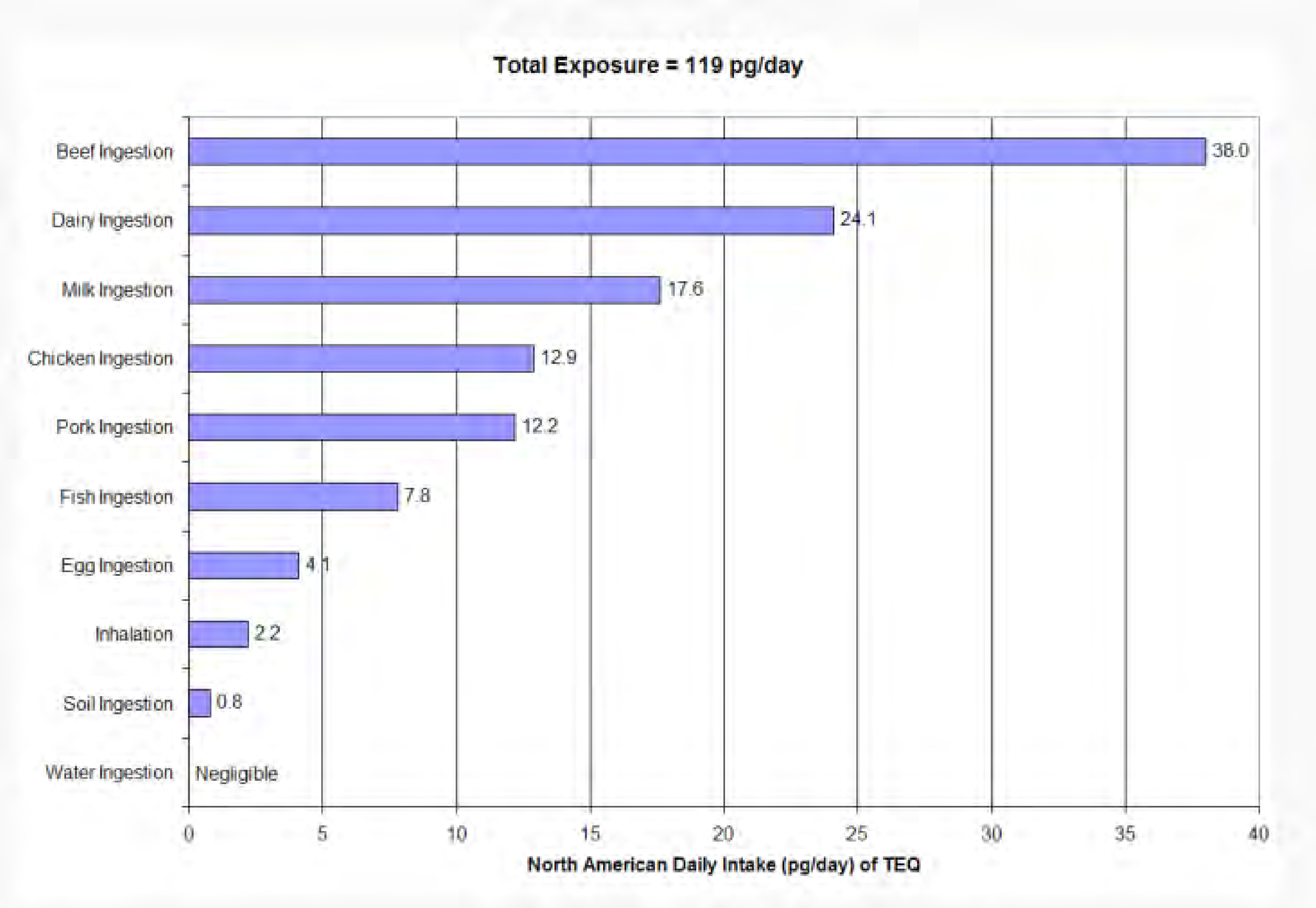


Source: Tunza Eco-Generation

Myth or Fact?

Microwaving or freezing plastic can release dioxins?

Dioxin…



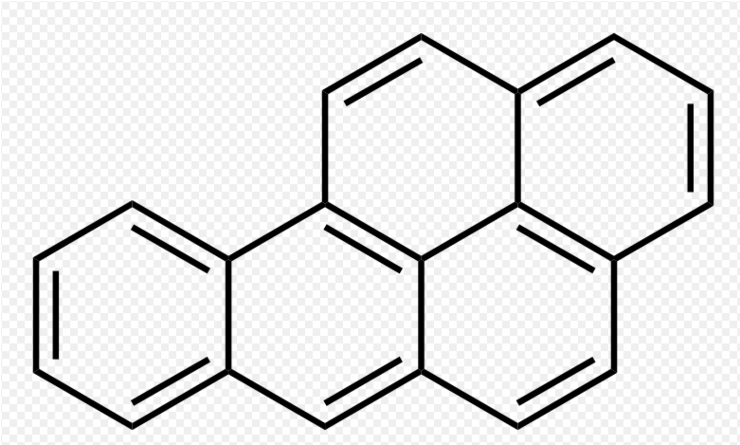
Schecter A, Cramer P, Boggess K, *et al* (2001)

Pesticides…

Pesticides…

PAHs…

(Polycyclic aromatic hydrocarbon)



What did we do and how did we do it?

Our Approach

1. Review of Resource Conservation & Recovery Act Provisions (RCRA)
2. Review of Literature and National Interviews
3. Field Sampling Program within UDFCD Boundary
4. Review of Sample Results
5. Legal Review
6. Conclusions & Recommendations

What is hazardous waste???

Does it exhibit one or more of these characteristics?

- Ignitability
- Corrosivity
- Reactivity
- Toxicity

Is it listed on one of these (developed by the EPA)?

- F-list (non-specific source wastes)
- K-list (source-specific wastes)
- P-list or U-list (discarded commercial chemical products)

What is hazardous waste???

What is hazardous waste???

CORROSIVE

REACTIVE

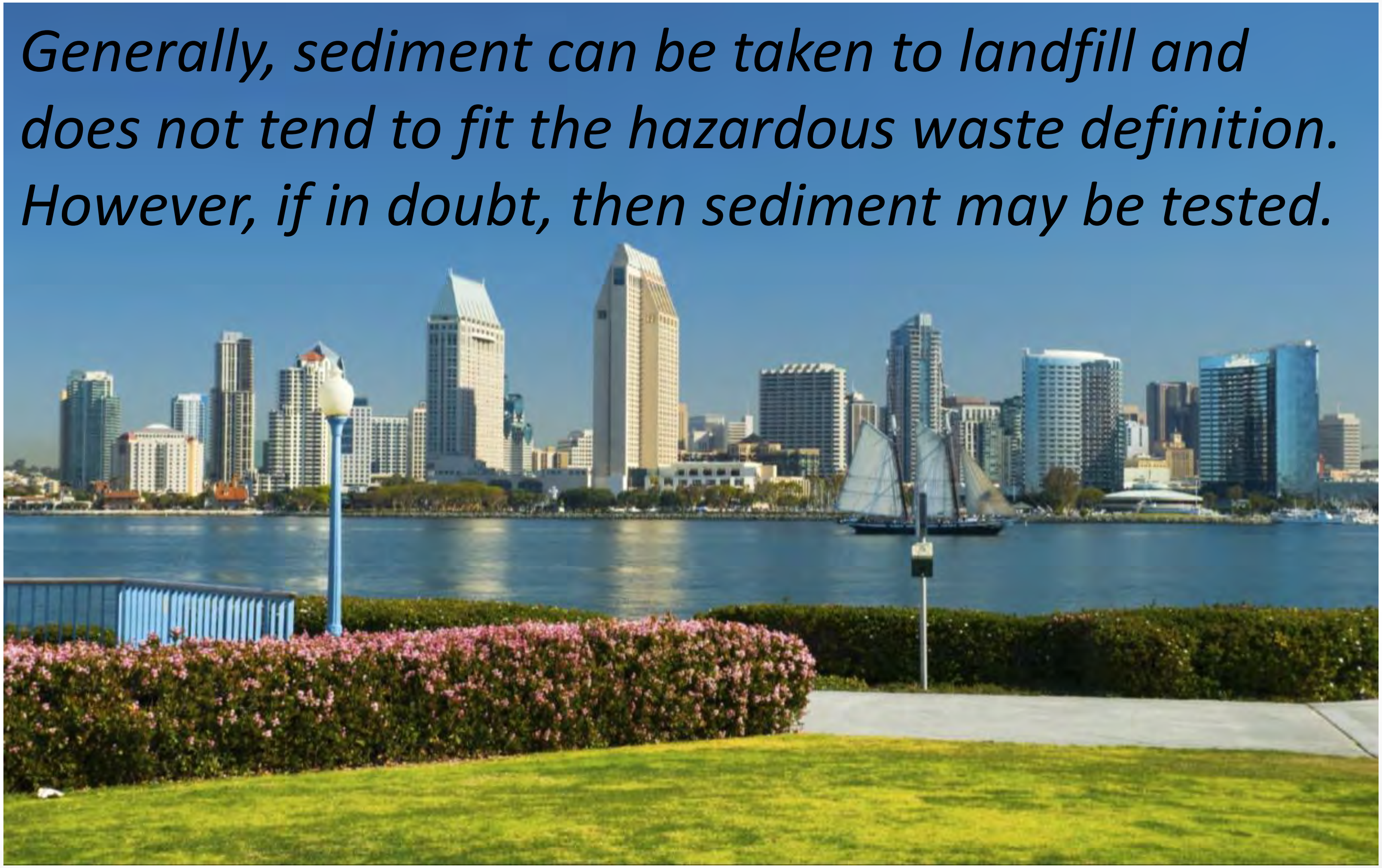
TOXIC

The Mixture Rule

The Derived-from Rule

The Contained-in Policy

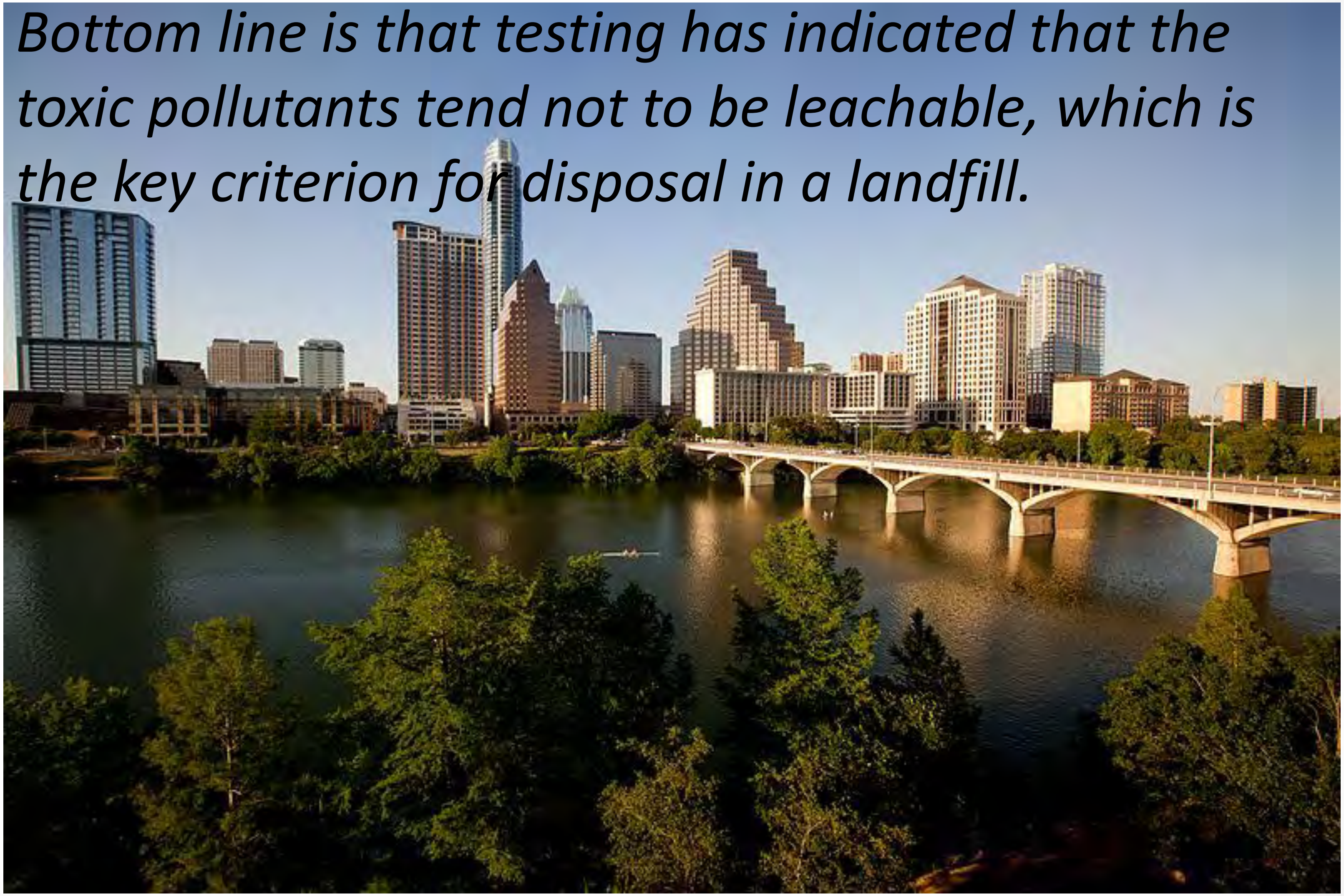
From around the nation…



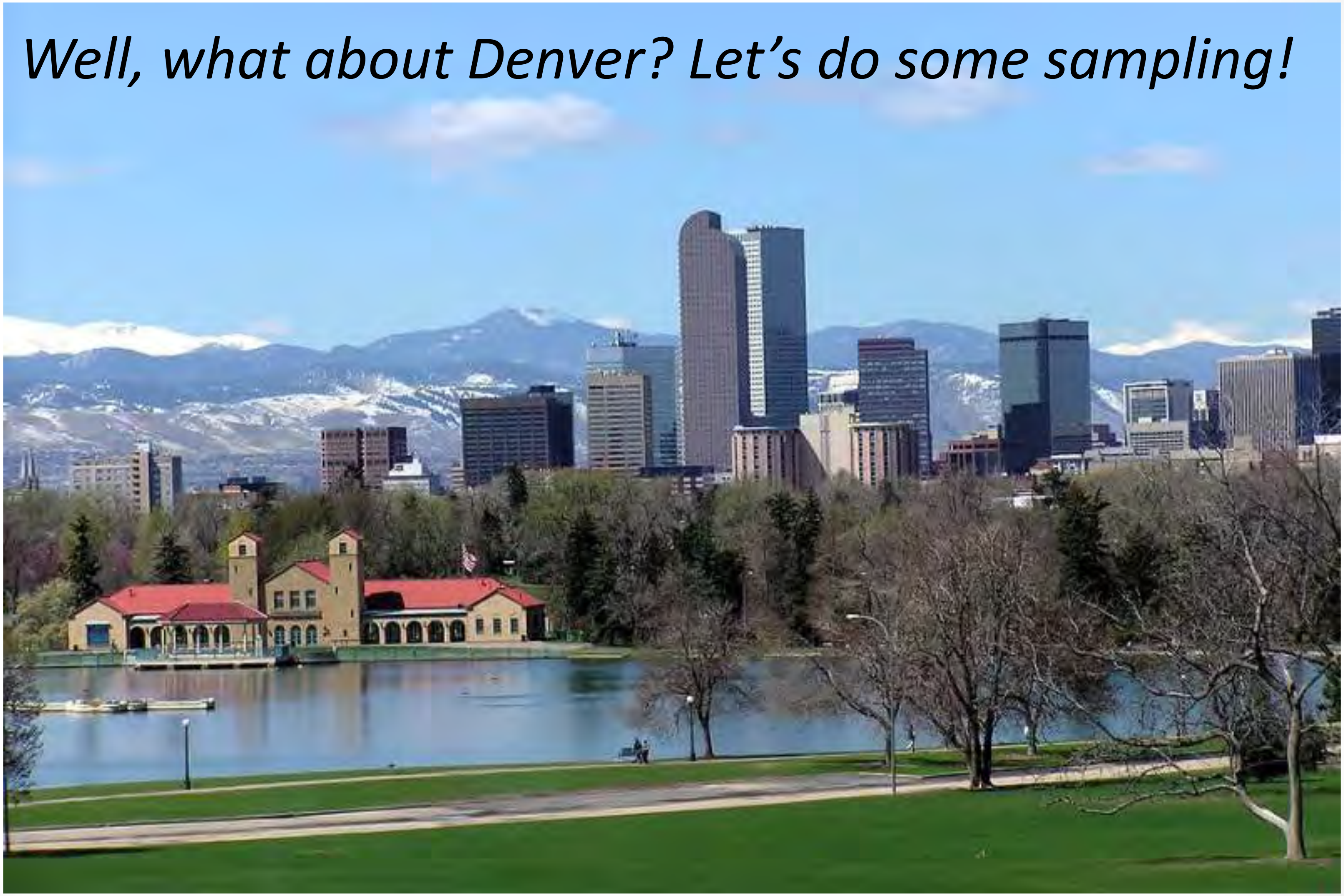
Jim Nabong, City of San Diego, California

Tracy Tackett, Seattle Public Utilities

Bottom line is that testing has indicated that the toxic pollutants tend not to be leachable, which is the key criterion for disposal in a landfill.



Leila Gosselink, City of Austin, Texas



Eliot Wong & Holly Piza, Denver, Colorado

Field Sampling Program

10 Sites

6 Detention Basins/4 Retention Ponds

- Residential
- Recreational/Open Space
- Commercial
- Airport
- Ex-military site

Sampling Sites

Residential detention basin - Denver

Tested for:

TCLP
Paint Filter

Sampling Sites

Residential detention basin - Denver

Tested for:

TCLP
Paint Filter
Reactivity/Ignitability/
Corrosivity
PAHs

Sampling Sites

Recreational retention pond - Westminster

Tested for:

TCLP
Paint Filter

Sampling Sites

Recreational /residential retention pond - Westminster

Tested for:

TCLP
Paint Filter
Reactivity/Ignitability/
Corrosivity

Sampling Sites

Commercial retention pond - Broomfield

Tested for:

TCLP
Paint Filter
PAHs

Sampling Sites

Jefferson County Airport detention basin - Broomfield

Tested for:

TCLP
Paint Filter
Reactivity/Ignitability/
Corrosivity
BTEX
PAHs

Sampling Sites

Commercial retention pond - Denver

Tested for:

TCLP
Paint Filter
Reactivity/Ignitability/
Corrosivity
BTEX

Sampling Sites

Commercial (ex-military) detention basin - Aurora

Tested for:

TCLP
Paint Filter
BTEX

Sampling Sites

Commercial detention basin - Golden

Tested for:

TCLP
Paint Filter
Reactivity/Ignitability/
Corrosivity
BTEX
PAHs

Sampling Sites

Commercial detention basin - Denver

Tested for:

TCLP
Paint Filter
PAHs

Sample Results

All 10 sites were BELOW hazardous levels for ALL constituents tested!

GOOD NEWS!

What does this mean?

Your BMP needs maintenance… now what?

Sampling Costs (Lab only)

- Full TCLP: \$800-\$1000
- Paint Filter: \$20-\$40
- RCRA Characteristics (reactivity, corrosivity, ignitability): \$100-\$120
- BTEX: \$40-\$60
- PAHs: \$180-\$200

Excavation/Haul/Disposal

$15/CY typically

$85/CY when hazardous

Solid Waste, Hazardous Waste, or Environmental Media?

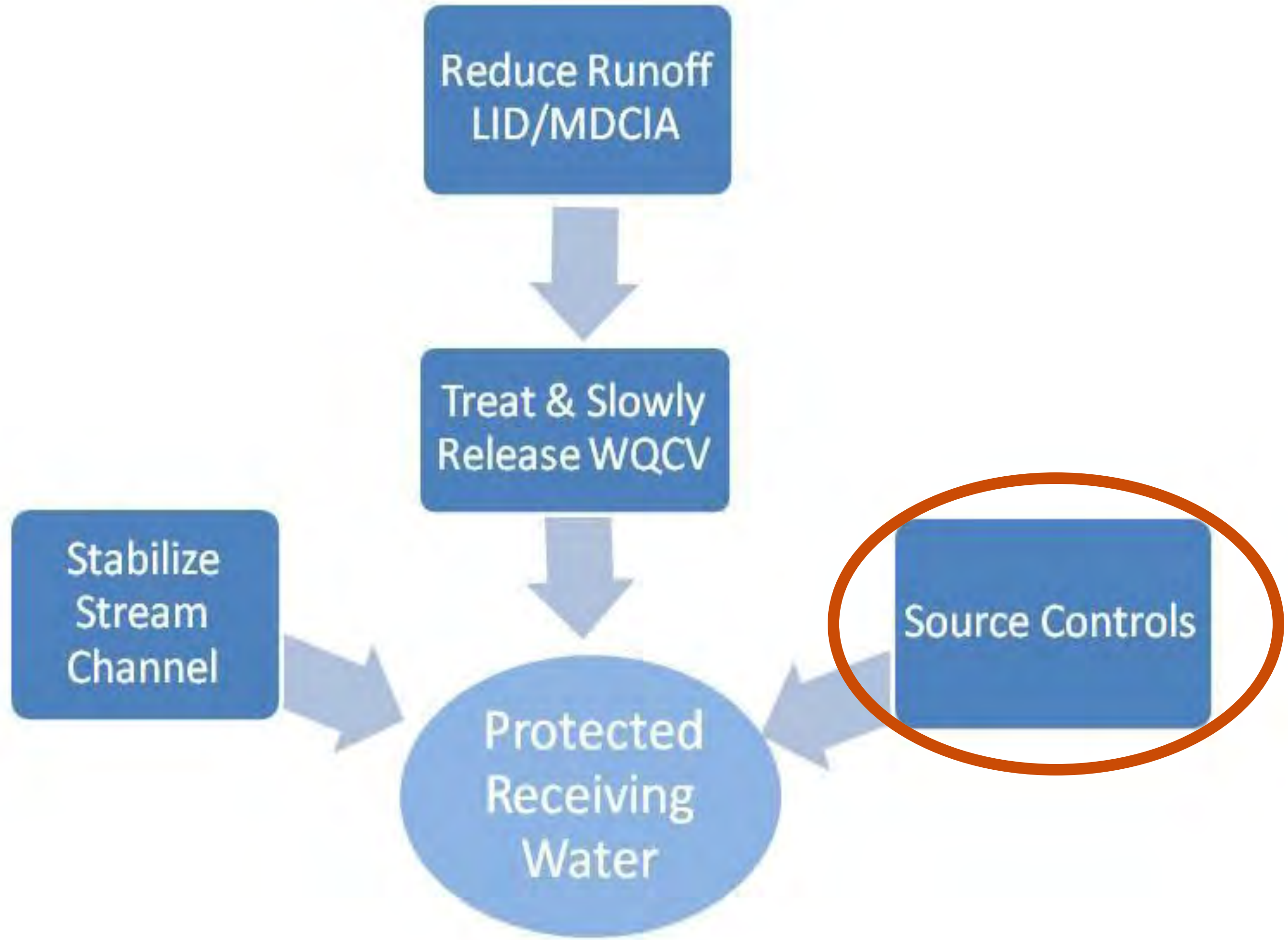
If the material is considered "solid waste", beneficial use is regulated by CDPHE and the material would need to be tested for any constituents that might be anticipated. Solid waste is source dependent. However, the State has not made a determination that sediment removed from a stormwater facility would be considered "solid waste". It may be considered "environmental media" which is not regulated.

(Per a phone call with David Snapp at CDPHE)

Beneficial Use?

March 2014
New Groundwater Protection (GPV) tables from CDPHE

Source Control



The Four Step Process for Stormwater Management

Thank you!

- Scot Anderson, Hogan Lovells US, LLP
- Seaton Thedinger, Hogan Lovells US, LLP
- Doug Eagleton, CDPHE

The full study is available at www.udfcd.org

New Approaches to Project Management

David Bennetts and Laura Kroeger, UDFCD
Mary Powell, ERO Resources

ABSTRACT:

How is UDFCD's Design, Construction, and Maintenance (DCM) program approaching projects differently and why? For organizations to stay relevant and effective, it's essential for them to reflect on their performance on a regular basis. The DCM program started this reflection process by first revisiting our **Program Core Values** to ensure decisions and projects were being led based on these principles. During this time, we realized that a program purpose statement would be a useful gage to help us stay in alignment with the District's overall mission and vision statements. The program purpose solidifies why drainage and flood control projects are funded and what the intended outcome is.

While developing the purpose statement, several different perspectives were sought out to ensure the statement would be universal in its application. This was also the opportunity to formalize and give recognition to the importance of stream health in floodplain management. Mary Powell, with ERO Resources, will share the ecological perspective on why stream health is a critical part of the equation on how the DCM program defines the success of a project.

DCM will share its purpose statement and how it is helping our program to think differently about how we approach and deliver projects to better meet the District's mission and vision. Two specific areas that will be discussed in detail are the overall project delivery methods followed by how routine work is being re-evaluated.

When examining the traditional Design-Bid-Build delivery approach and comparing it to our core values and purpose statement, there was a disconnect. DCM highly regards relationships and collaboration when implementing projects and the traditional construction delivery vehicle of Design-Bid-Build has combative relationships embedded in the process. We will introduce an alternative project delivery option called Project Partners that engages owners, consultants, and contractors at the onset of a project to work collaboratively to deliver project goals.

The District has been providing routine maintenance services on major drainageways throughout the metro area for over 40 years. Typically, these services have focused on mowing and debris removal with spot tree thinning, weed management, and sediment removal. The question that is now being asked is, "Is this the most efficient and effective way to maintain streams with the overall intent of protecting people and property?" DCM is developing a different approach that seeks the right balance of meeting public expectations; flood control function; and promotion of a healthy ecosystem to provide increased flood protection and better utilization of resources.

New Approaches to Project Management

David Bennetts, DCM Program

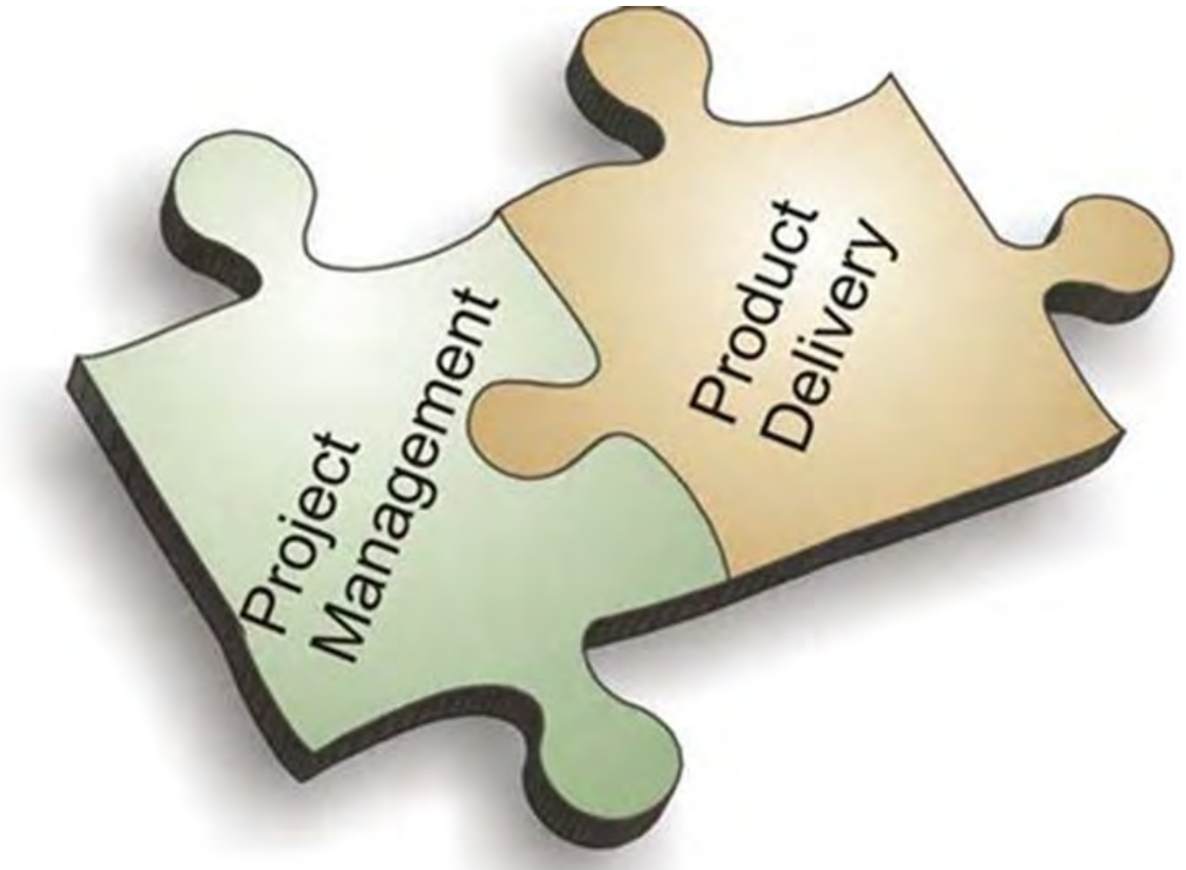
Laura Kroeger, DCM Program

Mary Powell, ERO Resources

New Approaches to Project Management

- DCM Program Core Values
- DCM Purpose Statement
- A Stream Health Perspective
- Alternative Project Delivery
- Changes in Vegetation Management

New Approaches to Project Management



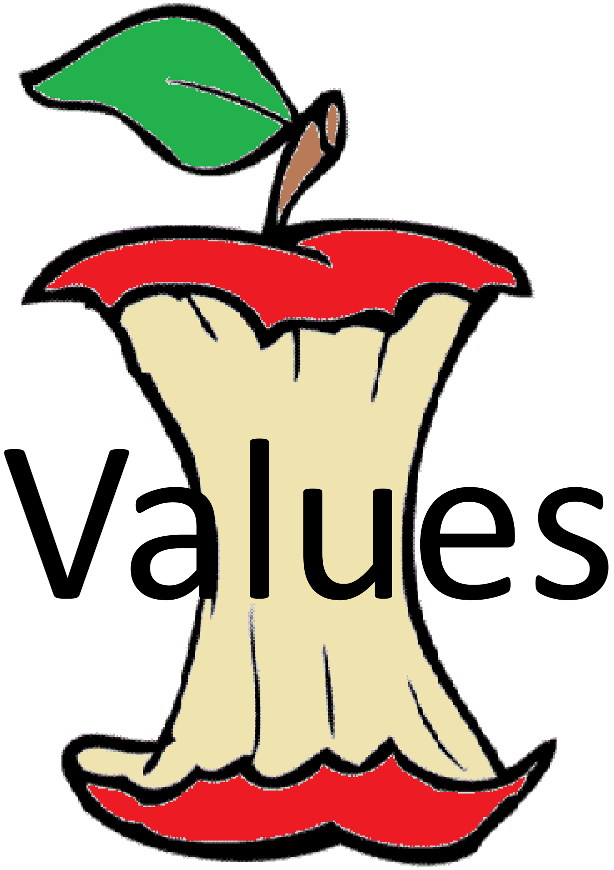
Mission Statement

The Urban Drainage and Flood Control District works with local governments to address multi-jurisdictional drainage and flood control challenges in order to protect people, property, and the environment.

Vision Statement

Achieve a sustainable network of safe, efficient, and environmentally sensitive drainage and flood control facilities to best serve an urban community that is aware of its flood risks. Lead the region and the nation by implementing innovative thinking and technology and by promoting wise use of public and private lands, while providing unsurpassed service to the community.

What are Core Values?



DCM Program Core Values

Safety is Paramount – Advocate for safety in all aspects of a project from design through construction to public use.

Wise stewards of tax dollars – Achieve the highest value for each project by pursuing funding partnerships and promoting multi-function facilities.

Drainage Diplomats – Foster strong relationships with coworkers, contractors, consultants, local governments, and the public based on mutual respect.

Respect the Stream- Understand and utilize stream processes and protect the natural and beneficial functions of the floodplain.

*Influence the Community- Pursue co*ntinuing education, strategic development of new ideas and advancement of technology.

DCM Purpose Statement

DCM Purpose Statement

To reduce flood risks by promoting healthy stream systems

Attributes of a Healthy System

- Dominated by natural physical, chemical, and biological processes
- Diverse terrestrial and aquatic conditions
- Natural patterns of disturbance
- Dynamic

Cherry Creek at Parker Jordan Open Space

Functions of a Healthy System

- Nutrient cycling
- Recreation
- Water storage
- Water quality protection
- Flood control

White Fence Farm

Indications of a Healthy System

- Water quality
- Fluvial geomorphology
- Aquatic and fish habitat
- Vegetation composition and structure
- Terrestrial wildlife habitat

Northwest Parkway Tributary H

Why a Healthy System Matters

- Slows flood velocities
- Reduces peak flows
- Soil stability
- Recharges groundwater
- Protects water quality
- Quickly rebounds

Cherry Creek at Kennedy Golf Course

Creating Healthy Systems

- Understand existing conditions and stressors
- Identify appropriate geomorphology
- Investigate soils, slope, and aspect
- Anticipate hydrology
- Develop site-specific revegetation plan
- Prepare long-term management plan

- ENGAGE ALL DISCIPLINES EARLY AND OFTEN

West Toll Gate Creek u/s of Hampden

= Functional

= Functional

+

Comfortable

= Functional

= Functional + Healthy

Good Neighbor Policy

Adopted by the Board of Directors
Urban Drainage and Flood Control District
February 1, 2011

WHEREAS, the Urban Drainage and Flood Control I
established by the Colorado General Assembly in 19
assist local governments with multijurisdictional drai
control problems, including the authority to levy prop
operations and planning; and

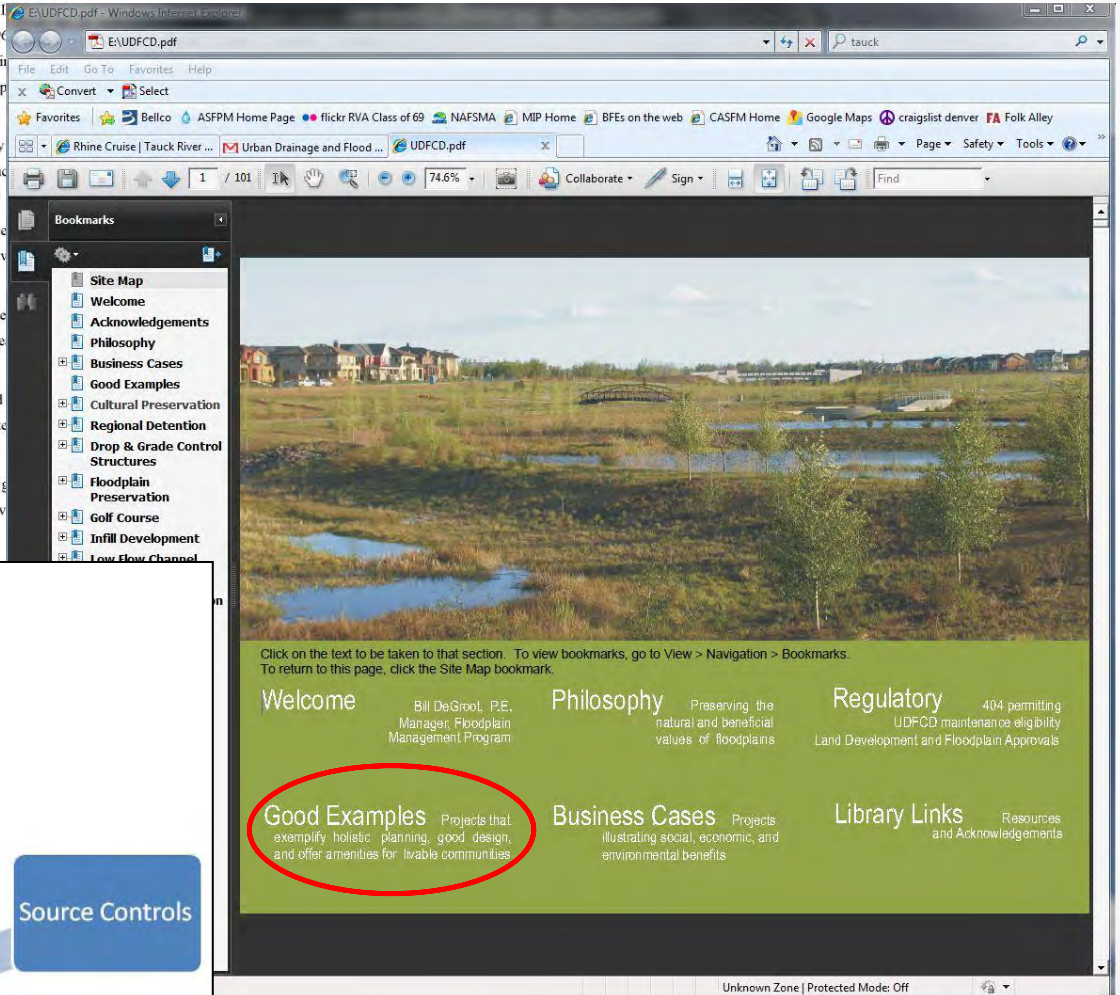
WHEREAS, the General Assembly has subsequently
District to levy property taxes for design and constru
for maintenance, and for the South Platte River; and

WHEREAS, the District has constructed approximate
in drainage and flood control projects in partnership
jurisdictions; and

WHEREAS, the District has contributed approximate
the acquisition and preservation of key floodplain are
with local jurisdictions and other partners; and

WHEREAS, many District projects are designed and
necessity, for rare events; and are therefore not utiliz
frequently for their primary intended purpose; and

WHEREAS, the District staff has worked with local
partners to enhance the projects to make them more
constituents on a daily basis; and



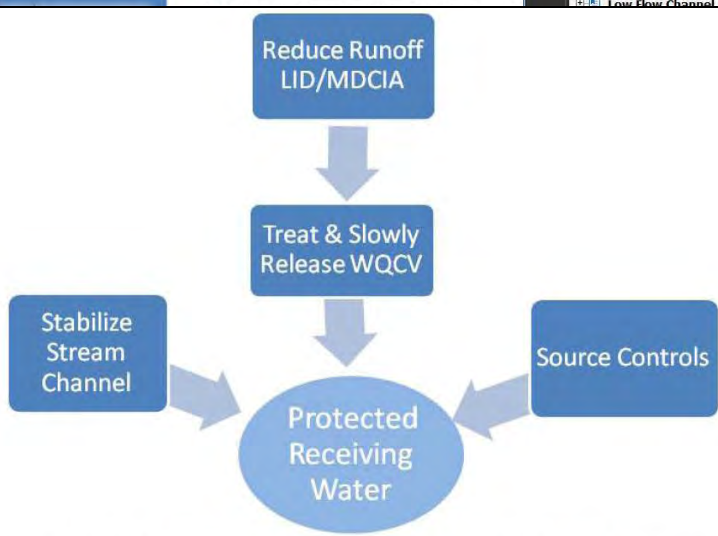


Figure 1-2. The Four Step Process for Stormwater Quality Management

Good Examples

Orange dot indicates link to photo

Projects	Cultural Preservation	Regional Detention	Drop & Grade Control Structure	Floodplain Preservation	Golf Course	Infill Development	Low Flow Channel	Open Space	Riparian Preservation	Trails / Recreation	Wetlands / Water Quality
Baldwin Gulch at Parker Auto Plaza			● sd					●		🟠 ts	
Bear Creek				🟠	🟠			●	🟠	●	
Big Dry Creek at Westminster City Park				●				●	●	🟠	
Big Dry Creek at Highlands Ranch		●	🟠 sd	●	●			●	●	●	●
Brantner Gulch		🟠 jd	●	🟠			🟠	●	●	●	● wp
Brantner Gulch at Eastlake Village		🟠						●		●	

Floodplain Preservation

Low Flow Channel

Open Space

Riparian Preservation

Trails/Recreation

Wetlands/Water Quality

95%

60%

Open Space 95%

Trails/Recreation 95%

Low Flow Channel

Riparian Preservation

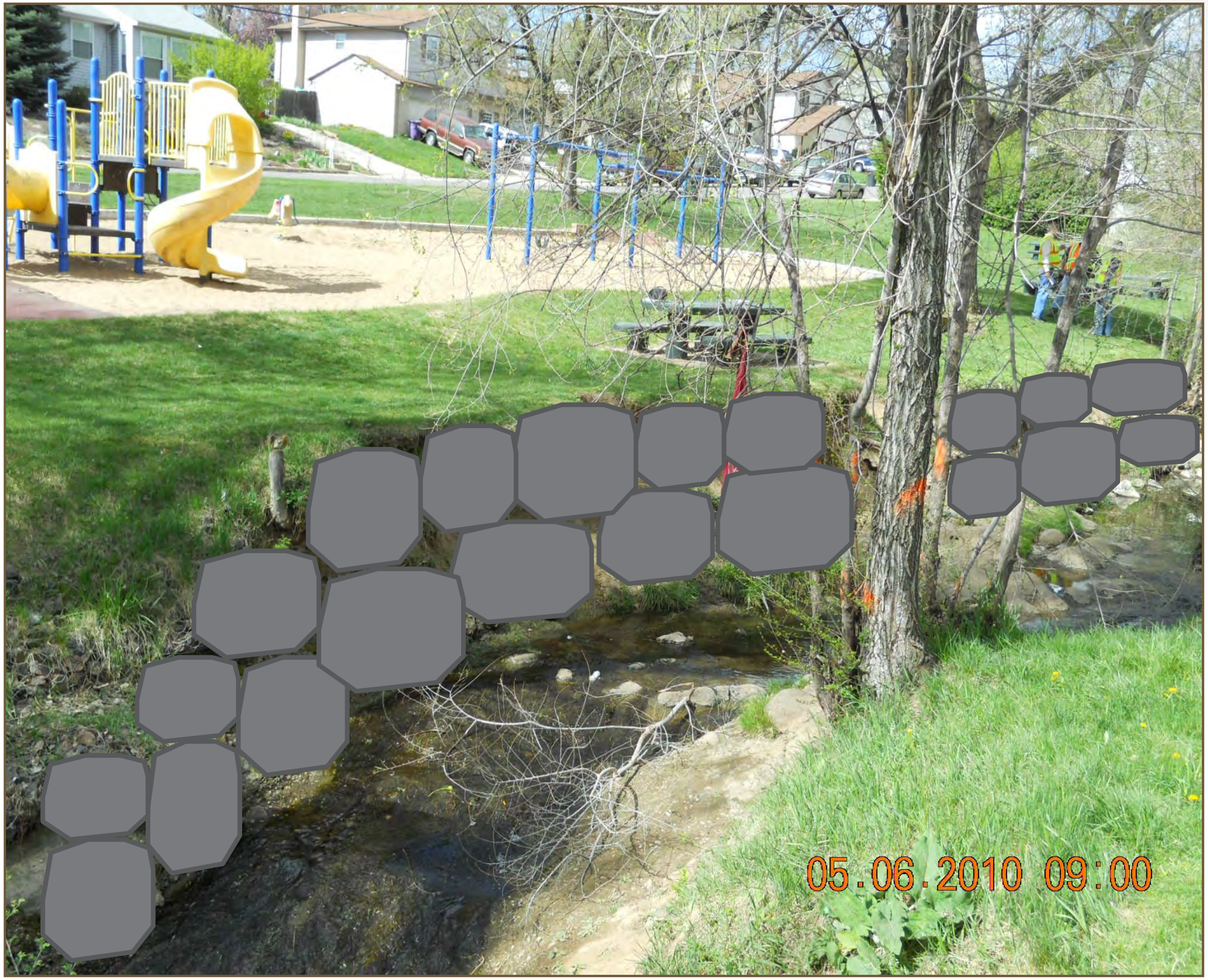
Wetlands/Water Quality

Expo Park on Westerly Creek

Parks and Trails


Cherry Creek


05.06.2010 09:00



Goal = Stabilize

To Reduce Flood Risks by Promoting Healthy Stream Systems

Purpose Statement → Project Team → Goals and Objectives → Delivery → Adaptive Management

Project Partners

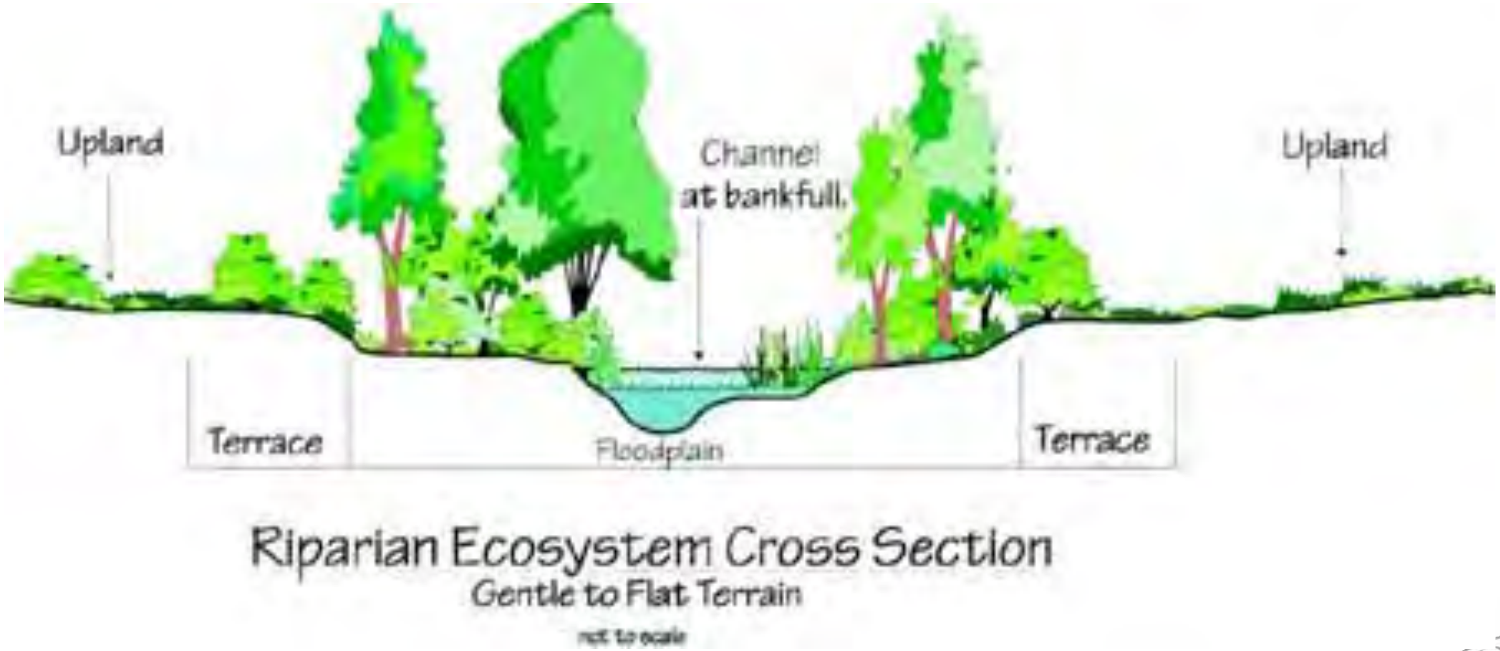



Changes in Vegetation Management

Routine Maintenance Services:

Debris Removal
Mowing of Vegetation
Weed Control
Tree Thinning
Sediment Removal

Changes in Vegetation Management



Changes in Vegetation Management

Changes in Vegetation Management

RIPARIAN STREAM RESTORATION

A new vegetation management plan is being implemented to focus on establishing healthier riparian and stream ecosystems.

DENVER
THE MILE HIGH CITY

For more information, contact Mike Sarmento with Urban Drainage and Flood Control District at 303-455-6277.

Community Benefits of Vegetation Management Instead of Mowing

What is a Riparian and Stream Ecosystem?

What makes a Healthy Ecosystem?

- Native grasses, shrubs, and trees
- Dense ground cover with limited exposed soil
- Minimal weeds
- Variety of vegetation species
- Absence of trash

Why Are Healthy Riparian and Stream Ecosystems Important to Our Community?

- Improve our water quality by filtering out pollutants like road oils and fertilizers
- Reduce soil erosion and damage to our bridges, properties, and parks during rainstorms
- Protect wildlife habitat and wildlife movement corridors linking other habitats
- Enhance our recreation and outdoor experiences along multifunction trail corridors
- Provide us with educational opportunities

What is Being Done to Protect the Health of These Valuable Resources?

Beginning in spring 2014, a new vegetation management approach will be implemented emphasizing weed control and trash removal. The resources previously used for mowing will be reallocated to more effectively improve and maintain the health of these riparian and stream ecosystems.

As these new routine management practices are being implemented, you will see visible changes, such as taller and healthier grasses and shrubs. Actively encouraging and allowing vegetation to grow is an important step in maintaining healthy riparian and stream ecosystems.

Our parks and natural areas are valuable assets to our community, and improving their health with an ecosystem management approach will help them become self-sustaining, ultimately reducing costs over time.

Will the New Vegetation Management Approach Cost More?

No. The new vegetation management plan approach will free up funds to focus on weed control and trash removal, which will help nurture healthy riparian and stream ecosystems.

For more information, contact Barbara Chongtoua with Urban Drainage and Flood Control District by email bchongtoua@udfcd.org or phone 303-455-6277.

DENVER

New Approaches to Project Management

2014 UDFCD Annual Seminar April 15,2014

URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

SESSION 4

Comprehending the Consequences of the September Floods of 2013

Kevin Stewart, UDFCD

ABSTRACT:

The floods of September may be the worst disaster most of us in the business will experience in our lifetime. After all, it was an event of "biblical" proportions…right? Regardless of what your future holds, we certainly hope that this will become true for majority of you and that you can apply the valuable lessons that you learned from this event to help others prepare for the next big one.

After overcoming the biblical reference, other early estimates of storm and flood magnitudes suggested that this was Colorado's 1,000-year event. NOAA's National Weather Service was quick to produce maps that reflected just how rare and amazingly widespread the rainstorm really was. As closer inspections of streamflow records and indirect peak flow estimates surfaced, some locations within the heaviest rainfall zones appeared to have experienced unexpectedly low flood peaks. For example, the flood peak for Boulder Creek was declared to be a 25-year event. How is this possible?

This presentation will take you deeper inside the storm by looking at peak rainfall rates and other storm characteristics to help explain the observed phenomenon. We will also explore streams reaches where some of the more extreme flood peaks were observed in an attempt to better understand the true nature of this historic flood.

Comprehending the Consequences of the September Floods of 2013

Kevin Stewart, Manager
Information Services & Flood Warning Program

The Consequences

Voice of the Rocky Mountain Empire

THE DENVER POST

SATURDAY, SEPTEMBER 14, 2013 · CHANCE OF RAIN ▲79° ▼54° »24A · © THE DENVER POST · $1.50

DP ONLINE TODAY: Breaking news updates on Colorado's historic flooding. »denverpost.com

The Flood's Toll

Four dead, thousands stranded or homeless

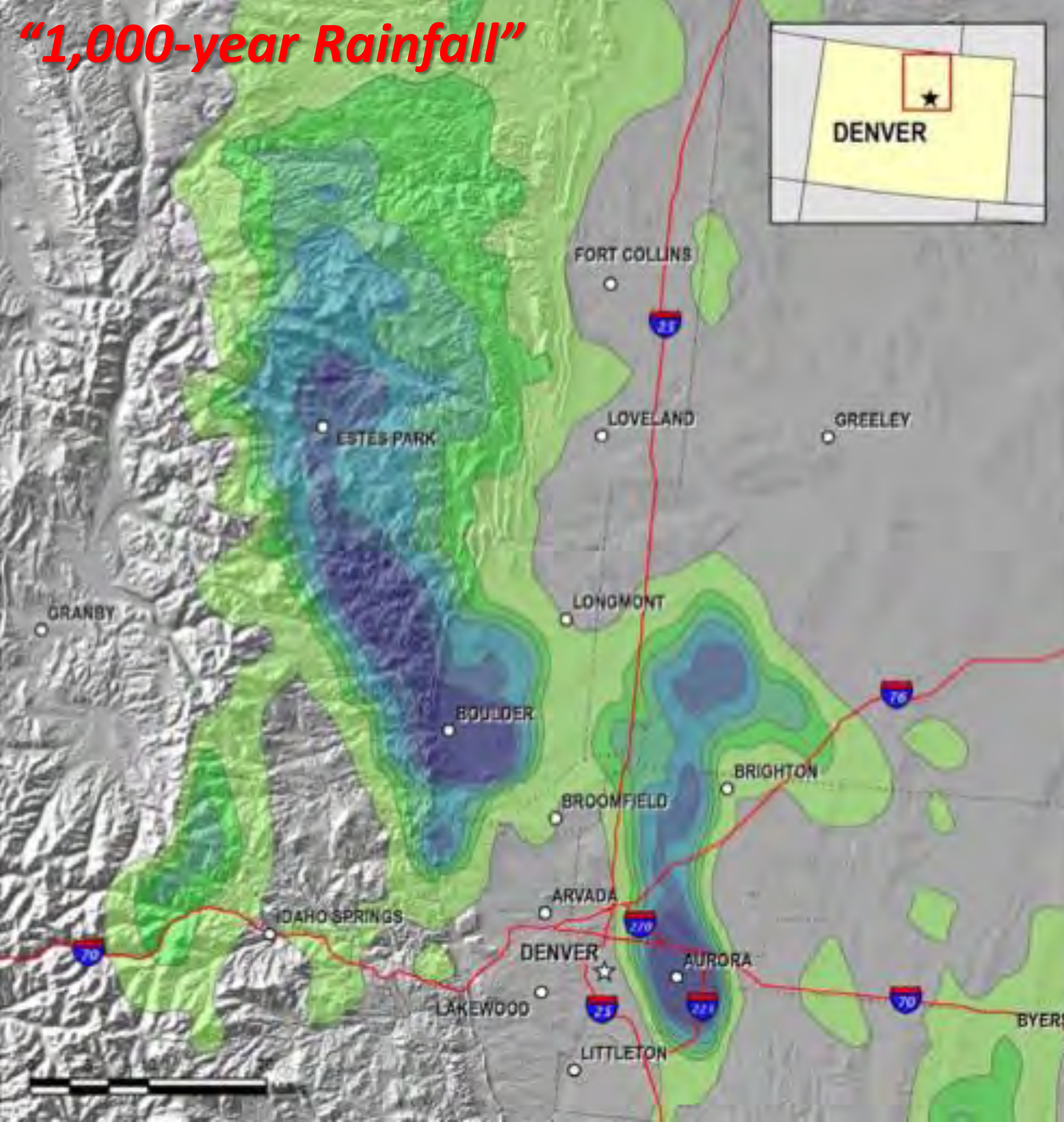
South Platte River: 50 times more water than it normally has this time of year.

