Bookmarks

CASFM 2010 PRESENTATIONS

Bookmarked Tracts:

1. Floodplain Management
2. H&H Modeling
3. Hydraulic Structures
4. Low Impact Development (LID)
5. Project Presentations
6. Stormwater Management and Water Quality
7. Watershed Management & Stream Restoration
8. Wednesday Sessions
9. Workshops

CASFM Presentation

Colorado's Flood Decision Support System

RIVERSIDE

Amy Volckens

Jay Day

AMEC

Graeme Aggett

CWCB

Carolyn Fritz

Chris Sturm

Colorado Water Conservation Board

Agency

To conserve, develop, protect and manage Colorado's water for present and future generations

Flood Section

To devise and formulate methods, means, and plans to prevent or mitigate human and infrastructure losses due to flooding, to educate the public about flood risk, and to protect the natural and beneficial functions of floodplains and watersheds.

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Objectives

- Provide a statewide clearinghouse of flood information
- Be useful to a varied audience
- Integrate state systems
- Provide dynamic information

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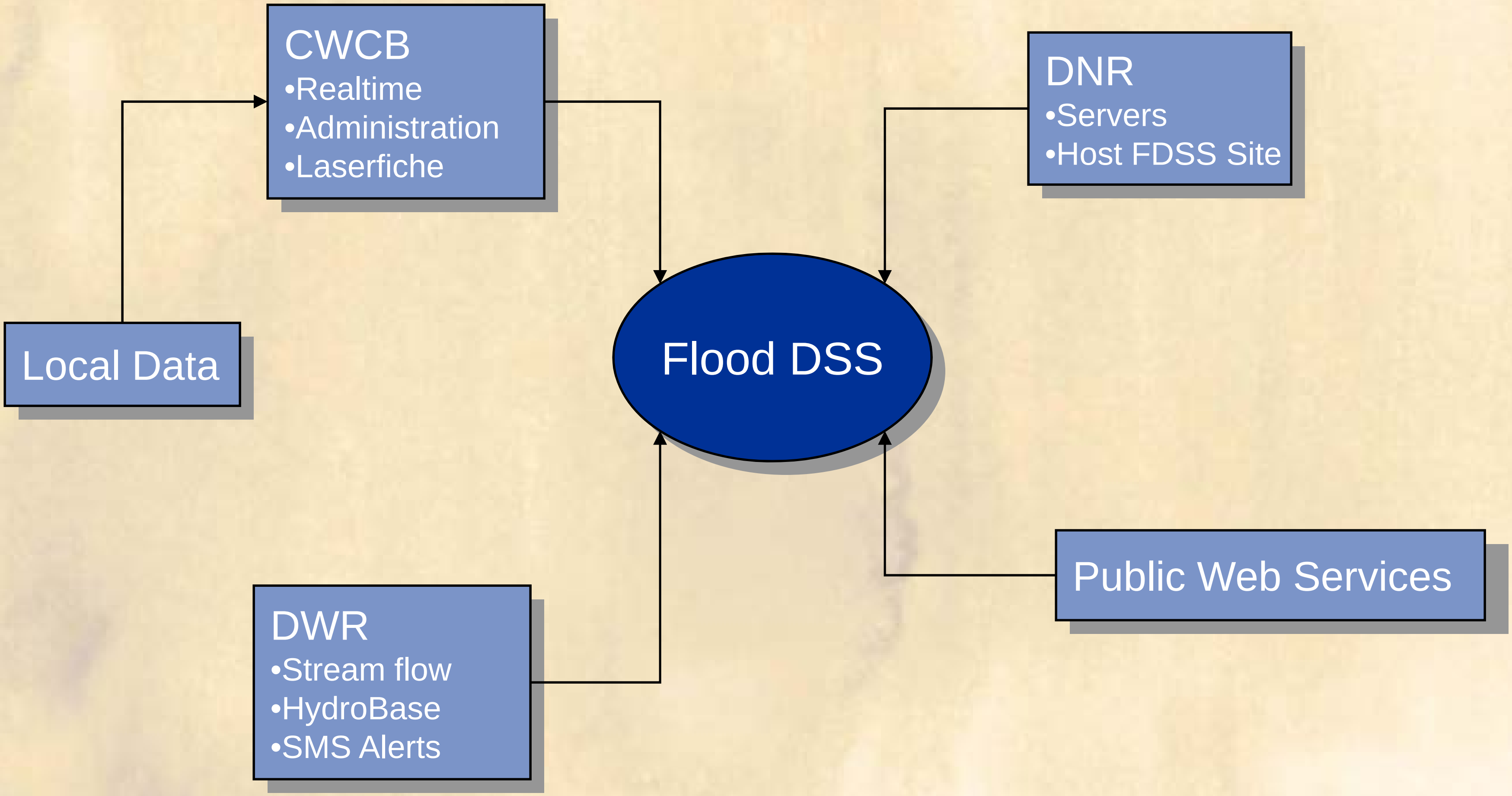
Colorado's Flood Decision Support System



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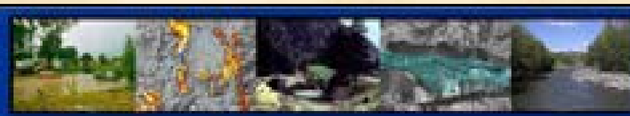
Colorado's Flood Decision Support System



Login

Home

Flood DSS Mapping Applications

The State of Colorado has developed the following interactive mapping applications to provide a statewide clearinghouse of flood-hazard and related information.

- Flood DSS Map Viewer
  - Review effective floodplain boundaries.
  - See real-time weather and streamflow conditions.
  - Access local and county data related to flooding.
  - Access data related to historical floods, hazards, weather modification, watershed restoration, and FEMA's National Flood Insurance Program.
- Weather Modification
  - Assess current snow conditions near weather modification locations.
- Watershed Restoration
  - Assess streamflow conditions near restoration project locations.

Latest NEXRAD Radar for Colorado

25 Minutes Ago

Additional Resources

System Requirements

At this time, the flood mapping applications support Internet Explorer 7 and Firefox 3.5 and higher. Most features are also available for other browsers. You may need to disable your pop-up blocker to view metadata or to print a formatted map.

Help

Please direct all questions or comments to the site administrator.

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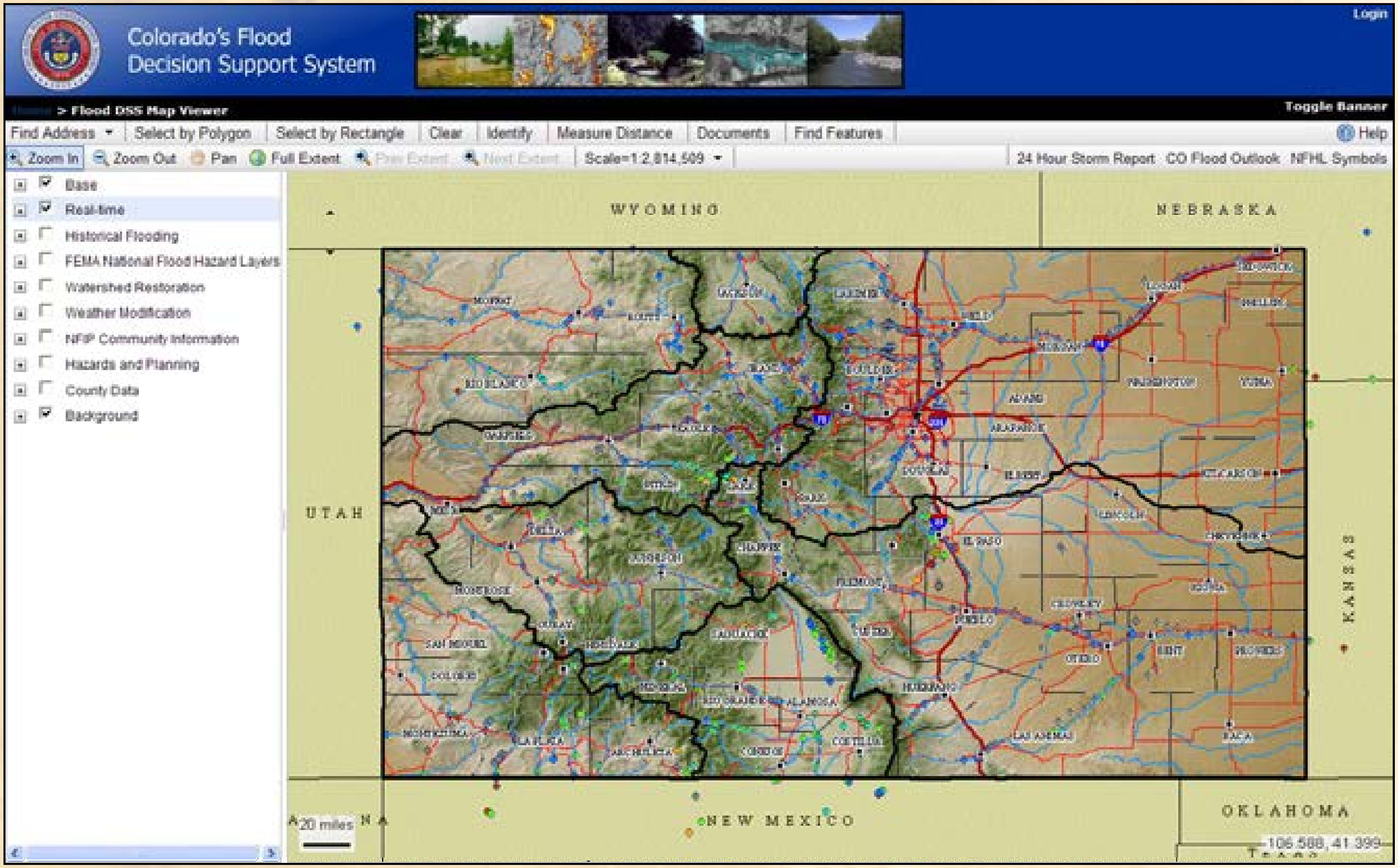

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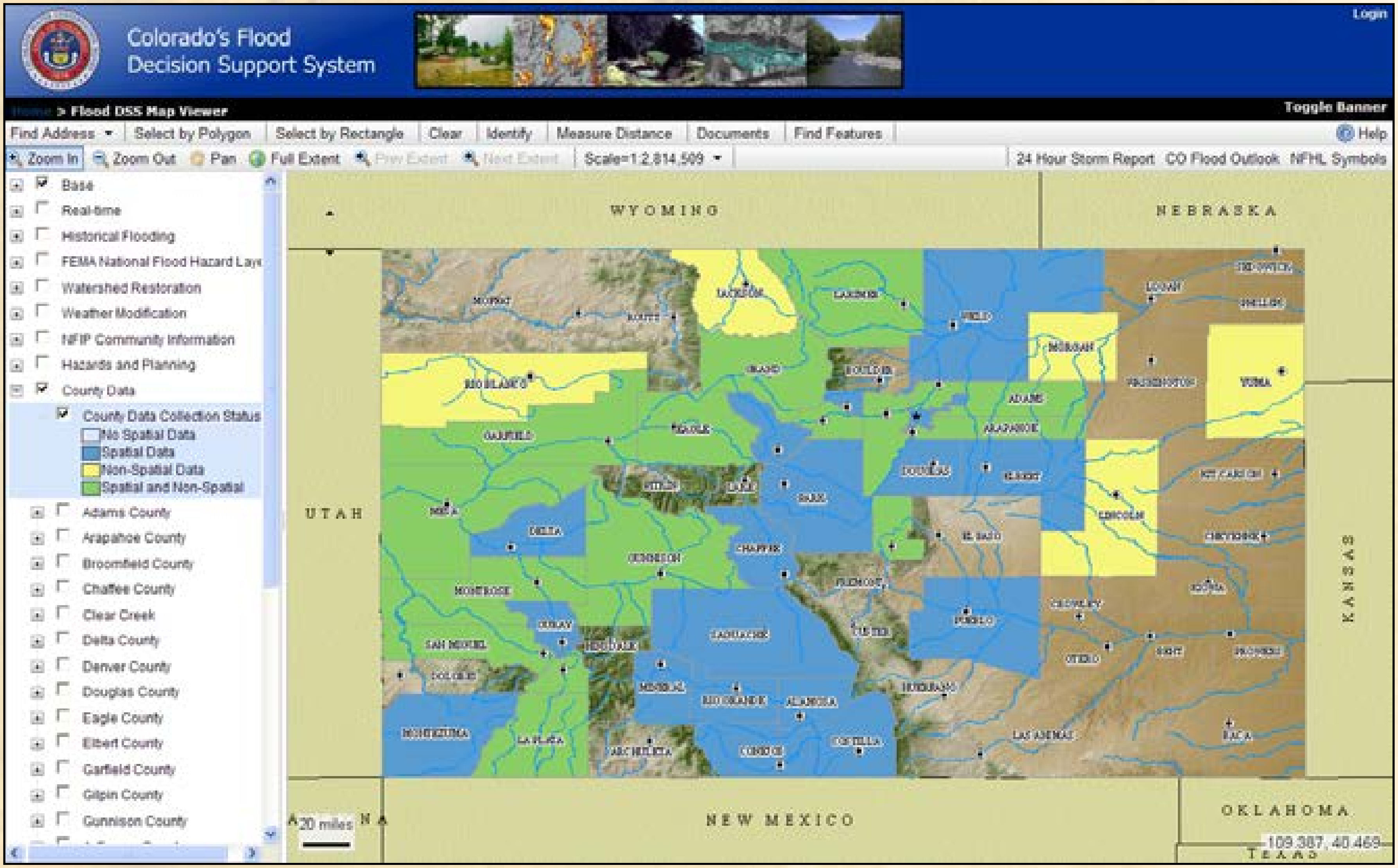

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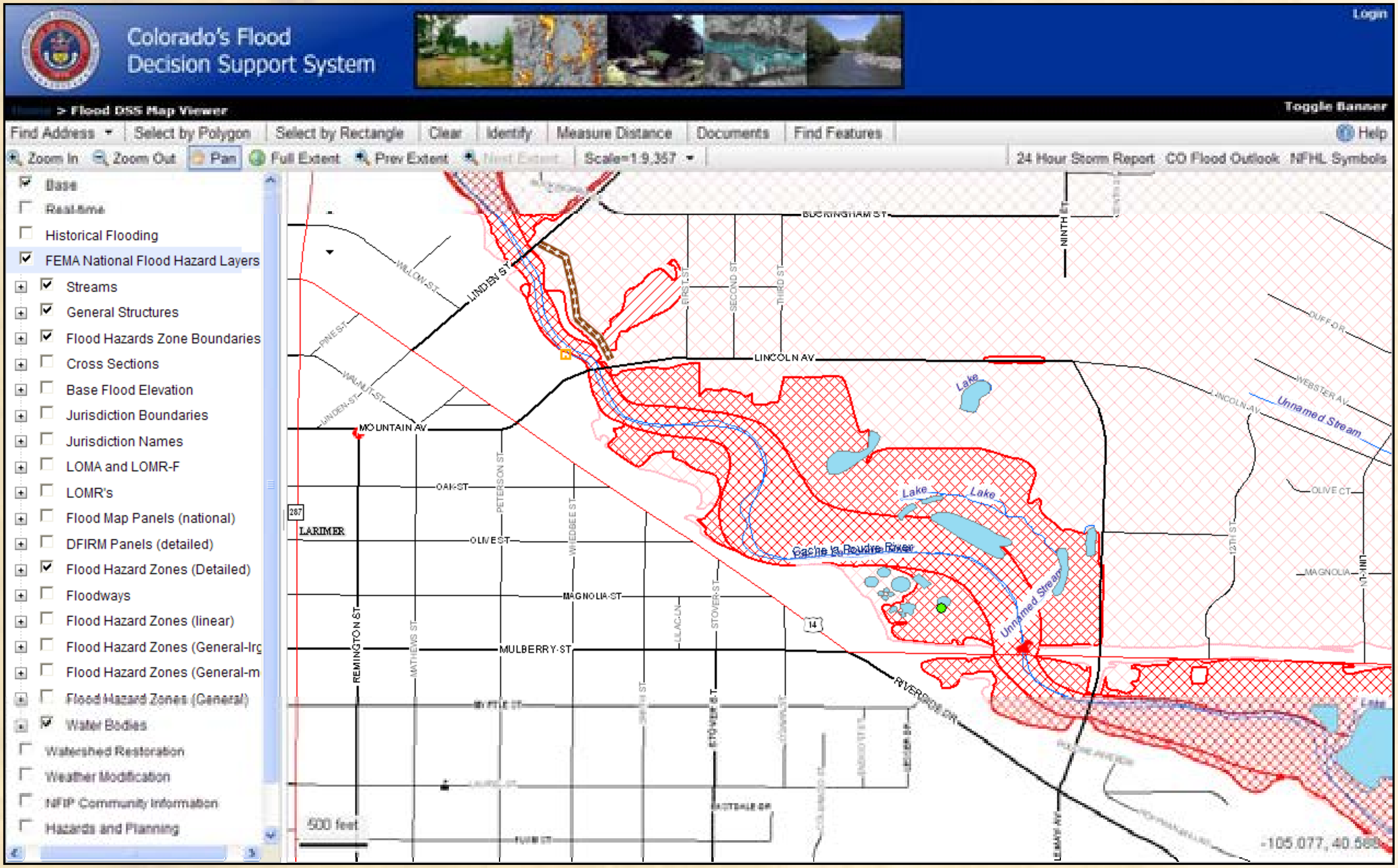

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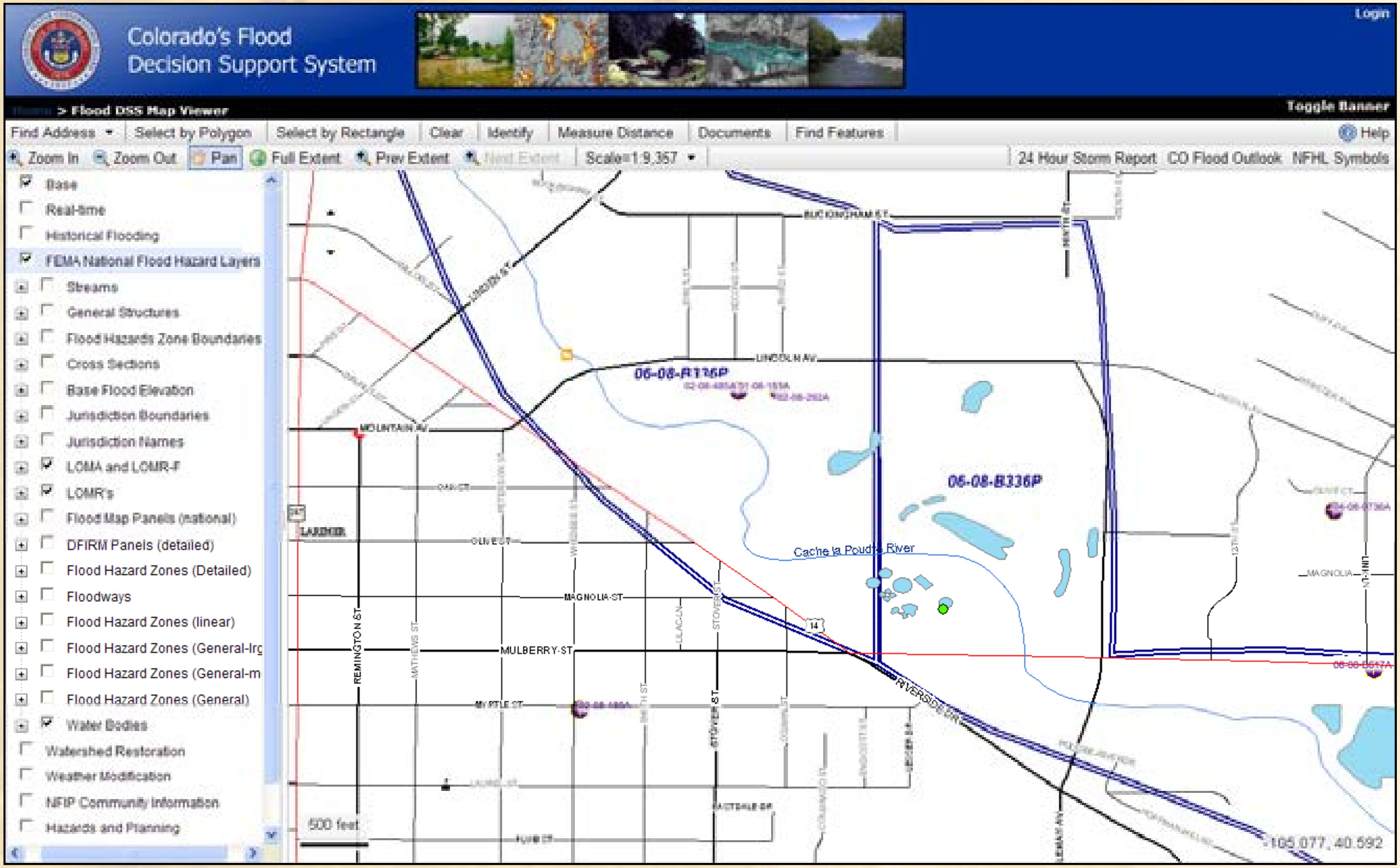

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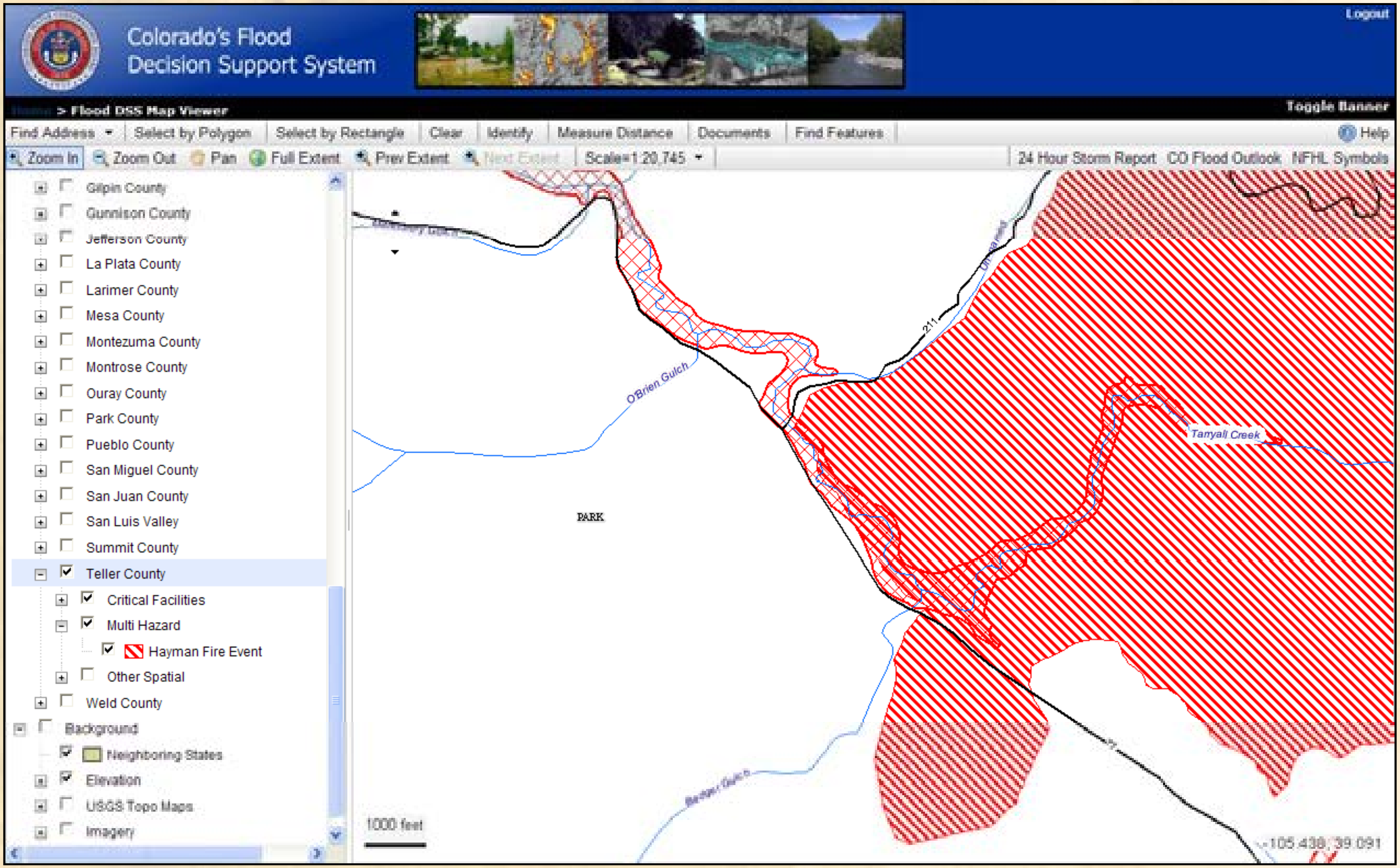
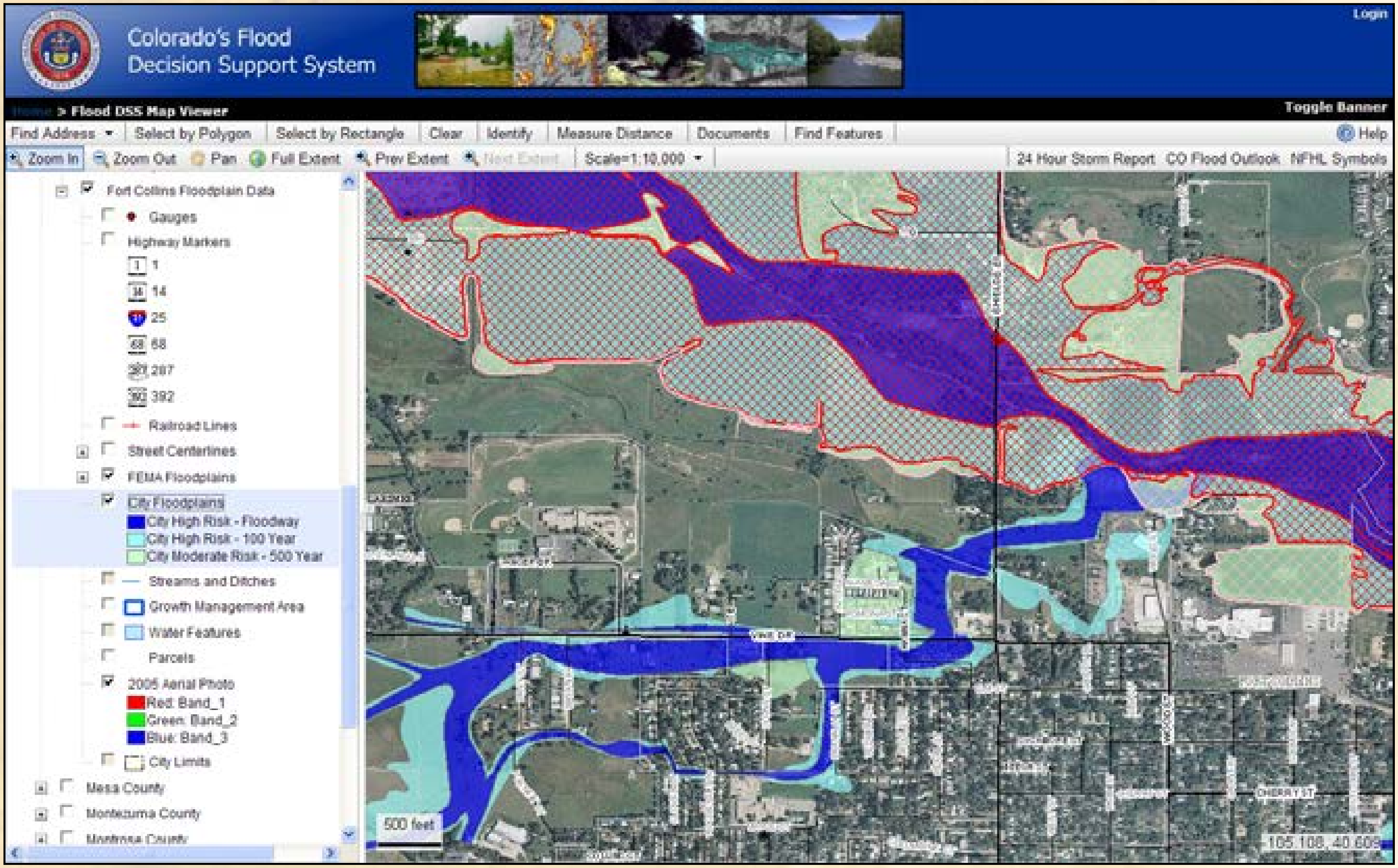

Colorado's Flood
Decision Support System
Logout
> Flood DSS Map Viewer
Toggle Banner
Find Address
Select by Polygon
Select by Rectangle
Clear
Identify
Measure Distance
Documents
Find Features
Help
Zoom In
Zoom Out
Pan
Full Extent
Prev Extent
Next Extent
Scale=1:20,745
24 Hour Storm Report
CO Flood Outlook
NFHL Symbols
Gilpin County
Gunnison County
Jefferson County
La Plata County
Larimer County
Mesa County
Montezuma County
Montrose County
Ouray County
Park County
Pueblo County
San Miguel County
San Juan County
San Luis Valley
Summit County
Teller County
Critical Facilities
Multi Hazard
Hayman Fire Event
Other Spatial
Weld County
Background
Neighboring States
Elevation
USGS Topo Maps
Imagery
O'Brien Gulch
Tanyall Creek
PARK
211
1000 feet
-105.438, 39.091



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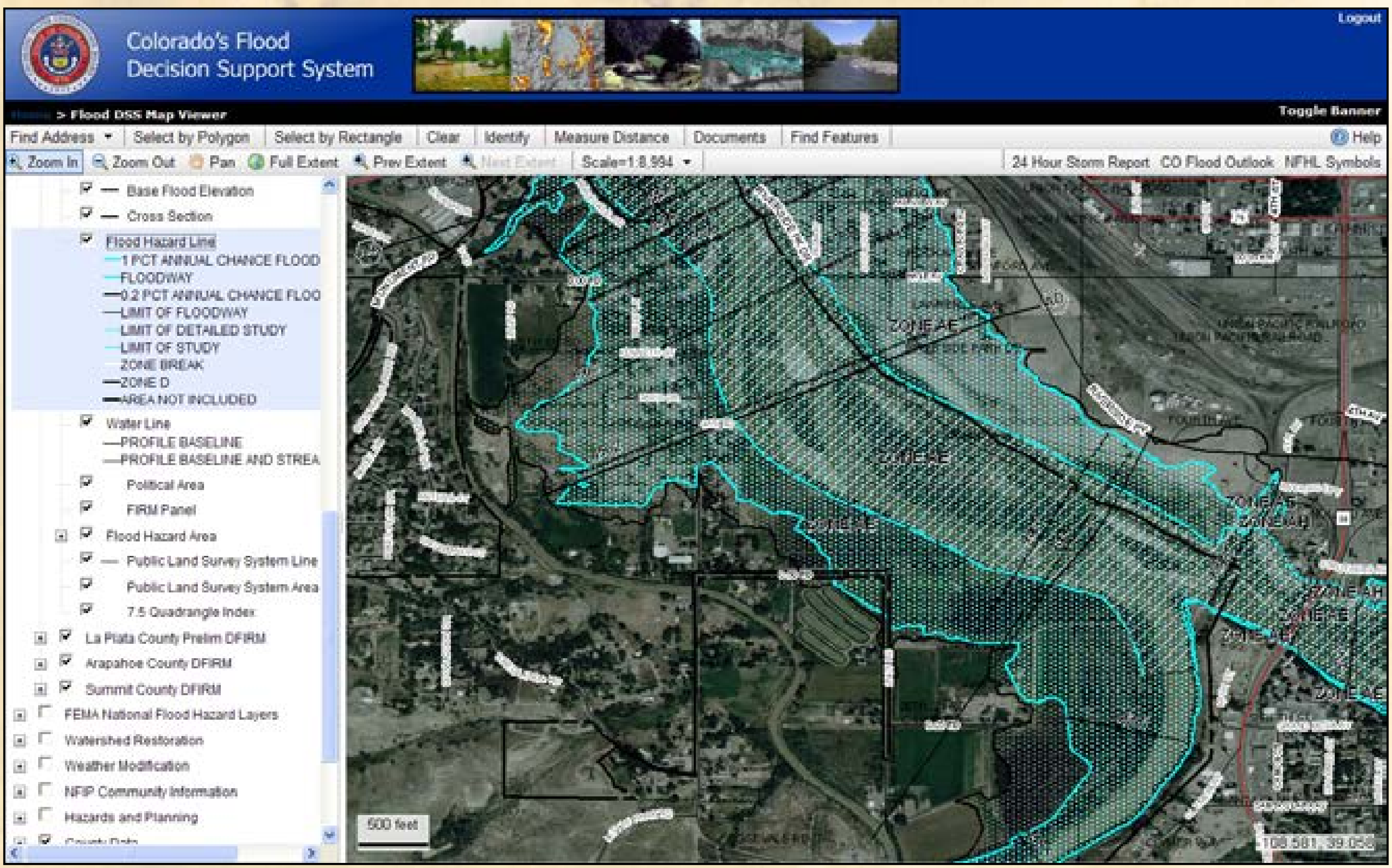

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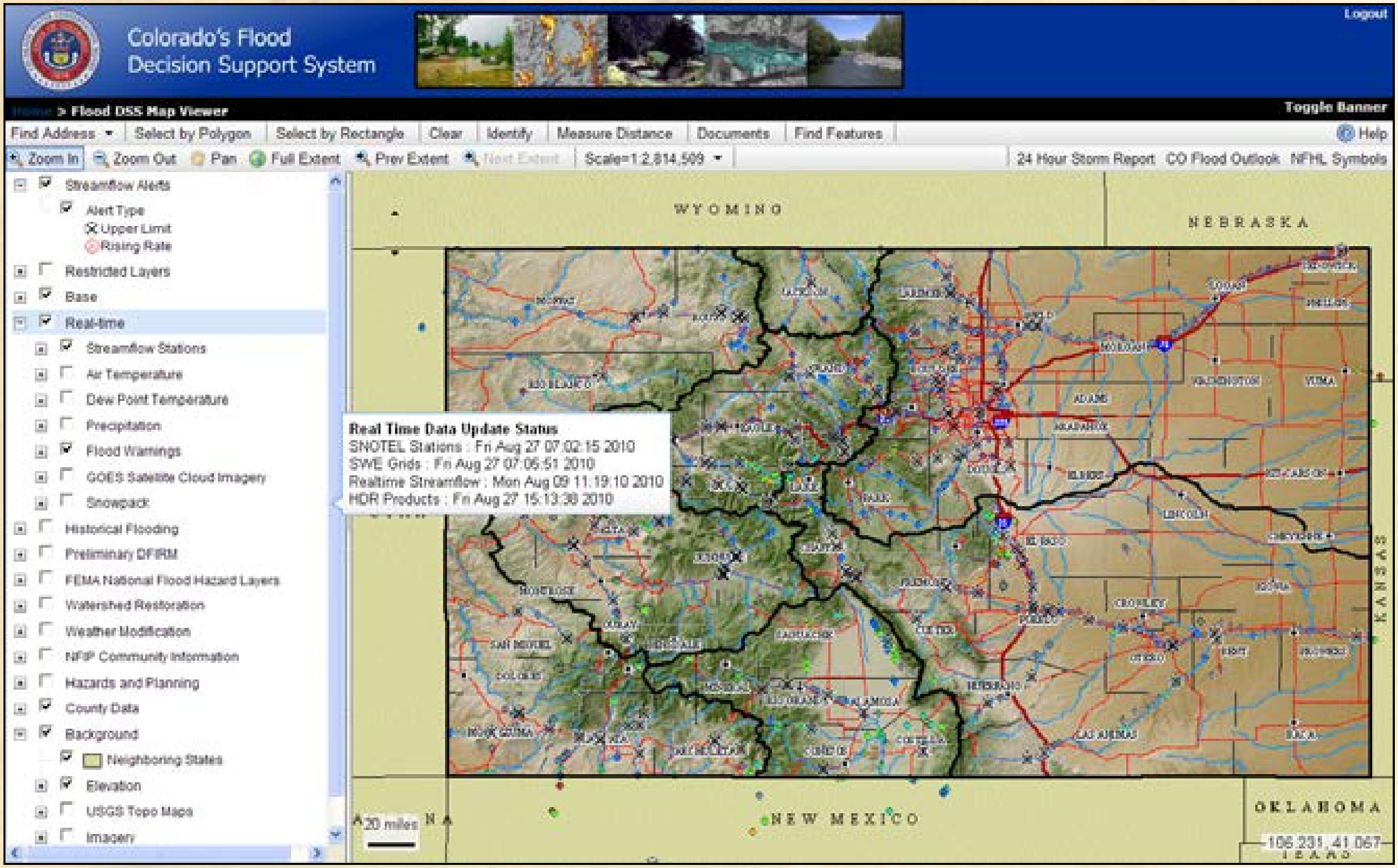

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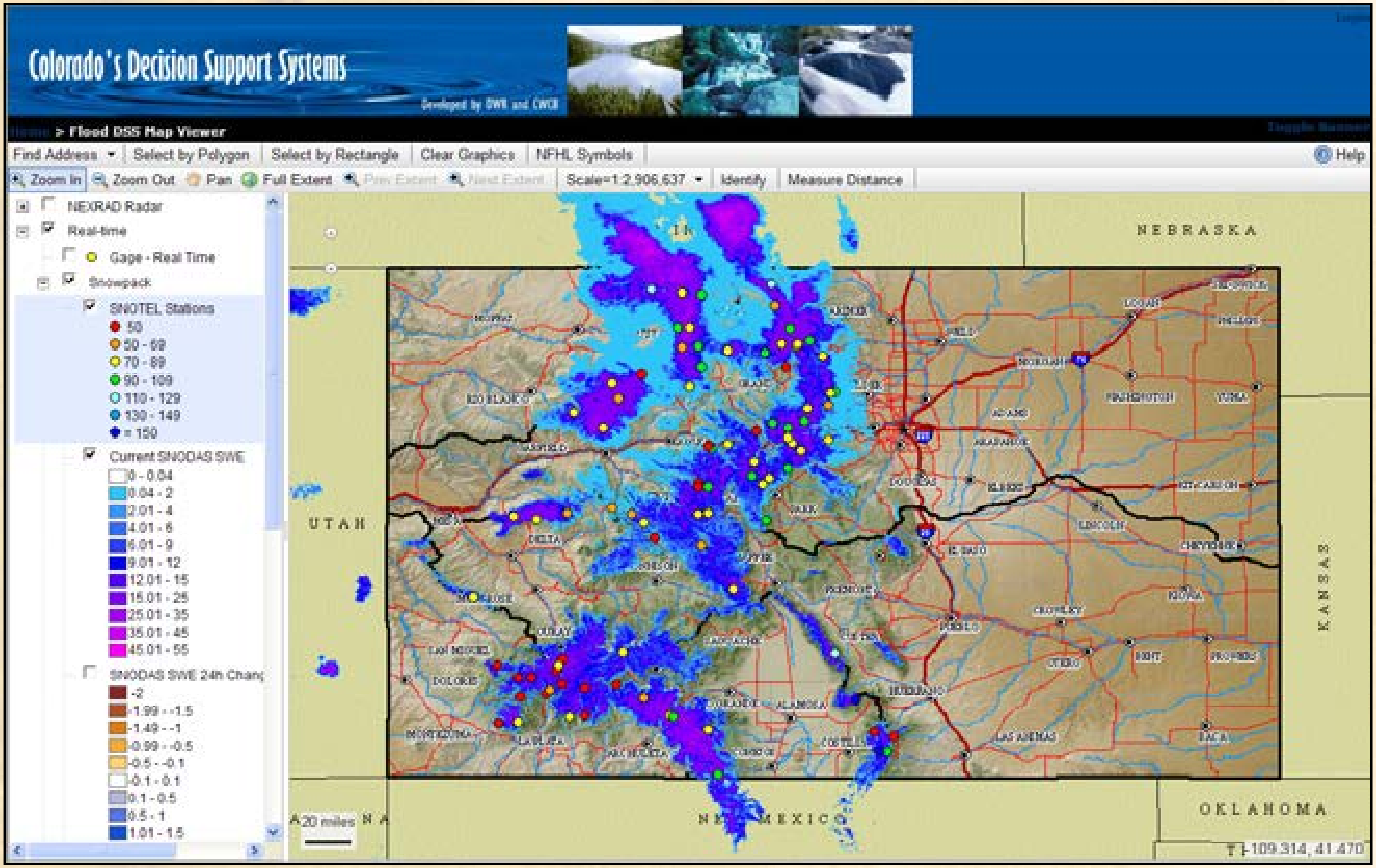

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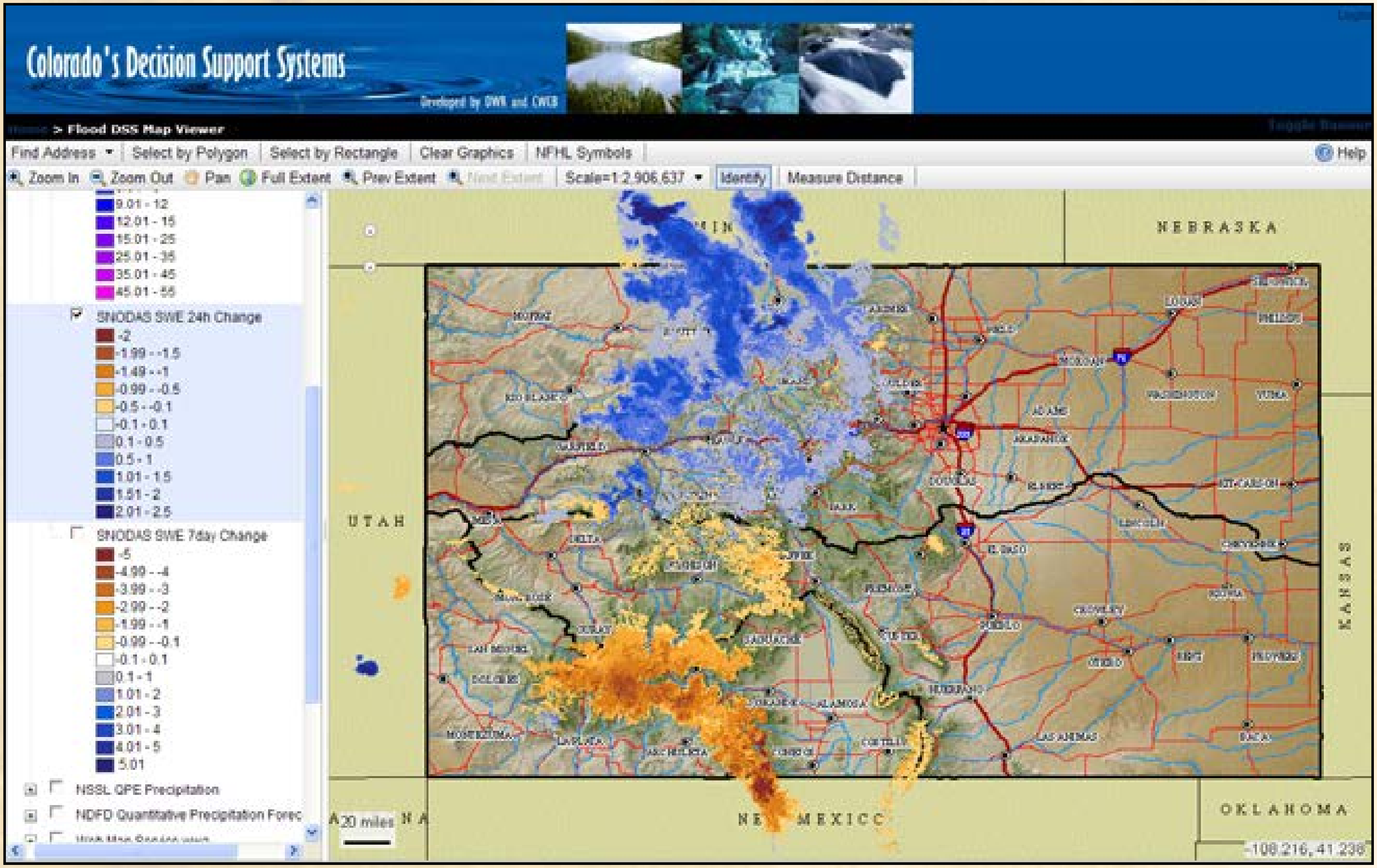

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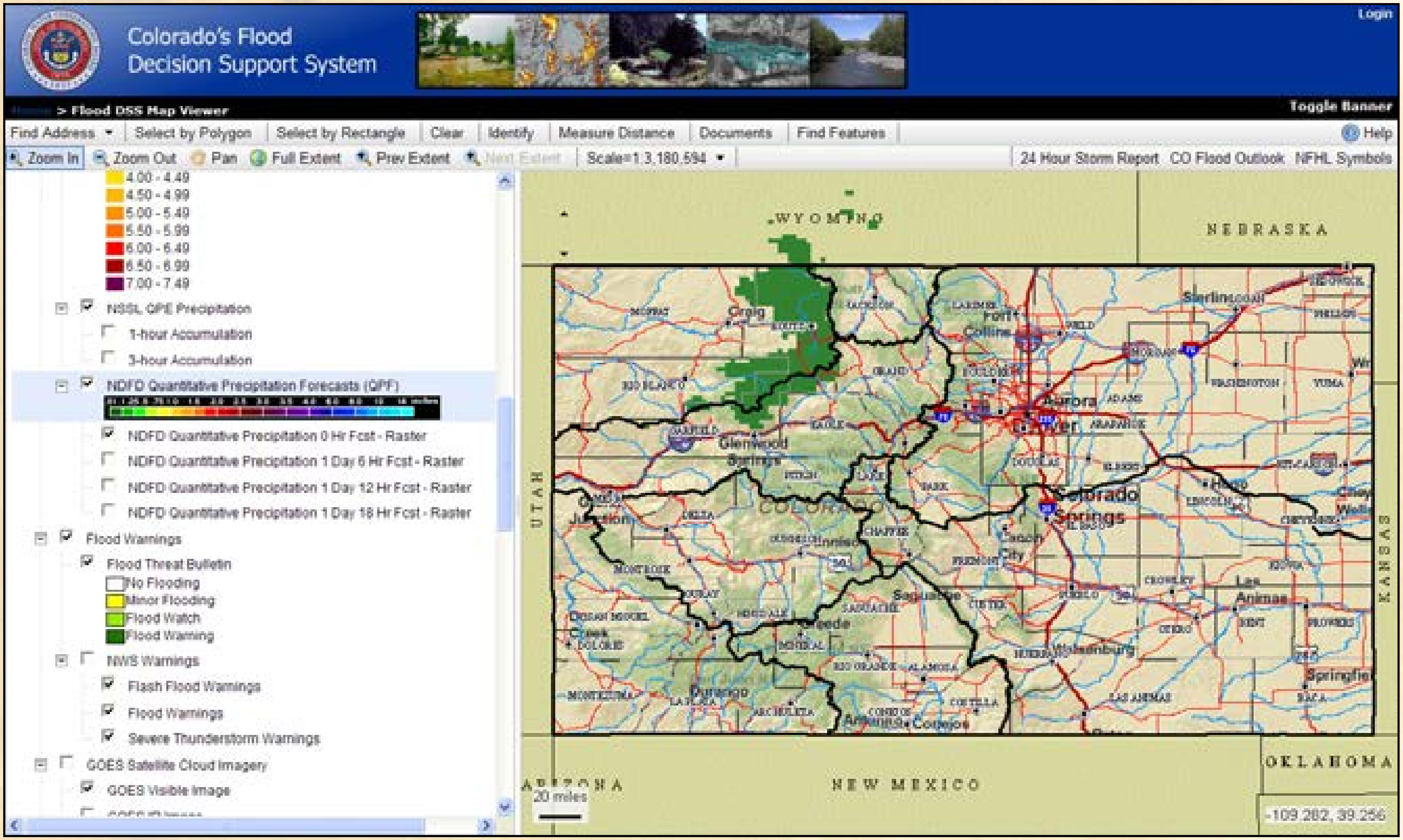
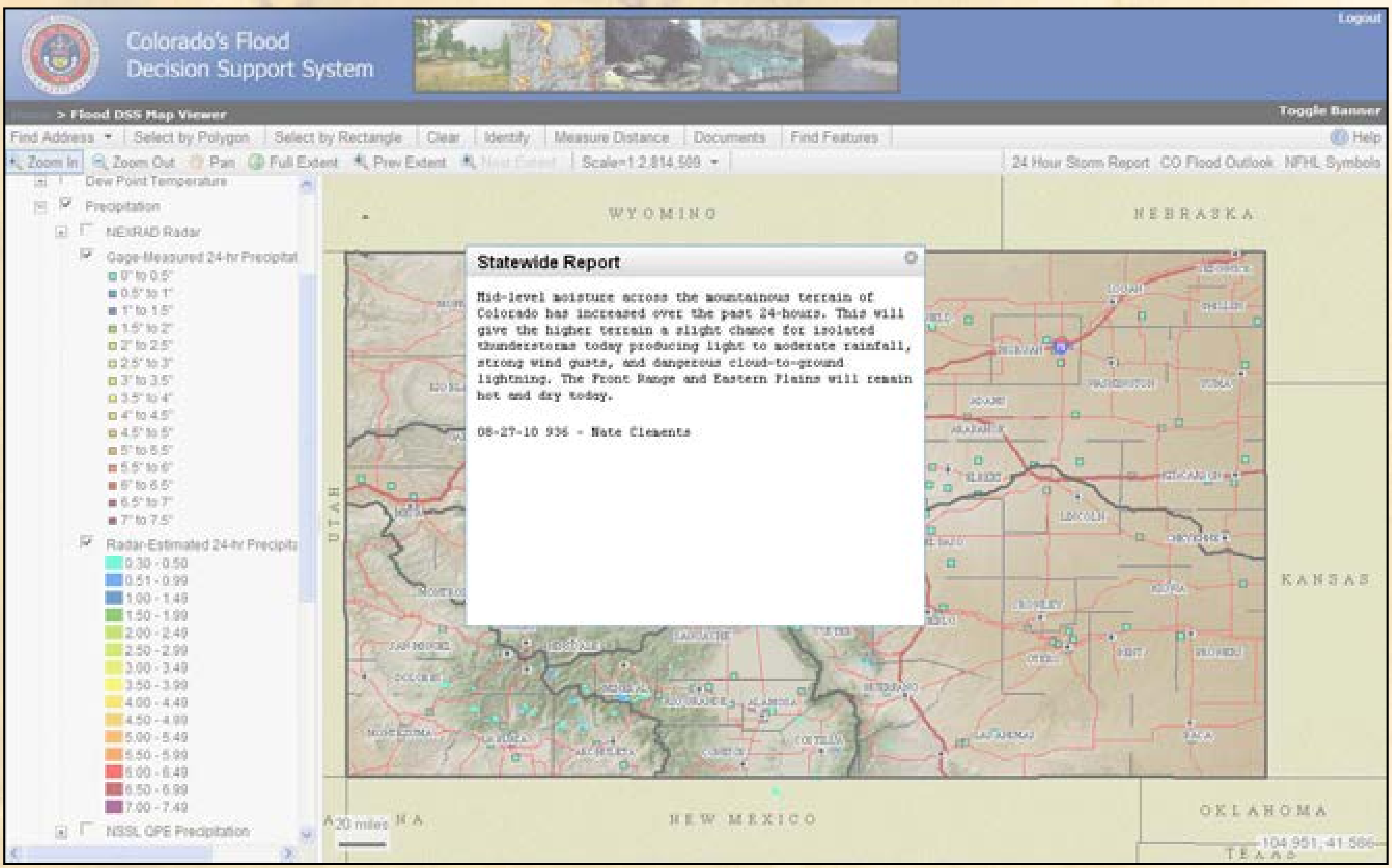


Colorado's Flood Decision Support System
Login
> Flood DSS Map Viewer
Toggle Banner
Find Address
Select by Polygon
Select by Rectangle
Clear
Identify
Measure Distance
Documents
Find Features
Help
Zoom In
Zoom Out
Pan
Full Extent
Prev Extent
Next Extent
Scale=1:3,180,594
24 Hour Storm Report
CO Flood Outlook
NFHL Symbols
4.00 - 4.49
4.50 - 4.99
5.00 - 5.49
5.50 - 5.99
6.00 - 6.49
6.50 - 6.99
7.00 - 7.49
NSSL QPE Precipitation
1-hour Accumulation
3-hour Accumulation
NDFD Quantitative Precipitation Forecasts (QPF)
NDFD Quantitative Precipitation 0 Hr Fcst - Raster
NDFD Quantitative Precipitation 1 Day 6 Hr Fcst - Raster
NDFD Quantitative Precipitation 1 Day 12 Hr Fcst - Raster
NDFD Quantitative Precipitation 1 Day 18 Hr Fcst - Raster
Flood Warnings
Flood Threat Bulletin
No Flooding
Minor Flooding
Flood Watch
Flood Warning
NWS Warnings
Flash Flood Warnings
Flood Warnings
Severe Thunderstorm Warnings
GOES Satellite Cloud Imagery
GOES Visible Image
WYOMING
NEBRASKA
UTAH
KANSAS
OKLAHOMA
NEW MEXICO
20 miles
-109.282, 39.256



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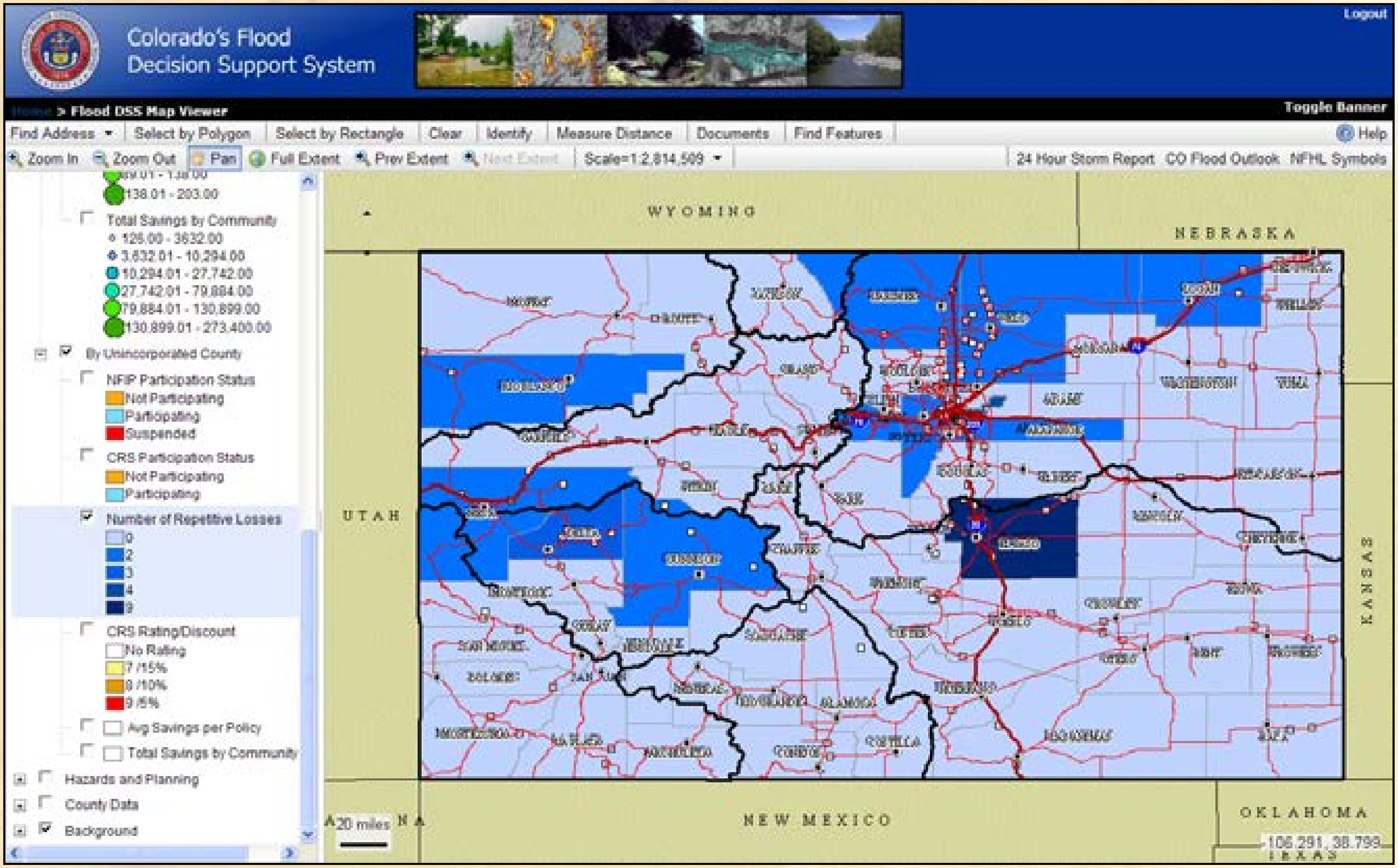

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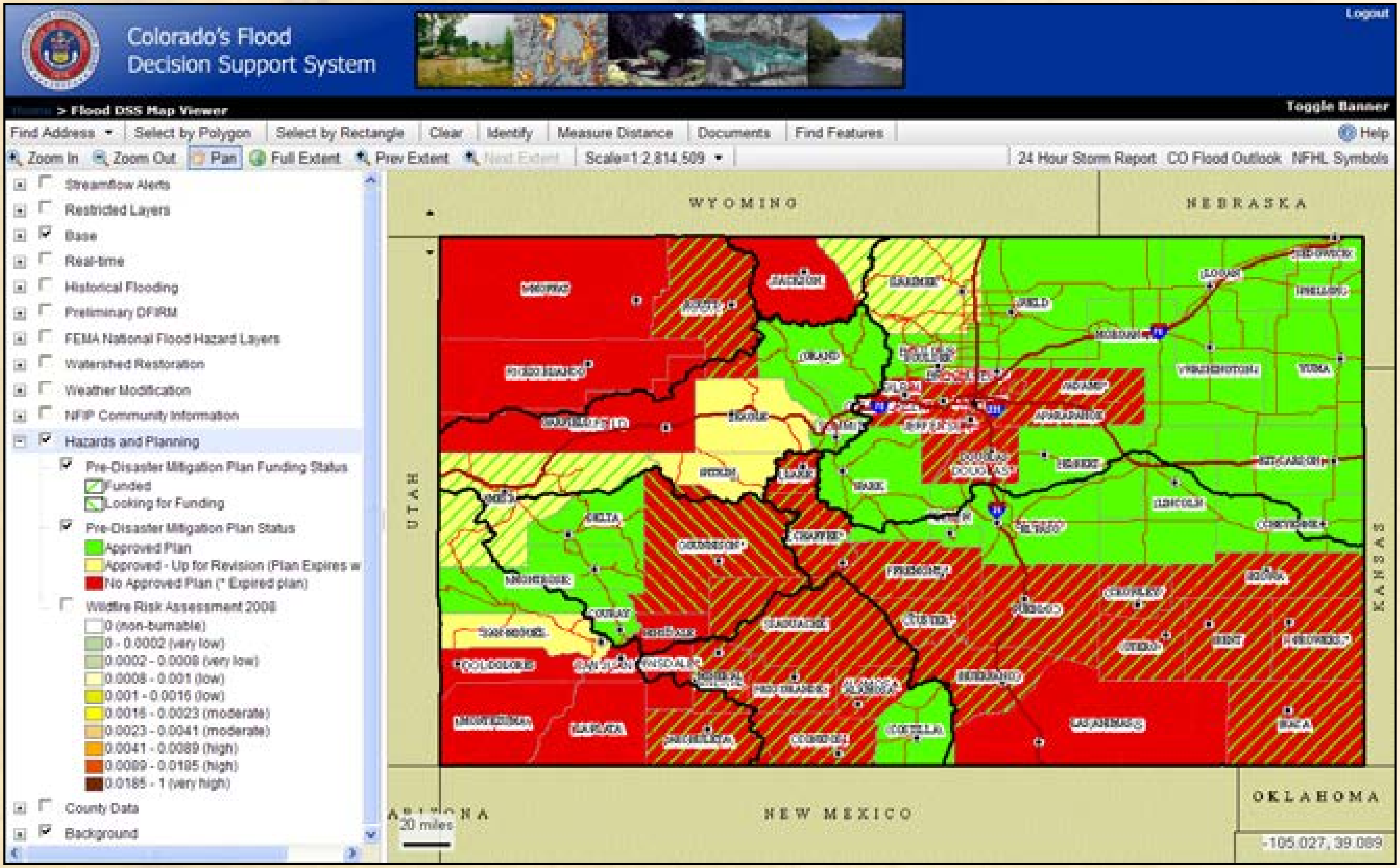

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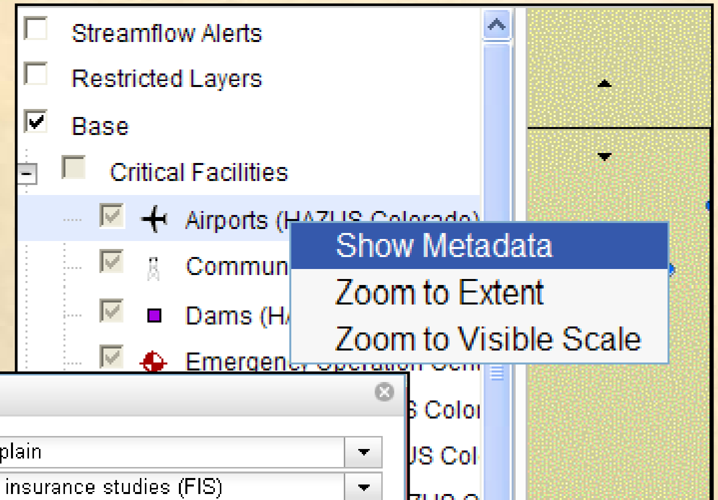
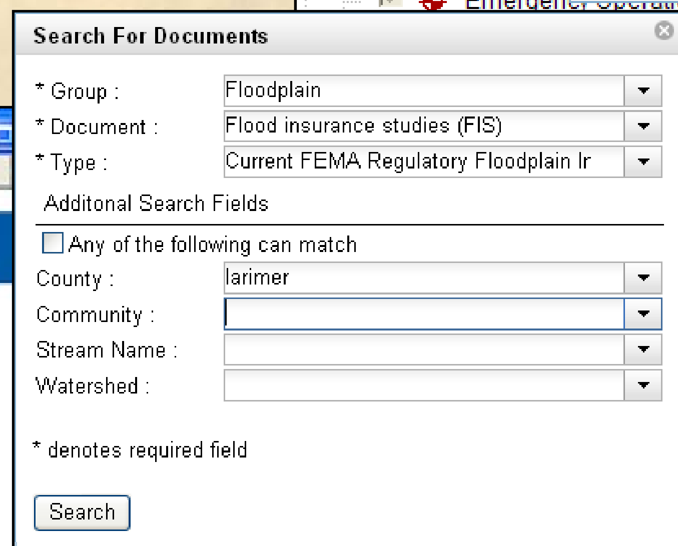
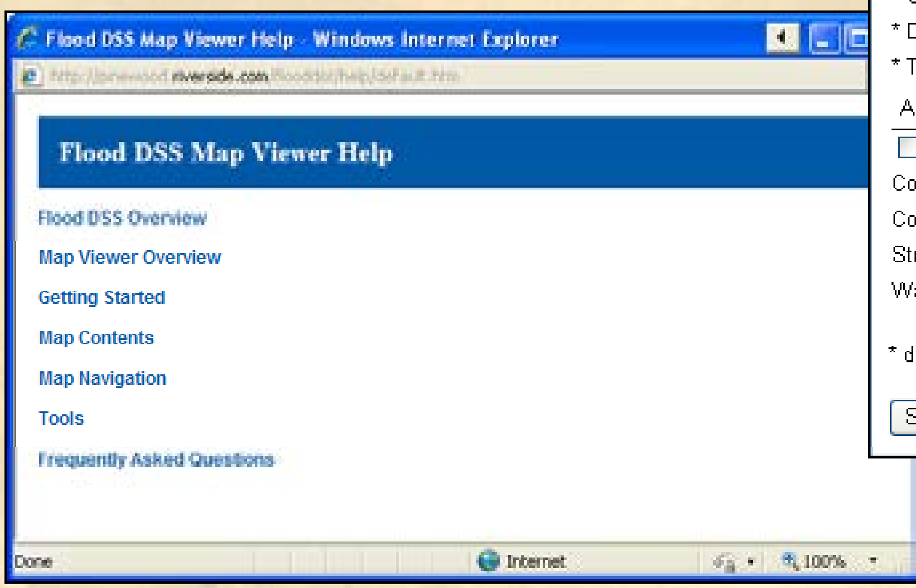
Additional Functionality

- Laserfiche
- Address search
- Quick search
- Metadata
- Help







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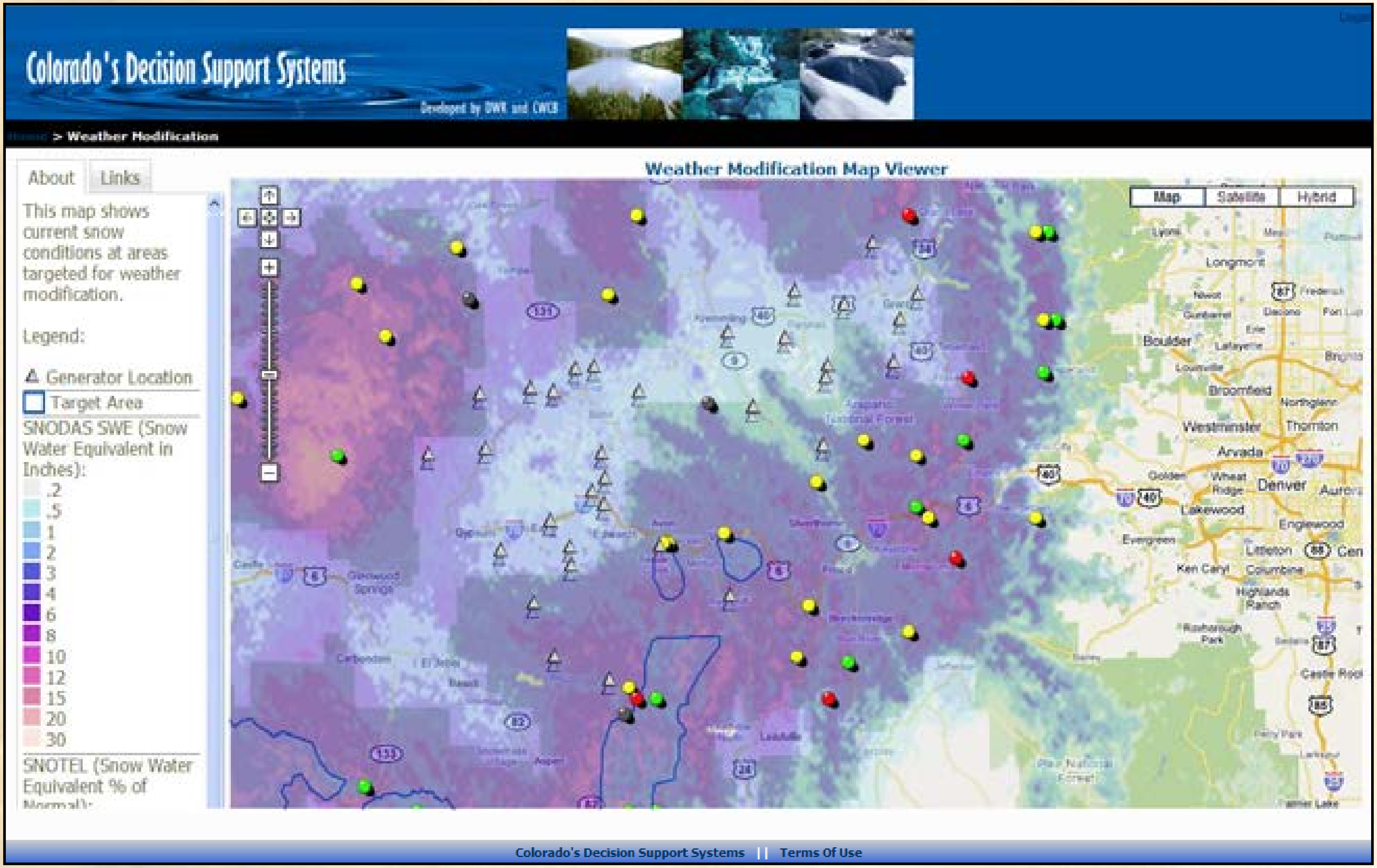

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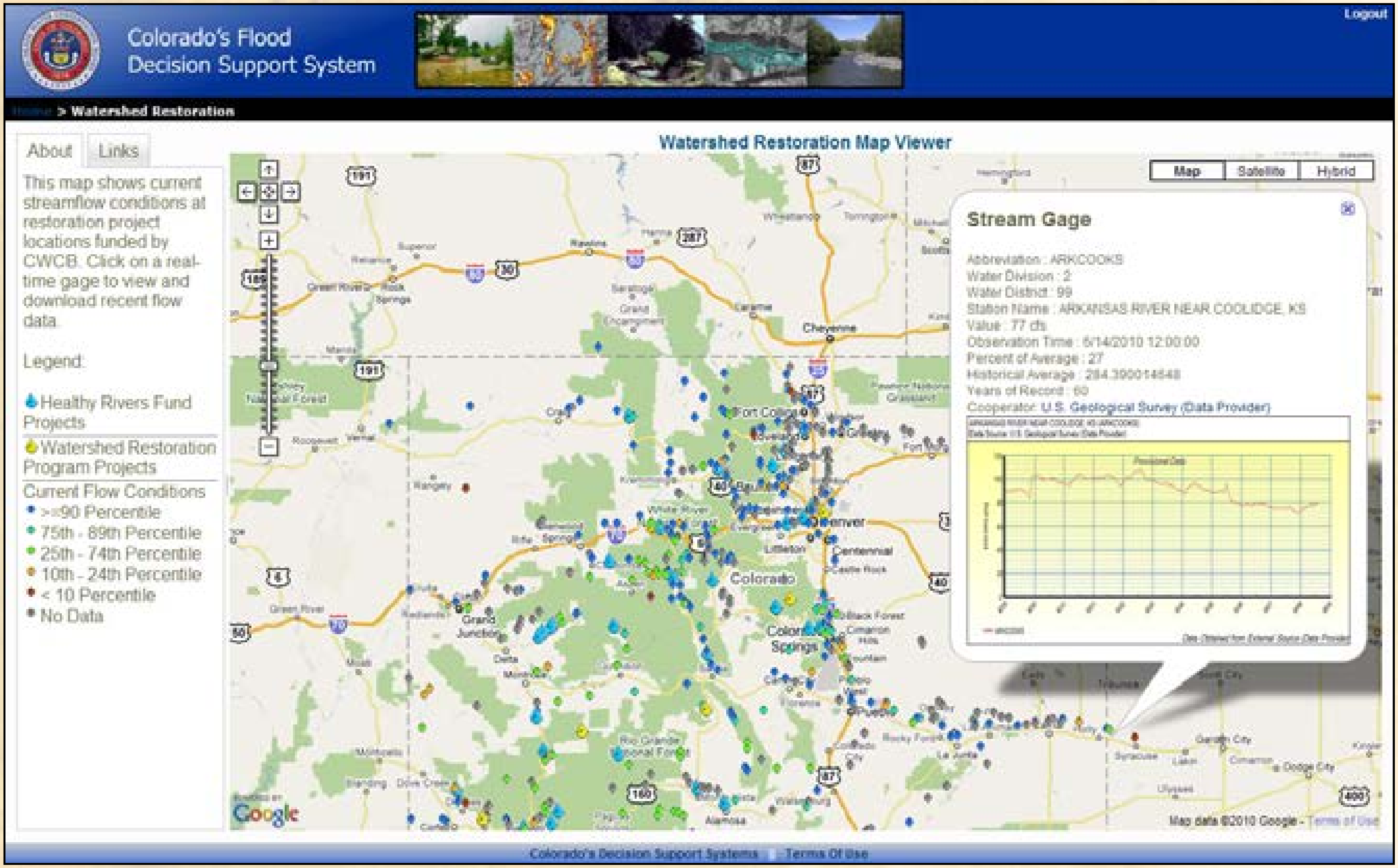

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Project Status and Plans

http://flooddss.state.co.us/

- Visit CWCB's booth!
- What next?
  – Statewide historical flood layer
  – Print functionality
  – Identify functionality for web services
  – Continue to identify use cases

Acknowledgements

For providing data and/or participating in the user needs assessment, we would like to thank:

- HDR
- CO Division of Water Resources
- CO Division of Emergency Management
- 5-2-1 Drainage Authority
- Anderson Consulting Engineers
- Colorado River Water Conservation District
- Dewberry
- FEMA Region 8
- NOAA National Severe Storms Laboratory
- NOAA National Operational Hydrologic Remote Sensing Center
- NRCS
- Pikes Peak Regional Building Department
- San Luis Valley GIS/GPS Authority
- Urban Drainage and Flood Control District
- Cities of Boulder, Fort Collins, Colorado Springs
- Counties of Adams, Arapahoe, Broomfield, Chaffee, Clear Creek, Delta, Denver, Douglas, Eagle, Elbert, Garfield, Grand, Gulpin, Gunnison, Jefferson, La Plata, Larimer, Mesa, Montezuma, Montrose, Ouray, Park, Pueblo, San Miguel, Summit, Teller, Weld

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More information?

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Thank you!

FEMA

Risk MAP Products & Datasets Overview

September 2010

Overall objective: *To provide participants with a functional understanding of what flood risk products and datasets will be developed and delivered in support of Risk MAP's vision and goals.*

RiskMAP
Increasing Resilience Together

BakerAECOM
An Integrated Production Team

Agenda

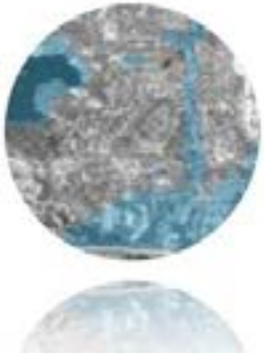
Overview of what will be covered

- **Map Mod to Risk MAP**
- **Overview of Datasets**
  - Changes Since Last FIRM
  - Flood Depth & Analysis Grids
  - Flood Risk Assessment Data
  - Areas of Mitigation Interest (enhanced)
- **Overview of Products**
  - Flood Risk Database
  - Flood Risk Report
  - Flood Risk Map
- **Flood Risk Assessment Process Overview**
- **Flood Risk Products – Project Lifecycle Overview**

The Paradigm Shift: Map Mod to Risk MAP

- Map Modernization used increasingly-available technology to increase the quality, reliability, and availability of flood hazard maps and data
- It focused on digitizing maps to provide timely, accurate information to community planners

Risk MAP further enhances the maps, involves communities during the assessment and planning stages, and guides and encourages them to communicate risk to their constituents

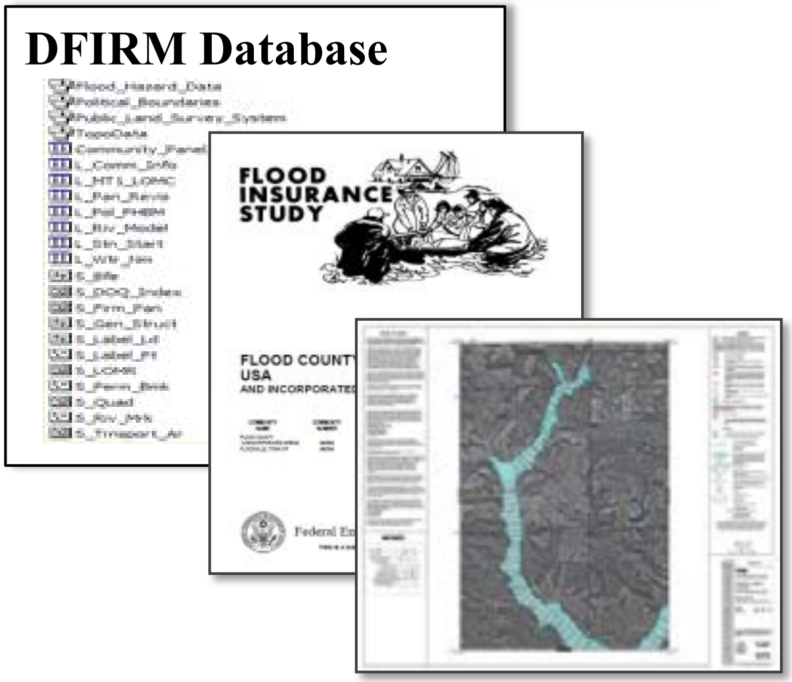


Risk MAP

Through collaboration with State, Local, and Tribal entities, Risk MAP will deliver quality data that increases public awareness and leads to action that reduces risk to life and property.

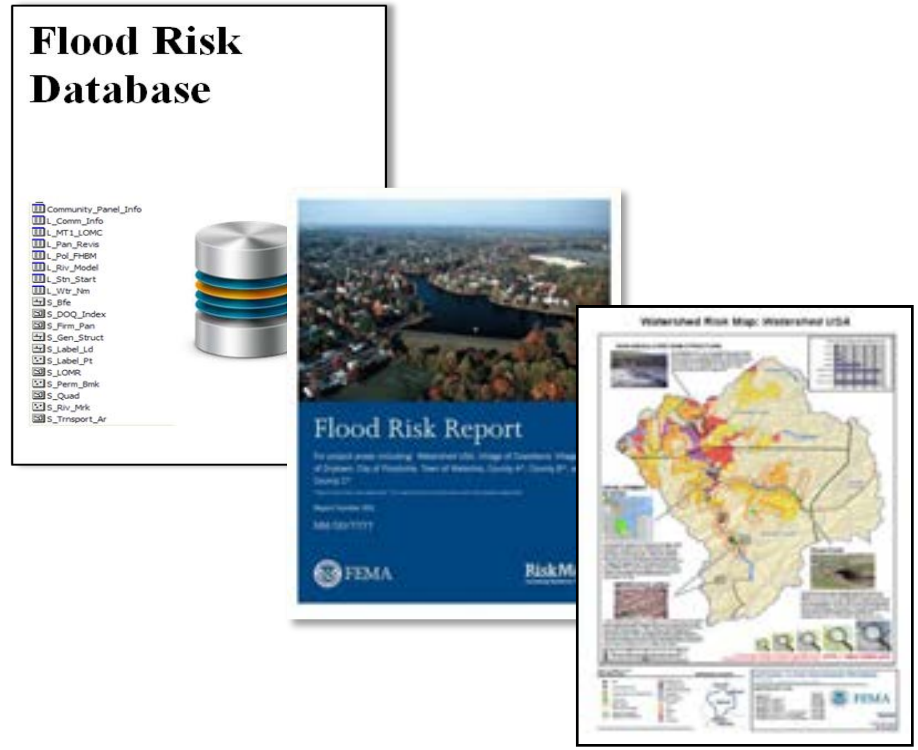
Program Product Comparisons

Traditional Regulatory Products



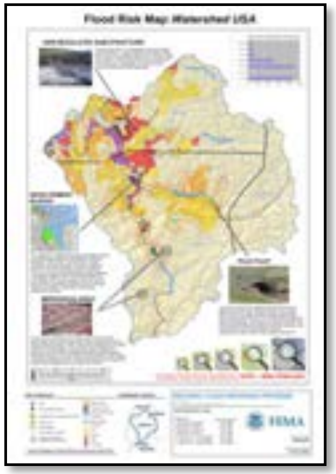
Traditional products are regulatory and subject to statutory due-process requirements

Non-Regulatory Products



Risk MAP products are non-regulatory and are not subject to statutory due-process requirements

Flood Risk Products and Data Model

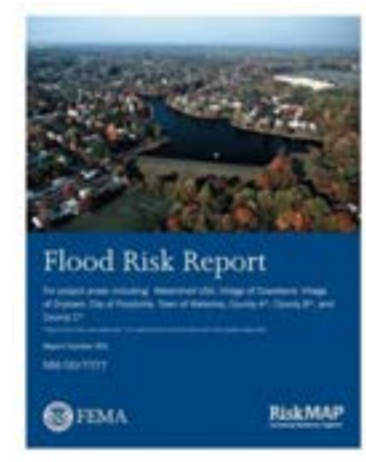


Flood Risk Map

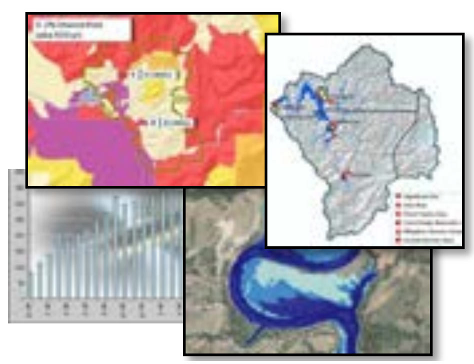
Flood Risk Database

Flood Risk Assessment Data
Flood Depth & Analysis Grids

Changes Since Last FIRM Data
Areas of Mitigation Interest



Flood Risk Report



Ad-Hoc Flood Risk Analyses

Flood Risk Datasets

- Changes Since Last FIRM
- Flood Depth & Analysis Grids
- Flood Risk Data
- Areas of Mitigation Interest

RiskMAP
Increasing Resilience Together

BakerAECOM
An Integrated Production Team

FEMA

Changes Since Last FIRM Dataset

RiskMAP
Increasing Resilience Together

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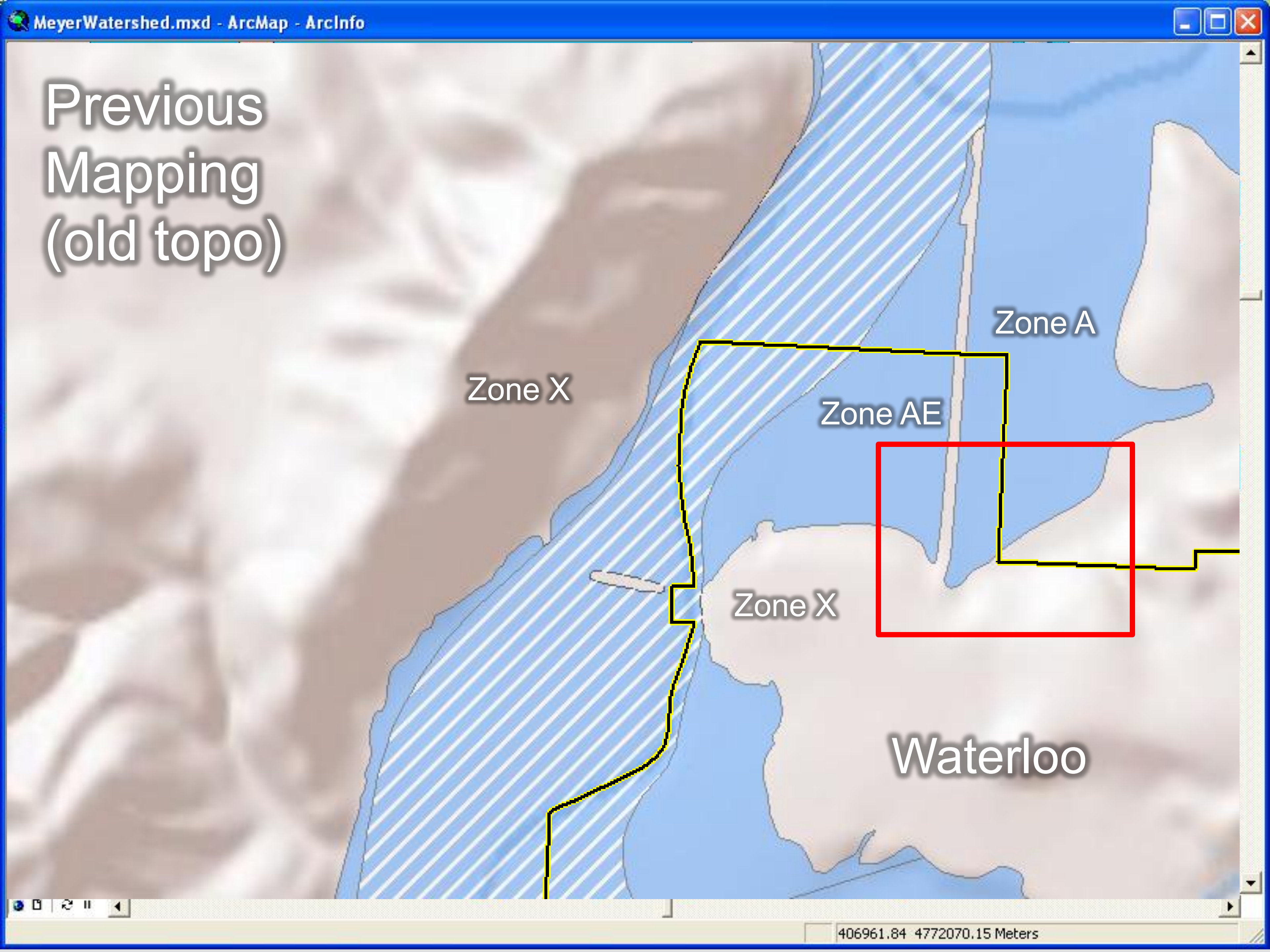
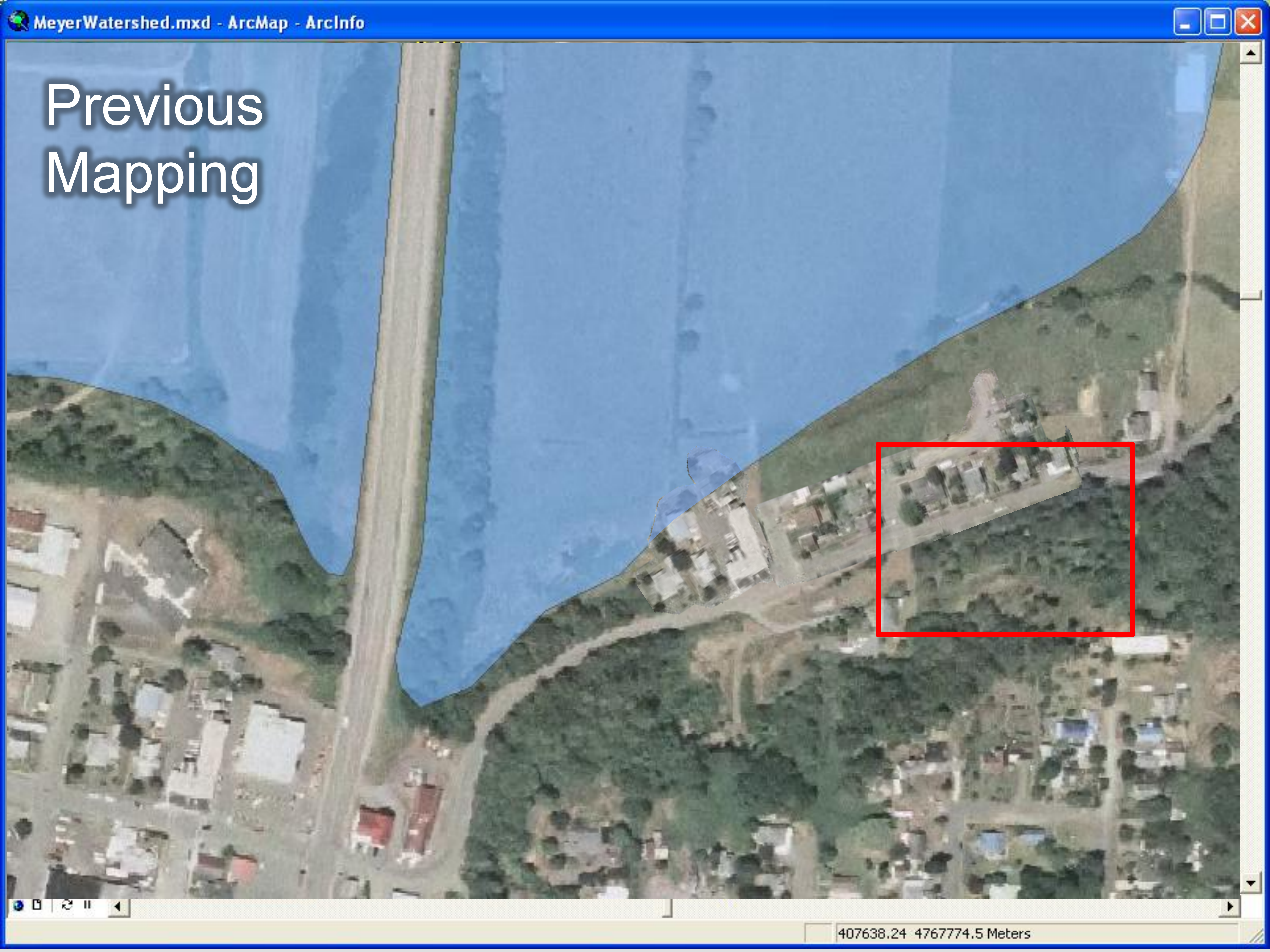
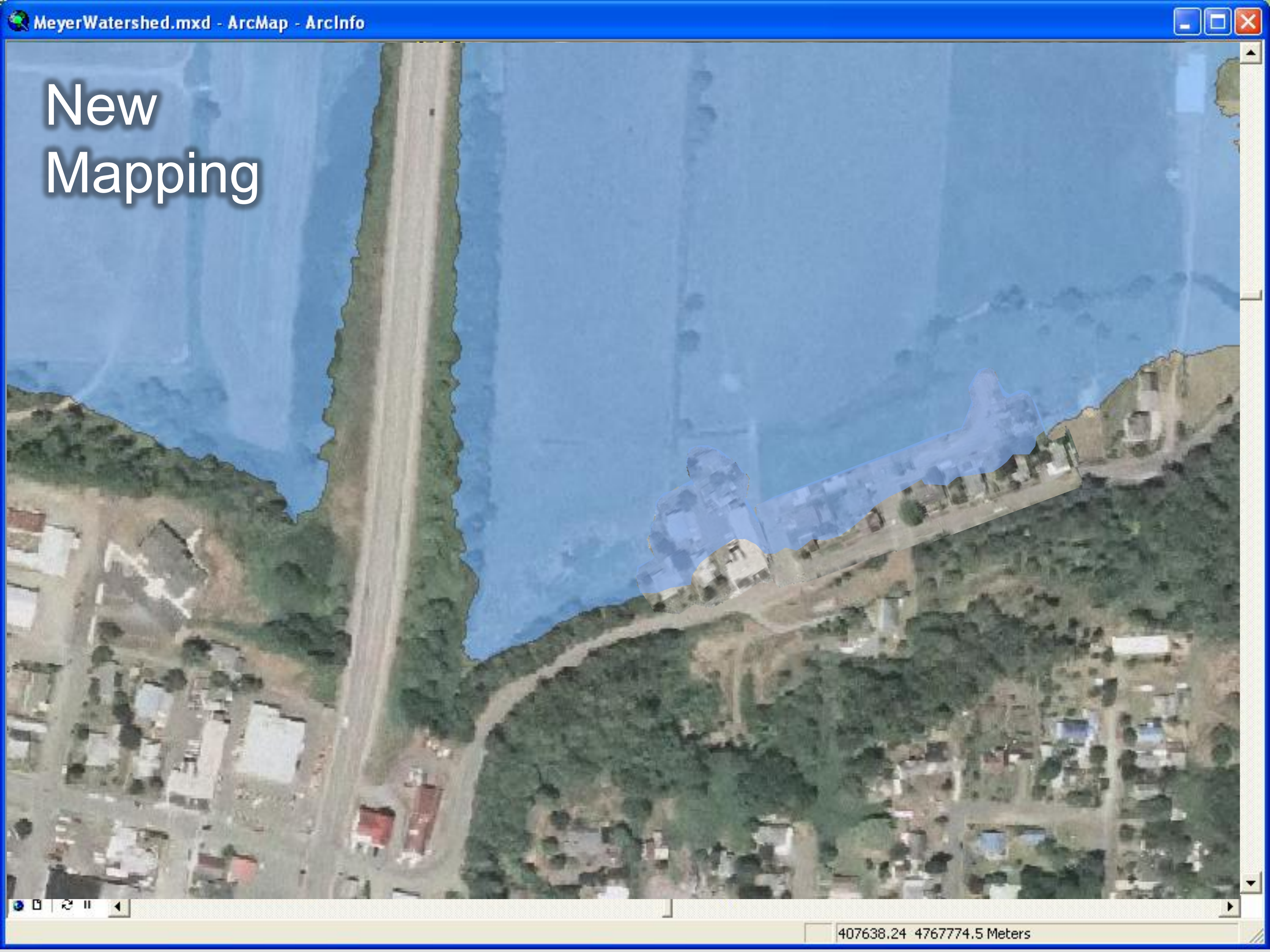
An Integrated Production Team

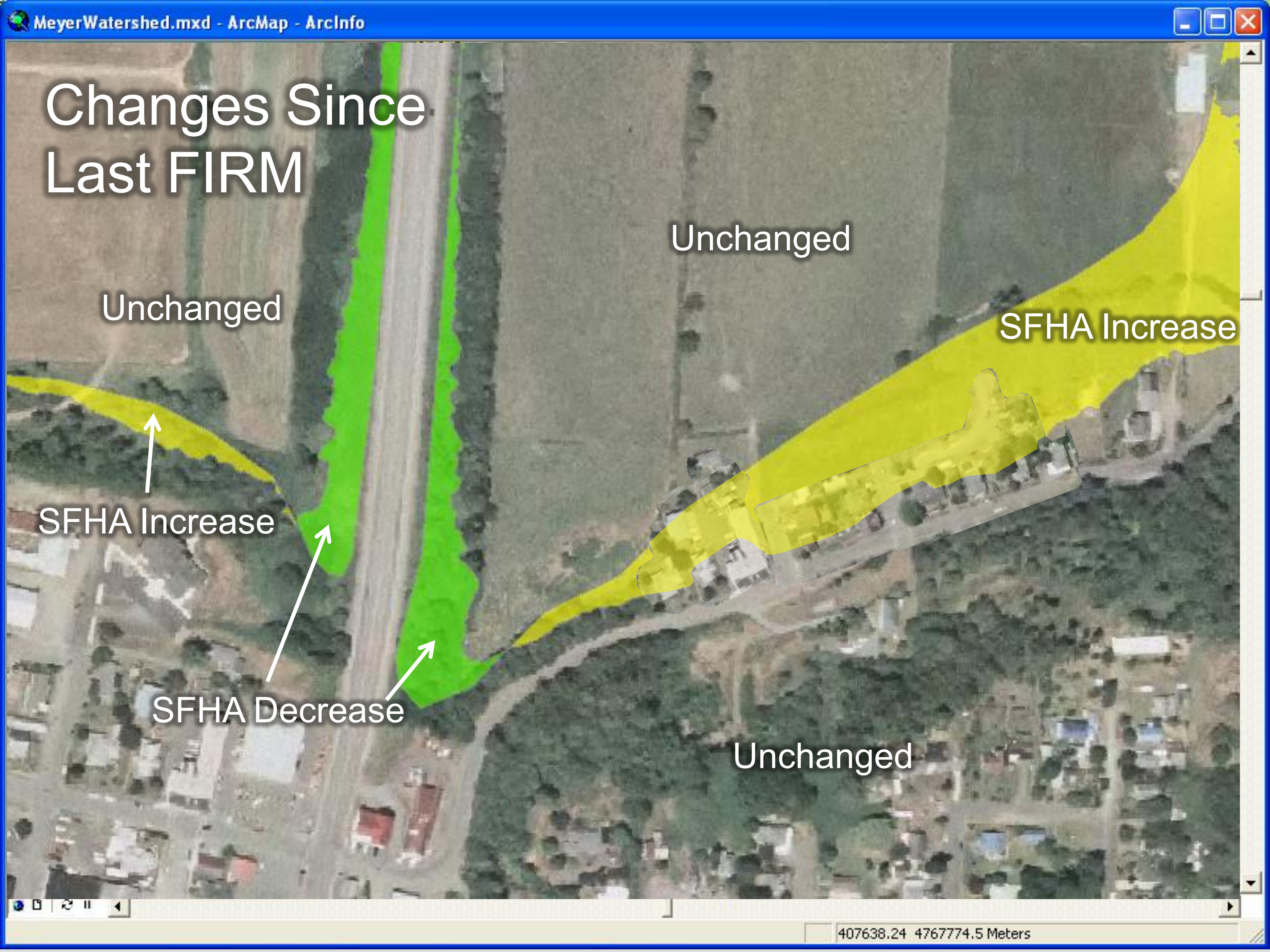
Purpose and Intended Uses

- **Identify Areas and Types of SFHA Change Between:**
  - Current Effective or Previous SFHAs (must be digital)
  - Proposed or New SFHAs
  - Results and/or SFHA Changes are Quantified
- **Provide Study/Reach Level Rationale for Changes Including:**
  - Methodology and Assumptions
  - Changes of Model Inputs or Parameters (aka Contributing Engineering Factors)
- **Offer Stakeholders Transparency and Answers to:**
  - Where has my SFHA increased or decreased?
  - Why has my SFHA increased or decreased?
  - Which communities are subject to new BFEs or ordinance adjustments.


MeyerWatershed.mxd - ArcMap - ArcInfo
Previous Mapping (old topo)
Zone X
Zone A
Zone AE
Zone X
Waterloo
406961.84 4772070.15 Meters


MeyerWatershed.mxd - ArcMap - ArcInfo
Previous Mapping
407638.24 4767774.5 Meters


MeyerWatershed.mxd - ArcMap - ArcInfo
New Mapping
407638.24 4767774.5 Meters


MeyerWatershed.mxd - ArcMap - ArcInfo
Changes Since Last FIRM
Unchanged
Unchanged
SFHA Increase
SFHA Increase
SFHA Decrease
Unchanged
407638.24 4767774.5 Meters

Changes Since Last FIRM

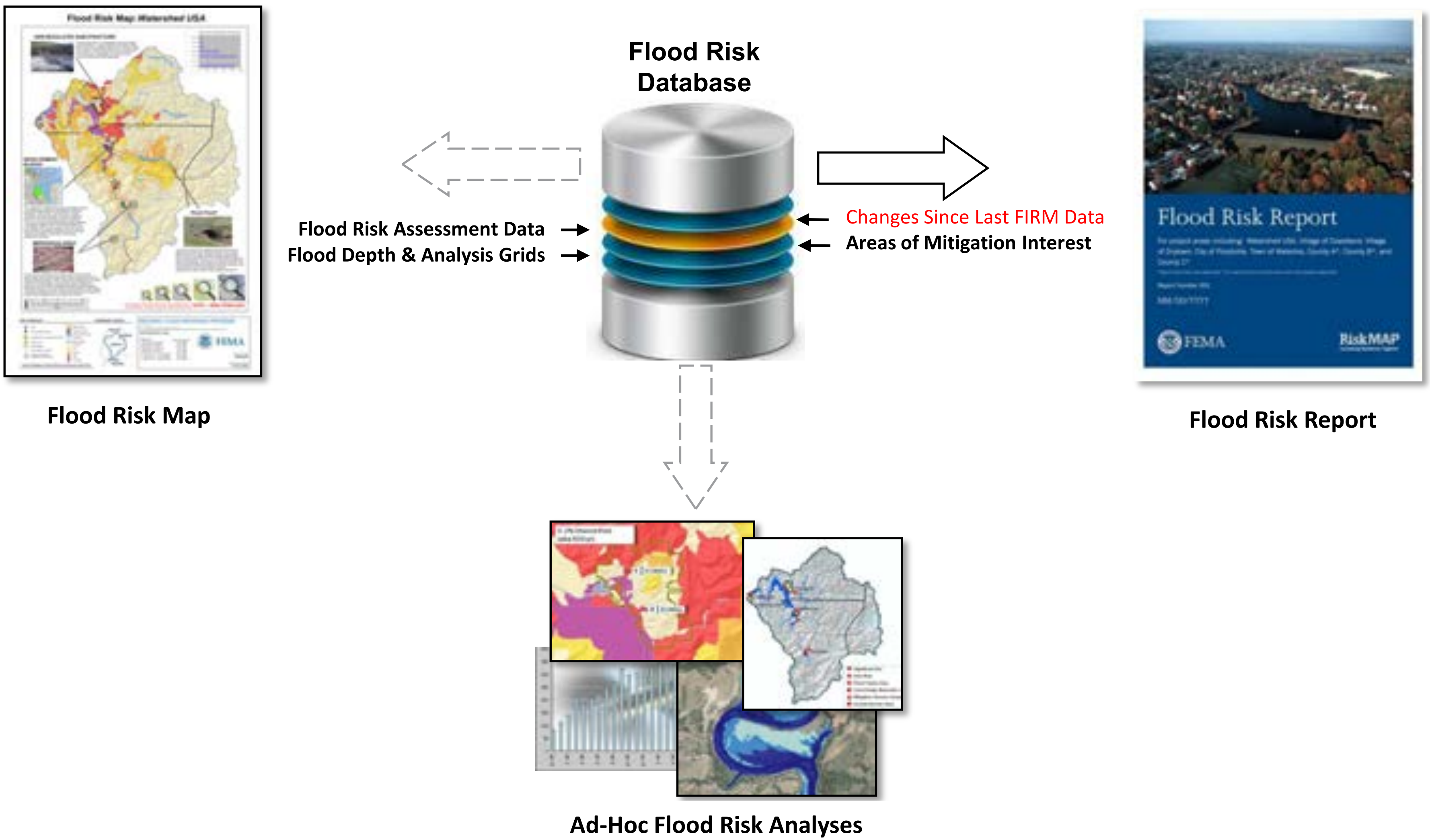
Data Fields Include	Example Data Values
Old Study Date	e.g. 1985
Old Model Type(s)	e.g. HEC-1 / HEC-2
Old Zone Type	e.g. Zone A
Old Topography	e.g. USGS 10-ft
New Study Info/Methods	Dates, Models, etc.
New Study Zone	e.g. Zone AE
New Topography	e.g. LiDAR 2-ft
New Study Engineering Factors / Changes	e.g. new structures, gages, topo, landuse, etc.
Estimated Structures	e.g. 9
Estimated Population	e.g. 27

Content Scalability

- **Base** ☑
  - ☑ GIS Layer (vector polygon based upon spatial intersect of pre and post SFHA datasets)
  - ☑ Attached table attributes containing pre and post SFHA zone designations and study information including contributing engineering factors.
- **Enhancements** ✸
  - ✸ Same as above with addition of structures and population impacts (requires locally provided input data, e.g. footprints, parcels, etc.)

Changes Since Last FIRM	Riverine	Coastal	Levee
Vector Polygon Boundaries	☑	☑	☑
Pre and Post SFHA Zone Information	☑	☑	☑
Contributing Engineering Factors	☑	☑	☑
Structure and Population Estimates	✸	✸	✸

Changes Since Last FIRM Distribution Context



FEMA

Flood Depth & Analysis Grids

RiskMAP
Increasing Resilience Together

Flood Depth & Analysis Grids Purpose and Intended Uses

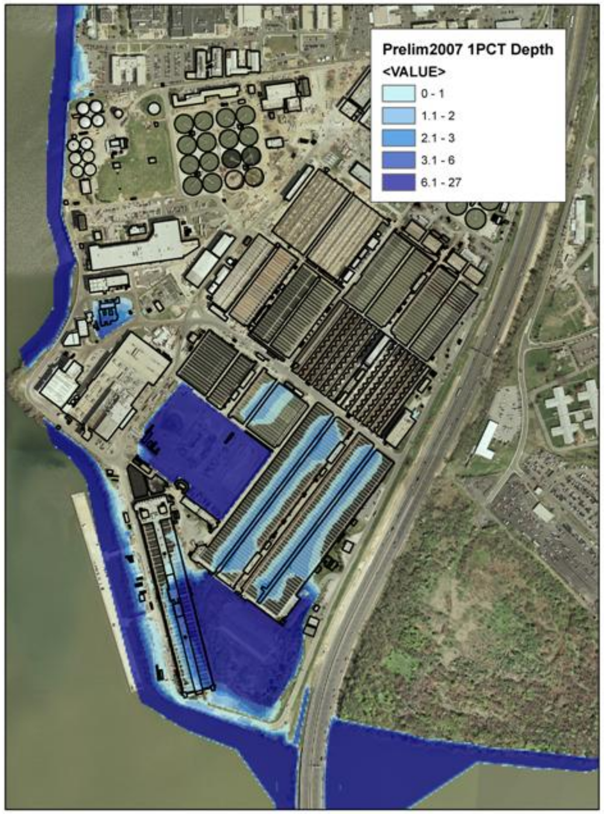
- Communicate / „Show" Flood Inundation as Function of Event"s Magnitude or Severity
- Serve as Key Inputs to HAZUS Risk Assessment Analyses
- Serve as pre-screening criteria for mitigation project potential (e.g. BCA > 1.0 with positive 10-yr depths)
- Increase Flood Risk Awareness as Acknowledged from Varied Contexts (Depth, Probability, Velocity, etc.)
- Communicate that Hazard, and by extension Risk, varies within the mapped floodplain

Flood Depth & Analysis Grids (red = enhanced)

- Depth: 10% (10-yr), 4% (25-yr), 2% (50-yr), 0.2% (500-yr) Annual Chance
- Depth: 1% (100-yr) Annual Chance
- Depth: Additional Flood Frequencies (e.g. 50% (2-yr), 20% (5-yr), 0.5% (200-yr), 1% “plus”, etc.)
- Percent Annual Chance of Flooding
- Percent Chance of Flooding over a 30-yr Period
- Water Surface Elevation: 10%, 4%, 2%, 1%, 0.2%
- Water Surface Elevation Change
- Depth: Annualized
- Velocity
- Top & Toe of Levee

Flood Depth Grids
(Depth_*XX*pct)

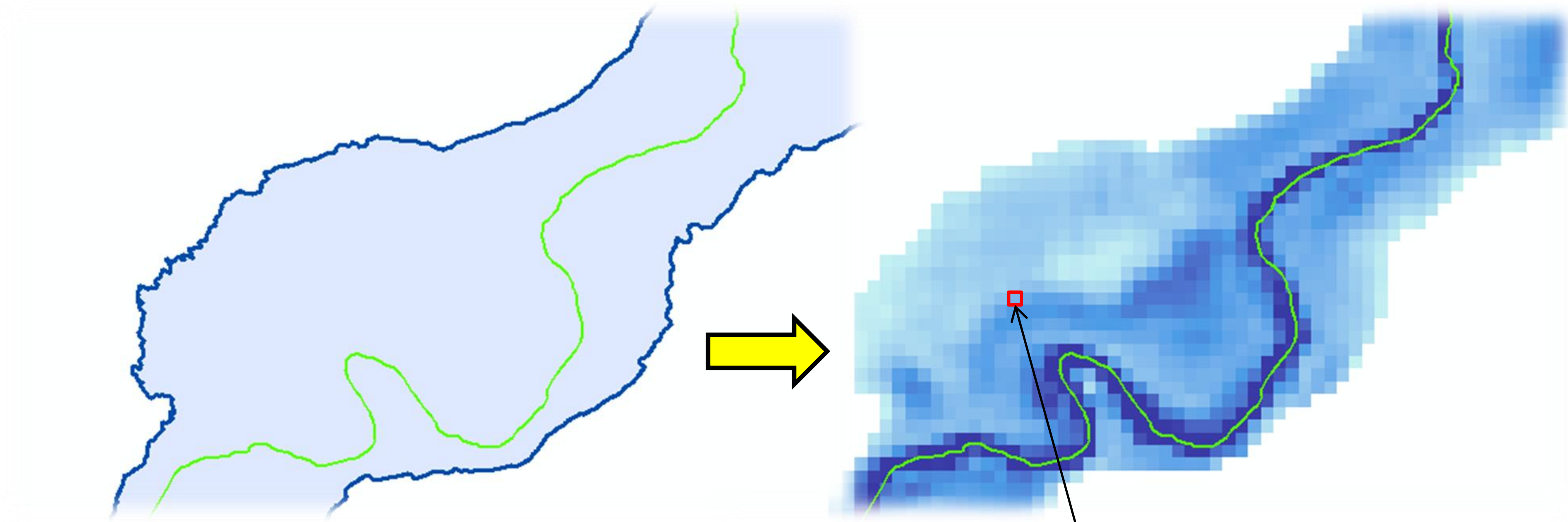
- ☑ **Base Datasets**
  - Riverine: 10%, 4%, 2%, 1%, & 0.2% Annual Chance (A.C.) Floods
  - Coastal: 1% A.C. Flood
  - Levee: 1% A.C. Flood
- ✸ **Enhanced Datasets**
  - Riverine, Coastal, and Levee: Any depth grid associated to a flood frequency other than those listed above as Base Datasets (e.g. the 2% Coastal depth grid, the 0.5% Riverine depth grid, etc.)



Flood Depth Grids

- **Each Grid Cell has a Unique Value**

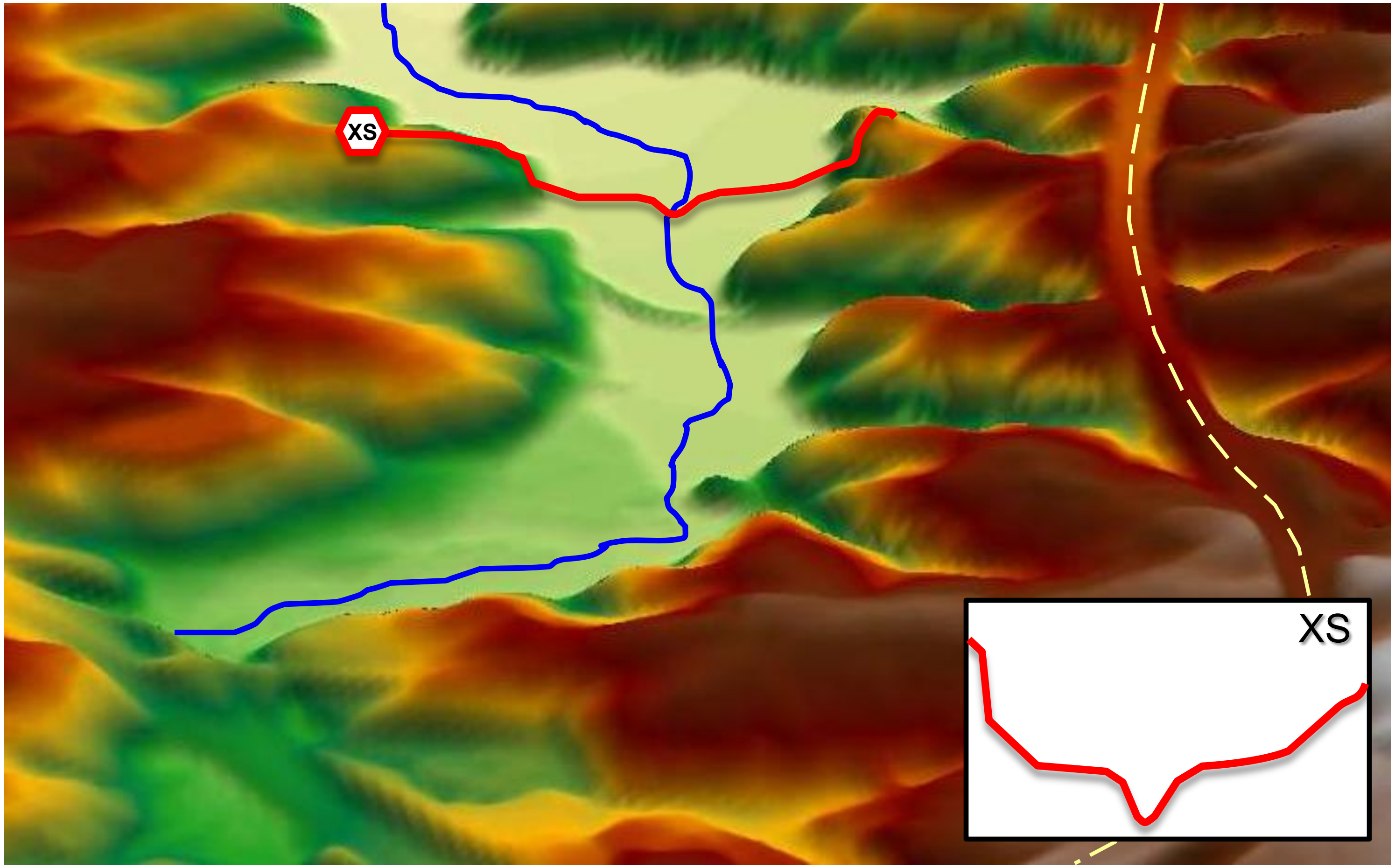
FIRM 1% Annual Chance (100-yr) Floodplain **1% Annual Chance Depth Grid**



Individual Grid Cell

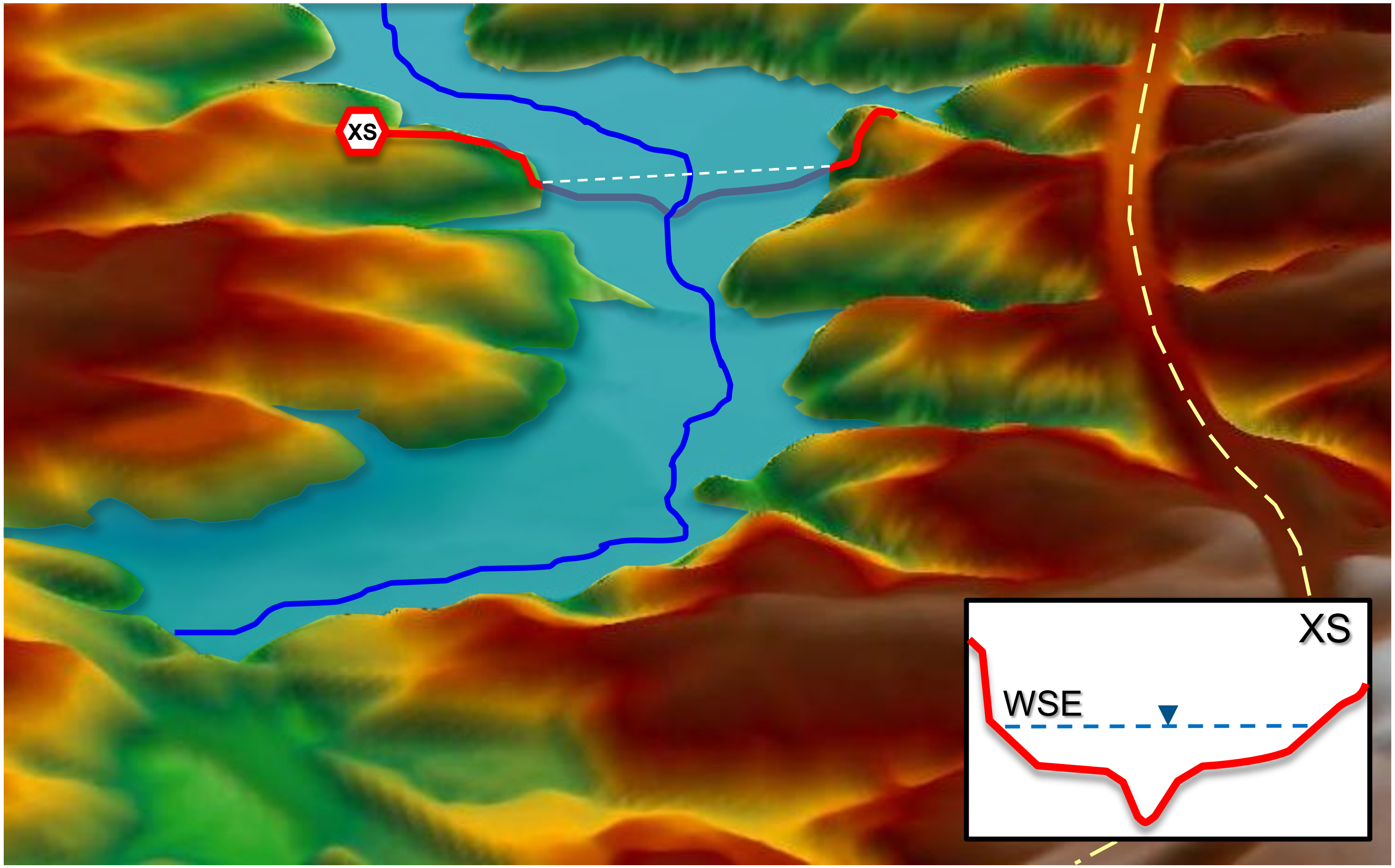
Flood Depth Grids

- **Flood Depth Grid Creation Process**



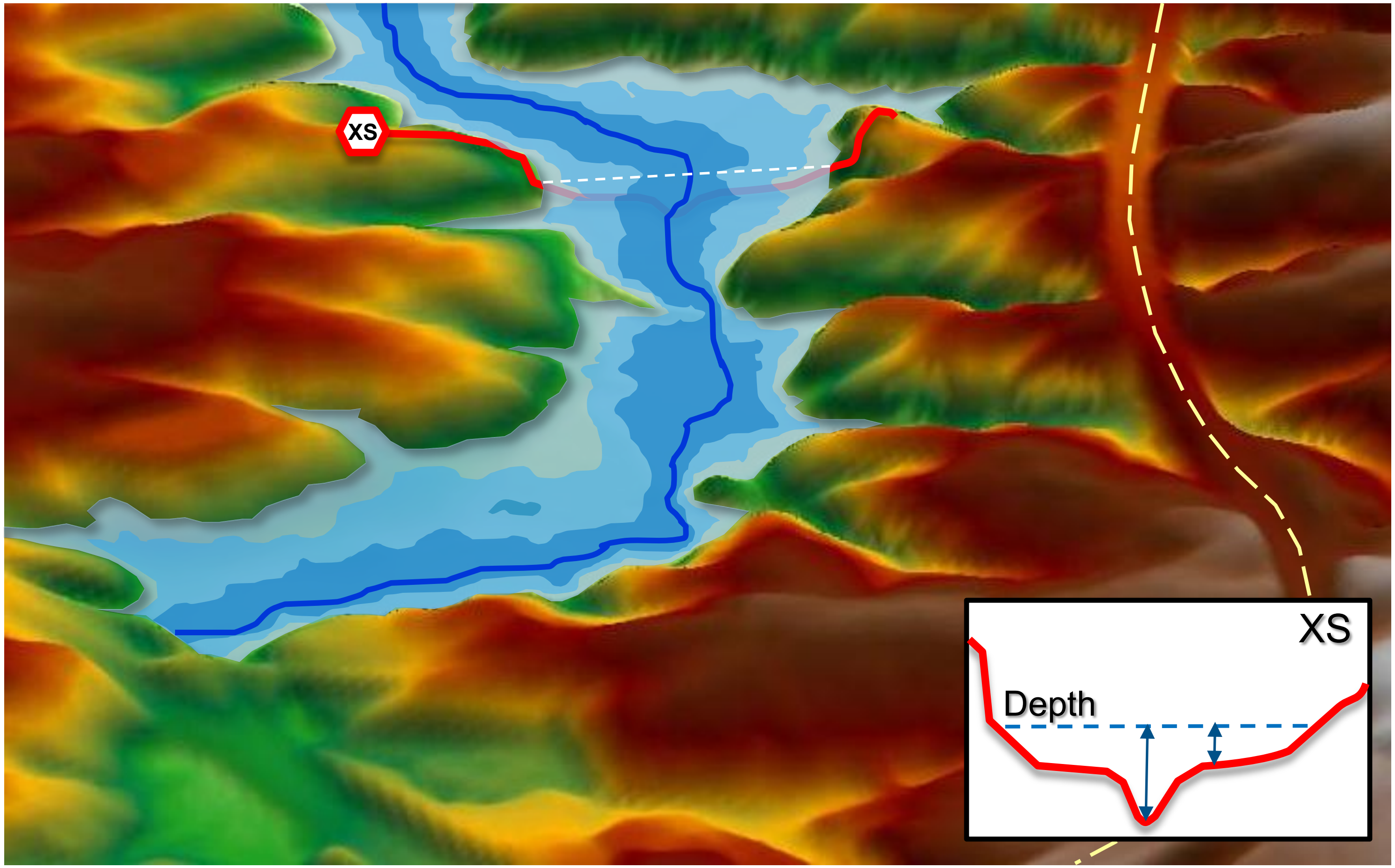
Flood Depth Grids

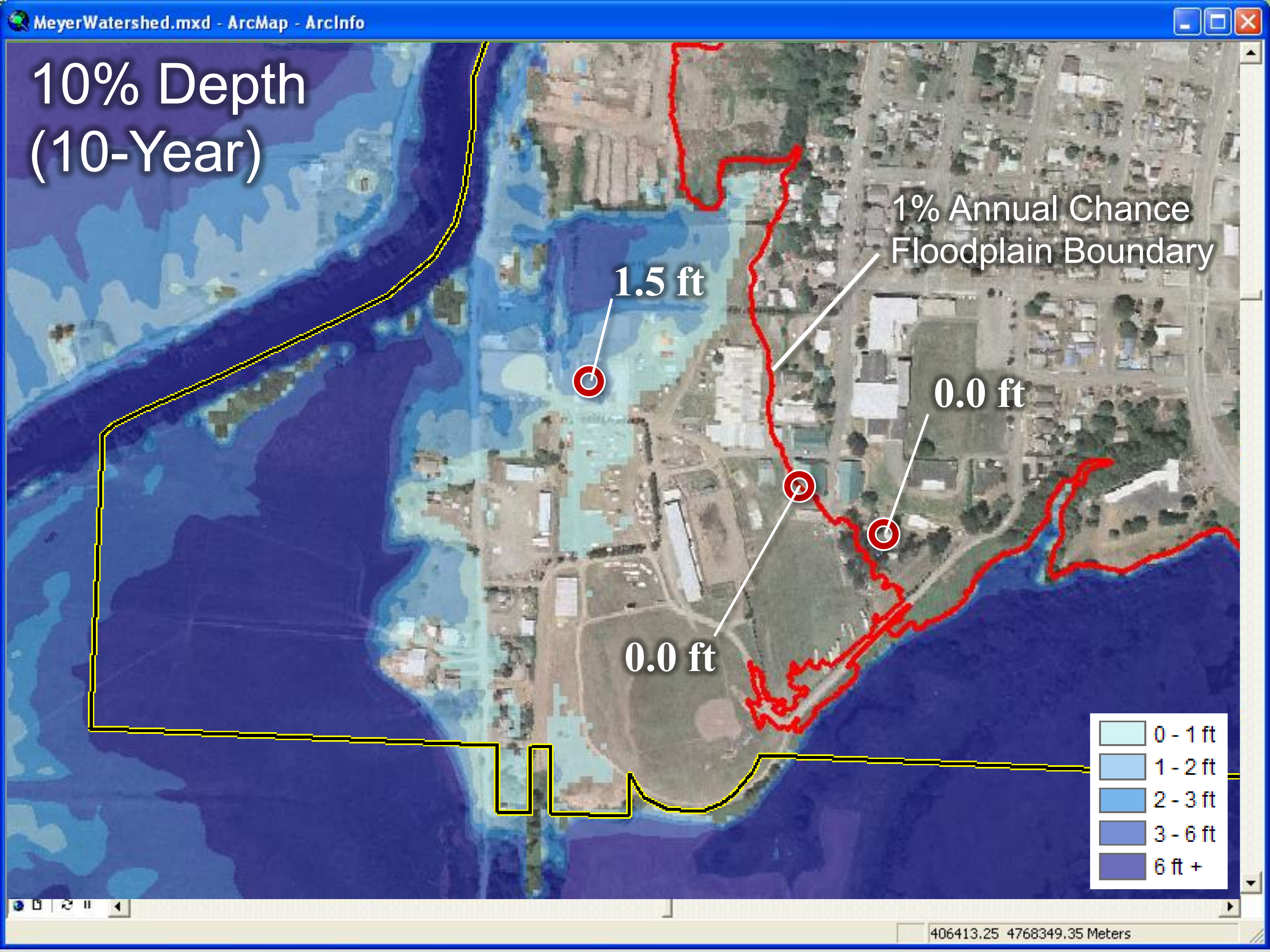
- **Water Surface Elevations (WSE) Calculated and WSE Grid Produced**

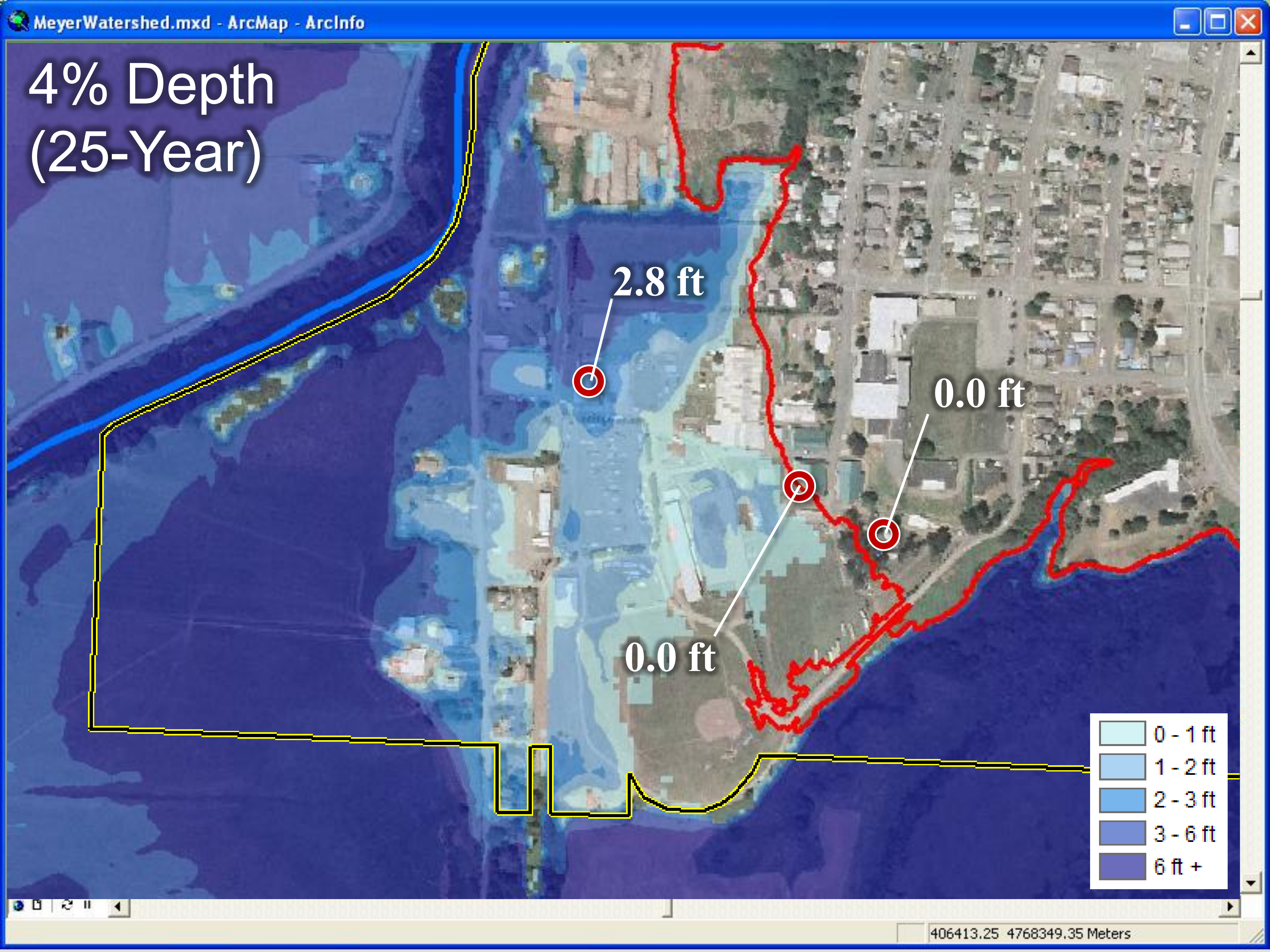


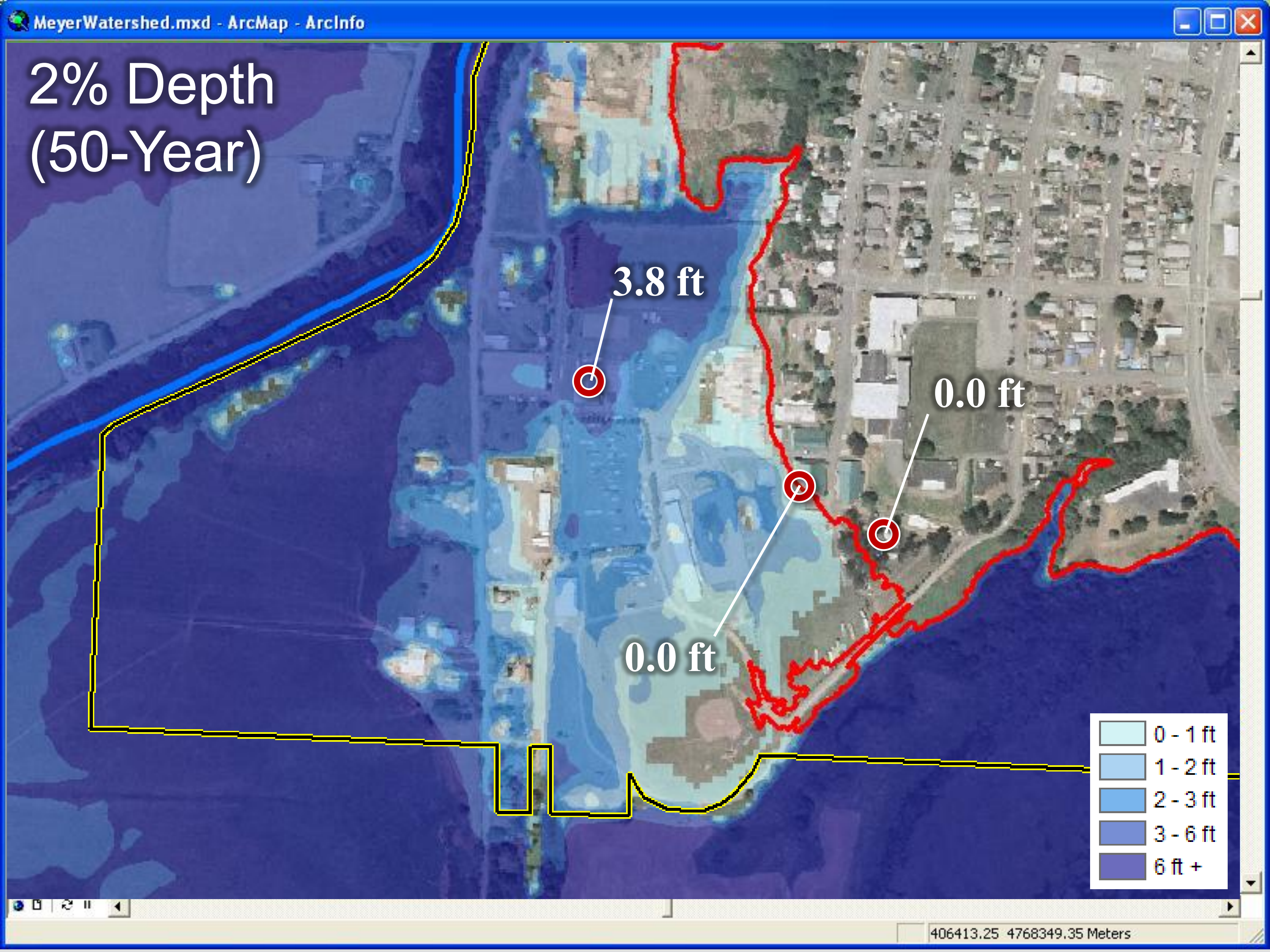
Flood Depth Grids

- **Depth Grid Calculated as Difference between WSE and Ground**

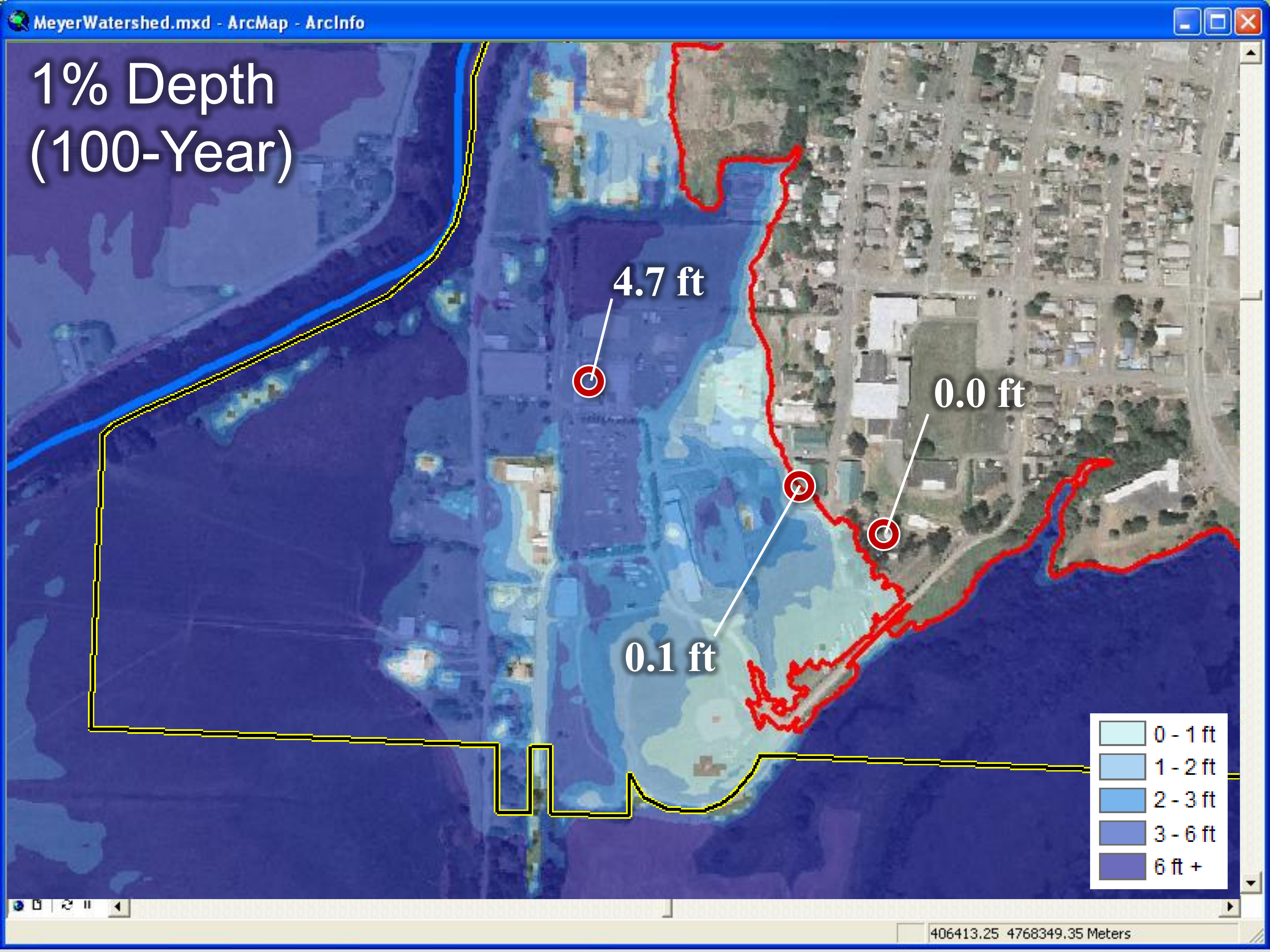


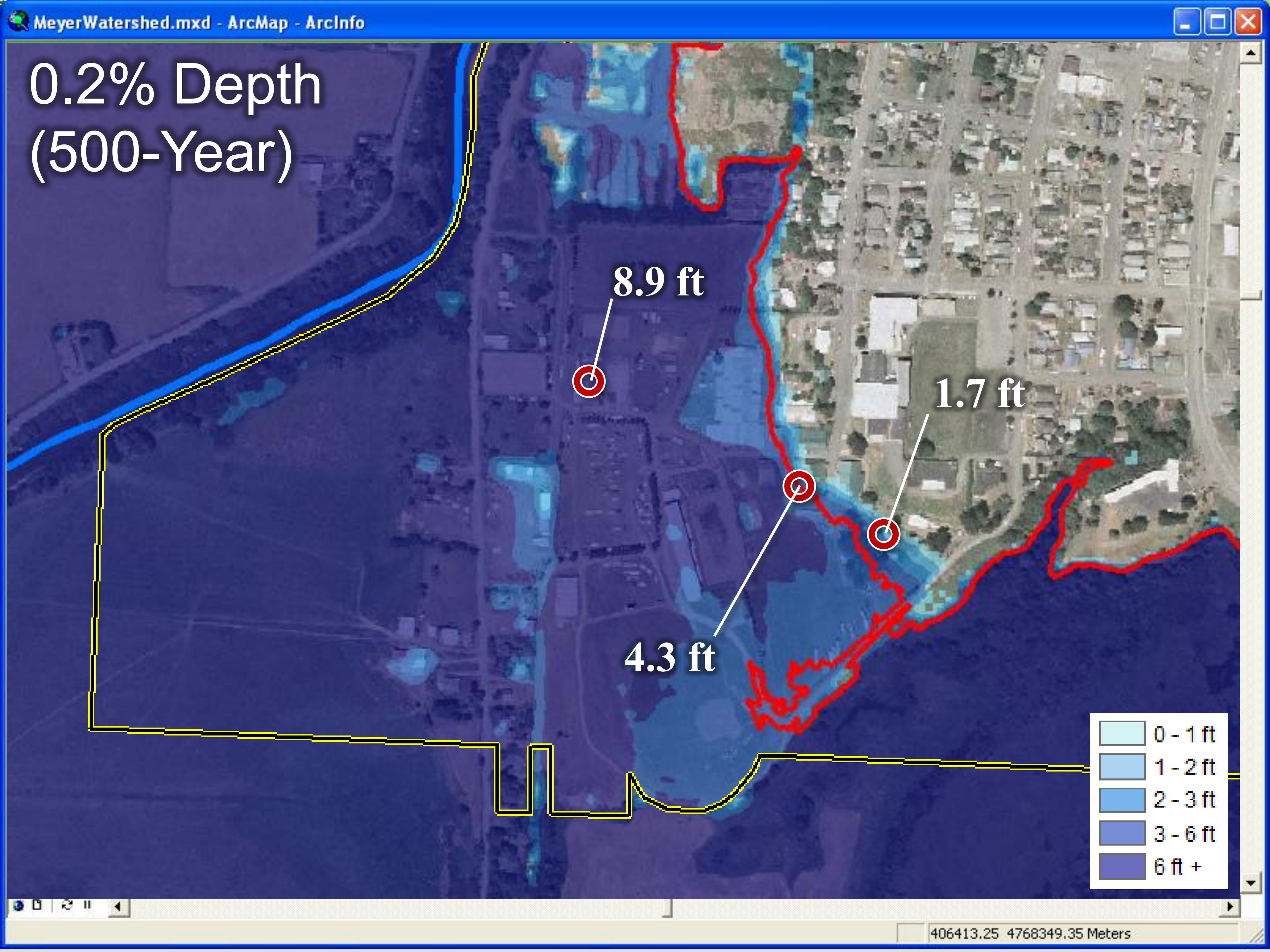

MeyerWatershed.mxd - ArcMap - ArcInfo
10% Depth
(10-Year)
1.5 ft
1% Annual Chance
Floodplain Boundary
0.0 ft
0.0 ft
0 - 1 ft
1 - 2 ft
2 - 3 ft
3 - 6 ft
6 ft +
406413.25 4768349.35 Meters


MeyerWatershed.mxd - ArcMap - ArcInfo
4% Depth
(25-Year)
2.8 ft
0.0 ft
0.0 ft
0 - 1 ft
1 - 2 ft
2 - 3 ft
3 - 6 ft
6 ft +
406413.25 4768349.35 Meters



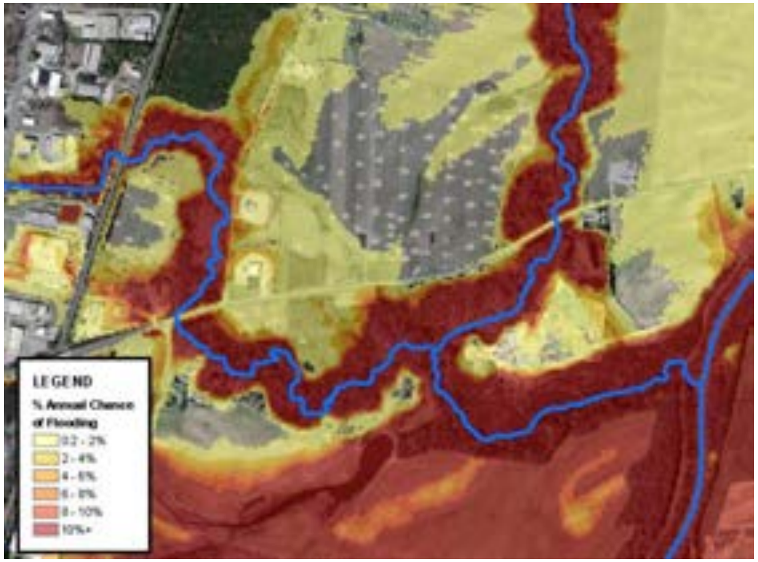
MeyerWatershed.mxd - ArcMap - ArcInfo
2% Depth
(50-Year)
3.8 ft
0.0 ft
0.0 ft
0 - 1 ft
1 - 2 ft
2 - 3 ft
3 - 6 ft
6 ft +
406413.25 4768349.35 Meters


MeyerWatershed.mxd - ArcMap - ArcInfo
1% Depth
(100-Year)
4.7 ft
0.0 ft
0.1 ft
0 - 1 ft
1 - 2 ft
2 - 3 ft
3 - 6 ft
6 ft +
406413.25 4768349.35 Meters

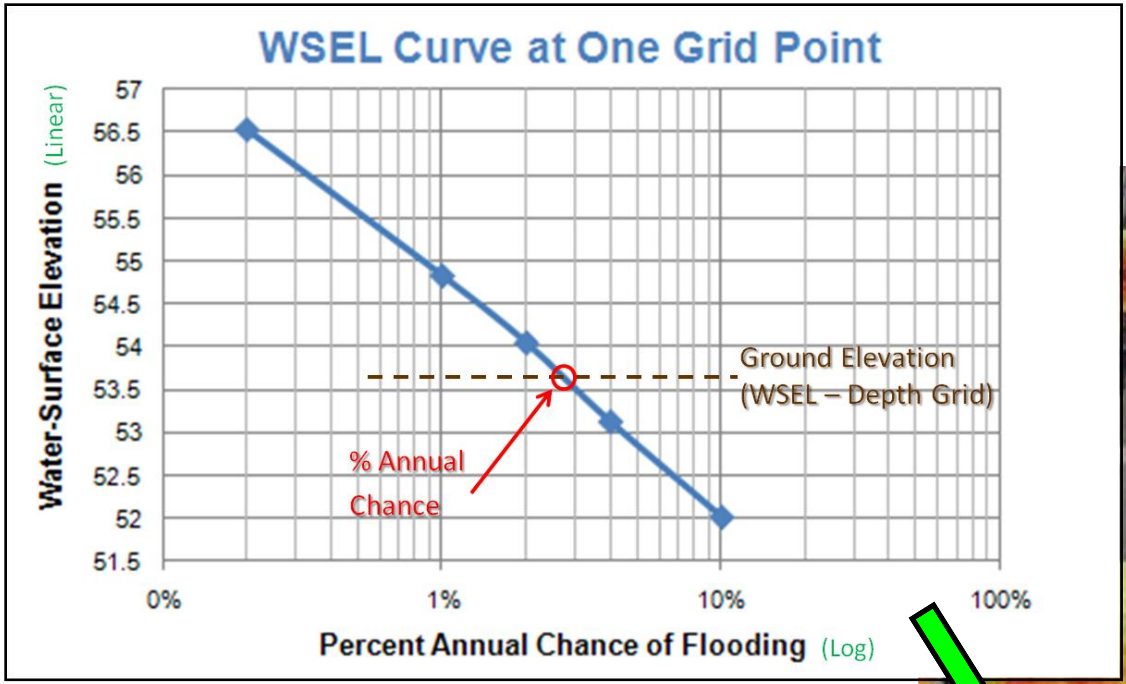

MeyerWatershed.mxd - ArcMap - ArcInfo
0.2% Depth
(500-Year)
8.9 ft
1.7 ft
4.3 ft
0 - 1 ft
1 - 2 ft
2 - 3 ft
3 - 6 ft
6 ft +
406413.25 4768349.35 Meters

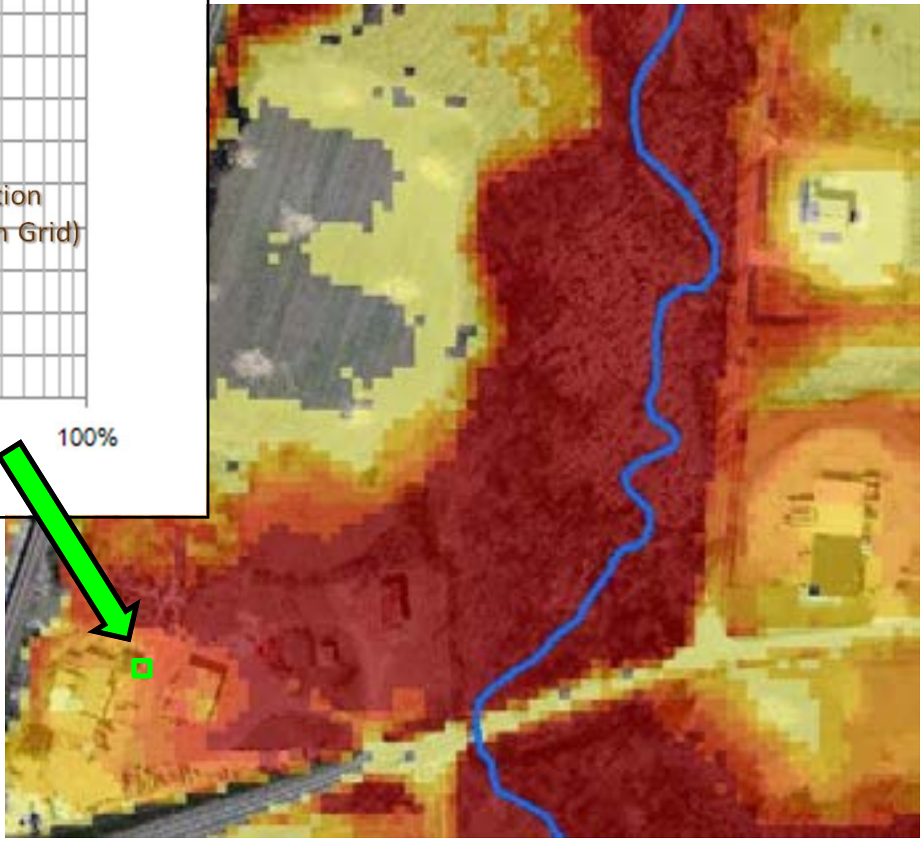
Percent Annual Chance of Flooding Grid (PctAnnual_Grd)

- ☑ **Base Dataset**
  - Riverine
- ✷ **Enhanced Datasets**
  - Coastal and Levee



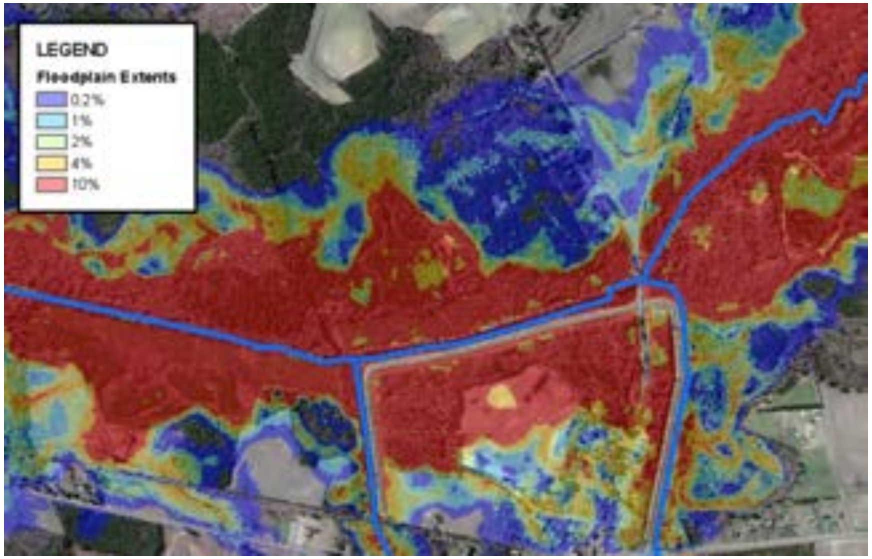
Percent Annual Chance of Flooding Grid



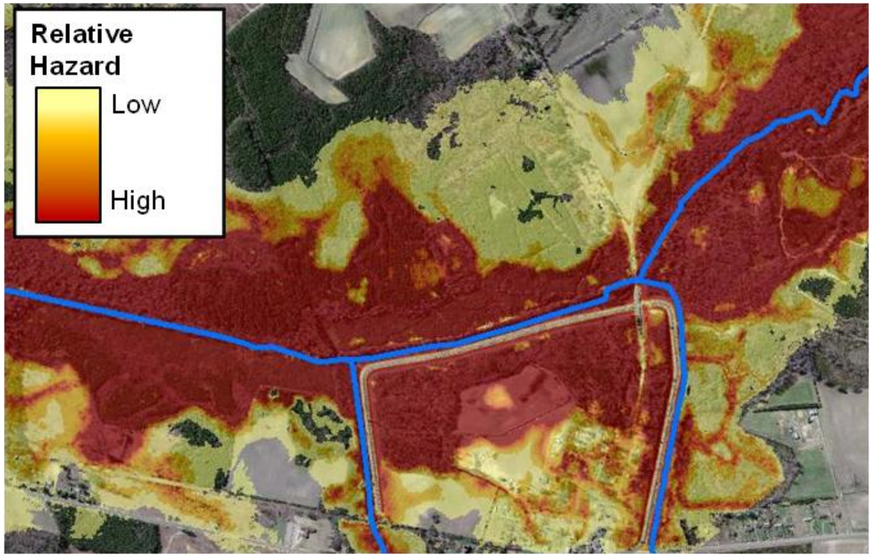


Percent Annual Chance of Flooding Grid

- Display Options



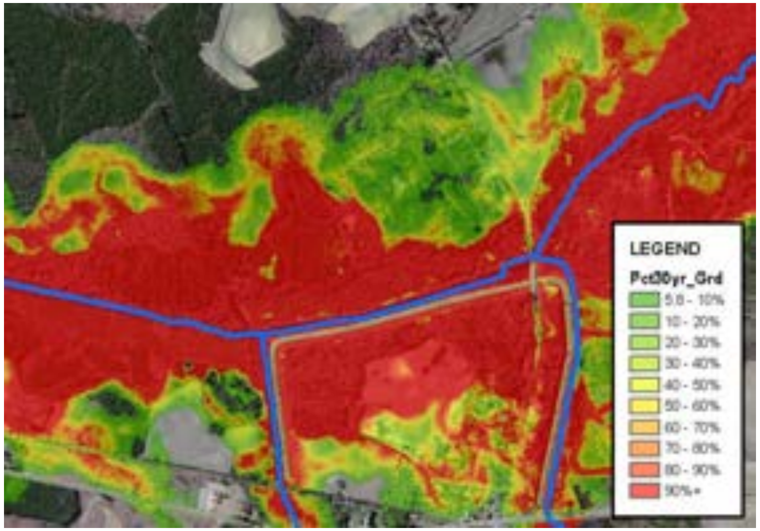
Floodplain Extents for Each Flood Frequency



Relative Flood Hazard within Floodplain

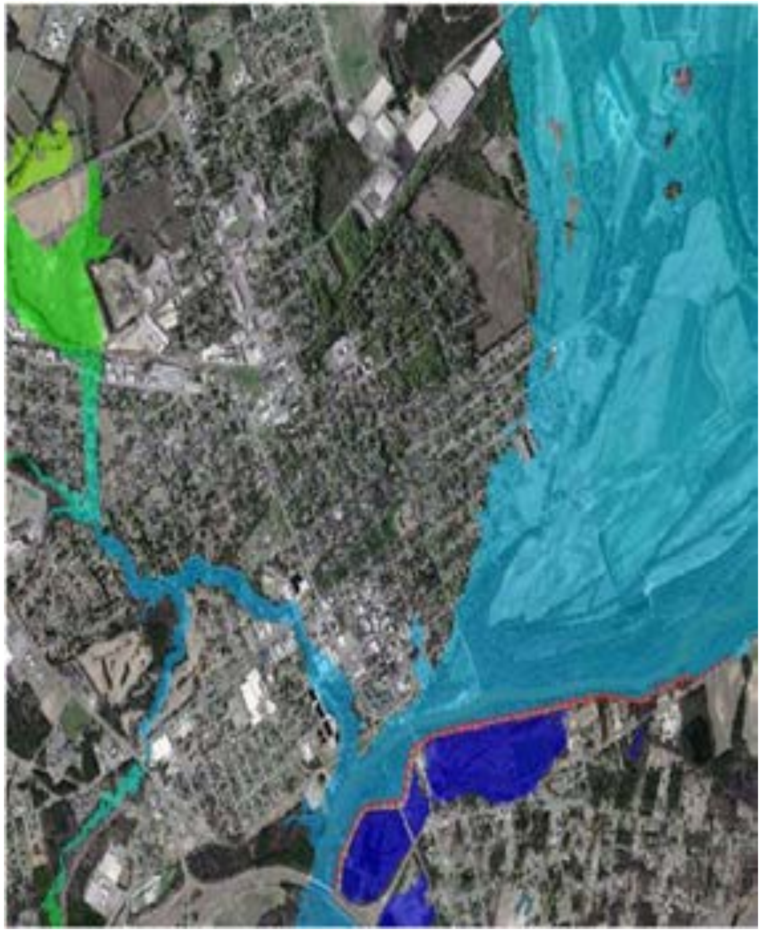
Percent Chance of Flooding over a 30-Year Period Grid (Pct30yr_Grd)

- ☑ **Base Dataset**
  - Riverine
- ✸ **Enhanced Datasets**
  - Coastal and Levee



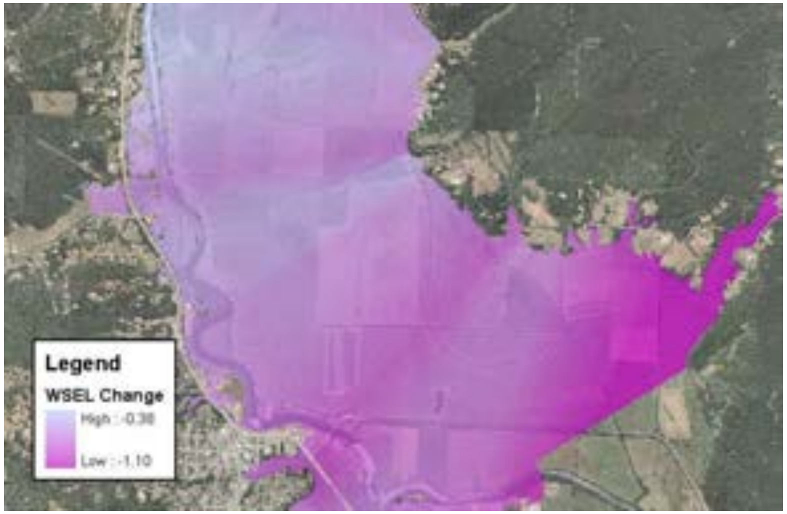
Water Surface Elevation Grids (WSEL_*XX*pct)

- **Enhanced Dataset**
  - All Riverine, Coastal, and Levee Flood Analyses
- Note:
  - Water Surface Elevation grids will be created for each flooding source studied during Risk MAP in order to produce many of the other grids
  - However, they will not be delivered as a base dataset so that they do not get misused as a regulatory product



WSE Change Grids (WSEL_Chng_Grd)

- ✷ **Enhanced Datasets**
  - All Riverine, Coastal, and Levee Analyses
- Displays the vertical change in Water Surface Elevation between the previous study and new study
- Requires that the previous study have published elevations (i.e. non-Zone A) or be backed by an available model



Annualized Depth Grid

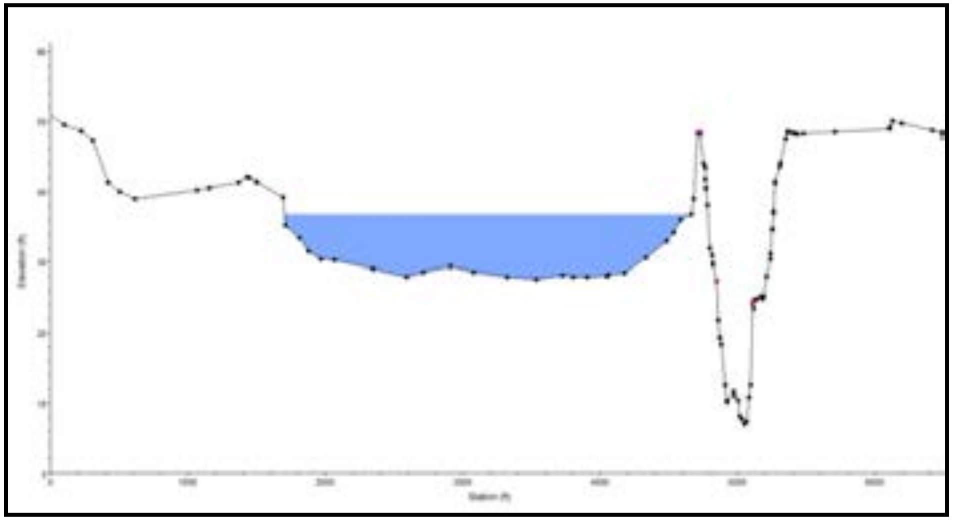
- ✷ **Enhanced Dataset**
  - All Riverine, Coastal, and Levee Analyses
- Provides end users with estimated flood risk (expressed as a flood depth) during any given year at a particular location
- Composite grid derived from the individual flood depth grids created for each modeled frequency

Flood Velocity Grids (Vel_XXpct)

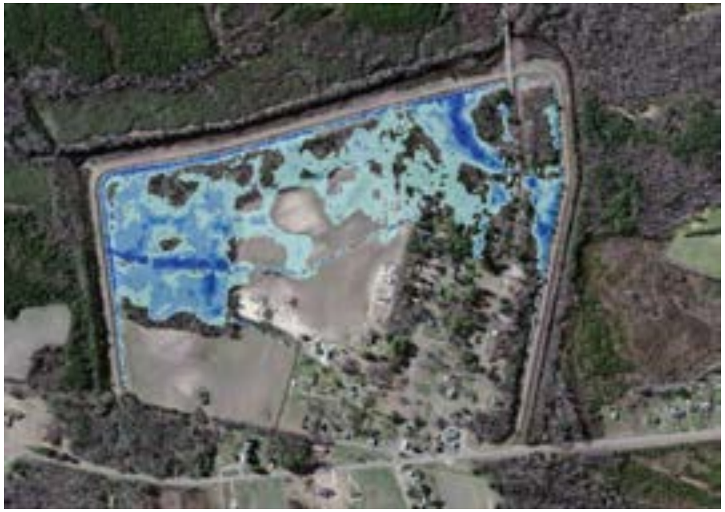
- ✷ **Enhanced Datasets**
  - All Riverine, Coastal, and Levee Analyses
- Can be generated for both 1-D (e.g. HEC-RAS, etc.) and 2-D (e.g. FLO-2D, etc.) models
- Velocity grid resolution (i.e. cell size) should be equal to that selected for the depth and other grids

Toe and Top of Levee Grids

- Toe of levee grid
  - ✸ Enhanced Dataset



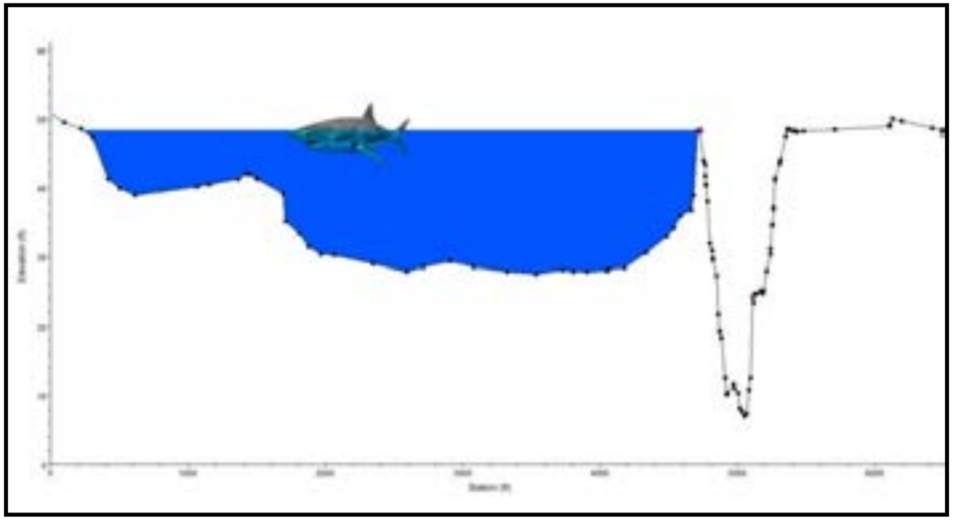
Cross Section View



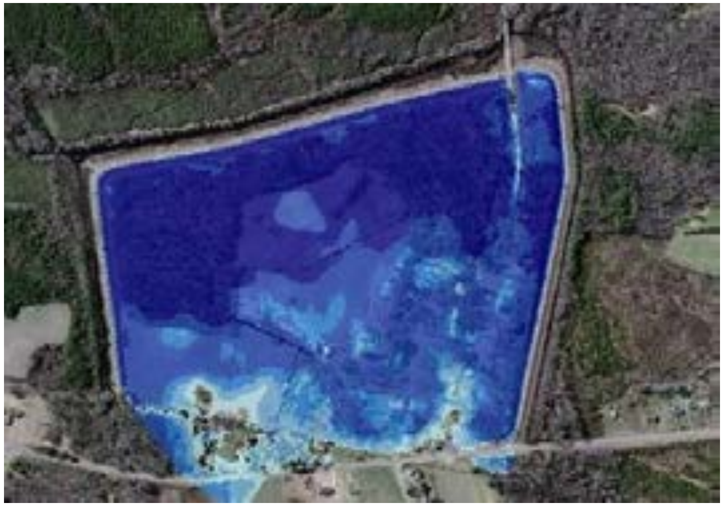
Plan (aerial) View

Toe and Top of Levee Grids

- Top of levee grid
  - ✷ Enhanced Dataset



Cross Section View



Plan (aerial) View

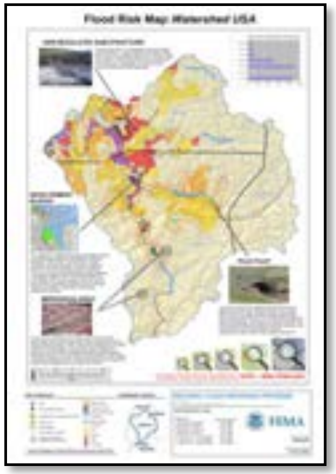
Content Scalability

- **Summary Table of Base (☑) vs. Enhanced (✸) Grids**

Grid(s)	Riverine	Coastal	Levee
Depth: 10%, 4%, 2%, 0.2% Annual Chance	☑	✸	✸
Depth: 1% (100-yr) Annual Chance	☑	☑	☑
Depth: Additional Flood Frequencies (e.g. 50%, 20%, 0.5%, 1% "plus", etc.)	✸	✸	✸
Percent Annual Chance of Flooding	☑	✸	✸
Percent Chance of Flooding over a 30-yr Period	☑	✸	✸
Water Surface Elevation : 10%, 4%, 2%, 1%, 0.2%	✸	✸	✸
Water Surface Elevation Change	✸	✸	✸
Depth: Annualized	✸	✸	✸
Velocity	✸	✸	✸
Top & Toe of Levee	N/A	N/A	✸

* Note that the delivery of water surface elevation grids is an enhancement

Flood Depth & Analysis Grids Distribution Context

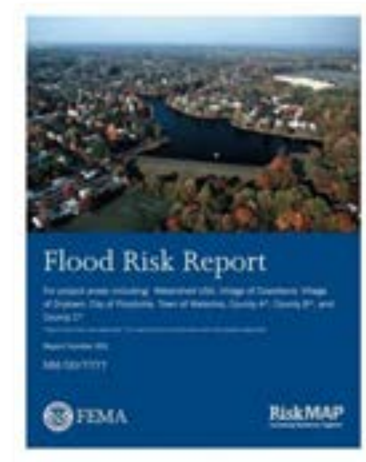


Flood Risk Map

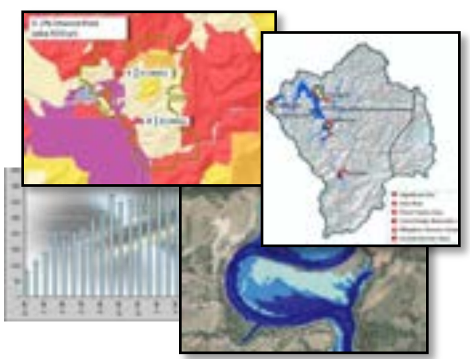
Flood Risk Database

Flood Risk Assessment Data →
Flood Depth & Analysis Grids →

← Changes Since Last FIRM Data
← Areas of Mitigation Interest



Flood Risk Report



Ad-Hoc Flood Risk Analyses

FEMA

Flood Risk Assessment Data

RiskMAP
Increasing Resilience Together

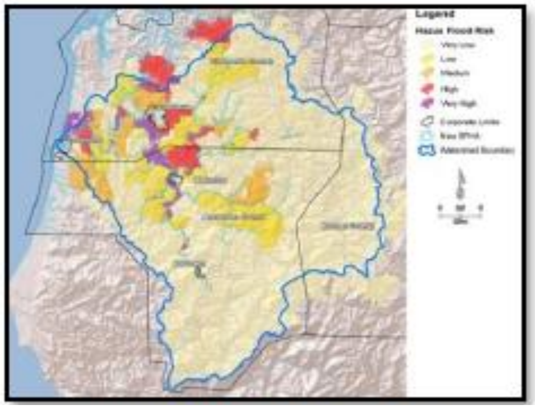
Purpose and Intended Uses

- **Identify Areas with Higher Relative Flood Risk:**
  - Floodprone Areas
  - Vulnerable people and property
- **Provide Flood Risk $:**
  - Potential damage severity for different flood frequencies
  - Identify locations with possible cost effective mitigation options
- **Improve on Existing Flood Risk Estimates:**
  - What was determined during the 2010 Average Annualized Loss Study?
  - What can be improved during a new flood study?