Jamestown: Military helicopters rescue nearly 300 people from isolated town.

A closer look at what cause the September 2013 floods

COMPREHENDING WHAT HAPPENED

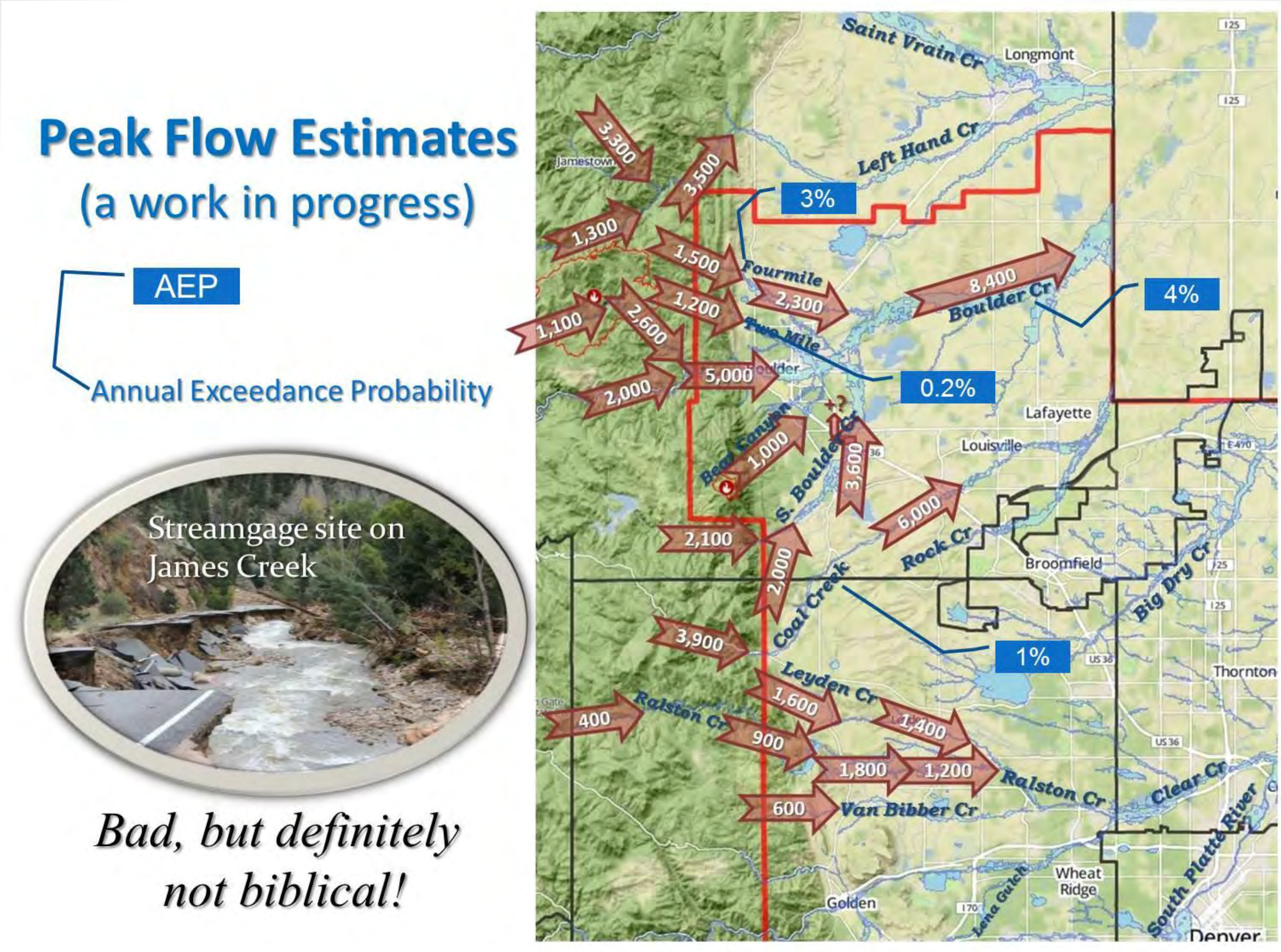
"1,000-year Rainfall"



Very early findings from our NOAA friends.

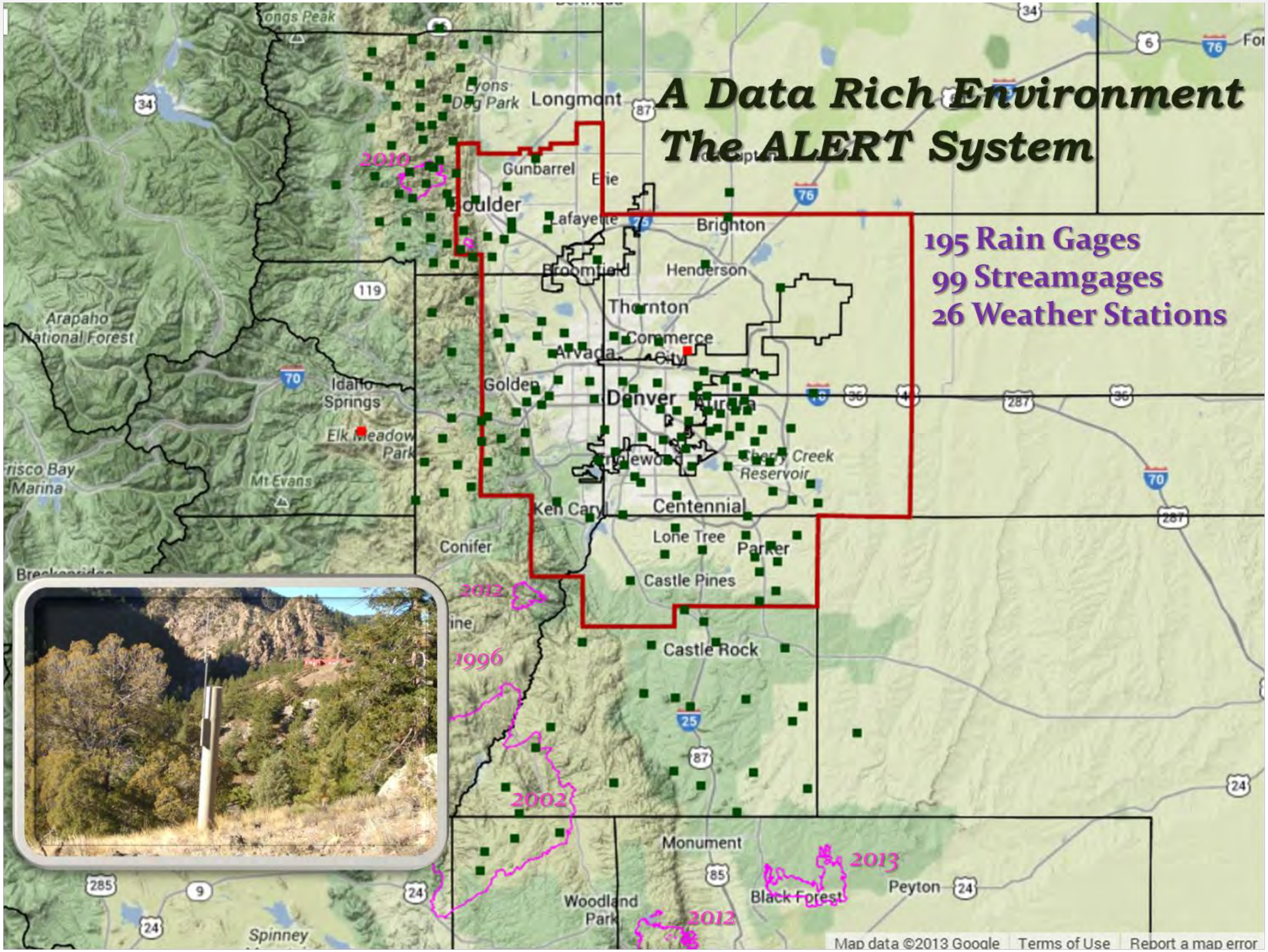
A "biblical" event!

September 17, 2013



Peak Flow Estimates & Corresponding AEP Values

AEP results vary widely.



Real-Time Flood Detection

Enabling rapid assessment of threats with alarm notifications

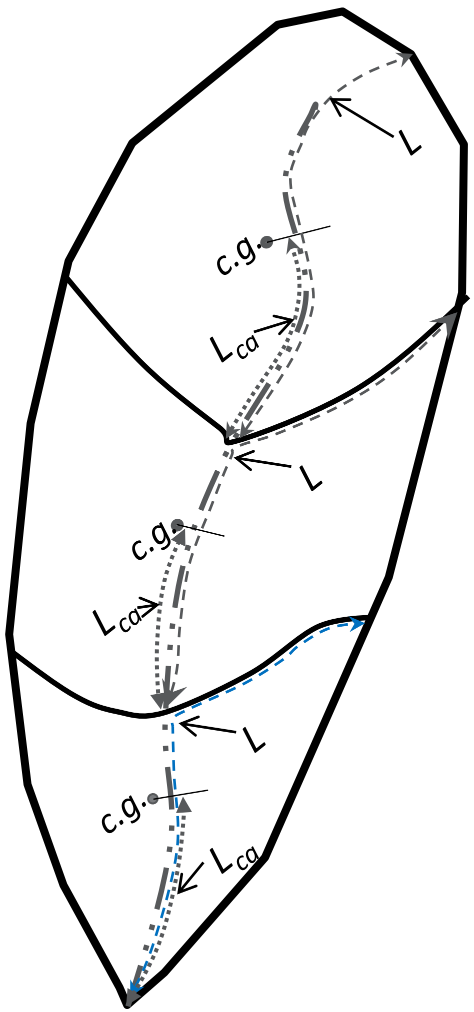
DRAINAGE CRITERIA MANUAL (V. 1) RUNOFF

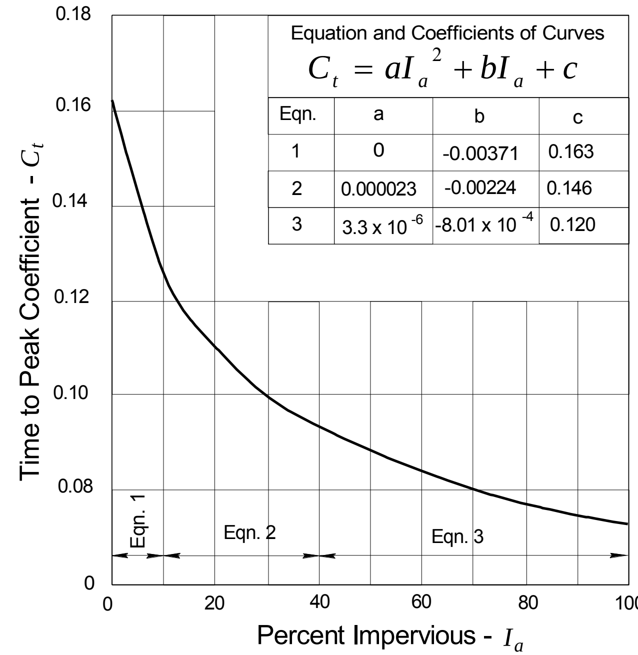
3.0 COLORADO URBAN HYDROGRAPH PROCEDURE

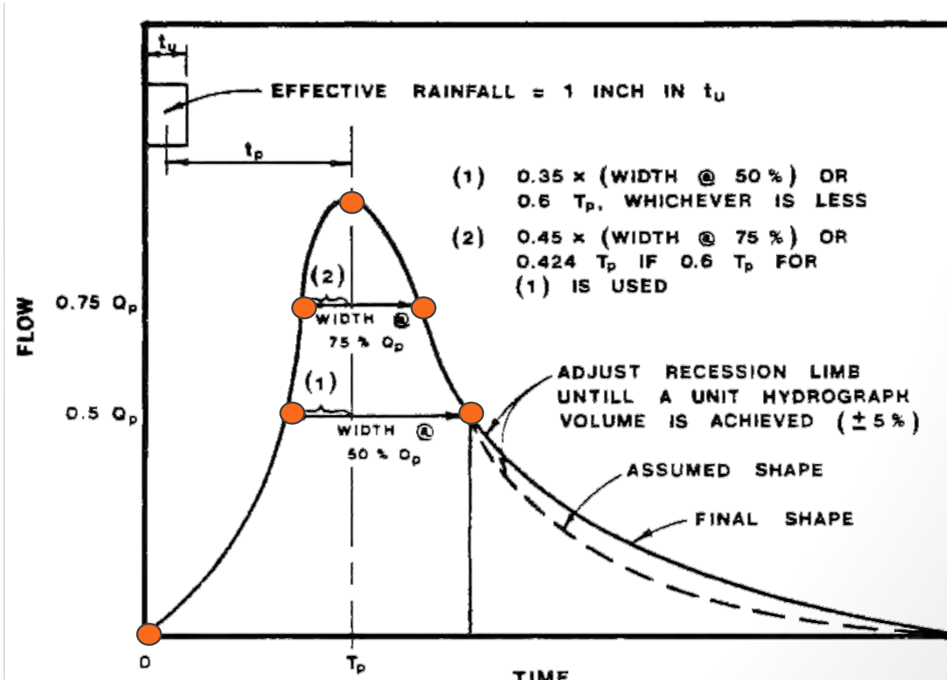
A short USDCM review for engineers

HYDROLOGY

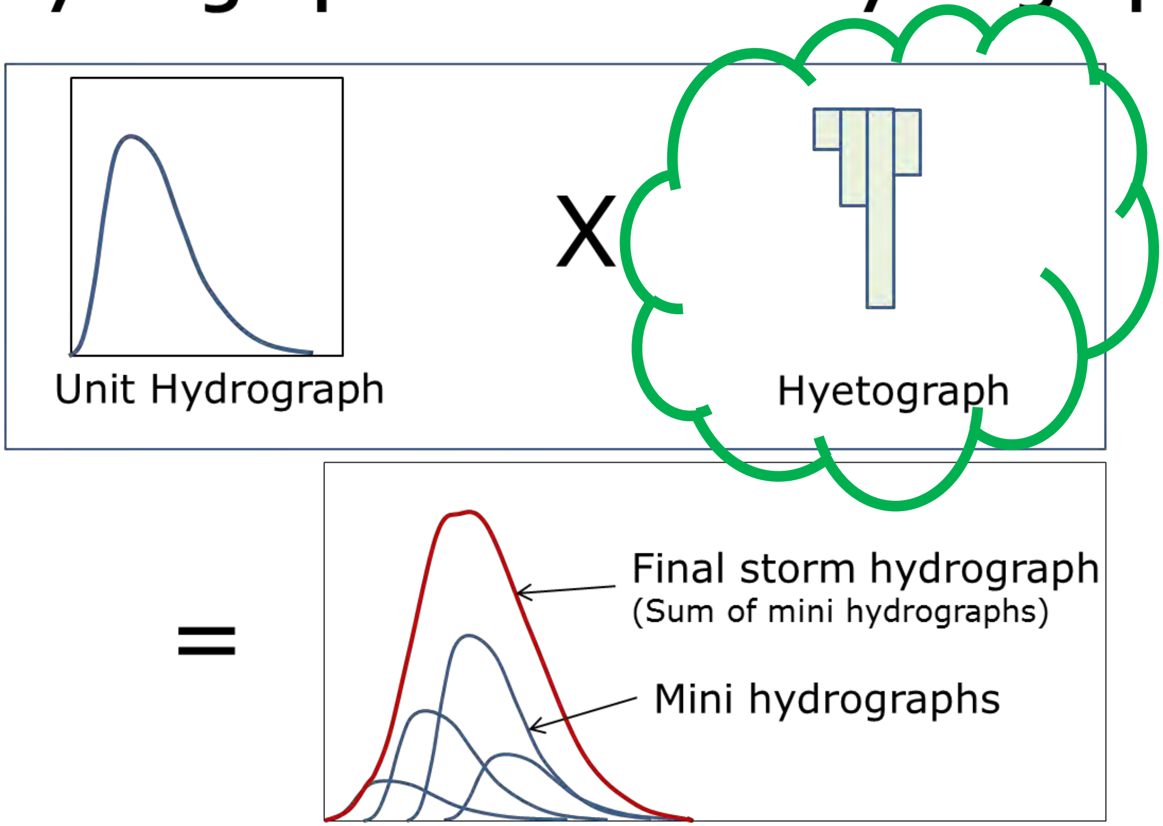
Rainfall/Runoff







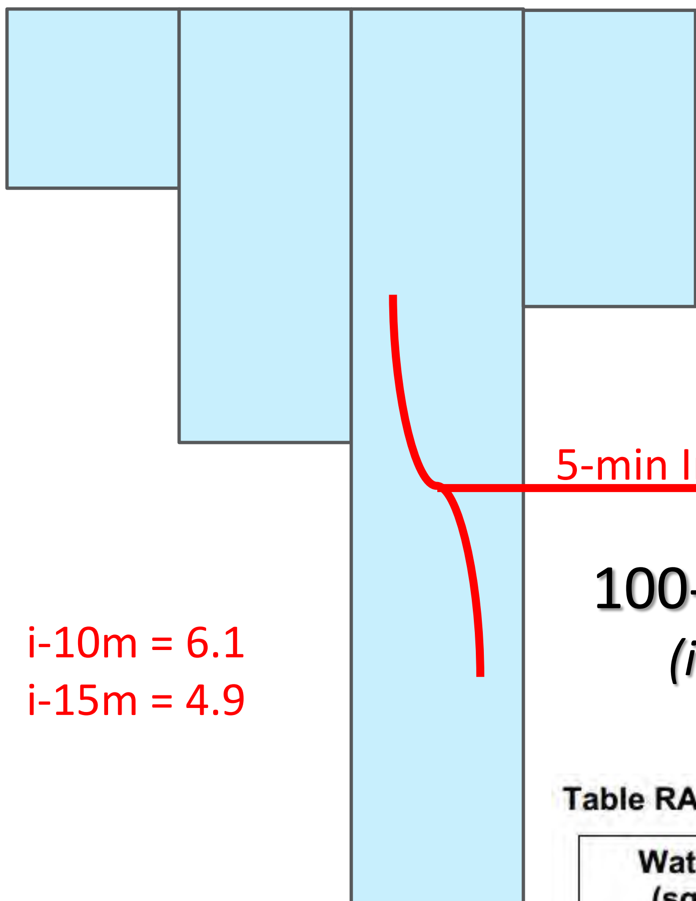
Convolution of Unit Hydrograph, Runoff Hyetograph into Storm Hydrograph



Design rainfall—the easy part, right?

Let's take a closer look.

1% AEP CUHP Design Rainfall



Time (min)	In (% of 1hr)	In/hr
20	0.21 (8%)	2.5
25	0.36 (14%)	4.4
30	0.65 (25%)	7.8
35	0.36 (14%)	4.4
40	0.21 (8%)	2.5

100-year, 1-hour NOAA Rainfall = 2.6”

(inherent in all design storm durations)

Table RA-1—Storm Duration and Area Adjustment for CUHP Modeling

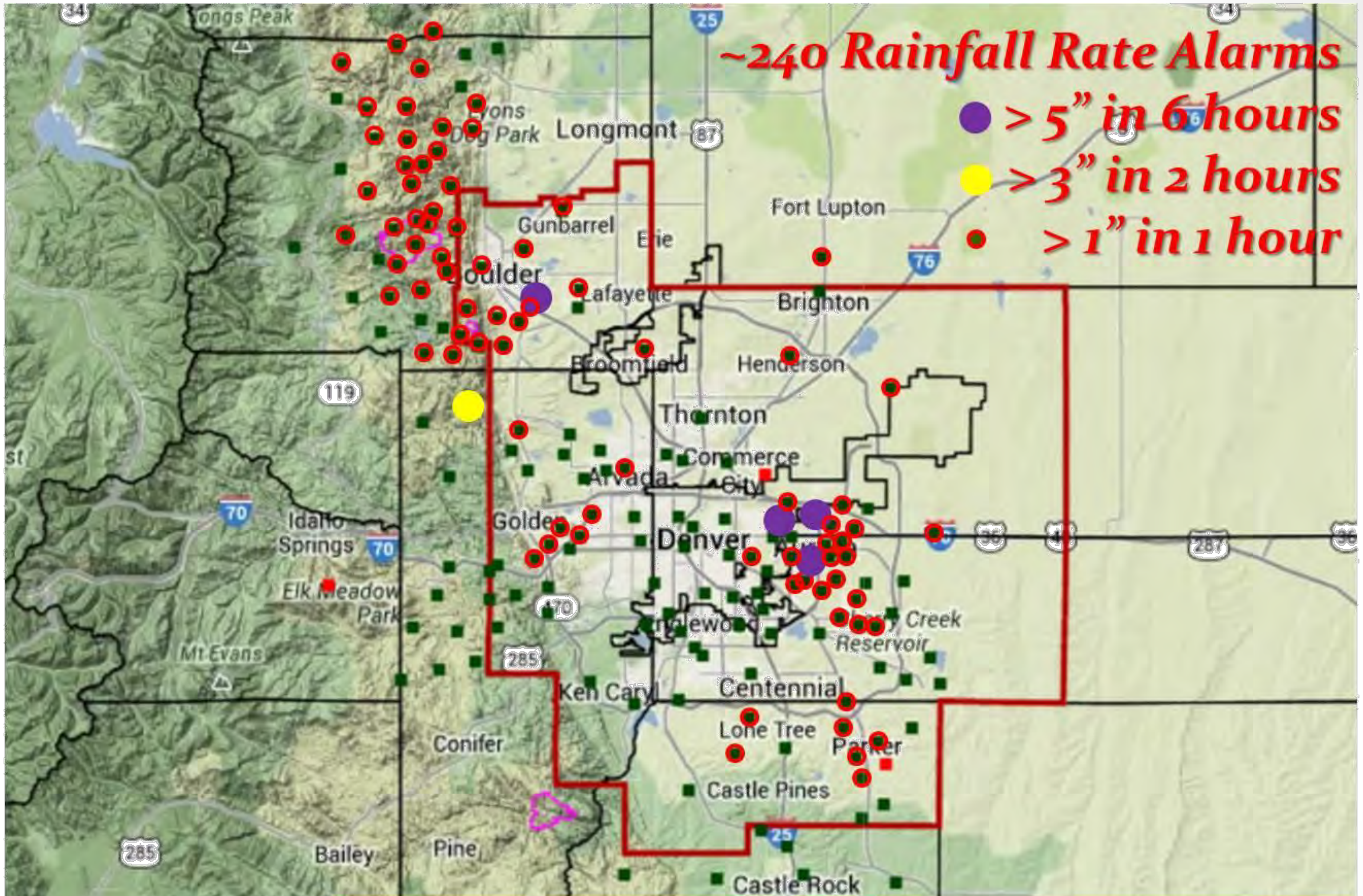
Watershed Area (square miles)	Suggested Minimum Storm Duration	Area Adjustment Required?
Less than 10.0	2 hours	No
10.0 to 20.0	3 hours	Yes
20.0 and larger	6 hours	Yes

Was the September 2013 rainfall a 1,000 -year event?

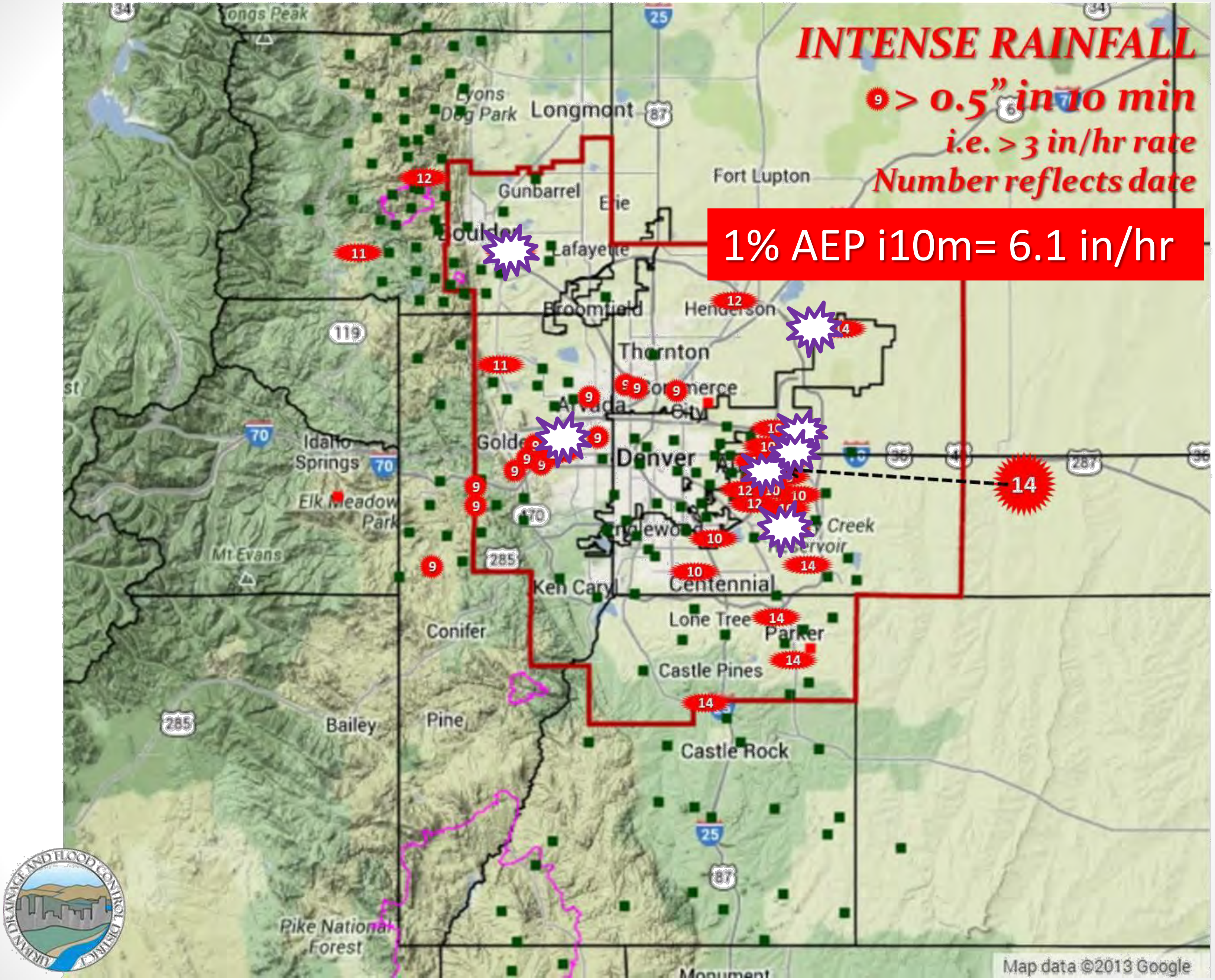
Did this extreme event cause 100-year flooding or worse?

Can we reach a consensus today? Let's try.

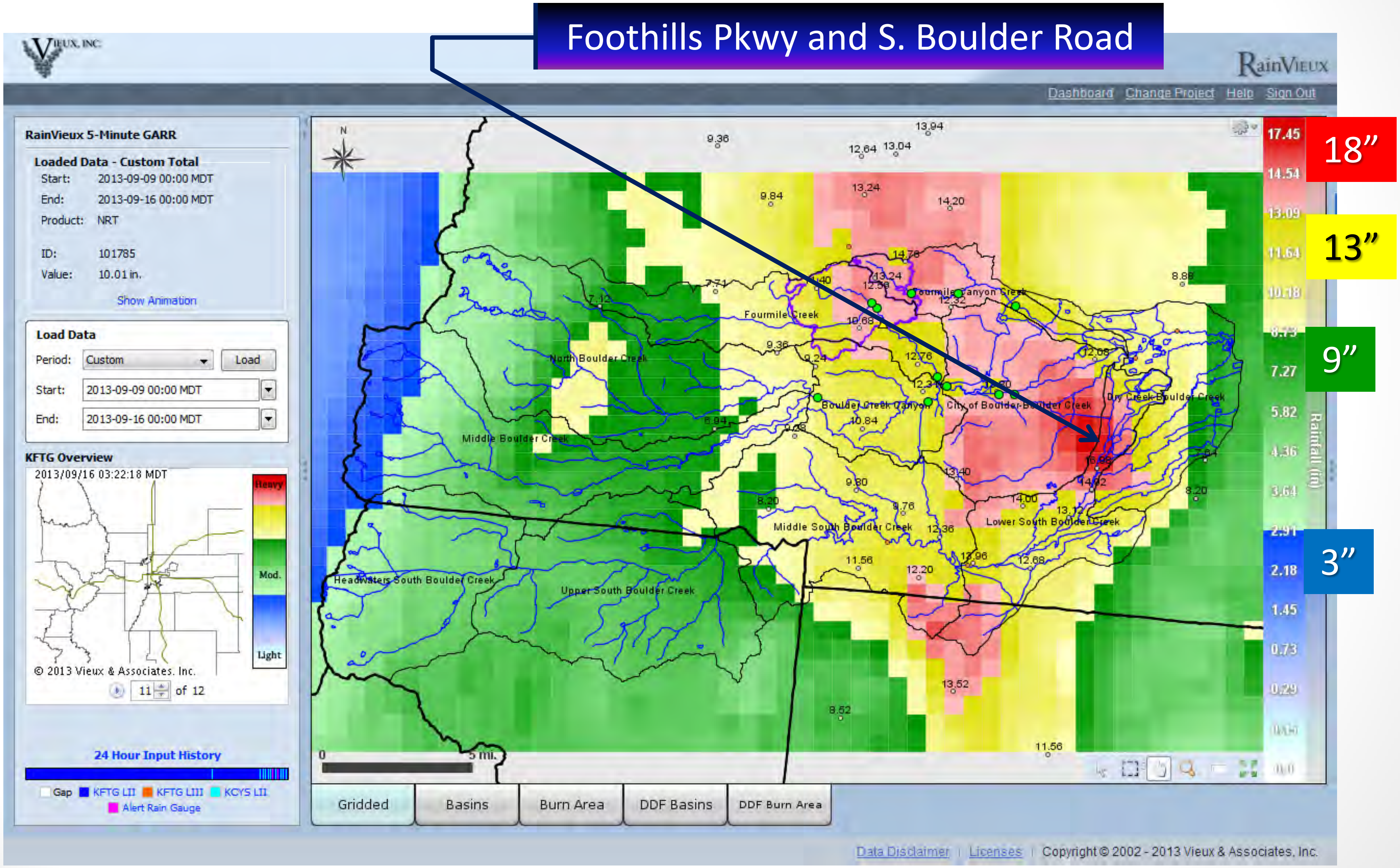
A REALITY CHECK



Duration	~1% Thresholds	Thresholds Exceeded at:
1-hour	>2.5"	3 gage sites (all in Aurora)
6-hour	>3.5"	49 sites
24-hour	>5"	59 sites

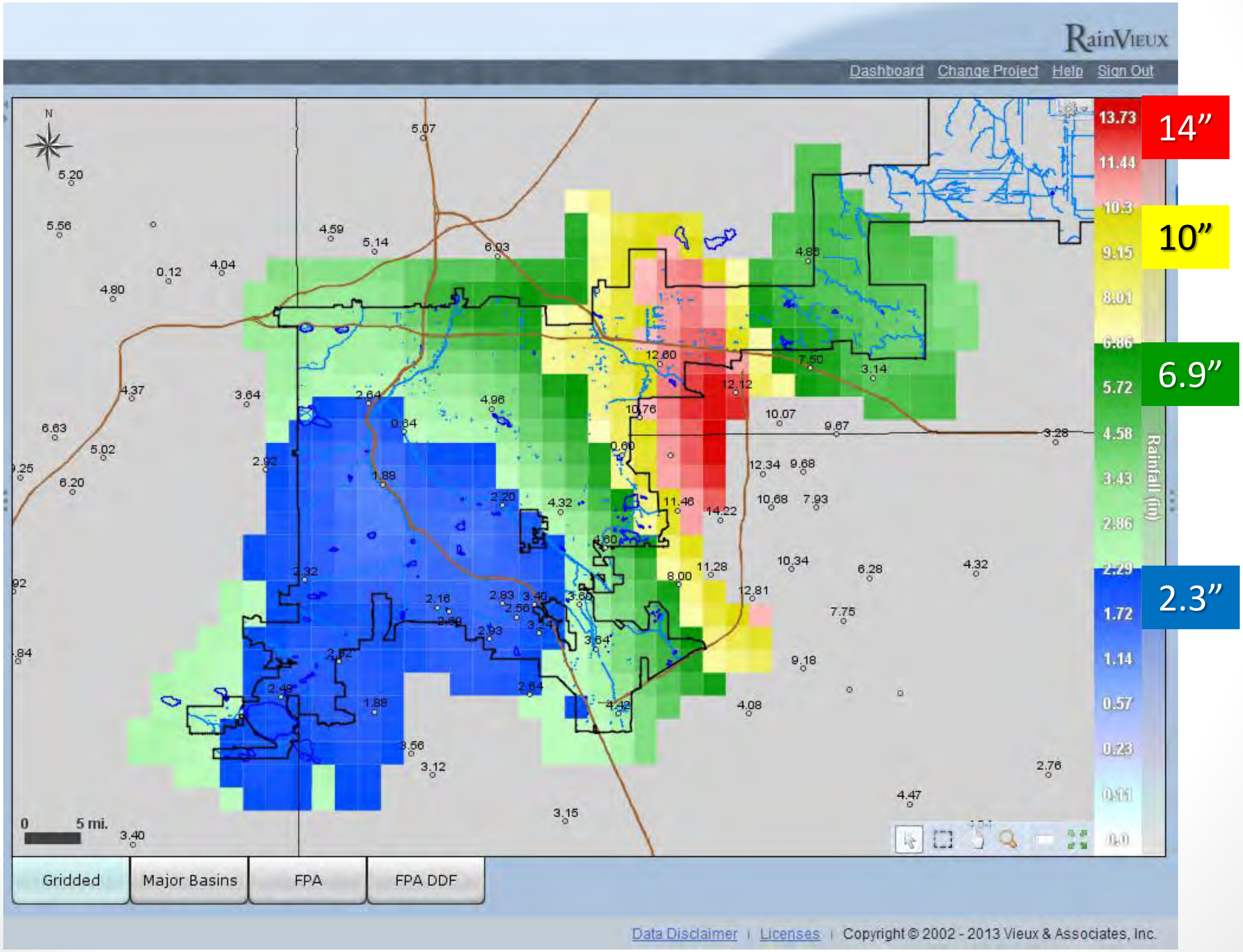

INTENSE RAINFALL
9 > 0.5" in 10 min
i.e. > 3 in/hr rate
Number reflects date
1% AEP i10m= 6.1 in/hr
Longmont
Lyons
Dog Park
Gunbarrel
Erie
Fort Lupton
Boulder
Lafayette
Broomfield
Henderson
Thornton
Commerce City
Arvada
Golden
Denver
Idaho Springs
Elk Meadow Park
Mt Evans
Englewood
Centennial
Ken Caryl
Conifer
Lone Tree
Parker
Castle Pines
Bailey
Pine
Castle Rock
Pike National Forest
Map data ©2013 Google

GARR—Gage Adjusted Radar Estimates



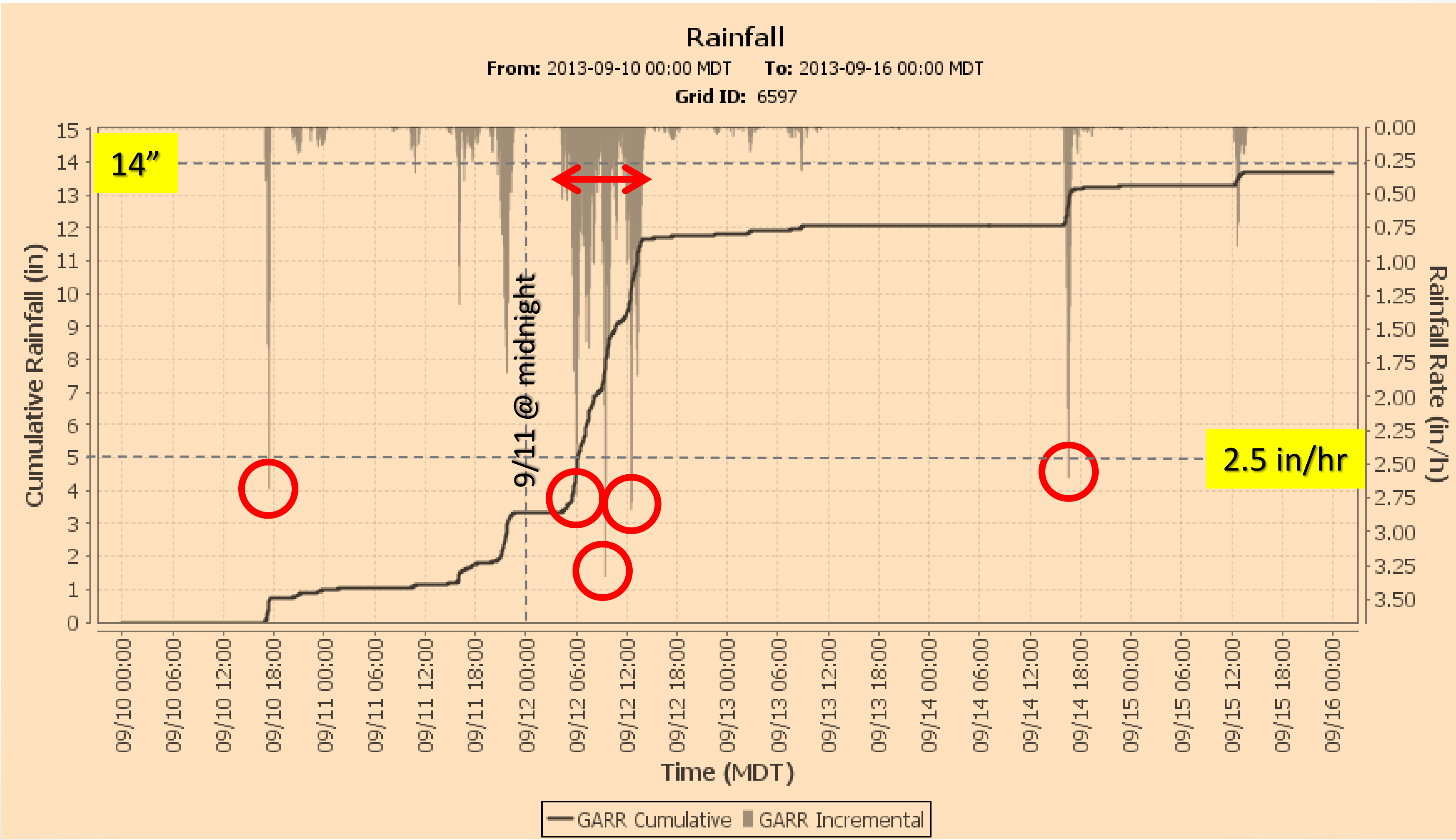
September 9-15, 2013

Radar-Rainfall estimates for Denver/Aurora



Westerly Creek Rainfall Time Series from GARR

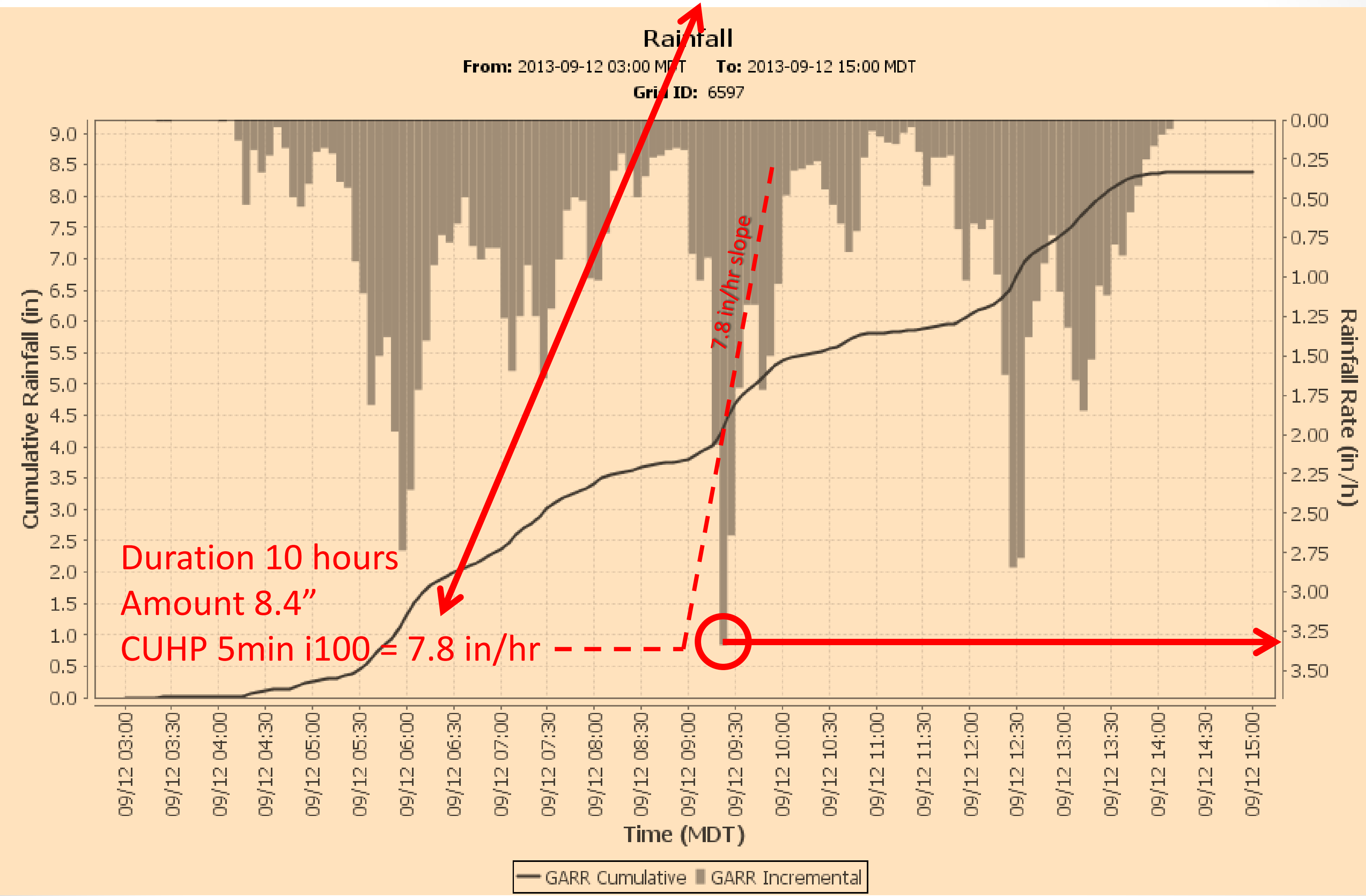
5 Periods of Peak Intensity > 2.5 in/hr



6-day rainfall amount ~14” with 10-hour period of heavy rainfall on September 12

Westerly Creek Rainfall Time Series

Peak GARR Grid Intensity: 3.34 in/hr @ 0925 on Sep. 12



Flood of September 2013 – Westerly Creek

A huge volume flood with variable AEP peaks throughout the 17.5 mi^{2} watershed.


Questions?

SESSION 5

The Colorado Stormwater Center

Dr. Larry Roesner, Emeritus Professor, Colorado State University

ABSTRACT:

The Colorado Stormwater Center was founded in 2013 with support provided by the Urban Drainage and Flood Control District (UDFCD), Colorado Association of Stormwater and Floodplain Managers (CASFM), Colorado Stormwater Council (CSC), the State of Colorado Water Quality Control Division, and CSU Extension. Our mission is to:

- Enhance the quality of the State's streams, rivers and lakes through education and training of both the public and professionals involved with design, construction, inspection and maintenance of stormwater management facilities in Colorado
- Educate stormwater management practitioners in the proper design, construction, operation and maintenance of best practices applicable to Colorado's semi-arid climate
- Provide education, training and certification to localities throughout the State of Colorado, emphasizing local climate and hydrogeographic features.

The Colorado Stormwater Center is housed within the Department of Civil and Environmental Engineering at Colorado State University (CSU) and is affiliated with the CSU Urban Water Center. Our education and training workshops are provided by a variety of experienced professionals that work within academia, consulting, local government and private business to provide stormwater-related education, training and research with the goal of maintaining and improving the health of lakes, rivers and streams through proper stormwater management.

The Center is staffed by Technical Director Dr. Larry Roesner (Emeritus Professor, Colorado State University), and Program Manager Chris Olson (Research Associate, Colorado State University). The Center also conducts stormwater research through our affiliation with the Colorado State University Urban Water Center.

SESSION 6

Friend of UDFCD Award: Cathy Reynolds

Presented by Paul Lopez, Scott Tucker, and Paul Hindman, UDFCD

ABSTRACT:

Honoring Cathy Reynolds for 23 Years as Chair of the Urban and Flood Control District. The UDFCD Board of Directors consists of 22 members, 20 of whom are locally elected officials including mayors, mayor pro-tems, county commissioners, and Denver City Council members. Cathy Reynolds was appointed by Denver Councilman Larry Perry, President of the City Council, to the UDFCD Board of Directors of the District on July 15, 1975, about 39 years ago.

Councilwoman Reynolds was sworn in as a District Board member on August 21, 1975 by District legal counsel Joe Shoemaker; and was the first woman to serve on the Board of Directors of the District. She was elected Secretary of the Board of Directors of the District in 1976 and 1977, Chairman Pro-Tern in 1978 and 1979, and Chair in 1980 and every subsequent year through January, 2003 for a total of 23 years. This means she served as Chairman of the District's Board of Directors for over half of the 45 years the District has been in existence!

Term limits now make it impossible for any other elected official to serve on the Board for more than twelve years, let alone serve as chair for 23 years, so there will never be another one like Councilwoman Reynolds. The Directors and staff of the Urban and Flood Control District want to take this opportunity to recognize Cathy Reynolds for her patience, prudence, persistence, leadership, intelligence and dedication to the District, and hereby extend our heartfelt thanks to Cathy Reynolds for this outstanding one-of a-kind public service contribution.

SESSION 7

The New "Open Channels" Chapter of the Urban Storm Drainage Criteria Manual

Holly Piza, UDFCD
Jim Wulliman, Muller Engineering Company

ABSTRACT:

Volumes 1 and 2 of the Urban Storm Drainage Criteria Manual (USDCM) were last updated in 2001. These volumes are currently undergoing another update in order to capture experience gained and incorporate relevant research conducted over the past decade. This presentation will highlight changes and expanded guidance in the "Open Channels" chapter (renamed from Major Drainage) including:

- ✓ Background and goals for chapter
- ✓ Design guidance for natural stream restoration
- ✓ Applying fluvial geomorphology principles
- ✓ Configuration of low-flow channel and adjacent benches
- ✓ Grade control strategy
- ✓ Bank protection
- ✓ Updated section on hydraulic evaluation
- ✓ New riprap design guidance
- ✓ Vegetative approaches
- ✓ Design of channels in constrained urban environments
- ✓ Construction of naturalized channels
- ✓ Design of small channels and swales

New *Open Channels* Chapter of the USDCM

Presented by: Holly Piza, UDFCD

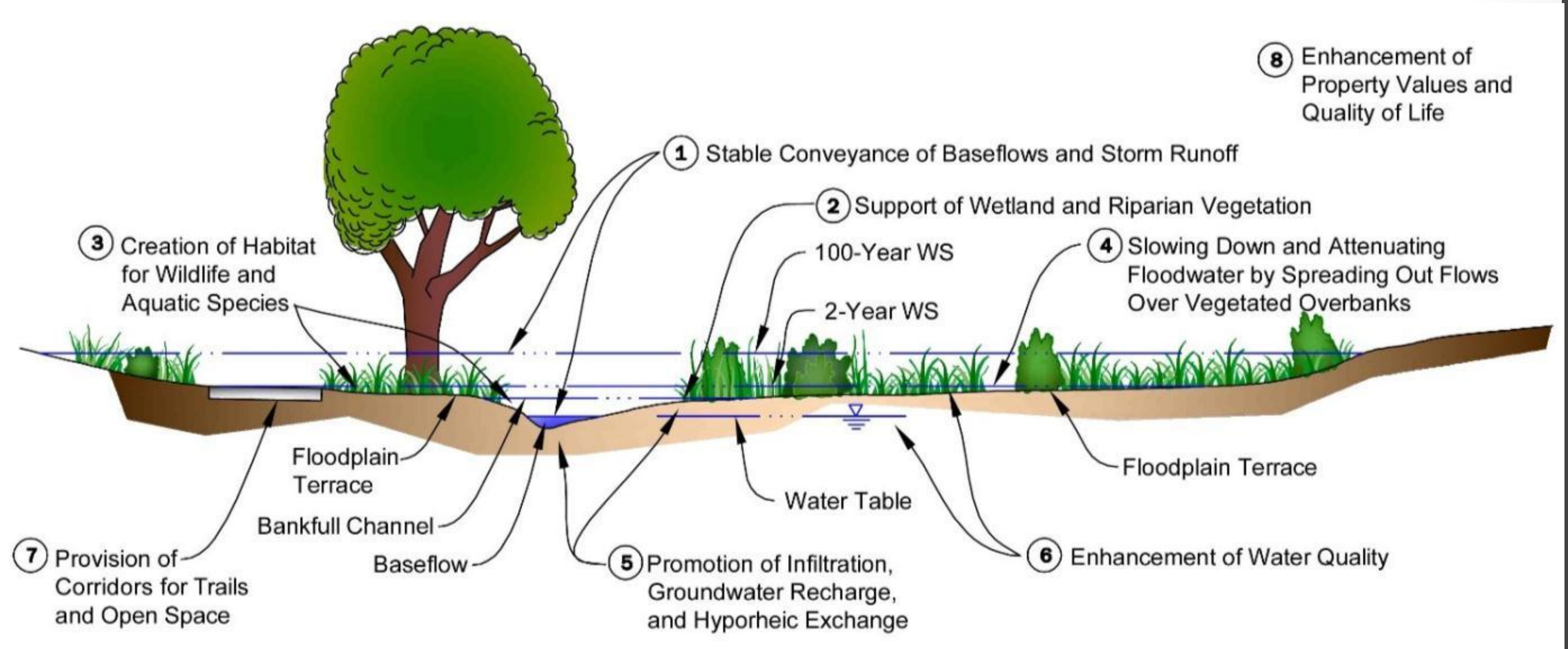
Jim Wulliman, Muller Engineering Company

Natural Streams

1. What are the fundamental characteristics, functions, and benefits of a healthy natural stream?

Photo by WildBasin Photography

Functions and Characteristics of Natural Streams



Natural Streams

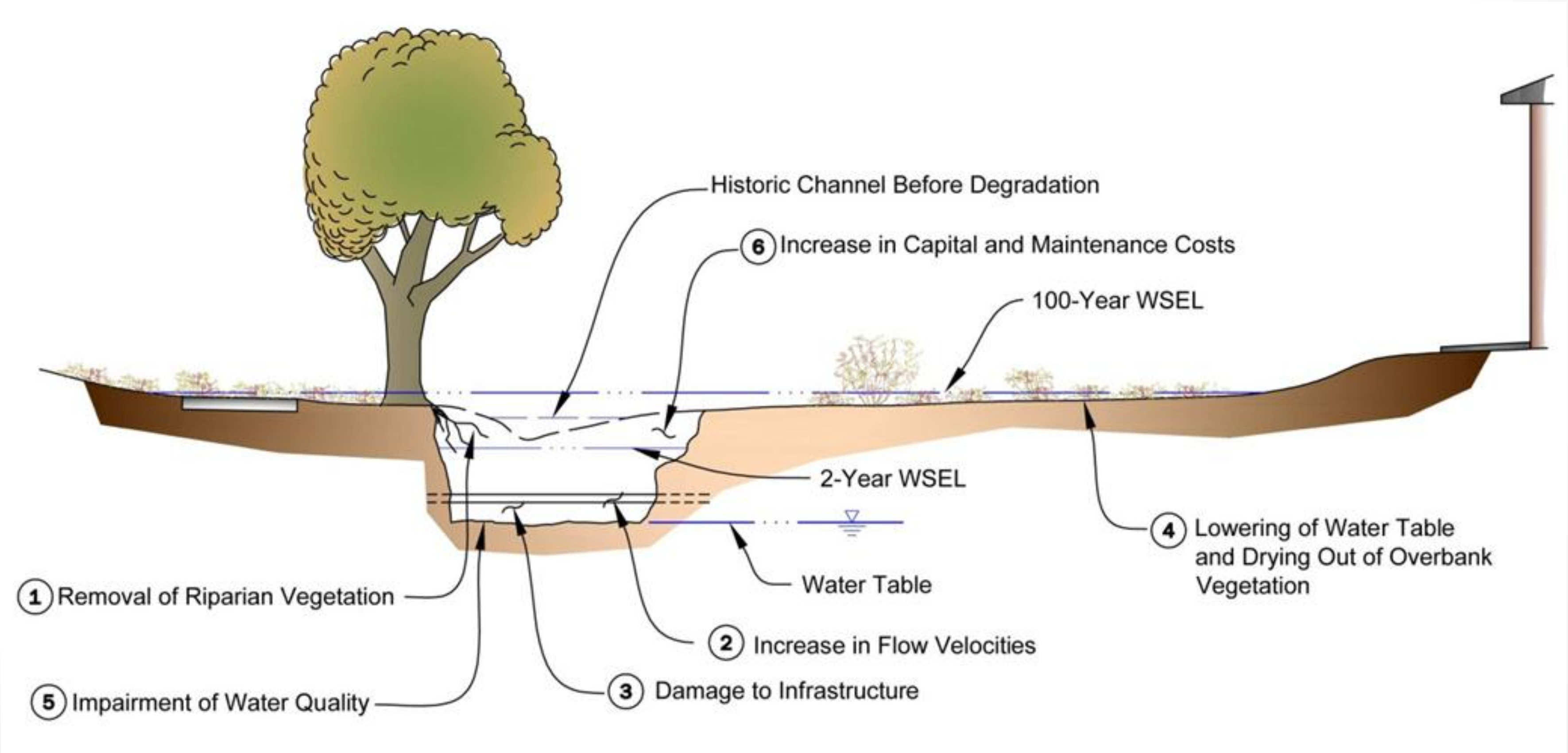
1. What are the fundamental characteristics, functions, and benefits of a healthy natural stream?

2. In what ways can stream health and function be impaired?

Structures constraining stream corridor

Stream degradation from increased urban runoff

Impairments to Natural Stream Function



Natural Streams

1. All of our efforts in master planning, floodplain management, water quality BMPs, construction erosion control, and environmental permitting are aimed at protecting stream function and health.

2. Projects in the stream are the most influential BMPs affecting stream function and physical, chemical, and biological health.

Helpful Mindsets

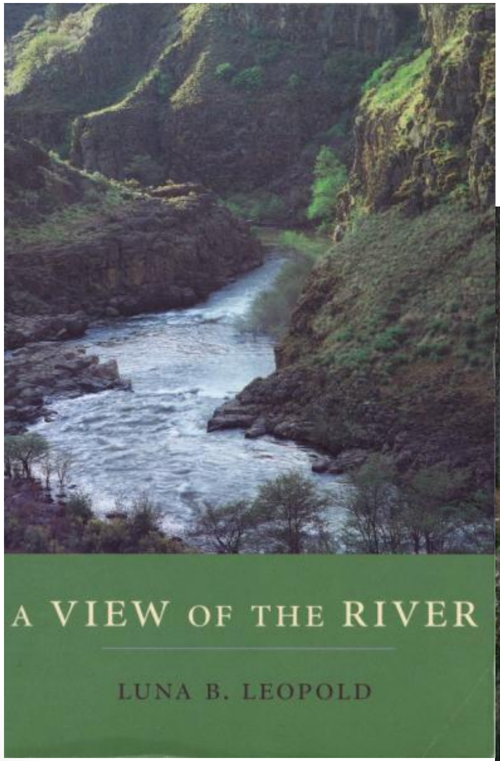
- Awe, wonder, care, respect

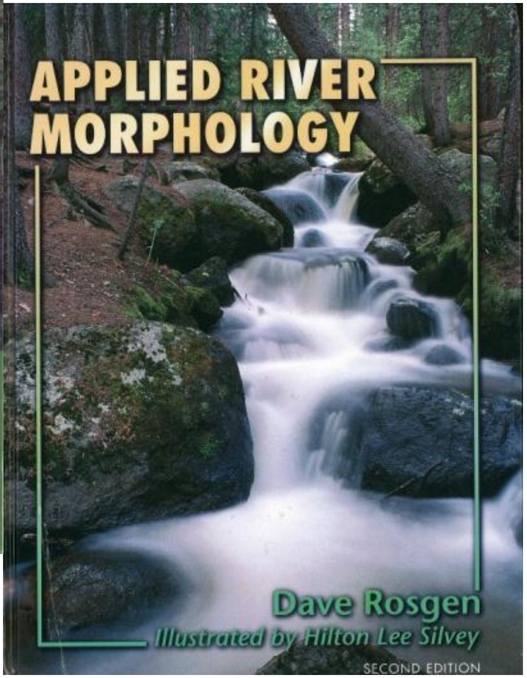
Helpful Mindsets

- Sense of responsibility

Helpful Mindsets

- Passion to learn and understand





References by Leopold, Rosgen, others

CASFM-sponsored Stream Restoration Training by Brian Bledsoe/CSU

Helpful Mindsets

- Become a student of the stream

Helpful Mindsets

- Anticipate and embrace dynamic nature of stream

Stream Restoration

Stream restoration is the process of assisting the establishment of improved hydrologic, geomorphic, and ecological processes in a degraded watershed system and replacing lost, damaged, or compromised elements of the natural system (Bledsoe, 2013).

Stream Restoration

1. Space
2. Flow
3. Sediment
4. Shape
5. Gradient
6. Vegetation
7. Rock
8. Hydraulics

Space

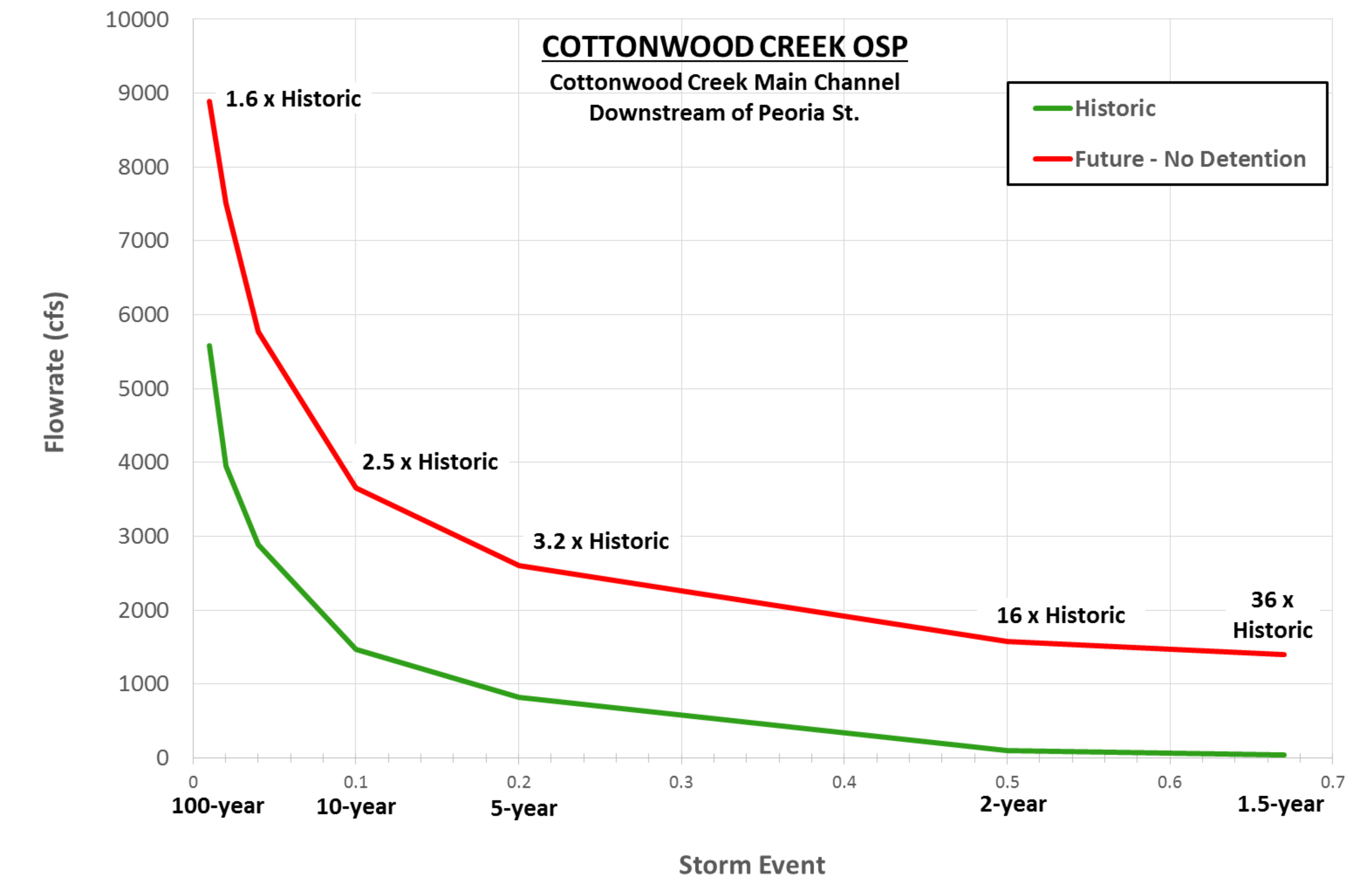
Fourmile Canyon Creek, Boulder

Space

Space

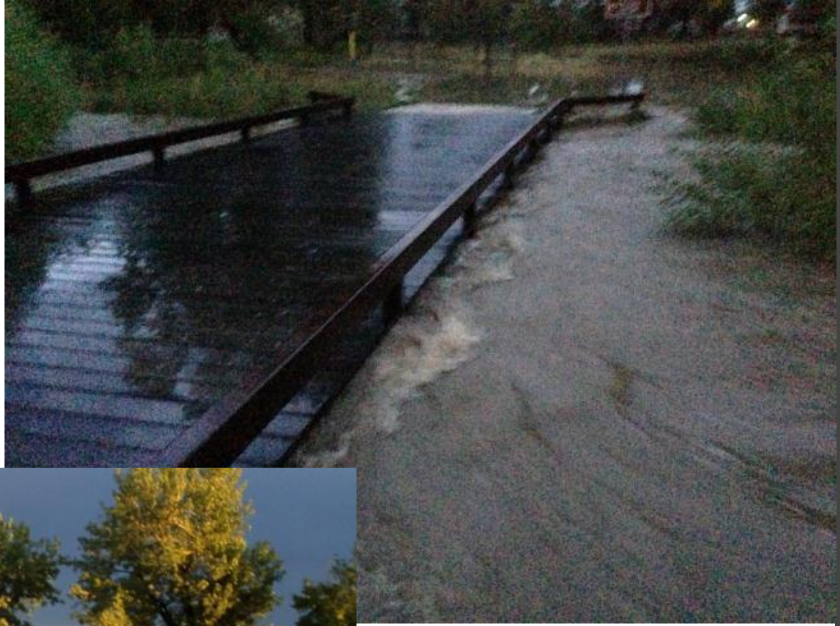
Space

Flow

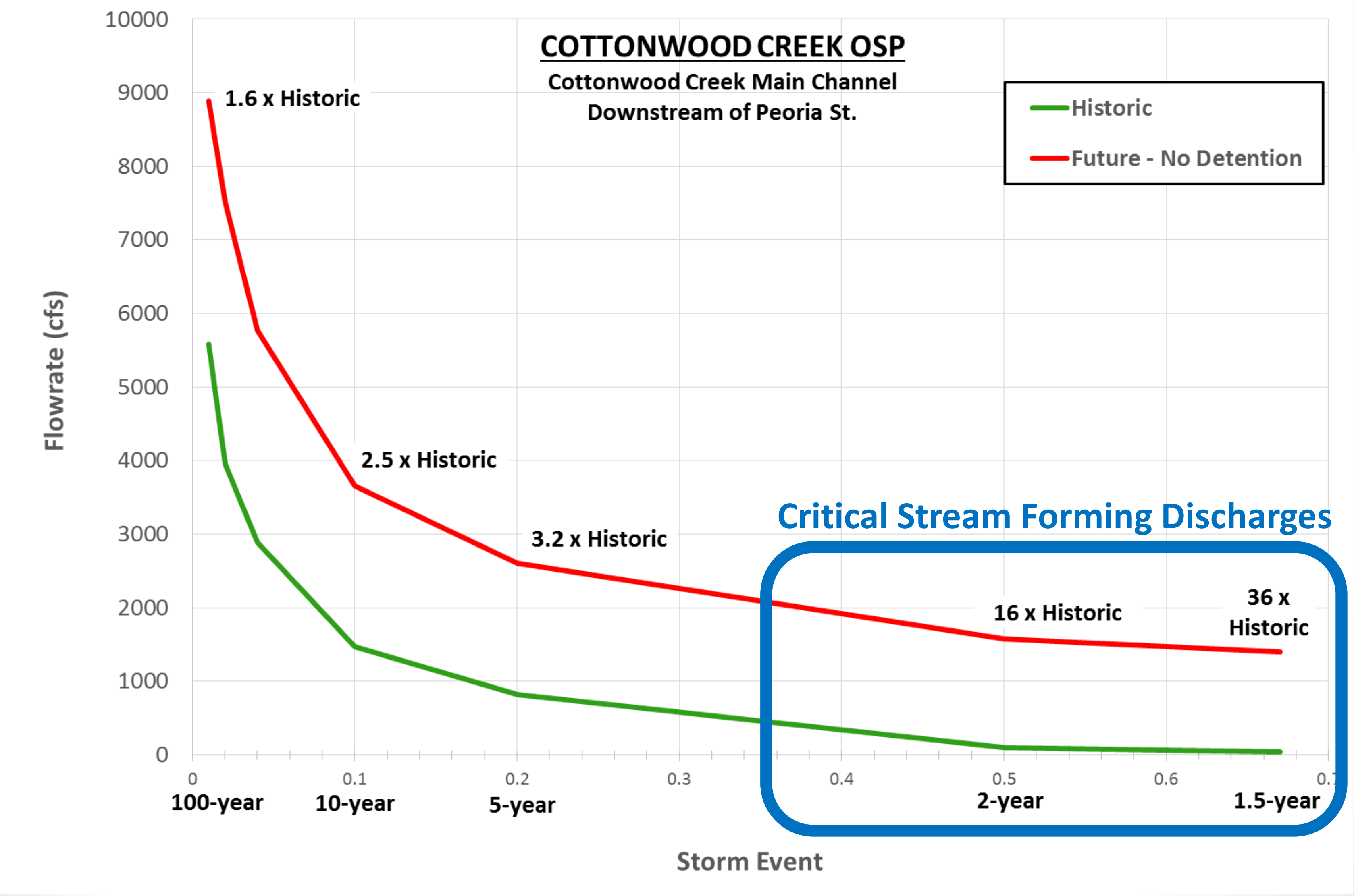


COTTONWOOD CREEK OSP
Cottonwood Creek Main Channel
Downstream of Peoria St.
Historic
Future - No Detention
1.6 x Historic
2.5 x Historic
3.2 x Historic
16 x Historic
36 x Historic
Flowrate (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
100-year
10-year
5-year
2-year
1.5-year
Storm Event

Flow

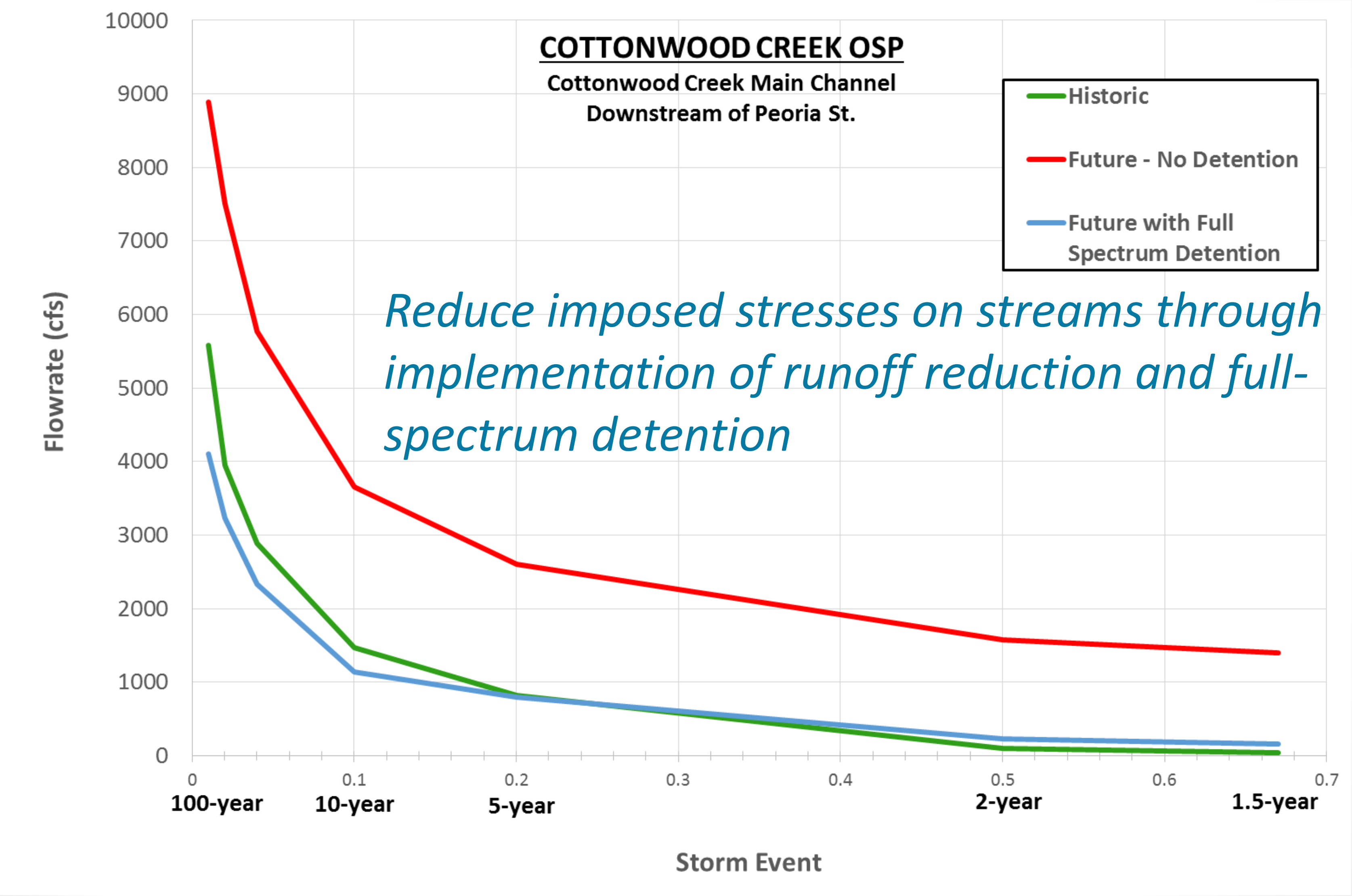


Flow



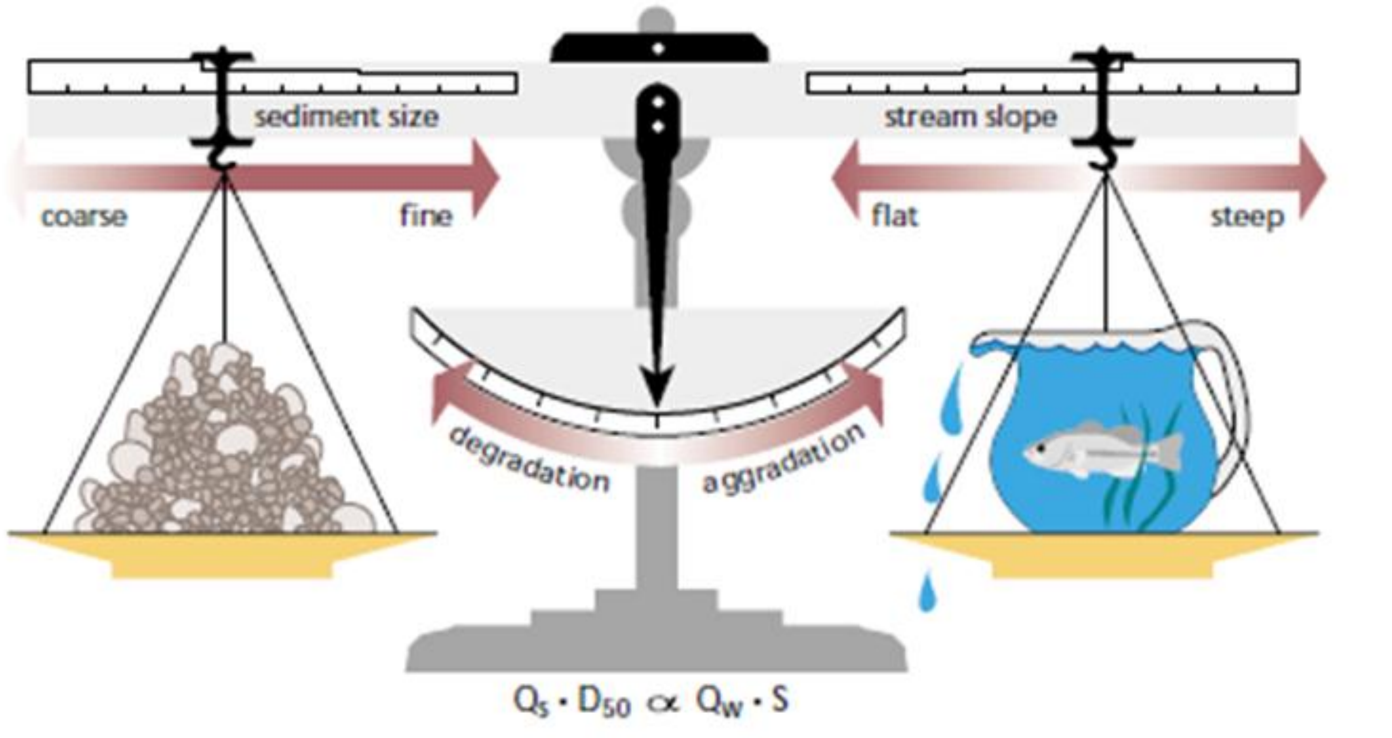
COTTONWOOD CREEK OSP
Cottonwood Creek Main Channel
Downstream of Peoria St.
Historic
Future - No Detention
1.6 x Historic
2.5 x Historic
3.2 x Historic
Critical Stream Forming Discharges
16 x Historic
36 x Historic
Flowrate (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
100-year
10-year
5-year
2-year
1.5-year
Storm Event

Flow



COTTONWOOD CREEK OSP
Cottonwood Creek Main Channel
Downstream of Peoria St.
Historic
Future - No Detention
Future with Full Spectrum Detention
Reduce imposed stresses on streams through implementation of runoff reduction and full-spectrum detention
Flowrate (cfs)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
100-year
10-year
5-year
2-year
1.5-year
Storm Event

Sediment



Lane's Sediment Balance

Sediment

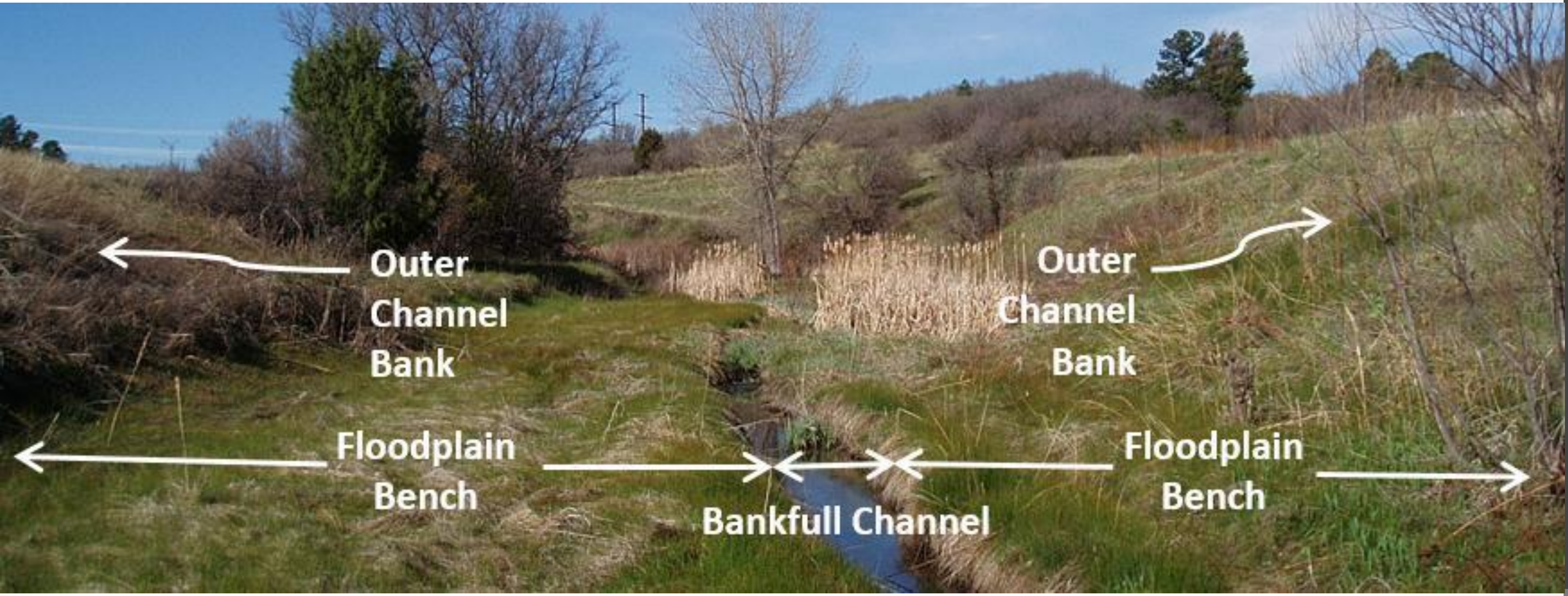
Degradation

Aggradation

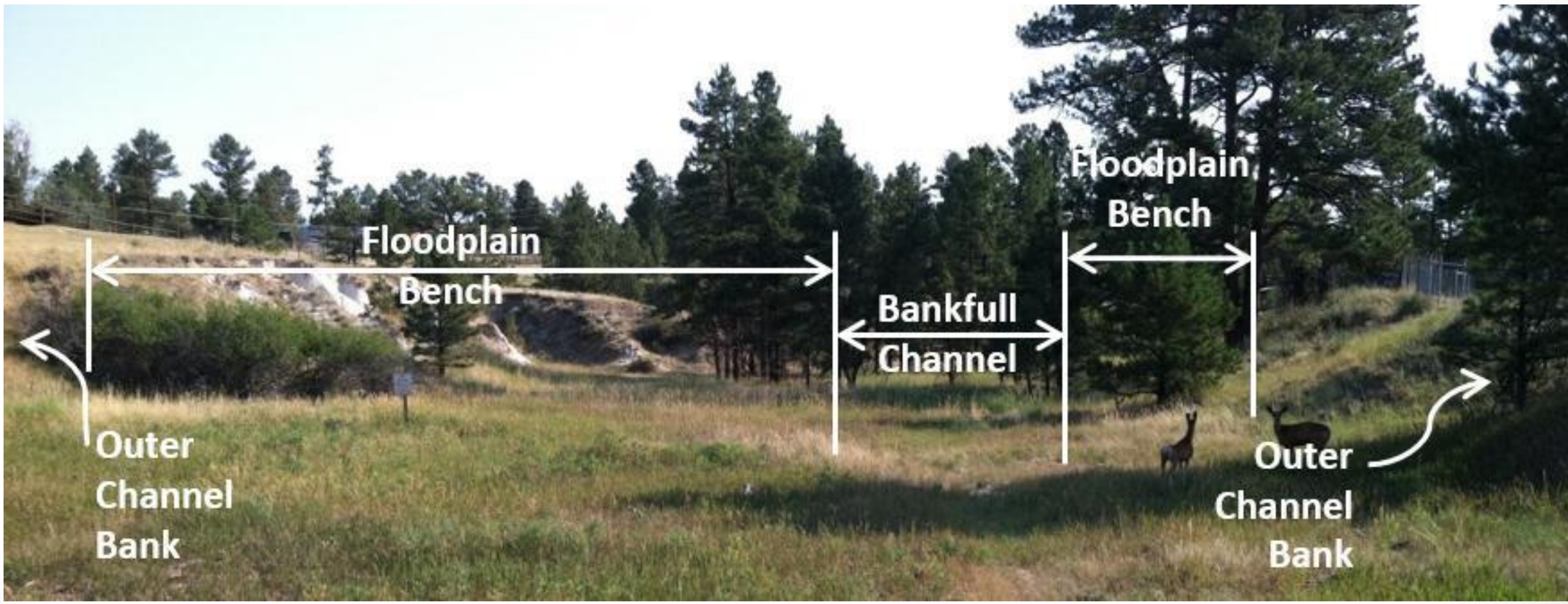
Shape

Outer
Channel
Bank
Outer
Channel
Bank
Floodplain
Bench
Bankfull Channel
Floodplain
Bench

Shape

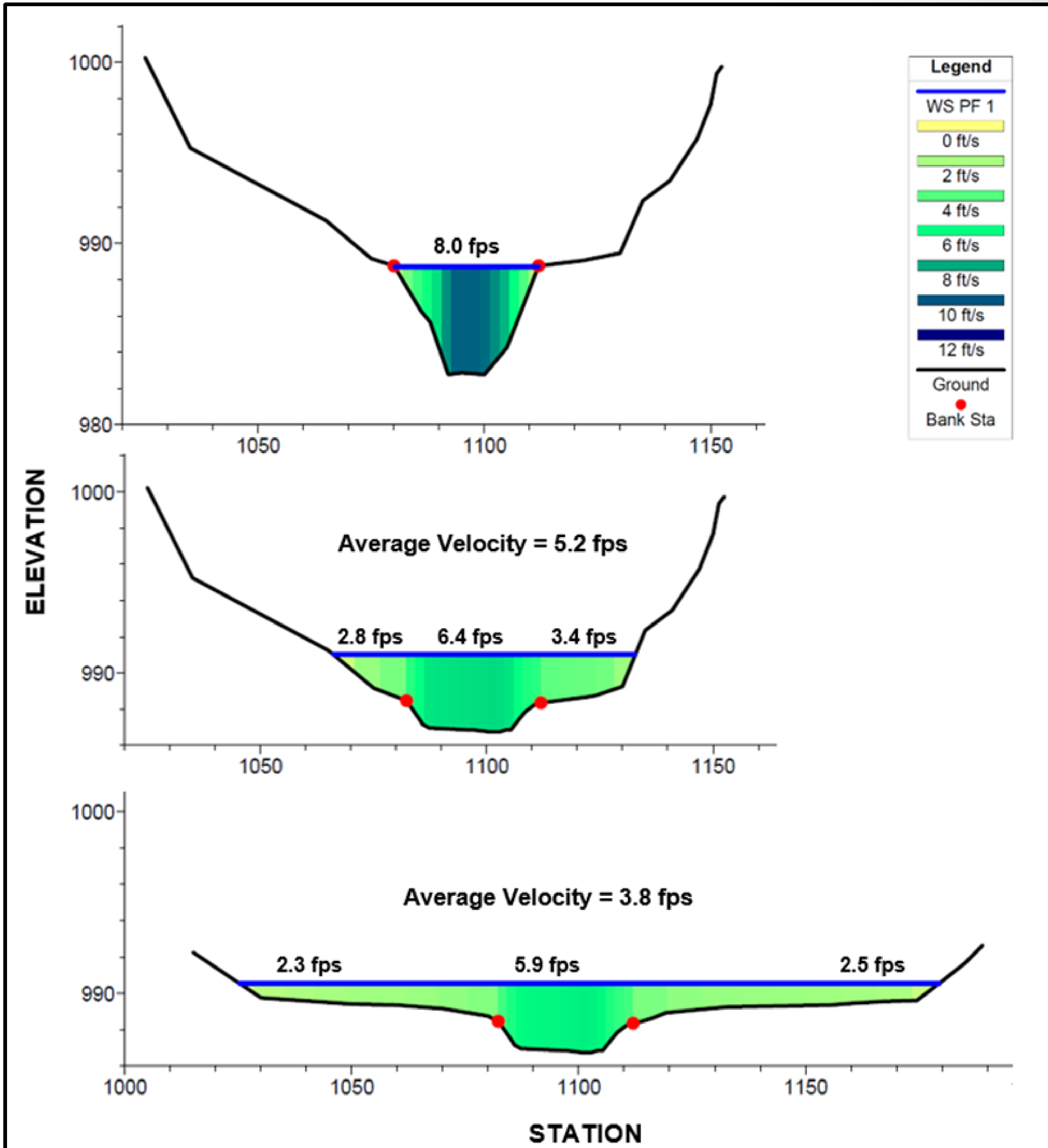

Outer
Channel
Bank
Outer
Channel
Bank
Floodplain
Bench
Bankfull Channel
Floodplain
Bench

Shape



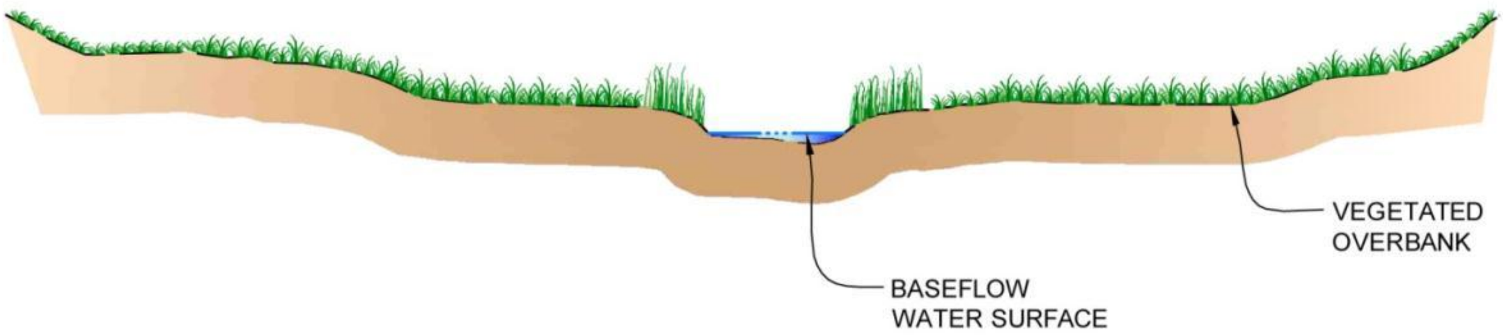
Floodplain
Bench
Bankfull
Channel
Floodplain
Bench
Outer
Channel
Bank
Outer
Channel
Bank

Shape

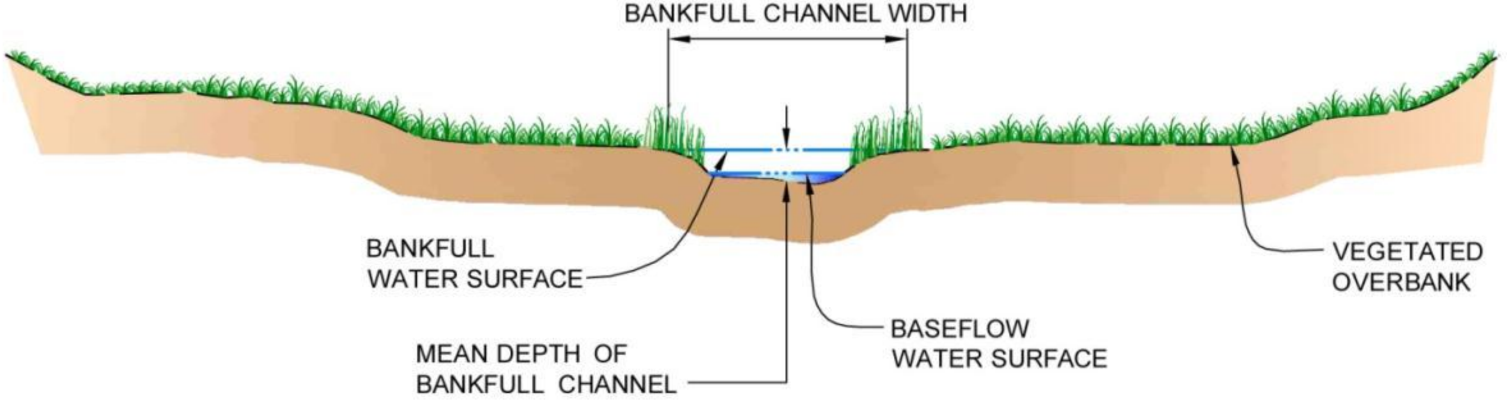


Legend
WS PF 1
0 ft/s
2 ft/s
4 ft/s
6 ft/s
8 ft/s
10 ft/s
12 ft/s
Ground
Bank Sta
8.0 fps
Average Velocity = 5.2 fps
2.8 fps
6.4 fps
3.4 fps
Average Velocity = 3.8 fps
2.3 fps
5.9 fps
2.5 fps
ELEVATION
STATION
1000
990
980
1050
1100
1150

Shape



Shape


BANKFULL CHANNEL WIDTH
BANKFULL
WATER SURFACE
MEAN DEPTH OF
BANKFULL CHANNEL
BASEFLOW
WATER SURFACE
VEGETATED
OVERBANK

Shape

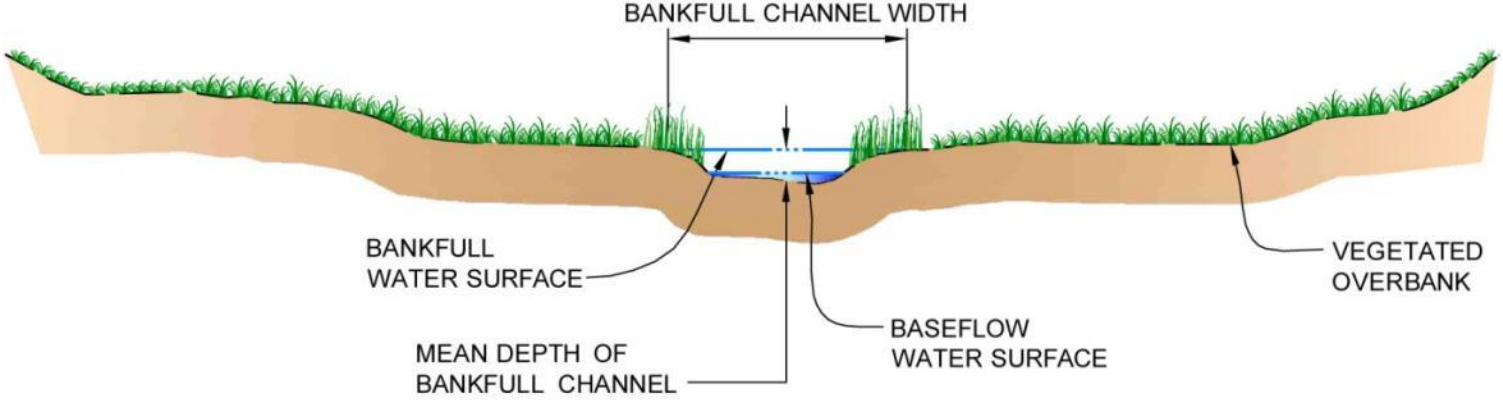
A Guide for Field Identification of Bankfull Stage in the Western United States

https://www.youtube.com/watch?feature=player_detailpage&v=UuS7H2NxJIM

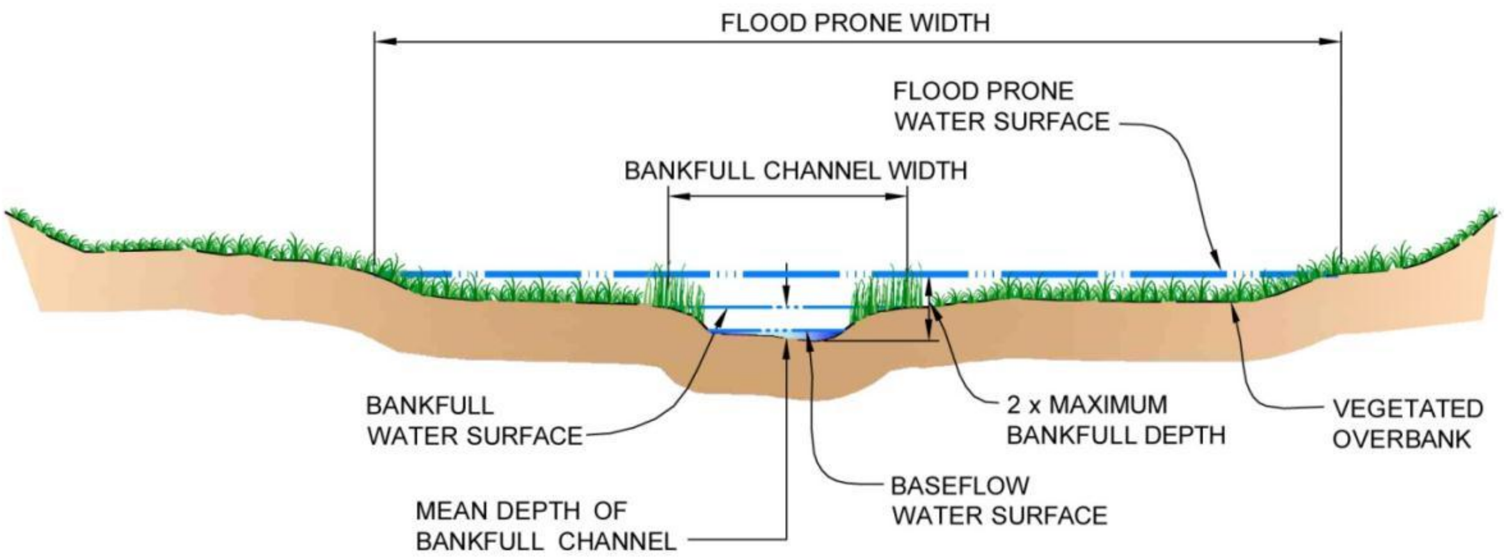
Shape

Bankfull Relationships

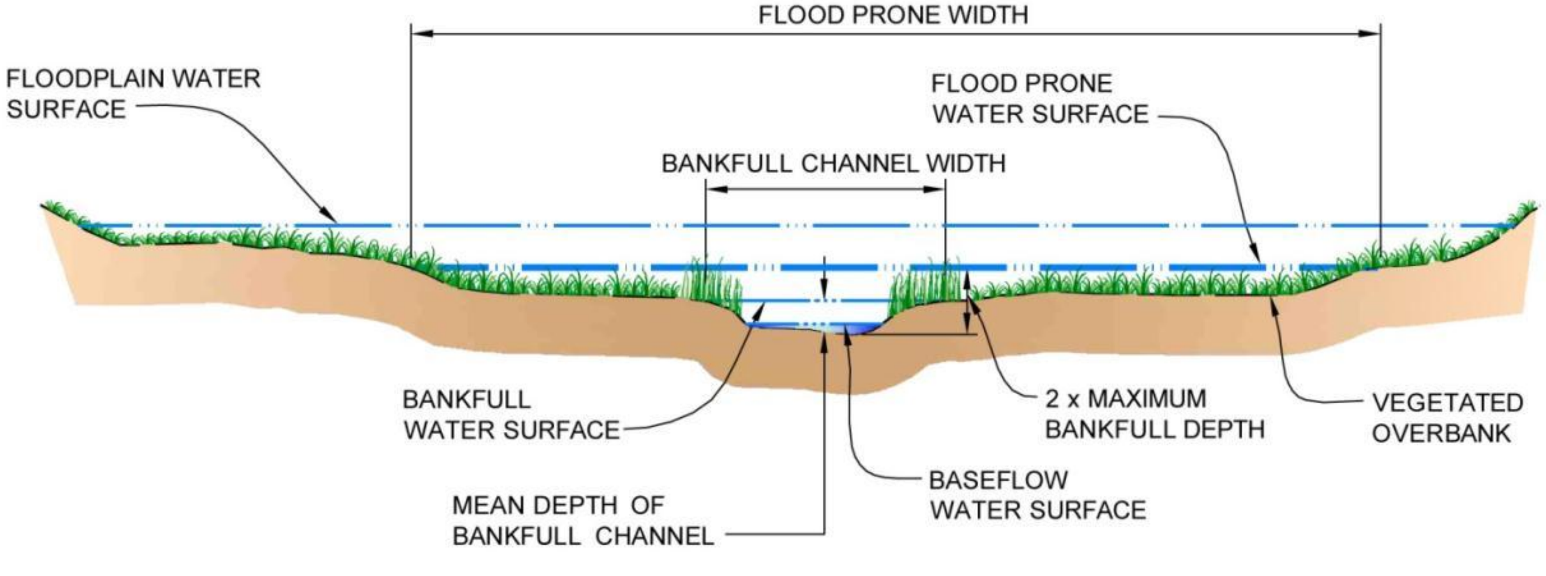
Geomorphic relationships between:
Bankfull Discharge and Bankfull Width
Bankfull Width and Bankfull Depth



Shape

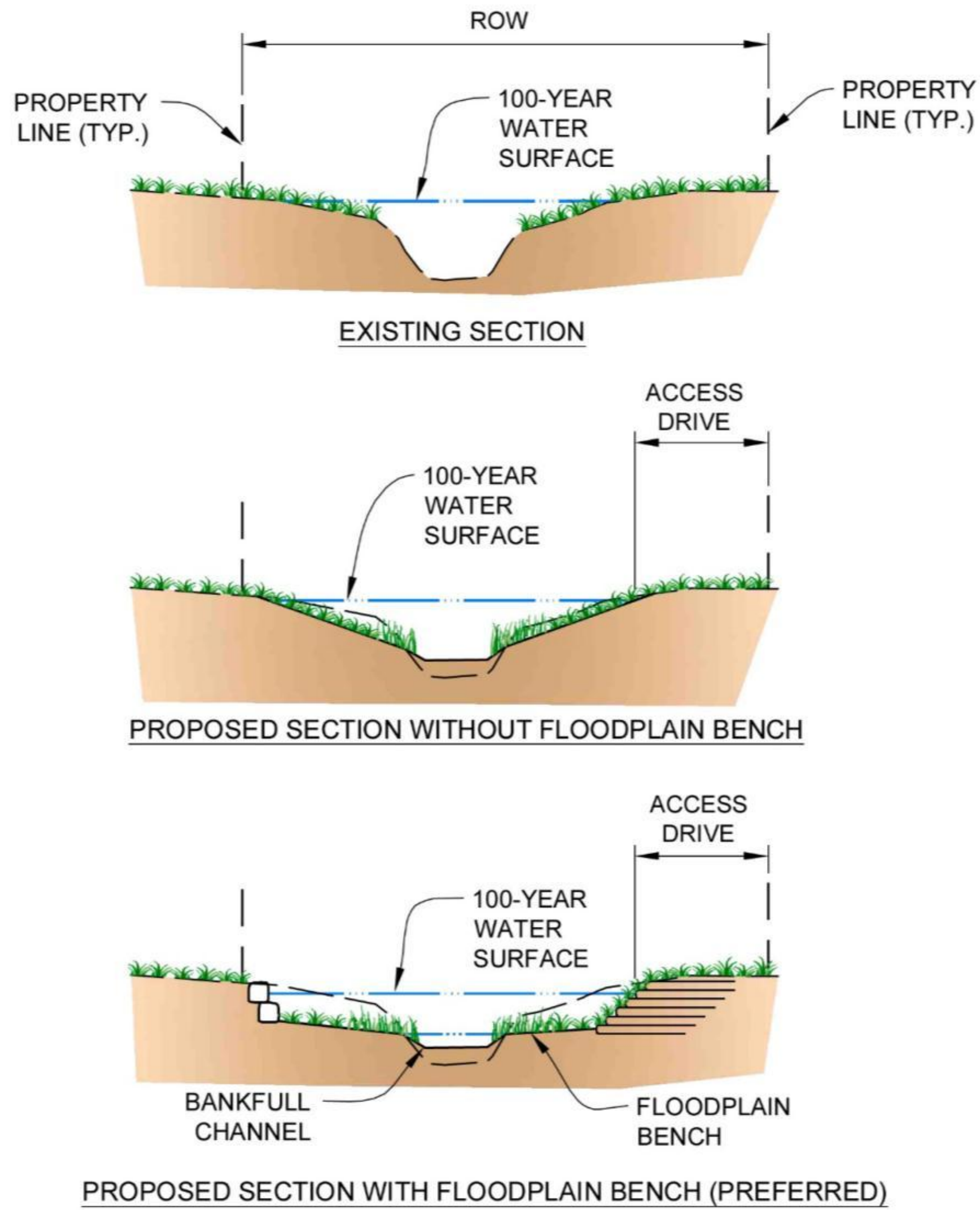

FLOOD PRONE WIDTH
FLOOD PRONE
WATER SURFACE
BANKFULL CHANNEL WIDTH
BANKFULL
WATER SURFACE
2 x MAXIMUM
BANKFULL DEPTH
VEGETATED
OVERBANK
BASEFLOW
WATER SURFACE
MEAN DEPTH OF
BANKFULL CHANNEL

Shape



FLOOD PRONE WIDTH
FLOODPLAIN WATER SURFACE
FLOOD PRONE WATER SURFACE
BANKFULL CHANNEL WIDTH
BANKFULL WATER SURFACE
2 x MAXIMUM BANKFULL DEPTH
VEGETATED OVERBANK
BASEFLOW WATER SURFACE
MEAN DEPTH OF BANKFULL CHANNEL

Shape


ROW
PROPERTY LINE (TYP.)
100-YEAR WATER SURFACE
PROPERTY LINE (TYP.)
EXISTING SECTION
ACCESS DRIVE
100-YEAR WATER SURFACE
PROPOSED SECTION WITHOUT FLOODPLAIN BENCH
ACCESS DRIVE
100-YEAR WATER SURFACE
BANKFULL CHANNEL
FLOODPLAIN BENCH
PROPOSED SECTION WITH FLOODPLAIN BENCH (PREFERRED)

Shape

South Platte River Environmental Enhancement:
Creating a bankfull channel with adjacent floodplain benches

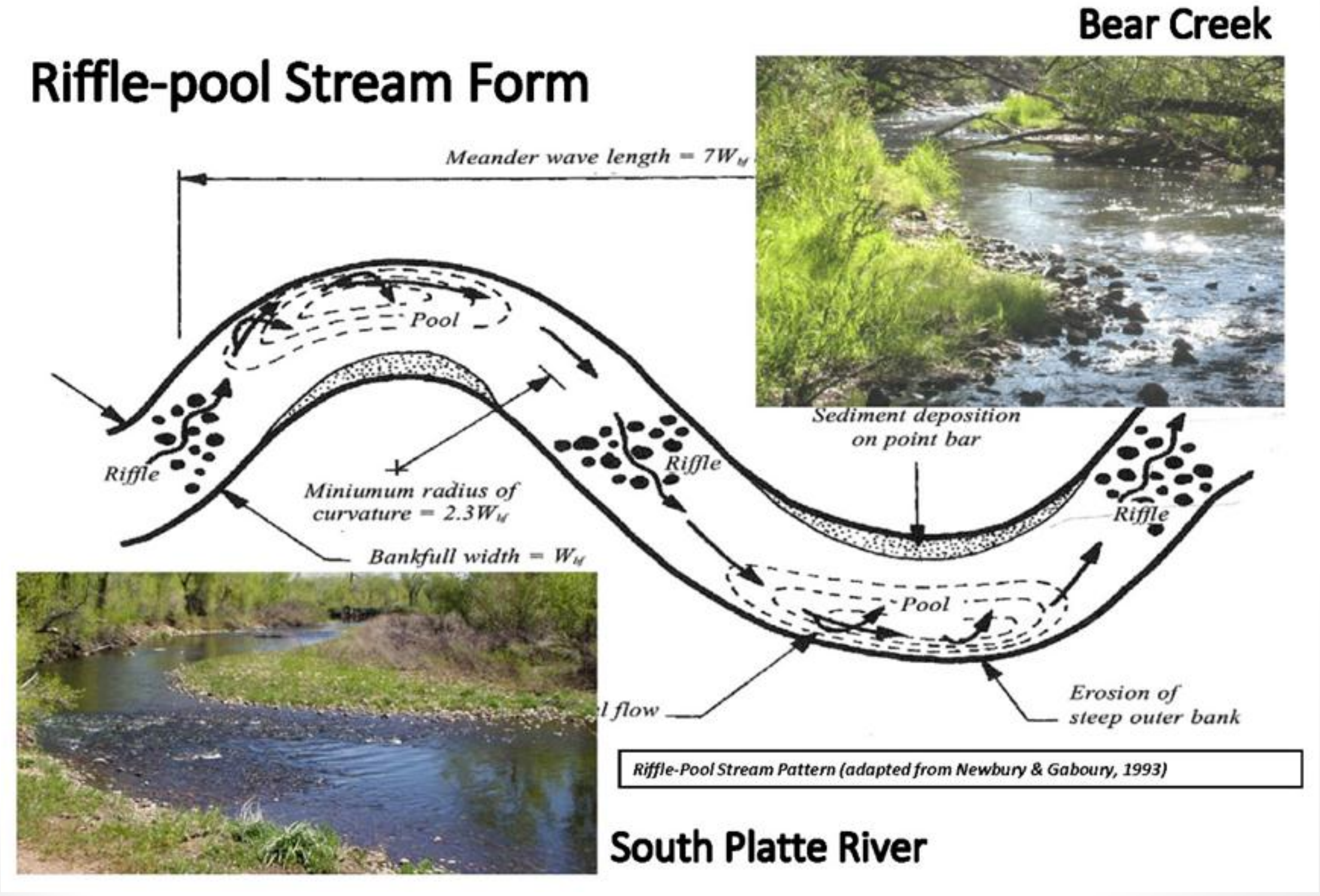
Shape

Avg. Channel Width
Meander Wavelength
Typical Riffle Spacing = ½ Meander Wavelength
Meander Radius
Historic Meander Belt Width
Min. Channel Width
Max. Channel Width
Meander Amplitude
Approx. Valley Centerline
Approx. Channel Centerline
Sinuosity = Channel Length/Valley Length