Flood Risk Assessment Datasets

- **Flood Risk Assessment Data**
  - 2010 HAZUS Average Annualized Loss (AAL) Study
  - Refined HAZUS and Other Risk Analyses

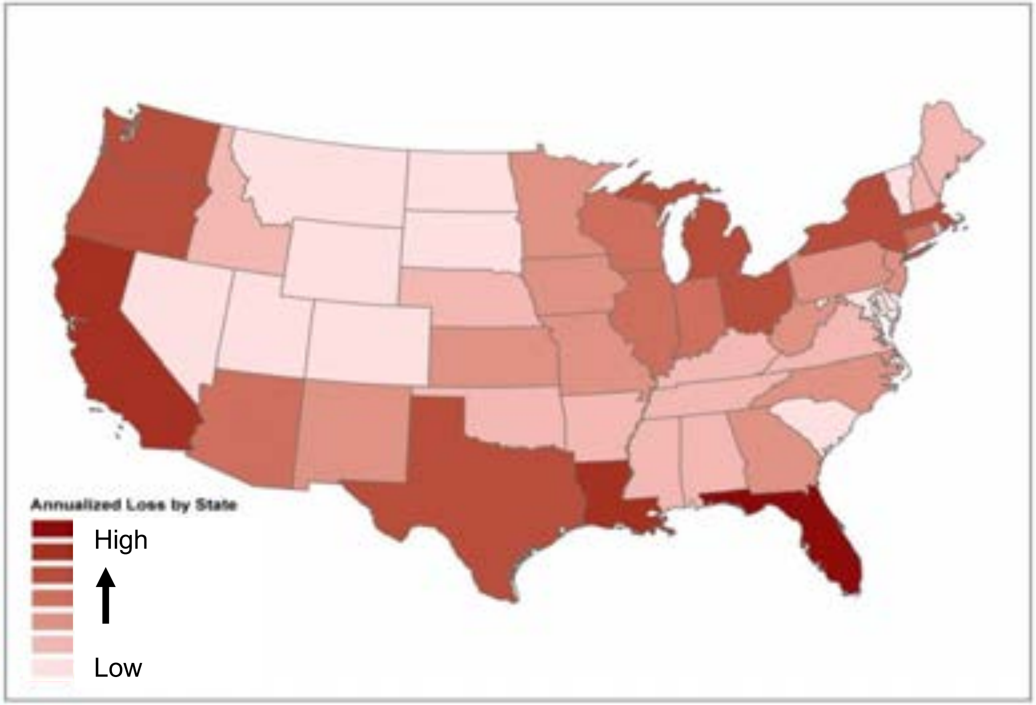
HAZUS MH



Flood Risk Assessment

2010 AAL HAZUS Study

- **2010 HAZUS-MH Flood Average Annualized Loss Estimation (AAL) was performed for continental U.S. using MR4**
- **Inputs:**
  - County-wide study regions
  - 30 meter DEM
  - Default Census data
- **Final Output included**
  - Total exposure
  - Average Annualized Loss
    - Annualized Loss Ratio

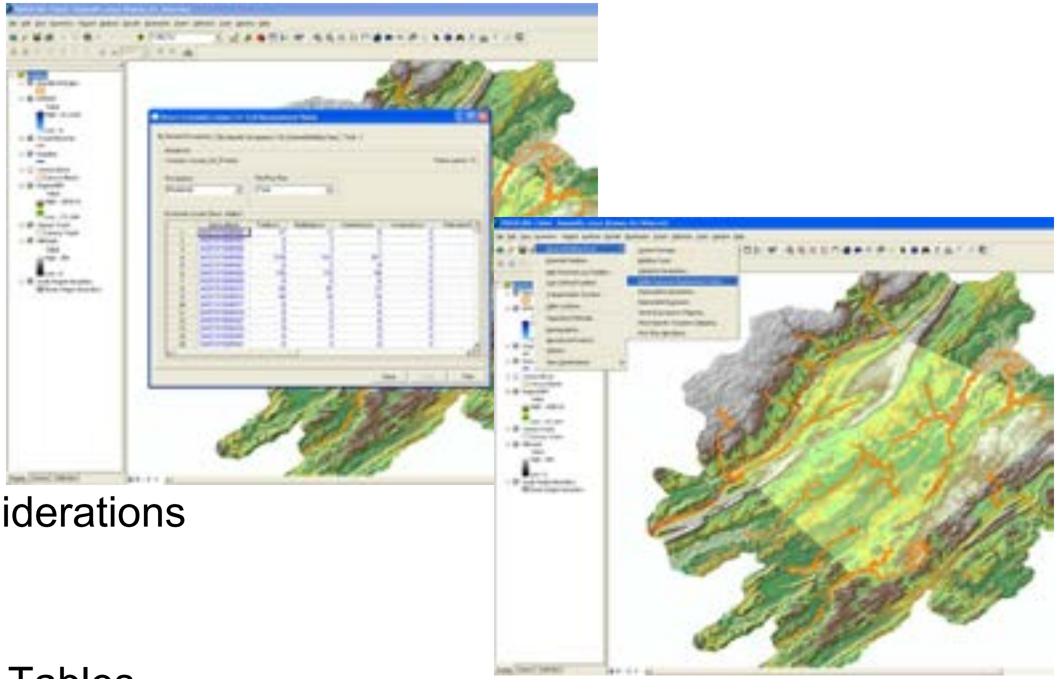


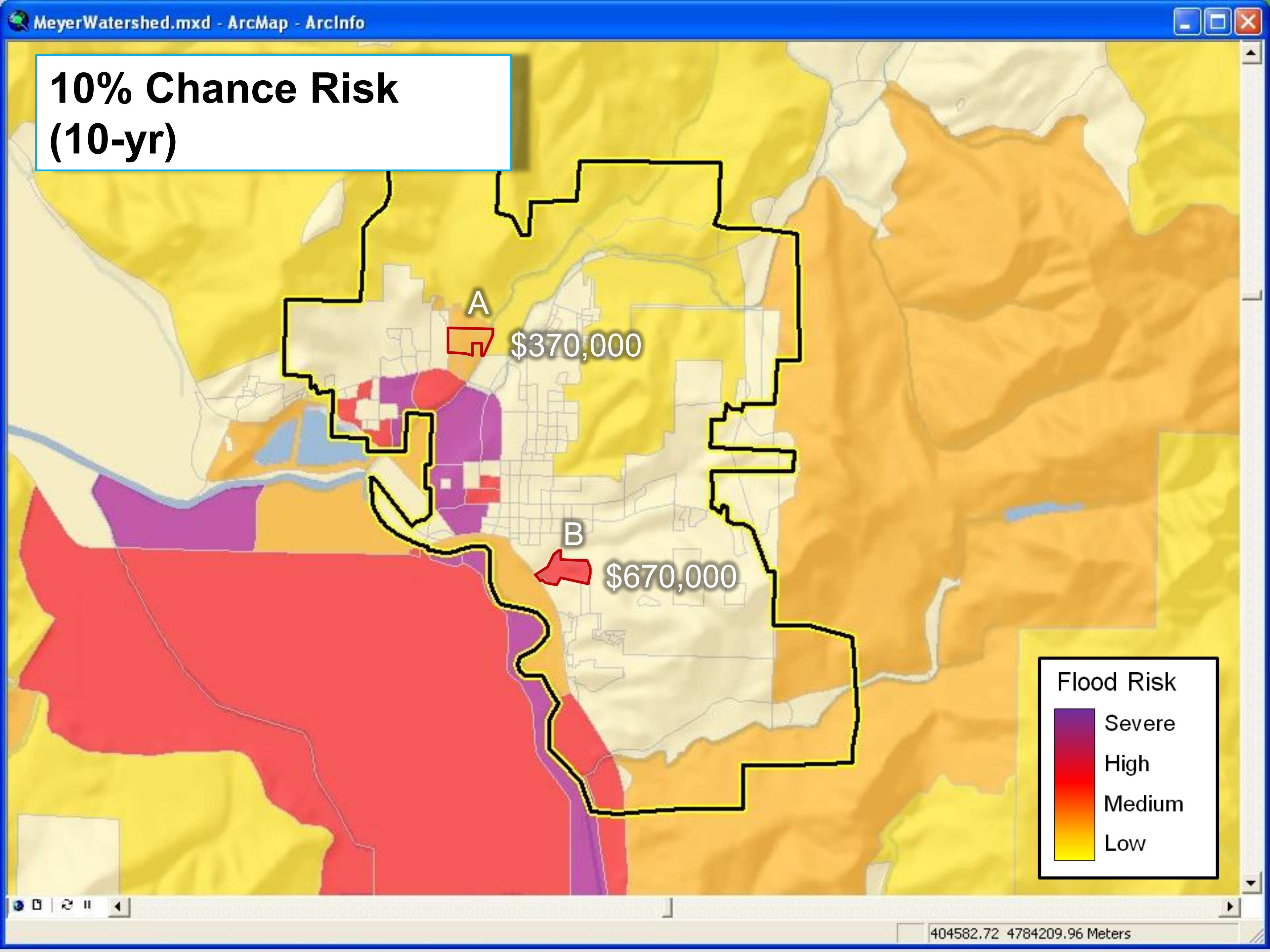
Refined HAZUS Analysis

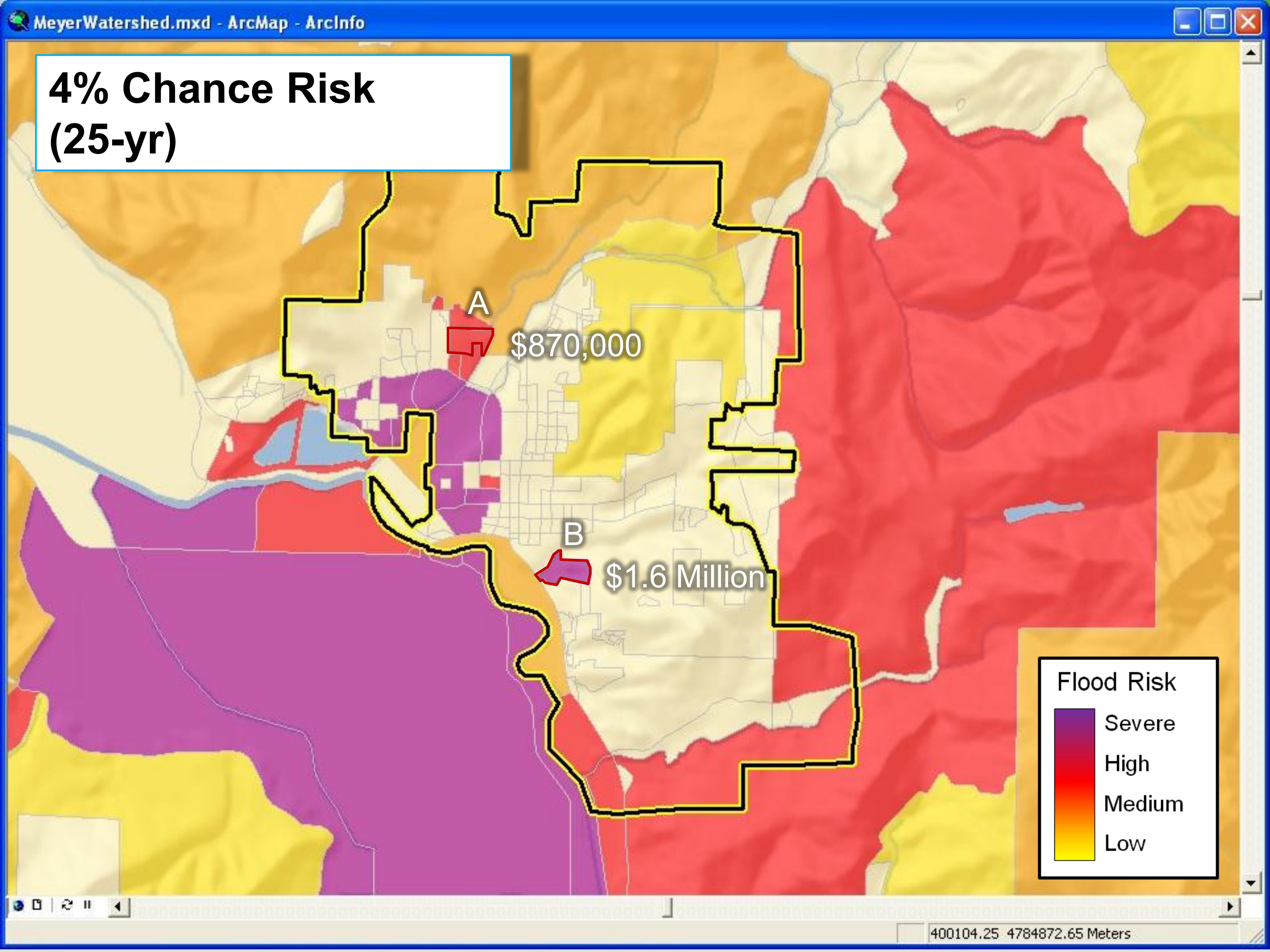
- **Overview:**
  - Depth Grids imported into HAZUS
    - Base: For new study areas
  - HAZUS run for each return period and annualized
  - HAZUS results exported and stored in Flood Risk Database

Estimation of Losses

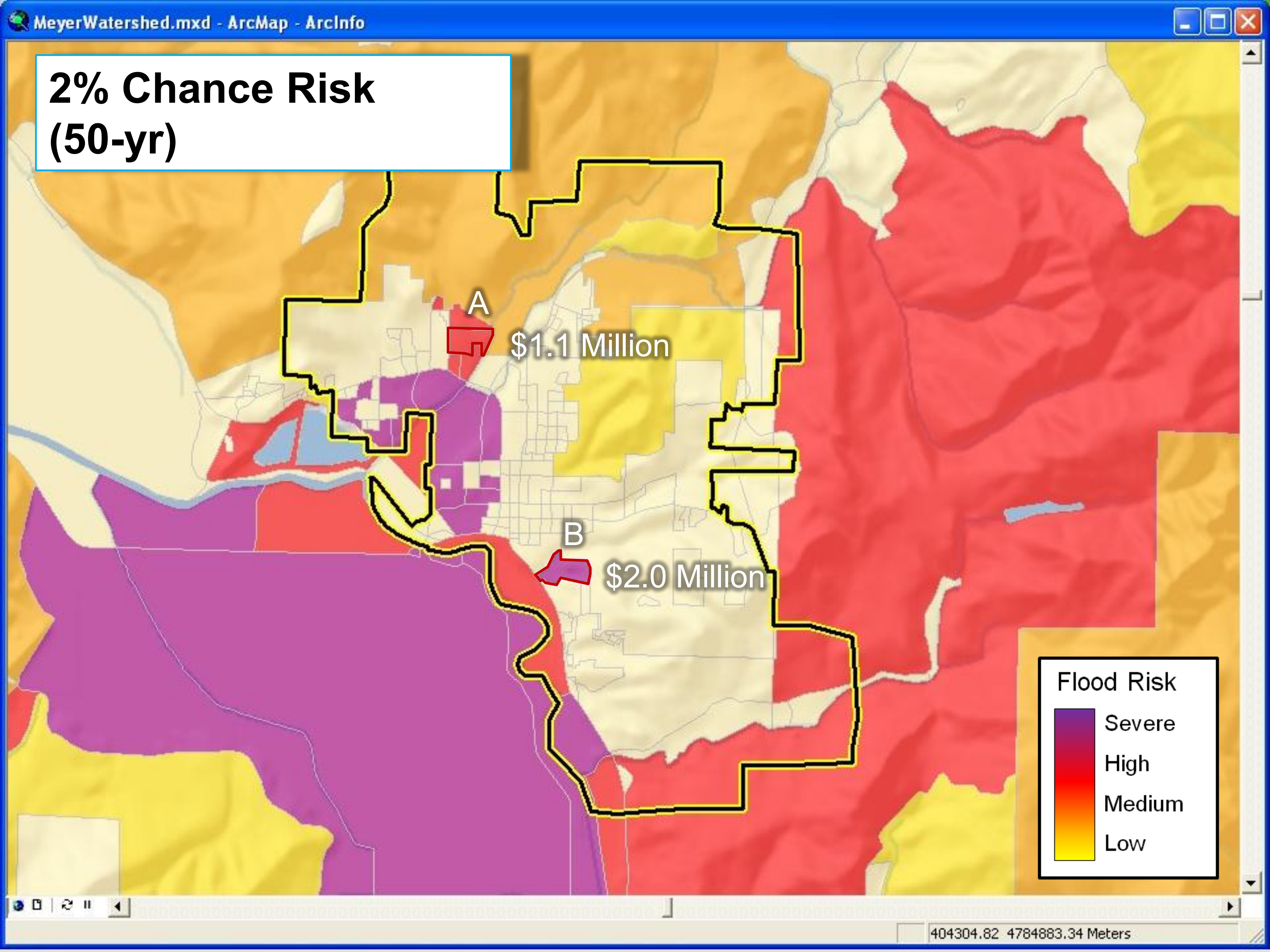
- **Dollar Losses**
  - Residential Loss
  - Commercial Loss
  - Other Asset Loss
- **Percent Damage**
  - Evaluates Building Stock
  - Structure and Content Considerations
- **Business Disruption**
  - Considers Total Occupancy Tables
  - Considers Lost Income and Wages

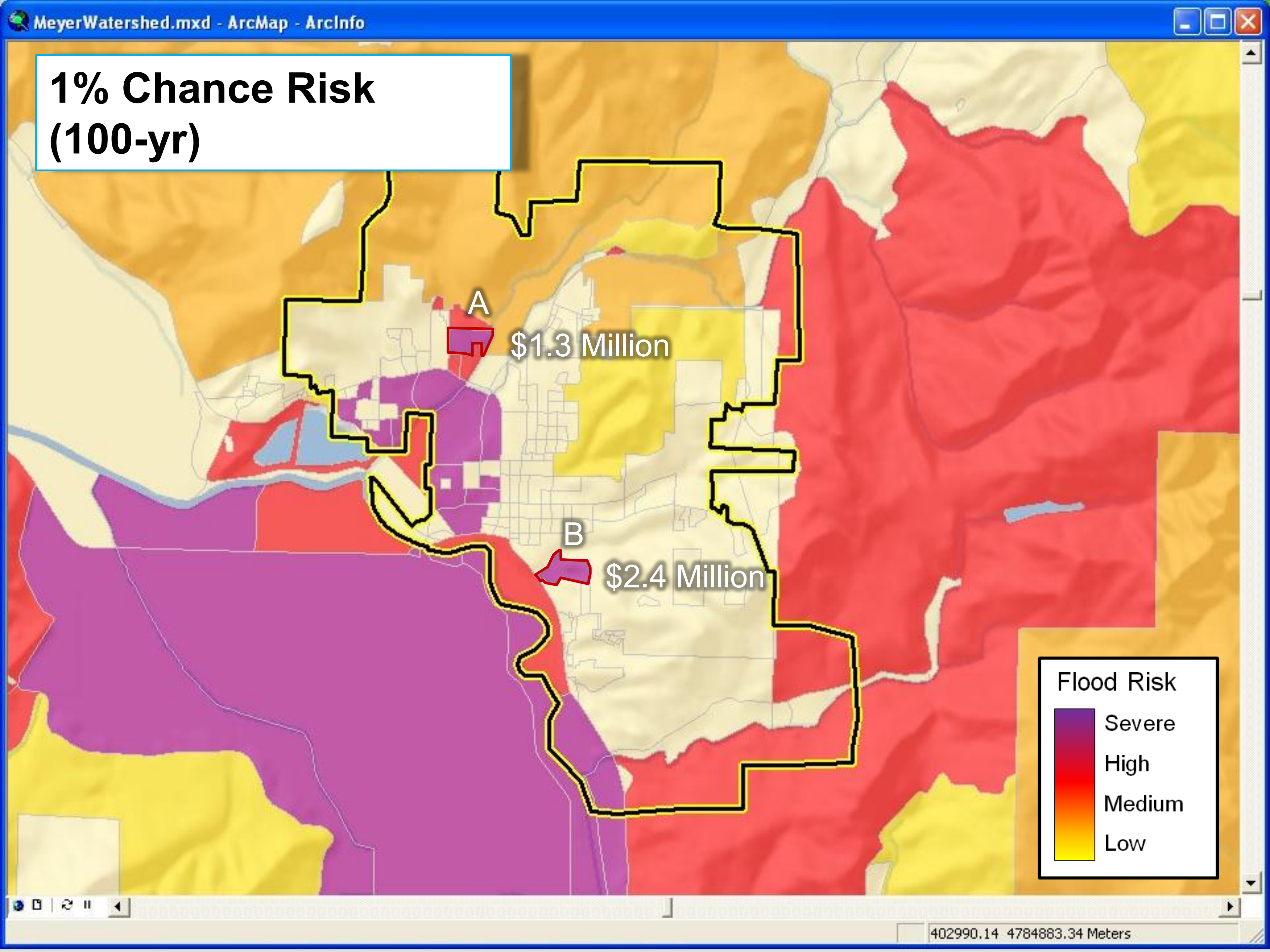



MeyerWatershed.mxd - ArcMap - ArcInfo
10% Chance Risk
(10-yr)
A
$370,000
B
$670,000
Flood Risk
Severe
High
Medium
Low
404582.72 4784209.96 Meters

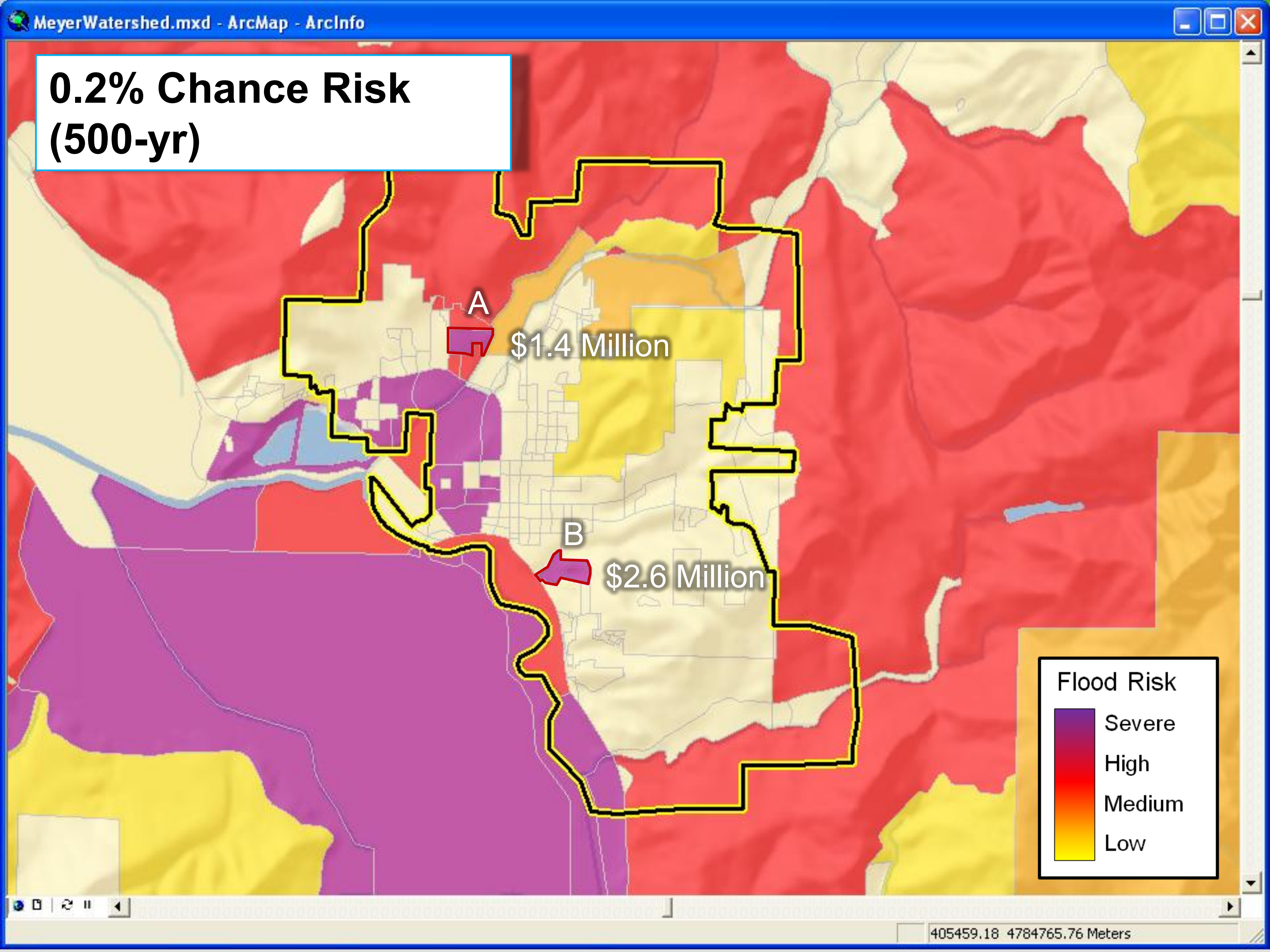


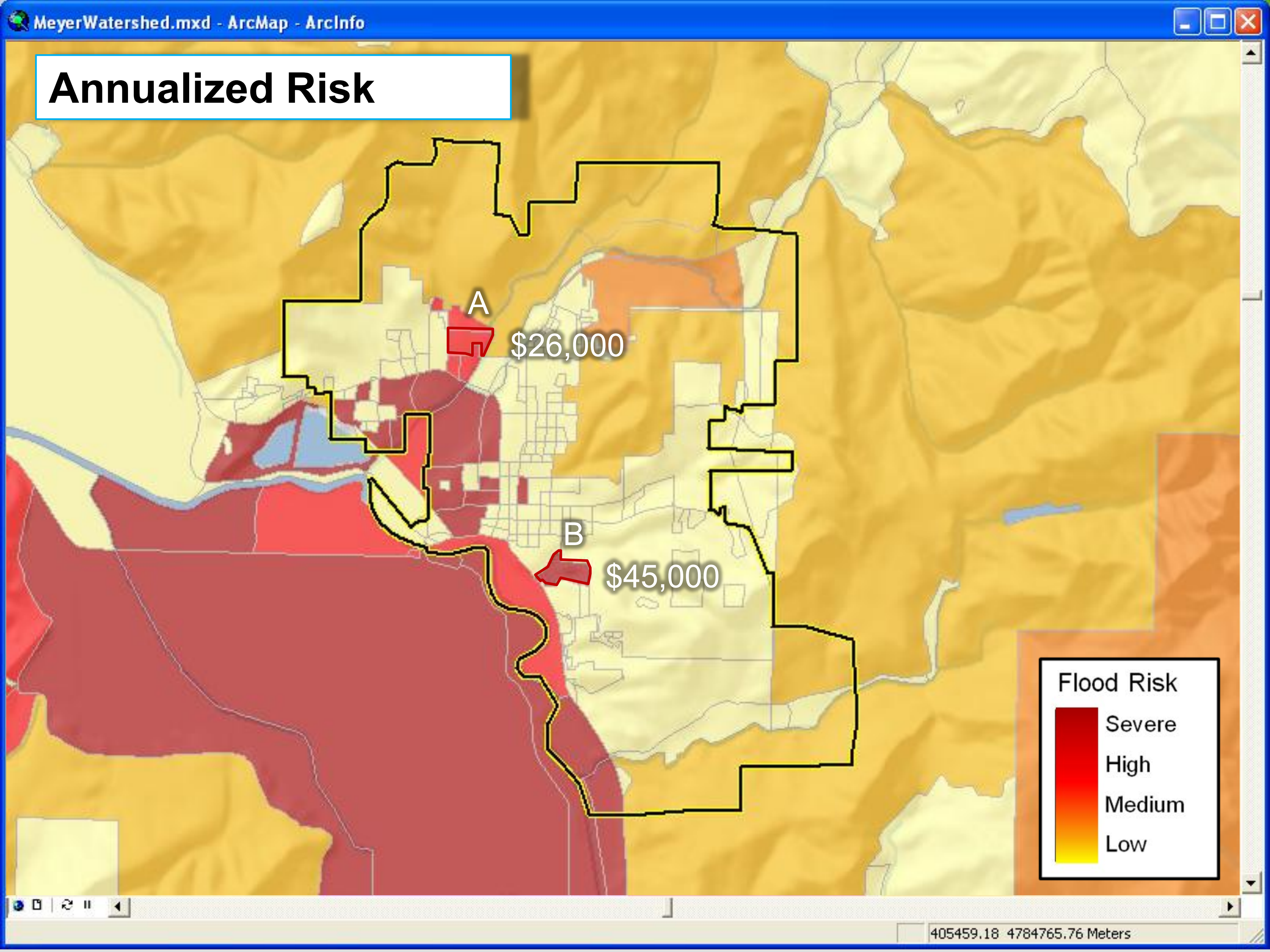
MeyerWatershed.mxd - ArcMap - ArcInfo
4% Chance Risk
(25-yr)
A
$870,000
B
$1.6 Million
Flood Risk
Severe
High
Medium
Low
400104.25 4784872.65 Meters


MeyerWatershed.mxd - ArcMap - ArcInfo
2% Chance Risk
(50-yr)
A
$1.1 Million
B
$2.0 Million
Flood Risk
Severe
High
Medium
Low
404304.82 4784883.34 Meters



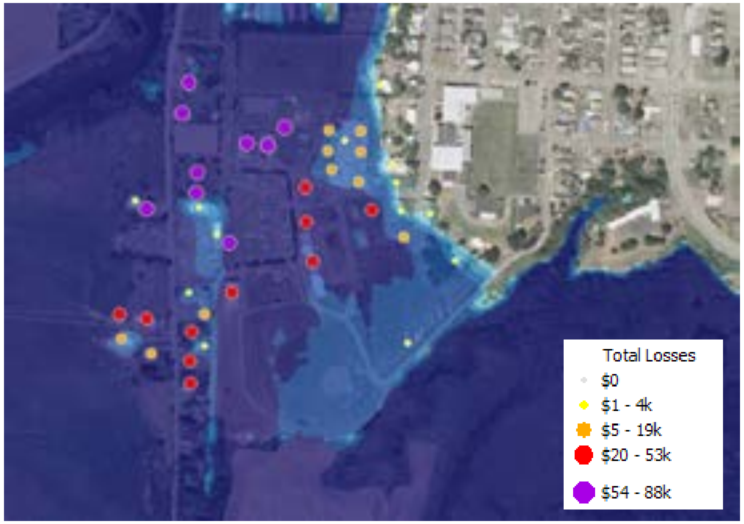
MeyerWatershed.mxd - ArcMap - ArcInfo
1% Chance Risk
(100-yr)
A
$1.3 Million
B
$2.4 Million
Flood Risk
Severe
High
Medium
Low
402990.14 4784883.34 Meters

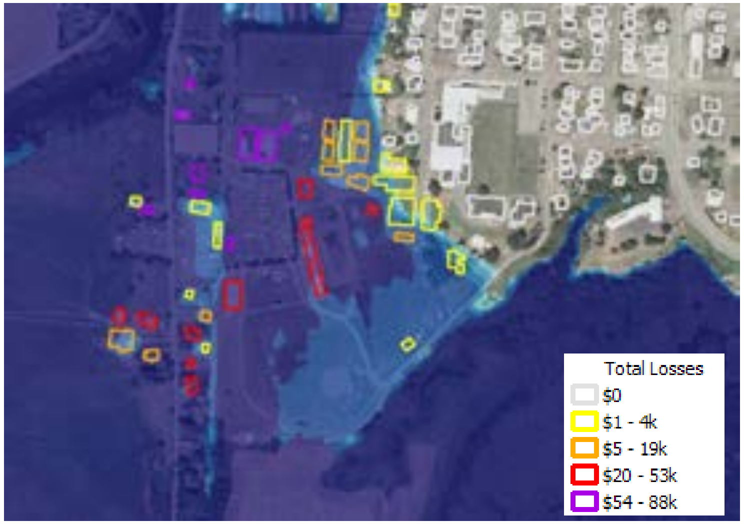

MeyerWatershed.mxd - ArcMap - ArcInfo
0.2% Chance Risk
(500-yr)
A
$1.4 Million
B
$2.6 Million
Flood Risk
Severe
High
Medium
Low
405459.18 4784765.76 Meters


MeyerWatershed.mxd - ArcMap - ArcInfo
Annualized Risk
A
$26,000
B
$45,000
Flood Risk
Severe
High
Medium
Low
405459.18 4784765.76 Meters

Enhanced Risk Assessment Analyses

- **Enhancements could include:**
  - Risk Assessments at site-specific locations
  - Incorporation of locally-provided inventory data (first-floor elevations and/or parcel data)
  - Additional sources of flood depth grids
  - Supplemental HAZUS analyses or other types of analyses





Content Scalability

- **Base** ☑
  - ☑ HAZUS analysis for reaches with new or updated studies where depth grids can be generated
  - ☑ Should include 10%, 4%, 2%, 1%, and 0.2% annual chance events and Annualized Loss
  - ☑ HAZUS GBS Losses (dollar losses, percent damage, business disruption)
- **Enhancements** ✸
  - ✸ Additional events
  - ✸ Additional HAZUS loss calculations (infrastructure, critical facilities, user-defined facilities)
  - ✸ Use of local data to updated/supplement HAZUS data
  - ✸ Non-HAZUS analysis methods (needs to provide same base loss estimates)

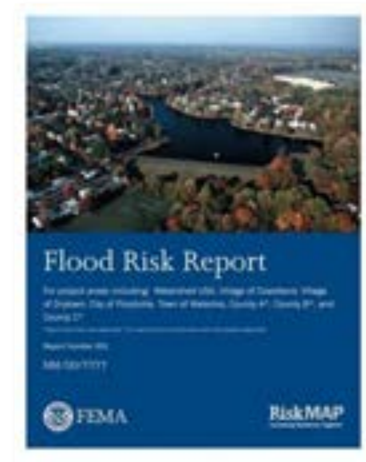
Flood Risk Assessment Distribution Context

Flood Risk Map

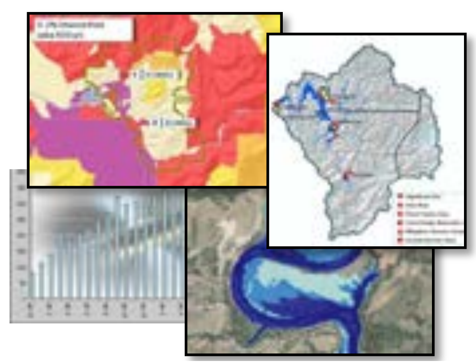
Flood Risk Database

Flood Risk Assessment Data →
Flood Depth & Analysis Grids →

← Changes Since Last FIRM Data
← Areas of Mitigation Interest



Flood Risk Report



Ad-Hoc Flood Risk Analyses

FEMA

Areas of Mitigation Interest (Enhanced)

RiskMAP

Increasing Resilience Together

Purpose and Intended Uses

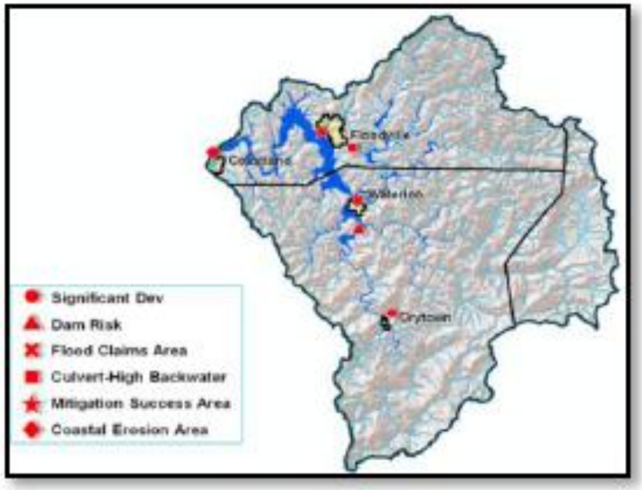
- Creating public and community awareness of issues affecting flooding and risk
- Providing “food for thought” for communities to sharpen focus and research toward future plan updates and project development
- Identifying interrelationships between upstream/downstream community issues within a watershed
- Using existing areas of focus in mitigation plans to broaden awareness to new audiences
- Showing examples between communities and the public of what has worked in other areas to reduce damages
- Demonstrating that both existing physical hydraulic features (e.g. pinch points) and future development actions (e.g. significant proposed development) can have impacts and much different mitigation techniques
- Increasing public awareness of areas where actions can be taken to reduce risks

Overview - Areas of Mitigation Interest

Items that may have an impact (positive or negative) on the identified flood hazards and/or flood risks- Examples include:

- Community Identified “Hot Spots”
- Previous Claim Areas (e.g. clusters of claim, RL, SRL)
- Riverine and Coastal Flood Control Structures

  (e.g. dams, levees, coastal berms, etc)
- Floodplain “Pinch Points” (e.g. undersized culverts and bridge openings, etc.)
- Significant proposed and recent floodplain development
- Locations of successful mitigation projects



Visualization of
Areas of Mitigation Interest

Sources of Data

- Community Provided Data
  - Interviews and survey from Discovery Meeting
  - Mining of existing mitigation plans
- Engineering Data
  - Review of existing H&H models
  - Engineering data from other reports (e.g. USACE)
- Other Government Agency Data
  - Claims data (inc. RL, SRL, clusters, etc)
  - CNMS data
  - Flood control structures

Verification and Ownership

Data primarily provided by the communities in the study area

- Intention is not to commit or prove that areas of interest are contributing to flooding or risk
- Intention is to provide focus on areas that the communities and the government think are worthy of further research to determine mitigation potential
- FEMA will not claim ownership or guarantee accuracy of the data but will not use data that does not pass the “straight face” test

Mitigation Planning Linkages

There are several required areas for mitigation plans for which Areas or Mitigation Interest might be helpful:

Risk Assessment Product	Mitigation Planning Requirement
Areas of Interest	✓*44 CFR Part 201(d)(3), revise plans to reflect changes* ✓*44 CFR Part 201.6(c)(2)(i), profiling hazards* ✓*44 CFR Part 201.6(c)(2), risk assessment* ✓*44 CFR Part 201.6(c)(3), developing mitigation strategies*

Content Scalability

- **Base** ☑
  - Not currently included within Base
- **Enhancements** ✸
  - In FY 2010 Areas of Mitigation Interest is being offered as an enhancement only
  - As the dataset is better defined it is anticipated that it will become a base product with enhancement options in future years

Areas of Mitigation Interest Distribution Context

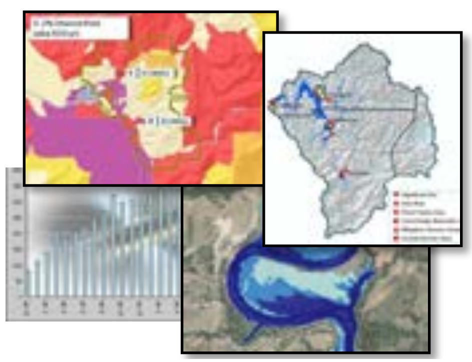
Flood Risk Map

Flood Risk Database

Flood Risk Assessment Data →
Flood Depth & Analysis Grids →

← Changes Since Last FIRM Data
← Areas of Mitigation Interest

Flood Risk Report



Ad-Hoc Flood Risk Analyses

FEMA

Flood Risk Products

- Flood Risk Database
- Flood Risk Report
- Flood Risk Map

RiskMAP
Increasing Resilience Together

FEMA

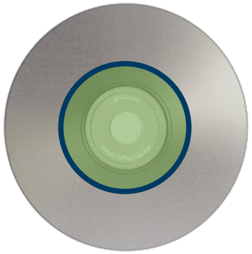
Flood Risk Database

RiskMAP

Increasing Resilience Together

Flood Risk Database

- **Primary Storage Device for:**
  - Flood Risk Data
- **Stores Data to Create:**
  - Flood Risk Report
  - Flood Risk Map
- **Delivered Digitally to Stakeholders:**
  - CD Delivery



Data Delivered

Flood Risk Database (red = enhanced)

Changes Since Last FIRM

- Horizontal Changes and Results
- Structure/Population counts impacted by change

Depth & Analysis Grids

- Depth (10, 04, 02, 01, 0.2 percent chance)
- Percent Annual Chance
- Percent 30-Year Grid
- Delivery of Water Surface Elevation (multi-freq)
- Water Surface Elevation Change Grid (multi-freq)
- Velocity Grids, Annualized Depth, Top and Toe of Levee
- Multi Freq Grids for Levee and Coastal Areas, etc.

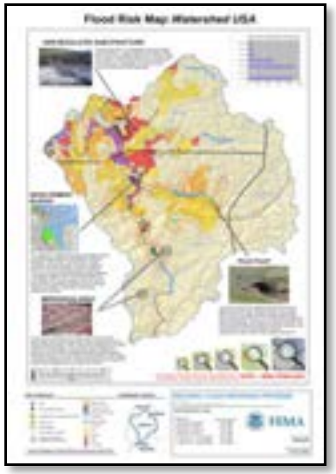
Flood Risk Assessment

- Average Annualized Loss – 2010
- Refined Flood Risk Assessment
- HAZUS or Non-HAZUS with improved data/assumptions

Areas of Mitigation Interest

- Areas of Mitigation Opportunity or Awareness

Distribution Context



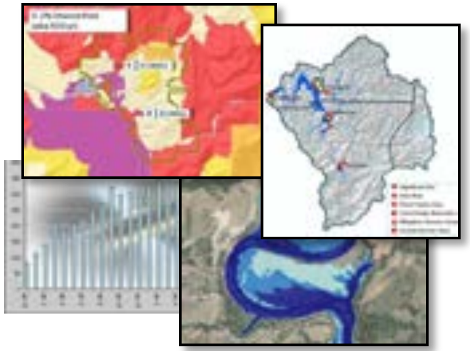
Flood Risk Map

Flood Risk
Database

Flood Risk Assessment Data →
Flood Depth & Analysis Grids →

← Changes Since Last FIRM Data
← Areas of Mitigation Interest

Flood Risk Report



Ad-Hoc Flood Risk Analyses

Flood Risk Report

RiskMAP

Increasing Resilience Together

Flood Risk Report – Potential Uses

- **Increase General Flood Risk Awareness**
  - Risk Definitions and Causes
  - Risk Reduction Techniques and Mitigation Practices
- **Deliver Community and Project Level Results**
  - Project Results Summarized by:
    - Communities
    - Watershed or Project Area
- **Provide Information to Augment or Enhance Other Efforts**
  - Local Hazard Mitigation Planning
  - Local Emergency Management Planning
  - Local Master Planning and Building Development

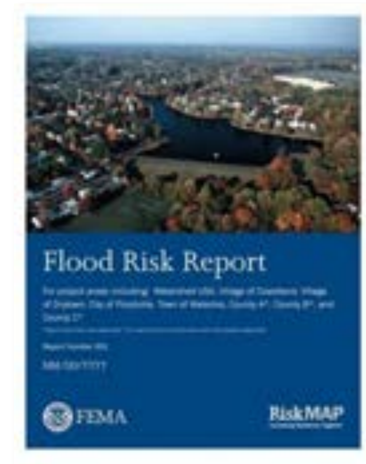
Flood Risk Report Distribution Context

Flood Risk Map

Flood Risk Database

Flood Risk Assessment Data →
Flood Depth & Analysis Grids →

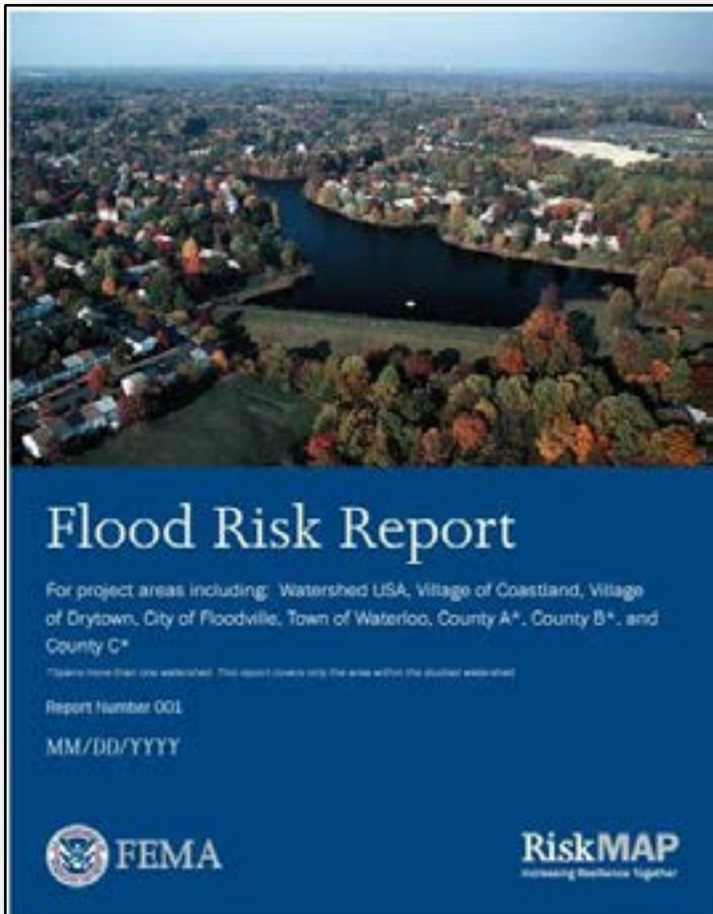
← Changes Since Last FIRM Data
← **Areas of Mitigation Interest**



Flood Risk Report

Ad-Hoc Flood Risk Analyses

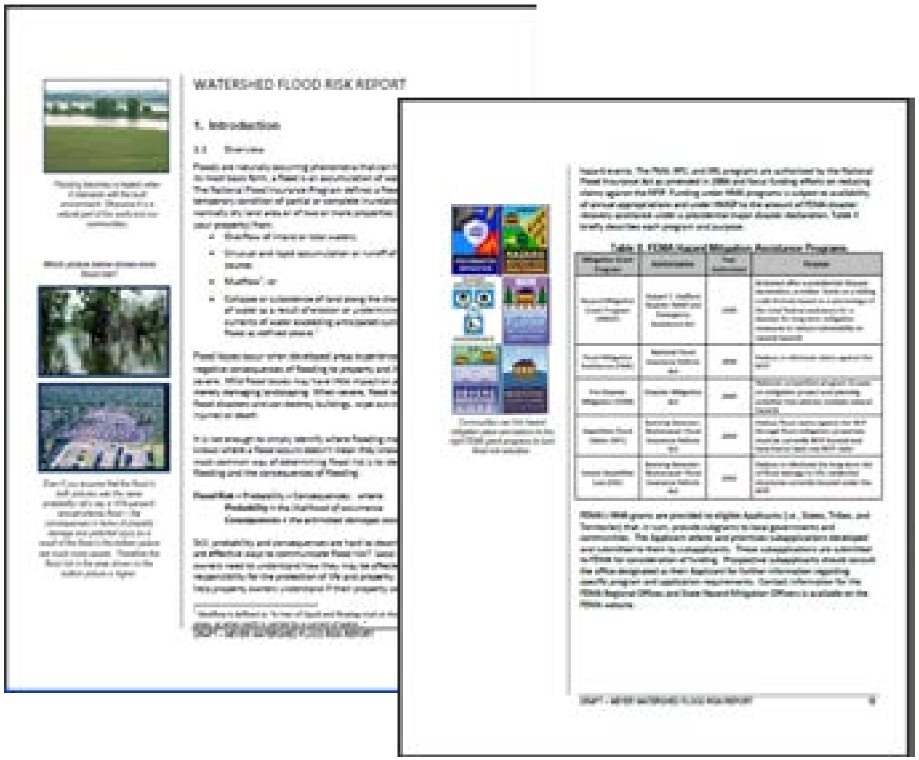
Content Overview



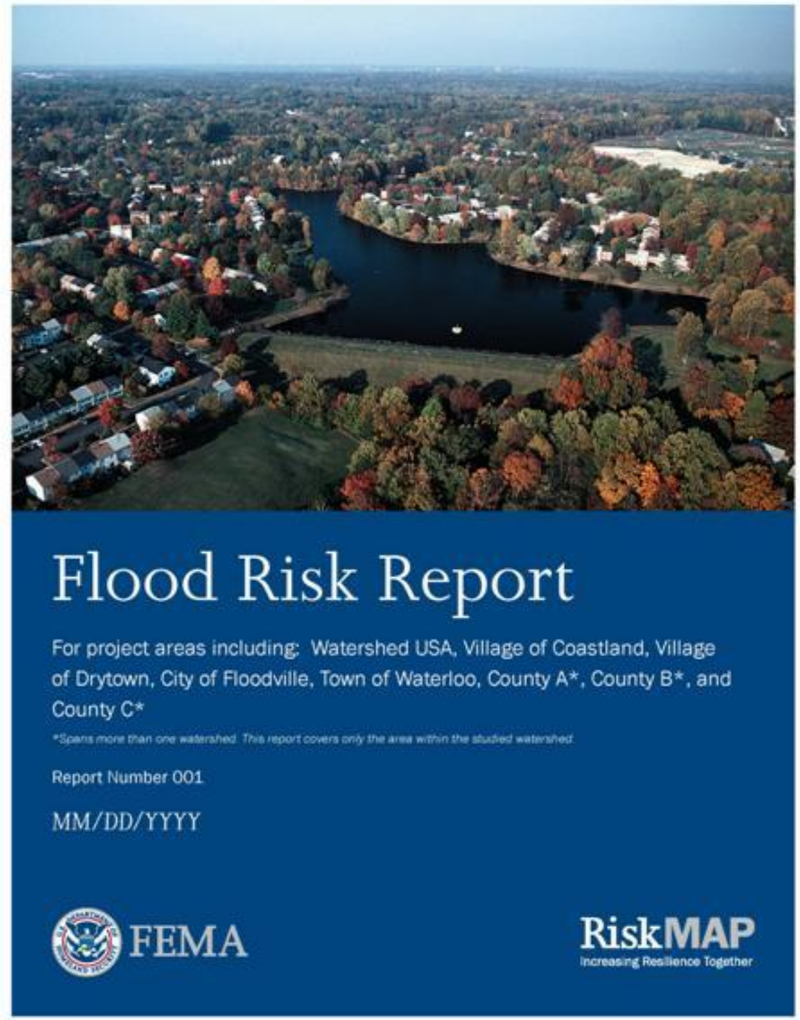
- **Background:**
  - Purpose, Methods
  - Risk Reduction Practices
- **Project Results**
  - Changes Since Last FIRM
  - Depth & Analysis Grids
  - Flood Risk Assessment
  - (enhanced analyses)
    - e.g. Areas of Mitigation Interest
- **Summarized by Locations**
  - Communities and Watersheds

Content – Details

Risk Awareness Information

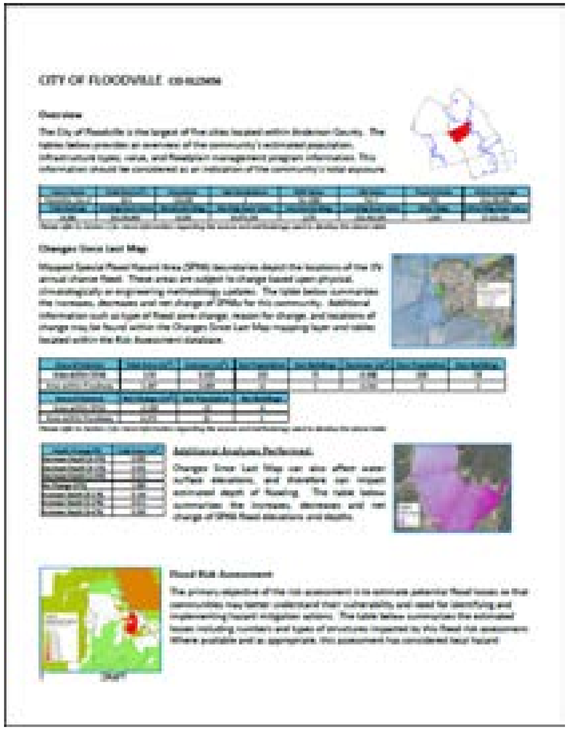

WATERSHED FLOOD RISK REPORT

1. Introduction



Content – Details

Community Summaries

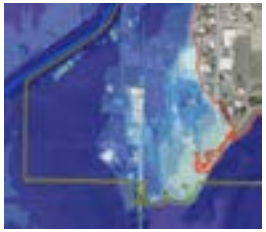

CITY OF FLOODVILLE

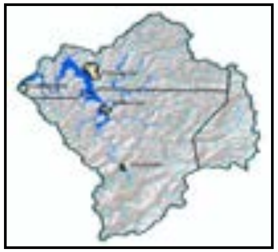
Overview

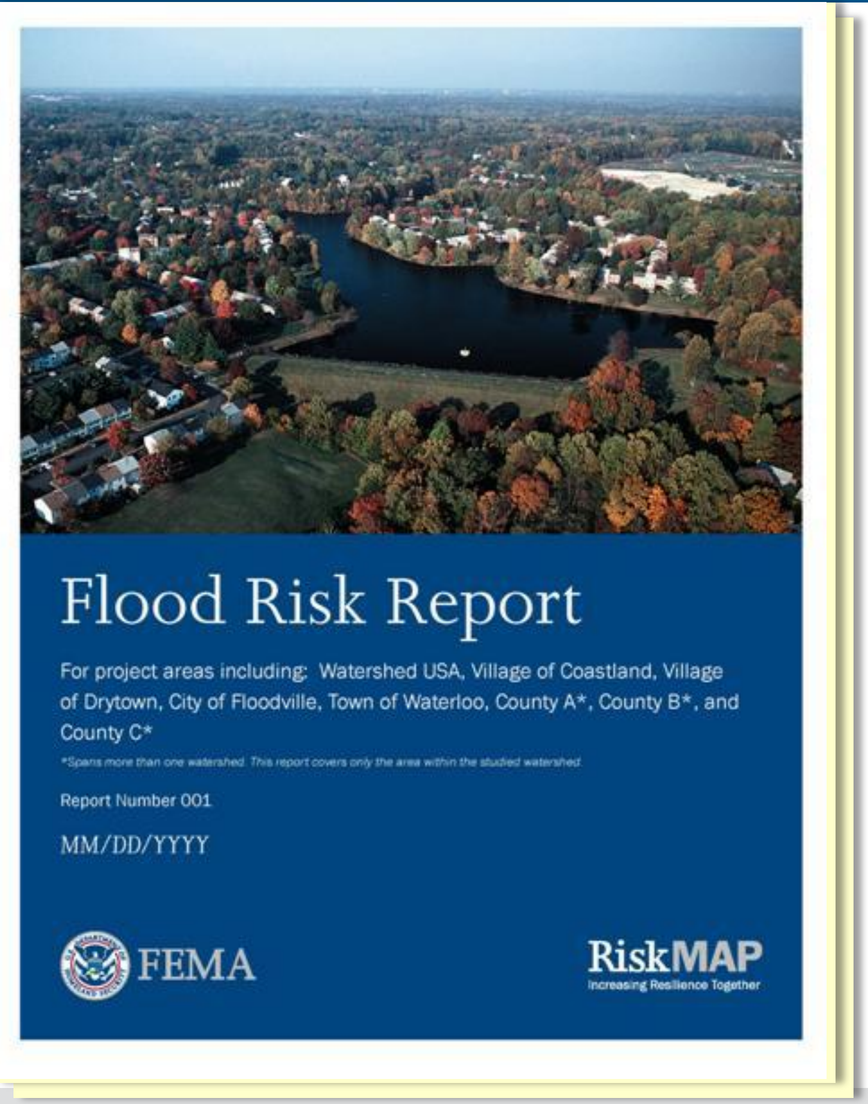
Changes Since Last Map

Additional Analyses Performed

Flood Risk Assessment

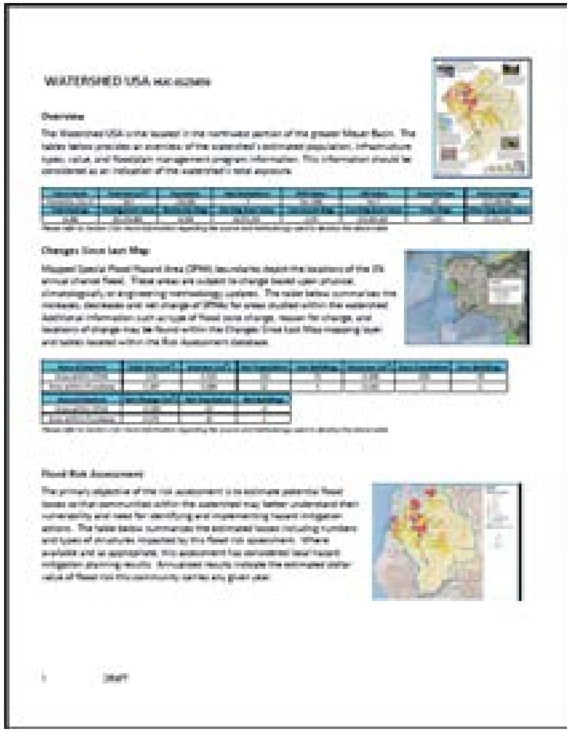


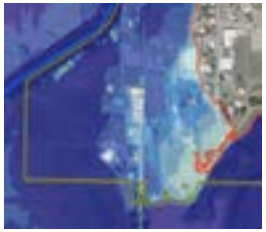


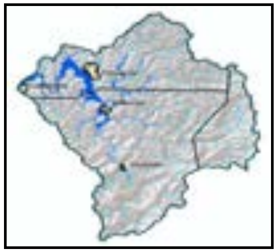


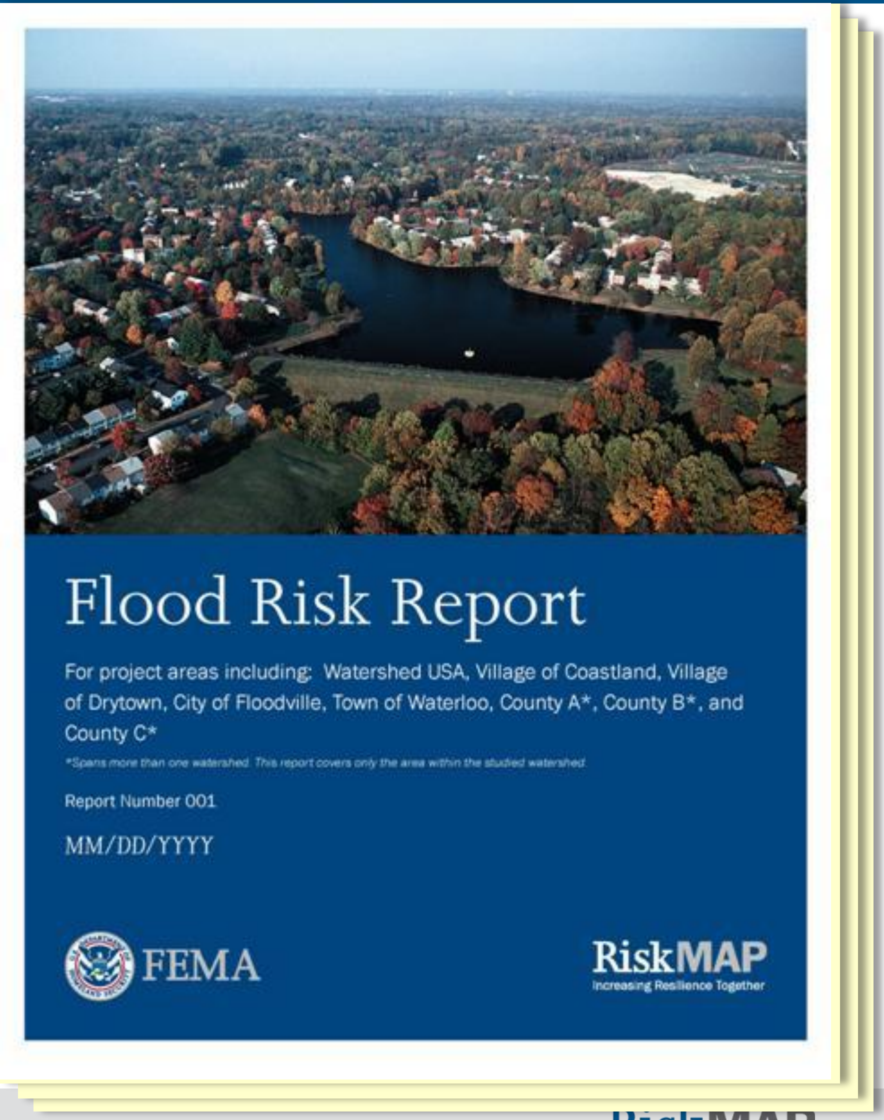
Content – Details

Watershed /Project Level Summary

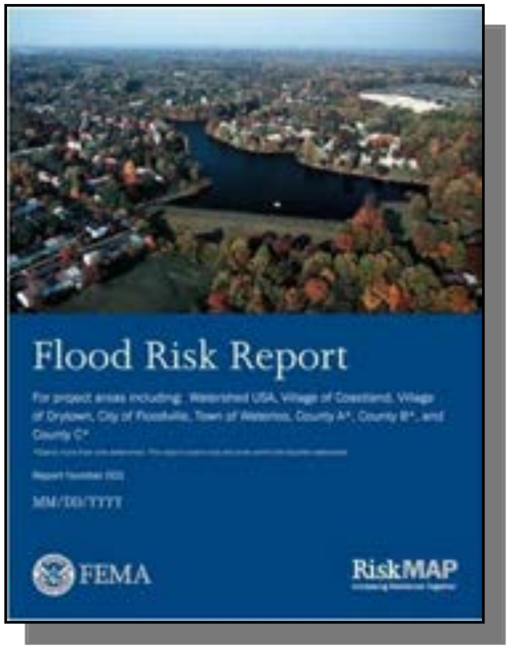


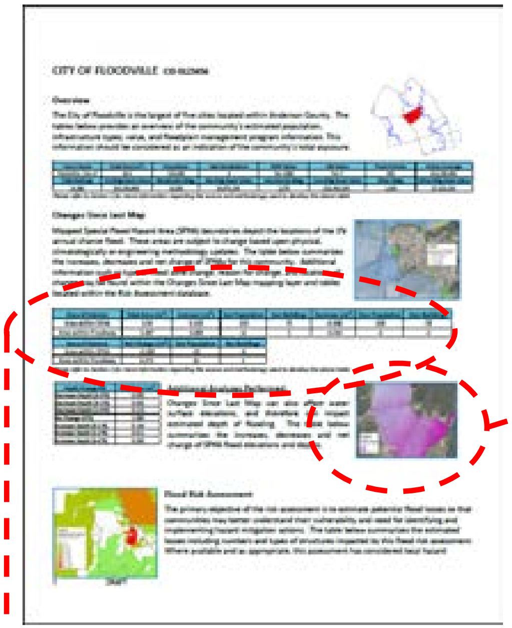






CSLF within the Flood Risk Report





Area of Interest	Total Area (mi^2)	Increase (mi^2)	Incr Population	Incr Buildings	Decrease (mi^2)	Decr Population	Decr Buildings
Area within SFHA	21.082	1.038	1,785	4,939	-2.556	-1,909	-647
Area within Floodway	3.2121	0.739	100	42	-0.1328	-17	-17

Area of Interest	Net Change (mi^2)	Net Population	Net Buildings
Area within SFHA	-1.519	-124	4,291
Area within Floodway	3.0793	83	25

Enhanced

Content – Details and Scalability

Flood Risk Report Tables

Flood Risk Assessment (example)

Watershed USA's flood risk assessment incorporates results from recently performed HAZUS-MH Level 1 and 2 analyses taken from local hazard mitigation plans. FEMA updated these analyses to account for newly modeled areas throughout the watershed and more detailed building locations and values provided by the local governments. The highest areas of flood risk were concentrated in the City of Floodville as well as unincorporated portions of the watershed along Indian Creek. This area accounts for nearly 70% of the watershed's total estimated flood risk and should be evaluated for potential risk reduction activities

Pecent Chance Event	Total Asset Loss		Residential Asset Loss			Commercial Asset Loss			Other Asset Loss			Business Disruption
	Dollar Losses	Percent Damage	Units	Dollar Losses	Percent Damage	Units	Dollar Losses	Percent Damage	Units	Dollar Losses	Percent Damage	
10% (10-yr)	$15,212,203	4.55%	706	$10,439,703	13.66%	42	$3,112,500	1.55%	33	$1,660,000	0.33%	$760,610
4% (25-yr)	$20,519,895	6.13%	913	$11,804,895	15.44%	66	$4,980,000	2.48%	75	$3,735,000	0.75%	$1,025,995
2% (50-yr)	$25,191,613	7.53%	1,079	$13,571,613	17.76%	83	$6,225,000	3.10%	108	$5,395,000	1.08%	$1,259,581
1% (100-yr)	$40,230,797	12.02%	1,992	$19,273,297	25.22%	125	$9,337,500	4.64%	232	$11,620,000	2.33%	$2,011,540
0.2% (500-yr)	$81,480,216	24.35%	2,532	$32,925,216	43.08%	415	$31,125,000	15.48%	349	$17,430,000	3.50%	$4,074,011
Annualized ($/yr)	$365,269			$176,029			$109,560			$79,680		$18,263

Content – Details and Scalability

Areas of Mitigation Interest (enhanced example)

Areas of Mitigation Interest

Factor	Data Source	Why a Contributing Factor	Possible Solutions
Dams (small)	National Inventory of Dams (USACE)	Increases flooding upstream along their impoundment shorelines. In there is an extremely high number of dams	Engineering assessment/EAP (State Dam Safety Program); dam removal (NRCS)
Non-Accredited Levee	National levee survey (USACE)		
Coastal Structures Creating Erosion	NOAA National Shoreline Survey State Coastal Zone Management Programs' Beach Management Plans	"Hardening" of the shoreline interrupts the dynamic processes of the littoral flow which results in accelerated coastal erosion. Structures include: jetties, groins, sea walls, breachways	Increase coastal setbacks for construction (State Coastal Zone Management Program) Habitat restoration programs (USACE) Wetland restoration and mitigation banking programs (EPA/ State DEM/DNR)
Flow Pinch Point	State Stormwater Management Programs (per EPA 310 Program). community surveys from scoping	These refer to drainage structures such as road/bridge culverts and when undersized and have outlived their intended capacity can result in increased flood depths within the vicinity and in areas immediately upstream	Engineering Analysis, re-engineering and replacement of structures pre- and post-disaster (FEMA HMA Grants, 406 mitigation, capitol improvement planning)
Undersized Culvert	State/Local Hazard Mitigation Plans Stormwater management plans, community surveys from scoping	These refer to drainage structures such as road/bridge culverts and when undersized and have outlived their intended capacity can result in increased flood depths within the vicinity and in areas immediately upstream	Engineering Analysis, re-engineering and replacement of structures pre- and post-disaster (FEMA HMA Grants, 406 mitigation, capitol improvement planning)
Impervious Area Hot Spot	Stormwater Management Plan; Water Quality Management Plan (EPA; State DEMs/DNRs)	Increases the speed and geographical extent of flood discharges; increases speed of discharges may also increase flood depths in vicinity of discharges	Stormwater BMPs, green buildings and infrastructure, higher regulatory standards, stormwater management utility creation
Past Claims Hot Spot	FEMA NEXTGEN database; NFIP State Coordinator	Past claims, Repetitive Loss and Severe Repetitive Loss structures are indications that the locations of structures are contributing to losses	Mitigate through acquisition, elevation, relocation, flood-proofing
Proposed Development in SFHA	Community Comprehensive Plans State Growth Management Plan	Increases impermeable surface areas; interrupts/alters drainage and results in more frequent flooding of properties in low frequency	Higher regulatory standards, Stormwater BMPs, Transfer of Development rights, compensatory storage and equal conveyance standards, etc.

Points of Risk MAP Integration with Mitigation Planning

Mitigation Planning Component	Flow	Risk MAP Component
Risk Assessment	⟷	Watershed Flood Risk Report Flood Insurance Study (History)
Mitigation Strategy	⟷	Watershed Flood Risk Report (Areas of Mitigation Interest) Discovery Meeting (Are there mitigation actions that identify mapping or risk assessment priorities?) Resilience Meeting (After Risk MAP process are there new mitigation actions?)
Planning Process	⟷	Enhanced Stakeholder Group (Mitigation plan update group) Synchronize update or at least annual maintenance/monitoring Four Risk MAP meetings to reflect stakeholder input

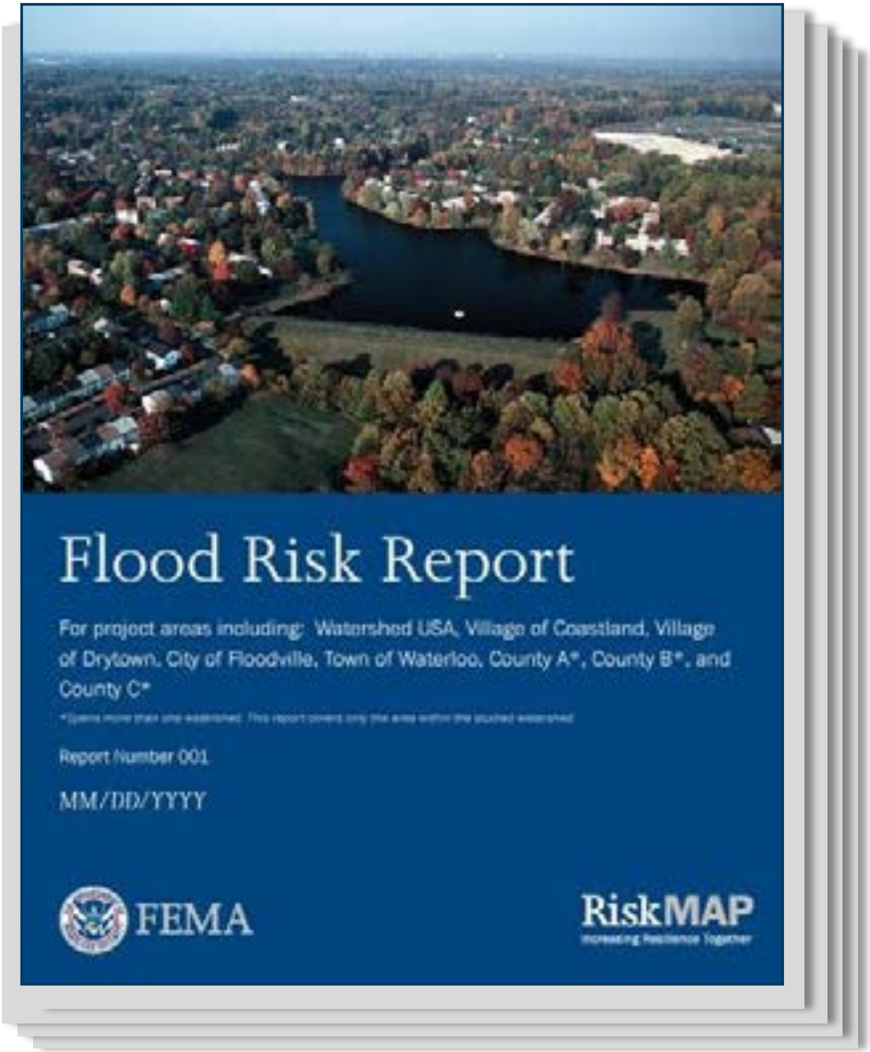
FEMA

Flood Risk Map

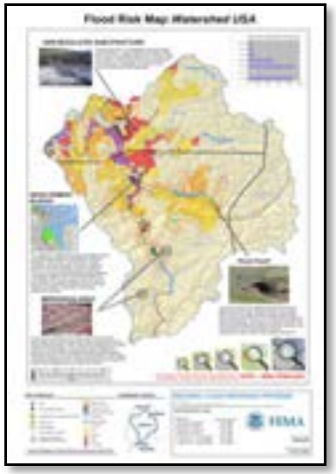
RiskMAP

Increasing Resilience Together

Flood Risk Map (accompanies and is a subset of the Flood Risk Report)



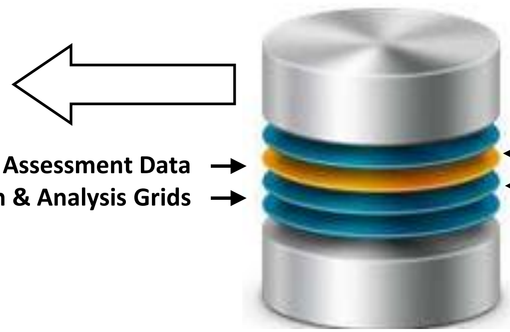
Flood Risk Map Distribution Context



Flood Risk Map

Flood Risk Database

Flood Risk Assessment Data →
Flood Depth & Analysis Grids →

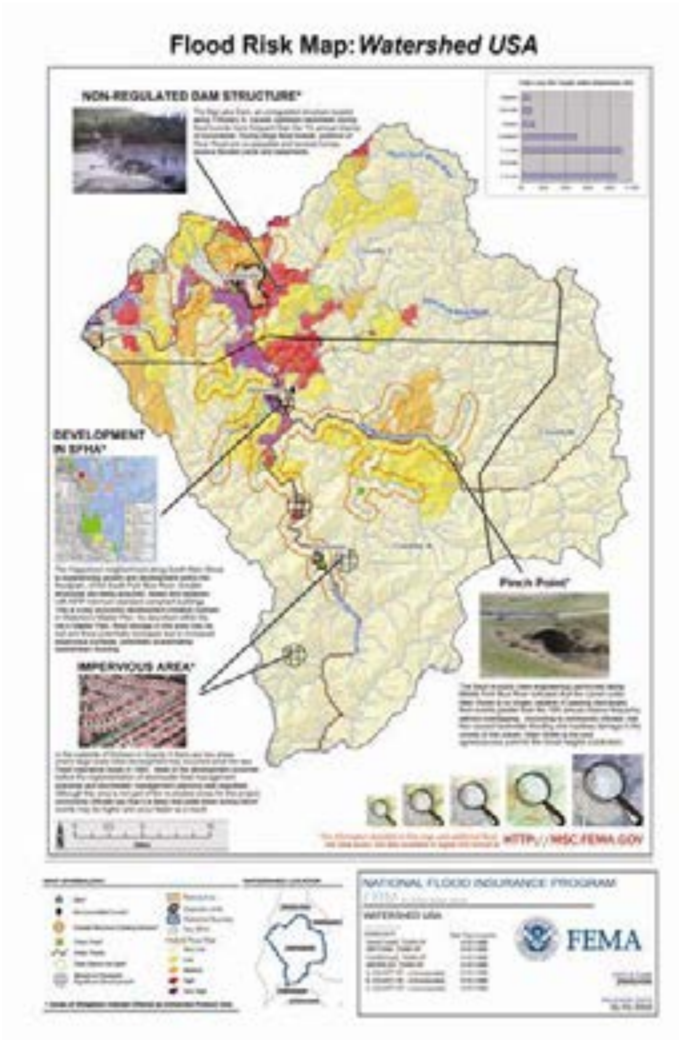


← Changes Since Last FIRM Data
← Areas of Mitigation Interest

Flood Risk Report

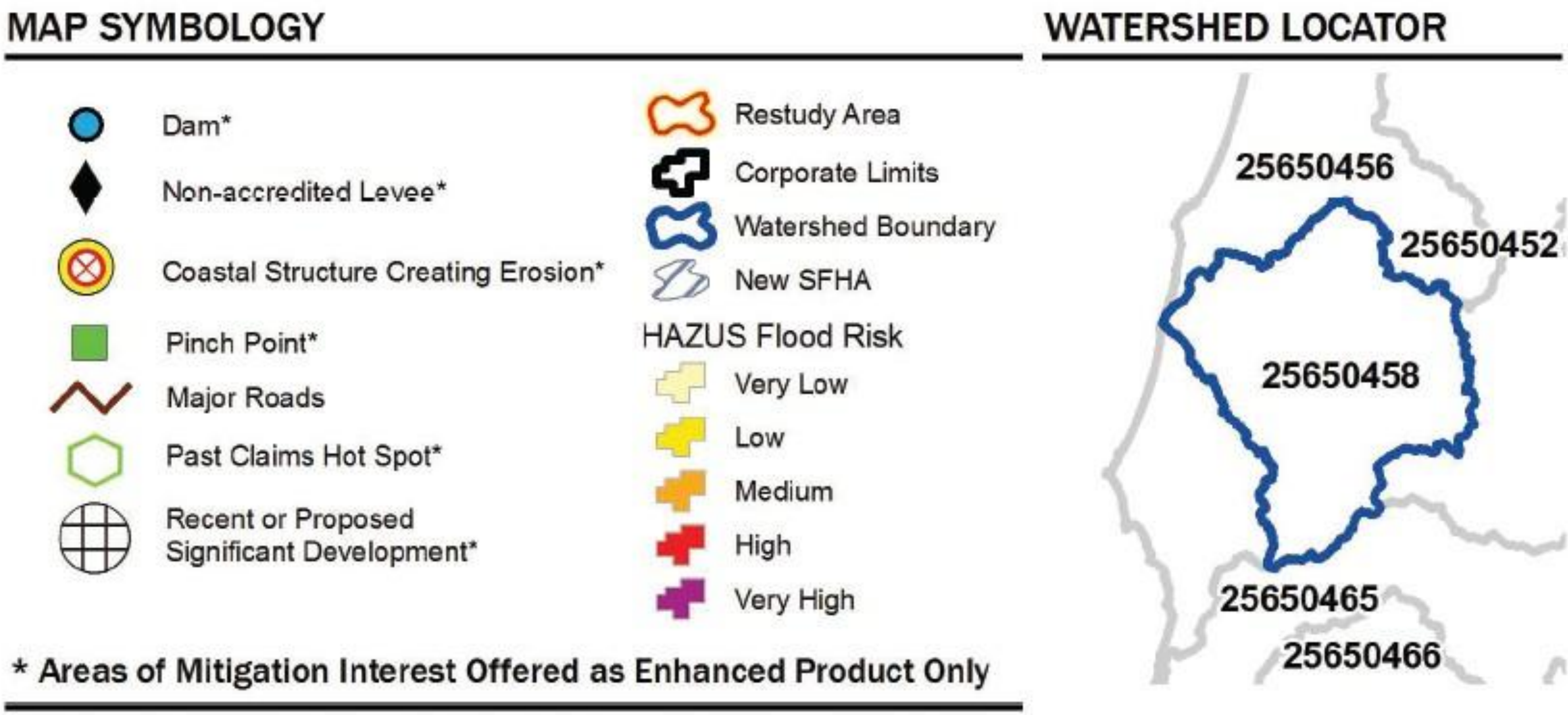
Ad-Hoc Flood Risk Analyses

Flood Risk Map



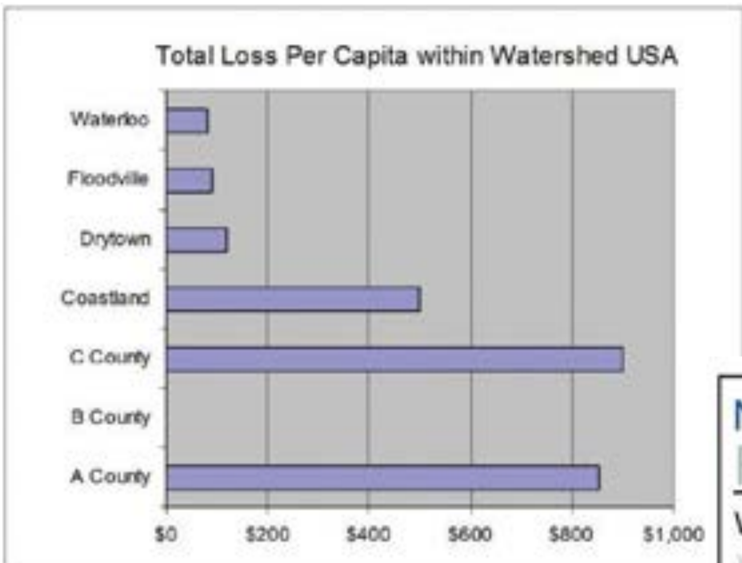
- **Visually Promotes Risk Awareness**
  - Contains results of Risk MAP project non-regulatory datasets
  - Promotes additional flood risk data not shown but located within the Flood Risk Database

Flood Risk Map



Flood Risk Map

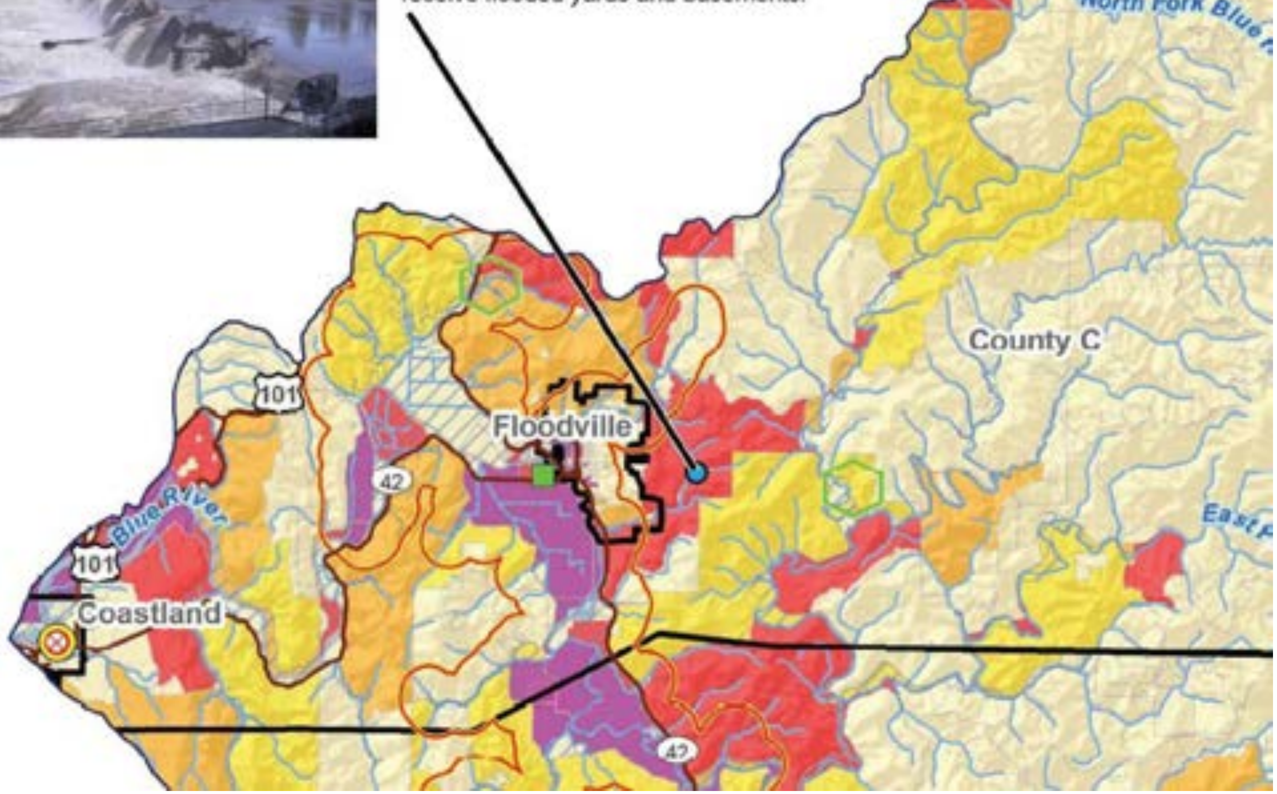
Community Level per Capita Losses



Flood Risk Map

NON-REGULATED DAM STRUCTURE*

The Big Lake Dam, an unregulated structure located along Tributary A, causes upstream backwater during flood events more frequent than the 1% annual chance of occurrence. During large flood events, portions of River Road are un-passable and several homes receive flooded yards and basements.



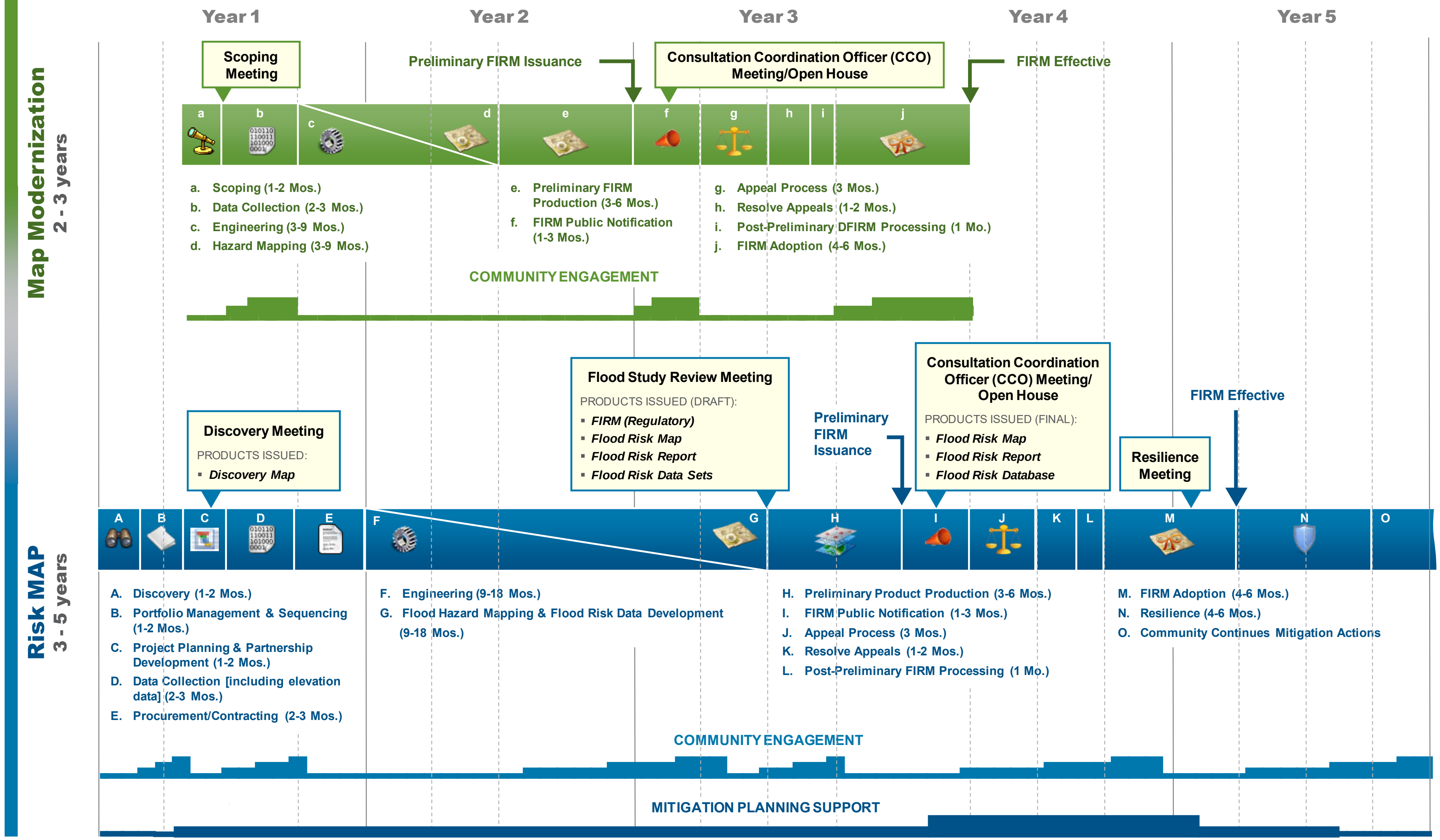
FEMA

Flood Risk Products – Project Lifecycle Overview

RiskMAP

Increasing Resilience Together

Map Modernization and Risk MAP Project Timelines



Questions???

RiskMAP
Increasing Resilience Together

Floodproofing Non-Residential Structures

Rules, Regulations and Structural Considerations

Presenters:

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Outline

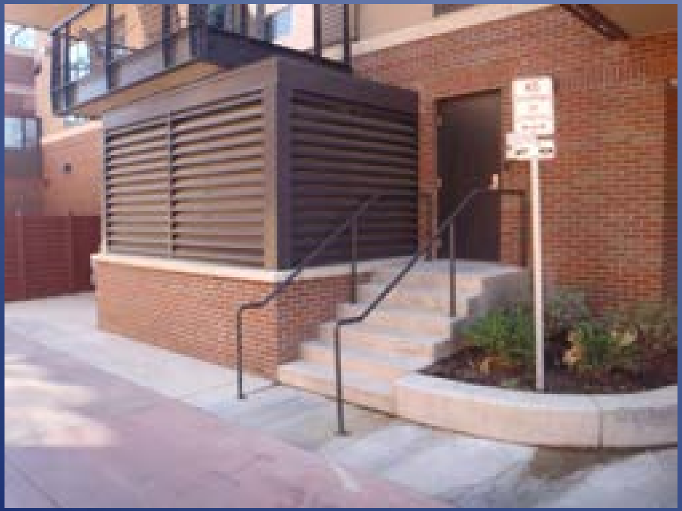
- Floodproofing Methods
- FEMA Requirements
- Structural Design
- Local Requirements
- Other Considerations

Floodproofing Methods

Wet Floodproofing

- Allow flood waters to enter and exit
- Equalize pressures
- Water resistant materials (TB-2)

Floodproofing Methods



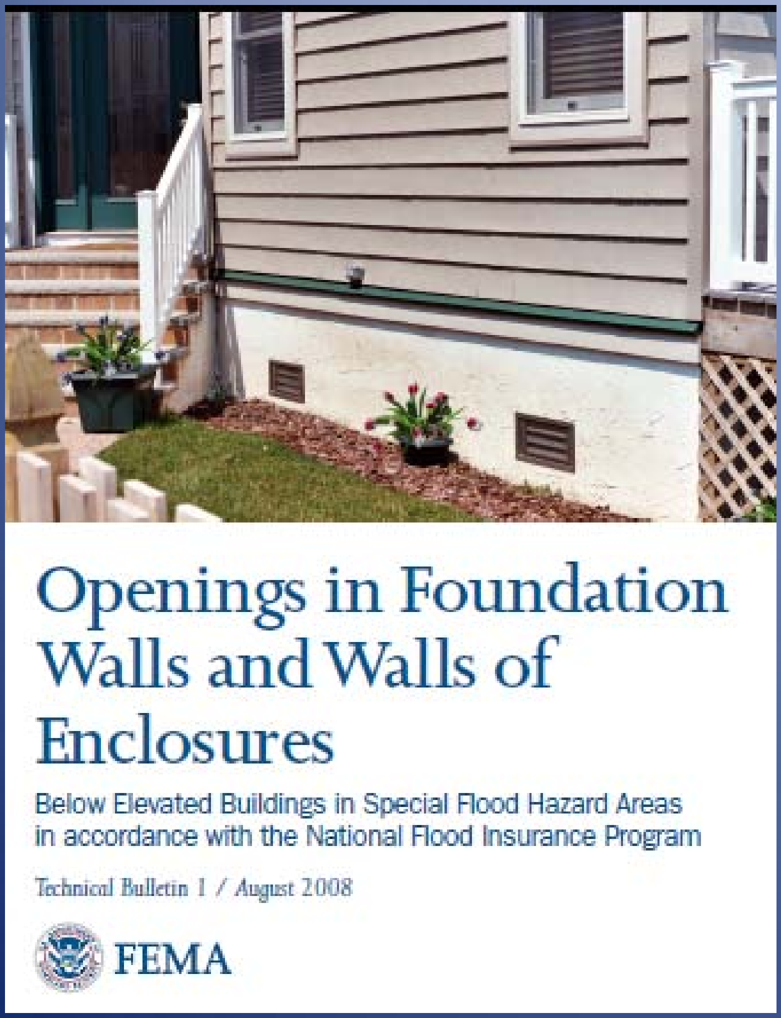
Dry Floodproofing

- Substantially impervious to water
- Allowable leakage (4-inches in 24 hours)

FEMA Floodplain Management Publications

- TB-1 – Openings in Foundation Walls
- TB-2 – Flood Damage-Resistant Materials Requirements
- TB-3 - Non-Residential Floodproofing -- Requirements and Certification
- TB-4 – Elevator Installation
- TB-5 - Free-of-Obstruction Requirements
- TB-6 - Below-Grade Parking requirements
- TB-7 - Wet floodproofing Requirements
- FEMA 102 - Floodproofing for Non-Residential Structures
- Army Corps of Engineers EP1165-2-314 - Flood Proofing Regulations

FEMA Technical Bulletins

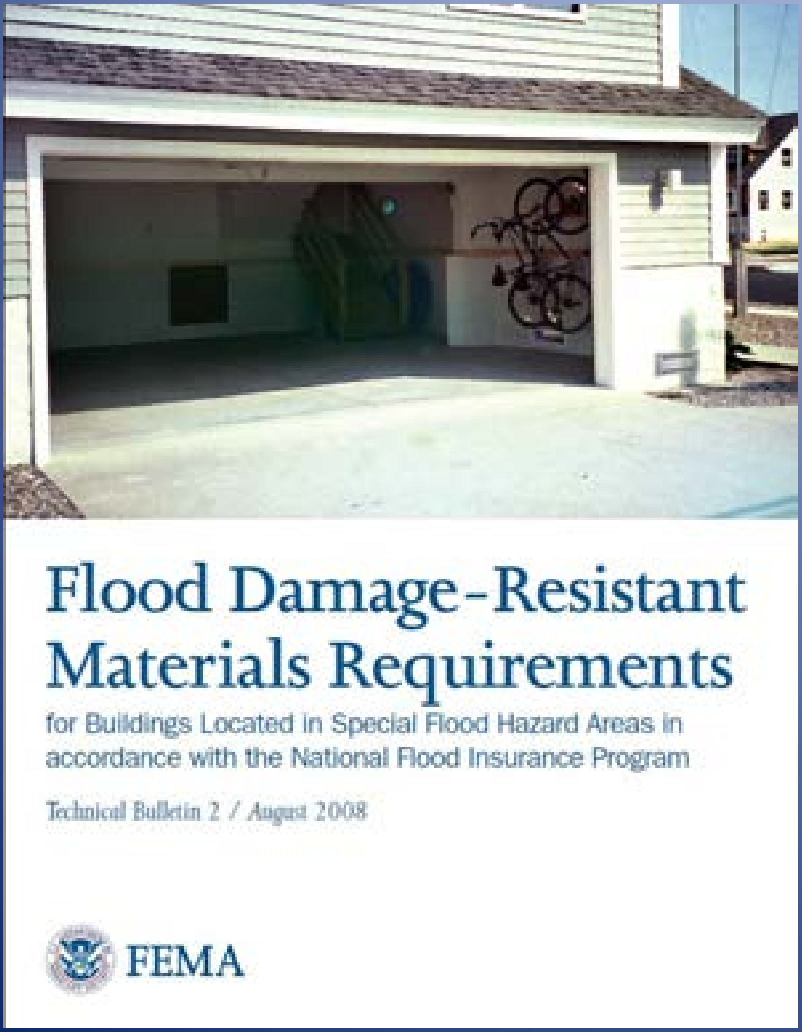


Technical Bulletin 1

Flood Vents – Wet Floodproofing

http://www.fema.gov/library/viewRecord.do?id=1579

FEMA Technical Bulletins

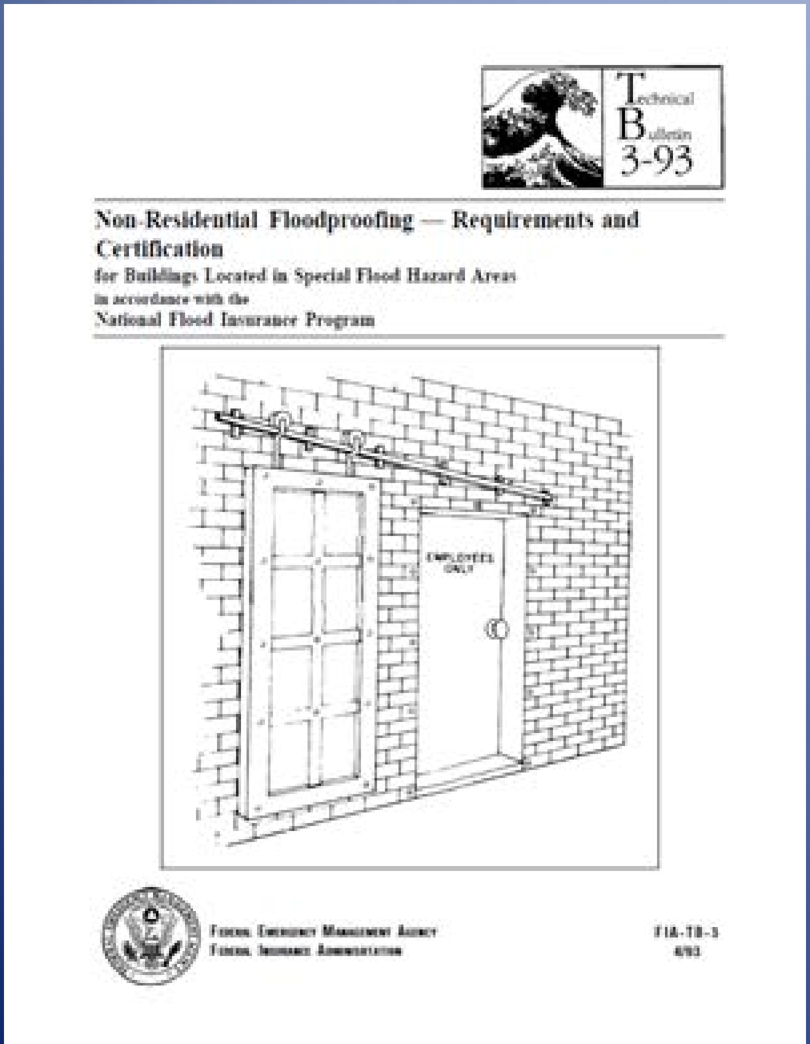


Technical Bulletin 2

Flood Resistant Materials

http://www.fema.gov/library/viewRecord.do?id=1580

FEMA Technical Bulletins

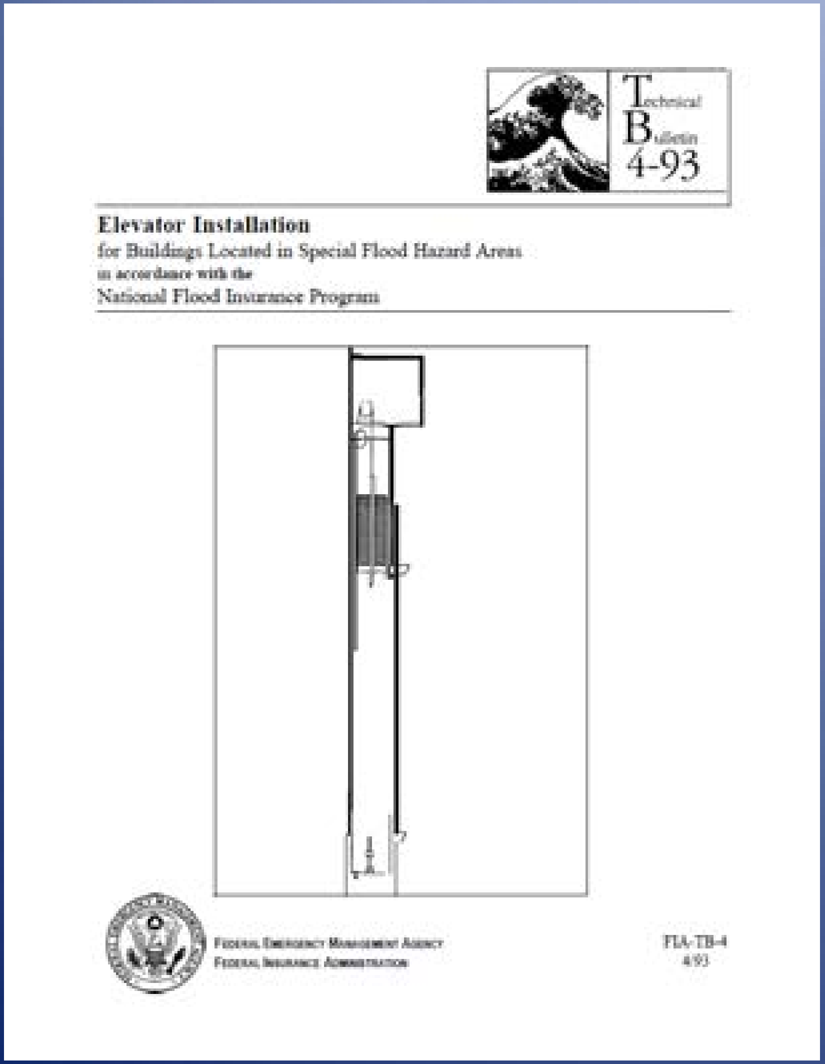


Technical Bulletin 3

Non-Residential Floodproofing

http://www.fema.gov/library/viewRecord.do?id=1716

FEMA Technical Bulletins

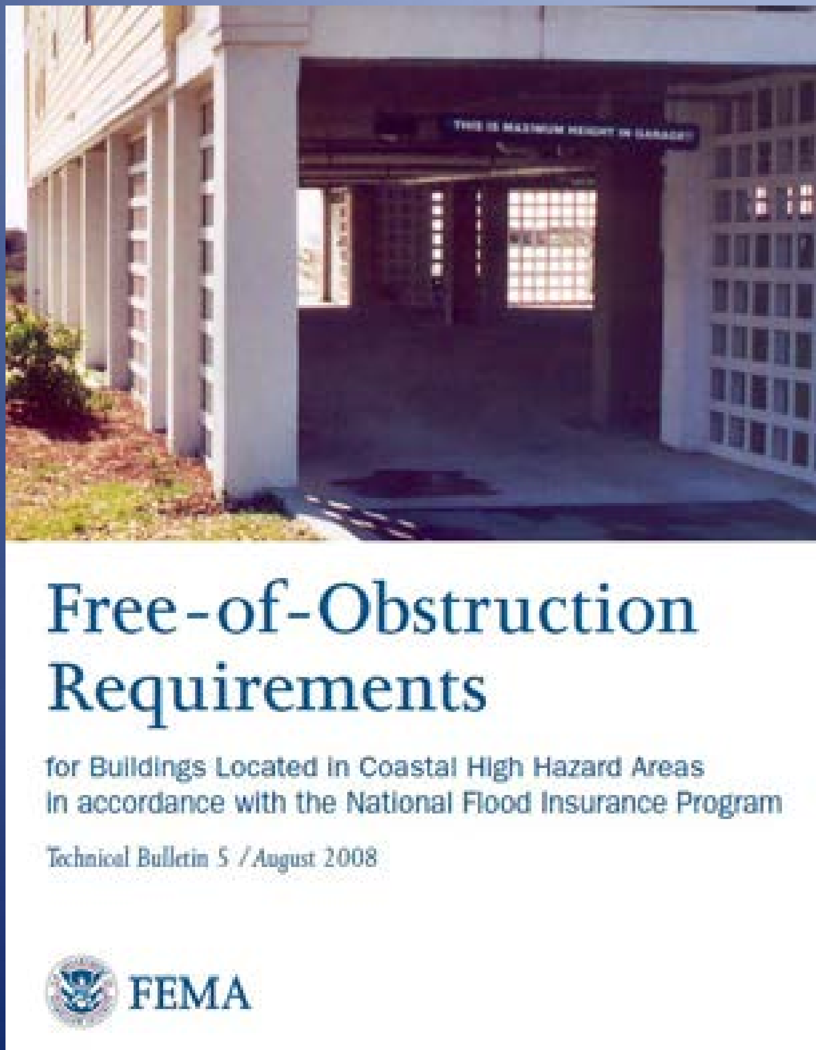


Technical Bulletin 4

Elevator Installation

http://www.fema.gov/library/viewRecord.do?id=1717

FEMA Technical Bulletins

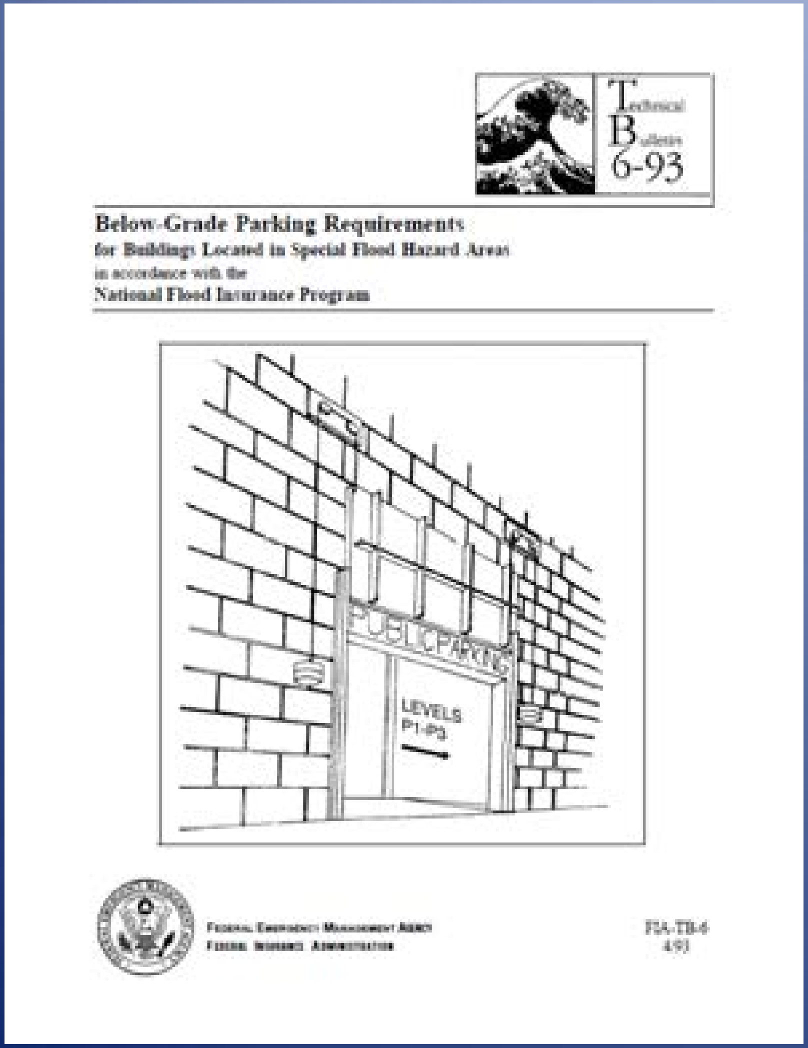


Technical Bulletin 5

Free-of-Obstruction

http://www.fema.gov/library/viewRecord.do?id=1718

FEMA Technical Bulletins



Technical Bulletin 6

Below Grade Parking

http://www.fema.gov/library/viewRecord.do?id=1719

FEMA Technical Bulletins


Technical Bulletin 7-93

Wet Floodproofing Requirements
for Structures Located in Special Flood Hazard Areas
in accordance with the
National Flood Insurance Program

Federal Emergency Management Agency
Mitigation Directorate
Federal Insurance Administration

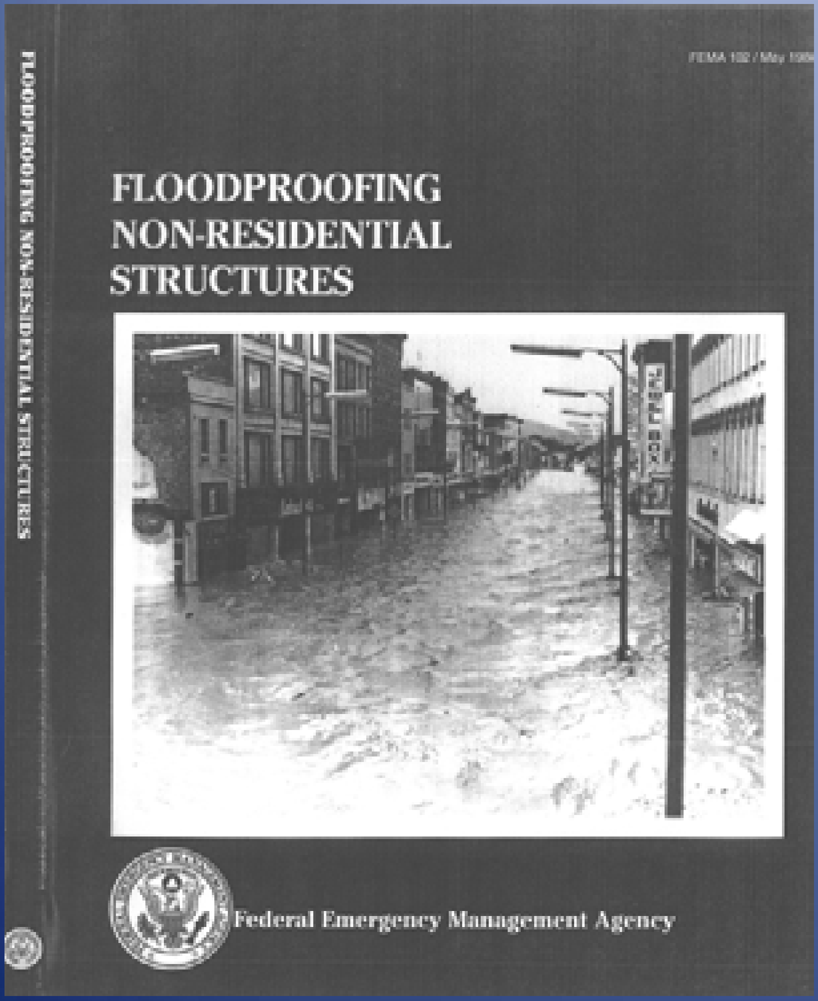
FIA-TB-7
12/93

Technical Bulletin 7

Wet Floodproofing

http://www.fema.gov/library/viewRecord.do?id=1720

FEMA Resource

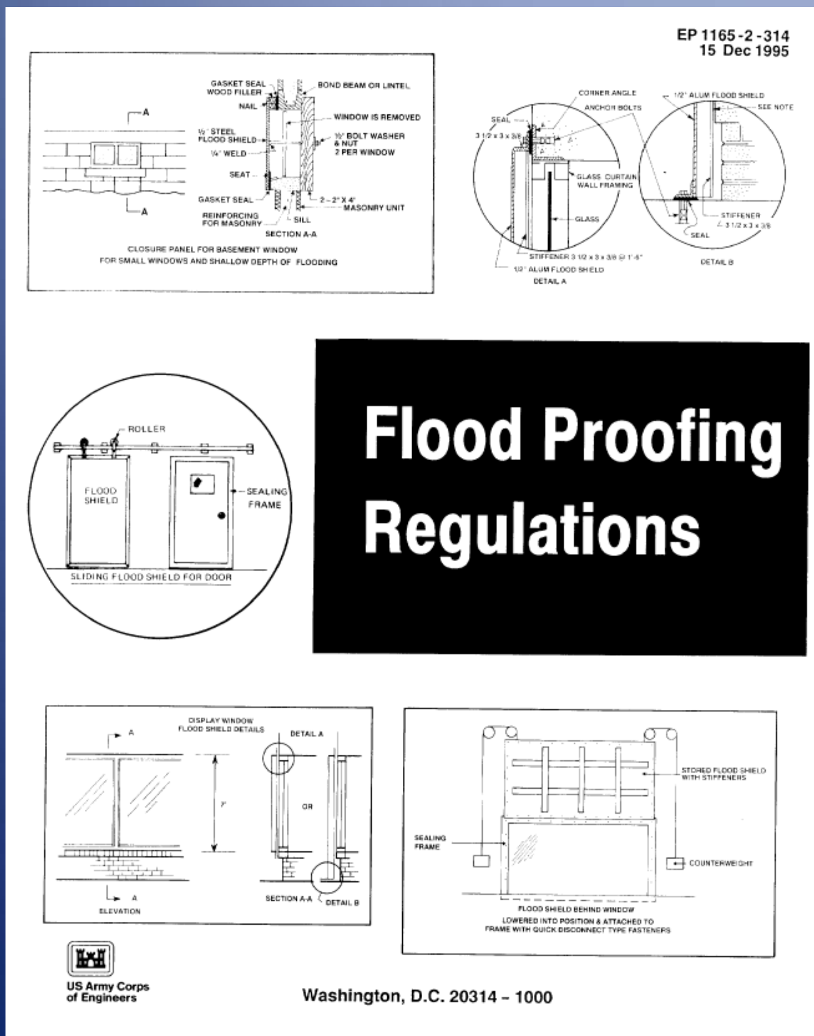


FEMA 102

Floodproofing Non-Residential Structures

http://www.fema.gov/library/viewRecord.do?id=3581

Army Corps of Engineers



EP1165-2-314

Flood Proofing Regulations

http://140.194.76.129/publications/eng-pamphlets/ep1165-2-314/toc.htm

Structural Considerations

- Design loads (FIA-TB-3)
- Load Path
- Flood Damage-Resistant Materials (FIA-TB-2)
- Glazing and Storefront Anchorage
- Flood Gates

Design Loads (FIA-TB-3)

- Hydrostatic Loading
  - Buoyant Forces
  - Lateral Forces
- Hydrodynamic Loading
- Impact Loading
- Special Impact Loading

Hydrostatic Loading

HYDROSTATIC PRESSURES BY WATER DEPTH	
HEIGHT (H) (WATER DEPTH)	Ph (LBS/SQ.FT.)
1	62.4
2	124.8
3	187.2
4	249.6
5	312.0
6	374.4
7	436.8
8	499.2
9	561.6
10	624.0

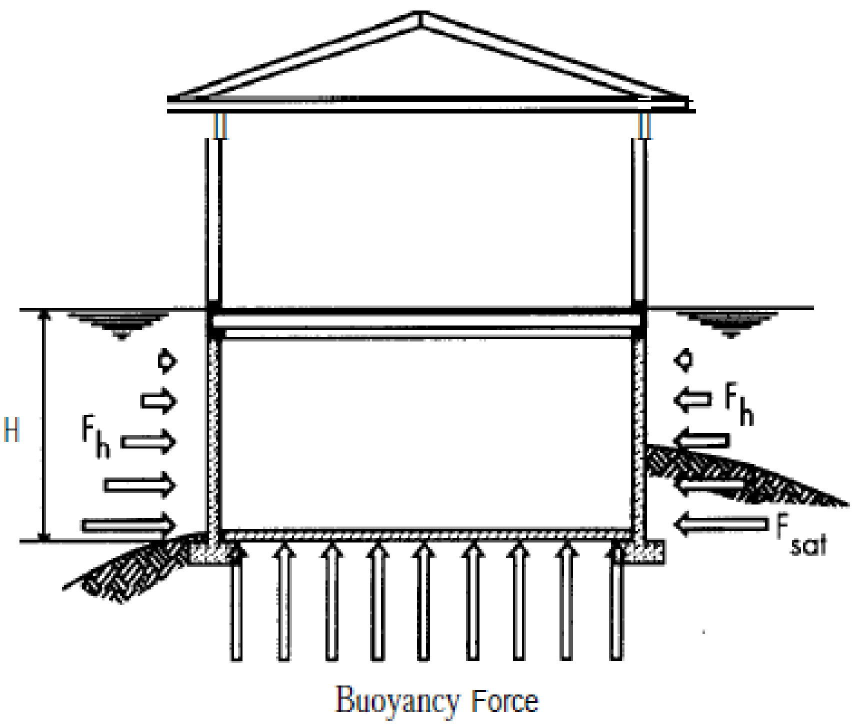


Figure 1. Hydrostatic Pressure Diagram

Hydrostatic Loading

Resultant Force Due to Hydrostatic Pressure from Free-Standing Water:

$F_h = 1/2 wH^2$

Where:

F_h = Lateral Force from Free-Standing Water (plf)

w = Specific Weight of Water (62.4 pcf)

H = Height of Standing Water to Flood Protection Elevation (Ft)

Hydrostatic Loading

Resultant Force Due to Hydrostatic Pressure from Saturated Soil:

$F_{sat}=1/2SD^2+F_h$

Where:

F_{sat} = Lateral Force from Saturated Soil (plf)

F_h = Lateral Force from Free-Standing Water (plf)

S = Equivalent Fluid Weight of Saturated Soil (pcf)

D = Depth of Saturated Soil (Ft)

Hydrostatic Loading

Buoyancy Force

$F_b = wAH$

Where:

Fb = Force Due to Buoyancy

w = Specific Weight of Water (62.4 pcf)

A = Area of Horizontal Surface Being Acted Upon (sf)

H = Depth of Floor Below Flood Protection Elevation (ft)

Hydrodynamic Loading

Hydrodynamic Force

$F_d = C_d(1/2)mV^2A$

Where:

F_d = Hydrodynamic Force (pounds)

C_d = Drag Coefficient

m = Mass Density of Water (1.94 slugs per cubic foot)

V = Velocity of Water (feet per second)

A = Area of Wall (sf)

Debris Impact Loading

Debris Impact Force

$Fi = WV/(gt)$

Where:

Fi = Debris Impact Force (pounds)

W = Weight of Object (pounds) – Generally 1000#, but may be reduced to 500# .

V= Velocity of Water (feet per second)

g = Acceleration Due to Gravity (32.2 ft/s^2)

t = Duration of Impact (seconds) – 1 second

Special Impact Loading

Special Impact Force

$F_s = w_s V/(gt)$

Where:

F_s = Special Impact Force (pounds)

w_s = Weight of Object (100 plf x width of structure)

V= Velocity of Water (feet per second)

g = Acceleration Due to Gravity (32.2 ft/s^2)

t = Duration of Impact (seconds) – 1 second

Load Path

- Building Veneer
- Glazing & Storefront
- Flood Gates
- Floor System

Building Veneer

- Flood Damage-Resistant Materials (FIA-TB-2) – Table 2, Structural Materials
- Class 4 & 5 are the only acceptable materials
- Includes:
  - Brick
  - Concrete Block (CMU)
  - Cast Stone
  - Concrete
  - Others

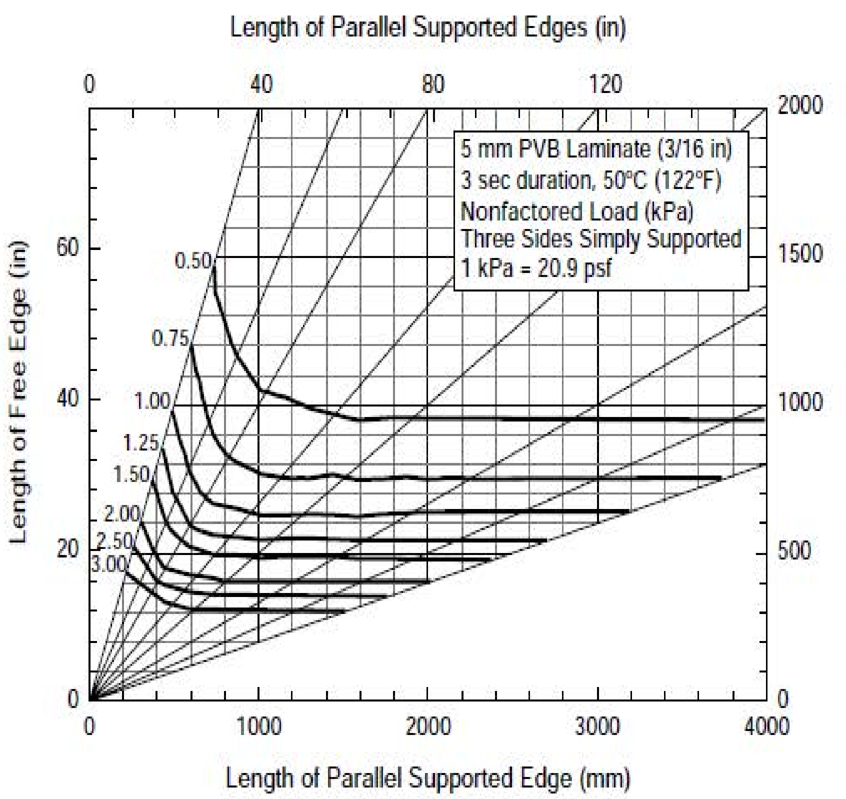
Building Veneer

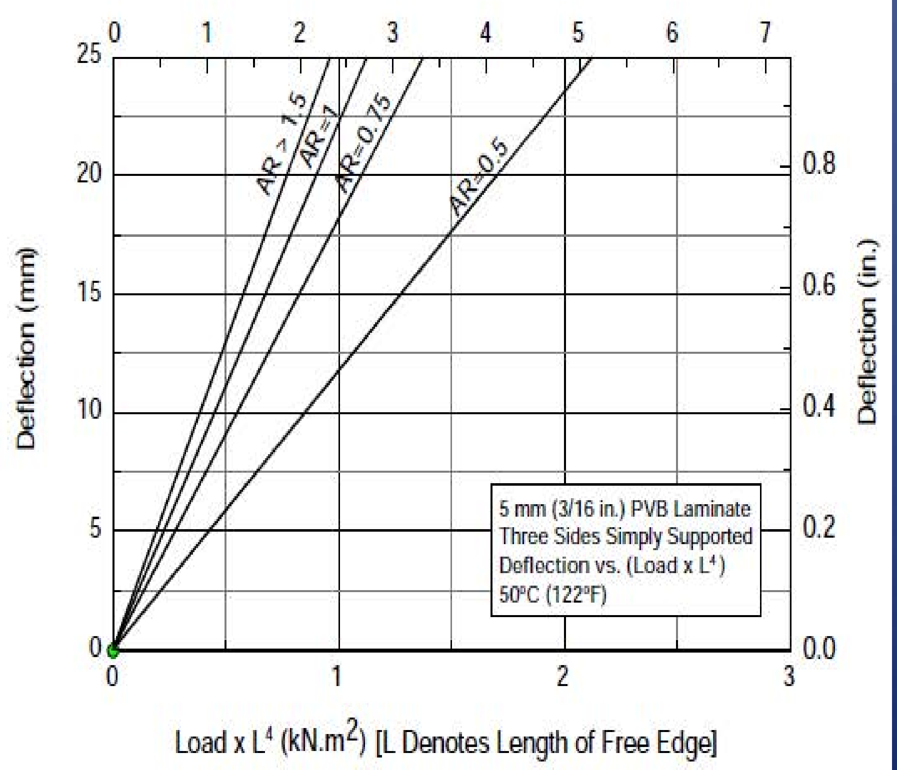
- Veneer Back-up Structure
  - Veneer ties must be capable of resisting flood loads
  - Metal/Wood Studs
  - Reinforced and Unreinforced Masonry
  - Reinforced Concrete

Glazing & Storefront

- Glass Thickness & Temper
  - Pressure Tables
- Mullions
  - Heavy Duty
- Connections
  - Adequate for High-Magnitude Reactions

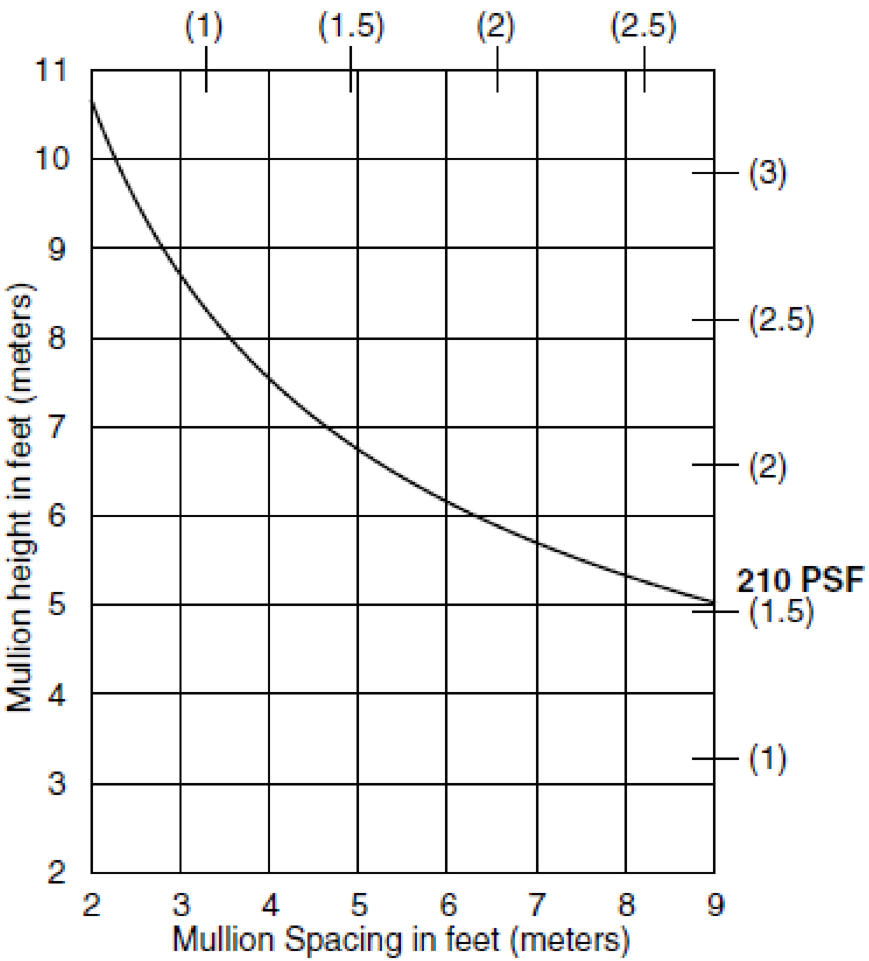
Glazing Design

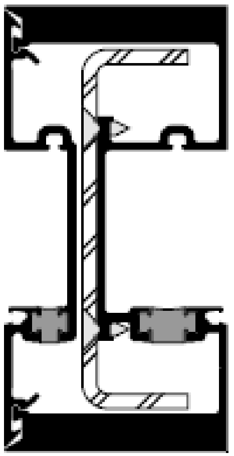




ASTM E-1300

Heavy-Duty Mullions





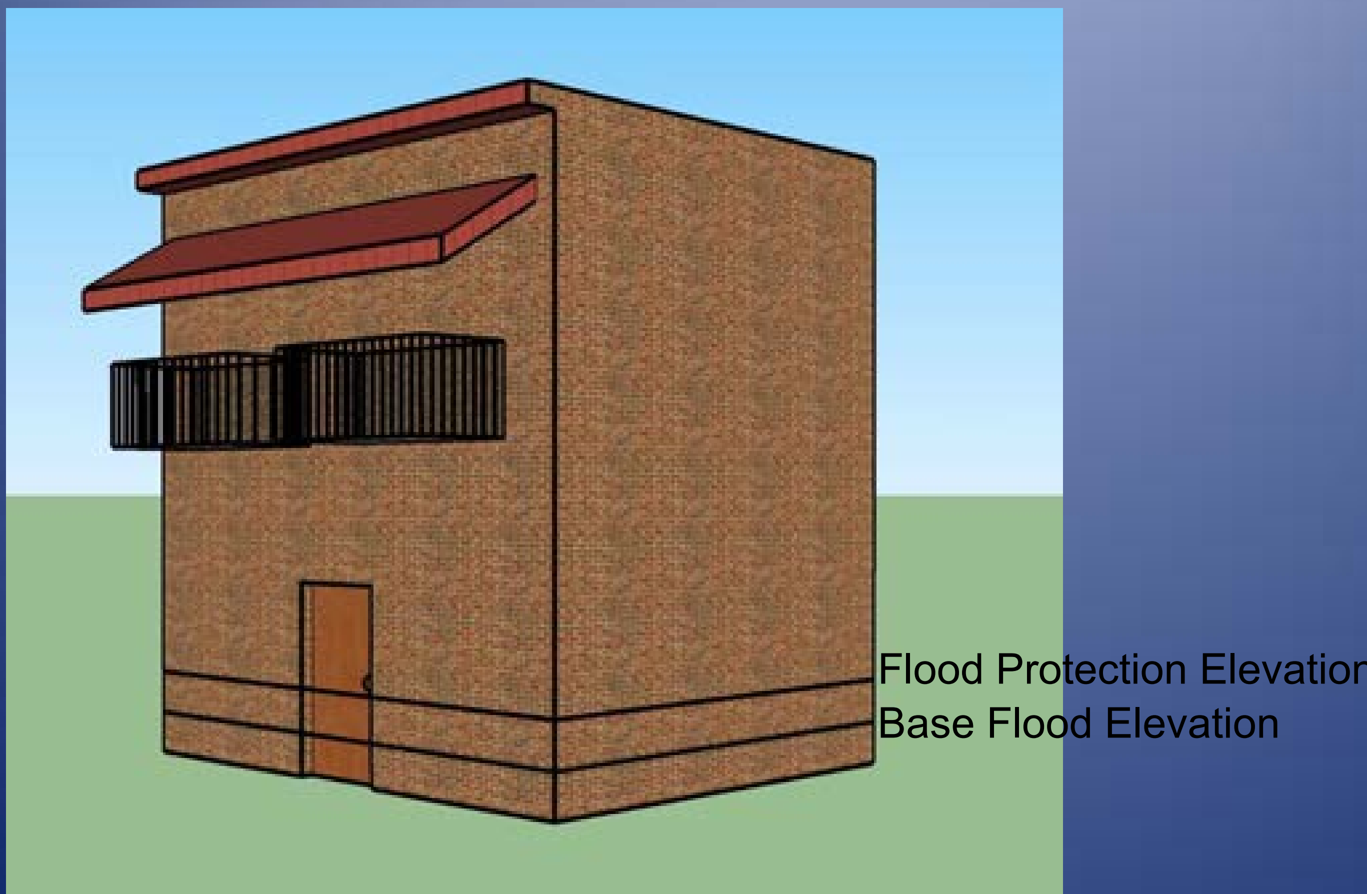
BT835 / BT804 / SS057
Mullion, Filler and Steel (Combined)
Ixx = 19.100 (794.98×10^4)
Sxx = 7.527 (123.52×10^3)

Local Requirements

- Flood Protection Elevation
- Manual versus Automatic
- Maximum Depth for Floodproofing
- Enclosure Limits
- Floodproofing Prohibition

Local Requirements

Flood Protection Elevation



Local Requirements

Automatic

Manually Installed

Local Requirements

Higher Regulatory Standards

- Enclosure Limits
- Floodproofing Prohibition

Other Considerations

- Elevate/Floodproof Mechanical and Electrical Components

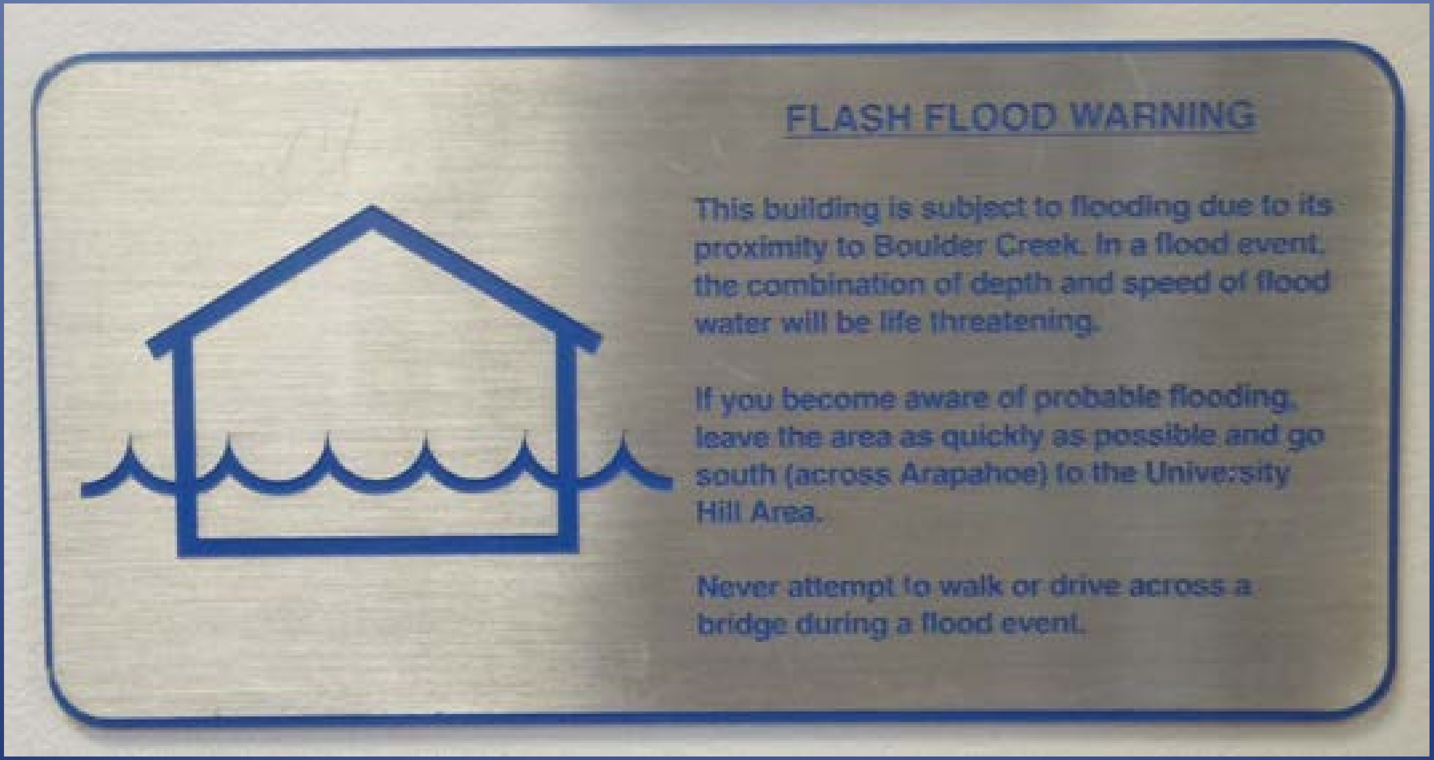
Other Considerations

Emergency Response Plan

- Evacuation
- Shelter in-Place

Other Considerations

- Signage



Other Considerations

- Maintenance
- Critical Facilities
- Flood Insurance Costs
- Groundwater Impacts

Questions?

eLOMA – Changing the Face of the Map Amendment Process

Ryan Carroll, CFM
Michael Baker Jr., Inc.

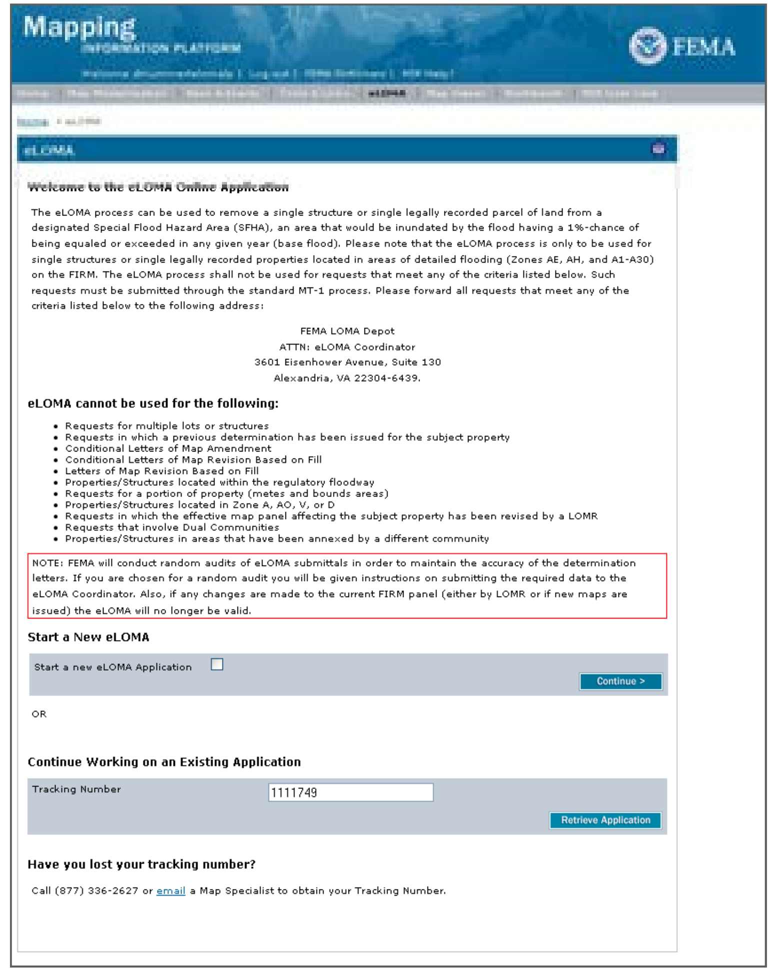
CASFM September 2010

FEMA

Baker

What is eLOMA and who can use it?

- **eLOMA is a MIP application designed to provide licensed land surveyors and professional engineers (Licensed Professionals or LPs) with a web-based system to submit and print simple LOMA requests**



What are the benefits of eLOMA?

- The eLOMA tool is designed to allow users to receive a determination from FEMA in minutes. The user can print a copy almost instantly.
- Electronic transfer of data
- Less mailing and printing uses less paper

Baker

When can't eLOMA be used?

FEMA

Current Limitations

Existing single residential structures or legally recorded parcels of land not involving the placement of fill

Detailed study areas (Zones AE, A1-A30, AH)

No approximate study areas (Zones A, V, AO, or D)

No floodways

No multi-lot requests or portions of properties

No previous LOMA/eLOMA determinations for same property

How do users gain access to eLOMA?

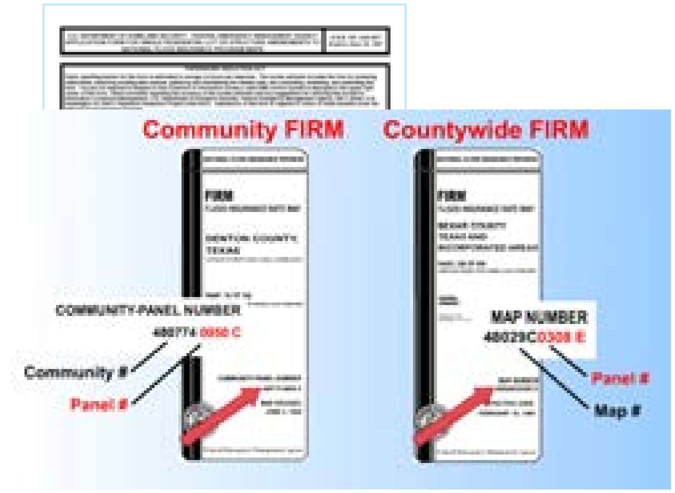
Surveyor or engineer must set up an account through MIP Help using individual certification information to become an eLOMA LP

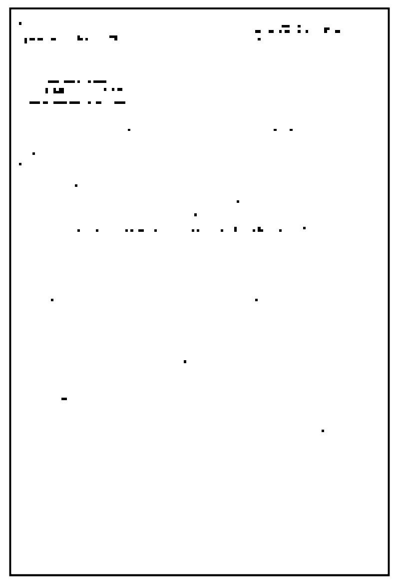
The LP logs into the MIP to access eLOMA and has the option to:

- Create a new application
- Resume a previously saved application

What data is required for eLOMA?

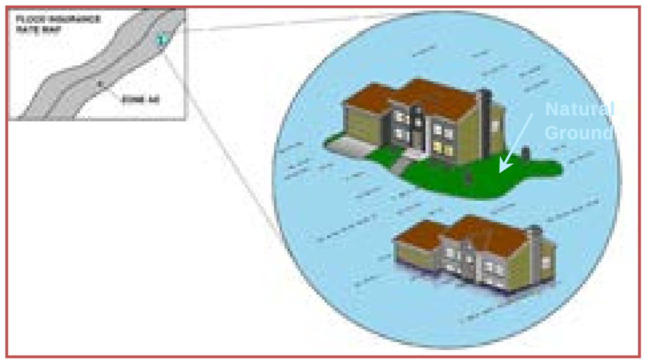
- **User will enter all applicable data:**
  - Legal property description
  - Requester information
  - Community information (CID number, etc…)
  - Map panel information
  - Latitude and longitude coordinates
  - Elevation information (LAG or LLE)
  - Subject information
  - BFE (calculated using FIS text/profile)





How does eLOMA make a determination?

- eLOMA will compare the submitted BFE to the submitted Lowest Adjacent Grade (LAG) or Low Lot Elevation (LLE)



- eLOMA will ensure all required information has been entered

How do the audits work?

- **Audit procedures ensure accuracy.**
- **The LP <u>must</u> submit supporting data to FEMA.**
- **If APPROVED, the LP will receive an email notification to log in and print the determination.**
- **If REJECTED, the LOMA request will be completed by FEMA and the LP will be audited again on the next submittal.**
- **After an initial successful audit, the LP can generate determinations online. However, he or she will still be subject to random audits.**

What are eLOMA auditors looking for?

Supporting Data from the LP Must Be Complete

- FIRM and profile must be annotated
- Legal description must conform to the approved format
- Subject elevations must be referenced to the datum used in the FIRM and in the FIS report

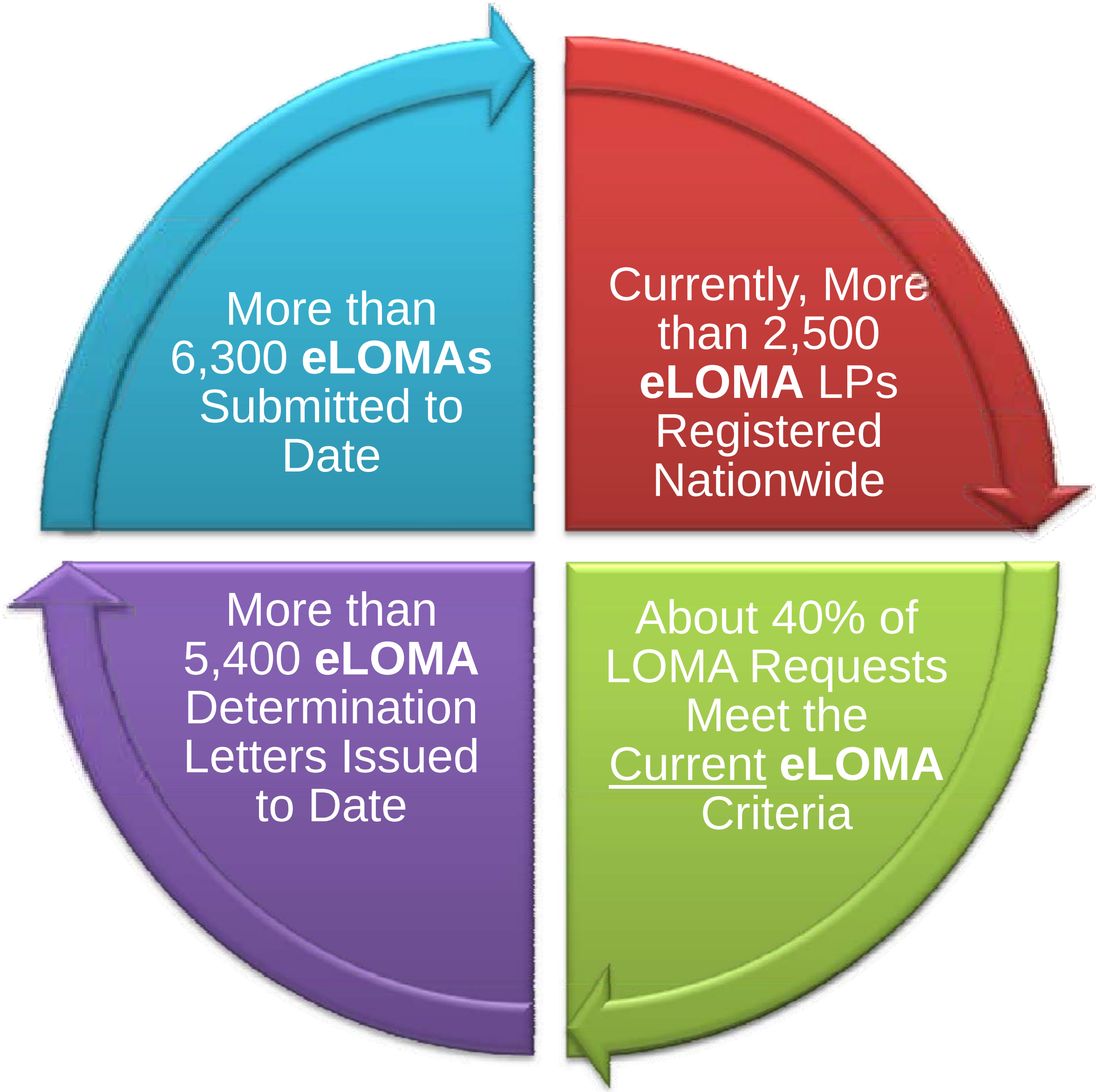
Requests Must Meet the eLOMA Criteria

- Subject must be in Zones AE, A1-A30, or AH
- Subject cannot be in the floodway
- No previous LOMAs/eLOMAs for the subject property

What errors do the eLOMA auditors find?

- Legal property descriptions that need to be revised
- Subject elevations not converted to the datum used on the FIRM and in the FIS report
- Inaccurate latitude/longitude
- Lot, block, and subdivision information
- FIRM panel numbers
- Flooding sources

How much is eLOMA being used?



Plans to expand eLOMA usage

Additional Types of LOMA Requests

- Multiple-lot requests
- Zone A requests
- LOMR-Fs
- Inadvertent Inclusions in the Floodway
- Annexations
- Out As Shown determinations
- Reissuances of previous LOMAs/eLOMAs

Proposed eLOMA enhancements

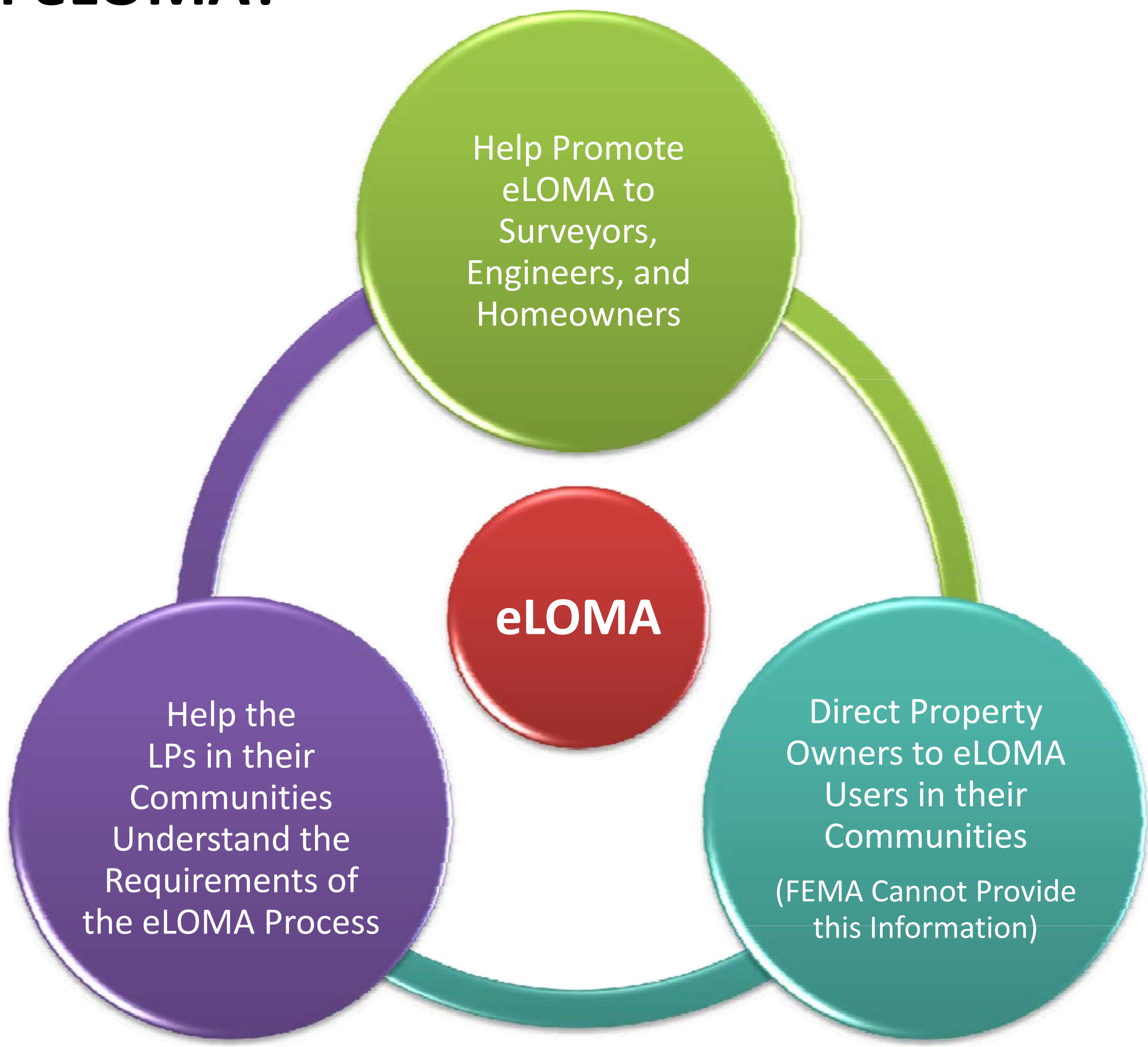
Improved /Additional Functionality

- Create an eLOMA workflow to improve tracking and support additional LOMC types
- Upload feature to improve the audit process
- Additional data quality checks and validation
- Improved web based training materials

How might eLOMA affect Floodplain Managers?

- **Floodplain Managers have expressed concern that eLOMAs containing errors could be issued in their community without an audit.**
  - All non-audited eLOMA determination letters are reviewed for noticeable errors.
  - Incorrect eLOMAs can be rescinded by FEMA and superseded by a standard LOMA.
  - Errors are often caught before the LP has disseminated the final determination letter.
  - To date, only two eLOMAs have warranted a correction LOMA.

How can Floodplain Managers play a role in eLOMA?



What is the future of eLOMA?