Shape

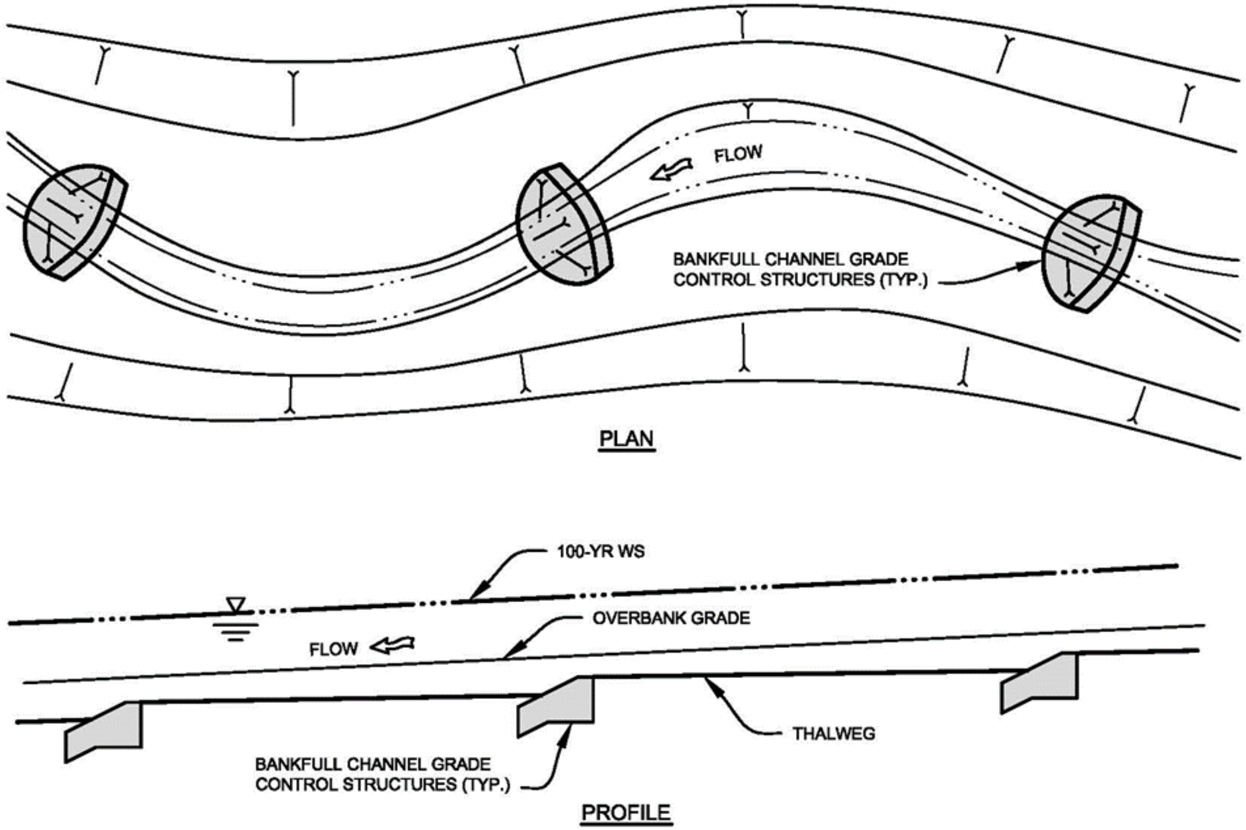

LEGEND
BASE FLOW CHANNEL
WETLAND
RIPARIAN FRINGE
RIPARIAN BENCH
UPLAND PRAIRIE
FLOOD FLOW
TRAIL
FUTURE TRAIL
TREES/SHRUBS
RIPPLE DROP

Shape



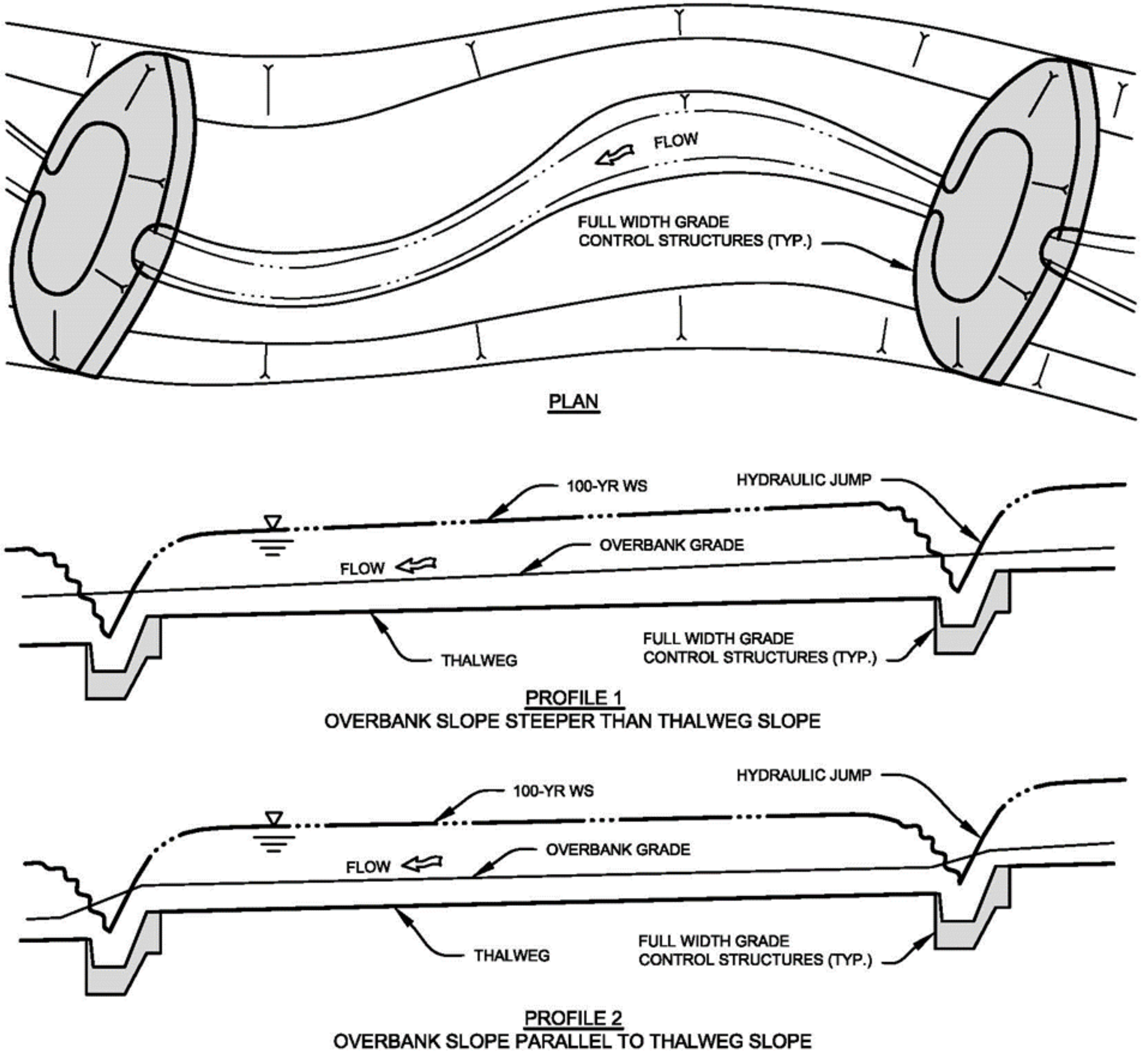
Riffle-pool Stream Form
Bear Creek
Meander wave length = $7W_{bf}$
Pool
Riffle
Miniumum radius of curvature = $2.3W_{bf}$
Bankfull width = W_{bf}
Sediment deposition on point bar
Riffle
Riffle
Pool
l flow
Erosion of steep outer bank
Riffle-Pool Stream Pattern (adapted from Newbury & Gaboury, 1993)
South Platte River

Gradient



FLOW
BANKFULL CHANNEL GRADE CONTROL STRUCTURES (TYP.)
PLAN
100-YR WS
OVERBANK GRADE
FLOW
THALWEG
BANKFULL CHANNEL GRADE CONTROL STRUCTURES (TYP.)
PROFILE

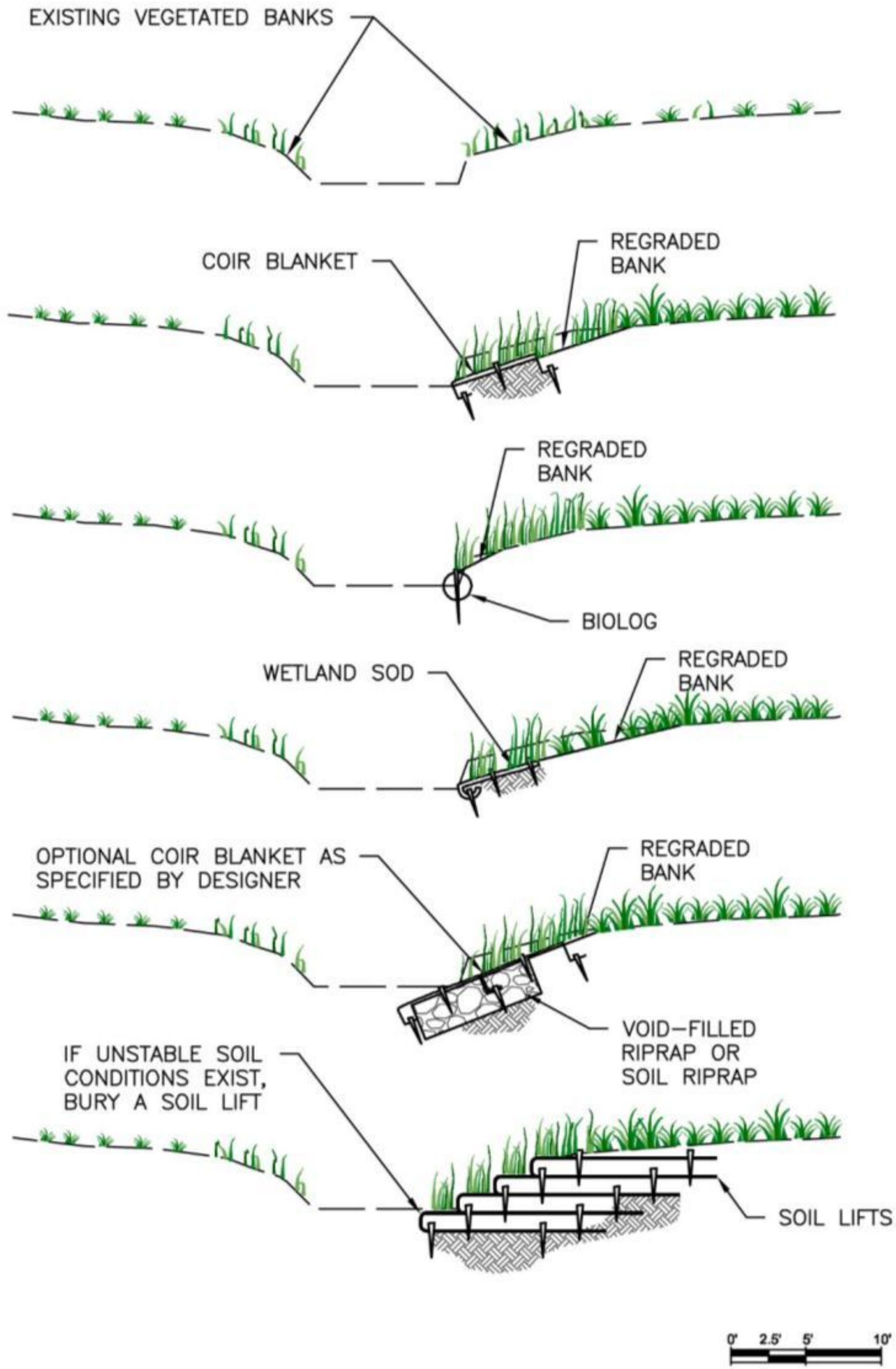
Gradient


FLOW
FULL WIDTH GRADE CONTROL STRUCTURES (TYP.)
PLAN
100-YR WS
HYDRAULIC JUMP
OVERBANK GRADE
FLOW
THALWEG
FULL WIDTH GRADE CONTROL STRUCTURES (TYP.)
PROFILE 1
OVERBANK SLOPE STEEPER THAN THALWEG SLOPE
100-YR WS
HYDRAULIC JUMP
OVERBANK GRADE
FLOW
THALWEG
FULL WIDTH GRADE CONTROL STRUCTURES (TYP.)
PROFILE 2
OVERBANK SLOPE PARALLEL TO THALWEG SLOPE

Gradient

Vegetation

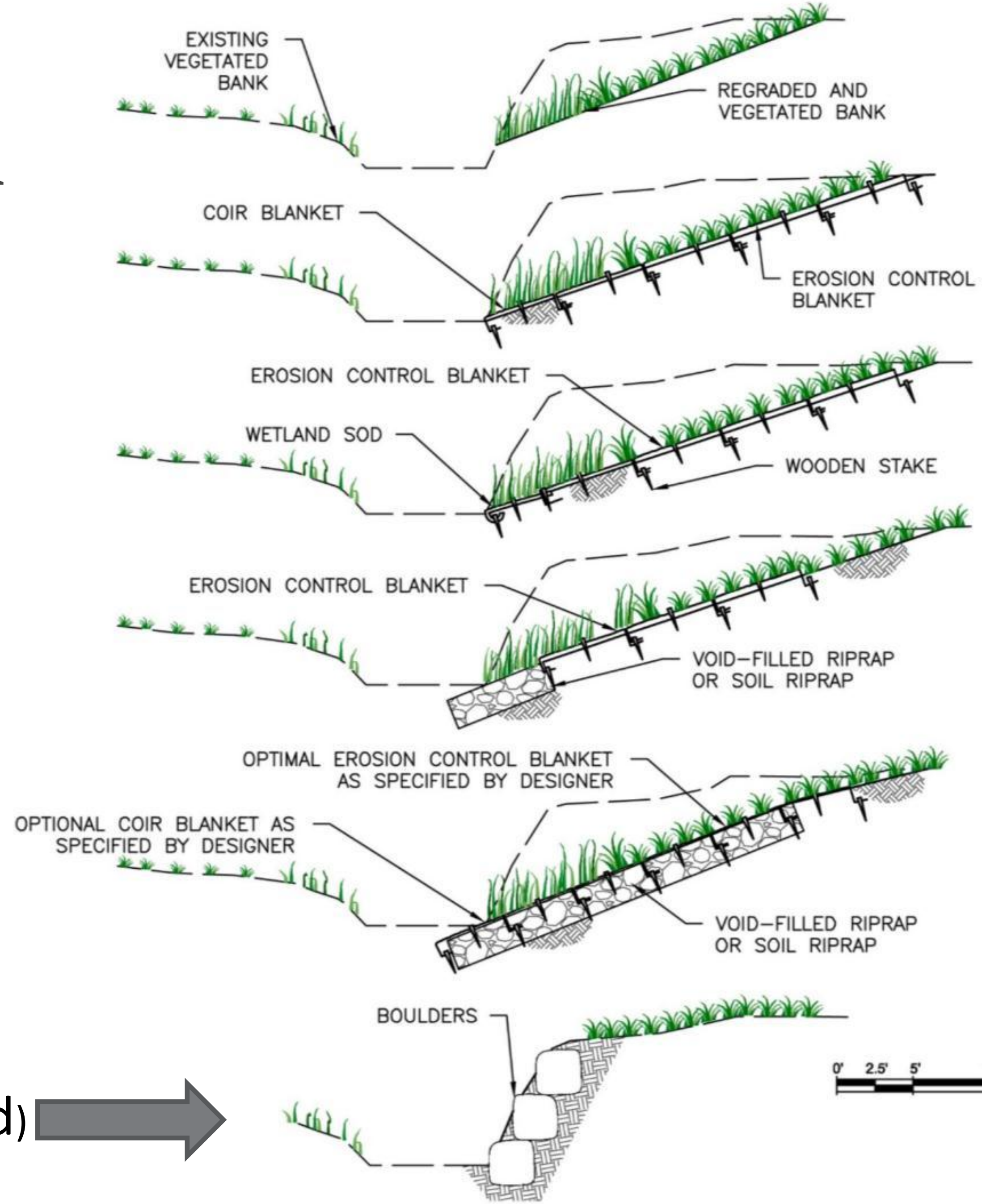
Vegetation



EXISTING VEGETATED BANKS
COIR BLANKET
REGRADED BANK
REGRADED BANK
BIOLOG
WETLAND SOD
REGRADED BANK
OPTIONAL COIR BLANKET AS SPECIFIED BY DESIGNER
REGRADED BANK
VOID–FILLED RIPRAP OR SOIL RIPRAP
IF UNSTABLE SOIL CONDITIONS EXIST, BURY A SOIL LIFT
SOIL LIFTS
0' 2.5' 5' 10'

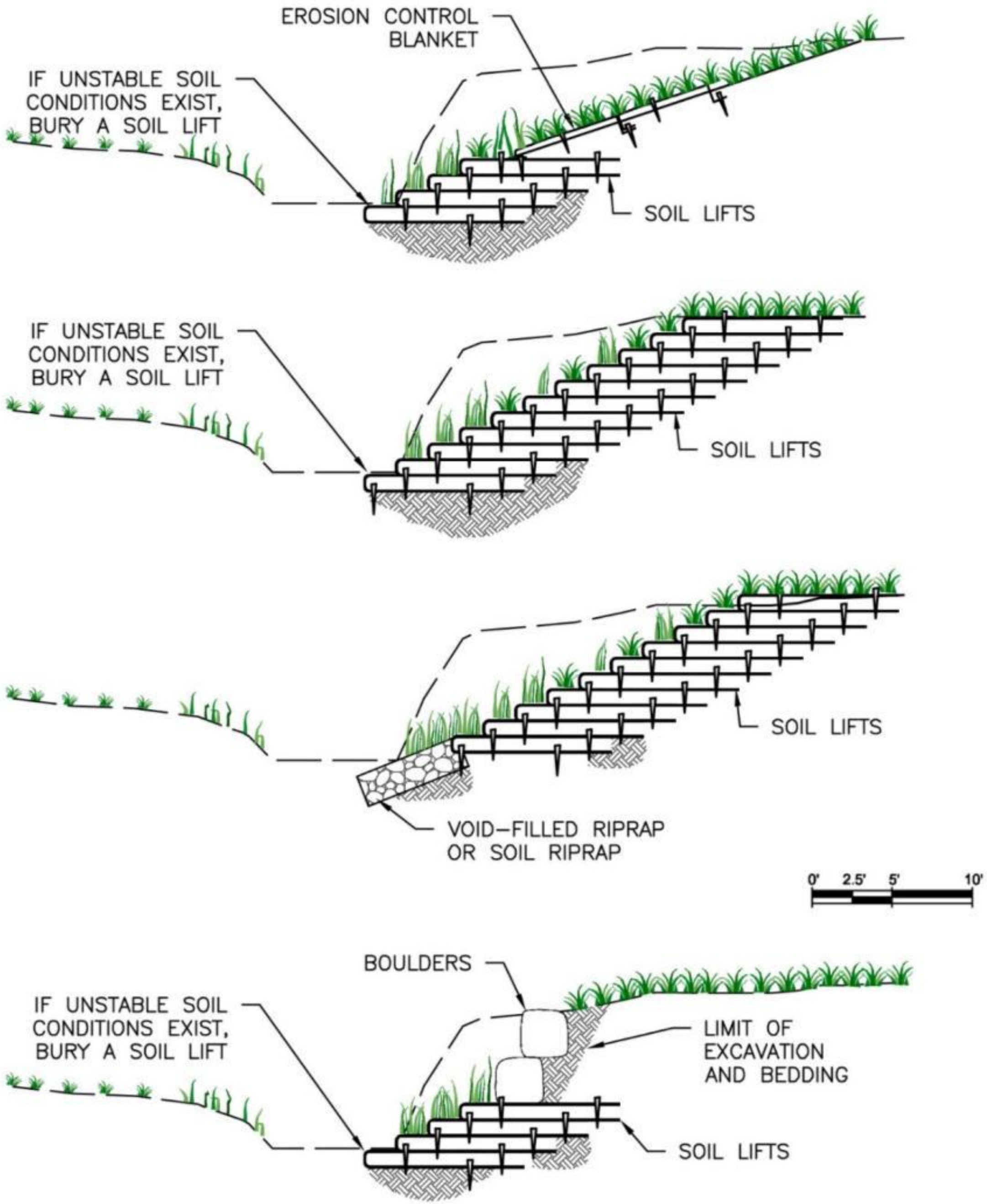
Vegetation

Vegetation



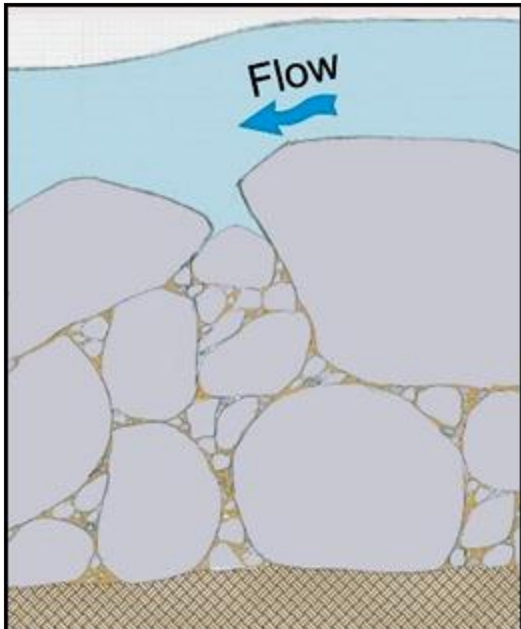
(Only when needed)

Vegetation



EROSION CONTROL BLANKET
IF UNSTABLE SOIL CONDITIONS EXIST, BURY A SOIL LIFT
SOIL LIFTS
IF UNSTABLE SOIL CONDITIONS EXIST, BURY A SOIL LIFT
SOIL LIFTS
SOIL LIFTS
VOID–FILLED RIPRAP OR SOIL RIPRAP
0' 2.5' 5' 10'
BOULDERS
IF UNSTABLE SOIL CONDITIONS EXIST, BURY A SOIL LIFT
LIMIT OF EXCAVATION AND BEDDING
SOIL LIFTS

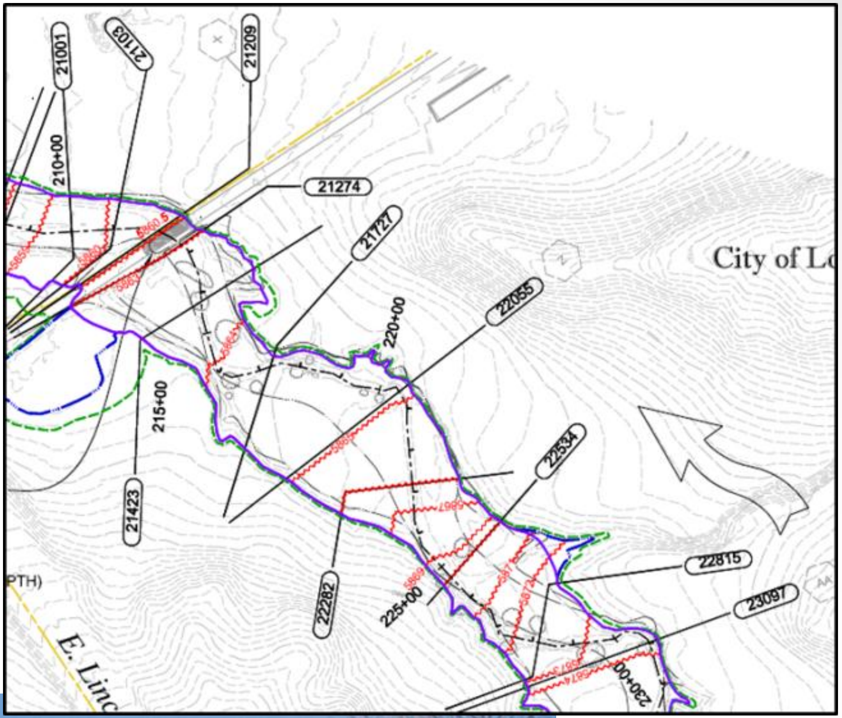
Rock

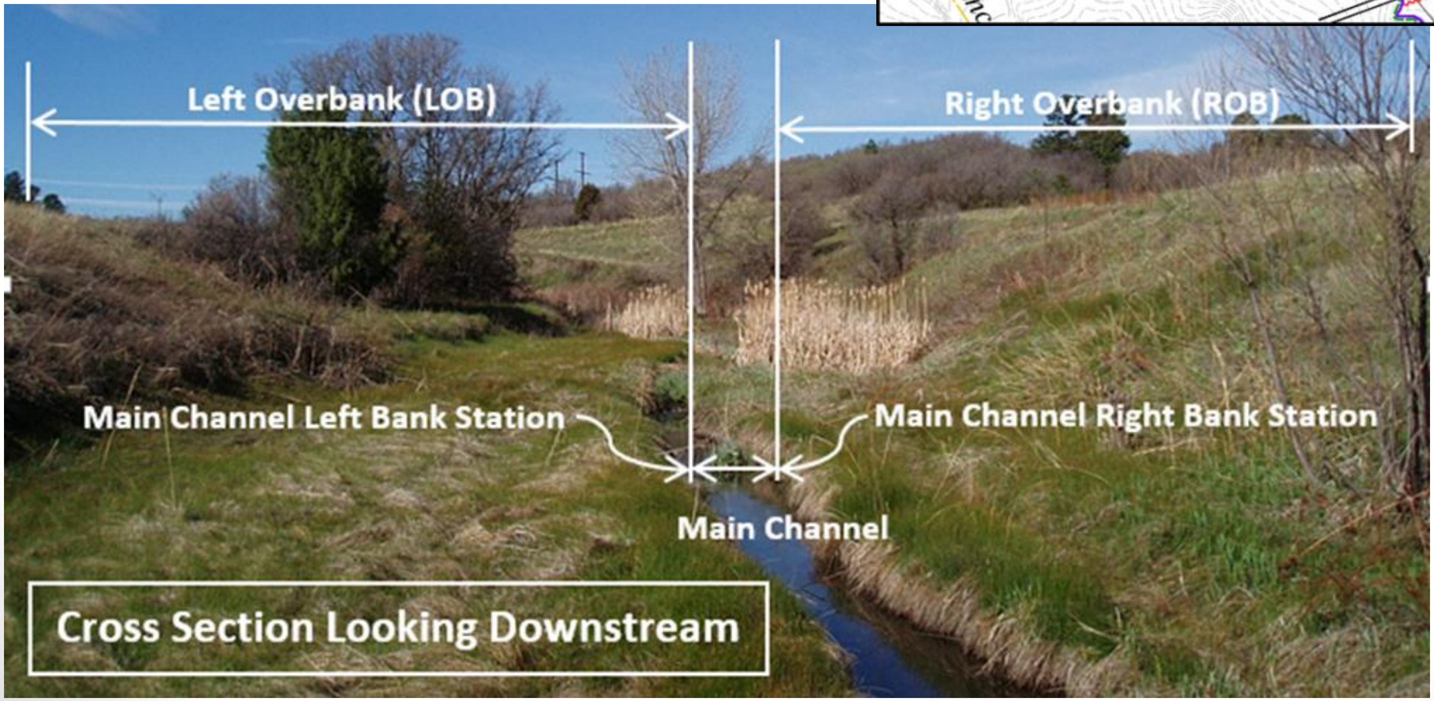


Rock

Hydraulics

Cross Section Placement





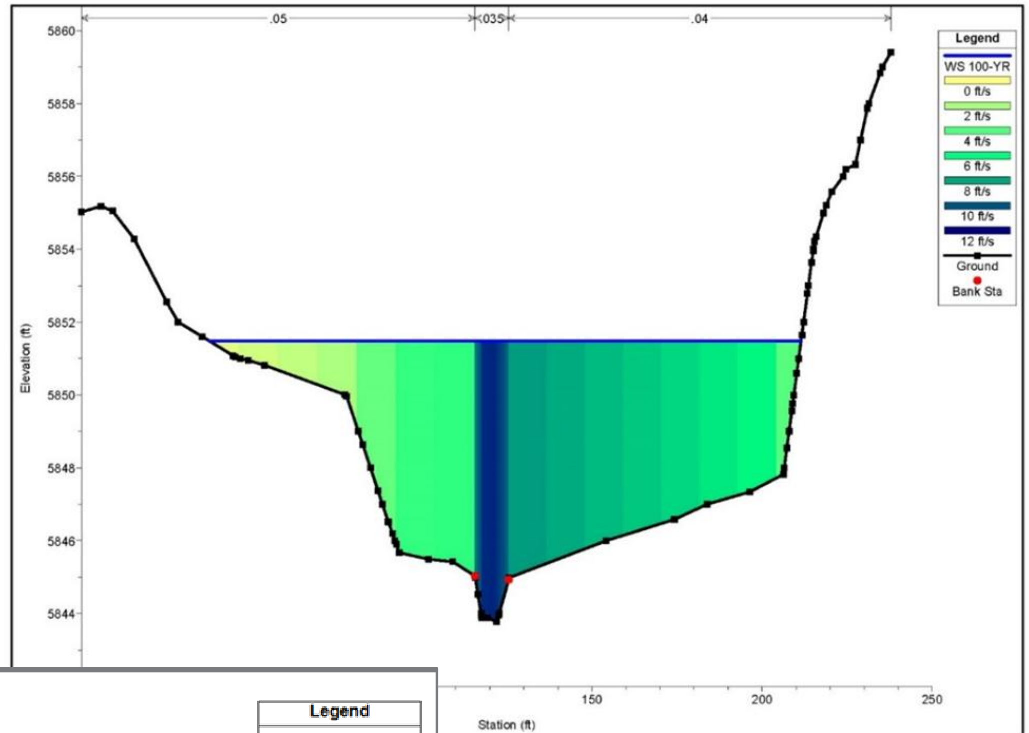
Cross Section Definitions

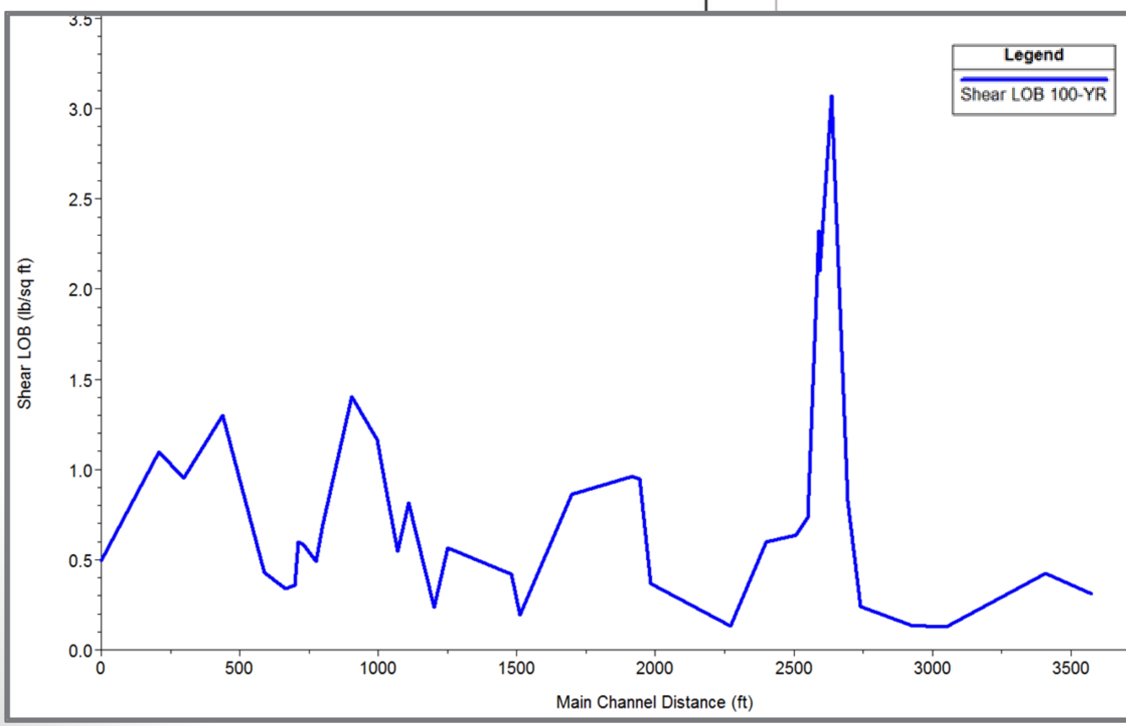
Hydraulics

Roughness Coefficients
Values for Initial Approximations

Hydraulics

Velocity Distribution at Cross Section





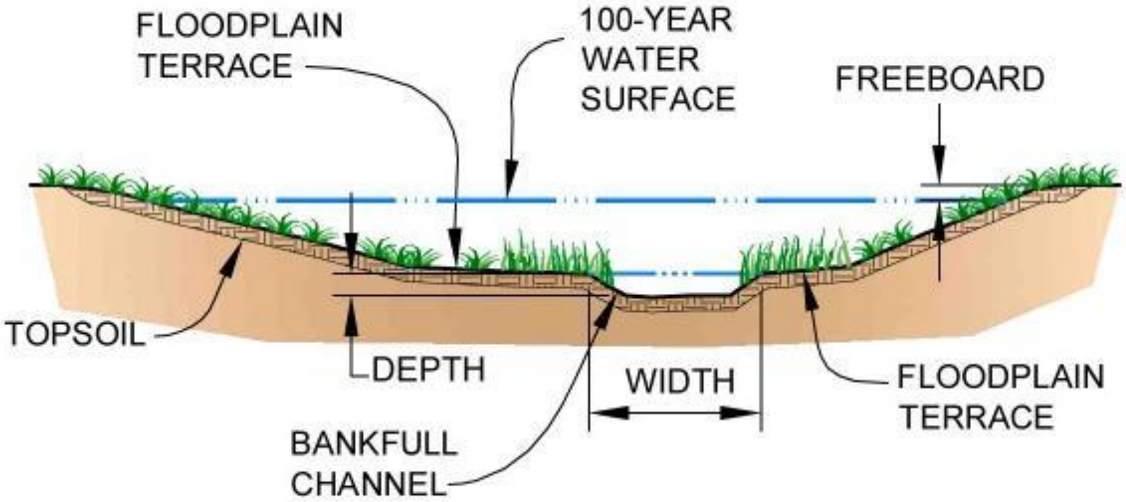
Profile Plot of Shear Stress

Stream Restoration

1. Space
2. Flow
3. Sediment
4. Shape
5. Gradient
6. Vegetation
7. Rock
8. Hydraulics

2014 UDFCD Annual Seminar April 15,2014

Naturalized Channels



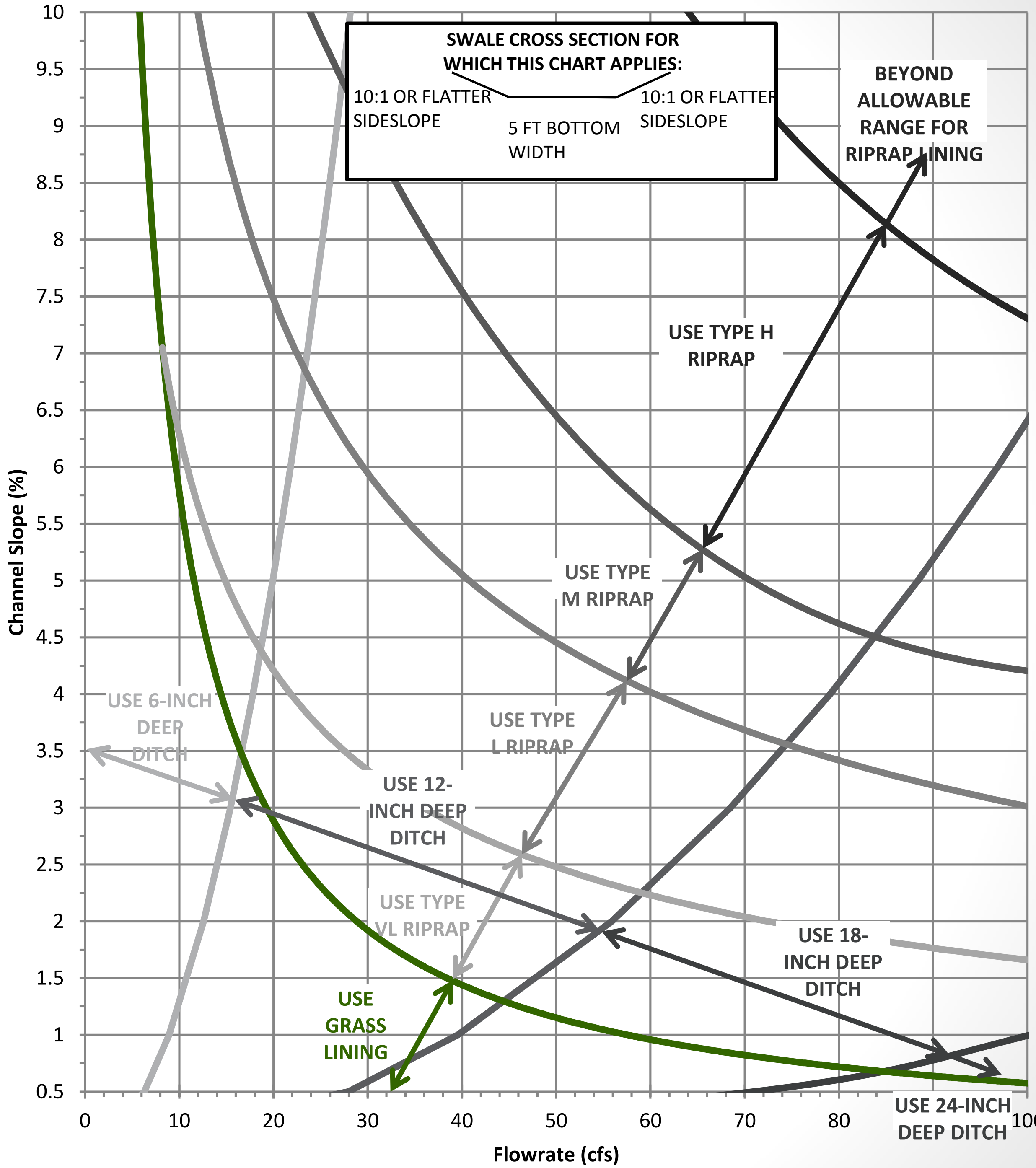
"Typical" Geometry

Naturalized Channels and Criteria

- Depth
- Roughness values
- Velocities
- Froude
- Shear Stress
- Bankfull capacity and geometry
- Entrenchment ratio
- Sinuosity
- Side slopes
- Radius of Curvature

Swales

Swales



SWALE CROSS SECTION FOR WHICH THIS CHART APPLIES:
10:1 OR FLATTER SIDESLOPE
5 FT BOTTOM WIDTH
10:1 OR FLATTER SIDESLOPE
BEYOND ALLOWABLE RANGE FOR RIPRAP LINING
USE TYPE H RIPRAP
USE TYPE M RIPRAP
USE TYPE L RIPRAP
USE 6-INCH DEEP DITCH
USE 12-INCH DEEP DITCH
USE TYPE VL RIPRAP
USE 18-INCH DEEP DITCH
USE GRASS LINING
USE 24-INCH DEEP DITCH
Channel Slope (%)
Flowrate (cfs)
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
10
20
30
40
50
60
70
80
100

Questions

SESSION 8a

Floodplain Management Program "Under New Management"

David Mallory and Terri Fead, UDFCD

ABSTRACT:

You may have heard that the Mighty Mitigator, my friend and mentor; Bill DeGroot retired from UDFCD the first part of February. Until now the only Program Manager of the Floodplain Management Program has been Bill. His role in leading us as a community and nation towards a safer and more resilient future cannot be overstated. We have much to do to continue and build on his vision.

Now there is a new team to get acquainted with and possibly new directions, goals and projects to discuss. Inevitably when the management changes it's time to reflect on what worked in the past and what should be reinvented for future greatness. The Colorado Flood of 2013 taught us some lessons. We learned that 40 years of mitigation worked well, but there is always room for improvement. Short Floodplain Management Program updates will be provided including the Floodplain Preservation video and two new initiatives to our Letter of Map Change (LOMC) processing.

Congratulations on Your Approved Conditional Letter of Map Revision (CLOMR)!

Terri Fead, P.E., CFM, Senior Project Engineer
David Mallory, P.E., CFM, Manager, Floodplain Management Program

2014 UDFCD Annual Seminar April 15,2014

MISCONCEPTIONS

WHEN Are

Flood Insurance Rate Map Changes

EFFECTIVE?

CLARIFICATION

The Urban Drainage
and Flood Control District (UDFCD)
Wants to
Help Clarify that Timeline!

LETTER OF MAP REVISION (LOMR)

Construct Project

As-built Drawings

Revise Analyses?

REMEMBER THESE?

- CLOMR Critical Items

Page 3 of 5	Issue Date: March 11, 2014	Case No.: 14-08-0463R	CLOMR-APP

Federal Emergency Management Agency
Washington, D.C. 20472

CONDITIONAL LETTER OF MAP REVISION
COMMENT DOCUMENT (CONTINUED)

COMMUNITY INFORMATION (CONTINUED)

Upon completion of the project, your community must submit the data listed below and request that we make a final determination on revising the effective FIRM and FIS report. If the project is built as proposed and the data below are received, a revision to the FIRM and FIS report would be warranted.

- Must Address!

PREPARE LOMR REQUEST

1
- Address CLOMR Critical Items

2
- Complete MT-2 Forms
- Get *ALL* Required Signatures

3
- Submit for Local Review

LOMR APPROVAL TIMELINE

SUBMIT TO LOCAL GOVERNMENT

From 2 Weeks to 2 Months

↓

SUBMIT TO UDFCD

60 Days – Based on *ALL* Data Received

↓

FEMA APPROVAL

30 Days for Determination

LOMR APPROVAL

You've received a

Letter of Final Determination

(a LOMR Approval),

BUT…

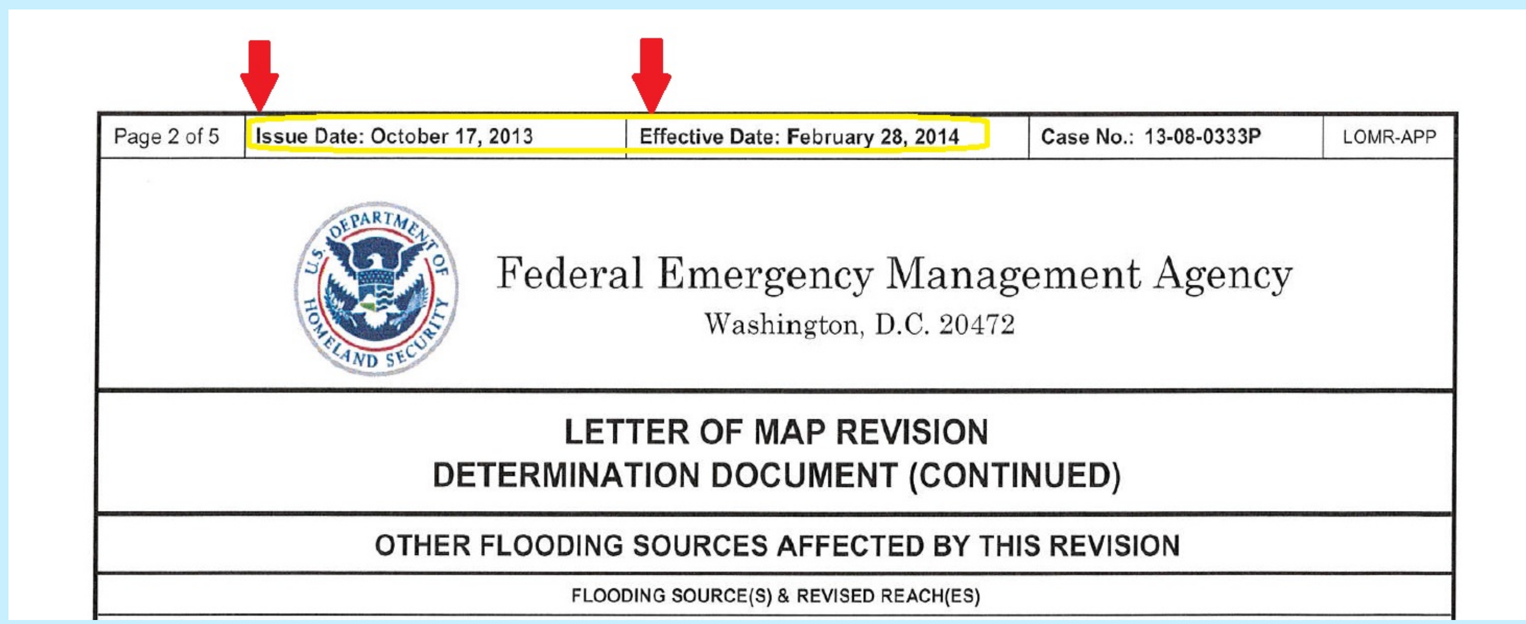
EXTENDED APPEAL PERIOD

LOMRs Are *NOT* Effective

Upon Approval!

LETTER OF FINAL DETERMINATION

- Check the Dates!



Page 2 of 5	Issue Date: October 17, 2013	Effective Date: February 28, 2014	Case No.: 13-08-0333P	LOMR-APP

Federal Emergency Management Agency
Washington, D.C. 20472

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

OTHER FLOODING SOURCES AFFECTED BY THIS REVISION

FLOODING SOURCE(S) & REVISED REACH(ES)

- This is an *APPROVAL*! This is not *EFFECTIVE*!

LOMR APPEAL PERIOD

APPEAL PERIOD	WHEN EFFECTIVE	
All LOMRs for ANY Flood Hazard Change	Compliant Community	Non-compliant or Require LOMR Adoption
90-days	120 Days	6 Months

START OF APPEAL PROCESS

Estimated Effective LOMR:

120 Days

AFTER 2nd Publication Date

LETTER OF MAP REVISION
DETERMINATION DOCUMENT (CONTINUED)

PUBLIC NOTIFICATION OF REVISION

A notice of changes will be published in the *Federal Register*. This information also will be published in your local newspaper on or about the dates listed below and through FEMA's Flood Hazard Mapping website at https://www.floodmaps.fema.gov/fhm/Scripts/bfe_main.asp.

LOCAL NEWSPAPER

Name: *The Littleton Independent*
Dates: March 13, 2014 and March 20, 2014

So Plan Ahead!

UDFCD FOLLOW-UP NOTICE

"JUST A REMINDER…
THERE IS AN
APPEAL PERIOD!"

SO INSTEAD OF…

After the **LOMR** Approval

IT WILL BE…

After the **CLOMR** Approval!

DURING THE APPEAL PERIOD

UDFCD Assists Communities
with Floodplain Management Issues
on a Case-by-case Basis
as Requested

QUESTIONS???

?

There's a reason it's called Sand Creek

David Mallory, UDFCD
Brian Murphy, CDM Smith

ABSTRACT:

From September 9, 2013 to September 16th, rain storms produced approximately 6.1 inches of precipitation within the basin, resulting in significant Sand Creek flooding in Aurora and Commerce City, Colorado. This flooding resulted in mass bank erosion and failures on the west side of Sand Creek, repositioning of the channel bottom, and damages to nearby access roads. The resulting damages caused unstable conditions along the west bank of Sand Creek jeopardizing the Metro Wastewater Reclamation District's (MWRD) disinfection building at the Robert W. Hite Treatment Facility (RWHTF) and increasing the risk of undermining to the siphon structure at the Burlington Ditch.

CDM Smith developed an interim stabilization option in coordination with Urban Drainage and Flood Control District (UDFCD) for Sand Creek downstream of the Burlington Ditch Siphon Structure. The work was performed by Left Hand Excavating, one of UDFCD's on-call contractors. UDFCD handled all permitting for the interim stabilization work, including the U.S. Army Corps of Engineers (USACE) Nationwide Permit 3 and Permit 45..

MWRD is proposing to improve the west bank and channel bed beyond the pre-flood conditions in order to prevent the bank erosion from occurring again. This session will cover the design of improvements, including alternative ananlysis, preliminary and final design, cost estimates and implementation. This project required coordination with USACE, Adams County, Commerce City, FRICO, UDFCD and several adjacent property owners. CDM Smith also supported MWRD's efforts to obtain public assistant funding and hazard mitigation funding from FEMA for the improvements along the west bank of Sand Creek. Construction of the improvements will start in late-March with completion anticipated in September 2014.