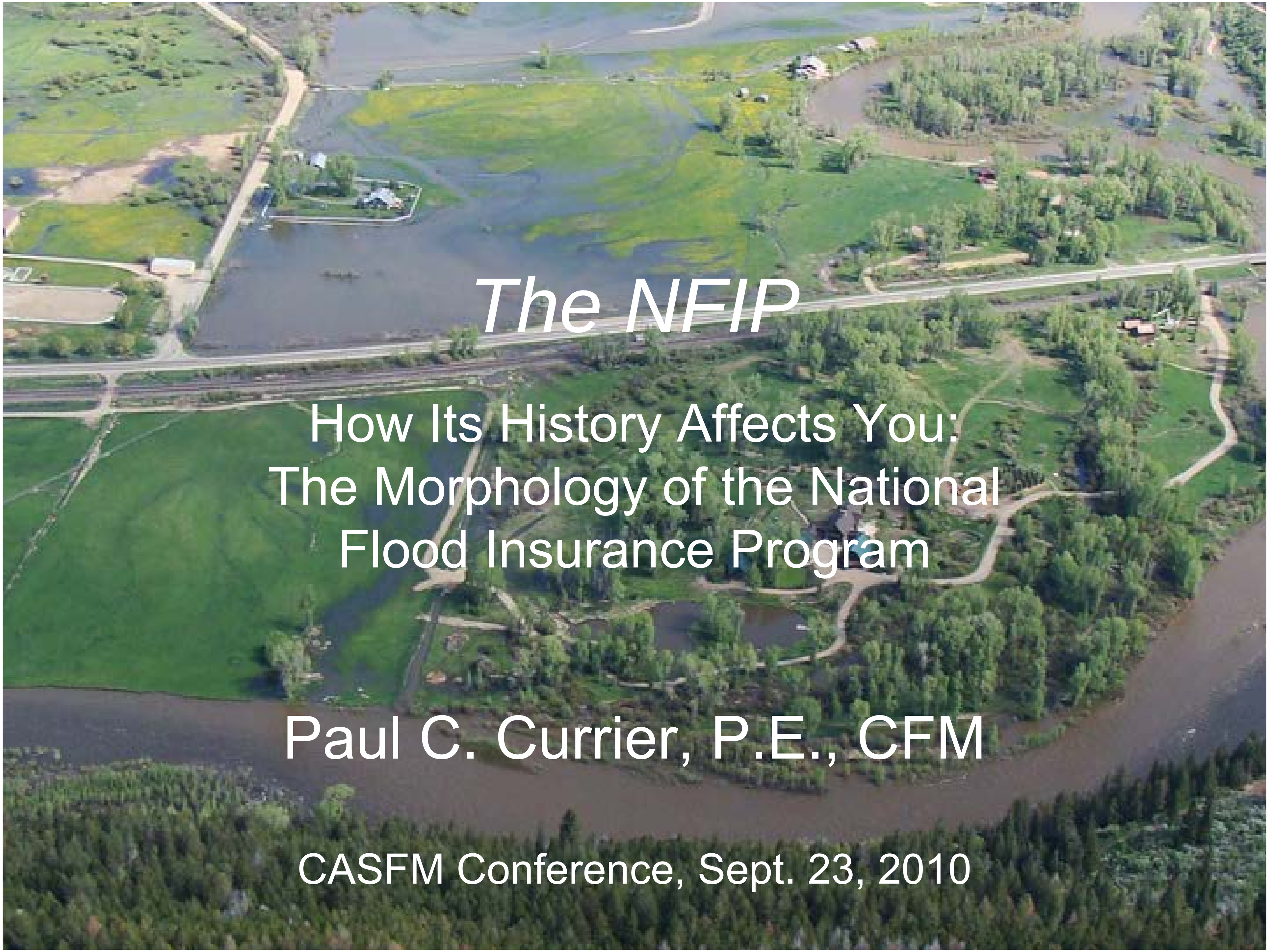
The plan is to…

- **Increase usage by allowing more requests to be processed using eLOMA**
- **Improve the eLOMA process to make it easier for LPs to issue fast and accurate determinations**
- **Save more time and resources for property owners, eLOMA users, and FEMA**
- **Ultimately provide faster determinations for property owners in your community**

Contacts and Links

- **MIP –** www.hazards.fema.gov
- **FEMA –** www.fema.gov
- **MIP Help –** miphelp@riskmapcds.com
- **BakerAECOM eLOMA Coordinator (FEMA Regions 4, 8, and 9) –** DMummert@mbakercorp.com

Questions and Answers

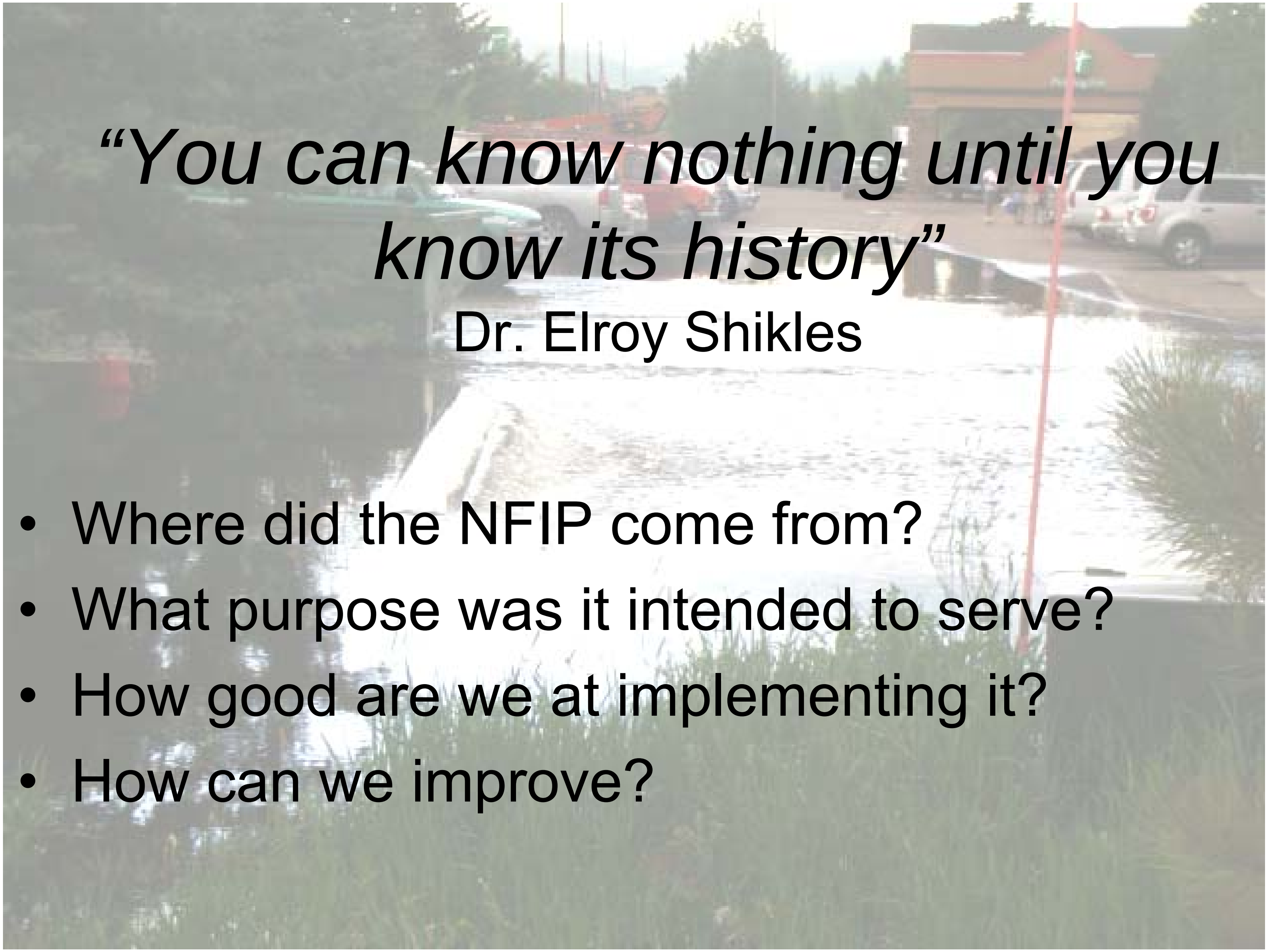


The NFIP

How Its History Affects You: The Morphology of the National Flood Insurance Program

Paul C. Currier, P.E., CFM

CASFM Conference, Sept. 23, 2010



"You can know nothing until you know its history"

Dr. Elroy Shikles

- Where did the NFIP come from?
- What purpose was it intended to serve?
- How good are we at implementing it?
- How can we improve?

The Setting

- 1920's
  - Insurance industry was in its infancy
  - Decided flood insurance wasn't profitable
- 1930's – 1950's
  - Public works era
  - Hard controls
  - Multitude of Congressional directives
  - Flood damage continued at great expense

The Last Straw

- 1960's: Too many "big" floods
  - Michigan
  - California
  - Denver
  - Others

Photo Courtesy of DCL

Congress Steps In

- 1968 – National Flood Insurance Act
  - Transfer costs to occupants of flood prone areas
  - Create a modicum of financial resilience via Federally backed insurance
  - Guide development and re-development within flood prone areas

But Did it Work?

- People didn't buy the insurance
- People still lived, worked and built in flood prone areas
- You decide: did it work?

Corrective Action

- A good hurricane (Agnes, 1973)
- Severe rainfall along the eastern seaboard
- “Most” expensive storm in U.S. history until that point
- Congress inquired as to why their Federal Insurance program wasn’t popular.
- And….

… Took Social Action

- Flood Disaster Protection Act (1973)
  - Flood insurance now mandatory if you want a property loan that's backed by the Feds.
- Result: by 1980 nearly 2,000,000 policies vs only 100,000 in 1973
- Self supporting by 1986

But did it stop floods?

State Street, Salt Lake City

City Creek flood - 1983

Opryland - 2010

So how is it that we are still getting flooded?

Why the “100 year” recurrence interval standard?

More correctly, why p=0.01 ?

One word…

$$$$$

The NFIP is not:

- A flood <u>prediction</u> program
- Nor a flood <u>protection</u> program

The NFIP is:

- A fiduciary management tool intended to create financial resilience:
  - On a **National** scale
  - **Paid for by the users** / beneficiaries
- It has ancillary benefits of reducing loss of life and property

So is $p=0.01$ arbitrary?

- Yes?
- No?

- If applied for reasons outside of its scope, its extremely arbitrary

What about other NFIP ideas?

- BFE?
- Floodway?
- No debris blockage?

Project “Creep” Happens

- Same is true with the NFIP
- Example: ASFM brainstorming on floodplain success
  - Disaster resilient communities
  - Room is provided for rivers and floodplains to function naturally
  - Human occupance in all high risk flood zones has been abandoned
  - The principle of individual responsibility is reflected in public policy.

Project Creep in the NFIP

- Trends of “ab”using it as a:
  - Poorly thought out ecological tool
  - Land use development tool
  - An attitude of “preservation” vs. “stewardship”
    - Good Stewardship = wise use
    - Preservation = avoidance

National Flood Insurance Program

Flood Insurance Manual

May 2008
Revised October 2008
Revised May 2009
Revised October 2009
Revised May 2010
Revised October 2010

FEMA

NFIP Insurance - 2010

I. AMOUNT OF INSURANCE AVAILABLE

BUILDING COVERAGE	EMERGENCY PROGRAM	REGULAR PROGRAM		
		Basic Insurance Limits	Additional Insurance Limits	Total Insurance Limits
Single Family Dwelling				
2-4 Family	$ 35,000 *	$ 60,000	$190,000	$250,000
Dwelling Other	$ 35,000 *	$ 60,000	$190,000	$250,000
Residential Non-	$100,000**	$175,000	$ 75,000	$250,000
Residential	$100,000**	$175,000	$325,000	$500,000
CONTENTS COVERAGE				
Residential	$ 10,000	$ 25,000	$ 75,000	$100,000
Non-Residential	$100,000	$150,000	$350,000	$500,000

* In Alaska, Guam, Hawaii, and U.S. Virgin Islands, the amount available is $50,000.

** In Alaska, Guam, Hawaii, and U.S. Virgin Islands, the amount available is $150,000.

NOTE: For RCBAP, refer to CONDO Section for basic insurance limits and maximum coverage available.

Back to Flood Resilience

- Do we have a flooding issue?
- Or do we have an Insurance issue?

Take Home Thoughts

- As a planner, consultant, regulator, have I been tempted to read more into floodplain regulations than I should?
- If we view ourselves as working for the good of the public, should we be asking different questions?
- Is the NFIP the only solution to floodplain management?

The Cherry Creek Flood, Denver 1864,
Photo by George D. Wakely.

The Triple Bottom Line (TBL) of Sustainable Floodplain Management

Brian Varrella, P.E., CFM
Floodplain Administrator
Fort Collins Utilities
970-416-2217 office
bvarrella@fcgov.com

The Triple Bottom Line (TBL) of Sustainable Floodplain Management

National Trends in Sustainable Floodplain Management

City of Fort Collins

National Trends in Sustainable Floodplain Management

Past practices are not working long-term

- **Conventional Approach** to floodplain regulation
  - **Control** the river to protect public from harm
  - **Convey** floodwaters through town
  - **Minimize** flooded area during storms
  - **Maximize** developable land
- Baseline principle -- human intervention over nature

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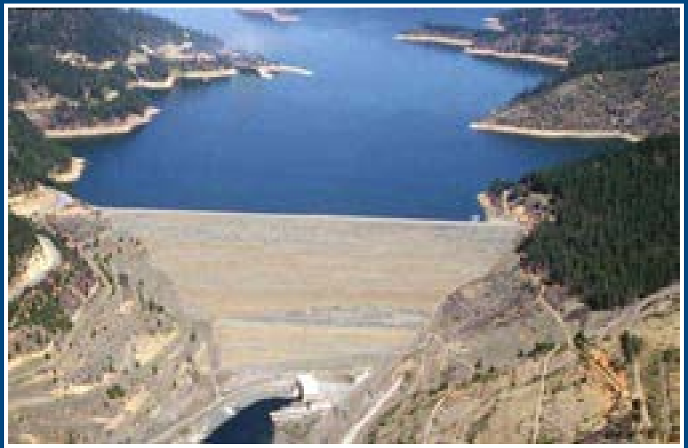
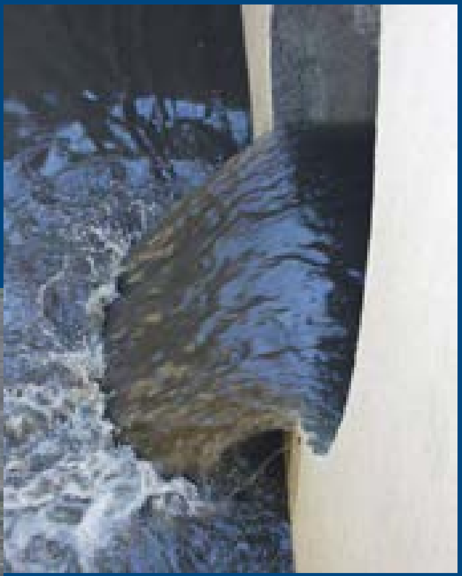
Human Intervention Over Nature



Human Impacts

Habitat Loss

Wildlife Conflicts



Water Pollution

National Trends in Sustainable Floodplain Management

Increasingly substantial evidence suggests that the present approach to managing flood threats in the United States is not sustainable with respect to public safety and economic and environmental consequences.

-- Darryl W. Davis, US Army Corps of Engineers retired (2007)

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National Trends in Sustainable Floodplain Management

New trends in thought are sweeping the nation

- National desire for long-term public safety solutions
- Recognizing flood losses are increasing
  - The NFIP is not working as intended
- States are increasing minimum FPM standards
- No Adverse Impact (NAI) is making sense
  - Encouraging tools that fit community values
  - Meeting community needs at the local level

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National Trends in Sustainable Floodplain Management

No adverse impact principles [can] *be applied in all land use and development decision making. The standard of "not causing harm". . . will result in the protection of people, property, and natural resources and functions* ***now and into the future****.*

-- ASFPM (2007, emphasis added), FPM 2050, Pg. 33

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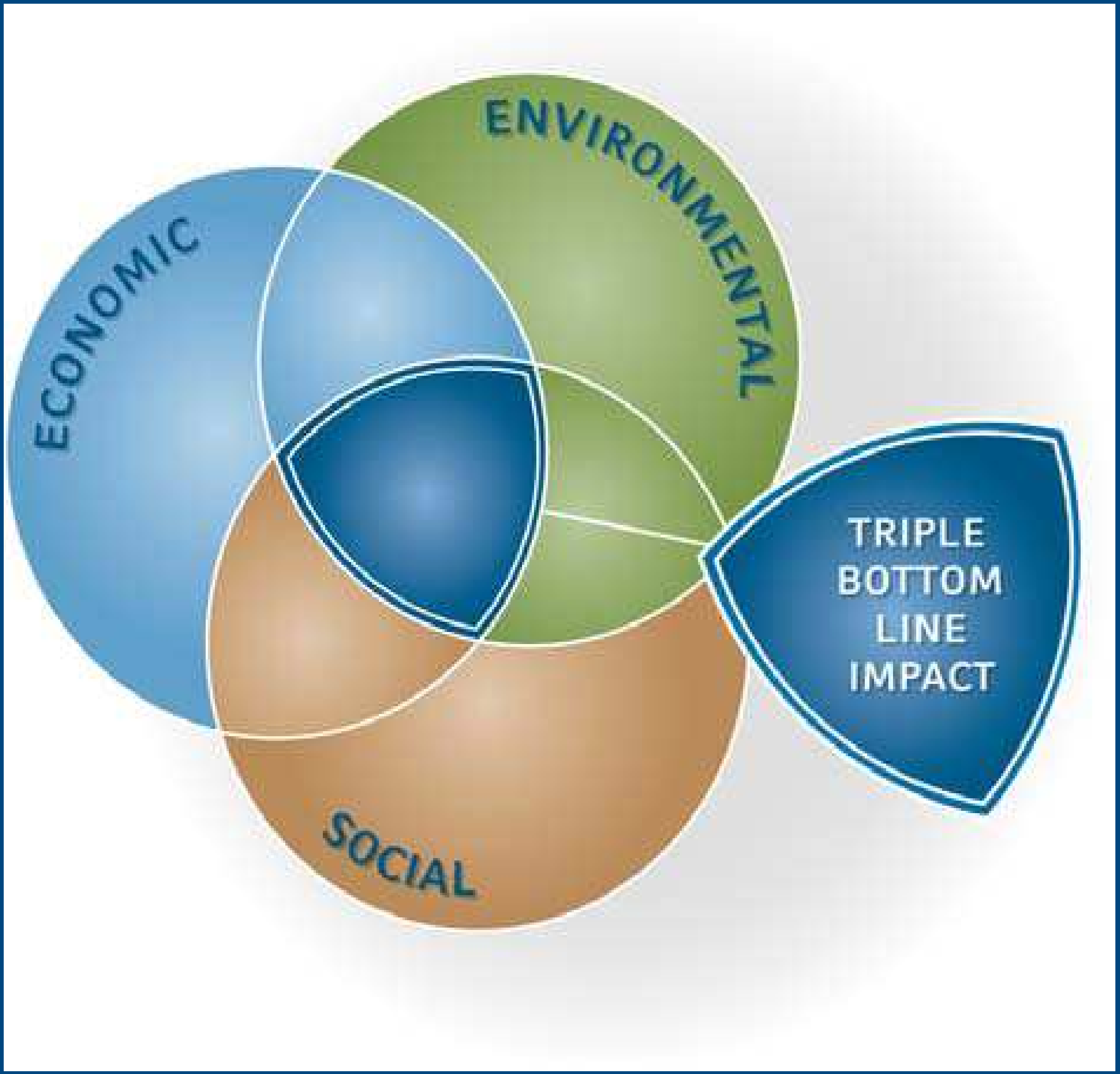
The Triple Bottom Line (TBL) of Sustainable Floodplain Management

Enter The
Triple Bottom Line
(TBL);

An Introduction

Enter the TBL; An Introduction



Enter the TBL; An Introduction

- Basic Principles:
  - **<u>Sustainability</u>** – development that meets the needs of the present without compromising the ability of future generations to meet their own needs.   *-- Brundtland Commission, 1987*
  - **<u>Triple Bottom Line</u>** – practices that optimize economic, environmental, and social considerations for sustainable outcomes.

Enter the TBL; An Introduction

Why a 3-fold bottom line?

- ***How do we give the environment equal consideration with public safety?***
  - *Utilities Management, 2008*
- ***How do we factor political will into a decision?***
  - *City Mgr.'s Office official, 2010*
- ***How do we make public safety a community indicator?***
  - *Plan Fort Collins vision team, 2010*

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Enter the TBL; An Introduction

Triple Bottom Line = Common Sense

- TBL is a method of framing decisions
- Allows one person to understand many perspectives on an issue or a decision
  - Reveals gaps in thinking
  - Removes personal bias
- Not unlike what you are doing right now

Enter the TBL; An Introduction

THIS IS NOT A REVOLUTION

Just a new way of describing different perceptions

The Triple Bottom Line (TBL) of Sustainable Floodplain Management

The
Triple Bottom Line
Analysis Map
(TBLAM)

TBLAM (front page)

Triple Bottom Line Analysis Map (TBLAM)

City of Fort Collins

Project or Decision: Text Text **Evaluated by:** name

Social		Environmental	Economic
WorkForce / Flex Column	**Community**		
STRENGTHS: • Capacity • Job Creation • Increase Morale/ Performance • In-House Expertise	**STRENGTHS:** • Engages • Better Service • Health Benefits • Awareness • Aesthetics • Safety • Economic Benefit	**STRENGTHS:** • Minimizes adverse impact • Increases efficient use of natural assets • Maximizes life cycle to minimize resource impacts • Meets, exceeds, or improves regulatory compliance	**STRENGTHS:** • Offers a positive Return on Investment (ROI) • Life Cycle Cost Analysis supports continued financial health of the organization • Local businesses or residents benefit from the project
LIMITATIONS: • Budget • Lack Of Support/ Resistance • Insufficient Staff • Lack Of Capacity • Lack Of Measures/ Material/ Space • Cost Of Staffing • Poor Management	**LIMITATIONS:** • Lack Of Support • Burdens • Conflicting Interests • Detrimental • Costly • Opposition • Short Term Benefit/ Long-Term Harm • Disruptive	**LIMITATIONS:** • Budget • Lack Of Support / Resistance • Cost of Staff / Lack Of Capacity • Lack Of Measures / Material / Space • Poor Management • Trade-Off Of Benefits (Helps In One Way, Hurts In Another) • Regulatory Concerns • Lack Of Technology	**LIMITATIONS:** • Increased collateral costs associated with project • Project-related opportunity costs • Local businesses or residents are adversely impacted by costs
OPPORTUNITIES: • Future Staff Increase • Professional Development • Diversified Staff • Leadership	**OPPORTUNITIES:** • Education • Follows Trend • Long-Term Benefit • Improved Economic Potential	**OPPORTUNITIES:** • Provides opportunity to demonstrate innovation and leadership • Provides opportunity to develop new metrics to measure success (Research Opportunities)	**OPPORTUNITIES:** • Project offers chance for job creation • Project attracts businesses to the area • Project encourages others to join in or follow example
THREATS: • Loss Of Revenue • Budget / RIFs • Health • Attrition • Economy • Backlash • Institutional Memory	**THREATS:** • Special Interests • Backlash • Political	**THREATS:** • Loss Of Revenue • Health • Institutional Memory • Political Opposition • Resource Allocation Constraints (staff / time, funding, etc.)	**THREATS:** • Loss of business or revenues • Political backlash • Competes with existing businesses •

Revision Date: April 2010

This form is based on research by the City of Olympia and Evergreen State College

Enter the TBL; An Introduction

This is a brainstorming tool

- The methodology can be applied to *any* decision
- Requires non-quantifiable input
- Flexible (made to be creative)
- Best input falls into multiple cells
- No wrong answers, and no weighting
  - All input is relevant
  - All input is equally-valuable

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TBLAM (back page)

NOTES:

S.L.O.T. analysis is a strategic planning and analysis method used to break a situation, project, or business opportunity down into and analyze the internal and external factors that will positively and negatively affect the objective under study. In this analysis, the **S**trengths, **L**imitations, **O**pportunities, and **T**hreats are identified and captured on a chart to offer a more detailed view of the interaction of the positive and negative aspects of the objective under review. Below are some typical examples of the kinds of issues that might figure into each of the categories in a S.L.O.T analysis.

Strengths: *(more tangible)*

- Advantages – improvement/ efficiency gain
- Available Resources
  - staff, funding, $$, qualifications, internal/external support, technology, location, product, BMP's
- Measurable

Limitations:

- Lack of resources – staffing, $$, qualifications
- No or limited gain in efficiency
- Lack of metrics (not measurable)
- Trends

Opportunities: *[less tangible (potential strengths)]*

- Increased possibilities (ROI, increased education, performance)
- Help accomplish goal or objective
- Industry or lifestyle trend
- Long term benefit

Threats:

- Uncontrolled variables
  - (out of sphere of control/ influence) – weather, nature, economy, society, political
- Major barriers – policies, laws, regulations, biological/ viral
- Fatal Flaw

Enter the TBL; An Introduction

- SLOT analysis by **rows (4)**
  - **S**trengths = tangible benefit *(today)*
  - **L**imitations = tangible detriment *(today)*
  - **O**pportunity = potential benefit *(future)*
  - **T**hreats = potential detriment *(future)*
- TBL by **columns (4)**
  - Social
  - Environmental
  - Economic
  - Flex column

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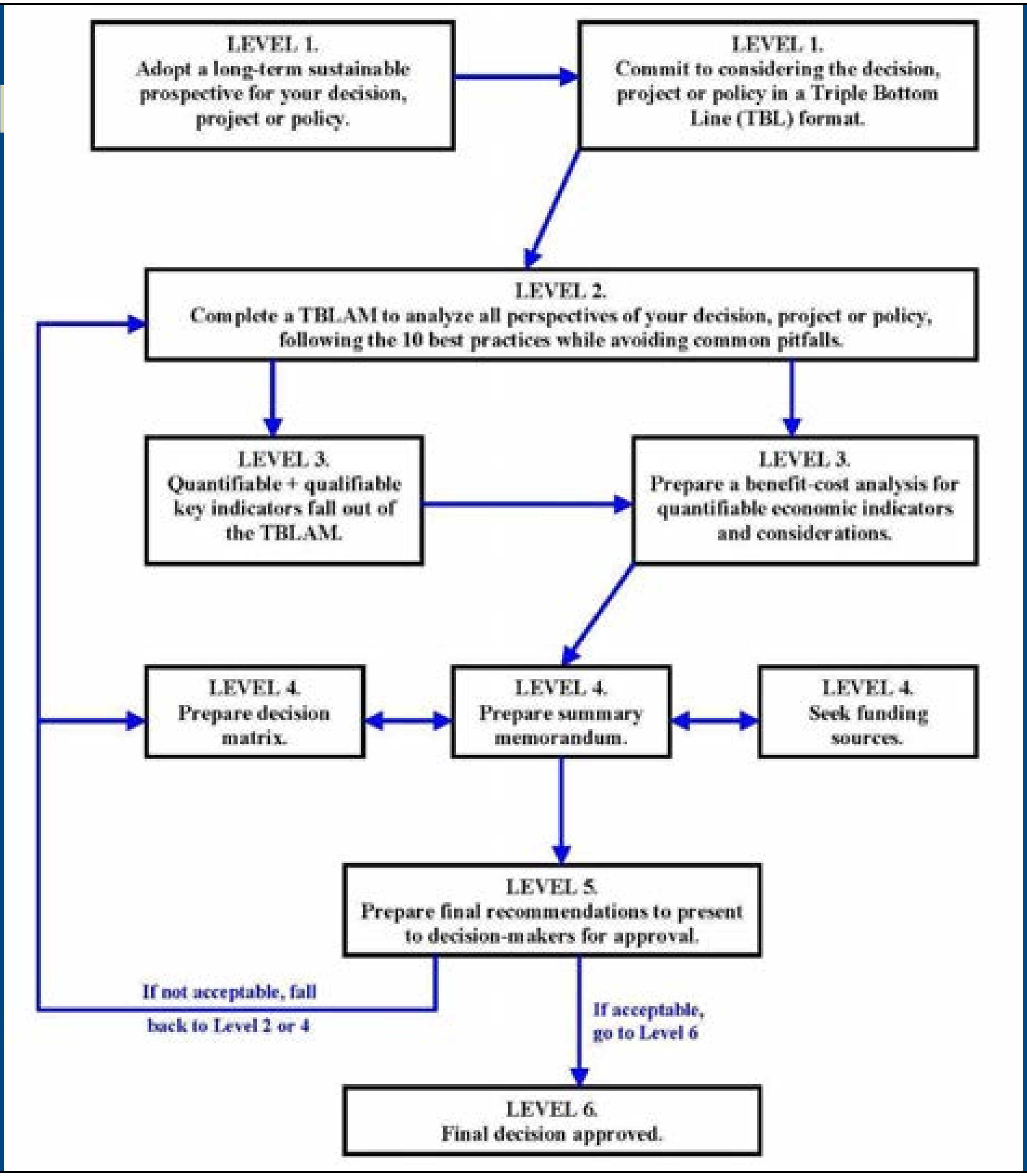

LEVEL 1.
Adopt a long-term sustainable prospective for your decision, project or policy.
LEVEL 1.
Commit to considering the decision, project or policy in a Triple Bottom Line (TBL) format.
LEVEL 2.
Complete a TBLAM to analyze all perspectives of your decision, project or policy, following the 10 best practices while avoiding common pitfalls.
LEVEL 3.
Quantifiable + qualifiable key indicators fall out of the TBLAM.
LEVEL 3.
Prepare a benefit-cost analysis for quantifiable economic indicators and considerations.
LEVEL 4.
Prepare decision matrix.
LEVEL 4.
Prepare summary memorandum.
LEVEL 4.
Seek funding sources.
LEVEL 5.
Prepare final recommendations to present to decision-makers for approval.
If not acceptable, fall back to Level 2 or 4
If acceptable, go to Level 6
LEVEL 6.
Final decision approved.

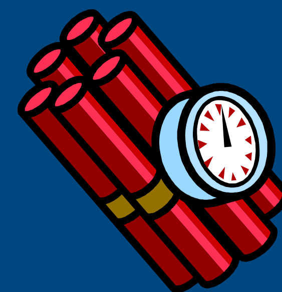
The Triple Bottom Line (TBL) of Sustainable Floodplain Management

Top 10
Best Practices
&
Myth-Busting

City of Fort Collins

TBL Best Practices & Myth-Busting

Top 10 Best Practices (Slide 1 of 4)



1. NO FATAL FLAWS
   – Find one? -- re-evaluate your goals
   – *No project, policy, or decision may have a fatal flaw and move forward*
2. Always use TBL before a decision is made, not after
   – If applied at the beginning, you will get a TBL product
   – If applied as a polish at the end, your product will NOT shine

City of Fort Collins

TBL Best Practices & Myth-Busting

Top 10 Best Practices (Slide 2 of 4)

3. Thou shalt not steal
   - Do not borrow from one column to feed the others
4. Do not attempt to quantify
   - This is not a spreadsheet
   - Intrinsic benefits cannot be attached to $$$
5. Support your TBLAM with real data
   - Attach memo, photos, web links, etc.
   - Attach spreadsheets, B/C calcs, graphs, etc.

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TBL Best Practices & Myth-Busting

Top 10 Best Practices (Slide 3 of 4)

6. Do not confuse **costs** with **detriments**
   - Cost is economics only
   - Limitations = current detriments
   - Threats = perceived future detriments
7. Air your dirty laundry too
   - Full disclosure, especially to the public (*SDIC*)
8. No greenwashing

City of Fort Collins

TBL Best Practices & Myth-Busting

Top 10 Best Practices (Slide 4 of 4)

9. No drama
   - Some ideas should be placed in multiple columns
   - Some benefits create detriments (and vice versa)
10. Never TBLAM alone
    - Group decisions require group input
    - No outside input = biased data

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TBL Best Practices & Myth-Busting

Myth-Busting the Triple Bottom Line

- This is just a green movement
- TBL analysis is difficult to do
- TBL analysis requires lots of paperwork
  - *How green is that?? Honestly . . .*
- This is a top-down order
  - *Policy flavor of the month*
  - *This too shall pass*
- The City is using TBL to finance economically irresponsible projects

City of Fort Collins

TBL Best Practices & Myth-Busting

The [Plan FC environmental vision] statement identifies and rationalizes triple bottom line objectives though appears to suggest environmental and social objectives can be achieved in the absence of economically sustainable practices.

-- Actual Plan FC public input, July 6, 2010

FALSE

City of Fort Collins

The Triple Bottom Line (TBL) of Sustainable Floodplain Management

TBL Pitfalls

and

Fine Print

City of Fort Collins

TBL Pitfalls and Fine Print

TBL challenges – the fine print (1 of 2):

- TBL thinking requires difficult decisions to be made
  - Economy, society, and environment are all given equal consideration in decision-making
- Requires a long-term focus with short-term sacrifices
  - Good business decisions today may create safety hazards and financial burdens tomorrow
  - Sustainable = good today, good tomorrow

City of Fort Collins

TBL Pitfalls and Fine Print

TBL challenges – the fine print (2 of 2):

- Some decisions require buy-in from other departments
- Money is tight, and cash is still king
  - Changing the benefit-cost analysis mindset is tough
  - Everyone wants to boil it down to $$$
- TBLAM format may not be compatible with the public or with decision-makers
- Alignment with community values is ever-changing
  - Every community has unique needs

City of Fort Collins

TBL Pitfalls and Fine Print

Will TBL survive?

- It must – our own existence depends on it
- Becoming a worldwide business movement
- Written into the FC Utilities mission statement
- Ingrained in City staff culture
  - Gaining grass-roots support
  - Largely at the office staff level

City of Fort Collins

DAILY COMMERCIAL NEWS
AND CONSTRUCTION RECORD

July 8, 2010

Sustainable construction

VIDEO: Green building critical in triple bottom line accounting

Building design and construction standards will undergo significant changes as "triple bottom line" accounting becomes more commonplace in the industry, a Saskatchewan-based economist says.

In addition to just financial performance, the triple bottom line takes into account social and environmental impacts – or, people, planet and profit.

"These form the three pillars for the sustainability of the economy," economist Grah the Construction Specifications Canada conference in Saskatoon recently.

"Life cycle analysis is central to triple bottom line accounting," he noted.

"Increasingly the public looks towards environmental accounts to start to understan And with that information they move billions of dollars in the consumer marketplace corporate marketplace, which also has to comply with an increasing amount of legis

Making Balanced Decisions

Making Balanced Decisions

We use the Sustainable Action Map (SAM) as a decision-making guide to ensure we are in alignment with Council's goal of community livability and the Public Works' vision of "balance and harmony between people and nature."

SAM is a simple, easy to use, one page worksheet that is a way for us to optimize a solution, rather than compromise one. The fundamentals of sustainability center on creating solutions that provide balance. Balance includes delivering the level of service citizens expect; doing it in an environmentally and socially responsible way; and insuring the best economic choice for the long term.

SAM has three key dimensions that work together:

1. NICE: There are four key components of sustainability - Natural, Individual, Community, and Economy. All four of these components must be in balance to achieve a sustainable solution.
2. SWOT: Strengths, Weaknesses, Opportunities, and Threats are described for each action (policy/decision) being considered and factored into the final decision.
3. Green, Yellow, Red Stoplight: This system provides an indicator for how well a particular action achieves the individual components (NICE) of sustainability.
   - Green: The action provides value to that component (more strengths and opportunities).
   - Yellow: There are risks, but they are manageable.
   - Red: There may be a fatal flaw (many weaknesses and threats). You should consider innovative solutions to overcome these risks before moving forward.

NICE

City of OLYMPIA

Sustainable Action Map (SAM)

Action:

Department

Leadership Required

Manageable Risk

Value Delivered

Awwa Research Foundation

Advancing the Science of Water®

CSIRO

Triple Bottom Line Reporting of Sustainable Water Utility Performance

ollins

TBL Pitfalls and Fine Print

Free TBL Resources

- This presentation
- TBL Staff at Fort Collins Utilities (970-221-6700)
- TBLAM document
- The Triple Bottom Line by Andrew W. Savitz (2006)
- Fort Collins wiki site *(coming in 2010/2011)*
- Fort Collins publication *(coming in 2011/2012)*

City of Fort Collins

ALBUQUERQUE WEST LEVEE LOMR: BENEFITS AND CHALLENGES USING FLO-2D

TETRA TECH

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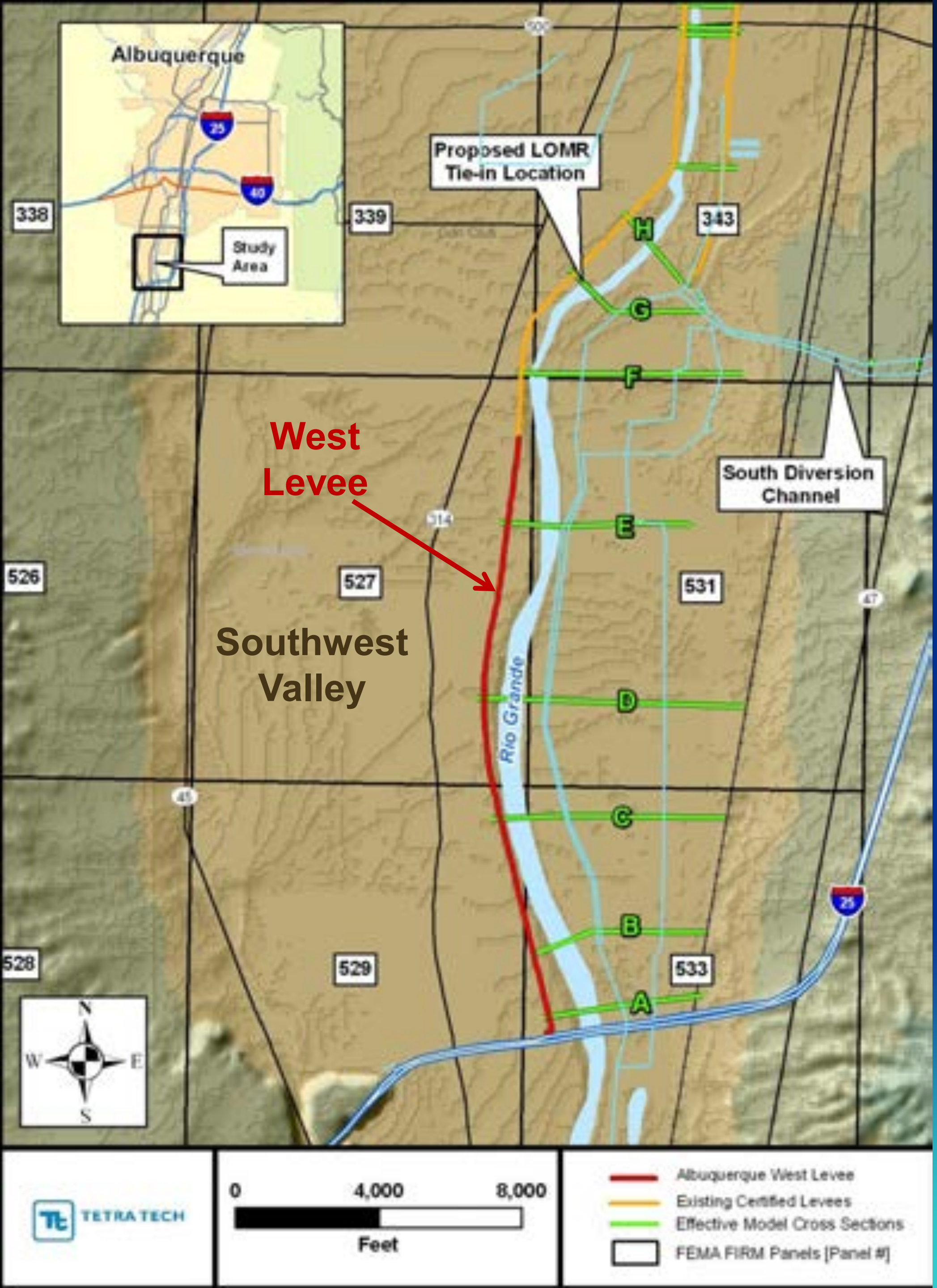
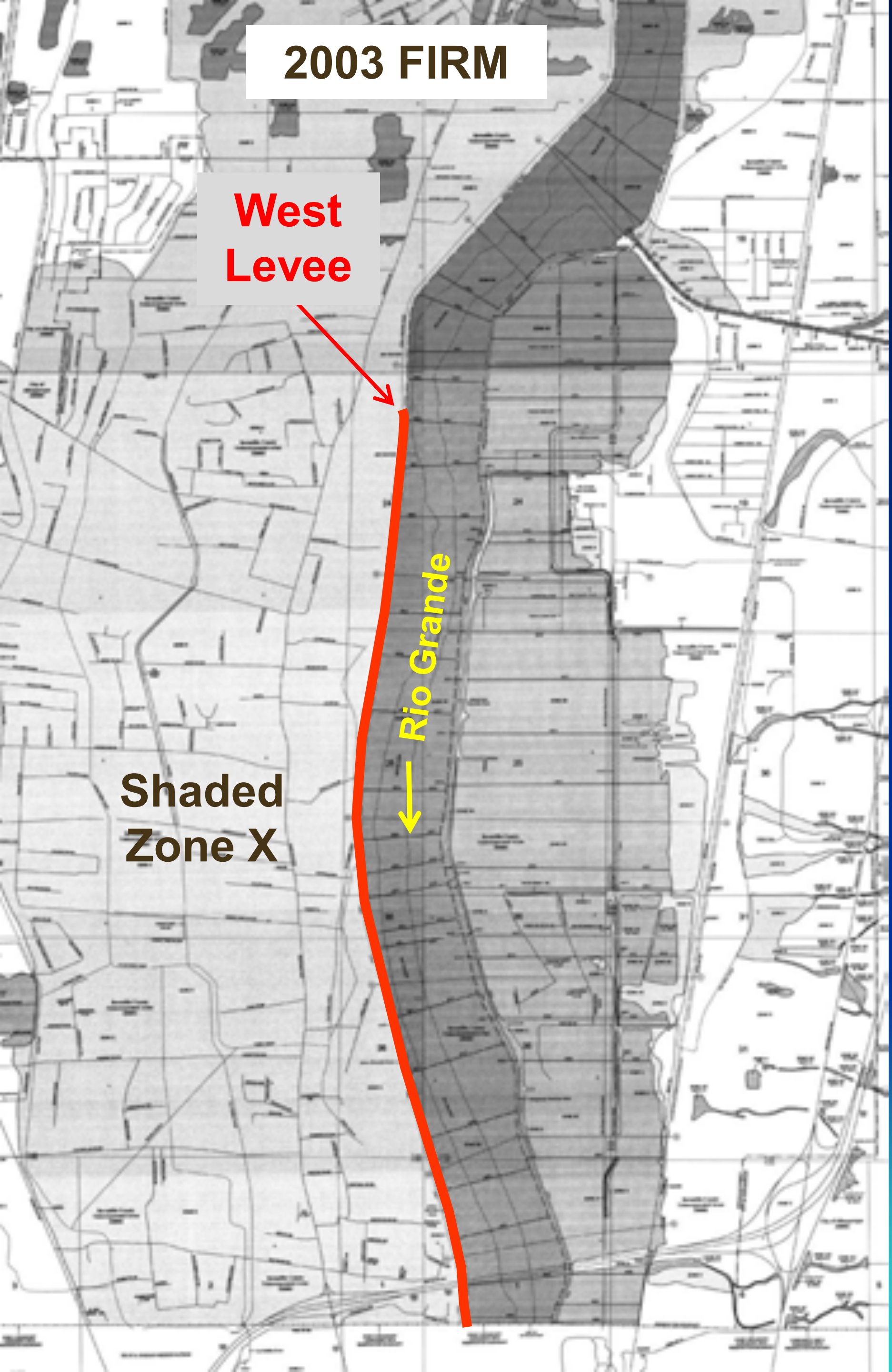
Arroyo Flood Control Authority

TETRA TECH

Albuquerque West Levee



TETRA TECH



BACKGROUND / HISTORY

- **2003**

  November 19, 2003 Effective FIS:

  West overbank area protected by the Albuquerque West Levee from the 1% annual chance flood (100-year event).

TETRA TECH

BACKGROUND / HISTORY

- **2006**
  - USACE completes study to determine certification status of certain levees within the Albuquerque District.

  - Study concludes that the Albuquerque West Levee, which is basically a spoil embankment levee, can not be certified.

- **2007**
  - FEMA develops plan to conduct restudy of Bernalillo County as part of Map Modernization Program.

TETRA TECH

BACKGROUND / HISTORY

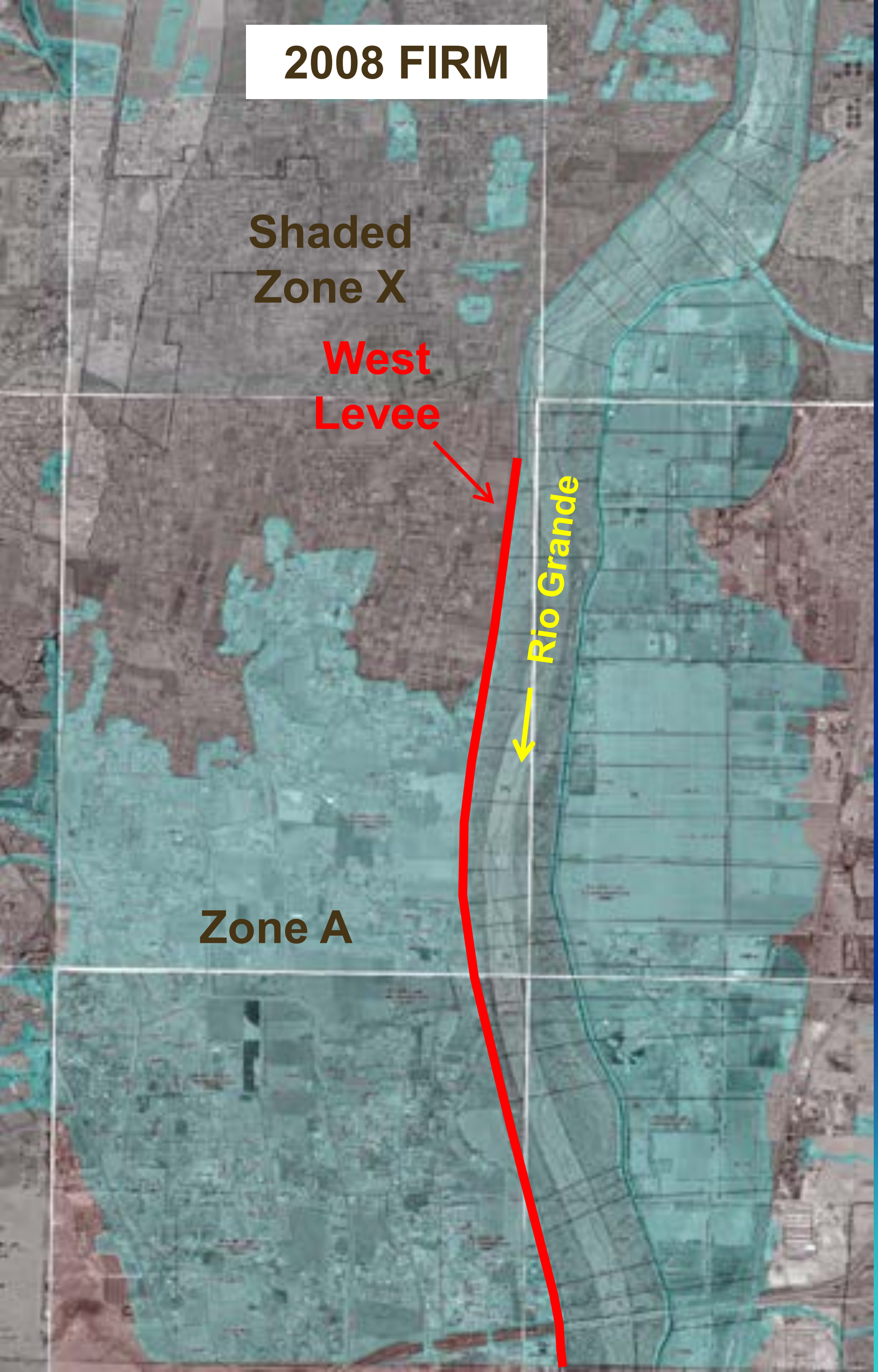
- **2008**
  - **FEMA completes county-wide restudy.**

Key Points of 2008 FIS

- **No changes to hydrologic analysis.***
- **Steady-state hydraulic analysis.**
- **West overbank modeled as separate flow path, using lateral structures to represent an assumed failure at the upstream end of the levee.**

*** Revised hydrology developed by USACE in 2006**

TETRA TECH



BACKGROUND / HISTORY

- **2008**

  September 26, 2008 Effective FIS

  – West overbank no longer protected from the 1% annual chance flood by the Albuquerque West Levee.

  – Approximately 2,550 acres of land in the Southwest Valley were placed inside the regulatory floodplain.

TETRA TECH

BACKGROUND / HISTORY

- **2008**
  - **Plan devised to construct engineered replacement levee.**
    - **Estimated Completion Date: Fall 2009**

Can anything be done in the meantime?

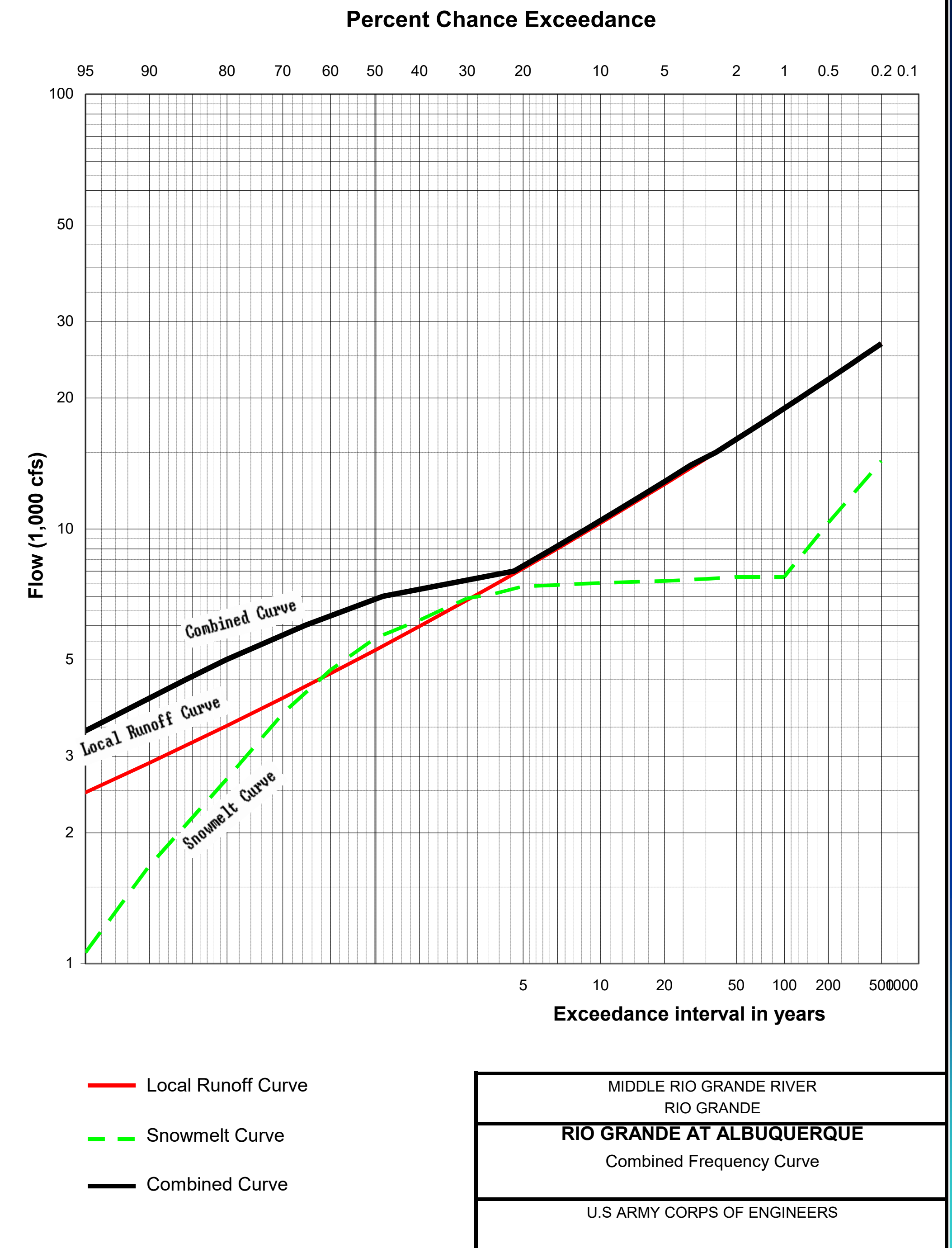
- **Revised hydrologic analysis?**
- **Revised hydraulic modeling approach?**

TETRA TECH

REVISED HYDROLOGY

- **2006**
  - USACE revises Rio Grande flood hydrology
  - Regulated vs. Unregulated Flows
  - Snowmelt Runoff vs. Local Rainfall Runoff

TETRA TECH



REVISED HYDROLOGY

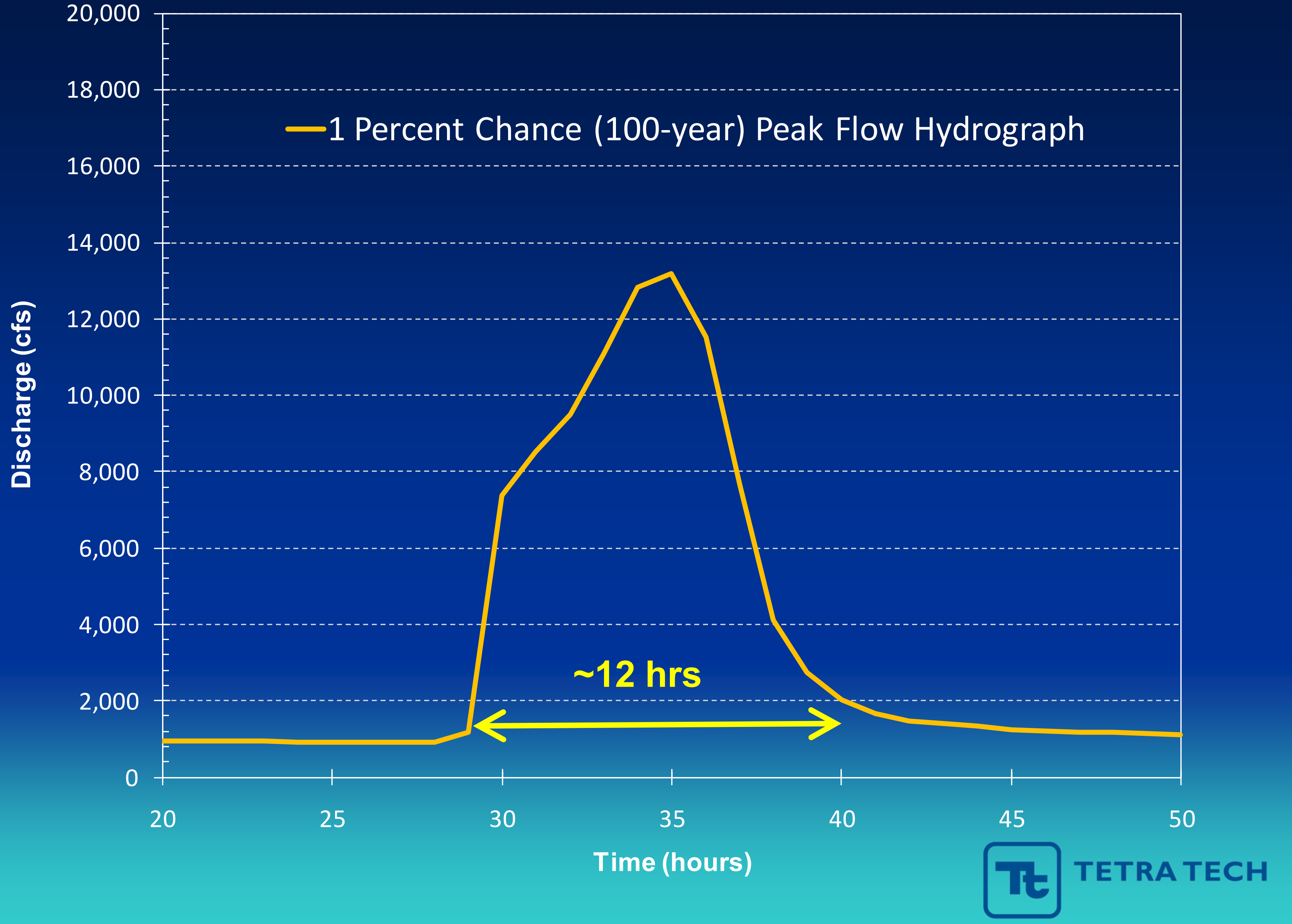
- Unregulated Rainfall Runoff greater than Regulated Snowmelt Runoff

TETRA TECH

HYDROLOGY RESULTS

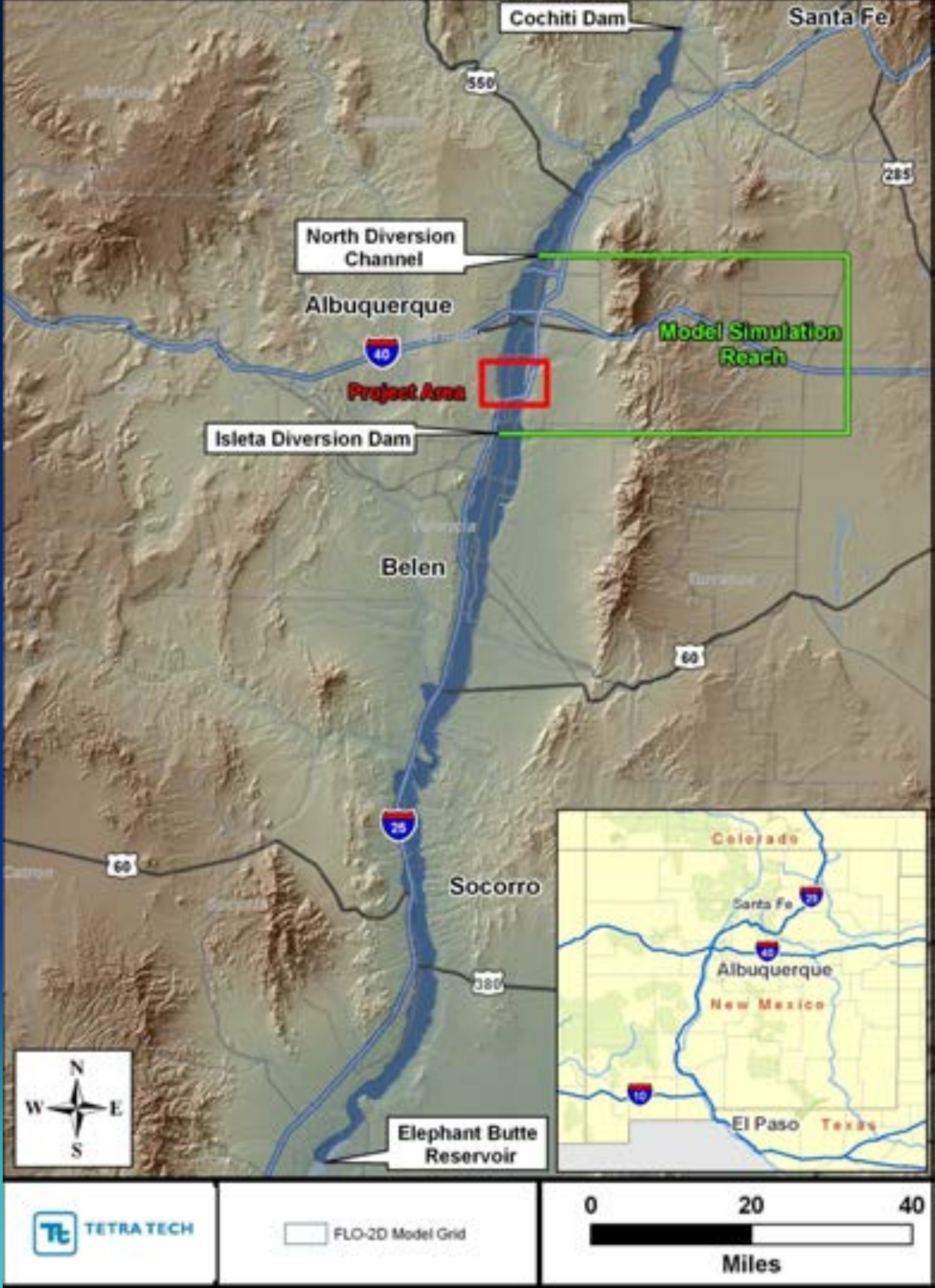
Annual Chance Flood (percent)	Recurrence Interval (years)	Effective FIS (cfs)	Revised (cfs)
10	10	7,100	8,180
2	50	14,700	10,790
1	100	21,700	13,170
0.2	500	41,000	21,330

TETRA TECH


1 Percent Chance (100-year) Peak Flow Hydrograph
~12 hrs
Discharge (cfs)
Time (hours)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
20
25
30
35
40
45
50
TETRA TECH

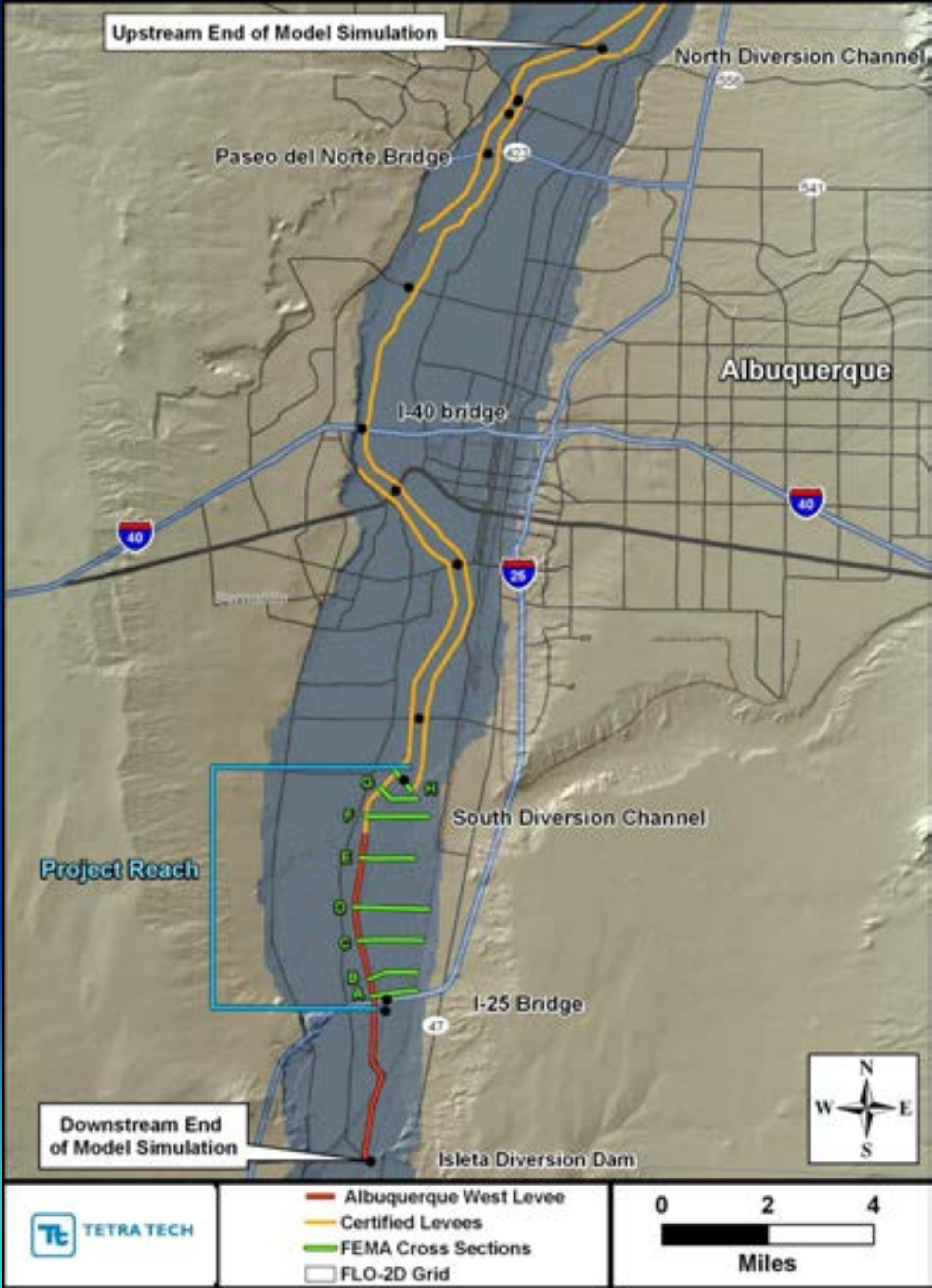
Hydraulic Model

- **FLO-2D**
  - 2-dimensional
  - Unsteady flow
- **Model Development**
  - Initially developed along entire Middle Rio Grande (180 miles)
  - Developed for USACE
  - Model Grid
    - 250' x 250'
    - 167,000 grid elements



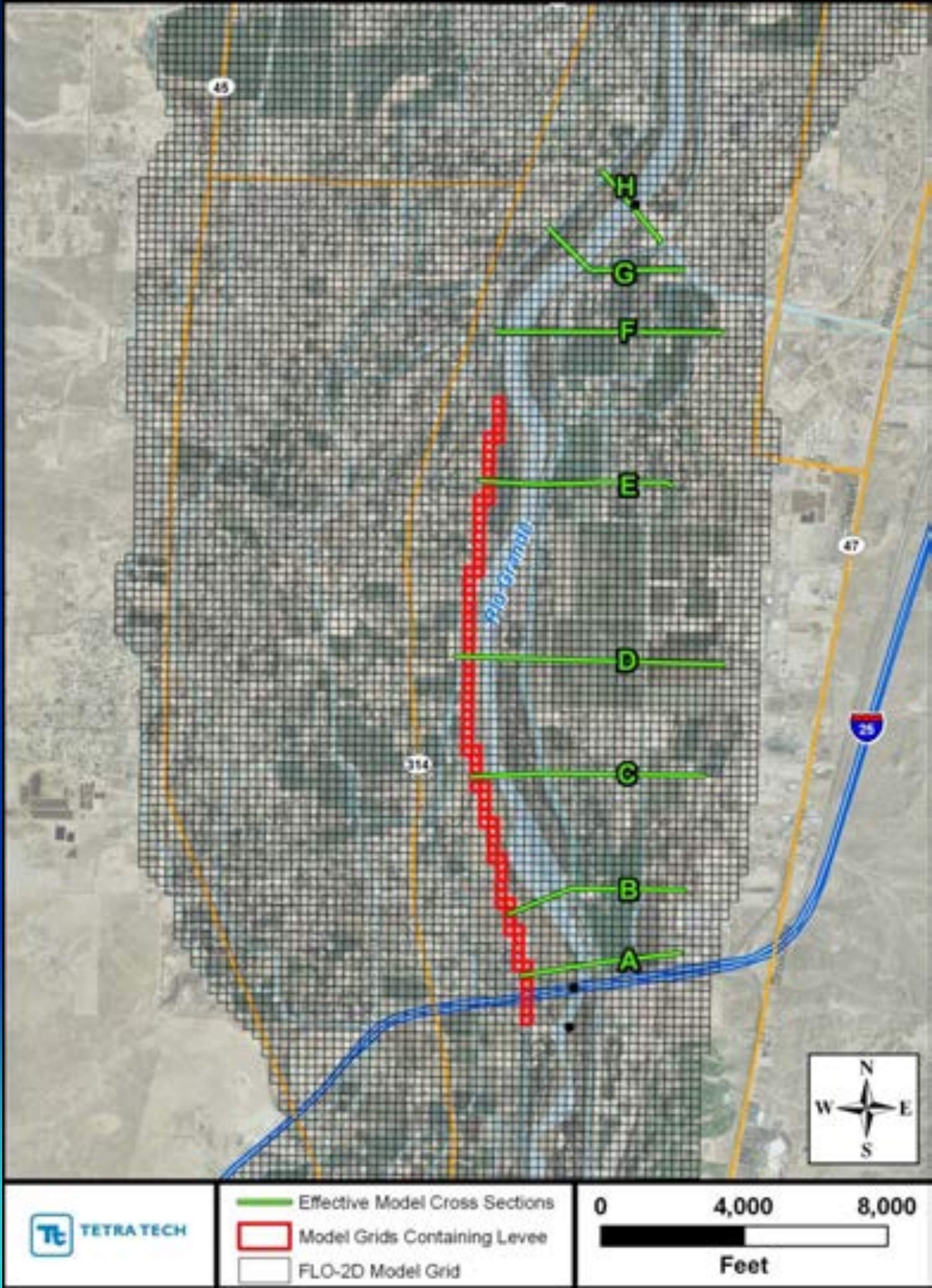
Simulation Reach

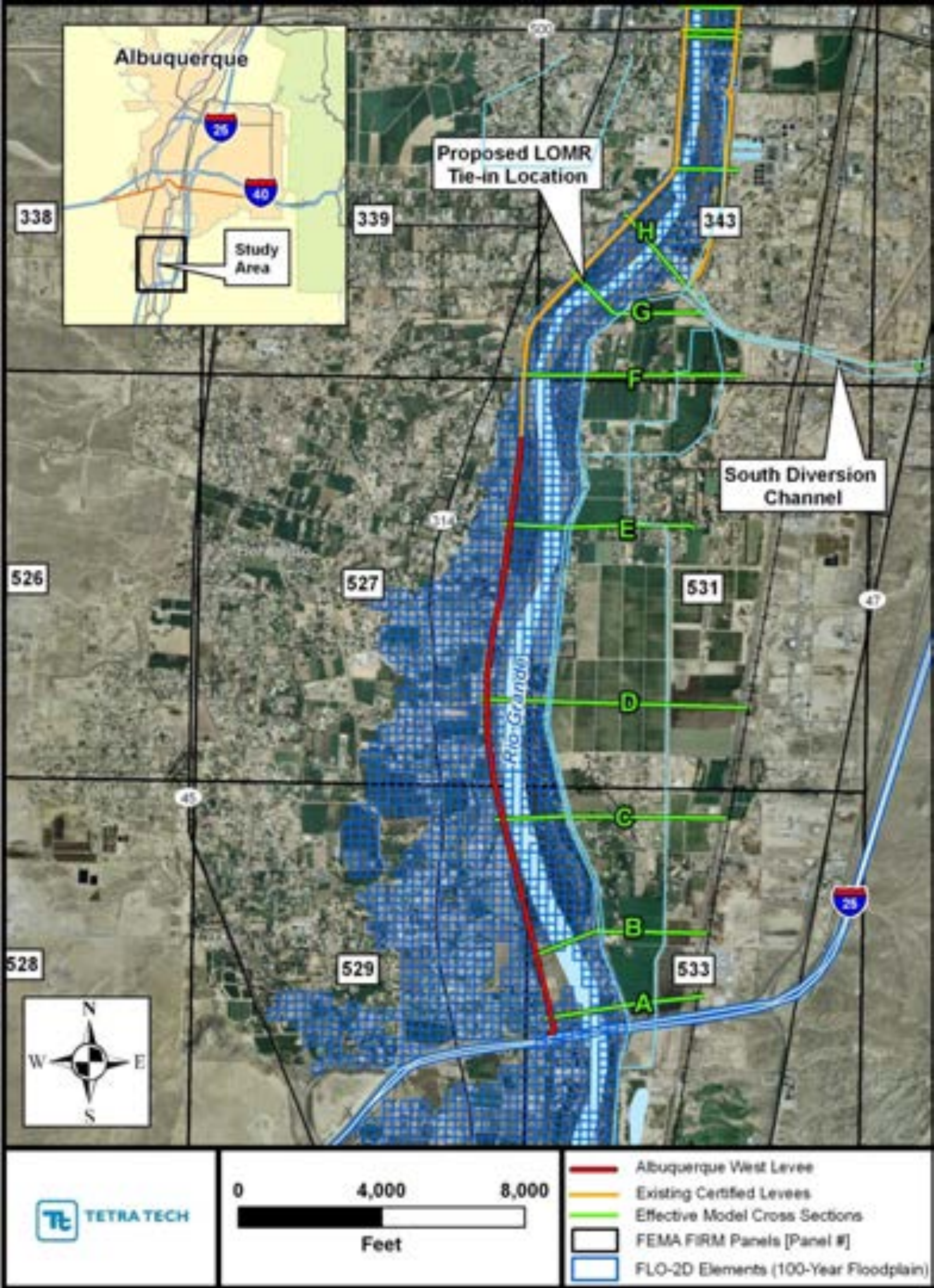
- Shorter Simulation Time
- Hydrologic Boundary Condition
- 21 miles long
- 27,000 grid elements



Project Reach

- Levee Removed
- 6,100 grid elements

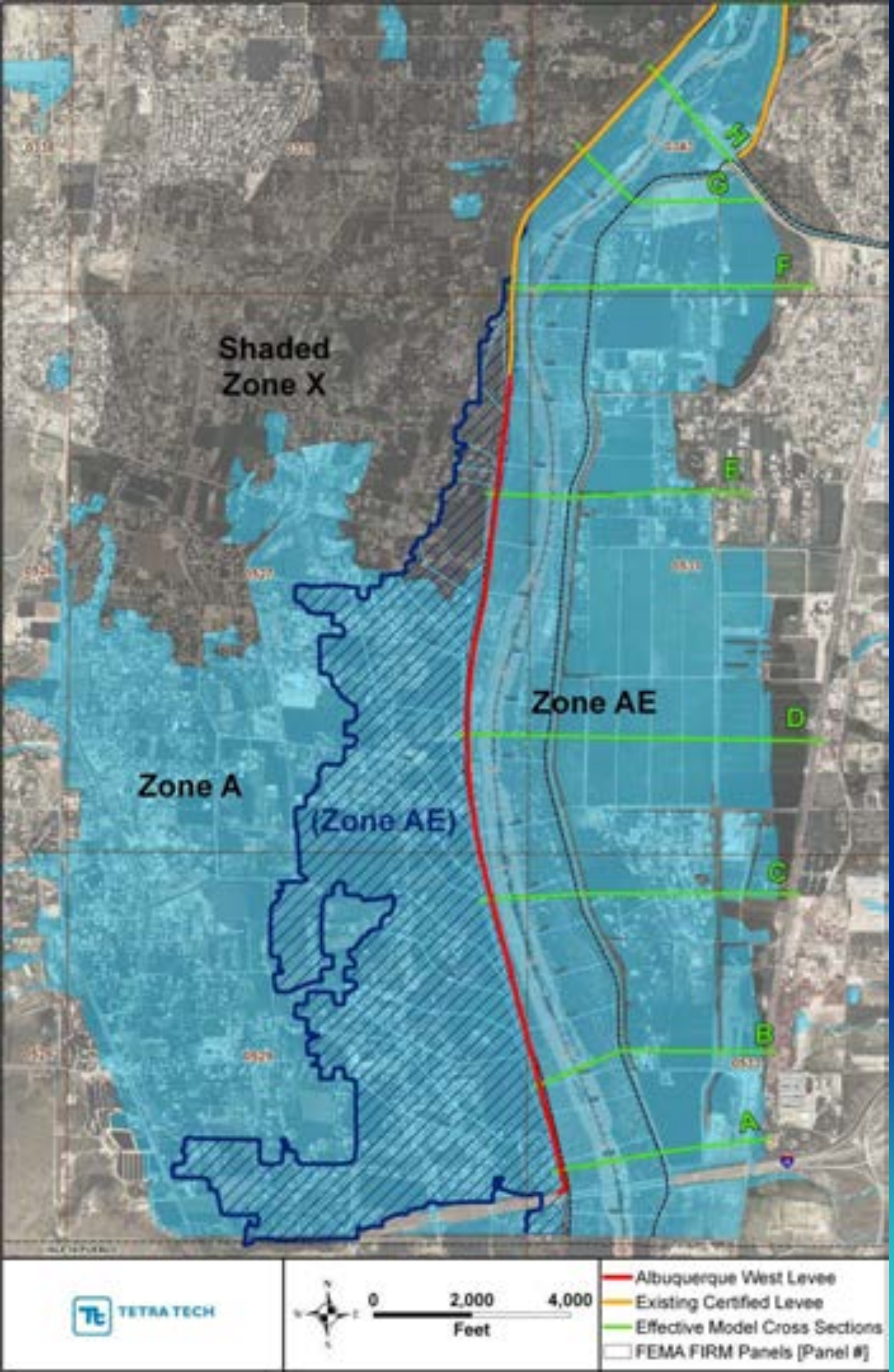




Hydraulic Results

100-year Event

TETRA TECH



Floodplain Reduction

- Regulatory Floodplain area reduced from 2,550 acres to 1,292 acres.
- 50% Reduction.
- Significant impact on flood insurance costs.

TETRA TECH

Benefits

- Improved hydraulic results based on limited-duration hydrographs.
  - Need to understand your hydrology
  - May not be applicable for long-duration snowmelt runoff events
- Provides ability to reduce extent of floodplain boundaries without physical changes to the project area.

TETRA TECH

Challenges

- Coordination with FEMA
  - FEMA representatives are generally not as familiar with this model format.
  - May require more explanation in LOMR application.
  - Accepted techniques may be dependent on the opinion of the specific reviewer or reviewing agency!

TETRA TECH

Challenges

- Output Format: Cross Sections vs. Grid Elements
  - Mapping, profiles, and tables
- Base Flood Elevations
  - Contour delineation

Challenges

- **Output Format: Cross Sections vs. Grid Elements**
  - **Mapping, profiles, and tables**
- **Base Flood Elevations**
  - **Contour delineation**
- **Floodplain Boundary Delineation**
  - **Compatibility with model elements**

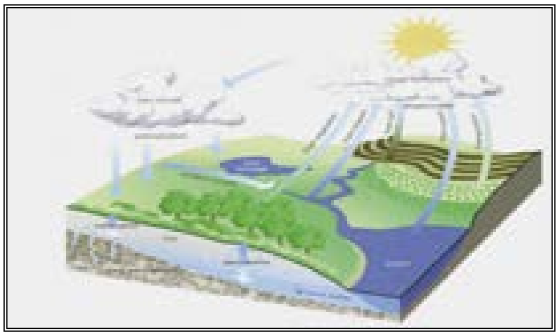
…Reminder: accepted techniques may be very dependent on the opinion of the specific reviewer or reviewing agency!

TETRA TECH

QUESTIONS?

West Levee
Southwest Valley
Rio Grande
25
Pan American Fwy
Pontiac Pl SW
TETRA TECH
Google

Colorado Urban Hydrograph Procedure
from Run-off to Run-on model for LID Designs



Dr. James C.Y. Guo, P.E. and Professor and Director, UCDenver
Ben Urbonas, President, Urban Watersheds Research Institute
presented in
2010 CASFM Annual Conference, Snow Mass, Colorado,
September 21-25, 2010

Storm Water Modeling Approaches

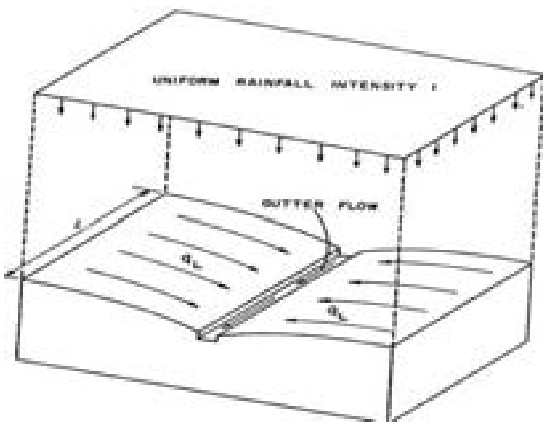
- **Linear versus Nonlinear**
  Rational method vs Hydrograph method
- **Lumped versus Distributed**
  Single watershed vs Several subareas
- **Deterministic versus In-deterministic**
  Constant soil infiltration vs Soil antecedent moisture
- **Statistic versus Stochastic**
  Independent event vs dependent event in time series
- **Event-based versus Long-term Simulation**
  100-yr flow prediction vs reservoir operation
- **Annual Series versus Complete Data Series**
  Extreme, partial, and complete data series
- **Small Watershed versus Large Watershed**
  Point rainfall depth vs Area average with a reduction
- **Others**

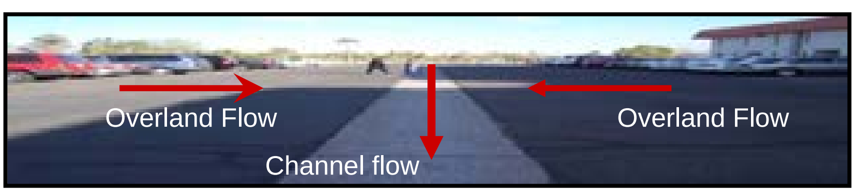
Guo, James C.Y. , Urbonas, Ben, and MacKenzie, Ken (2008), a Key Note on " Modeling Consistency for Integrated Stormwater Management Approach Adopted for Denver Area, Colorado", presented in Conference for Watershed Integrated Approach for Water Management held in Taipei, Taiwan, Dec 2008.

Storm Water Simulation Models

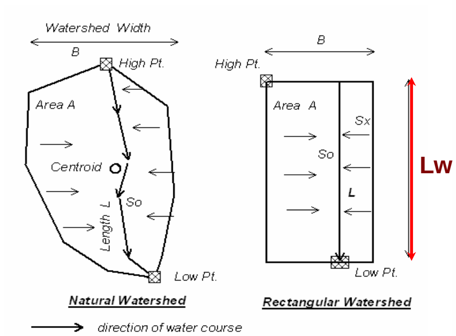
- **Physical Model using Laboratory Data**
  Laboratory test -- shower + sprinkler man-made rainfall
  <u>Major problem: scale effect in the laboratory settings</u>
- **Probabilistic Model using Historical Data**
  Time-dependent vs Time-independent
  Homogeneous vs Non-homogeneous data
  <u>Major problem: watershed subject to continuous development</u>
- **Empirical Model using Local Data**
  Regional analysis for a hydrologic zone ($Q = a\, A^b S^c$)
  <u>Major problem: how to generalize the local empirical formula</u>
- **Numerical Model using Numerical Simulation**
  A. Unit Hydrograph
  B. Kinematic Wave (KW) Overland Flow
  Numerical models firstly provide <u>consistent predictions</u> among events and various watershed conditions, and can be calibrated for <u>accurate predictions</u> when local data becomes available.

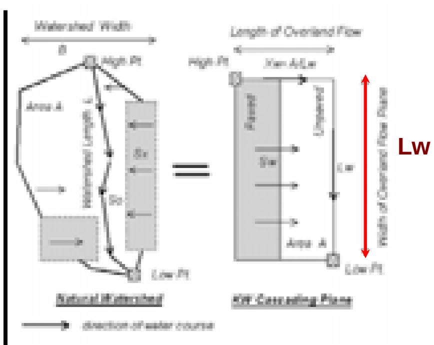
KINEMATIC WAVE for Overland Flow on a Rectangular Plane





How to Define the Width of KW Rectangular Plane?





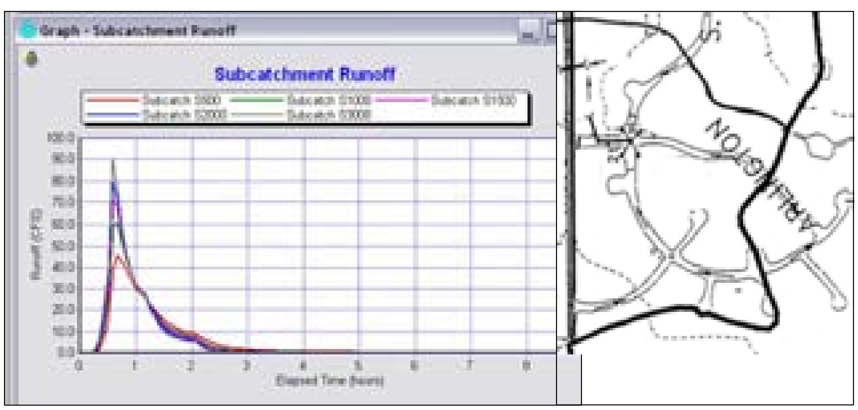
Rectangular Sloping Plane
Good for the conventional method

What is width of the KW plane?

Rectangular Cascading Plane
Good for the Low Impact Development (LID) method

What is width of the KW plane?
How to divide the width for Imp%?

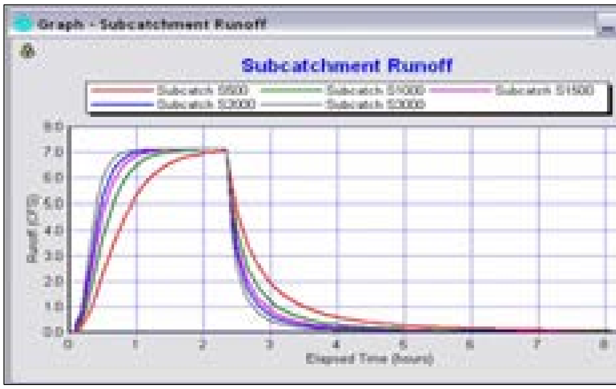
Sensitivity to KW Plane Width (Non-uniform rainfall)

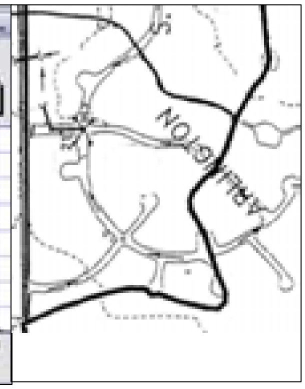


The unit catchment has: Area=21.76 ac, Imperviousness =50%. Slope =1%.
The width of KW plane was tested for Lw=500, 1000, 1500, 2000, to 3000 feet.
The peak flow varies from 45 to 90 cfs under a non-uniform 100-yr rainfall.
Which one is for design?

Guo, J.C.Y. and Urbonas, B. (2007) "Conversion of Watershed into Kinematic Wave Plane",
2007 EPA SWMM Conference Proceedings, held in Arcadia, California.

Sensitivity to KW Plane Width (uniform rainfall)

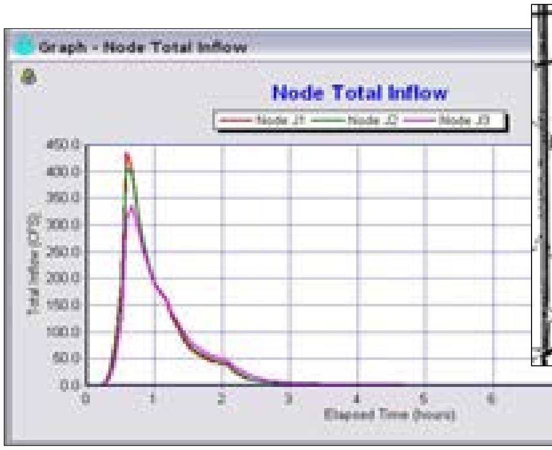


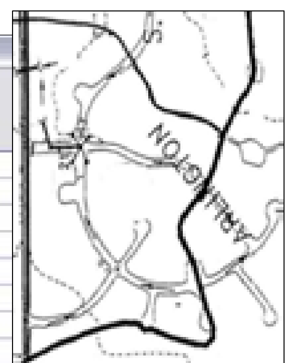


The unit watershed has A=21.76 acre, S=1%, and Imp=50%. Five waterway lengths were tested for Lw = 500, 1000, 1500, 2000, to 3000 ft. Under a uniform rainfall, the longer the waterway, L, the less the runoff. **Which width shall represent this natural watershed?**

Guo, James C.Y. and Urbonas, B. (2009) "*Conversion of Natural Watershed to Kinematic Wave Cascading Plane*", ASCE J. of Hydrologic Engineering, Vol 14, No. 8, August.

Sensitivity to Watershed Size and Discretization

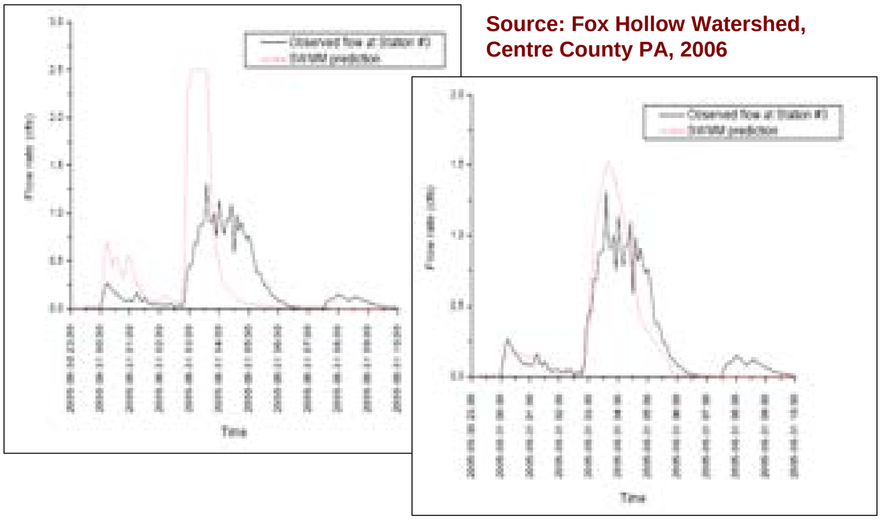




Unit Catchment

Node J1 = collection of six individual unit catchments A=21.76 ac x 6
Node J2 = collection of three 2-unit catchments with A= 43.52 ac x 3
Node J3 = collection of one catchment with A= 130.56 ac
The peak flow varies from 330 to 440 cfs. **Which one is for design?**

Current Practice with EPA KW SWMM - Calibration

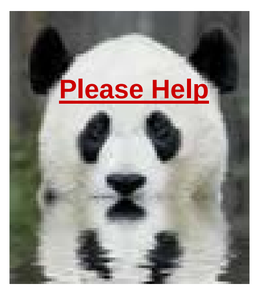


Source: Fox Hollow Watershed, Centre County PA, 2006

If I have data for calibration, I do not need a KW model.
If I do not have data, how can I calibrate a KW model !

We are facing the facts:

(1) Laboratory models are subject to scale effects.
(2) Statistic methods do not predict the future urban hydrologic outcomes.
(3) The KW method has a fundamental challenge on rectangular shape conversion.



What else do we have?

How about the unit graph method?

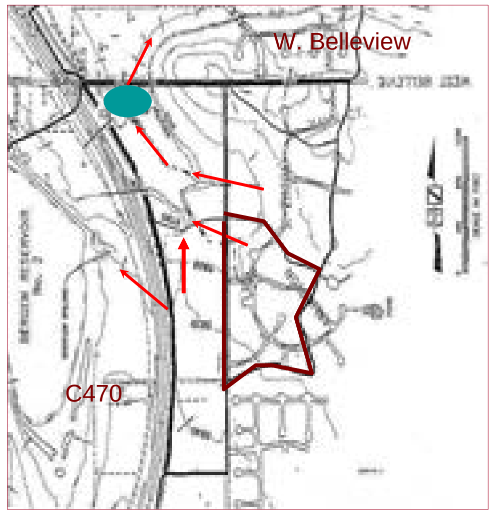
1. It starts with a set of empirical equations for overland hydrograph predictions. It can be a quick start.
2. The specified protocol defines its consistency. It needs a drainage manual to define the regional design criteria and master drainage planning.
3. Watershed monitoring and model calibration will lead the model to its accuracy, but it takes 10 to 20 years to collect adequate data.

Colorado Urban Hydrograph Procedure (CUHP) Unit Graph Approach

CUHP was developed for master drainage planning and designs in the metro Denver, Boulder, Ft. Collins areas, and has been used for Colorado Sprgs, Albuquerque, and others

Regional Master Drainage Plan is the regional strategy to convey flood flows within the defined floodplains and to mitigate flooding damage using regional detention and retention facilities.

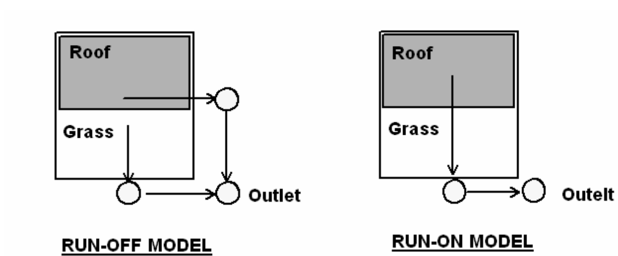
On-site (Local) Designs shall comply with the regional master drainage plan with all required on-site stormwater BMP and LID



Development of CUHP

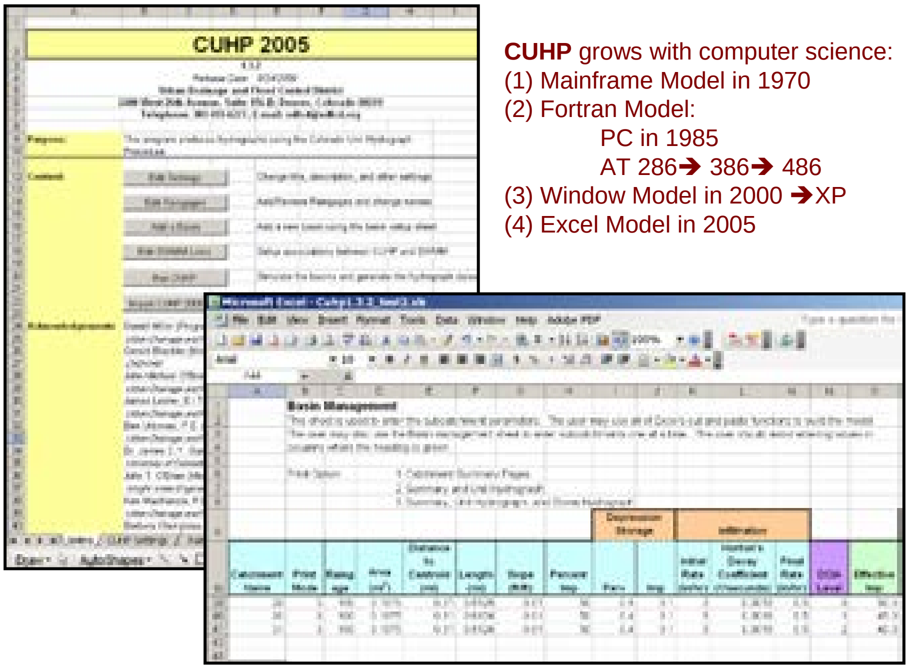
Basics of CUHP

1. synthetic **unit graph method**,
2. applicable tributary area ranging from **10 to 3000 acres**,
3. **imperviousness-based** approach for watershed stormwater modeling, and
4. conventional ***RUNOFF approach*** to combine hydrographs.



History of CUHP

1970 CUHP mainframe model,
1985 CUHP+UDSWMM PC model (Tc and Tp)
2000 CUHP+UDSWMM Window Operational Model (Tc and Tp)
2005 CUHP +SWMM5 to include SMALL (on-site) watershed hydrology
2010 CUHP +Swmm5 to model to include RUN-ON flows (LID layout).



CUHP grows with computer science:

(1) Mainframe Model in 1970

(2) Fortran Model:

PC in 1985

AT 286➔ 386➔ 486

(3) Window Model in 2000 ➔XP

(4) Excel Model in 2005

CUHP2000 UNIT GRAPH

$$C_p = PC_t A^{0.15}$$

$$t_p = C_t \left(\frac{LL_c}{\sqrt{S_0}} \right)^{0.48} \quad \text{(hour)}$$

$$q_p = 640 \frac{C_p}{t_p} \quad \text{(cfs/sq mile)}$$

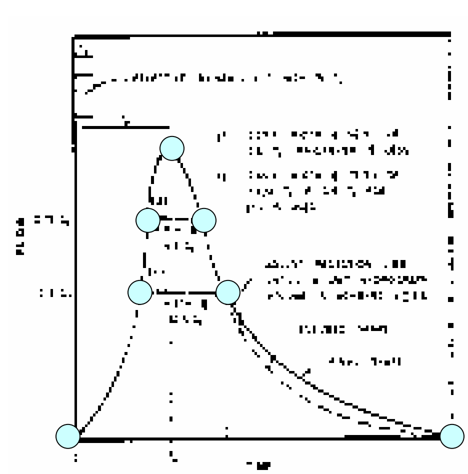
$$T_p = 60 t_p + 0.5 t_u \quad \text{(hour)}$$

$$Q_p = q_p A \quad \text{(cfs)}$$

$$t_u = \max\left(\frac{1}{3} t_p \times 60,\ 5 \right) \text{(minutes)}$$

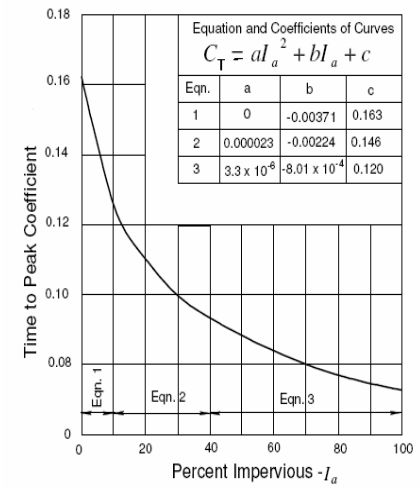
$$W_{50} = \frac{500}{q_p} \quad \text{(hour)}$$

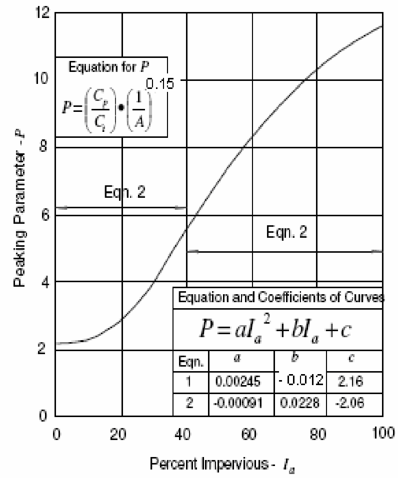
$$W_{75} = \frac{260}{q_p} \quad \text{(hour)}$$



Two major variables, C_T and P --- depending on watershed imperviousness.

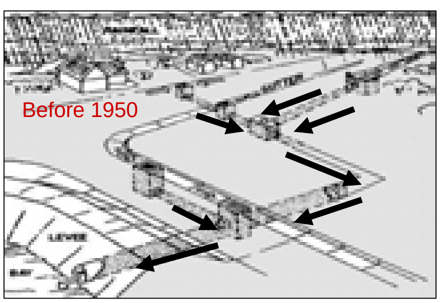
CUHP2000 Empirical Coefficients

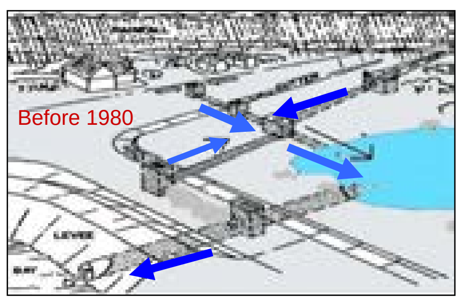




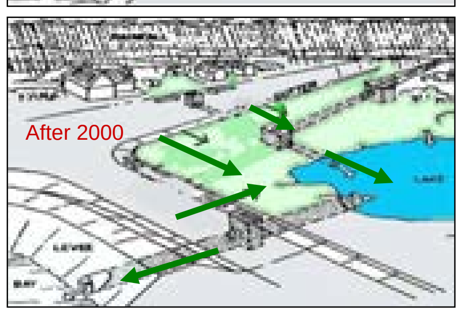
Q1: Should C_t and P be also function of the SIZE of watershed?
Q2: Can area-weighted Imp be used for LID cascading flows?

Evolution in Urban Watershed Management (1950 to 2000)





We removed old trees
We buried new pipes
We leveled the surfaces
We paved everywhere
Then we found we made mistakes.
We dig and remove pavements,
We add porous pavers,
After we paid them all,
we now feel that we are green-er.



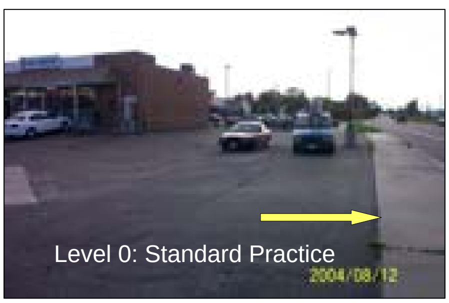
On-site Stormwater Treatment to retrofit a run-off to a run-on layout

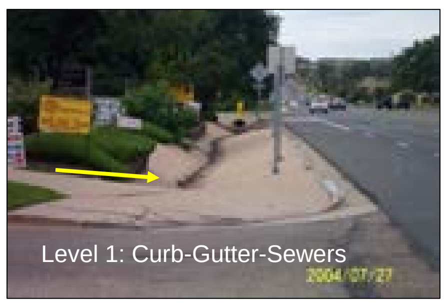
One-site Management
1. **Small Watershed**
2. **Run-on Hydrology**

Guo, James C.Y. and Cheng, J. Y.C.(2008) "*Retrofit Stormwater Retention Volume for Low Impact Development*", ASCE J. of Irrigation and Drainage Engineering, Vol 134, No 6, December.

Guo, James C.Y.(2009) "*Retrofitting Detention Basin with a Water Quality Control Pool*", ASCE J. of Irrigation and Drainage Engineering, Vol 135, No 6, October.

Street Drainage Patterns: Levels: 0 to 3





New Applications to CUHP

1. Application to small watersheds (1 to 90 acres)

a. IDF curve vs Design Rainfall Curve

b. Runoff coefficient vs Horton's infiltration

c. C_T (imp, size of Area) and C_P (imp, size of Area)

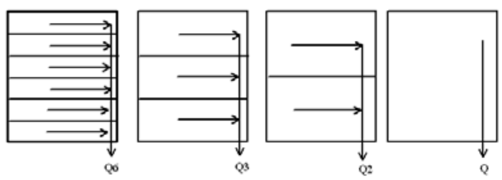
2. **Application to RUNON cascading flows**

a. convert area-weighted method into volume-weight method

b. area-weighted imperviousness Ia vs effective imperviousness Ie

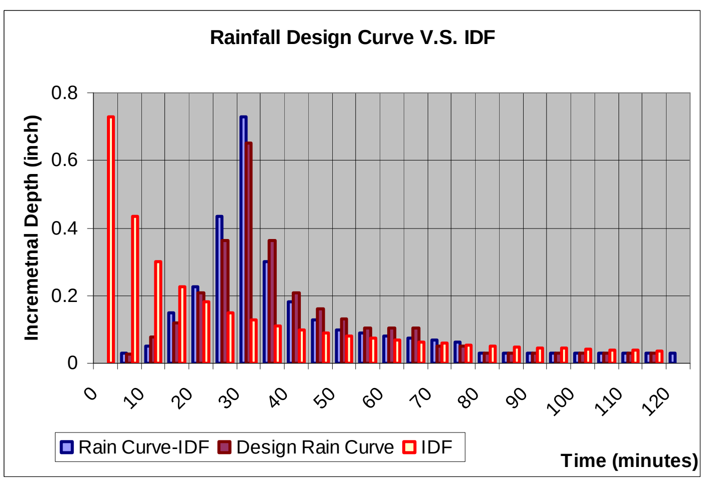
3. **Size effect on Model Outcome**

- How to define small watershed that will use the Rational method?
- How to define large watershed that will use the unit-graph method?
- How to model the LID cascading "RUNON" flow?
- How to divide a large watershed into subareas??



How come Q6>Q3>Q2>Q?

Consistency between Denver Rainfall Curve and IDF



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

P_1 = one-hr rainfall depth in inch

Td = duration in minutes

Revision to Peak Time Coefficient C_T

$$t_p = C_T\left(\frac{LL_{cs}}{\sqrt{S}}\right)^{0.48}$$

FACTS

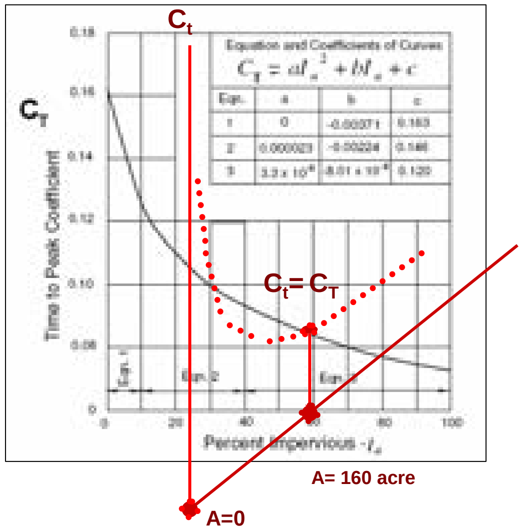
(1) C_T is related to the flow time through the watershed.
(2) C_T decreases when watershed imperviousness increases.
(3) C_T increases when watershed size increases.

Exiting Empirical Formula

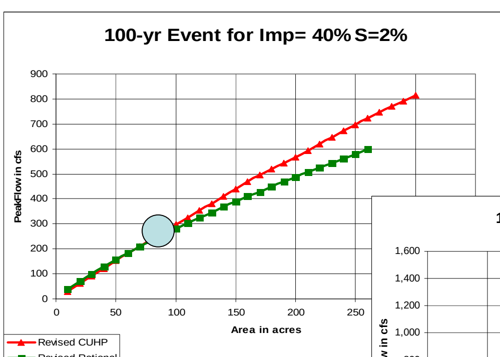
$C_{T\,=}$ fct (Imp%)

Revisions to

$C_t = C_T$ when Area>160 cfs
$C_t = C_T\ (0.65\ A^{-0.31})$

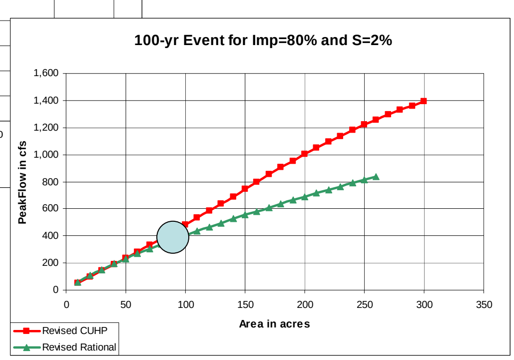


Good Agreements between CUHP and Rational Method up to 90 acres



The size of 90 acres separates small from large watersheds.

Cheers!



Predictions for Various Sub-area Discretized Models

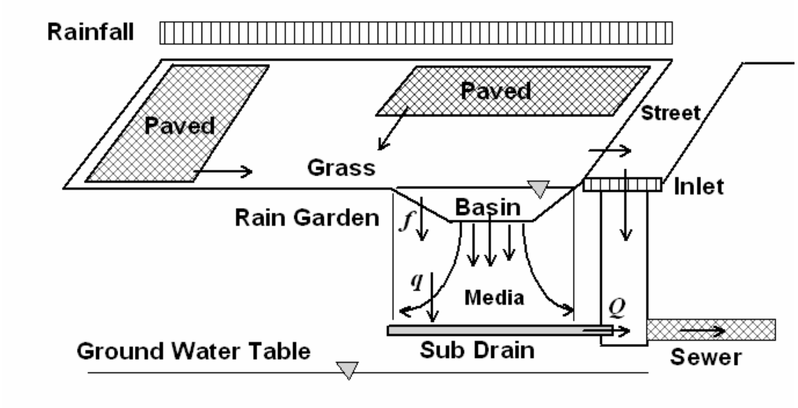
The test square watershed has a total area of 300 acres on a slope of 2.0% and imperviousness of 40%. Four cases were developed for testing. They are:
Case 1. The watershed is divided into **6 sub areas of 50 acres**
Case 2. The watershed is divided into **3 sub areas of 100 acres**
Case 3. The watershed is divided into **2 subareas: 200- and 100-acre**
Case 4. The watershed is modeled as **a 300-acre single tributary area**
All sub-areas are modeled as a square with a diagonal waterway on a 2.0% slope. Between sub-areas, the channel was defaulted to be a 5-ft trapezoidal channel of 500-ft in length.

Cases	CUHP2005-now Q in cfs	CUHP2005-revised Q in cfs	Comments
Six Areas of 50 acres	947	761	six small basins
Three Areas of 100 acres	885	763	a small + a large basin
Two Areas of 200 and 100 acres	833	793	mixed sizes
Single Area of 300 acres	718	718	a large basin

Cheers !

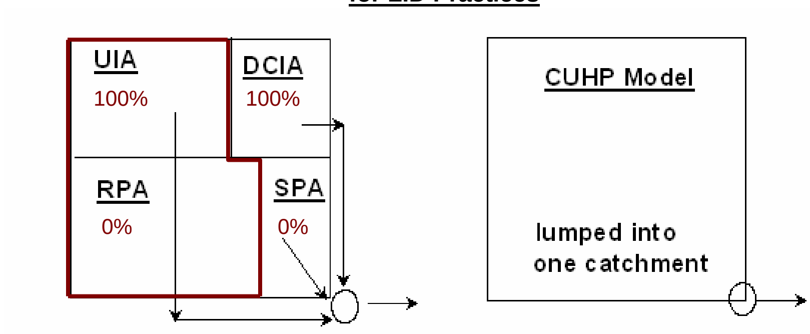
CUHP Applications to RUN-ON FLOW for LID Layout

- Level 0 = Standard Practice (for regional planning only)
- Level 1 = Urban Setting with Curbs and Gutters (for local area planning)
- Level 2 = Rural Setting with Riprap Ditch and Grass Swales (for on-site design)
- Level 3 = Rural Setting plus on-site Water Quality Control Pond (for on-site design)



CUHP LUMPED MODEL VS SWMM Distributed Model

for LID Practices

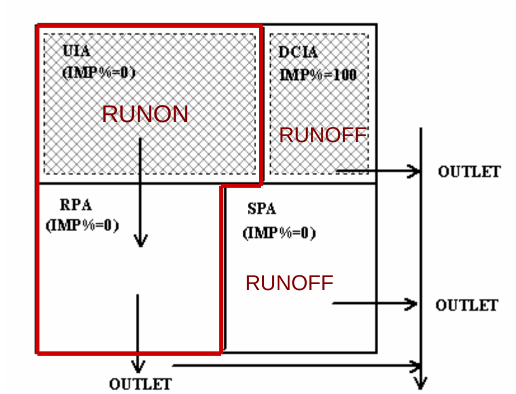


SWMM5 distributed model **CUHP lumped model**

Can SWMM5 serve as a basis to improve CUHP for runoff-on flow applications?

Guo, James C.Y. (2010)"Preservation of Watershed Regime for Low Impact Development using Detention", ASCE J. of Engineering Hydrology, Vol 15, No 1., January, 2010

LID Challenge to CUHP Revision: RUN-ON FLOW



Definition:

IA= DCIA+UIA
PA=SPA+ RPA
TA=IA+PA

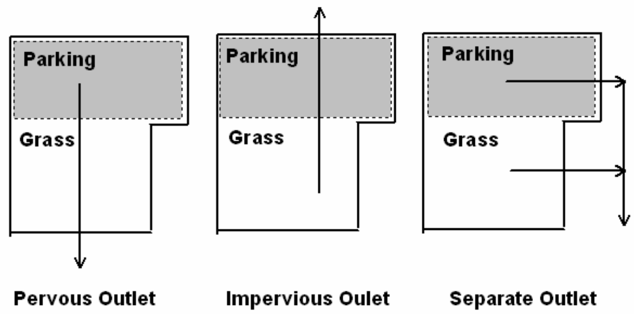
D=DICA/IA
R=RPA/PA

Ia = IA/TA

*Site Imp = DCIA *100% + SPA * 0% + (UIA+RPA)* Ie%*
*Ie % = PARK * Ia%*

How to derive the Paved Area Reduction Factor (PARF) for the run-on plane?
(a) Tool – SWMM5 and
(b) Method -- Volume-weighted

SWMM5 for RUNON and RUNOFF Cascading Flows



THREE TYPES OF OUTLETS (Sub-area Routing Schemes)
Impervious outlet = upper pervious area onto lower impervious area
Pervious Outlet = upper impervious area onto lower pervious area
Separate Outlet = two independent flow paths draining into two outlets.

FLOW INTERCEPTION PERCENTAGE (Internal Routing Percentage)
% of the upper plane flow runs onto the lower plane

So, these two options allow SWMM5 to calculate the runoff volumes with and without a LID porous plane.

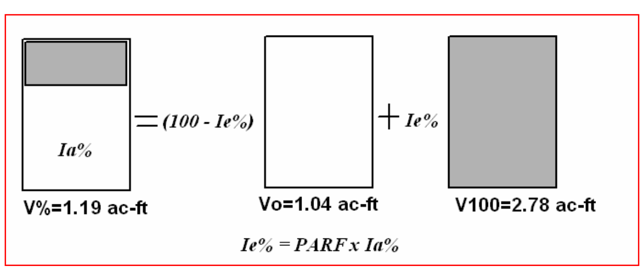
Proposed New Approach Runoff-Volume Weighted Imperviousness Porous Pavement

A 2-acre watershed is developed with the paved area of 0.4 acre or *Ia%=20%*. The outfall area is covered with porous grass buffers.

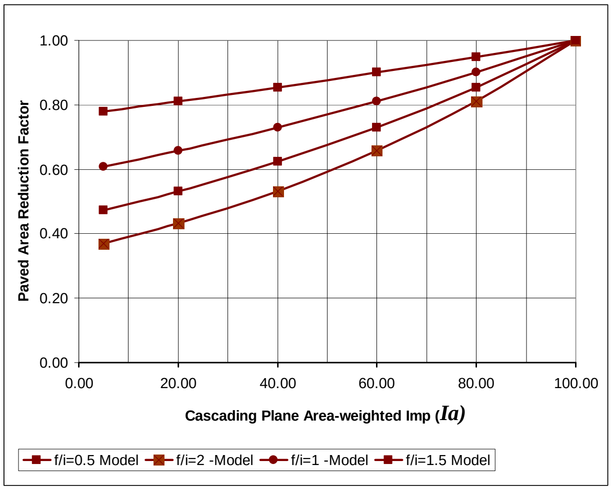
Using the Denver's 2-hr, 2-yr design rainfall, f /I = 2.0, SWMM5 reports the volumes for various conditions.

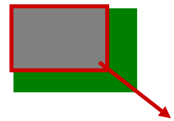
Solve for Ie% = (1.19-1.04) / (2.78-1.04) = 8.68%
Ie% = PARF x Ia% or PARF = 8.68 / 20 = 0.43

Set *f /I* = 0.5, 1.0, 1.5, and 2 and *Ia*= 5% to 90% to produce a design chart.



LID Conveyance-Based PARF for Porous Pavements
Ie%=PARF x Ia%



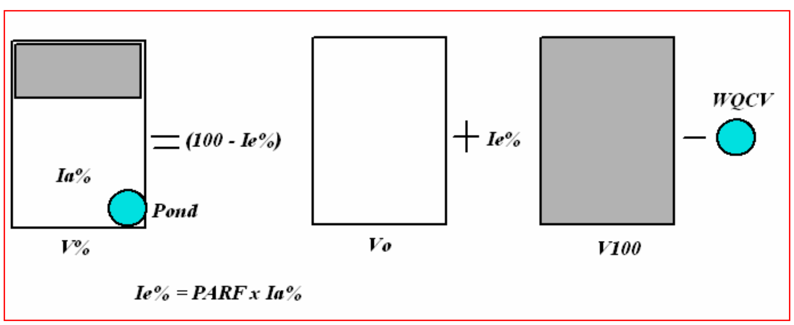


Example:

Paved Area = 3.0 ac
Porous Area = 2.0 ac
Ia% =60 %
f/i = 2.0
PARF =0.65
Ie% = 60% x 0.65=39%

Downstream sewers are Designed with Ie= 39%

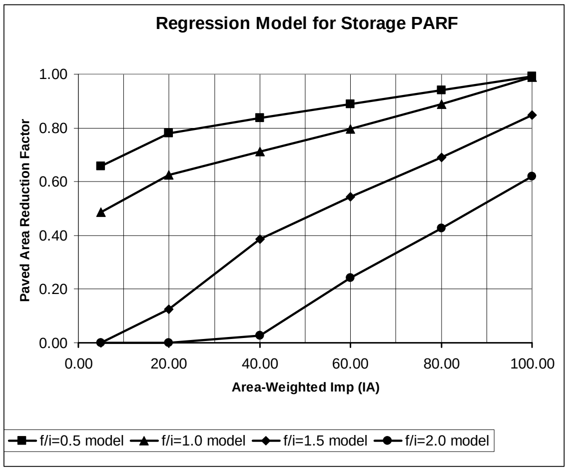
Proposed Runoff-Volume Weighted Imperviousness
Porous Pavement + Water Quality Control Pond

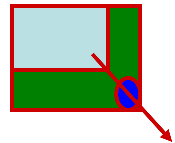


Guo, James C.Y. Guo, Blackler, E G, Earles, A, and MacKenzie, K (2010) "Effective Imperviousness as Incentive Index for *Stormwater LID Designs*" ASCE J. of Irrigation and Drainage Engineering, Vol 136, No12, Dec, 2010.

Guo, James C.Y. (2008) *Runoff Volume-Based Imperviousness Developed for Storm Water BMP Designs*", ASCE J. of Irrigation and Drainage Engineering, Vol 134, No 2, April.

LID Storage-based PARF for WQCV Basins
Ie%=PARF x Ia% for LID Flow

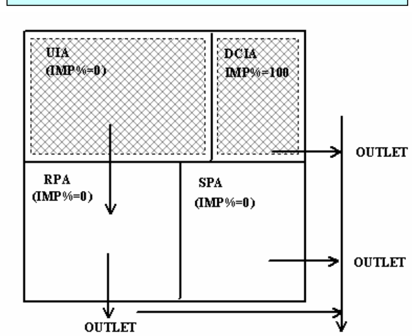


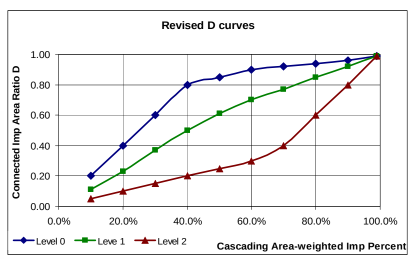


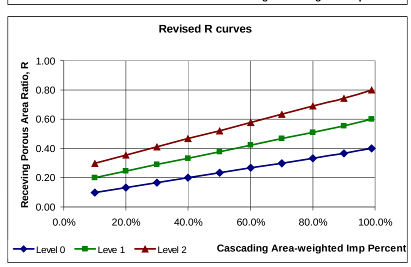
Example:
Paved Area = 3-ac
Porous Area = 2-ac
f/i = 2.0
Ia = 60%
With a WQCV basin
PARF =0.25
Ie% = 60% x 0.25=15%

The downstream sewers are down-sized with Ie%=15%.

Denver's LID Practice
R and D Curves







D = UIA/IA directly connected area
R= RPA/PA receiving pervious area

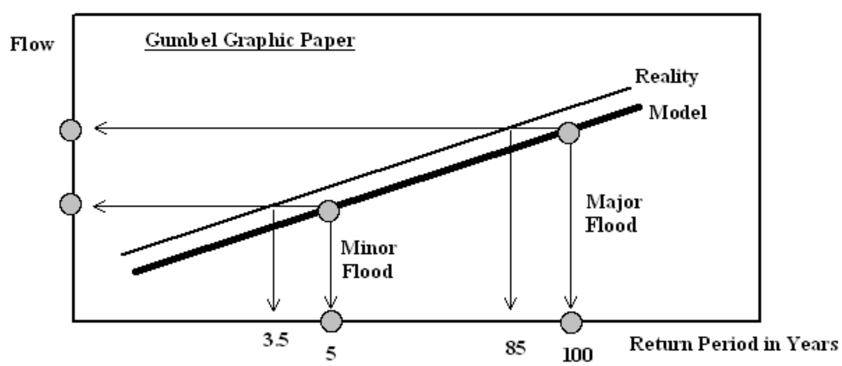
Site area-weighted : IA%=IA/TA
LID plane area-weighted: Ia% = UIA/(UIA+RPA) for LID Plane
Ie% = PARF x Ia%
*Site Imp IE% = Ie% * [(1-D)IA%+R(1-IA%)]+D* IA% and*

Example: A 2-acre lot is developed using the R and D curves. Consider f/i=2 for 2-yr event and f/i=0.77 for 100-yr event, Estimate the LID impact on the site imperviousness

									Cascading Plane						
Land Use Imp **IA%** *(<1.0)*	BMP Level	R	D	TA total Area acres	IA Imp Area IA%*TA acres	PA Perv Area TA-IA acres	DICA area D*IA acres	SPA area (1-R)*PA acres	Upper UIA area acres	Lower RPA area acres	Areal Imp *Ia%* *(<1.0)*	*f/i* ratio	PARF	Effective Imp *Ie%* *(<1.0)*	Site Imp **IE%** *(<1.0)*
0.60	0	0.25	0.90	2.00	1.20	0.80	1.08	0.60	0.12	0.20	0.38	2.00	0.65	0.24	**0.58**
0.60	1	0.41	0.70	2.00	1.20	0.80	0.84	0.47	0.36	0.33	0.52	2.00	0.65	0.34	**0.54**
0.60	2	0.59	0.30	2.00	1.20	0.80	0.36	0.33	0.84	0.47	0.64	2.00	0.65	0.42	**0.45**
0.40	2	0.42	0.20	2.00	0.80	1.20	0.16	0.70	0.64	0.50	0.56	2.00	0.65	0.36	**0.29**
0.60	2	0.58	0.30	2.00	1.20	0.80	0.36	0.34	0.84	0.46	0.64	2.00	0.65	0.42	**0.45**
0.80	2	0.70	0.60	2.00	1.60	0.40	0.96	0.12	0.64	0.28	0.70	2.00	0.65	0.45	**0.69**
0.40	2	0.42	0.20	2.00	0.80	1.20	0.16	0.70	0.64	0.50	0.56	0.77	0.82	0.46	**0.34**
0.60	2	0.58	0.30	2.00	1.20	0.80	0.36	0.34	0.84	0.46	0.64	0.77	0.86	0.55	**0.54**
0.80	2	0.70	0.60	2.00	1.60	0.40	0.96	0.12	0.64	0.28	0.70	0.77	0.91	0.63	**0.77**

1. A LID layout has more runoff reduction on the frequent events than the extreme.
2. A LID layout has more runoff reduction on Level 2 than that on Level 0
3. The R and D curves are developed for planning and can be overridden by on-site design.
4. Two sets of PARF work consistently. PARF has been adopted as the STORMWATER LID Incentive index for stormwater fees and taxes.

REGIONAL MODELING CONSISTENCY VERSUS ACCURACY

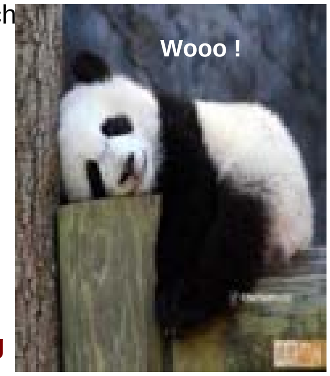


Guo, James C.Y. and Urbonas, B (2008) "*Consistency between Colorado Urban Hydrograph Procedure and Rational Methods,*", Annual Natural Hazards News, published by Urban Drainage and Flood Control District, Denver, Colorado

Q and A

Visit Dr. Guo's webpage at:
www.UCDenver.edu/~jguo
to download FREE software, articles, research reports,

Visit www.UDFCD.org
to download FREE software and manual



The Hydrology and Hydraulics Graduate Program at UCDenver provides M.S. and PhD studies in the areas of:

1. **Stormwater LID Management**
2. **Flood Mitigation Designs**
3. **Surface and Sub-surface Flow Modeling**
4. **Water Resources and Groundwater**

Contact Dr. James Guo

Hydrographs Comparison of SWMM5 and CUHP 2005

CASFM Annual Conference 2010
September 21-24, 2010

AMEC Earth & Environmental

Jeffrey Y.C. Cheng, PE

Szu-Min Yang , ASLA

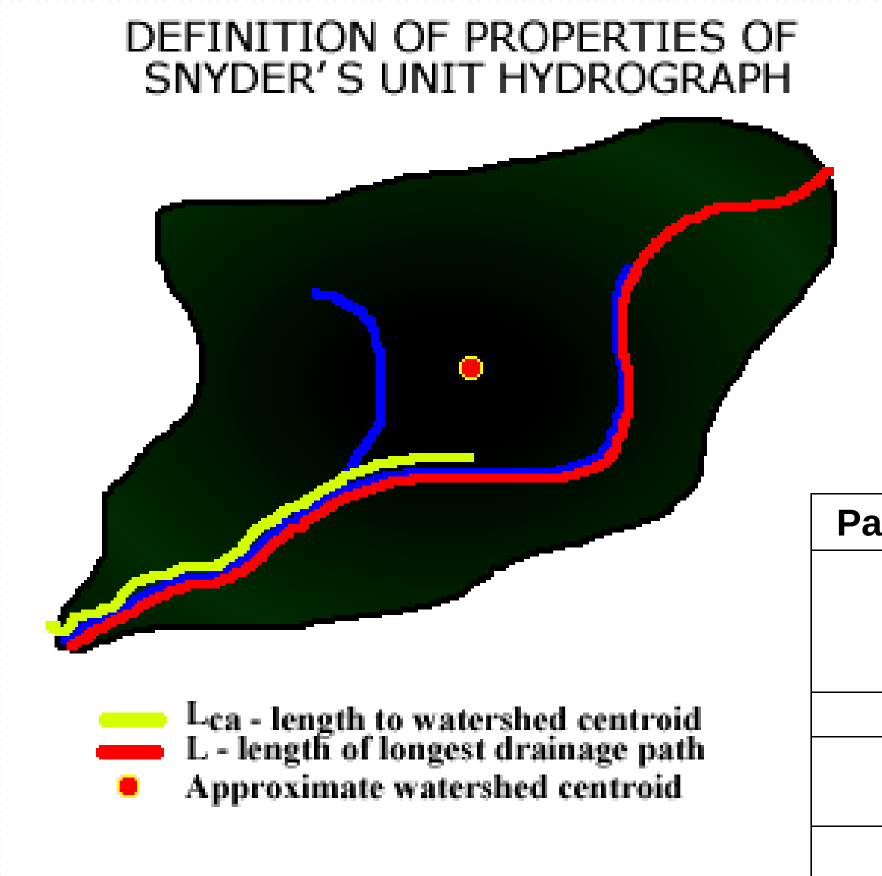
SEMSWA

Monica Bortolini, PE CFM

CUHP and SWMM5 Hydrograph Generation

- The Colorado Urban Hydrograph Procedure (CUHP) is an evolution of the Snyder unit hydrograph. (CUHP Manual 2010)
- EPA-SWMM5's subcatchment flow calculations are based on overland flow length and width uses the Kinematic Wave method. (SWMM application Manual 2009)

Snyder Unit Hydrograph

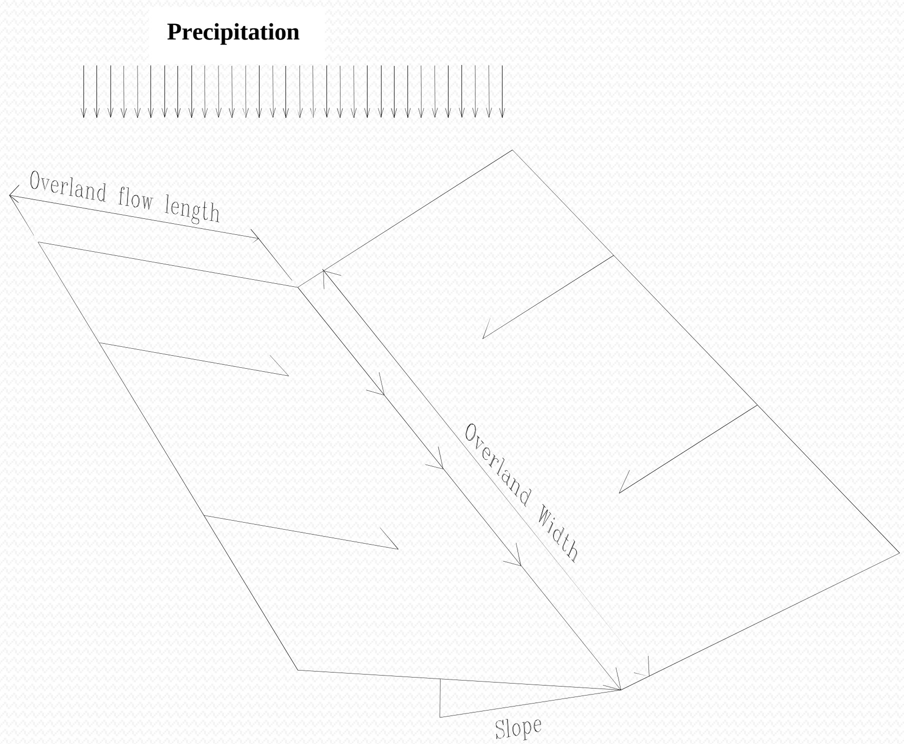


$$t_{lR} = t_l = C_1 C_t (L L_c)^{0.3}$$

$$q_p = \frac{C_2 C_p A}{t_l}$$

Parameter	Typical Value(s)	Comments
C_t	1.8 - 2.2	Both C_t and C_p should be calibrated or developed from existing UHG's.
C_p	0.5 - 0.7	
L	TBD	The length of the longest drainage path in miles
L_c	TBD	The main channel length from outlet to a point opposite the center of gravity of the basin (miles).
A	TBD	Drainage area in square miles.

Kinematic Wave Unit Hydrograph



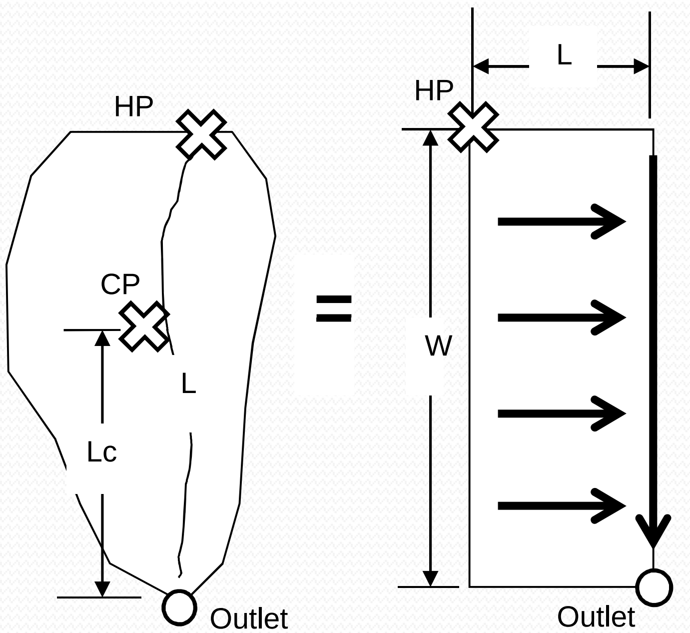
$$\frac{\partial q}{\partial x} + \frac{\partial y}{\partial t} = i_e$$

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} + g\frac{\partial y}{\partial x} - g(S_0 - S_f) = 0$$

$$q = \frac{1.49}{n} Y^{\frac{5}{3}} \sqrt{S_o} \qquad S_0 = S_f$$

- Watershed has to be rectangular in shape
- Watershed has to include both overland flow area and a concentrated flow channel

Snyder Unit hydrograph and KW Unit Hydrograph



CUHP / Snyder unit Hydrograph

Kinematic Wave method Hydrograph

Snyder method variable

- Watershed flow length (L)
- Distance to Centroid (Lc)
- Lag Time factor Ct
- Peak Flow Factor Cp

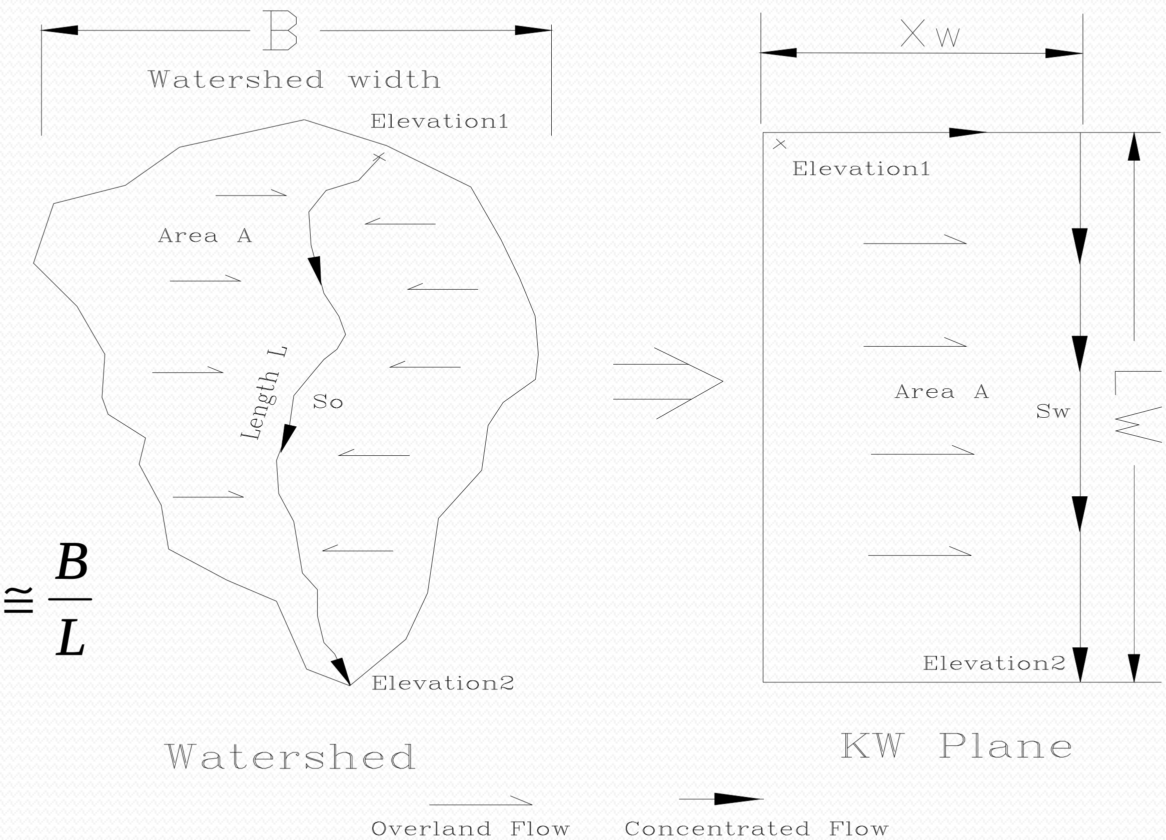
KW method variable

- Watershed overland flow width (W)
- Impervious “n”
- Pervious “n”

MSOffice1

Phase1

Watershed and KW Shape Factors -- X and Y



$$X = \frac{A}{L^2} \cong \frac{B}{L}$$

$$Y = \frac{Lw}{L}$$

$$A = L_w X_w$$

X factor describes the basin shape using width and length

Y factor represents the watershed width and length shape factor as it compares to the KW rectangular plane e.g. narrow and long

<u>Shape Function Y = fct (X)</u>

Slide 6

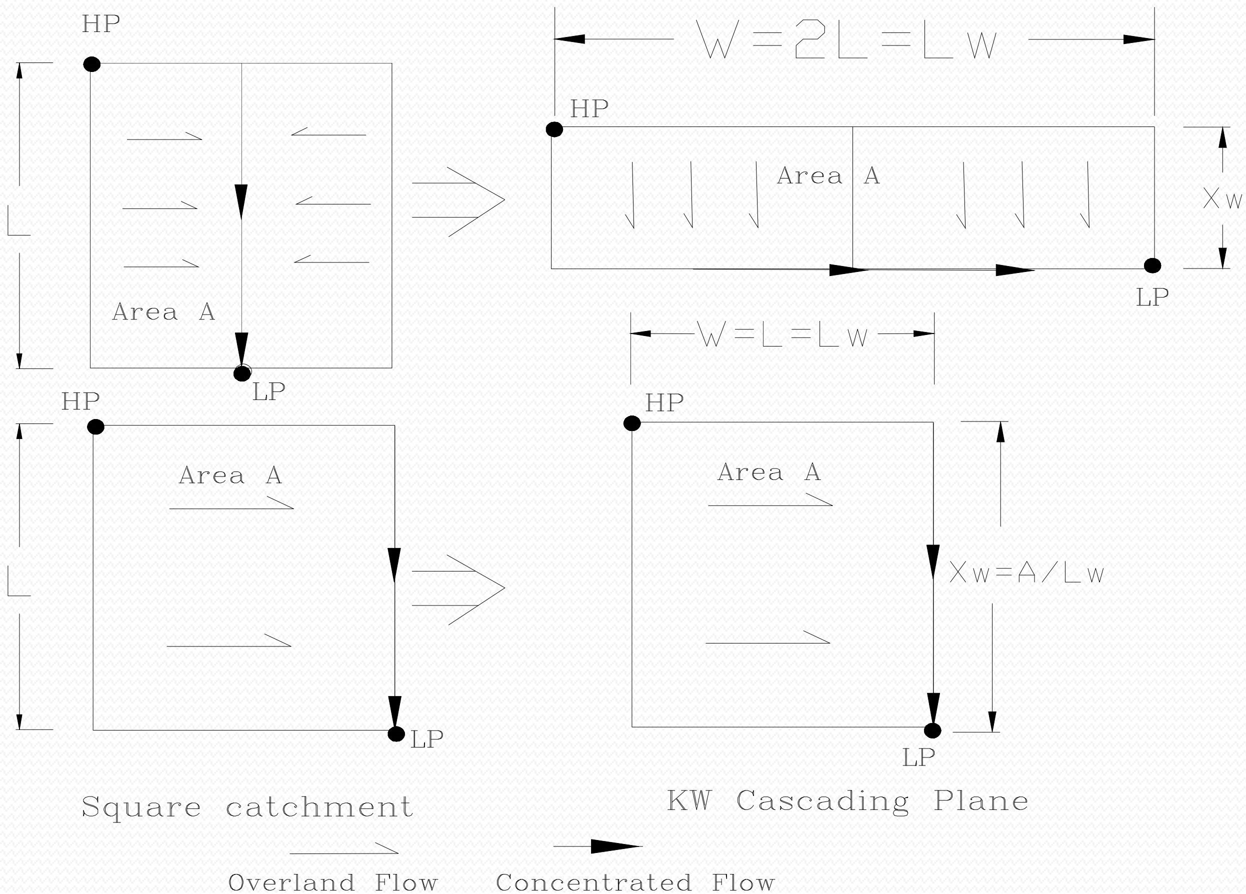
MSOffice1 Jeff - what is phase 2? You only show phase 1

, 9/10/2010

MSOffice2

Phase 1

SPECIAL CASES



Square with Central Channel:

$$X = \frac{A}{L^2} = 1$$

$$Y = \frac{Lw}{L} = 2$$

Square with Side Channel:

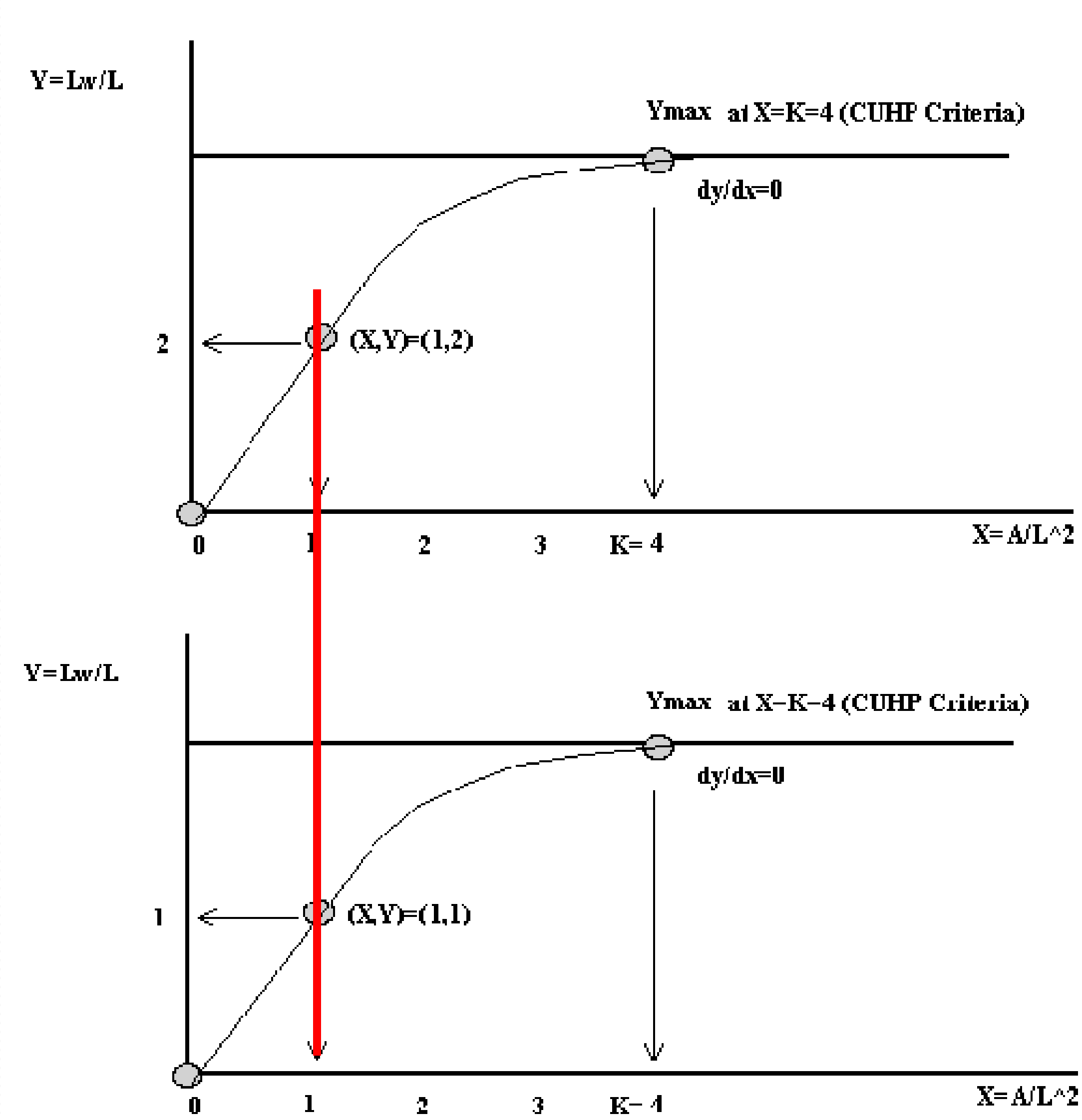
$$X = \frac{A}{L^2} = 1$$

$$Y = \frac{Lw}{L} = 1$$

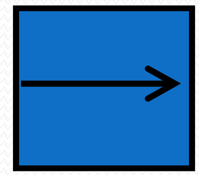
Slide 7

MSOffice2 Same comment
, 9/10/2010

Conditions for Shape Function



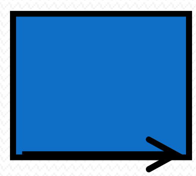
Square with Central Channel:



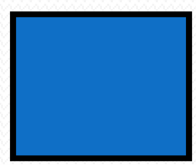
$$X = \frac{A}{L^2} = 1$$

$$Y = \frac{Lw}{L} = 2$$

Square with Side Channel:

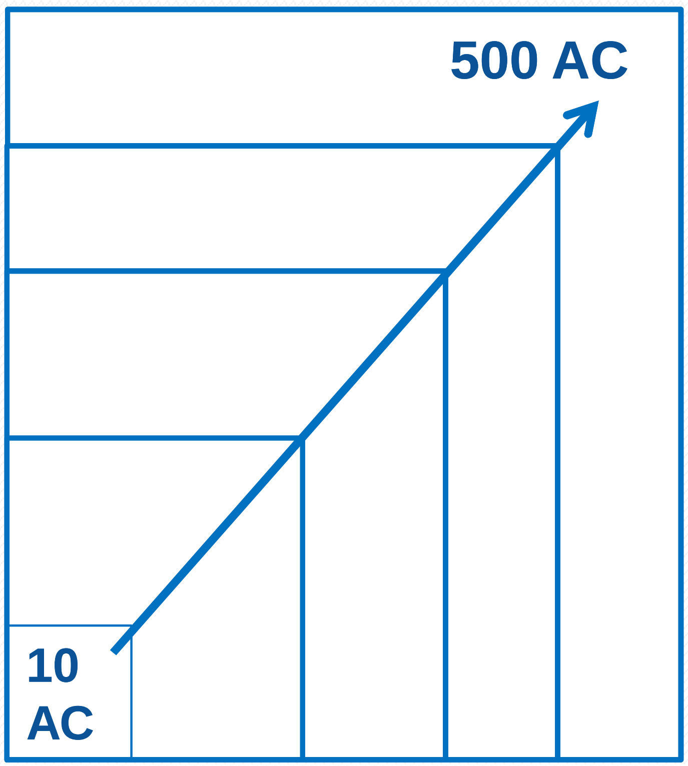


$$X = \frac{A}{L^2} = 1$$



$$Y = \frac{Lw}{L} = 1$$

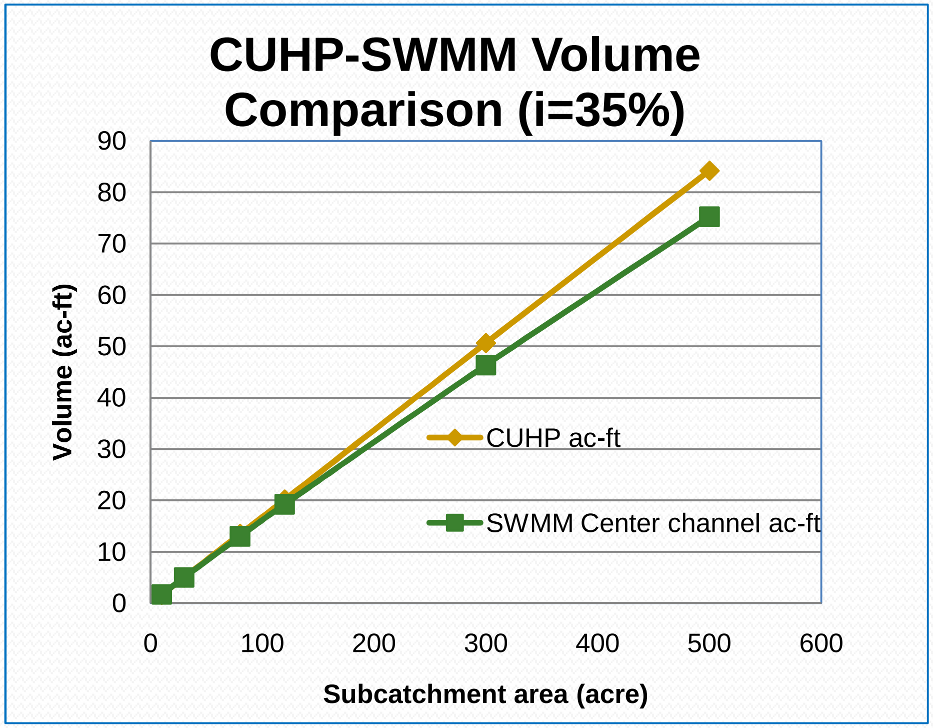
Comparison of CUHP-SWMM Stormwater Volume

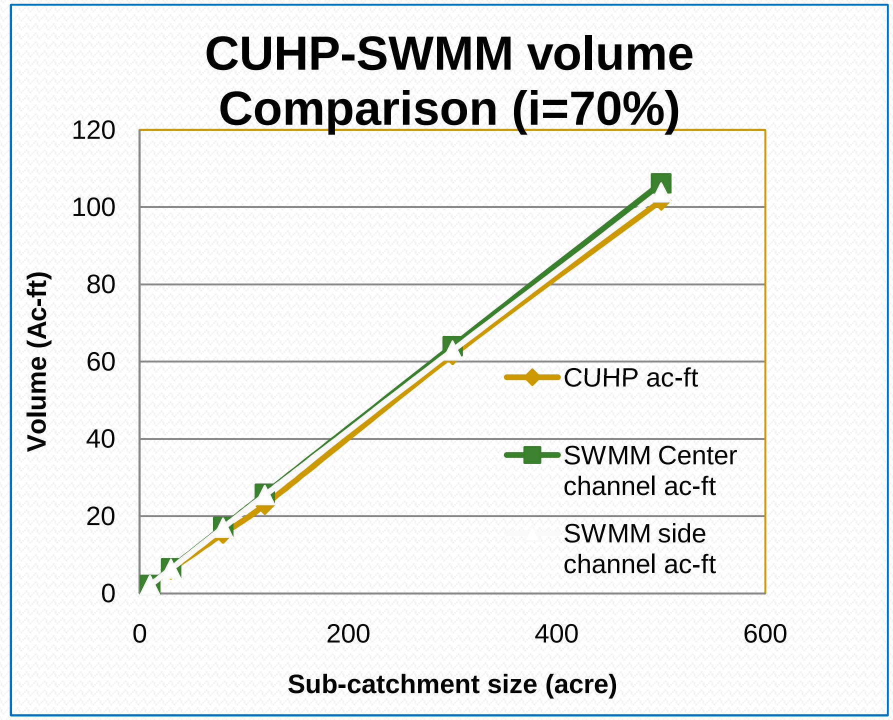


CUHP Input information				
Area (sq Mi)	Distance to Centroid (mi)	Length (mi)	Slope (ft/ft)	Percent Imperviousness
0.0156	0.0625	0.1250	0.01	70
0.0469	0.1083	0.2165	0.01	70
0.1250	0.1768	0.3536	0.01	70
0.1875	0.2165	0.4330	0.01	70
0.4688	0.3423	0.6847	0.01	70
0.7813	0.4419	0.8839	0.01	70

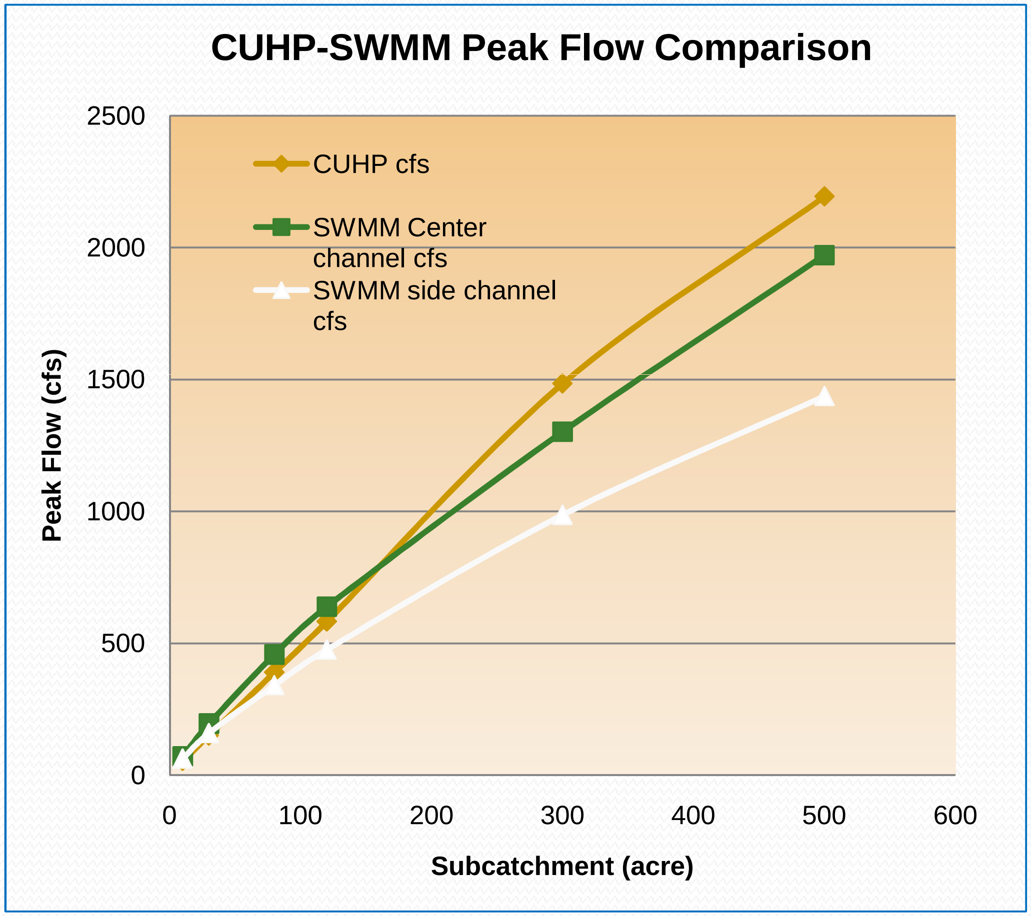
SWMM Input information			
Area (acre)	Width (ft)	Slope (ft/ft)	Percent Imperviousness
10	1320	0.01	70
30	2286.3071	0.01	70
80	3733.5238	0.01	70
120	4572.6141	0.01	70
300	7229.9378	0.01	70
500	9333.8095	0.01	70

Comparison of CUHP-SWMM Stormwater Volume





Comparison of CUHP-SWMM Peak Flow



Peak Flow Comparison					
Area (acre)	CUHP	SWMM Center channel	SWMM side channel	SWMM Center channel	SWMM side channel
acre	cfs	cfs	cfs	%	%
10	54.86	71.43	63.24	30.2%	15.3%
30	151.23	196.09	159.77	29.7%	5.7%
80	390.52	458.01	341.56	17.3%	-12.5%
120	583.00	639.13	476.41	9.6%	-18.3%
300	1484.74	1302.18	987.12	-12.3%	-33.5%
500	2193.59	1971.65	1437.31	-10.1%	-34.5%

Testing watershed selection criteria

MSOffice7

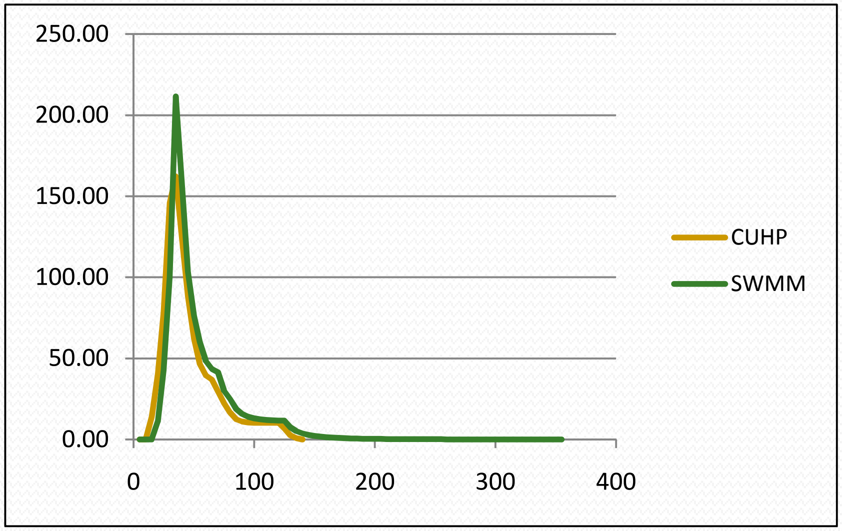
- Mature urban developed watershed with rain gage and stream gage.
- Watershed size should be less than 2000 acres.
- Stream gage location should not impact by backwater effect.
- Watershed width/Length ratio between 0.75 to 4.

Slide 12

MSOffice7 Jeff - please add the Littles Creek watershed here with the proposed stream gages locates where you think they should be with a large mark.

, 9/10/2010

Test Case – Littles Creek



CUHP					SWMM			
Area	L	Slope	Lc	Qp	Z	Lw	Sw	Qp
acre	ft	%	ft	cfs	%	ft	%	cfs
33.51	1934.97	1.94%	771.61	162.27	1	1682.45	1.47%	211.67

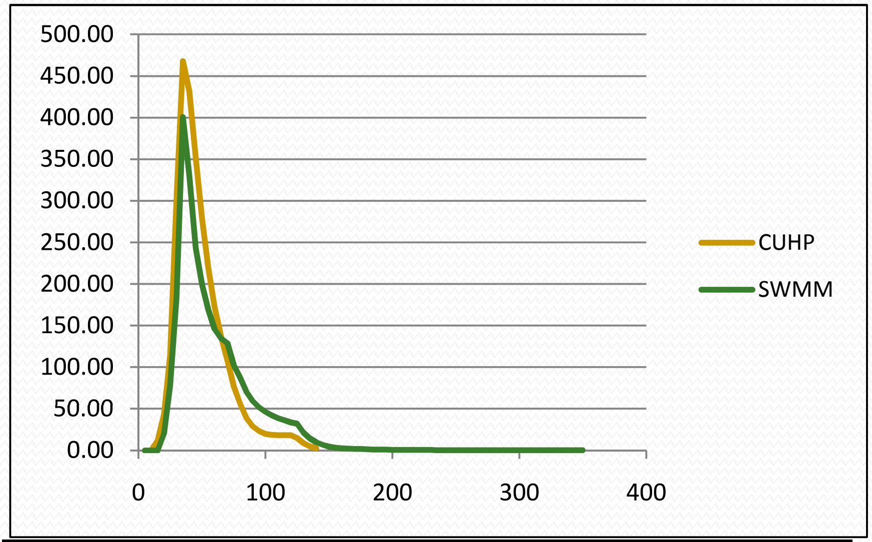
Slide 13

MSOffice3 Jeff - add what this test is showing under the title. Is it a special shape? Is it random subbasin? If so, which number basin is it? Should be show the whole basin and the subbasins used for comparison with CUHP?

, 9/10/2010

MSOffice4

Test Case – Littles Creek



CUHP					SWMM			
Area	L	Slope	Lc	Qp	Z	Lw	Sw	Qp
acre	ft	%	ft	cfs	%	ft	%	cfs
122.09	3560.78	1.77%	1221.32	467.91	0.6	3253.03	1.29%	400.57

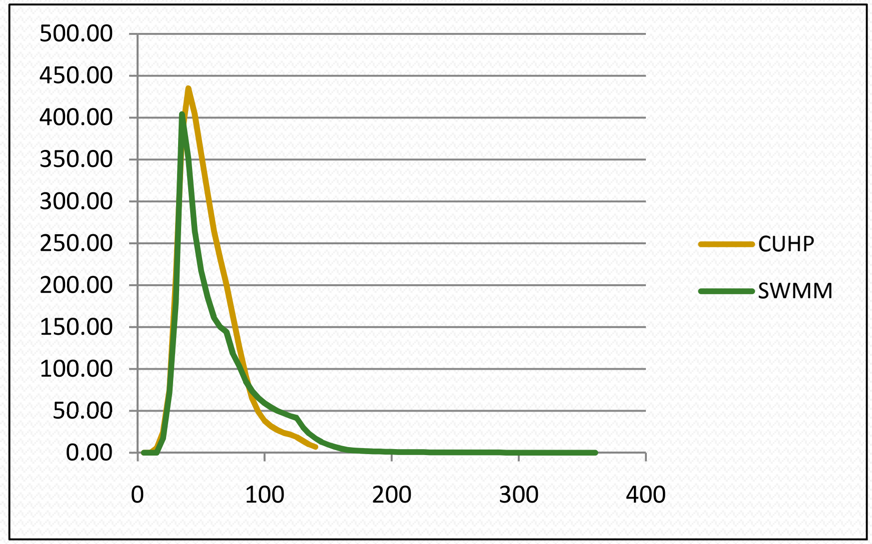
Slide 14

MSOffice4 Same comment

, 9/10/2010

Test Case – Littles Creek

MSOffice5



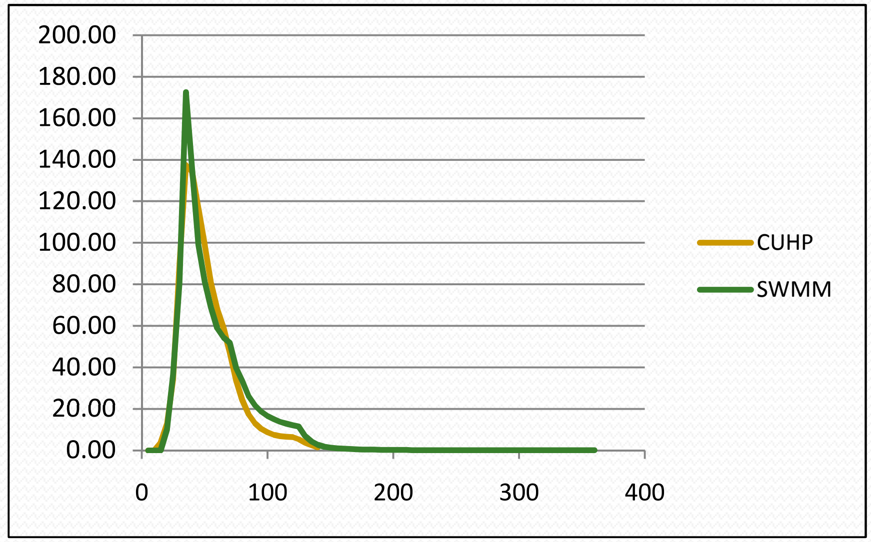
CUHP					SWMM			
Area	L	Slope	Lc	Qp	Z	Lw	Sw	Qp
acre	ft	%	ft	cfs	%	ft	%	cfs
149.57	4971.85	1.13%	1762.52	435.18	0.9	2936.38	1.09%	404.22

Slide 15

MSOffice5 Same comment

, 9/10/2010

Test Case – Littles Creek



CUHP					SWMM			
Area	L	Slope	Lc	Qp	Z	Lw	Sw	Qp
acre	ft	%	ft	cfs	%	ft	%	cfs
47.69	2024.93	1.24%	1112.64	137.43	1	2270.88	0.79%	172.62

Slide 16

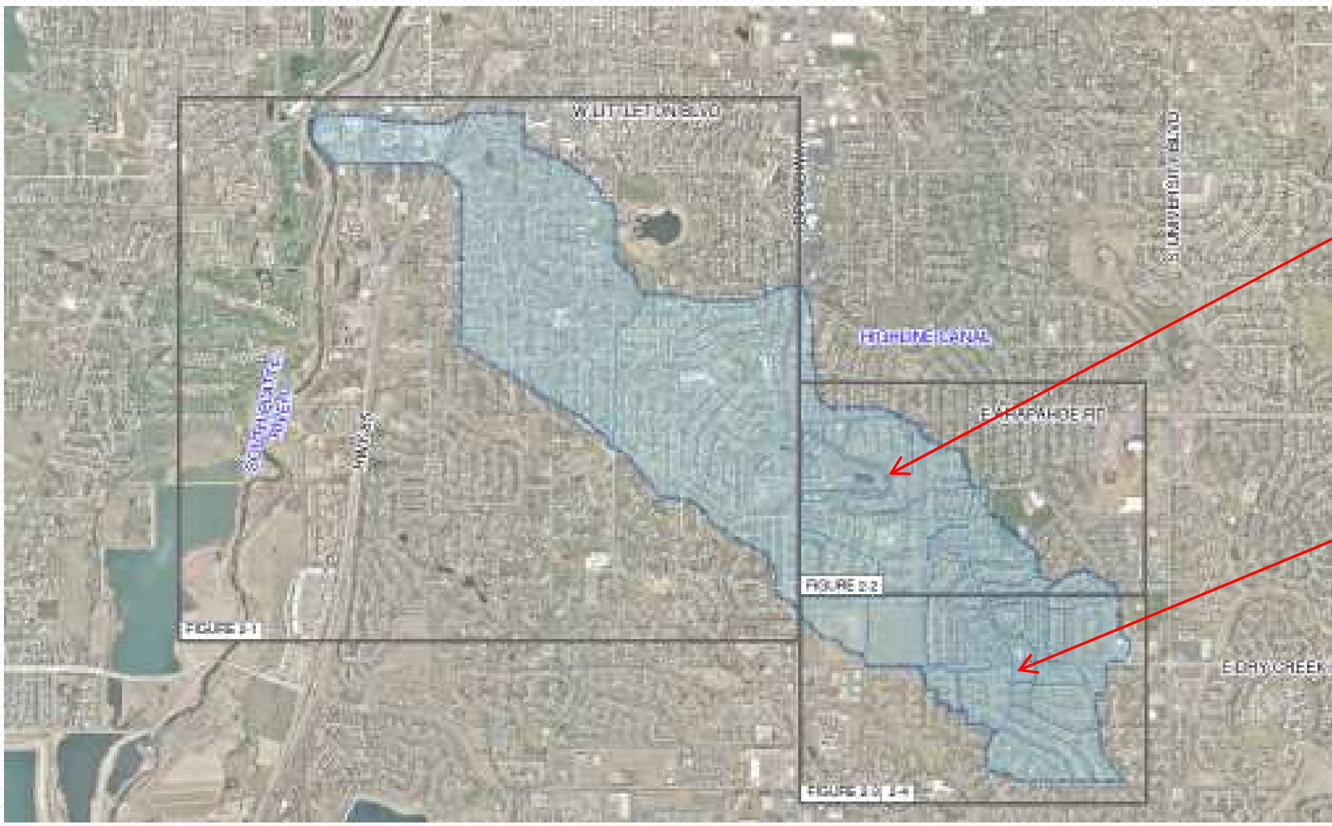
MSOffice6 same comment
, 9/10/2010

Summary of Test Case Results

- Compare peak flow
- Compare volume
- Compare time to peak

Next Steps:

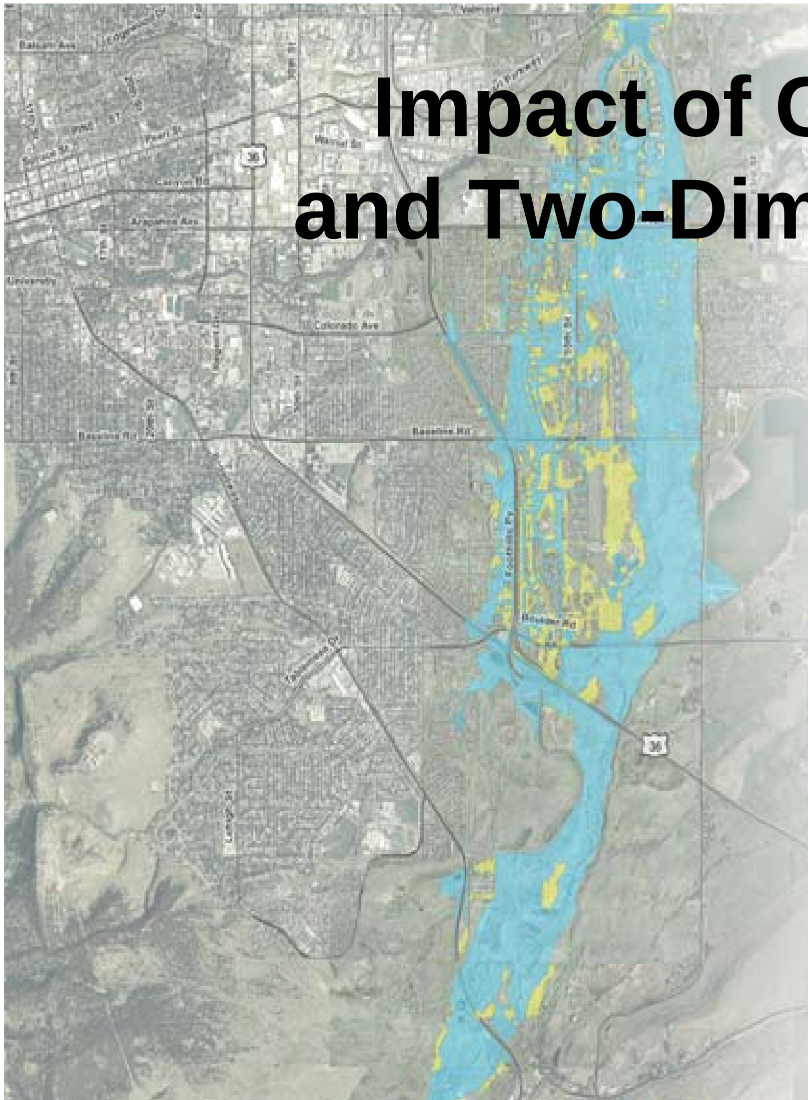
- Watershed size analysis



Highline Cannel crossing Tributary area =715 acres

Dry Creek Pond. Tributary area=164 acres

Conclusions



Impact of Coupled One-Dimensional and Two-Dimensional Model in Master Planning Studies

September 23, 2010

Aaron Cook

CH2MHILL

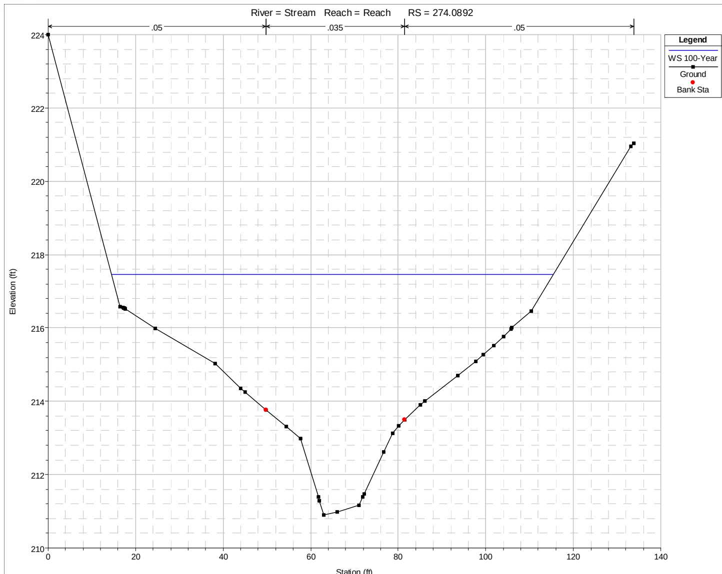
Presentation Outline

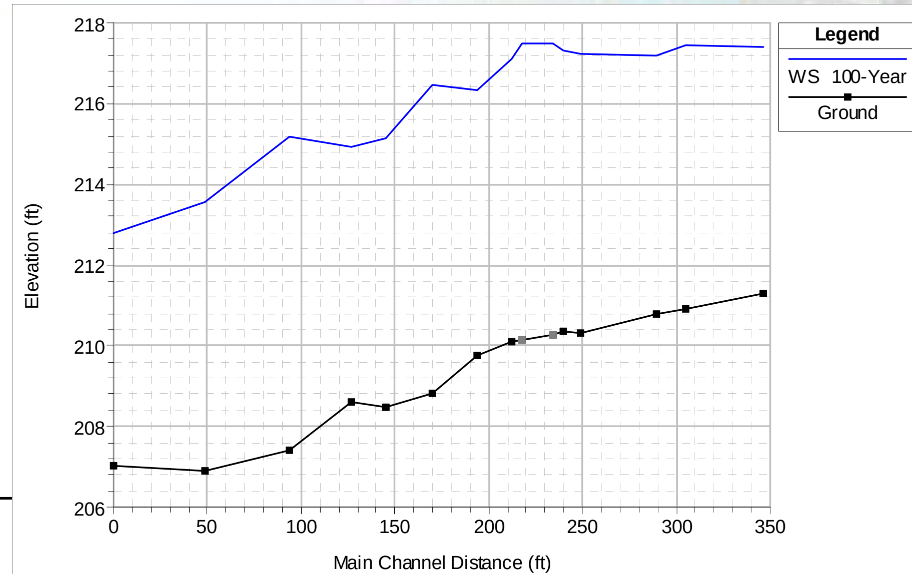
- One-Dimensional Modeling
- Two-Dimensional Modeling
- Coupled Modeling
- Benefits of Coupled and Two-Dimensional Modeling
- Challenges of Coupled and Two-Dimensional Modeling
- Examples
- Summary/Conclusions

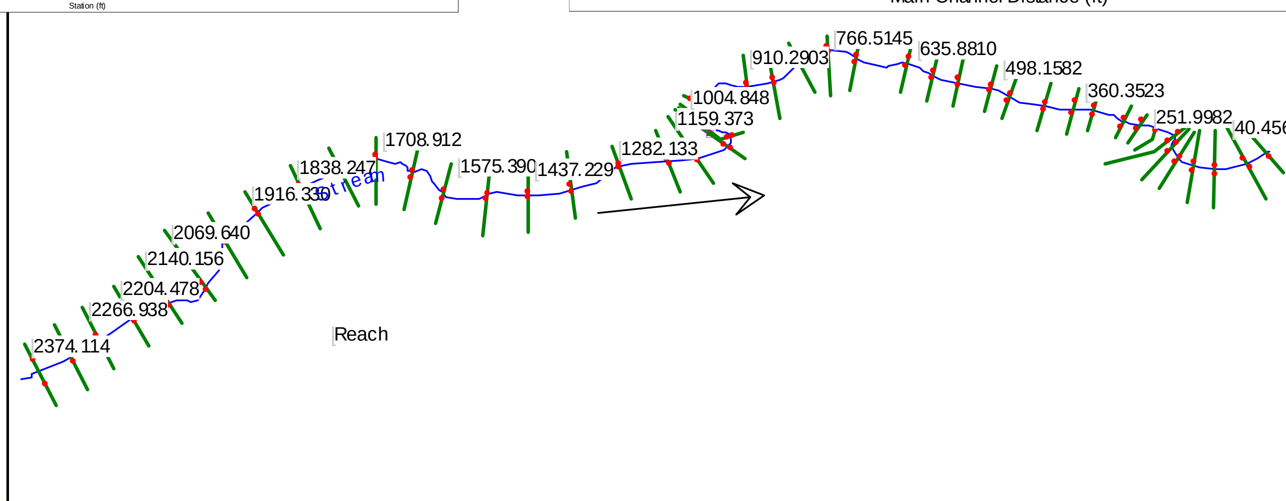
One-Dimensional Modeling

- Typical approach to determining peak flows and floodplain extents
- Steady state
- Water flow is computed in the longitudinal direction
- Terrain represented as a series of cross sections
- Water surface profile determined by solving the energy equation
- Maximum instantaneous peak flow

One-Dimensional Modeling







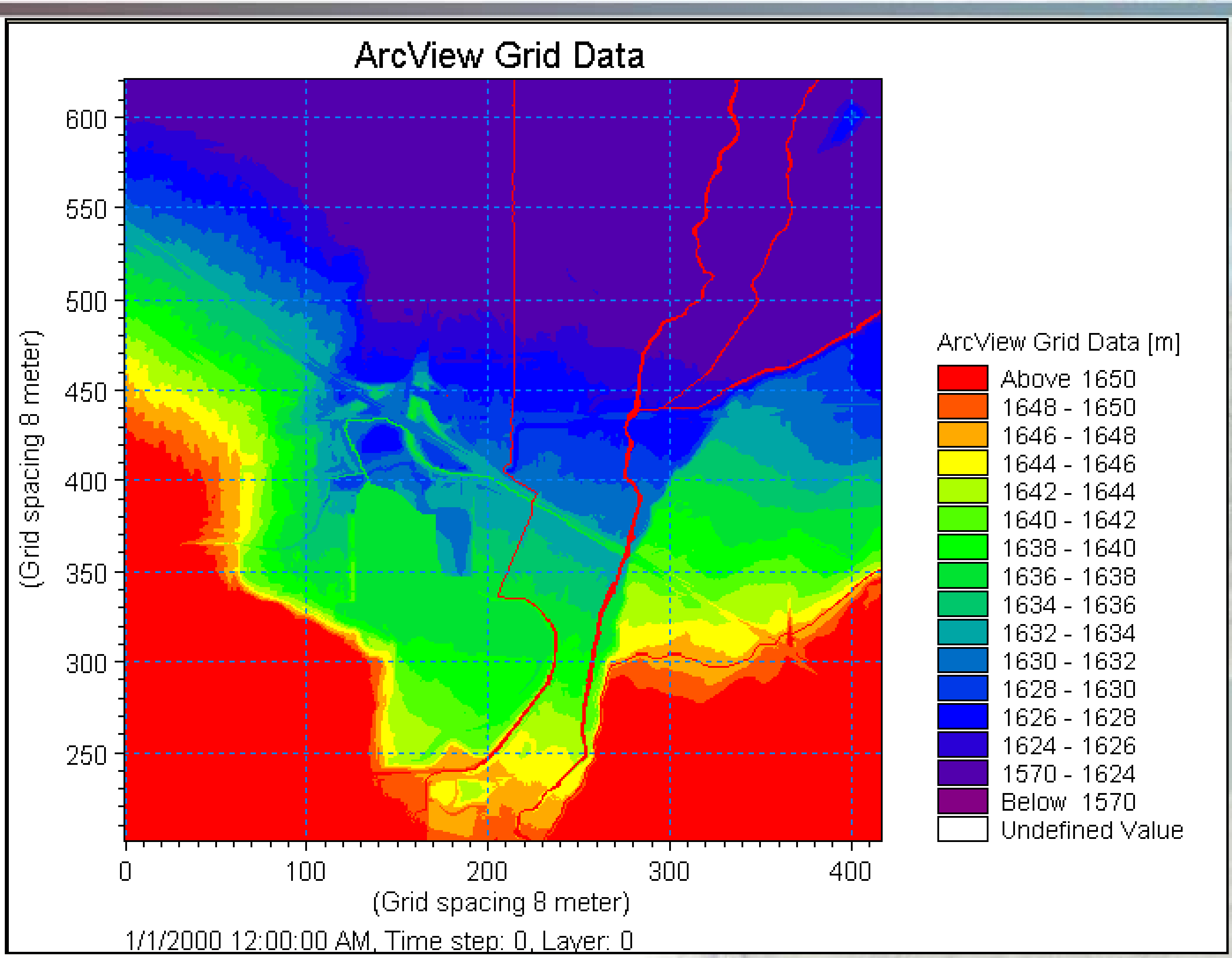
One-Dimensional Modeling

- **No floodplain storage**
- **Peak flow remains relatively unchanged downstream**
- **Not an accurate reflection of reality**
- **Examples:**
  - HEC-RAS (Hydrologic Engineering Center – River Analysis System)
  - MIKE 11

Two-Dimensional Modeling

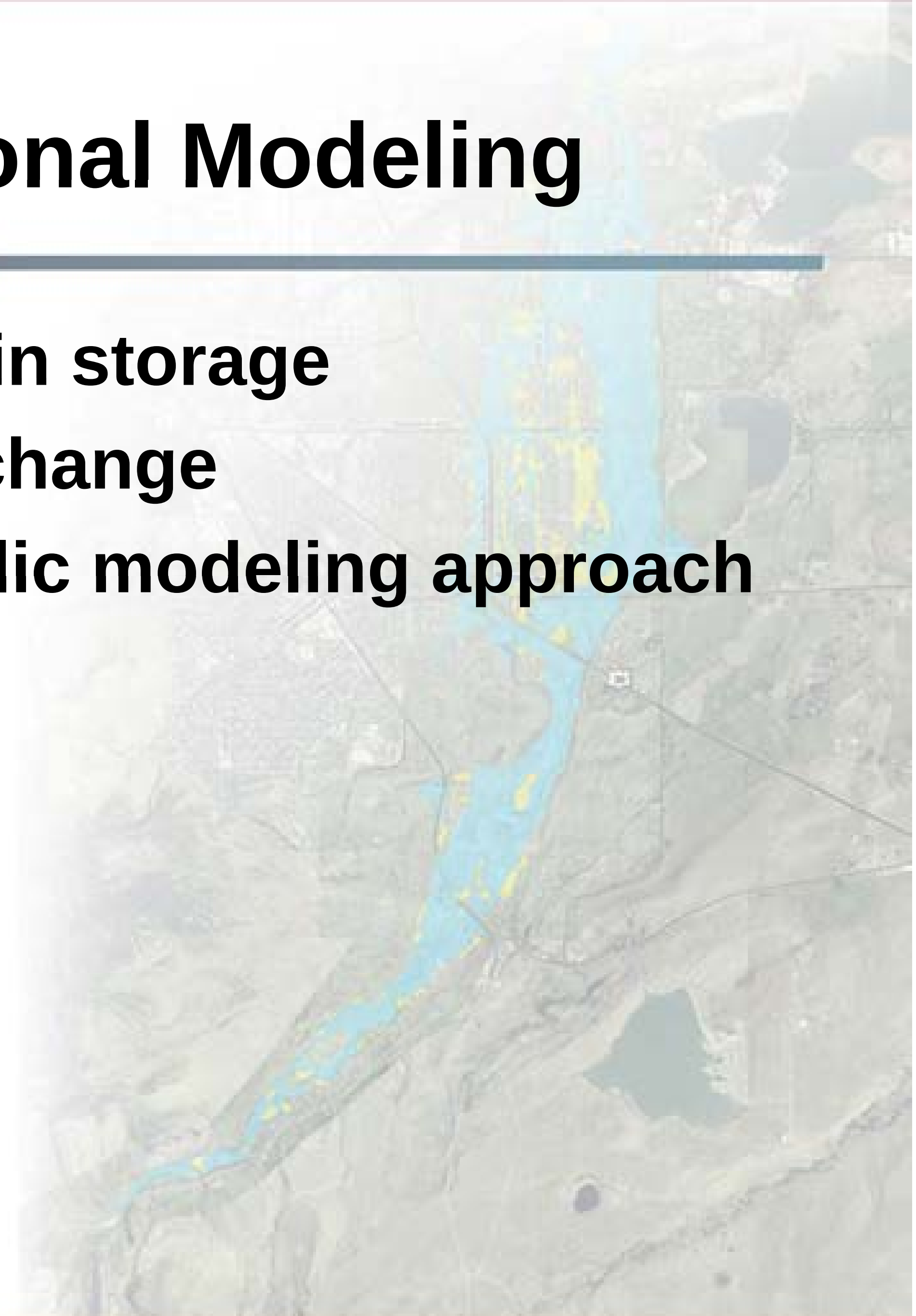
- Terrain represented as a continuous surface through a finite element mesh
- Water is allowed to flow in the longitudinal or lateral direction at each element in the mesh
- Hydrographs loaded at elements in the mesh

Two-Dimensional Modeling



Two-Dimensional Modeling

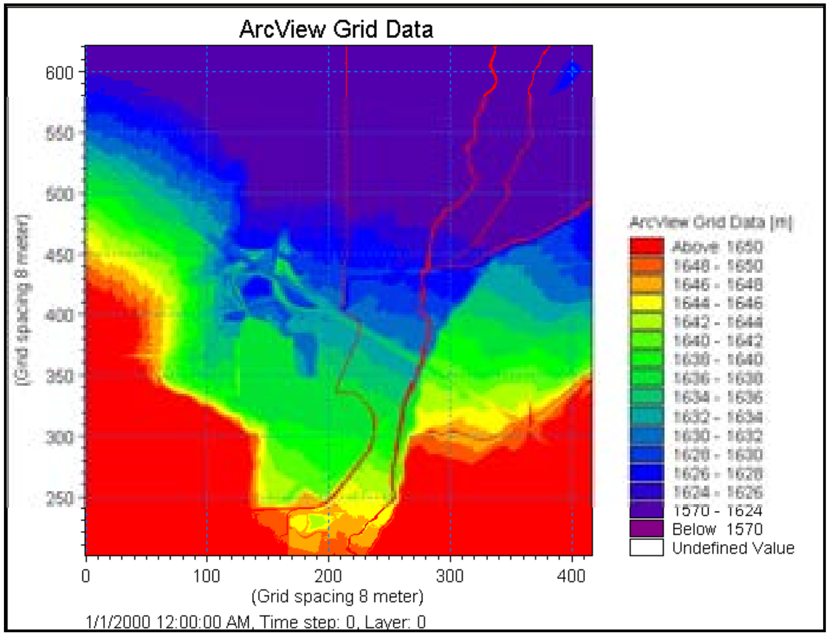
- **Accounts for floodplain storage**
- **Peak flow allowed to change**
- **More accurate hydraulic modeling approach**
- **Examples**
  - MIKE 21
  - FLOW 2D

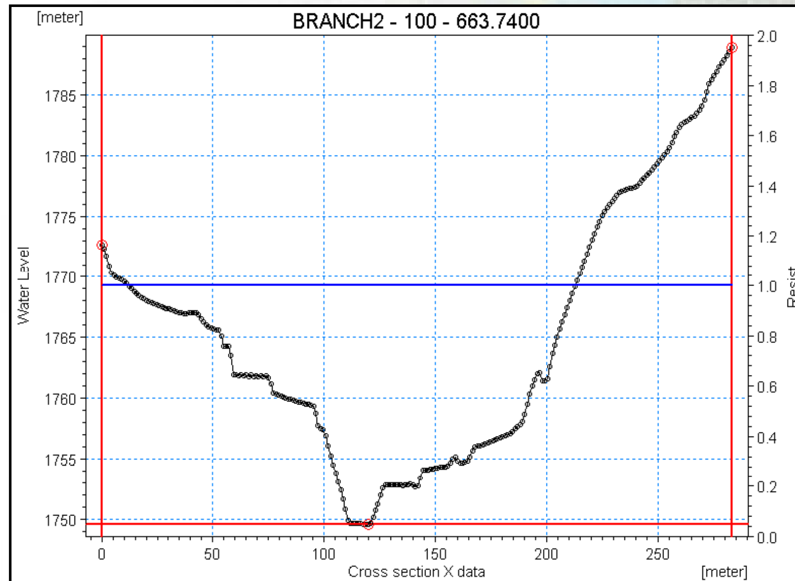


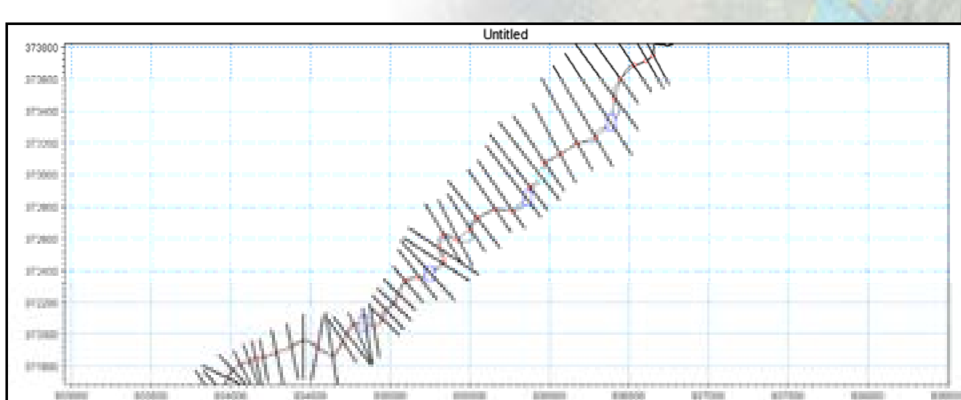
Coupled One-Dimensional and Two-Dimensional Modeling

- **Channels/Pipes represented as a series of cross sections/culverts/bridges**
- **Floodplains represented as a finite element mesh**
- **Water moves between the 1D cross sections and 2D mesh in the direction of the hydraulic gradient**
- **Example:**
  - MIKE FLOOD

Coupled One-Dimensional and Two-Dimensional Modeling







Benefits of Two-Dimensional and Coupled Modeling in Master Planning

- **Complicated floodplain systems**
  - Multiple flow paths/split flows
- **Complicated urban flooding**
  - Flow in streets
- **Accounts for floodplain storage**
- **Attenuation of hydrographs**
  - More accurate results
- **More accurate results**

Challenges of Two-Dimensional and Coupled Modeling in Master Planning

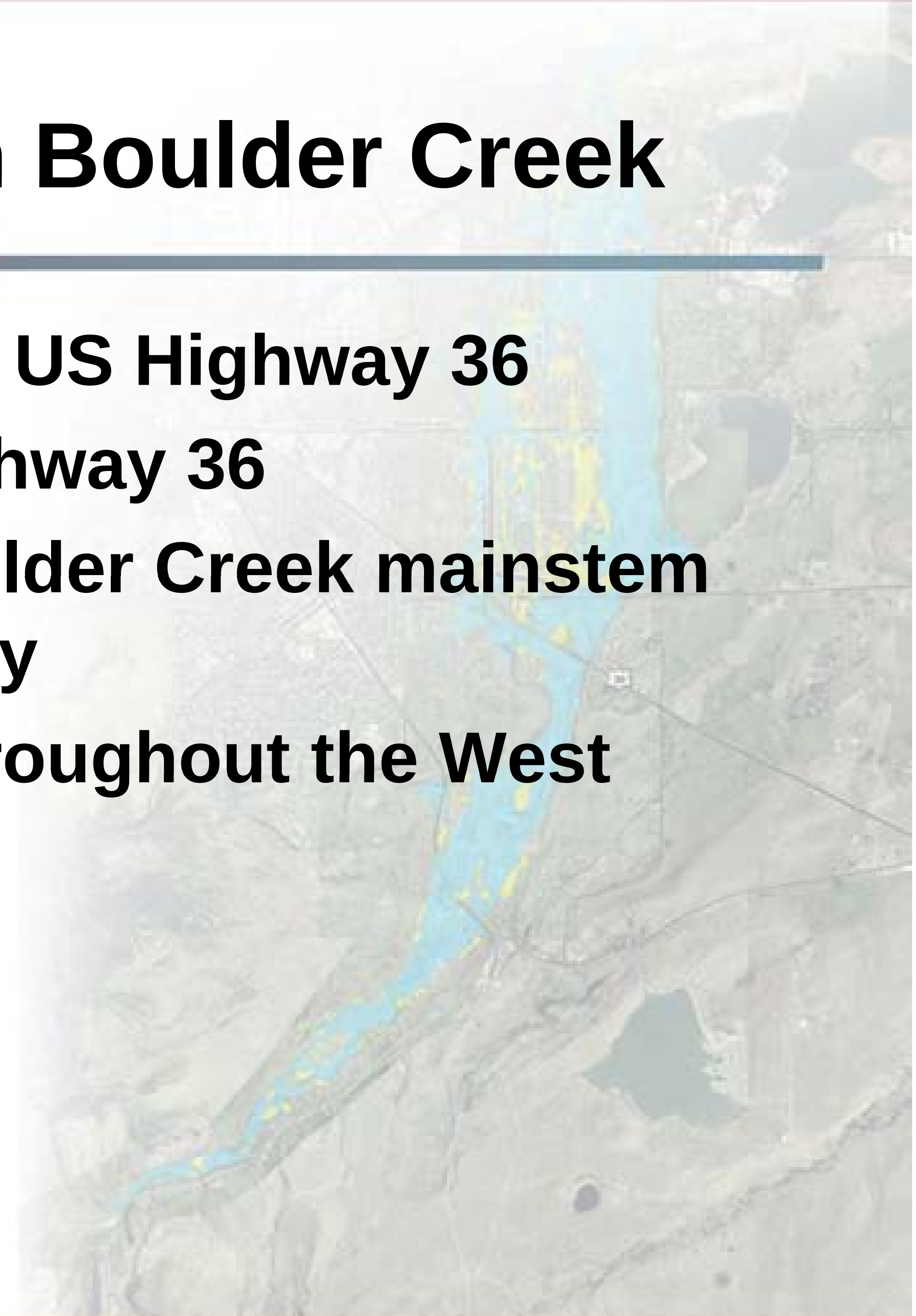
- **Improvements such as increased conveyance through channels and pipes decreases floodplain storage and attenuation of hydrographs**
  - Floodplain storage often caused by undersized infrastructure
  - Floodplain management issues
- **Increased flow rates downstream**
- **Previous estimates for peak flow rates likely underestimate the peak flow with proposed improvements**

Challenges of Two-Dimensional and Coupled Modeling in Master Planning

- **Coupled or 2D Model must be re-run to determine the new peak flow rate downstream**
  - Not cost effective
- **More accurate peak flows required to size improvements downstream**
- **Several hours/days to run simulation versus minutes/seconds for 1D model**
  - Simplified approach to save computation time

Example: South Boulder Creek

- **Split flow upstream of US Highway 36**
- **Flow overtops US Highway 36**
- **Flow along South Boulder Creek mainstem and flow in West Valley**
- **Floodplain storage throughout the West Valley**
  - Road Crossings



Example: South Boulder Creek

Similar flooding along South Boulder Creek Mainstem

Note West Valley Flooding

Existing Regulatory Floodplain Boundary

Proposed and Accepted Floodplain Boundary

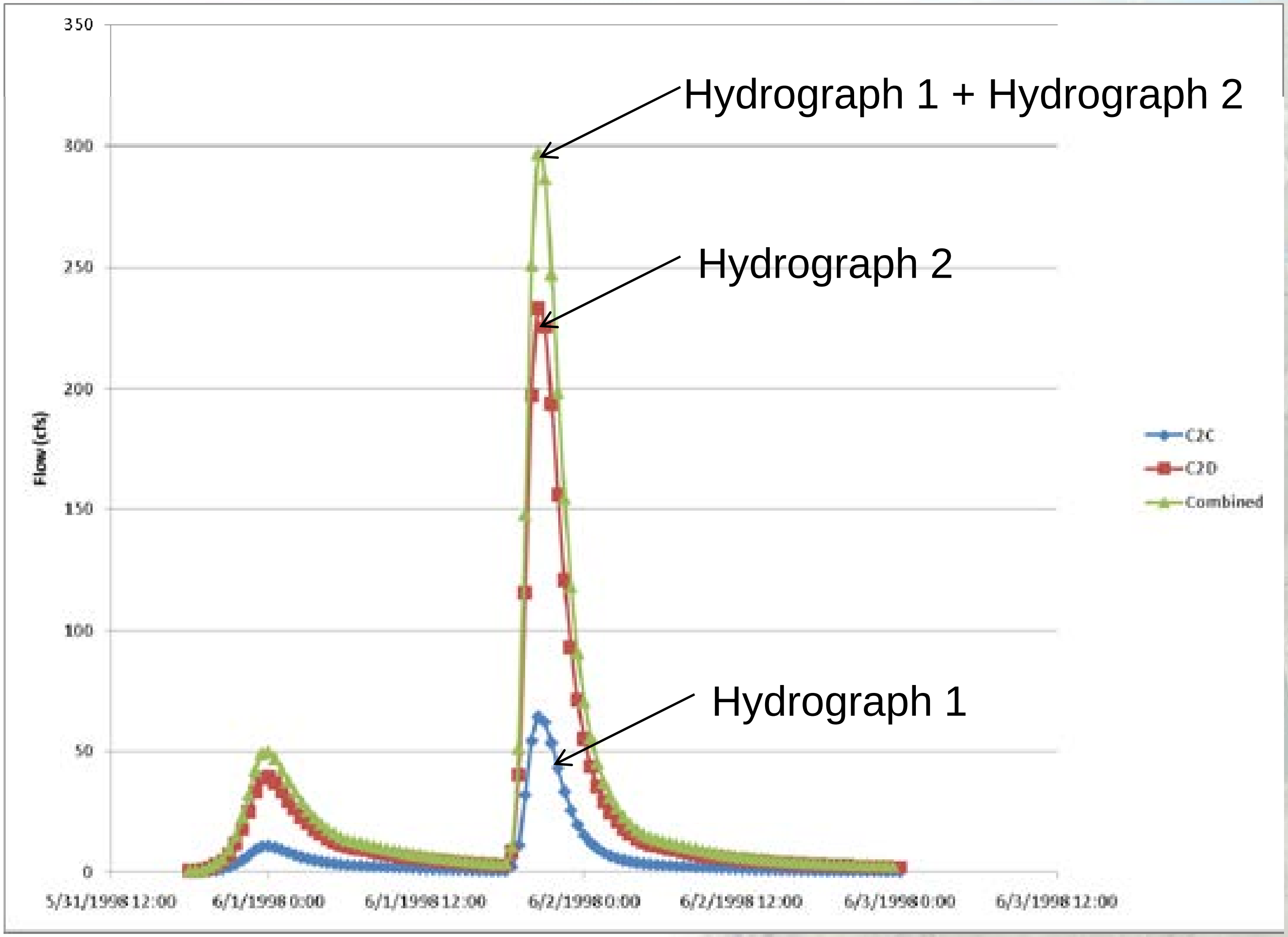
Example: South Boulder Creek

- **2D Model identified flood threat to West Valley**
- **Computation time for regulatory model > 2 Weeks**
  - Not time effective to develop model for each alternative
- **Simplified approach necessary for master planning purposes**

Example: South Boulder Creek

- **Simplified approach:**
  - Use coupled model to determine peak flows at key locations
  - Assume that known peak flow rates are additive downstream
  - Adding peak flow rates may overestimate actual peak flow rates but provides a conservative estimate
    - Assumes no floodplain storage or attenuation of hydrographs
    - Other programs to size infrastructure
      - EPA SWMM 5, FlowMaster, CulvertMaster

Example: South Boulder Creek

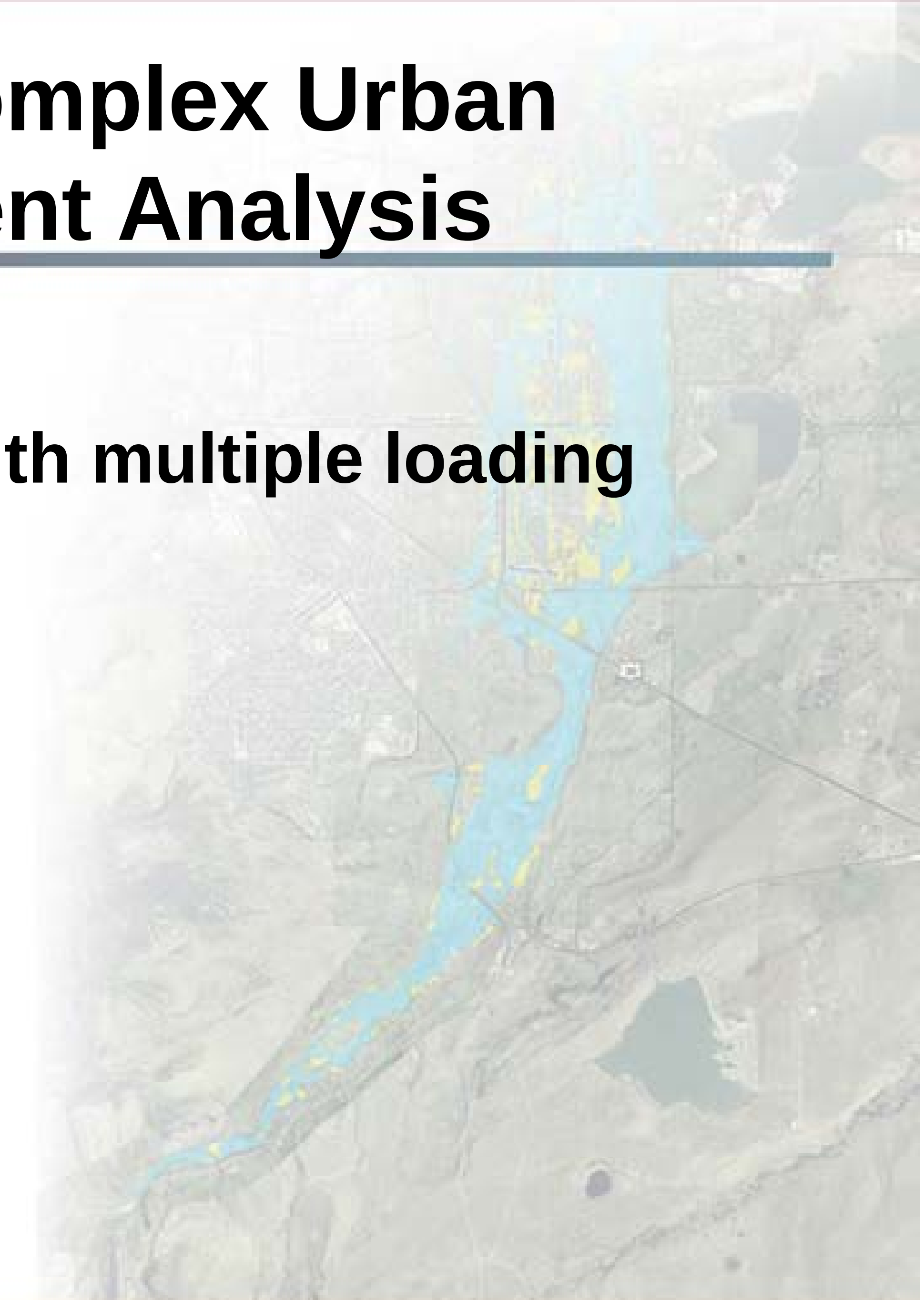


Example: South Boulder Creek

- **Simplified approach:**
  - Initial master plan recommendations made based on this approach
    - Cost effective approach
  - Best alternative plans input into coupled model
    - More accurate results
  - Best alternative plans modified based on results

Example: Complex Urban Development Analysis

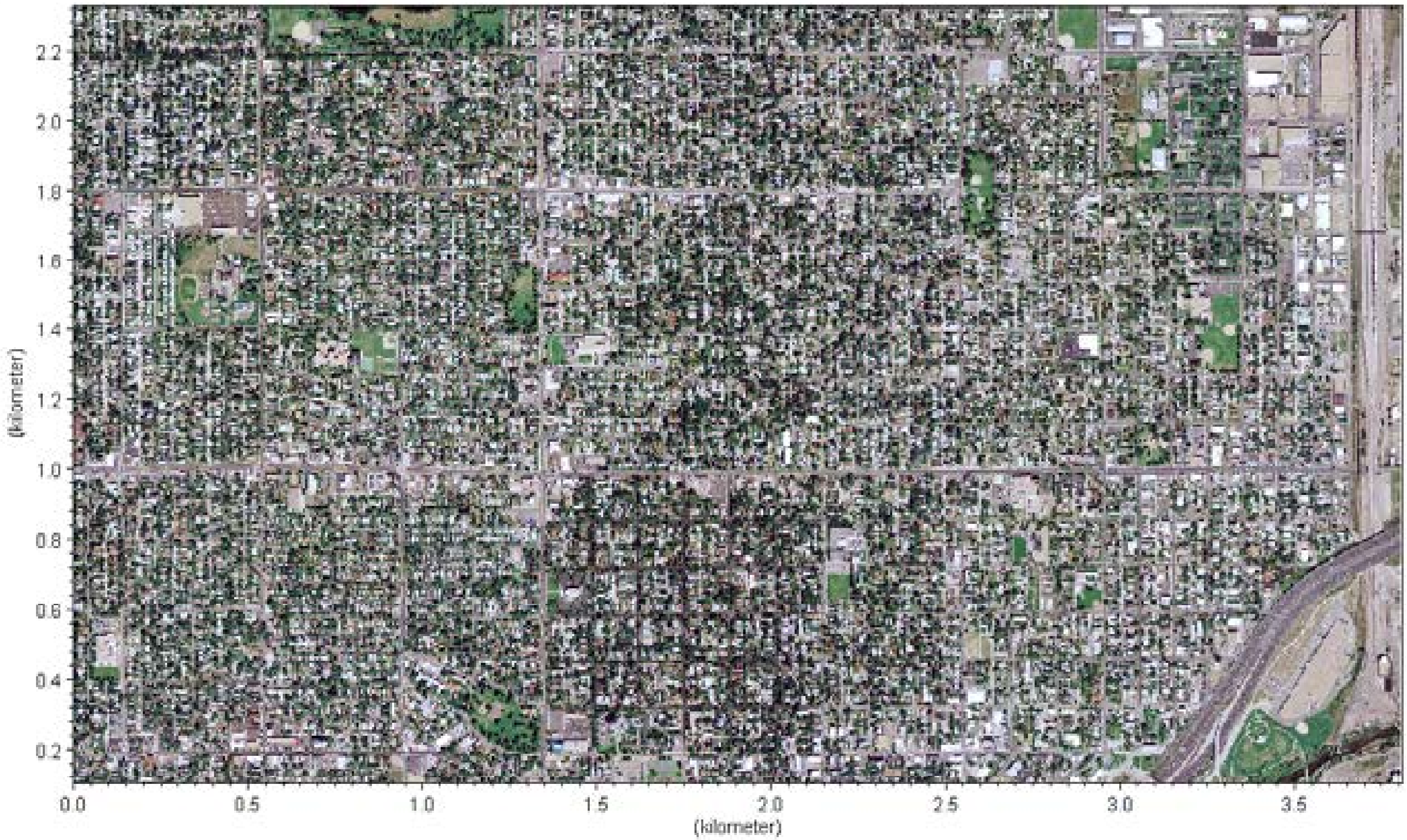
- Urban flooding
- Multiple flow paths with multiple loading points



Example: Complex Urban Development Analysis

- **2D Modeling Approach**
  - Flow in pipes removed from hydrographs
  - Remaining hydrograph loaded to 2D finite element mesh
  - Sinks added where flow leaves the 2D system
  - Determine peak flows on surface at key locations
  - 2D run time approximately 1 hour
- **Best alternative plans can be input into coupled model**
  - Coupled run time expected to be greater than 1 hour
    - Interaction between 1D and 2D systems

Example: Complex Urban Development Analysis



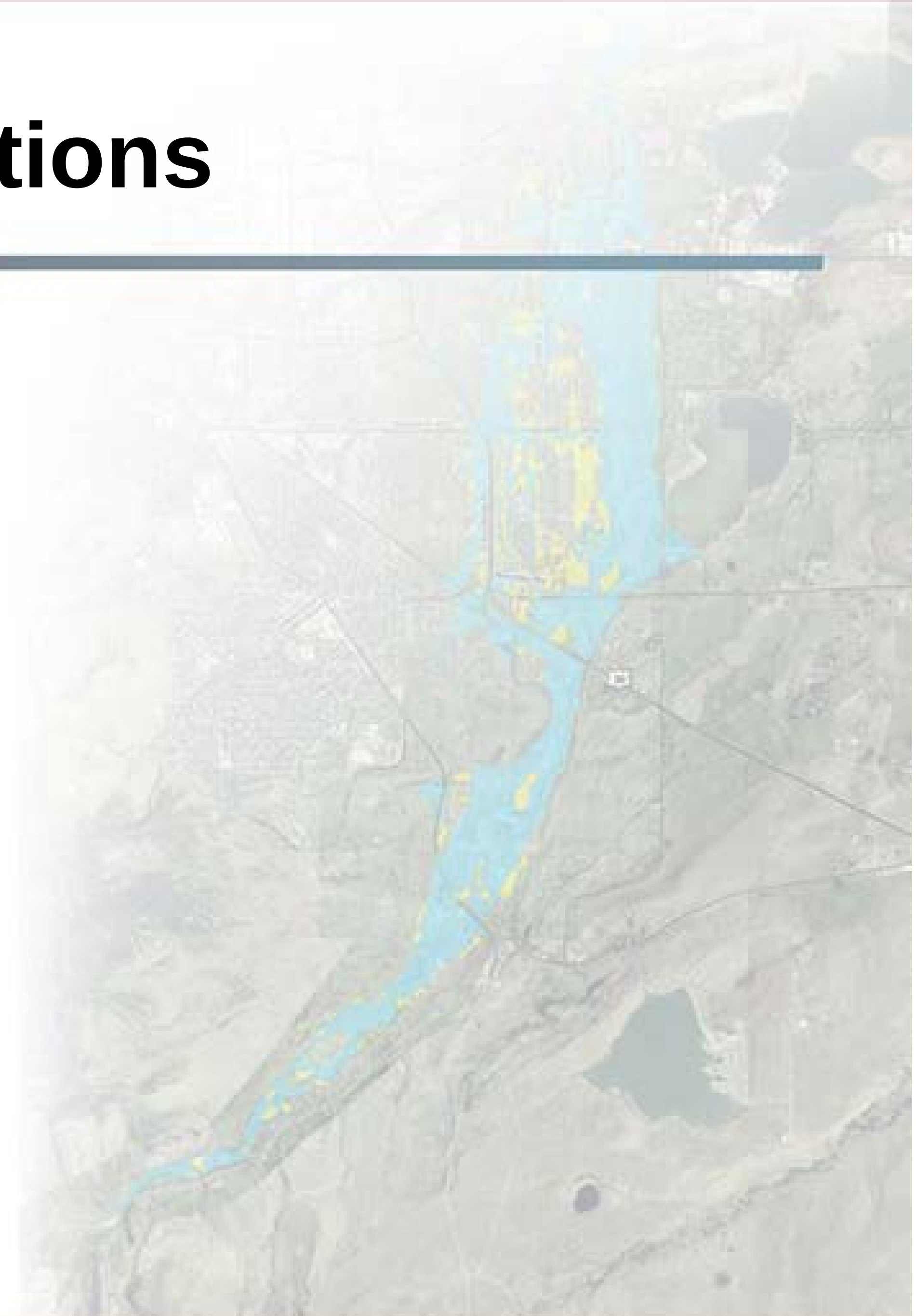
Summary/Conclusions

- **Coupled or 2D models may provide more accurate floodplain results and may identify additional flood threats**
  - Floodplain storage
  - Attenuation of hydrographs
  - Better representation of topography
  - Flow in longitudinal and lateral directions
- **Coupled or 2D models used for complicated floodplain situations**
  - Multiple flow paths/split flows
  - Urban flooding – flow in streets

Summary/Conclusions

- **Simplified approach may be necessary**
  - Cost effective
  - Saves time
  - Input best alternative plans into Coupled model
  - 2D Model still run for best alternatives
    - More accurate results

Questions



Modern Stream Equilibrium Analysis

By George Cotton, PE

GK Cotton Consulting, Inc.

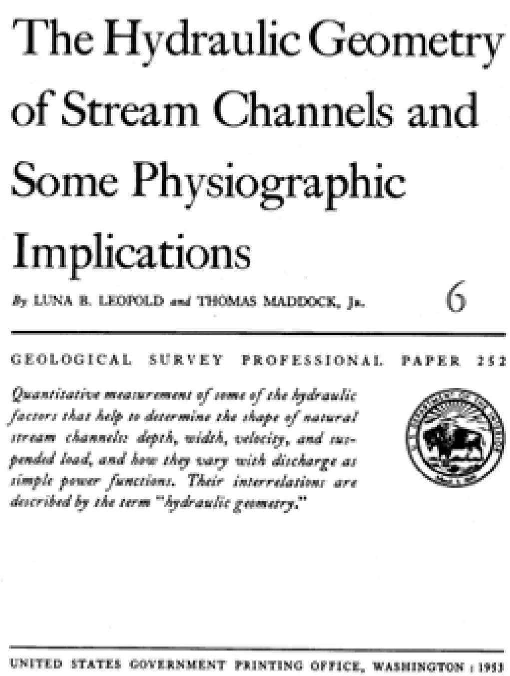
BACKGROUND

- Very fundamental geomorphic tools where developed in the 1950's by the USGS and USBR including:
    - Leopold and Maddock (1953),
    - Lane (1955),
    - Leopold and Miller (1956),
    - Leopold and Wolman (1957)
- These tools have been used extensively for channel assessment, reclamation and restoration. They link four important stream physical process variables to stream shape.
    - Stream discharge
    - Sediment load
    - Stream gradient
    - Bed material size

→

- Width
- Depth

Empirical Hydraulic Geometry



The Hydraulic Geometry of Stream Channels and Some Physiographic Implications

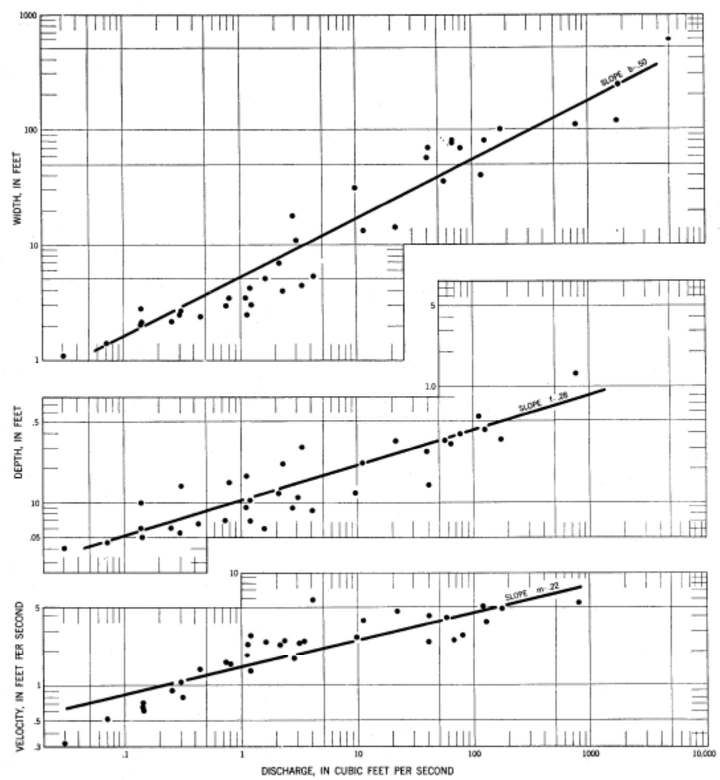
By LUNA B. LEOPOLD *and* THOMAS MADDOCK, Jr.

6

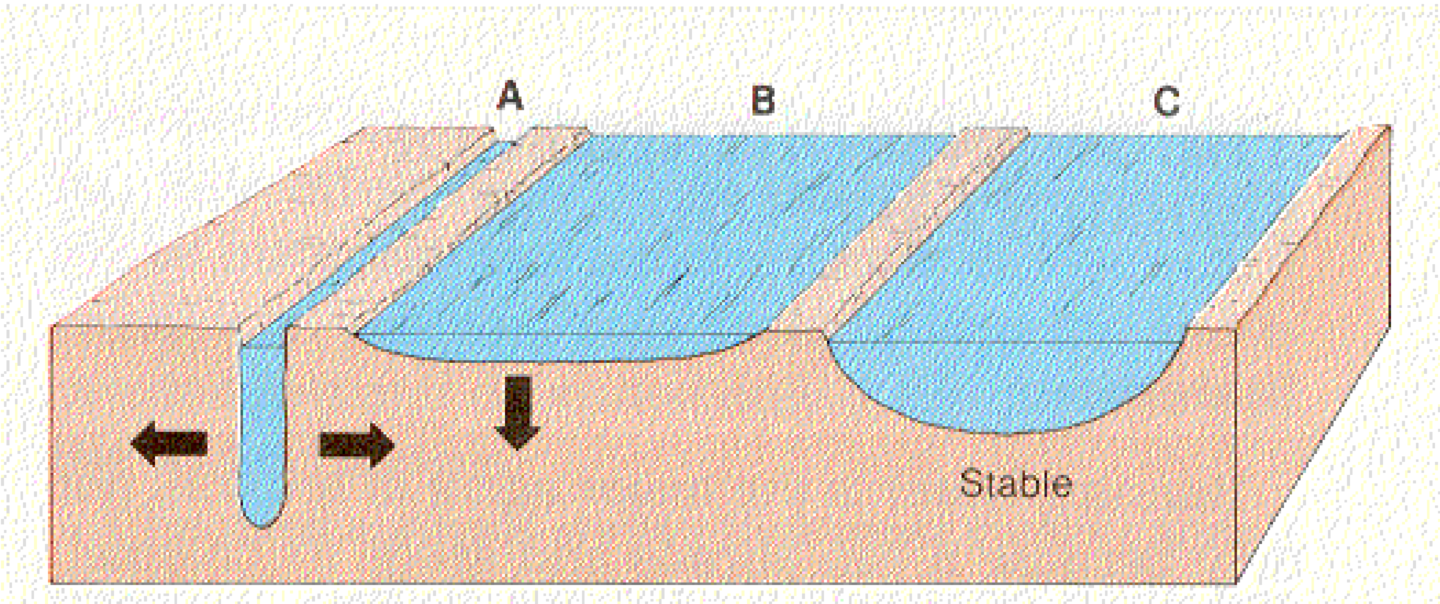
GEOLOGICAL SURVEY PROFESSIONAL PAPER 252

Quantitative measurement of some of the hydraulic factors that help to determine the shape of natural stream channels: depth, width, velocity, and suspended load, and how they vary with discharge as simple power functions. Their interrelations are described by the term "hydraulic geometry."

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1953



Hydraulic Geometry



Equilibrium Condition

American Society of Civil Engineering, Proceedings, 1955,
Vol 81, paper 795, pp. 1–17

8

The Importance of Fluvial Morphology in Hydraulic Engineering

E. W. LANE

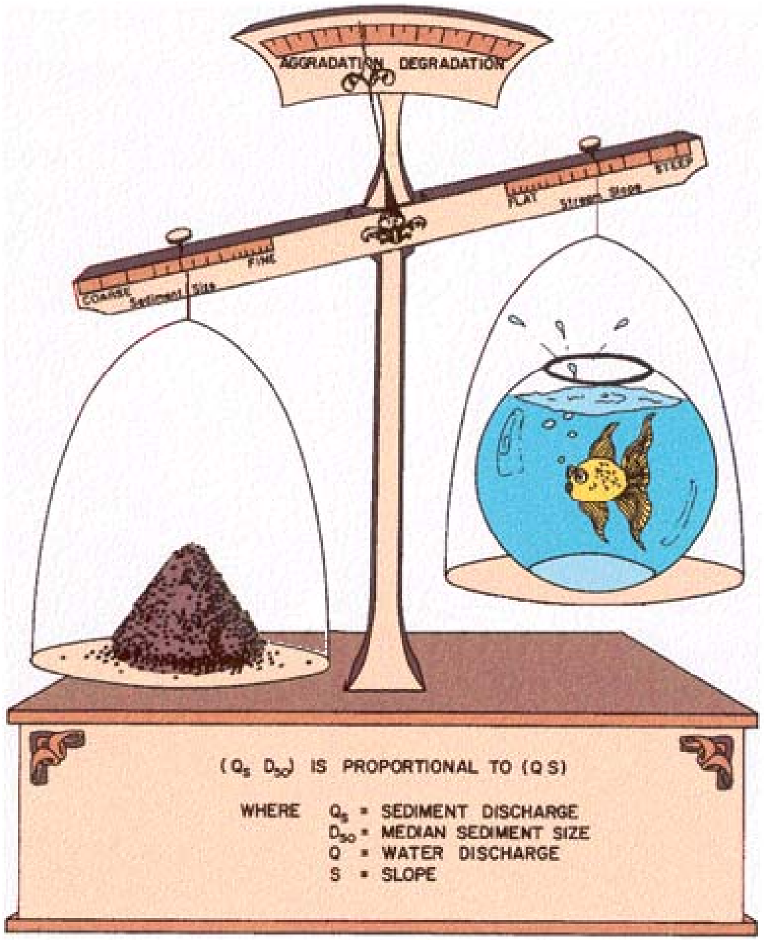
The following very general expression will be found useful in analyzing qualitatively many problems of stream morphology:

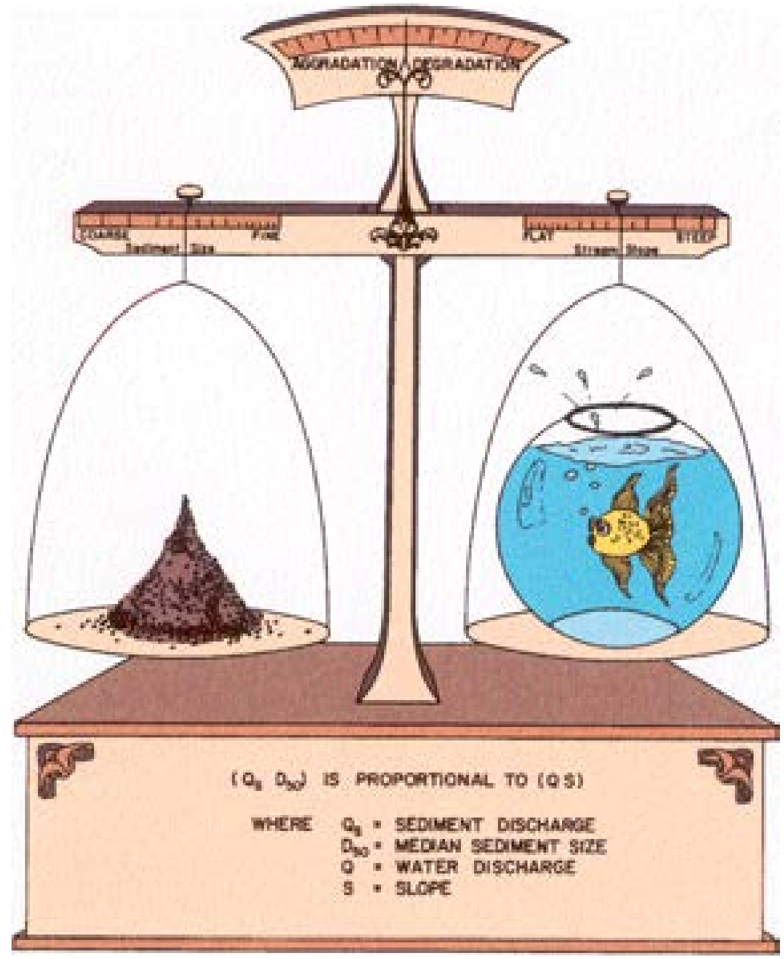
$$\boxed{Q_s\, d \sim Q_w S}$$

Here Q_s is the quantity of sediment, d is the particle diameter or size of the sediment, Q_w is the water discharge, and S is the slope of the stream. This is an equation of equilibrium and if any of the four variables is altered, it indicates the changes which are necessary in one or more of the others to restore equilibrium. For example, if a stream with its sediment load is flowing

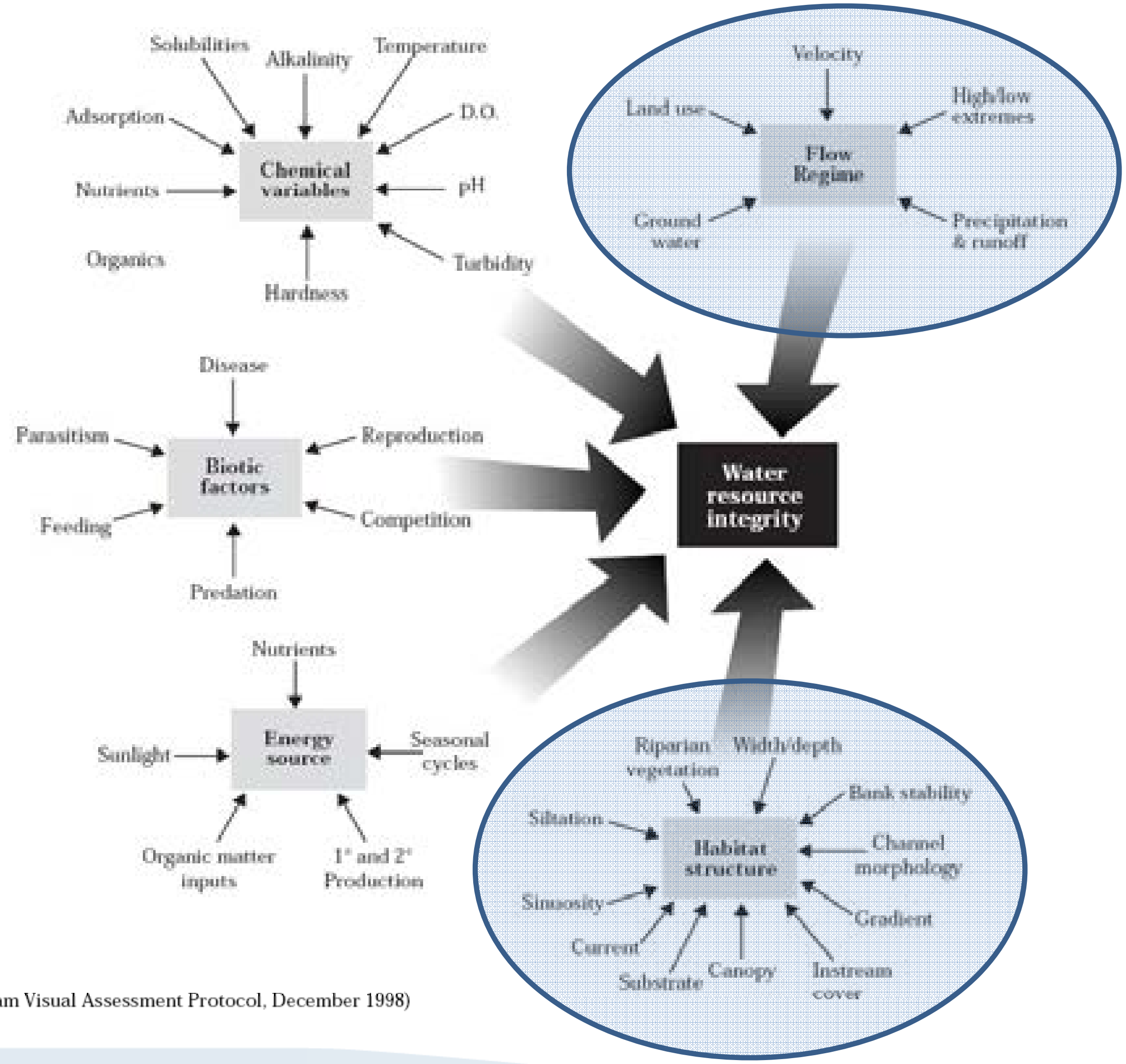
Channel Equilibrium

(original illustration was by Whit Borland, USBR)





Stream Health



(NWCC Technical Note 99–1, Stream Visual Assessment Protocol, December 1998)

Prototype/Model Similitude

$$\frac{dD}{dx}\left(1 - \alpha Fr^2\right) = S - S_f$$

$$\frac{dD_p}{dx_p}\left(1 - \alpha Fr_p{}^2\right) = S_p - S_{fp}$$

$$\frac{dD_m}{dx_m}\left(1 - \alpha Fr_m{}^2\right) = S_m - S_{fm}$$

$$\frac{1}{S_p}\frac{dD_p}{dx_p}\left(\frac{D_r}{S_r\, x_r}\right)\left(1 - \alpha\, Fr^2{}_p\ \left(Fr^2{}_r\right)\right) = 1 - \frac{S_{fp}}{S_p}\left(\frac{S_{fr}}{S_r}\right)$$

$$\frac{D_r}{S_r\, B_r} = 1 \quad (B_r = x_r) \qquad \frac{S_{fr}}{S_r} = 1 \qquad Fr_r{}^2 = 1$$

Roughness and Sediment Transport

Effect of Roughness

$$S_{fr} = \left(\frac{n_r^{\;2}}{D_r^{\;1/3}} \right) Fr_r^{\;2}$$

$$n_r = d_r^{\;1/6}$$

$$S_{fr} = \left(\frac{d_r}{D_r} \right)^{1/3} Fr_r^{\;2}$$

Sediment Transport

$$g_b = b' \, V^{m1} \, D^{m2}.$$

$$G_b = B \, g_b$$

$$G_{br} = B_r \, V_r^{\;m1} \, D_r^{\;m2}$$

Derived Scaling Relationships

$$D_r = Q_r^{6/17}\, d_r^{2/17}$$

$$B_r = Q_r^{8/17}\, d_r^{-3/17}$$

$$V_r = Q_r^{3/17}\, d_r^{1/17}$$

$$S_r = Q_r^{-2/17}\, d_r^{5/17}$$

$$G_{br} = Q_r^{e}\, d_r^{f}$$

where: $e = (8 + 3m1 + 6m2)/17$

$f = (-3 + m1 + 2m2)/17$

Comparison: Theoretical to Empirical

Scaling Variable	Empirical*	Theoretical	
	j	j'	k'
B_r	0.5	0.47	-0.18
D_r	0.4	0.35	0.12
V_r	0.1	0.18	0.06
S_r	-0.1	-0.12	0.29
G_{br}	none	Function of sediment transport relationship	

*Leopold and Maddock (1953)

Lane Relationship Enhanced

$$G_b\, d \propto Q\, S$$

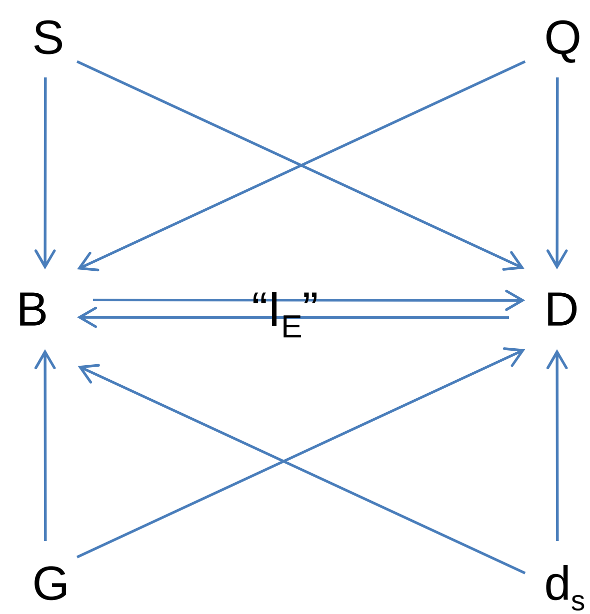
$$G_{br}\, d_r^{\,g} = Q_r^{\,h}\, S_r$$

where:

$g = 5/17 - f$

$h = 2/17 + e$

$$I_E = \frac{Q_r^{\,h}\, S_r}{G_{br}\, d_r^{\,g}}$$



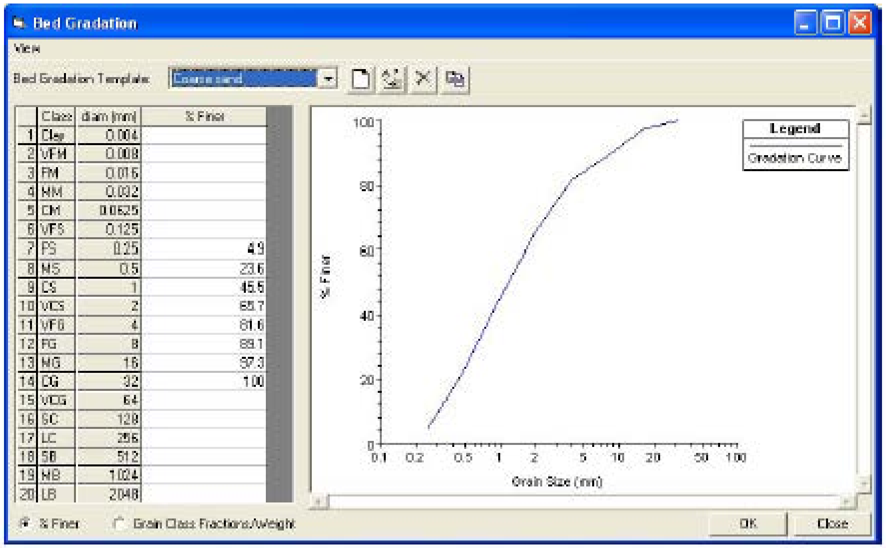
Upper Cherry Creek Case Study

Reach	UDSWM DP	Location	DA (sq.mi.)	2-yr Existing
	286	Park Boundary	361	2,142
1				
	280	County Line	338	1,798
2				
	337	Cottonwood Drive	333	1,567
3				
	276	E-470	310	1,558
4				
	274	Lincoln Avenue	305	1,544

Reach	UDSWM DP	Location	DA (sq.mi.)	2-yr Existing
	274	Lincoln Avenue	305	1,544
5				
	266	West Parker Road	288	1,302
6				
	262	Stroh Avenue	267	1,170
7				
	250	Scott Road	241	972
8				
	247	SH 86	207	664

HEC-RAS 4 Derived Sediment Transport Equation

A test relationship was developed from data on the Platte River (Big Bend reach) to demonstrate how HEC-RAS 4 can be used to develop a power function for sediment transport. The sediment gradation is as follows:



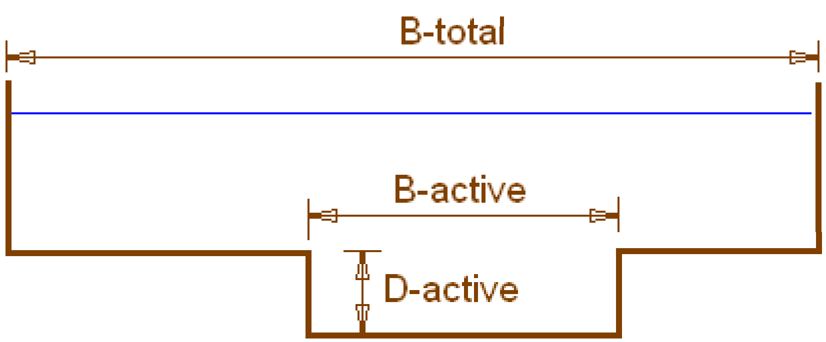
Eq	Q (cfs)	Tons	Tons/day	C (ppm)	V (ft/s)	R (ft)	So (ft/ft)
Ackers	100	0.0095	9.48	35	1.8	2.53	0.0005
Ackers	200	0.0291	29.13	54	2.2	3.44	0.0005
Ackers	500	0.1013	101.26	75	2.7	4.85	0.0005
Ackers	1000	0.2311	231.10	86	3.1	6.02	0.0005
Ackers	2000	0.5021	502.10	93	3.6	7.26	0.0005
Ackers	5000	1.3658	1365.81	101	4.2	9.13	0.0005
Ackers	10000	2.6533	2653.31	98	4.5	10.41	0.0005
Ackers	100	0.0368	36.76	136	2.2	2.14	0.0010
Ackers	200	0.1029	102.90	191	2.8	2.96	0.0010
Ackers	500	0.3397	339.74	252	3.5	4.29	0.0010
Ackers	1000	0.7635	763.54	283	4.1	5.43	0.0010
Ackers	2000	1.6314	1631.38	303	4.7	6.63	0.0010
Ackers	5000	4.3717	4371.74	324	5.5	8.39	0.0010
Ackers	10000	8.8831	8883.06	330	6.2	9.82	0.0010
Ackers	100	0.1222	122.24	453	2.8	1.80	0.0020
Ackers	200	0.3262	326.19	605	3.5	2.53	0.0020
Ackers	500	1.0577	1057.74	785	4.6	3.76	0.0020
Ackers	1000	2.3848	2384.84	885	5.4	4.85	0.0020
Ackers	2000	5.1164	5116.41	949	6.3	6.02	0.0020
Ackers	5000	13.6302	13630.21	1011	7.4	7.69	0.0020
Ackers	10000	28.5359	28535.93	1059	8.3	9.14	0.0020
Ackers	100	0.2354	235.37	873	3.2	1.63	0.0030
Ackers	200	0.6189	618.88	1148	4.1	2.30	0.0030
Ackers	500	2.0050	2005.02	1488	5.3	3.46	0.0030
Ackers	1000	4.5570	4556.96	1690	6.4	4.52	0.0030
Ackers	2000	9.8705	9870.45	1831	7.4	5.67	0.0030
Ackers	5000	26.3605	26360.51	1956	8.8	7.30	0.0030
Ackers	10000	55.5673	55557.33	2061	9.8	8.70	0.0030

$$g_b = 0.042\, V^{4.56}\, D^{0.445}$$

$$I_E = \frac{Q_r^{1.55}\, S_r}{G_{br}\, d_r^{0.15}}$$

Existing Conditions

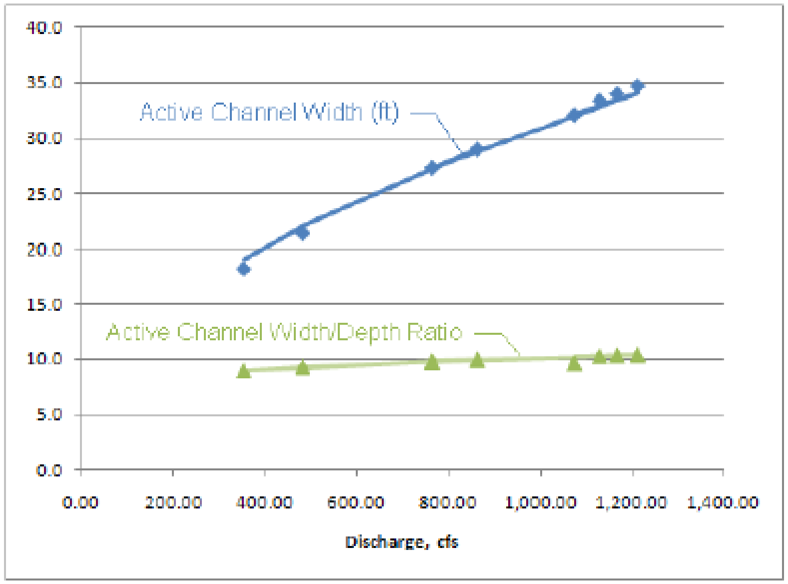
Reach	Q_{2yr} (cfs)	So (%)	B-active (ft)	B-total (ft)	D-active (ft)	Y_{2yr} (ft)	Qactive (cfs)	$V_{ave\text{-}active}$ (ft/s)	G_b (T/day)
1	1798	0.409	30.0	300	2.9	4.4	986	7.5	23,963
2	1567	0.394	28.0	280	3.4	4.7	983	7.5	22,911
3	1558	0.369	21.0	210	4.0	5.6	910	7.7	20,707
4	1544	0.369	22.0	220	3.4	5.1	832	7.4	17,820
5	1302	0.414	27.0	270	3.0	4.2	809	7.2	17,329
6	1170	0.365	16.0	165	3.8	5.5	632	7.2	11,519
7	972	0.408	24.0	240	3.1	4.0	666	6.9	12,305
8	664	0.392	16.0	160	3.7	4.6	485	6.6	7,340
P	664	0.390	18.0	160.0	2.0	3.2	347	5.9	4,266



Reach	G_{br}	d_r^g	Q_r^h	S_r	I_E
1	5.62	1.00	5.05	1.05	0.94
2	5.37	1.00	5.02	1.01	0.95
3	4.85	1.00	4.46	0.95	0.87
4	4.18	1.00	3.88	0.95	0.88
5	4.06	1.00	3.71	1.06	0.97
6	2.70	1.00	2.54	0.94	0.88
7	2.88	1.00	2.75	1.05	1.00
8	1.72	1.00	1.68	1.01	0.98
P	1.00	1.00	1.00	1.00	1.00

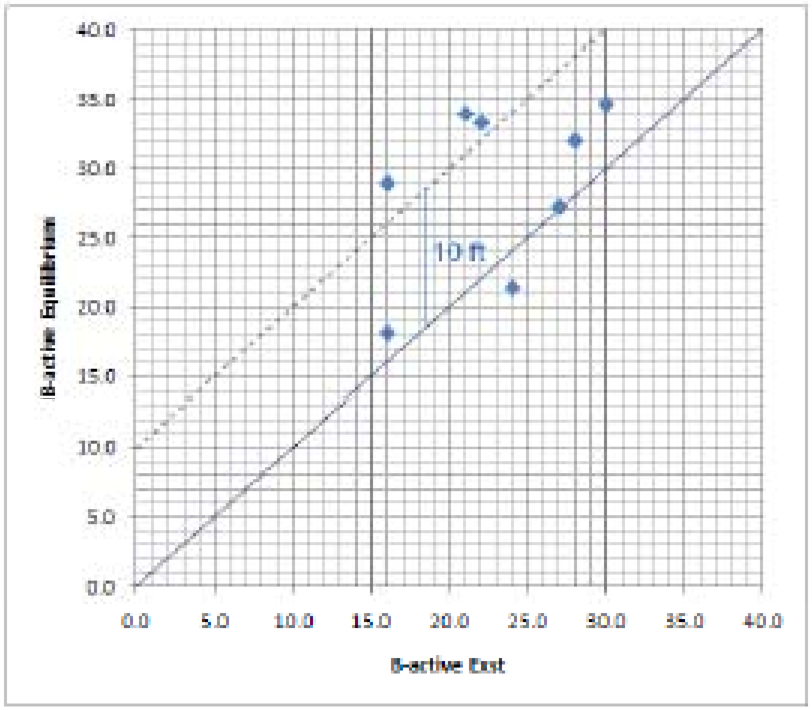
Existing Conditions Adjusted to Equilibrium

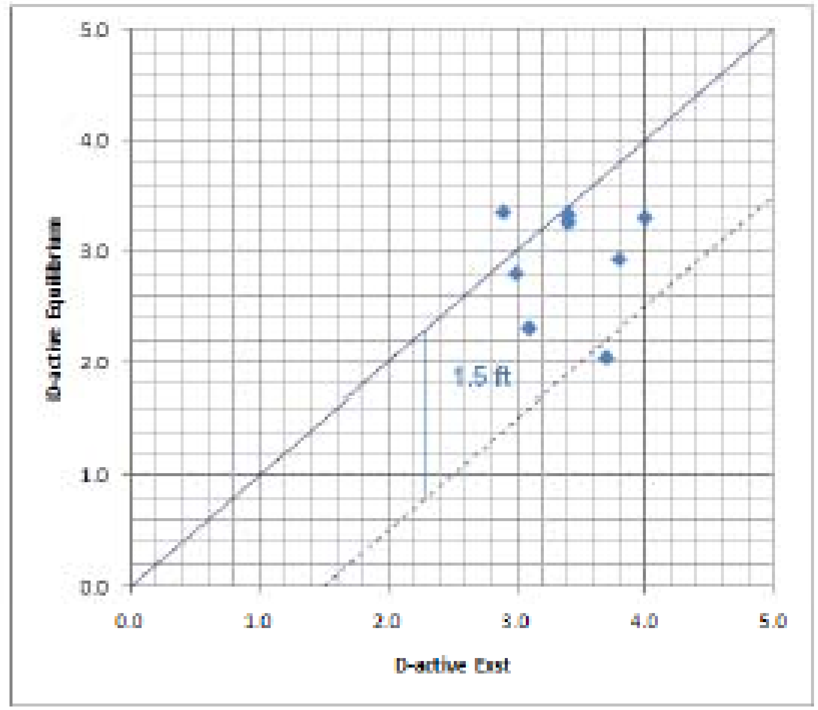
Reach	Q_{2yr} (cfs)	So (%)	B_{active} (ft)	B_{total} (ft)	D_{active} (ft)	Y_{2yr} (ft)	Q_{active} (cfs)	$V_{ave\text{-}active}$ (ft/s)	Gb (T/day)
1	1798	0.390	34.7	300	3.4	4.6	1213	7.6	29,684
2	1567	0.390	32.1	280	3.3	4.5	1074	7.4	24,599
3	1558	0.390	34.0	210	3.3	4.6	1168	7.5	28,005
4	1544	0.390	33.4	220	3.3	4.5	1130	7.5	26,616
5	1302	0.390	27.3	270	2.8	4.0	764	6.9	14,466
6	1170	0.390	29.0	165	2.9	4.2	863	7.1	17,511
7	972	0.390	21.4	240	2.3	3.6	482	6.3	7,099
8	664	0.390	18.2	160	2.0	3.3	354	6.0	4,398
P	664	0.390	18.0	160.0	2.0	3.2	347	5.9	4,266



Reach	G_{br}	d_r^g	Q_r^h	S_r	I_E
1	6.96	1.00	6.96	1.00	1.00
2	5.77	1.00	5.77	1.00	1.00
3	6.56	1.00	6.56	1.00	1.00
4	6.24	1.00	6.24	1.00	1.00
5	3.39	1.00	3.40	1.00	1.00
6	4.10	1.00	4.10	1.00	1.00
7	1.66	1.00	1.67	1.00	1.00
8	1.03	1.00	1.03	1.00	1.00
P	1.00	1.00	1.00	1.00	1.00

Comparison:
Existing to Equilibrium Conditions





Questions?

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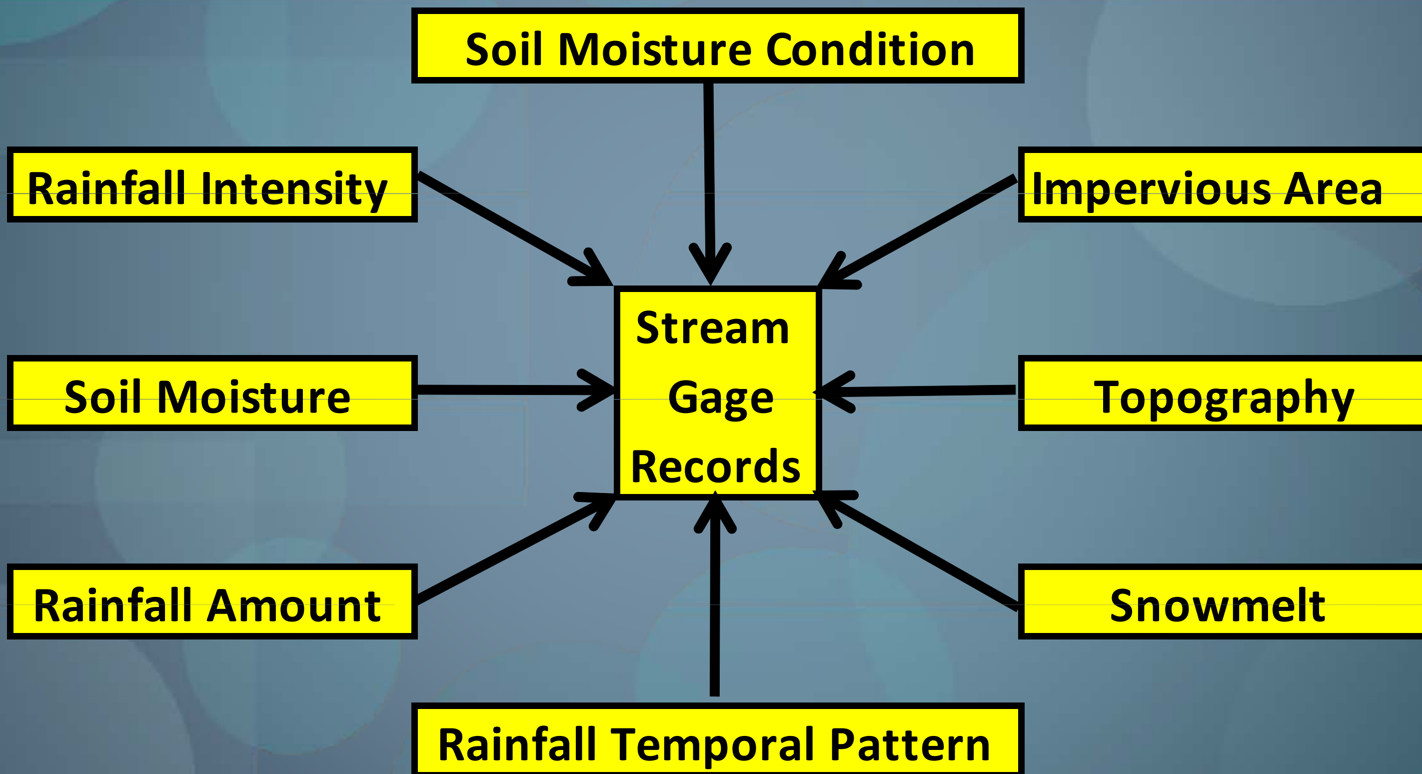
Statistical Methods in Flood Hydrology

Benefits of the Using Statistical Analysis of Gage Records for determining flood frequency-discharge relationships

Stream Gage Records integrate the consideration of all stochastic hydrologic variables that are determinant of stream flood flow for rural watersheds that have not experienced significant urbanization

Stream Gage Records represent the result of all the random hydrologic variables that contribute stream flow



Statistical Analysis of U.S.G.S Stream Gage Records

- Statistical Analysis of Stream Gage flow records is accomplished using the Log Pearson Type III Distribution as proposed in Bulletin 17 B published by the U.S. Water Resources Council
- The Log Pearson Type III distribution is characterized by Three Moments (Mean, Variance and Skew)
- Without consideration of the third order Moment (Skew) the Log Pearson Type III distribution becomes the log normal distribution

Analysis of Measured Stream Flow

- Analysis of stream flow data from reliable gage sites (Typically USGS Stream Gaging Stations) allows for consideration of all random hydrologic variables that are determinant of stream flow as represented in

- Stream gage records are useful in the prediction of flood peaks for various return periods at un-gaged sites

- Stream flood flow relationships between watershed descriptors such as drainage area ;Mean channel slope, and Lake and Marsh Area are generally non-linear with respect to observed flow - The principles of linear modeling and multiple regression analysis can be used with non-linear prediction equations that have been transformed to an equation that is linear in the coefficients.

Increased Sampling Variation Occurs for Higher Order Moments

- Due to the significant sampling error associated with skew (the third order moment in the Log Pearson Type III Distribution) - Station Skew should be weighted with the regional skew as determined by the using iso-skew map included in Bulletin 17B.
-

Historic Flood Data

- Historic flood information should be incorporated into the systematic stream gage record when this can be done with reasonable accuracy
- Comparisons should be made with similar watersheds when possible
- Gage Comparisons should be made with other gage stations in a homogeneous region for a flood event .

Evaluation of Flood Risk

- When events can be considered to be independent the Binomial Theorem can be used to evaluate Risk - The Binomial Theorem can be used to evaluate the probability of (I) flood events over the course of N Years with a given exceedance probability.
-

Application of the Binomial Theorem

- The binomial expression for risk is:
  - RI= N!/(I!((N-I)! * (1-P)^N-1)

- In which RI is the estimated risk of obtaining in N Years exactly I number of flood events exceeding a flood magnitude with annual exceedance probability P.
  - When I equals 0 equation 10-1 reduces to
    - Ro = (1-P)^N

Risk Evaluation for Independent Events

- Example for evaluating risk using the binomial theorem. The Binomial Theorem can be used to evaluate the probability of independent events
  - Example:
- A bridge with a design life of 40 years is designed to pass a 100-year flood. The design engineer is interested in determining the probability that the bridge will be submerged two times during its design life.
- The probability of the bridge being submerged in exactly two times in 40 years is
  - PI*(1-p) ^(n-x)* .01^2
  - (.01)^2*.98^.38 =.050

Flood Estimates based on Precipitation Data

- Flood Estimates based on precipitation data and a valid watershed model can be integrated with the systematic gage records when adequate precipitation data , land use and soil type data is available is available for use in a hydrologic model

Advantages of Predicting Peak Flood Flows using Statistical Inference from Peak flow Data

- Stream Gage records represent the end data that includes consideration of all random hydrologic variables that combine to determine Peak Flow for a flood event

- Pertinent hydrologic variables include:
  - Precipitation Amount
  - Precipitation Intensity
  - Antecedent Soil Moisture Condition
  - Soil Permeability
  - Temporal Pattern of Precipitation

Randomness of Precipitation Events

- In general, an array of flood events may be considered a random sample of independent events
- Even when a test of serial correlation indicates a deviation from this assumption; the annual peak data may provide for an unbiased estimate of return period for flood events

Estimating Generalized Skew

- The skew in the Log –Pearson Type III distribution is sensitive to extreme events
- There are two generalized methods of determining the appropriate skew.
- Calculating the skew of 40 Stations within a 100 mile radius of the stream gage station being evaluated
- Development of a skew iso-line map from skew calculations for all gaging stations used in the analysis

Skew Isoline Map from Bulletin 17B

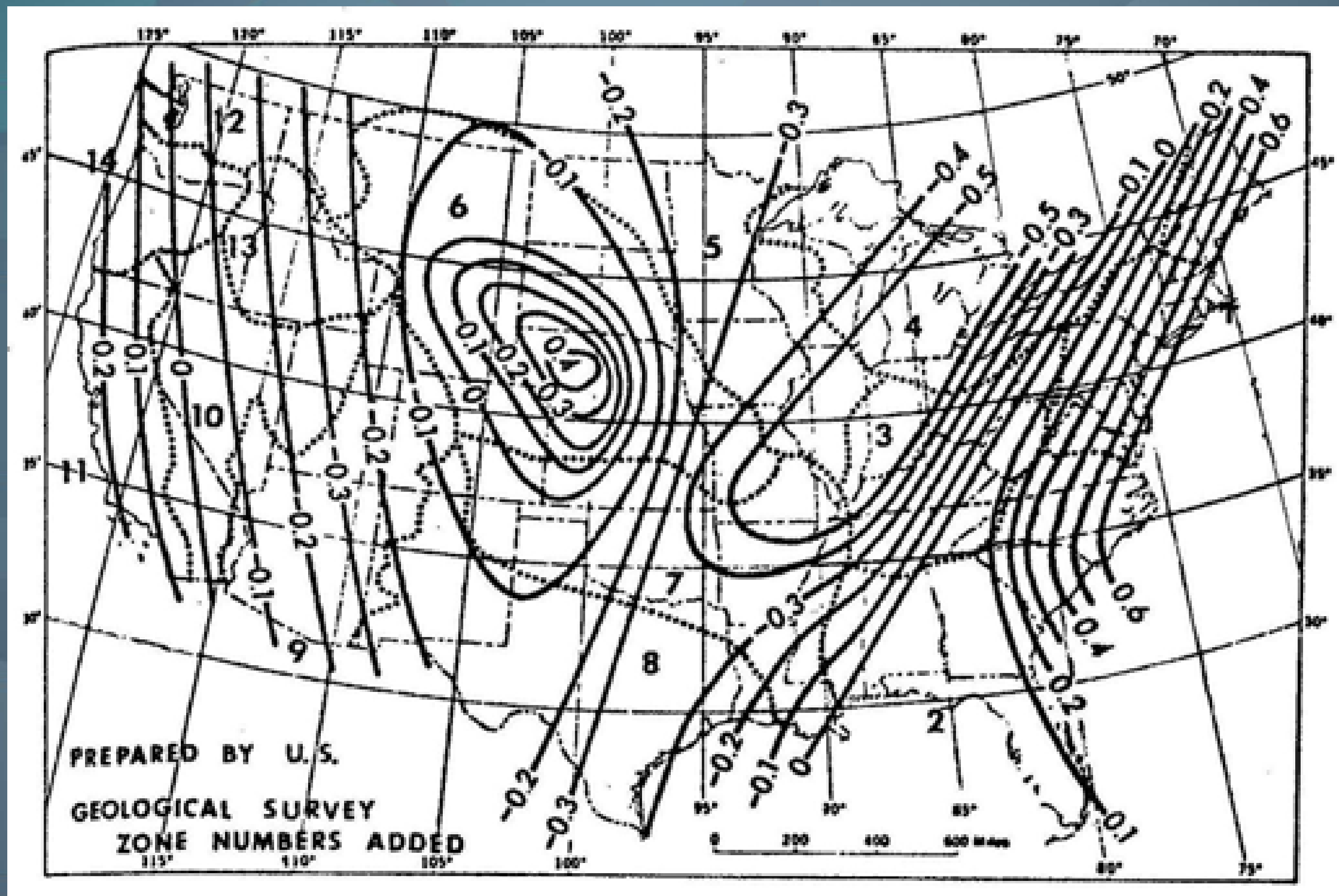
Bulletin 17B includes a skew map for the United States

- Weighting of Station Skew and Generalized Skew
  - Following is the equation for weighting:
    - the

Station Skew and Generalized Skew

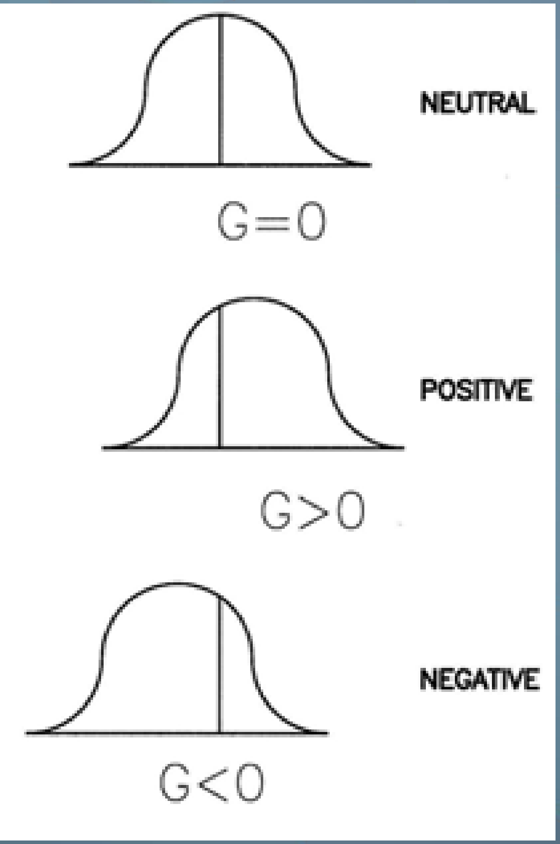
Gw =Weighted Skew

Generalized Skew Map



Skew Coefficient

- Effects of Neutral, Positive and Negative Skew



Skew results in asymmetric distribution

Statistical Inference for Flood Flows

- The non-linear equations that typically relate flood peak discharge and watershed characteristics must be transformed to equations that are linear in the coefficients

Quantifiable Drainage Area Characteristics

Drainage Area Characteristics typically related to drainage area characteristics in a non-linear manner

Example:

Q(2)= (Peak Flow for the two year flood)

Q(2)= (D.A.^X1)*(LMA^X2)*(CS^X3)

Where D.A. = Drainage Area in Square miles

LMA = Lake and Marsh Area in Square Miles

CS = Average Channel Slope in (ft. per mi.)

Predictive Equations transformed to be linear in the Coefficients

Example

Q2 = X1*(log D.A.(Sq. Mi.)) +X2*(log C.S.))(ft./mi.

+X3*((log LMA)(Sq. Mi.))

Mathematics of the Linear Model

Normal Equations in the Linear Model

Watershed Changes

- It has become increasingly difficult to find watersheds that have not changed significantly over the period of record for the gaged location.

- The use of statistical inference in the form of a linear model should be used for watersheds that have not experienced significant increases in impervious area in the recent past

Determination of the Flood Frequency Relationship

- An annual or partial duration series can be employed when determining a flood frequency relationship

- The annual series consists of only the annual peak in any Water Year

Statistical Analysis of Stream Gage Records

- The log Pearson Type III distribution has been adopted in Bulleting 17B

- All flows in the period of record should be transformed to the logarithm of the peak flow

Drawing inference from un-gaged sites

- Use of Linear Modeling techniques to draw inference about peak flood flows based on Linear Modeling (Regression) techniques
- The relationships between a watershed response and a measureable watershed characteristic is generally non-linear
- This condition is dealt with by transforming prediction equations an equivalent predictive equation that is linear in the coefficients

Predictive Equations that express are transformed to be linear in the coefficients

- Non-linear equations that can be used to predict flood flows as a function of watershed characteristics if the predictive equations are transformed to be linear in the coefficients

Non-linear Equation

$$Q=\beta_0 *(D.A.^{\wedge}\beta_1)*(LMA^{\wedge}\beta_2)*(CS^{\wedge}\beta_3)$$

- Transformed Equation that is linear in the Coefficients

Example :

$$Q = \log \boldsymbol{\beta_0} + \boldsymbol{\beta_1} * \log D.A. + \boldsymbol{\beta_2} * \log LMA + \boldsymbol{\beta_3} * \log CS$$

Coefficient Matrix for the Linear Model

Ordinary Least Squares

n	Σx1	Σx2	Σx3
Σx1	Σ(X1^2)	Σ(X1*X2)	Σ(X1*X3)
Σx2	Σ(X1*X2)	(Σx2^2)	Σx3*^2
Σx3	Σ(X1*X3)	(Σx2*x3)	Σx3*^2

XT.X

β0
β1
β2

Solution Vector

Σ(Y)
Σ(X*Y)

XT.Y

Right Hand Vector

Generalized Least Squares

n	Σx1	Σx2	Σx3
Σx1	Σ(X1^2)/v	Σ(X1*X2)	Σ(X1*X3)
Σx2	Σ(X1*X2)	(Σx2^2)/v	Σx3*^2
Σx3	Σ(X1*X3)	(Σx2*x3)	Σx3^2/v

XT.X

β0
β1
β2

Solution Vector

Σ(Y)
Σ(X*Y)

XT.Y

Right Hand Vector

Solving the Linear Model Simultaneous Equations

- EXCEL Math Tools can be used to invert the coefficient Matrix and multiply the inverted coefficient matrix times the right hand vector for an ordinary least squares model or a generalized least squares model

Stream Stats by the U.S Geological Survey

- Stream Stats by the U.S Geological Survey
  - Allows for generalized least squares (variance weighted)
  - Ordinary Least Squares (not variance weighted)

  - Stream Stats allows for access to all USGS Stream Gage Records and development of linear model for prediction of flood flows

Techniques for Integrating Hydrologic Analysis with Statistical Hydrologic Methods

- Simulating a period of hydrologic record to produce peak annual flood flows can serve as another hydrologic analysis technique that allows for inclusion of all of the random variables in the determination of annual flood flows

- Is there any reason to think that the peak flows obtained from a model that can simulate flood flows would not fit a Log Pearson Type III Distribution ?

Good References for Statistical Hydrology

Bulletin 17 B Published by the U.S
Water Resource Council

Statistical Hydrology by C. T. Haan

Stochastic Processes in Hydrology
Probability and Statistics in Hydrology
by Vujica Yevjevich

Statistical Analysis is Fun!

- Imagine the excitement that comes with collecting your own flood data from the USGS Stream Gage Records and doing the math using excel
  - Excel can multiply two matrices
  - Invert matrices
  - Multiply an inverted coefficient matrix with a vector to obtain a solution vector

- Or........exercise your own good judgment and let Stream Stats predict flood flows accepted stream gage records using

Aquatic Organism Passage Design Guidelines for Culverts

Roger Kilgore, Kilgore Consulting and Management

CASFM Conference

September 21-24, 2010

Snowmass Colorado

Goal for AOP Culvert Designs (HEC 26)

- Culvert designs providing aquatic organism passage (AOP).
- Culvert designs satisfying peak hydraulic criteria and protective of the public.
- Objective and reproducible design criteria and procedure.
- Fill a void where guidance is lacking or not subject to consensus.
- Defensible procedure for justifying expenditures.

FHWA HEC 26 Approach

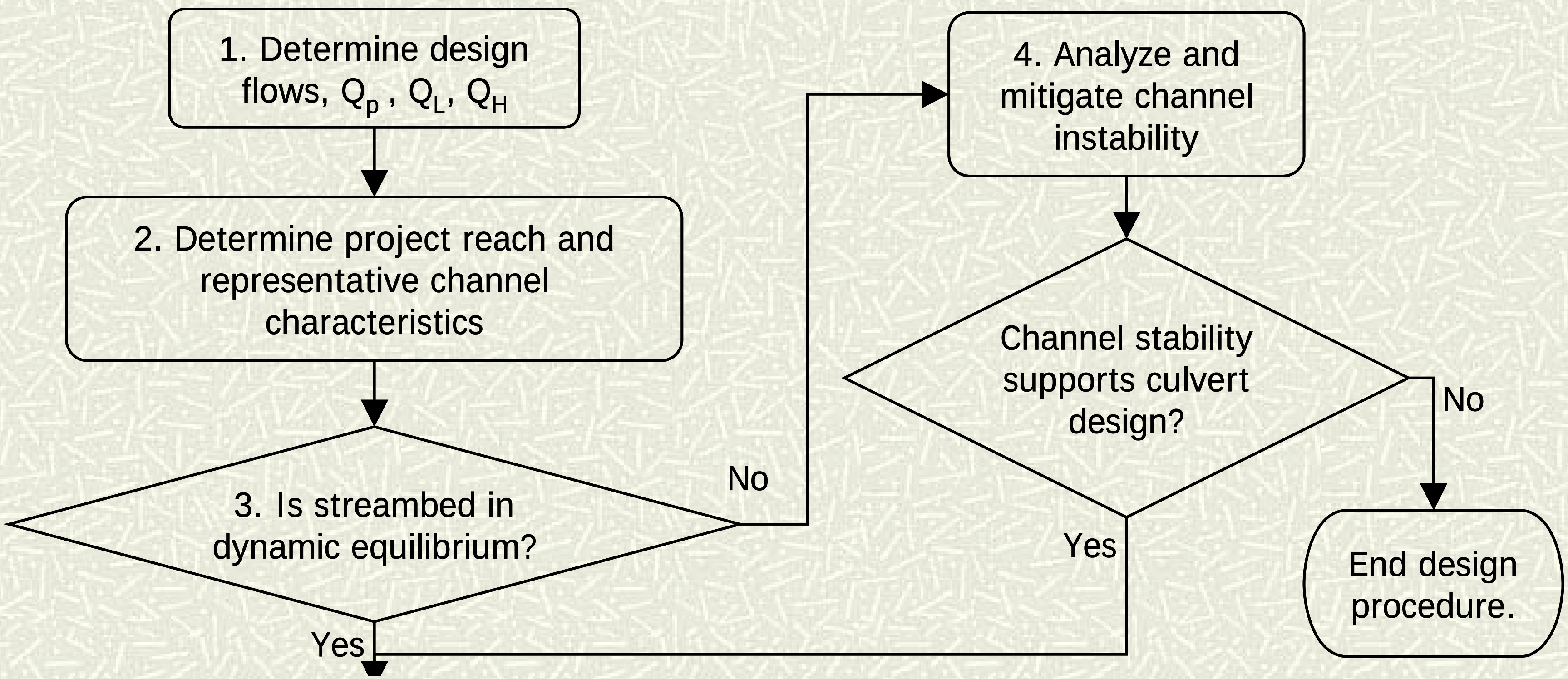
- Create conditions within the crossing similar to those in the natural channel in both bed structure and function.
- Presumption: Bed material experiences same forces as aquatic organisms (AO). If bed behavior is similar in crossing, AO that pass stream can pass crossing.
- Proxy approach. Range of flow from low passage to high passage.
- Use where no other approach is already accepted or for comparison.

Presentation Outline

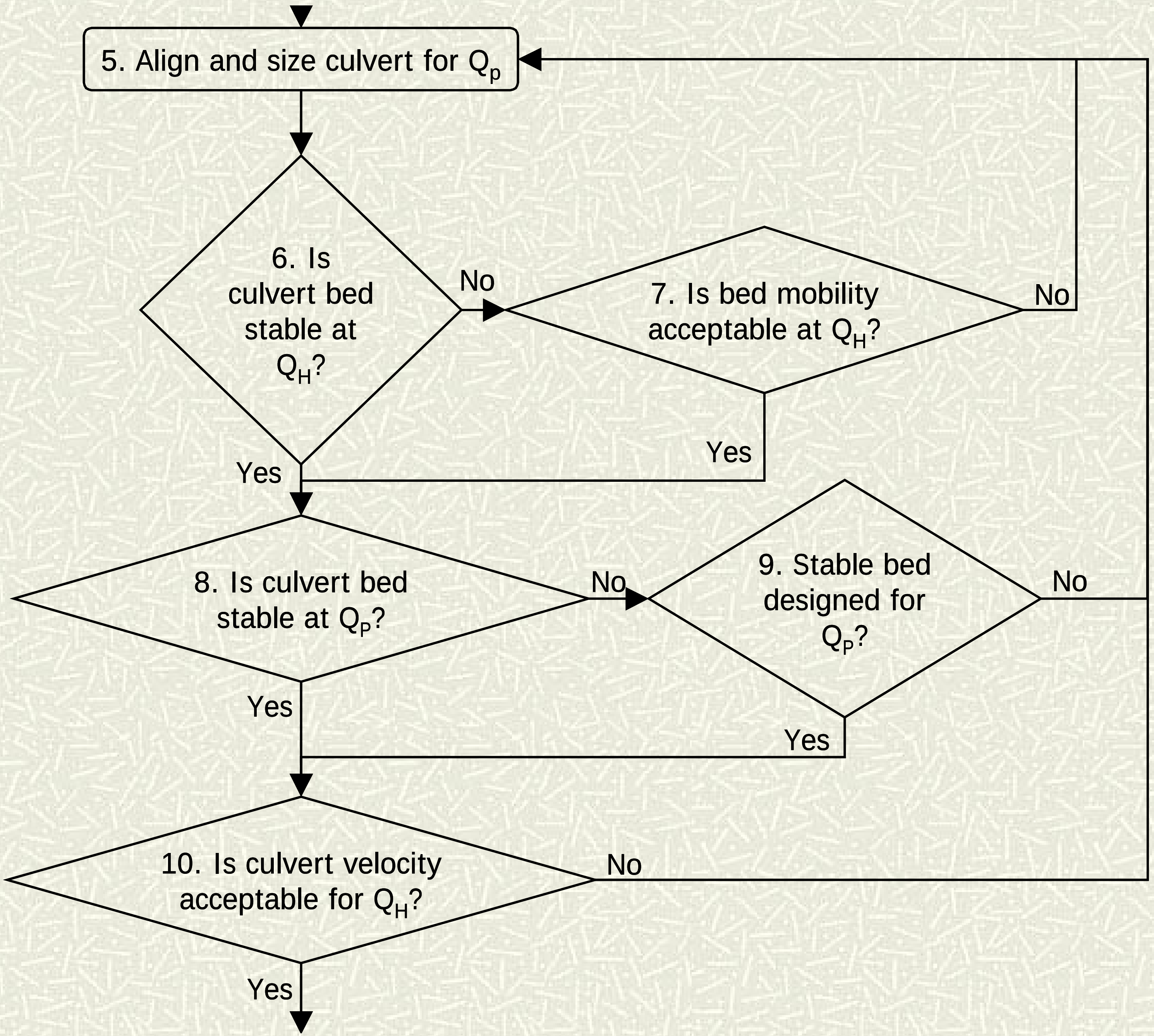
- Design procedure outline
- Case studies
  - North Thompson Creek, Colorado
  - Sickle Creek, Michigan
- Results comparison

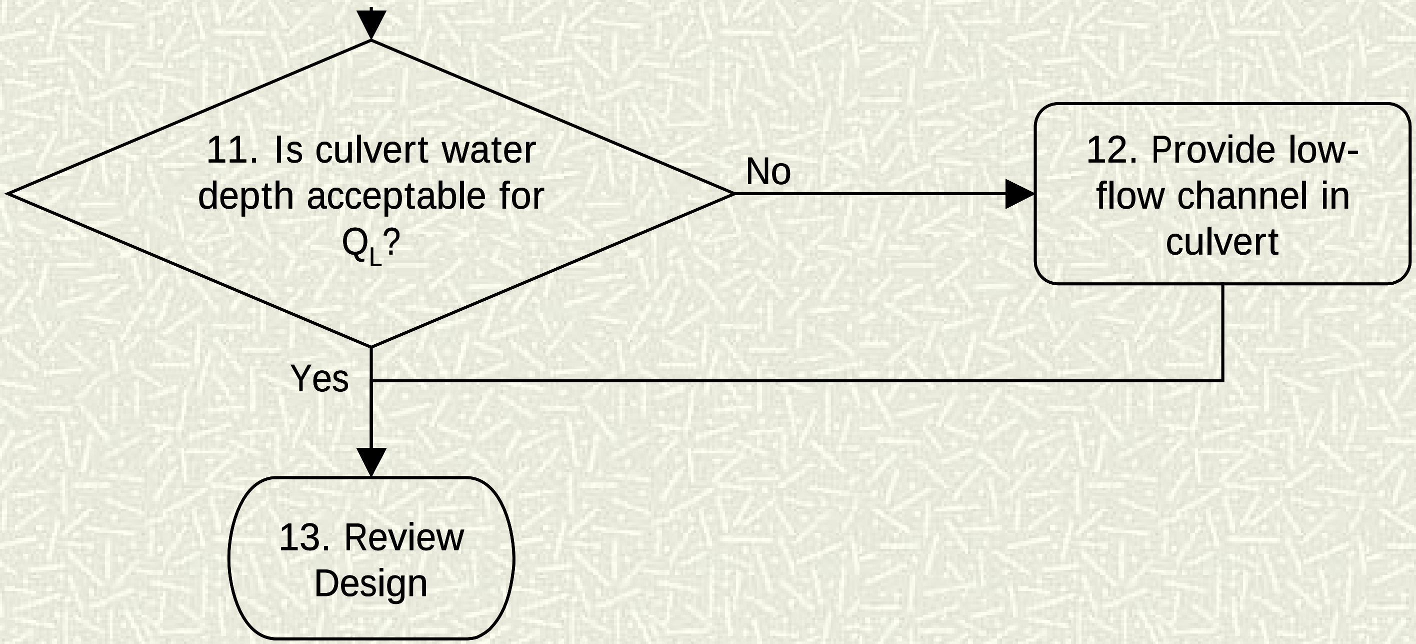
Fundamental Tests in Design Procedure

- Does culvert satisfy peak flow, Q_P requirements?
- Is bed material stable or in equilibrium for high passage flow, Q_H?
- Is bed stable/protected at peak flow.
- Is velocity acceptable compared to stream?
- Is depth acceptable compared to stream?



1. Determine design flows, Q_p , Q_L, Q_H
2. Determine project reach and representative channel characteristics
3. Is streambed in dynamic equilibrium?
No
Yes
4. Analyze and mitigate channel instability
Channel stability supports culvert design?
No
Yes
End design procedure.


5. Align and size culvert for Q_p
6. Is culvert bed stable at Q_H?
No
7. Is bed mobility acceptable at Q_H?
No
Yes
Yes
8. Is culvert bed stable at Q_P?
No
9. Stable bed designed for Q_P?
No
Yes
Yes
10. Is culvert velocity acceptable for Q_H?
No
Yes

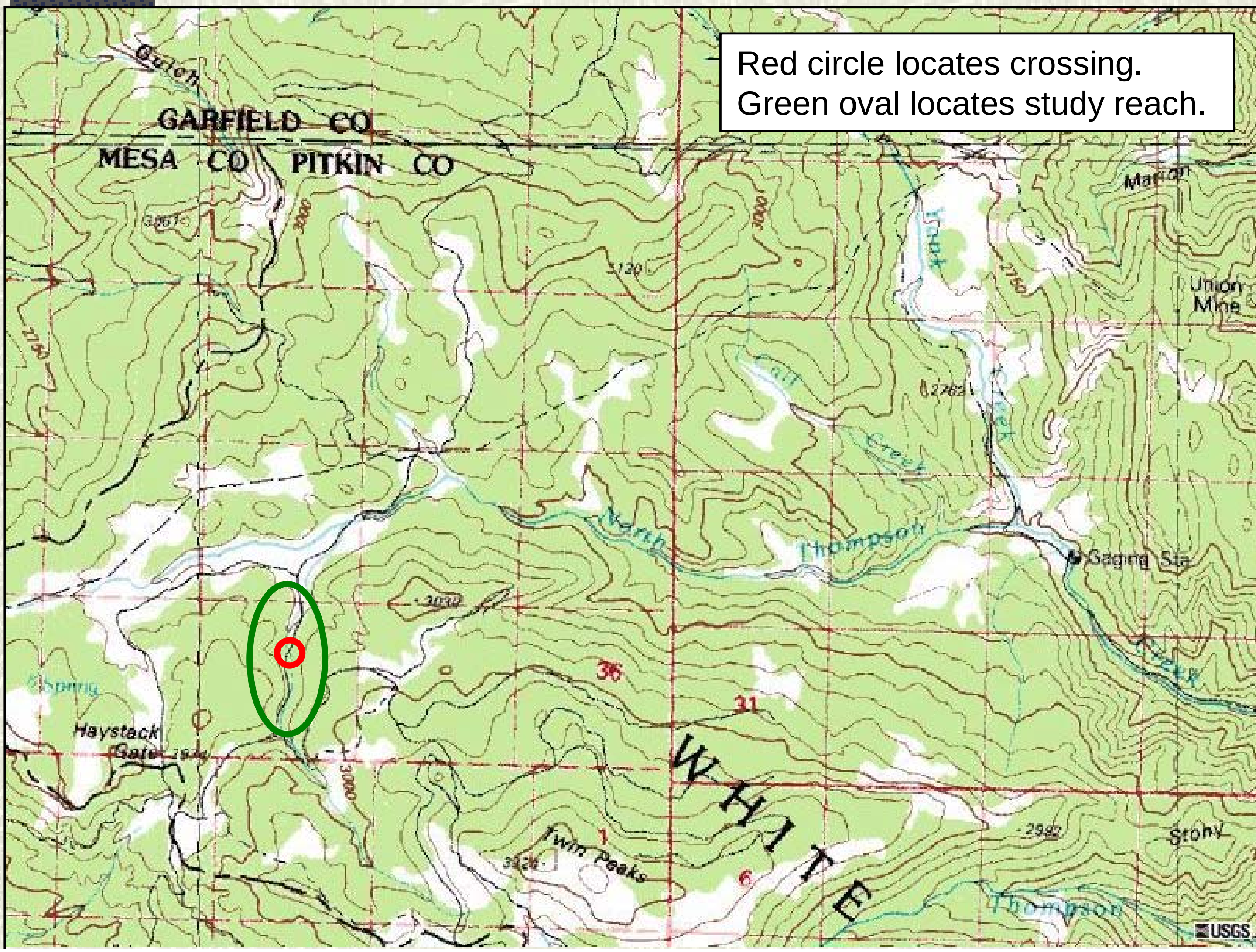


11. Is culvert water depth acceptable for Q_L?
No
12. Provide low-flow channel in culvert
Yes
13. Review Design

Tools Available

- Culvert hydraulics
  - HEC-RAS
  - HY8/Normal depth computations
- Channel analysis
  - HEC-RAS
  - Normal depth computations
- HEC 26 spreadsheet (channel stability and data management)

Case Study: North Thompson Creek, Colorado



Source: Mark Weinhold (USFS)

Existing 36” CMP culvert.

Outlet

Inlet

Step 1. Determine design flows: Q_P, Q_H, Q_L

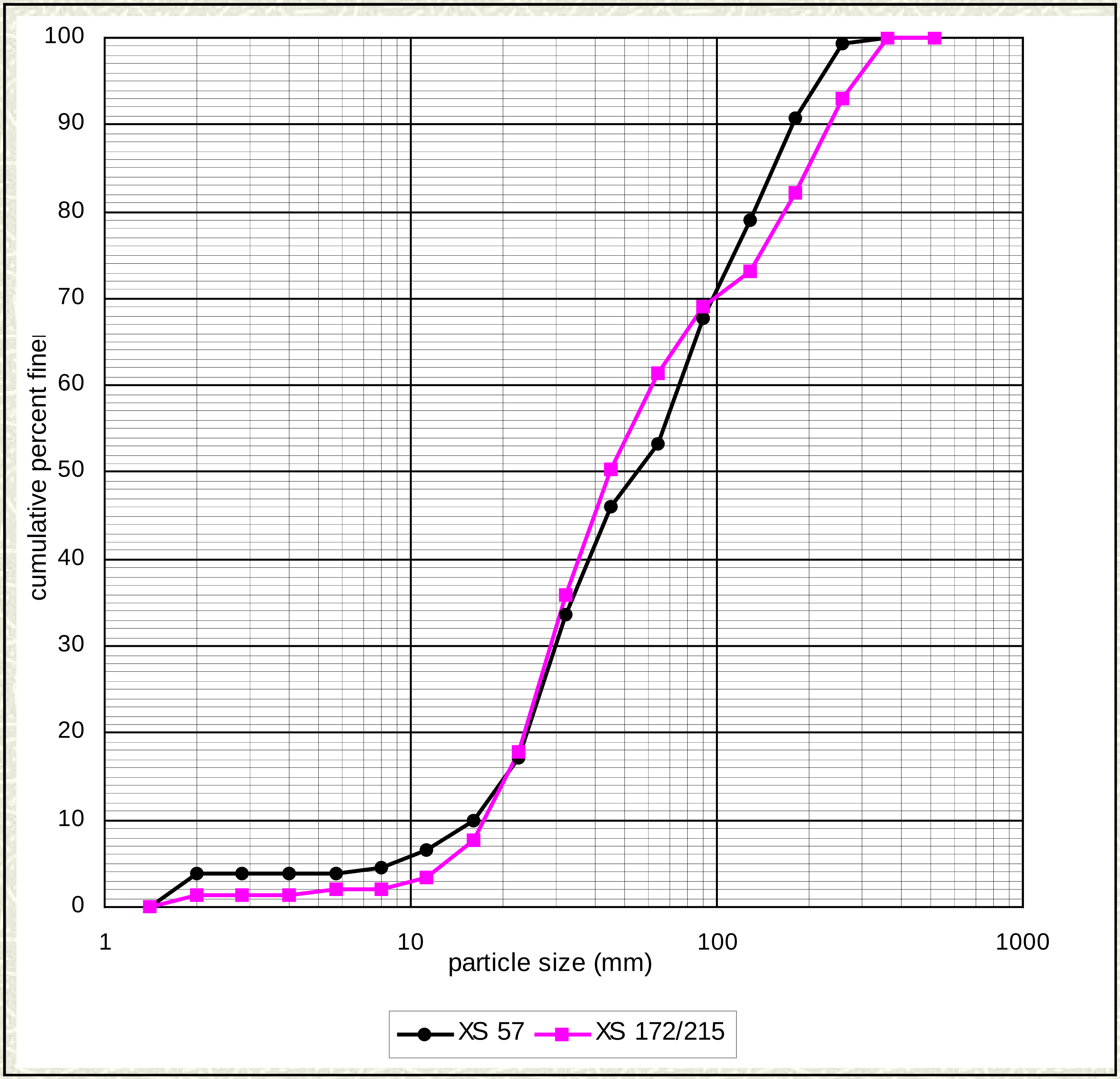
- Peak discharge, Q_P.
  - Based on pertinent high flow criteria.
- High passage discharge, Q_H.
  - Site-specific guidelines
  - 10% exceedance on annual flow duration curve
  - 0.25 of Q_2
- Low passage discharge, Q_L.
  - Site-specific guidelines
  - 90% exceedance on annual flow duration curve or 7Q2.
  - 1 ft^3/s minimum

Discharge Estimates

Discharge Quantity	Blakemore, et al. (1997) High Elevation Region 1, ft^3/s (m^3/s)	Kircher, et al. (1985) Mountain Region, ft^3/s (m^3/s)
Q_{25}	Q_P = 103 (2.92)	66 (1.9)
Q_2	41 (1.2)	30 (0.85)
$Q_{10\%}$	--	Q_H = 8.8 (0.25)
$0.25Q_2$	10.2 (0.3)	7.5 (0.21)
$Q_{90\%}$	--	0.15 (0.0042)
7Q2	--	0.13 (0.0037)
Q_L (min)		Q_L = 1 (0.028)

Step 2. Determine Project Reach and Characteristics

- Reach length upstream and downstream:
  - Three culvert lengths (3 x 46 = 138 ft)
  - 200 ft
  - Selected: 200 ft downstream, 300 ft upstream
- Cross sections. Min of 3 upstream and downstream (4 downstream, 5 upstream)
- Bed material.



100
90
80
70
60
50
40
30
20
10
0
cumulative percent finer
1
10
100
1000
particle size (mm)
XS 57
XS 172/215

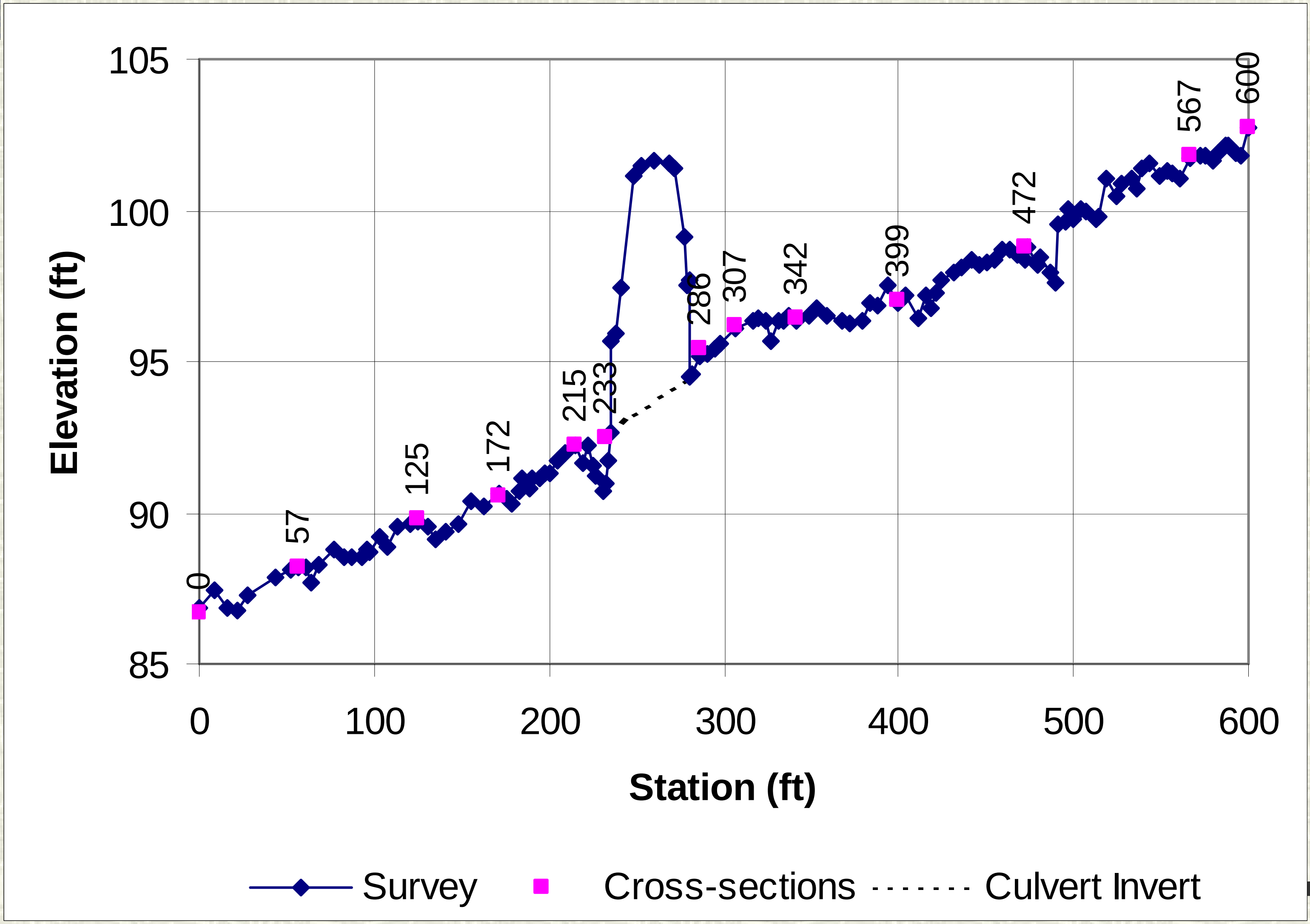
Steps 3 and 4.

- Step 3. Check for dynamic equilibrium.
  - No indicators of instability at site.
- Step 4. Analyze and Mitigate Channel Instability.
  - Not necessary at this site.
  - If mitigation was necessary, other tools beyond HEC 26 are required.

Step 5.
Align and Size Culvert for Q_P

- Determine design criteria.
- Select Bed Material (Use natural, D_5 no greater than 2 mm)
- Horizontal alignment.
- Vertical alignment.
- Embedment criteria.

Vertical profile of project reach



Bed Material Gradation

Quantile	XS 57 (mm)	XS 172/215 (mm)	Design (mm)	Design with added fines (mm)
D_{95}	218	285	250	250
D_{84}	151	194	170	170
D_{50}	55	45	50	50
D_{16}	22	21	21	20
D_{5}	13	13	13	2

Align and Size Culvert for Q_P

- Design criteria: HW/D < 1.2 or 1.0 (for larger culverts) and no overtopping.
- Select Bed Material. Manning's n for bed (0.044)/walls (0.035). Need composite n
- Horizontal alignment: maintain existing.
- Vertical alignment: S=0.0267 ft/ft (Existing culvert S=0.0395 ft/ft)
- Embedment depth: 30% (for circular pipe) minimum 2 ft rise.

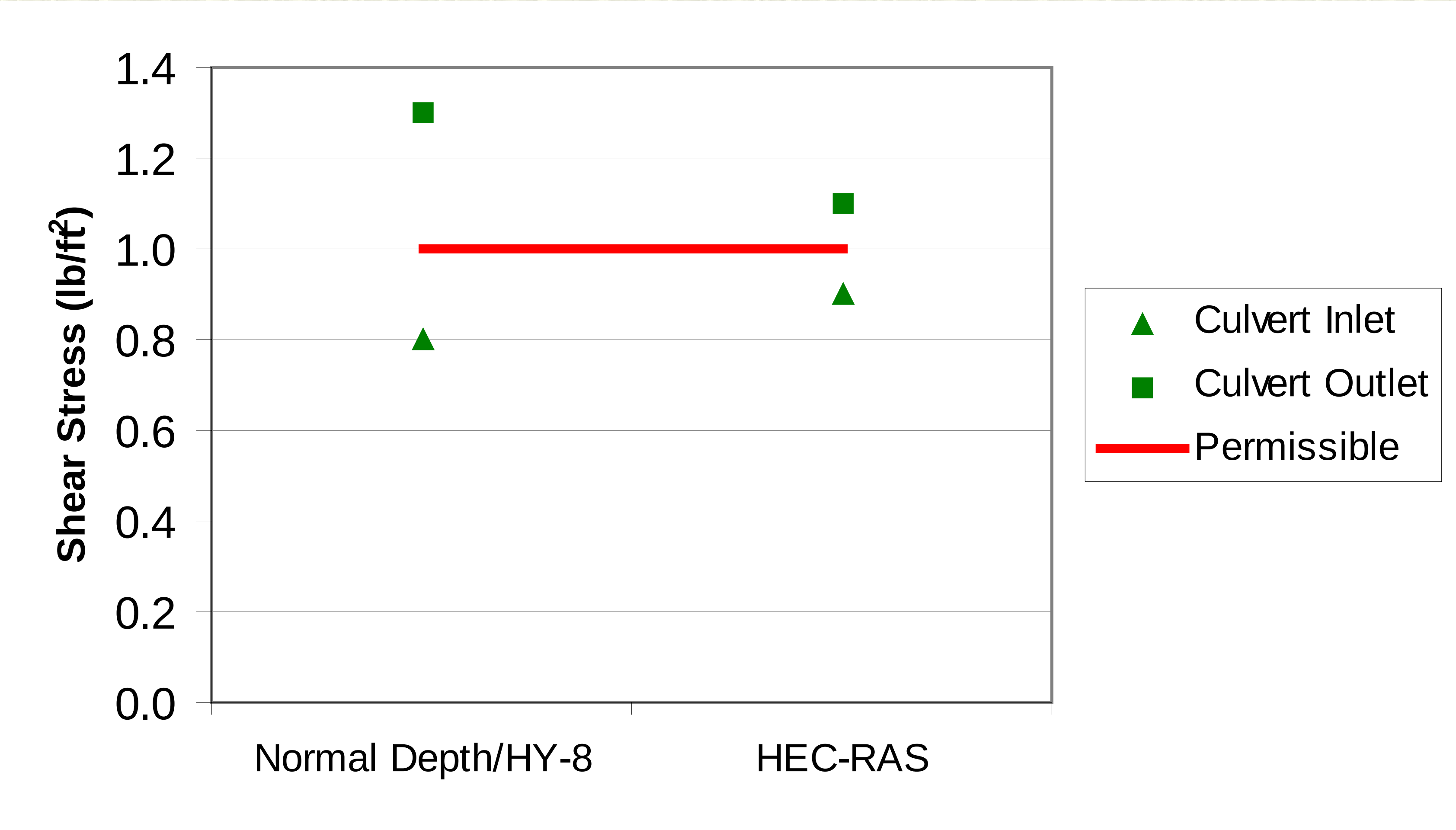
Initial Trial: 6.5 ft CMP with 2.0 ft embedment.

Step 6. Is culvert bed stable at Q_H?

- Determine Manning's n for bed
- Determine permissible shear stress.
  - Modified permissible shear stress.
  - Critical unit discharge.
- Determine applied shear stress:
  - Inlet and outlet of culvert
  - Upstream and downstream cross-sections.

$$\tau = \gamma y S_e$$

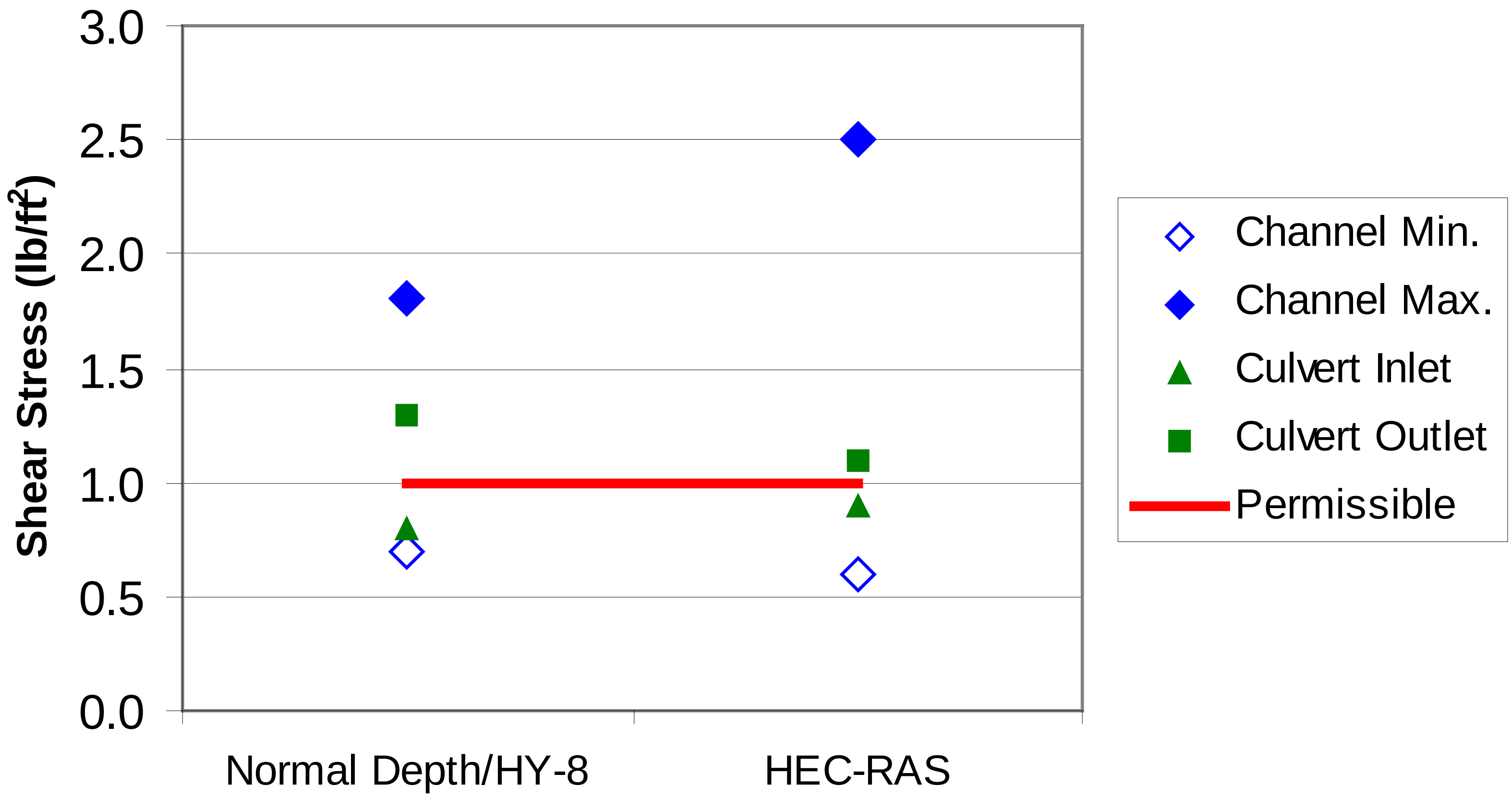
Culvert bed in 6.5 ft CMP not stable.



Step 7. Check Channel Bed Mobility at Q_H.

- If shear stress in any channel XS is less than permissible redesign culvert.
- If shear stresses in all channel XS are greater than permissible, bed is considered mobile.
  - Culvert shear stresses within range in channel? OK.
  - Culvert shear stresses exceed channel shear stresses? Redesign culvert.

Culvert bed in 6.5 ft CMP and in channel. Redesign culvert.



2^{nd} Trial

- Try 7.5 ft CMP.
  - Passes peak flow in Step 5.
  - Culvert bed stable in Step 6. (No need for Step 7.)
- Proceed to Step 8.

Step 8. Check Culvert Bed Stability at Q_P

- Few sites will exhibit bed stability at Q_P.
- For 7.5 ft CMP on North Thompson Creek the shear stresses range from 2.6 to 3.2 lbs/ft^2 at the inlet and outlet of the culvert with either HEC-RAS or HY-8.
- Permissible shear stress is 1.0 lbs/ft^2.
- Bed not stable, go to Step 9.

Step 9. Design Stable Bed

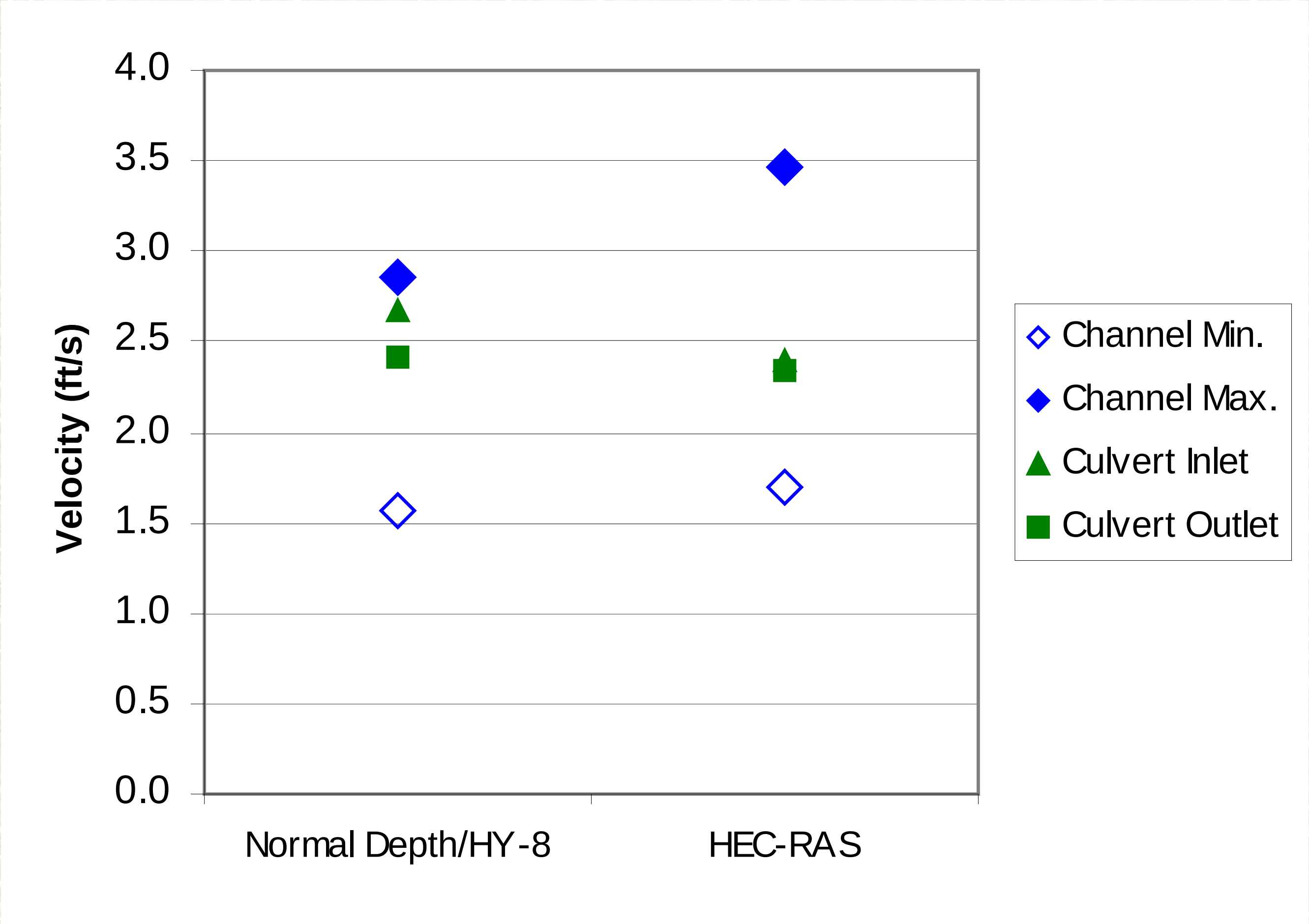
- *Provide an oversized sublayer to resist further lowering of bed and to provide a rough base for replenishment of native materials.*
- Minimum Criteria:
  - Native streambed layer: Largest of D_{95} (native material) or 1ft.
  - Oversized sublayer: 1.5 D_{95} (oversize material) for circular pipes.
  - Two layers combined should be no less than the minimum required embedment.

Oversize Bed Gradation

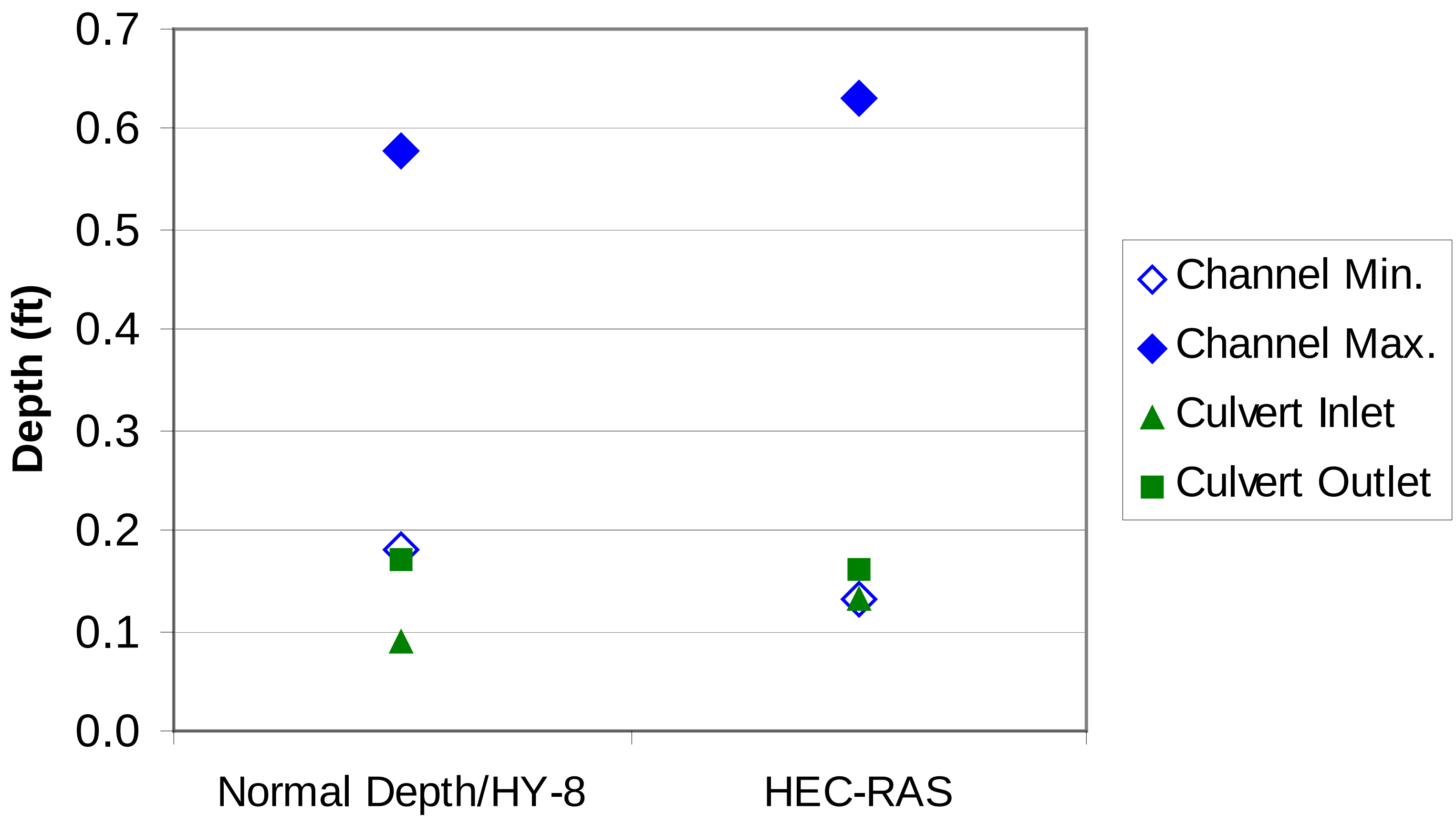
Quantile	Native (mm)	Oversize (mm)
D_{95}	250	305
D_{84}	170	226
D_{50}	50	162
D_{16}	20	36
D_{5}	2	2

- Initial trials were unsuccessful. (Spreadsheet tool available.) Culvert increased to 8.5 ft CMP.
- Native layer = 1.0 ft
- Oversize layer = 1.55 ft
- Total embedment = 2.55 ft

Step 10.
Check Velocity at Q_H.



Step 11.
Check depth at Q_L.



Step 12. Provide Low-flow Channel in Culvert.

- Design triangular low-flow channel.
- 1:8 (V:H) side slopes
- Result: Thalweg 0.5 ft deeper than edges. (Note that native D_{84} is 0.55 ft.)
- Stream processes will modify channel over time.

Step 13. Review Design

- 8.5 ft CMP
- 2.5 ft Embedment
- Oversize layer
- Cover
- Constructability
- Service life.
- Other shapes or materials?
- Open-bottom design?

Design Comparison

	North Thompson Creek, Colorado	Tributary to Bear Creek, Alaska	Sickle Creek, Michigan
AOP barrier/ Existing	3-ft CMP	5-ft CMP	Twin 3-ft CMPs
As-built	12’x ? squash pipe	9.75’x 6.6’ pipe arch	16’x 6’ concrete arch bridge
HEC-26 procedure	8.5’ CMP	12’ CMP	10’ CMP
Difference in span	-3.5 ft	+2.25 ft	-6 ft
Bankfull Width Estimate (ft)	8 - 17	7 - 11	not available

- Not surprisingly, AOP Design results in larger openings than “hydraulically efficient” design.
- Some culverts larger, some smaller, compared to alternative methods, e.g. stream simulation.

Summary

- HEC 26 provides a documented reproducible procedure based on sound analytical tools for designing culverts for AOP.
- All AOP design methods use a proxy for aquatic organism behavior. For HEC 26 the proxy is bed stability with checks for velocity and depth. For stream simulation the proxy is bank full width.
- Where other methods are adopted by agreement for AOP, those methods should be used. HEC 26 provides a tool set where one is needed or can be used as a check.

CONSTRUCTION VIBRATION MONITORING

2010 ANNUAL

CASFM CONFERENCE

SEPTEMBER 23, 2010

PRESENTED BY:

SOUTHEAST METRO STORMWATER AUTHORITY

URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

RECENT PROJECTS

- –CONSTRUCTION COMPONENTS AND METHODS
- –UNFORESEEN COSTS TO ADDRESS VIBRATION CONCERNS
- –VIBRATION MONITORING RESULTS
- –LESSONS LEARNED

FUTURE PROJECT CONSIDERATIONS

- –BUDGET CONSIDERATION
- –DESIGN CONSIDERATIONS
- –CONSTRUCTION CONSIDERATIONS

CONCLUSION

LITTLE DRY CREEK

LITTLE DRY CREEK

BEFORE

AFTER

LITTLE DRY CREEK

CONSTRUCTION COMPONENTS

- –DEMOLITION
- –DELIVERY OF MATERIALS
- –PAVING OPERATIONS
- –CUTOFF WALL
- –CAISSON DRILLING

CONSTRUCTION METHODS

- –CUTOFF WALL (SHEET PILE VS. CONCRETE)

PINEY CREEK

SHEET PILE DROP STRUCTURE

BRIDGE ABUTMENTS

SHEET PILE DROP STRUCTURE

PINEY CREEK

BEFORE

AFTER

PINEY CREEK

CONSTRUCTION COMPONENTS

- –DELIVERY OF MATERIALS – BOULDERS
- –SHEET PILE DRIVING FOR DROP STRUCTURES
- –H-PILE DRIVING FOR BRIDGE ABUTMENTS
- –PAVING

CONSTRUCTION METHODS

- –NO ALTERNATIVES

UNFORESEEN COSTS
TO ADDRESS VIBRATION CONCERNS
LITTLE DRY CREEK

RESIDENTIAL STRUCTURAL INSPECTION AND ANALYSIS OF DAMAGE CLAIMED

COST = $1,840.70

VIBRATION MONITORING

COST = $2,516.67

TOTAL COSTS = $4,357.37

UNFORESEEN COSTS
TO ADDRESS VIBRATION CONCERNS
PINEY CREEK

RESIDENTIAL STRUCTURAL INSPECTION
    COST = $3,638.80 X 2 (PRE & POST)
RESIDENTIAL WELL INSPECTIONS
    COST = $5,500.00 X 2 (PRE & POST)
RESIDENTIAL SEPTIC INSPECTIONS
    COST = $540.00 X 2 (PRE & POST)
VIBRATION MONITORING
    COST = $4,000.00
CONSTRUCTION DELAY COSTS
    COST = $13,500.00

TOTAL COSTS = $36,857.60

VIBRATION MONITORING RESULTS

LITTLE DRY CREEK

VIBRATION FROM SHOVEL FALLING (.445 in/sec)

HIGHEST READING (.805 in/sec) FROM TECH STEPPING NEXT TO MONITORING UNIT

MAX READING (.750 in/sec) THRESHOLD THAT COULD CAUSE DRY WALL CRACKING

DAMAGE OBSERVED IN HOME WAS INCONCLUSIVE

VIBRATION MONITORING RESULTS

PINEY CREEK

HIGHEST READING (.660 in/sec) 18-INCHES FROM H-PILE DRIVING WITH COMBUSTION HAMMER

MAX READING (.750 in/sec) THAT COULD CAUSE CRACKING OF DRY WALL

LESSONS LEARNED

BE PROACTIVE VS. REACTIVE

CONSIDER INVESTIGATION THAT CAN BE DONE AT GEOTECHNICAL ENGINEERING LEVEL

VIBRATION MONITORING IS CHEAPEST INSURANCE

IDENTIFY ANY PRE-EXISTING STRUCTURAL OR FOUNDATION ISSUES

IDENTIFY RURAL UTILITIES AND ISSUES

FUTURE PROJECT CONSIDERATIONS

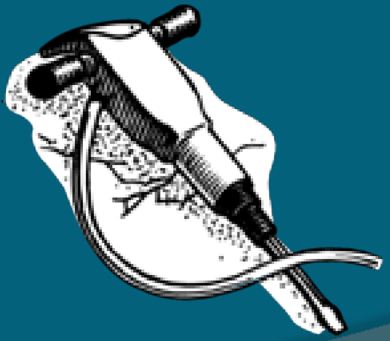
BUDGET CONSIDERATIONS

DESIGN

- GEOPHYSICIST INCLUDED WITH SCOPE OF GEOTECHNICAL INVESTIGATION
- EVALUATION OF CONSTRUCTION COMPONENTS AND METHODS

CONSTRUCTION

- MONITORING
- INSPECTIONS



FUTURE PROJECT CONSIDERATIONS

DESIGN CONSIDERATIONS

- CONDITIONS THAT VIBRATION EVALUATION IS NEEDED
- GEOTECHNICAL SCOPING AND INVOLVEMENT
  - GEOPHYSICIST TO DETERMINE INFLUENCE LIMITS
- TYPE OF PROJECT COMPONENTS AND CONSTRUCTION METHODS
- CONTINUOUS ON-SITE MONITORING FOR HIGH RISK ACTIVITIES
- SCHEDULE/TIME OF WORK

FUTURE PROJECT CONSIDERATIONS

CONSTRUCTION CONSIDERATIONS

INSPECTIONS PRE AND POST CONSTRUCTION

- STRUCTURAL, WELL, SEPTIC
  - NEW CRACKS VS. OLD
  - IMPACTS TO WELL FROM TESTING

VIBRATION MONITORING DURING CONSTRUCTION

- MONITORING READINGS
- TECH EVALUATES READINGS CLOSE TO THRESHOLDS

FUTURE PROJECT CONSIDERATIONS

CONSTRUCTION CONSIDERATIONS

SOMETHING NOT ANTICIPATED (#$&%!)

- DUE TO PROPERTY OWNER COMPLAINT
- CHANGE IN CONSTRUCTION METHOD

SCHEDULE IMPACT TO PROJECT

- POTENTIAL CLAIMS FROM CONTRACTOR
- LIMITING CERTAIN TYPES OF WORK OUTSIDE NORMAL WORKING HOURS
- DELAYS FOR UNKNOWN UTILITIES
- HOMEOWNER FRUSTRATIONS AND COMPLAINTS
  - START FINDING PROBLEMS

CONCLUSION

PLAN ON SPENDING A LOT OF MONEY TO SHOW PEOPLE THAT THERE IS NO DAMAGE

MONITORING AND INSPECTIONS ARE INSURANCE TO AVOID PROPERTY OWNER CLAIMS

BETTER TO BE PROACTIVE VS. REACTIVE TO SAVE POTENTIAL DELAY COSTS AND CLAIMS

THIS PRESENTATION IS A ROUGH OUTLINE OF GUIDELINES THAT WE ARE WORKING ON WITH A CONSULTANT IN ORDER TO REFINE AND USE FOR FUTURE PROJECTS

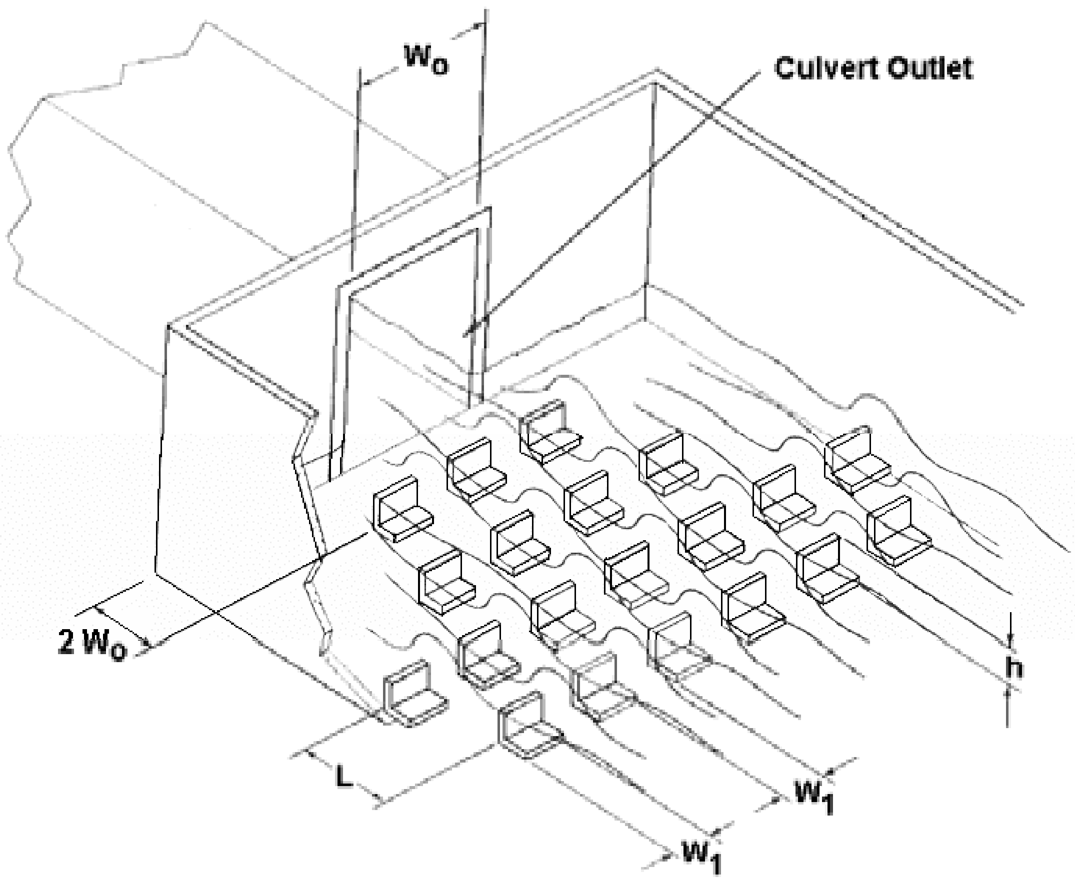
QUESTIONS

Using the HEC-14 CSU Rigid Boundary Basin Method with Grouted Boulders for Storm Sewer Outfalls

Getting Aesthetically Softer Results from hard protection

1. Background – HEC-14 CSU Rigid Boundary Basin
2. Rigid Outfalls in Natural or Park Areas
3. Overview of Method with Boulders
4. Construction and End Results
5. Conclusion

CSU Rigid Boundary Basin



CSU Rigid Boundary Basin

- Uses staggered rows of rectangular roughness elements in a concrete apron to initiate a hydraulic jump.
- Basic relationships for roughness element geometry and the size/shape of the element array are given.