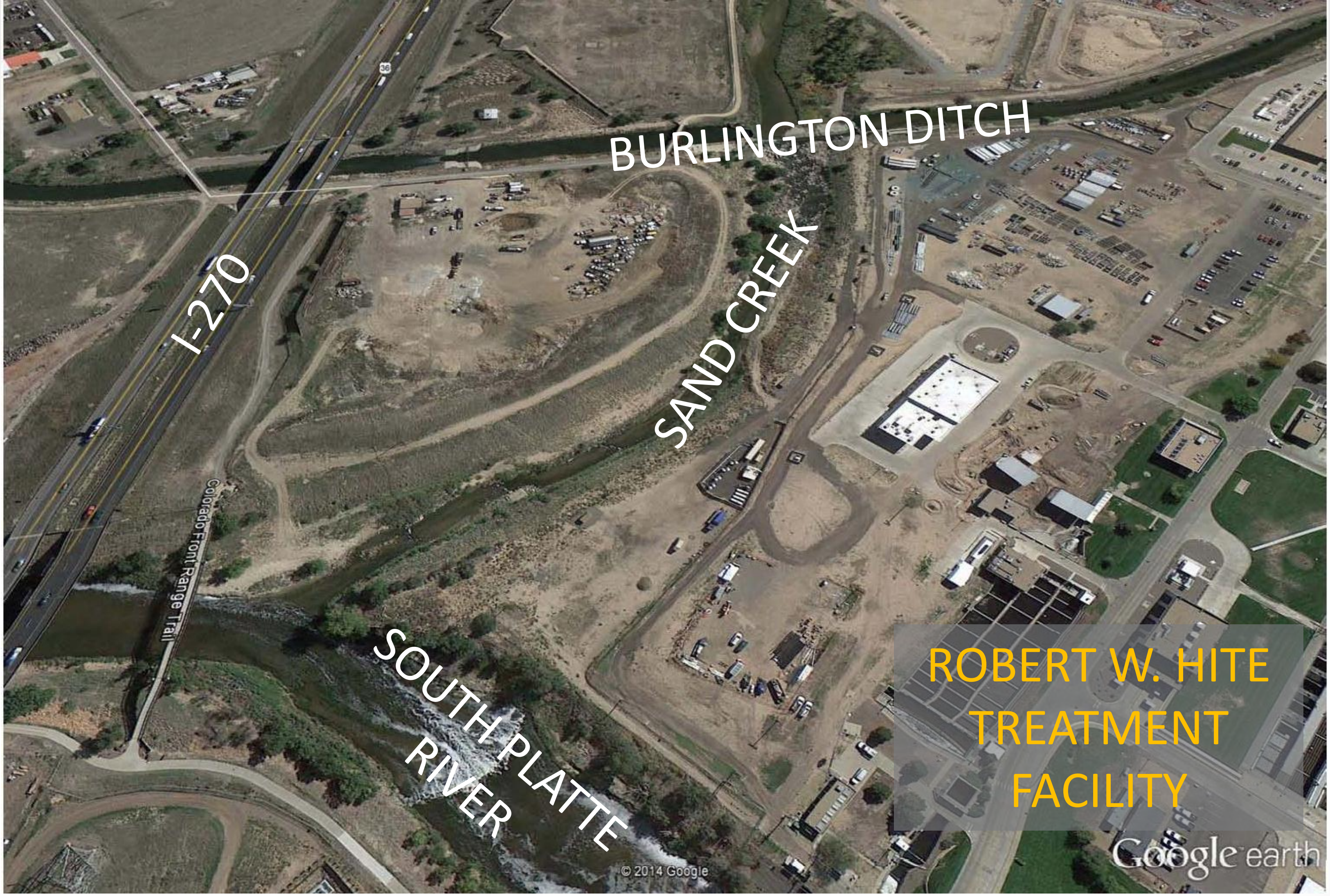
There's a Reason It's Called Sand Creek

Brian Murphy, P.E., P.H., CFM
David Mallory, P.E., CFM

2014 UDFCD Annual Seminar April 15,2014

Presentation Outline

- Background
- September Flood Impacts
- UDFCD Interim Improvements
- Property Ownership
- FEMA public assistance funding
- Permanent Improvements
- CLOMR
- Cost of improvements



Sand Creek

Project Location

Sand Creek

Project Location

- September 9th through 16th, 2013
  - 6 to 15 inches of precipitation fell in the Sand Creek basin
  - Approx. peak flow on Sand Creek
    - 10,000 and 17,000 cfs (~10 yr flood)
    - 100-yr flood = 30,500 cfs
- Significant flooding along Sand Creek in Aurora and Commerce City
- Flooding eroded portions of the west bank of Sand Creek
  - Along the boundary of the Metro District's RWHTF
    - Jeopardized disinfection building
    - Increased risk of undermining siphon structure
- MWRD hired CDM Smith to design and construct improvements

Sand Creek

Background

Sand Creek

September Flood

Sand Creek

September Flood

Sand Creek

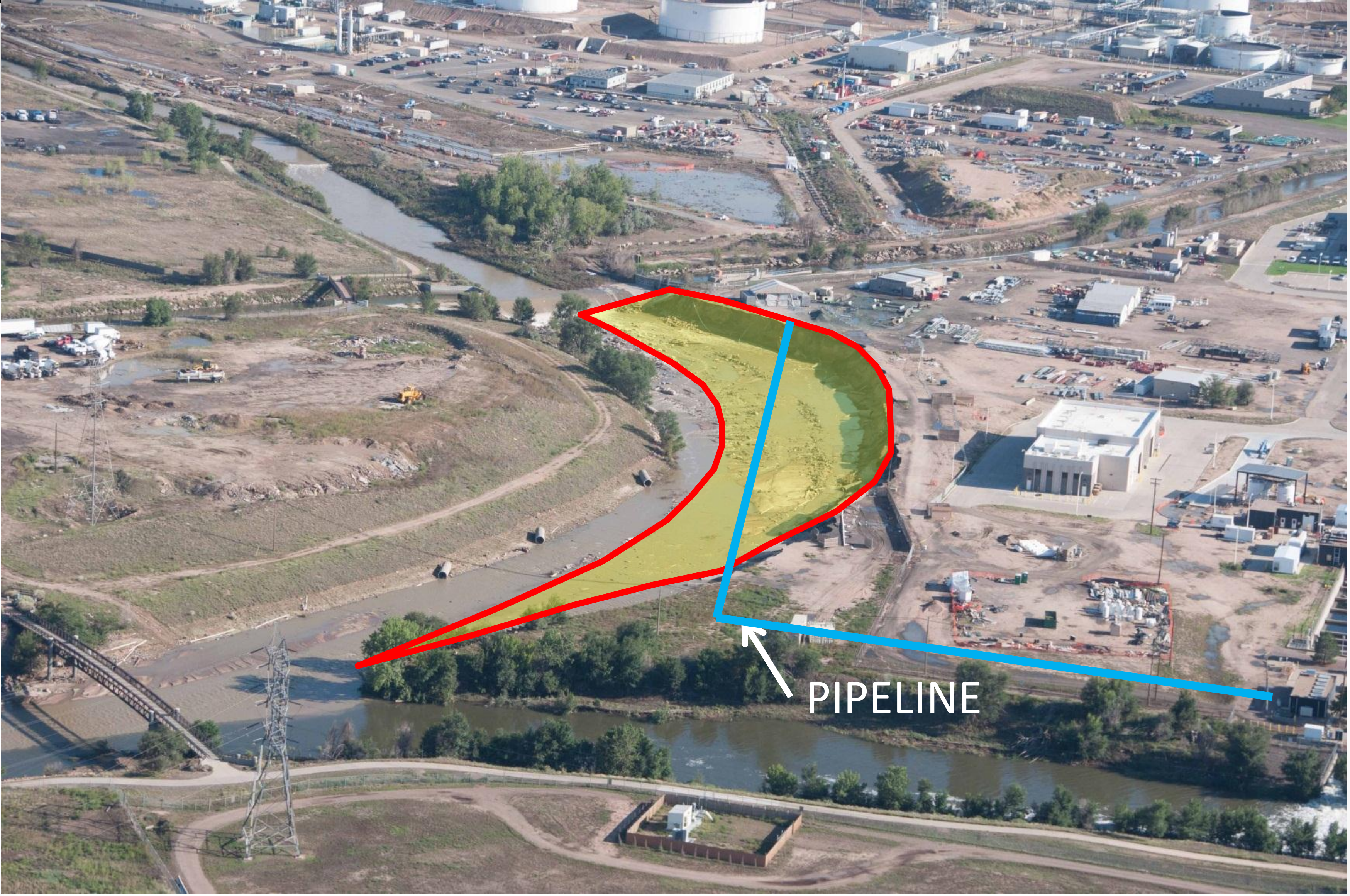
September Flood

Sand Creek

September Flood

Sand Creek

Flood Impacts



Sand Creek

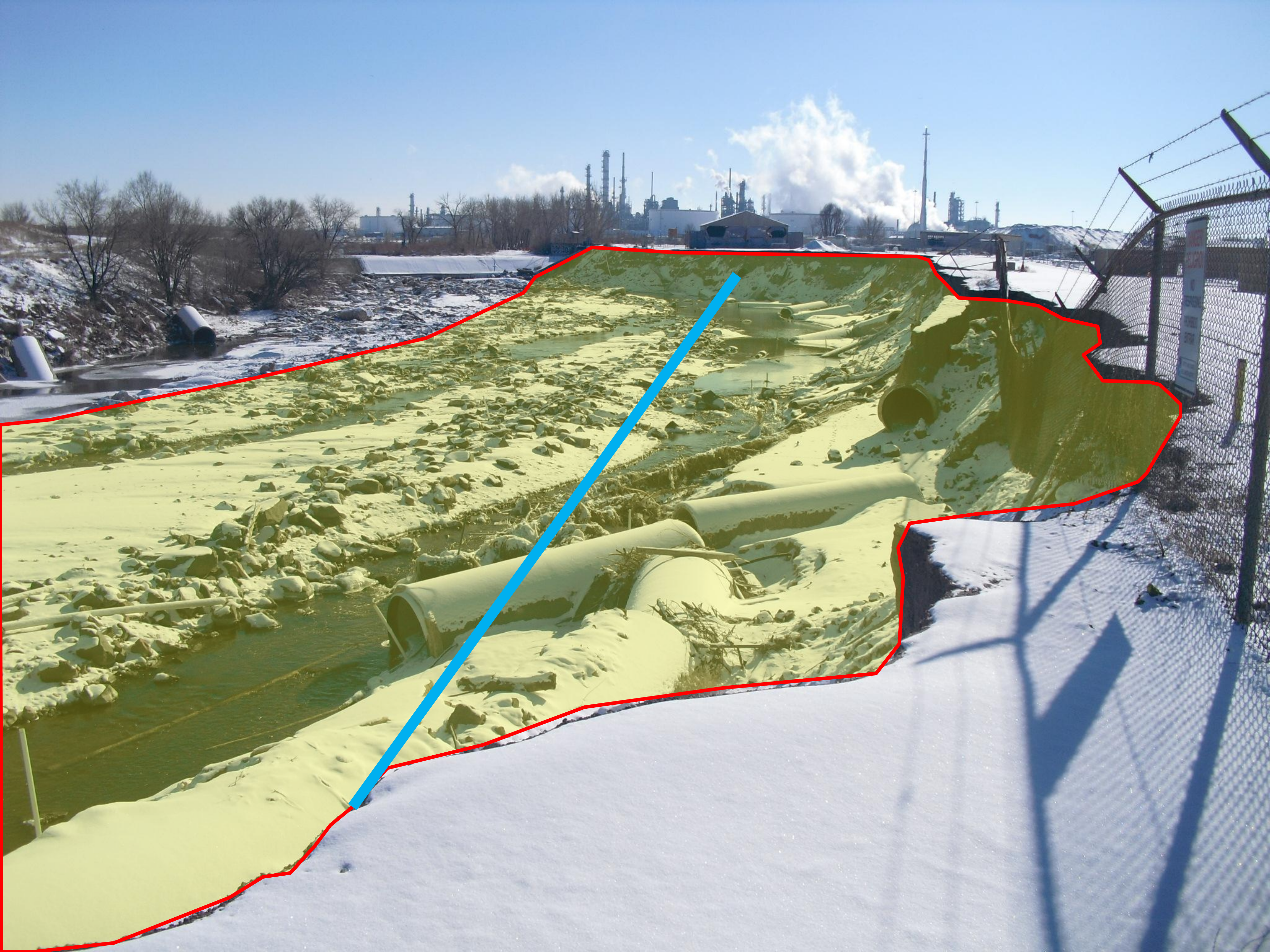
Flood Impacts

Sand Creek

September Flood

Sand Creek

Flood Impacts



Sand Creek

Flood Impacts

Sand Creek

Flood Impacts

Sand Creek

Flood Impacts

Sand Creek

UDFCD Interim Improvements

Sand Creek

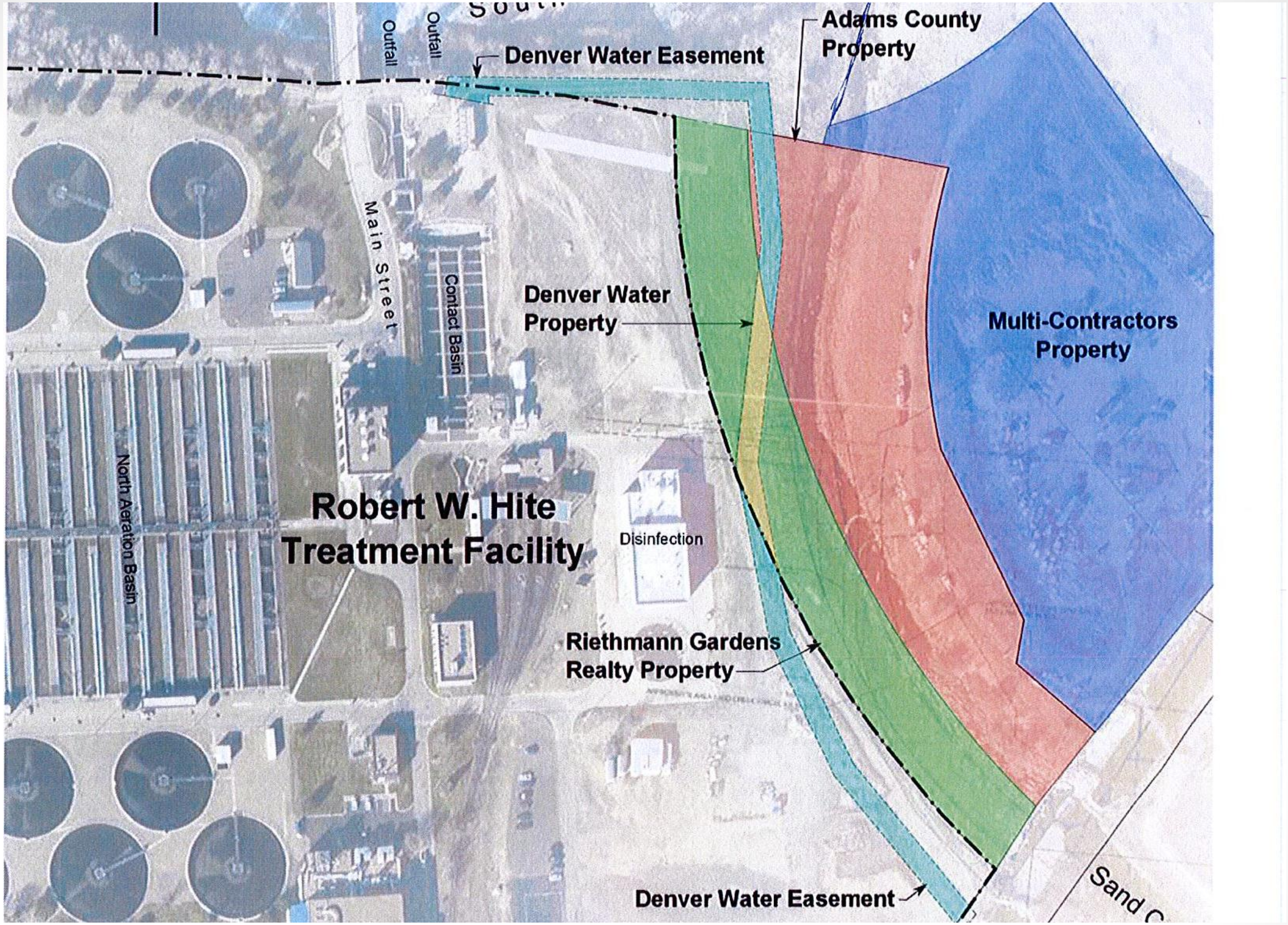
UDFCD Interim Improvements

Sand Creek

UDFCD Interim Improvements

Sand Creek

UDFCD Interim Improvements



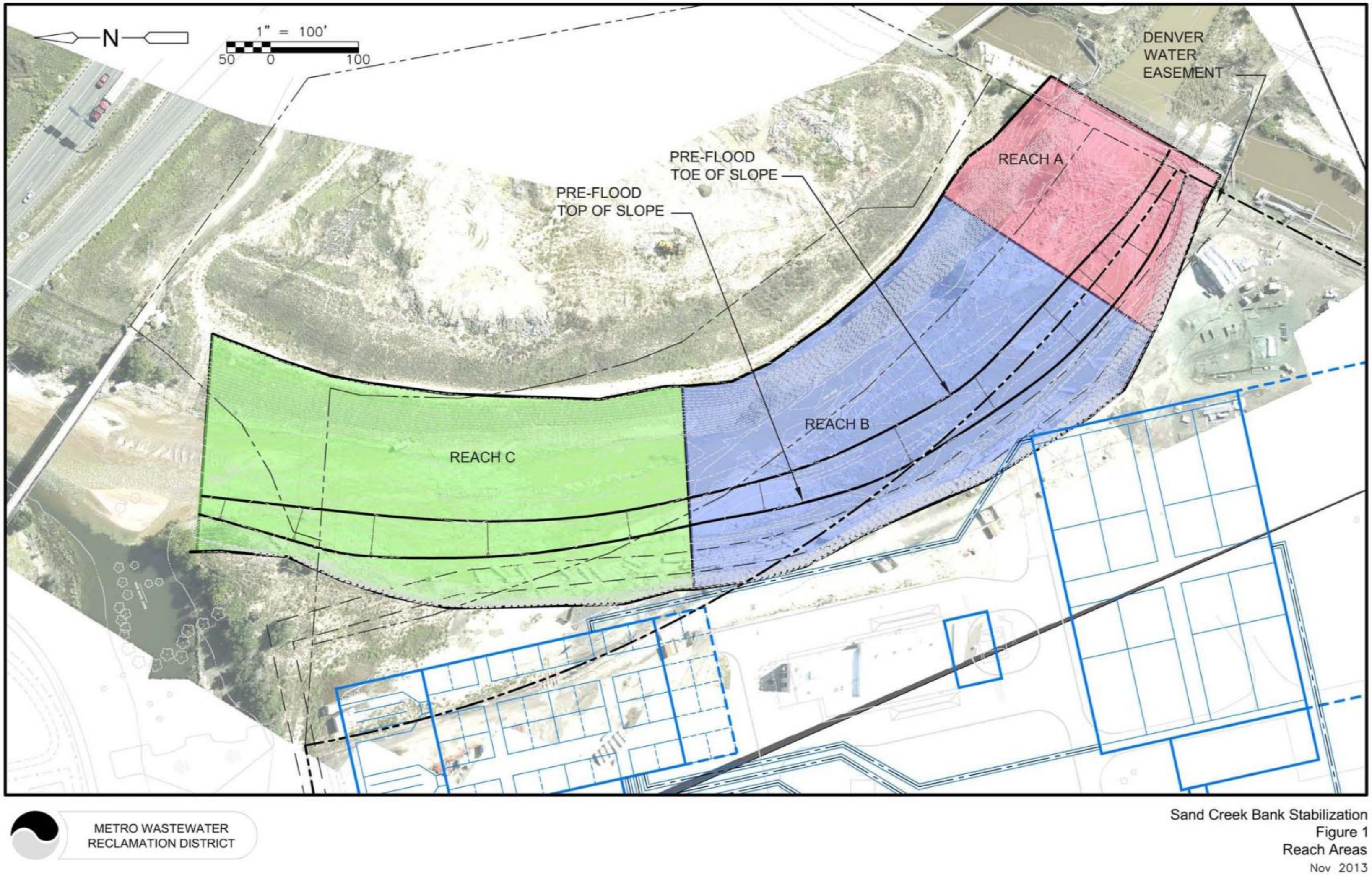
Sand Creek

Property Ownership

- Other property owners are not restoring their property
  - MWRD cannot repair their property without restoring west bank
- MWRD undertaking the repair to property owned by others
- MWRD seeking FEMA public assistance from FEMA
  - Public facility & critical facility
  - FEMA has agreed to reimburse MWRD
    - Damages on their property
    - Portion required to restore their property

Sand Creek

FEMA Public Assistance



Sand Creek

Permanent Improvements

- The permanent improvements include:
  - A combination of bank stabilization methods for each reach:
    - Reach A: Reinforced concrete bank with secant pile wall,
    - Reach B: Vegetated/soil riprap with toe protection, and
    - Reach C: Vegetated/soil riprap with toe protection.
  - Two gra
  - Selectio
    - MW ty as possible
    - Must

Sand Creek

Permanent Improvements

- Permanent Improvements cause a rise in regulatory WSE
  - Change in bed slope from pre-flood to post-flood
  - Required a CLOMR

- UDFCD expedited a CLOMR Review
  - Pre-submittal consultation – January 23, 2014
  - Submitted – February 5, 2014
  - Resubmitted with additional information – February 14, 2014
  - Forward to FEMA by UDFCD – February 18, 2014
  - Approved by FEMA – March 11, 2014

- Unique modeling scenario

Sand Creek

CLOMR

- Cost opinion to return to pre-flood conditions
  - $3,200,000
- Restore damage solely on MWRD property
  - $900,000
- MWRD is proposing to improve beyond the pre-flood conditions
  - $4,500,000
- Construction started April 4, 2014
- Denver Water pipeline will not be reinstalled at this time

Sand Creek

Cost of Improvements

Closing

- Thank you for your attention

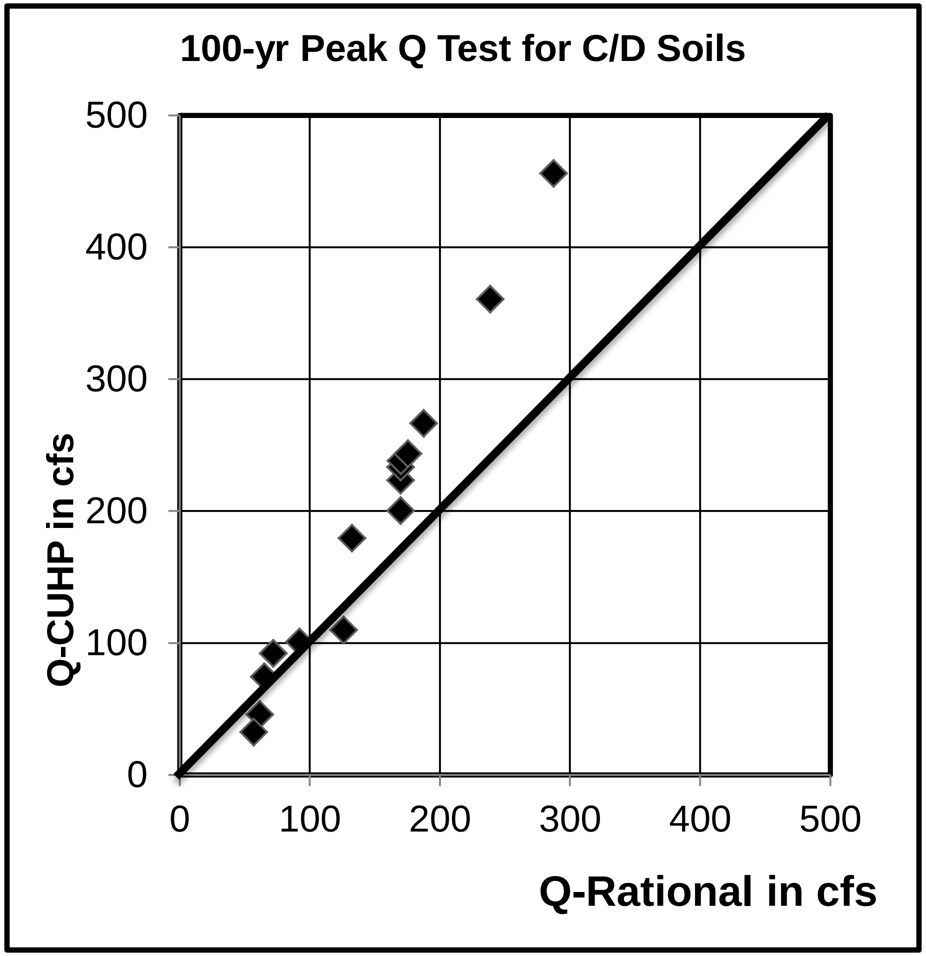
- Questions

MODEL CONSISTENCY
between Rational Method and CUHP

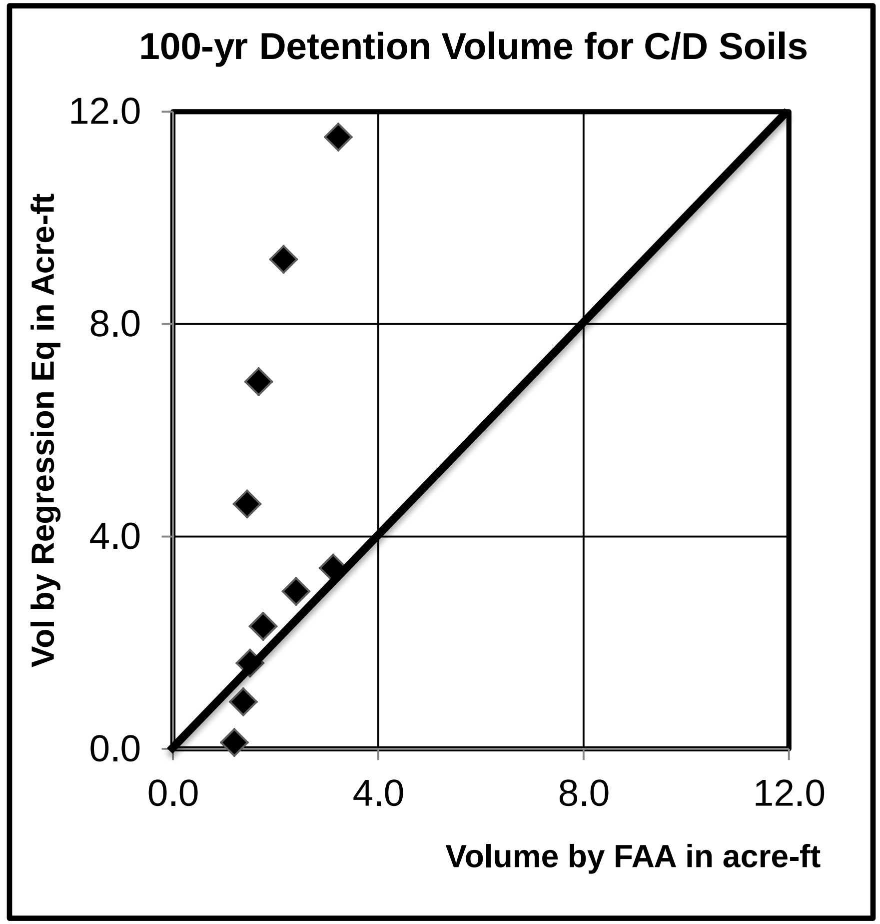
Dr. James Guo, Prof and PE
Director, Civil Engineering, UC Denver

As of 2014, On-going Problems

Urban catchments
20 to 100 acre



Discrepancy on Peak Flow



Discrepancy on Volume

Review: RATIONAL METHOD since 1889

The peak rate of runoff generated from a small watershed is linearly related to watershed area and rainfall intensity (Kuichling, 1889)

Peak Runoff $Q_P = KCIA$

I = average rainfall intensity in inch/hr for <u>a selected</u> "$T_d = T_c$"

A = drainage area,

Q_p = peak runoff

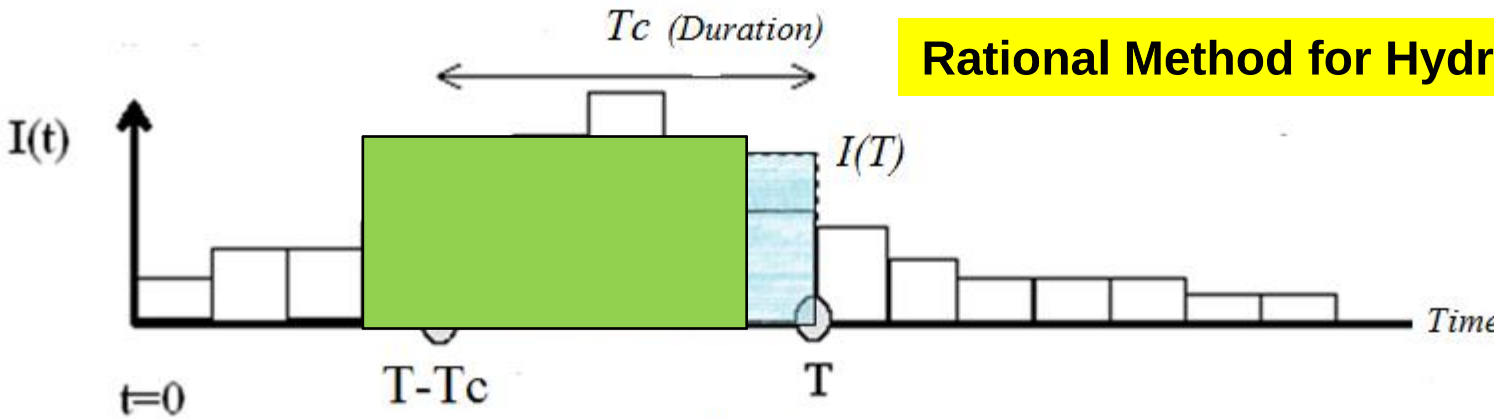
C = runoff coefficient

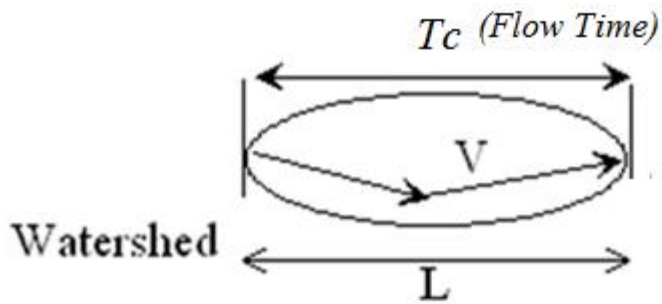
K=1 for acre-inch/hr-cfs or 1/360 for hectare-mm/hr-cms

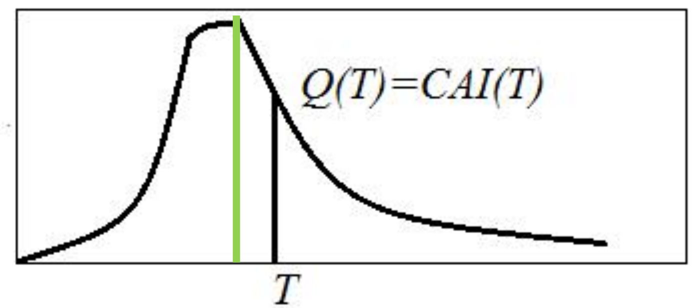
$$I_{T_d}^{\;Tr}(in/hr) = \frac{28.5 P_1^{Tr}(inch)}{(10+T_d)^{0.789}}$$ **for Denver area**

$$T_d = T_c = Initial\ Time + Flow\ Time$$ **applied to the waterway**

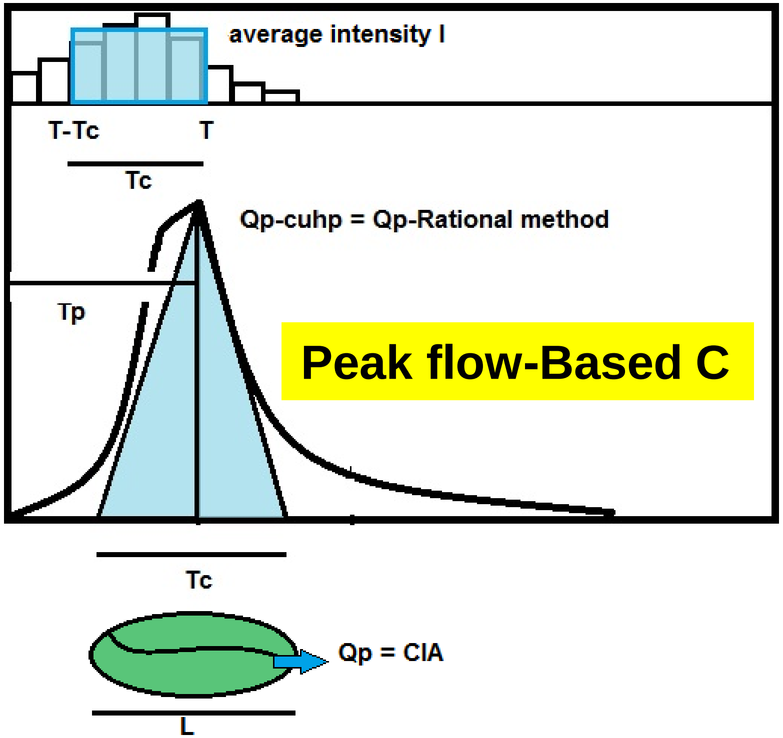
Rational Method for Hydrograph

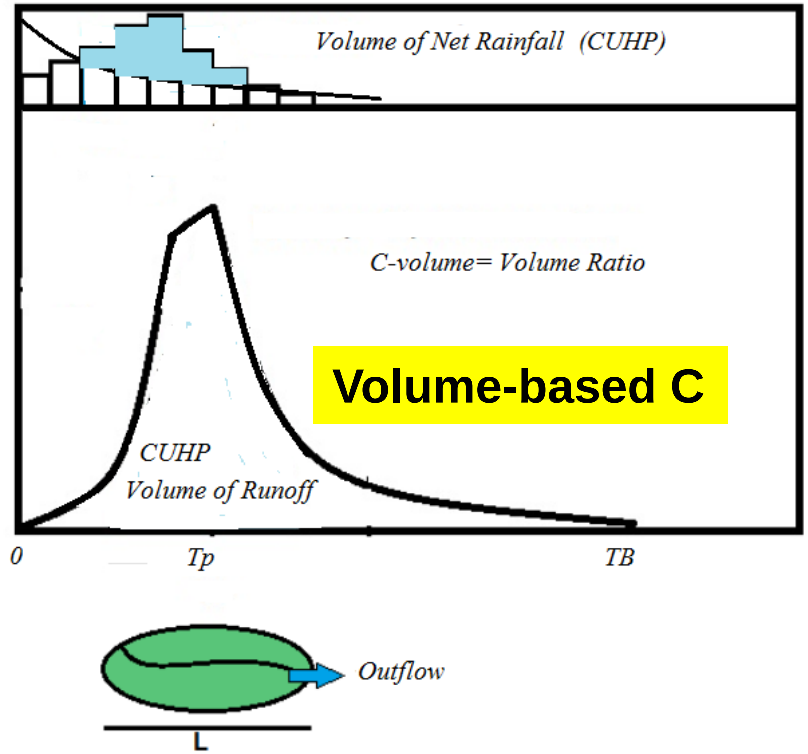






Definition: Runoff Coefficient





Rational Method
Peak Flow-based

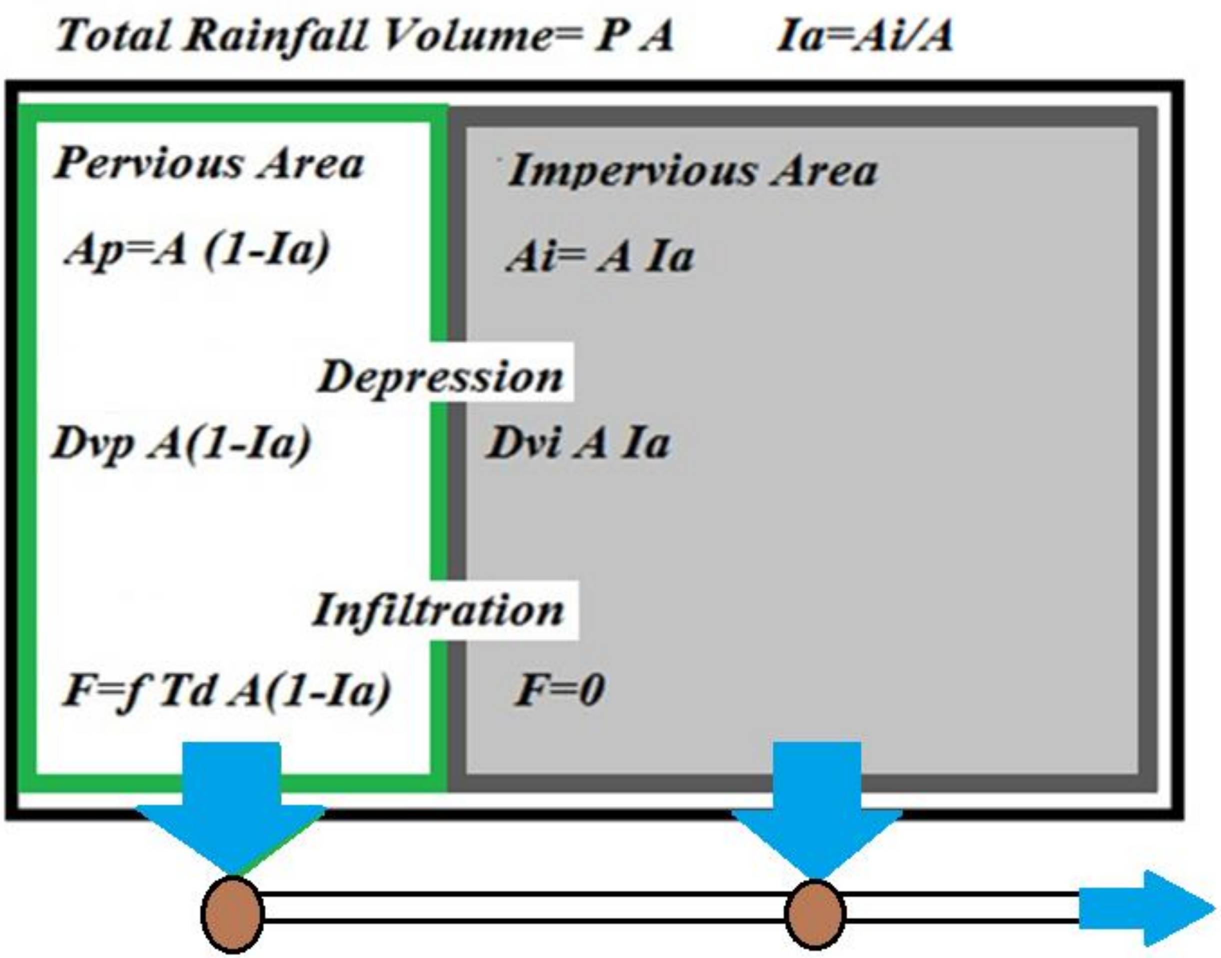
$$C = \frac{Q_p}{AI}$$

$$C = \frac{V_{Runoff}}{V_{Rain}} = \frac{\sum_{T=0}^{T=T_B} Q(T)\Delta T}{A\sum_{T=0}^{T=T_d} \Delta P(T)} = \frac{\text{Volume of Runoff Hydrograph}}{\text{Volume of Hyetograph}}$$

How to define average I?
We need to know Tc

CUHP provides Volume-based C
to calibrate the Rational method

Theoretical RUNOFF COEFFCIENTS



Summary:

1. **Two-flow system**
2. **Linear**
3. **Non-dimensional**
4. **(P,Tr) dependent**
5. **(*f*, soil) dependent**

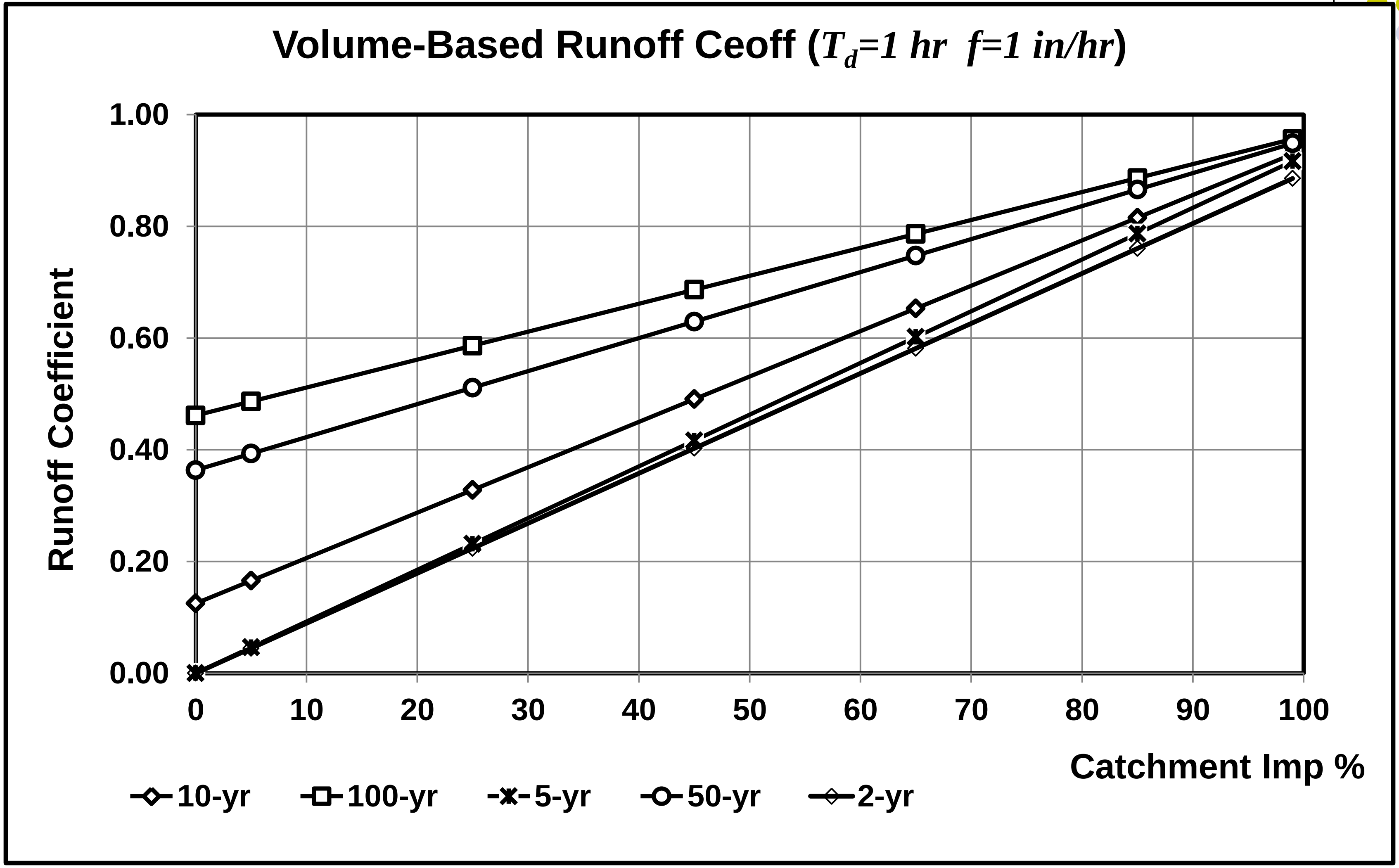
$$C = \frac{V_{runoff}}{V_{rain}} = \frac{PA - D_{VI}\ I_a A - D_{VP}(1 - I_a)A - fT_d(1 - I_a)A}{PA} = 1 - \frac{D_{VI}}{P} I_a - [\frac{D_{VP}}{P} + \frac{f}{I}](1 - I_a)$$

Theoretical Runoff C (Assumption: T_d=1 hr, f= 1 in/hr)

$$C = \frac{V_{Runoff}}{V_{Rain}} = \frac{PA - D_{VI}\ I_a A - D_{VP}(1-I_a)A - fT_d(1-I_a)A}{PA} = 1 - \frac{D_{VI}}{P} I_a - [\frac{D_{VP}}{P} + \frac{f}{I}](1-I_a)$$

Hyrologic Variables	Dvp=	0.40	inch	Td=	1.00	hr	
	Dvi=	0.10	inch	f=	1.00	inch/hr	
Land Use	Variable		Return Peroid		in years		
	Tr(yr)=	2	5	10	50	100	
	P(inch)=	0.95	1.35	1.61	2.20	2.60	
	Dvi/P=	0.11	0.07	0.06	0.05	0.04	
	Dvp/P=	0.42	0.30	0.25	0.18	0.15	
	f/i=	1.05	0.74	0.62	0.45	0.38	
	Imp *Ia*	(1)	(2)	(3)	(4)	(5)	
			Runoff Coeff				
Paved Streets &Roof	1.000	0.895	0.926	0.938	0.955	0.962	
Business/Commercial	0.900	0.758	0.830	0.857	0.895	0.912	
Light Industrial	0.800	0.621	0.733	0.776	0.836	0.862	
Business/neighborhood	0.700	0.484	0.637	0.696	0.777	0.812	
High-Density Apt	0.600	0.347	0.541	0.615	0.718	0.762	
Schools	0.500	0.211	0.444	0.534	0.659	0.712	
Low-Density Apt	0.400	0.074	0.348	0.453	0.600	0.662	
Gravel Streets	0.300	0.000	0.252	0.373	0.541	0.612	
Railroad Yard Area	0.200	0.000	0.156	0.292	0.482	0.562	
Playground	0.100	0.000	0.059	0.211	0.423	0.512	
Parks/Cemeteries	0.050	0.000	0.011	0.171	0.393	0.487	
Lawns, sandy soil	0.020	0.000	0.000	0.147	0.375	0.472	

Theoretical Runoff C – Linear and Nondimensional



Approach – Set up Data Base

- UDFCD Data Base : 292 sample catchments

Tributary	Waterway	Length to Centroid	Waterway Slope
Area	Length	LC	S
sq mile	mile	mile	ft/ft
0.0310	0.3980	0.1790	0.0220
0.3300	1.4000	0.6300	0.0343

- Tests on: Soils A, B, C/D for hydrologic losses

SCS Soil Type	Initial infiltration *fi* in/hr	Final Infiltration *fo* in/hr	Decay Factor *K* 1/hr	Impervious Depression *Dvi* in	Pervious Depression *Dvp* in
A	5.0	1.0	0.0007	0.1	0.4
B	4.5	0.6	0.0018	0.1	0.4
C/D	3.0	0.5	0.0018	0.1	0.4

- Rainfall events including 2, 5, 10, 50 and100-yr
- Impervious%= 5%,25%,45%,65%,85% or 99%
- A total of 3*5*6=90 simulations for 292 watersheds

  or a total of samples of 90*292=2628

Analysis on Runoff Coef

(A) **For a single watershed:**

$C = V_{runoff} / V_{rain}$ for selected soil and imperviousness

Rational T_c= Overland flow time + Gutter flow time

I = IDF formula with Td=min (Regional Tc, Rational Tc)

$$I = \frac{28.5 P_1}{(10 + T_d)^{0.789}}$$

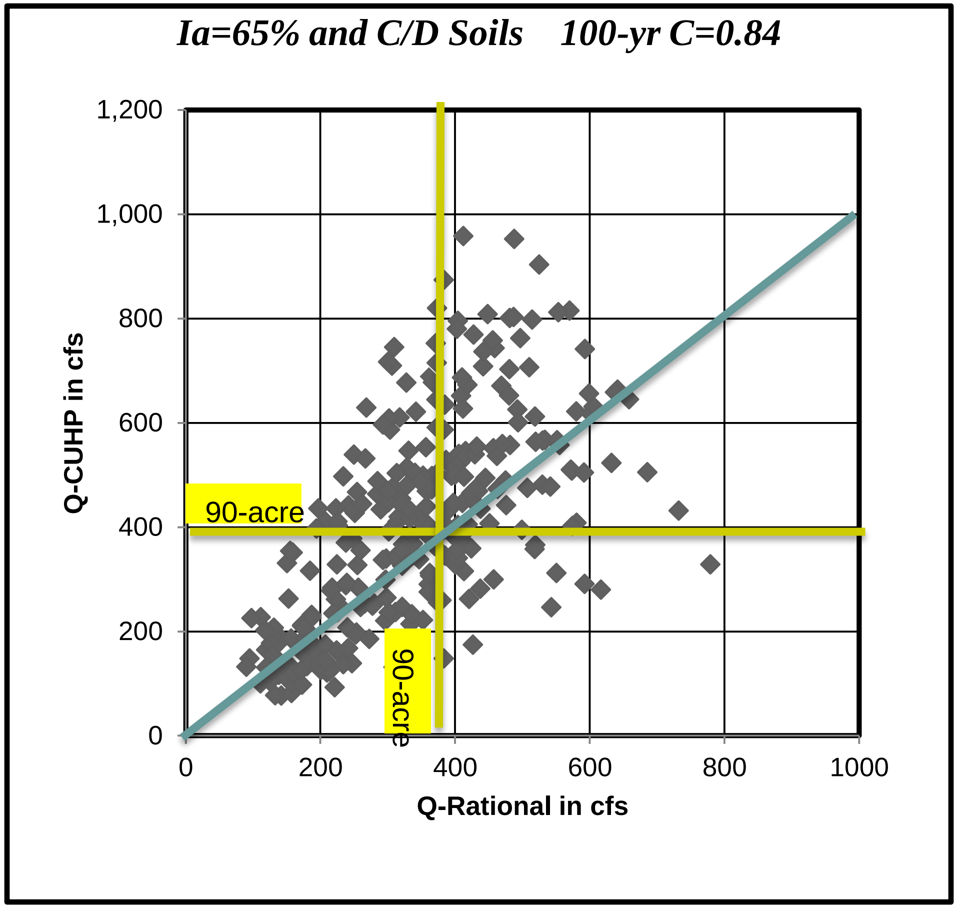
Qp= C I A

(B) **For N=292 watersheds**

$$E = Min \sum_{j=1}^{j=N} (Q_{cuhp} - Qp)_j^{\ 2}$$

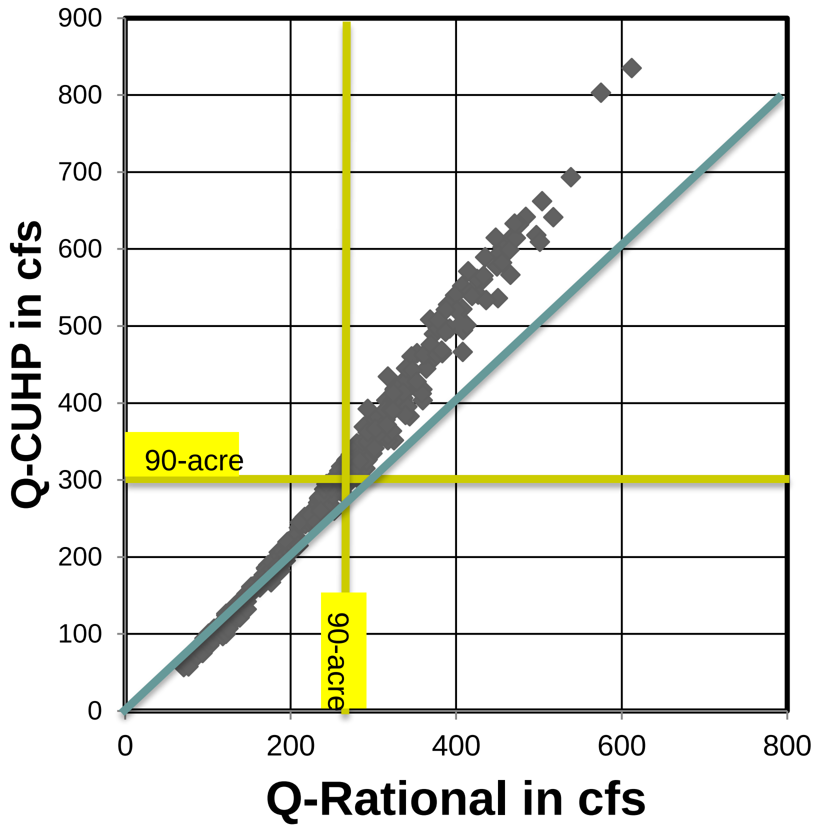
Min E to find C and Regional Tc

Repeat (A) and (B) for selected Soils and Impervious%

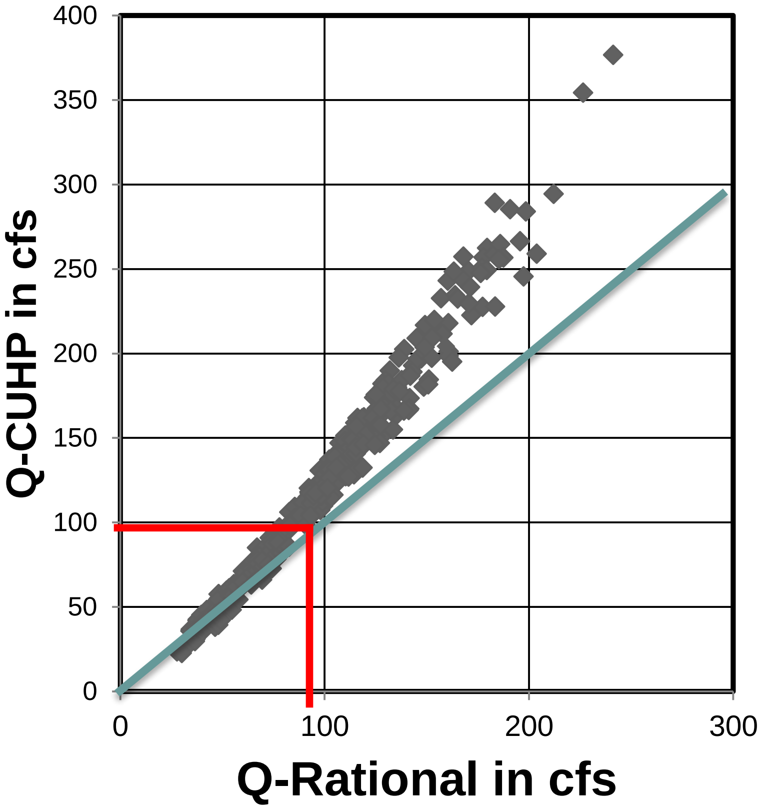


Examples of Runoff C Analyses

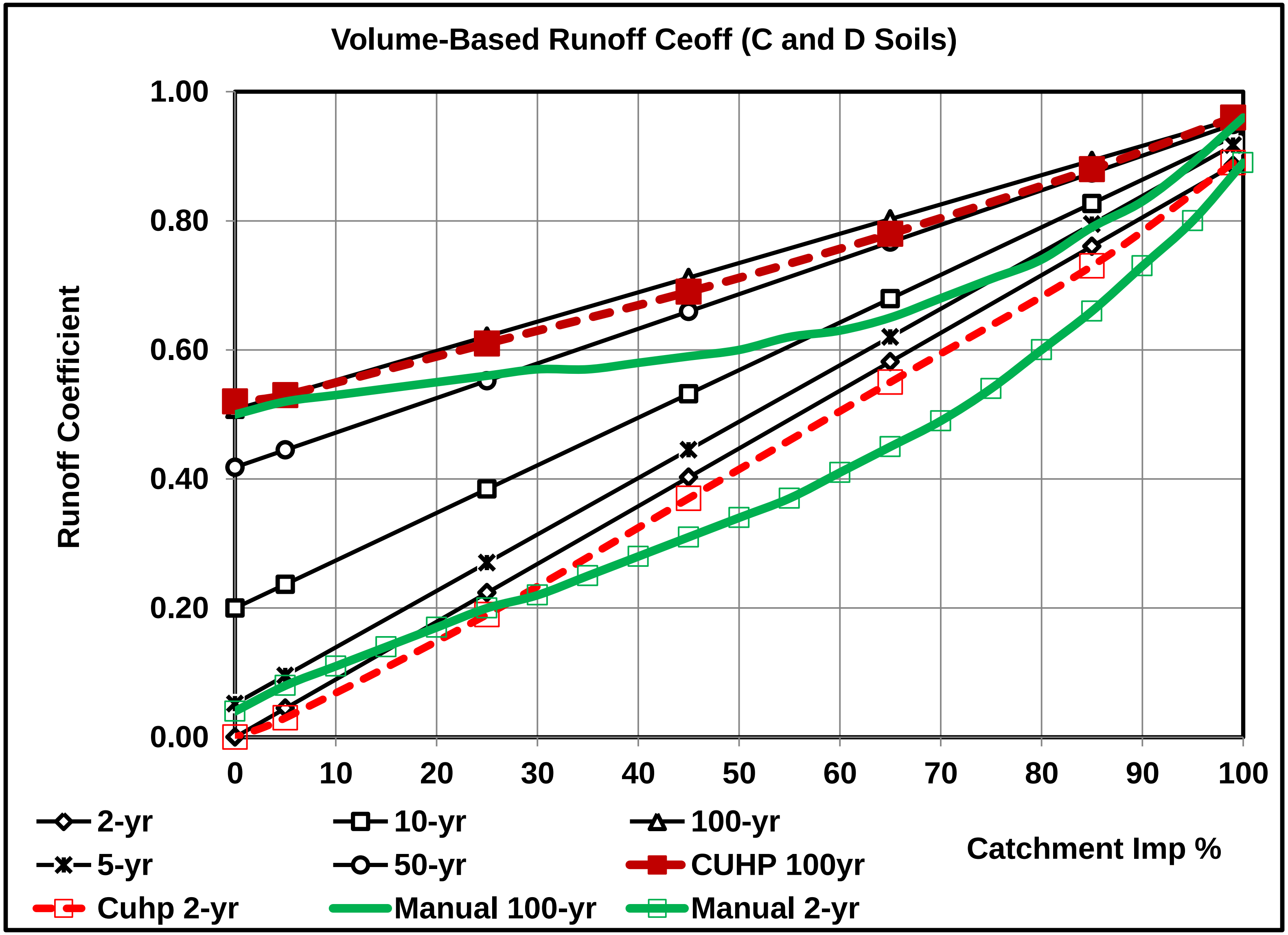
Ia=45% and C/D Soils 100-yr C=0.66



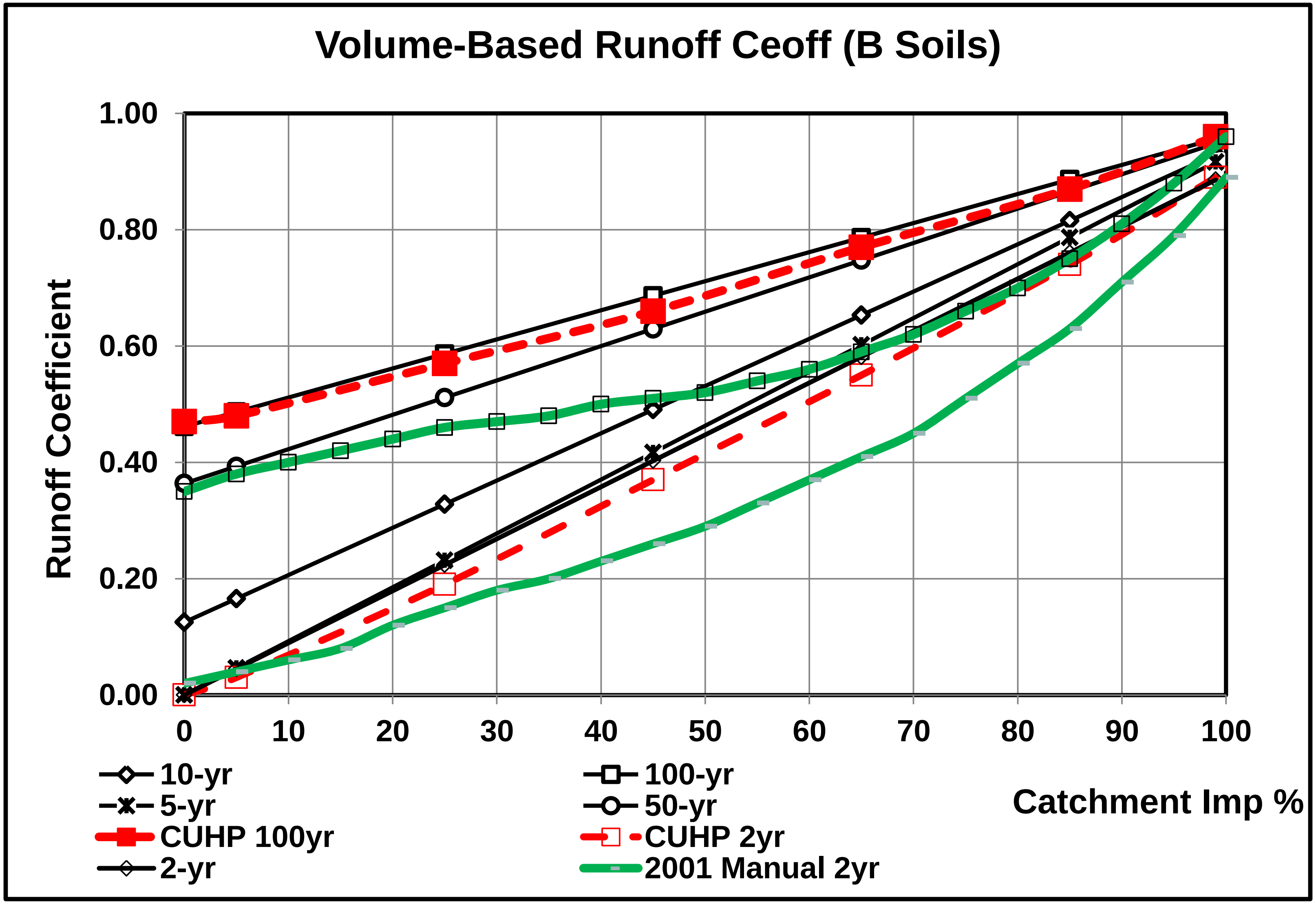
Ia=25% and C/D Soils 100-yr C=0.40



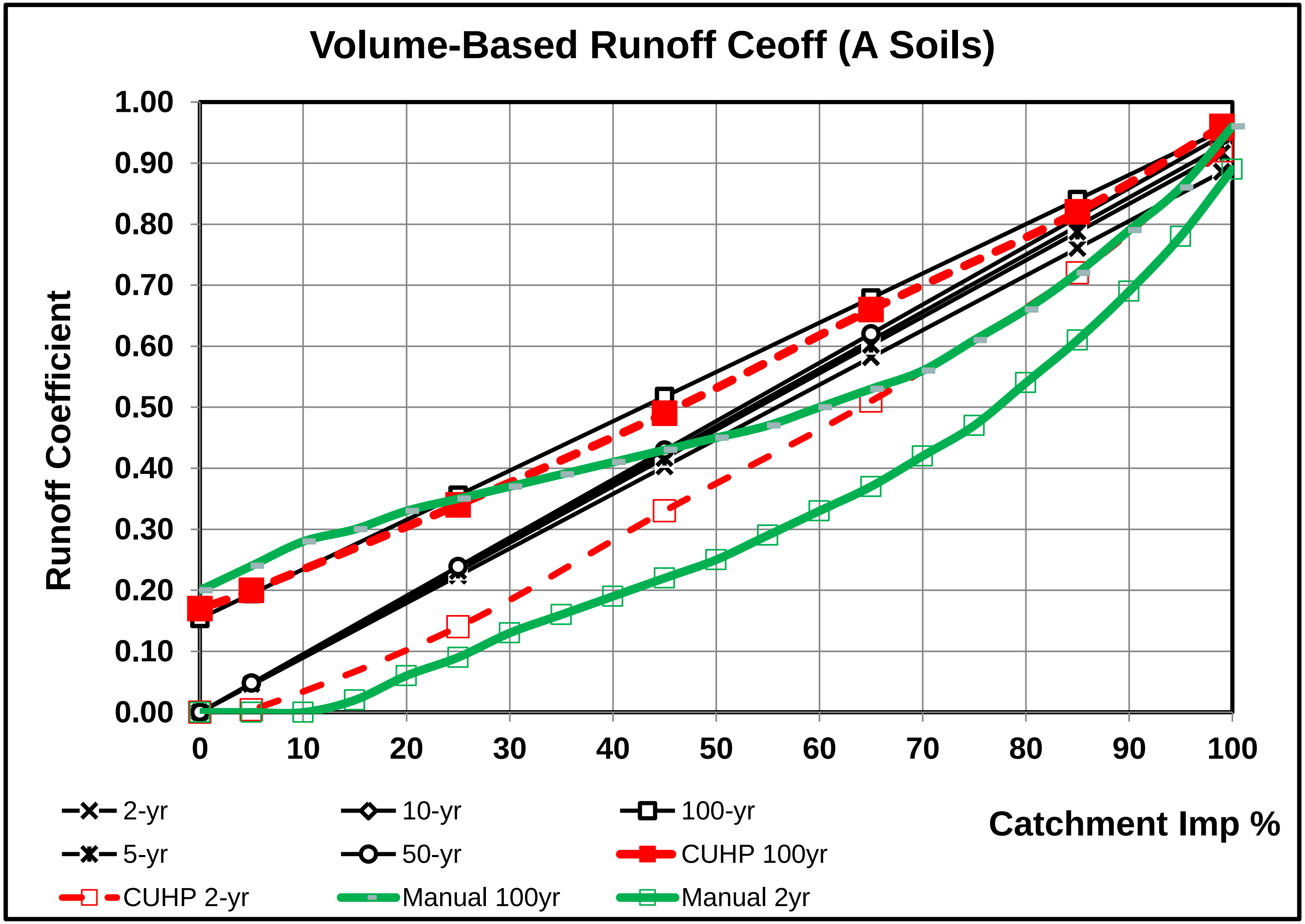
Runoff Coefficients for Soil C/D Soils



Runoff Coefficients for Soil B



Runoff Coefficients for Soils A



Analysis on Regional Tc

$$T_{comp} = T_o + T_f$$

$$T_o = \frac{0.395(1.1 - C_5)\sqrt{L_o}}{S_o^{\,0.33}}$$

for overland flow where $L_o \leq L_*$ *(300 ft for Urban)*

So = overland flow slope

$$T_f = \frac{L_f}{60\,[20\,\sqrt{S_f}\,]}$$

for gutter flows and S_f = gutter flow slope

$$L = L_f + L_o$$

$$T_{reg} = T_* + \frac{L}{60K_*\sqrt{S}}$$

New Formula for Regional Tc

S= average slope

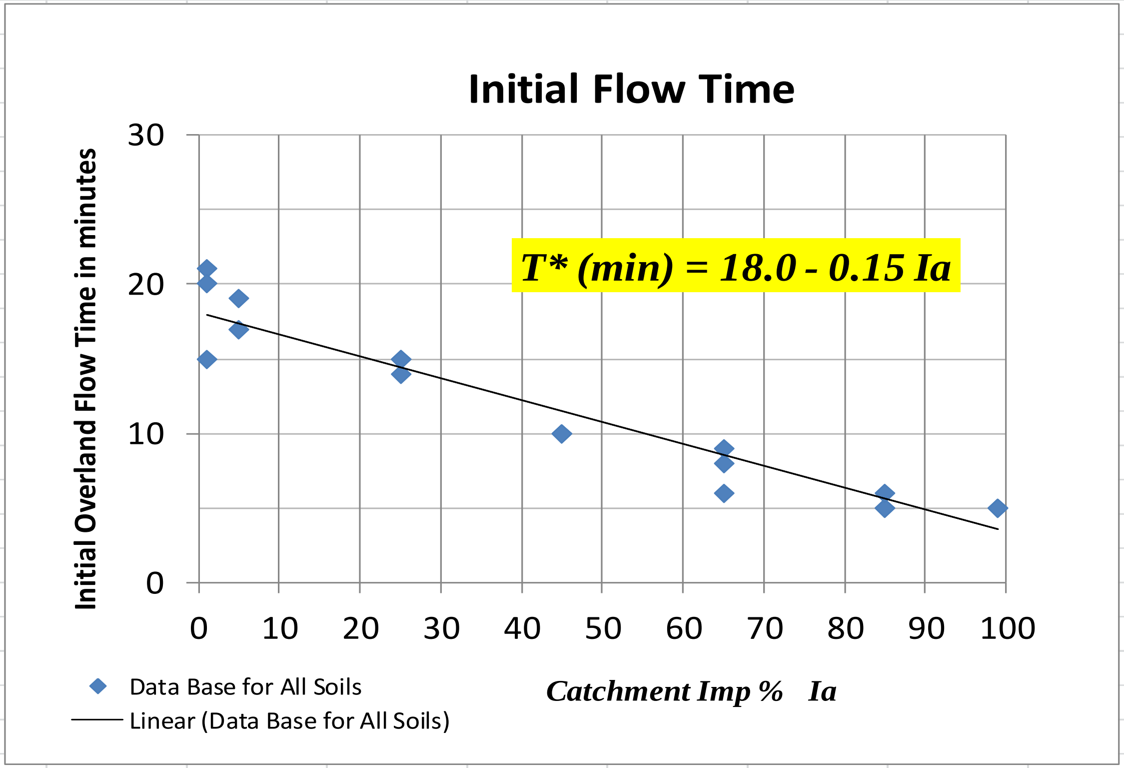
T and K* shall be related to Ia*

$$T_c = \min\,(T_{reg}, T_{comp})$$

$$E = Min\sum_{j=1}^{j=N}(T_{reg} - T_{comp})_j^{\,2} = Min\sum_{j=1}^{j=N}[(\frac{L}{60K_*\sqrt{S_o}} + T^*) - T_{comp}]_j^{\,2}$$ where N= 293