PARSONS BRINCKERHOFF

Rock Structures

Prepared by:	Eugene Vodarsky	Checked By:	C. Haggerty
Project Name:	Hampden Heights Outfall	Date:	2/19/2009
Location:	Denver, CO	Task No:	31597A

HEC-14 - CSU Rigid Boundary Basin Calculation

Sizing of Energy Dissipator

Given:

Culvert =	3	height (ft) RCB
W_o =	8	width (ft)
L =	53	length (ft)
S =	0.003	slope (ft/ft)
Q =	360	discharge (ft^3/s)
n =	0.013	roughness coefficient
y_c =	2.31	critical depth (ft) [Value acquired from FlowMaster]
y_n =	3	normal depth (ft) [Full Pipe]

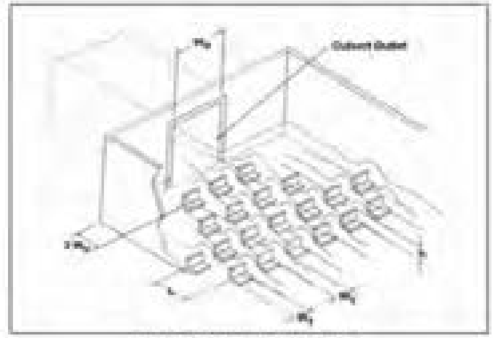


Figure 9.1. CSU Rigid Boundary Basin

Downstream natural channel:

W =	36	channel width (ft)	
TW =	3.08	tailwater depth (ft)	[Value acquired from FlowMaster] Tailwater Depth actualy 2.09 ft plus 1 ft freeboard

Solution

Step 1

Compute the velocity, V_o, depth, y_o, and Froude number, Fr, at the culvert outlet

$y_o = y_n$ =	3	outlet depth (ft) [Value acquired from FlowMaster]
$V_o = V_n$ =	15	culvert outlet velocity (f (velocity at normal depth) [Value acquired from FlowMaster]
Fr =	1.526	froude number = $V_o/(y_o g)^{1/2}$

Step 2

Select a trial basin from table 9.1 based on the W_B/W_o expansion ratio best suited for site geometry constraints:

Choose W_B/W_o, number of rows, Nr, number of elements, N, and ratios h/y_A and L/h

channel/culvert widths = 4.50

Try the following rectangular basin [Table 9.1]

W_B/W_o =	4.5	basin width to culvert width ratio	
W_1/W_o =	0.5	element width to culvert width ratio	
N_r =	3	rows	
N =	12	elements	
h/y_A =	1	element height to approach flow average depth ratio	h=2'
L/h =	3	element length spacing to element height ratio	spacing=6'

PARSONS BRINCKERHOFF

Rock Structures

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HEC-14 - CSU Rigid Boundary Basin Calculation

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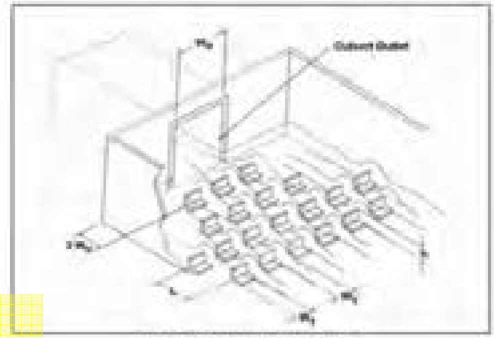

Figure 9.1. CSU Rigid Boundary Basin

Given:

Culvert =	3	height (ft) RCB
W_o =	8	width (ft)
L =	53	length (ft)
S =	0.003	slope (ft/ft)
Q =	360	discharge (ft^3/s)
n =	0.013	roughness coefficient
y_c =	2.31	critical depth (ft) [Value acquired from FlowMaster]
y_n=	3	normal depth (ft) [Full Pipe]

Downstream natural channel:

W =	36	channel width (ft)	
TW =	3.09	tailwater depth (ft)	[Value acquired from FlowMaster]
			Tailwater Depth actualy 2.09 ft plus 1 ft freeboard

<u>Solution</u>

Step 1: *Compute the velocity, V_o, depth, y_o, and Froude number, Fr, at the culvert outlet.*

$y_o = y_n$ =	3	outlet depth (ft) [Value acquired from FlowMaster]
$V_o = V_n$ =	15	culvert outlet velocity (f (velocity at normal depth) [Value acquired from FlowMaster]
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Step 2: *Select a trial basin from table 9.1 based on the W_B/W_o expansion ratio best suited for site geometry constraints.*
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HEC-14 - CSU Rigid Boundary Basin Calculation

Sizing of Energy Dissipator

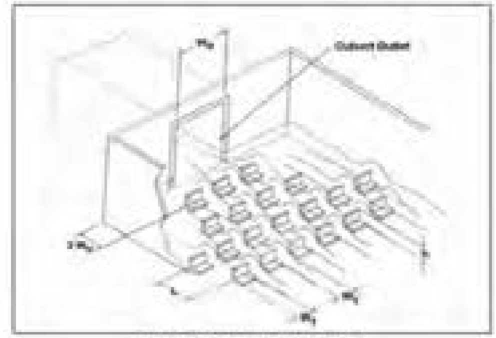

Figure 9.1. CSU Rigid Boundary Basin

Given:

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L =	53	length (ft)
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Q =	360	discharge (ft³/s)
n =	0.013	roughness coefficient
y_c =	2.31	critical depth (ft) [Value acquired from FlowMaster]
y_n =	3	normal depth (ft) [Full Pipe]

Downstream natural channel:

W =	36	channel width (ft)
TW =	3.09	tailwater depth (ft) [Value acquired from FlowMaster] Tailwater Depth actualy 2.09 ft plus 1 ft freeboard

Solution

Step 1: *Compute the velocity, V_o, depth, y_o, and Froude number, Fr, at the culvert outlet.*

$y_o = y_n$ =	3	outlet depth (ft) [Value acquired from FlowMaster]
$V_o = V_n$ =	15	culvert outlet velocity (f (velocity at normal depth) [Value acquired from FlowMaster]
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Step 2: *Select a trial basin from table 9.1 based on the W_B/W_o expansion ratio best suited for site geometry constraints. Choose W_B/W_o, number of rows, Nr, number of elements, N, and ratios h/y_A and L/h.*

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PARSONS BRINCKERHOFF

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HEC-14 - CSU Rigid Boundary Basin Calculation

Sizing of Energy Dissipator

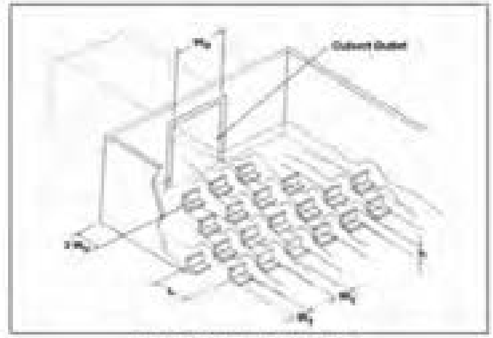

Figure 9.1. CSU Rigid Boundary Basin

Given:

Culvert =	3	height (ft) RCB
W_o =	8	width (ft)
L =	53	length (ft)
S =	0.003	slope (ft/ft)
Q =	360	discharge (ft^3/s)
n =	0.013	roughness coefficient
y_c =	2.31	critical depth (ft) [Value acquired from FlowMaster]
y_n=	3	normal depth (ft) [Full Pipe]

Downstream natural channel:

W =	36	channel width (ft)
TW =	3.09	tailwater depth (ft) [Value acquired from FlowMaster] Tailwater Depth actualy 2.09 ft plus 1 ft freeboard

Solution

Step 1. *Compute the velocity, V_o, depth, y_o, and Froude number, Fr, at the culvert outlet*

$y_o = y_n$ =	3	outlet depth (ft) [Value acquired from FlowMaster]
$V_o = V_n$ =	15	culvert outlet velocity (if (velocity at normal depth) [Value acquired from FlowMaster]
Fr =	1.526	froude number = $V_o/(y_o g)^{1/2}$

Step 2. *Select a trial basin from table 9.1 based on the W_B/W_o expansion ratio best suited for site geometry constraints. Choose W_B/W_o, number of rows, Nr, number of elements, N, and ratios h/y_A and L/h.*

channel/culvert widths = 4.50

Try the following rectangular basin [Table 9.1]

W_B/W_o =	4.5	basin width to culvert width ratio	
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N_r =	3	rows	
N =	12	elements	
h/y_A =	1	element height to approach flow average depth ratio	h=2'
L/h =	3	element length spacing to element height ratio	spacing=6'

- Empirically developed Drag Coefficients, array

Table 9.1. Design Values for Roughness Elements

W_B/W_o			2 to 4			5			6			7		8
W_1/W_o			0.57			0.63			0.6			0.58		0.62
Rows (N_r)			4	5	6	4	5	6	4	5	6	5	6	6
Elements (N)			14	17	21	15	19	23	17	22	27	24	30	30
	h/y_A	**L/h**	**Basin Drag Coefficient, C_B**											
RECTANGULAR	0.91	6	0.32	0.28	0.24	0.32	0.28	0.24	0.31	0.27	0.23	0.26	0.22	0.22
RECTANGULAR	0.71	6	0.44	0.40	0.37	0.42	0.38	0.35	0.40	0.36	0.33	0.34	0.31	0.29
RECTANGULAR	0.48	12	0.60	0.55	0.51	0.56	0.51	0.47	0.53	0.48	0.43	0.46	0.39	0.35
RECTANGULAR	0.37	12	0.68	0.66	0.65	0.65	0.62	0.60	0.62	0.58	0.55	0.54	0.50	0.45
CIRCULAR	0.91	6	0.21	0.20	0.48	0.21	0.19	0.17	0.21	0.19	0.17	0.18	0.16	
CIRCULAR	0.71	6	0.29	0.27	0.40	0.27	0.25	0.23	0.25	0.23	0.22	0.22	0.20	
CIRCULAR	0.31	6	0.38	0.36	0.34	0.36	0.34	0.32	0.34	0.32	0.30	0.30	0.28	
CIRCULAR	0.48	12	0.45	0.42	0.25	0.40	0.38	0.36	0.36	0.34	0.32	0.30	0.28	
CIRCULAR	0.37	12	0.52	0.50	0.18	0.48	0.46	0.44	0.44	0.42	0.40	0.38	0.36	

Layout Configurations

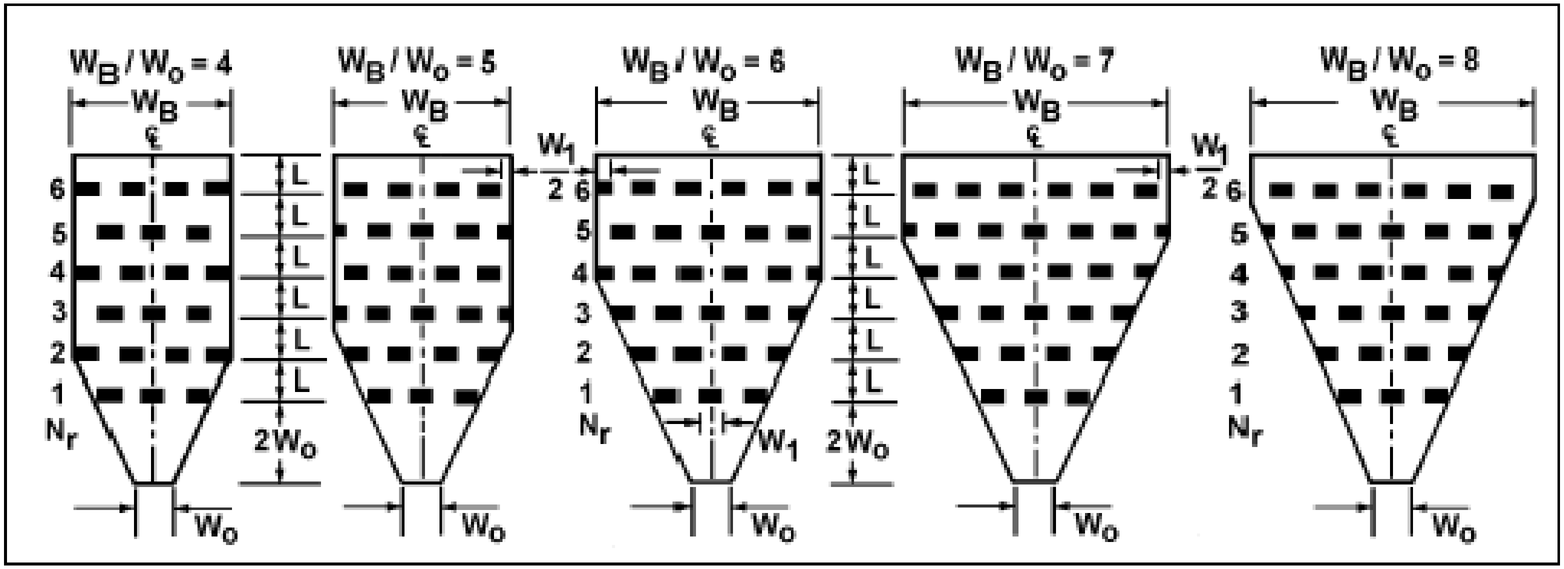

Figure 9.3. Roughness Configurations Tested

Step 3. *Determine flow condition V_A and y_A at the approach to the roughness element field (two culvert widths downstream).*

$2(W_o)$ =	16	two culvert widths (ft) [distance from end of culvert to first row of elements]	
Transit exit flow conditions			
V_A/V_o =	1.192	Equation 4.1 (for boxes)	$= 1.65 - 0.3Fr$
V_A/V_o =	-0.181	Equation 4.2 (for circular pipes)	$= 1.65 - 0.45\ Q/\sqrt{gD^5}$
V_A =	17.88	velocity at culvert outlet (ft/s) [If circular pipe is being utilized PLEASE revise formula for V_A to account for this change]	

For $4 < W_B/W_o < 8$, read y_A from Figure 4.3 (Rectangular) or 4.4 (Circular).

Fr =	1.526	
L =	1.0*B	
y_A/y_o =	0.23	obtain from Figure 4.3 [average depth for abrupt expansion below rectangular culvert outlet]
y_A =	0.69	approach flow average depth (ft)

Step 4. *For the trial roughness height to depth ratio h/y_A and length to height ratio determine dissipator parameters from Table 9.1.*

a. $h = (h/y_A)y_A$ =	0.7	roughness element height (ft)	
b. $L = (L/h)h$ =	2.1	spacing between rows of elements (ft)	
c. $W_B = (W_B/W_o)W_o$ =	36	width of basin (ft)	
d. $W_1 = (W_1/W_o)W_o$ =	4	element width (ft)	4 (ft) - rounded value
e. $u_E = 4/7 + 10L/(7W_o)$ =	0.94	divergence	1 rounded value
f. C_D =	0.4	basin drag coefficient [from Table 9.1]	
g. $A_F = W_1\ h$ =	2.76	roughness element frontal area (ft^2)	
h. C_p =	0.7	from Figure 9.4 [energy and momentum coefficients for rectangular culverts]	
i. $L_B = 2W_o + LN_r$ =	22.2	Total basin length (ft)	

Step 5. *Use the normal flow conditions and solve Equ. 9.1 for $C_D A_F N$ and compare to $C_D A_F N$ for basin.*
Calculated $C_D A_F N$ for basin parameters for basin resistance.

Calculate $C_D A_F N$ from Equation 9.1

Since W_B =	36	(ft) compare the downstream channel width	36 (ft) to trial basin using option 1.
y_n =	3.09	Downstream (ft) [TW]	
$V_B = Q/(W_B y_n)$ =	3.2	Velocity of the basin (ft/s)	

Equation 9.1 = $\rho V_o Q + C_p \gamma y_o^2 W_o/2 = C_D A_F N \rho V_A^2/2 + \rho V_B Q + \gamma Q^2/(2V_B^2 W_B)$

Terms with V_o and y_o:	12048.5	$= \rho V_o Q + C_p \gamma y_o^2 W_o/2$	ρ = density of water = 1.94 slugs/ft^3
Terms with V_B:	12984.6	$= \rho V_B Q + \gamma Q^2/(2V_B^2 W_B)$	γ = unit weight of water = 62.4 lbs/ft^3
Terms with $C_D A_F N$ is $C_D A_F N$:	310.2	$= (\rho V_A^2/2)$	
$C_D A_F N$ =	-3.0		

Calculate $C_D A_F N$ for basin based on parameters determined in steps 2 and 4 ((N_r="X", C_D="X", A_F="X" ft^2)).

Using these values: $C_D A_F N$ = 13.25

Basin resistance test: **Basin Sufficient** -- If "Revise Basin" is required revise the values located within Step 2.
-- If "Basin Sufficient, Resistance of Dissipator Greater than Forces on it.

Step 6. *Verify element width to roughness element height is between the target range of 2 to 8.*

W_1/h = 5.80

Values obtained from HEC-14

Step 3. *Determine flow condition V_A and y_A at the approach to the roughness element field (two culvert widths downstream).*

$2(W_o)$ =	16	two culvert widths (ft) [distance from end of culvert to first row of elements]

Transit exit flow conditions

V_A/Vo =	1.192	Equation 4.1 (for boxes)	$= 1.65 - 0.3Fr$
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Step 4. *For the trial roughness height to depth ratio h/y_A and length to height ratio determine dissipator parameters from Table 9.1.*

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Equation 9.1 = $\rho V_o Q + C_p \gamma y_o^2 W_o/2 = C_D A_F N \rho V_A^2/2 + \rho V_B Q + \gamma Q^2/(2V_B^2 W_B)$

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Terms with $C_D A_F N$ is $C_D A_F N$:	310.2	$= (\rho V_A^2/2)$	
$C_D A_F N$ =	-3.0		

Calculate $C_D A_F N$ for basin based on parameters determined in steps 2 and 4 ((N_r="X", C_D="X", A_F="X" ft^2)).

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W_1/h = 5.80

Values obtained from HEC-14

Rigid Outfalls in Natural or Park Areas

- Not always popular with parks departments or park users.
- Tend to collect and display trash and debris form the storm sewer system.
- Visual impact can extend beyond the immediate area for large outfalls.

Modified CSU Grouted Boulder Outfall Construction Methods

Construction Techniques

- Layout edges first
- Place “Teeth” and Floor
- Add Soil Riprap

Layout of Edges

Laying out the “Teeth”

Spacing of Boulders is Important

Detailed Spacing

Filling the Floor

Grouting the Boulders

Utilize a pencil vibrator

Brush finish is sufficient

Brush and Clean

Finished Boulders, but…..

Soil Riprap can be used to fill voids

Don’t forget plantings!

The finished products

Thank you!

21st Annual CASFM Conference

September 21-24, 2010

Snowmass Conference Center

Scour Critical Bridges in Colorado
Colorado Department of Transportation

Stuart Gardner, PE – CDOT
Rick Moser, PE – Moser & Associates

What is Bridge Scour?

What Put Bridge Scour on the Radar?

What is CDOT Doing Now?

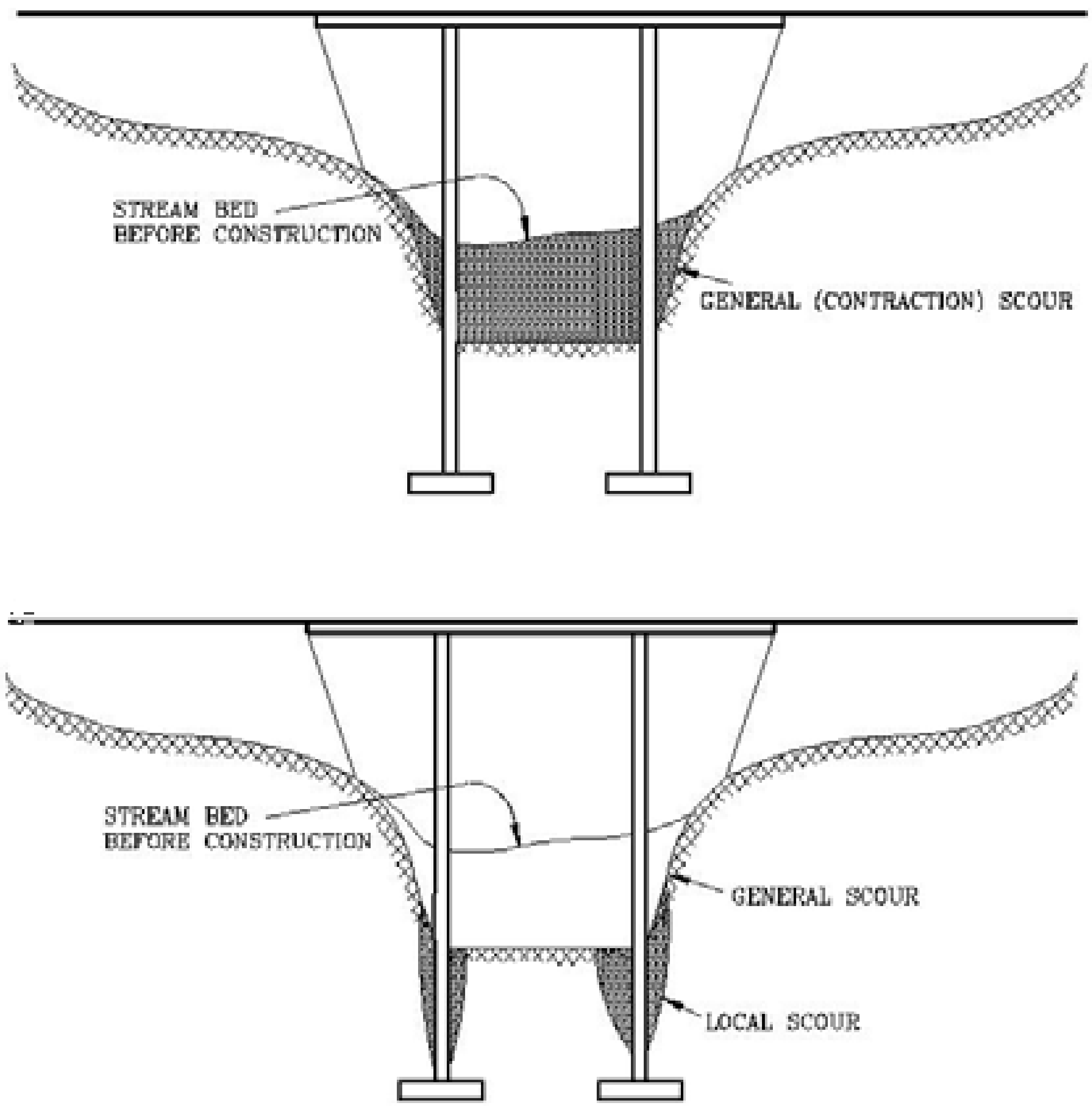
What is Bridge Scour?

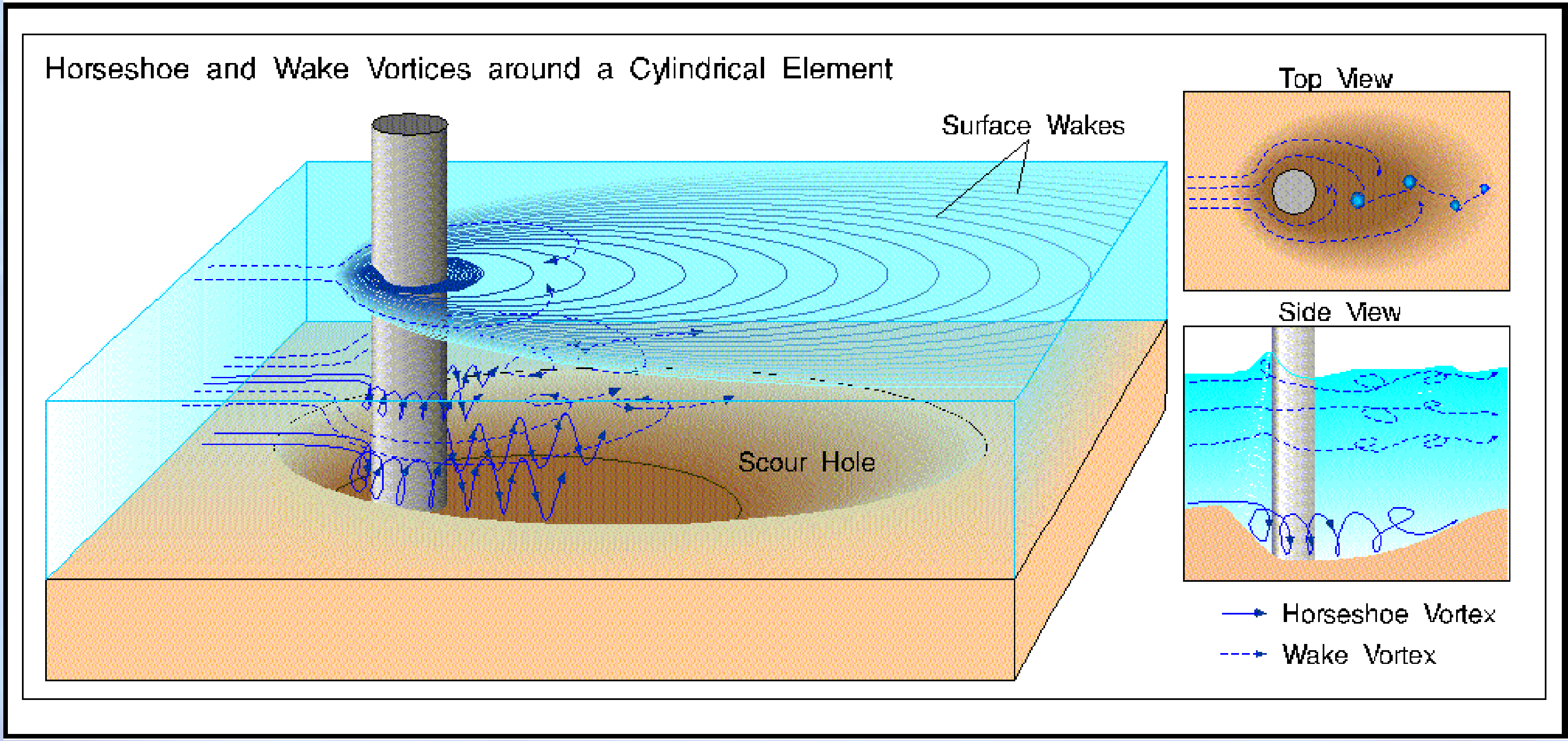
Scour is the phenomena of moving water removing bed material from around and underneath a structure.

Fast, Clean Water is “Hungry” Water.

Three Basic Types of Scour

- Contraction Scour
- Abutment Scour
- Pier Scour


STREAM BED
BEFORE CONSTRUCTION
GENERAL (CONTRACTION) SCOUR
STREAM BED
BEFORE CONSTRUCTION
GENERAL SCOUR
LOCAL SCOUR



Horseshoe and Wake Vortices around a Cylindrical Element
Surface Wakes
Scour Hole
Top View
Side View
Horseshoe Vortex
Wake Vortex

CASFM

What is Bridge Scour?

What Put Bridge Scour on the Radar?

What Put Bridge Scour on the Radar?

In 1987, the 30 year old Schoharie River Bridge at Fort Hunter New York collapsed due to Pier Scour, resulting in ten deaths.

Subsequent to this disaster, the Federal Highway Administration ordered all State DOT’s to analyze their bridge inventories with regard to scour. All bridges considered to be susceptible to failure during a 500 year runoff event or below were classified as "scour critical". The State of Colorado completed its inventory in 1992. Over 250 bridges were listed as scour critical.

State DOT's are not the only agencies with Bridge Inventories.

CDOT inspects "Off-Systems" bridges using consultants, but only inspects the physical condition of the structures. A scour inventory or study is not included.

N Bridge not over waterway.
U Bridge with unknown foundation
T Bridge over tidal waters
9 Bridge foundations on dry land well above flood water elevations.
8, 5 Bridge foundations stable for the assessed or calculated scour condition.
7 Countermeasures have been installed to mitigate scour and to reduce the risk of bridge failure during a flood event.
6 Scour calculation/evaluation has not been made.
4 Bridge foundations stable for the assessed or calculated scour condition. Field review indicates action is required to protect exposed foundations
3 Bridge is scour critical; bridge foundations determined to be unstable for assessed or calculated scour conditions.
2 Bridge is scour critical; field review indicates that extensive scour has occurred at bridge foundations, which are determined to be unstable
1 Bridge is scour critical; field review indicates that failure of piers/abutments is imminent. Bridge is closed to traffic. Failure is imminent
0 Bridge is scour critical. Bridge has failed and is closed to traffic.

Item 113 Code 9 - Bridge foundations on dry land well above flood water elevations.

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2009 Inventory

Item 113	Number of Bridges (3,429 total)
0	-
1	-
2	-
3	176
4	3
5	576
6	-
7	16
8	1,519
9	20
N	1,076
U	30

What is Bridge Scour?

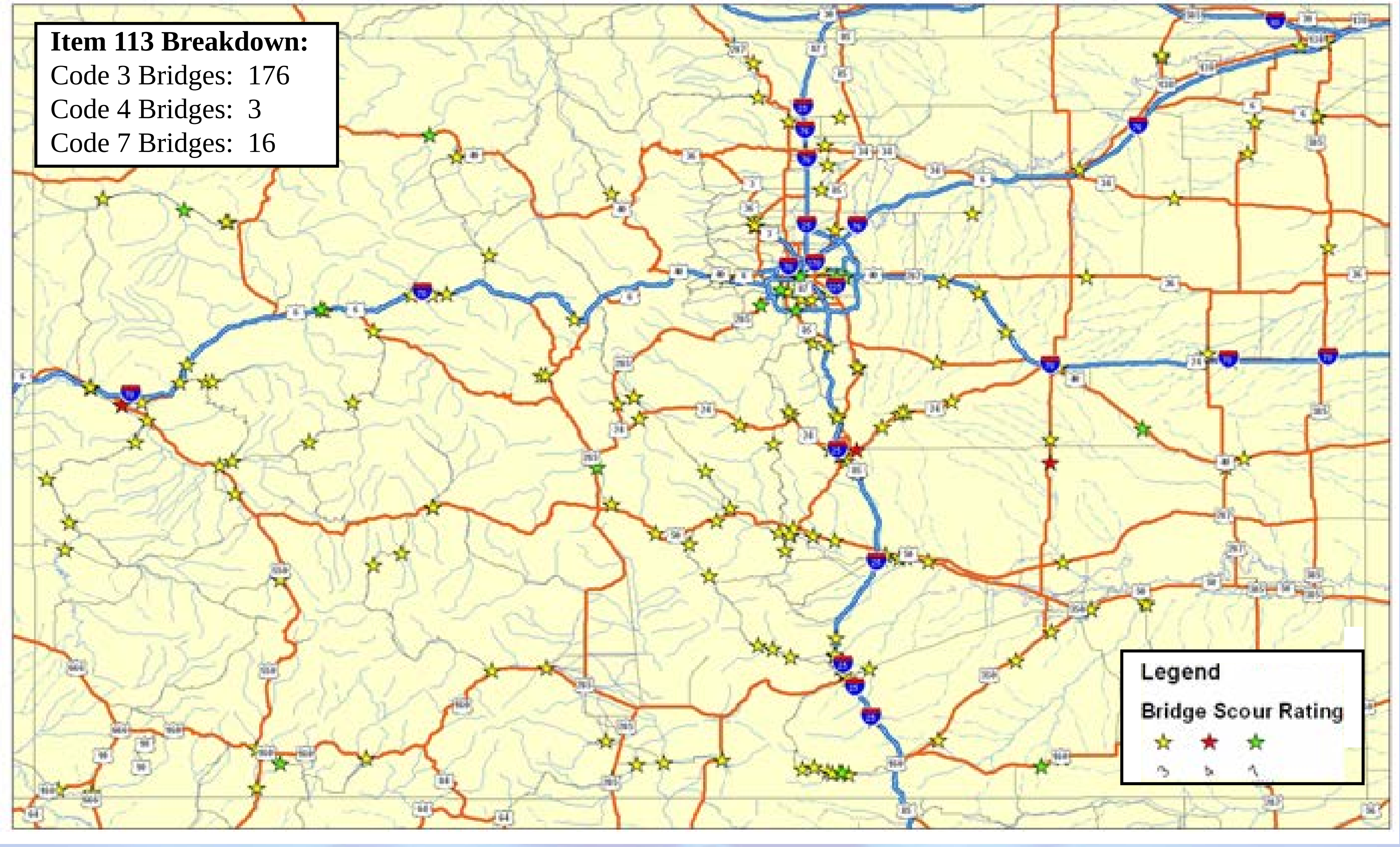
What Put Bridge Scour on the Radar?

What is CDOT Doing Now?

Since 1992, there has not been a systematic effort to remove bridges from the Scour Critical list.

In 2010, a contract was awarded to Moser and Associates to re-assess CDOT bridges statewide and develop a Plan of Action (POA) for each structure.

Scour Critical Bridges



CDOT Bridge Scour POA Program

Selection of Bridges for FY 2011 POAs

- Scour Critical Bridge Weighting
  - Criteria initially considered:
    - Route classification
    - AADT
    - Detour length should the structure be closed
    - Age of structure
    - Condition of structure
    - Waterway adequacy
    - Schedule for replacing the bridge

CDOT Bridge Scour POA Program

Selection of Bridges for FY 2011 POAs

POA Prioritization Methodology					
Category	**Weight**	**Weighting Breakdown**			
Code 113	25	3 = 25	4 = 15	7 = 0	
Condition	25	Poor = 25	Fair= 15	Good= 0	
ADT	50	>10000 = 50	5000-10000 = 35	1500-5000 = 20	<1500 = 0
Total	**100**				

CDOT Bridge Scour POA Program

Selection of Bridges for FY 2011 POAs

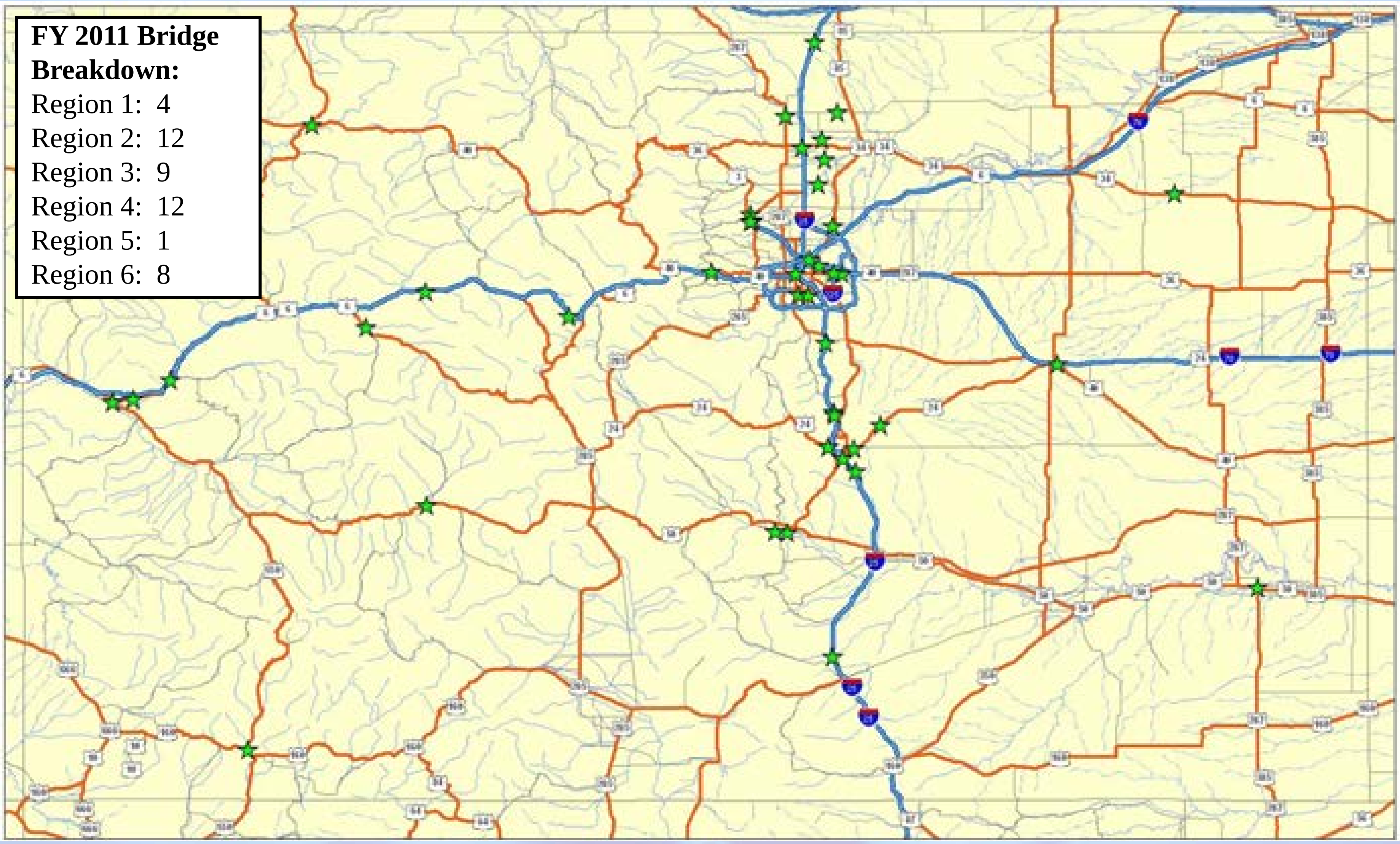
Condition (25)	ADT (50)	Total Score (out of 100)
25	50	100
25	50	100
25	50	100
25	50	100
15	50	90
15	50	90
15	50	90
15	50	90
15	50	90
15	50	90

Region	Bridge Enterprise	County	Structure Number	Facility Carried	Feature Intersected	Basic Classification	Structure Type	Basic Type	Condition	Deck Area	ADT	Detour Length	Year Built	Year Reconstructed	Item 113 Scour Critical Bridges	Code113 (25)	Condition (25)	ADT (50)	Total Score (out of 100)
6	No	ADAMS	E-17-AR	SH 7 ML	SOUTH PLATTE RIVER	Non-Interstate	Concrete Prestressed Girder	Bridge	Poor	10,033	14,200	2	1965	-4	3	25	25	50	100
6	No	DENVER	F-16-BM	SH 88 ML	RR, LAKEWOOD GULCH	Non-Interstate	Concrete Arch	Bridge	Poor	7,986	37,700	3	1922	1960	3	25	25	50	100
2	No	EL PASO	I-18-G	US 24 ML	DRAW	Non-Interstate	Treated Timber Stringer w/Timber Deck	Bridge	Poor	735	12,400	1	1932	-4	3	25	25	50	100
5	No	LA PLATA	O-05-AQ	US 160 ML	ANIMAS RIVER	Non-Interstate	Welded Girder Continuous and Composite	Bridge	Poor	25,024	40,400	1	1974	1983	3	25	25	50	100
4	No	BOULDER	D-15-AQ	SH 7 ML WBND	BOULDER CREEK	Non-Interstate	Concrete on I beam	Bridge	Fair	5,387	15,500	1	1938	-4	3	25	15	50	90
4	No	BOULDER	D-15-B	US 36 ML	FOUR MILE CANYON CREEK	Non-Interstate	Concrete Slab and Girder	Bridge	Fair	3,162	17,200	1	1957	-4	3	25	15	50	90
6	No	DENVER	E-17-HD	SH 35 ML	SAND CREEK	Non-Interstate	Concrete Slab and Girder	Bridge	Fair	33,431	53,100	4	1962	1978	3	25	15	50	90
1	No	SUMMIT	F-12-AL	I 70 ML WBND	CORRAL CREEK	Interstate	Steel Box Girder Continuous	Bridge	Fair	16,003	19,600	1	1979	-4	3	25	15	50	90
1	No	DOUGLAS	C-17-S	PLUM CREEK PARKWAY	EAST PLUM CREEK AR	Interstate	Concrete Slab and Girder	Bridge	Fair	5,300	65,500	1	1964	1966	3	25	15	50	90
2	No	EL PASO	I-17-EG	US 24 ML WBND	FOUNTAIN CREEK	Non-Interstate	Concrete Slab and Girder	Bridge	Fair	2,490	19,700	1	1964	-4	3	[illegible]	15	[illegible]	90
2	No	EL PASO	I-17-EQ	US 24 ML EBND	FOUNTAIN CREEK	Non-Interstate	Concrete Slab and Girder	Bridge	Fair	2,485	19,700	1	1964	-4	3	25	15	50	90
2	No	EL PASO	J-18-B	US 85 ML	DRAW	Non-Interstate	Concrete on I beam	Bridge	Fair	734	12,700	3	1930	-4	3	25	15	50	90
4	No	WELD	D-17-AK	SH 66 ML	ST VRAIN River	Non-Interstate	Concrete Slab and Girder	Bridge	Poor	5,845	7,000	6	1956	-4	3	25	25	35	85
2	No	EL PASO	I-18-BG	W FRONTAGE ROAD	SAND CREEK	Non-Interstate	Concrete Box Culvert	Culvert	Fair	4,319	37,800	1	1995	-4	4	15	15	50	80
4	No	LARIMER	B-16-H	US 287 ML	SPRING CREEK	Non-Interstate	Concrete on I beam	Bridge	Good	3,496	41,700	1	1948	1959	3	25	0	50	75
4	No	WELD	B-17-L	SH 14 ML	COALBANK CREEK	Non-Interstate	Treated Timber Stringer w/Metal Plank Deck	Bridge	Fair	3,487	6,100	2	1935	1999	3	25	15	35	75
4	No	LARIMER	C-17-BL	I 25 ML SBND	BIG THOMPSON RIVER	Interstate	Concrete Slab and Girder Continuous	Bridge	Good	6,923	33,600	1	1962	-4	3	25	0	50	75
4	No	WELD	C-17-C	SH 60 ML	LITTLE THOMPSON RIVER	Non-Interstate	Concrete Slab and Girder	Bridge	Fair	3,196	7,200	1	1958	-4	3	25	15	35	75
4	No	WELD	C-17-CZ	SH 257 ML	DRAW	Non-Interstate	Concrete Slab and Girder	Bridge	Fair	2,380	8,700	5	1963	-4	3	25	15	35	75
4	No	BOULDER	D-15-AR	US 36 ML WBND	BOULDER CREEK	Non-Interstate	Concrete on I beam Continuous	Bridge	Good	3,279	21,700	1	1952	2005	3	25	0	50	75
4	No	BOULDER	D-15-AX	US 36 ML EBND	BOULDER CREEK	Non-Interstate	Concrete on I beam Continuous	Bridge	Good	3,781	21,700	1	1960	-4	3	25	0	50	75
6	No	ADAMS	E-17-IE	I 270 ML EBND	SOUTH PLATTE RIVER	Interstate	Concrete Prestressed Girder	Bridge	Good	12,517	45,550	1	1969	-4	3	25	0	50	75
3	No	EAGLE	F-09-L	US 6	GYPSUM CREEK	Non-Interstate	Concrete on I beam	Bridge	Fair	2,110	8,800	1	1933	-4	3	25	15	35	75
6	No	ARAPAHOE	F-16-B	US 85 ML	BIG DRY CREEK	Non-Interstate	Concrete on I beam Composite	Bridge	Good	6,210	72,200	3	1939	1978	3	25	0	50	75
6	No	ARAPAHOE	F-17-AA	SH 177 ML	LITTLE DRY CREEK	Non-Interstate	Concrete Slab and Girder	Bridge	Good	5,609	33,600	3	1965	-4	3	25	0	50	75
3	No	GARFIELD	G-07-B	SH 82 ML	CATTLE CREEK	Non-Interstate	Steel Arch Culvert/Multiplate Arch Culvert	Culvert	Good	1,820	24,200	3	1967	-4	3	25	0	50	75
3	No	MESA	H-02-S	SH 340 ML EBND	COLORADO RIVER	Non-Interstate	Riveted Girder Continuous	Bridge	Good	31,000	11,350	1	1950	-4	3	25	0	50	75
3	No	MESA	H-03-L	I 70 ML	PLATEAU CREEK	Interstate	Welded Girder Continuous and Composite	Bridge	Good	10,658	16,300	1	1965	1986	3	25	0	50	75
3	No	MESA	H-03-Z	I 70 BUSINESS RT	LEWIS WASH	Non-Interstate	Concrete Slab Continuous	Bridge	Good	6,791	20,600	13	1956	1974	3	25	0	50	75
2	No	EL PASO	H-17-AG	I 25 ML NBND	MONUMENT CREEK BRANCH	Interstate	Concrete Box Culvert	Culvert	Good	923	37,100	1	1953	-4	3	25	0	50	75
2	No	EL PASO	H-17-L	I 25 ML SBND	BLACK SQUIRREL CREEK	Interstate	Concrete on I beam Continuous	Bridge	Good	4,696	37,100	1	1954	1976	3	25	0	50	75
2	No	EL PASO	I-17-R	US 85 ML	FOUNTAIN CREEK	Non-Interstate	Welded Girder Continuous	Bridge	Good	11,461	10,700	3	1965	-4	3	25	0	50	75
3	No	GUNNISON	J-09-AB	US 50 ML	GUNNISON RIVER	Non-Interstate	Concrete on I beam Continuous	Bridge	Fair	5,202	7,100	1	1957	-4	3	25	15	35	75
2	No	FREMONT	K-16-V	SH 115 ML	ARKANSAS RIVER	Non-Interstate	Concrete on I beam Continuous and Composite	Bridge	Fair	6,799	5,100	4	1951	-4	3	25	15	35	75
2	No	FREMONT	K-16-Y	SH 115 ML	OAK CREEK	Non-Interstate	Concrete on I beam	Bridge	Fair	2,683	5,200	2	1936	-4	3	25	15	35	75
2	No	PROWERS	L-26-H	US 50 EBND	ARKANSAS RIVER	Non-Interstate	Concrete on I beam Composite	Bridge	Fair	18,225	5,300	1	1967	-4	3	25	15	35	75
2	No	HUERFANO	N-17-BN	I 25 ML SBND	CO RD 640, BUTTE CREEK	Interstate	Welded Girder Continuous	Bridge	Fair	6,596	5,850	1	1967	-4	3	25	15	35	75
1	No	CLEAR CREEK	F-15-D	I 70 FRONTAGE RD	CLEAR CREEK SR	Interstate	Concrete on I beam	Bridge	Poor	3,920	4,280	4	1936	-4	3	25	25	20	70
1	No	LINCOLN	G-22-J	US 24 ML	DRAW	Non-Interstate	Treated Timber Stringer w/Timber Deck	Bridge	Poor	2,131	2,000	1	1934	-4	3	25	25	20	70
6	No	ARAPAHOE	F-17-BS	US 40 ML WBND	SAND CREEK	Non-Interstate	Concrete on I beam Continuous	Bridge	Fair	10,649	10,650	1	1955	-4	7	0	15	50	65
3	No	MESA	H-02-GC	SH 340 ML WBND	COLORADO RIVER	Non-Interstate	Welded Girder Continuous and Composite	Bridge	Good	40,817	11,350	1	1974	-4	4	15	0	50	65
4	No	WELD	A-17-AD	I 25 ML SBND	LONE TREE CREEK	Interstate	Concrete Slab and Girder	Bridge	Good	5,229	8,800	1	1963	-4	3	25	0	35	60
3	No	MOFFAT	B-06-S	US 40 ML EBND	FORTIFICATION CREEK	Non-Interstate	Concrete Slab and Girder Continuous	Bridge	Good	7,111	5,600	1	1977	-4	3	25	0	35	60
4	No	WASHINGTON	D-24-B	US 34 ML	SURVEYOR CREEK	Non-Interstate	Concrete on I beam	Bridge	Fair	7,015	3,400	1	1935	-4	3	25	15	20	60
6	No	ADAMS	E-17-IZ	POTOMAC STREET	TOLLGATE CREEK AR	Interstate	Concrete Slab and Girder Continuous	Bridge	Good	7,626	5,990	3	1964	-4	3	25	0	35	60
3	No	EAGLE	F-09-AF	I 70 ML EBND	COTTONWOOD CREEK	Interstate	Concrete Prestressed Girder Continuous	Bridge	Good	17,960	9,900	1	1979	-4	3	25	0	35	60

46 Bridges for FY 2011

CDOT Bridge Scour POA Program

FY 2011 POAs



Scour Causes & Significance

Causes of Bridge Scour:

1. Flow larger than design/small structure size
2. Heavy debris
3. Change in stream alignment
4. Stream degradation
5. Failure of downstream grade control structure

Significance of Bridge Scour:

1. Predicted/observed scour depth above pier cap or spread footer, no significance
2. Scour depth into pier cap or spread footer, potential bridge stability issue
3. Scour depth below pier cap or spread footer, potential bridge collapse

Flow larger than the design flow

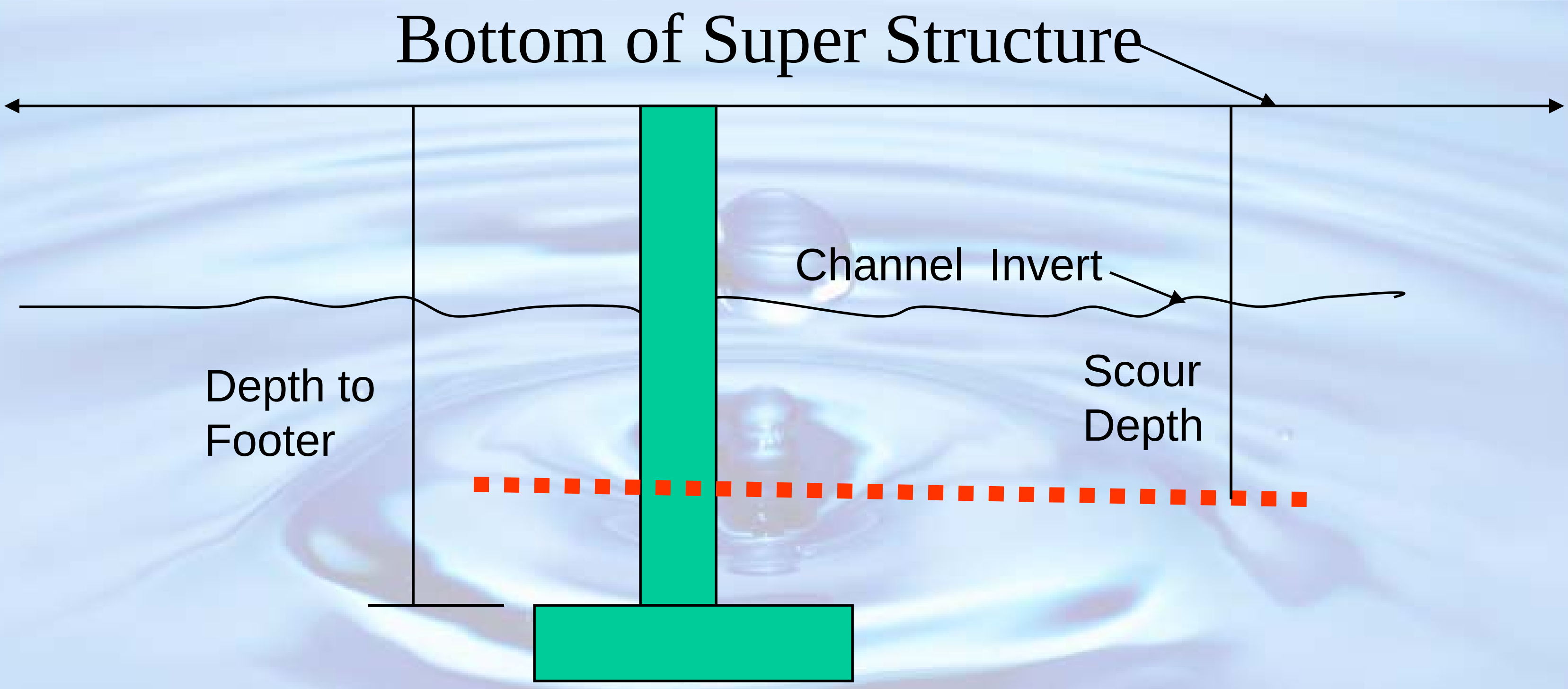
Heavy Debris

Change in Upstream Stream Alignment

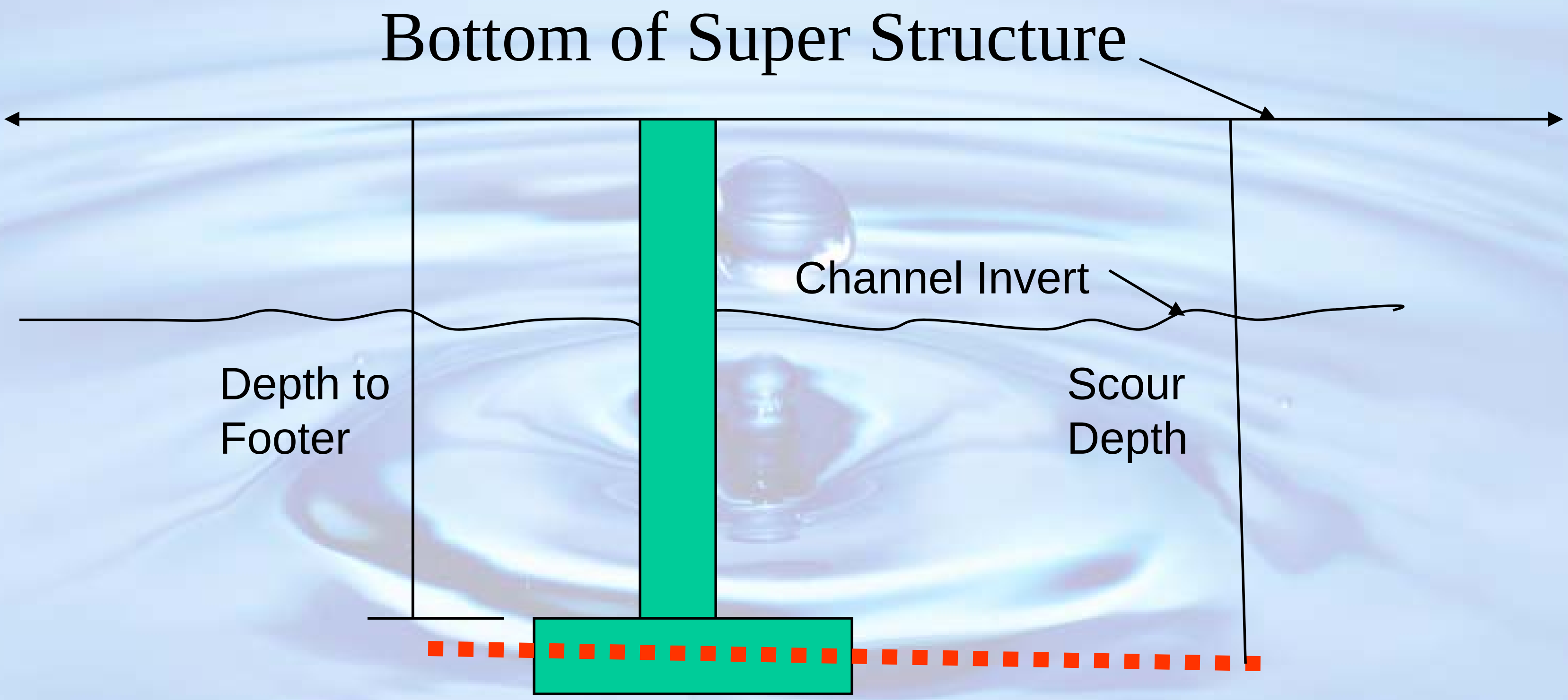
Stream degradation

Failure of downstream grade control structures

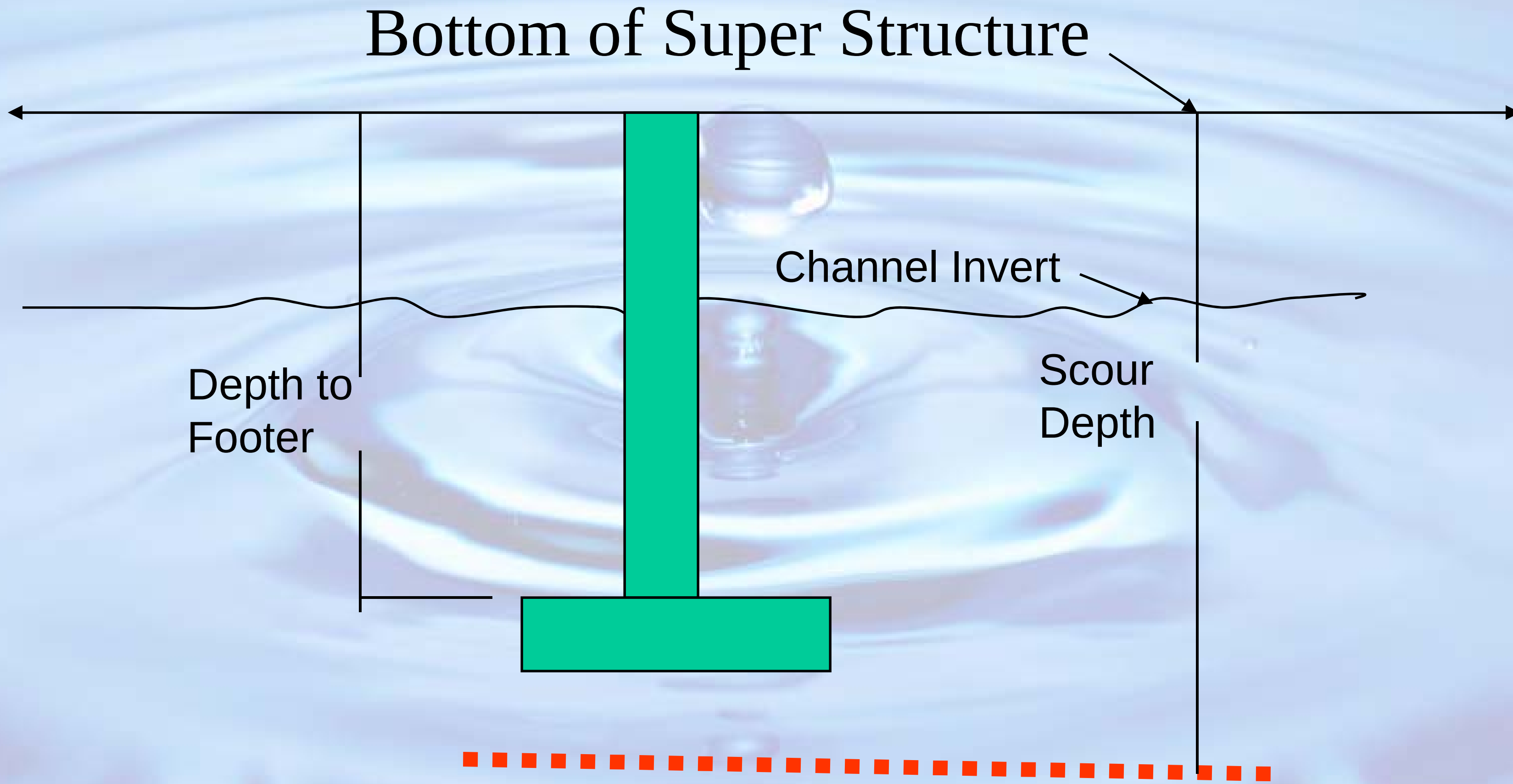
Scour Depth Above Top of Footing
No Work is Needed



Scour Line Within of Footing
Potential Stability Issue



Scour Line Below Footing. Potential Bridge Collapse, Mitigation Required



CDOT Bridge Scour POA Program

POA Elements

- Main Points of POA:
  - Describe procedures to implement before, during, and after flood event to protect traveling public
  - Create an Interdisciplinary Team consisting of:
    - Hydraulics Engineer
    - Structural Engineer
    - Geotechnical Engineer
    - Maintenance (CDOT)
  - Reassess Code 113 prior to implementing countermeasures
  - Develop appropriate POA framework

CDOT Bridge Scour POA Program

Potential POA components

- Main Points of POA:
  - Monitor During Flood
  - Instrumentation
  - Road Closure & Detour Plan
  - Bendway Weirs/Spurs/Check Dams/Drop Structures
  - Riprap Revetment/Riprap Design for Embankment Overtopping
  - Replacement of Bridge

COUNTERMEASURES FOR BRIDGE PIER PROTECTION

- Articulating Concrete Block Systems at Bridge Piers
- Grout-Filled Mattresses at Bridge Piers
- Rock Riprap or Grouted Rock at Bridge Piers

COUNTERMEASURES FOR ABUTMENT PROTECTION

- Rock Riprap at Bridge Abutments
- Guide Banks

STREAM CORRIDOR STABILIZATION

A COMPARISON OF APPROACHES USING LARGE & SMALL HEIGHT GRADE CONTROLS

Matrix Design Group Inc.

INTRODUCTION

❖ BASIS FOR PRESENTATION:

- Update to 1991 Cherry Creek Stabilization Plan (currently underway)

❖ EXISTING 1991 STABILIZATION PLAN:

- 27 Drops (12.5 mi University to Dam) - Avg. Height = 7.5 ft
- 9 Drops Remaining (Avg. Height = 7.0 ft)

Typical drop on Cherry Creek is large

Large Height Drops are Very Common Throughout the Front Range

❖ PROPOSAL TO UDFCD INCLUDED EVALUATING SMALLER HEIGHT DROP STRUCTURES

INTRODUCTION

WHY CONSIDER SMALLER DROPS?
(SUBJECT OF THIS PRESENTATION)

1) Large drops have a significant adverse impact on stream corridor
   - Stability
   - Ecological Function
   - Character

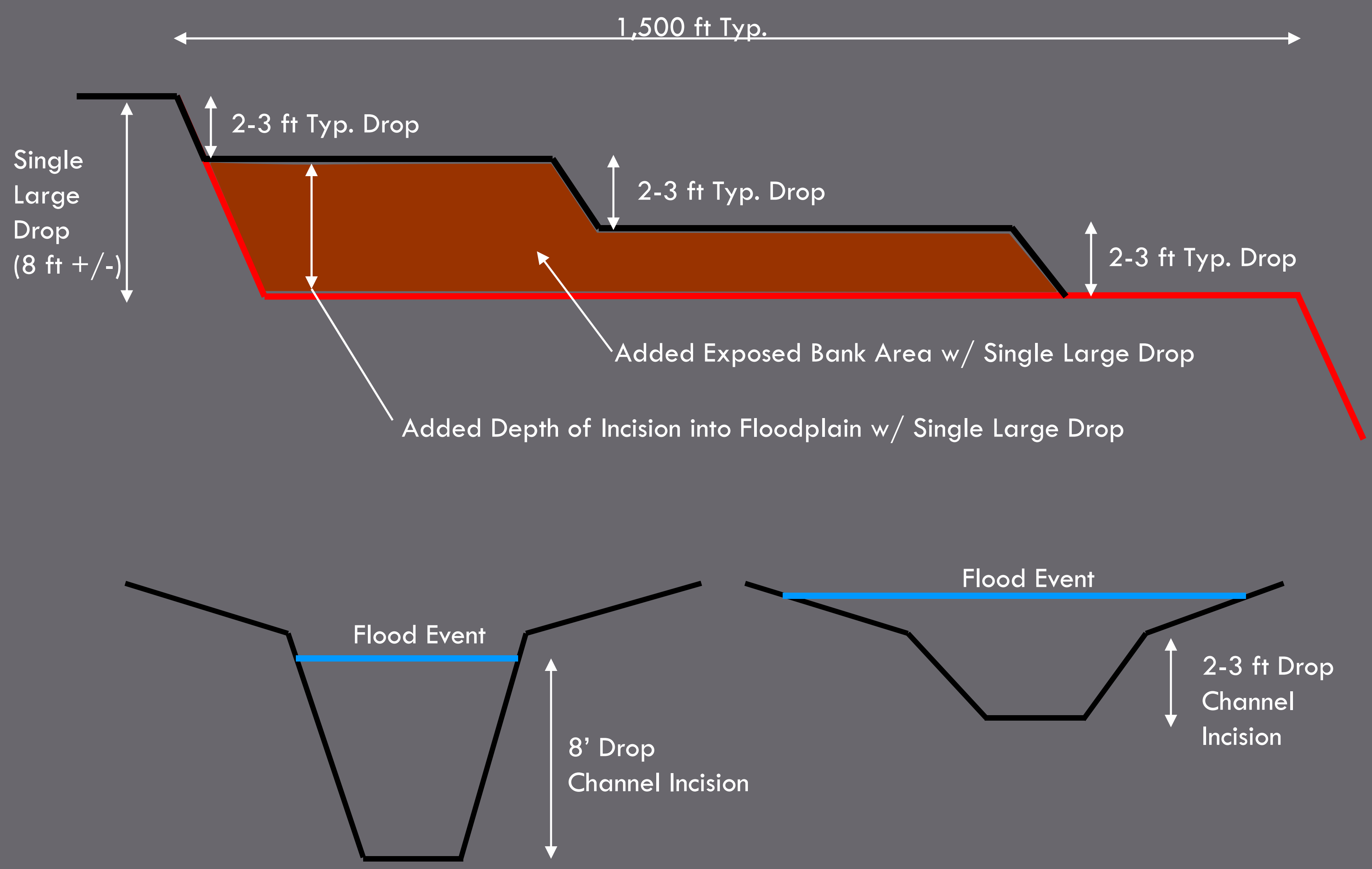
2) Small drops may have a lower overall long-term cost when costs for long-term bank stabilization are considered

ORGANIZATION OF PRESENTATION

- ILLUSTRATE IMPACTS OF LARGE HEIGHT DROPS ON STREAM CORRIDOR
  - Impact on Stream Profile and Cross Section
  - Impact on Vegetation
  - Impact on Shear Stress
  - Impact on Habitat
  - Impact on Recreation and Aesthetics
- COST ANALYSIS SUPPORTING IDEA THAT LARGE HEIGHT DROPS MAY NOT BE THE LOWEST COST APPROACH (When bank protection costs considered)
  - Drop Cost
  - Bank Protection Costs
  - Other Potential Costs
  - Cherry Creek Example Cost Calculations

IMPACT ON PROFILE AND CROSS SECTION

CHERRY CREEK EXAMPLE:



IMPACT ON PROFILE AND CROSS SECTION

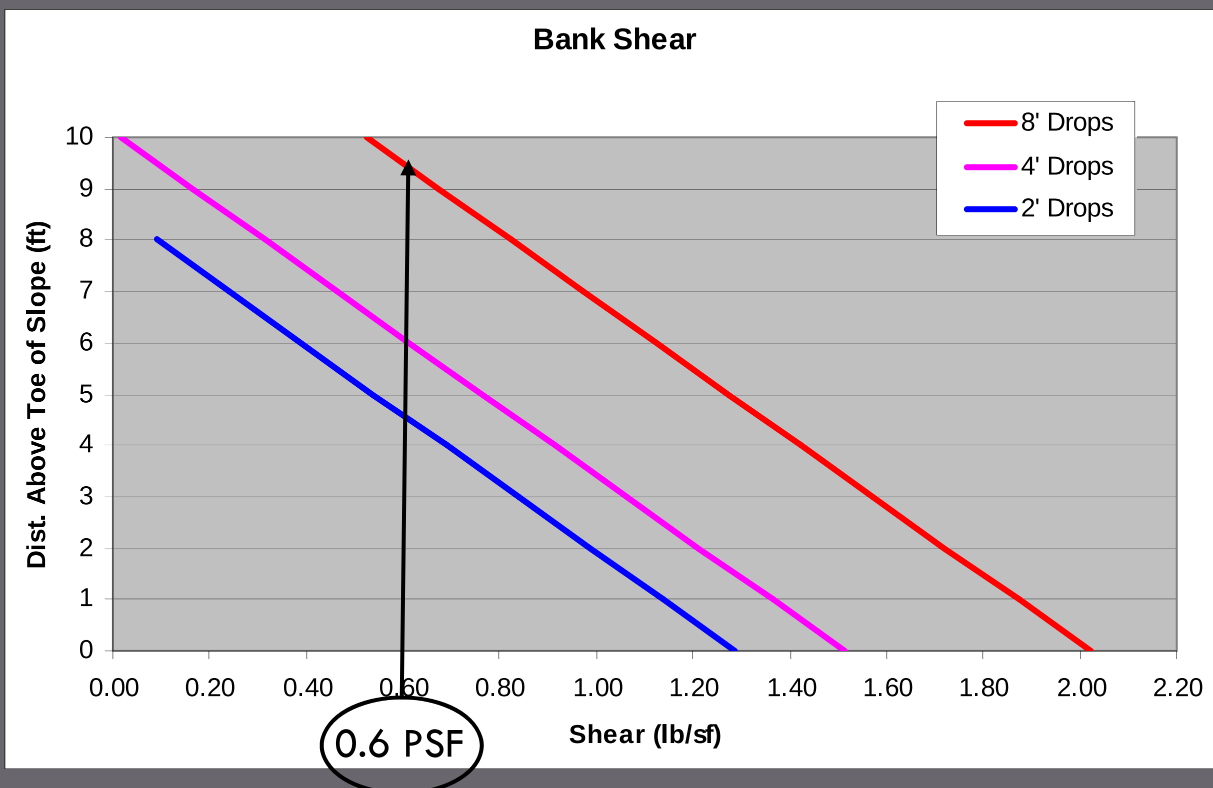
Looks Good Upstream ☺

Not So Good Downstream ☹

IMPACT ON CHANNEL HYDRAULICS

- Channel incision → increased shear + increased velocity
- More aggressive hydraulics have to be resisted by poorer upland vegetation

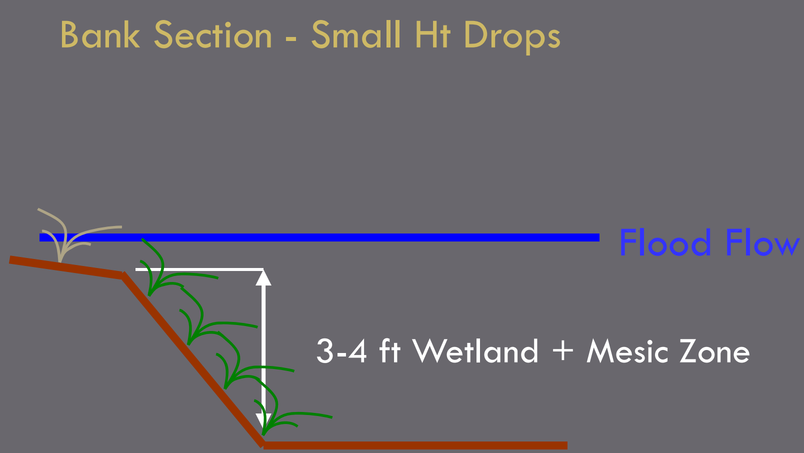
Cherry Creek Example:

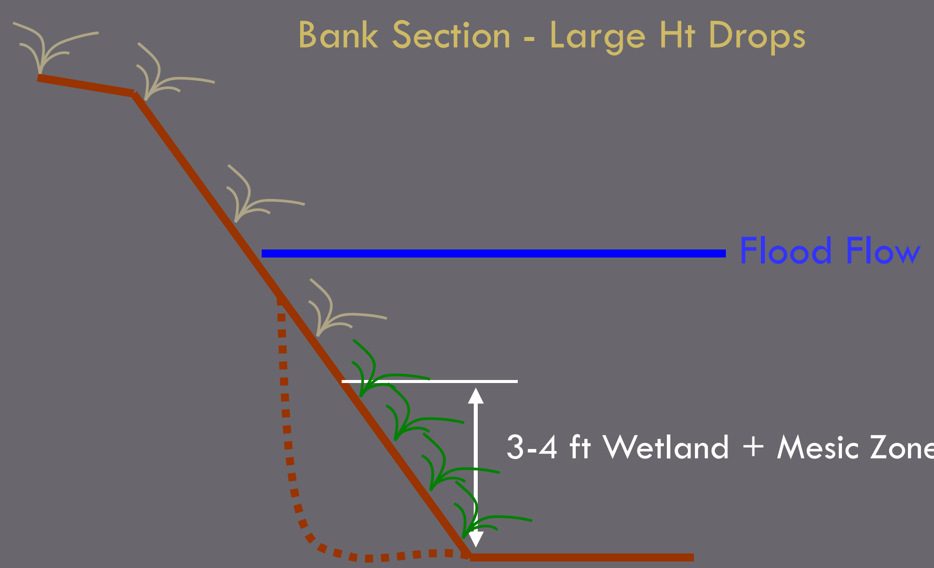


- 100-yr flow
- 0.6 psf limit for veg.

Drop Ht.	Vulnerable Bank Ht.
2 ft	4.5 ft
4 ft	6.0 ft
8 ft	9.5 ft

IMPACT ON VEGETATION



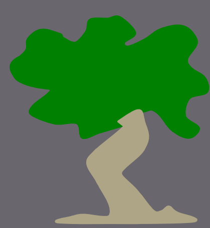


VEGETATION NEGATIVEY IMPACTED:

- INCREASED SHEAR & VELOCITY
  - Channel widening → lost/narrowed wetland edge
- LOWERED WATER TABLE
  - Vegetation stress (dying trees)
  - Conversion of wetland/mesic slopes to upland

    - Vegetation on surface = more sparse

    - Root structures = less dense, less vigorous



IMPACT ON VEGETATION

Narrowed Wetland/Mesic Edge

Wetland Edge Completely Lost

IMPACTS ON HABITAT

Terrestrial Habitat

- Channel Incision → Conversion of bank and floodplain to upland vegetation
  - Narrowed band of dense riparian vegetation (good habitat)
  - Upland vegetation more sparse (poor cover) = poor habitat
  - 75% of species in Colorado depend on, or benefit from wetlands for some portion of their life cycle

Monument Creek

Aquatic Habitat

- Reduced riparian vegetation + vertical cut banks = loss of cover for fish (protection from preditors, reproduction, water temps)
- Large drops are barriers to fish movement.
  - Scientific studies of small plains fishes indicate they have very limited jumping ability and are relatively weak swimmers - even small drops may be barriers.

Flathead Chub in Fountain Creek

IMPACTS ON RECREATION AND AESTHETICS

- Safety Hazard – High cut banks can be a safety hazard
- Trails – High cut banks and deep incision into the floodplain limits access to the creek and separates trail users from the creek environment
- Aesthetics - negatively impacted by loss of vegetation and bank erosion

IMPACTS ON RECREATION AND AESTHETICS

- Small drops easier to blend into surroundings and make look natural

Large (XX ft) Drop on Cherry Creek

IMPACTS ON MAINTENANCE

- Reduced vegetation protection and increased shear result in:

  - Banks more susceptible to erosion

  - Deposition of sediment downstream

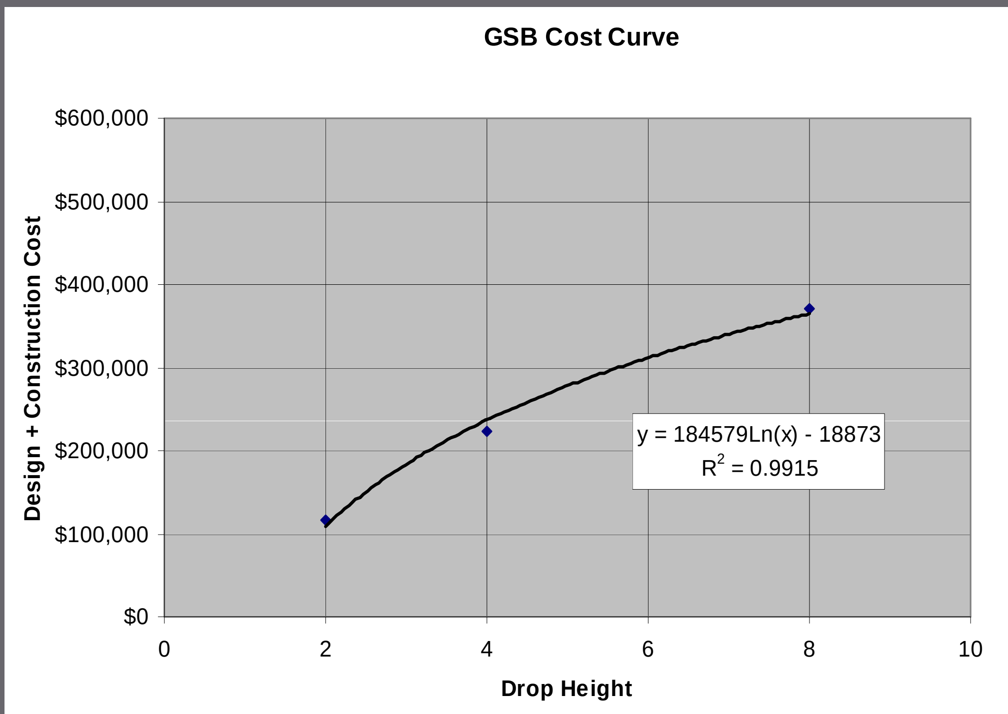
  - Increased cost for bank protection (greater area to protect and heavier protection required)

COST ANALYSIS

CHERRY CREEK STABILIZATION PLAN UPDATE

- Typical Drop Costs
- Typical Bank Protection Costs
- Overall Long-Term Cost (Drops + Bank Protection)
- Un-accounted For Costs (Maintenance)

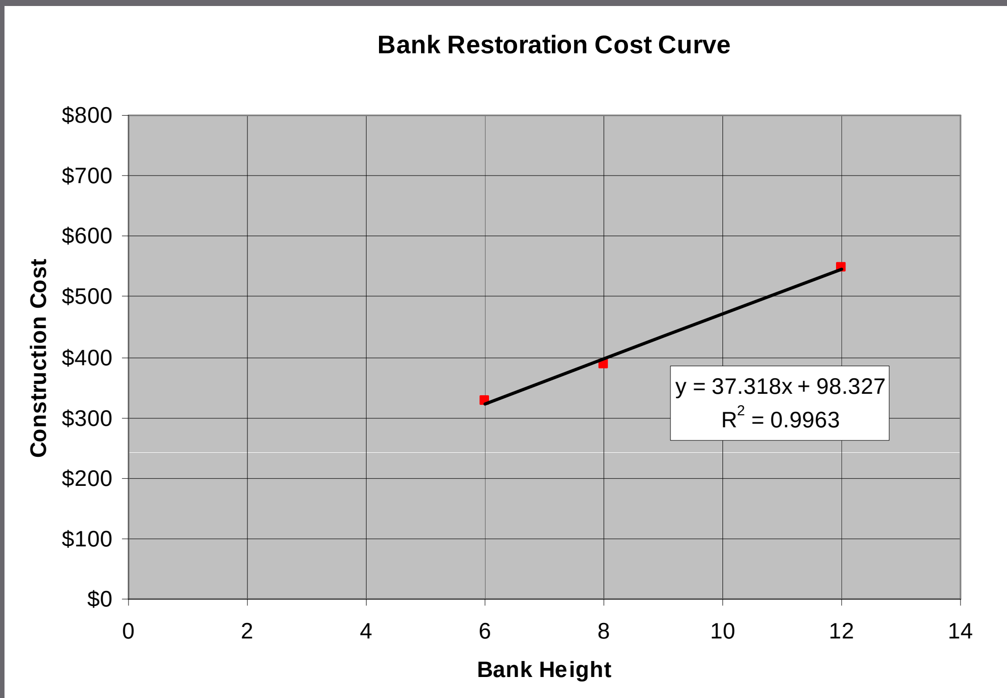
GROUTED BOULDER DROP COSTS



- Costs based on grouted boulder construction

- Costs account for different:
  - Boulder/grout thickness
  - Cutoff wall depth
  - Stilling basin length
  - Bank height to be protected

BANK PROTECTION COSTS



Costs based on:

- Planted soil riprap construction
- Typical Cherry Creek reach and dimensions
- Variation in shear stress with different degrees of channel incision

OVERALL COST ANALYSIS

Alternative	Cost
1- Large Drops (8' Typical)	$17.3 million
2 - Small Drops (3' Typical)	$17.8 million

- 3% increase in cost for reduced height drops.
- Assumes 50% of bank length will ultimately require protection.
- Costs for sediment removal not accounted for.
  - UDFCD budgets $500k +/- per year for this

Alternative 1 (Large Drops)	Alternative 2 (Small Drops)
Advantages	**Advantages**
1. Lower Initial Cost (lower drop cost)	1. Lower long-term (overall cost) - bank protection - sediment production - maintenance
2. Fewer work/access/easement areas	2. Improved vegetation health - bank stability - aesthetics - habitat
	3. Improved trail user experience - aesthetics - safety - creek accessibility

CONCLUSIONS

- WHY LARGE HEIGHT DROPS SO COMMON?
  - Lack of Funding for Proper Phasing
  - Reactive Band-Aid Approach (Emergency Infrastructure Protection)
  - Impacts of Large Drops on Stream Corridor not Fully Appreciated
  - True Cost of Large Drops Not Understood
    - Economic
    - Environmental

CONCLUSIONS

- LARGE HEIGHT GRADE CONTROL STRUCTURES RESULT IN AN OVERALL GREATER LEVEL OF CHANNEL INCISION IN THE FLOODPLAIN
- INCISION DESTABILIZES BANKS RESULTING IN:
  - Loss of Vegetation
  - Loss of Habitat
  - Degradation of Aesthetics and Recreational Potential
  - Sediment Production
- COST EVALUATIONS FOR DROPS SHOULD CONSIDER LONG-TERM COSTS ASSOCIATED WITH IMPACTS TO BANK STABILITY INCLUDING:
  - Cost for additional bank protection
  - Costs for maintenance
- ALL OF THE ABOVE FACTORS SHOULD BE CONSIDERED WHEN EVALUATING GRADE CONTROL PROJECTS

Constructing Sculpted Concrete Drop Structures

Laura Kroeger, UDFCD
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Ugly, Tolerable or Wow?

Beauty is in the Eye of the Beholder

-Author: William Shakespeare

Function is the Responsibility of the Engineer

-Author: Missing

Ugly, Tolerable or Wow?

Ugly, Tolerable or Wow?

Ugly, Tolerable or Wow?

Ugly, Tolerable or Wow?

The 5 C's to Sculpted Drops

- Context
- Configuration
- Construction Documents
- Contractor
- Color

Context

Structure to fit into the surrounding landscape

Context

Questions to Ask

- What are the existing characteristics?
  - natural features
  - man made features
- What is the scale of landscape features?
- What is the public access?
- Environmental/Aquatic considerations?
- What will complement the existing landscape?

Context

Configuration

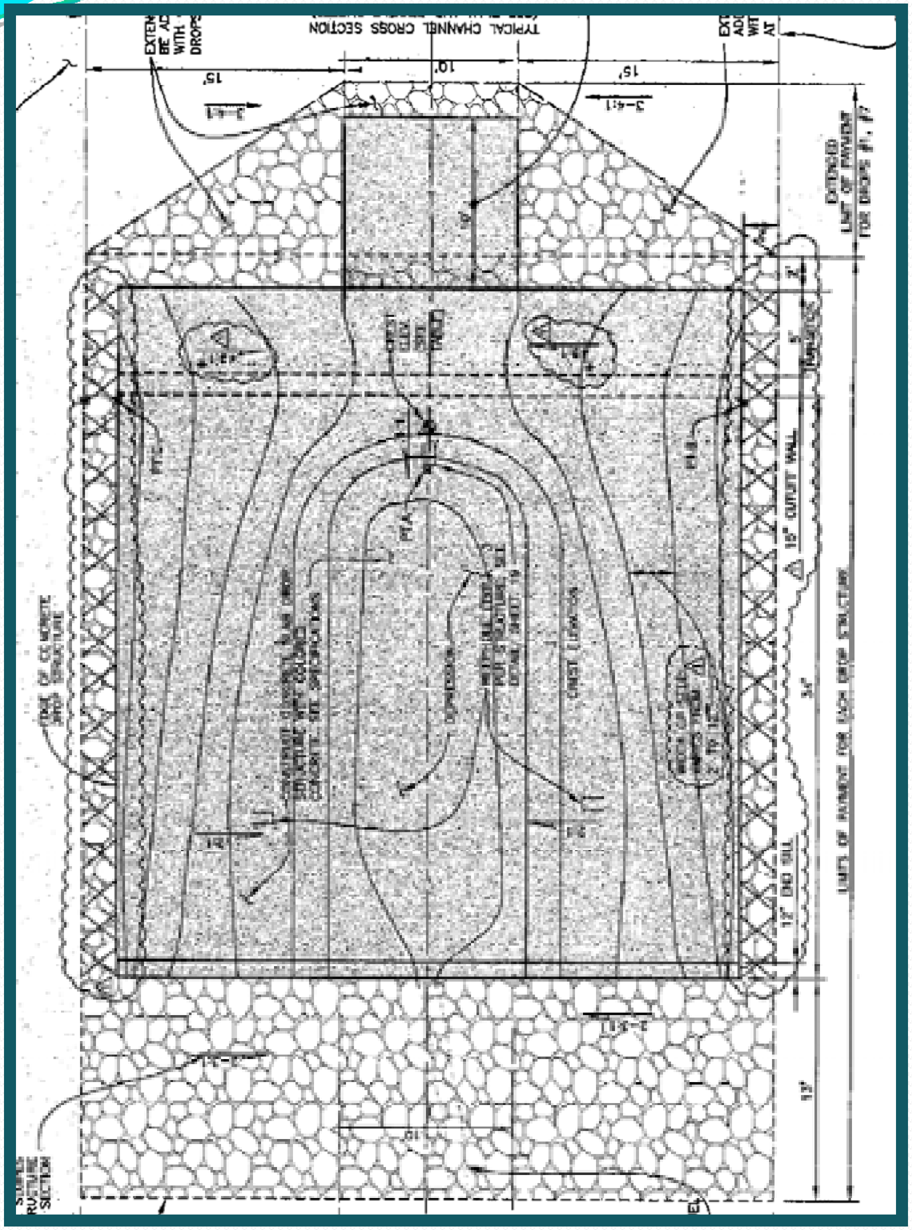
- Size
- Shape
- Scale
- Safety
- Uniformity

Configuration

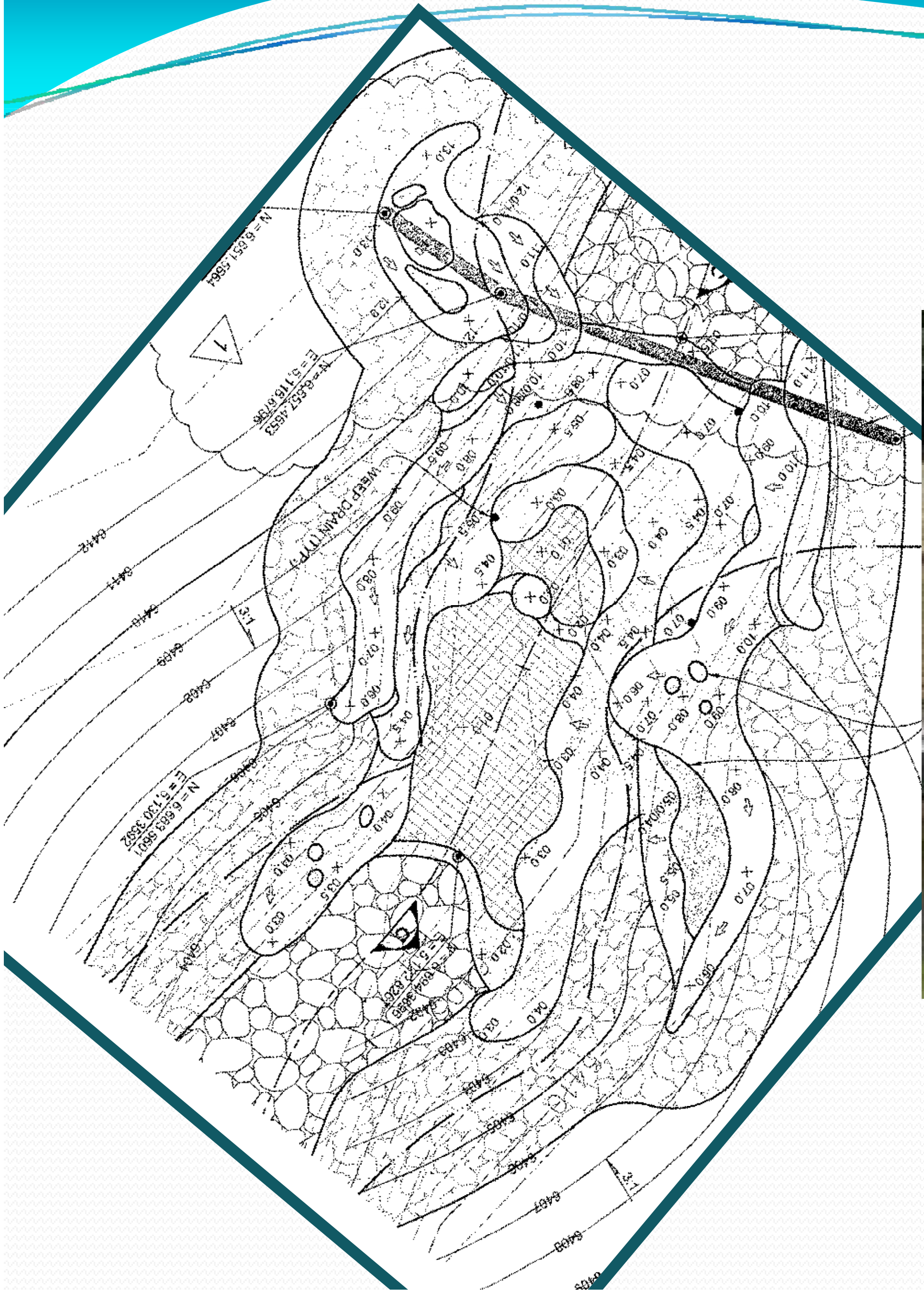
- Size
- Shape
- Scale
- Safety
- Uniformity

Contract Documents

DETAILS NEED TO REFLECT WHAT YOU WANT BUILT



TYPICAL CHANNEL CROSS SECTION
12" CUTOFF WALL
12" END SILL
LIMITS OF PAYMENT FOR EACH DROP STRUCTURE



Contractor

- Write your specifications to get a qualified contractor
- Use additional tools to communicate with
  - 3-d modeling of structures
  - Pictures
  - Field trip
  - Rock out-cropping

Color and Finishing

- Color
  - Integral color
  - Staining/painting
  - Nature, water

Finish

- Finishing
  - Powerwashing
  - Stamping
    - Skins, burlap, foil
  - Carving and shaping
  - Depressions
  - Vegetation
- Texture Additives
  - Sand, rock, wood

Factors to Consider During Construction

Diversions

Dewatering


G03333

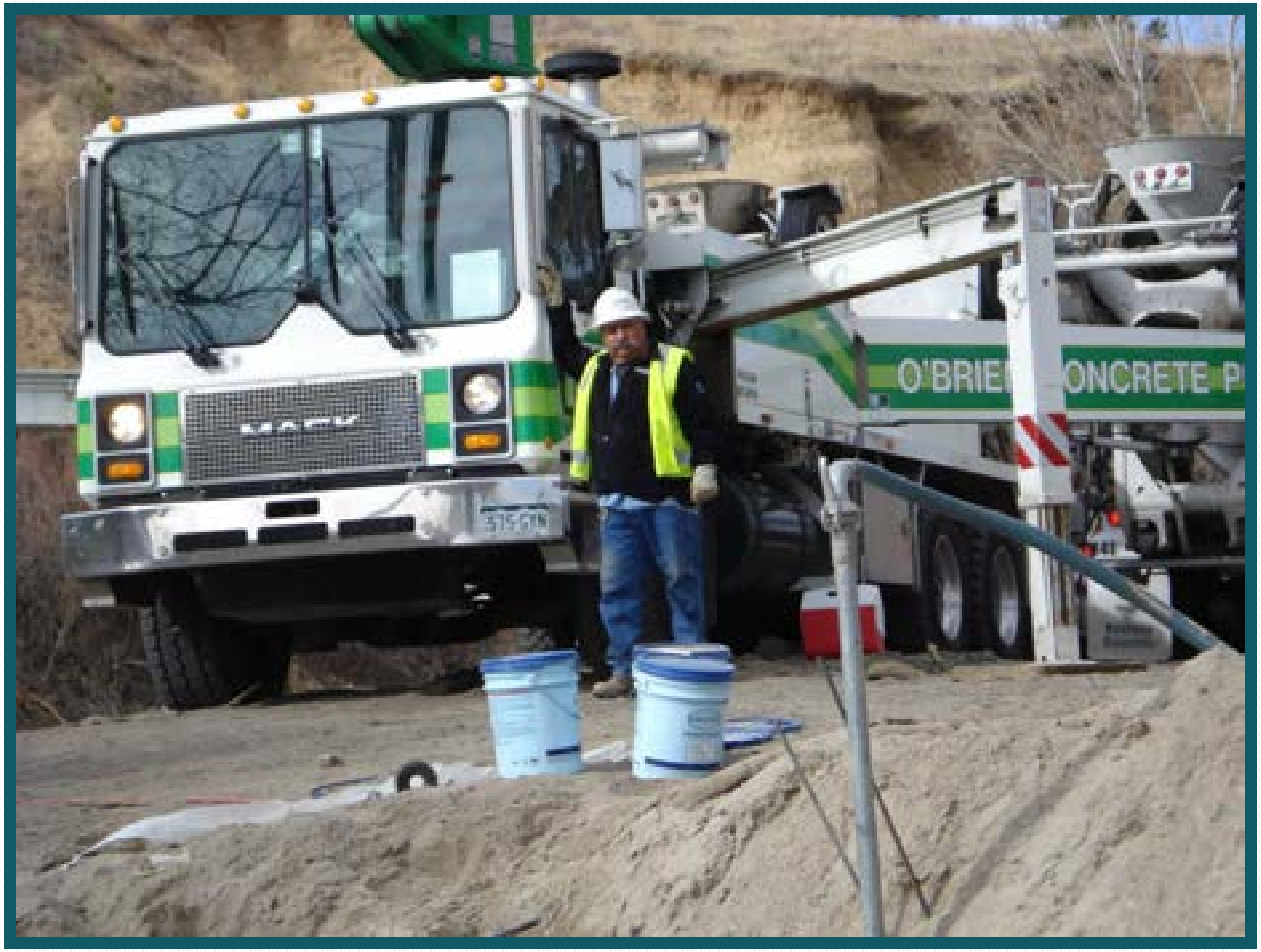
Ugly

Cut-off Walls

Preparing the Subgrade

Reinforcing

Concrete



Concrete Testing

Concrete Placement

Crest Elevation

Weather

Weather Protection

Constructing Concrete Drop Structures:
The Contractor's Perspective

Subgrade Shaping and Prep

Rebar Tying

Chicken Wire

Pump Setup

Concrete Arrival

Concrete Arrival - Timing

Checking The Batch

Pumping/Pouring

Vibrating

Shaping

Sculpting

Applying Release

Texture Stamping

Line Production

Time Lapsed Process:

Staining

Finished Pour

What makes a good design?

- Designer has a style in mind from previous projects
- Design shows critical elevations throughout the entire structure, not just slopes
- Collaborate with crew during construction, innovate together.

Hydrologic Performances of Pervious Concrete and Porous Asphalt Pavement Systems

Thomas Ballestero, PE, PhD, PH, CGWP, PG, Federico Uribe, Robert Roseen, PE, PhD, D.WRE, James Houle, CPSWQ, Timothy Puls

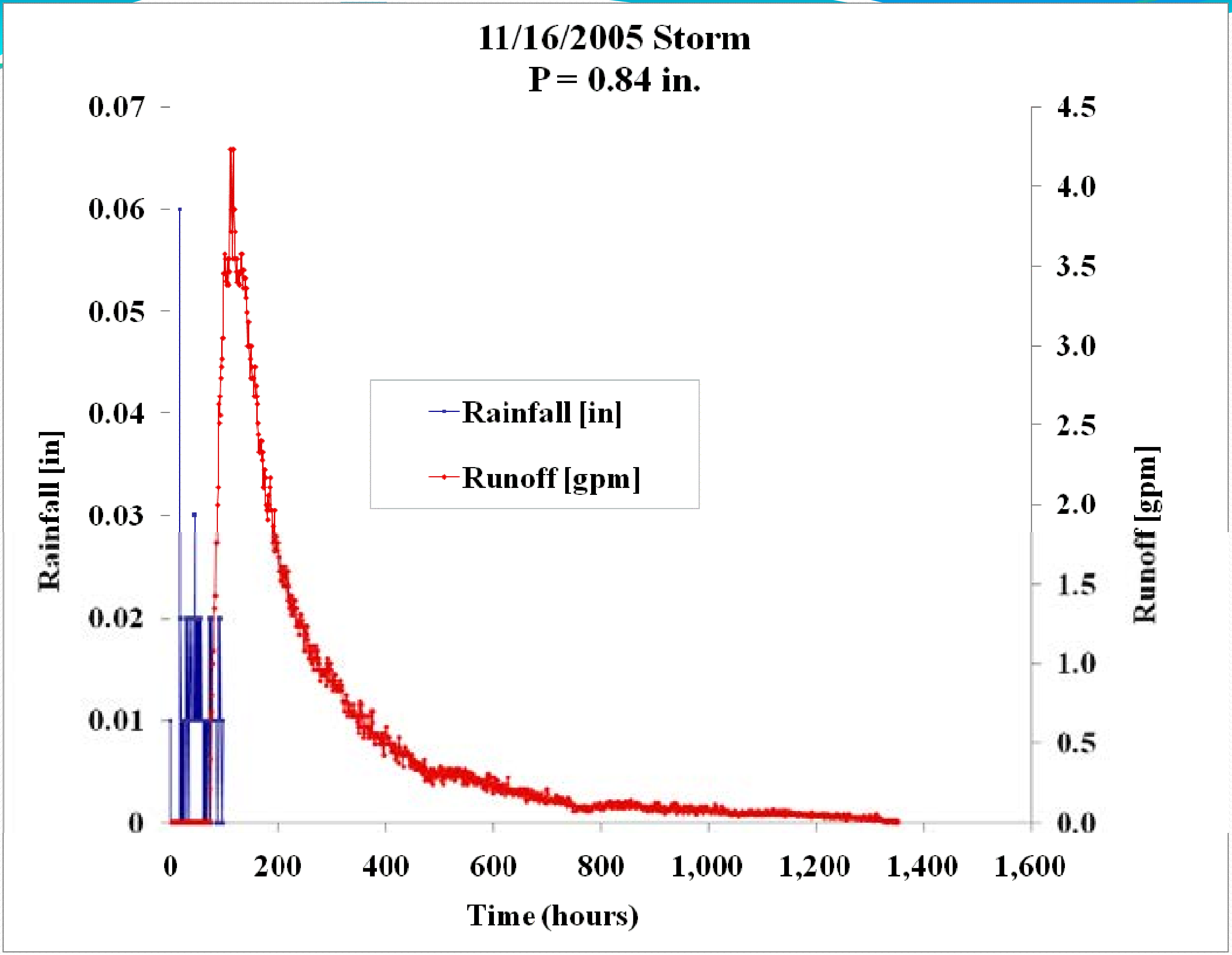
University of New Hampshire Stormwater Center

2010 CASFM CONFERENCE *Snowmass Village, Colorado*

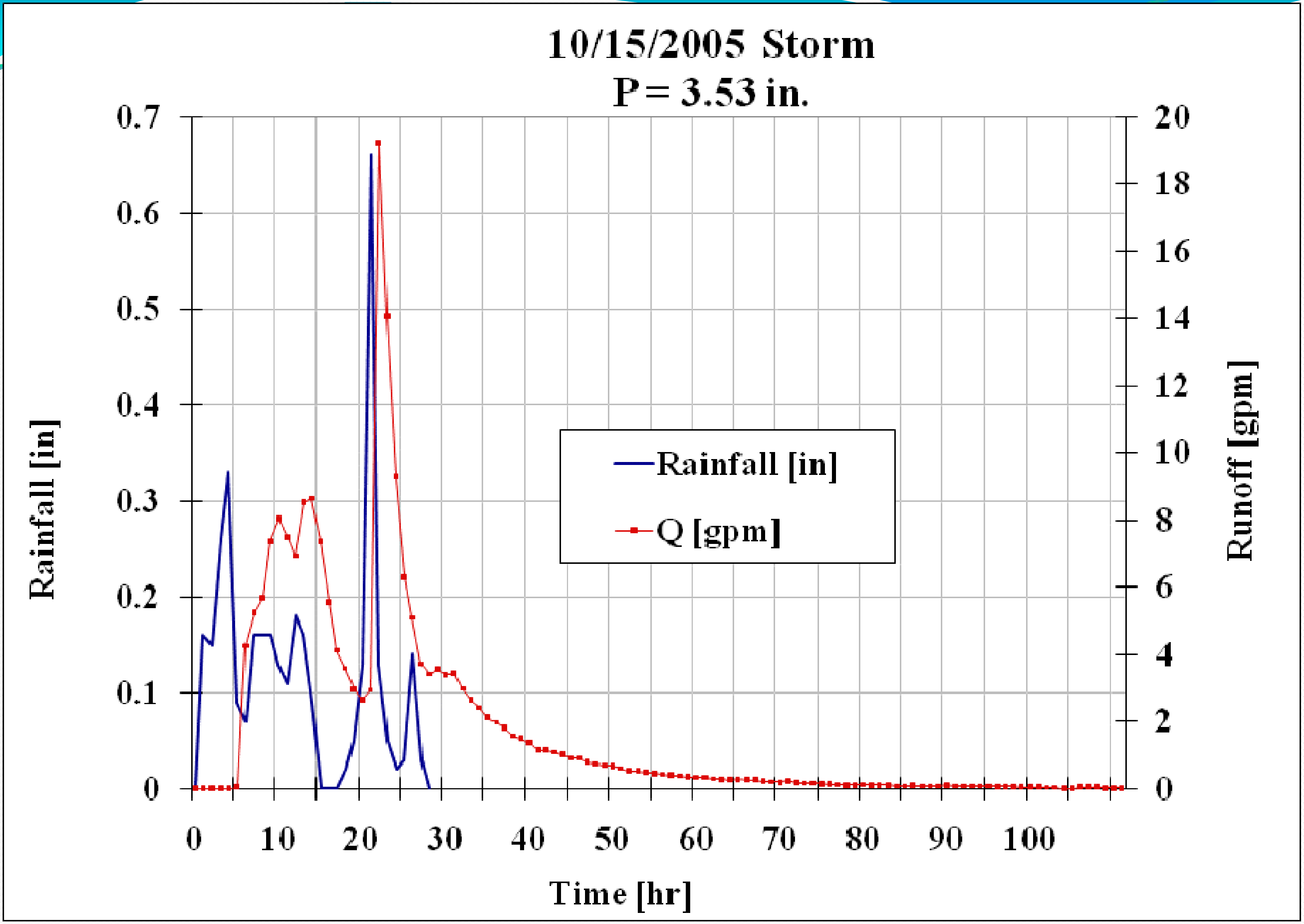
SC
UNIVERSITY OF NEW HAMPSHIRE
STORMWATER CENTER

Objective

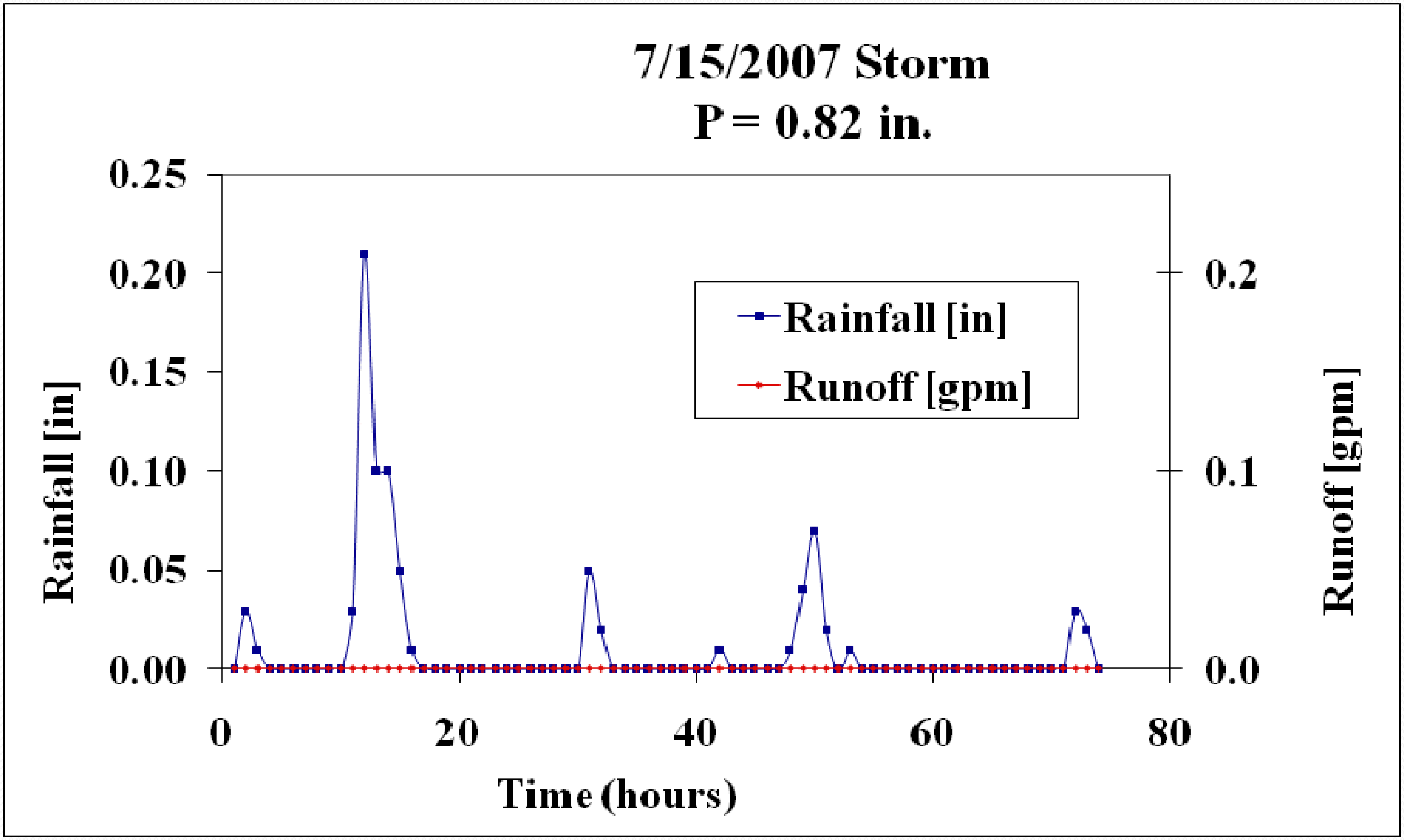
- What are the "runoff characteristics of permeable pavements?



11/16/2005 Storm
P = 0.84 in.
Rainfall [in]
Runoff [gpm]
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
200
400
600
800
1,000
1,200
1,400
1,600
Time (hours)
Rainfall [in]
Runoff [gpm]



10/15/2005 Storm
P = 3.53 in.
Rainfall [in]
Runoff [gpm]
Time [hr]
Rainfall [in]
Q [gpm]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60
70
80
90
100


7/15/2007 Storm
P = 0.82 in.
Rainfall [in]
Runoff [gpm]
0.25
0.20
0.15
0.10
0.05
0.00
0.2
0.1
0.0
0
20
40
60
80
Time (hours)
Rainfall [in]
Runoff [gpm]

What is the Curve Number For Porous Pavement?

Who wants to know?!?

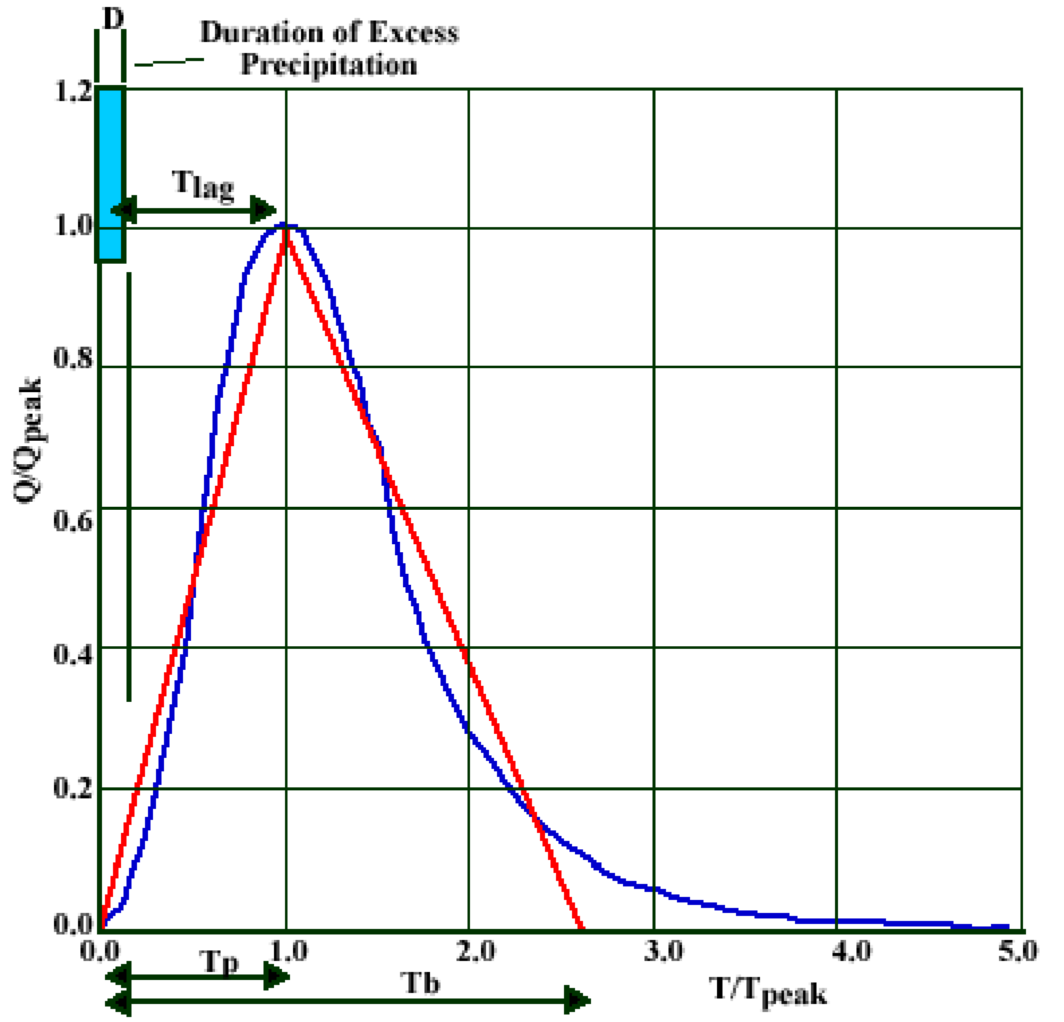
(***What is your OBJECTIVE?)***

The SCS (NRCS) Curve Number

Originally conceived to translate rainfall *depth* into runoff *depth* on agricultural watersheds…method worked best for large storms

This was then translated into a runoff hydrograph

SCS Dimensionless Unit Hydrograph



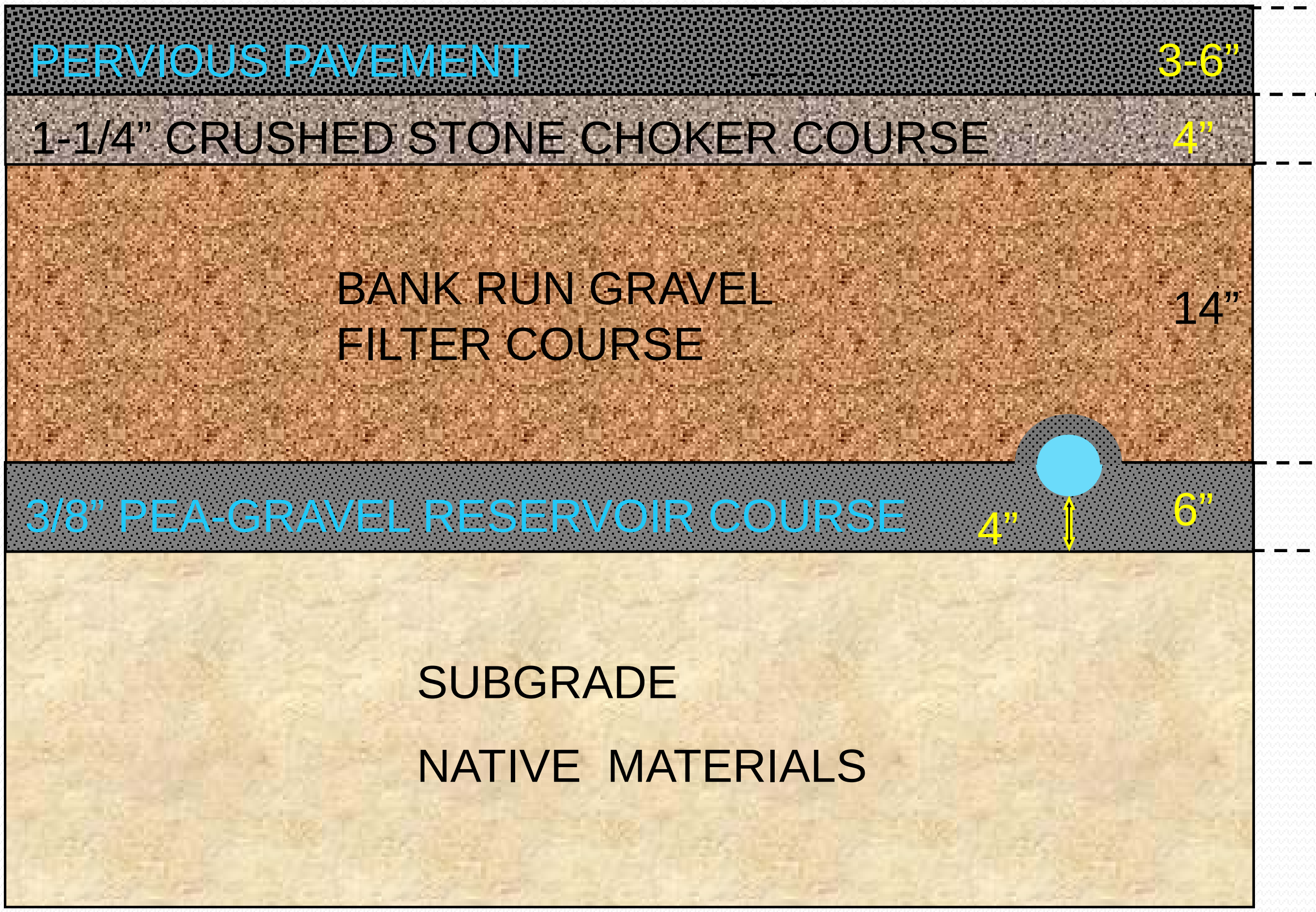
UNHSC Porous Pavement Sites

Permeable Pavement Sites

UNHSC Porous Asphalt Lot

UNHSC Porous Concrete Lot

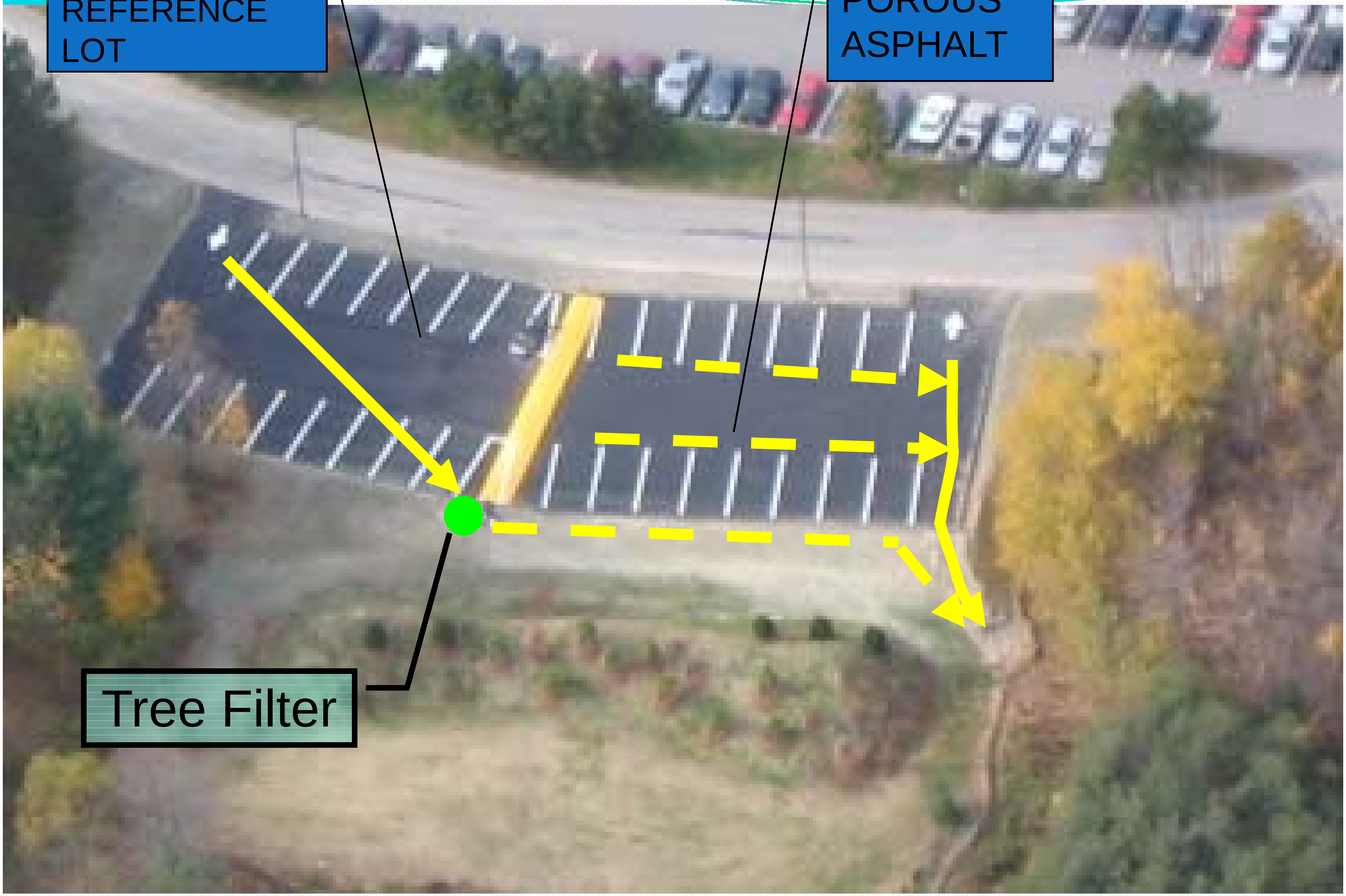
Typical Cross-Section Construction



Sub-base design matches that of the UNHSC Porous Asphalt Parking Lot

UNHSC Porous Pavement Monitoring

- Compound weir
- Pressure transducer
- Datalogger

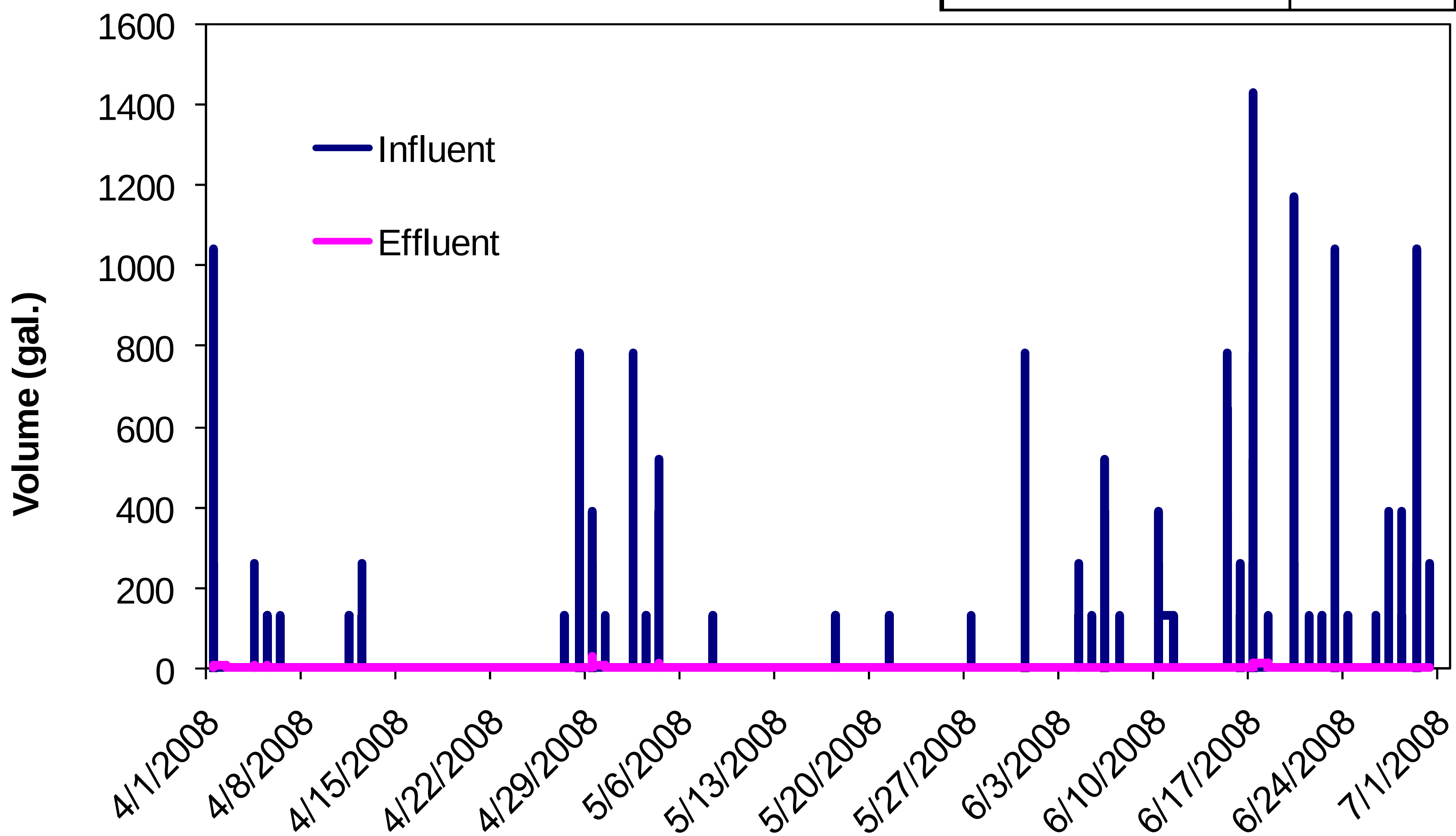

REFERENCE LOT
POROUS ASPHALT
Tree Filter

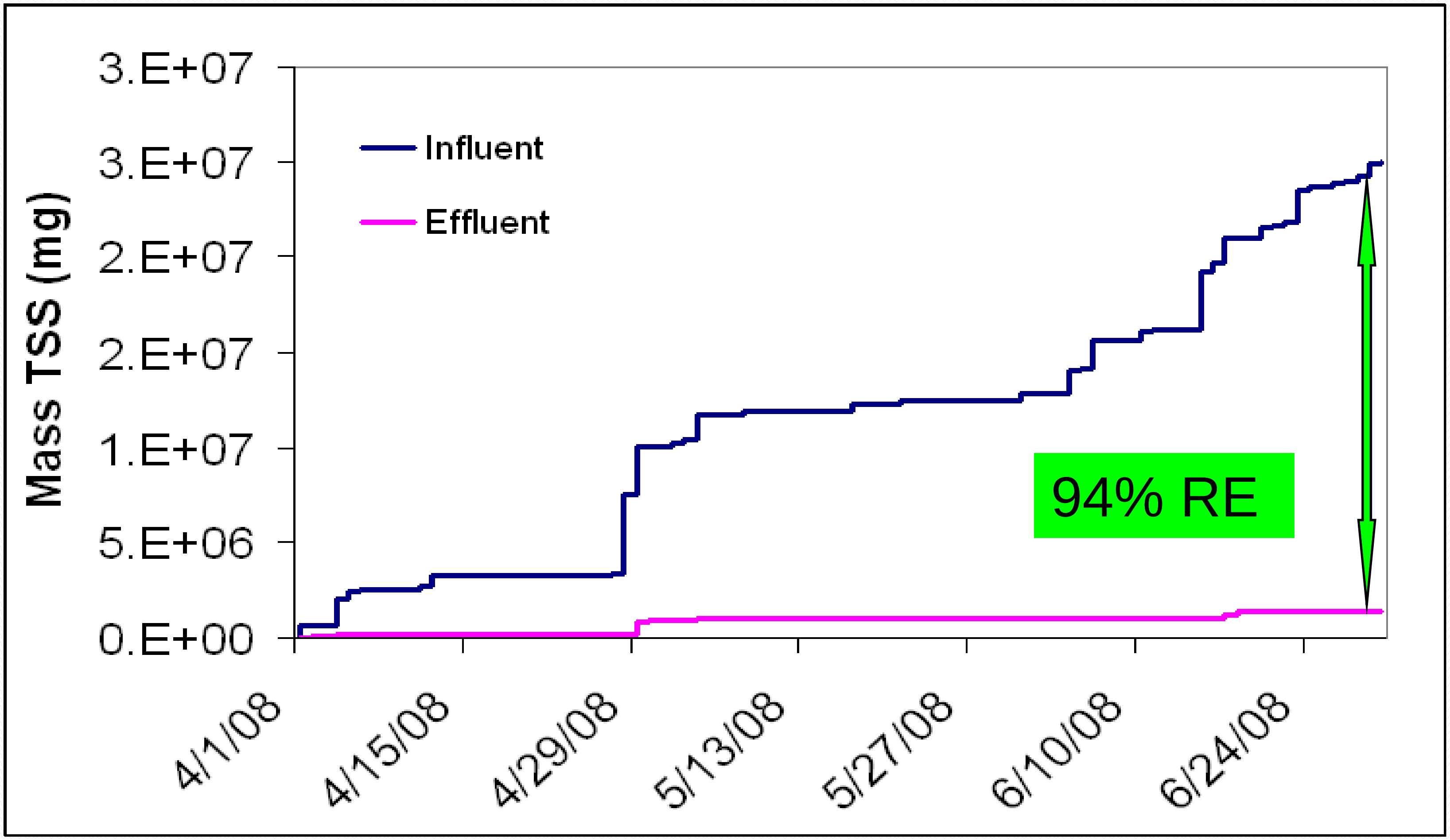
UNHSC Porous Pavement Hydrologic Data

- “Real time” flow monitoring…5-minute time step
- “Real time” rainfall monitoring…5-minute time step

PC Flow Attenuation

4/1/08 - 6/30/08		
	Influent	Effluent
Total Volume (liters)	446,034	25,585
# of Flow Events	15	5





Mass TSS (mg)
3.E+07
3.E+07
2.E+07
2.E+07
1.E+07
5.E+06
0.E+00
Influent
Effluent
94% RE
4/1/08
4/15/08
4/29/08
5/13/08
5/27/08
6/10/08
6/24/08

Methods of Teasing CN from the Data

- Measure P and Q, invert basic SCS equation
- Measure P and outflow hydrograph (q), measure lag, estimate CN from lag equations
- Measure Q and q_p, estimate CN from peak discharge equations

Method 1 - Depth of Runoff (Q)Method

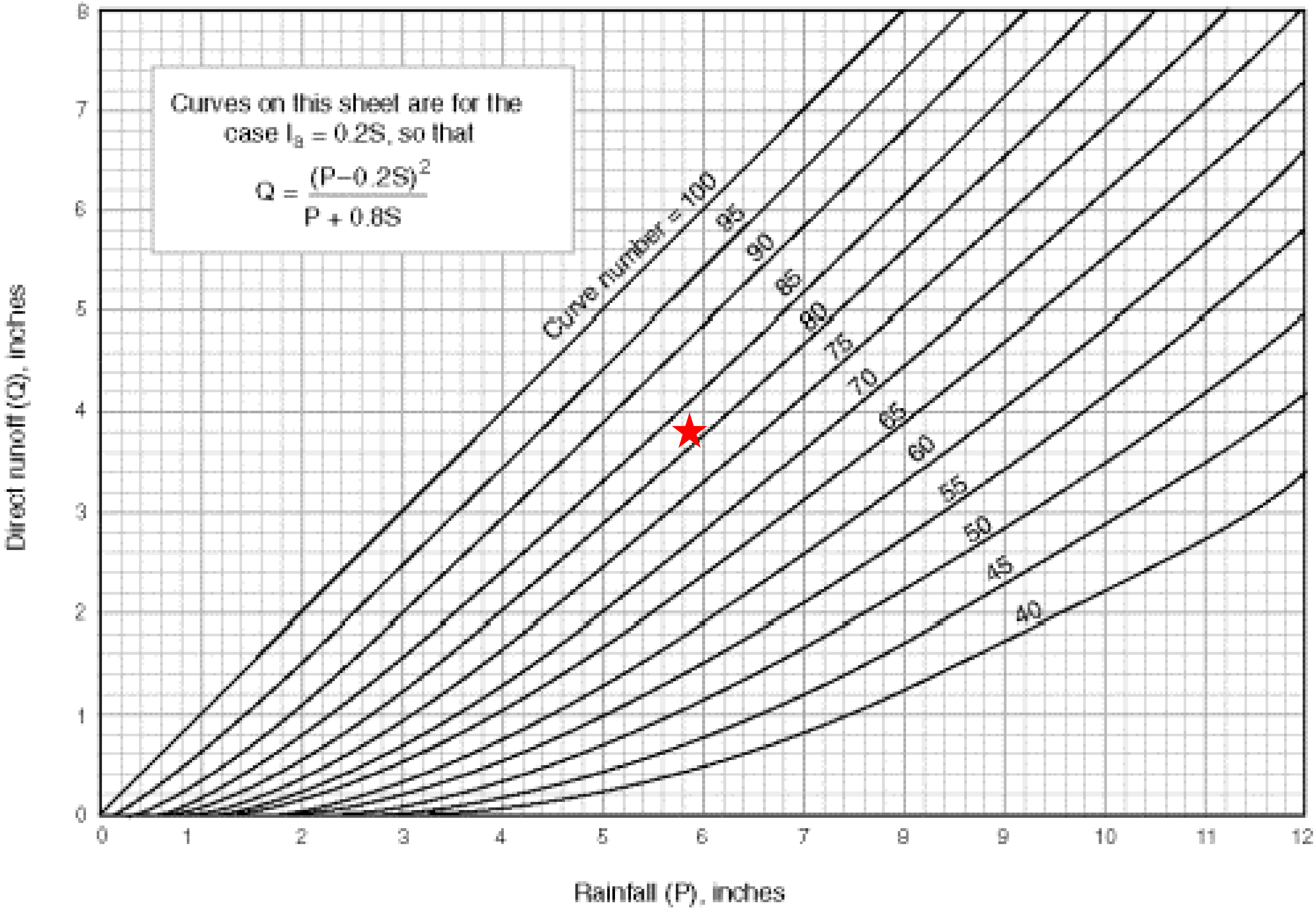
$$Q = \frac{(P - I_a)^2}{P - I_a + S} \quad Eq.\ 1.$$

Q: Total Runoff Depth (in)
P: Total Precipitation Depth (in)
I_a: Initial Abstraction (in)
S: Storage Parameter (in)

$$I_a = 0.2\,S \quad Eq.\,2.$$

$$Q = \frac{(P - I_a)^2}{P + 0.8S} = \frac{(P - 0.2S)^2}{P + 0.8S} \; Eq.3.$$

$$S = \frac{1000}{CN} - 10 \quad Eq.\,4.$$

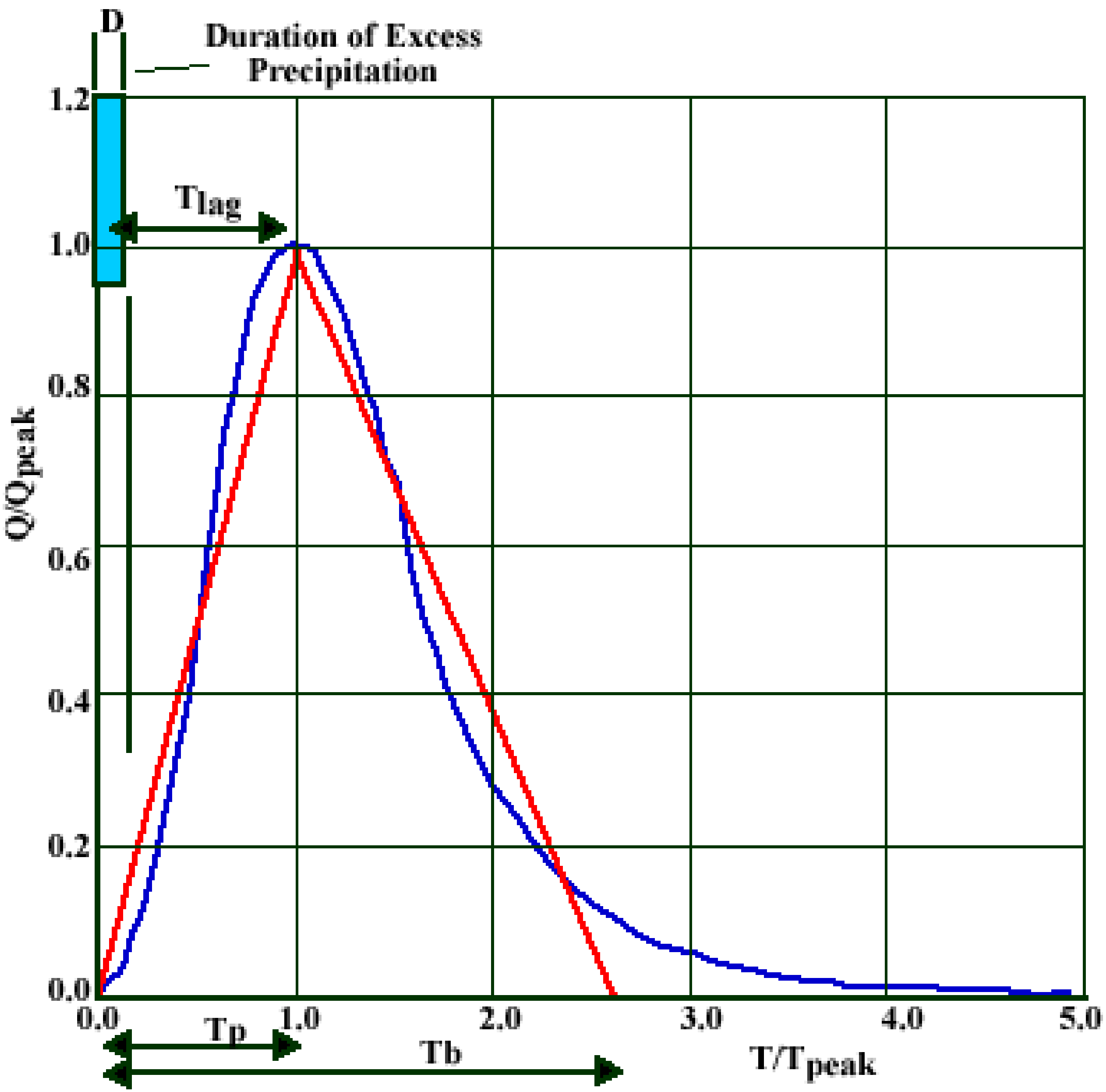


Curves on this sheet are for the case $I_a = 0.2S$, so that
$$Q = \frac{(P-0.2S)^2}{P+0.8S}$$
Curve number = 100
95
90
85
80
75
70
65
60
55
50
45
40
Direct runoff (Q), inches
Rainfall (P), inches
0
1
2
3
4
5
6
7
8
9
10
11
12

Method 2 -Lag Methods

- Study how the timing of the “runoff” is transformed

- Time of concentration
- Lag time
- Time base
- Peak time


D
Duration of Excess Precipitation
Tlag
Q/Qpeak
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
1.0
2.0
3.0
4.0
5.0
Tp
Tb
T/Tpeak

Method 2 -Lag Methods

$$T_{lag} = \frac{L^{0.8}(S+1)^{0.7}}{1900 \cdot Y^{0.5}} \qquad Eq.\ 5.$$

$$T_c = \frac{5}{3} T_{lag} \qquad Eq.\ 6.$$

$$S = \frac{1000}{CN} - 10 \qquad Eq.\ 7.$$

T_{lag}: Lag Time (hr)
T_c: Concentration Time (hr)
Y: Surface Slope (%)
S: Storage Parameter (in)

Lag Methods

3 APPROACHES

LAG METHOD (1)

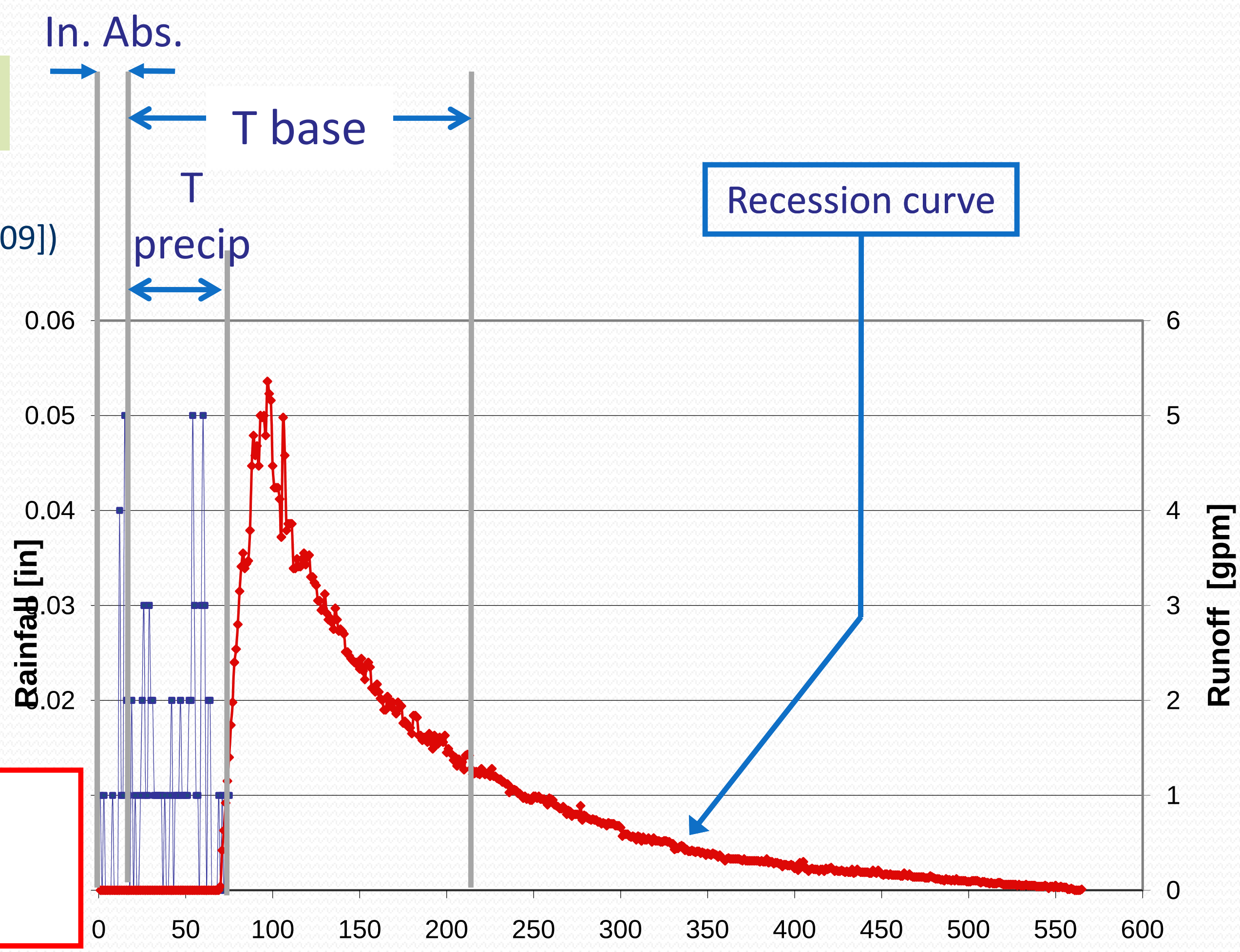
1. *T base* (Sánchez San Román [2009])

T base = T precip + T conc

T conc = T base – T precip

Using Eq. 5 and Eq. 6
used into Eq.7.,
*solve for **CN***

$$CN = \frac{1000}{\left(\frac{1140\, T_C\ Y^{0.5}}{L^{0.8}}\right)^{1.428} + 9}$$



Lag Methods

LAG METHOD (2)

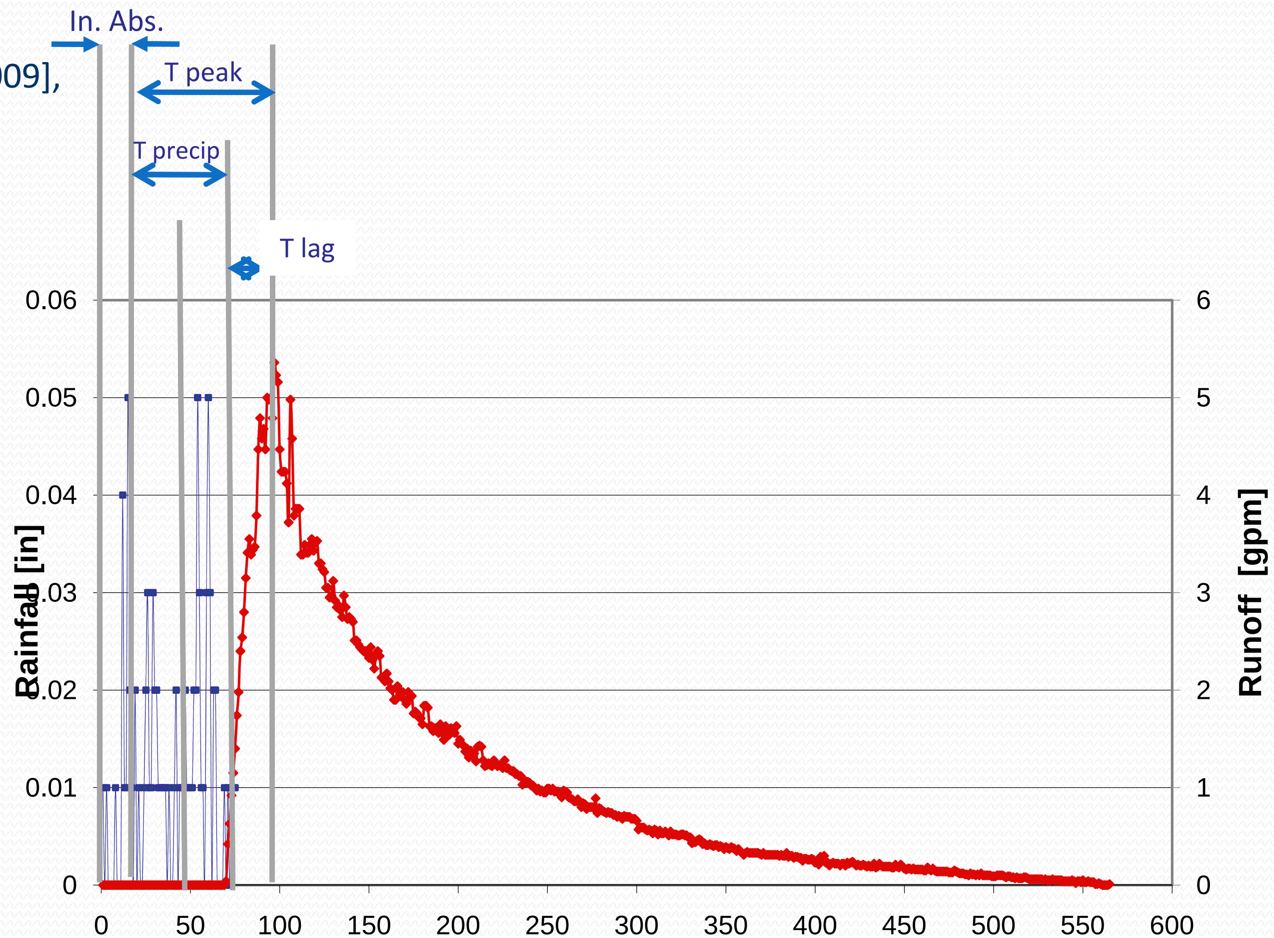
2. *T peak* (Sánchez San Román [2009], Folmar, Miller and Woodward [2007])

T peak = T lag + T precip/2

T lag = T peak– T precip/2

*Insert Eq. 1 into Eq.3 and solve for **CN:***

$$CN = \frac{1000}{\left[\dfrac{1900\ T_{LAG}\ Y^{0.5}}{L^{0.8}}\right]^{1.423} + 9}$$



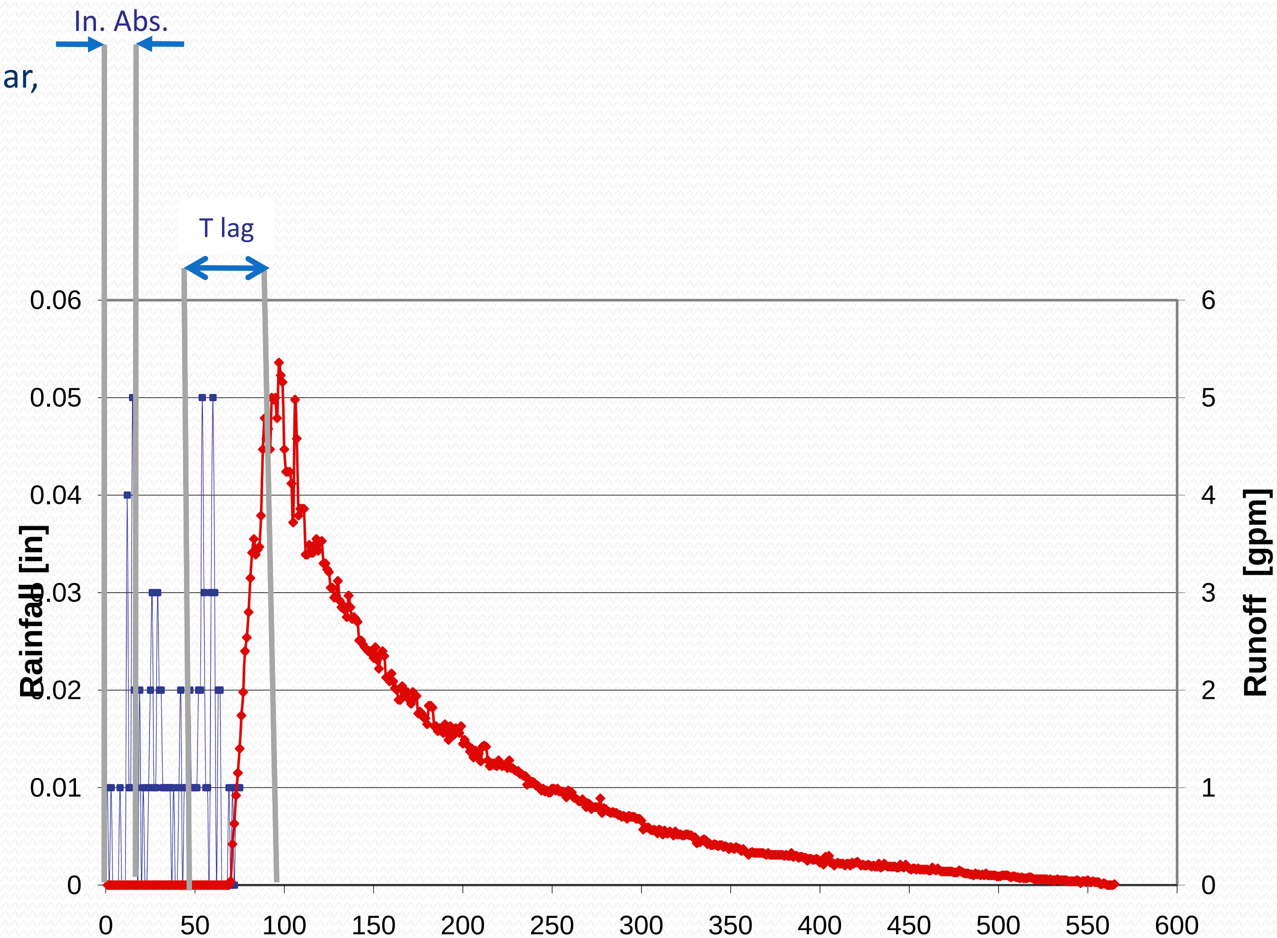
Lag Methods

LAG METHOD (3)

3. *T centroid* (NRCS [2009], Folmar, Miller and Woodward [2009])

T lag: time from the centroid of excess precipitation to the peak of the hydrograph.

$$CN = \frac{1000}{\left[\frac{1900\ T_{LAG}\ Y^{0.5}}{L^{0.8}}\right]^{1.423} + 9}$$



Method 3
GRAPHICAL PEAK DISCHARGE METHOD

$$q_p = q_u A_m Q$$

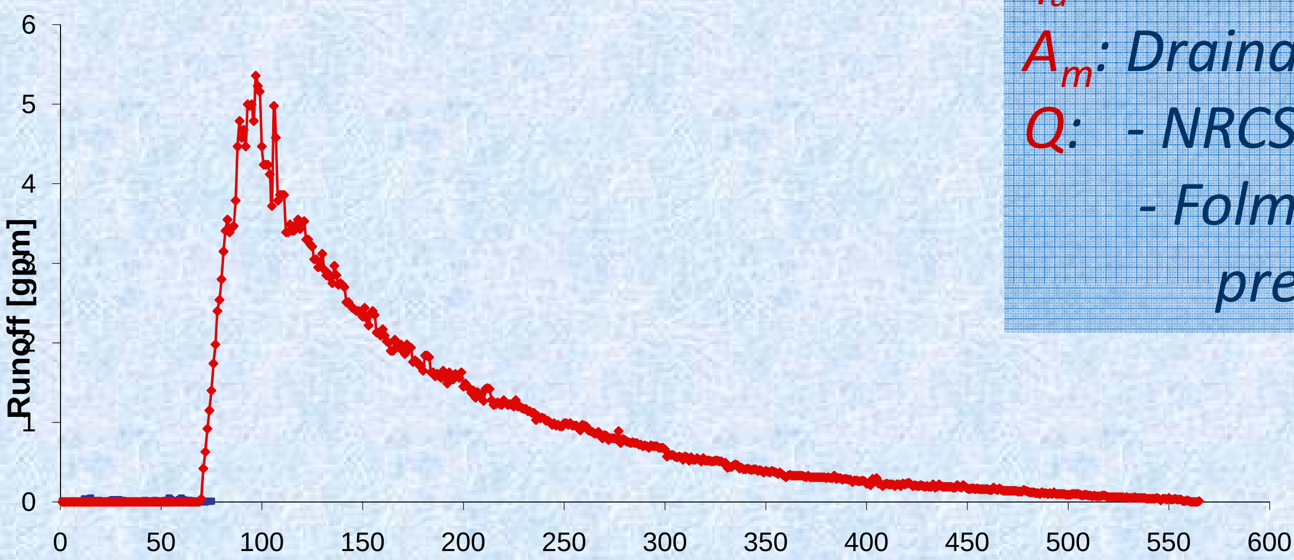
q_p: *Peak Discharge (cfs)*

q_u: *Unit Peak Discharge (csm/in)*

A_m: *Drainage area (mi^2)*

Q: *- NRCS Storm Runoff (in)*

- Folmar, et. al Excess precip. prior to peak.

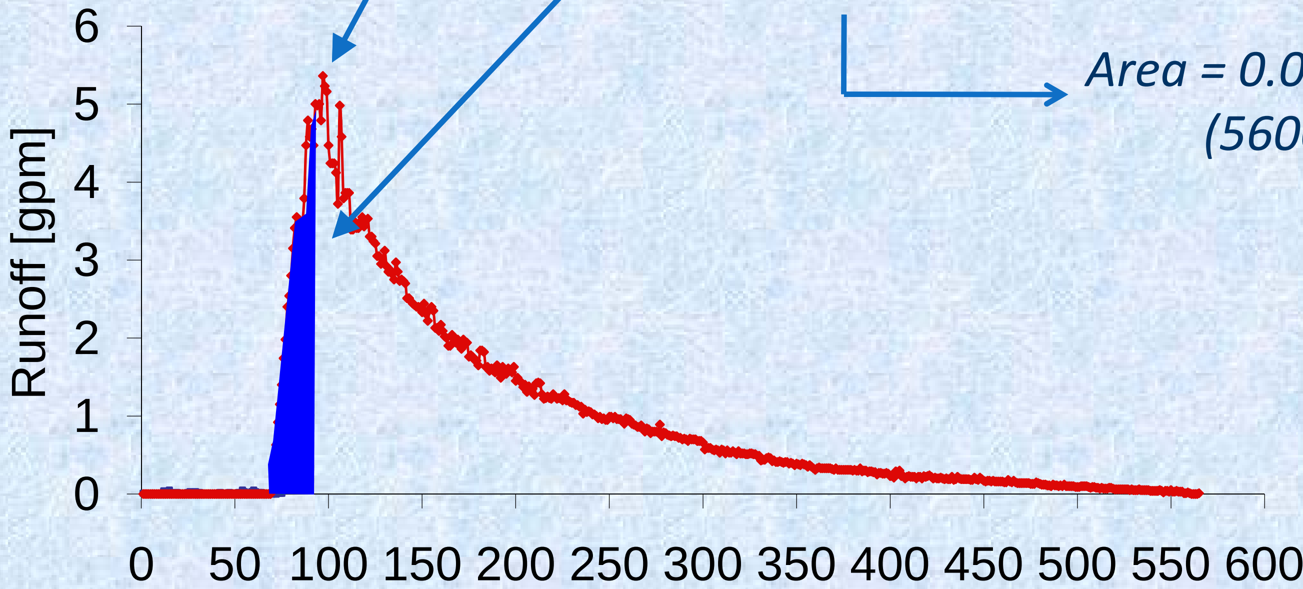


GRAPHICAL PEAK DISCHARGE METHOD

$$q_p = q_u \, A_m \, Q \qquad Eq. 8.$$

$$q_u = \frac{q_p}{Q\,A_m} \qquad Eq. 9.$$

Area = 0.000201 mi^2 (5600 ft^2)



Method 3 – Graphical Peak Discharge

Unit Peak discharge for NRCS type III rainfall distribution chart.