New formula for Initial Time, T*

	Initial Time (min)		
Imp %	Soil C/D	Soil B	Soil A
99.00	5.00	5.00	5.00
85.00	5.00	5.00	6.00
65.00	6.00	9.00	8.00
45.00	10.00	10.00	10.00
25.00	14.00	15.00	15.00
5.00	17.00	19.00	17.00
1.00	15.00	21.00	20.00

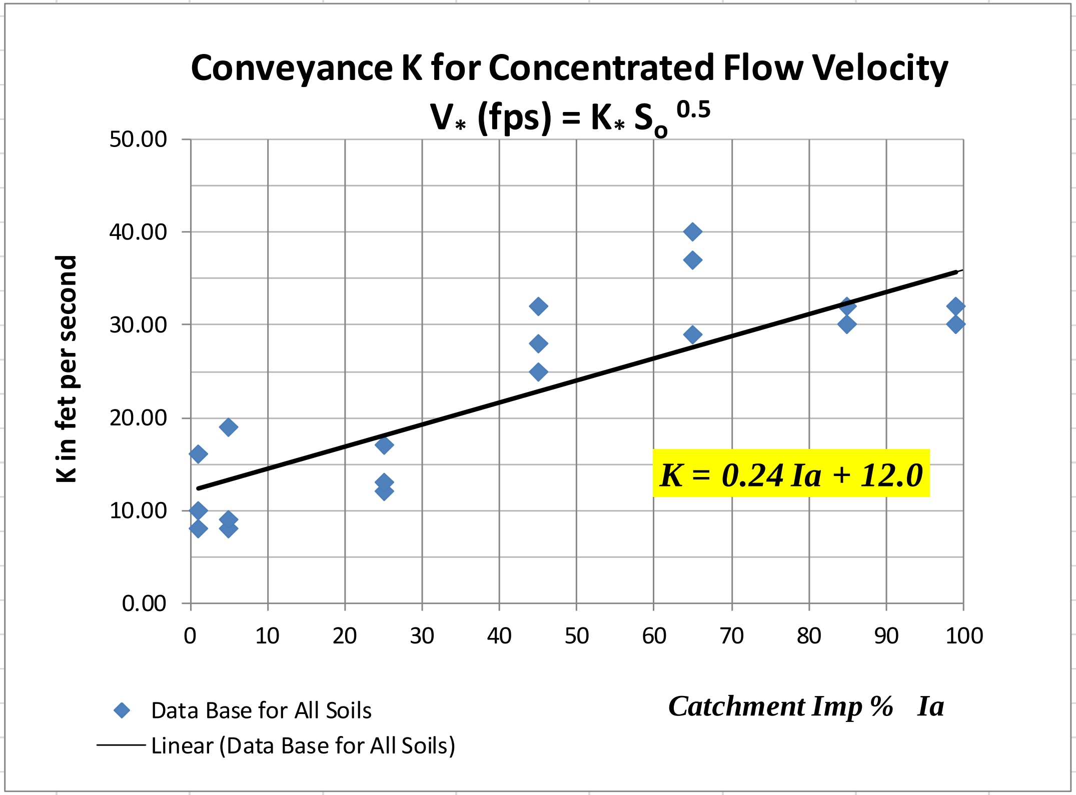


Initial time varies from 18 min for Ia=0%, to 3 min for Ia=100%,

Manual 2001 recommends an average of 10 min for initial time

New formula for Flow Conveyance, K*

Imp %	Flow Conveuence K* (ft/sec) Soil C/D	Soil B	Soil A
99.00	30.00	30.00	32.00
85.00	30.00	30.00	32.00
65.00	29.00	37.00	40.00
45.00	28.00	25.00	32.00
25.00	12.00	13.00	17.00
5.00	8.00	9.00	19.00
1.00	8.00	10.00	16.00

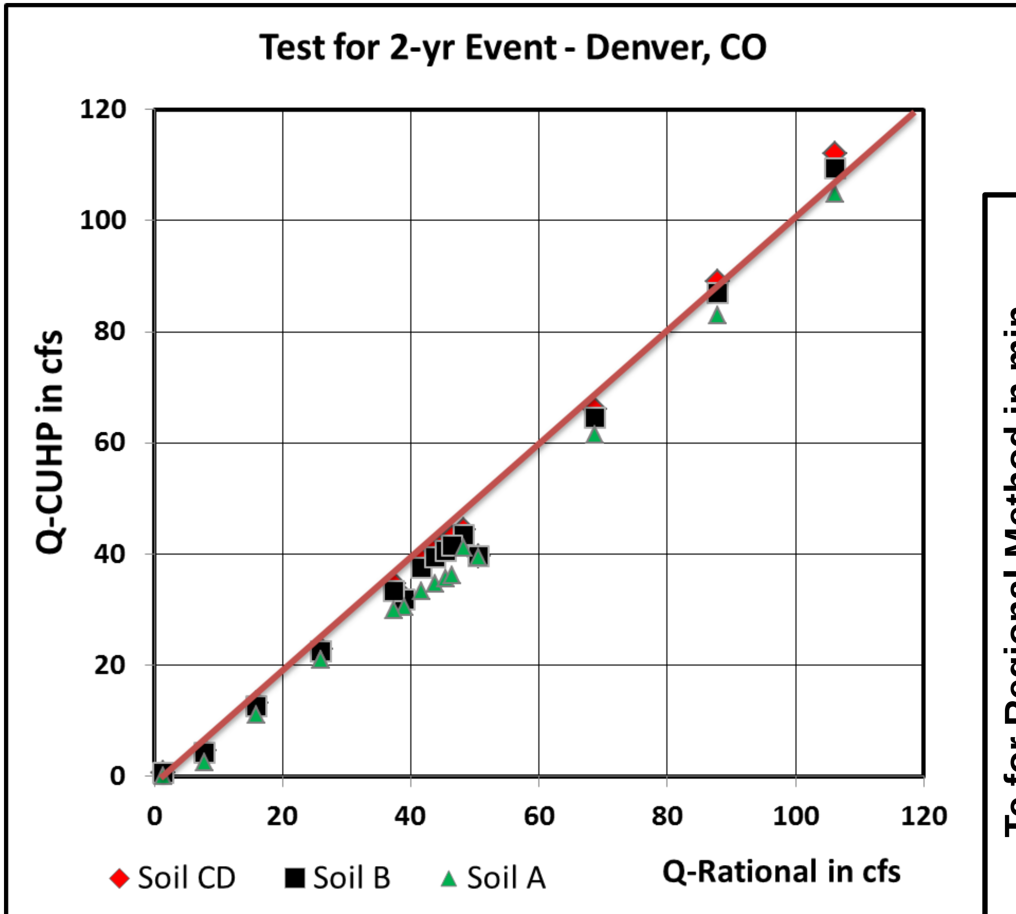


Flow conveyance factor varies from 12 cfs for Ia=0% to to 36 fps for Ia=100%.

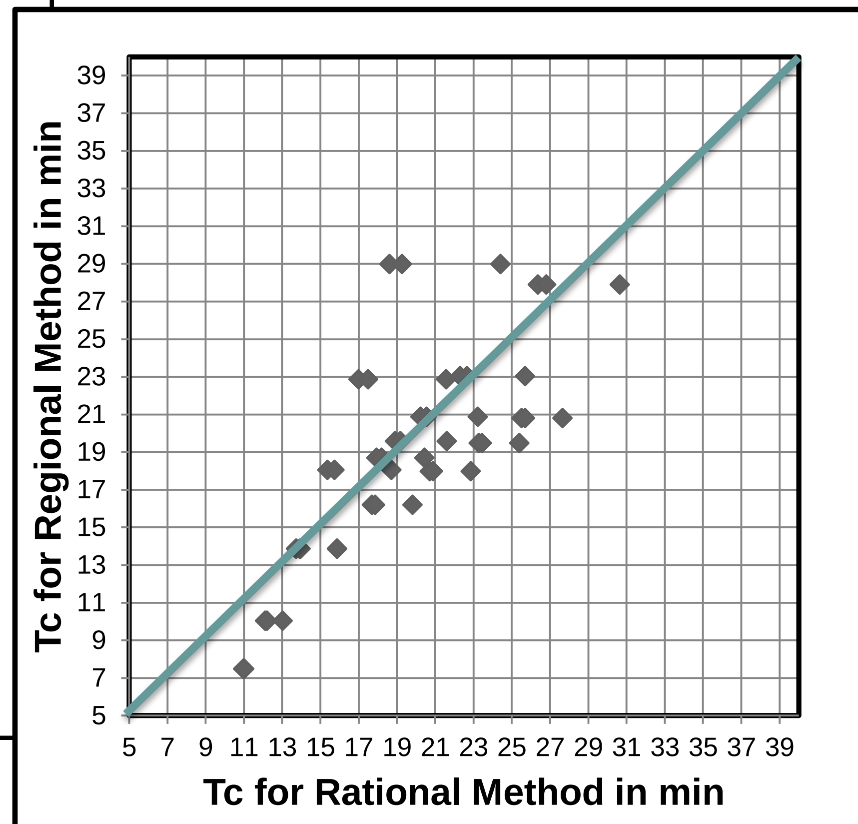
It is noted that the SCS conveyance factor of 20 cfs is recommended for paved surfaces.

Test and Verification on 2-yr events

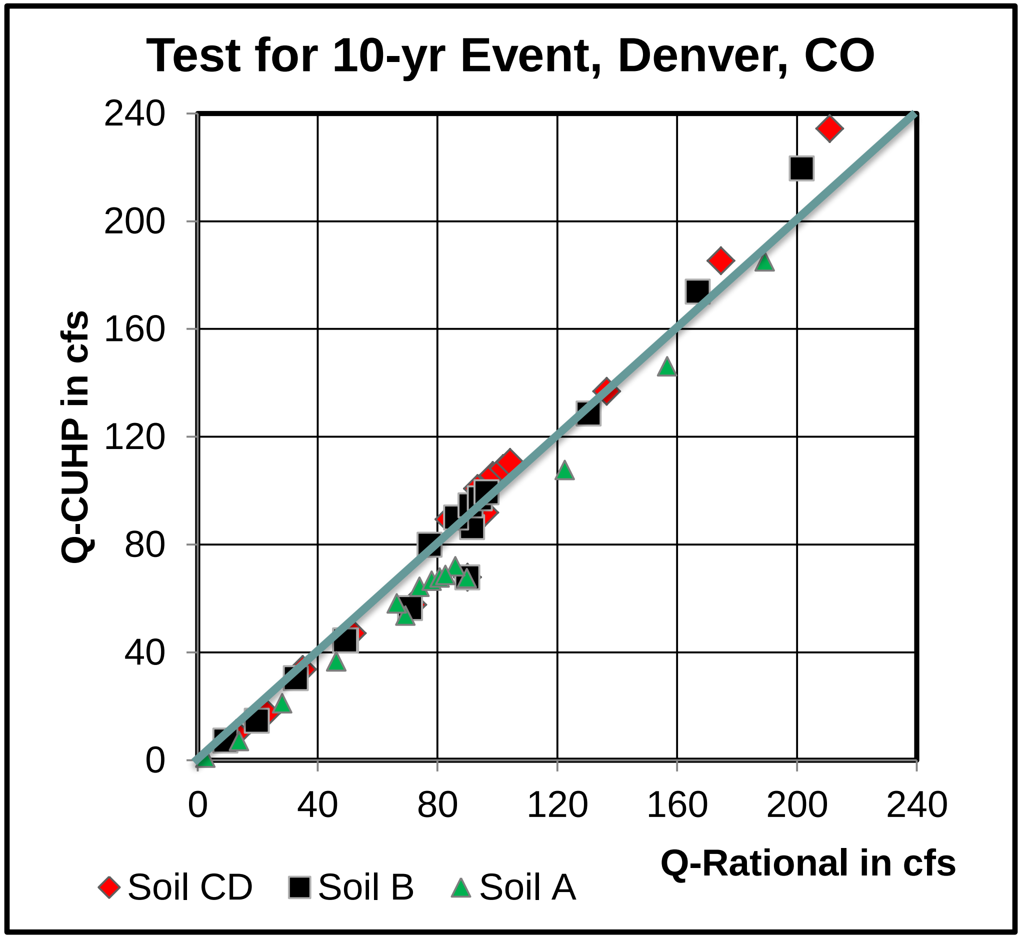
Use a new set of urban catchments from 20 to 100 acres



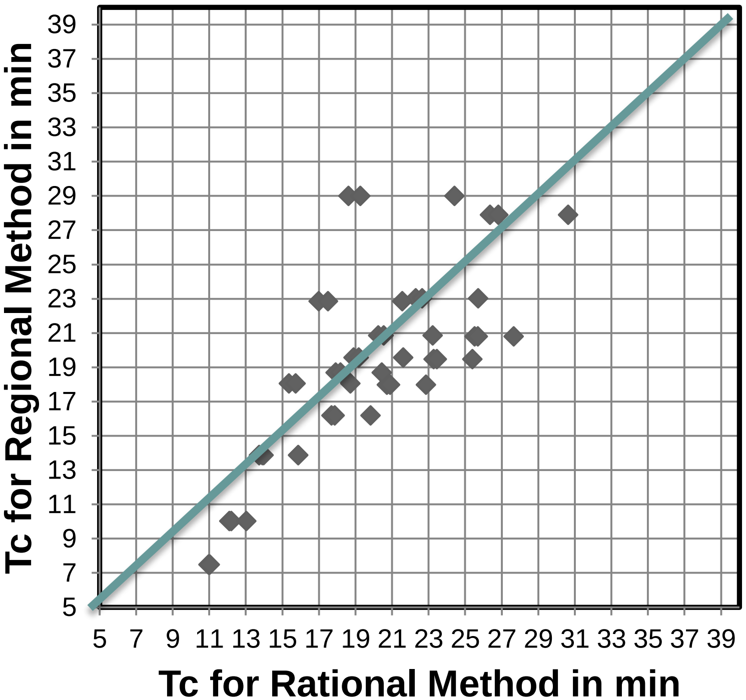
Regional Tc serves as the envelop curve for rational Tc.



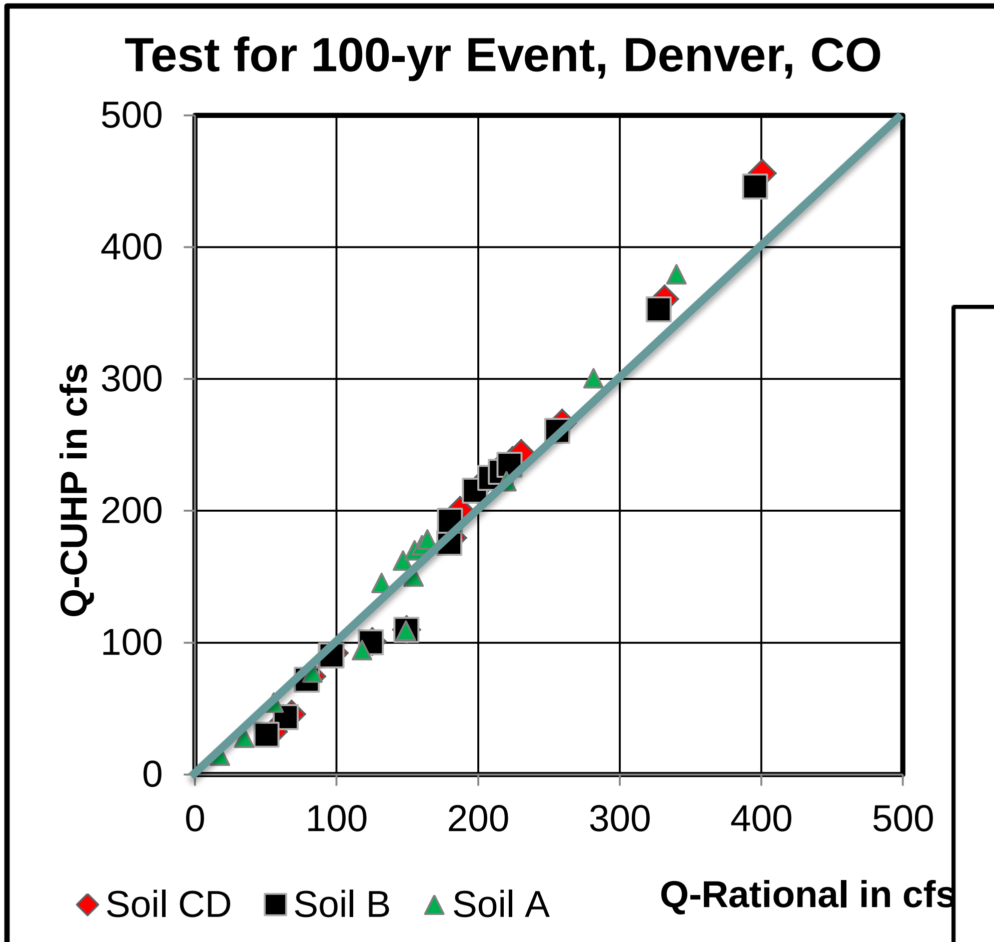
Test and Verification on 10-yr events



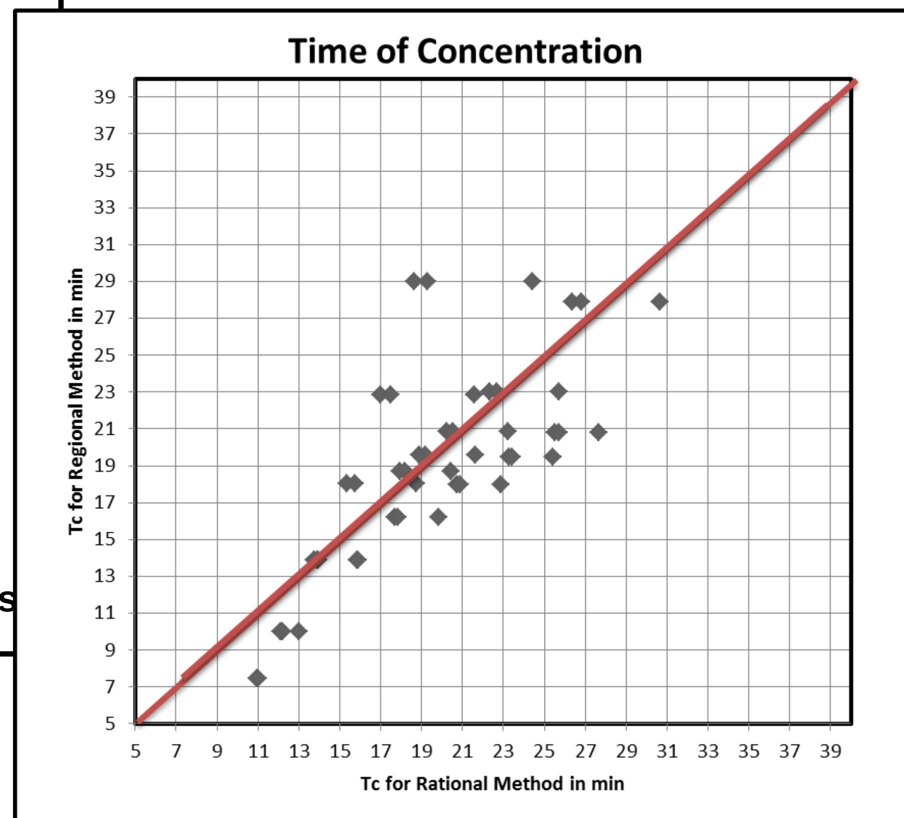
Regional Tc serves as the envelop curve for rational Tc.



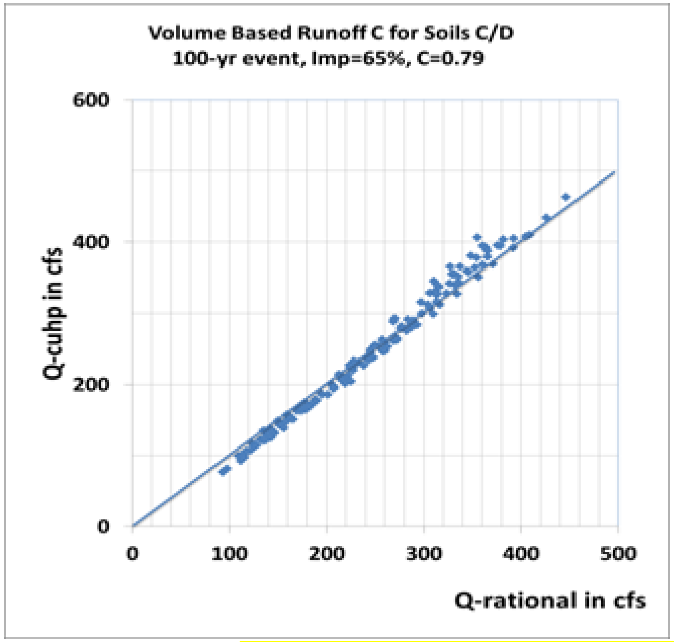
Test and Verification on 100-yr events

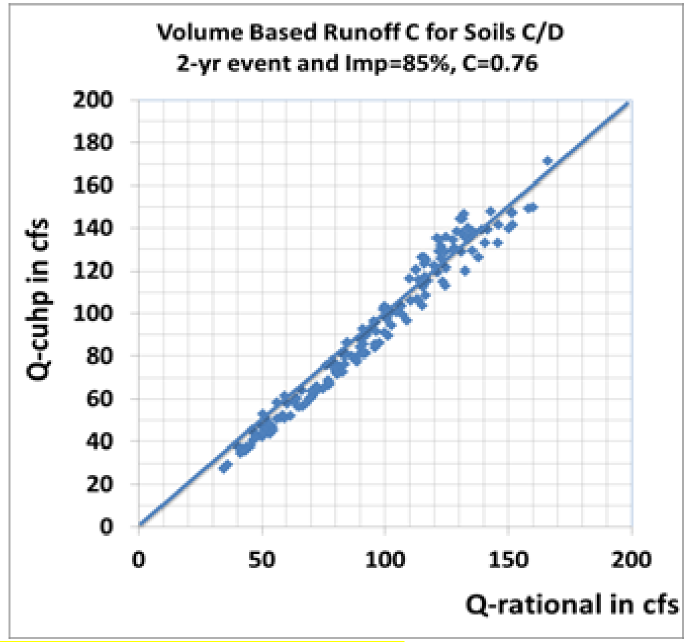


Regional Tc serves as the envelop curve for rational Tc.

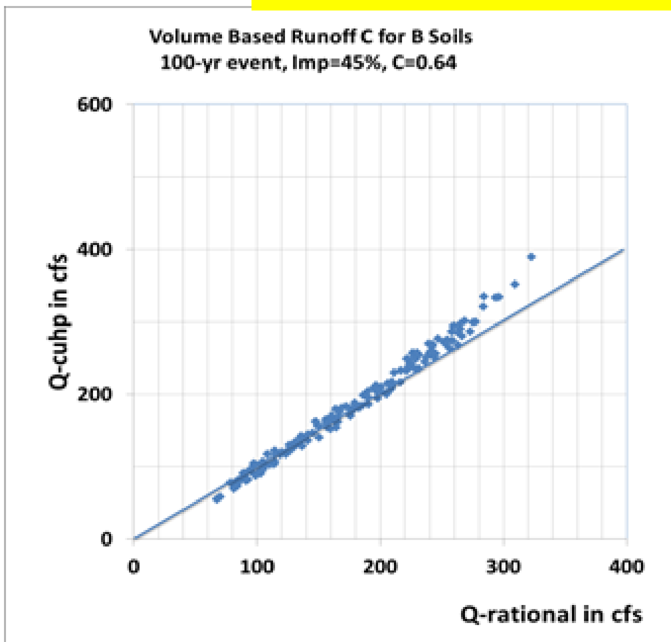


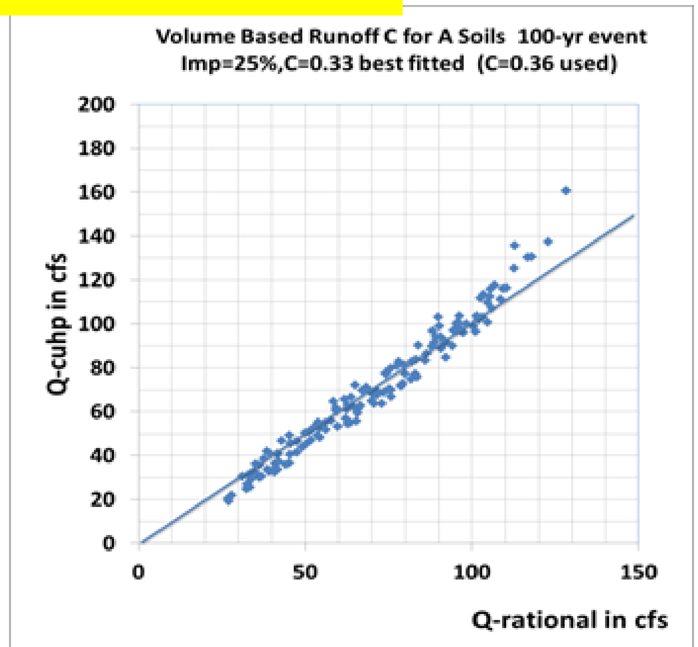
Check on UDFCD sample watersheds <90 acres



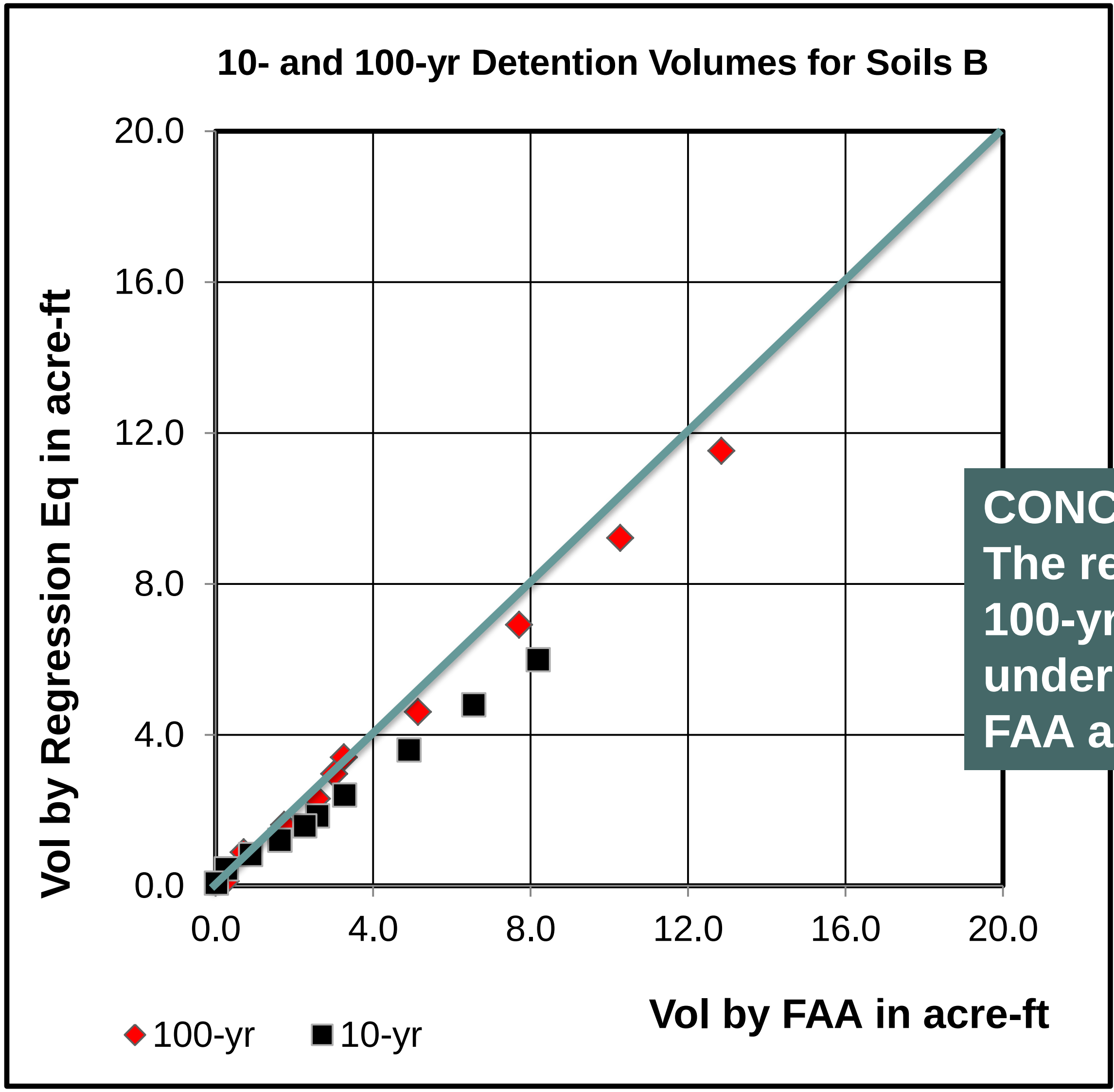


Verification of CUHP-based Rational Method



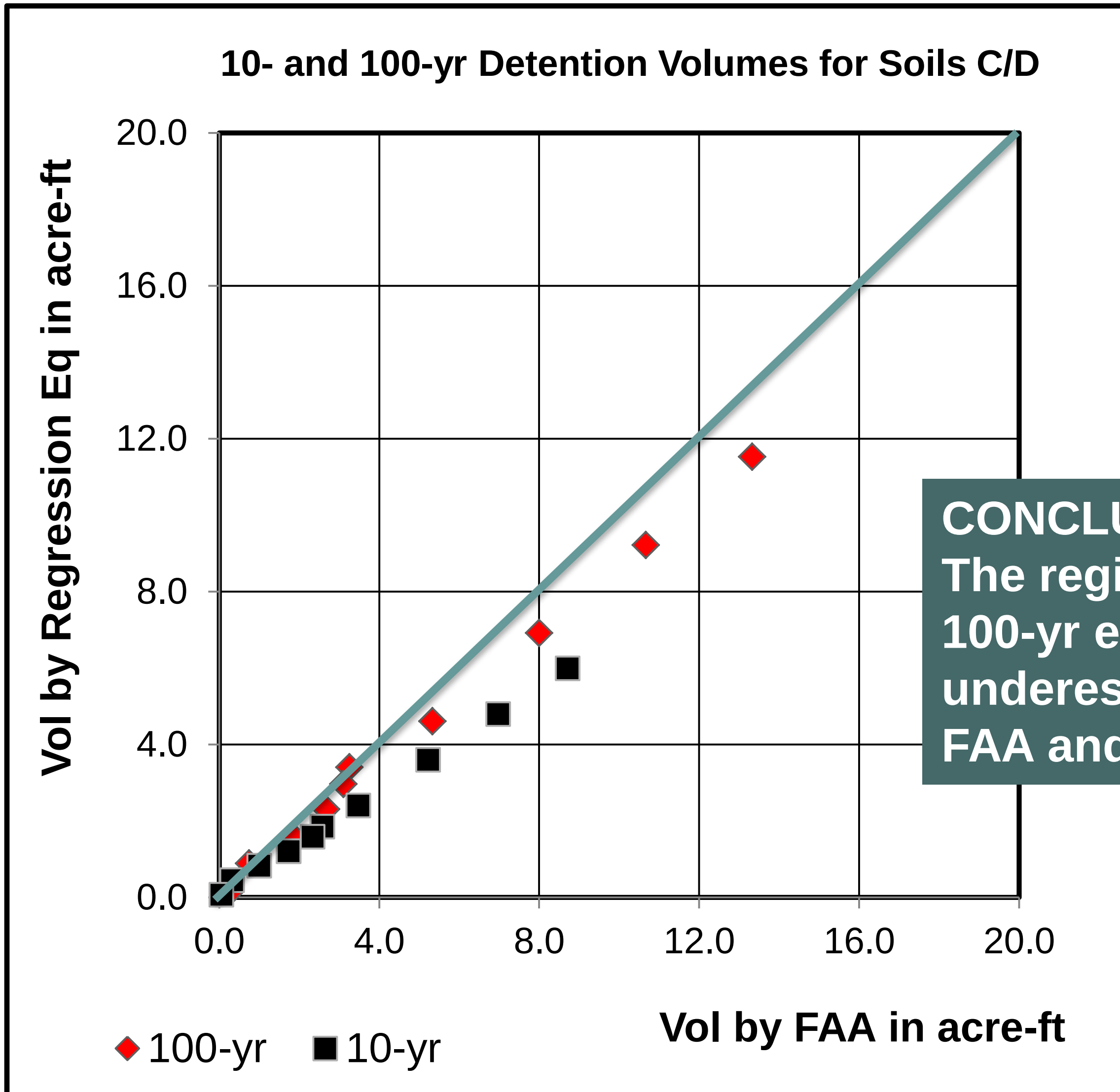


Test and Verification on FAA Method-Soil B

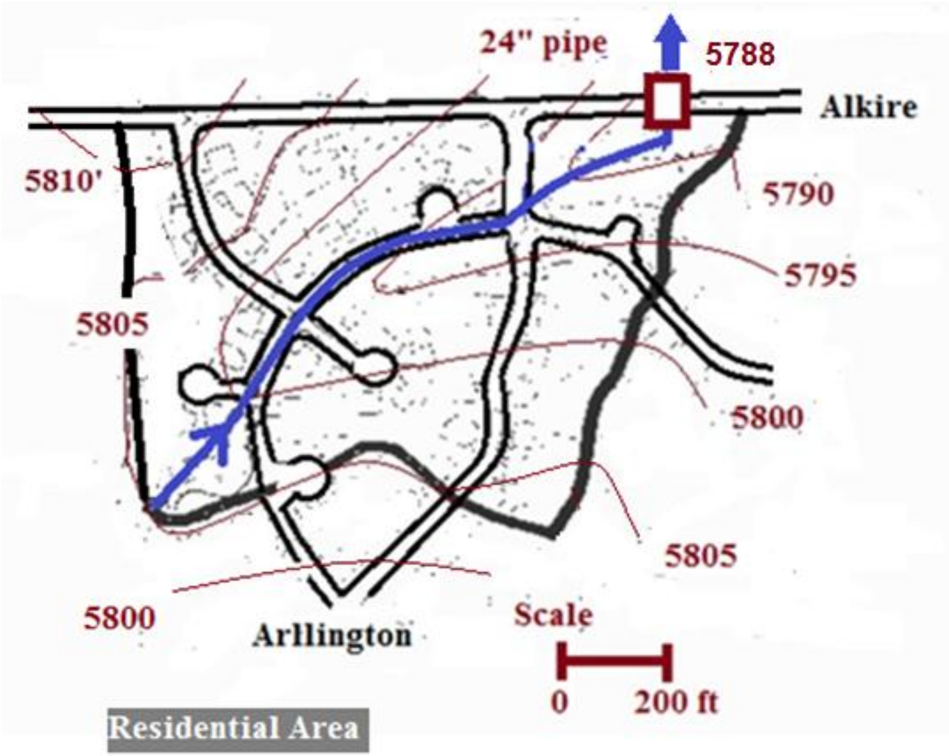


CONCLUSION for Soil B:
The regional formula for 10 and 100-yr event consistently underestimate DV, compared to FAA and CUHP

Test and Verification on FAA Method-Soil D



CONCLUSION for Soils C/D:
The regional formula for 10 and 100-yr event s consistently underestimate DV, compared to FAA and CUHP



Determine Q2=?

Watershed Info:
At Denver
A= 10 acre
Imp%=55
Soil Type B

Runoff Coefficeint	Overland Flow			Gutter Flow				Swale Flow				Computed Tc
	Slope	Length	Time	Slope	Length	SCS K	Time	Slope	Length	SCS K	Time	Tc
	%	ft	min	%	ft	fps	min	%	ft	fps	min	min
C	So	Lo	To	S2	L2	K2	T2	S3	L3	K3	T3	Tc-comp
0.52	1.67	300.00	15.28	1.00	700.00	20.00	5.83	1.00	400.00	15.00	4.44	25.56

Drainage Area	CA Product	Imp Percent	Total Flow Length	Average Slope	Initial Time	Convey Factor	Flow Velocity	Flow Time	Regional Tc	Design Storm Duration	Rainfall Intensity 2-yr	Peak Flow
acre	acre	%	ft	%	min	fps	fps	min	min	min	in/hr	cfs
A	CA	Ia	L	S	T*	K*	V*	Tf	Tc-reg	Td	I	Qp
10.00	10.52	55.00	1400.00	1.21	9.75	25.20	2.78	8.40	18.15	18.15	1.90	20.03

2001 UDFCD Manual Regional Tc= 17.78 min

Closing

- The hydrologic loss in the CUHP is verified to be consistent with the theoretical formula derived for runoff coefficients.
- The design rainfall distributions used in CUHP agree well with the Denver's IDF formula.
- The new equations derived for runoff coefficient are linear in nature. These new runoff coefficients agree with parameters used in Horton formula for hydrologic losses, but they do not reflect the additional infiltration benefits from an LID cascading flow.
- Rational method in the UDFCD manual needs to be updated
- Excel work books for rational method, street hydraulic capacity and inlet sizing need to be updated
- The default regional Tc in the CUHP computer program needs to be updated
- All regression equations for stormwater detention volume need an over all check to see if they are optimized in comparison with the latest version of CUHP.

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

SESSION 10

Putting it All Together: Linking Your Favorite Models

Dr. A. Charles Rowney, ACR, LLC

ABSTRACT:

One of the many challenges faced by the practitioner charged with conducting analysis to support planning, designing and/or operation of BMPs is selecting the ‘right’ tool for the job. The range of models currently available in this arena is substantial, and the technical options are broad enough to encompass virtually every common need. However, experience shows that practical problems very often require that more than one model be applied, because no single tool has the full range of capabilities needed for a particular real world situation. For example, it is common to find that watershed modeling is best done with one type of tool, receiving water modeling with another, and statistical and graphical interpretation with tools or spreadsheets distinct from the actual modeling tools. This leads to increased time and effort on a project, and potentially to errors as information is moved back and forth between whatever tools or procedures the user has elected to apply. There is an ongoing WERF project targeting the theme ‘Linking BMPs to Receiving Waters’ which has moved in a direction that will make life easier when multiple models must be used. This project is conducted by a consortium of universities and consulting firms, guided by a WERF Issue Area Team. Options such as adding more capabilities to existing tools, or creating a super-tool incorporating all the features that would be needed to solve common BMP problems were considered, but it was concluded that these approaches would be expensive and ultimately would not solve the underlying problem. Instead, a Framework was designed to allow users to run models from a library that will include the major common tools used in practice today, and link them quickly and easily. The models each run as designed by their providers, but the Framework enables movement of data between them. This is achieved by a set of converters and coordinating software which automate the data migration. The system sits on a database that keeps track of the models being used, the information being transferred, and other aspects of the modeling process. In addition, the Framework includes a modeling tool called the BMP Selection/Receiving Water Protection Toolbox (Toolbox), which has the ability to develop common statistics and charts (time series, histograms of seasonal or periodic effects, exceedance curves and so on). The net result of this is an ability to efficiently use widely varying models in a common platform, and with common interpretive aids purpose-built for BMP/receiving stream analysis.

Benefits:

- Summarizes BMP performance research and interpretive options.
- Establishes a framework for efficiently linking BMPs to receiving water protection.
- Provides an approach and specification for developing converters enabling the migration of data from one model to another.

Putting it all together: Linking your favorite models

A. Charles Rowney

Denver
April 16th, 2014

The Work of Many
(Project Team, Issue Area Team, and Testers)

- WERF
- US EPA
- Colorado State University
- University of Utah
- Geosyntec
- ACR, LLC
- University of Texas
- Texas Tech University
- City of Austin
- City of Toronto
- City of Los Angeles
- CDMSmith
- Contech
- City of Philadelphia
- CH2M Hill
- Wisconsin DNR
- Fresno Metropolitan Flood Control District
- Denver Urban Drainage and Flood Control District
- City of Seattle
- New England Interstate Water Pollution Control Commission
- Metropolitan Water Reclamation District of Greater Chicago
- And others!

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- Wisconsin DNR
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- **Denver Urban Drainage and Flood Control District**
- City of Seattle
- New England Interstate Water Pollution Control Commission
- Metropolitan Water Reclamation District of Greater Chicago
- And others!

Ken MacKenzie, Larry Roesner, Ben Urbonas

Objectives

1. Provide an basic understanding of the WERF ‘Linking BMPs to Receiving Waters’ program, where it is going, and why it matters

2. Provide an introduction to the WERF Framework 2.0, what it does, how it does it.

3. Provide information on how to get involved, who to call, and what the future might bring.

Added Outcomes

- We are looking for your feedback!
- What kinds of features would you like to see?
- What kinds of things would you like us to change?

- We can’t promise everything, but we’ll work hard to respond to the community.

The Genesis

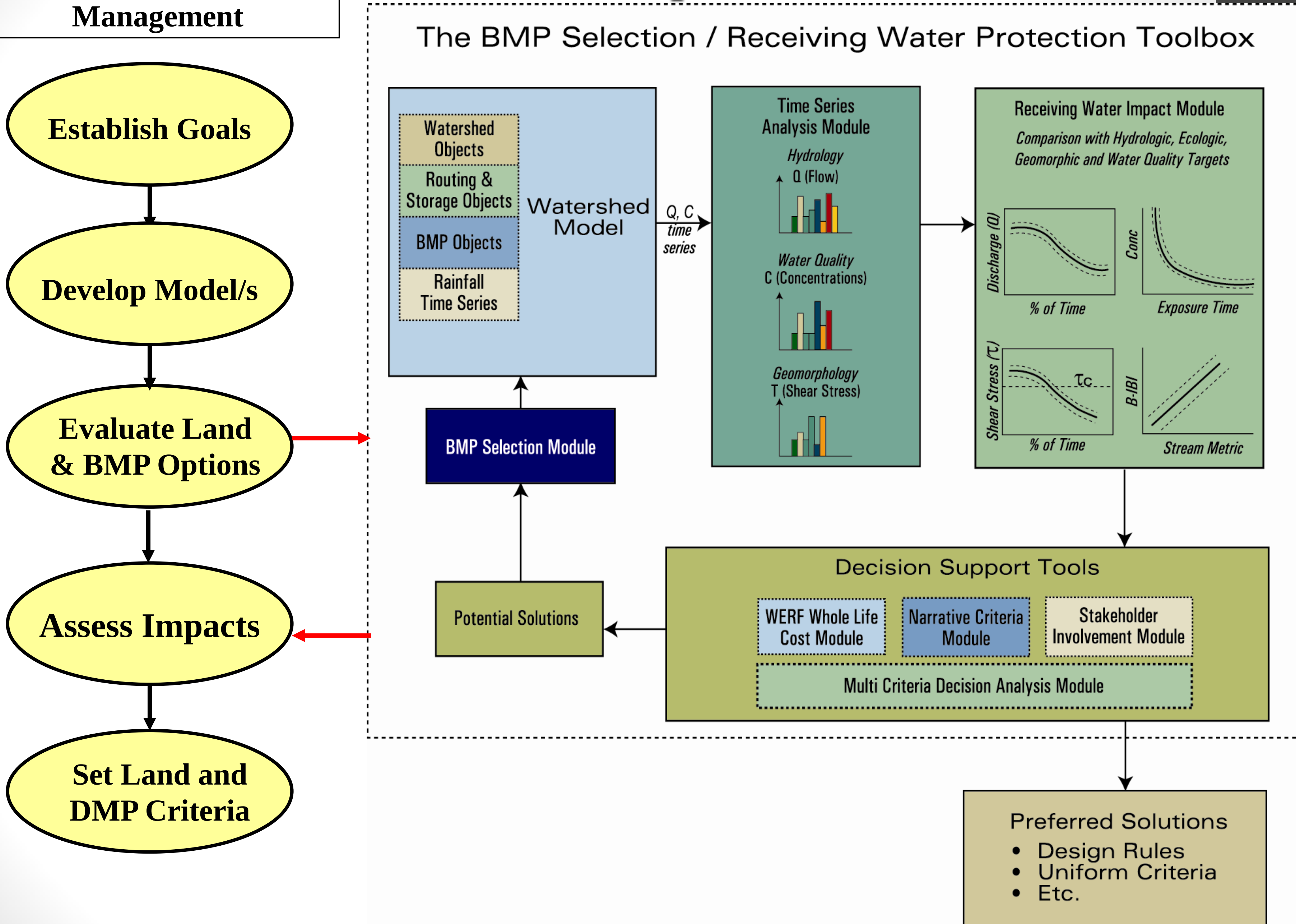
- The WERF Stormwater TAC
- Stormwater Challenge (06-SW-1) “Linking BMP Systems Performance to Receiving Water Protection to Improve BMP Selection and Design”

Goal of SW Challenge 06-SW-1

To link BMP control effectiveness for specific pollutants and flow to receiving water loadings, impacts and water quality objectives to improve selection and design of BMP systems.