Measure q_p, Am, Q

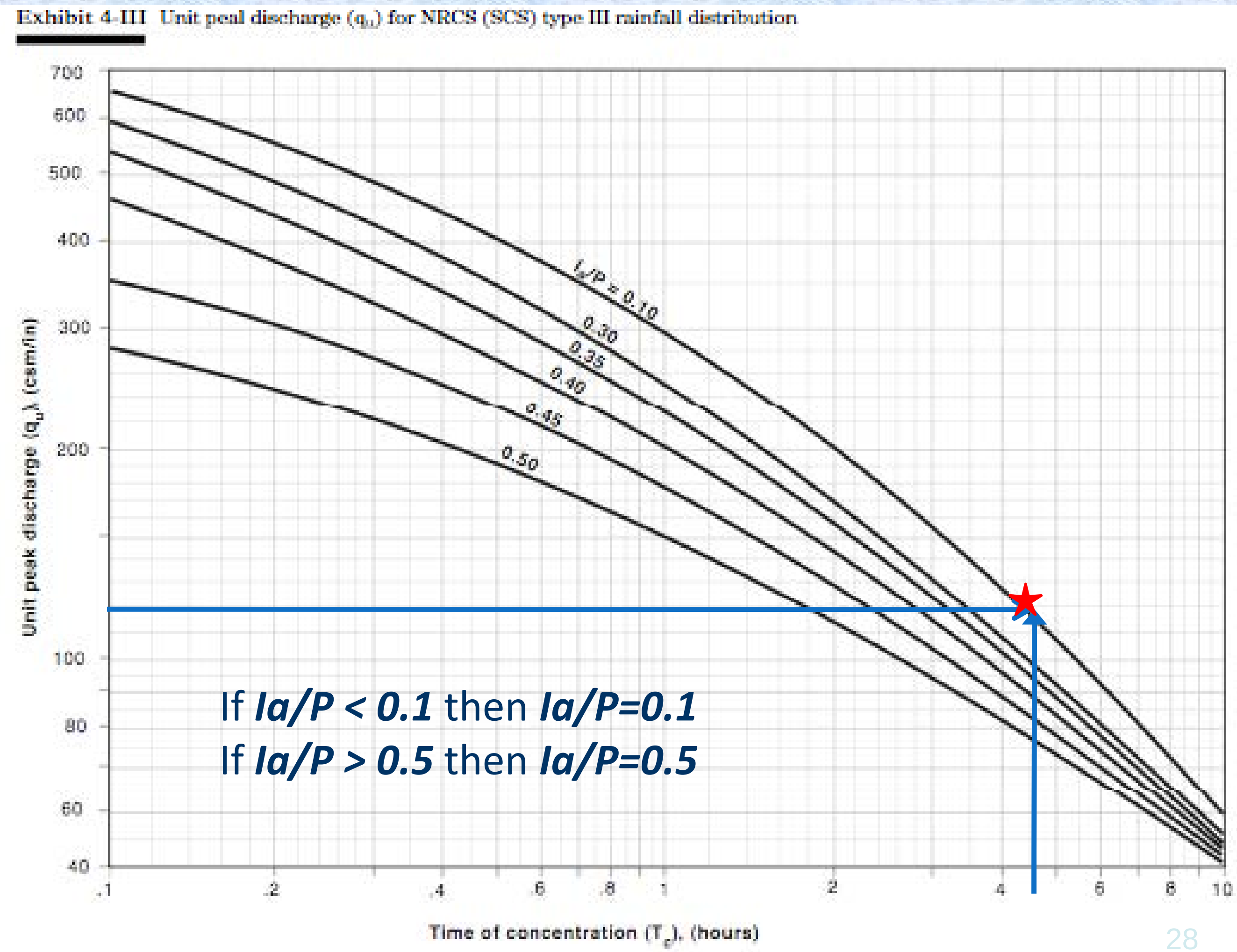
Compute q_u

Ia/P = 0.1

Determine Tc

Compute S, CN

Check Ia/P



Method 3 – Graphical Peak Discharge

$$q_p = q_u A_m Q$$

$$Tc = f(q_u)$$

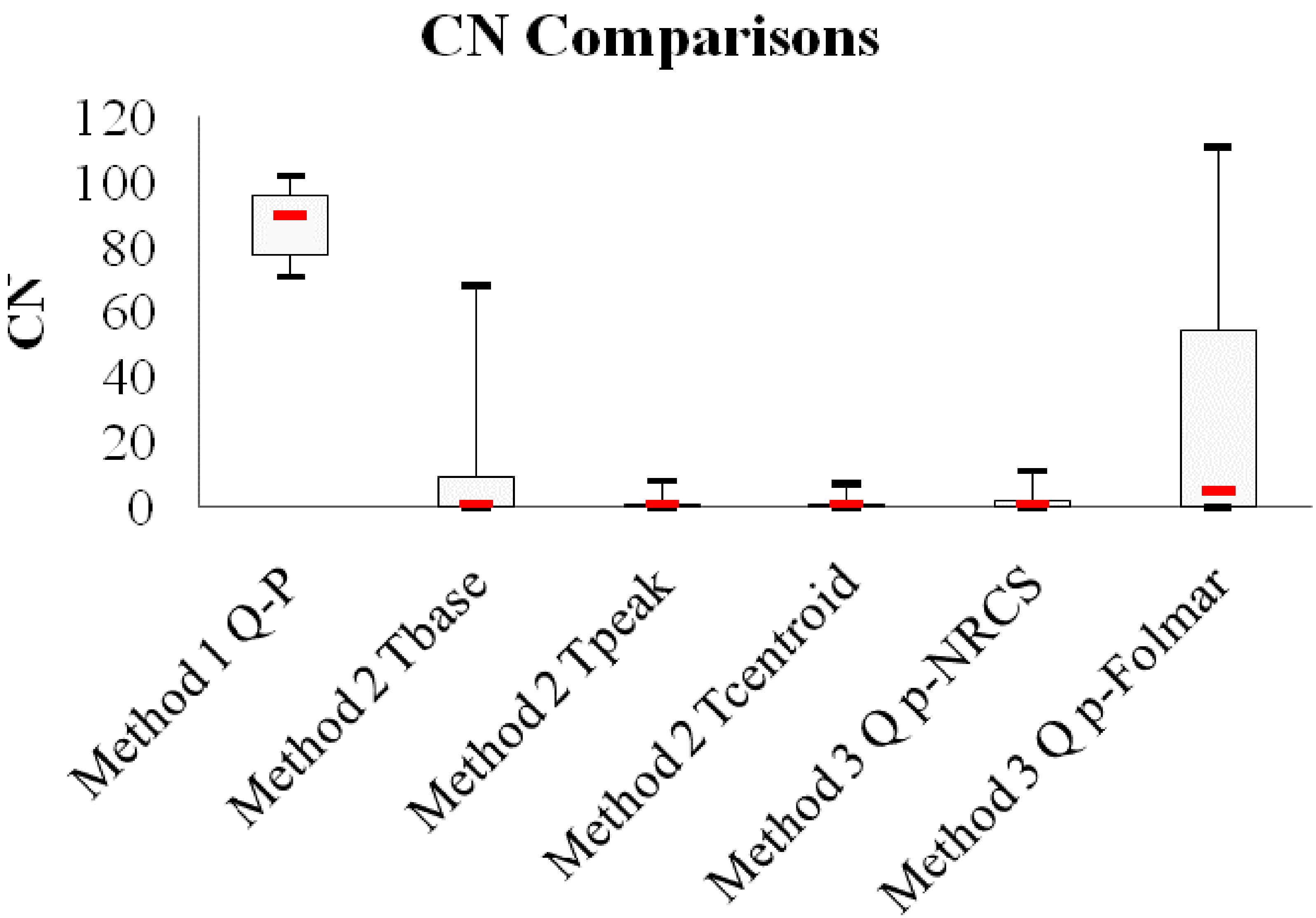
$$\boxed{CN = \frac{1000}{\left[\dfrac{1900\ T_{LAG}\ Y^{0.5}}{L^{0.8}}\right]^{1.423} + 9}}$$

CN (Clean Data)									
Storm	Date	Rainfall [in]	Runoff [in]	Method 1 Q-P	Method 2 Lag			Method 3 Q peak	Method 3 Q peak
					Tbase	Tpeak	Tcentroid	NRCS	Folmar
1	10/8/2005	5.00	3.99	91.1	68	R>P	R>P	1	106
2	10/15/2005	3.53	3.45	99.3	24	R>P	R>P	1	5
3	10/11/2006	2.78	1.68	88.8	9	R>P	R>P	5	69
4	5/2/2006	2.37	1.40	89.8	1	R>P	R>P	0	3
5	8/20/2006	1.92	0.92	88.4	13	R>P	R>P	11	111
6	4/3/2006	1.57	0.77	90.6	10	R>P	R>P	2	55
7	12/16/2005	1.38	0.45	87.0	-	2	2	2	48
8	7/12/2006	1.35	0.75	93.2	11	8	7	2	59
9	7/19/2007	1.28	0.43	88.0	2	1	1	1	4
10	12/23/2006	1.21	0.85	96.4	-	1	1	1	13
11	9/11/2007	1.12	0.41	90.1	-	3	3	2	98
12	7/8/2005	1.02	0.35	90.5	1	1	1	1	3
13	10/10/2005	0.87	0.74	98.8	4	1	1	1	56
14	11/16/2005	0.86	0.94	100.6	1	1	1	1	22
15	7/15/2007	0.82	0.00	70.9	0	0	0	0	0
16	5/16/2007	0.69	0.90	101.5	1	1	1	0	6
17	8/4/2006	0.68	0.00	74.6	0	0	0	0	0
18	7/9/2007	0.66	0.33	96.0	-	2	2	2	50
19	9/19/2006	0.63	0.00	76.0	0	0	0	0	0
20	7/28/2007	0.63	0.00	76.0	0	0	0	0	0
21	9/3/2006	0.62	0.00	76.3	0	0	0	0	0
22	4/23/2006	0.58	0.00	77.5	0	0	0	0	0
23	12/26/2006	0.58	0.86	101.8	0	1	1	0	8
24	5/9/2006	0.56	0.00	78.1	0	0	0	0	0
25	7/4/2007	0.55	0.00	78.4	0	0	0	0	0
26	4/27/2007	0.54	0.53	99.9	-	0	0	0	2

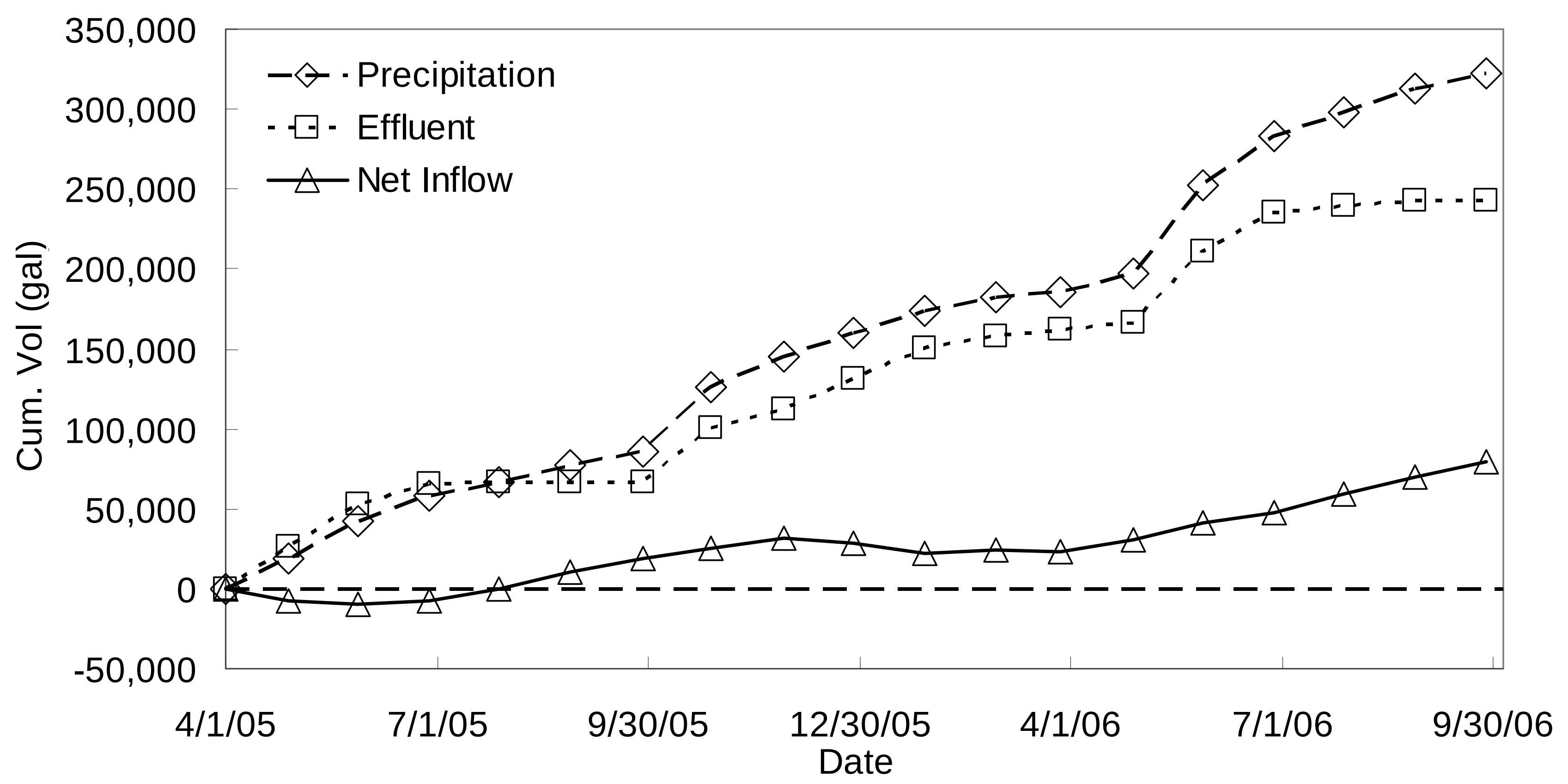
R>P: The rainfall center of mass exceeds hygrograph peak timing

RESULTS

	Method 1 Q-P	Method 2 Lag			Method 3 Q p	Method 3 Q p
		Tbase	Tpeak	Tcentroid	NRCS	Folmar
Mean	88	7	1	1	1	28
Median	90	1	1	1	1	5
Standar Deviation	10	15	2	2	2	37


CN Comparisons
CN
120
100
80
60
40
20
0
Method 1 Q-P
Method 2 Tbase
Method 2 Tpeak
Method 2 Tcentroid
Method 3 Q p-NRCS
Method 3 Q p-Folmar

Long Term Water Balance - PA



Long Term Mass Balance (Q vs P)

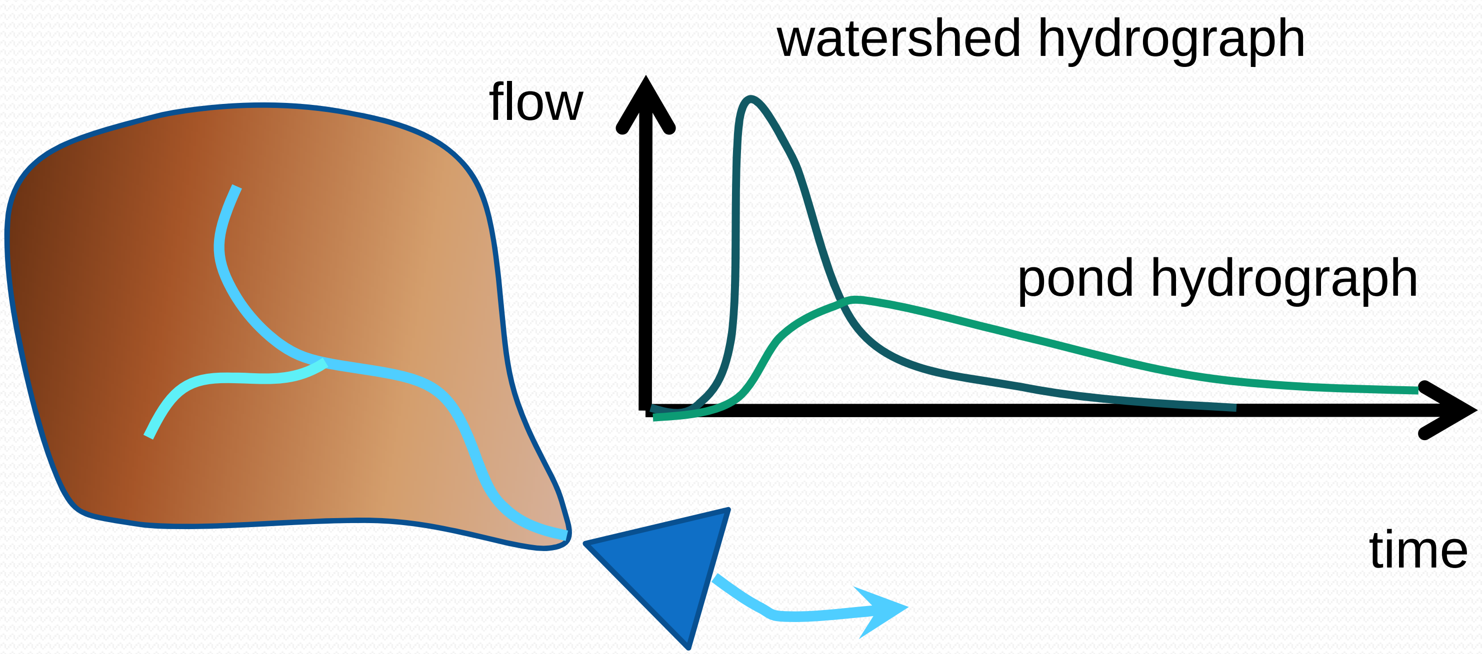
	Curve Numbers	
	A soil system	C soil system
Winter	8	85
Spring	22	100+
Summer	0	63
Fall	2	77

So….Which to Use?

- Events
  - Peak Outflow from Drain
    - Peak flow method
  - No net increase in benchmark storms
    - Lag method
- Long Term Simulation
    - Lag method
    - Runoff depth method
- Watershed Simulation
  - Seasonal CN
  - Lag method

Philosophically Speaking.....

- What is the CN for a detention pond?



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FOLMAR,N.D; MILLER, A.C.; AND WOODWARD, W.E; 2007. "HISTORY AND DEVELOPMENT OF THE NRSC LAG TIME EQUATION". JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION. VOL. 43(3): 829-838.

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UNITED STATES DEPARTMENT OF AGRICULTURE. NATIONAL RESOURCES CONVERSATION SERVICE. 1986. "URBAN HYDROLOGY FOR SMALL WATERSHEDS TR-55". ONLINE HTTP://WWW.WSI.NRCS.USDA.GOV/PRODUCTS/W2Q/H&H/TOOLS_MODELS/OTHER/TR55.HTML

Acknowledgements

Funding Source:

Questions?

http://www.unh.edu/erg/cstev/

or Simply Search for “UNHSC”

INNOVATIVE STORMWATER MANAGEMENT FACILITIES

INFRASTRUCTURE MODIFICATIONS –
BUILDING A GREEN STREET VISION

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- Masters Public Administration – Environmental Affairs, CU Denver
- Registered in 3 states:
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- Worked for many government agencies
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DISCLAIMER

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WATER QUALITY IN OUR EXISTING INFRASTRUCTURE

HOW DO WE DEVELOP A GREEN STREET VISION?

EXISTING PROGRAMS

- UDFCD – Criteria Manuals. Address drainage and water quality of NEW development
- EPA – TMDLs. Total Maximum Daily Loads.
- If A is your TMDL, then B + C + D + E + (etc.) better be less than or equal to A.
- One of the biggest issues we face in meeting this requirement is our EXISTING infrastructure. Most of the runoff from this is untreated.

NEW DEVELOPMENT – EASY

- Codes
- Design Procedures
- Criteria Manuals
- Masterplanning

EXISTING INFRASTRUCTURE – DIFFICULT

- Little or no room
- Facilities can't be modified
- New facilities are expensive or
- No room to retrofit
- Limited technology or facilities out there to utilize.
- Expensive to purchase property
- Public Relations issue(s) – Would you want your parking lot taken away?

SO WHAT DO WE DO?

- Rip-up existing infrastructure and replace it? (Expensive)
- Reduce the impervious footprint. Not as easily done as said. (Expensive)
- Existing technology is a hit and miss as far as what you're trying to do and achieve, and along with its effectiveness.
  - Are you going to street sweep "every day?"
  - Underground WQ & detention is going where?
  - Are you going to take away the valuable parking of a business?

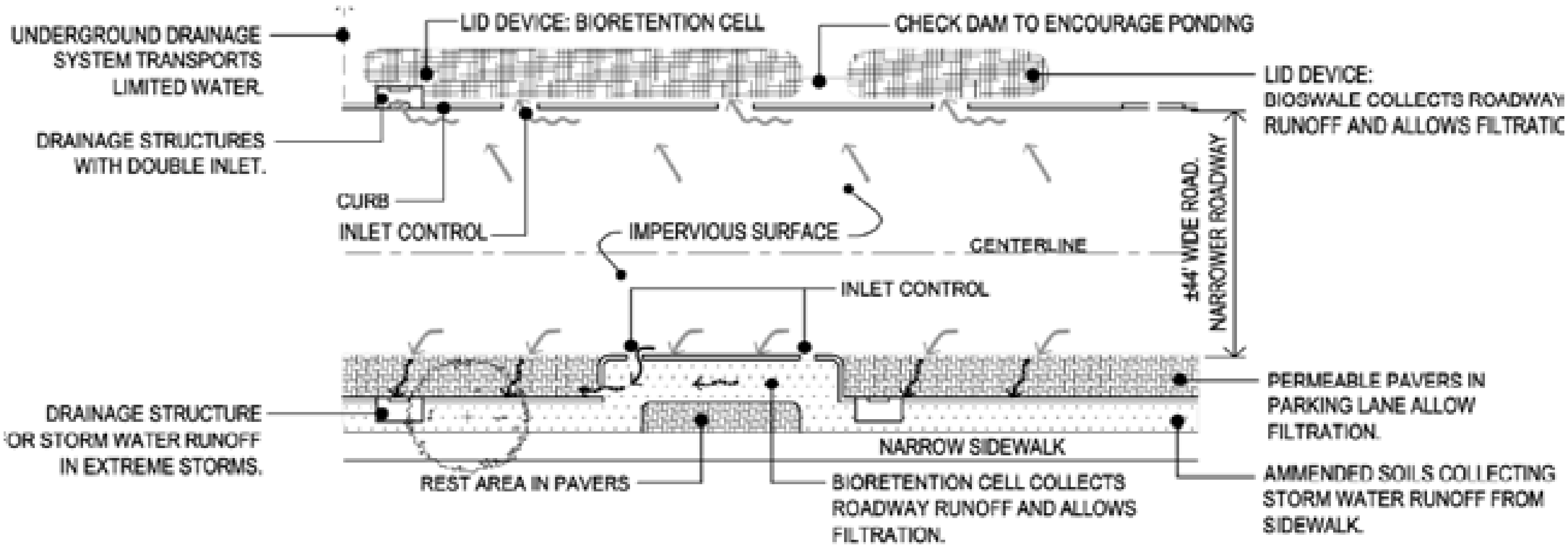
WHAT IS AVAILABLE TO US?

- We need easy, effective, and less expensive water quality facilities in order to meet our TMDLs.
- Some we have. We just need to push the programs and or provide funding or incentives to use them.
- Others need to be included with CIP improvements or upgrades (like ADA)
- Spend the money directly on water quality facilities.

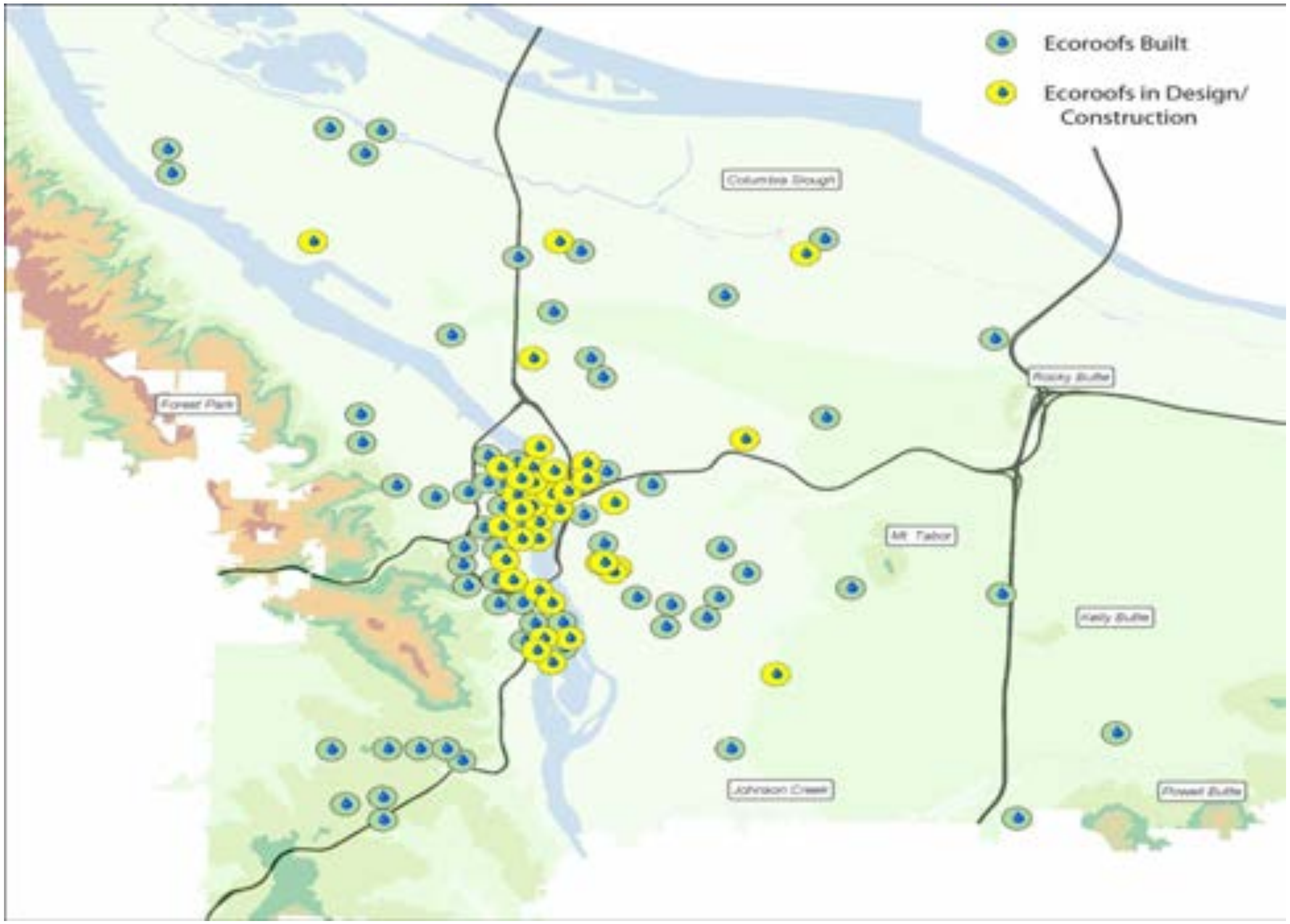
EXISTING PROGRAMS

- ROOFS: Eco-roofs and roof gardens
- These are in UDFCD Manuals.
- Problem – Most roofs aren't structurally sound enough to support eco-roofs.
- Semi-arid region, we need to have the vegetative material appropriate to our region.
- Owner, or developer, is not going to spend the money on an eco-roof. So there needs to be some other kind of funding or incentives to convert roofs of existing structures.

WASHINGTON DC GREEN STREET VISON



ECO – ROOFS AND ROOF GARDENS



ECO – ROOFS AND ROOF GARDENS

REDIRECT THE ROOF DRAINAGE

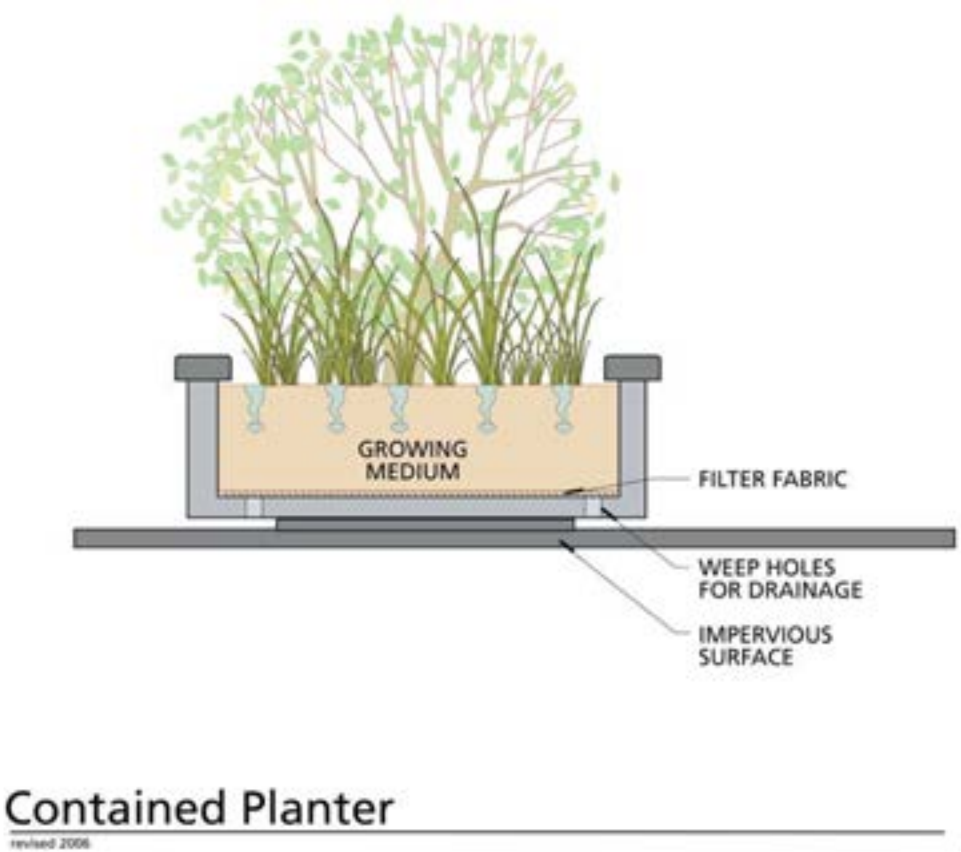
- Disconnect if roof drains and downspouts are directly connected to the street or storm sewer system.
- Redirect the roof drainage to a water quality facility.

LANDSCAPED, OR CONTAINED, PLANTERS

FLOW THROUGH PLANTERS

TREES AND TREE GRATES

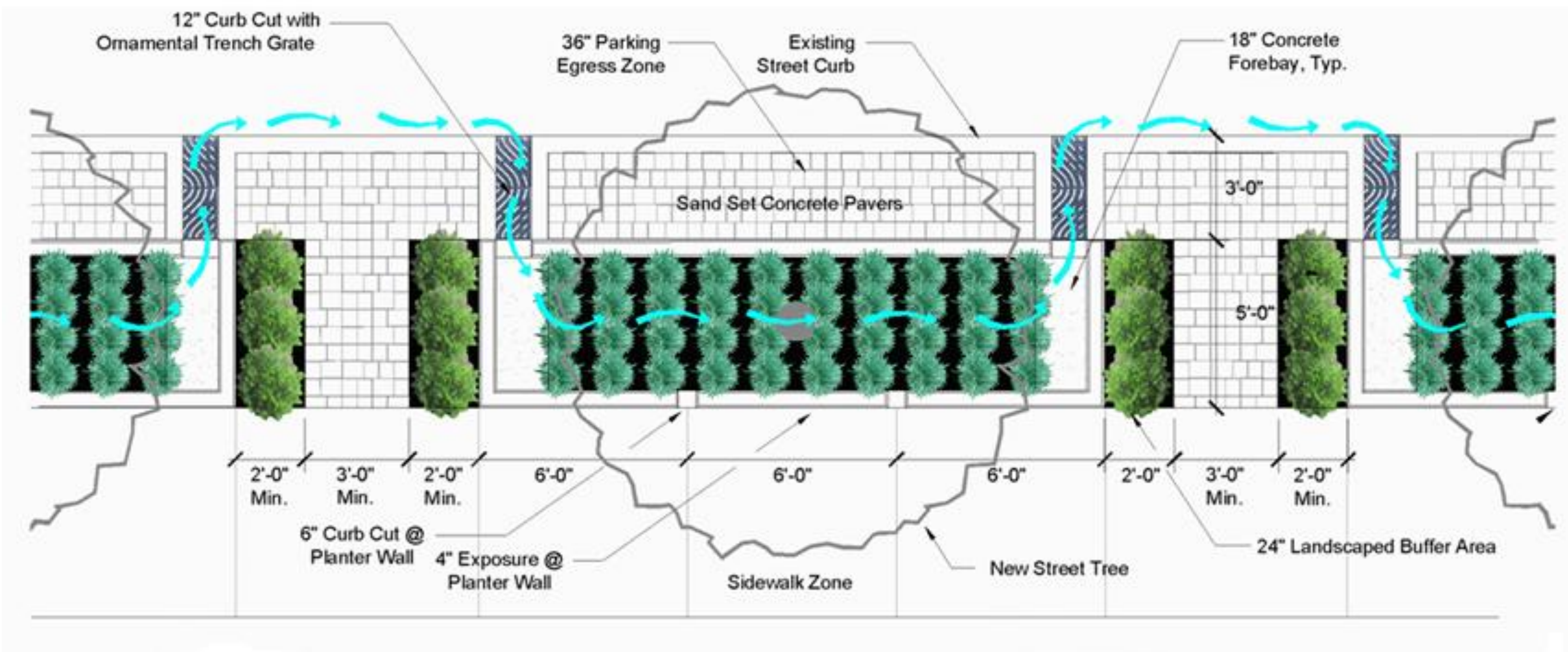
CONTAINED PLANTERS CAN BE USED



VEGETATIVE WALLS

- Modify roof drains to a level spreader, or drip system.
- Also helps with energy conservation. Sun doesn't beat on bare walls.

MEANDERING FLOW LANDSCAPE FACILITIES

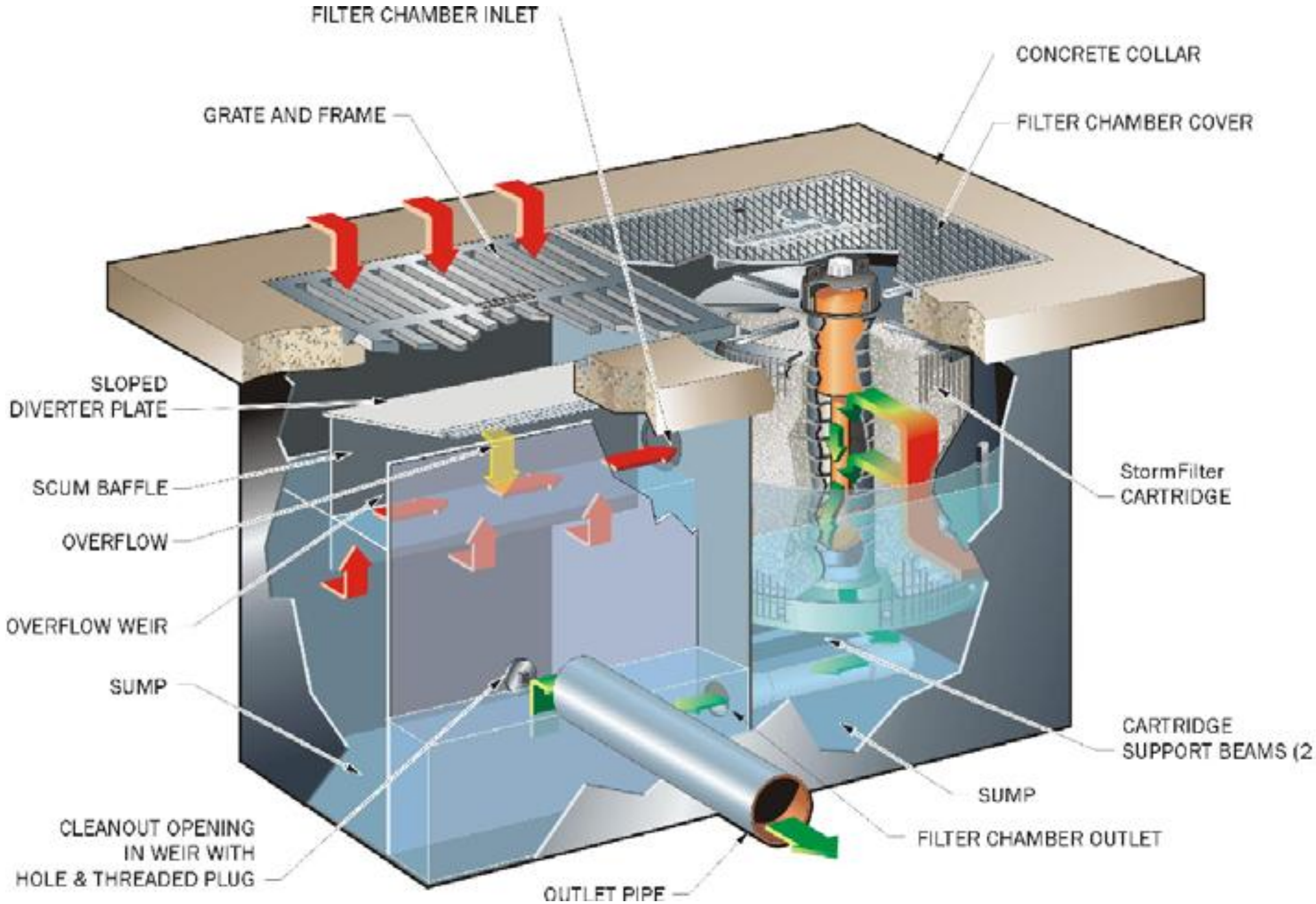



2010/5/11

THIS SHOWS HOW PLANTERS FILTER STORMWATER

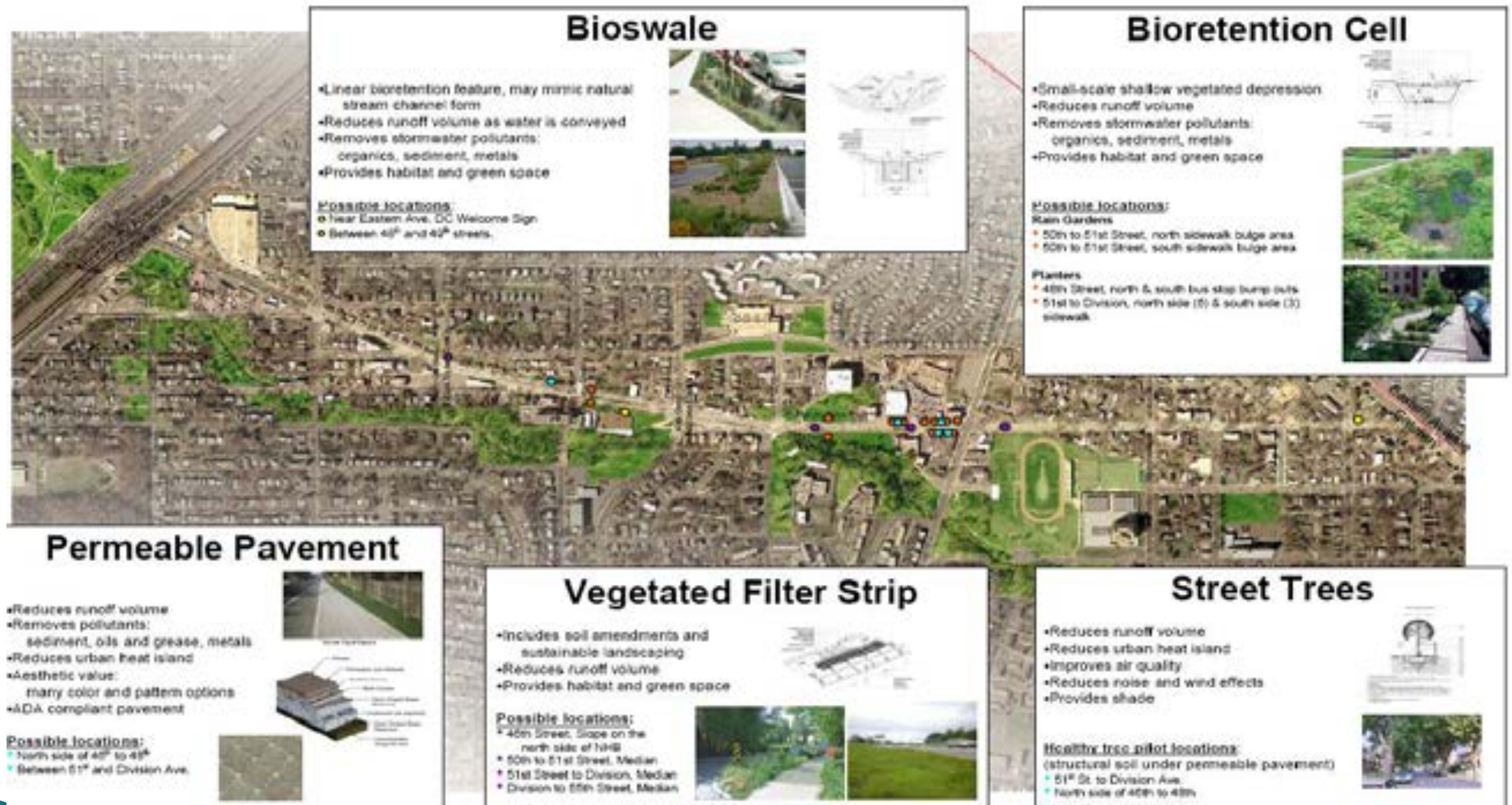
ANOTHER INFILTRATION PLANTER

Stormwater Management – Catchbasin Stormfilter



PAVING BLOCKS IN PARKING STRIPS

DC GREEN STREET “TOOLBOX”



RECHARGE GROUNDWATER (INFILTRATION)

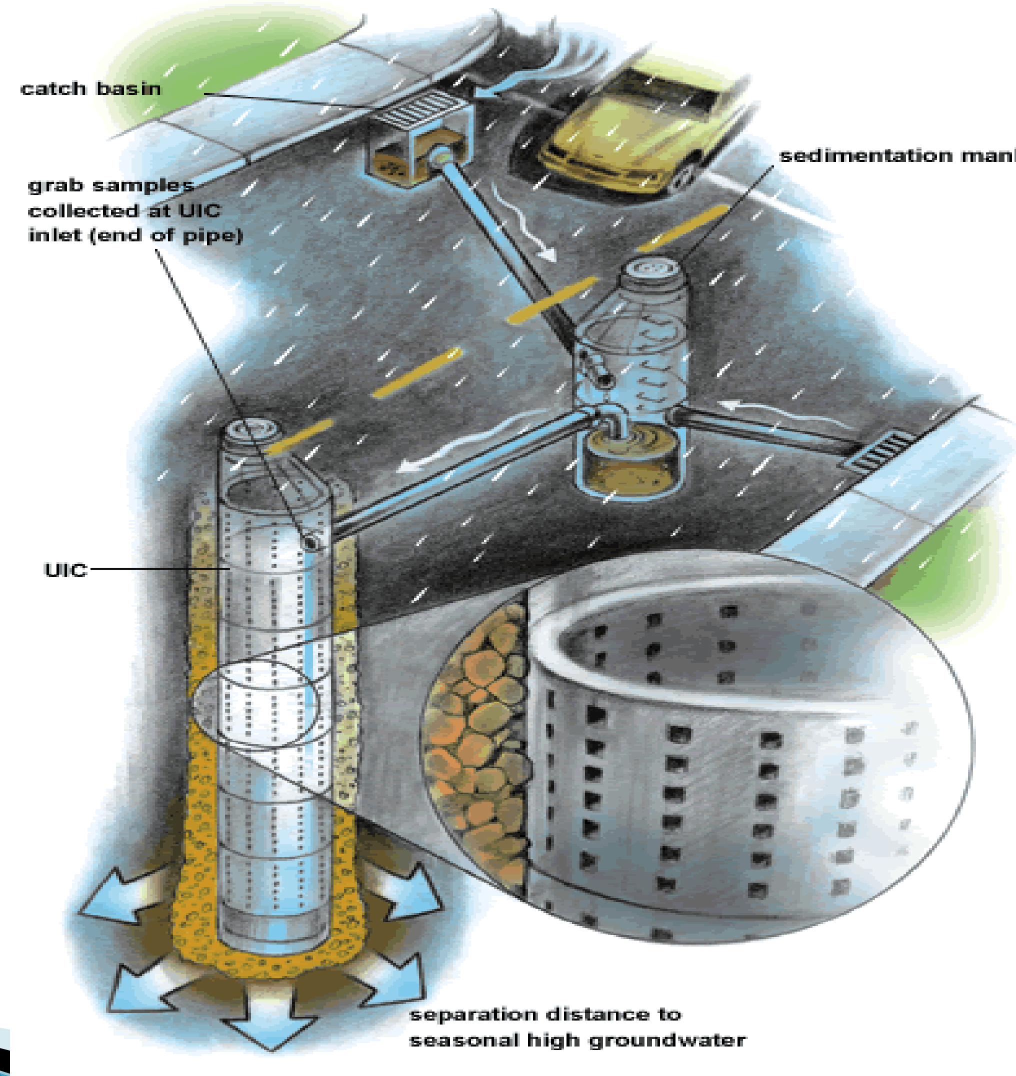
- Portland's program called UIC (Underground Injection Control).
- These are facilities that allow the stormwater runoff to recharge the groundwater rather than be swept away by a sewer system.
- Program needs to be permitted, and is regulated by Oregon's Department of Environmental Quality.

RECHARGE GROUNDWATER

- UICs can be an essential element of a City's comprehensive watershed strategy to use stormwater as a resource by infiltrating it back into the ground.
- UICs quickly and efficiently reintroduce stormwater into subsurface soils, which filter and cool the runoff before it finds its way to groundwater and, eventually, helps recharge streams.
- UICs are an essential element of street-side swales and green street applications because they provide an overflow point during large storm events when stormwater cannot be fully infiltrated through swales, planters, or other surface infiltration systems.
- UICs also preclude the need to install or increase the capacity of piped stormwater infrastructure that eventually discharges into local surface water bodies.

PARKING LOT UIC

STREET UIC CONFIGURATION



CLEAN WATER ACT

- The federal government started the Underground Injection Control Program in 1974 as a means of implementing the Safe Drinking Water Act. The program's goal is to protect groundwater as a drinking water resource and to prevent groundwater contamination from underground injection systems.

- Congress enacted UIC rules in 1974 and modified the rules in 1999. The U.S. Environmental Protection Agency (EPA) administers these rules under Title 40 of the Code of Federal Regulations (CFR) Parts 144-148. In Oregon, EPA has delegated UIC regulation to DEQ. Oregon Administrative Rule (OAR) 340-044 regulates all groundwater as a potential source of drinking water and requires municipalities with more than 50 UICs to operate under a permit. DEQ issued a WPCF permit to the City of Portland on June 1, 2005 (DEQ Permit Number 102830) in response to the OAR.

EVALUATION–SITE ASSESSMENT Portland prohibits UIC's if:

- 1. Receives drainage from motor vehicle maintenance floor drains, indoor parking facilities, fire station bay drains;
- 2. Receives drainage from Superfund Amendment and Reauthorization Act (SARA) Title III facilities;
- 3. Receives drainage from commercial/industrial properties that have site activities that may result in a permit violation;
- 4. Has inadequate separation distance to groundwater; or
- 5. Is within 500 feet of a drinking water well or within 2-year time of travel.

TYPES OF FACILITIES

- Sedimentation Manhole – Primary purpose is to remove particulates from stormwater prior to getting into the UIC.
- Cylindrical drywells – the sides of this UIC are perforated and allow exfiltration of stormwater into the surrounding soils.
- Soakage Trenches/Perforated Pipes. Use in landscaped areas, medians, tree strips.
- Drywells – For smaller sites and parking lots

WHAT ELSE?

- Modify existing inlets.
  - Turn into drywells
  - Modify them by adding filter media
  - Connect them to a filter strip or soakage trench
- Street Sweeping – expensive, and needs to be performed regularly.
- ??? New ideas are always coming along…

Pueblo Low Impact Development (LID) Concepts

Short Elliott Hendrickson Inc. (SEH)

Lakewood, Colorado

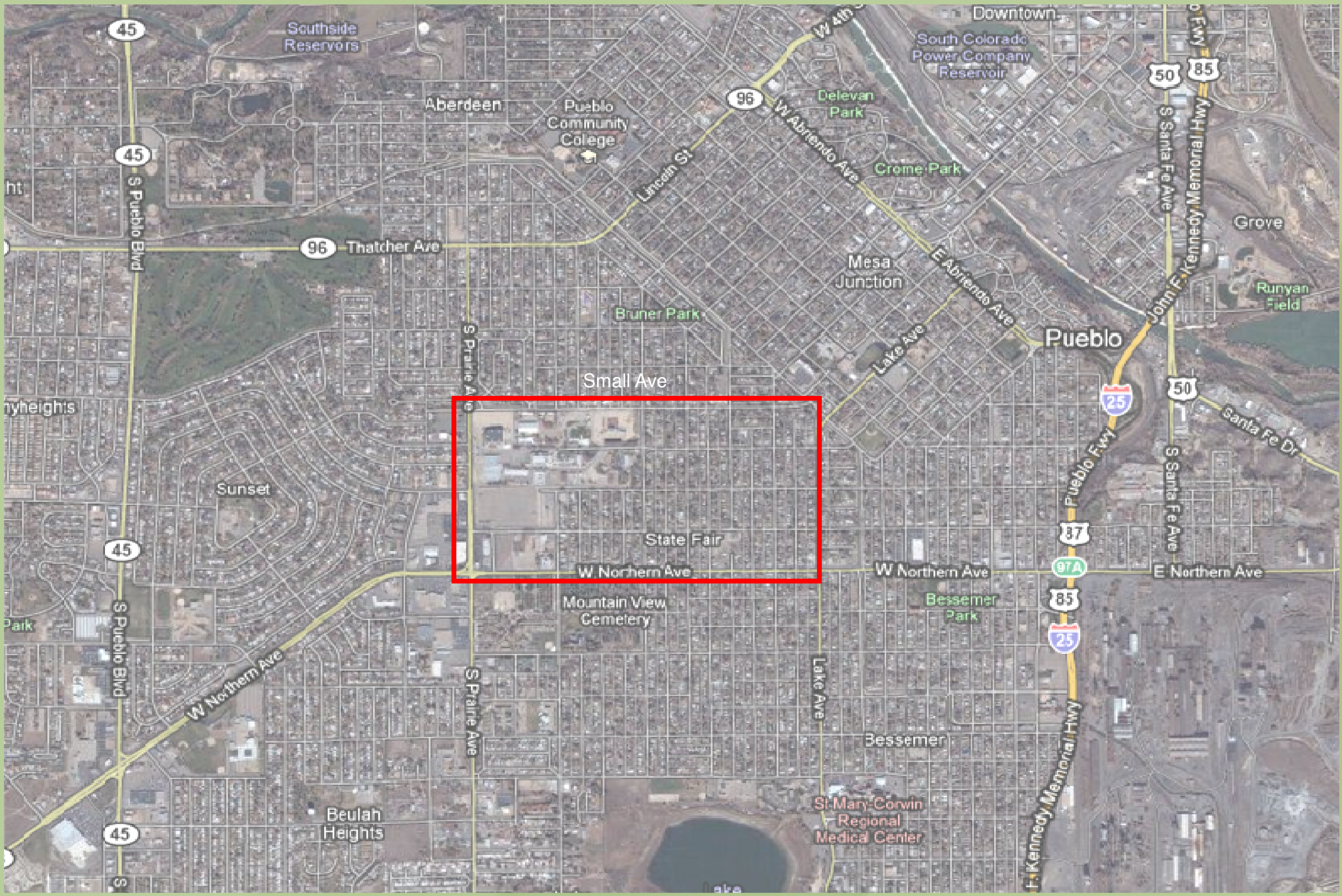
Kelly Jankowski, EI

SEH

Project Overview

- Scope of work
  - Site visit and photo documentation
  - Best Management Practices (BMPs) selection
  - Plans and details showing the location of BMPs
  - Hydrologic impact
  - Hydrologic benefit of BMPs

Site Location
Pueblo, Colorado



Best Management Practices (BMP) Selection

Table 1: BMP Scoring Matrix

BMP	Purpose	Source	Most Applicable to Site for Flow Reduction	Temporary BMPs	Project Appropriate (Infiltration/ Detention)	Hydrologic Impact	Costs	Environmental Impact	Proven/ Acceptance/ Simplicity	Score Frequent Event	Score Major Event
Reduce Impervious Surfaces	To minimize runoff by reducing impervious surfaces, therefore reducing the need for storm systems, and letting natural surfaces infiltrate runoff.	Low Impact Development Applications for Water Resource Management ASCE	✓		+	++	+	+	+	6	N/A
Grass Buffer	To promote filtration, infiltration and settling to reduce runoff pollutants. Sheet flow is necessary for these to be beneficial. Irrigation is crucial to maintain healthy, dense grass.	Urban Storm Drainage Criteria Manual, Vol. 3 Urban Drainage & Flood Control District	✓		+	+	+	+	+	5	N/A
Grass Swale	To facilitate sedimentation while limiting erosion.	Urban Storm Drainage Criteria Manual, Vol. 3 Urban Drainage & Flood Control District	✓		+	+	+	+	+	5	N/A
Minimize Clearing & Grading	To minimize sediment laden runoff by preserving and utilizing the existing environment.	Low Impact Development Applications for Water Resource Management ASCE			0	++	+	++	0	5	N/A
Depression Storage	To increase localized detention storage and increase infiltration possibility.	Low Impact Development Applications for Water Resource Management ASCE	✓		++	+	+	+	0	5	N/A
Conservation Plans/Regulations	To conserve natural resources such as forests, streams, wetlands, habitats, parks, critical areas, trails, shore lines, agricultural lands, minerals, etc. promoting historic hydrologic conditions.	Low Impact Development Applications for Water Resource Management ASCE			0	++	0	++	0	4	N/A
Conserve A & B Type Soils	To conserve the A & B type soils to allow for better drainage. A & B type soils have higher infiltration rates than C & D types soils allowing them to absorb runoff easier.	Low Impact Development Applications for Water Resource Management ASCE	✓		+	++	0	+	0	4	N/A
Wet Swale	To filter pollutants as stormwater runoff moves through the swale. Grass or other vegetation is used to provide conveyance and to filter out pollutants. Essentially the same as a dry swale except there is a ponding area at the bottom of the slope.	Erosion Control & Stormwater Quality Guide Colorado Department of Transportation	✓		+	+	+	+	0	4	4
Slow Release Detention Basin	To facilitate pollutant and sediment removal. This is a sedimentation basin designed to totally drain after stormwater runoff ends. The outlet of this basin is much smaller than that of a detention basin, therefore extending the emptying time (usually 40 hours) of more frequently occurring storm events.	Urban Storm Drainage Criteria Manual, Vol. 3 Urban Drainage & Flood Control District	✓		++	++	0	0	0	4	4
Rain Gardens/Bioretention	To provide storage in the form of a garden for stormwater runoff. These gardens are typically placed in low areas and capture runoff from storm events.	Low Impact Development Applications for Water Resource Management ASCE	✓		++	+	+	+	-	4	N/A
Dry Swale	To filter pollutants as stormwater runoff moves through the swale. Grass or other vegetation is used to provide conveyance and to filter out pollutants.	Erosion Control & Stormwater Quality Guide Colorado Department of Transportation			0	+	+	+	0	3	N/A
Seeding	To quickly germinate vegetative cover on disturbed areas to stabilize soils and control erosion.	Drainage Criteria Manual, Vol. 2 Stormwater Quality Policies, Procedures & BMPs			0	0	+	+	+	3	N/A
Increase Disconnects	To reduce the amount of impervious surfaces connected directly to storm systems. This lengthens the time of concentration and allows for more infiltration to take place.	Low Impact Development Applications for Water Resource Management ASCE			+	++	+	0	-	3	N/A
Porous Pavement	To help reduce runoff & pollutants from developed sites. These pavements allow rainwater to pass through the surface to a stone recharge bed constructed using crushed aggregate with high voids that allow room to store water.	www.[illegible].com	✓		+	+	+	0	0	3	N/A
Reduce Pipe, Curb and Gutter	To utilize natural drainage methods, such as open channel flow, to deal with runoff while trying to mimic existing hydrologic conditions.	Low Impact Development Applications for Water Resource Management ASCE			+	++	+	0	-	3	N/A
Extended Detention Shallow Wetland	Acts the same as a wetland basin except it has additional detention storage.	Erosion Control & Stormwater Quality Guide Colorado Department of Transportation	✓		++	+	0	+	-	3	N/A
[illegible]	To capture and treat a volume of stormwater runoff. The bioretention area is an excavated pit filled with planting [illegible]	Erosion Control & Stormwater Quality Guide [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

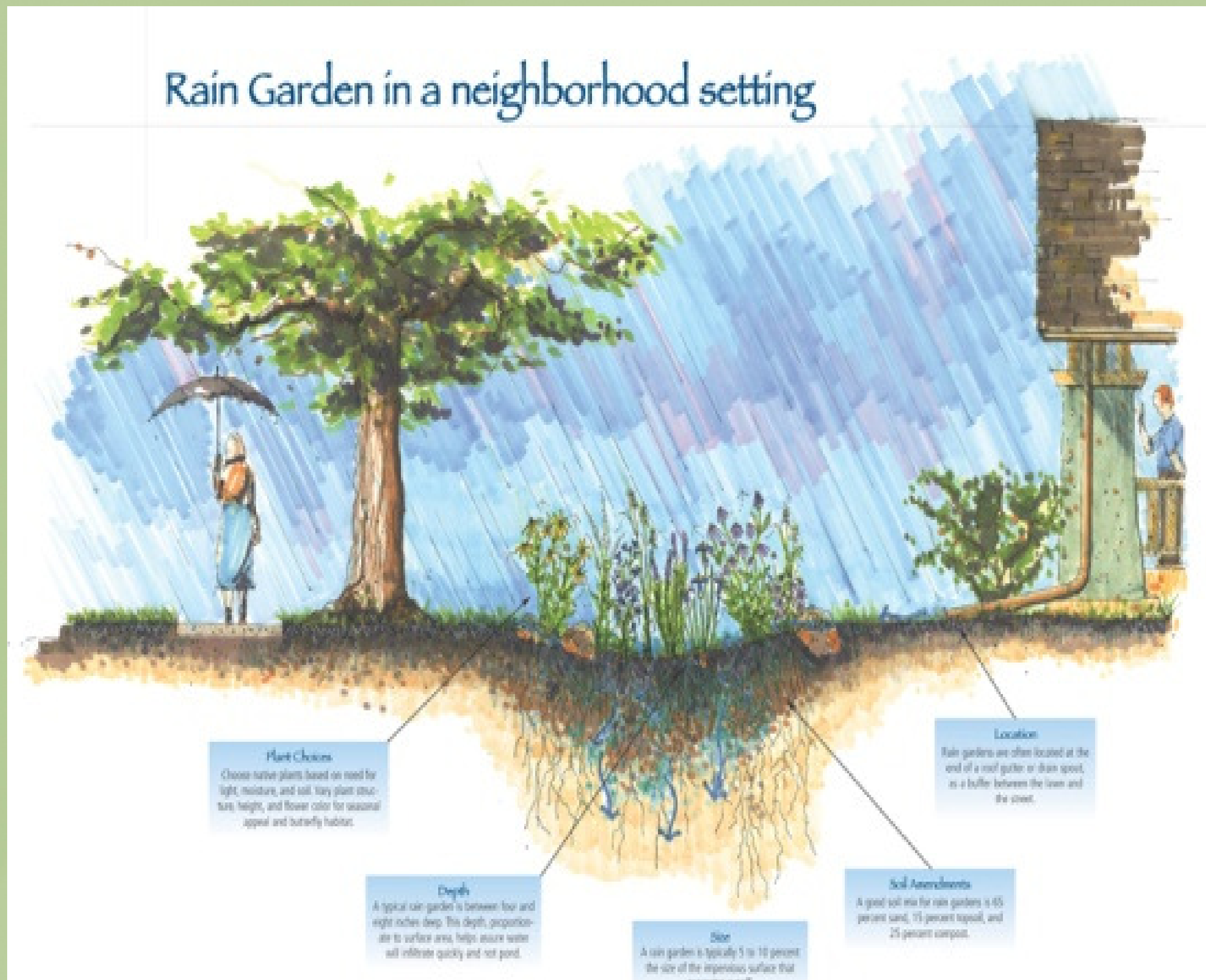
Best Management Practices (BMP) Selection

- State Fairgrounds
  - Rain Barrels (72-hour release)
  - Rain Gardens
  - Depressed Parking/ Slow Release Detention
  - Reduced Impervious Surface Area
  - Porous Landscape Detention
- Residential Area
  - Rain Barrels (72-hour release)
  - Porous Pavers
  - Local Detention
  - Short Street Calming Devices at Intersections with Porous Landscape Detention and Rain Gardens

Rain Barrel

http://www.stltoday.com/blogzone/political-fix/files/2009/04/rain-barrel.jpg

Rain Garden



http://www.ia.nrcs.usda.gov/news/images/Pics/RainGardensmall.jpg

Slow Release Detention Basin

http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=67

Porous Landscape Detention

http://www.casfm.org/stormwater_committee/images/IMGP6666.gif

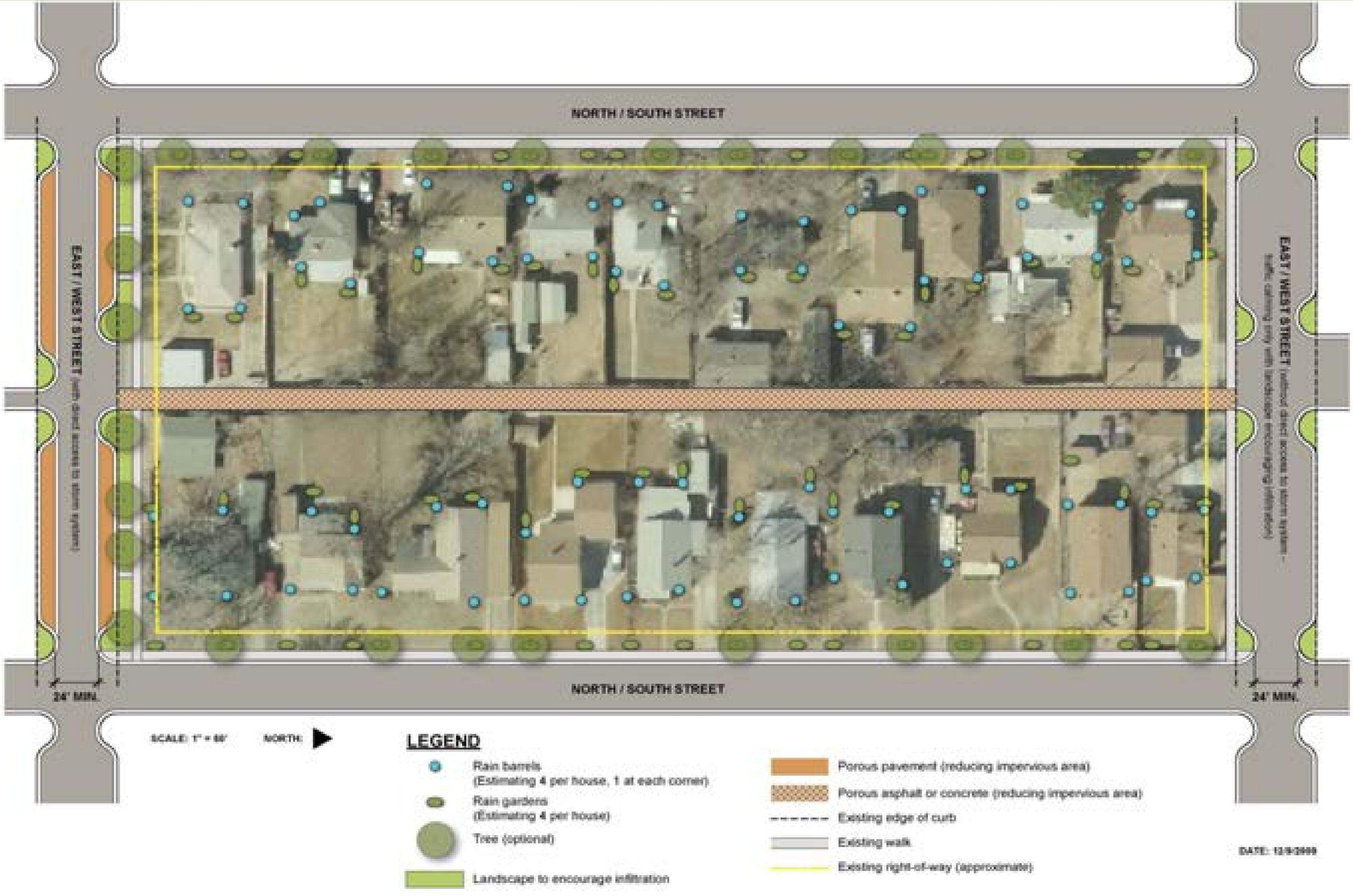
Porous Pavement

Street Calming Devices

http://www.lowimpactdevelopment.org/greenstreets/images

Overall Site Aerial

Typical Residential Block



Residential Area - Before

Residential Area - After

State Fairgrounds - Before

State Fairgrounds - After

Streetscape - Before

Streetscape - After

Hydrologic Impact - Methodology

- Colorado Urban Hydrograph Procedure (CUHP) v. 2000
- Models
  – Base Hydrologic Model
  – Rain Barrels
  – Porous Pavement and Rain Gardens
  – Street Calming Devices and Porous Landscape Detention
  – Slow Release Detention
  – Reduced Impervious Area

Impact of Rain Barrels on Storm Runoff Characteristics

Storm Frequency	Δ Vol. (%)	Δ Qp (%)
Annual	-17%	-25%
2yr	-5%	-5%
5yr	-3%	-3%
10yr	-3%	-2%
100yr	-1%	-1%

Assumptions:

- Typical Rain Barrel capacity of 50 gallons
- Average roof area of 1500 sf
- Four Rain Barrels per building

Model Modifications:

- Impervious Depression Storage Parameter (0.1 in -> 0.16 in)

Impact of Porous Pavement and Rain Gardens on Storm Runoff Characteristics

Storm Frequency	Δ Vol. (%)	Δ Qp (%)
Annual	-25%	-24%
2yr	-5%	1%
5yr	-2%	1%
10yr	-1%	1%
100yr	-1%	0%

Model Modifications:

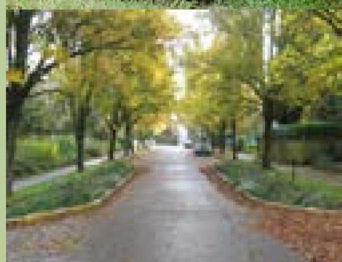
- Minimum Directly Connected Impervious Area (MDCIA) – Level 1

Impact of Street Calming Devices and Porous Landscape Detention on Storm Runoff Characteristics

Storm Frequency	Δ Vol. (%)	Δ Qp (%)
Annual	-68%	-73%
2yr	-13%	-7%
5yr	-5%	-8%
10yr	-3%	-9%
100yr	-1%	-9%

Model Modifications:

- Minimum Directly Connected Impervious Area (MDCIA) – Level 2


Impact of Rain Barrels, Street Calming Devices and Porous Landscape Detention on Storm Runoff Characteristics

Storm Frequency	Δ Vol. (%)	Δ Qp (%)
Annual	-75%	-78%
2yr	-18%	-13%
5yr	-8%	-12%
10yr	-5%	-12%
100yr	-3%	-10%

Model Modifications:

- Impervious Depression Storage Parameter (0.1 in -> 0.16 in)
- Minimum Directly Connected Impervious Area (MDCIA) – Level 2

Impact of Slow Release Detention on Storm Runoff Characteristics

Storm Frequency	Δ Vol. (%)	Δ Qp (%)
Annual	-78%	-79%
2yr	-22%	-19%
5yr	-13%	-17%
10yr	-10%	-20%
100yr	-8%	-16%

Assumptions:

- Slow Release Detention areas are fully detained and do not contribute to the stormwater volumes and discharges of the sub-basin.

Model Modifications:

- Remove the sum of the area to be Slow Release Detention from the total sub-basin area

http://www.apartmenttherapy.com/boston/outdoor/oldfashioned-ribbon-driveways-119857

Impact of Reduced Impervious Area on Storm Runoff Characteristics

Storm Frequency	Δ Vol. (%)	Δ Qp (%)
Annual	-78%	-84%
2yr	-22%	-23%
5yr	-11%	-19%
10yr	-8%	-19%
100yr	-4%	-17%

Model Modifications:

- Reduce the percent impervious of each basin by three (3) percent

Conclusion

- Rain Barrels are a very cost effective way to reduce frequent storm event flows
- Slow Release Detention is the most effective way to reduce flows from large storm events
  - Location Critical
- For this retrofit project, LID was not able to reduce the large storm events enough to significantly downsize diameters of receiving storm sewers

Low Impact Development on a Federal Installation

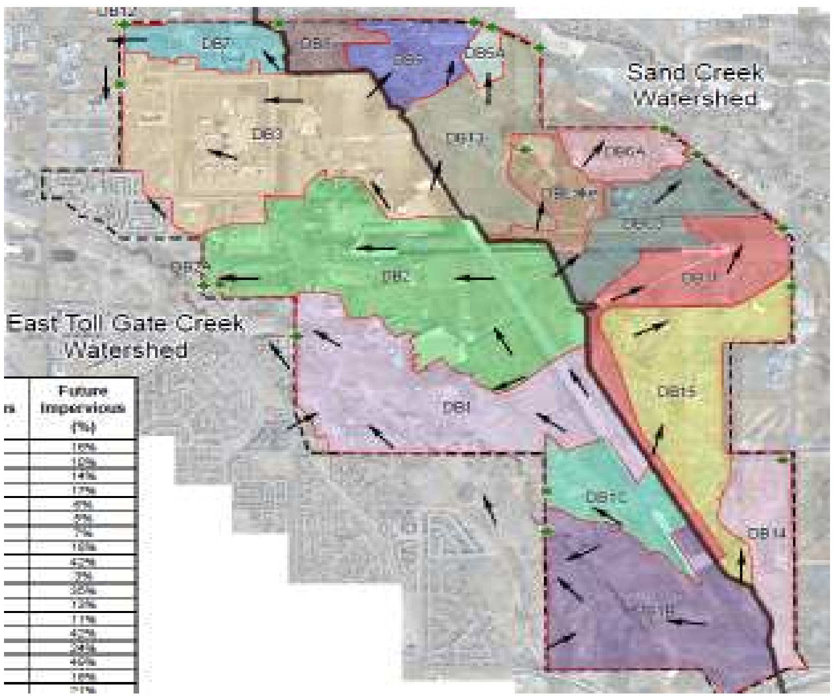
E. John Loranger PE, CFM AMEC Earth and Environmental
Jeff Cheng PE, AMEC Earth and Environmental
Dorothy Eisenbraun PE, AMEC Earth and Environmental
Chad Callan, 460 CES Engineering Flight

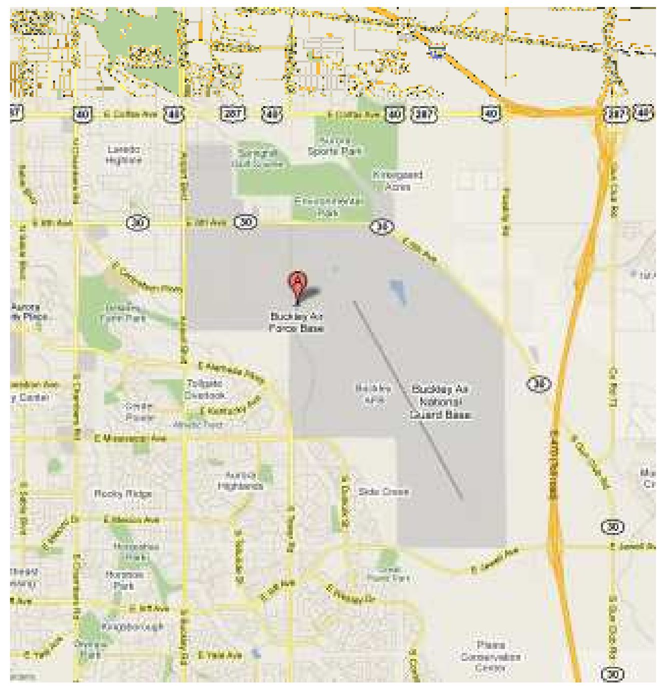
Overview

- Background
- EISA 2007 Section 438
- EO 13514
- Technical Guidance
  - EPA 814-B-09-001
- Conventional/LID Approach
- EPA SWMM5 Lumped Model
- Distributed Model
- LID Benefits to the Master Plan

Background

- **Buckley Air Force Base**
  - **Location, size**
  - **Describe watersheds/drainages**
  - **Fast Growing**





Background

- Approach to Master Plan
  - Military installation vs. municipal
  - Existing Conditions Evaluation
  - Future Conditions Evaluation
  - Recommendations
    - Upsizing
    - Maintenance
    - Expansion
    - LID

Energy Independence and Security Act of 2007

- **Federal Stormwater Runoff Requirements**
  - **New Development > 5000 ft^2 footprint**
  - **Re-Development > 5000 ft^2 footprint**
- **Replicate Pre-development Hydrology**
  - **"The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 ft^2 shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow."**

Executive Order 13514

- **Section 14**
  - ***Stormwater Guidance for Federal Facilities.*** **Within 60 days of the date of this order, the Environmental Protection Agency, in coordination with other Federal agencies as appropriate, shall issue guidance on the implementation of section 438 of the Energy Independence and Security Act of 2007.**

EPA Technical Guidance

- EPA 841-B-09-001
  - How to Achieve, Measure and Evaluate
- Pre-Development Hydrology
  - Volume
  - Flowrate
  - Duration
  - Temperature
- Retain the 95th Percentile Storm
- Site Specific Hydrologic Analysis

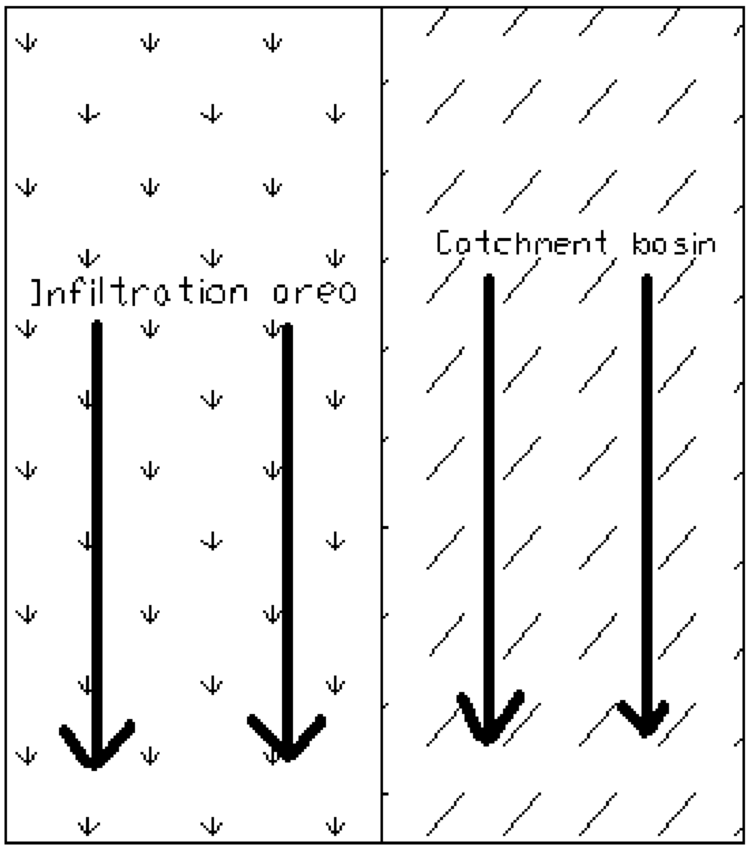
Conventional/LID Approach

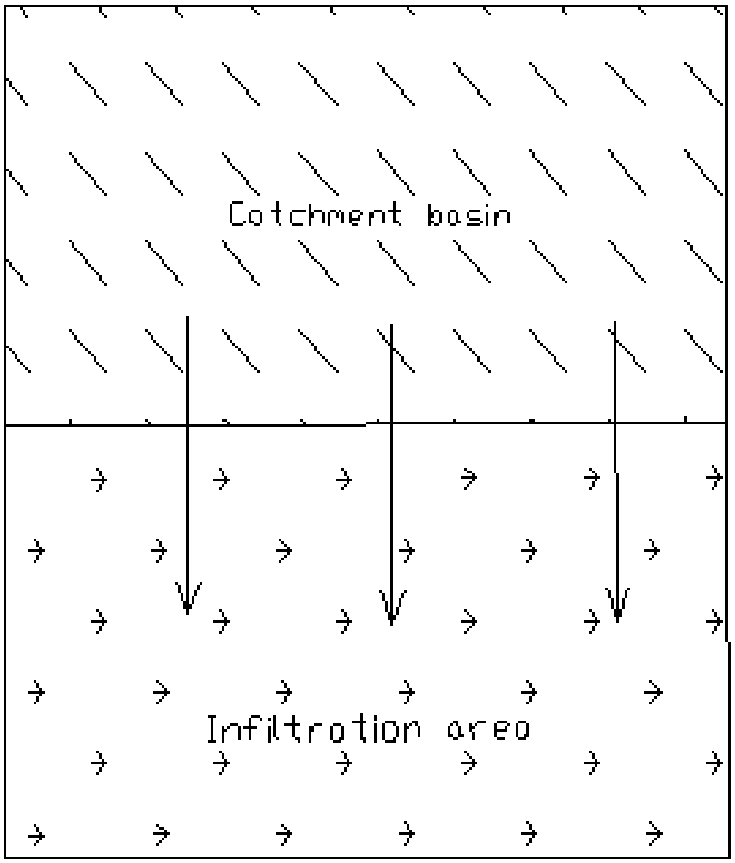
- **Future Conditions Build out**
  - **LID Approach**
- **Existing Infrastructure**
  - **Conventional Approach**

Conventional/LID Modeling Approach

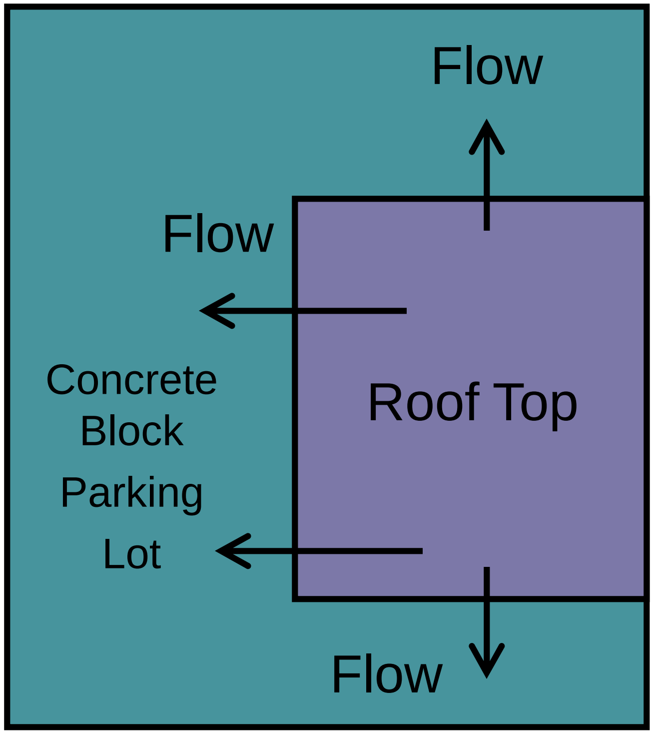
- **Conventional Watershed Model**
  - **EPA SWMM5 natural plan method**
  - **Impervious to outlet**
  - **Pervious to outlet**
- **Cascading Plane Model**
  - **Pervious to Outlet**
  - **Impervious to outlet**
  - **Impervious to Pervious to Outlet**

Cascading Plane on Central Channel and Cascading Planes

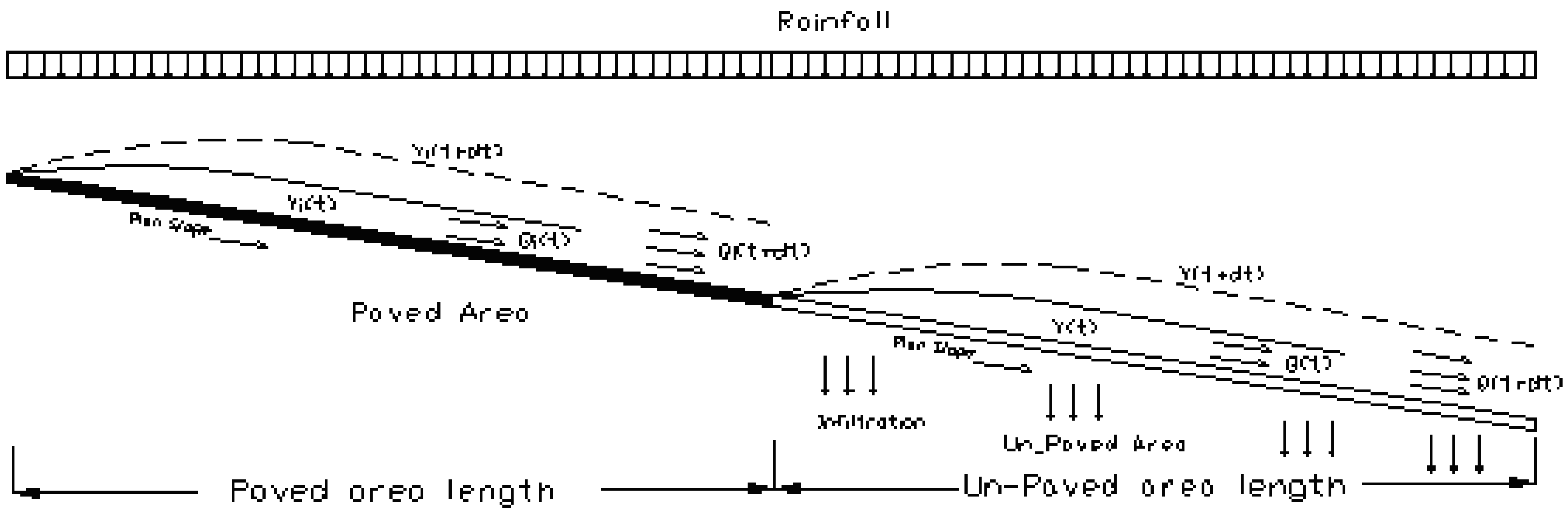




Example of Cascading Plane



Cascading Overland Flow



Distributed Approach

The cascading KW model needs to follow two major principles:

Continuity principles, which can be described as:

$$\frac{q_i(t+\Delta t)+q_i(t)}{2}+[\frac{I_e(t+\Delta t)+I_e(t)}{2}\Delta x-\frac{q_o(t+\Delta t)+q_o(t)}{2}]=\frac{Y(t+\Delta t)-Y(t)}{\Delta t}\Delta x$$

$$I_e = I - f$$

q = flow per unit width, I = rainfall intensity, Y= flow depth, X = length of reach, and f = infiltration loss.

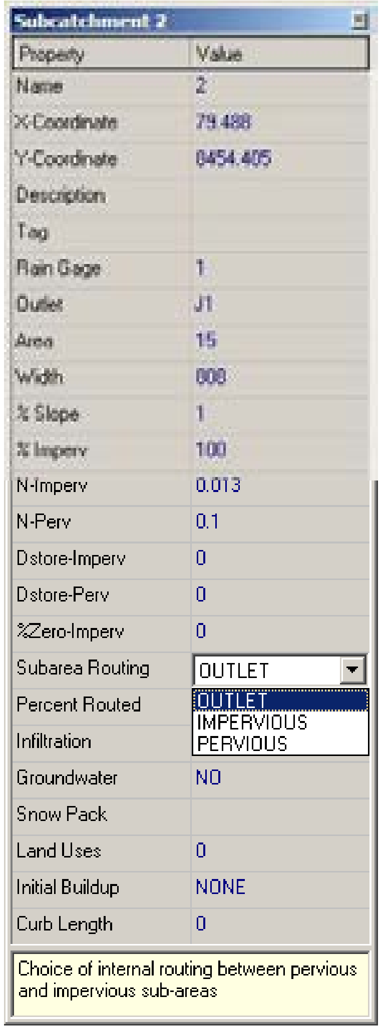
Momentum principles for KW plane considers the flow slope as same as friction slope, which the equation can be described as :

$$S_0 = S_f$$

$$q_o(t+\Delta t)=\frac{1.49}{n}[Y(t+\Delta t)]^{\frac{5}{3}}\sqrt{S_o}$$

Lumped Approach

- **SWMM5 employed to conduct the lumped model approach**
- **Comparisons between lumped and distributed models can provide guidance to generalize the application of KW shape function to the LID layout**



LID Benefits to the Master Plan

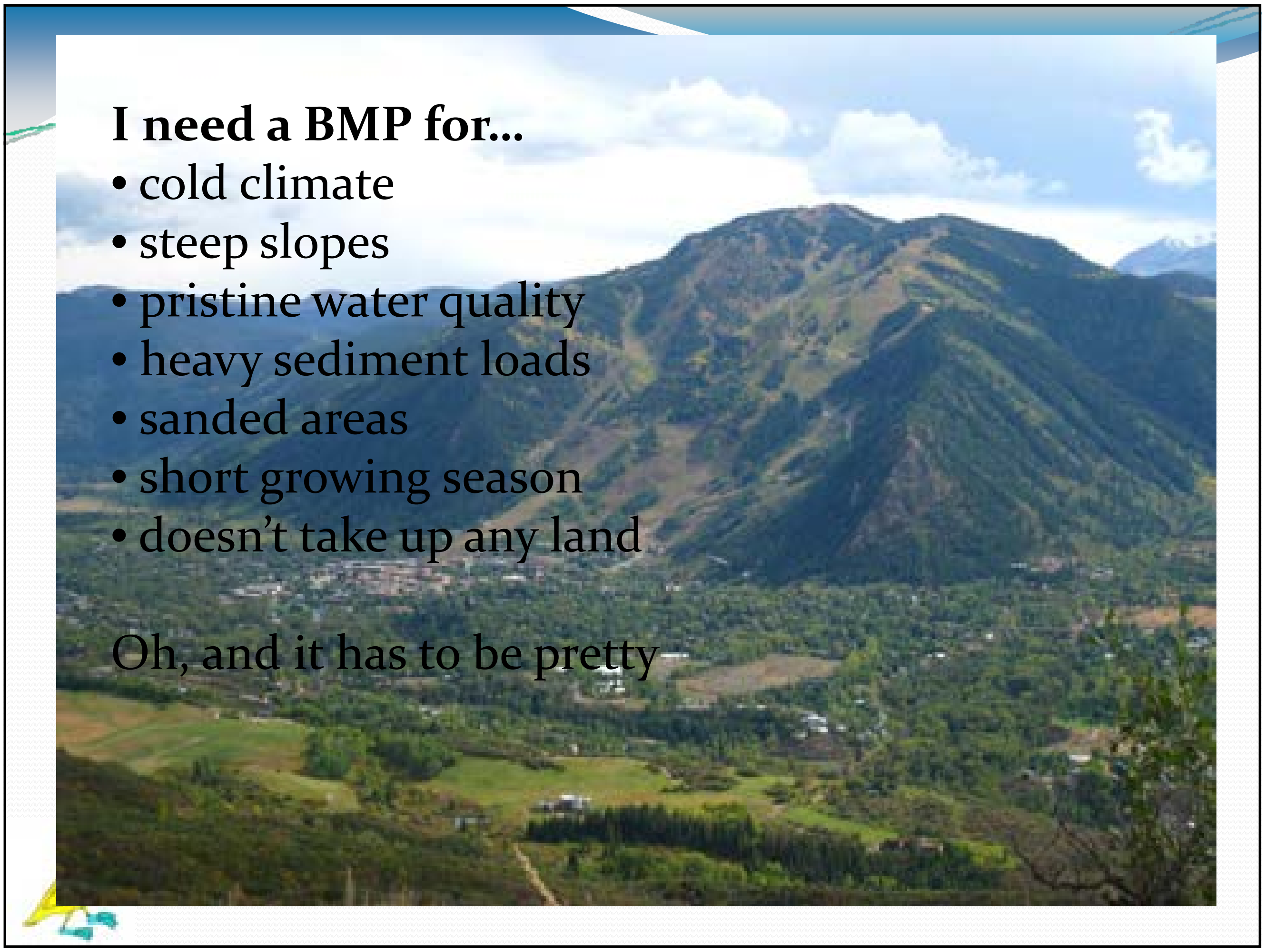
- **One of the 1st LID Masterplans in Colorado**
- **Quantify On-Site Infiltration Volume**
  - **Minor Event**
  - **Major Event**
- **LID Reduction in Conventional Stormwater Management Costs/Infrastructure**
- **Less Downstream Stormwater Impact**

QUESTIONS?

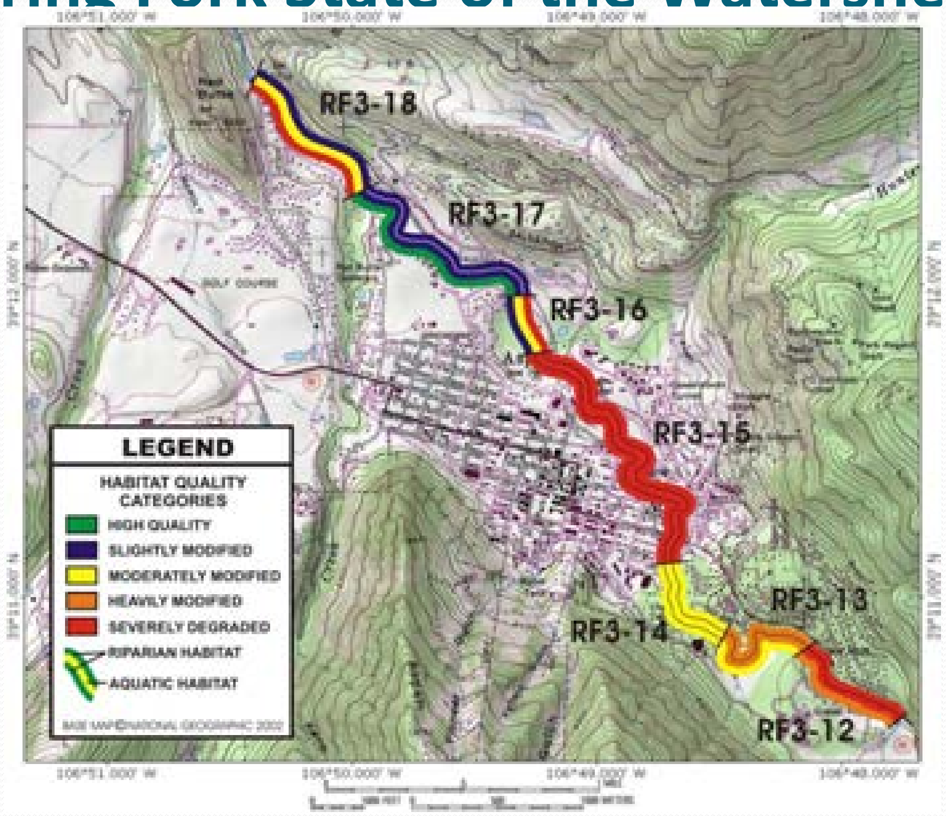
City of Aspen
Urban Runoff Management Plan
Low Impact at High Elevations

September 23, 2010

April Barker, COA Stormwater Manager


I need a BMP for…
• cold climate
• steep slopes
• pristine water quality
• heavy sediment loads
• sanded areas
• short growing season
• doesn't take up any land
Oh, and it has to be pretty

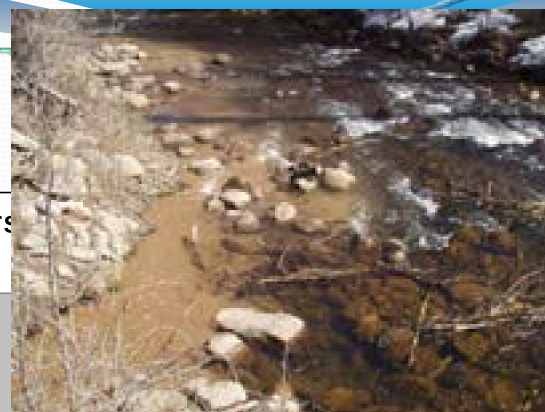
Roaring Fork State of the Watershed

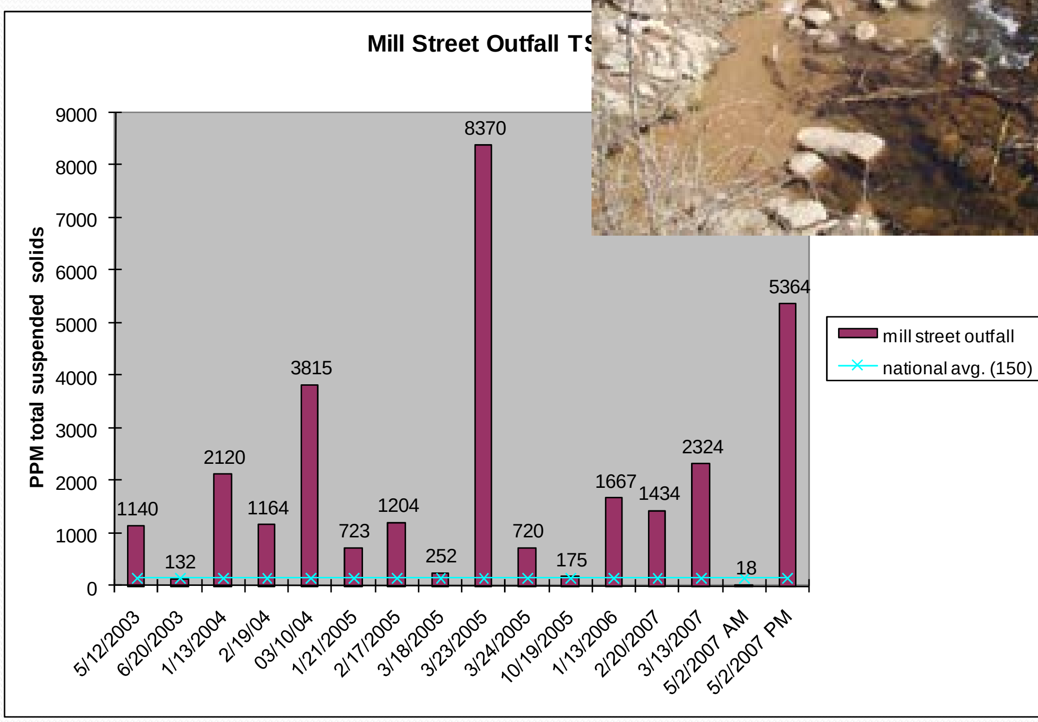


Common Urban Pollutants

- Increases with impervious area:
- Total Suspended Solids (TSS)
- Nutrients
- Metals
- Oxygen Demand
- Hydrocarbons
- Pathogens

Priority Pollutants





A message from our sponsors…

- AMEC Earth and Environmental – *Jon Sorenson, Dr. Jim Guo, Jeff Cheng*
- Wright Water Engineers – *Andrew Earles*
- Wenk and Associates – *Greg Dorolek*
- UDFCD Volume 3

Undeveloped in Aspen
Runoff 30 times per year

Developed in Aspen
Runoff 80 times per year

Aspen Specific Data…

	Annual Average
Max Temp	55.5 F
Min Temp	27.7 F
Precipitation	24.37 inches
Snowfall	173.8 inches

Elevation = 8000

Population = 6000 – 20,000

Area = 3 square miles

Event	Intensity (inches/hour) 1-hour
2-year	0.64
5-year	1.00
10-year	1.20
25-year	1.40
50-year	1.60
100-year	1.69

Snow on ground, in town
7 months of year

Challenges Unique to Aspen

- Cold Temperatures
- Deep Frost Line
- Short Growing Season
- Significant Snowfall
- Midwinter Snowmelts
- Rain on Snow
- Spring Runoff
- Sanding Practices
- Steep Slopes
- Resort Setting
- Dense Development

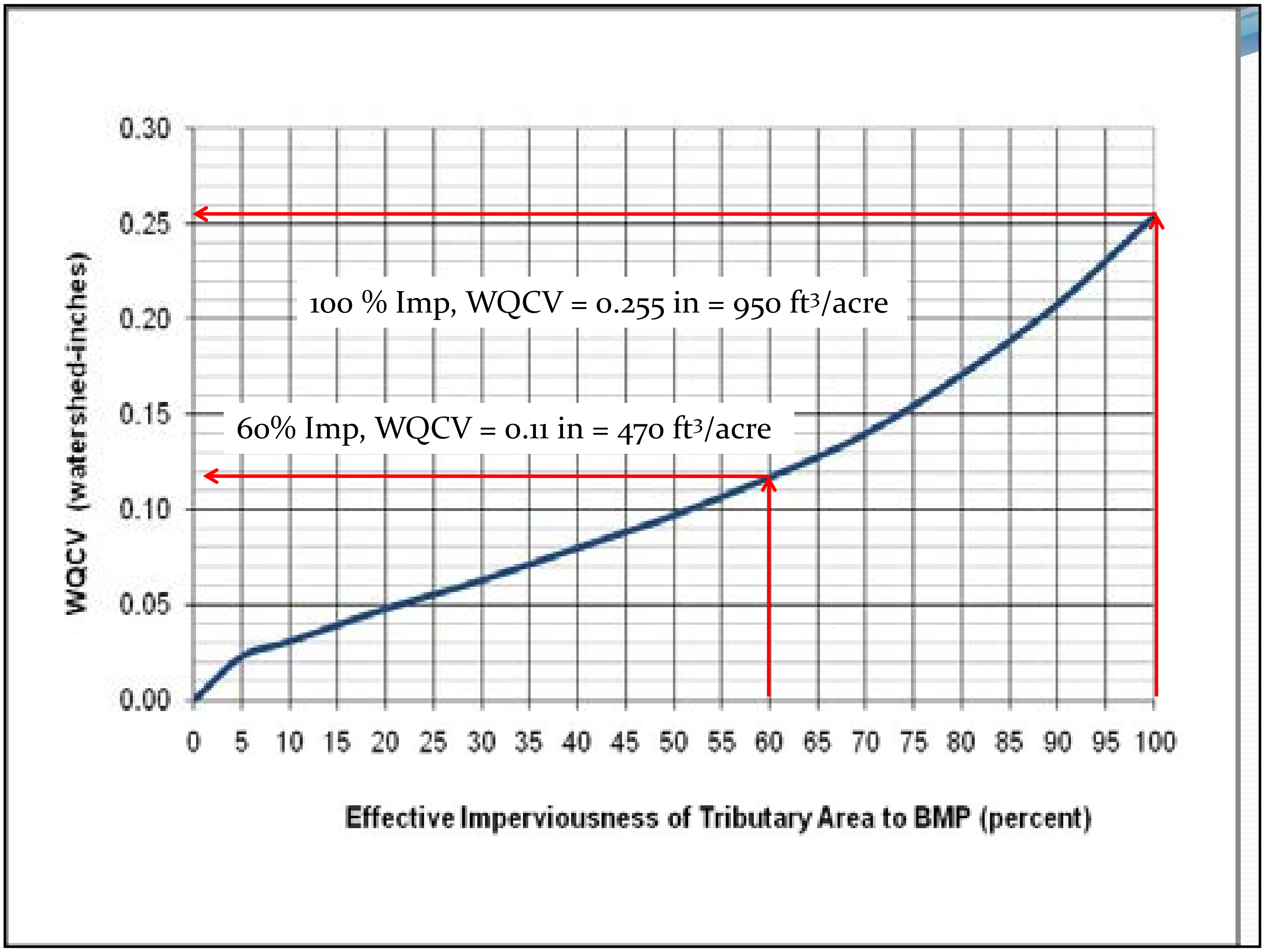
Goals for water quality…

- Provide full water quality treatment for up to the 80th percentile runoff event
- For events larger than the 80th percentile event, BMPs will provide treatment of the "first flush"
- Based on 12-hour drain time, removal in excess of 90 percent of particles fine-sand sized and larger is expected

Treatment train - Runoff will then be treated downstream by regional treatment facilities (Jenny Adair)

Minimum Requirements

- Better Site Design, **Low Impact Development**
- **WQCV** – volume based on ¼ inch of runoff from hard surfaces on site
- **Detention** – To pre-developed rates for 10 and 100-year events
- **Conveyance** – 5 or 10-year and 100-year; downstream analysis
- Floodplains – no rise in water surface and lowest floor 1ft above BFE (100 year fp), FP Development Permit, Elev Certificate
- Mudflows – mitigate impacts to self and neighbor



0.30
0.25
0.20
0.15
0.10
0.05
0.00
WQCV (watershed-inches)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Effective Imperviousness of Tributary Area to BMP (percent)
100 % Imp, WQCV = 0.255 in = 950 ft3/acre
60% Imp, WQCV = 0.11 in = 470 ft3/acre

Particle Size

110 microns

(60 microns)

20 microns

Planning Stages

- Consider stormwater EARLY in design process
- Rough layout, estimate impervious area
  - 10-15% of imp area should be estimated for wq treatment
  - Aim for several smaller areas, rather than one large
  - Space constraint? Consider ROW
- BMPs
  - Options that meet character of site
  - Maintenance and accessibility
  - Function – infiltrating?
- Conveyance – surface, green, don't direct pipe
- Flood control, detention – integrate, multi-purpose

Minor vs. Major

Minor Project

- 200 – 1000 sf disturbance
- Green – improve wq
- Urban – WQCV for disturbed/new area
- No professional engineer
- Much less on drainage report
- Sketch for drainage plan

Major Project

- Over 1000 sf disturbed
- Detention to pre-developed for entire site
- If < 50% of site, only WQCV for disturbed area
- If > 50% of site, WQCV for entire site
- Requires PE and full drainage analysis

LID – Plans Review

- **Step 1** - Describe what efforts have been made to reduce runoff and increase infiltration…

  Reduce impervious area
  Disconnect impervious area
  Reduce runoff via surface flow – grass swales, grass buffers

WQCV – Plans Review

- **Step 2** – Treat the WQCV
    - Pervious paver with detention
    - Street BMPs/sediment traps
    - **Bioretention**
    - Extended Detention Basin
    - Sand Filter
    - Constructed Wetland
    - **Subsurface treatment – vaults, drywells**

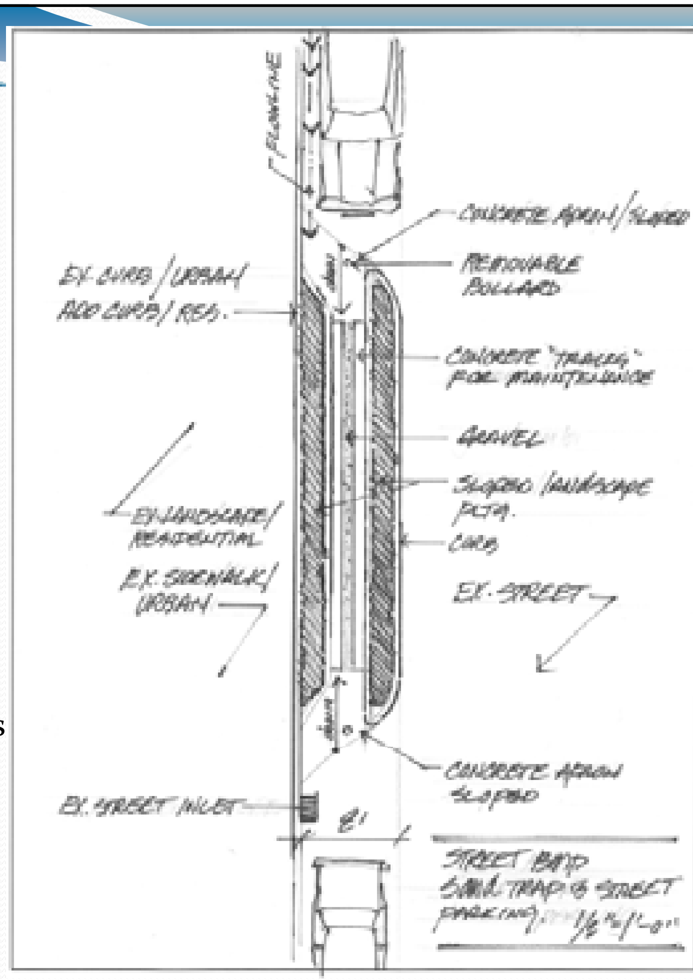
Water Quality in the Manual

- **Planning Principles**
  - Based on UDFCD – Early, entire site, avoid unneccessary impervious area, reduce runoff, match natural, integrate
- **BMP based on land use**
  - Ultra-urban, streets, dense residential, parks
  - Consider sanding, infiltration, groundwater, etc
- **Each BMP:**
  - Description and general application
  - Advantages/Disadvantages
  - Physical Site Suitability
  - Pollutant Removal Ability
  - Cold Weather Considerations
  - Design Considerations, Procedure, Criteria
  - Maintenance Requirements

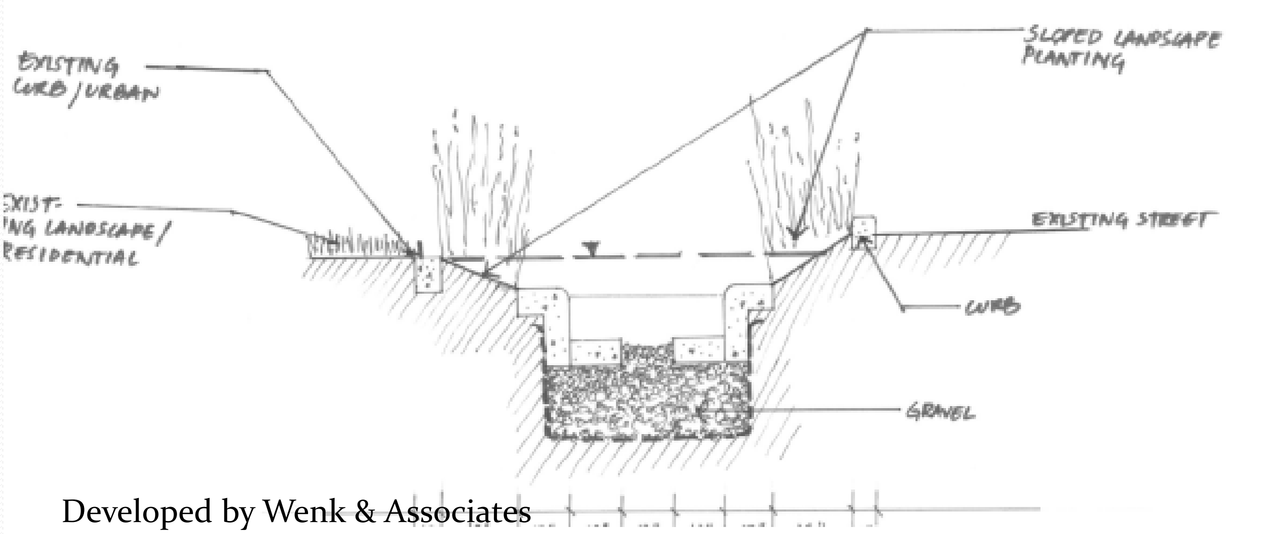
Unique in Aspen

- **Subsurface Treatment Systems**
- **Use of Right of Way** – allowing private development use of public property for stormwater management

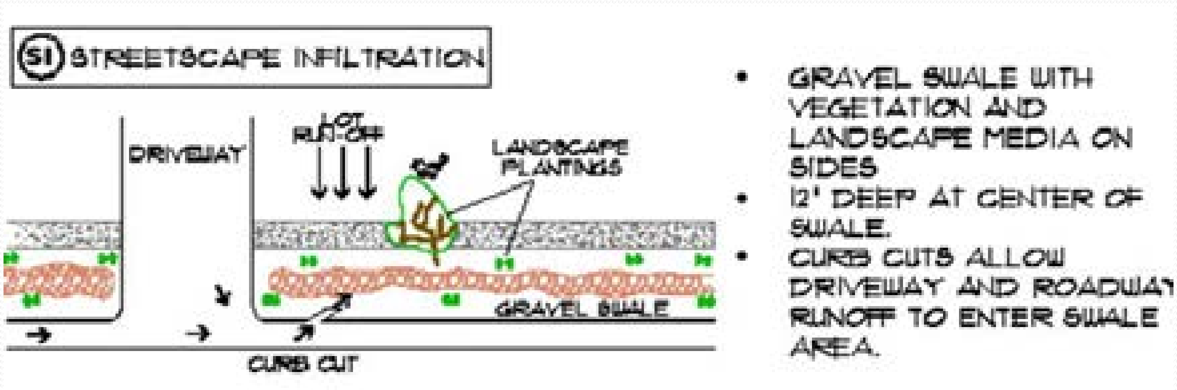
Street/ Sediment Management BMPs



Developed by Wenk & Associates



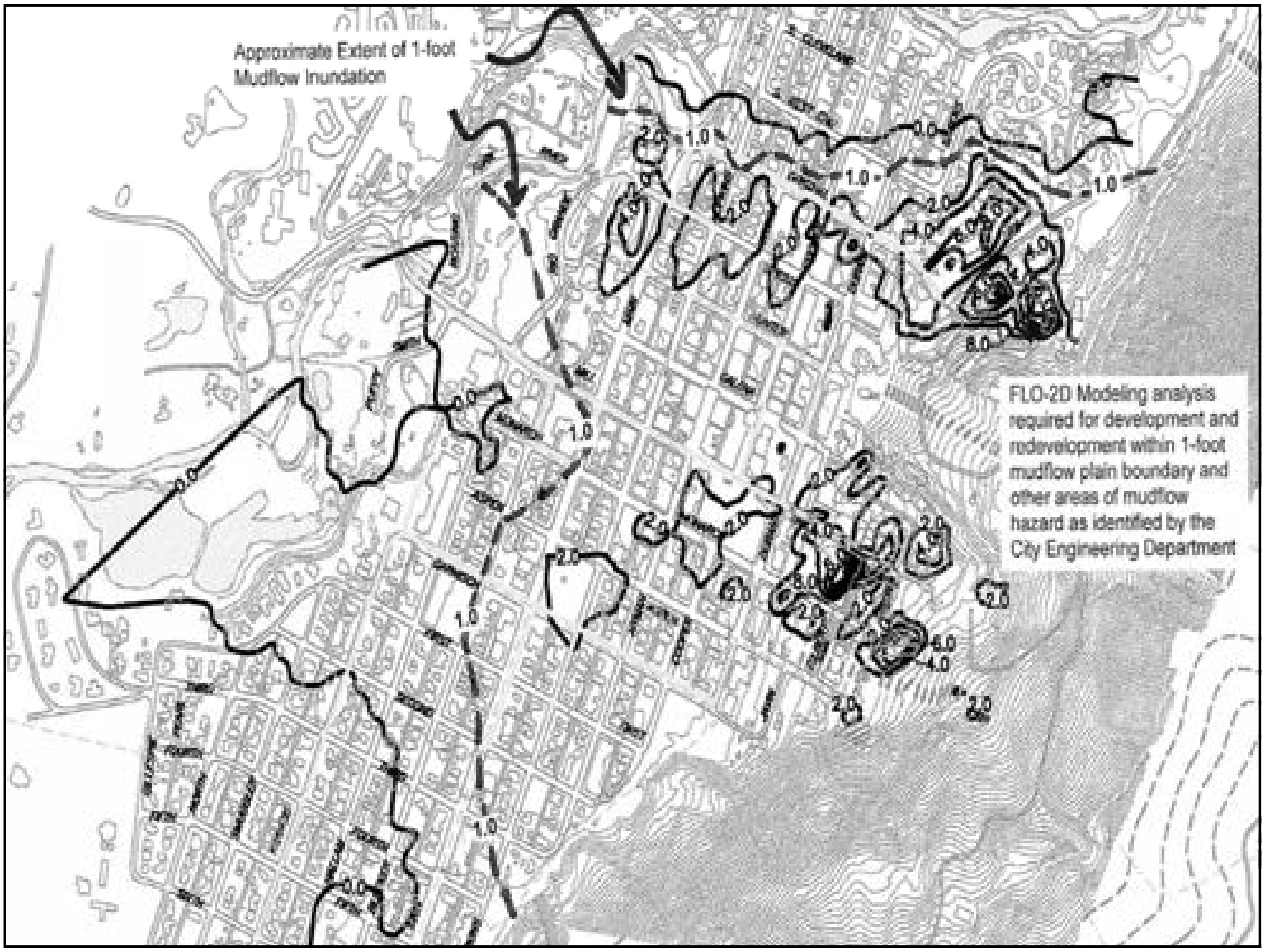
Developed by Wenk & Associates



Developed by Wenk & Associates

Landscaped beds collect and filter roof drainage. Beds have under-drains which drain to drainage swales.

The parking lot drains to landscaped swales.


Approximate Extent of 1-foot
Mudflow Inundation
FLO-2D Modeling analysis
required for development and
redevelopment within 1-foot
mudflow plain boundary and
other areas of mudflow
hazard as identified by the
City Engineering Department

Contents

- Introduction
  - 7 page, includes everything you need
- Chapter 1 – Permit Requirements
- Chapter 2 – Rainfall
- Chapter 3 – Runoff
- Chapter 4 – Street Drainage Design
- Chapter 5 – Detention
- Chapter 6 – Floodplains
- Chapter 7 – Mudflow
- Chapter 8 – Water Quality
- Appendices: Appendix A - Checklists

“Out Of The Box Off The Shelf”

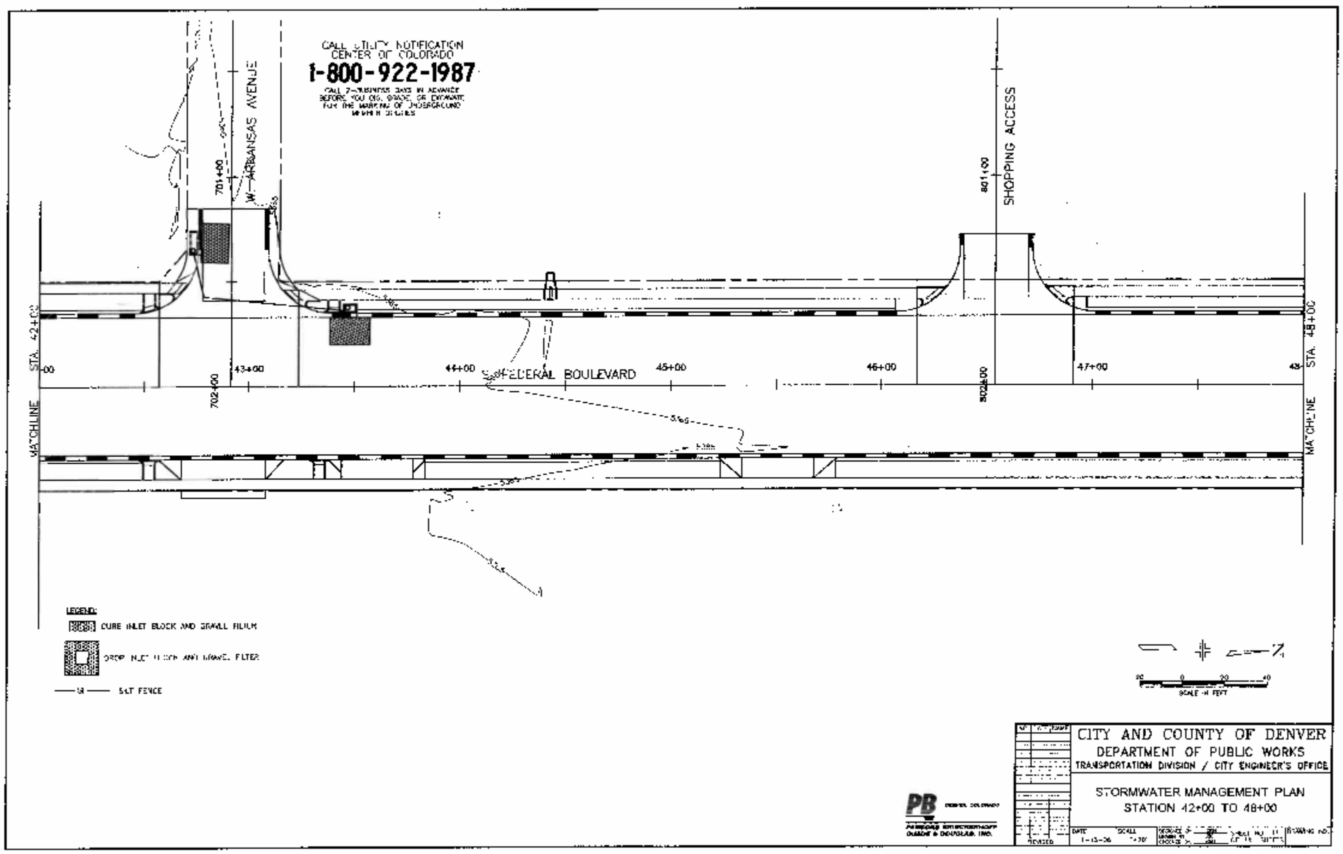
Linear Project Hybrid PLD Pilot Study Shows Promise

Darren Mollendor, PE
City and County of Denver
Public Works
Wastewater Management

South Federal Blvd. Project Background

- Reconstruction of state highway
- Drains to Harvard Gulch in SW Denver
- Located in urbanized retail / multi-family residential area
- Project extends from Jewel Ave. north to Florida Ave.
- PLD pilot study area is located between Florida Ave. and Arkansas Ave.

Pilot Study Area



Out of the Box Approach
Linear Project WQ Concerns

- Right of Way take for Surface WQ BMP
- Underground design considerations
  - Site conditions
  - Location
  - Operation and Maintenance
- Constructability
  - Use of Rain Store 3 for underground storage
- Monitoring data
  - Phase 1 hydrograph analysis
  - Phase 2 Hydrograph, analytical, and *piezometric* evaluation

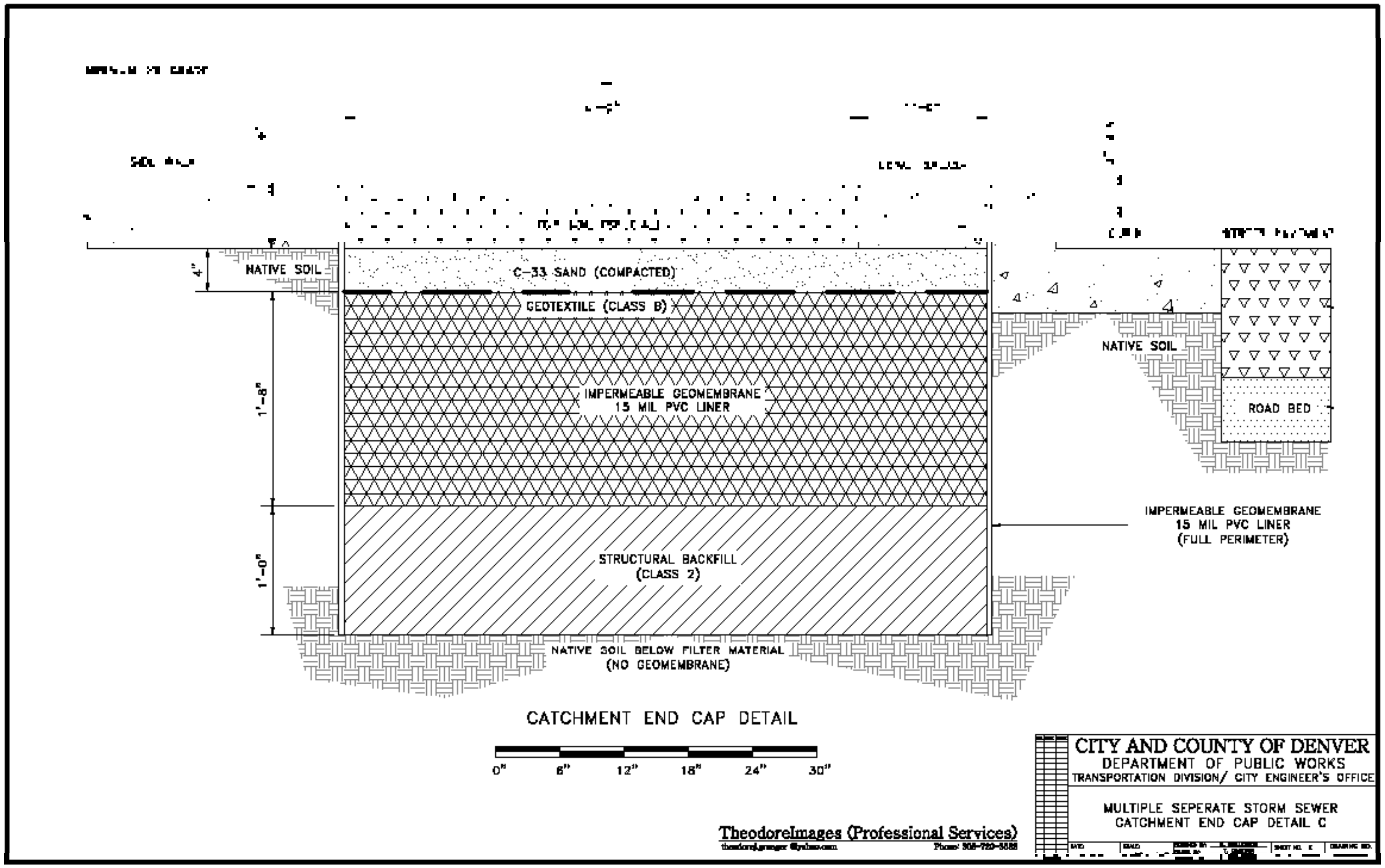
Pilot Design and Installation

- Combined PLD and Sand Filter designs
- Used Rainstore 3 for volumetric control
- No under drain
- Elevated outlet structure
  - Goal to infiltrate WQCV
- Impermeable Perimeter Liner
- In series treatment train
- Concentrated storm inflow from adjacent parking lot

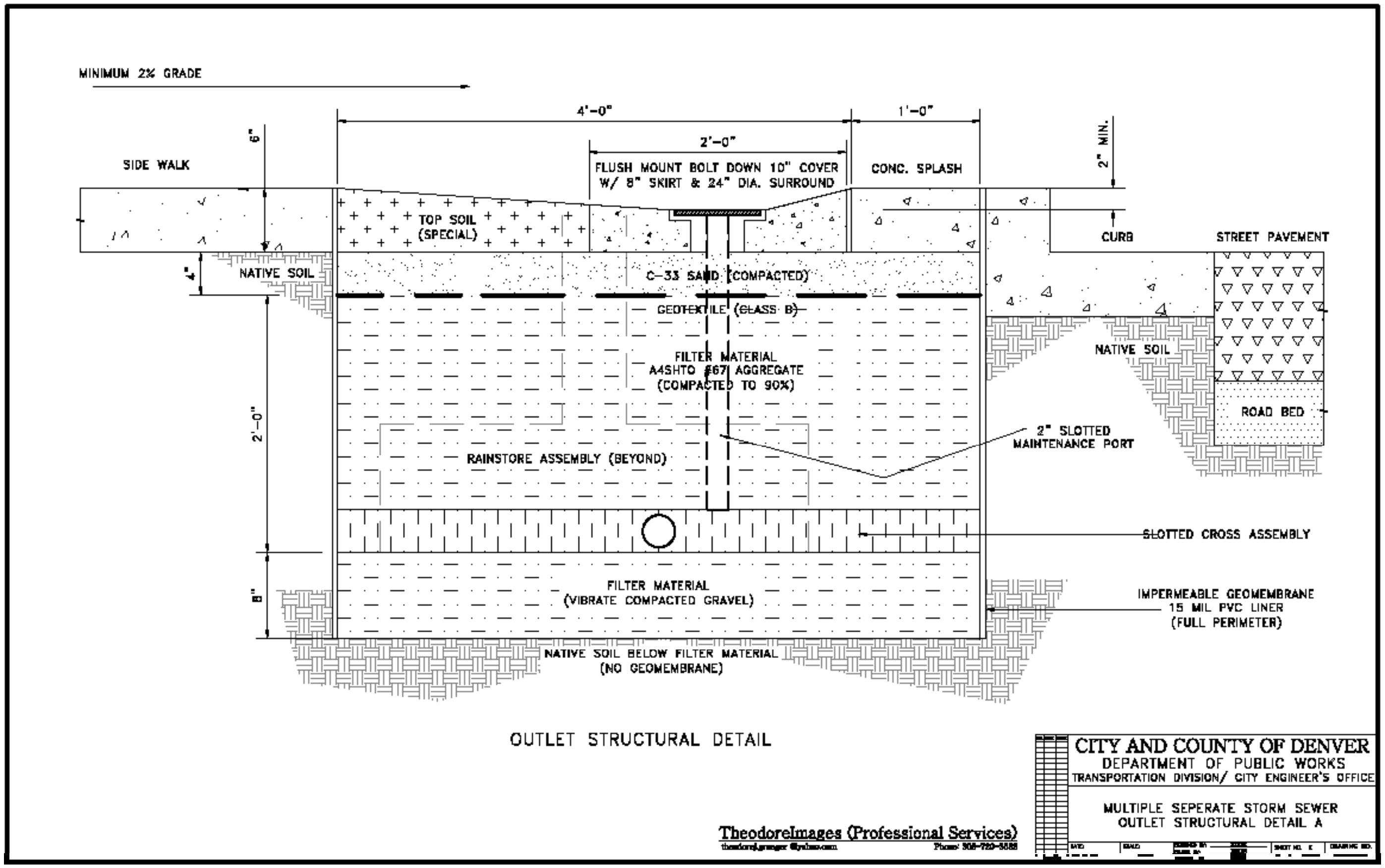
Multi Basin Schematic Diagram

- To Be Provided

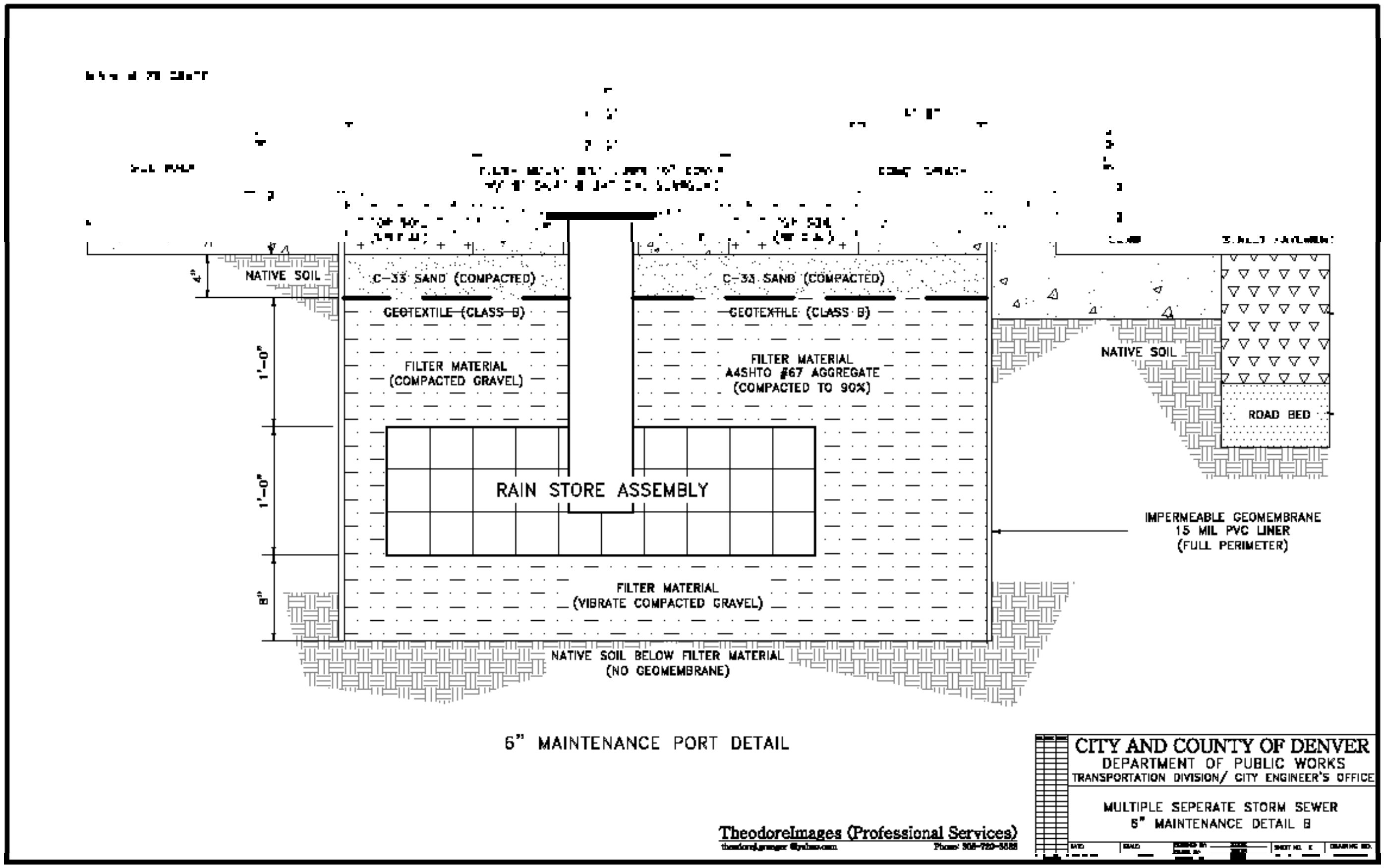
End Cap Cross Section



Typ. Outlet Cross Section



Typ. Maintenance Port Cross Section



Rainstore 3
Underground Volumetric Storage

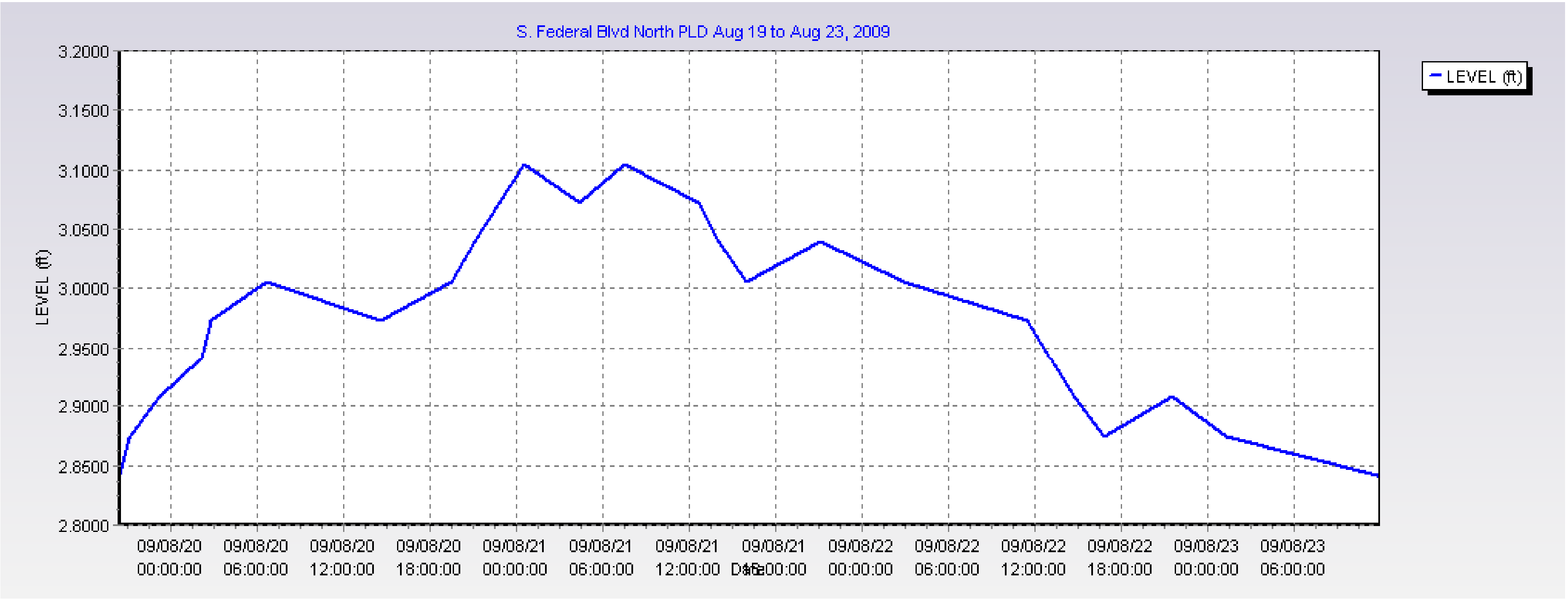
Rainstore 3 Details

Rainstore is a stackable, plastic structure designed to store large amounts of stormwater underground. Rainstore has a 94% void space and is designed to support heavy loads (such as light vehicular traffic) when used in combination with Geogrid materials. Approximate pricing for Rainstore units and additional required products are as follows:

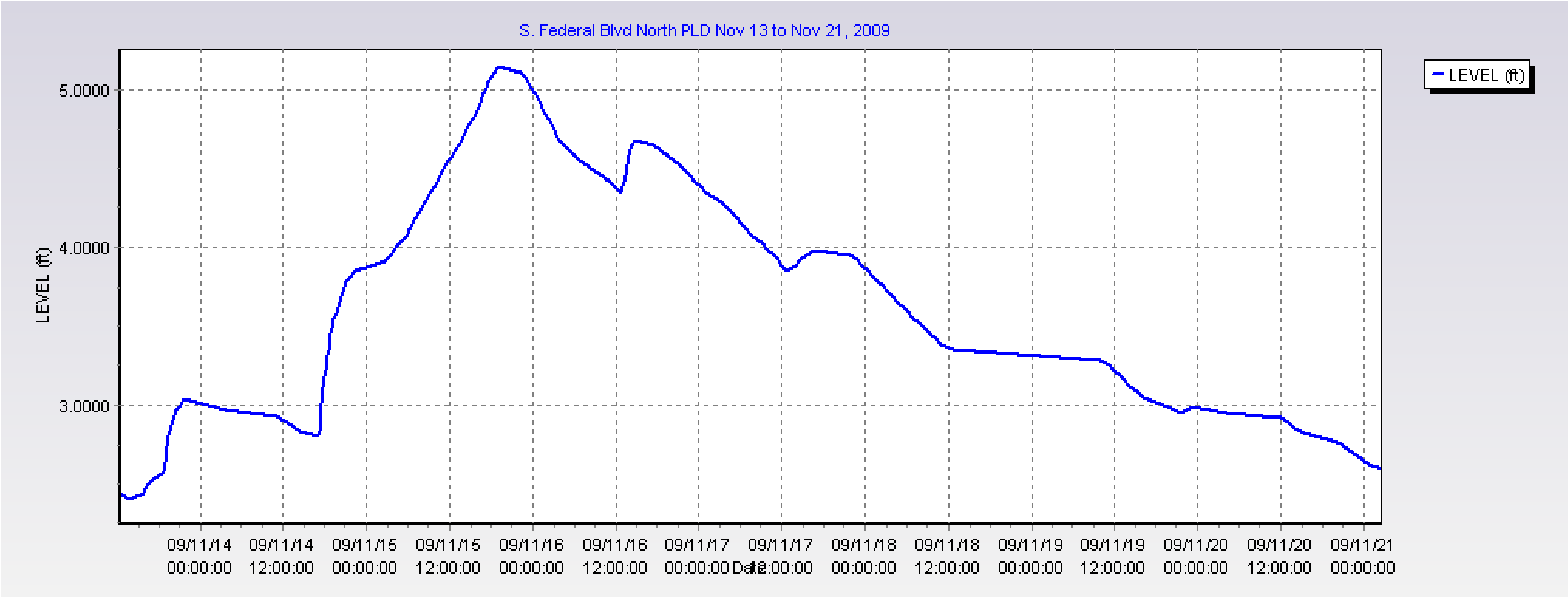
- • Rainstore3 Unit: $30-$38 per unit
- • Geogrid: Tenax $11 per linear foot (13 foot width); Meeks
    - StrataGrid $3.44 per linear foot (6 foot width); The Rock Garden
- • Geotextile Fabric: $2 per linear foot (12 foot width)

- **Materials:**
    - • Rainstore Units (40” x 40” x 4”)
    - • Non-Woven Geotextile Fabric (Filter Fabric)
    - • Geogrid –Tenax, StrataGrid, or equivalent. *Recommended for all driveway infiltration applications*
    - • Zip Ties
    - • Drain Rock (¾ – 1 ½”)
    - • Sediment Trap or Catch Basin

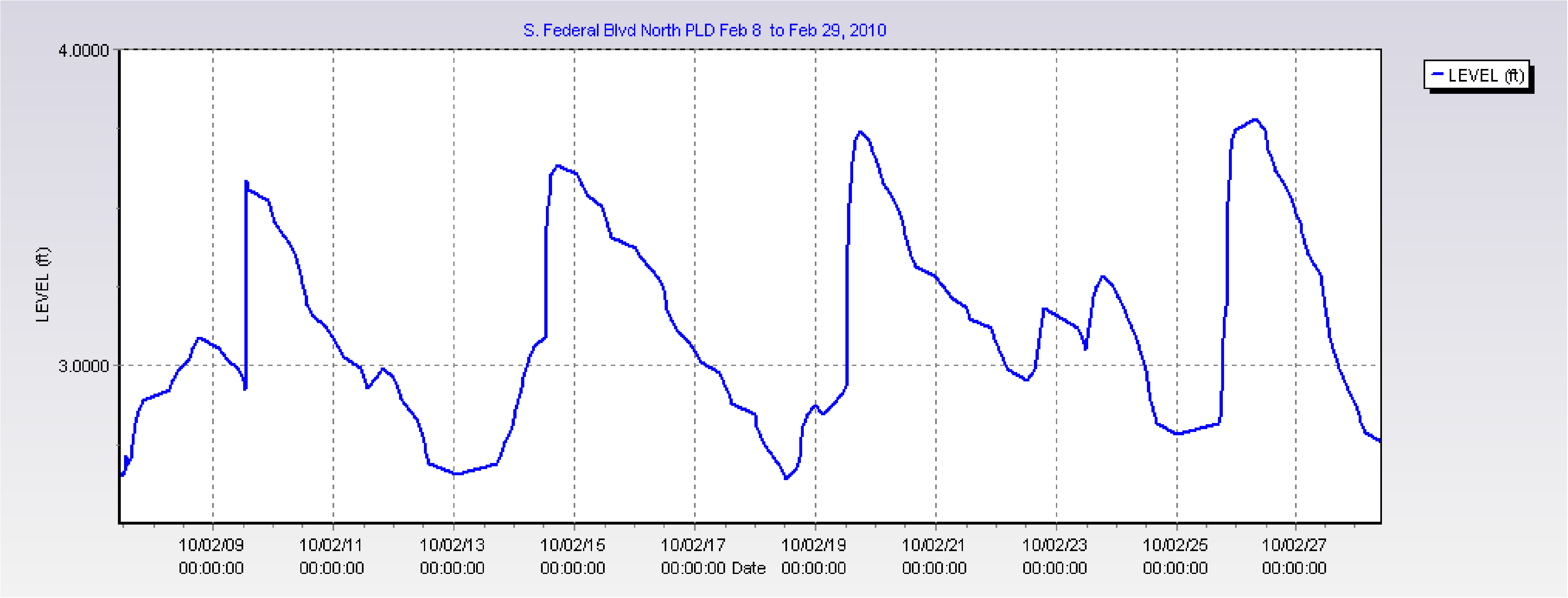
North PLD Treatment Basin Hydrograph Data (1)



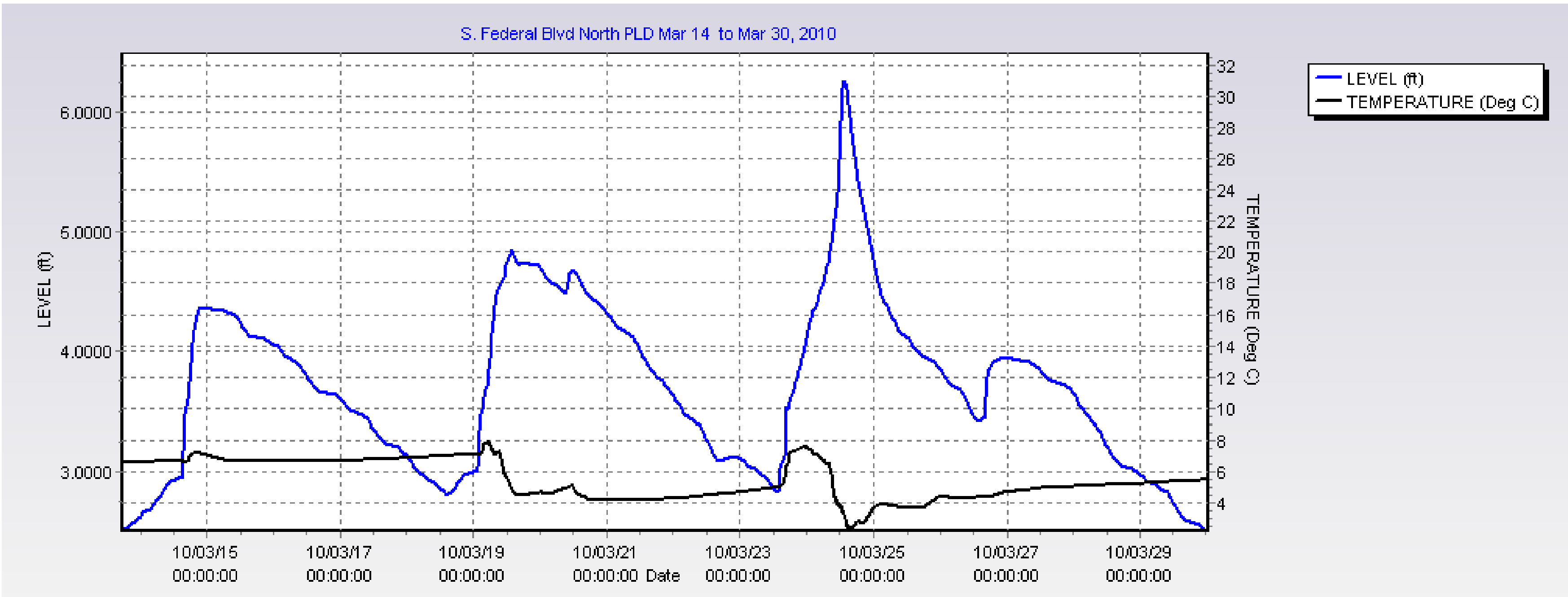
North PLD Treatment Basin Hydrograph Data (2)



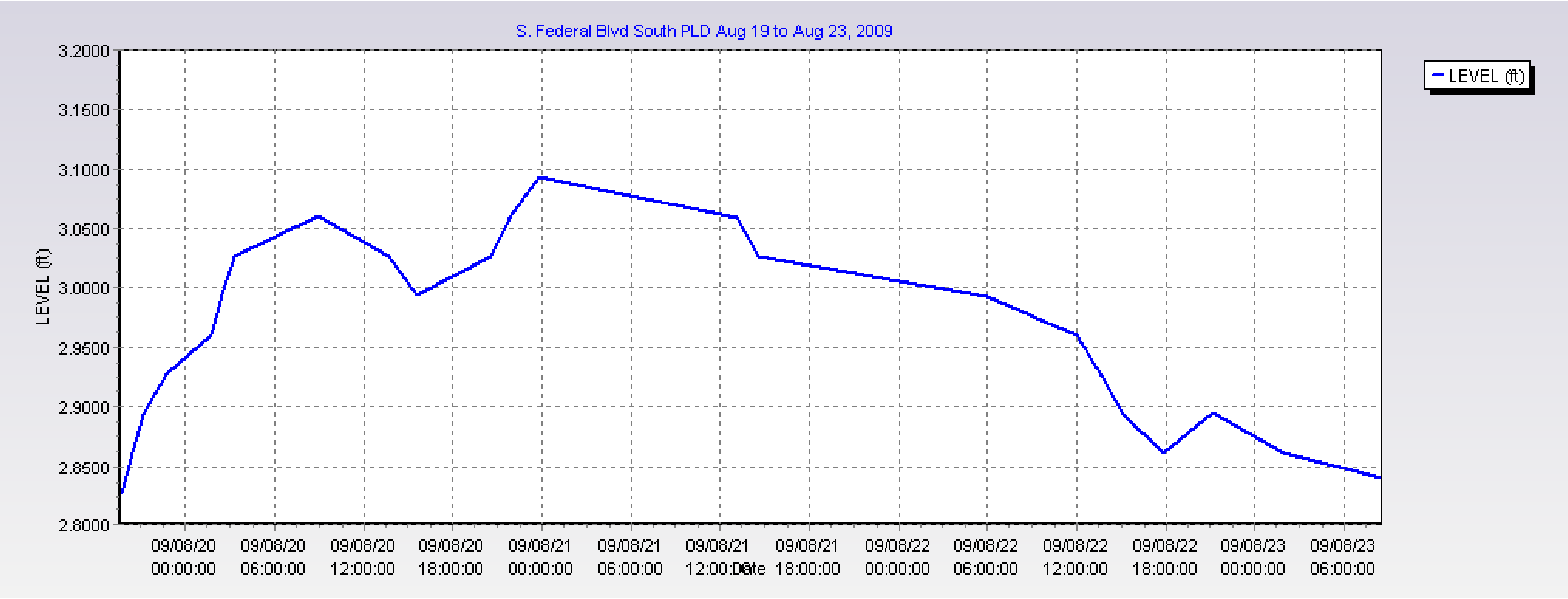
North PLD Treatment Basin Hydrograph Data (3)



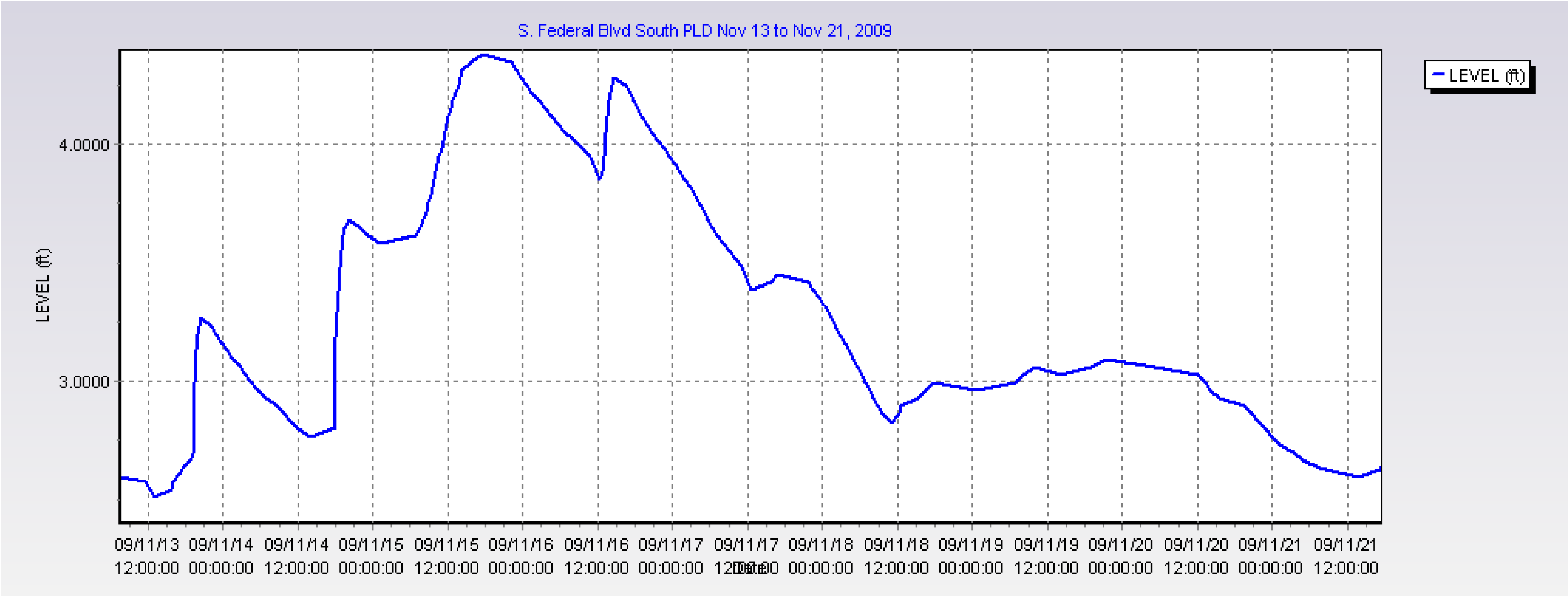
North PLD Treatment Basin Hydrograph Data (4)



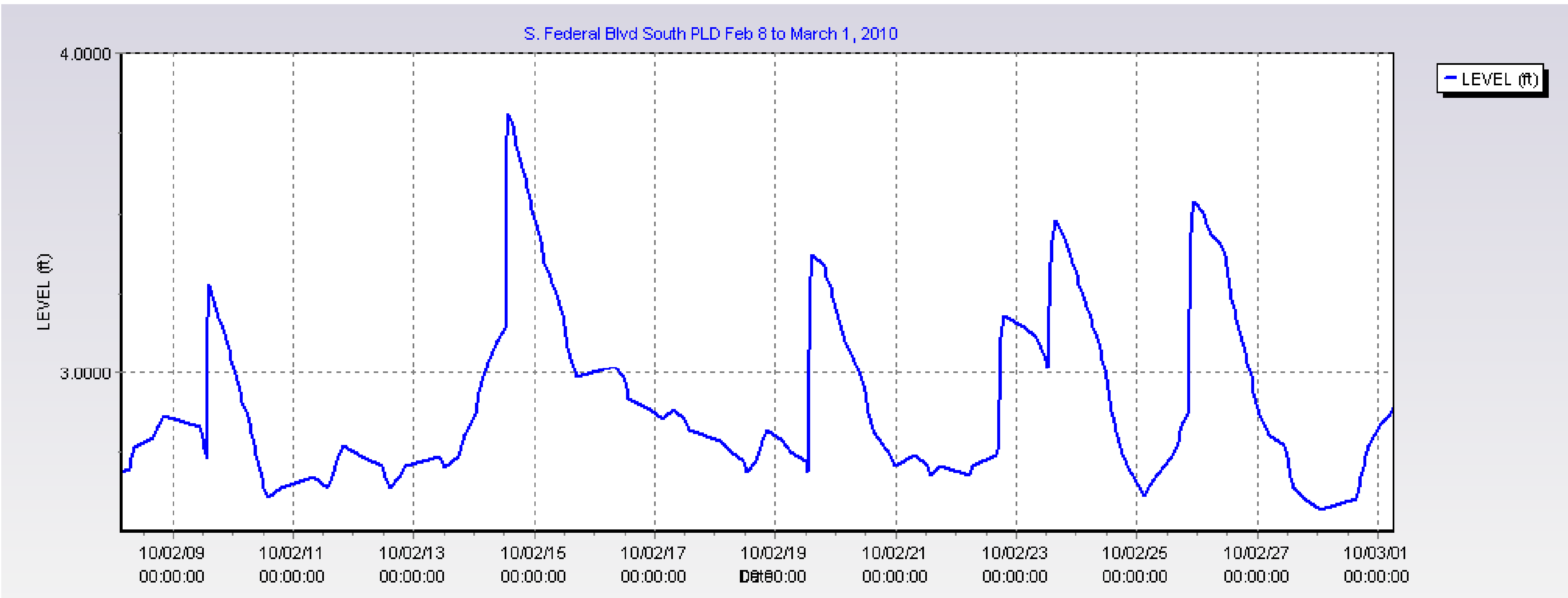
South PLD Treatment Basin Hydrograph Data (1)



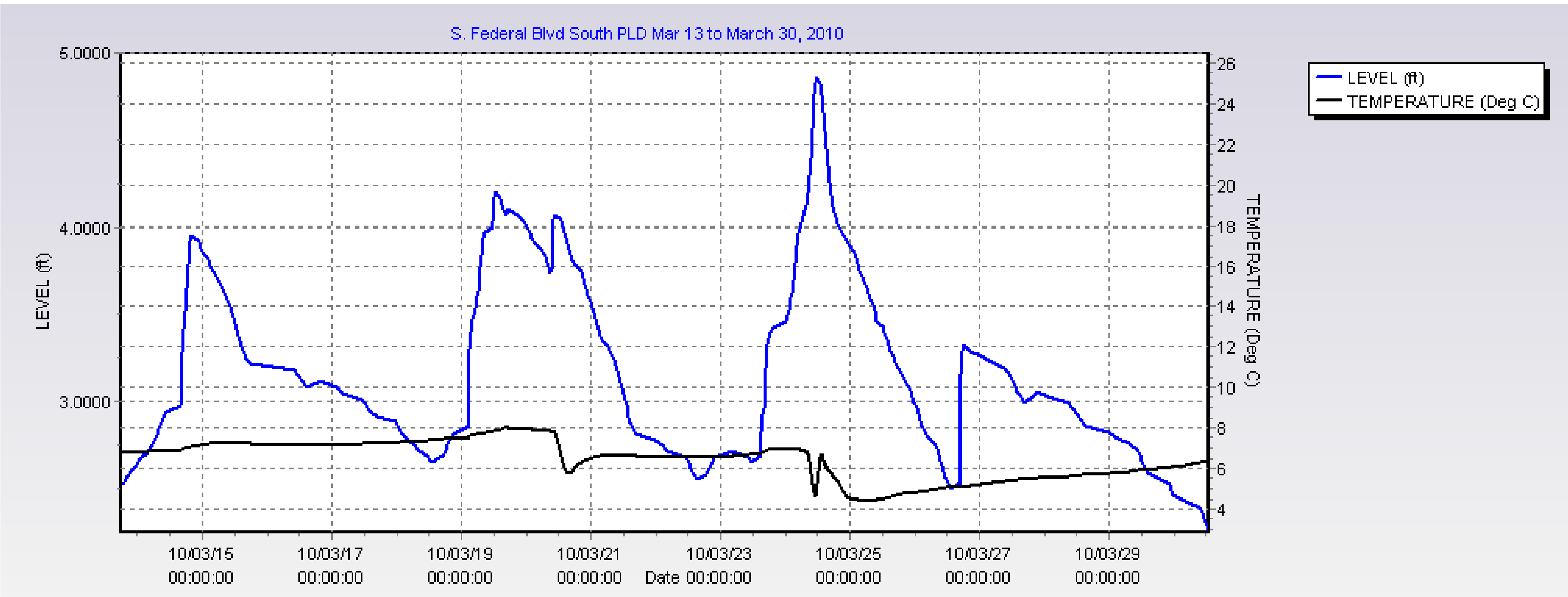
South PLD Treatment Basin Hydrograph Data (2)



South PLD Treatment Basin Hydrograph Data (3)



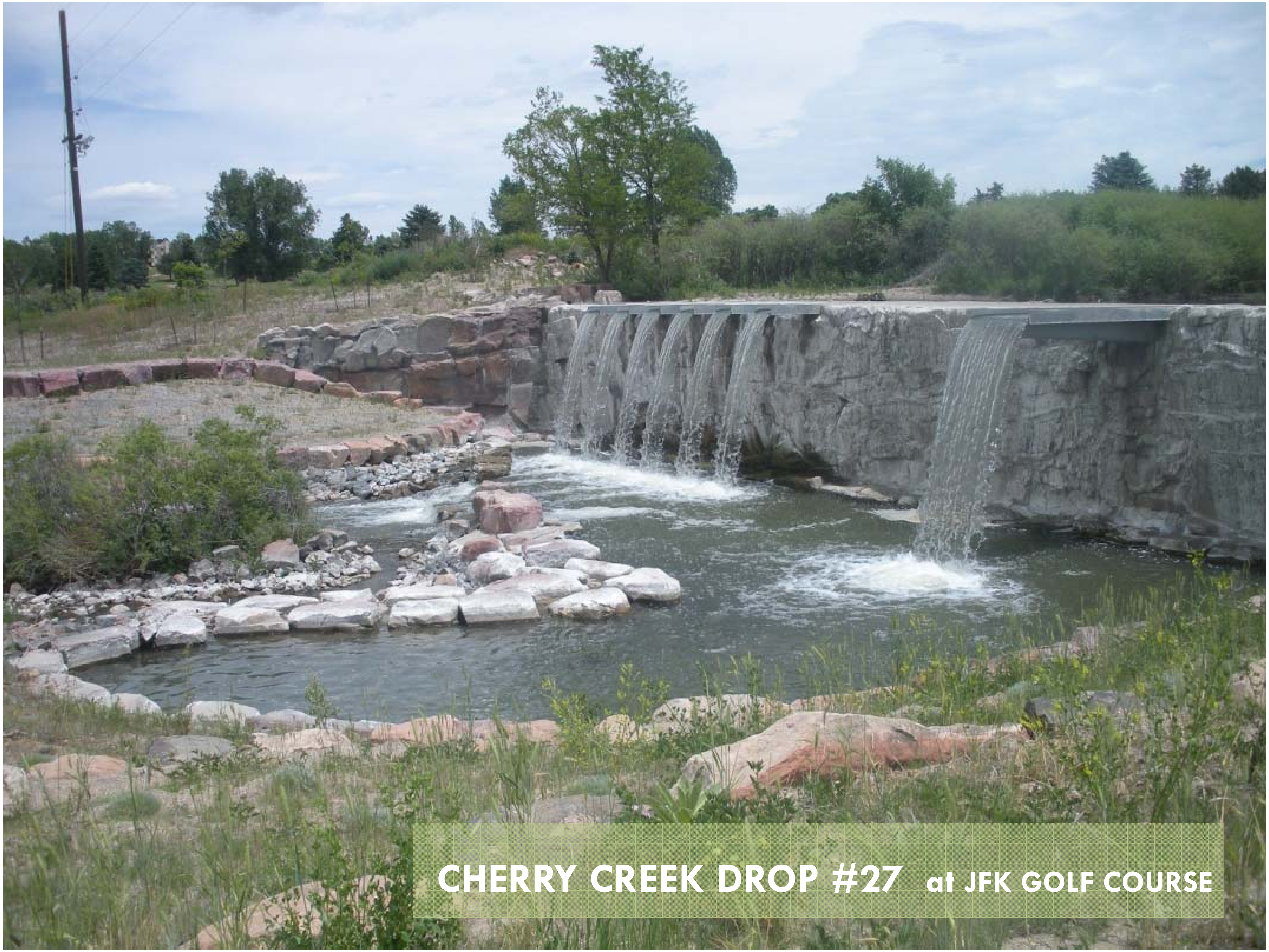
South PLD Treatment Basin Hydrograph Data (4)



“Out Of The Box Off The Shelf”

Linear Project Hybrid PLD Pilot Study Conclusions

- Pilot PLD is functioning as intended
- No significant maintenance is required to date
- Hydrographs show Class “C” soil allow infiltration (entire WQCV)
- Stormwater Rip Rap intake insure system functionality
- System treats frequent (2yr) and 1.35”+ Storms



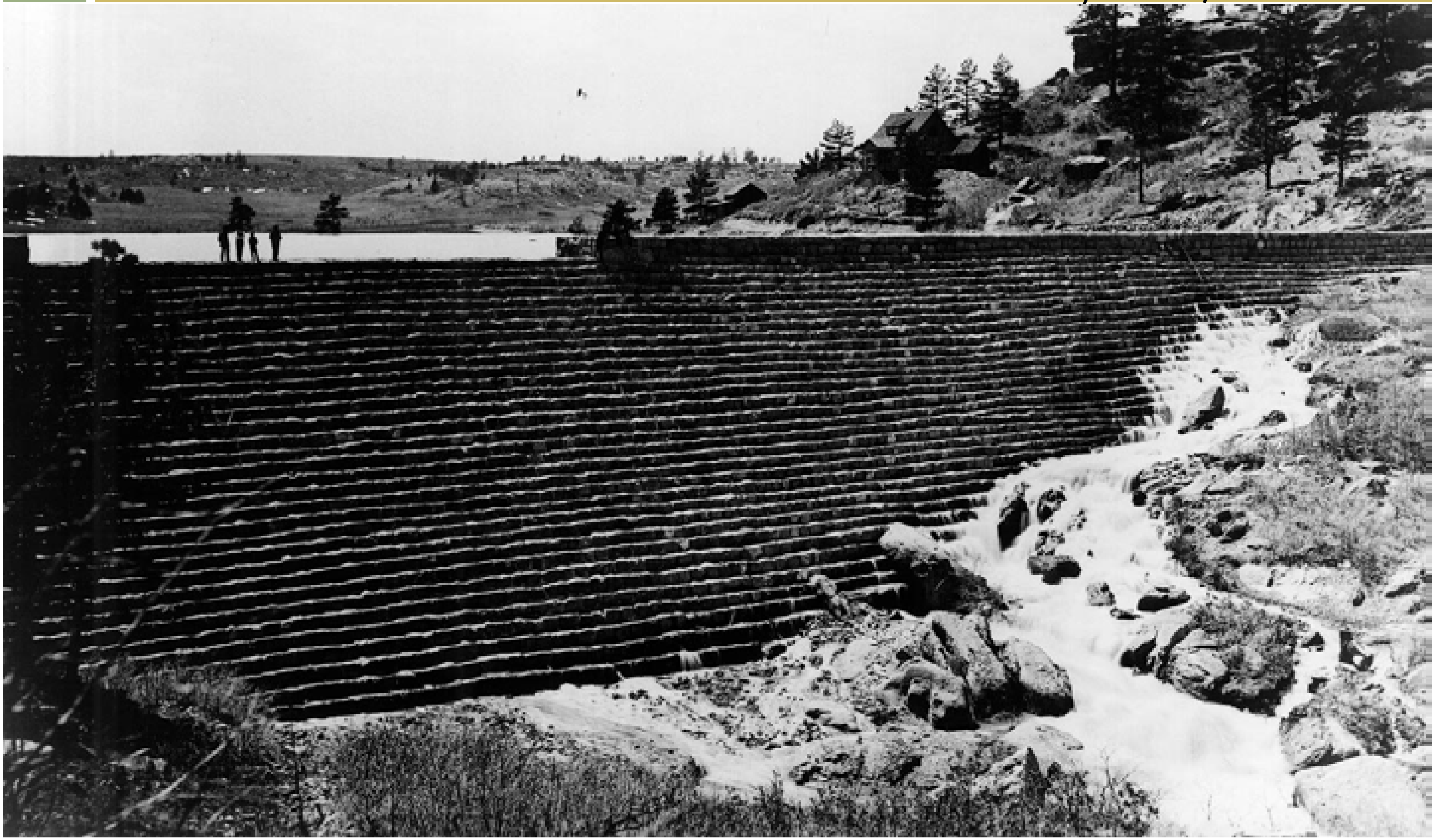
CHERRY CREEK DROP #27 at JFK GOLF COURSE

CHERRY CREEK
DROP #27

castlewood canyon dam, 5300 acre-ft

the flood of 1933

castlewood canyon dam, the leak



the flood of 1933

cherry creek at colorado blvd

the flood of 1933

cherry creek at 11th Ave

the flood of 1933

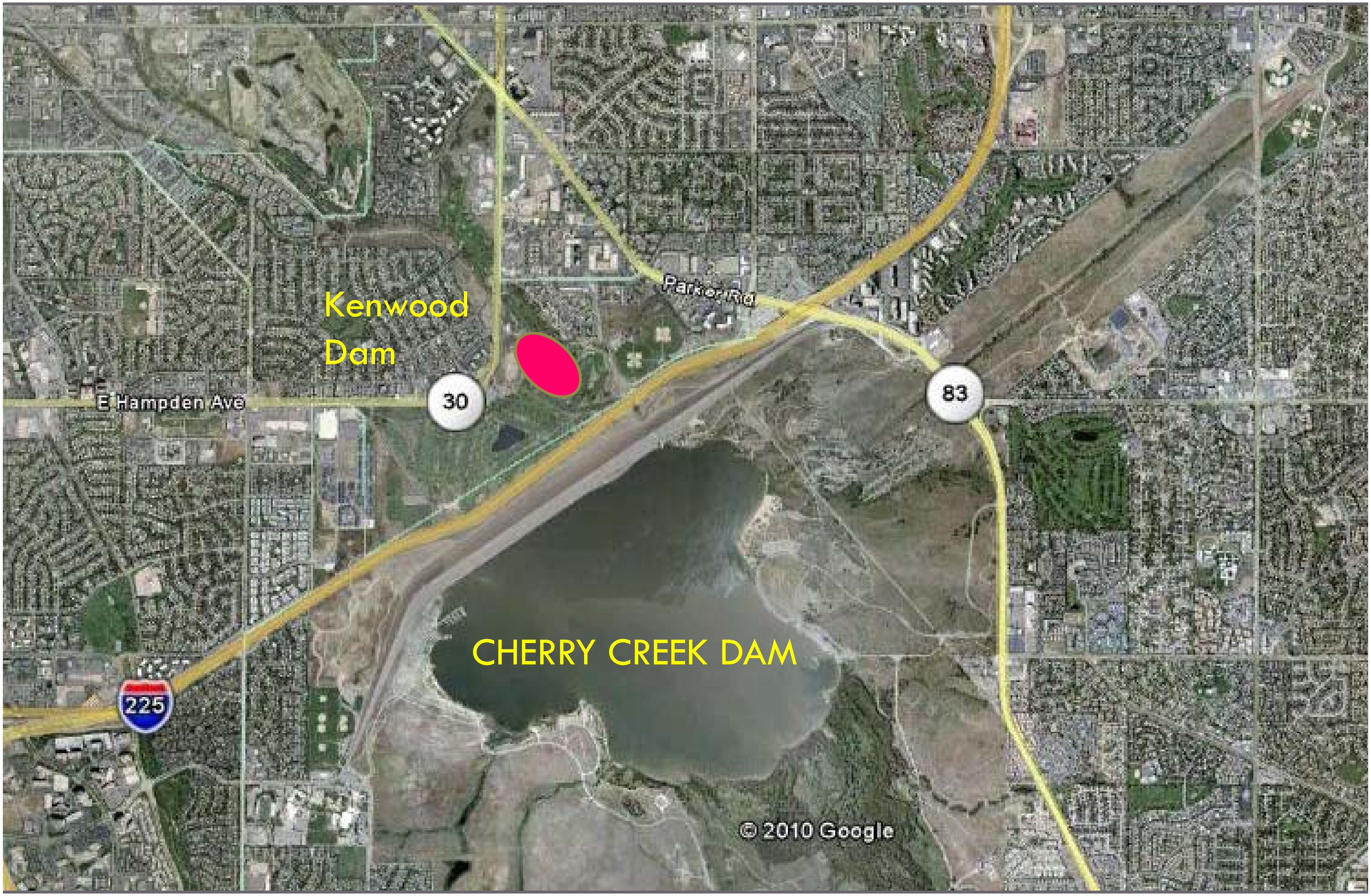
union station

the flood

larimer street

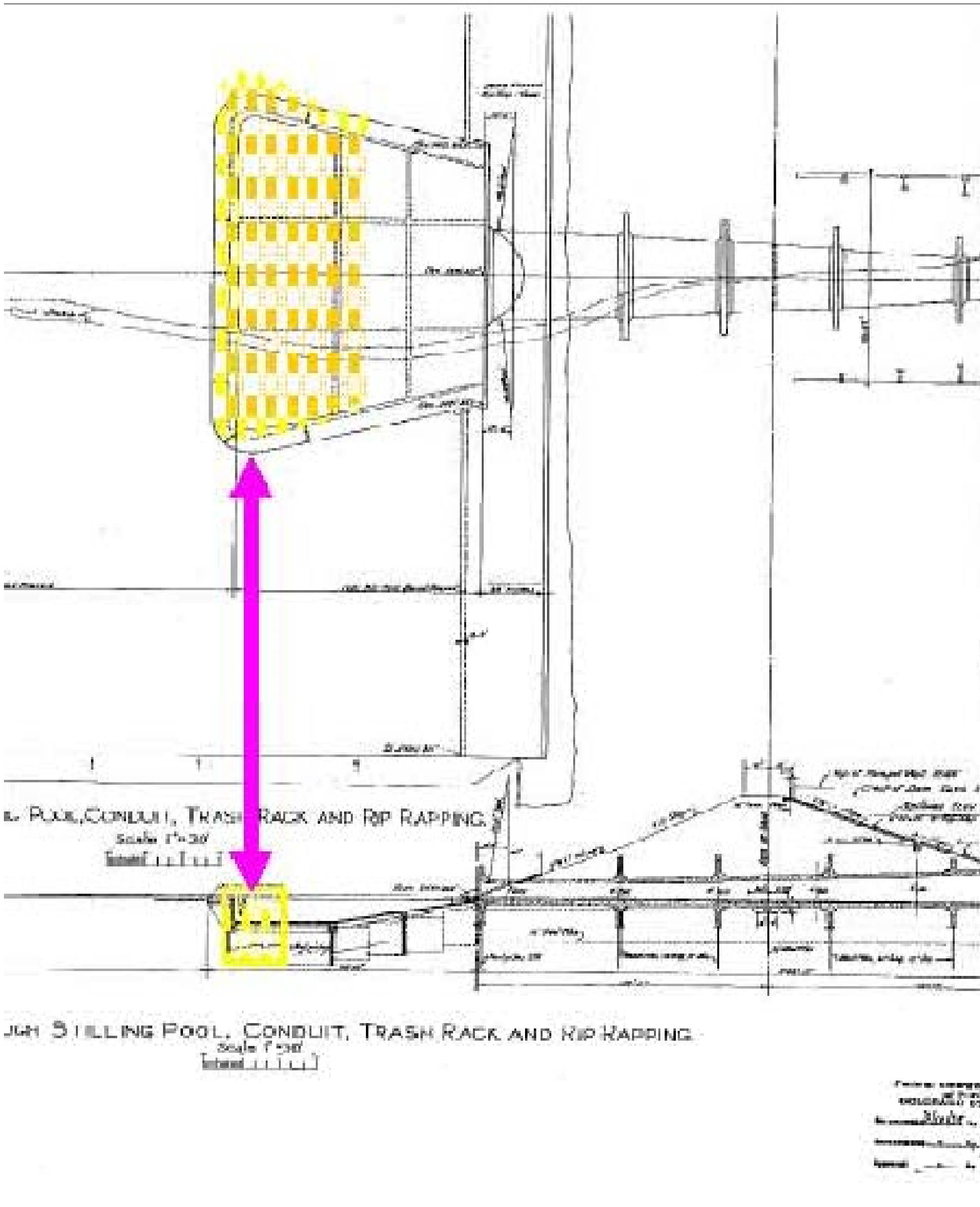
the flood of 1933

south platte and speer blvd



CHERRY CREEK
DROP #27

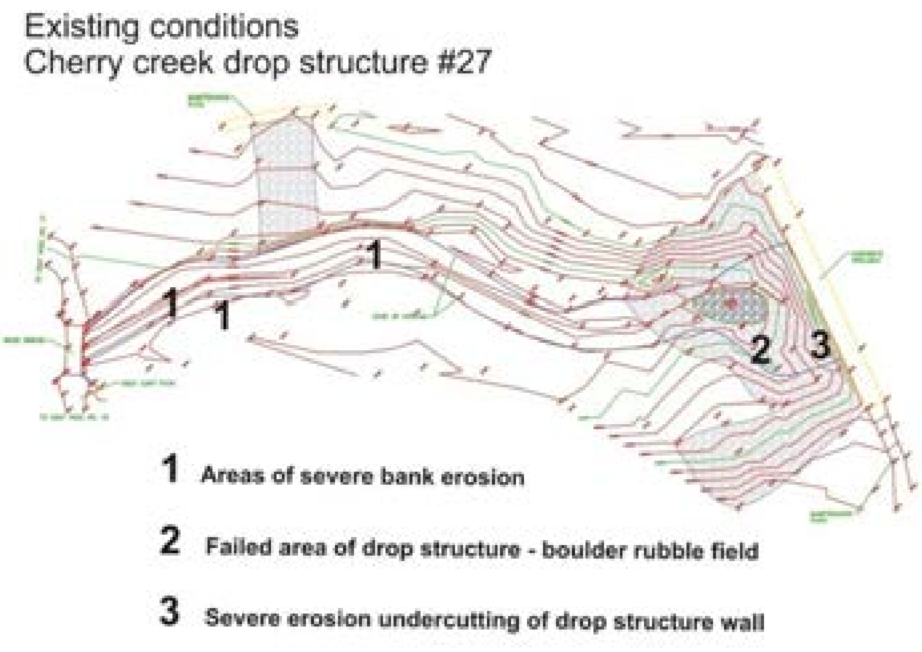
area of interest

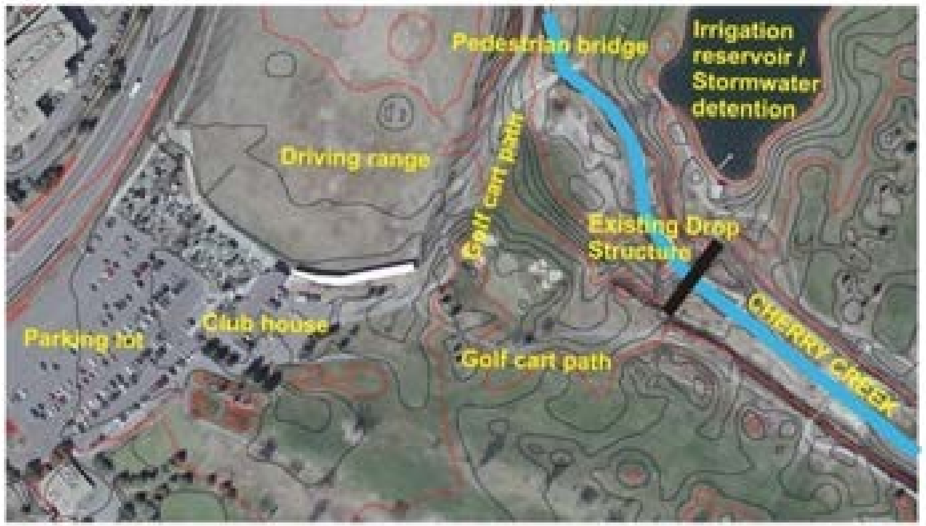


- 1935 Kenwood Dam was constructed to provide flood protection for the City following a disastrous flood in 933 that conveyed 34,000 cfs towards downtown.
- Republican River flooding in 1935 indicated it was under-designed.
- In 1944, the Kenwood Dam was decommissioned to accommodate the construction of the Cherry Creek Reservoir.
- The end sill of the stilling basin forms the crest and face of this existing drop structure.