The Concept of the Framework

Urban Water Resources Management



Focus Areas of the Challenge

- Build a Modeling Framework that allows users to link the watershed model of their choice to the receiving water model of their choice
- Include BMP performance algorithms that are practical and represent the water quality behavior of BMPS
- Include uncertainty in pollutant removal estimates for BMPs and resulting uncertainty in receiving water concentrations
- Include Decision Support Tools to help users evaluate the relative effectiveness of alternative stormwater management scenarios

A 2007 Workshop Provided Guidance

- There are LOTS of tools already
- The need was for production – integration of existing tools
- Non-proprietary technologies preferred
- Platform independence desired
- Specific users targeted – non-specialists
- Detailed spec developed

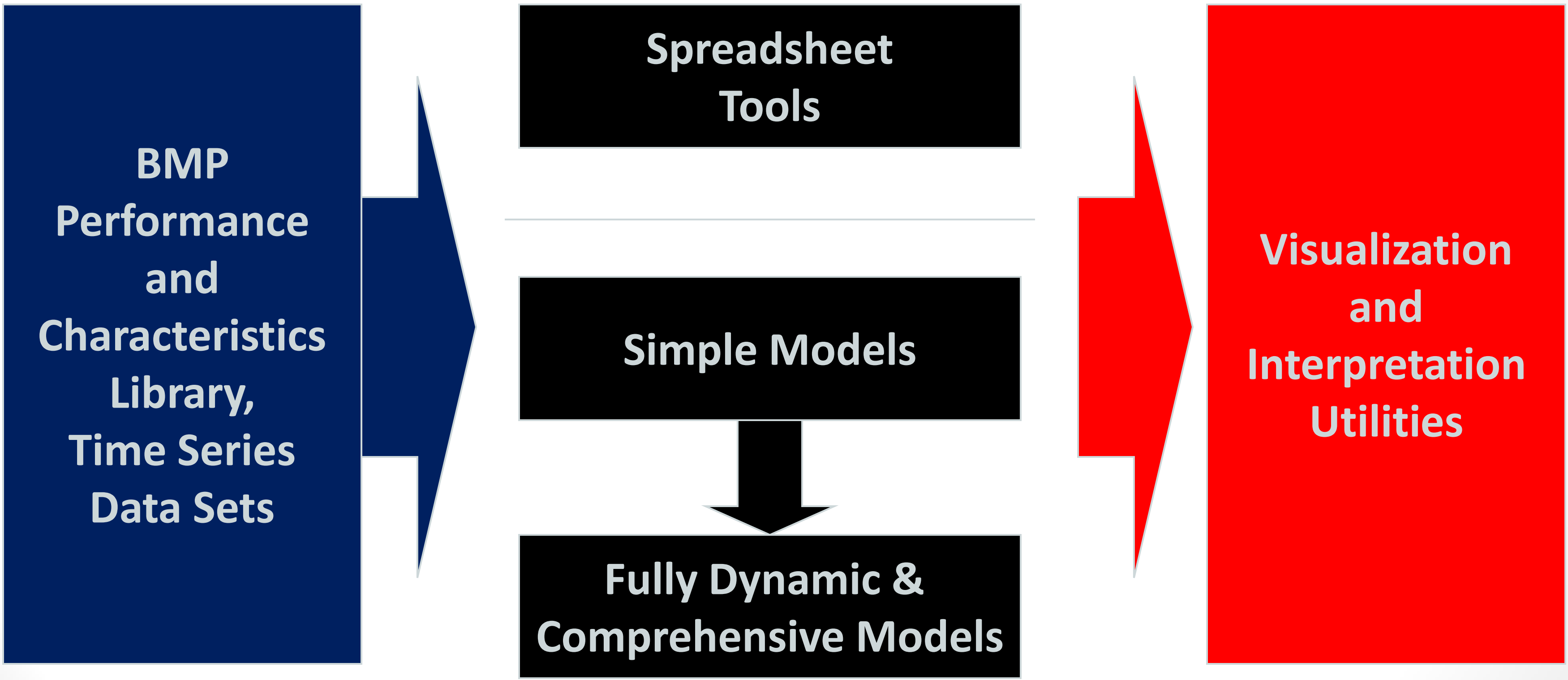
THE FRAMEWORK

A Fundamental Premise

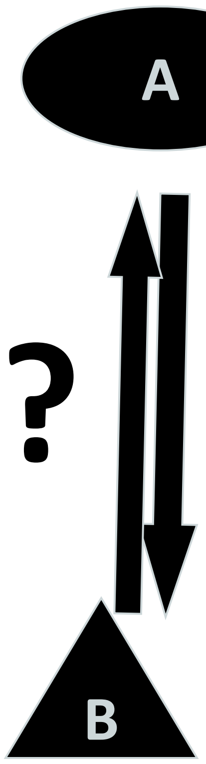
- Since we have lots of models already, what we need is to have a way to use them better
- The key deficits are
  - Getting the tools to talk to each other
  - Improving the decision support components

Science matters, but PRODUCTION is also a major issue.

Coming to Grips with the Problem



How models are typically made to communicate



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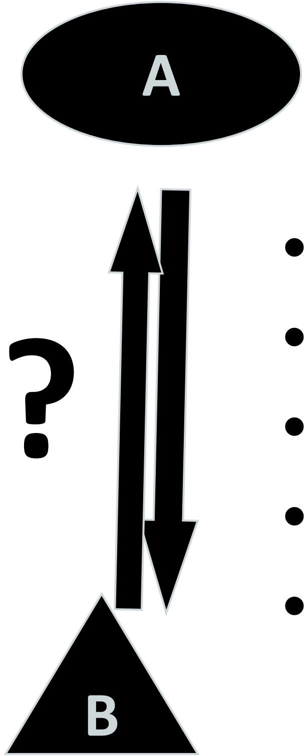
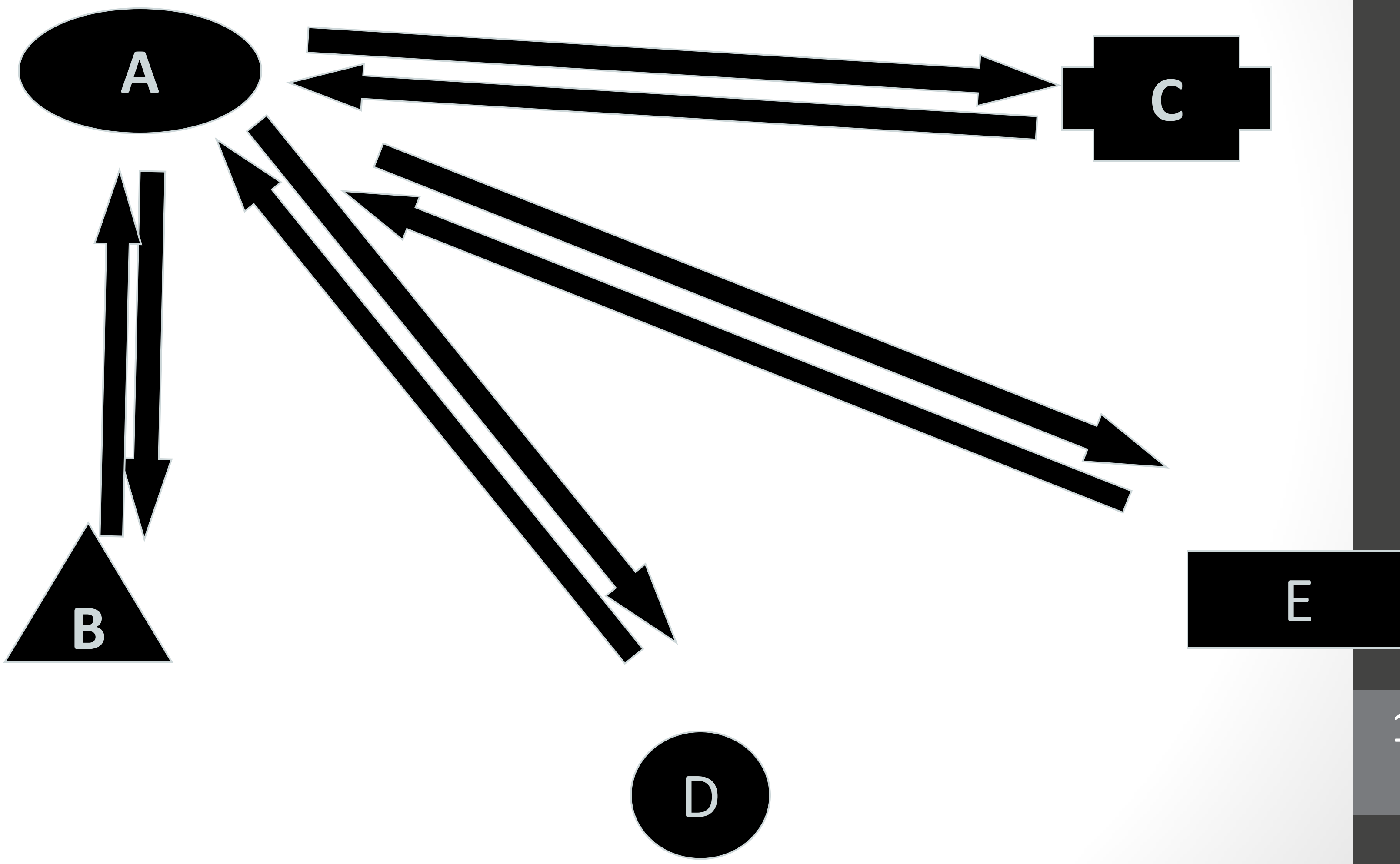
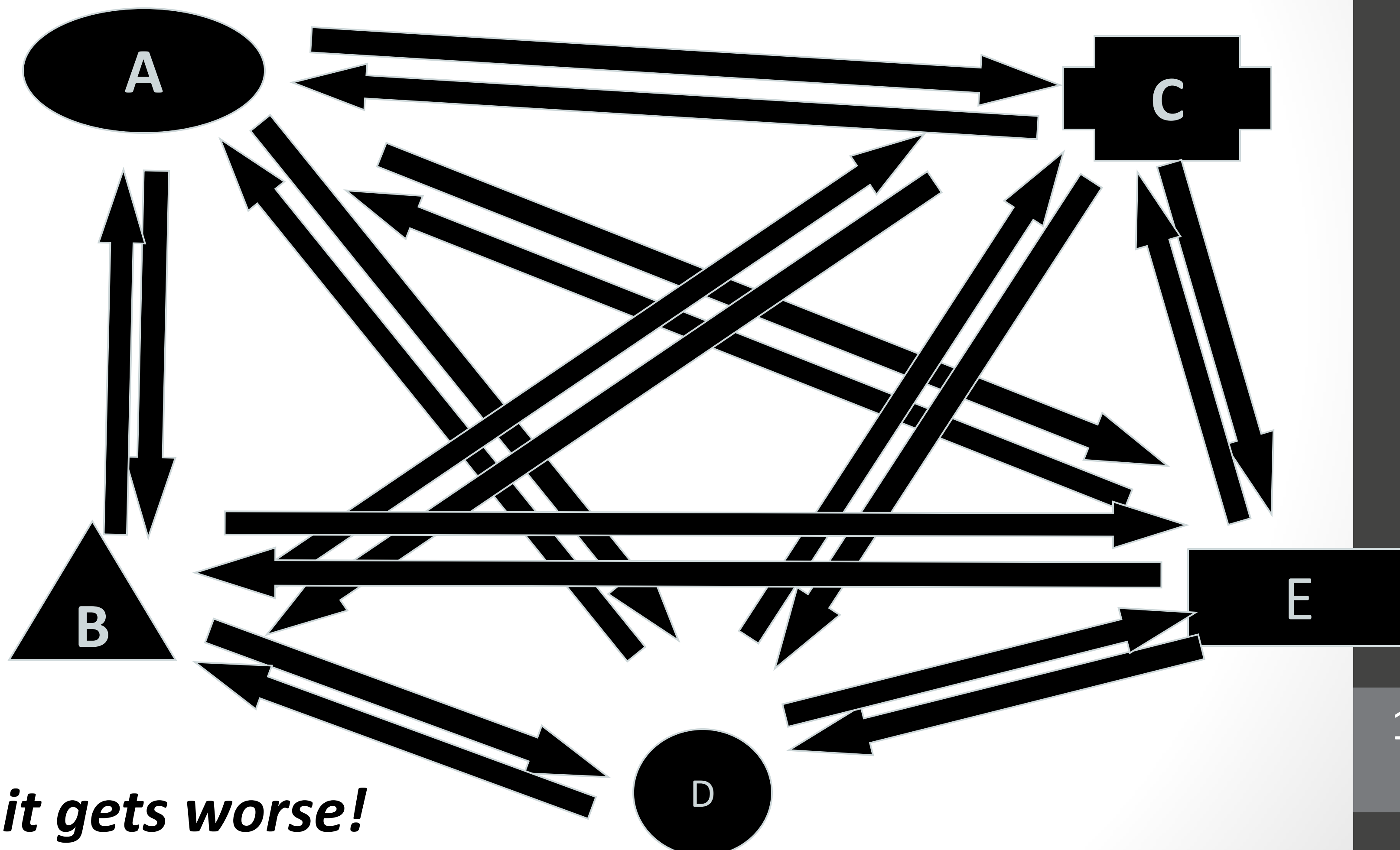


- Conversion is usually ad hoc
- QC is required every time
- Documentation may be fragmentary
- Reproduction may be difficult
- The exercise is repeated individually by lots of users
- The net result is increased cost and needless QC questions

How models are typically made to communicate

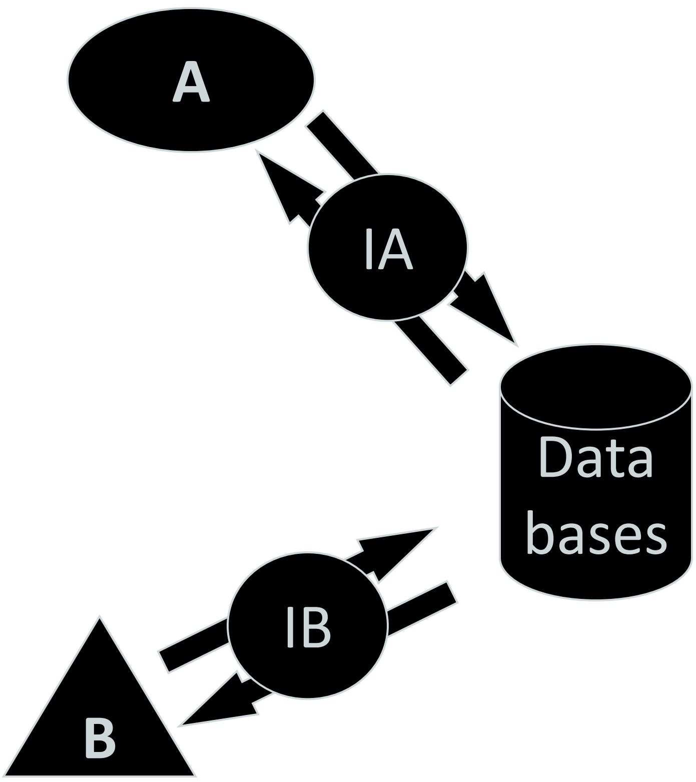


How models are typically made to communicate

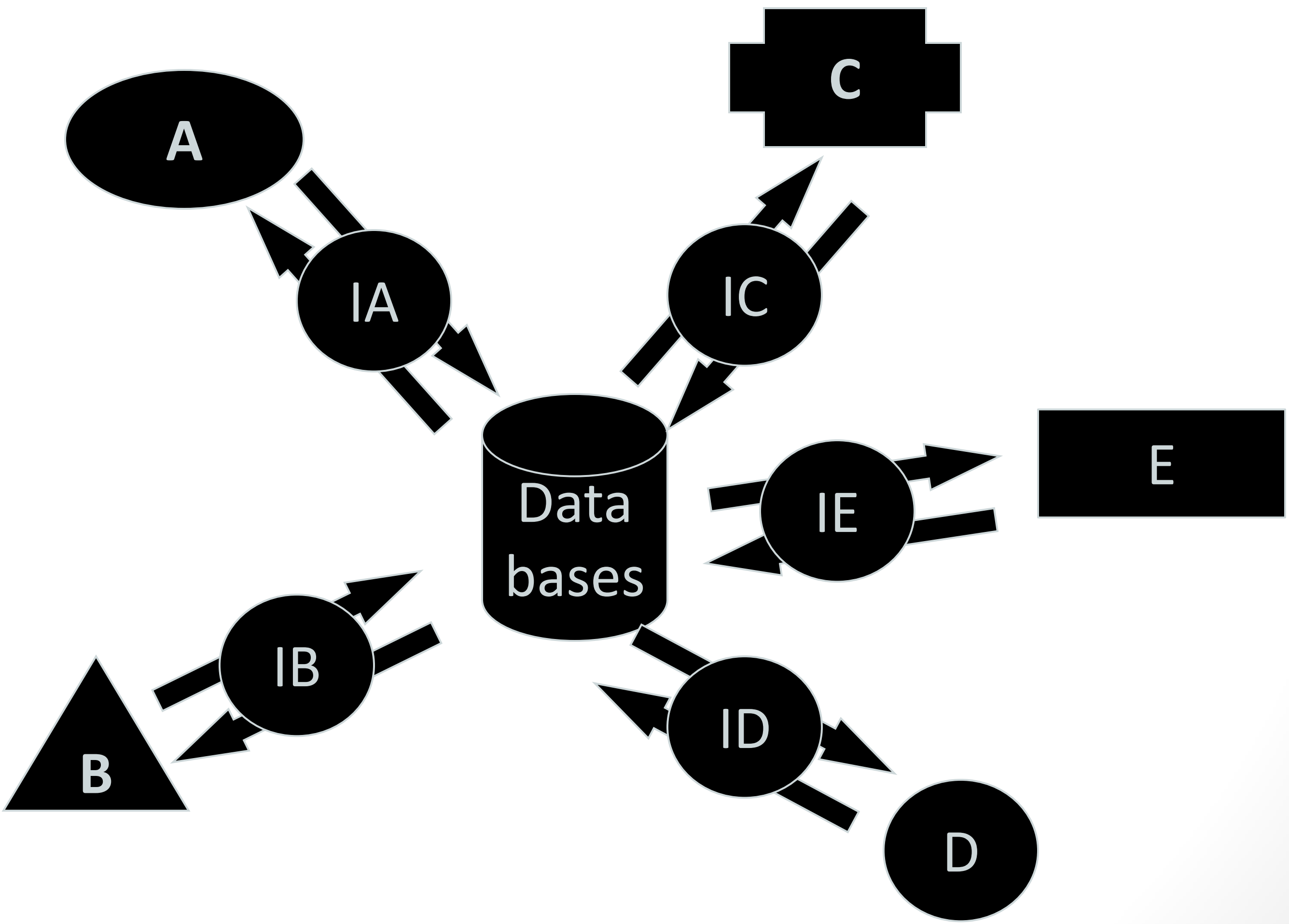


And it gets worse!

The data interface solution



The data interface solution



A Word on Topology

- The RI model
  - 4 nodes = 12 connections
  - 7 nodes = 42 connections
  - 10 nodes = 90 connections

- Hub model
  - 10 nodes = 20 connections

A Word on Topology

- RI model
  - 1 change in 10 nodes = 9 updates

- Hub model
  - 1 change = 1 update

A Word on Topology

- Consider a shift from 10 to 11 nodes
- The RI model
  - Add 20 connections
- Hub model
  - Add 2 connections

Conceptual Model of the Framework 2.0

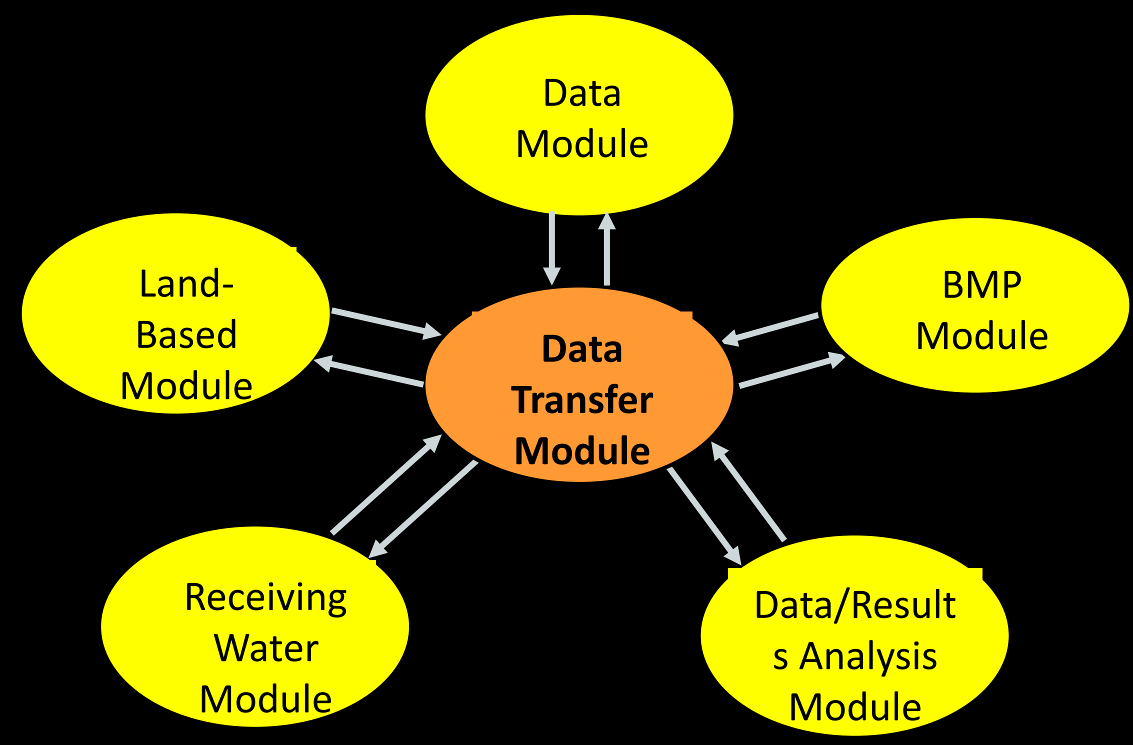
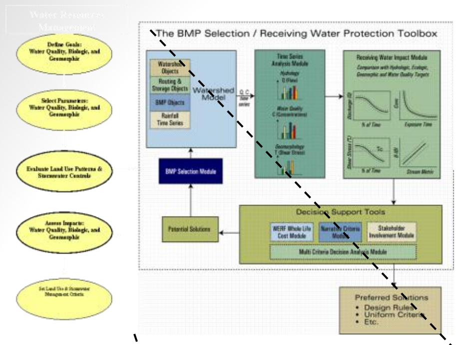
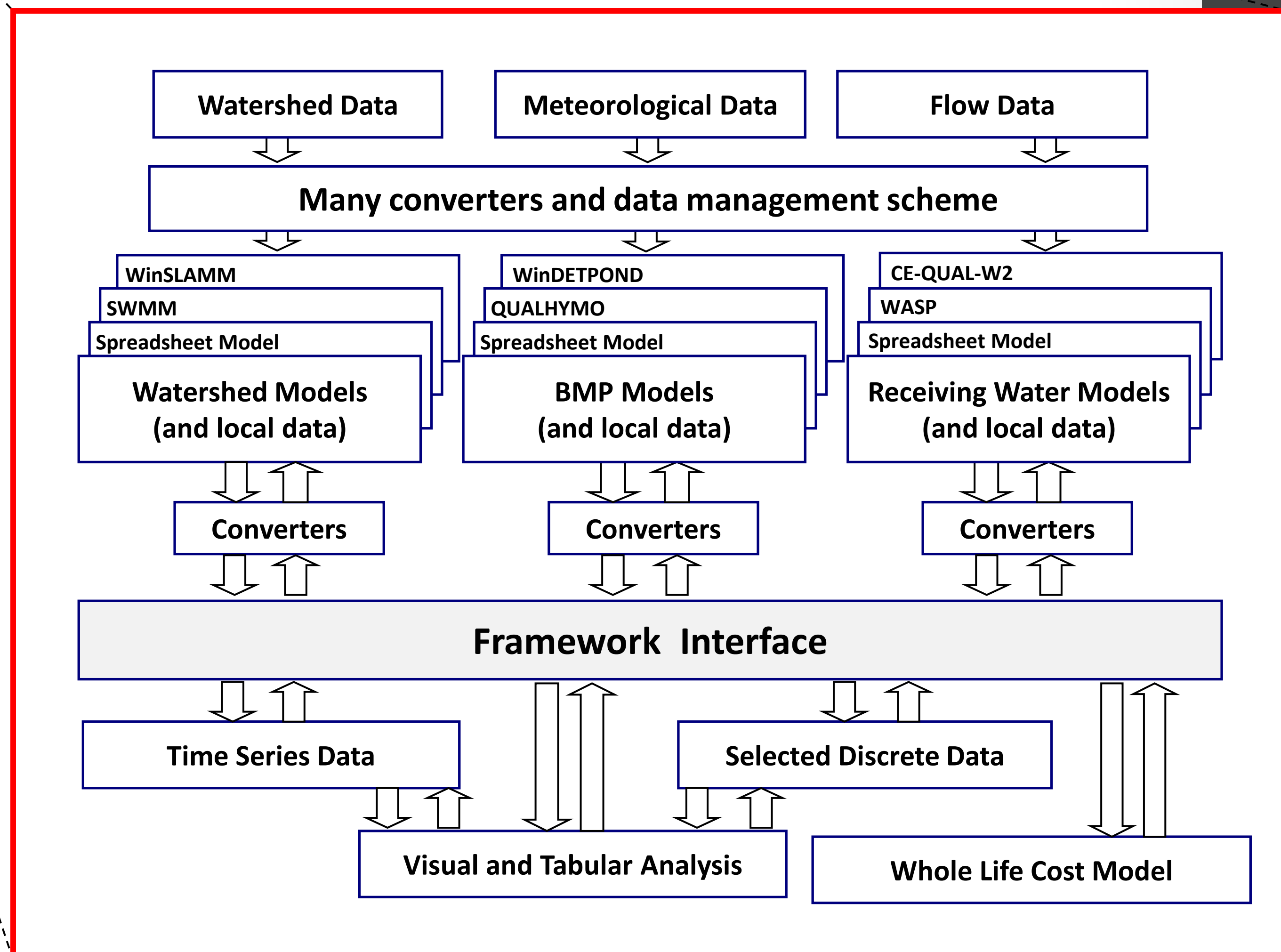


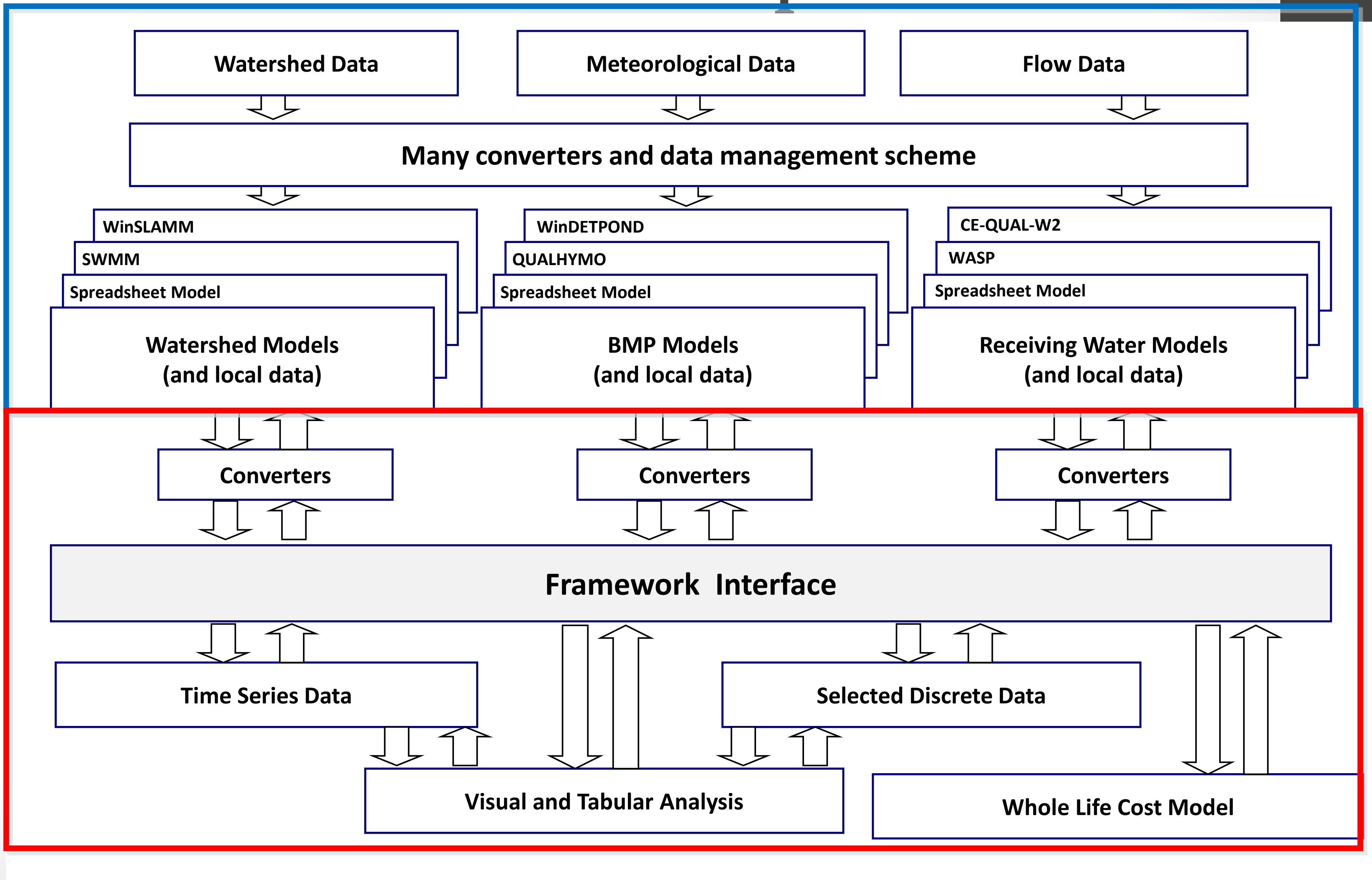
Figure 4: Major Data Conduits in the BMP ToolBox



From Vision to Definition



ToolBox Functional Representation



Model Spec – overview

- the Framework contain a suite of tools enabling assessments of the link between BMPs and receiving waters
- the models be non-proprietary and if possible open source,
- modifiable by users if needed,
- operable on MS Windows but also be extendable to Unix-type operating systems if possible,

Model Spec – overview

- scalable to large and small watershed areas,
- rapid and simple to use,
- usable in both greenfields and built environment contexts,
- duplication of existing technologies or model features be avoided,

Model Spec – overview

- avoid a reliance on expensive or third party enabling software such as GIS software for core capabilities,
- include a library of interpretive tools that will enable statistical interpretation and graphical display of critical results, specifically including the ability to develop exceedance curves,
- include a graphical user interface and not just a text type of input system, and
- make it usable by water resources practitioners without unusually advanced technical and/or IT capabilities.

Model Spec – overview

- Windows 7 32 bit
- Note that as usual, Microsoft updates, patches etc have an effect
- Generally ok on Windows XP 32 bit and Windows 8.1 32 bit
- Properly installed and running versions of supported models INCLUDING DRIVERS (and all pre-requisites for those models)

The User

- would usually be engaged in planning, rather than detailed design,
- has the need to use multiple models,
- could be working for a municipality or regulatory agencies, or might work for a consultant,
- commonly, accomplishing tasks on behalf of municipalities or regional authorities

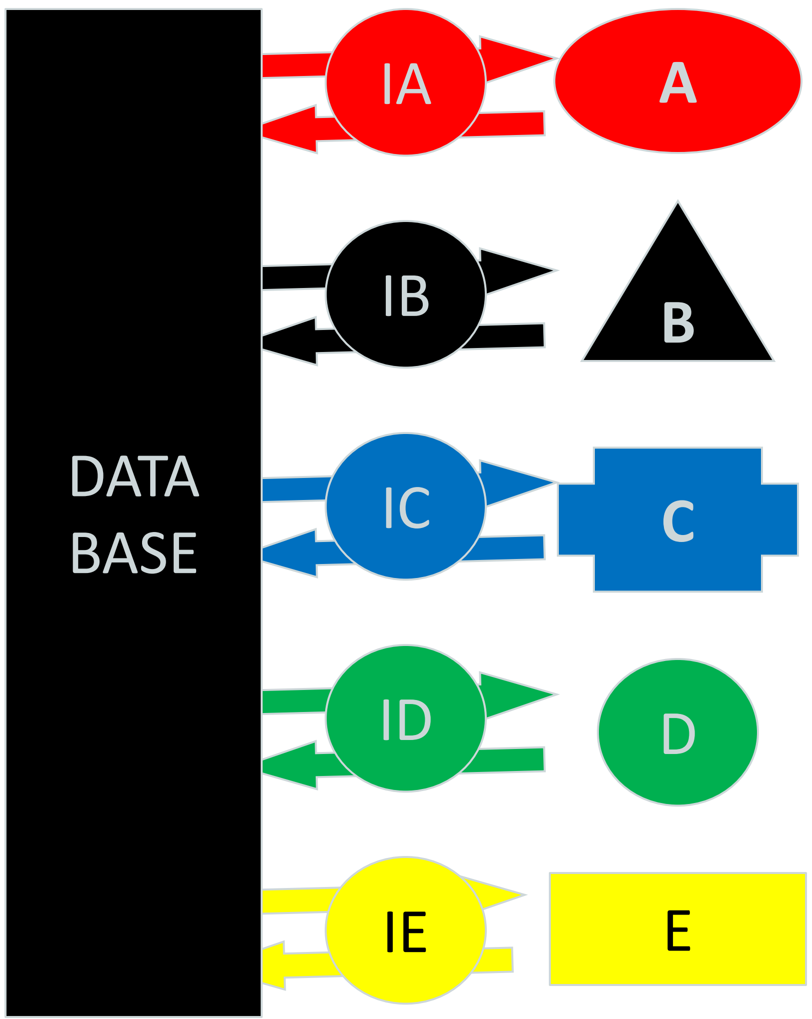
The User

- formal background in water resources with specific knowledge in hydrology, water quality management and planning and decision making,
- would be at a ‘hands on’ technical career stage - an experienced but not necessarily highly sophisticated water resources user,
- UNDERSTANDS THE UNDERLYING MODELS

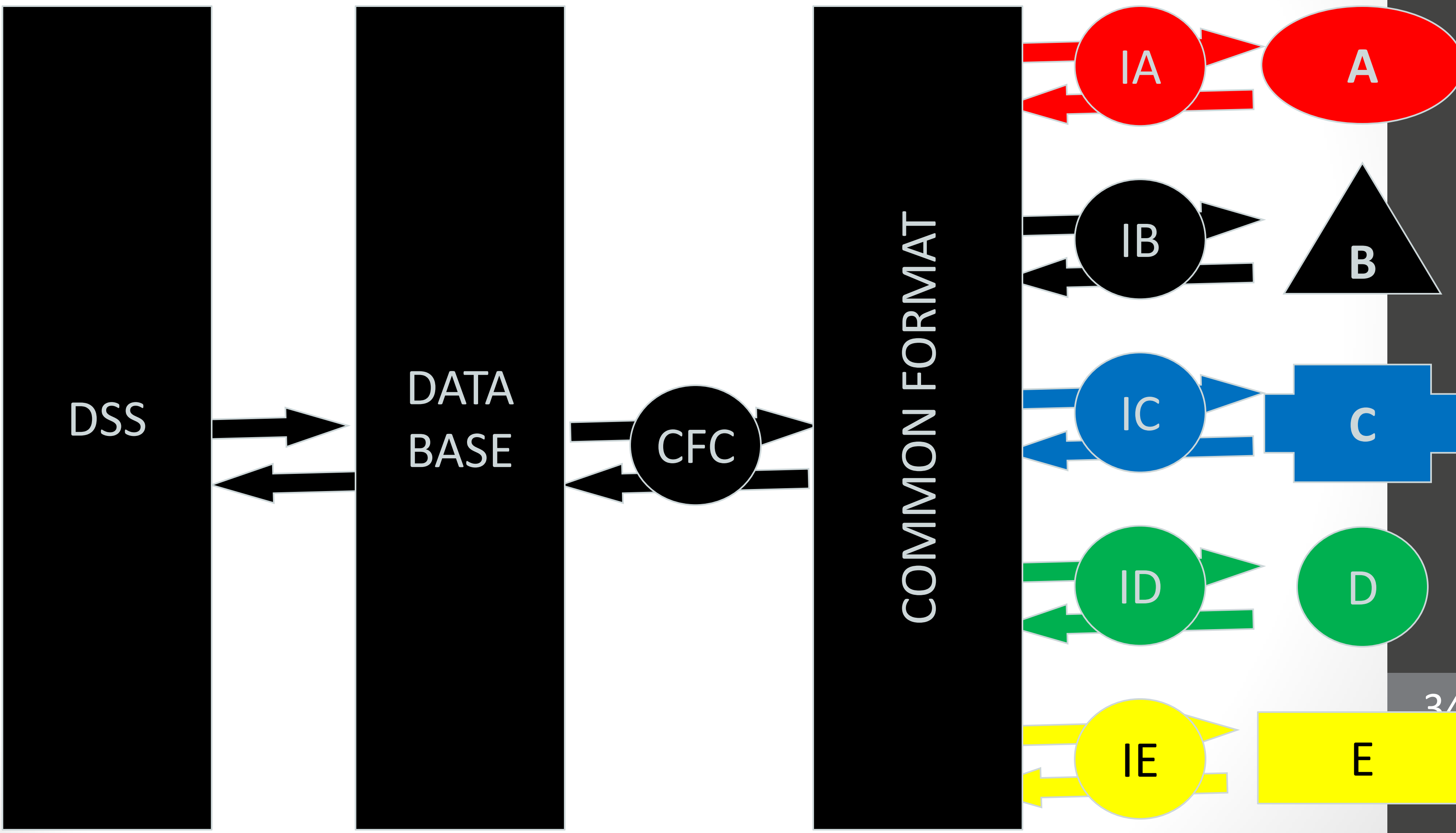
The Developer

- Still trying to figure this one out
- Avoid restrictions to the extent possible
- Keep things simple
  - No ‘satisfying’ but obscure code
  - Lots of internal documentation
- Recognize from the outset that things are going to change

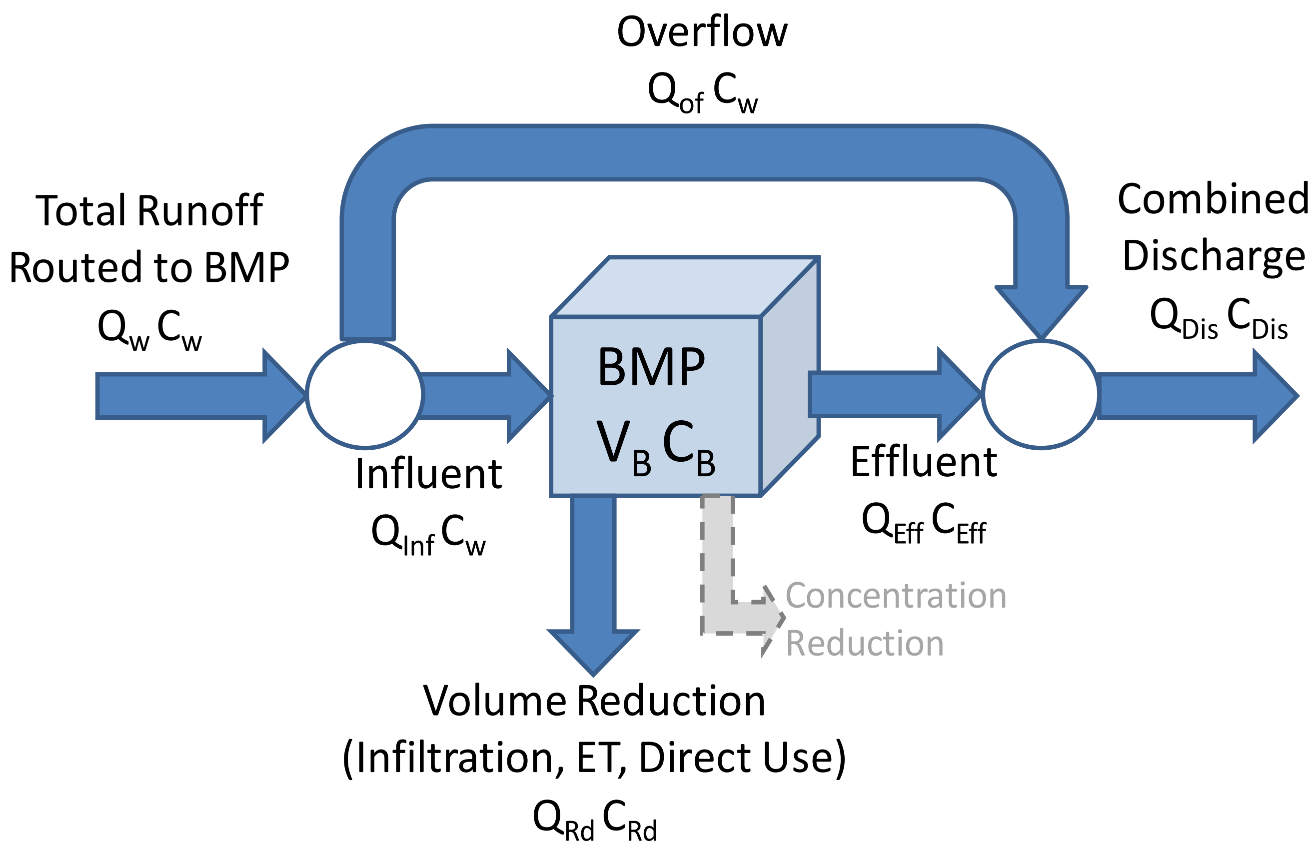
The data interface solution

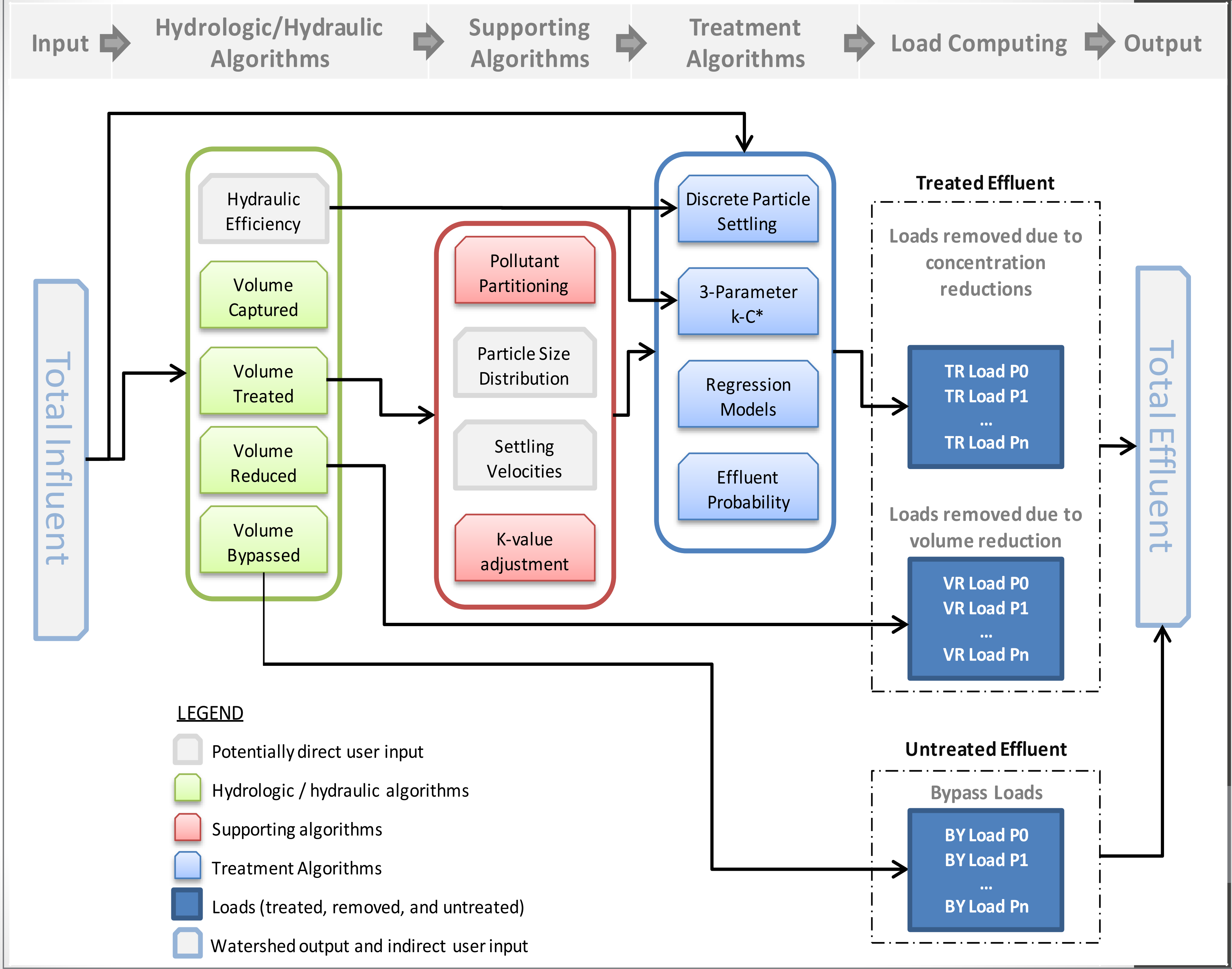


The data interface solution



General BMP Modeling Approach

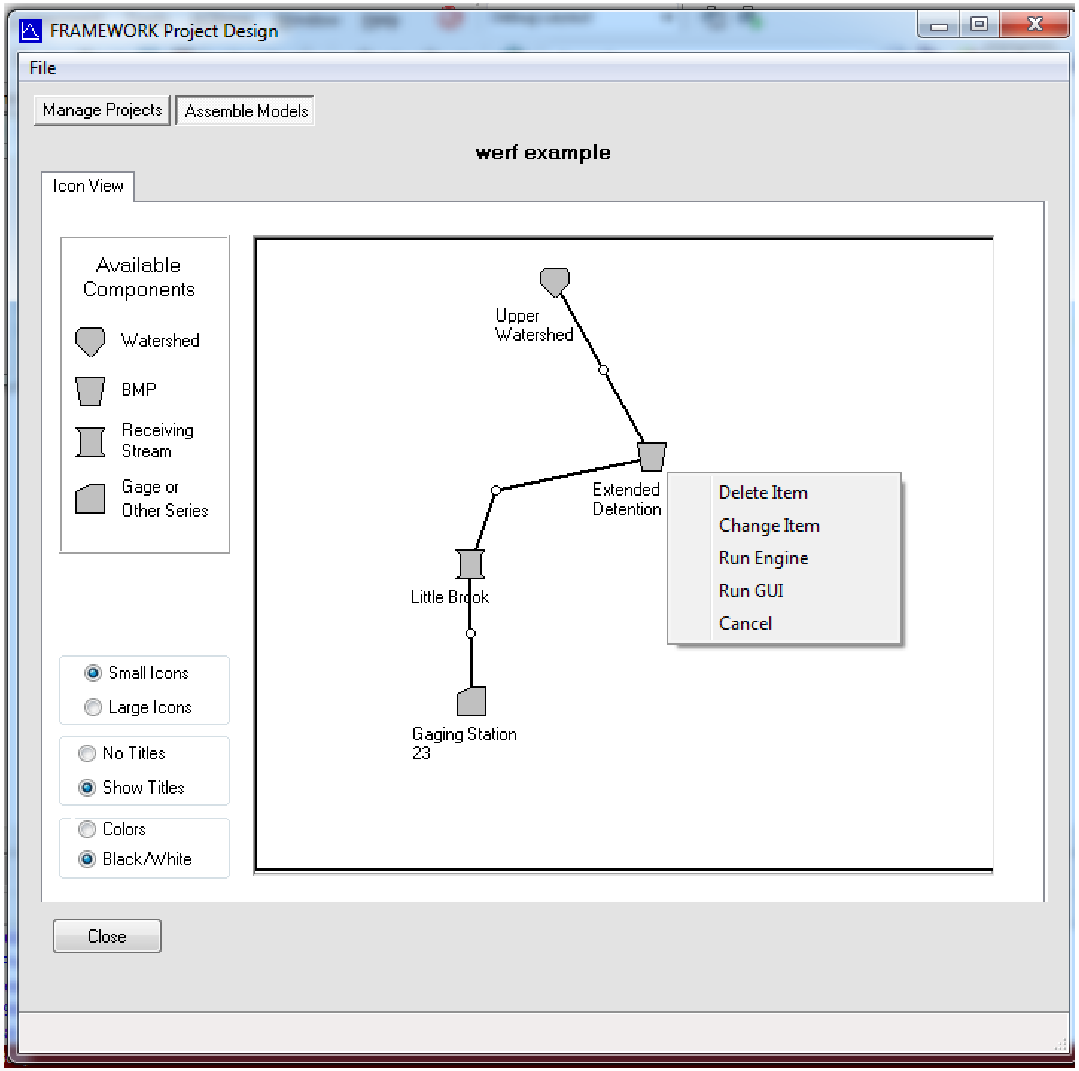




Input
Hydrologic/Hydraulic Algorithms
Supporting Algorithms
Treatment Algorithms
Load Computing
Output
Total Influent
Hydraulic Efficiency
Volume Captured
Volume Treated
Volume Reduced
Volume Bypassed
Pollutant Partitioning
Particle Size Distribution
Settling Velocities
K-value adjustment
Discrete Particle Settling
3-Parameter k-C*
Regression Models
Effluent Probability
Treated Effluent
Loads removed due to concentration reductions
TR Load P0
TR Load P1
...
TR Load Pn
Loads removed due to volume reduction
VR Load P0
VR Load P1
...
VR Load Pn
Untreated Effluent
Bypass Loads
BY Load P0
BY Load P1
...
BY Load Pn
Total Effluent
LEGEND
Potentially direct user input
Hydrologic / hydraulic algorithms
Supporting algorithms
Treatment Algorithms
Loads (treated, removed, and untreated)
Watershed output and indirect user input

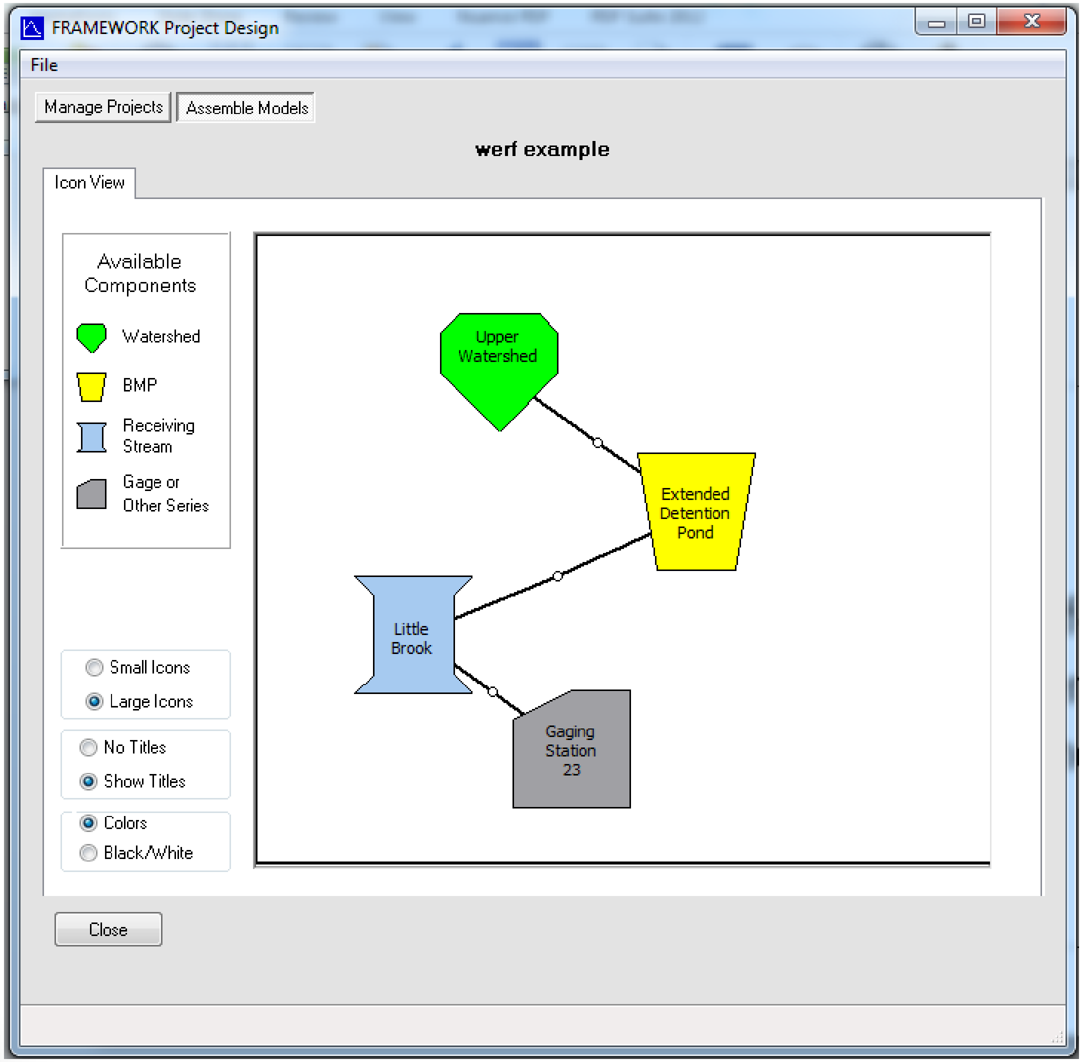
Decision Support Systems – Some Examples of Framework Capabilities

Decision Support Systems



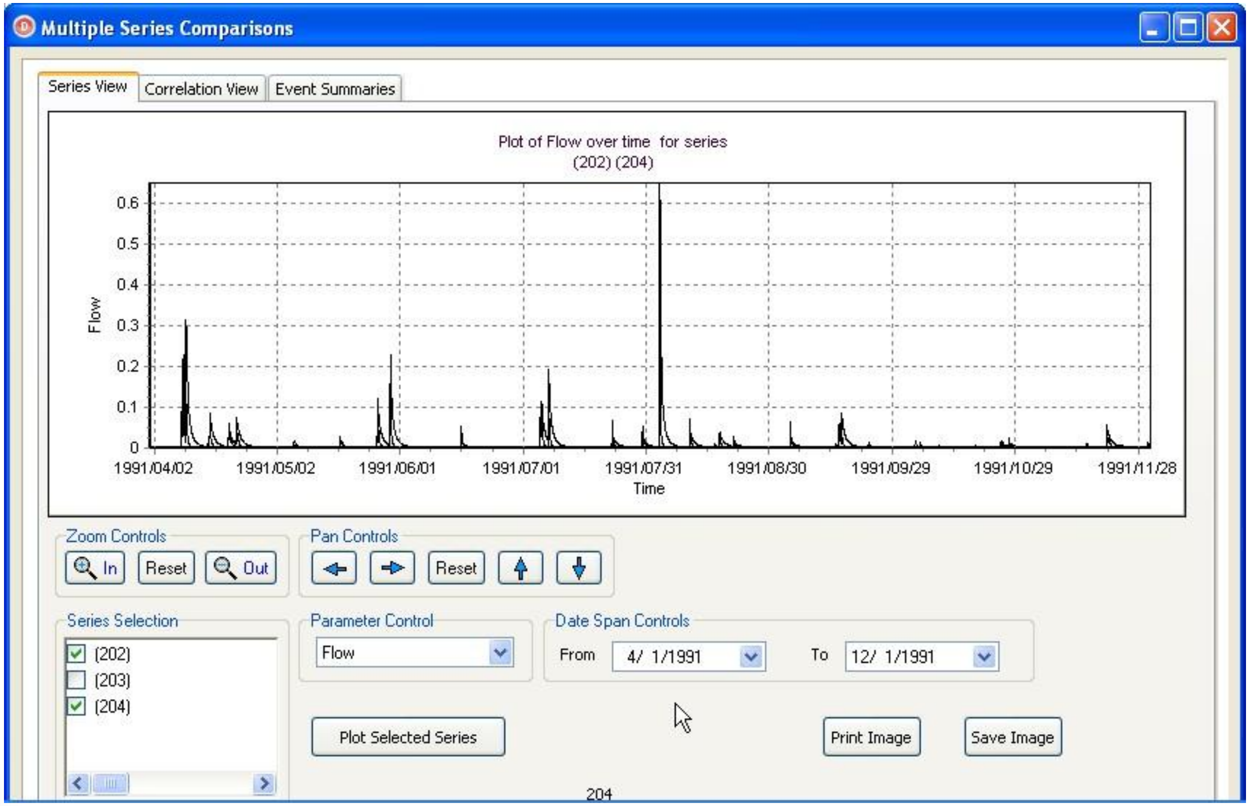
A visual interface for component management