CHERRY CREEK DROP #27

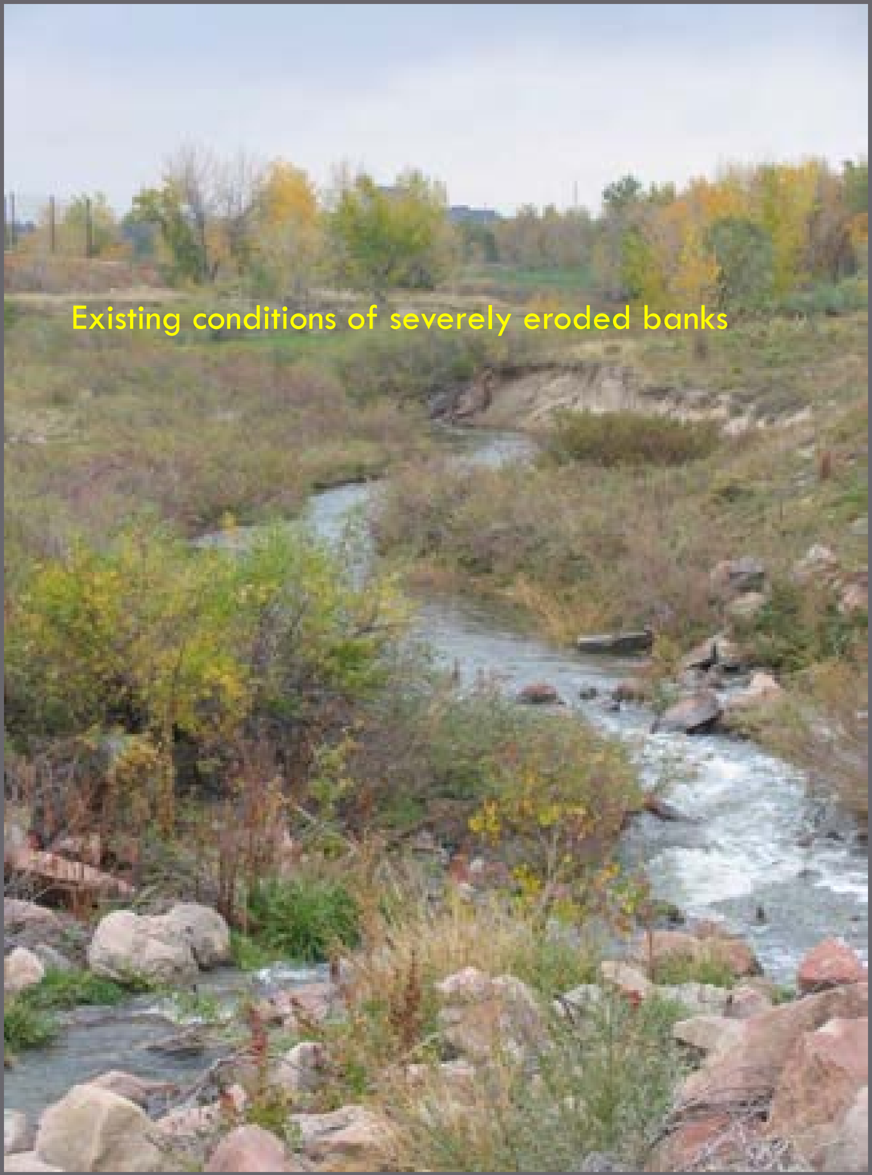
genealogy of drop structure #27

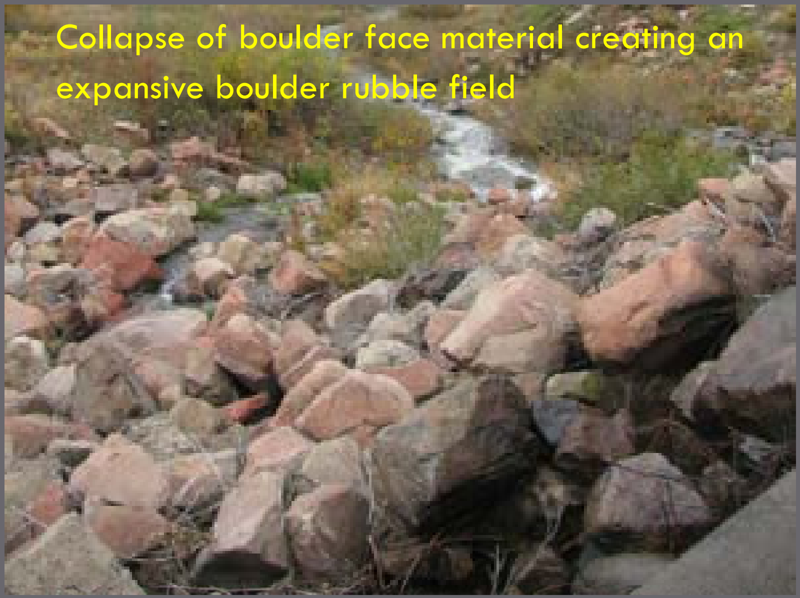




CHERRY CREEK DROP #27

area of concern





CHERRY CREEK
DROP #27

challenging issues

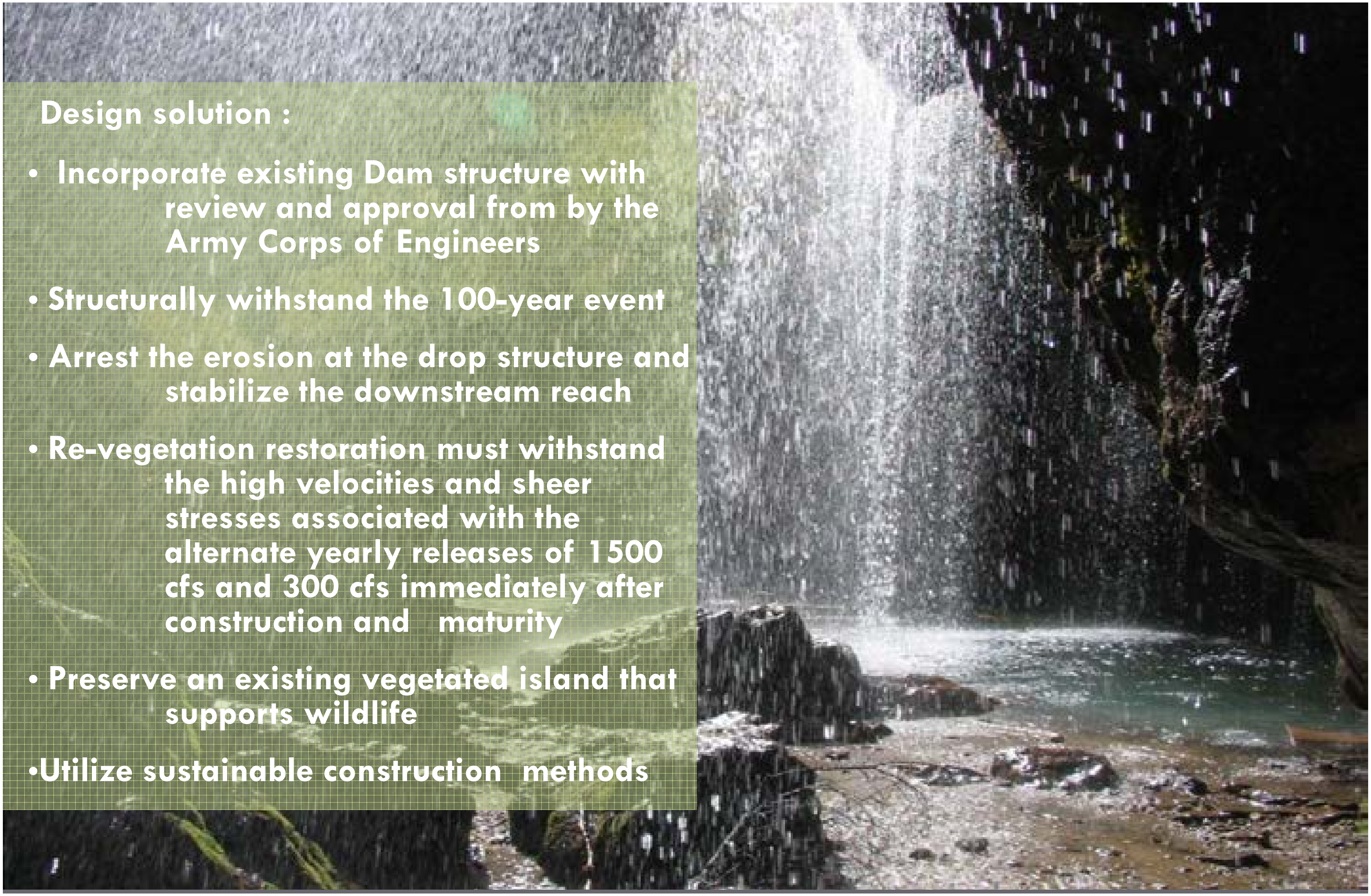
CHERRY CREEK DROP #27

challenging issues

- **Rehabilitate a failing drop structure**
- **Stabilize eroded channel and banks**
- **Dissipate the yearly releases from the DAM to protect downstream infrastructure, properties and channel integrity**
- **Enhance the riparian corridor ecosystem**
- **Create an aesthetic amenity**

CHERRY CREEK
DROP #27

project purpose

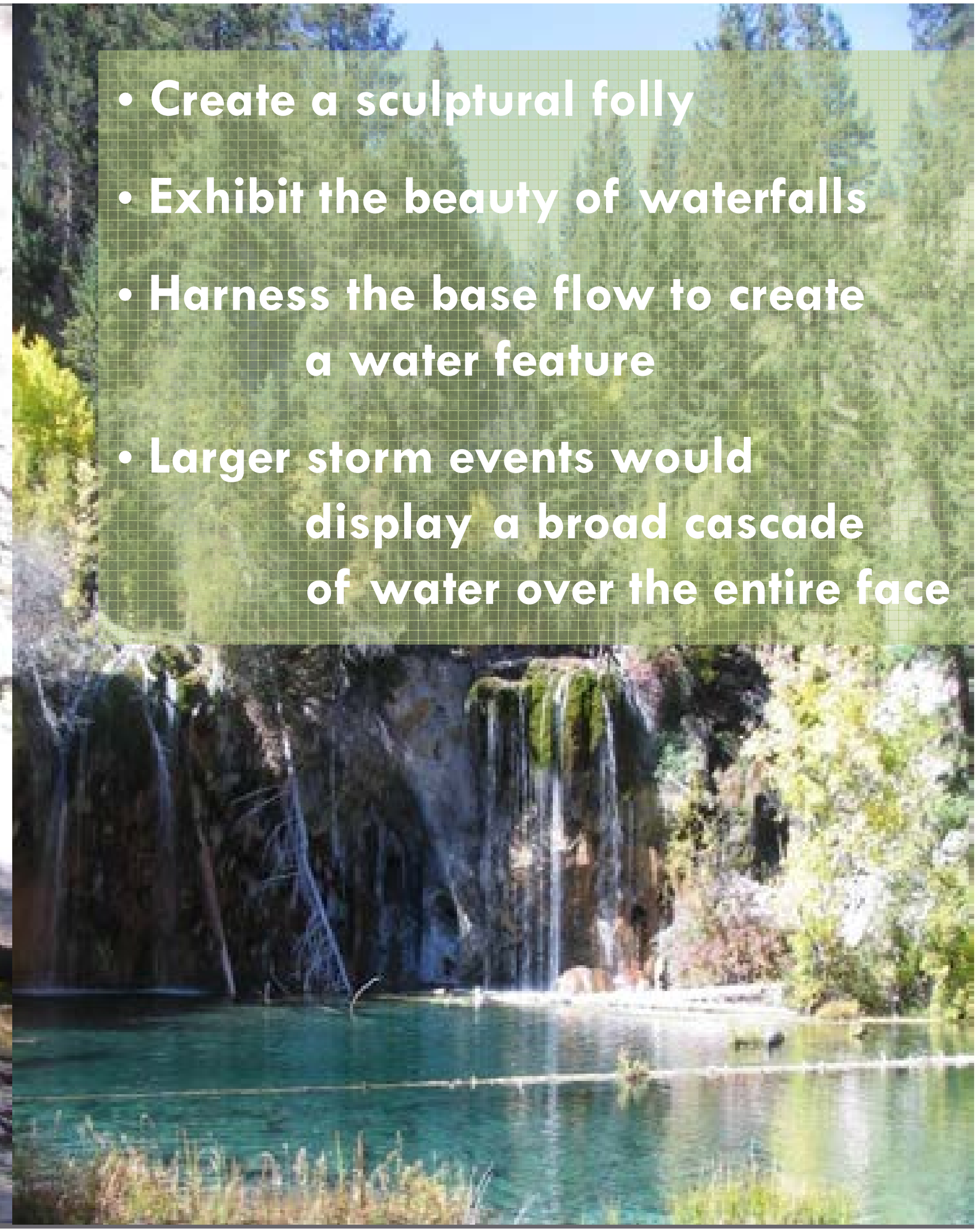


Design solution :

- Incorporate existing Dam structure with review and approval from by the Army Corps of Engineers
- Structurally withstand the 100-year event
- Arrest the erosion at the drop structure and stabilize the downstream reach
- Re-vegetation restoration must withstand the high velocities and sheer stresses associated with the alternate yearly releases of 1500 cfs and 300 cfs immediately after construction and maturity
- Preserve an existing vegetated island that supports wildlife
- Utilize sustainable construction methods

CHERRY CREEK
DROP #27

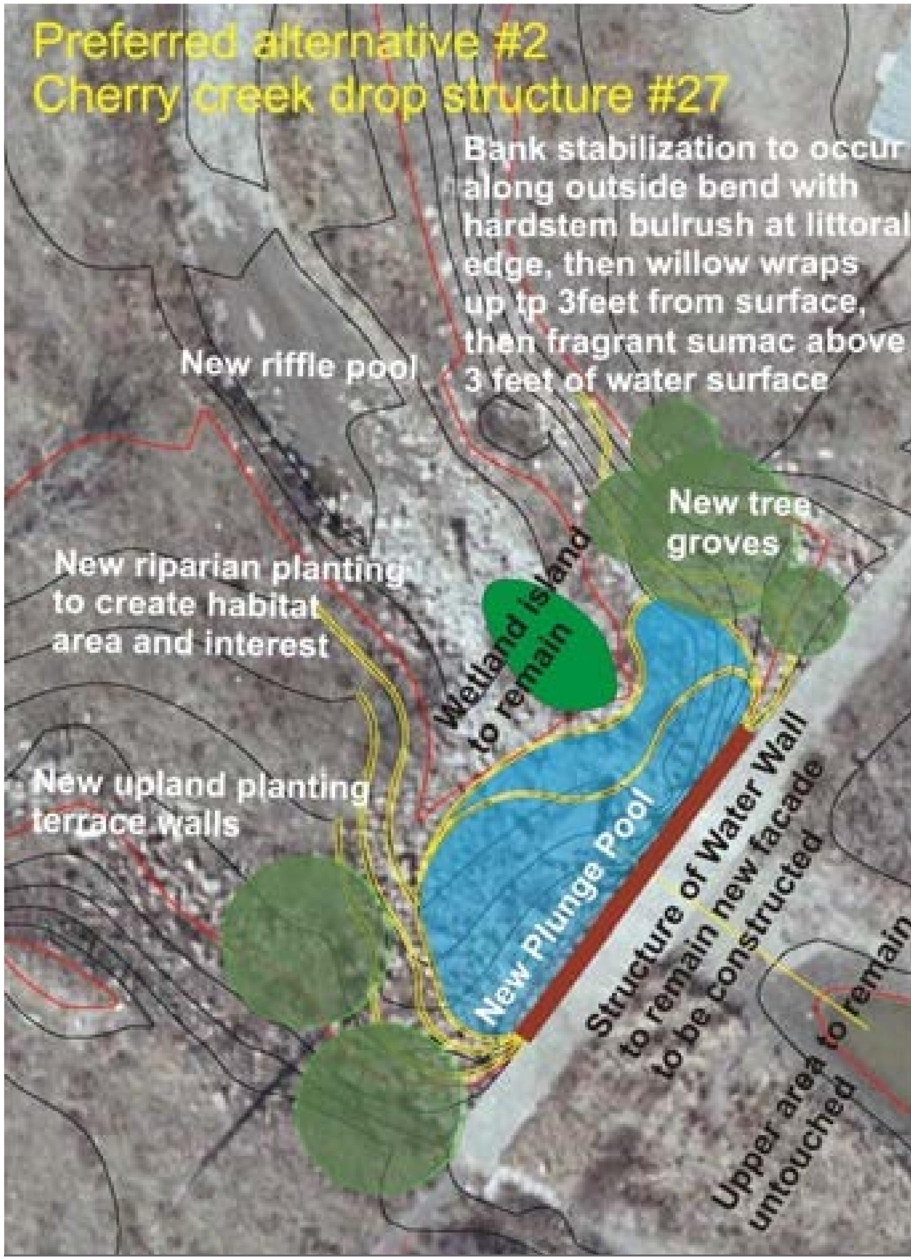
project approach

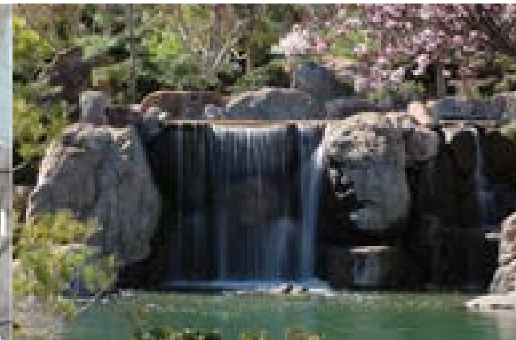


- Create a sculptural folly
- Exhibit the beauty of waterfalls
- Harness the base flow to create a water feature
- Larger storm events would display a broad cascade of water over the entire face

CHERRY CREEK
DROP #27

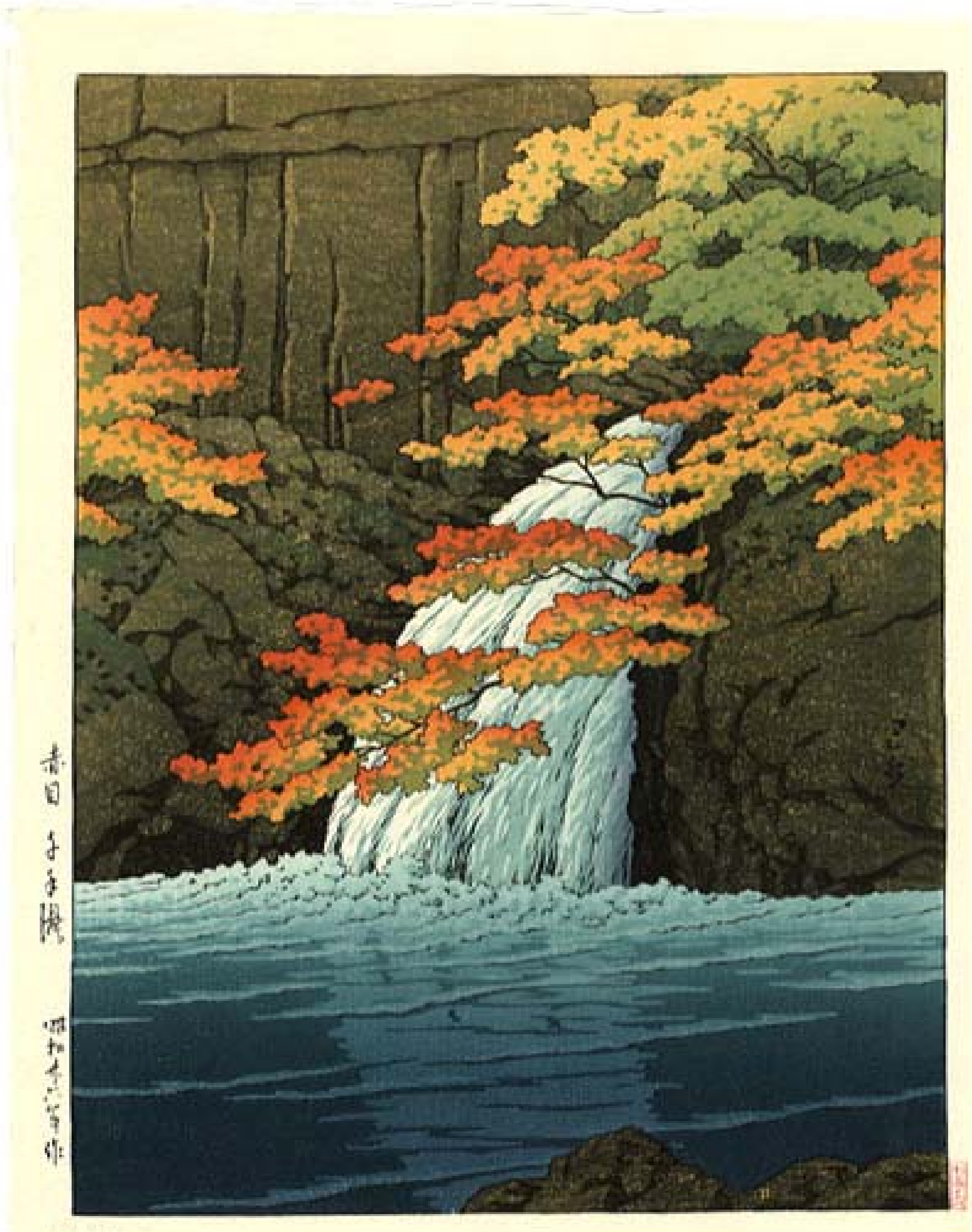
design inspiration





CHERRY CREEK
DROP #27

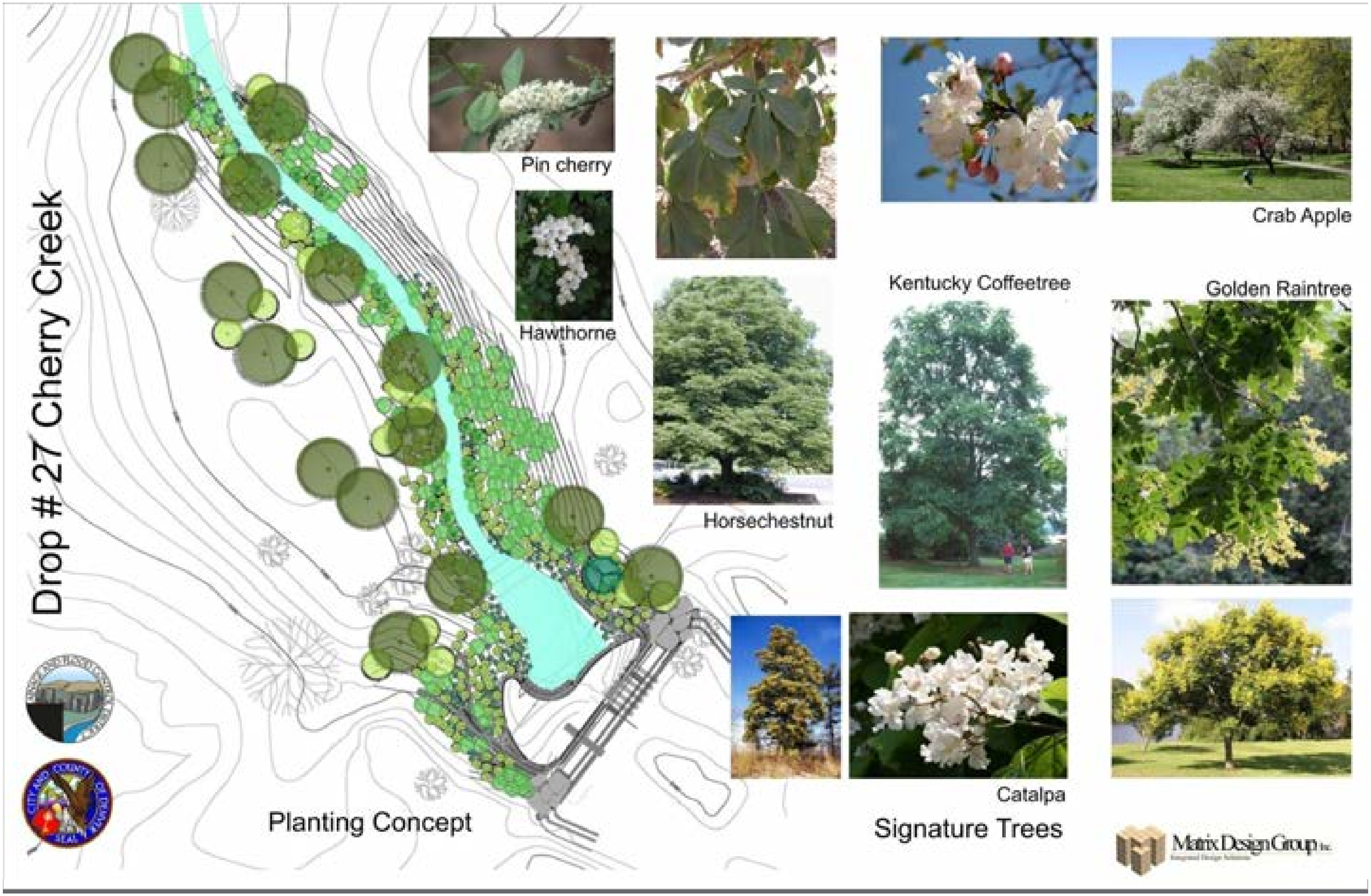
project concept



- Removal of existing riprap along the dam face, reuse material for channel stabilization
- Confine the crest width from 164’ to approximately 92’
- Base flow will be contained in 6 cantilevered galvanized steel troughs
- Face the wall of the drop structure with Glass Fiber Reinforced Concrete
- Re-alignment of channel and grading of overbanks
- Installation of a grouted boulder plunge pool
- Utilize bioengineering methods to stabilize channel toe
- Re-vegetation that incorporates riparian and upland species

CHERRY CREEK
DROP #27

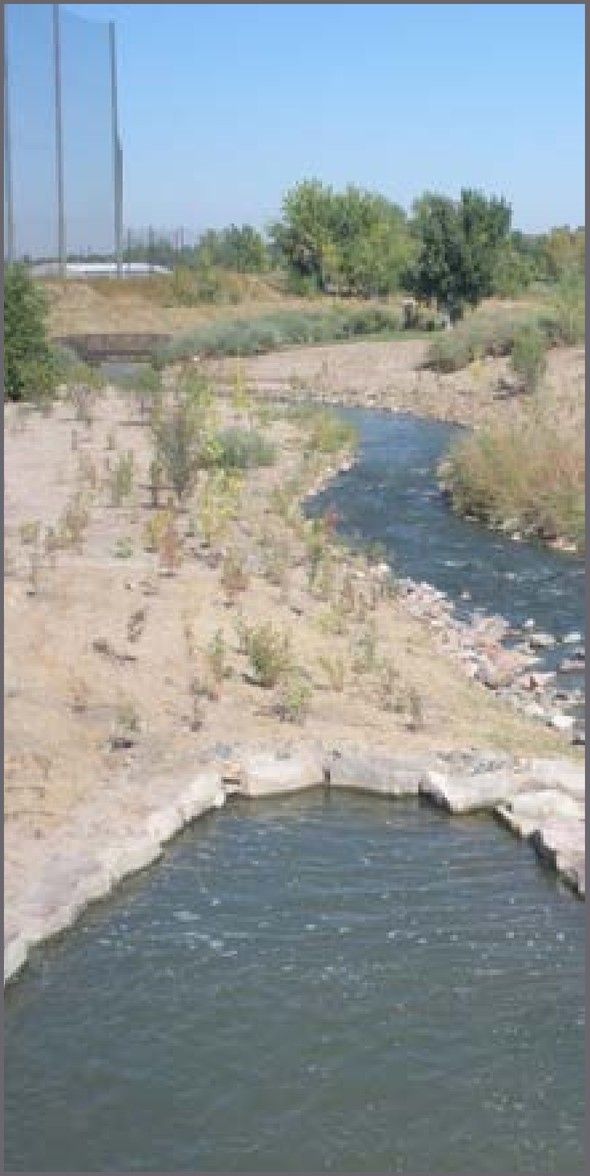
project improvements



CHERRY CREEK
DROP #27

planting concept





CHERRY CREEK
DROP #27

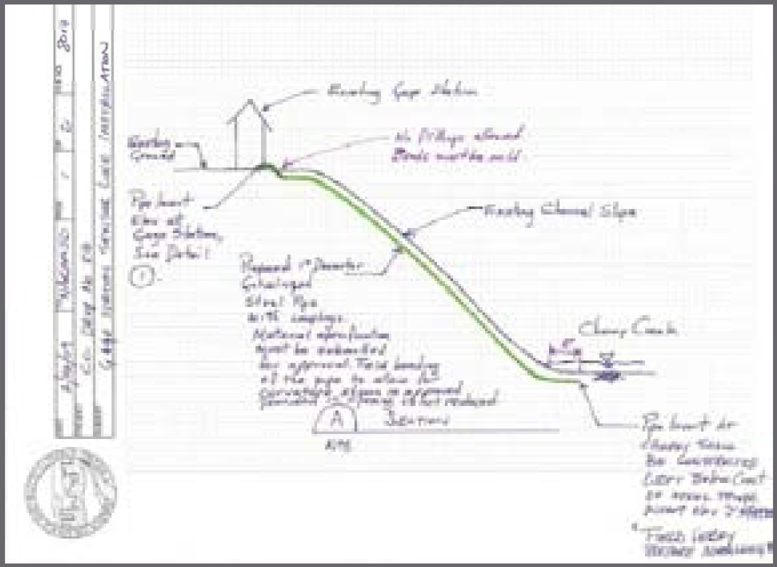
vegetation restoration

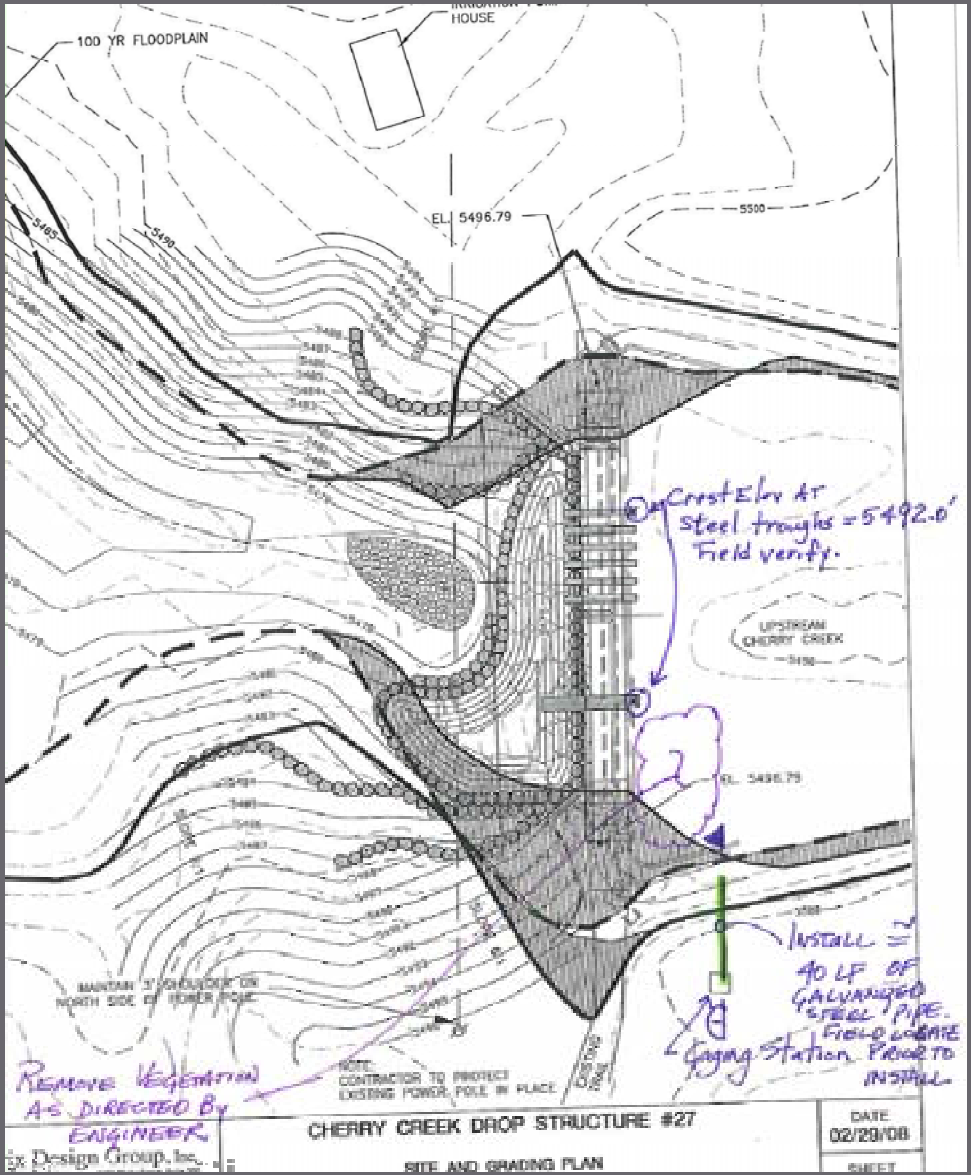
•Accommodate the design flows of 1500 cfs and 5000 cfs

•Average daily stream flow of 8.4 cfs will crest over 6 new low flow notch weirs ranging from 10 feet wide to 4 feet wide

CHERRY CREEK
DROP #27

hydrology and hydraulics





CHERRY CREEK
DROP #27

critical USGS gauging station enhanced


Cutting 2' of the concrete crest (existing wall)


Fitting and hanging GFRC panels


Building armature to hang Glass Fiber Reinforced Concrete (GFRC) panels


Mortaring GFRC panels

CHERRY CREEK
DROP #27

building the vision

CHERRY CREEK
DROP #27

building the vision

CHERRY CREEK
DROP #27

the flood of 2008

CHERRY CREEK
DROP #27

the flood of 2008

CHERRY CREEK
DROP #27

the flood of 2008

CHERRY CREEK
DROP #27

post construction October 2009

CHERRY CREEK
DROP #27

post-construction May 2010

CHERRY CREEK
DROP #27

post construction May 2010

Project team

Urban Drainage Flood Control District

City and County of Denver

Matrix Design Group

Naranjo Construction

Muller Engineering

Abstract
Elmer's Twomile Greenways Project
Boulder, Colorado

Annie Noble – City of Boulder
Mark Post – Centennial Engineering
Mike Galuzzi – WH Pacific

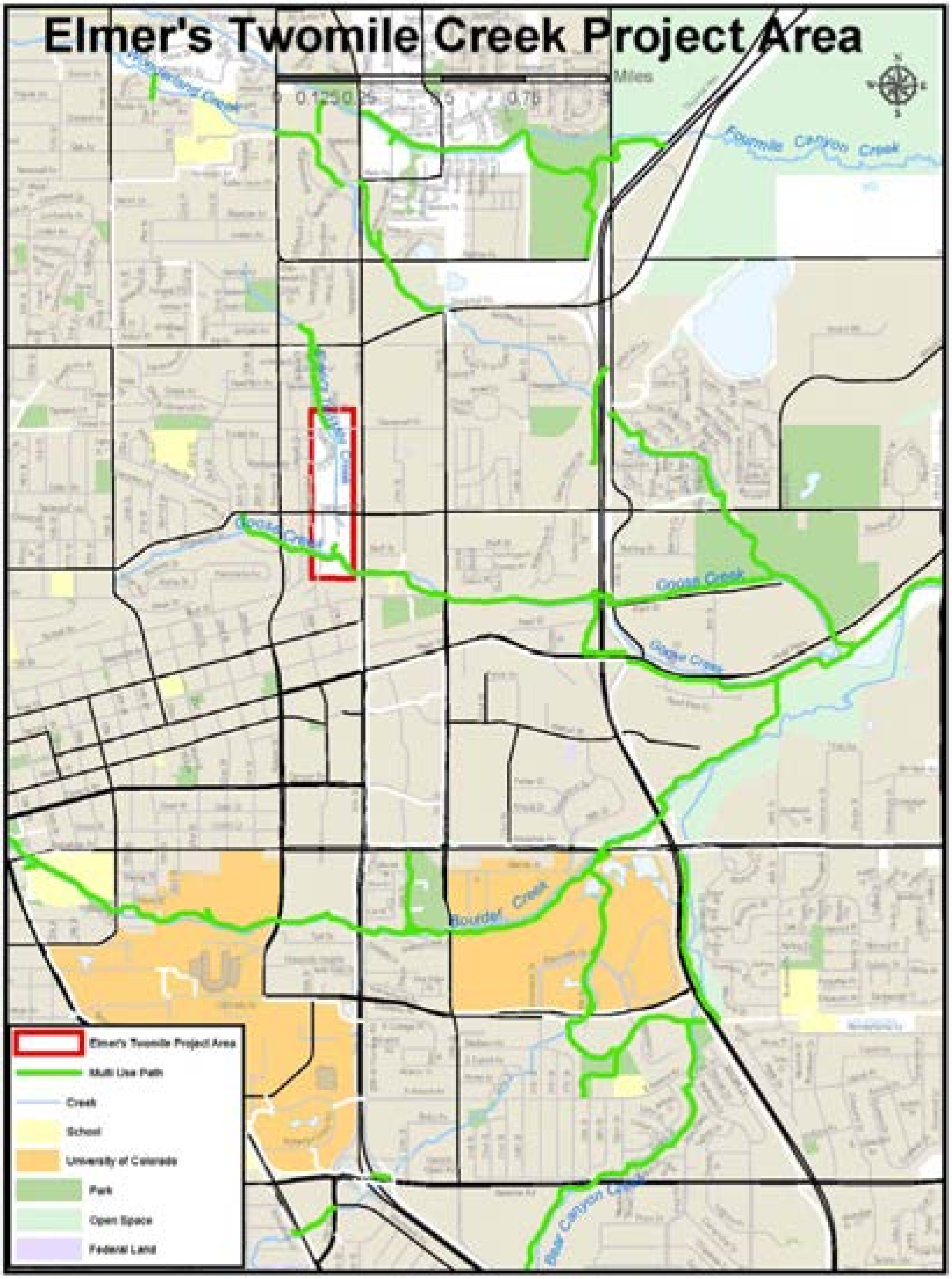
The Elmer's Twomile Greenways project is located in north Boulder between 26th and 28th Streets in one of the most developed urban corridors of the city. The project included a grade-separated, multi-use path connection from Goose Creek to Glenwood Drive, a combined bicycle/pedestrian and flood conveyance underpass at Valmont Road and 100 year flood mitigation improvements. In addition to a completed multi-use path connection, the City's overall goals included complete conveyance of the 100 year storm event, limiting impacts on existing development, and providing areas of open channel and wetlands wherever space allowed.

The transportation improvements provided a missing link in the path system between the area north of Glenwood Drive and the entire Boulder Greenways path system. The flood mitigation improvements address flooding that would occur south of Glenwood Drive to the confluence with Goose Creek during a 100-year storm event. Numerous properties east of the Elmer's Twomile channel along 28th Street were in the 100-year conveyance zone, and portions were also in the city of Boulder's high hazard zone. This project removed these properties from the 100-year floodplain by containing the flows within the newly completed Elmer's Twomile channel. In addition to providing flood and transportation improvements, the project also included habitat and water quality enhancements.

As part of this project, the city purchased a 1 acre easement which allowed for the development of a constructed wetland in a narrow urbanized corridor. This project was a cooperative effort with funding and oversight provided by the City of Boulder, the Urban Drainage and Flood Control District and the Colorado Department of Transportation. The Elmer's Twomile Greenways project from Goose Creek to Glenwood Drive including design, property acquisition, construction and the Letter of Map Revision cost approximately $8.8 million. The project was funded through the city's Flood ($2.87 million) and Greenways ($1 million) Capital Improvement Program, with additional funding contributions from outside funding sources including the Federal Transportation Improvement Program ($3.25 million) and the Urban Drainage and Flood Control District ($1.68 million).

Project Background

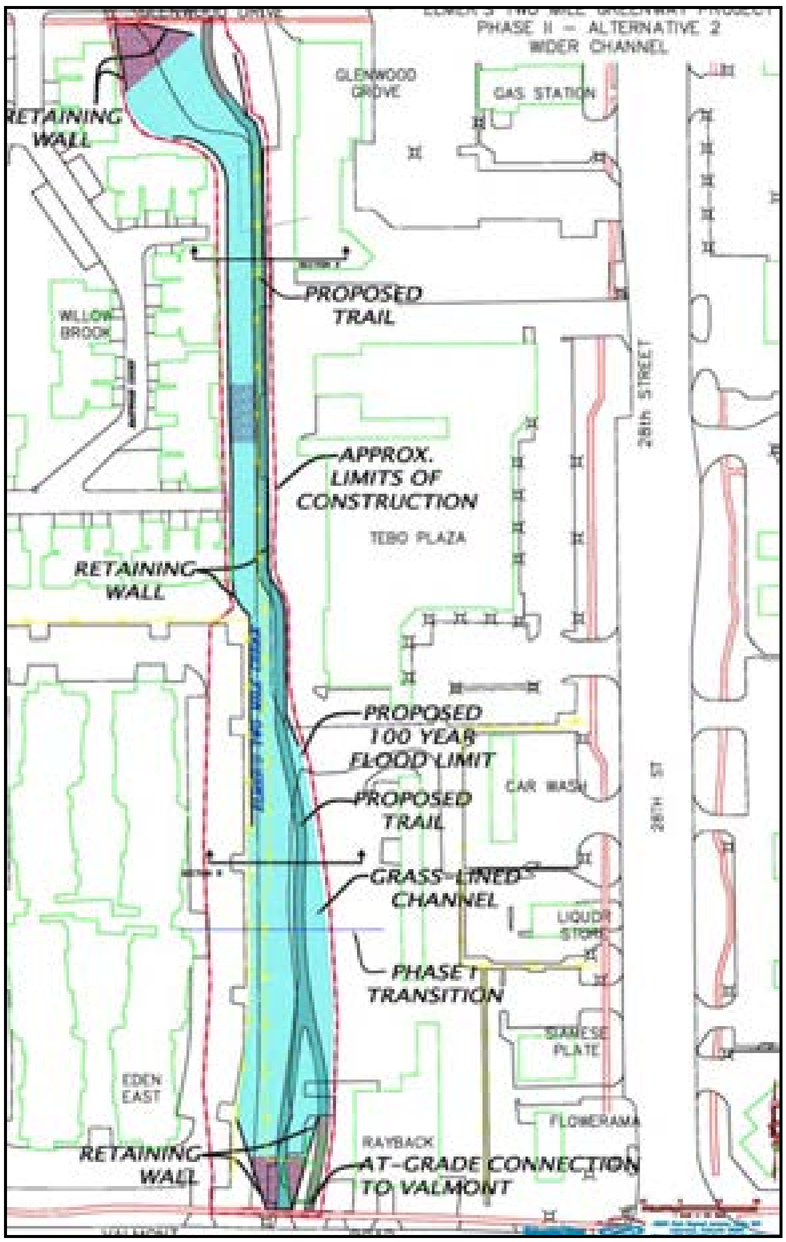
The City of Boulder recently completed the construction of the Elmer's Twomile Greenways project. Elmer's Twomile Creek is part of the City of Boulder's Greenways system, which is comprised of a series of corridors along riparian areas including Boulder Creek and its tributaries. The purpose of the Greenways program is to integrate multiple objectives, including habitat protection, water quality enhancement, storm drainage and floodplain management, alternative transportation routes for pedestrians and bicyclists, recreation and cultural resources. The Elmer's Twomile project provided an opportunity to maximize the overlap of these objectives through the coordination of various city departments and outside agencies. The overall project was a team effort, combining input from Flood Utilities, Transportation, Parks and Recreation, Water Quality and Environmental Services, Environmental Affairs, Planning and Open Space and Mountain Parks, in addition to two outside agencies: the Urban Drainage and Flood Control District and the Colorado Department of Transportation. Engineering and design was provided by the City's on-call consultant team of Centennial Engineering and WH Pacific.



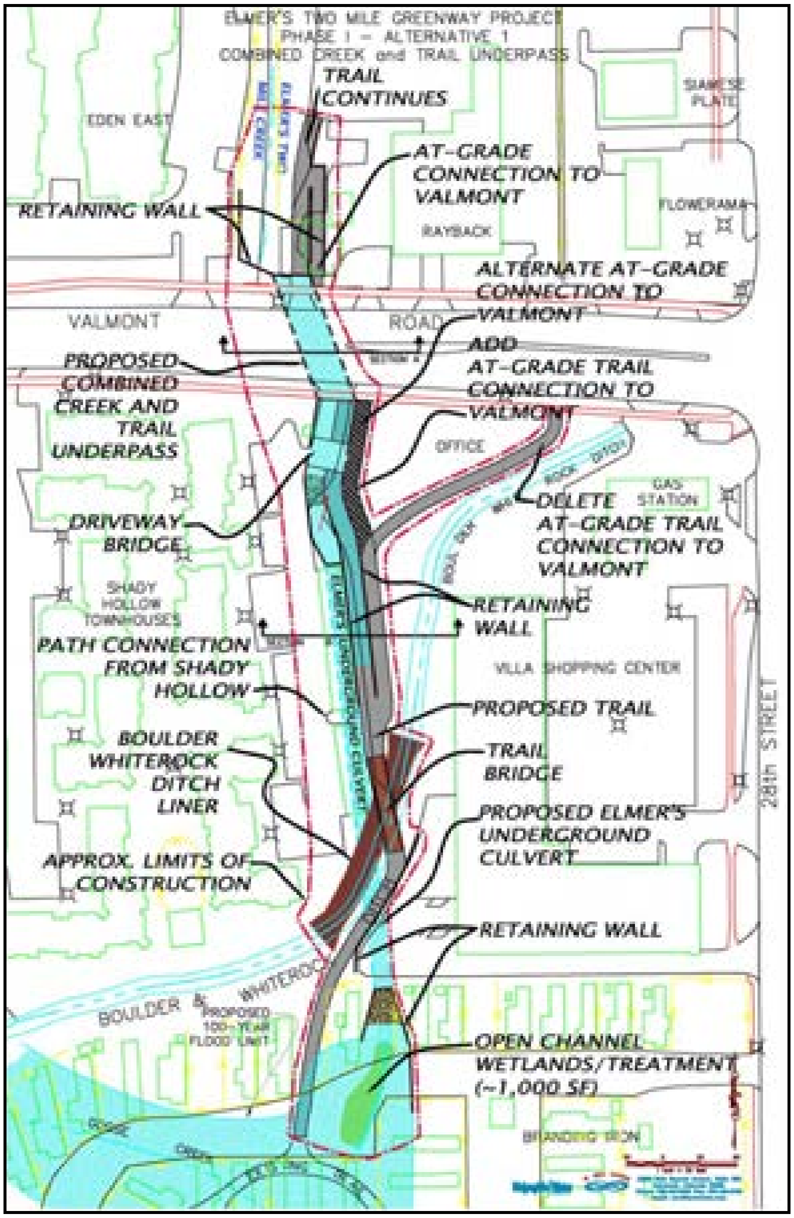
The Elmer's Twomile Greenways project is located in north Boulder between 26th and 28th Streets in one of the most developed urban corridors of the city.


City of Boulder - Elmer's Two Mile Greenways Project
Elmer's 2 Mile @ Iris Underpass (Pending)
City 100 Year Flood Plain
Phase II
Project Limits
Phase I

The conceptual design for the project was initiated in March 2004 with the first open house, as part of the city of Boulder's extensive Community and Environmental Assessment Process (CEAP). The CEAP evaluated three alternatives for the southern portion (Phase I) of the project and two alternatives for the northern section (Phase II). The chosen alternatives included a combined pedestrian and flood drainage underpass at Valmont Road, with a wider channel width north of Valmont Road.



Northern Section of Elmer's Twomile



Southern Section of Elmer's Twomile

Through the public input process, the plans for the northern portion of the project were changed to include an underground box culvert between the Willow Brook Condominiums and Tebo Plaza rather than an open channel. This modification was made to limit impacts on trees and reduce encroachment on the Willow Brook properties and parking spaces at Tebo Plaza, due to limited space for a conveyance channel. The at-grade connection from the Elmer's Twomile path south of Valmont was also modified to reduce impacts on trees along the Boulder and White Rock Ditch.

The project completed 0.5 mile of a missing link in the multi-use path system between Glenwood Drive and Goose Creek, including a grade separated underpass at Valmont Road. The Flood mitigation improvements removed numerous properties from the 100 year floodplain. South of Valmont Road, the flood mitigation improvements included 359 feet of 13'X5' box culvert between Valmont Road and the confluence of Goose Creek, which passes under the Shady Hollow parking lot. The box culvert opens up into a 6000 sq. ft. pond and wetland area at the confluence with Goose Creek. North of Valmont Road there is a 10,000 sq. ft. pond and wetland area. Upstream of this wetland is a 643 ft section of 12'X6' box culvert which passes under the Tebo Plaza parking lot. At the north end of the project, at Glenwood Drive is a third wetland area of approximately 3000 sq. ft.

Public Health Safety and Welfare
The Elmer's Twomile Greenways project provided enhancements to public health, safety and welfare from the perspective of removing properties from the 100 year flood plain and the city of Boulder's high hazard flood zone, as well as improving the safety of pedestrians and bicyclists. In addition to improving safety, the improvements promote public health by encouraging people to use alternative transportation.

This path connection is located in a densely populated neighborhood, with three different condominium associations located adjacent to the project on the west side and the commercial strip along 28th Street on the east side of the project. This project also serves a significant population density to the north and south, providing access to commercial centers along 28th Street and connectivity to the Goose Creek and Boulder Creek path system. Attached is a map which depicts the floodplain prior to the flood mitigation improvements.

Enhancement of the Surrounding Environment through Unique Solutions
This project enhances the surrounding environment. Prior to the construction of these improvements, Elmer's Twomile Creek was an undersized small concrete trapezoidal channel with chain link and wooden fences on both sides. Rayback Plumbing used the one acre parcel to the east of the channel, and north of Valmont Road as a storage area for hundreds of used sinks, toilets, bathtubs and plumbing parts. South of Valmont Road, the channel passed behind a strip mall and flowed into the Boulder and White Rock

Ditch. The area adjacent to the channel was viewed as a no man's land and was a dumping ground.

The existing channel passed through a very developed urban corridor, with limited space to allow for an open channel that would contain the 100 year storm event. Several channel width options were evaluated prior to eliminating the open channel concept for the underground box culvert. A wider, open channel (36 feet wide) would have required the removal of 50 parking spaces in Tebo Plaza and all of the mature trees east of Willow Brook Condominiums. The channel would have retaining walls five to eight feet high on both sides, with the distance between the retaining wall on the west side of the channel and the Willow Brook Condominiums as close as 10 feet. By reducing the channel width to 30 feet and moving the channel closer to the Willow Brook Condominiums, the number of parking spaces impacted would be reduced significantly, but the height of the retaining walls would increase and the distance between the retaining wall on the west side of the channel and the condominiums would be as close as four feet. In these areas, box culverts were installed in order to minimize impacts on adjacent properties.

Underpass structures were designed with a minimum cover, which shortened lengths and maximized the natural lighting and openness. Where space was available, wetland pond areas were created to provide water quality, habitat and aesthetic enhancements. The project was also landscaped in such a way to provide privacy to adjacent property owners and enhance the user experience. While it is not the city of Boulder's preference to utilize box culverts in lieu of an open channel, this approach made it possible to minimize impacts on existing vegetation and urban development.

Multiple Objects, Budget and Schedule

This project achieved multiple objectives. It provided a missing link in the grade separated path system, with connectivity to commercial areas and the entire Greenways path system. It removed numerous properties from the 100 year floodplain and the City of Boulder's high hazard zone. It provided water quality, habitat and environmental improvements and it enhanced the economic vitality of an important commercial area, as well as improving the aesthetics of a high density residential neighborhood. The project was designed and built by the City of Boulder in cooperation with the Urban Drainage and Flood Control District and the Colorado Department of Transportation. Flood utilities funds were leveraged with federal transportation funding. The project required 22 easements from nine property owners, three of which were homeowners associations with numerous residents. In addition to addressing the various interests and concerns of adjacent property owners (privacy, security and aesthetics) water rights issues and ditch crossing concerns were also addressed with the Boulder and White Ditch Company. This project was completed within the specified budget and schedule.

This project can serve as a model for other communities and other city of Boulder projects.

Before and After Photographs

Before – (Looking North) South End of Project at Confluence with Goose Creek

After – (Looking North) South End of Project at Confluence with Goose Creek

Before – (Looking North) Just North of Valmont Road

After – (Looking North) Just North of Valmont Road

Before – (Looking North) North of Valmont

After – (Looking North) North of Valmont

Valmont Road Underpass


Confluence with Goose Creek


Path Connection on North Side of Valmont Road


Wetlands at Glenwood Drive


Wetlands at Confluence with Goose Creek


Wetlands North of Valmont Road

Hildebrand Ranch Open Space Park

Trailhead Parking Area

Use of Permeable Interlocking Concrete Pavers

B.J. Ellison, Jefferson County Open Space
Matt Andrews, Muller Engineering Company
Carolyn Roan, Muller Engineering Company

Project Problem Statement - Goals

- Over 1653 acres
- Preserve agricultural heritage
- Preserve natural resources
- Provide trail-based recreation
- Provide public access for trailhead (currently 4 miles of trail)
  -Bicycling
  -Equestrian
  -Hiking
- Expandable for future use

Public Health, Safety & Welfare

- Maintains water quality
- Reduces runoff volume and peak flows
- Facilitates groundwater recharge

Enhancing the Environment

- Addressed water quality requirements
- Enhances natural surroundings
- Appropriate to setting with organic shades of brown
- Sensitivity to environment is core value of Open Space and expected by its constituents

Unique and Innovative Project

- First PICP project approved by Jefferson County P&Z
- One of the largest PICP installations in Colorado
- Unique partnering and collaboration

Multiple-Objective Management

- Jefferson County:
  - Open Space Maintenance
  - Planning & Zoning
  - Transportation & Engineering
  - Road & Bridge
  - Construction Management
- UDFCD
- Advanced Pavement Technology and Michelle DeLaria

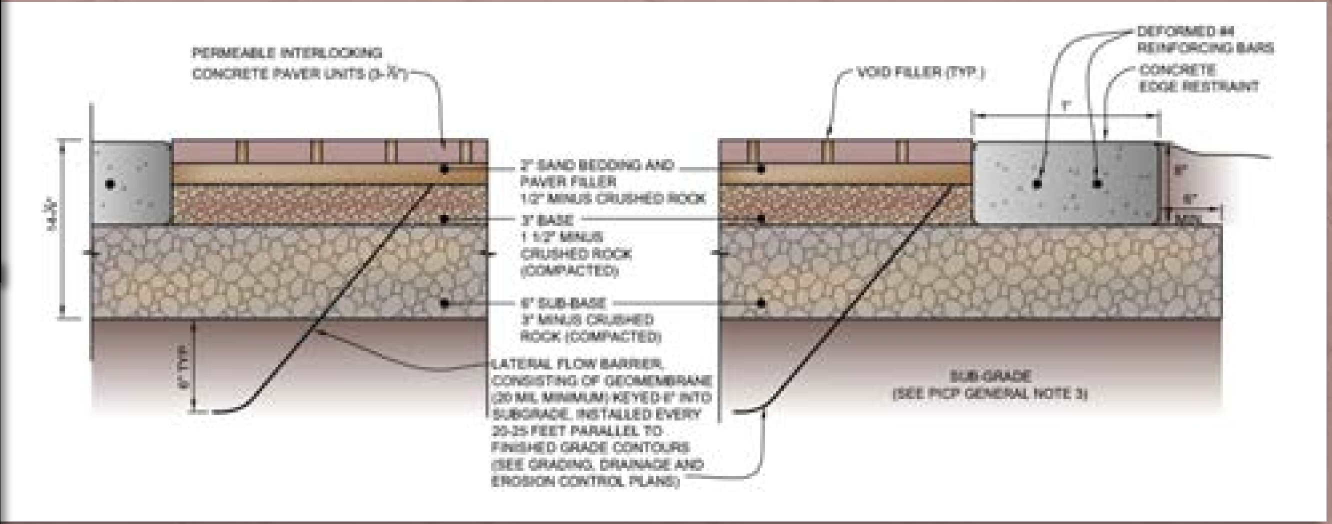
Parking Lot Design - Layout

Alternatives Evaluated

- Traditional asphalt
- Porous Asphalt
- Pervious Concrete
- PICP

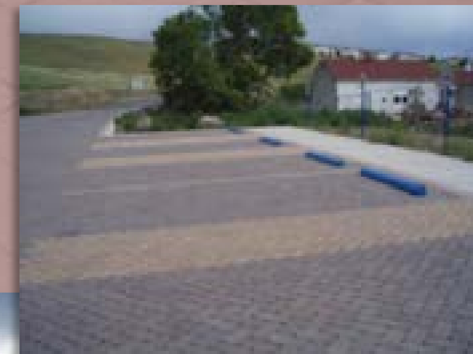
Parking Lot Design – Paver Subgrade

- Existing soils below sub-base
- Open-graded aggregate layers
- Compaction
- Interlocking Concrete Pavement Institute (ICPI) criteria



Parking Lot Design - Pavers

- Aqua-Bric (Borgert)
- Selection criteria
- Use of colors
- Recycled plastic wheel stops
- Mechanical installation



Project Meets Goals Effectively

- Budget
  - ✓ Overall
  - ✓ Cost per square foot
  - ✓ Life cycle benefits
- Schedule

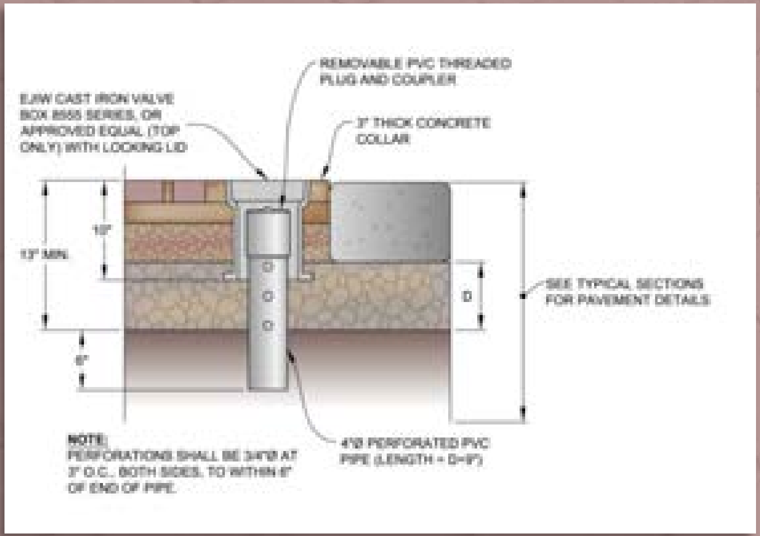
Drainage Design Goals

- ✓ Obtain a waiver from Jefferson County detention requirements
- ✓ Avoid a FEMA floodplain revision
- ✓ Utilize existing alluvial sandy soils for infiltration of runoff

Drainage Design Elements

- Overall drainage pattern
- Detention waiver criteria
- Water quality treatment
- "Modified" Porous Landscape Detention (PLD)

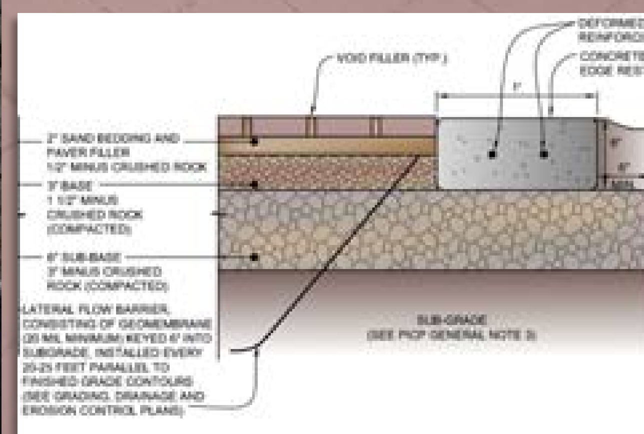
Monitoring Wells



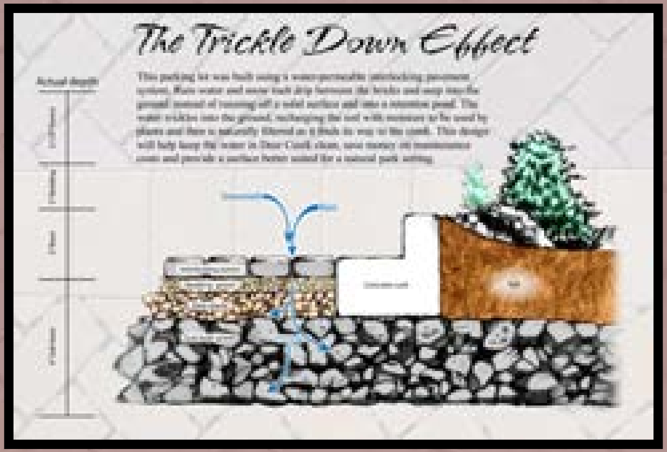
- UDFCD is monitoring water levels in comparison with nearby rain gage data
- Determine drain time and changes over time; clogging
- No water quality chemical data collected

Lateral Flow Barriers - Lessons

- Liner thickness recommendations: 40-50 mil
- Lateral flow patterns



Model Project



- Demonstrate applicability to Colorado
- Introduce technique to Jefferson County work groups
- Increased public awareness of water quality with interpretive signs
- Mechanical installation training
- Maintenance buy in and training
- UDFCD test site

Thank You For Coming!
Questions?


CASFM

JEFFERSON COUNTY OPEN SPACE

MULLER

McIntyre Gulch Enhancement at the St. Anthony's Hospital Site, Denver Federal Center, Lakewood, Colorado

The new St. Anthony's Hospital in Lakewood, Colorado is scheduled to open in the spring of 2011. Although not yet helping patients, the hospital has already brought considerable benefit to the 900- foot section of McIntyre Gulch within its boundaries, as voluntary enhancements of this urban stream were completed as a part of the site remediation and hospital construction project. Walsh Environmental Scientists and Engineers, LLC (Walsh) provided assessment, design, permitting, construction documentation preparation, and construction support services.

Pre-project conditions in the Gulch were typified by a deeply incised and actively eroding corridor, including a 180- foot section of near vertical bank with heights reaching up to 15 feet. Such conditions posed a potential safety threat, increased fine sediment loading to downstream waters, and limited both floodplain function and public access to the gulch. Historic channelization of a meandering portion of the reach, and placement of construction debris in the cut-off meander left waste south of the Gulch, and right up to the channel in some locations. Both the understory vegetation and riparian canopy were intermittent and sparse due to a lack of sustainable hydrology, and were primarily comprised of upland grasses and weeds. Further compromising the stability of the reach, the confluence of the south branch of McIntyre Gulch with the main stem was constructed decades ago at a hydraulically unfortunate 90 degree angle.

Constraints and challenges were numerous for this small stretch of urban stream. Physical constraints included the narrow and deeply incised corridor, as well as lateral constraints imposed by remediation requirements and proposed land uses. The project employed multiple-objective management to fulfill its widely varied goals of landfill remediation, stream corridor enhancement, and providing safe accessible recreation opportunities for all.

To accomplish the multiple goals, Walsh utilized a creative approach that mimics natural features to improve the health and function of this stream reach, as well as its safety and opportunities for public enjoyment. All waste adjacent to the Gulch was removed and banks were regraded to mild slopes in a manner that maximized preservation of isolated mature cottonwoods and willow stands. Walsh designs applied varied grading such as low planting benches and small boulder walls to break up the uniformity of the channelized section, restore floodplain function, and provide unique local diversities in soil and water conditions to enable specialized plantings. Natural bedrock formations were exposed during waste removal, prompting the upgrade of a proposed grouted sloping boulder drop structure at the south branch confluence to a sculpted concrete cascade that fits the natural setting of the gulch, provides increased stability to the reach, and ensured preservation of the largest streamside cottonwood tree. The cascade was shaped and stained to match the existing bedrock and included innovative micro-grading to create "precip pools" to hold water for birds and other wildlife. All enhancements were designed to be consistent with UDFCD guidelines and standards to ensure maintenance eligibility for the project reach. The project has already served as a model for other projects, as UDFCD has recommended it as an example for a downstream section of the gulch. The project stayed within budget even with the upgraded drop structure, as the sculpted cascade

Blair E. Hurst, P.E.
bhurst@walshenv.com
Walsh Environmental Scientists and Engineers, LLC

naturally accommodated the steep gulch sideslopes and eliminated the need for expensive grouted boulders.

Further successes include accommodating several proposed land uses, such as vehicular and pedestrian crossings, a new bike path paralleling the north bank, and surface water spillways and pipe outlets in to the Gulch, in a way that would impart the most natural function and appearance on this stream system. The vehicular crossing is a free span, open bottomed structure that reduces impacts on stream hydraulics and the natural channel bed. Spillways were vegetated with native grasses and shrubs.

Vegetative improvements, such as removal of weed tree species acting as a seed supply, and extensive planting of a diverse mix of native trees, shrubs and grasses replenish what was lost in this urban area - the invaluable “green line” of a healthy and functional riparian corridor.

Blair E. Hurst, P.E.
bhurst@walshenv.com
Walsh Environmental Scientists and Engineers, LLC

Views of near vertical cutbank in McIntyre Gulch prior to project initiation

Looking upstream (west) from top of bank at the future Routt Street crossing area. Note bedrock cascade in the distance for reference.

View to the west from within the channel at sediment loading from vertical cutbank. Note building in the background for reference.

Bank heights limited floodplain function and access to the gulch.

Views of regraded banks and planting of native vegetation

Looking upstream (west) from the new Routt Street crossing. Note bedrock cascade and building in right corner for reference. South bank has been regraded after waste removal, seeded and planted with native shrubs and grass plugs.

Also visible are small boulder walls to add topographic variety to banks, bikepath, and preserved willow stand.

Looking downstream (east) at south bank just below the sculpted concrete cascade. Note preserved cottonwood trees.

Large corrugated metal pipe is a temporary pedestrian crossing. A permanent pedestrian bridge will be installed, whose location was carefully selected to preserve trees.

View to the east of rock-log deflectors placed at the toe of the newly graded slope immediately upstream of the bedrock outcrop exposed during waste excavation. The Routt Street crossing is visible in the background. Note existing stand of willows on left; a soil riprap rundown from the north bank was planned in this area. It was decreased in size to preserve this quality vegetation

South branch confluence area, before cascade construction

View upstream at confluence. Note 90 degree angle between South branch structure wingwalls and McIntyre Gulch mainstem, as well as scour hole.

Pre-project conditions looking downstream from confluence. Note lack of floodplain access and riparian vegetation.

Construction of the sculpted concrete cascade included raising the channel bed to repair and reinforce the scoured area, protecting the north bank from south branch flows, and preserving all of the cottonwood trees in the vicinity.

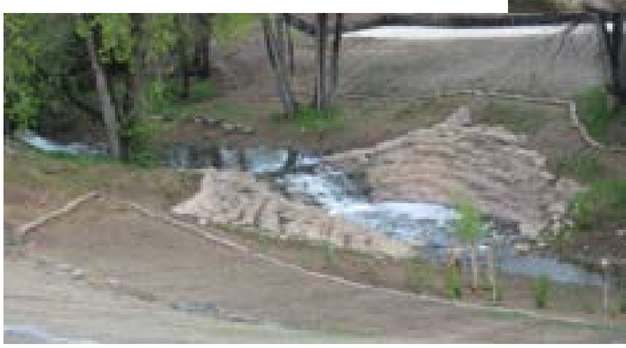
The cascade was sculpted in a naturalized fashion and includes small “precip pools” to hold water for birds and other wildlife.

Constructed sculpted concrete cascade

View to the west

View to the southeast

View from parking area



Natural bedrock outcrop exposed during waste excavation used as a model for the sculpted concrete cascade.

Staining of the sculpted concrete to match existing outcrop.

A System Approach to Watershed Planning

Lucas Babbitt, PE, CFM

Matrix Design Group, Inc.
An Employee Owned Company

September 23, 2010

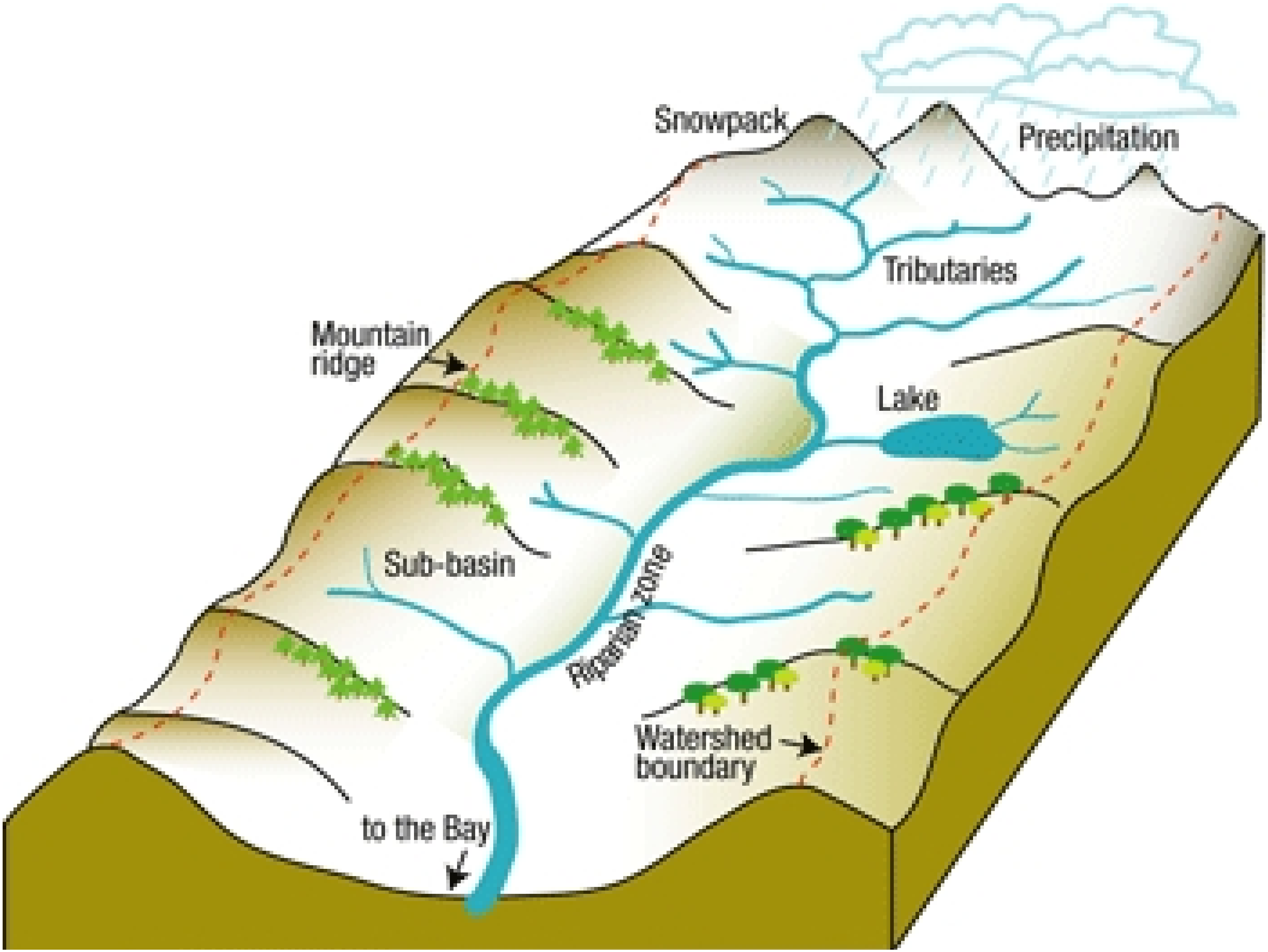
Overview

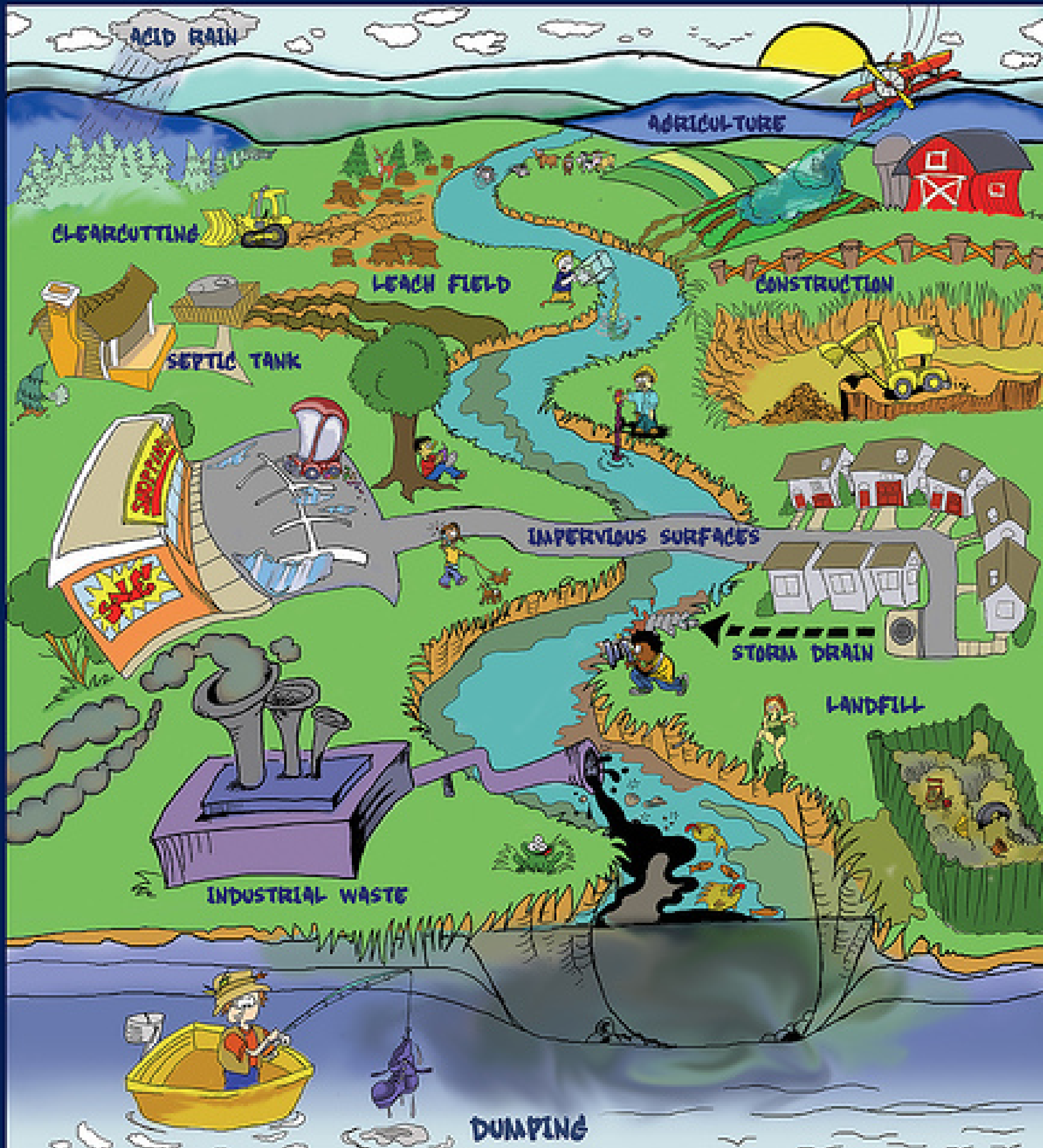
- Watershed Impacts from Development
- Purpose of Watershed Planning
- Conventional Watershed Planning
- System Approach to Watershed Planning
- Summary

What is a Watershed?

A watershed is the area of land where all of the water that is under it or drains off of it goes into the same place.

John Wesley Powell, scientist geographer, put it best when he said that a watershed is: "that area of land, a bounded hydrologic system, within which all living things are inextricably linked by their common water course and where, as humans settled, simple logic demanded that they become part of a community." [1]


Snowpack
Precipitation
Tributaries
Mountain
ridge
Lake
Sub-basin
Riparian zone
Watershed
boundary
to the Bay


ACID RAIN
AGRICULTURE
CLEARCUTTING
LEACH FIELD
CONSTRUCTION
SEPTIC TANK
SHOPPING
IMPERVIOUS SURFACES
SALE
STORM DRAIN
LANDFILL
INDUSTRIAL WASTE
DUMPING

System Definition

A group of interacting, interrelated, or interdependent elements forming a complex whole.[2]

Watershed Impacts from Development

- Increased Runoff
- Increased Flooding
- Water Quality Problems
- Stream Degradation
- Habitat Destruction
- etc…

Purpose of Watershed Planning

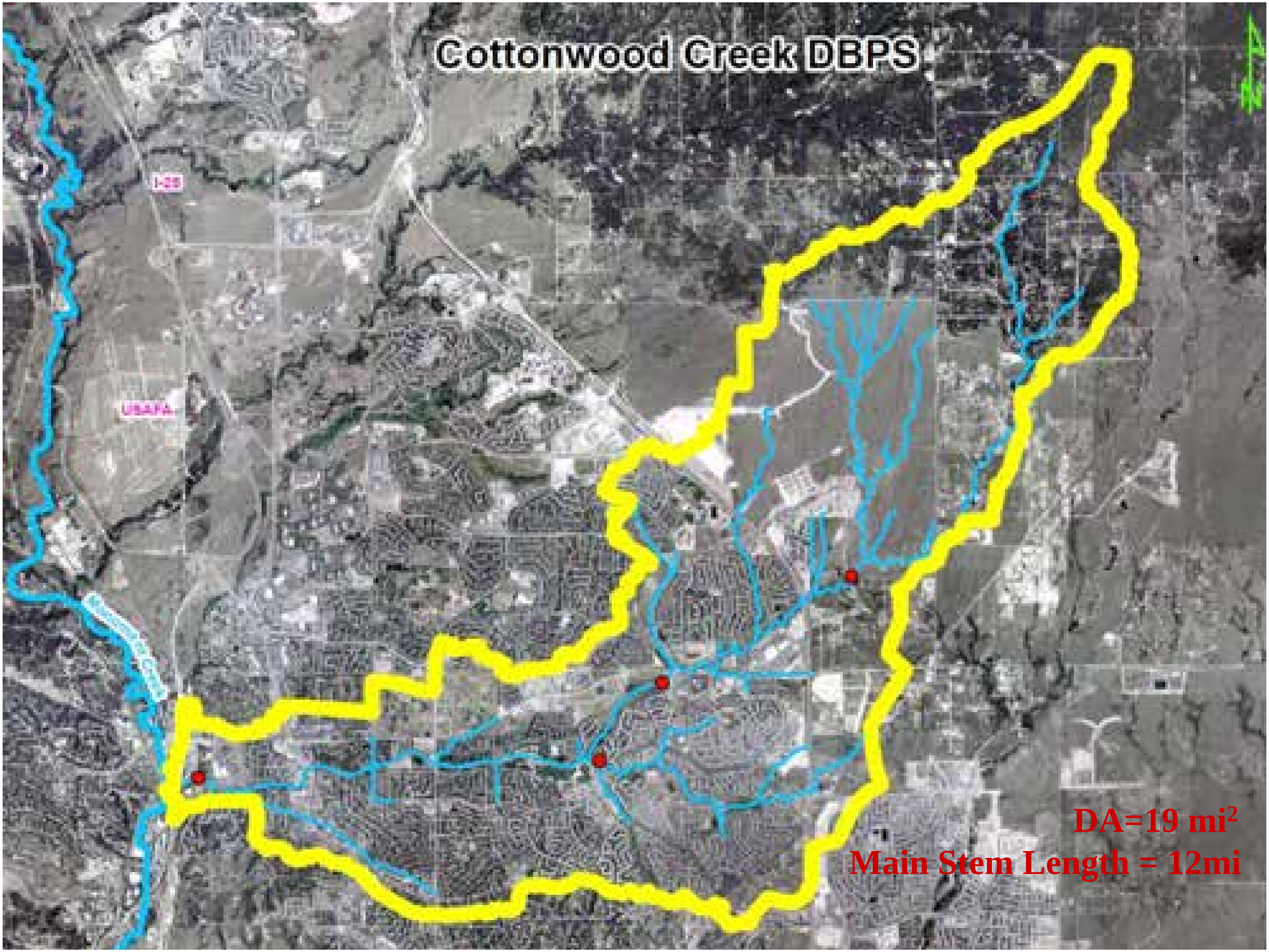
- Infrastructure Sizing
- Detention Sizing
- Channel Improvements
- Fee Development

Conventional Watershed Planning

- Flood Control
- Flood Conveyance
- Safety

System Approach to Watershed Planning

Cottonwood Creek


Cottonwood Creek DBPS
DA=19 mi²
Main Stem Length = 12mi

Watershed Concerns

- Higher than Historic Peak Flows are Being Released
- Channel Instability
- Habitat Destruction
- Water Quality Issues

Goal & Objectives

Goal

Create a Sustainable Watershed Plan

Objectives

- Provide an Amenity to the Community by Restoring the Aesthetic Value of the Corridor
- Protect the Environment by Restoring Habitat & Implementing Water Quality
- Provide an Economic Benefit to the City by Implementing cost-effective and low maintenance solutions
- Provide Flood Control & Safety

Philosophy

- Floodplain Preservation is Paramount
- Incorporate Natural Channel Design Everywhere Possible
- Manage Low Flow Hydrology

Alternatives Analysis & Screening

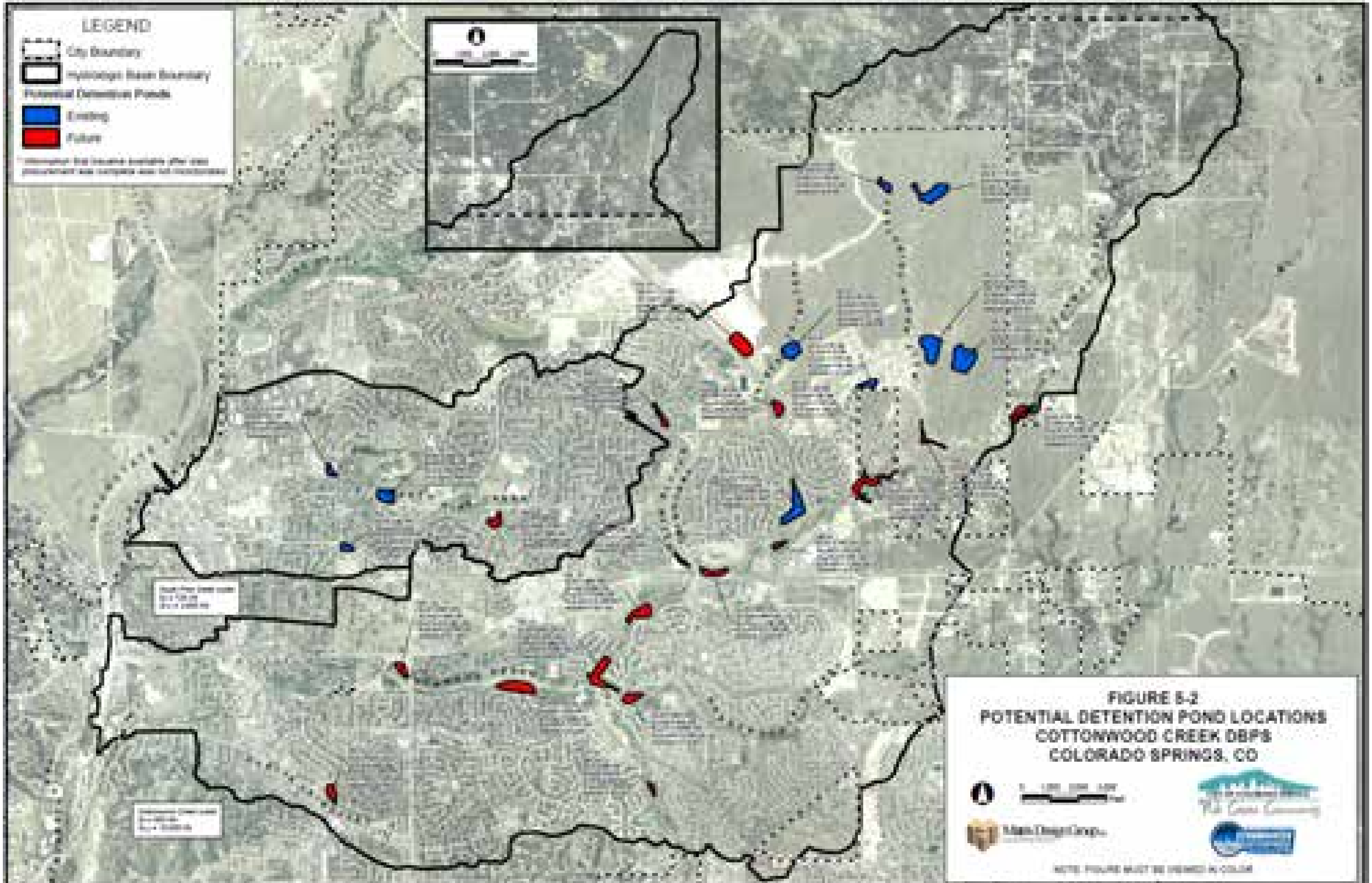
- Hydrology
- Detention Ponds
- Reaches

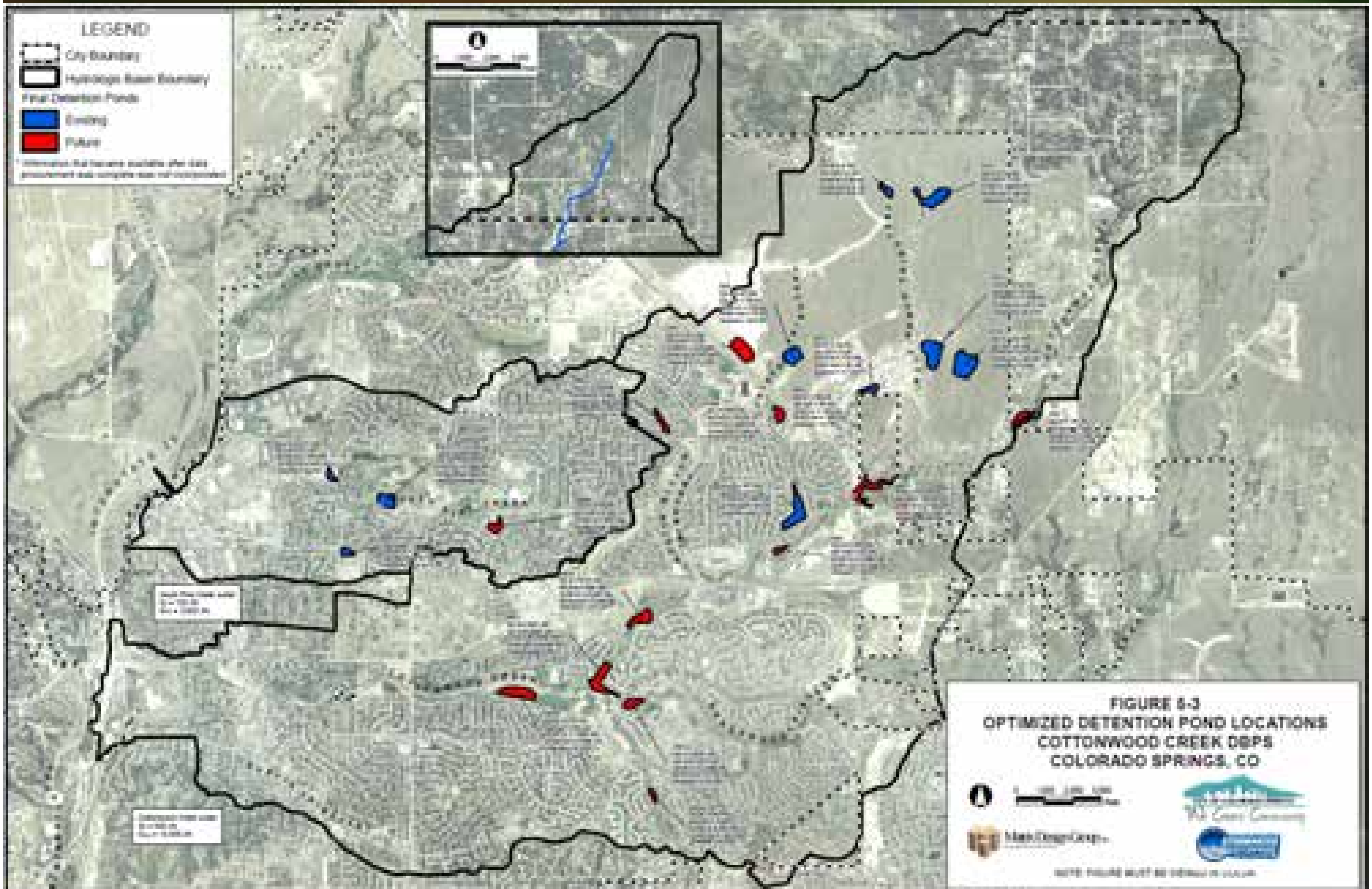
Importance of Hydrology

- Foundation of a Watershed Plan
- Has to be Done Correctly
- Low Flow Hydrology is Critical
- Impact on Alternatives
- Impact on Costs

Detention Pond Analysis & Screening

- Detention Pond Alternatives
  - None (Full Channel Conveyance)
  - 2-yr Flood Control
  - 100-yr Flood Control
  - Full Spectrum Detention (EURV + 100-yr)
- Evaluated All Possible Locations
- Optimized Locations Based on Peak Flow Reduction
- Retrofit Existing Ponds Where Possible


LEGEND
City Boundary
Hydrologic Basin Boundary
Potential Detention Ponds
Existing
Future
FIGURE 5-2
POTENTIAL DETENTION POND LOCATIONS
COTTONWOOD CREEK DBPS
COLORADO SPRINGS, CO



LEGEND
City Boundary
Hydrologic Basin Boundary
Final Detention Ponds
Existing
Future
FIGURE 6-3
OPTIMIZED DETENTION POND LOCATIONS
COTTONWOOD CREEK DBPS
COLORADO SPRINGS, CO

Parameter	Full Conveyance	2-Year Detention	100-Year Detention	Full Spectrum Detention
Detention Pond Construction Costs	+ +	-	- -	- -
Reach Construction Costs	- -	- -	-	-
Detention Pond O&M Costs	-	- -	- -	- -
Reach O&M Costs	-	-	-	-
Full Benefit of Previously Constructed Reaches	+ +	+	-	-
Cost for Unimproved Reaches	- -	- -	+	+
Control of the 2-year Flood Event	- -	+ +	- -	+ +
Control of the 100-year Flood Event	- -	- -	+	+
Reduced Peak Discharge into Monument Creek	- -	-	+	+ +
Flexibility for Development	- -	-	+	+
Lot Premium	-	+	-	+
Habitat Improvements	- -	+	-	+
Water Quality	-	+	+	+ +
Total	-14	-6	-6	3

Detention Pond Analysis & Screening

Pros

- Control of the 2-yr Flood
- Reduced Peak Discharge into Monument Creek
- Water Quality

- Construction Costs ~Same as 100-yr Detention
- O&M Costs ~Same as 100-yr & 2-yr Detention

Reach Analysis & Screening

- Implement Natural Channel Design Everywhere Possible
- Small Drop Structures (<3ft height)
- Large Drop Structures (<6ft height)
- Fully Lined Channel

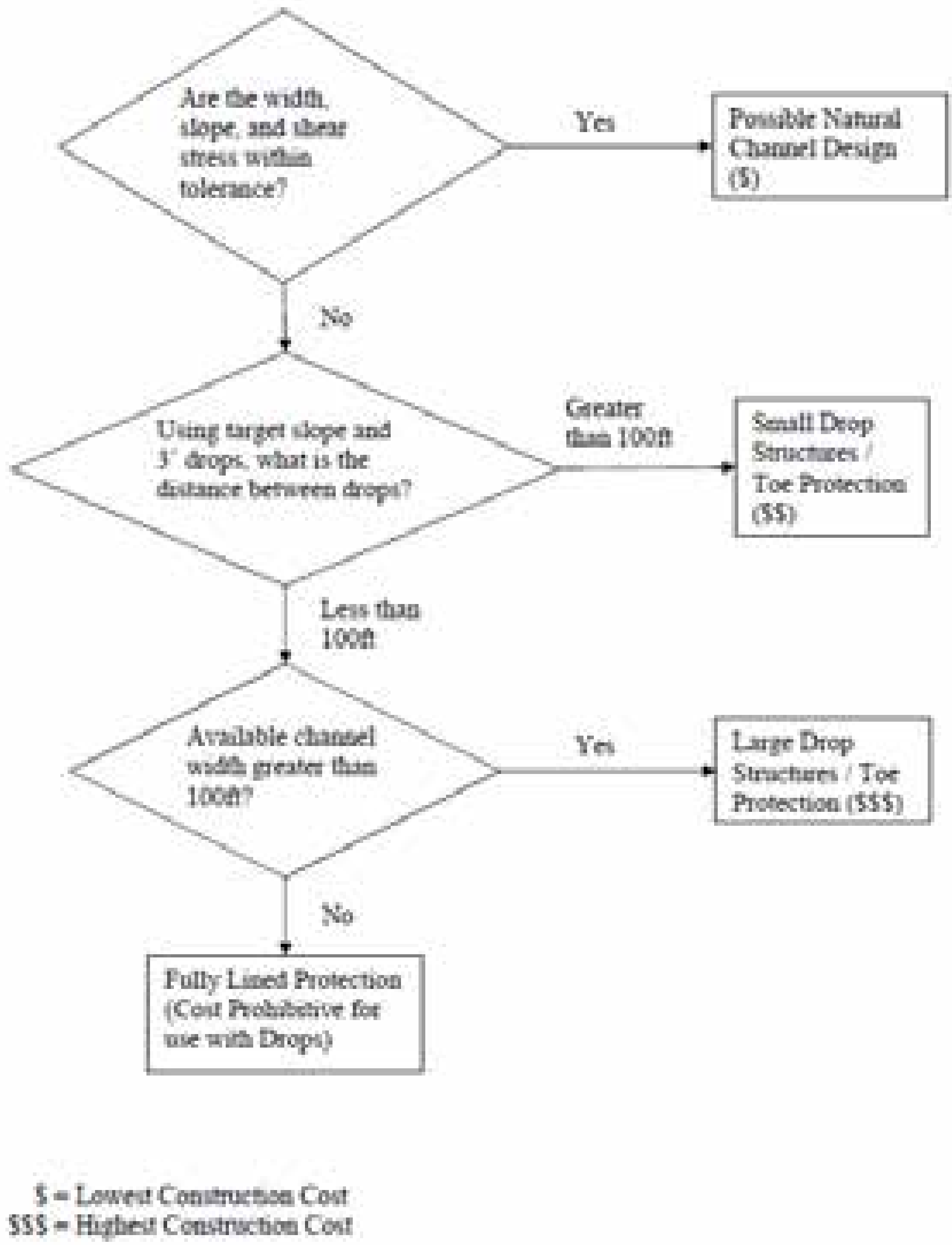
➢ Provide a Continuous Wildlife Corridor

Natural Channel Design Benefits

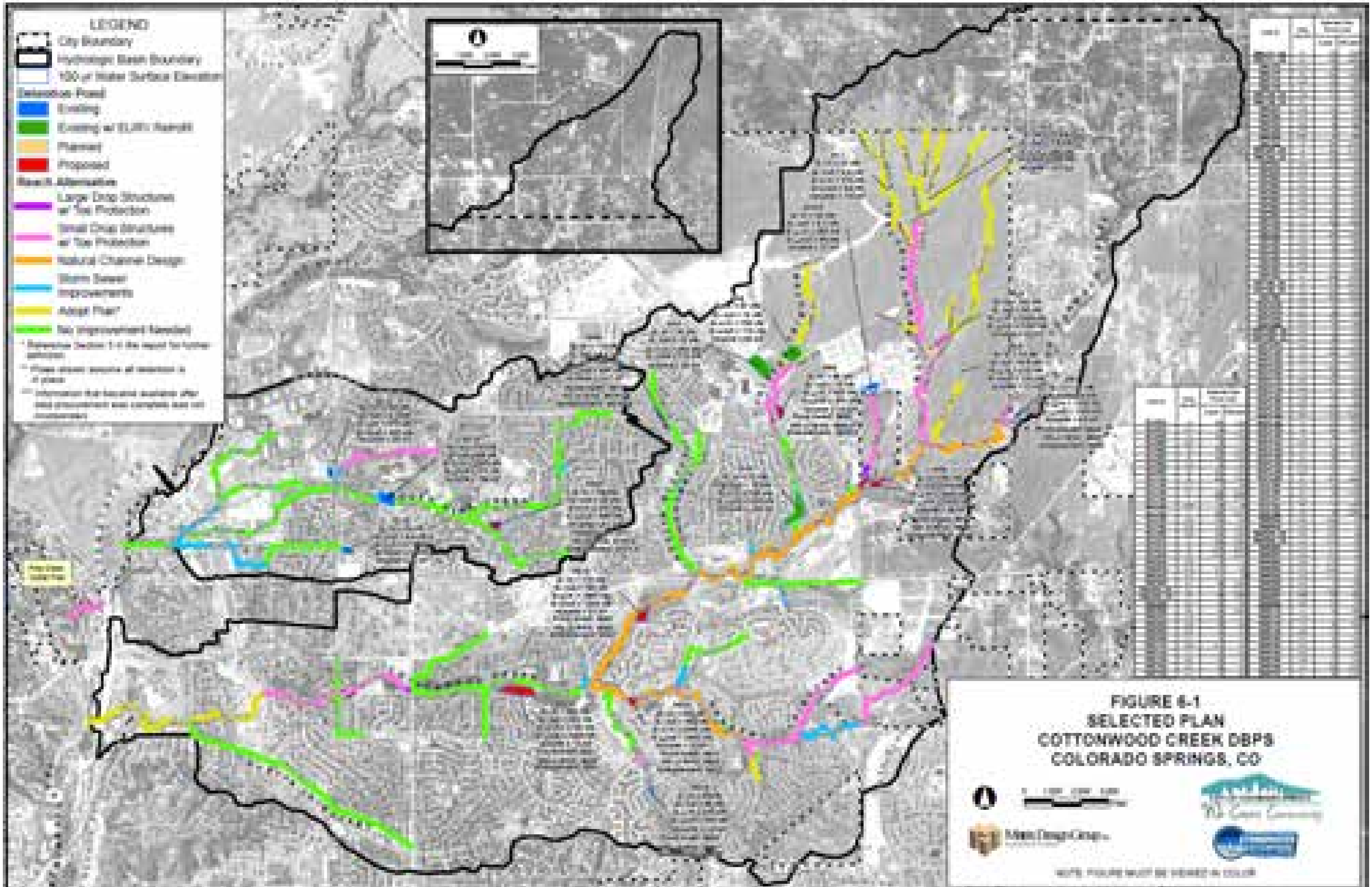
- Aesthetic Value
- Habitat Creation and Preservation
- Typically Lower Construction Cost Than Conventional Approaches
- Water Quality Benefits
- Channel Function
- DCM Criteria for Limiting Erosion

Natural Channel Design Screening Parameters

- Shear Stress < 2lb/ft^2
- Channel Slope < 2%
- Belt Width < Available Width



Are the width, slope, and shear stress within tolerance?
Yes
Possible Natural Channel Design ($)
No
Using target slope and 3' drops, what is the distance between drops?
Greater than 100ft
Small Drop Structures / Toe Protection ($$)
Less than 100ft
Available channel width greater than 100ft?
Yes
Large Drop Structures / Toe Protection ($$$)
No
Fully Lined Protection (Cost Prohibitive for use with Drops)
$ = Lowest Construction Cost
$$$ = Highest Construction Cost


LEGEND
City Boundary
Hydrologic Basin Boundary
Detention Pond
Existing
Planned
Proposed
Reach Alternative
Large Drop Structures w/ Toe Protection
Small Drop Structures w/ Toe Protection
Natural Channel Design
Storm Sewer Improvements
No Improvement Needed
FIGURE 6-1
SELECTED PLAN
COTTONWOOD CREEK DBPS
COLORADO SPRINGS, CO

Reach Analysis & Screening Summary

Alternative	Length (ft)
No Alternative Needed	79,523
Adopt Alternative	51,803
Infrastructure Sizing[1]	13,163
Natural Channel Design	28,759
Small Drop Structures	43,358
Large Drop Structures	938
Fully-Lined Channel	0
Total	217,546

[1]Only includes storm sewer infrastructure sizing, not bridge or culvert crossing sizing.

Cost Comparison

Summary

Thank You!

Lucas Babbitt, PE, CFM

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lucas_babbitt@matrixdesigngroup.com

Developing New Local Construction Stormwater Discharge Regulations Through Partnership and Stakeholder Collaboration

Colorado Association of Stormwater and Floodplain Managers

21st Annual Conference: "Coming of Age"

Stormwater Management and Water Quality Session

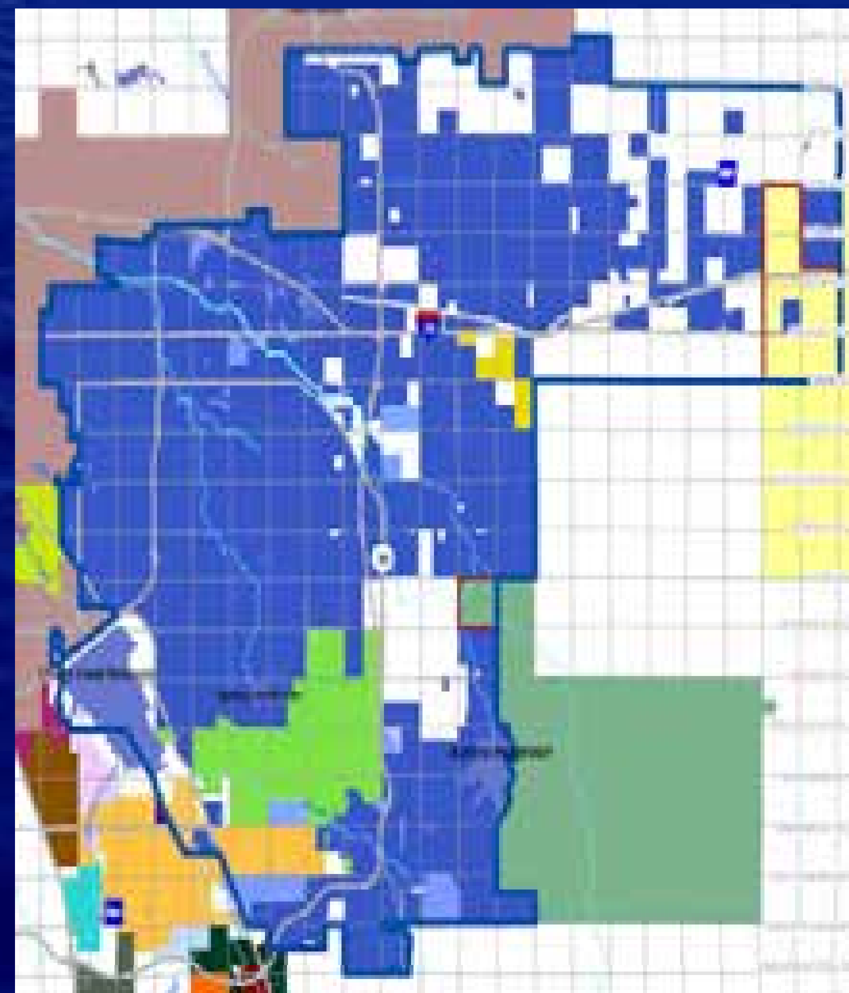
Silvertree Lodge - September 23, 2010

Sean Lieske
Permitting and Environmental Compliance Manager
Aurora Water

Tiffany McEachen PE CFM
Project Manager
CH2M HILL

Services – Drinking Water, Wastewater & Stormwater

Service Area – 151 sq. miles



Population – > 314,000

Accounts – > 75,000

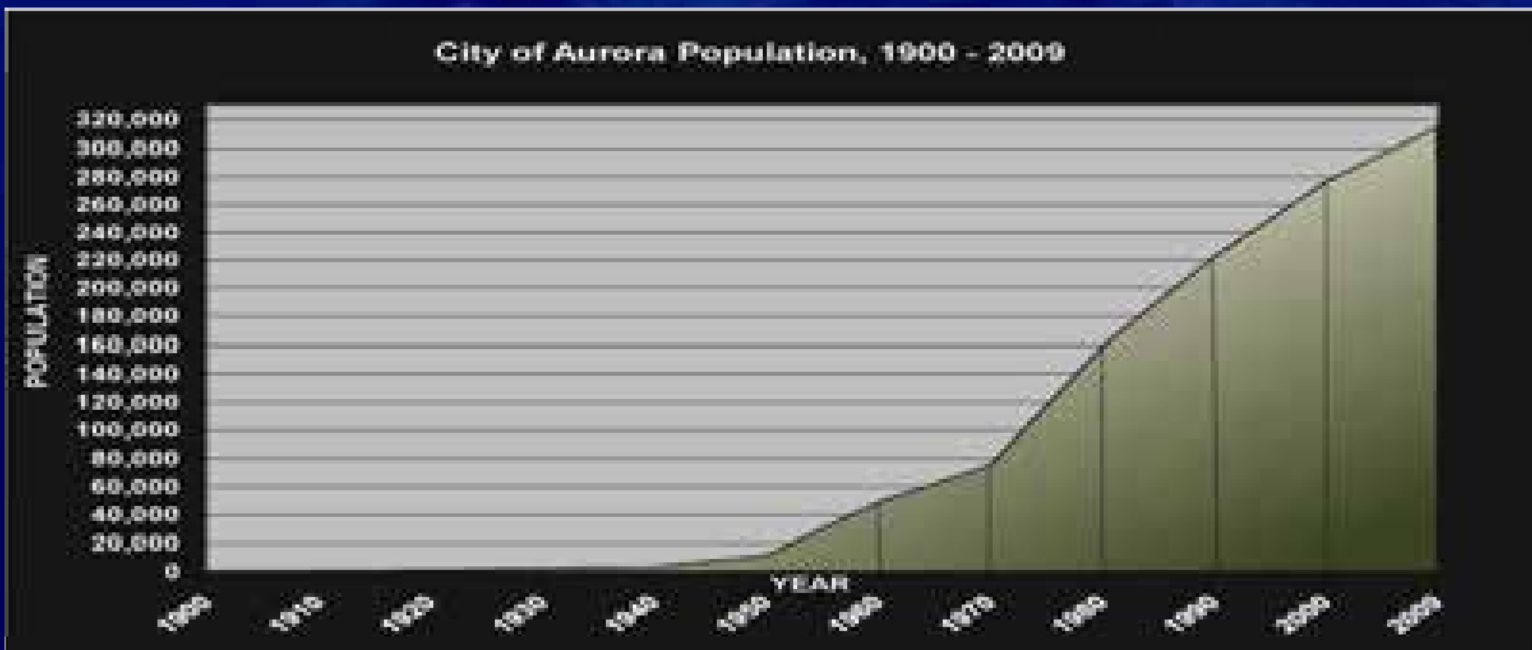
Background

Aurora

All-America City

2008

CITY OF AURORA	
Year	Official Estimate
2000	276,393
2001	284,606
2002	287,895
2003	292,158
2004	298,303
2005	303,833
2006	306,908
2007	309,416
2008	313,144
2009	314,326



AURORA WATER

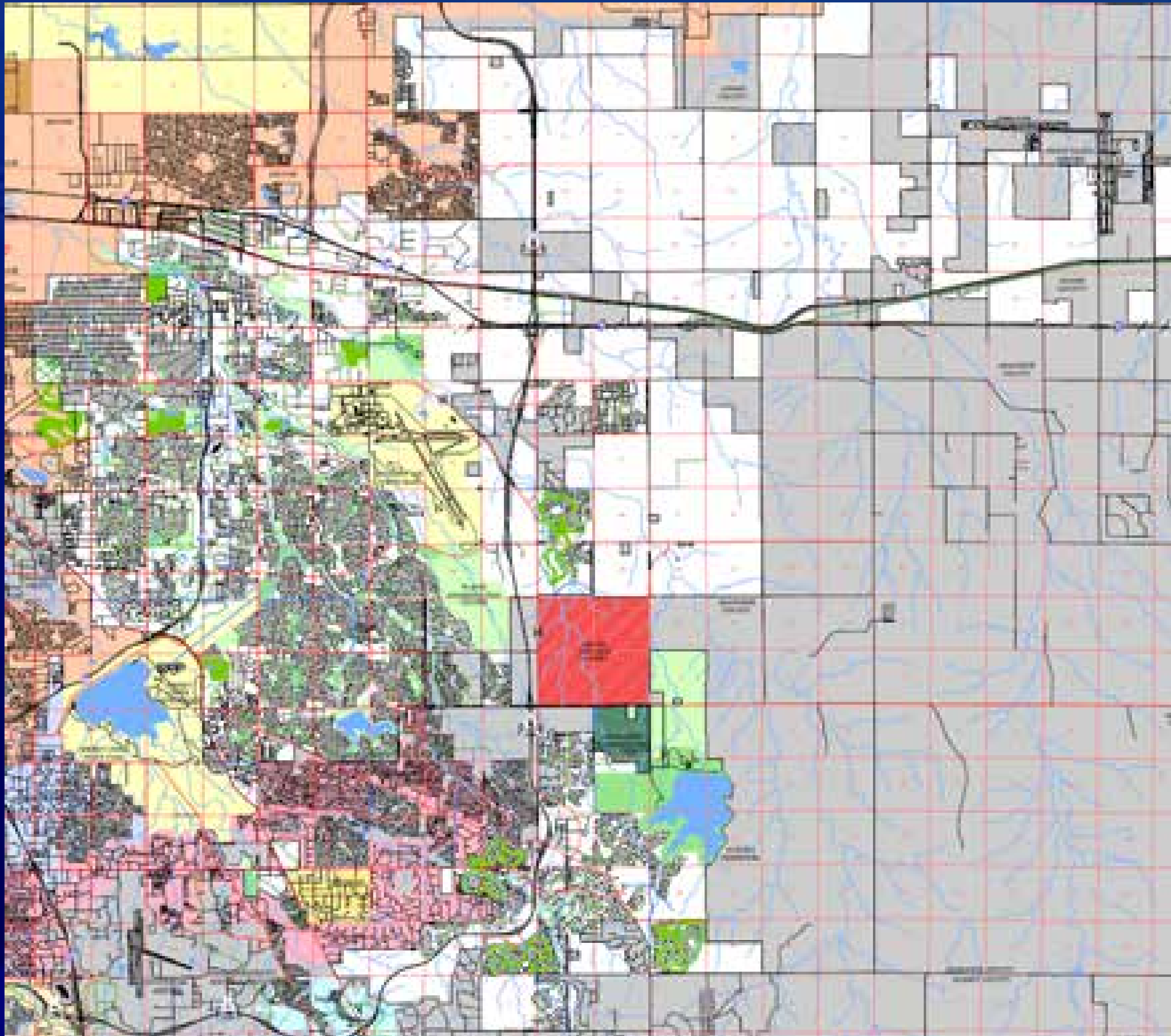
Background

Aurora

All-America City

2008

AURORA WATER



Aurora

All-America City

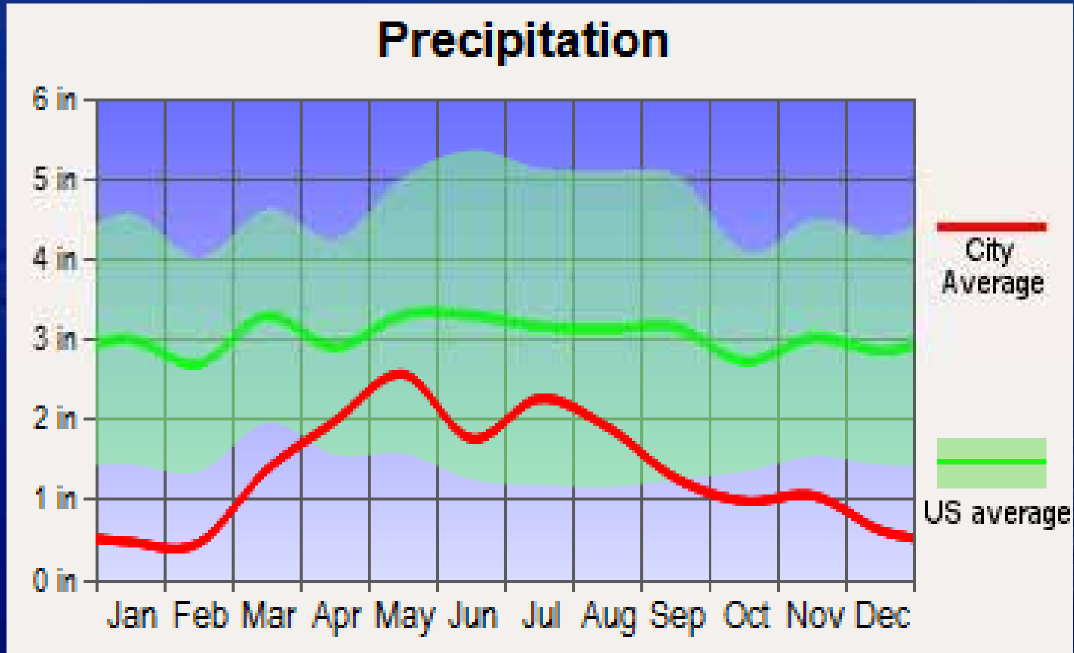
2008

General Stats

- *Operating Budget–*
  $101 million (2010)
- *Treated Water–*
  45,364 AF (2009)*
- *Raw Water Supply –*
  69,843 AF
- *Average Use –*
  121 gpcd (2009)*

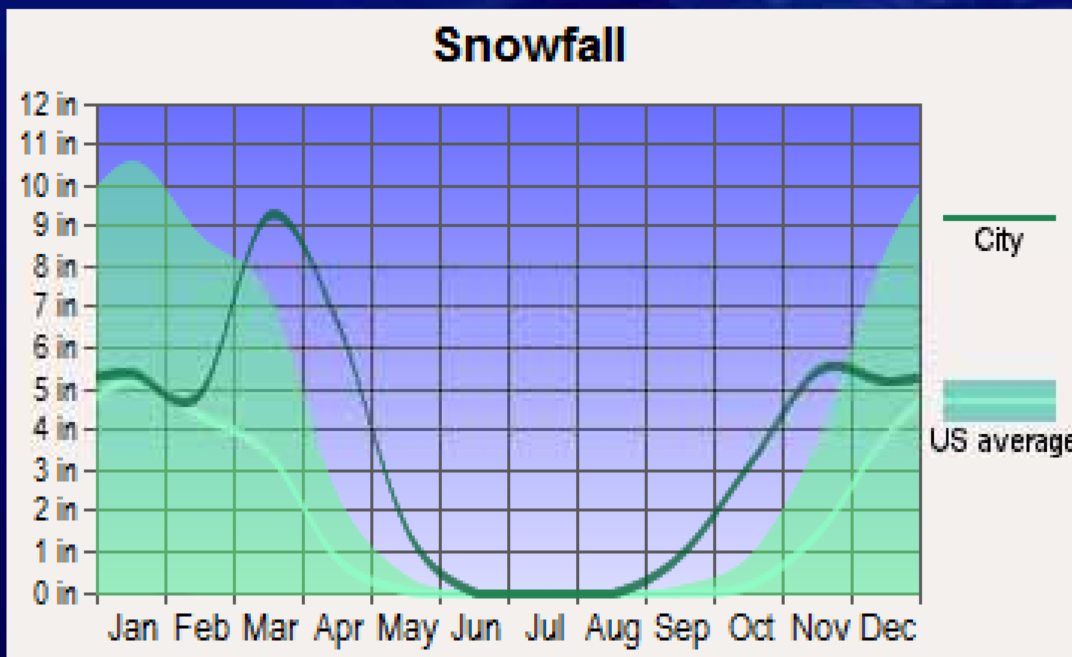
AURORA WATER

Background



Average Precipitation
15 – 18” per year

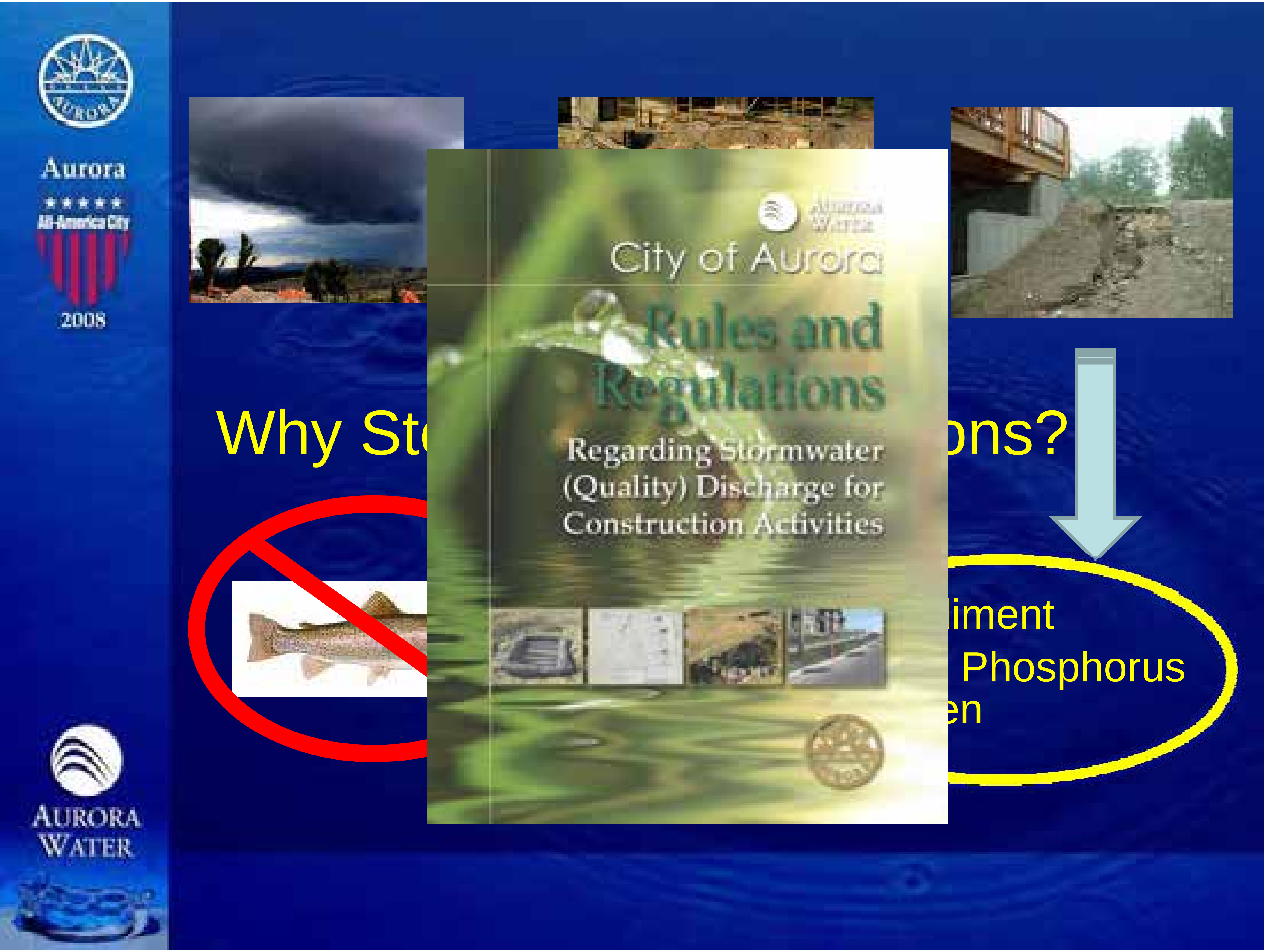
US Average
30 – 40” per year



Average Snowfall
50 – 63” per year

US Average
20 – 28” per year

Background


Aurora
All-America City
2008
Why St
ons?
City of Aurora
Rules and Regulations
Regarding Stormwater (Quality) Discharge for Construction Activities
iment
Phosphorus
en
Aurora Water

Why Develop Regulations?

- MS4 Permit Requirements
- Growing City
- Tension Between Inspections and Development Community
- Stand Alone, Easy to Understand Regulations
- Setting Clear Expectations

Context for Development of New City Construction Stormwater Regulations

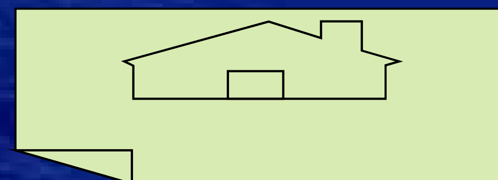
- The Mandate
  - Start Over
  - Develop a Clear, Consistent Regulations Manual
  - Be Collaborative, Reasonable, Fair
  - Train Staff
  - Implement the New Regulations



Aurora
All-America City
2008

AURORA WATER

Development of Aurora's Construction Stormwater Discharge Regulations



- Overall Vision

- External Stakeholder Concerns and Collaboration
    - o Consideration of Other Municipalities' Programs and Manuals

- Internal Stakeholder Concerns and Collaboration
    - o Applying Consistent Standards to Internal City Projects

Development of Aurora's Construction Stormwater Discharge Regulations

Overall Vision

- One Clear Process and Set of Requirements
- Appropriate Opportunities for Flexibility
- Stormwater vs. 'All Things Environmental'
- Regulations vs. 'Specifications'

Aurora
All-America City
2008

AURORA WATER

Development of Aurora's Construction Stormwater Discharge Regulations

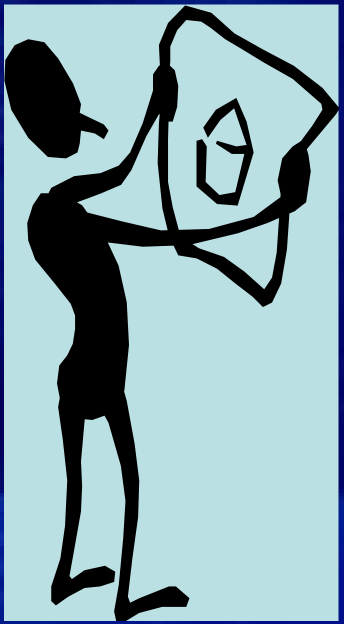
- External Stakeholder Concerns and Collaboration

  - Consideration of Other Municipalities' Programs and Manuals

Development of Aurora's Construction Stormwater Discharge Regulations

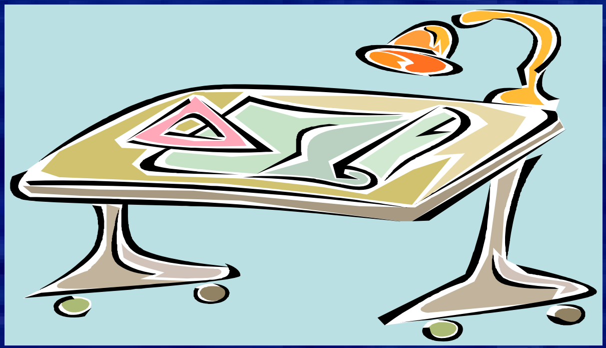
- External Stakeholder Concerns and Collaboration
  - Terminology
  - Clarity

  - Reasonableness
  - Announced vs. Unannounced Inspection



Development of Aurora's Construction Stormwater Discharge Regulations

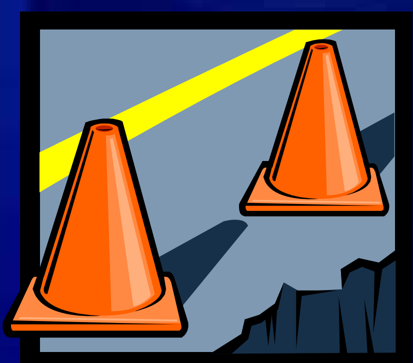
- Internal Stakeholder Concerns and Collaboration
  - Plans Review

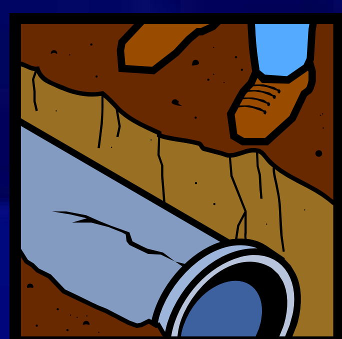


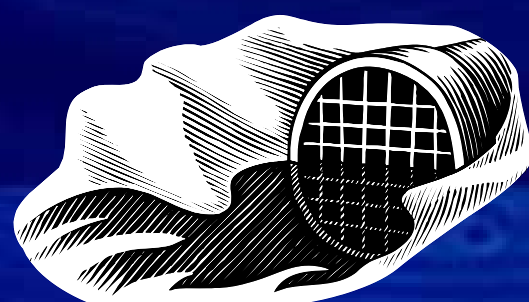
  - Inspection

Development of Aurora's Construction Stormwater Discharge Regulations

- Internal Stakeholder Concerns and Collaboration
  - o Applying Consistent Standards to Internal City Projects







Development of Aurora's Construction Stormwater Discharge Regulations

- Internal Stakeholder Concerns and Collaboration

  - Need to Improve the Quality of Stormwater Management Plans
  - Need to have clear requirements for inspection

  - Need to have clear enforcement processes

Aurora
All-America City
2008

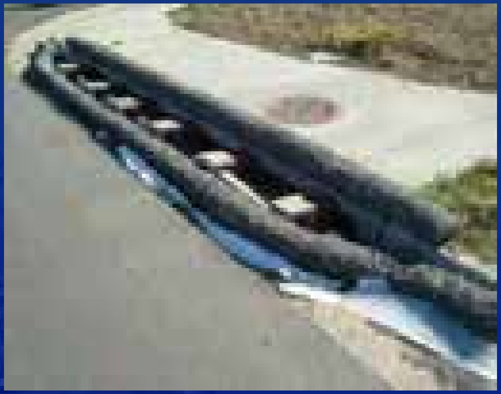
AURORA WATER

Implementation

1. Training
2. Communication
3. Good Judgment
4. Fine Tuning

Standard Details

Good



Bad

Ugly

Information Needed

- ***Who*** **–** **who's responsible?**
- ***What*** **–** ***what are they requesting?***
- ***When*** **–** ***timeframe?***
- ***Where*** **–** **specifics on location?**
- **How - application?**

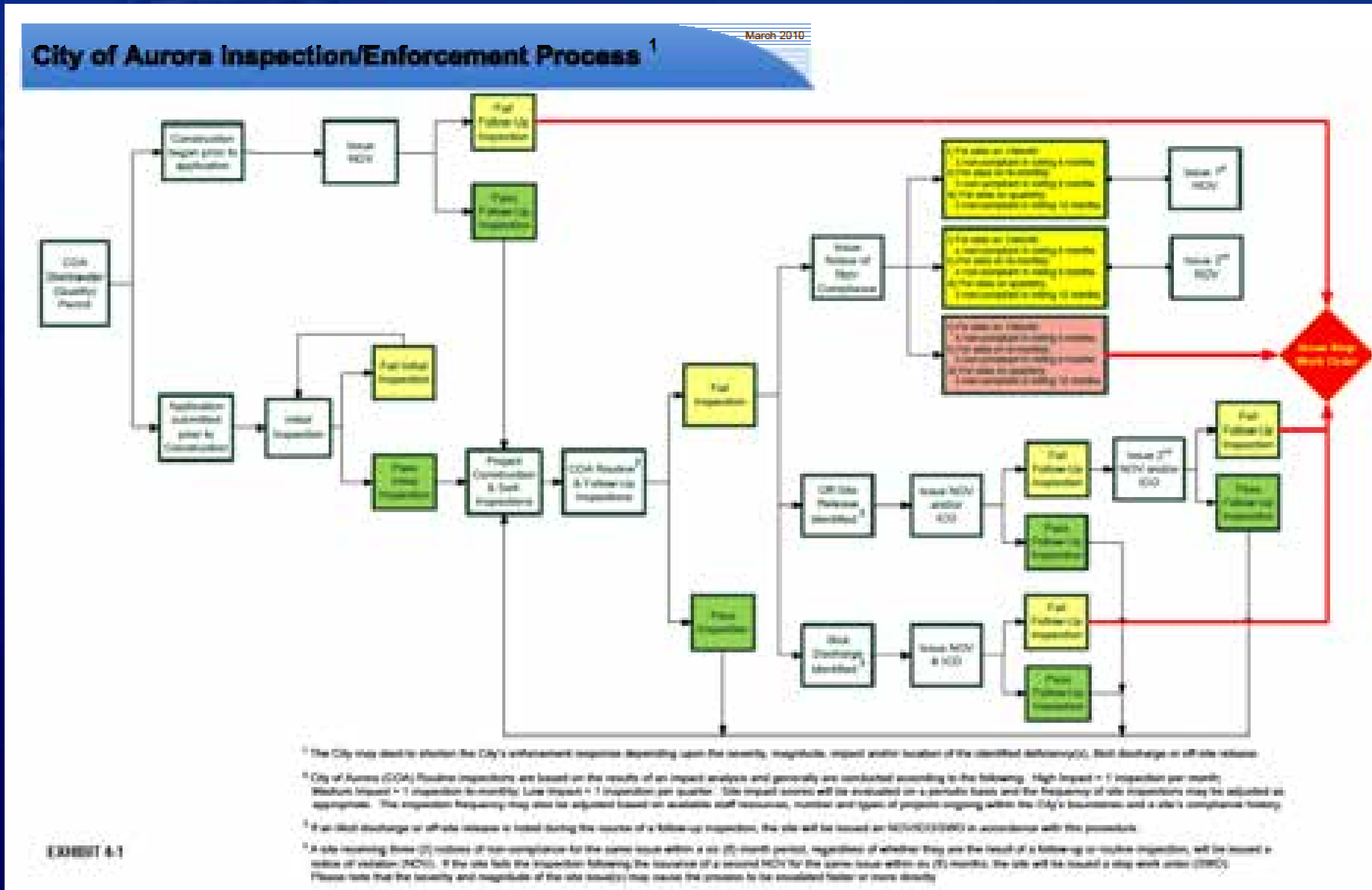
Variances

Aurora

All-America City

2008

AURORA WATER



Inspection & Enforcement

Process

- *What* – Construction Sites Program Oversight Review
- *Who* – CDPHE Staff & Contractor
- *When* – April 2009 – July 2010
- *Where* – Phase I MS4 (Aurora, Denver, Colorado Springs)
- *How* - Phased Approach

Aurora ★★★★★ All-America City 2008

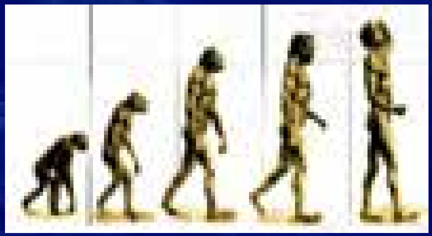
AURORA WATER

CDPHE Oversight

✓ Involve Stakeholders

✓ Limit Opportunities for Comment

✓ Expect Future Revisions



✓ Implementation is Key

Lessons Learned

Ongoing Efforts

Aurora
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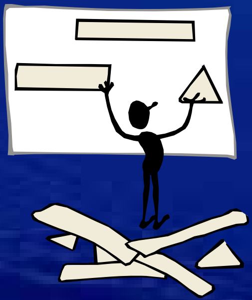
2008

Aurora Water

- Stormwater Check-in Meetings



- Reviewing and Modifying Regulations

- Training

- Internal Auditing

- Enforcement

Questions/Comments

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Holly Hills Detention Ponds

RETROFITTING A DETENTION POND WITHIN LOT(S) OF AN ESTABLISHED RESIDENTIAL SUBDIVISION.

Holly Hills Detention Ponds

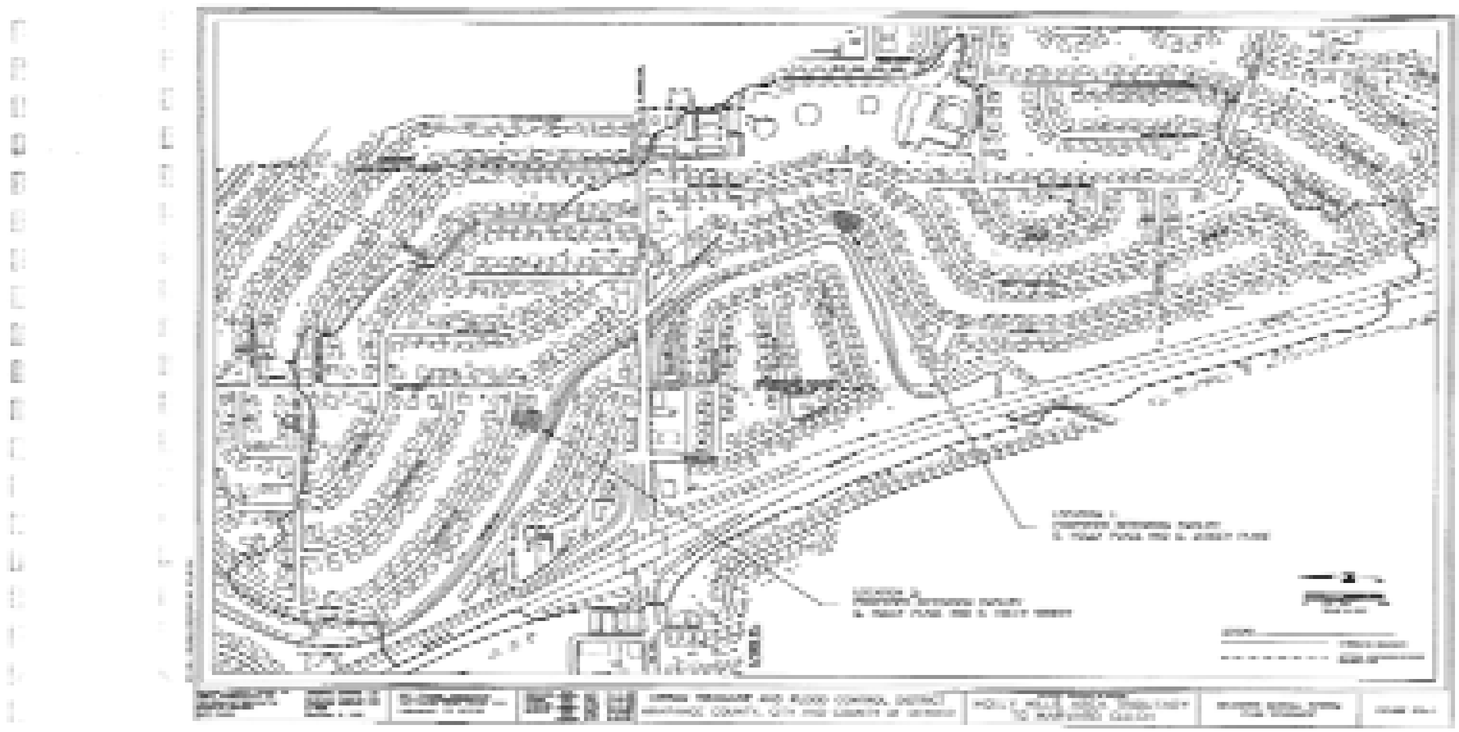
Located within Arapahoe County, East of I-25 near Yale Avenue

Holly Hills Detention Ponds

Participants:
UDFCD, Arapahoe County, and SEMSWA

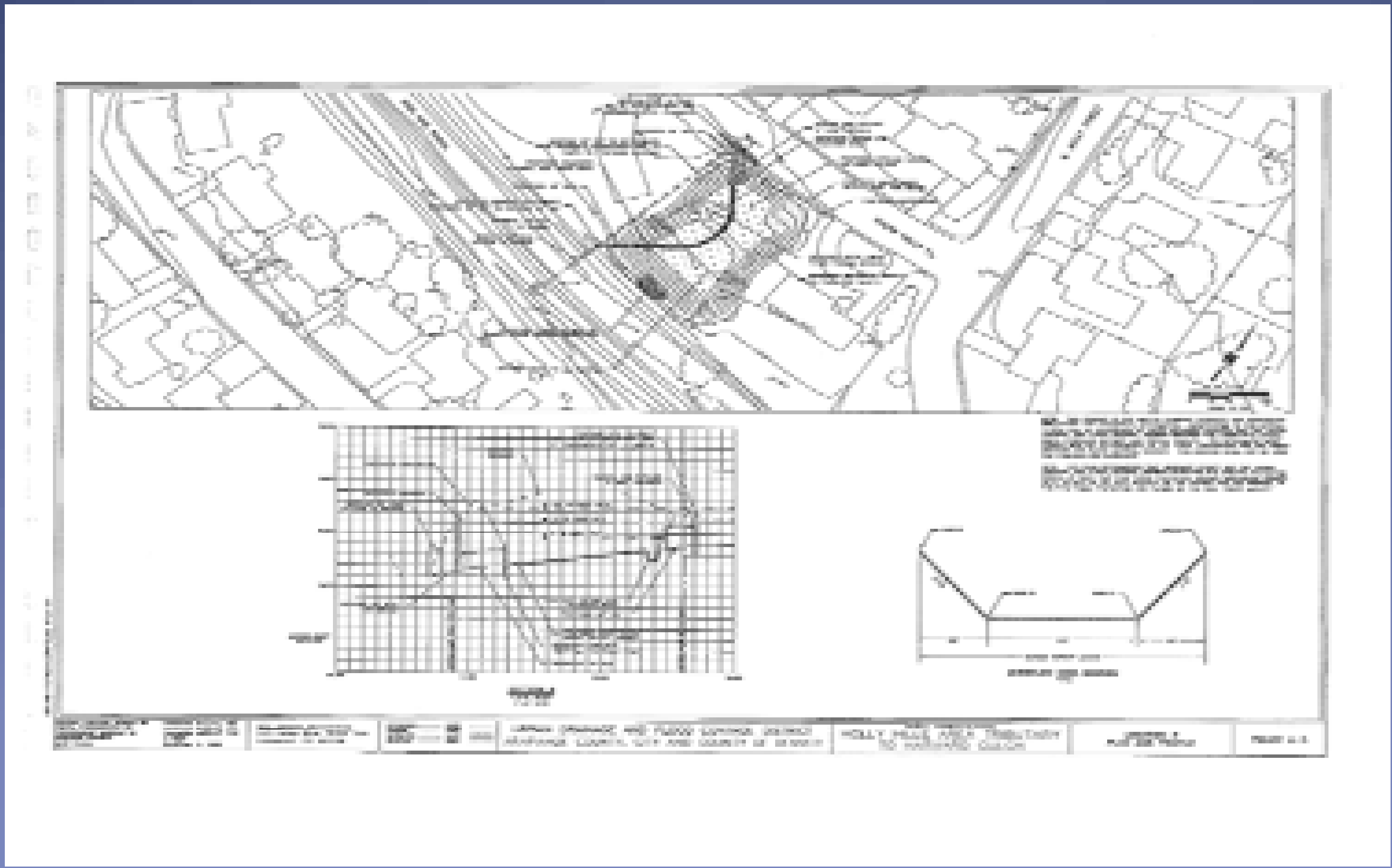
Muller Design/Construction Team:
Muller, Wenk Associates, Koch Environmental, Poitra Visual and Territory Unlimited

Holly Hills Detention Ponds



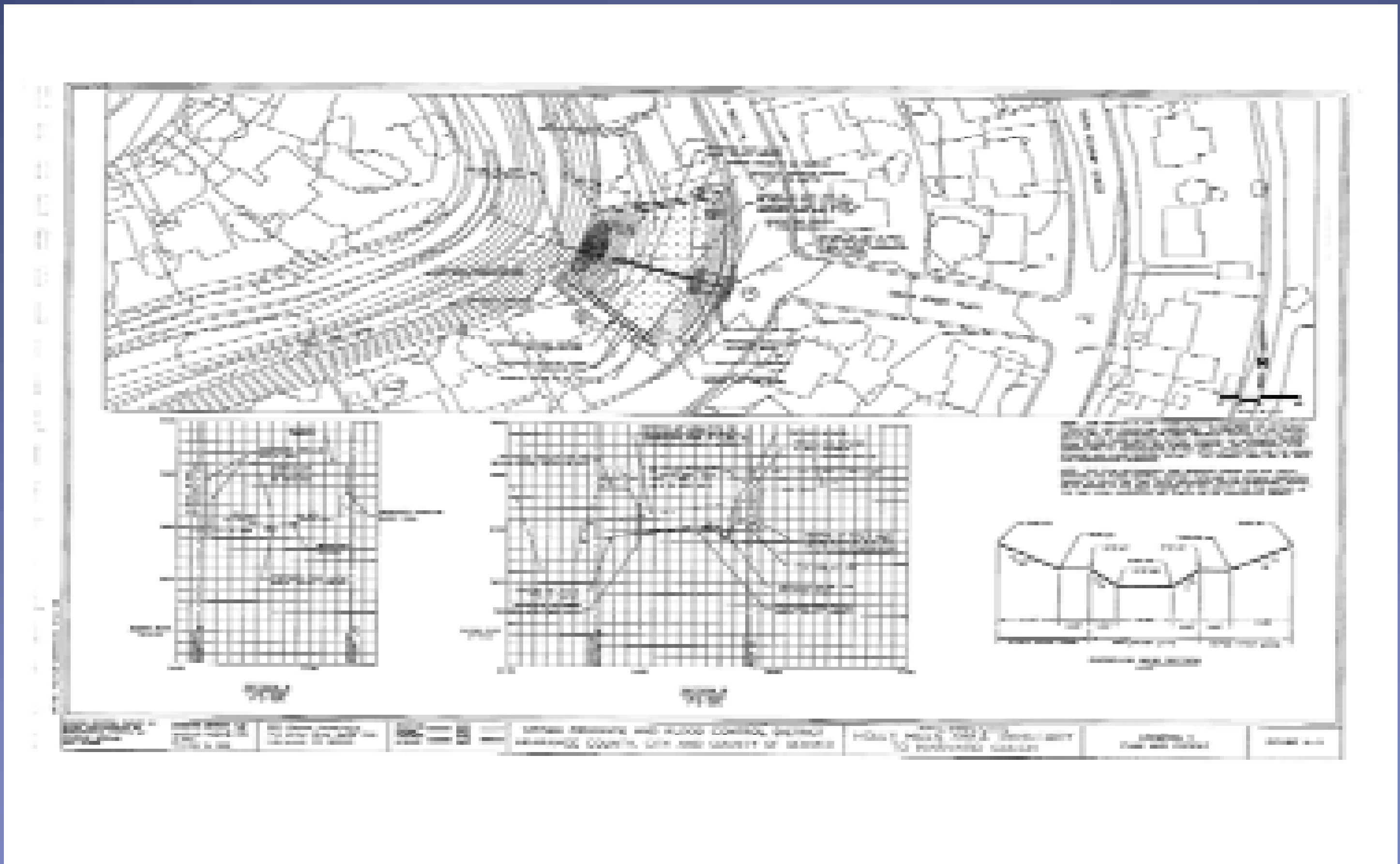
Holly Hills Detention Ponds

2585 OSP Plan



Holly Hills Detention Ponds

3001 OSP Plan



Holly Hills Detention Ponds

Arapahoe County acquired two properties; one at each pond site

Holly Hills Detention Ponds

Houses need to be removed

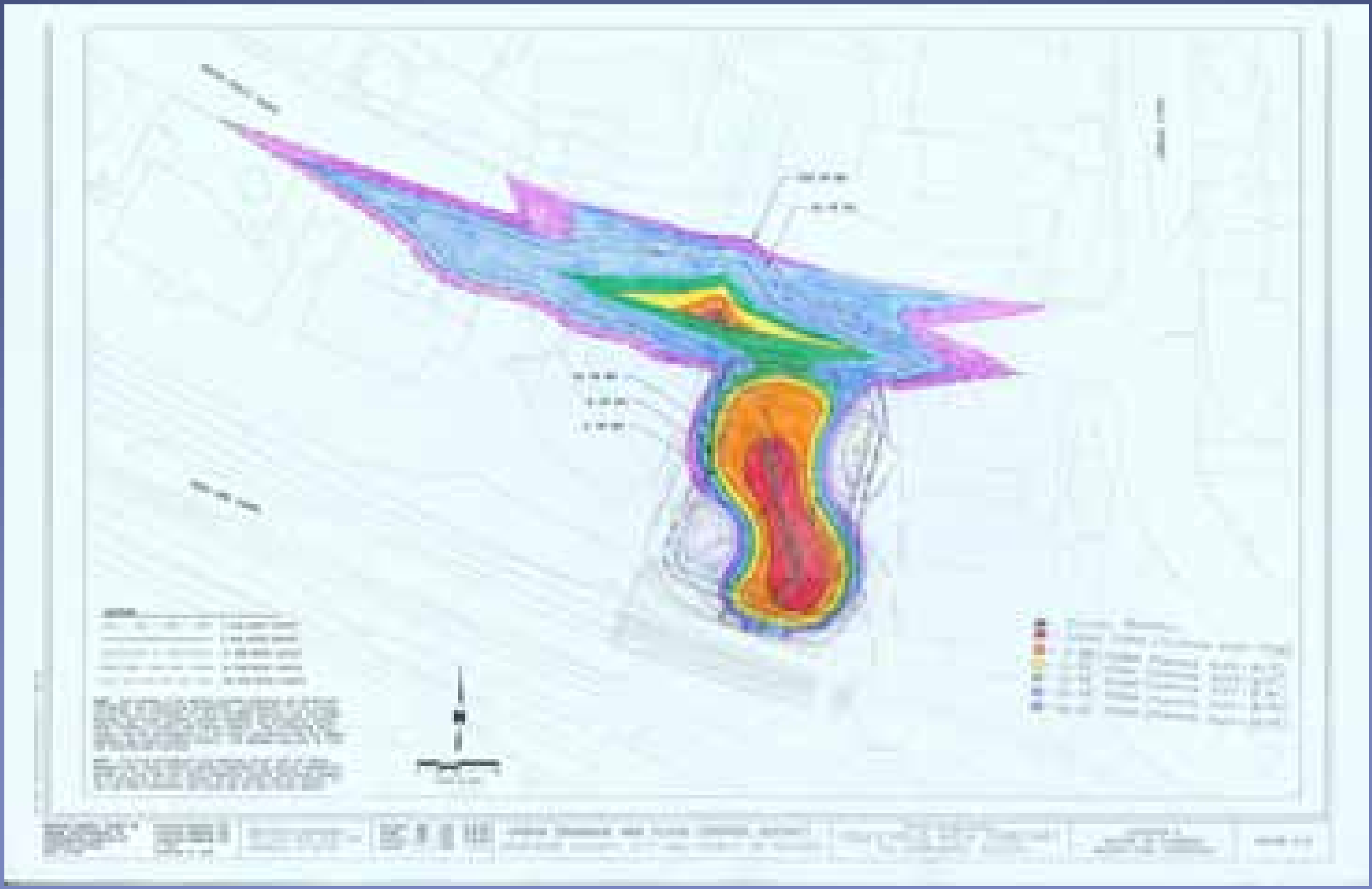
Holly Hills Detention Ponds

Design Phase:

- Look at the Pre- and Post-Flooding Conditions, for multiple frequency storm events
- Show the Public how the project will reduce flooding problems
- Evaluate the demolition issues
- Refine the OSP plans into a final design

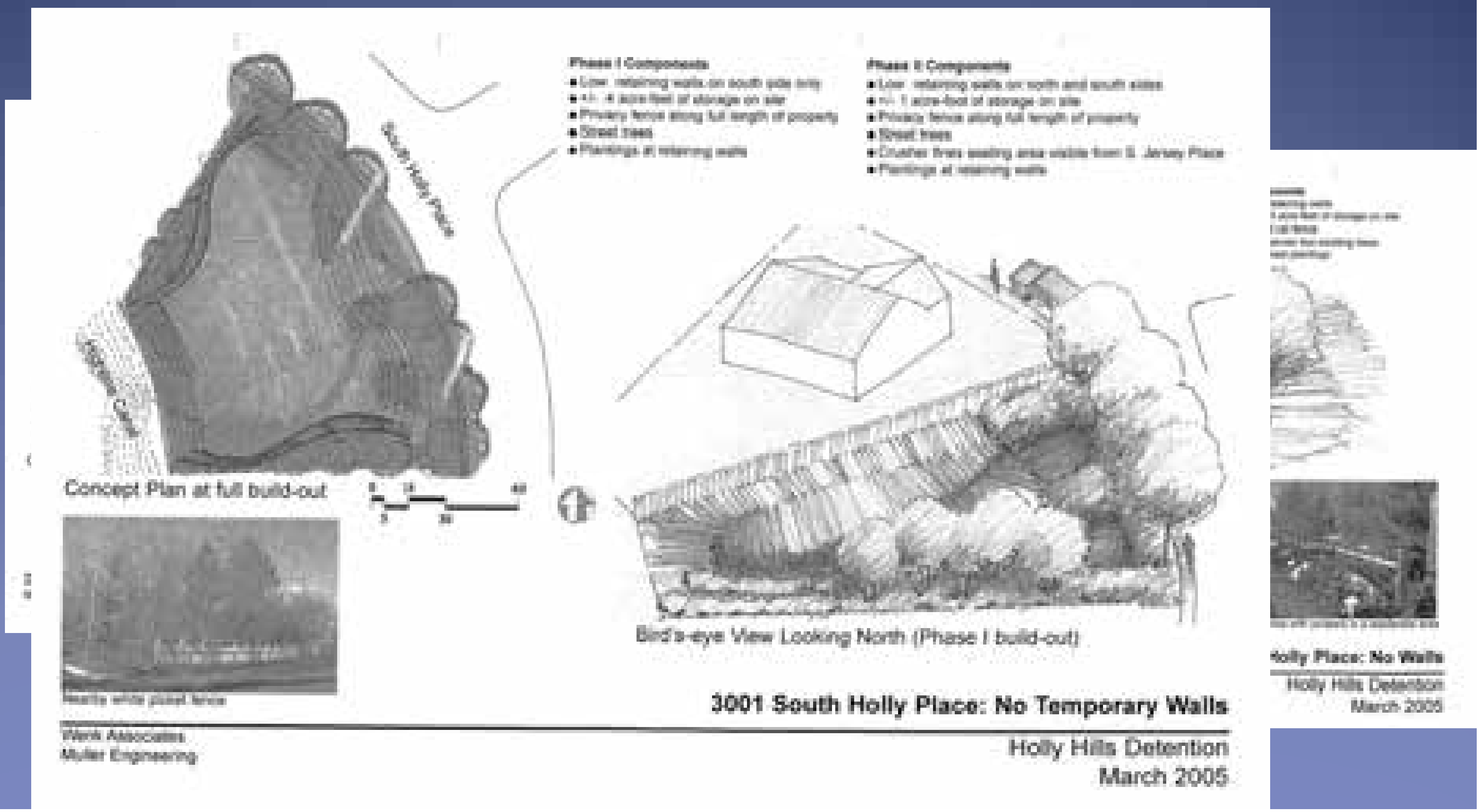
Holly Hills Detention Ponds

Illustration of flooding levels : Post Project Conditions



Holly Hills Detention Ponds

Public Involvement Meetings were conducted



Holly Hills Detention Ponds

Insert video animation here or pause power point and come back to it later.