Decision Support Systems



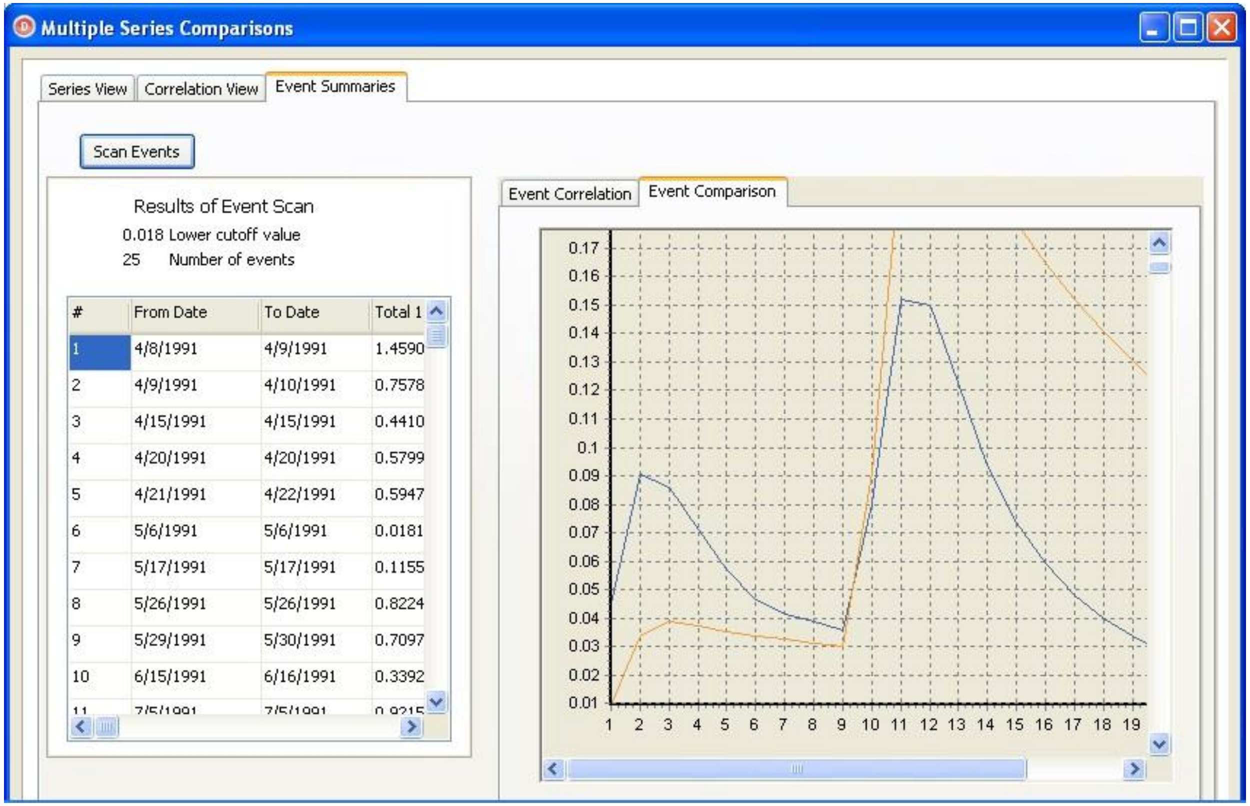
A visual interface for component management

Decision Support Systems



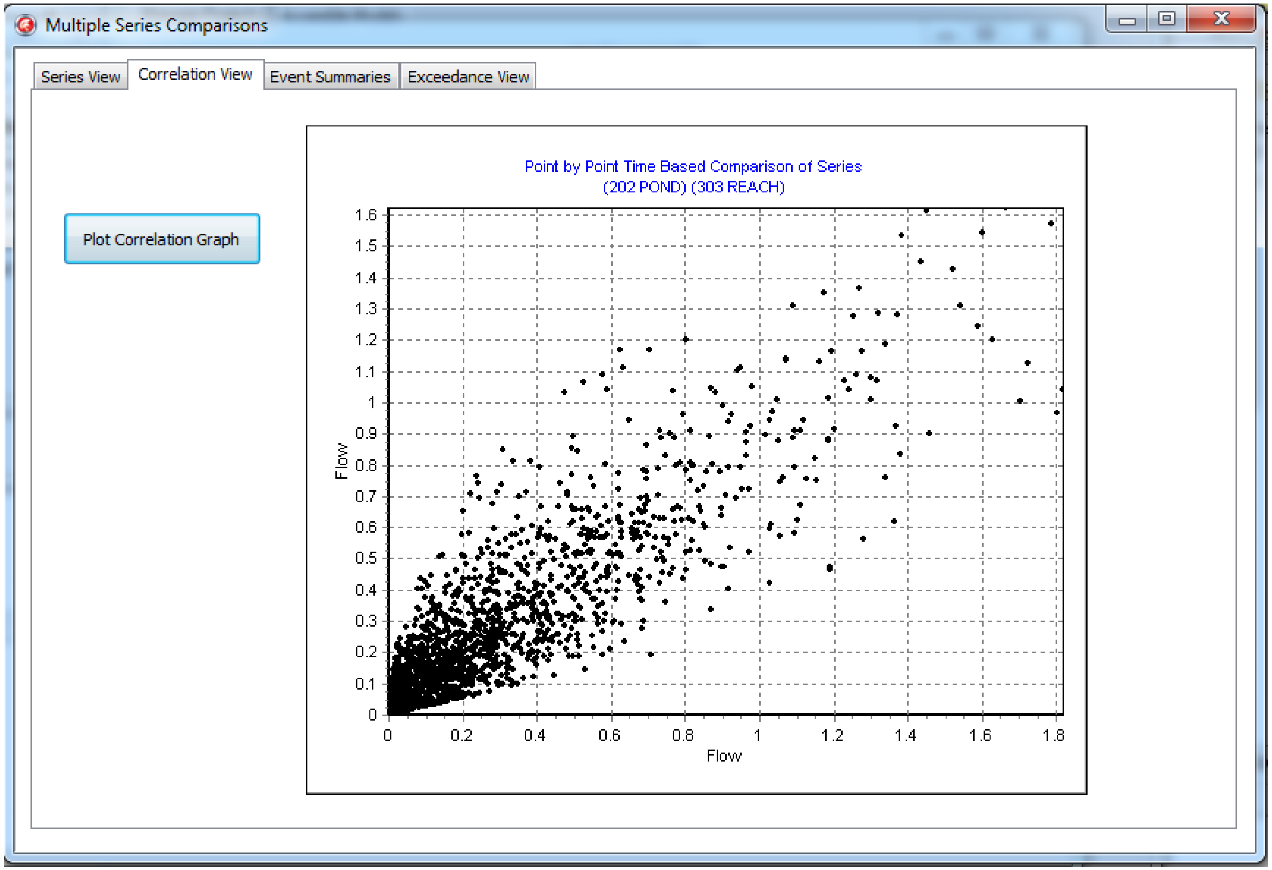
Series plots are fully scalable and can access any component equally

Decision Support Systems



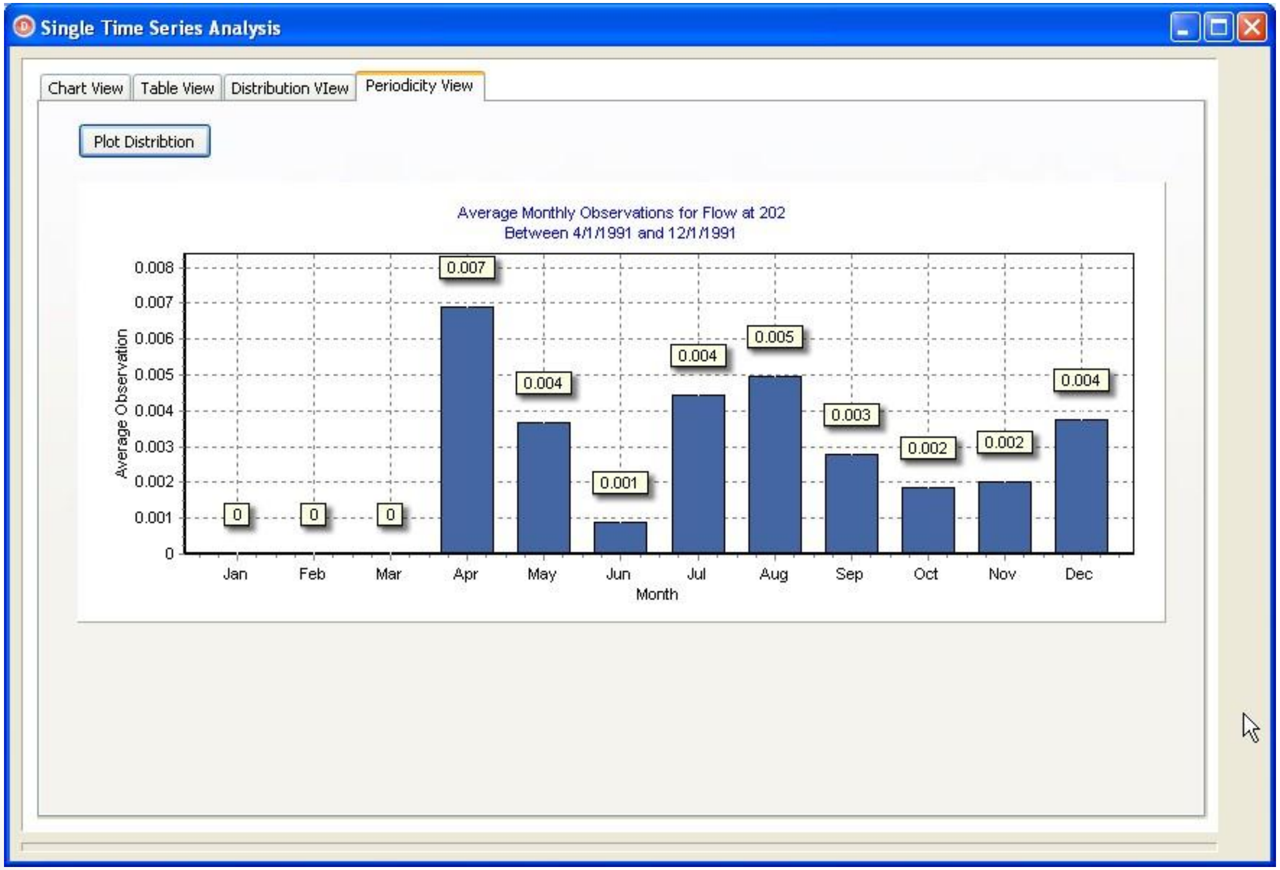
Automated event separation is built in to series analysis component

Decision Support Systems



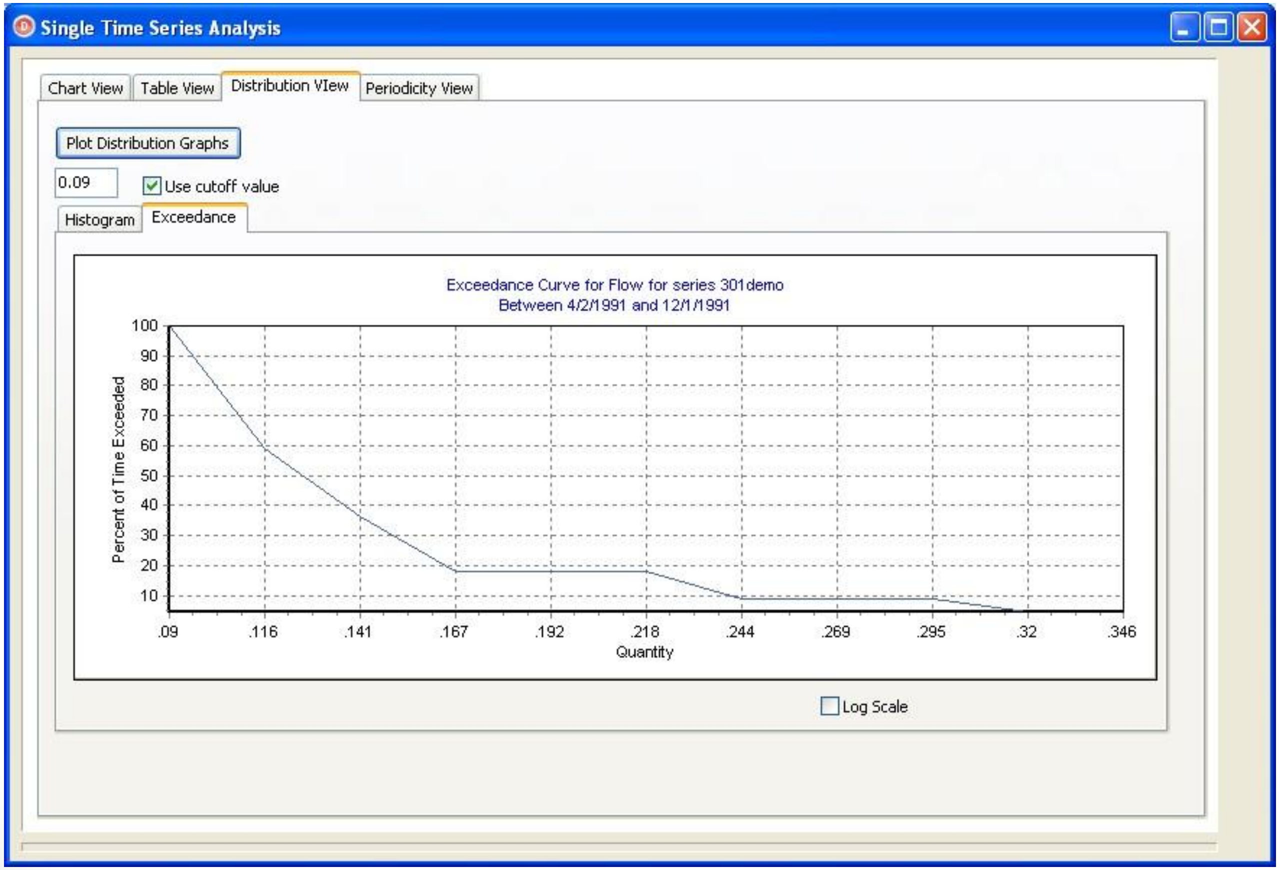
Event by event correlation analysis is built In

Decision Support Systems



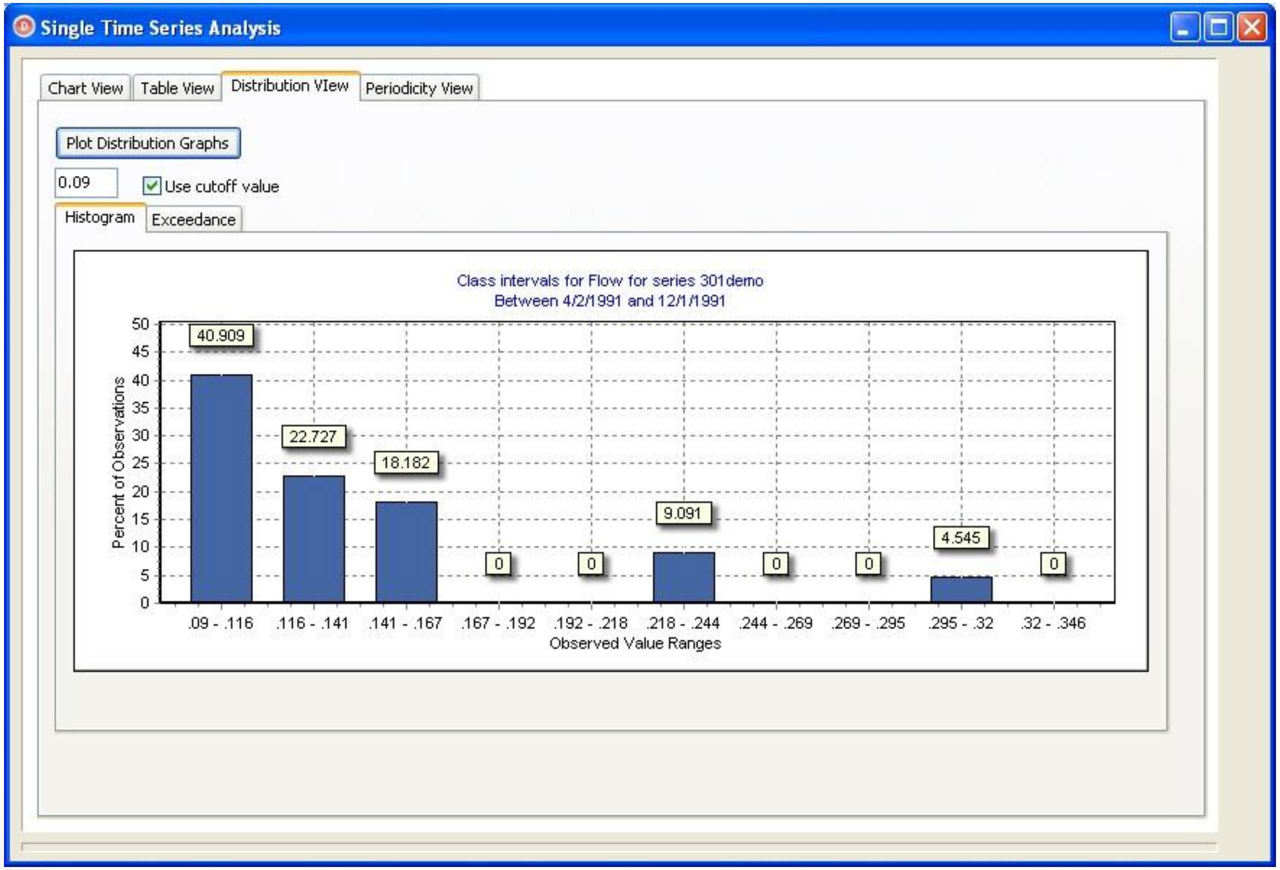
Seasonal or periodic analysis is user selectable

Decision Support Systems



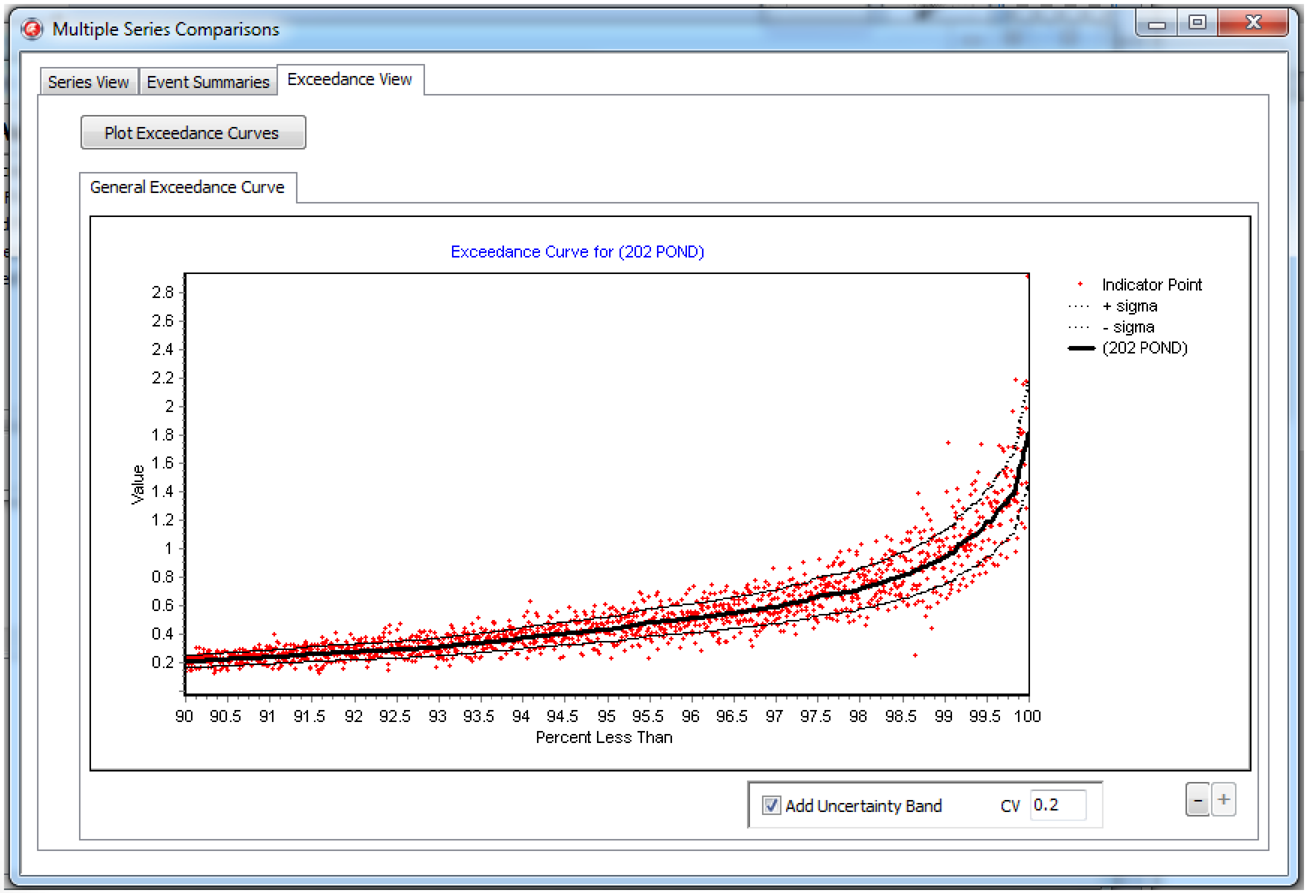
Exceedance curves are automatic

Decision Support Systems



Frequency histograms are also automatic

Uncertainty



Several uncertainty engines have been developed

Keys to the Future

- A repertoire of converters, to enable interaction between a wider range of models
- Further agreement and consolidation on the data format and interchange requirements
- Extension/expansion of the Decision Support System
- Movement towards an accepted standard for data interchange (ASCE?)

Current Status

Version 2.0

- fully spec’ed and under active development
- beta testing now being scheduled
- available in the fall of 2014.

Some Current Interest Areas

- Cost
- Quality
- Quantity
- Uncertainty
- Event separation
- BMP mechanics

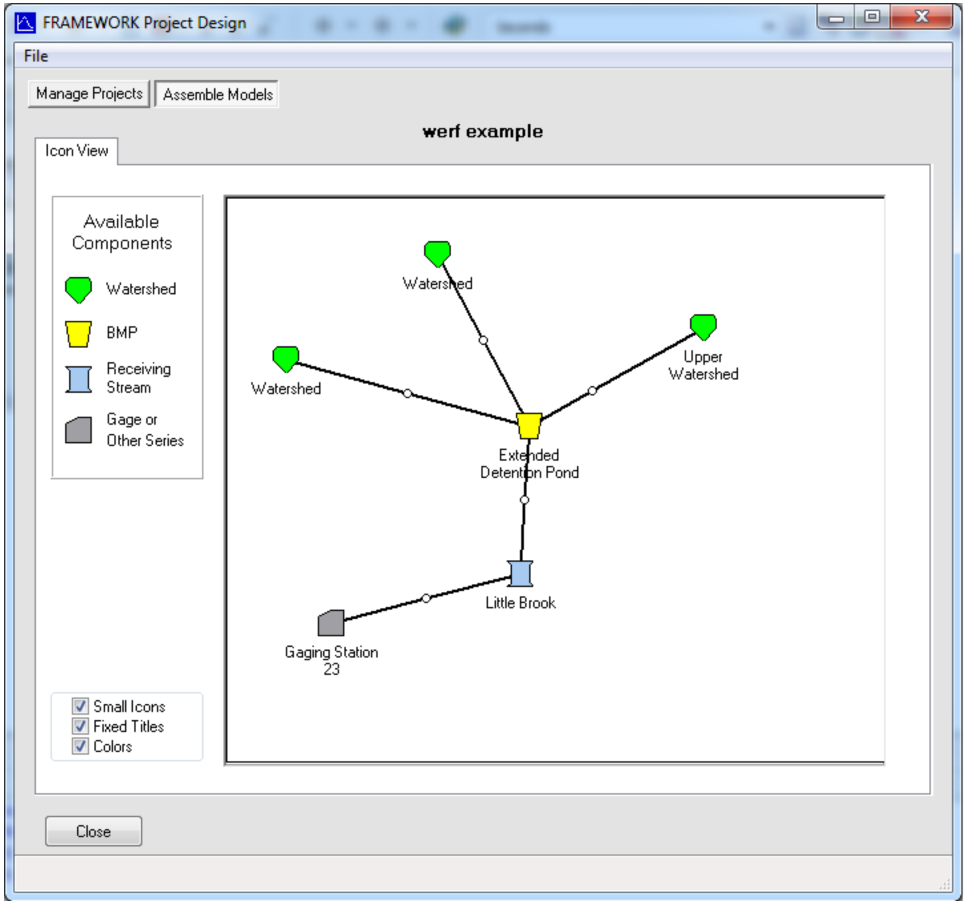
Some Emerging Interest Areas

- Areal distribution
- Groundwater
- Operational data
- Holistic planning

Feedback and Advice

- Critical needs and user preferences being sought – please chime in!
- Case studies in particular now being sought
- Those interested in producing converters also welcome

A Recent Development



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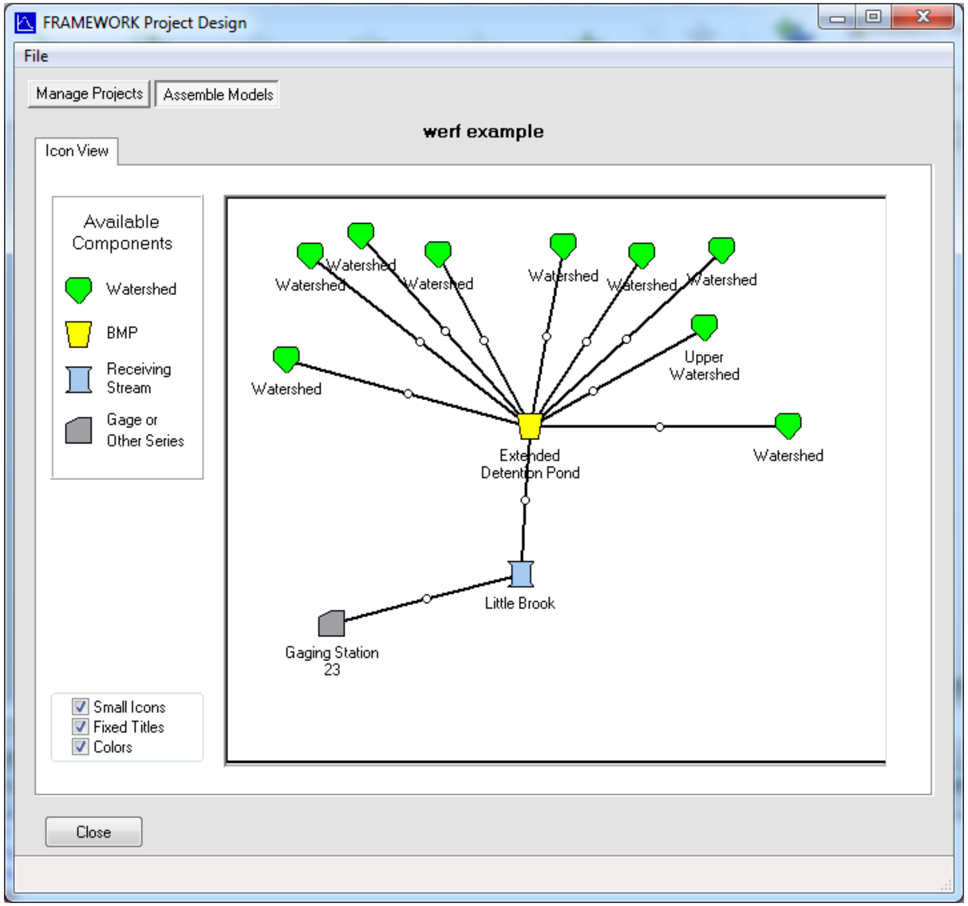

What we have accomplished

1. Provided an basic understanding of the WERF 'Linking BMPs to Receiving Waters' program, where it is going, and why it matters

2. Provided an introduction to the WERF Framework 2.0, what it does, how it does it.

3. Provided information on how to get involved, who to call, and what the future might bring.

No.	Last Name	First Name	Business Name	City	State	CFM
1	Acre	Pam	City of Northglenn	Northglenn	CO	No
2	ADAM	VERN	City of Aurora / Capital Projects Division	Aurora	CO	No
3	Adams	Matthew	Felsburg Holt & Ullevig	Centennial	CO	No
4	Adkinson	Jerry	Anderson & Hastings	Lakewood	CO	No
5	Alirez	Krystle	Urban Drainage & Flood Control District	Denver	CO	No
6	Allen	Dan	Peak Civil Consultants	Englewood	CO	Yes
7	Alverson	Lee	City of Thornton	Thornton	CO	No
8	Anderson	Michael	City and County of Denver	Denver	CO	No
9	Anderson	Kathy	URS	Denver Co	CO	No
10	Anderson	Scot	Hogan Lovells US LLP	Denver	CO	No
11	Armfield	Kenneth	Armfield Engineering	Longmont	CO	Yes
12	Asquith	Aaron	Merrick & Company	Denver	CO	No
13	Babbitt	Lucas	SEH	Denver	CO	Yes
14	Bailey	Julia	UDFCD	Denver	CO	No
15	Baker	Rebecca	City and County of Broomfield	Broomfield	CO	Yes
16	Bauer	Kurt	City of Boulder Public Works	Boulder	CO	Yes
17	Beatty	Matt	Anderson & Hastings	Lakewood	CO	No
18	Beck	Charles	Anderson & Hastings	Lakewood	CO	No
19	Beedle	Jacob	Atkins	Denver	CO	Yes
20	Bennetts	David	Urban Drainage and Flood Control District	Denver	CO	Yes
21	Besse	Jeff	City of Colorado Springs	Colorado Springs	CO	No
22	Bishop	Axel	Design Concepts	Lafayette	CO	No
23	Blackman	Tom	City and County Of Denver	Denver	CO	No
24	BONSER	TRISTAN	JR ENGINEERING	CENTENNIAL	CO	No
25	Borchardt	Richard	UDFCD	Denver	CO	Yes
26	Bortolini	Monica	SEMSWA	Englewood	CO	Yes
27	Bouchard	Michael	Denver Parks and Recreation	Denver	CO	No
28	Boudreau	Andy	HDR EOC	Englewood	CO	No
29	Bousselot	Aaron	ICON Engineering Inc.	Centennial	CO	Yes
30	Boyle	Jeanne	WHPacific	Lakewood	CO	Yes
31	Bradshaw	Darren	UDFCD	Denver	CO	Yes
32	Bromberger	Fred	City of Littleton	Littleton	CO	No
33	Brown	Scott	JR Engineering	Centennial	CO	No
34	Brown	Margaret	Brown Civil Engineering	Lafayette	CO	No
35	Buchanan	Joseph	City of Lakewood	Lakewood	CO	No
36	Buckley	Patrick	City of Commerce City	Commerce City	CO	Yes
37	Burke	John	City of Westminster	Westminster	CO	Yes
38	Byrne	Ryan	Martin/Martin Inc.	Lakewood	CO	Yes
39	Camphouse	Bryan	Anderson & Hastings	Lakewood	CO	No
40	Cantrell	Chad	JVA, Inc	Boulder	CO	Yes
41	Carmann	Troy	ICON Engineering Inc	Centennial	CO	Yes
42	Carpenter	David	Accurate EngiSurv	Westminster	CO	No
43	Castelli	Chris	WHPacific	Lakewood	CO	No
44	Cecil	Ken	J3 Engineering Consultants	Centennial	CO	Yes
45	Chenard	Melanie	Muller Engineering Company	Lakewood	CO	No
46	Chervu	Shweta	Dewberry	Denver	CO	Yes
47	Chevalier	Brian	Merrick & Company	Denver	CO	No

No.	Last Name	First Name	Business Name	City	State	CFM
48	Choi	Steve	City and County Of Denver	Denver	CO	No
49	Christianson	Ted	City and County Of Denver	Denver	CO	No
50	Clark	Tiffany	SEMSWA	Englewood	CO	Yes
51	Clark	Jesse	Stream Design - Landscape Architecture	Denver	CO	No
52	COKELEY	JAMES	CVL Consultants of Colorado, Inc.	Englewood	CO	Yes
53	Comerer	William	UDFCD	Denver	CO	No
54	Conn	John	Jefferson County	Golden	CO	Yes
55	Cook	Aaron	CH2M HILL	Englewood	CO	No
56	Cordts	Joesph	City of Denver - Dept. of Public Works	Denver	CO	No
57	Cotten	Kurtis	Town of Castle Rock	Castle Rock	CO	No
58	Crum	Ryan	City & County of Denver Wastewater Mgmt	Denver	CO	Yes
59	Czarnecka	Joanna	UDFCD	Denver	CO	Yes
60	Dam	Erik	Town of Castle Rock	Castle Rock	CO	No
61	Dankenbring	Shawn	Hartwig & Associates	Englewood	CO	Yes
62	Danley	Paul	SEMSWA	Englewood	CO	No
63	Debesu	Henok	City of Denver - Dept. of Public works	Denver	CO	Yes
64	Dederick	Jim	Douglas County	Castle Rock	CO	Yes
65	DeGroot	William	Retired	Denver	CO	No
66	Delagarza	David	RESPEC Consulting & Services	Denver	CO	Yes
67	Deleon	Amelia	UDFCD	Denver	CO	No
68	DeVargas	Wanda	City of Greenwood Village	Greenwood Village	CO	No
69	Dillin	Matthew	Muller Engineering	Lakewood	CO	No
70	Donelson	Mark	MD Consulting	Aurora	CO	Yes
71	Donnelly	Erin	SEMSWA	Englewood	CO	No
72	Dougherty	Patrick	City of Arvada	Arvada	CO	Yes
73	Earles	Andrew	Wright Water Engineers, Inc.	Denver	CO	No
74	Egan	Bret	Jehn Engineering	Arvada	CO	No
75	Eisenbraun	Dorothy	RESPEC Consulting & Services	Denver	CO	No
76	Elsner	Danny	SEH	Denver	CO	Yes
77	Eom	Moosub	CDM Smith	Denver	CO	Yes
78	Erichsen	Matt	7175 West Jefferson Ave	Lakewood	CO	No
79	Ewy	John	Regional Transportation District	Denver	CO	Yes
80	Fairley	Tom	Kiowa Engineering Corporation	Lakewood	CO	No
81	fanselau	erik	AECOM	Denver	CO	Yes
82	Fead	Terri	Urban Drainage and Flood Control District	Denver	CO	Yes
83	Feero	Frank	Phelps Engineering Sevices	Denver	CO	Yes
84	Fisher	Jeff	UDFCD	Denver	CO	No
85	Fisher	Debbie	Wright Water Engineers, Inc.	Denver	CO	Yes
86	Forvilly	Steve	City of Denver - Dept. of Public Works	Denver	CO	No
87	Fry	Timothy	Enginuity Engineering Solutions	Littleton	CO	No
88	Gabor	Amy	Olsson Associates	Golden	CO	Yes
89	Galuzzi	Mike	Merrick & Company	Denver	CO	No
90	Gardner	Joseph	UDFCD	Denver	CO	No
91	Gardner	Steve	City of Colorado Springs	Colorado Springs	CO	Yes
92	Gehrke	Mark	City and County Of Denver	Denver	CO	No
93	Gingery	Kevin	City of Loveland	Loveland	CO	Yes
94	Good	George	City of Sterling Colorado	Sterling	CO	Yes

No.	Last Name	First Name	Business Name	City	State	CFM
95	Gore	Tom	Altitude Training Associates	Golden	CO	No
96	Graham	Peggy	ADS	Longmont	CO	Yes
97	Gross	Alfred	CDOT	Denver	CO	No
98	Gudorf	Carrie	Mesa County	Grand junction	CO	Yes
99	Guo	James	U of Colorado Denver	Denver	CO	No
100	Haggerty	Colin	Parsons Brinckerhoff	Denver	CO	Yes
101	Hahn	Eric	RJH Consultants	Englewood	CO	No
102	Hamer	Jeremy	City of Denver - Dept. of Public Works	Denver	CO	Yes
103	Hansen	Heidi	City of Boulder	Boulder	CO	Yes
104	Harberg	Robert	City of Boulder	Boudler	CO	Yes
105	Hargrave	Ken	City of Lakewood	Lakewood	CO	No
106	Harris	Wayne	Martin/Martin Inc	Lakewood	CO	No
107	Hastings	James	Anderson & Hastings	Lakewood	CO	No
108	Hawthorn	Andrew	City of Westminster	Westminster	CO	Yes
109	Hayes	Susan	Susan L. Duba Hayes	Fort Collins	CO	Yes
110	Henke	Clint	ERO Resources Corp	Denver	CO	No
111	Henry	Brett	City of Thornton	Thornton	CO	Yes
112	Higgins	Christopher	Colorado School of Mines	Golden	CO	No
113	Hime	Walt	City and County OF Denver	Denver	CO	No
114	Hindman	Paul	Urban Drainage and Flood Control District	Denver	CO	Yes
115	Hinton	Geanesia	UDFCD	Denver	CO	No
116	Ho	Hung-Teng	Matrix Design Group, Inc.	Denver	CO	Yes
117	Hollingsworth	David	City of Longmont	Longmont	CO	Yes
118	Hollon	Joshua	Atkins	Denver	CO	Yes
119	Honer	Bill	City of Arvada	Arvada	CO	Yes
120	Hooper	Cory	CH2M HILL	Englewood	CO	No
121	Horn	Patrick	Martin/Martin	Lakewood	CO	Yes
122	Horton	Barbara	Town of Castle Rock	Castle Rock	CO	Yes
123	Houck	Kevin	CO. Water Conservation Board	Denver	CO	Yes
124	Howard	Angela	SEMSWA	Englewood	CO	Yes
125	Hufford	Randi	City of Aurora	Aurora	CO	No
126	Jackson	Brad	Douglas County	Castle Rock	CO	No
127	Jacobsen	James	City of Lakewood	Lakewood	CO	No
128	Jacobson	Craig	ICON Engineering Inc.	Centennial	CO	Yes
129	James	Jacob	Town of Parker	Parker	CO	Yes
130	Jankowski	Kelly	City and County of Denver	Denver	CO	No
131	Jefferson	Jennifer	Colorado School of Mines	Golden	CO	No
132	Johnson	Matt	HDR Engineering, Inc.	Colorado Springs	CO	Yes
133	Jones	Matt	Ayres Associates	Westminster	CO	No
134	Jula	Dave	Michael Baker Jr., Inc.	Lakewood	CO	Yes
135	Kaiser	Jim	City of Thornton	Thornton	CO	Yes
136	Kaslon	Brent	Valerian	Denver	CO	Yes
137	Kemme	Frank	City and County Of Denver	Denver	CO	Yes
138	Kidder	Andrew	CenterPoint Integrated Solutions	Evergreen	CO	No
139	Kim	Philip	City and County Of Denver	Denver	CO	No
140	Kindt	Laura	Otak, Inc	Denver	CO	No
141	Klein	Heath	City of Thornton	Thornton	CO	No

No.	Last Name	First Name	Business Name	City	State	CFM
142	Klopf	Ross	Jefferson County Planning & Zoning	Golden	CO	Yes
143	Klosowski	Selena	City and County Of Denver	Denver	CO	No
144	Kohlenberg	Bryan	Urban Drainage and Flood Control District	Denver	CO	Yes
145	Krawczyk	Steve	Jefferson County Planning & Zoning	Golden	CO	Yes
146	Krehbiel	Robert	Matrix Design Group	Denver	CO	No
147	Kreutzer	Jenelle	ERO Resources Corp	Denver	CO	No
148	Krickbaum	David	Olsson Associates	Golden	CO	Yes
149	Kroeger	Laura	UDFCD	Denver	CO	No
150	Kroeger	Chris	Muller Engineering Company	Lakewood	CO	No
151	Kuehster	Steve	City of Colorado Springs	Colorado Springs	CO	No
152	Kula	Deborah	City of Aurora	Aurora	CO	No
153	LaForce	Gilbert	El Paso County	Colorado Springs	CO	Yes
154	Lamarque	Wes	City of Fort Collins	Fort Collins	CO	No
155	Lammers	Jessica	Matrix Design Group	Denver	CO	No
156	Langlais	Brian	City of Lakewood	Lakewood	CO	No
157	LAUVER	LISA	Stantec Consulting	Denver	CO	Yes
158	Leak	Alan	RESPEC Consulting & Services	Denver	CO	No
159	Leslie	Steve	Drexel, Barrell & Co.	Boulder	CO	Yes
160	Leutbecher	Kelly	SEMSWA	Englewood	CO	No
161	Lindburg	Matt	Brown and Caldwell	Golden	CO	No
162	Liu	Suping	Arapahoe County	Centennial	CO	Yes
163	Loewen	Daniel	ICON Engineering Inc	Centennial	CO	No
164	Lopez	Paul	Office of Councilman Paul Lopez	Denver	CO	No
165	Lorenz	Wayne	Wright Water Engineers, Inc.	Denver	CO	No
166	Love	Nancy	J3 Engineering Consultants, Inc.	Louisville	CO	Yes
167	Love	Matt	Felsburg Holt & Ullevig	Centennial	CO	No
168	Lynch	Morgan	CH2M Hill	Englewood	CO	Yes
169	MacKenzie	Ken	UDFCD	Denver	CO	Yes
170	Mackey	Joel	City of Colorado Springs	Colorado Springs	CO	No
171	Madden	Sean	Jefferson County Planning & Zoning	Golden	CO	Yes
172	Madison	Daniel	Manhard Consulting	Centennial	CO	No
173	Mahanke	Ward	City of Lone Tree	Lone Tree	CO	No
174	Mallory	David	UDFCD	Denver	CO	Yes
175	Mancini	Mark	City and County of Denver	Denver	CO	No
176	Mann	Jason	URS Corporation	Denver	CO	No
177	Manning	Preston	Matrix Design Group	Colorado Springs	CO	No
178	Maring	Lydia	City of Colorado Springs	Colorado Springs	CO	No
179	Marron	Brenden	City and County Of Denver	Denver	CO	Yes
180	McCarty	John	SEMSWA	Englewood	CO	No
181	McCormick	William	City of Aurora	Aurora	CO	Yes
182	McDade	Robert	Colorado Dept of Transportation	Denver	CO	Yes
183	McDaniel	Eric	EMK Consultants, Inc.	Centennial	CO	Yes
184	McDermid	Ramsy	CCWRE	Lakewood	CO	No
185	Mehmen	Ben	City of Lakewood	Lakewood	CO	No
186	Messamer	Jason	Olsson Associates	Golden	CO	No
187	Mestdagh	Alex	Town of Parker	Parker	CO	No
188	Mieden	Roger	Osage Engineering	Westminster	CO	Yes

No.	Last Name	First Name	Business Name	City	State	CFM
189	Miller	Michele	AECOM	Denver	CO	No
190	Mitros	Tim	City of Colorado Springs	Colorado Springs	CO	No
191	Mogen	Dan	City of Fort Collins	Fort Collins	CO	No
192	Mommandi	Amanullah	Colo Dept of Transportation	DENVER	CO	Yes
193	Montoya	Eleanor	Brown Civil Engineering	Lafayette	CO	Yes
194	Moore	Suzanne	City of Greenwood Village	Greenwood Village	CO	No
195	Morgan	David	URS	Denver	CO	No
196	Morin	Joshua	RESPEC Consulting & Services	Denver	CO	Yes
197	Mulqueen	Steve	CDOT	Denver	CO	No
198	Murphy	Brian	CDM Smith	Denver	CO	Yes
199	Nelson	Adam	Town of Parker	Parker	CO	No
200	Nelson	Jon	SEMSWA	Englewood	CO	Yes
201	Newby	Jennifer	Matrix Design Group	Denver	CO	No
202	Nolle	Jessica	RESPEC Consulting & Services	Denver	CO	No
203	Nothaft	Mark	URS	Denver	CO	No
204	Nowka	Matthew	URS	Denver	CO	No
205	Ohlinger	Debra	Olsson Associates	Golden	CO	Yes
206	Olsen	Dan	SEMSWA	Englewood	CO	No
207	Olson	Katherine	City of Aurora	Aurora	CO	No
208	Orloff	Megan	Olsson Associates	Golden	CO	No
209	Ort	Douglas	Accurate EngiSurv	Westminster	CO	No
210	O'Shea	Jason	City of Thornton	Thornton	CO	No
211	Palmer	Scott	SEMSWA	Englewood	CO	Yes
212	Palmer	Wendi	Town of Erie	Erie	CO	Yes
213	Patterson	Teresa	UDFCD	Denver	CO	Yes
214	Pease	Scott	Core Consultants	Littleton	CO	Yes
215	Pennington	Walter	Ayres Associates	Eau Claire	WI	Yes
216	Perry	John	City of Aurora	Aurora	CO	Yes
217	Peters	Jay	Bowman Consulting	Golden	CO	No
218	Peterson	Allan	Douglas County	Castle Rock	CO	No
219	Pflaum	John	Independent	Denver	CO	No
220	Pittenger	Natalie	City of Thornton	Thornton	CO	No
221	Pitts	Tim	City of Aurora	Aurora	CO	No
222	Piza	Holly	Urban Drainage & Flood Control District	Denver	CO	No
223	Plas	Seth	Jefferson County	Golden	CO	No
224	Pond	Tracey	City of Golden	Golden	CO	No
225	Price	Russell	City and County Of Denver	Denver	CO	No
226	Prochno	Jamie	CO. Water Conservation Board	Denver	CO	Yes
227	Quinney	Patrick	CVL Consultants of Colorado, Inc.	Englewood	CO	No
228	Quintana	Al	City of Thornton	Thornton	CO	No
229	Rabinowitz	Geoff	City of Aurora	Aurora	CO	No
230	Rafferty	Catherine	Denver International Airport	Denver	CO	Yes
231	Rapp	Derek	Peak Stormwater Engineering	Louisville	CO	Yes
232	Raymond	Lanae	SEMSWA	Englewood	CO	No
233	Redmond	Jim	City of Littleton	Littleton	CO	No
234	Reed	Stephanie	City and County Of Denver	Denver	CO	No
235	Reinhardt	Peter	SEMSWA	Englewood	CO	Yes

No.	Last Name	First Name	Business Name	City	State	CFM
236	Renneker	Jason	City and County of Denver	Denver	CO	No
237	Repp	Tom	Douglas County	Castle Rock	CO	Yes
238	Reynolds	Cathy	UDFCD	Denver	CO	No
239	Reynolds	Rick	UDFCD	Denver	CO	No
240	Rice	Jeff	El Paso County	Colorado Springs	CO	Yes
241	Richardson	Bradley	City of Aurora	Aurora	CO	Yes
242	Robenstein	Brad	Douglas County	Castle Rock	CO	Yes
243	Robinson	Tyler	Manhard Consulting	Centennial	CO	No
244	Rogers	Terry	City of Lakewood	Lakewood	CO	No
245	Rowney	Charles	ACR,, LLC	Longwood	FL	No
246	Sarmento	Michael	UDFCD	Denver	CO	No
247	Schat	Brian	City and County Of Denver	Denver	CO	No
248	Schield	Jessup	Town of Castle Rock	Castle Rock	CO	No
249	Schlueter	Glen	City of Fort Collins	Fort Collins	CO	No
250	Schneider	Amy	Denver Botanic Gardens	Denver	CO	No
251	Schreiber	Scott	Matrix Design Group	Denver	CO	No
252	Schwab	John	JPS Engineering	Colorado Springs	CO	Yes
253	Scott	Sheri	Town of Castle Rock	Castle Rock	CO	Yes
254	Searcy	Alan	City of Lakewood	Lakewood	CO	No
255	Seymour	Nathan	Jefferson County Planning & Zoning	Golden	CO	Yes
256	Seymour	Brooke	Merrick & Company	Denver	CO	Yes
257	Sheets	Ben	City of Colorado Springs	Colorado Springs	CO	No
258	Shirley	Megan	CDPHE	Denver	CO	No
259	Shumate	Noah	Cultura Land Design	Englewood	CO	No
260	Siljenberg	Benny	Brierley Associates	Denver	CO	No
261	Simpson	Matt	City of Greeley	Greeley	CO	Yes
262	Skuodas	David	UDFCD	Denver	CO	Yes
263	Slovensky	George	RJH Consultants	Englewood	CO	No
264	Smith	Carol	Jefferson County Planning & Zoning	Golden	CO	No
265	Smith	Charles	Douglas County	Castle Rock	CO	Yes
266	Soderlin	Brent	Jefferson County Transportation and Engineering	Golden	CO	No
267	Song	Yong	RTD	Denver	CO	Yes
268	Stafford	Edward	City of Boulder	Boulder	CO	No
269	Staten	Elizabeth	HDR Engineering, Inc.	Colorado Springs	CO	Yes
270	Staub	Mason	SEMSWA	Englewood	CO	No
271	Steenerson	Rachel	Urban Drainage and Flood Control District	Denver	CO	No
272	Stewart	Kevin	Urban Drainage and Flood Control District	Denver	CO	No
273	Stream	Eric	Kiowa Engineering	Lakewood	CO	Yes
274	Tanner	Michael	Atkins	Denver	CO	No
275	Taylor	Ryan	Muller Engineering Company	Lakewood	CO	No
276	Thomas	Shea	UDFCD	Denver	CO	No
277	Thompson	Stacey	SEMSWA	Englewood	CO	Yes
278	Torrents	Xavier	JVA Inc	Boulder	CO	Yes
279	Tran	Hoanh	City of Aurora	Aurora	CO	Yes
280	Tran	Tony	RESPEC Consulting & Services	Denver	CO	Yes
281	Trieste	Douglas	Flow Technologies	Breckenridge	CO	No
282	Troester	Bryan	Petroleum Field Services	Denver	CO	Yes

No.	Last Name	First Name	Business Name	City	State	CFM
283	Trujillo	Molly	SEMSWA	Englewood	CO	Yes
284	Tucker	Scott	Scott Tucker	Golden	CO	No
285	Turner	Deb	City of Thornton	Thornton	CO	No
286	Twiss	Chad	Felsburg Holt & Ullevig	Centennial	CO	Yes
287	Uhernik	Bruce	City and County Of Denver	Denver	CO	No
288	Uhrich	Chance	Olsson Associates	Golden	CO	No
289	Unger	Monica	Peak Civil Consultants	Englewood	CO	Yes
290	Unger	Jeremiah	SEMSWA	Englewood	CO	No
291	Urbonas	Ben	Urban Watersheds Research Insitute	Denver	CO	No
292	Ursetta	Matthew	ICON Engineering Inc	Centennial	CO	No
293	Urso	Rachelle	City of Commerce City	Commerce City	CO	No
294	Van Dellen	David	Town of Castle Rock	Castle Rock	CO	Yes
295	Vieth	Andy	Design Concepts	Lafayette	CO	No
296	Vogt	Megan	S.A. Miro, Inc.	Denver	CO	No
297	Vondreele	Stephen	City of Denver, Dept. of Public Works	Denver	CO	No
298	Watt	James	Muller Engineering	Lakewood	CO	Yes
299	Webster	Dave	Boulder County Transportation Dept.	Boulder	CO	Yes
300	Weeks	Gregory	TST Inc of Denver	Lone Tree	CO	Yes
301	Wegener	Kevin	City of Aurora	Aurora	CO	No
302	Weiss	Chuck	WHPacific, Inc	Lakewood	CO	Yes
303	Welker	Michael	Petroleum Field Services	Denver	CO	Yes
304	Welp	Gary	RGA	Wheat Ridge	CO	Yes
305	West	Mark	Bohannan Huston, Inc.	Englewood	CO	No
306	Westberg	Mark	City of Wheat Ridge	Wheat Ridge	CO	Yes
307	Whalen	Jessica	City of Thornton	Thornton	CO	No
308	Wilgenbusch	Matt	Em Dub Design llc	Denver	CO	No
309	William	Brandy	El Paso County	Colorado Springs	CO	Yes
310	Williams	Joe	Urban Drainage and Flood Control District	Denver	CO	No
311	Williams	Tom	Town of Parker	Parker	CO	No
312	Williams	Matthew	Douglas County	Castle Rock	CO	Yes
313	Williams	Jeff	City and County of Denver	Denver	CO	No
314	Williams	Douglas	ICON Engineering Inc.	Centennial	CO	No
315	Winters	Jennifer	Brown and Caldwell	Golden	CO	No
316	Winzent	Bob	SEMSWA	Englewood	CO	No
317	Wong	Eliot	Wright Water Engineers	Denver	CO	Yes
318	Woods	Ann	City of Greenwood Village	Greenwood Village	CO	Yes
319	Worah	Moneka	ERO Resources	Denver	CO	No
320	Wright	Mikele	City of Westminster	Westminster	CO	No
321	Wulliman	Jim	Muller Engineering Company	Lakewood	CO	No
322	Yager	John	Muller Engineering Company	Littleton	CO	Yes
323	Yuan	Zhixu	City of Denver - Dept. of Public Works	Denver	CO	No
324	Zimmermann	Scott	Stanley Consultants	Centennial	CO	No
325	Zivkovich	Brik	UDFCD	Denver	CO	No
326	Zullali	Abdullah	Urban Drainage and Flood Control District	Thornton	CO	No