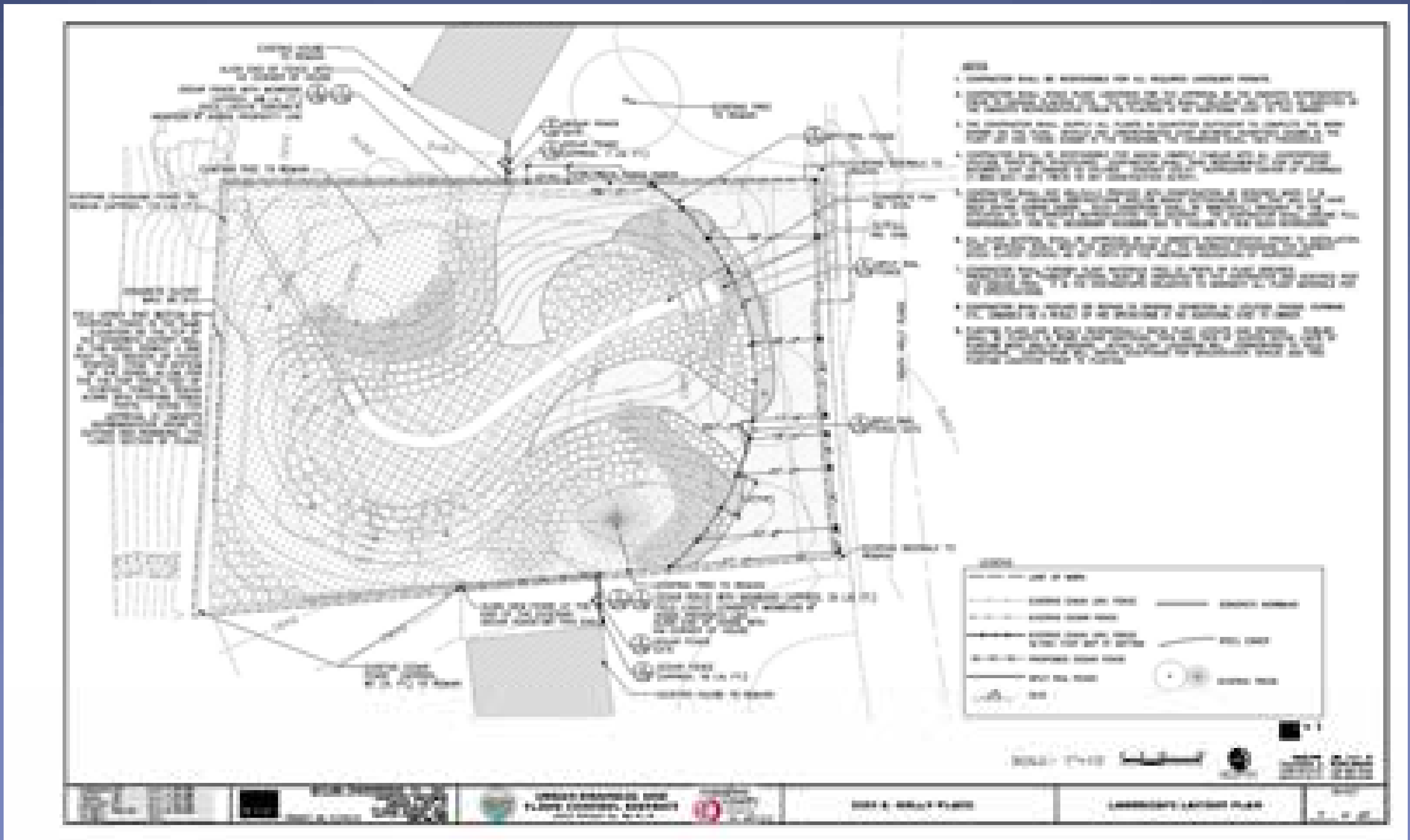
Holly Hills Detention Ponds

The demolition of the dwelling structures brought in a hazardous waste evaluation due to the age of the structures.

Koch Environmental assisted with the evaluation and determined that special demolition procedures were required.

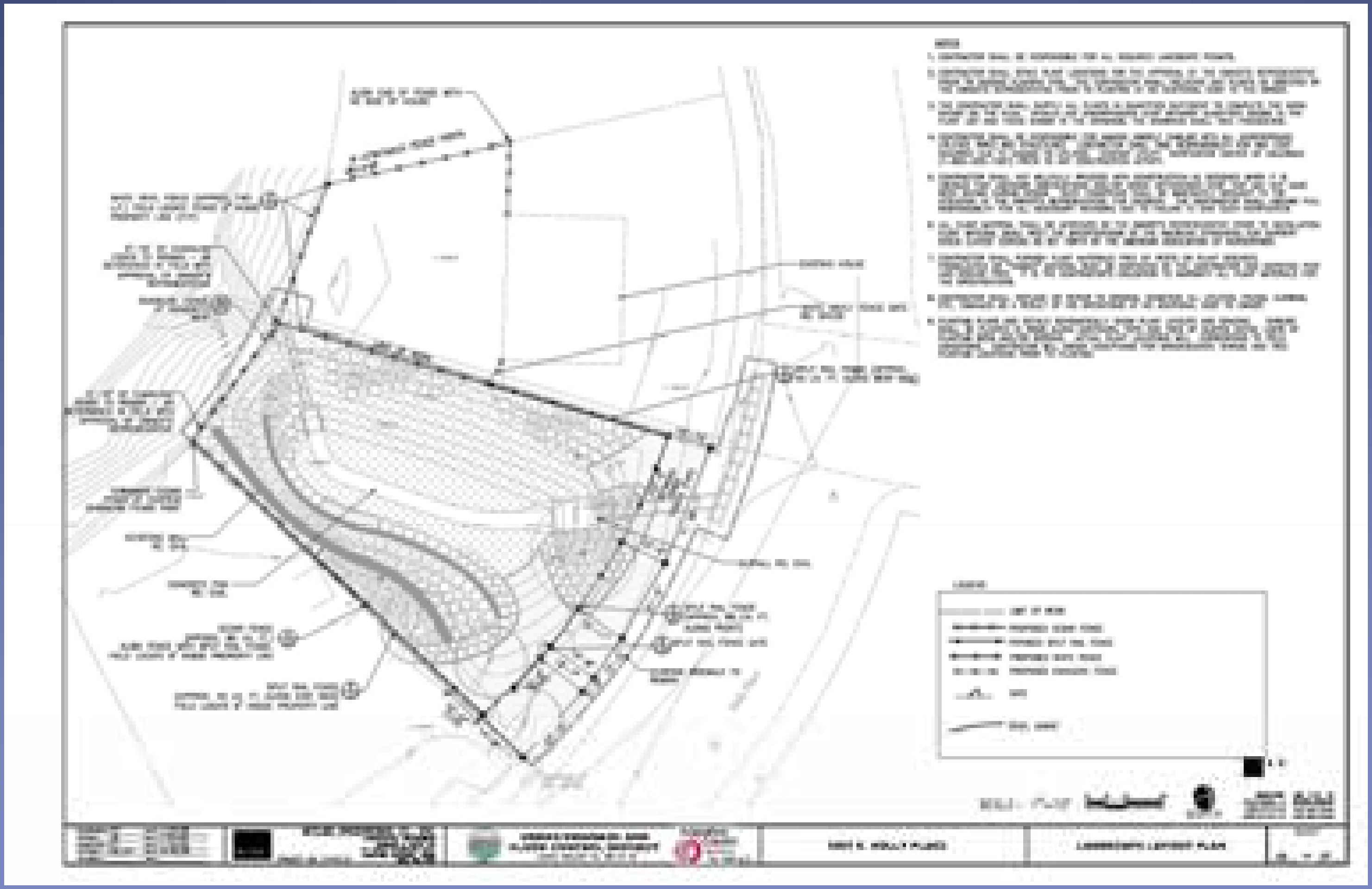
Holly Hills Detention Ponds

2585 Design Plan



Holly Hills Detention Ponds

3001 Design Plan



Holly Hills Detention Ponds

Construction Phase:

The Demolition was contracted separately due to the special demolition required.

Holly Hills Detention Ponds

Holly Hills Detention Ponds

Pond Construction Phase:

Holly Hills Detention Ponds

Holly Hills Detention Ponds

2585 S Holly Street

Holly Hills Detention Ponds

3001 S Holly Street

Holly Hills Detention Ponds

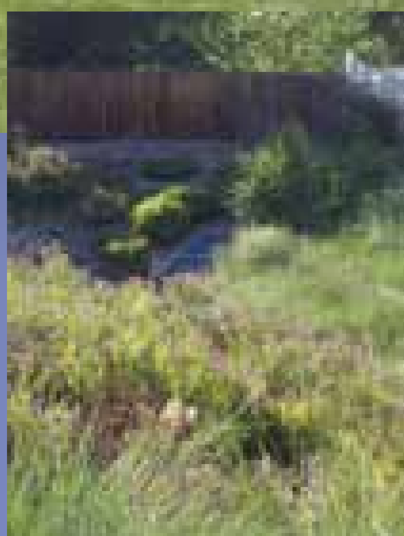
2585 S Holly Street

Holly Hills Detention Ponds

2585 S Holly Street

Holly Hills Detention Ponds

3001 S Holly Street



Retail Drainage

or

How to Design Local Site Drainage for Safety, Exceptional Appearance, and Problem Avoidance

by

Peter L. Nelson, PE, EXW

- **Poorly executed grading and drainage :**
  - Detract from the functionality of the civil infrastructure
  - Damage buildings and pavements
  - Increase liability issues
- **Thoughtful design approaches:**
  - Avoid civil infrastructure problems
  - Enhance safety
  - Enhance aesthetics.

Truly "Magnificent" Construction Details

•Chase does not drain!

•Curb is cut and it still does not drain.

This is embarrassing.

•Trench drain runs into block wall.

•Below grade extensions have sags.

•Walk traps runoff.

•Runoff slope is flat.

"Magnificent" Construction Details

Truly "Magnificent" Construction Details

Truly "Magnificent" Construction Details

Truly "Magnificent" Construction Details

•Downspout extension is built with a sag.

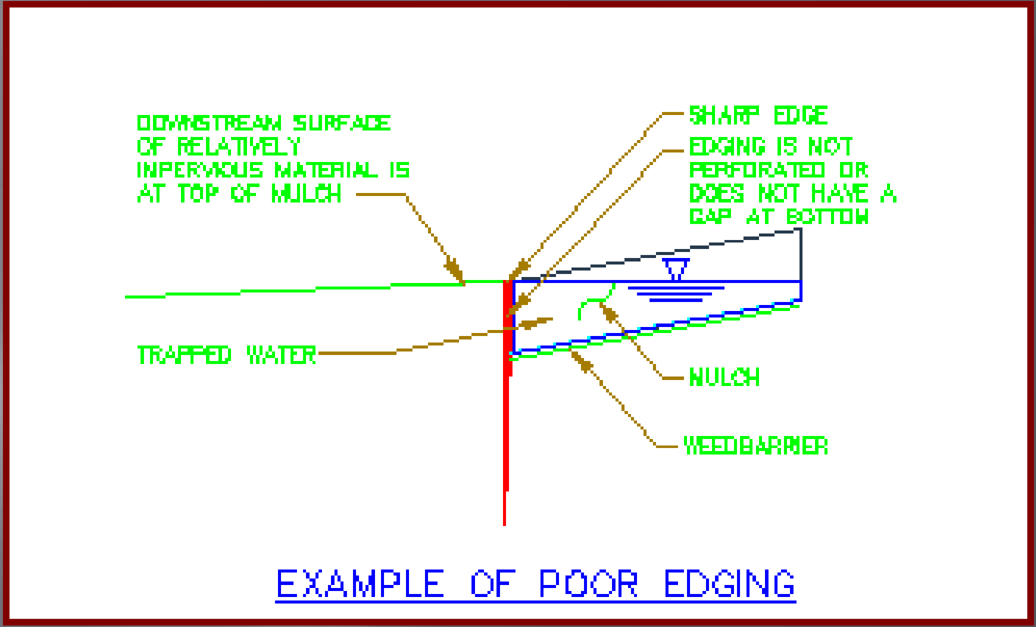
•Stain patterns indicate runoff is going elsewhere.

Photo courtesy of Holly Piza

•Downspout extension cannot be lowered to the correct position.

•Where was quality control construction observation?

Depending on geometry, poorly drained sites can retain up to **80%** of precipitation runoff within the immediate vicinity (~10-feet) of buildings.



What is volume available for storage?

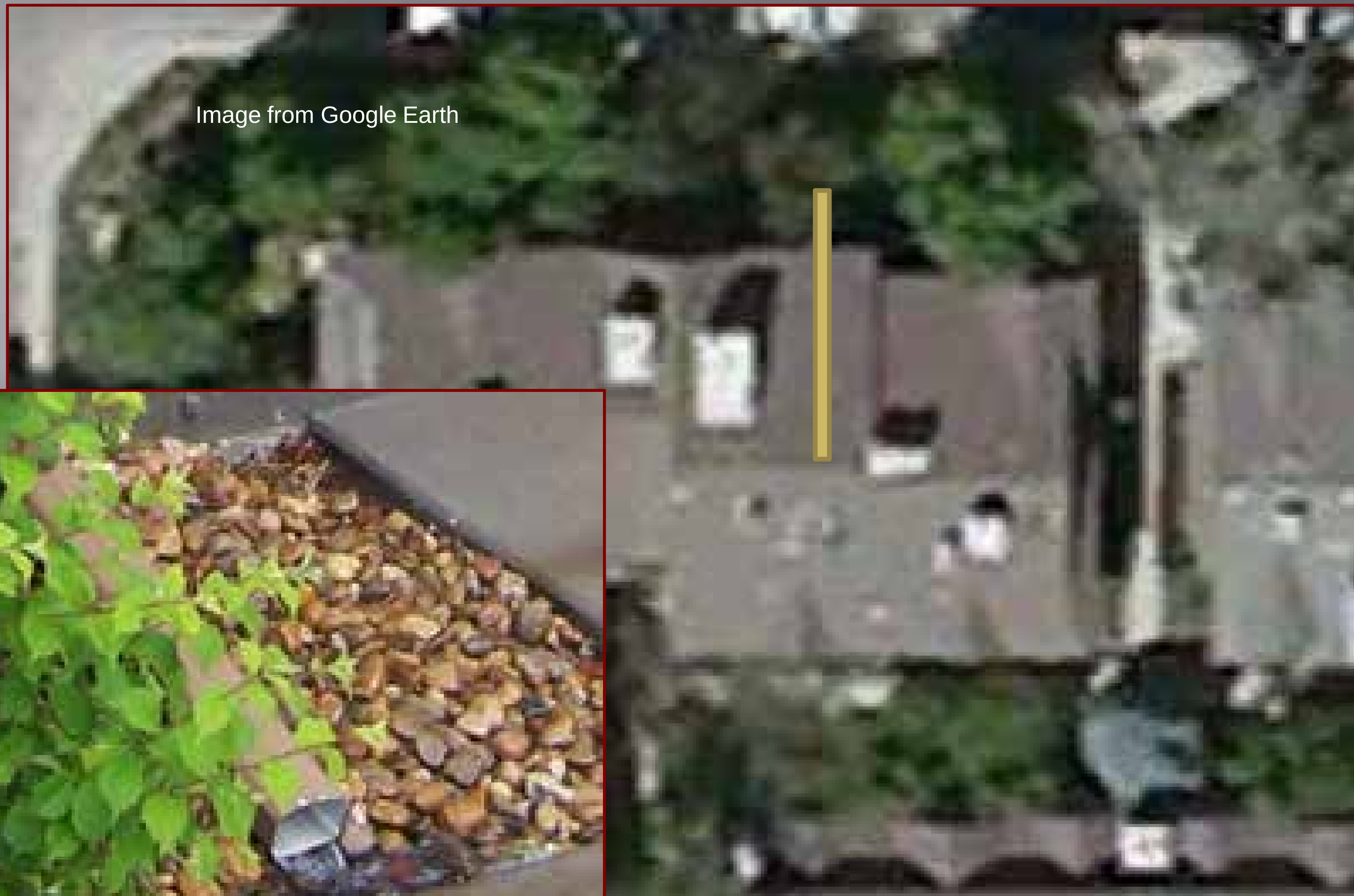
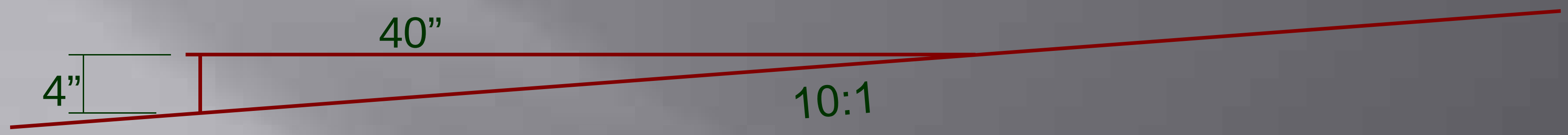


Image from Google Earth



Calculations use 1-inch of width for volume.

$4 \times 40 / 2 = 80 \text{ in}^3$

Assume uniformly graded gravel, 44% porosity.

Max volume stored = $80 \times 0.44 = 35.2 \text{ in}^3$

Building Width = 60’ ; ½ BW = 30’

Tributary Area = $(60 / 2 + 10) * 12$ in / ft = 480 in^2

Depth of runoff stored = $35.2 / 480 = 0.073$ in

Pervious area = $10/(60 / 2 + 10) * 100 = 25\%$

Initial Abstractions (use 5-min):

depression storage = 0.05” (UDCM tbl RO-6 sr)

infiltration = 0.201” (hsg C or D tbl RO-8)

evaporation = insignificant in 5 minutes

Volume of rainfall not running off =

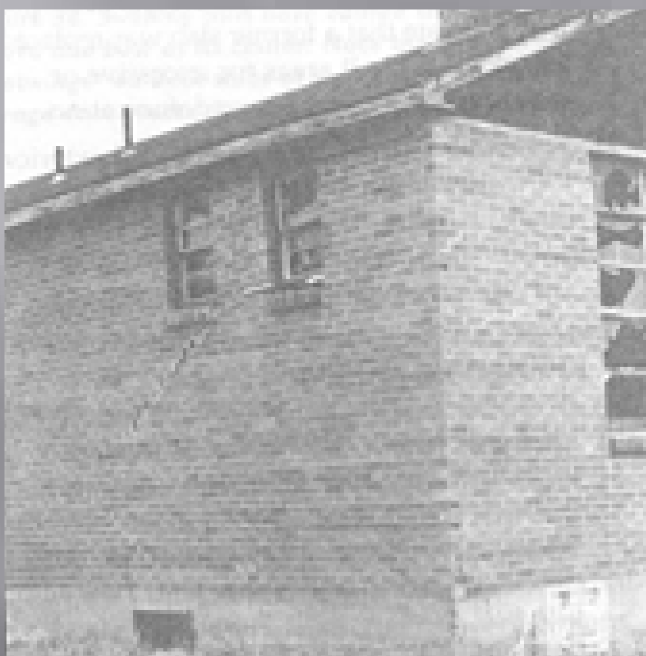
0.073 + .05 * .75 + .201 * .25 = 0.161”

Rainfall (NOAA)	2-yr	100-yr
6-hr	1.5”	3.55”
24-hr	2.1”	4.9”
1-hr	0.98”	2.32
5-min	0.28”	0.67”
% captured	0.57%	0.24%

The water thus retained:

- Infiltrates into the ground next to the building.
- Raises the water table.
- Detracts from the functionality.
- Detracts from the safety of the site.
- Increases damage to buildings including:
  - Deterioration of the structure (mold, rot, etc.).
  - Intrusion of water into interior spaces.
  - Cracked walls and sticking doors.

When expansive soils are present, the damage from poor drainage may exceed ordinary damage and render a building useless.



Images are from Special Publication 43, A Guide to Swelling Soils.

Pavements are damaged through soil movement where drainage is poor.

Image is from Special Publication 43, A Guide to Swelling Soils.

Ice accumulates where drainage is poor.

Where drainage is poor, pavements are damaged through the process of scaling, sometimes called salt scaling. Scaling is not a chemical process. It is a mechanical process wherein flakes of concrete are lifted from the surface of otherwise weakened concrete.

Lots of salt but no damage.

Scaling.

Crazing.

Safety is compromised by creating unexpected drop-offs where none existed a few months ago.

Much of poor drainage is hidden from view beneath the mulch and/or vegetation.

Trapped water is normally accounted among the initial abstractions in hydrologic modeling.

Methods for reducing retained runoff:

The cost of repairs frequently out runs the cost of the original civil infrastructure.

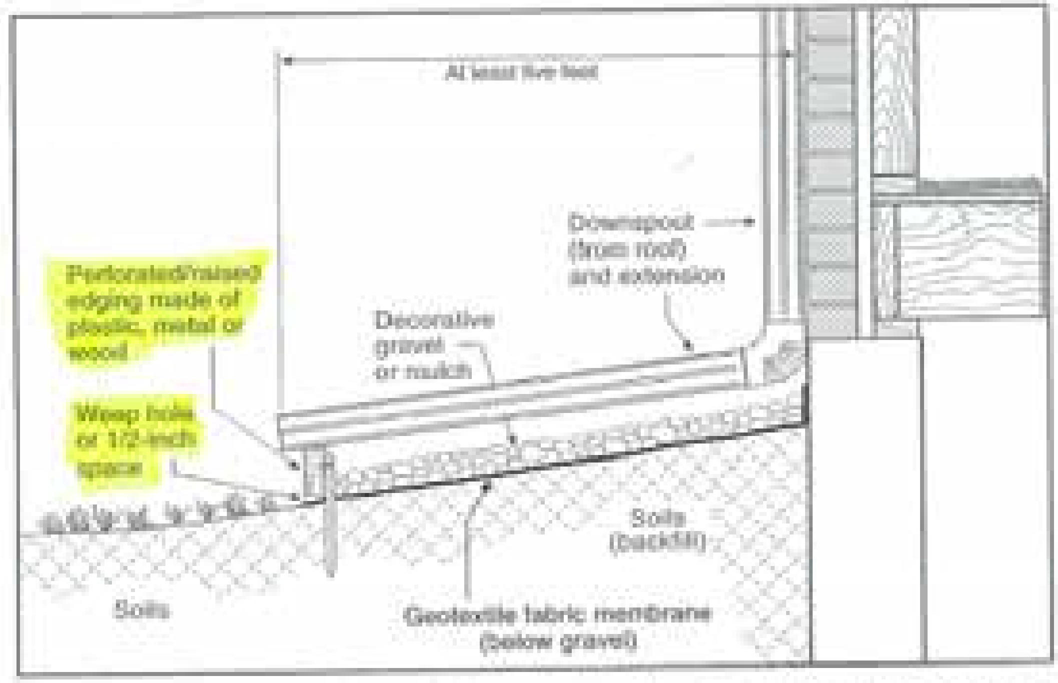


Figure 28. Properly designed runoff slope next to a house foundation. Note that roof drainage is carried by a downspout extension to a point beyond the slope. (From Holtz and Hart, 1978.)

Figure 28 from Special Publication 43, A Guide to Swelling Soils.

A Site with exceptional appearance that also functions well begins with design.

Once water is allowed to drain away from buildings, pavements, and other at risk facilities, a site design should provide conveyance without ponding. These conveyance facilities contribute to a safe site and to exceptional appearance.

Not a project of PLNE or Peter Nelson.

Once water is collected at a safe location, a site design should provide detention storage to release runoff in a manner similar to historical patterns. These storage facilities contribute to a safe site and to exceptional appearance.

Not a project of PLNE or Peter Nelson.

Tackling Erosion Caused by Roadway Deicing Agents—Project Results

Presented to CASFM 2010

by Catherine Rafferty, PE—Denver International Airport
Rich Ommert, PE—Moser & Associates Engineering
Lee Rosen, EI—Moser & Associates Engineering

September 23, 2010

Presentation Outline

- Introduction to DIA's roadway deicing operations & erosion issues
- Observations
- Alternatives developed
- Alternatives installed
- Findings
- Future efforts

Introduction
DIA Roadway Deicing

- DIA is located approximately 20 miles northeast of downtown Denver
- Access to DIA is via Peña Boulevard, which is a private road maintained by the airport
- DIA is a critical facility, as defined by the State, therefore Peña Boulevard must remain open at all times
- Standard operating procedure is to apply deicing agents as needed to maintain open road conditions even if application rates are higher than average

DIA—December 22, 2006 Blizzard

Introduction
Erosion Issues

– Excessive roadside erosion exists
– Purpose of this study was to evaluate erosion mitigation measures along the roadway shoulder

Introduction
Study Location

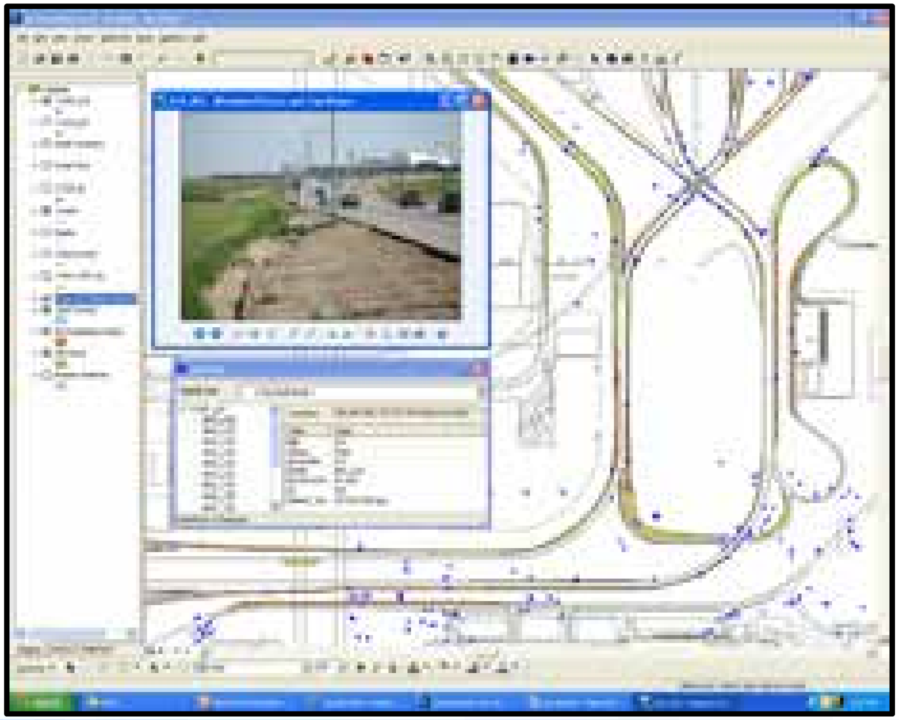
- Peña Boulevard from Tower Road to the Terminal
- Includes potential development areas
- Study area = 2,863 acres or 4.5 square miles

Observations
Site Inventory

- Define location & types of problems occurring
- Over 500 photos were collected within the project area documenting problem erosion areas

Observations
Site Inventory

- Collected data entered into GIS database to analyze potential patterns to the erosion that might indicate the root source of the problem



Observations
Primary Causes

– Vehicular traffic pulling off the paved shoulder

Observations
Primary Causes

– Lack of stabilized maintenance paths

Observations
Primary Causes

– Lack of topsoil

Observation
Erosion Pattern

– Minimal to no vegetation on shoulders receiving runoff

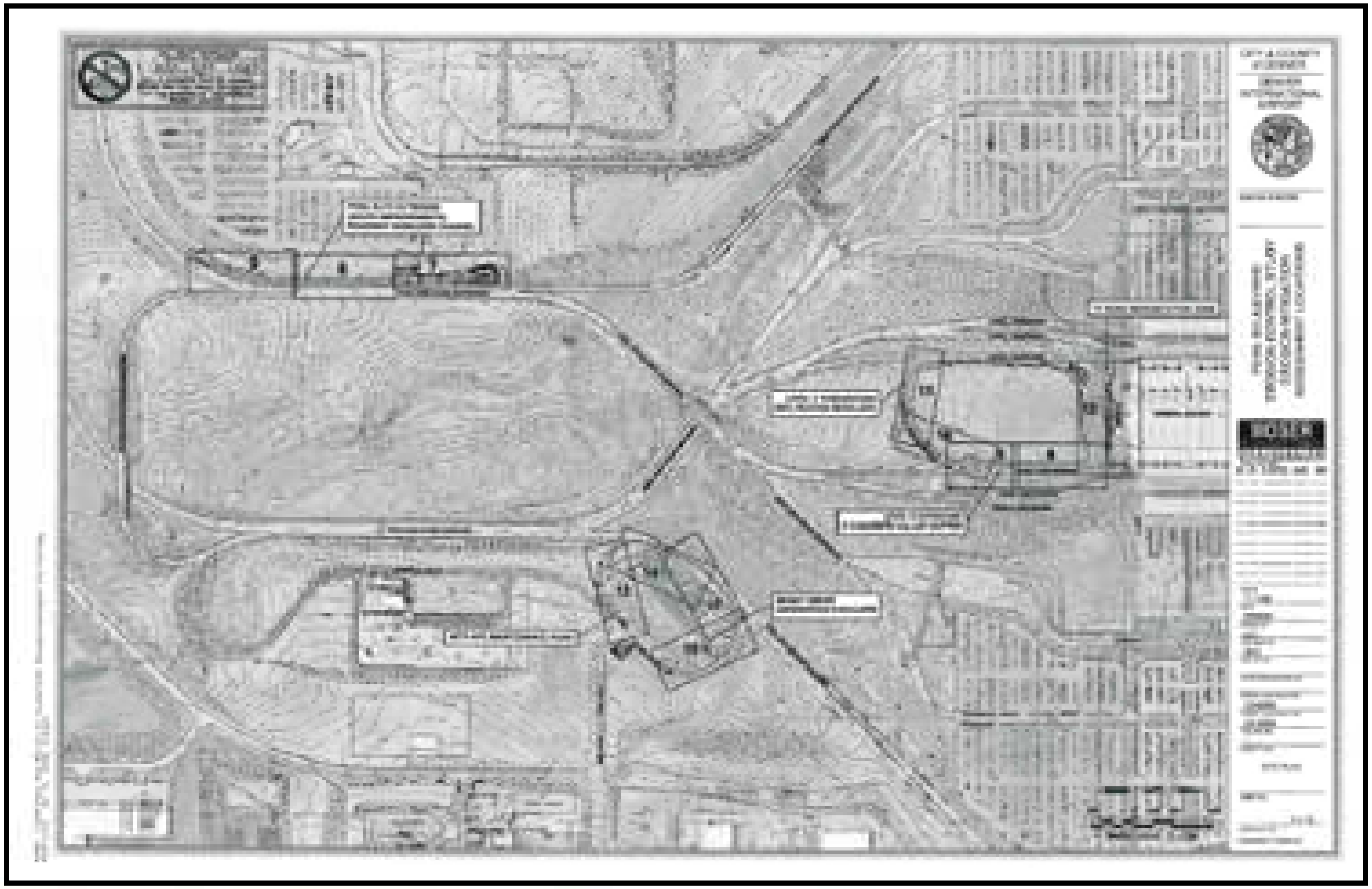
Observations Hypothesis

– Based upon the observations, and upon additional soils testing, it was concluded that DIA's roadside erosion was a result of:
  – Higher than average applications of deicer on the road salinating the shoulder soils such that vegetation was no longer viable
  – People attempting to avoid parking fees by pulling off onto the beyond the shoulders to wait for arriving passengers such that the soils are rutting and seed and mulch applications are torn up
  – Maintenance vehicles accessing areas that were never provided with drivable paths such that stabilized areas are disturbed
  – Poor soil conditions for establishing vegetation (high plasticity clay, no irrigation, no topsoil, etc.)

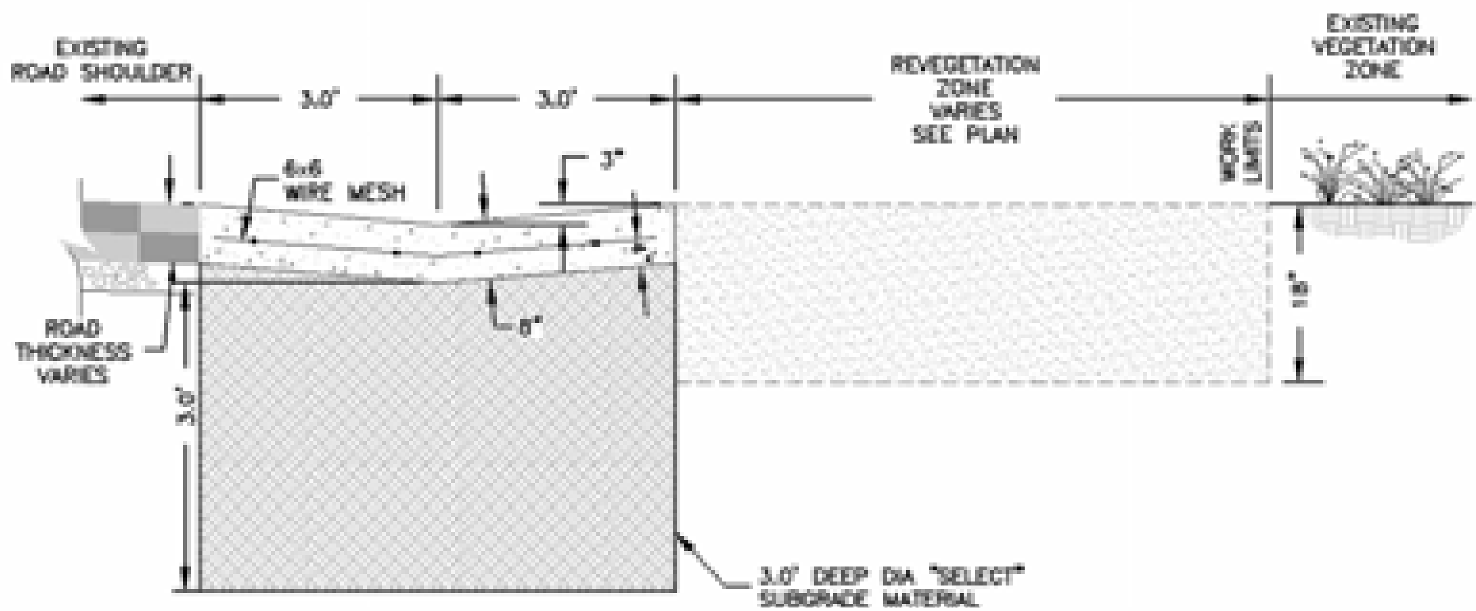
Alternatives Developed

- Evaluated both “hard” and “soft” engineering solutions
  - “Hard” alternatives included installation of engineered structures
  - “Soft” alternatives included improving the soils with amendments, modifying the seed mix, run-on diversion, and operational modifications

Alternatives Developed



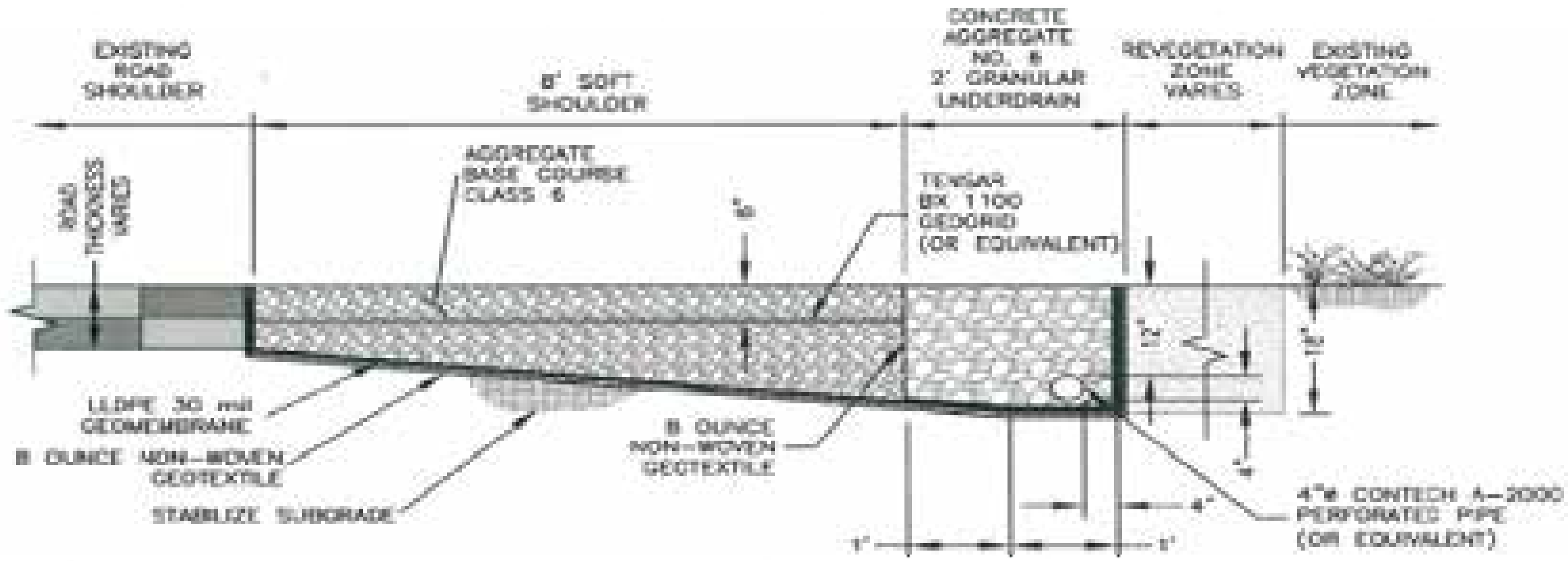
Alternatives Developed
Valley Gutter



6' CONCRETE VALLEY GUTTER DETAIL

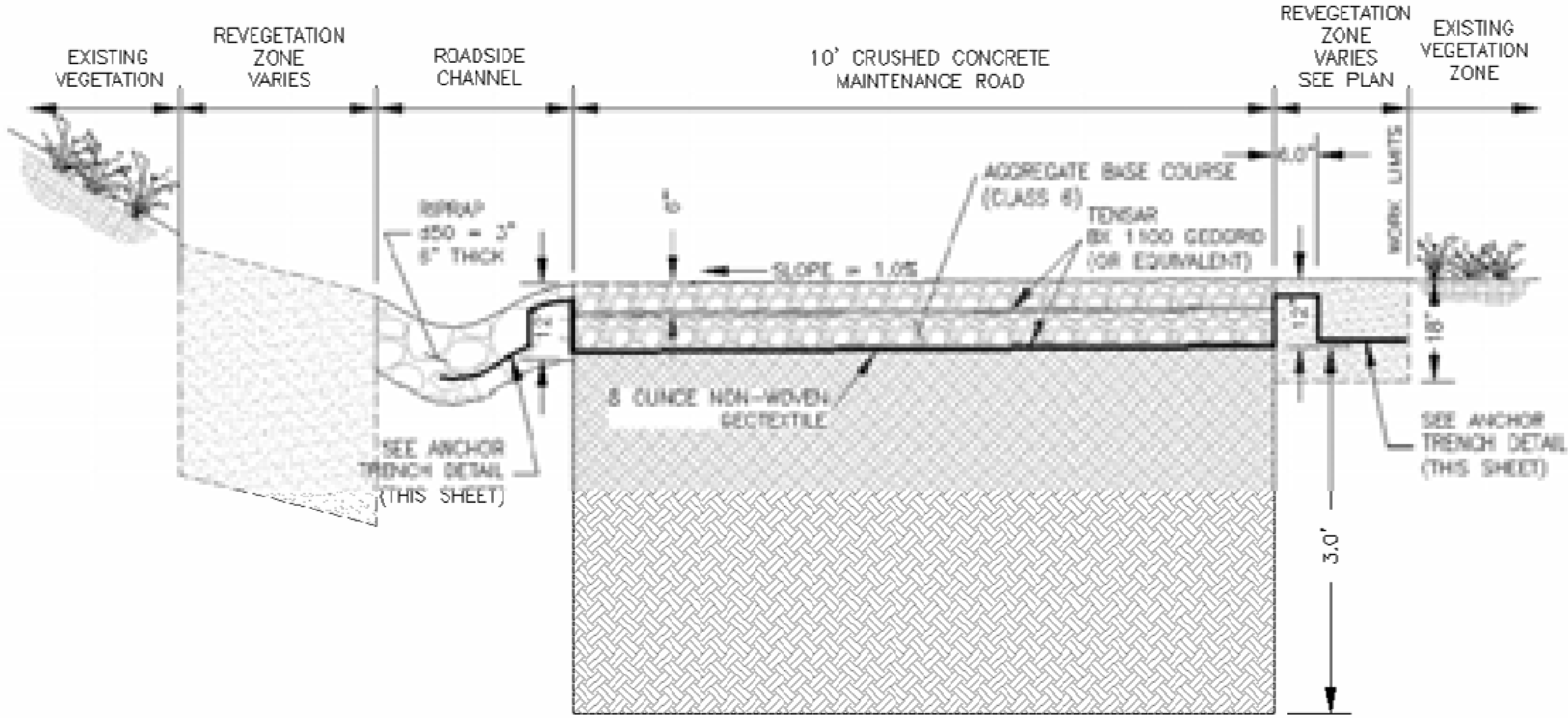
N.T.S.

Alternatives Developed
Underdrain Shoulder



UNDERDRAIN SHOULDER
RILL EROSION

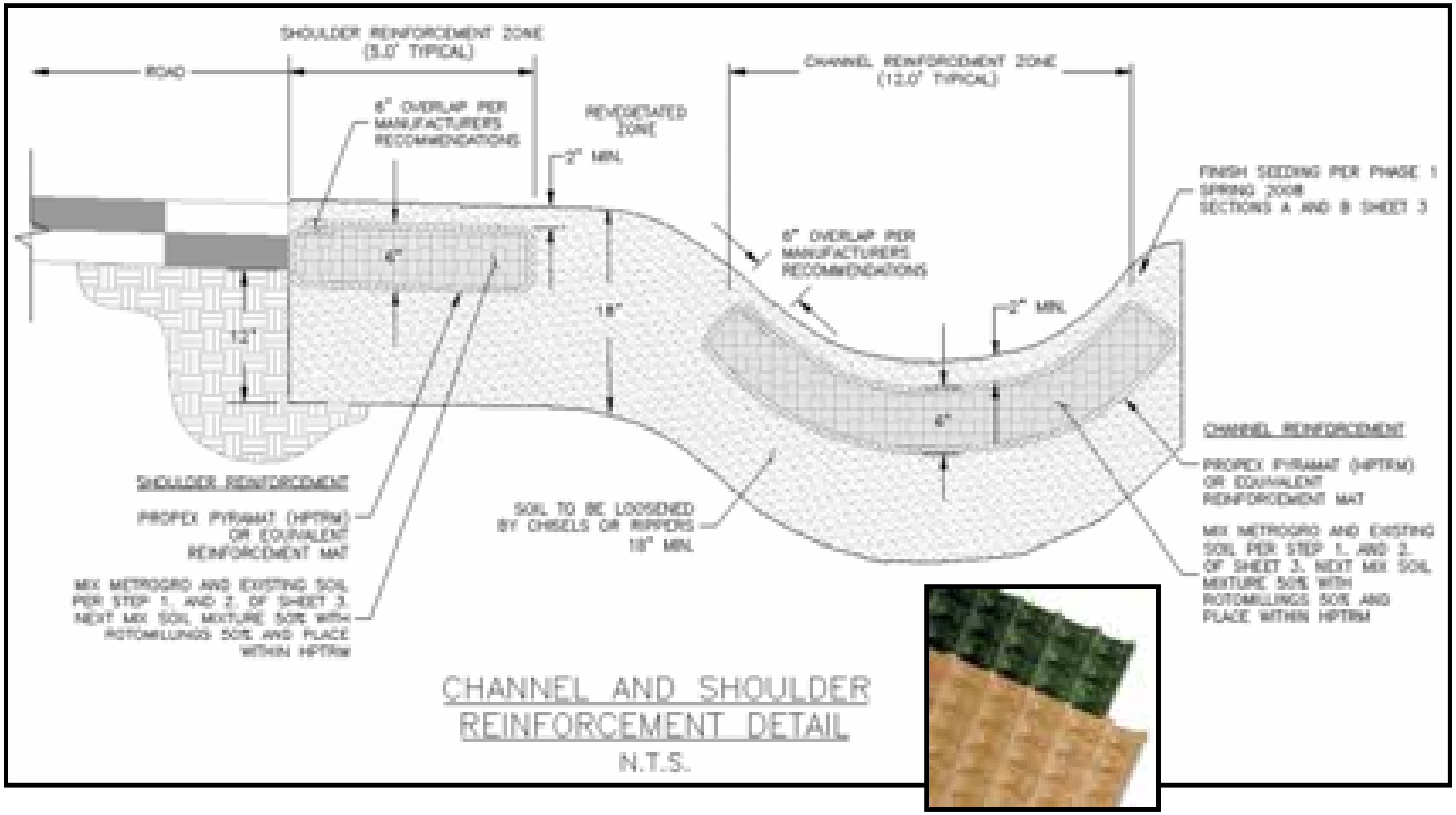
Alternatives Developed
Maintenance Path



MAINTENANCE ROAD DETAIL

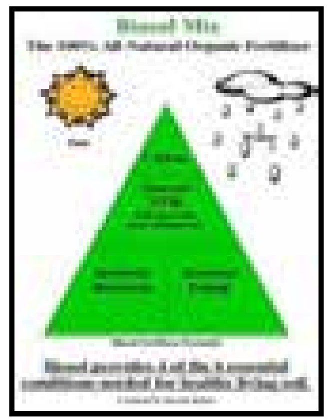
N.T.S.

Alternatives Developed
Reinforced Channel



Alternatives Developed
Soil Amendment

- Balance mag chloride
- Amend soil & blanket
  - Rip soil
  - MetroGro compost
  - Biosol
  - Humate



Alternatives Developed
Seeding

NATIVE SEED MIX

COMMON NAME	VARIETY	% IN MIX	LBS PLS / ACRE
INLAND SALTGRASS	NATIVE	16%	2.4
ALKALI SACATON	SALADO	4%	0.6
WESTERN WHEATGRASS	ARRIBA	43%	6.3
ALKALIGRASS	FULTS	4%	0.6
NUTTALL ALKALIGRASS	NATIVE	2%	0.3
GARDNER SALTBUSH	NATIVE	8%	1.2
SIDEOATS GRAMA	NINER	8%	1.2
LITTLE BLUESTEM	PASTURA	6%	0.9
GREEN NEEDLEGRASS	LOWDORM	8%	1.2
TOTAL			14.7

ANNUAL SEED MIX

COMMON NAME	VARIETY	% IN MIX	LBS PLS / ACRE
SORGHUM*	FORAGE	100%	8.0

*NOTE: SEED SHALL BE STERILE, HYBRID, FORAGE SORGHUM

Alternatives Developed
Seed Mix

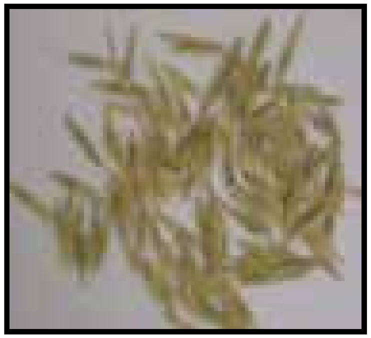
– Oats (annual)

– Side Oats Gramma (native)

Alternatives Developed
Seed Mix

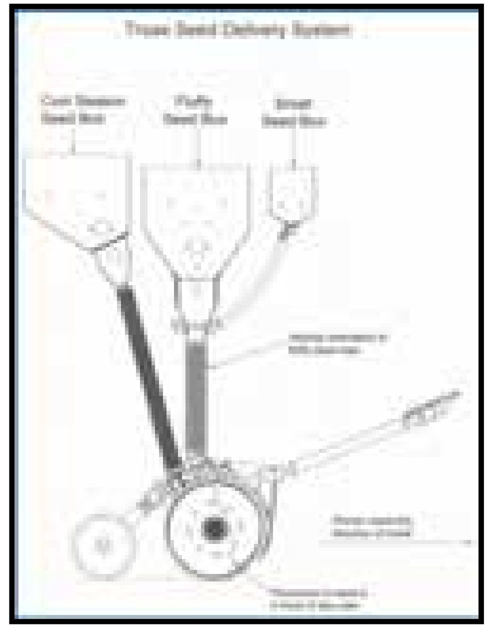
– Western Wheat Grass(native)

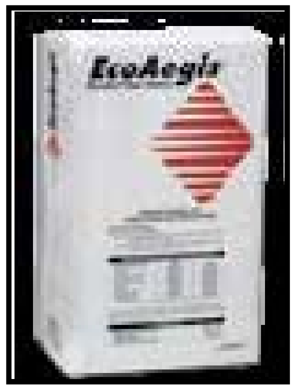
– Inland Salt Grass(native)



Alternatives Developed
Seed Application

- Drill Seeding
  - Truax Seeder
  - Depth
- Protection
  - ECB
  - Hydromulch
- Patience
  - Typically 2 to 3 yrs





Alternatives Developed
Estimated Costs

– Valley Gutter	$50/LF
– Underdrain Shoulder	$60/LF
– Maintenance Path	$45/LF
– Reinforced Channel	$50/LF
– Riprap-Lined Channel	$50/LF
– Soil Amendment	$400/AC
– Seeding	$1,500/AC

Alternatives Installed

– Underdrain Shoulder

– Maintenance Path

– Reinforced Channel

Alternatives Installed Locations

Alternatives Installed Locations

- Outbound Peña Boulevard
  - Highly visible
  - Exhibits areas of rill erosion, ditch erosion, and loss of vegetation

Alternatives Installed Locations

– Shady Grove Street
  – Contains a WQ basin that needs a maintenance path
  – Exhibits areas of rill erosion and loss of vegetation

Alternatives Installed
Outbound Peña Boulevard

– Channel graded for constant longitudinal slope
– Reinforced shoulder constructed, then reinforced channel
– Annual seed mix/nurse crop not planted
– Soil was well mixed and clod free
– Entire area covered with ECBs
– Erosion control logs installed
– Delineator posts not reinstalled

Alternatives Installed
Outbound Peña Boulevard

Alternatives Installed
Shady Grove Street

- Relocated electric utilities for clearance
- Soft shoulder built with geogrid, geomembrane, and underdrain in a linear progression
- Longitudinal slope critical for underdrains
- Multiple geogrids were installed to evaluate durability
- ECBs used over only part of the site
- Sterile sorghum nurse crop incorporated into seed mix

Alternatives Installed
Shady Grove Street

Findings
Outbound Peña Boulevard

- No rill erosion adjacent to pavement
- Channel appears stable and invert has not deteriorated
- Almost no sediment transport has occurred
  - Less maintenance
  - Improved aesthetics
  - Improved WQ
- Spontaneous growth of “Poor Man’s Alfalfa” (Kochia) successfully replaced function of annual nurse crop

Findings
Outbound Peña Boulevard

Findings
Outbound Peña Boulevard

- Delineators not replaced; shoulder took some vehicular traffic in saturated conditions before vegetation established
  - Minimal damage occurred
  - Repeated traffic would permanently damage HPTRM/ECB
  - Repairs to subgrade and channel were very difficult
- Native grass began overtaking Kochia in 2nd season

Findings
Outbound Peña Boulevard

Findings
Shady Grove Street

- No rill erosion adjacent to pavement
- Provides safe solid area that vehicles can pull off onto
  - Locations need to be evaluated for potential to encourage loitering on shoulders
- Runoff is infiltrating the granular material (recycled PCCP from runway rehabilitation)
- Vegetation struggling to establish
- Underdrain surface configuration allows for easy visual identification of the BMP and of the need for maintenance

Findings
Shady Grove Street

Findings
Shady Grove Street

- ECB not installed over all disturbed areas
  - Vegetation minimal in unprotected areas
  - Reseeding implemented with limited success
    - Working with NRCS to evaluate potential causes
    - May improve with soil conditioning, use of ECBs, and temporary watering (which may or not be permissible within the WQ basin)

Findings
Shady Grove Street

Findings
Conclusions

– Reinforced Shoulder & Channel

Findings
Conclusions

– Maintenance Path

Findings
Conclusions

– Underdrain Shoulder

Findings
Conclusions

- The installations have shown that these alternatives can work
- Ongoing maintenance and observation will help to refine the designs for future installations
- Research into additional alternatives needs to continue to address the diverse issues and conditions at DIA

Future Efforts

- Alternative outlet structures
- Alternative WQ features
- Alternatives to outlet protection
- Alternatives for low-flow channels
- Additional alternatives for shoulder stabilization

Future Efforts
Geoweb Shoulder Installation

Future Efforts
Geoweb Shoulder Installation

Future Efforts
Geoweb Shoulder Installation

Future Efforts
Geoweb Shoulder Installation

Future Efforts
Geoweb Shoulder Installation

Future Efforts
Geoweb Shoulder Installation

Future Efforts
Geoweb Shoulder Installation

Future Efforts
Geoweb Shoulder Installation

- Issues raised and being investigated
  - Roll over potential
  - Motorcycles
  - Aggregate thrown back on roadway
  - Vehicles getting stuck, high-centered, dips, etc.
  - Stability for changing tires
  - Potential for pull up or snagging
  - Inspections
  - Hazmat cleanup
  - Flammability

Questions?

- Contacts
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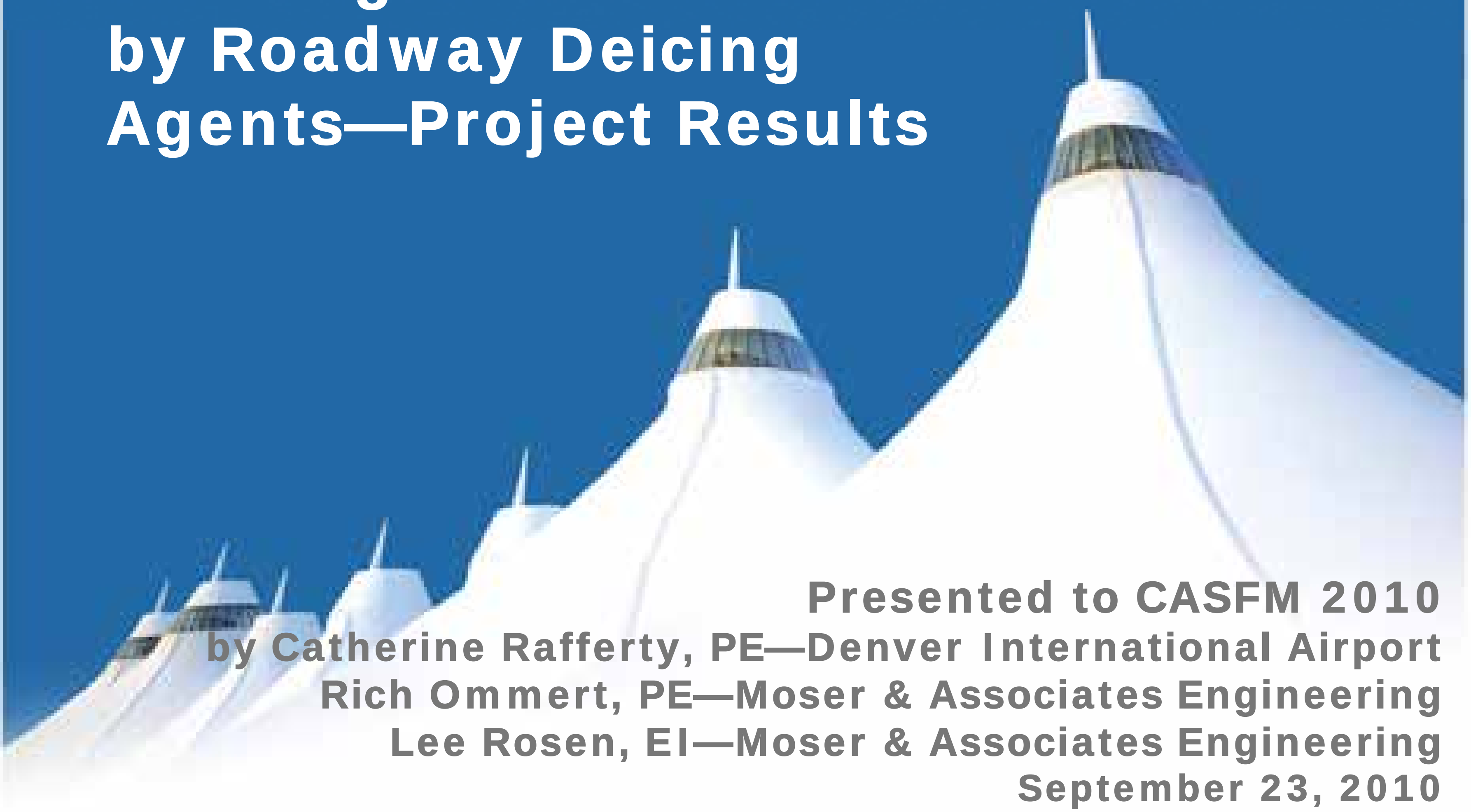
    - rosen@moser-eng.com
    - 303-757-3655

DENVER INTERNATIONAL AIRPORT
TOGETHER WE SOAR

Tackling Erosion Caused by Roadway Deicing Agents—Project Results



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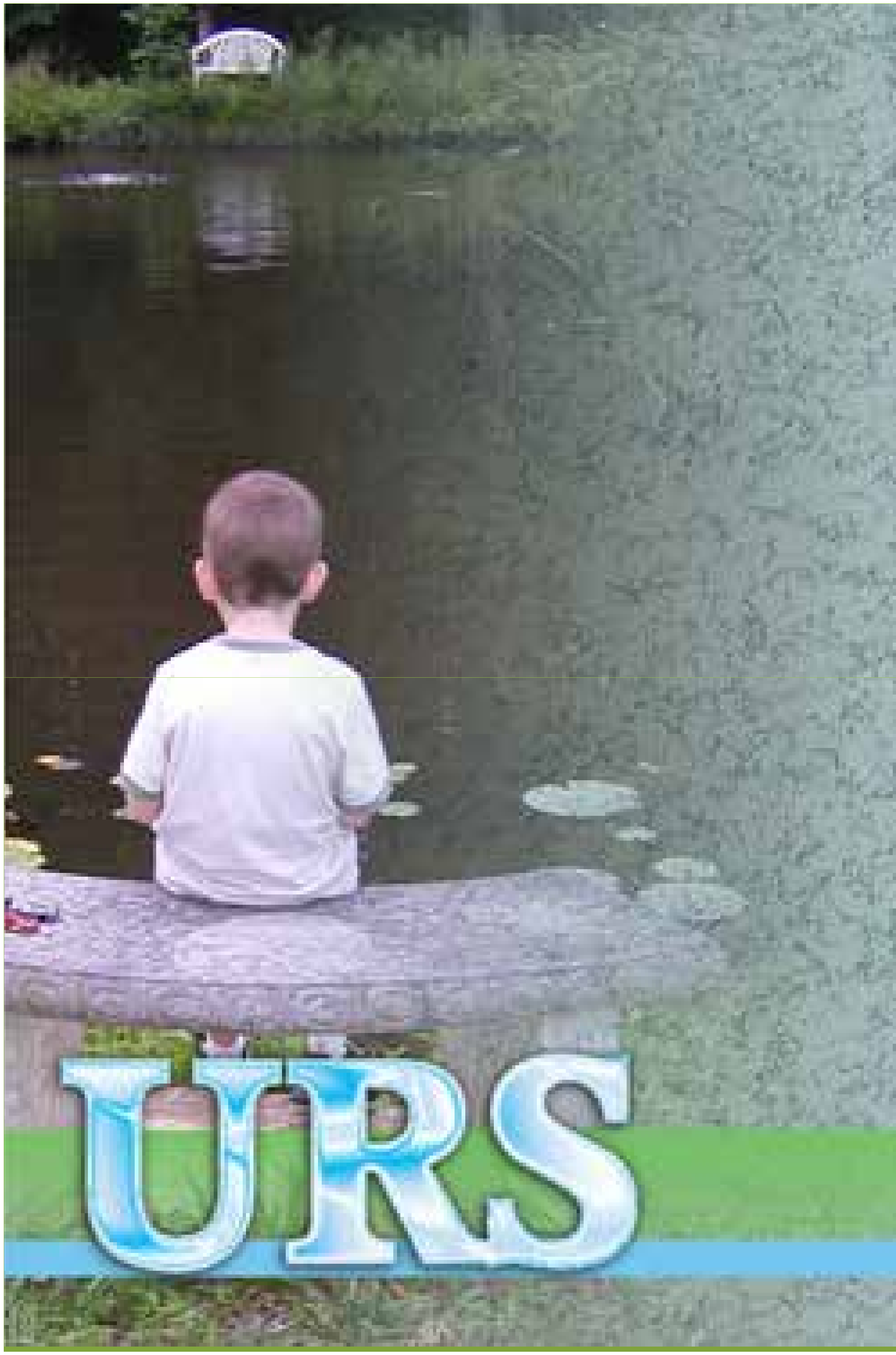
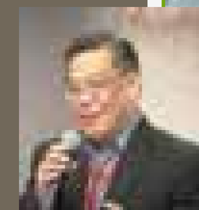
Lee Rosen, EI—Moser & Associates Engineering

September 23, 2010



Hui-Ming "Max" Shih
PhD, PE, CFM
URS Corp., Denver



James C.Y. Guo
PhD, PE
University of Colorado Denver

Bill Sabatka
PE
URS Corp., Denver

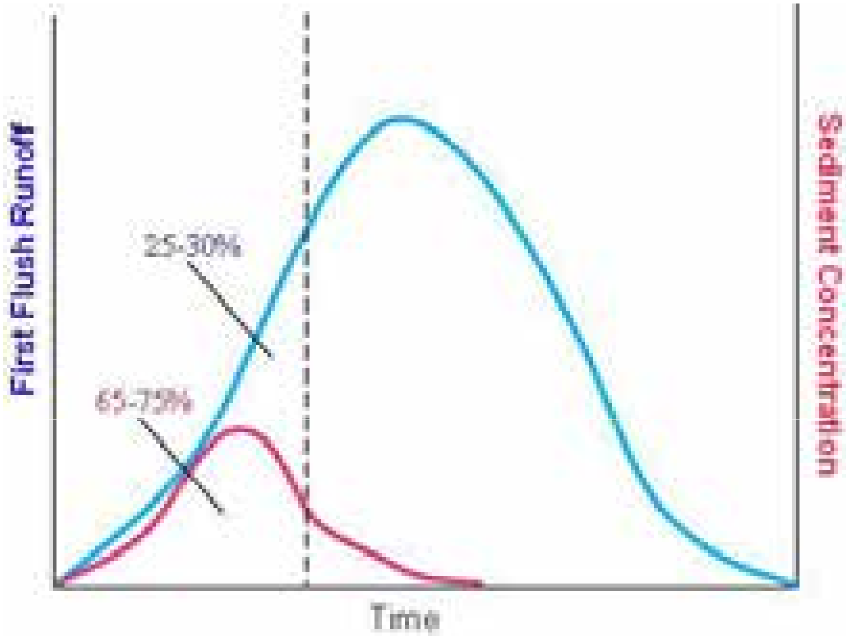
TOTAL SUSPENDED SEDIMENT REMOVAL RATE FOR WATER QUALITY PONDS

First Flush Runoff

- Event mean concentrations of the maximum pollutant are consistently observed to occur in response to the initial 12~15mm (0.5 inch) of effective rainfall-runoff with significantly lower runoff concentrations occurring thereafter (Ellis, 1991)

First Flash Video

Water Quality Volume (WQV)



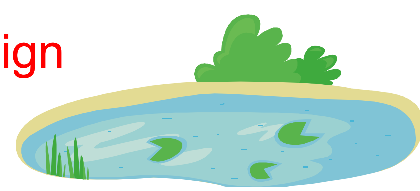
(Verbanck et al., 1994)

- By capturing and treating the runoff volume of First Flush, up to 90% of pollutants that are washed off of the land can be removed from the storm water.

Methods of Estimating WQV

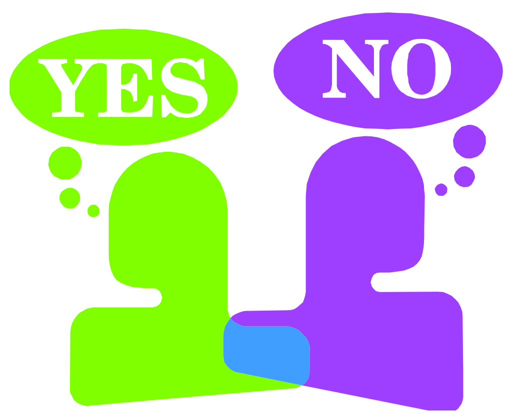
- 90% of the average annual stormwater runoff volume.
- Half-Inch Rule (0.5 inch rainfall depth)
- EPA Simple Method (EPA, 1986)
- Water Quality Capture Volume (WQCV) (Guo and Urbonas, 1996)

Applied for determining Water Quality Volume
in
A Pond Design



Does WQV Trap Pollutants in Ponds?

- Quantity ? Quality?
- WQV contains the washed off sediment and associated pollutant.
- Do WQV ponds trap the sediment and associated pollutants?



Total Suspended Sediment (TSS)

- Suspended sediment is one of primary pollutants and transport agency attached by associated pollutants.
- Associated pollutant concentration is commonly proportional to TSS concentration.
- Easily sampled
- Indicator of water quality or water treatment efficiency.

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TSS Removal Efficiency (%)

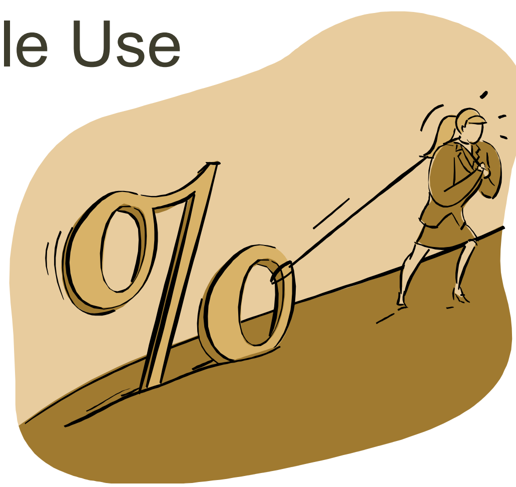
- J. Bryan Ellis (1996)
  - Extended detention dry basin 5-90%
  - Wet Pond -30-91%
- National Pollutant Removal Performance Database (2007)
  - Dry Pond -1-90%
  - Wet Pond -33-99%

“No Consistent Performance”

URS

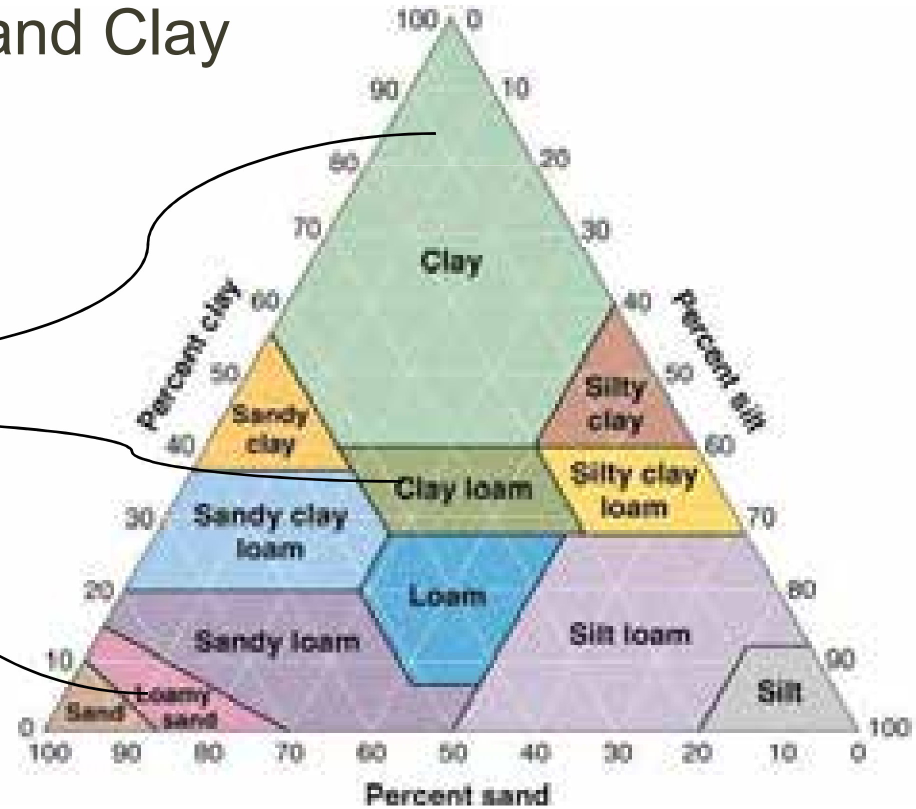
Engineers' Struggles for Water Quality Pond Design

- Anticipated TSS Removal Rate?
- Pond Performance for Best Management Practice (BMP)
- Receiving Leadership in Energy and Environmental Design (LEED) Credit
- Pond Maintenance and Sustainable Use



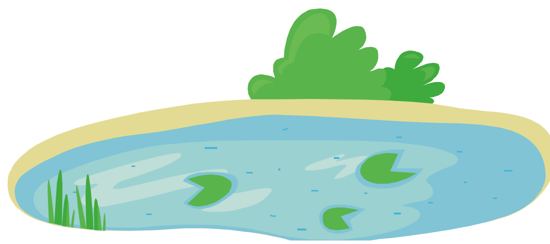
Inflow Particles

- Suspended particles: smaller than coarse sand (Ackers et al., 1994)
- Topsoil: Sand, Silt, and Clay



TSS Removal Rate
Dominant Factors

- Inflow Sediment
- Drain Time
- Temperature



- Geometry
- Depth
- Turbulent Flow
- Dry/Wet Pond

URS

Theory Approach

- Advection-diffusion equation $\frac{\partial C}{\partial t}+\frac{\partial q_{s-x}}{\partial x}+\frac{\partial q_{s-y}}{\partial x}+\frac{\partial q_{s-z}}{\partial z}=\frac{\dot{m}}{dxdydz}$
- Turbulent Flow $q_{s-x}=V_x C-(D+\varepsilon_x)\frac{\partial C}{\partial x}$
- Particle Settling Velocity $\omega_i=\frac{8\nu}{d_s}\left[\left(1+0.0139d_*^3\right)^{0.5}-1\right]$
- Non-ideal sediment settling $V_{c-non}=1.2V_c$
- Water-Sediment Mixing Condition $C_{mixing}=\beta\cdot\alpha\cdot C_i$

Performance TSS Removal Rate Indictor

Sediment Fraction

Unit Discharge

Stream Path

Sediment Size & Settling Velocity

$$T_E = 1 - \beta \cdot \alpha \cdot \sum_{i=1}^{n} \left[e^{-L\omega_i / 1.2q} \cdot \Delta X_i \right]$$

Flow Viscosity

Turbulent Flow

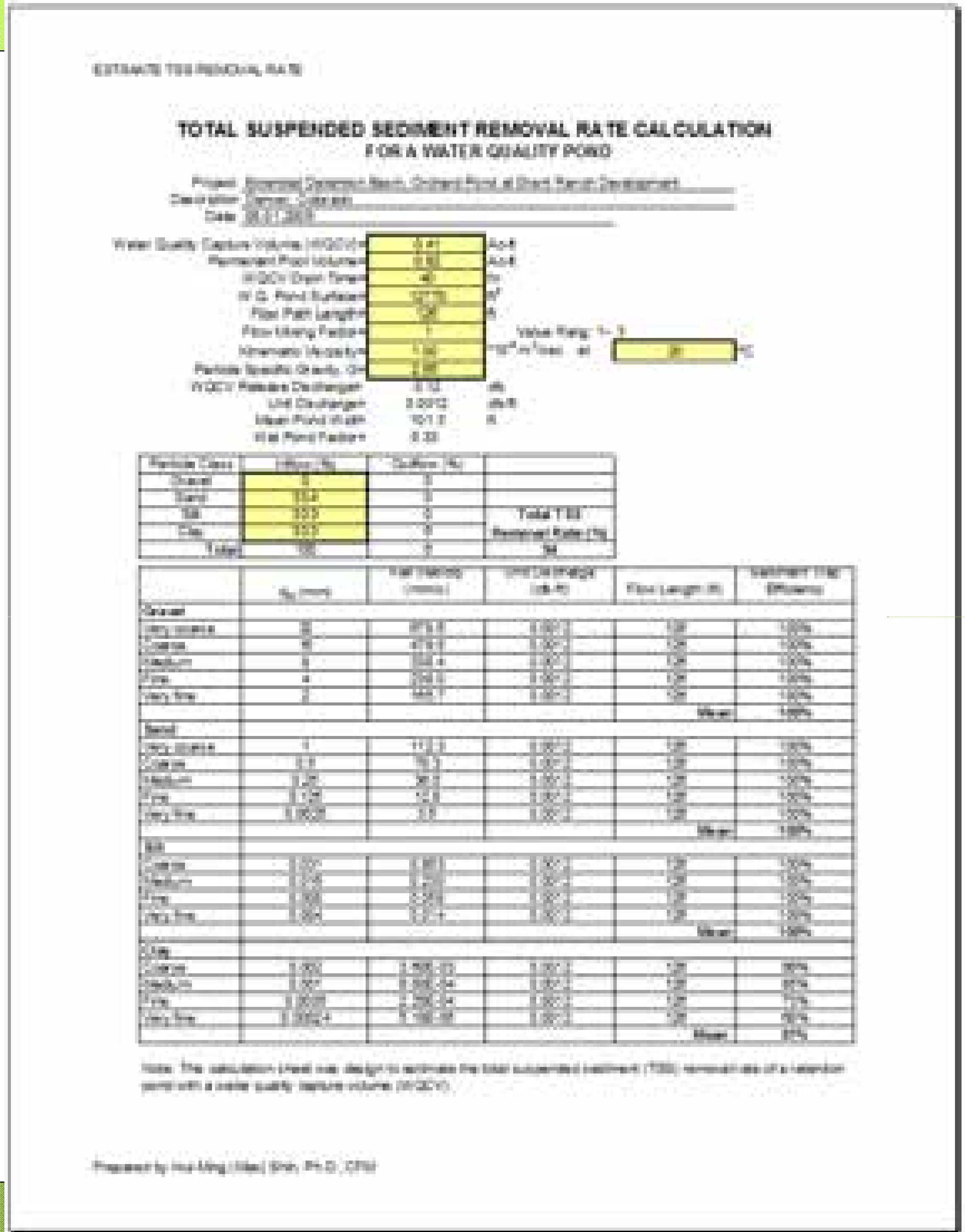
Water-Sediment Mixing

Calculation Sheet

$$T_E = 1 - \beta \cdot \alpha \cdot \sum_{i=1}^{n} \left[e^{-L\omega_i/1.2q} \cdot \Delta X_i \right]$$

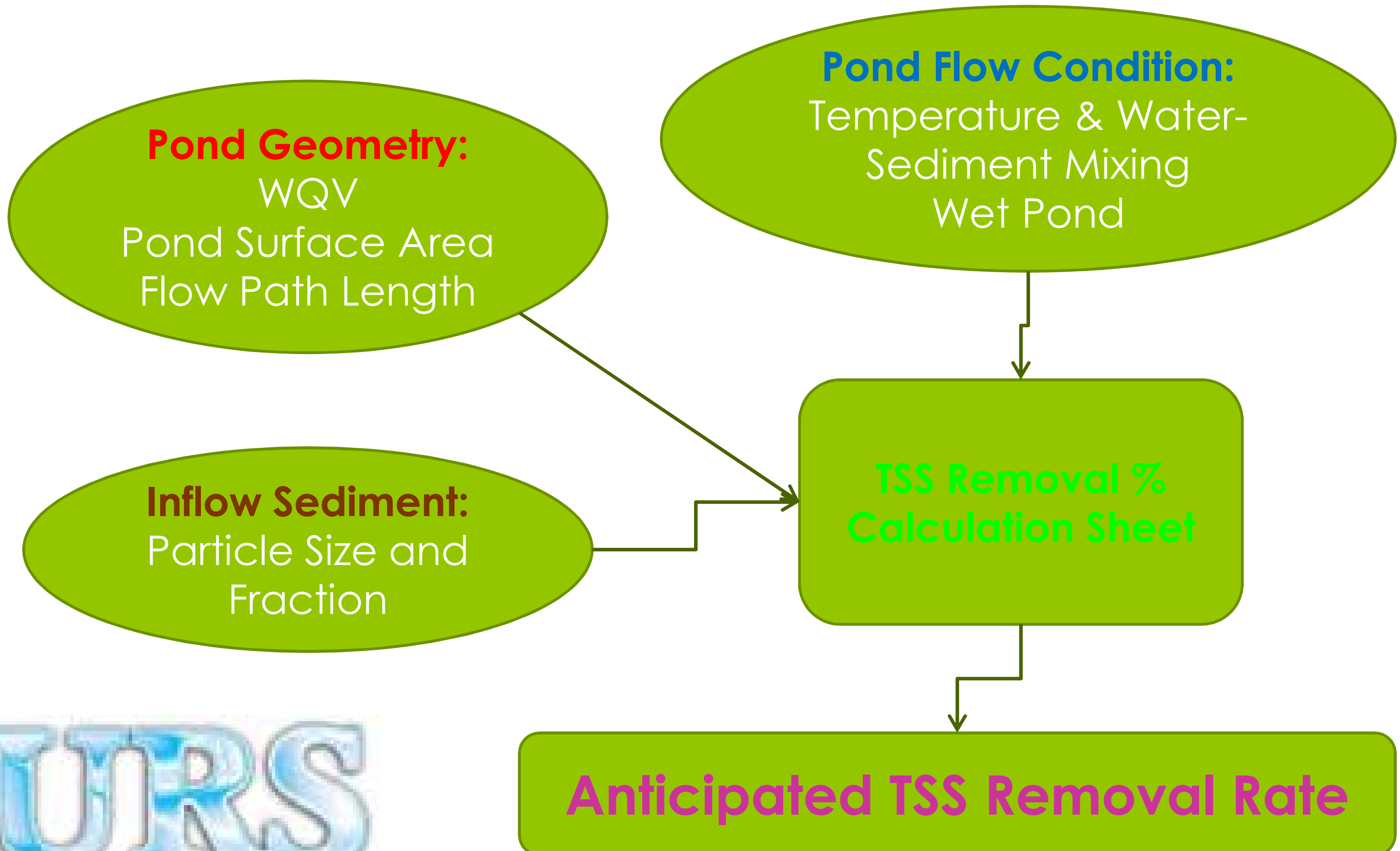
$$\omega_i = \frac{8\nu}{d_s}\left[\left(1 + 0.0139 d_*^3\right)^{0.5} - 1 \right]$$

$$d_* = d_s \left[\frac{(G-1)g}{\nu^2} \right]^{1/3}$$


ESTIMATE TSS REMOVAL RATE

TOTAL SUSPENDED SEDIMENT REMOVAL RATE CALCULATION
FOR A WATER QUALITY POND

Approach Flow Chart



Case Study – Orchard Detention, Denver, Colorado

- Extended Detention Basin
- catchment is 16.9 acres
- site imperviousness rate of 50%.
- (WQCV) of 0.41 acre-ft based on a 40-hour drain time
- surface area of WQCV is 12,770 ft^2. The Stream path is 126ft

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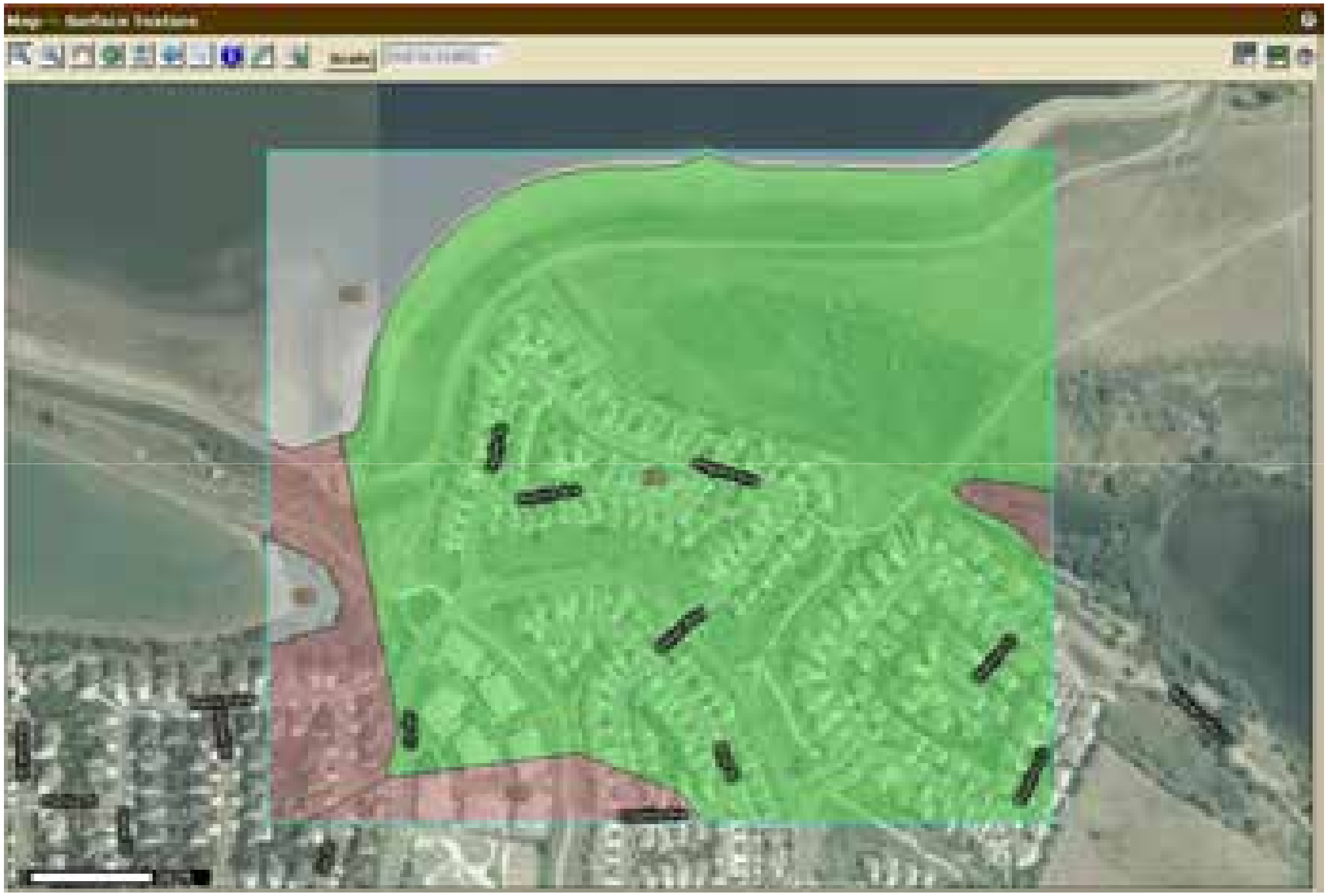
Inflow Particles – Native Topsoil



- Renohill Loam, containing 33.4% of sand, 33.3% of silt, and 33.3% of clay

TSS Removal Calculation

TOTAL SUSPENDED SEDIMENT REMOVAL RATE CALCULATION
FOR A WATER QUALITY POND

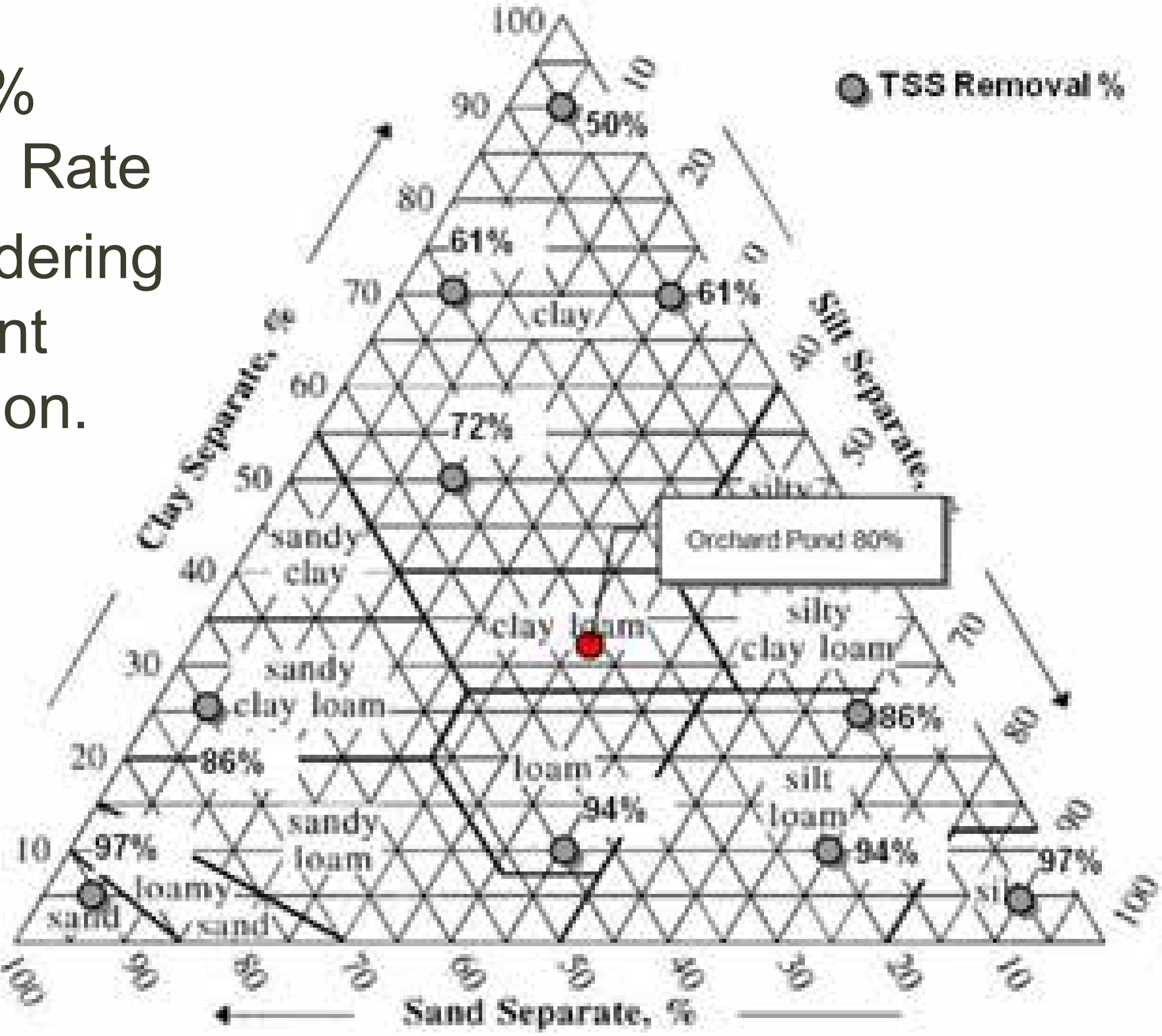
Project: Extended Detention Basin, Orchard Pond at Grant Ranch Development
Description: Denver, Colorado
Date: 08.01.2009

Water Quality Capture Volume (WQCV)=	0.41	Ac-ft			
Permanent Pool Volume=	0	Ac-ft			
WQCV Drain Time=	40	hr			
W.Q. Pond Surface=	12770	ft^2			
Flow Path Length=	126	ft			
Flow Mixing Factor=	1	Value Rang: 1~ 1			
Kinematic Viscosity=	1.00	$*10^{-6}$ m^2/sec	at	20	°C
Particle Specific Gravity, G=	2.65				
WQCV Release Discharge=	0.12	cfs			
Unit Discharge=	0.0012	cfs/ft			
Mean Pond Width	101.3	ft			
Wet Pond Factor=	1.00				

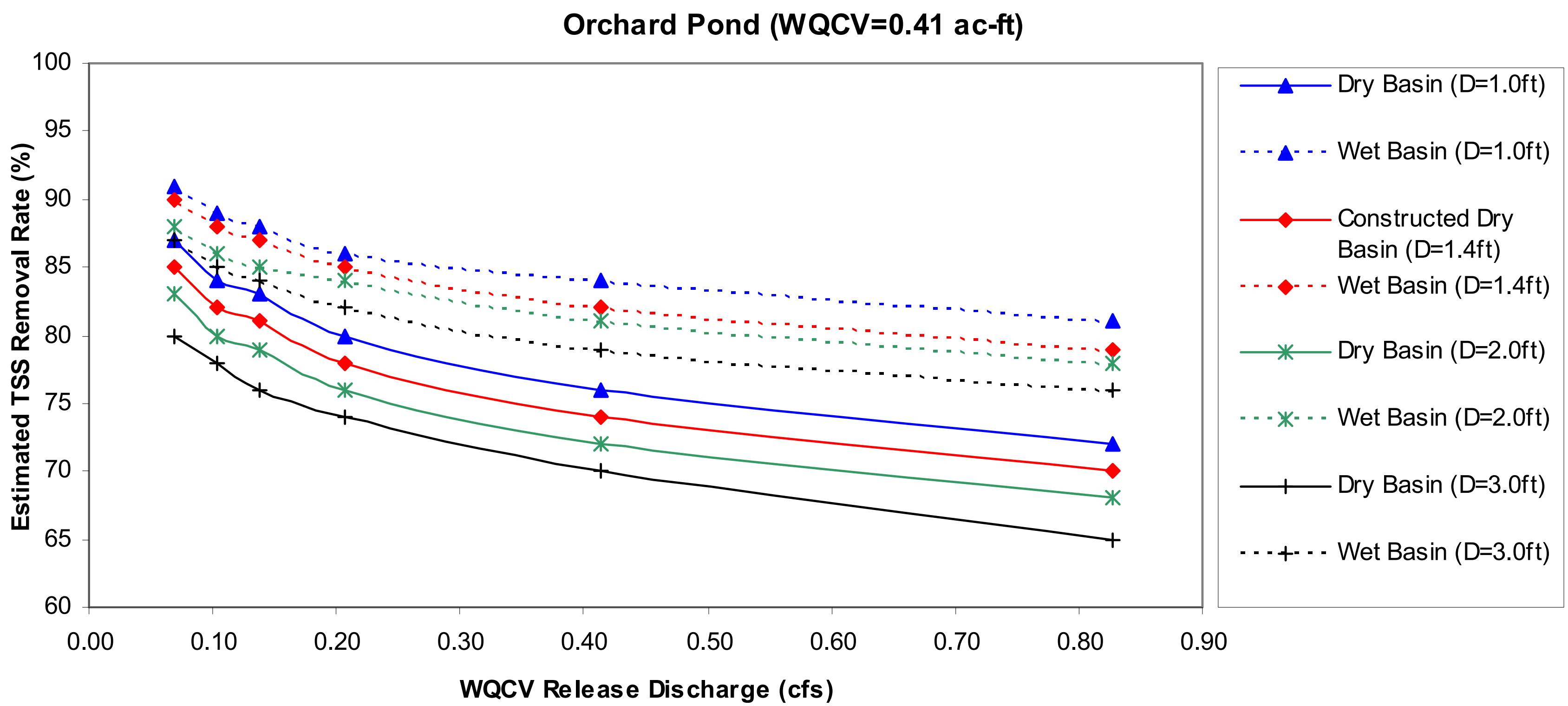
Particle Class	Inflow (%)	Outflow (%)	
Gravel	0	0	
Sand	33.4	0	
Silt	33.3	0	Total TSS
Clay	33.3	19	Removal Rate (%)
Total	100	19	81

Estimated TSS Removal Rate

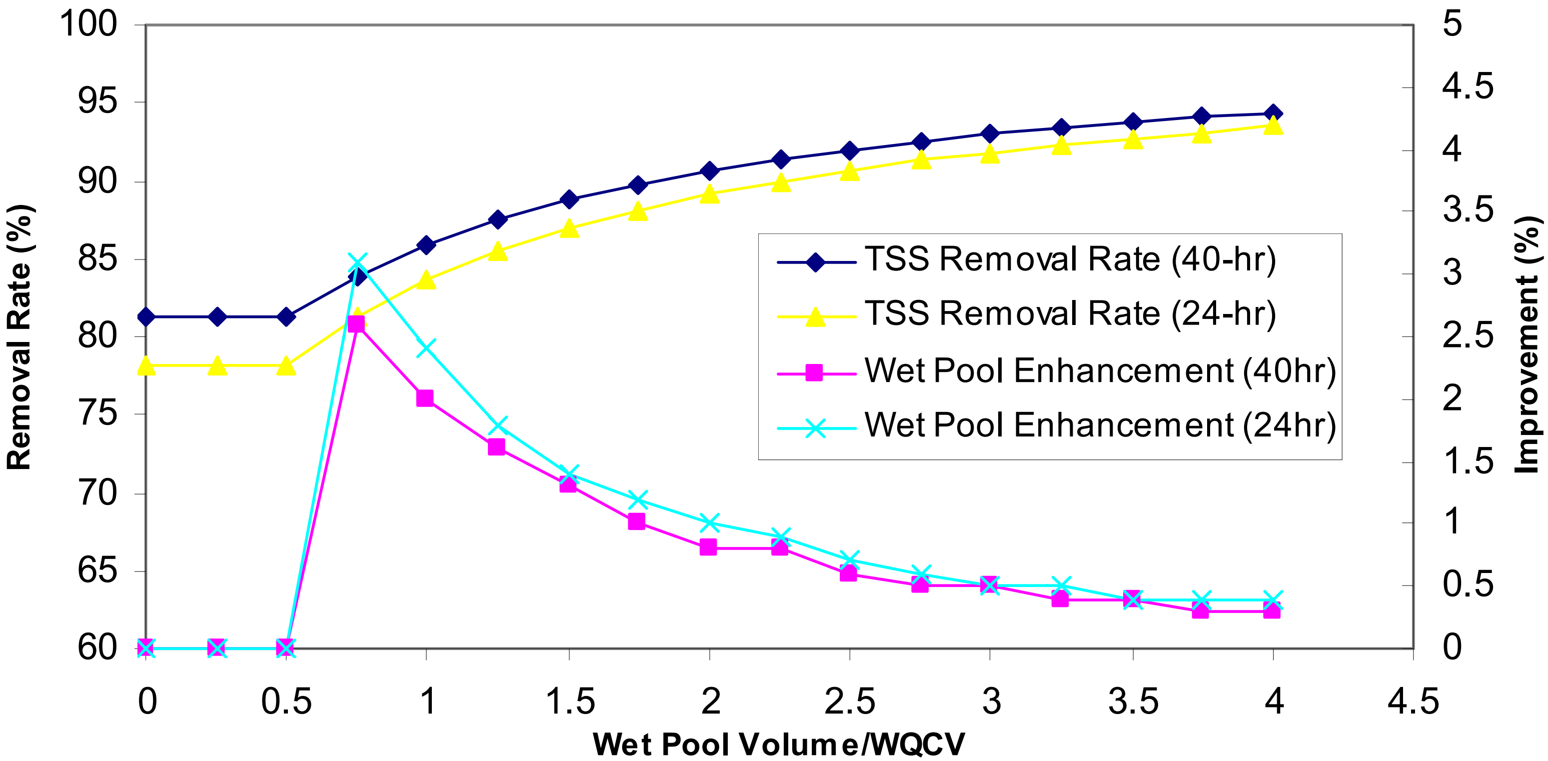
- Estimated 80% TSS Removal Rate
- Without considering inflow sediment size and fraction.
  - 50%~97%



Drain Time v.s. TSS Removal %



Wet Pond Enhancement



Conclusions

- Total Suspended Sediment (TSS) Removal Rate does not only depend on the pond type and drain time.
- Anticipated TSS removal rate could be estimated by considering inflow sediment, pond geometry, water-sediment mixing condition, drain time, and wet pond enhancement.
- This study provides a theoretical approach and an indictor tool for estimating TSS removal %.

THANKS…………

Further Questions & Requests….
Feel free to contact Max Shih by
(720)262-6600; max_shih@urscorp.com

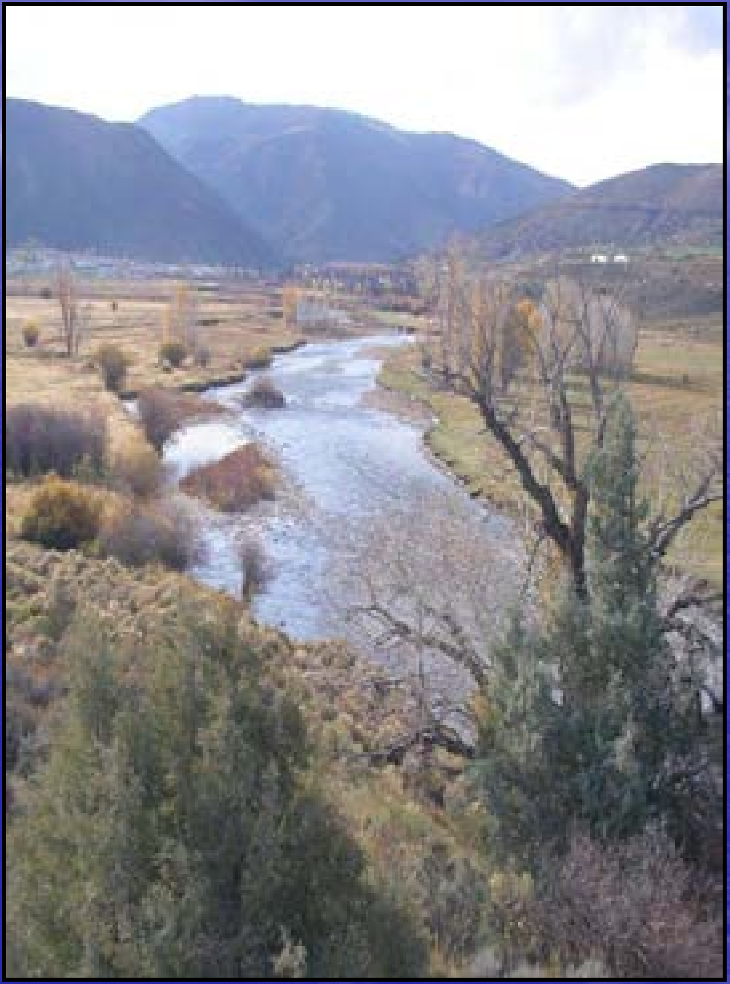
EAGLE RIVER RESTORATION PROJECT
"Edwards Reach"

Julie E. Ash, P.E. & Susan Nordstrom, RLA
Walsh Environmental Scientists & Engineers, LLC

21st ANNUAL CASFM CONFERENCE
Snowmass Village, Colorado
September 23, 2010

SELECTED PROJECT HIGHLIGHTS

- Project overview
- Site orientation
- Pre-existing conditions
- Goals
- Approach
- Treatments
- Construction sediment control
- Performance
- Future



PROJECT OVERVIEW

PROJECT OWNER: Eagle River Watershed Council

PHASE 1 PROJECT PARTNER:

Eagle River Water & Sanitation District

PHASE 1 (2008) EXTENTS:

Length = 0.9 miles

Area = 40 acres

Approx. 55% of total 1.6 miles

PHASE 1 COST:

Instream = $1.4M

Planting = $0.3M

Construction Total = $1.7M

PROJECT OVERVIEW

MULTI-PHASE PROJECT OUTCOMES:

Restored riparian corridor = 80 acres

- 30 ac aquatic habitat
- 50 ac terrestrial habitat

Restored river corridor = 1.6 miles

- Reconnects 50 continuous miles of high-quality riparian & aquatic habitat

Additional info in CPWJ, Vol.5, Issue 8 - 2009

PROJECT OVERVIEW - FUNDING

- Eagle Mine Natural Resource Damage Recovery Fund (NRDF)

  For the restoration of natural resources damaged or lost as a result of the operations of the Eagle Mine within the Eagle River basin, $2.4M awarded in January 2007, 2nd distribution

- Eagle River Water & Sanitation District (ERWSD)
- Eagle County (ECO)
- Western Eagle County Metro. Recreation District (WECMRD)
- Edwards Metropolitan District (Metro)
- Colorado Water Conservation District (CWCB)

  Healthy Rivers Fund, Watershed Restoration Program

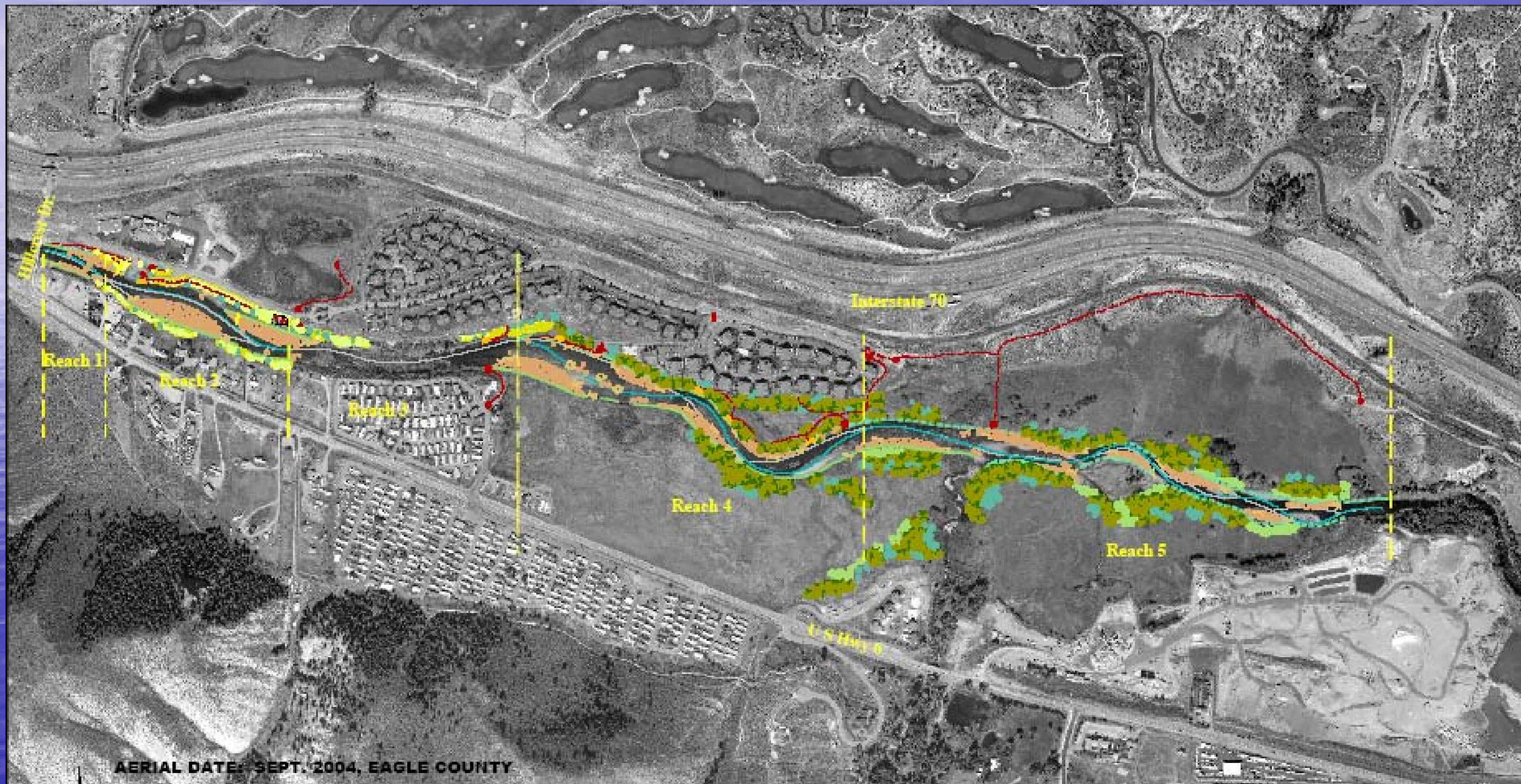
- EPA Section 319 Grant (EPA 319)
- Colorado Department of Transportation (CDOT)

PROJECT OVERVIEW - FUNDING

FUND	PROJECT COMPONENT	VALUE	TERM
NRDF	Instream & riparian, Phase 1	$1.44M	One-time
ERWSD	Instream & mixing zone, Phase 1	$450K+	Potential future
ECO	Instream & riparian Multiple Phase	$75K, $50K	Potential future
WECMRD	Recreation along river corridor	$50K+	Potential future
Metro	Recreation along river corridor	$40K+	Potential future
CWCB	Maintenance & Monitoring Multiple Phase	$50K, $35K+	3-year grants
EPA 319	Instream & riparian, Phase 2	$600K	3-year grant
CDOT	Phase 2	$10K	Potential future

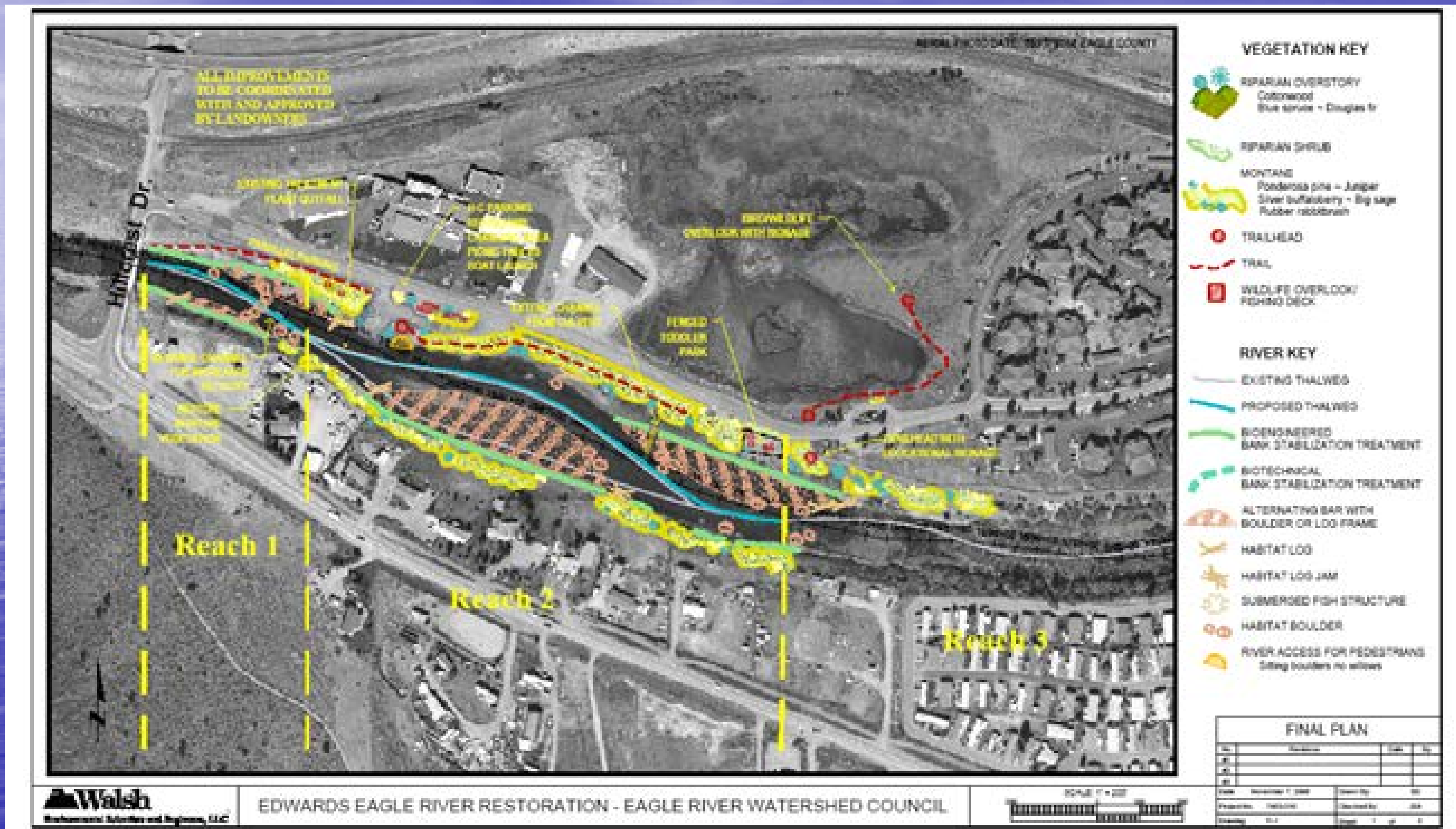
SITE ORIENTATION

1/2 mile downstream of Edwards Spur Road Bridge to Hillcrest Drive Bridge
1.6 mile project reach, 80 acre project area, unique characteristics



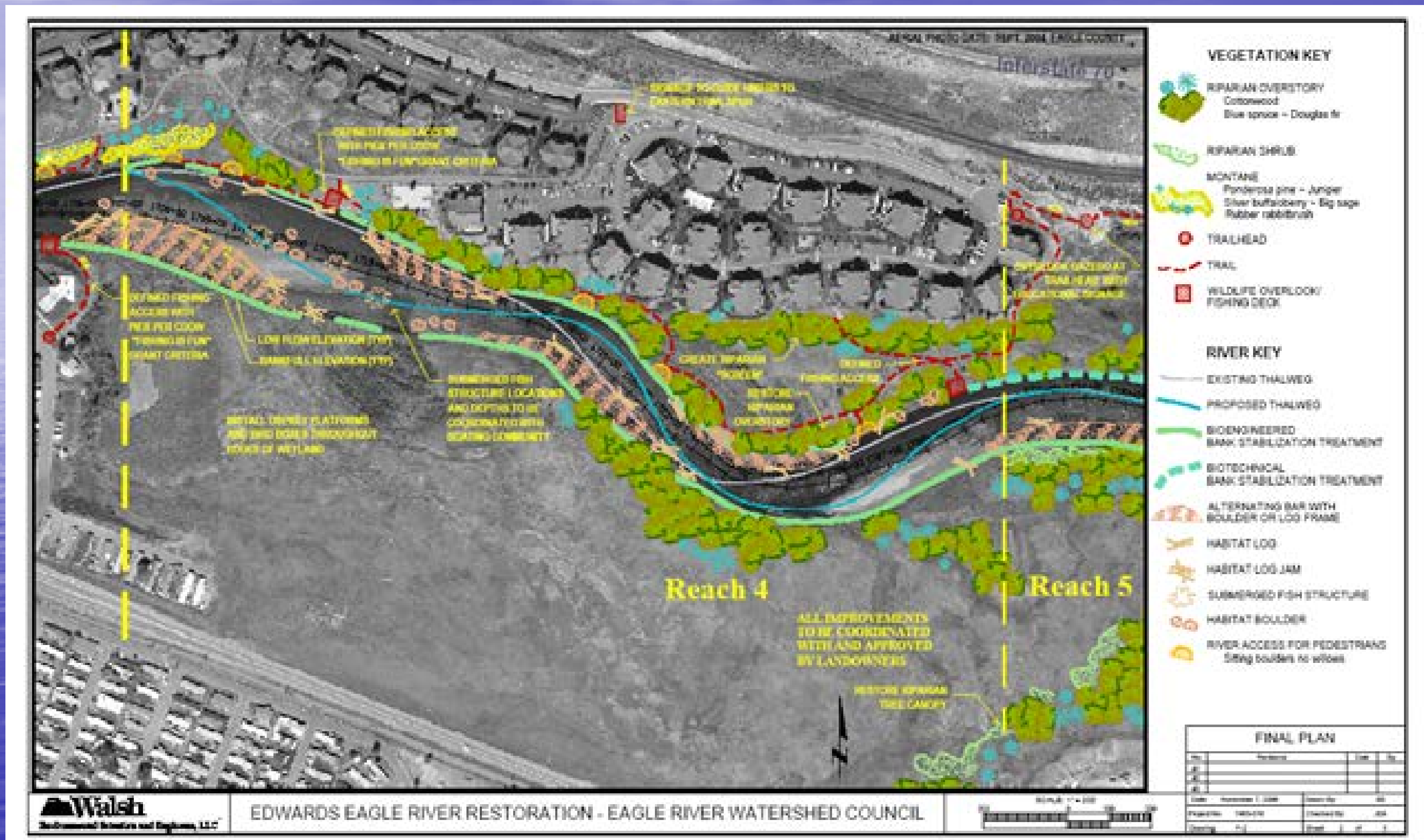
OVERVIEW ORIENT. EX.COND. GOALS APPROACH TMTS SED PERFORM. FUTURE

SITE ORIENTATION : PHASE 1 – REACHES 1 & 2



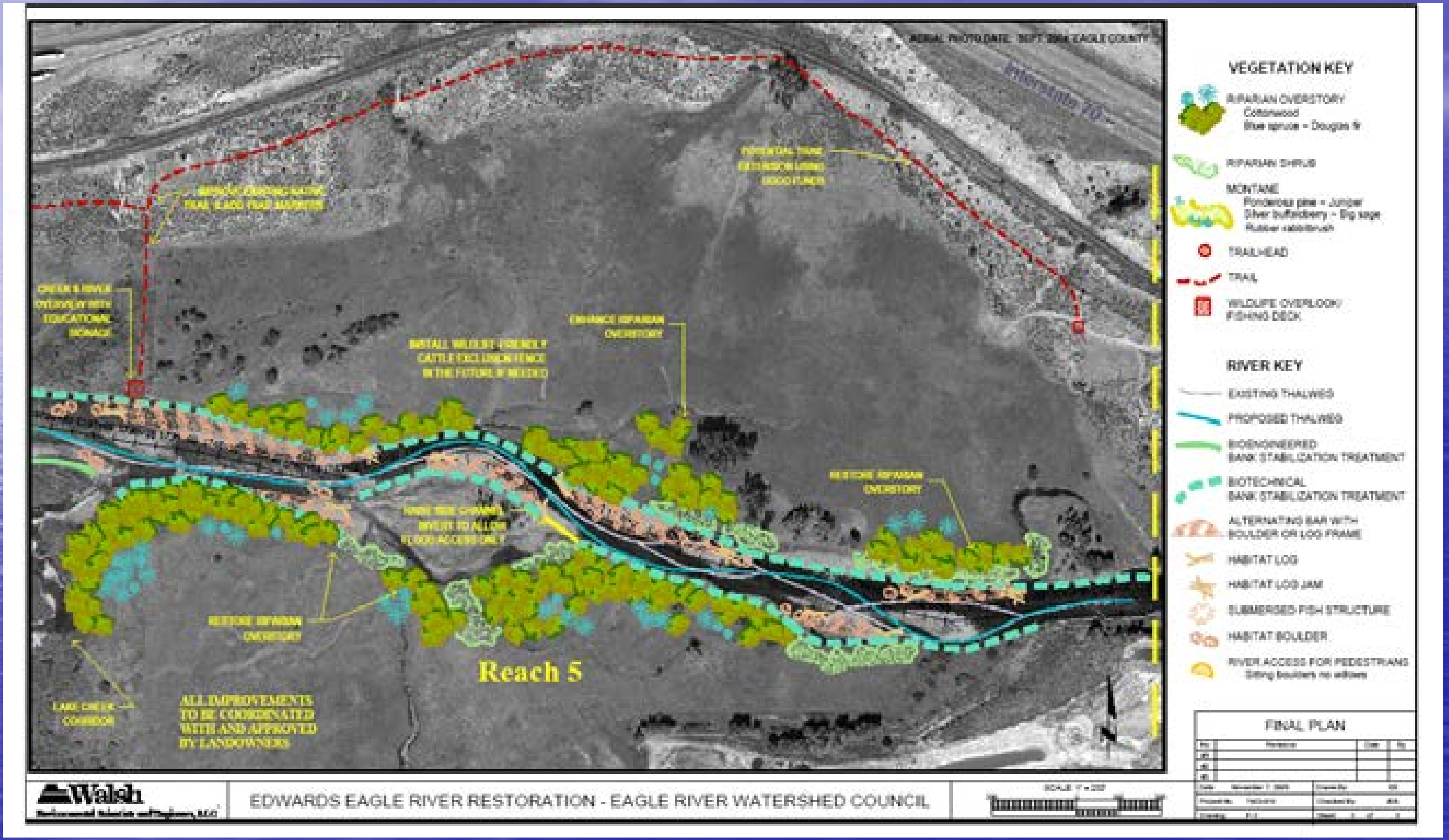
OVERVIEW ORIENT. EX.COND. GOALS APPROACH TMTS SED PERFORM. FUTURE

SITE ORIENTATION: PHASE 2 & 3 – REACH 4



OVERVIEW ORIENT. EX.COND. GOALS APPROACH TMTS SED PERFORM. FUTURE

SITE ORIENTATION:
PHASE 1 & 2 – REACH 5



OVERVIEW ORIENT. EX.COND. GOALS APPROACH TMTS SED PERFORM. FUTURE

PRE-EXISTING CONDITIONS

Frequency-Discharge Data

Discharge (cfs)		
	Upstream of Lake Creek	Downstream of Lake Creek
Low Flow (approx.85% exceedance)	105	120
Mean Annual Flow	1990	2060
Bankfull Flow (1.5-year)	2430	2730
10-year	3980	4530
100-year	5430	6170

PRE-EXISTING CONDITIONS

"One of the most severely degraded reaches in the valley"

-Eagle River Inventory & Assessment (CSU, 2005)

Degraded instream conditions & riparian corridor

- Overly wide & shallow channel
- High instream temps
- Low dissolved oxygen levels
- Deposition of fines
- Tubifex worm habitat

PRE-EXISTING CONDITIONS

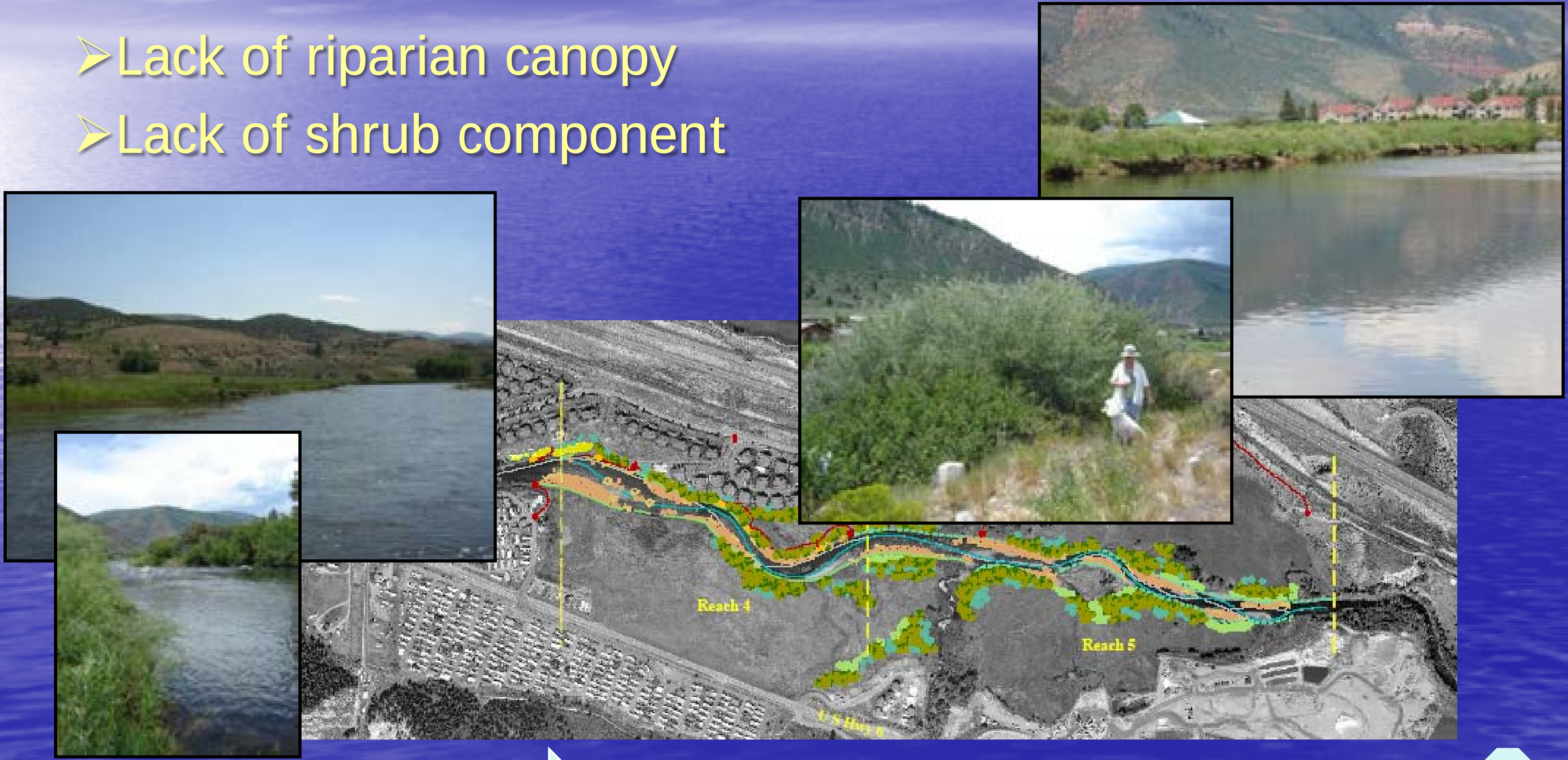
Degraded instream conditions & riparian corridor

- Localized bank erosion
- Poor aquatic habitat

PRE-EXISTING CONDITIONS

Degraded instream conditions & riparian corridor

- Lack of riparian canopy
- Lack of shrub component



PRE-EXISTING CONDITIONS

Land Use History

- Grazing, historical to present
- Railroad
- Roads and highways
- Offsite development
- Hillcrest bridge
- Treatment plant

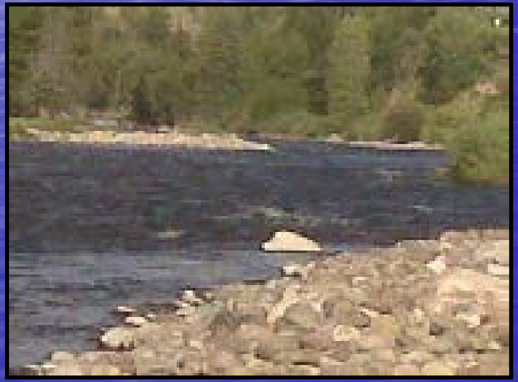
RESTORATION GOALS

To improve the habitat and function of the Eagle River through the Edwards Reach

- Surface Water Quality
- Sediment Control
- Stream Health and Function
- Aquatic Habitat
- Riparian and Wildlife Habitat
- Land Use Management

RESTORATION GOALS

- Surface Water Quality
  - *Reduce instream temps*
  - *Raise DO levels*
- Sediment Control
  - *Reduce fine sediment supply*
  - *Improve mobility at lower flows*



OVERVIEW ORIENT. EX.COND. GOALS APPROACH TMTS SED PERFORM. FUTURE

RESTORATION GOALS

- Stream Health and Function

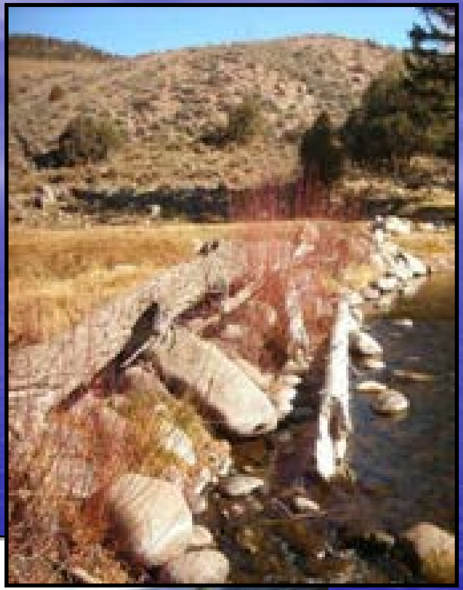
  Correct overly wide, shallow condition

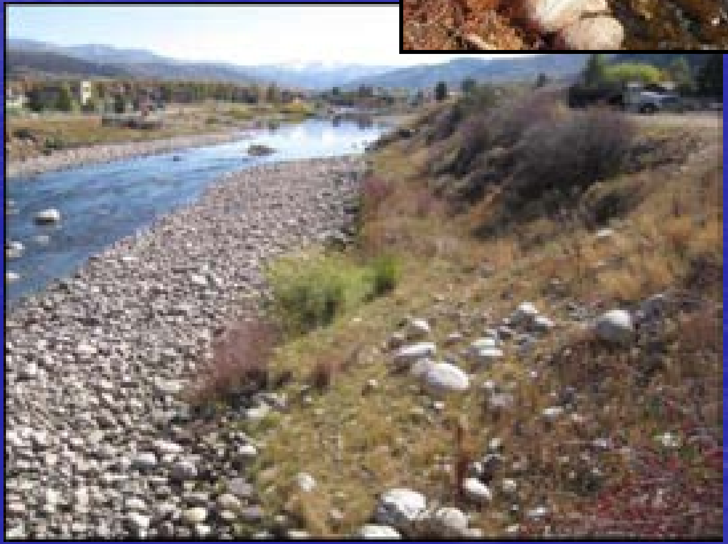
  Restore low flow sinuosity

- Aquatic Habitat

  Increase cover & flow diversity

  Reduce tubifex worm habitat





RESTORATION GOALS

- Riparian and Wildlife Habitat

  Restore overhead canopy to reconnect riparian corridor

  Increase shrub layer

  Increase species diversity

- Land Use Management

  Cattle exclusion fencing

  Controlled recreational access

  Educational signage

  Strategic plantings

RESTORATION APPROACH

- Watershed level
- Maximize natural form and function
- Habitat focused
- First rule of ecological restoration

"To protect your rivers, protect your mountains"
-Emperor Yu of China (1600 B.C.)

"How would Mother Nature do it"

RESTORATION APPROACH

Don't do more harm than good

- tread most lightly
- protect downstream fisheries

- Exceeded construction impact standards
- Construction sediment control BMPs
  - 2 Structural
  - 2 Non-Structural
- Bio-oil in excavators
- Carefully aligned access routes
- Coordination with fly fishing community
- No weekend work in channel through Oct. 14th

RESTORATION TREATMENTS - INSTREAM

BEFORE

AFTER

Recreate cobble/gravel point bars

- Alternating alignment
- Boulder framework
- Natural substrate

Bar 1-22 in Reach 1

RESTORATION TREATMENTS - INSTREAM


BEFORE


AFTER

Recreate cobble/gravel point bars

- Boulder framework
- Reconnect remnant depositional areas

Bar 1-4 in Reach 5

RESTORATION TREATMENTS - INSTREAM

BEFORE

AFTER

Enhance channel bars

- Boulder framework
- Reduce split flow
- Concentrate low flows

Bar 1-5 in Reach 5

RESTORATION TREATMENTS - INSTREAM

BEFORE

AFTER

Enhance channel bars

- Boulder framework
- Shape and stabilize confluence with side channel

Bar 1-1 in Reach 5

RESTORATION TREATMENTS - INSTREAM

BEFORE

AFTER

Plug gap between existing channel bars

- Concentrate low flows in main stem
- Boulder/Cobble Plug
- Integrate habitat logs

Treatment 1-6 in Reach 5

RESTORATION TREATMENTS - INSTREAM

BEFORE

AFTER

Restore boulder/cobble toe

- Natural groupings
- Integrate habitat logs, spurs, and habitat boulders

Treatment 1-16 in Reach 2

RESTORATION TREATMENTS - INSTREAM

Aquatic Habitat Features

- Habitat boulders
- Habitat logs
- Log spurs

PLANTING APPROACH

- Structure
- Function
- Plant associations
- Density

RESTORATION TREATMENTS - VEGETATIVE

BEFORE

AFTER

Plant Groups/Bank Treatments

Continuous Willow Bank Treatment

- Bebb's willow
- Whiplash willow
- Planeleaf willow

Tall Willow Group

- Rocky Mountain willow
- Whiplash Willow
- Planeleaf Willow
- Thinleaf alder

RESTORATION TREATMENTS - VEGETATIVE

Plant Groups/Bank Treatments

Narrowleaf Cottonwood Group

- Narrowleaf cottonwood
- Blue spruce
- Thinleaf alder
- Red-twig dogwood
- Prickly currant
- Golden currant

Shrub Bank Treatment

- Woods rose
- Golden currant
- Prickly currant
- Twinberry honeysuckle
- Thinleaf alder
- River hawthorn

RESTORATION TREATMENTS - VEGETATIVE

BEFORE

AFTER

Plant Groups/Bank Treatments

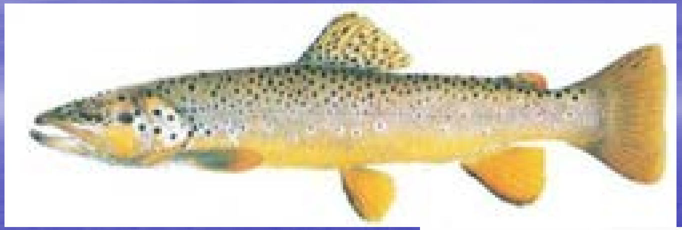
Mixed Shrub Group

- Red-twig dogwood
- Wood's rose
- Golden currant
- Prickly currant
- Twinberry honeysuckle
- Mountain snowberry
- Shrubby cinquefoil
- Thinleaf alder
- River hawthorn
- Rocky Mountain Willow

Tall Willow Group

Narrowleaf Cottonwood Group

CONSTRUCTION SEDIMENT CONTROL



- 2 Structural BMPs
  - Aqua Dam
  - Floating Silt Curtain
- 2 Non-Structural BMPs
  - No equipment tracking in channel
  - Spawning monitoring by fly fishing guides
- $180K for Phase 1 voluntary sediment controls
- 10% of $1.7M Phase 1 construction budget

CONSTRUCTION SEDIMENT CONTROL

LAYFIELD

www.geomembranes.com
www.aquadam.com

AQUA DAM™ Water-Controlling Water

Water-filled AQUA DAM combines weight and counter friction creating an effective, stable water control barrier.

CONSTRUCTION SEDIMENT CONTROL

AQUA DAM

LAYFIELD

www.geomembranes.com
www.aquadam.com

Water-Controlling Water

- $140K for Phase 1, 8% of construction
- Less for future phases

CONSTRUCTION SEDIMENT CONTROL

Another reason to consider the Aqua Dam...

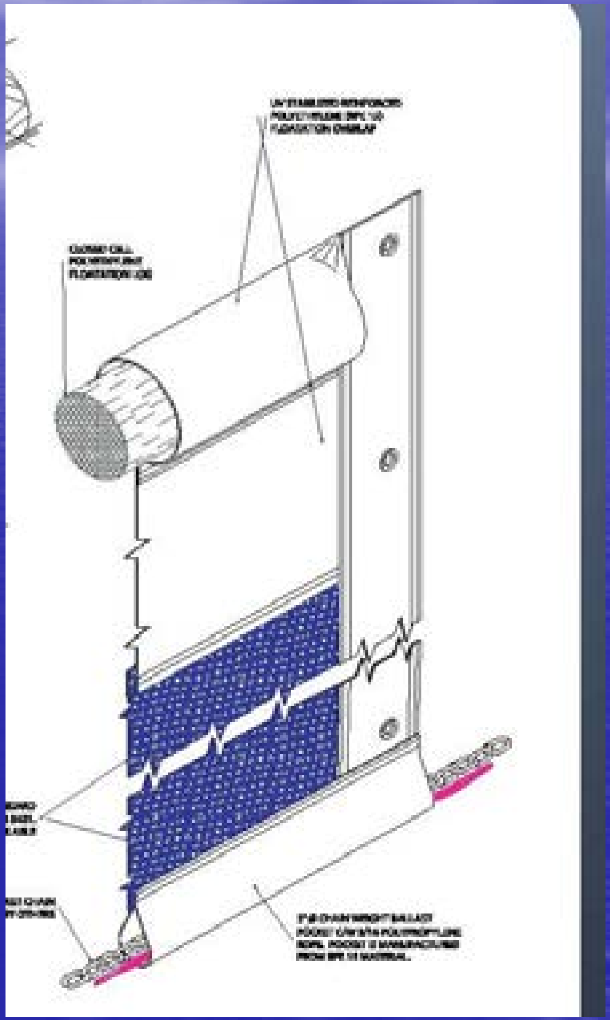
Active work area

No work within Dam...
not our impact!

CONSTRUCTION SEDIMENT CONTROL

Floating silt curtains

- Stationary at downstream end
- Mobile curtains at work areas



CONSTRUCTION SEDIMENT CONTROL

Floating silt curtains

- $40K for Phase 1, 2% of construction
- Reconsider for future phases

OVERVIEW ORIENT. EX.COND. GOALS APPROACH TMTS SED PERFORM. FUTURE

PHASE 1 PROJECT PERFORMANCE

Instream features installed Nov.2008

- Bars and plug intact after 2009 peak flows
- Bars and plug concentrating low flows
- Minor repair on 1 cobble toe bank treatment
- Willow cutting installation in 2010

Plantings installed Sep.2009

- Wire caging, future sand painting
- Minor beaver predation during installation
- Intensive maintenance program
- Awaiting first full growing season

FUTURE

Phase 2 in Fall 2010

PROJECT PARTNERS:

- EPA 319 Award, CDPHE
- Eagle County
- CWCB
- CDOT

COMPLETE REACH 5

START REACH 4

Phase 3 in Fall 2011

EVAPORITE SINKHOLE IN LOWER REACH 4

CONTACT INFORMATION

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Eagle River Watershed Council

Avon, Colorado

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Genesis of Regional Hydraulic Geometry Relationships for the Fountain Creek Watershed, CO

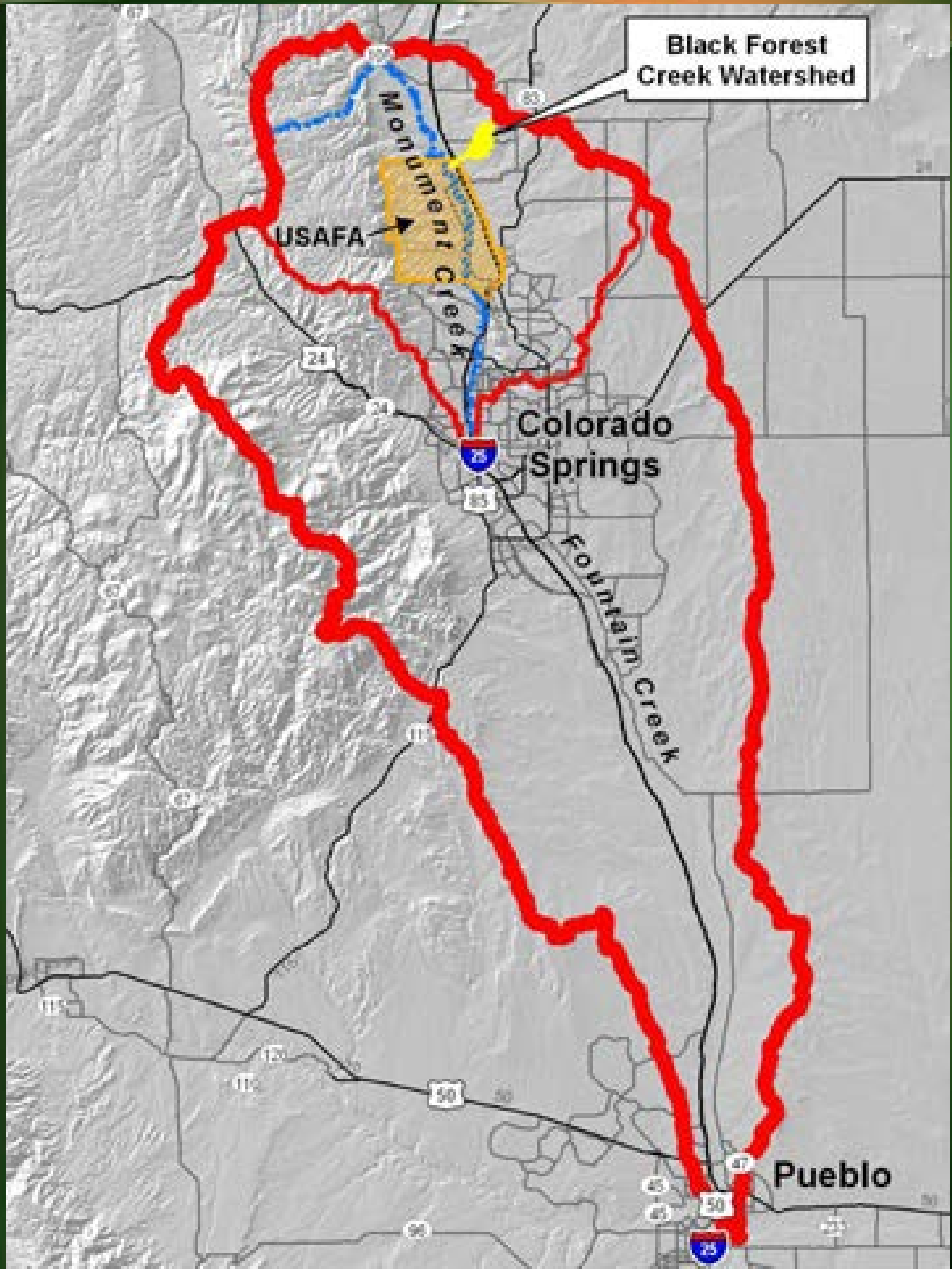
Graham Thompson, PE

Matrix Design Group, Inc.
Integrated Design Solutions

September 23, 2010

Vicinity Map

- Fountain Creek Watershed
- 930 square miles
- 10,000 ft of relief



Watershed Issues

Flooding

Erosion

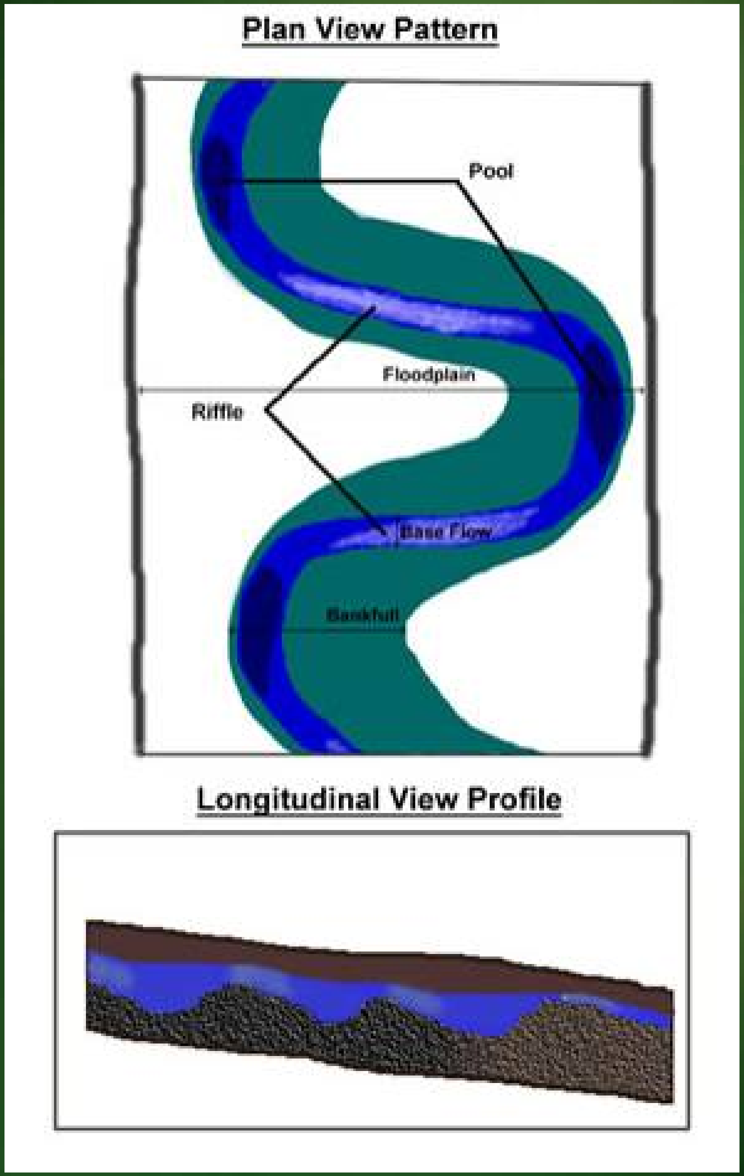
Sedimentation

Hydraulic Geometry Concepts

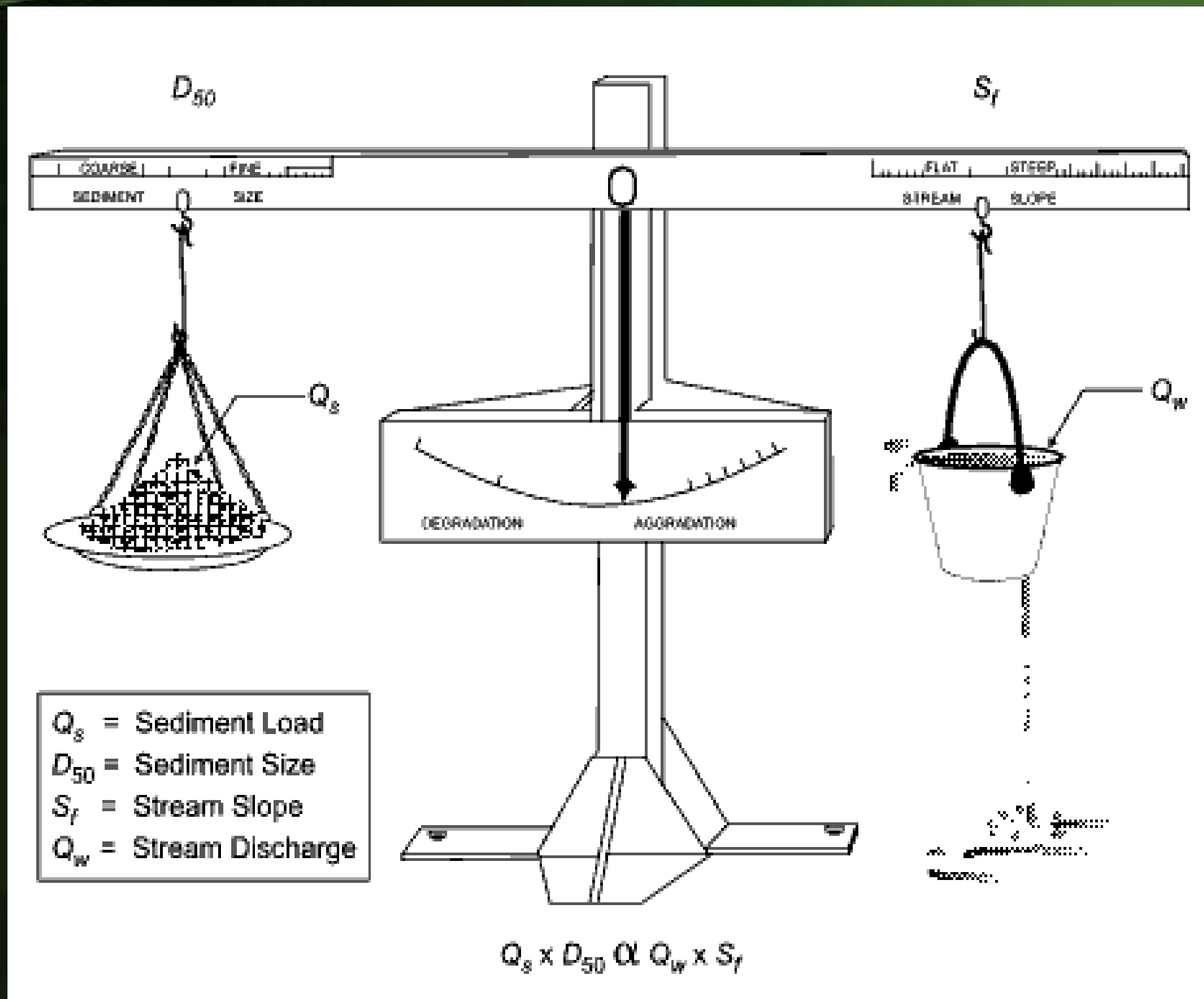
- Plots comparing dependent channel variables
  - Width
  - Depth
  - Cross-sectional Area
- To an independent variable
  - Drainage Area
  - Discharge

Hydraulic Geometry Premise

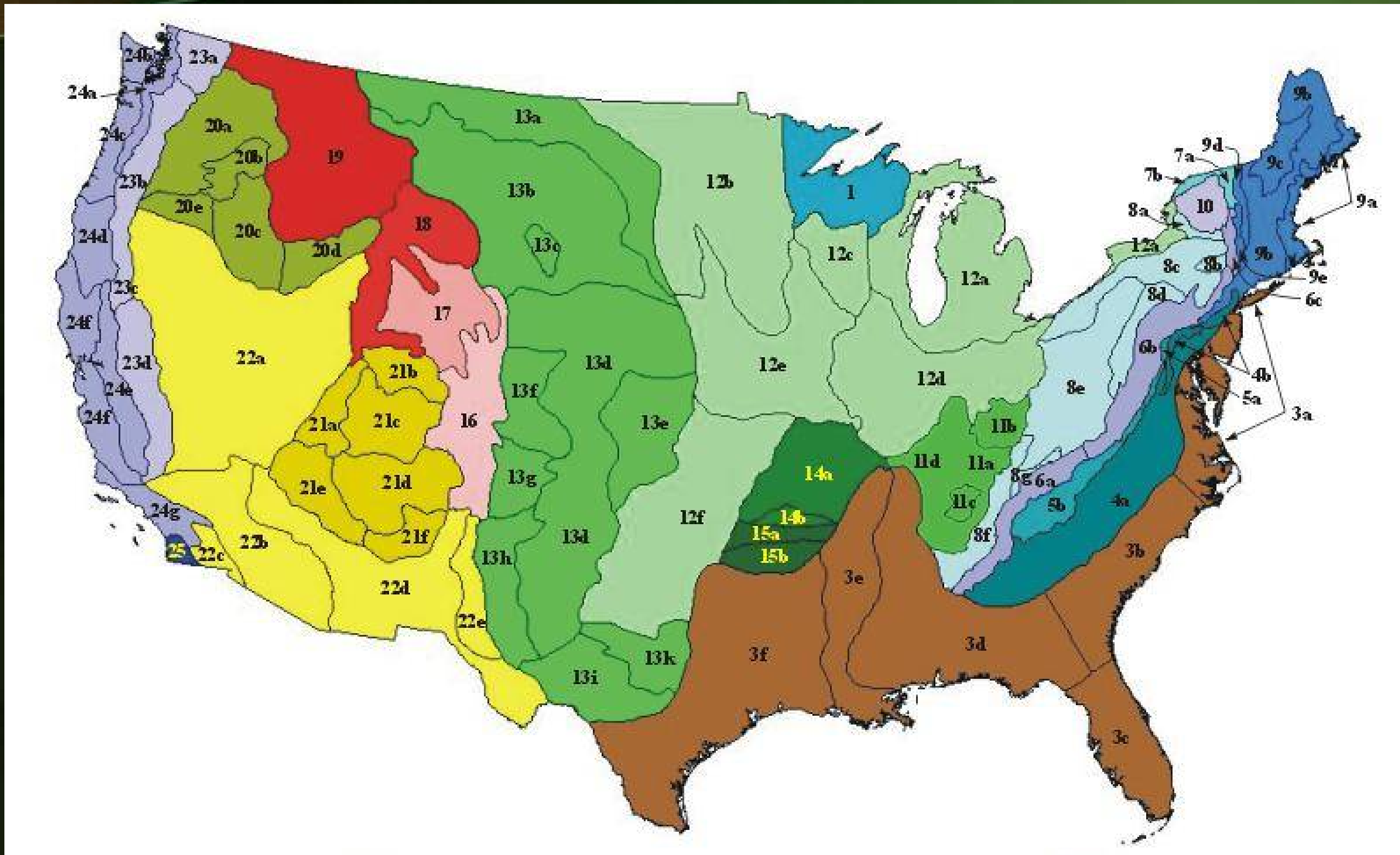
- Channels develop in measurable, reproducible forms
- Function of their formative factors
  - Climate
  - Hydrology
  - Sediment load
  - Vegetation
  - Bed material
  - Others



Lane's Sediment Balance



Hydrophysiographic Regions



Fenneman, Nevin M., 1946, *Physical Divisions of the United States:* U.S. Geological Survey

http://wmc.ar.nrcs.usda.gov/technical/hhswr/geomorphic/index.html

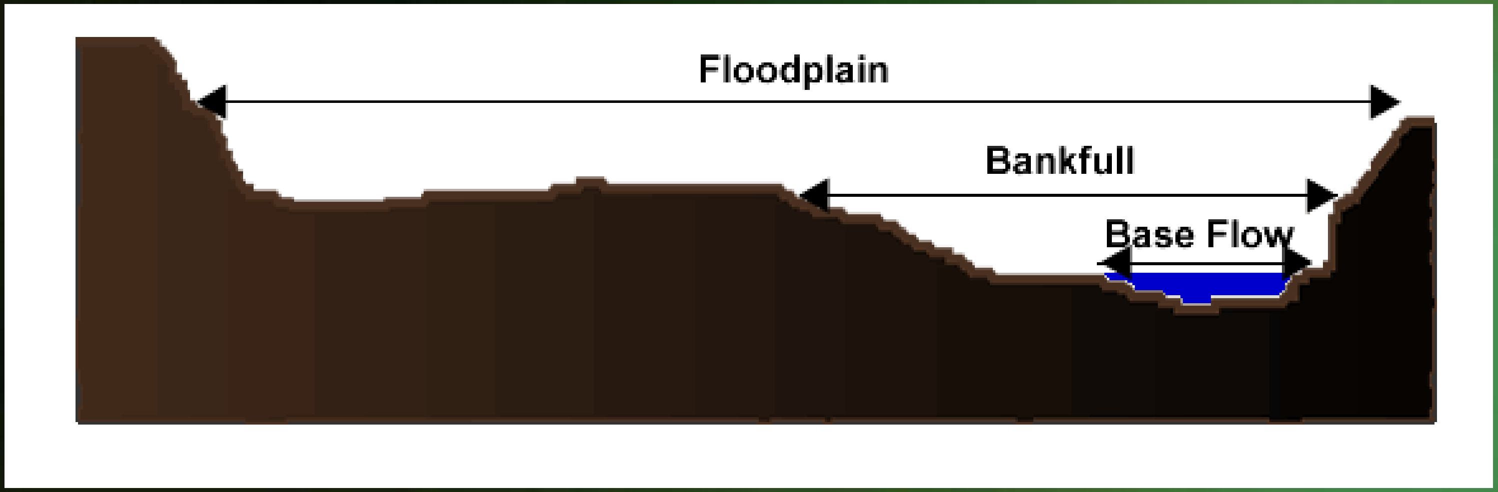
"The concept of channel-forming or dominant discharge is now a cornerstone of river channel restoration design"

(Channel-Forming Discharge Selection in River Restoration Journal of Hydraulic Engineering Volume 133, Issue 7, pp. 831-837 July 2007)

Channel-Forming Flow

- Representative flow that is responsible for shaping the natural channel over time
- 3 methods
  - Bankfull discharge (field morphology)
  - Specified recurrence interval (flow statistics)
  - Effective discharge (mathematical)
- Methods should all agree??

Bankfull Discharge



- The maximum discharge that the channel can convey without overflowing onto the floodplain.
- Represents the breakpoint between the processes of channel formation and floodplain formation.

Specified Recurrence Interval

- Range of 1- to 3-year flood
- 1.5-year flood on average
- This flow occurs 1 to 2 times each year

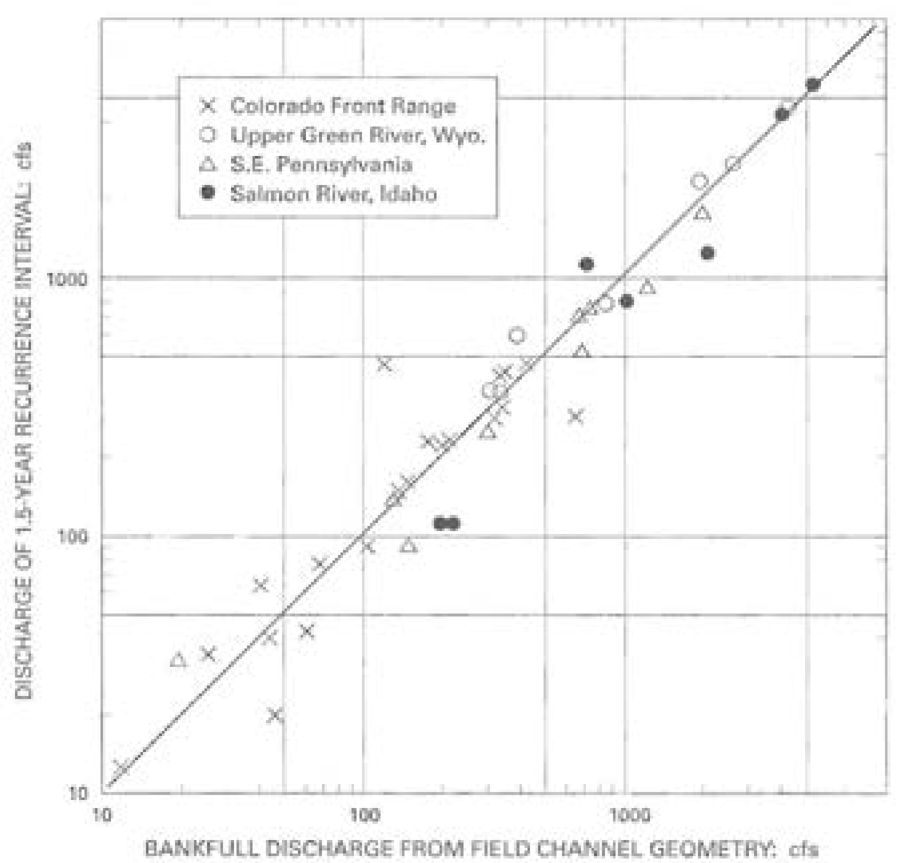
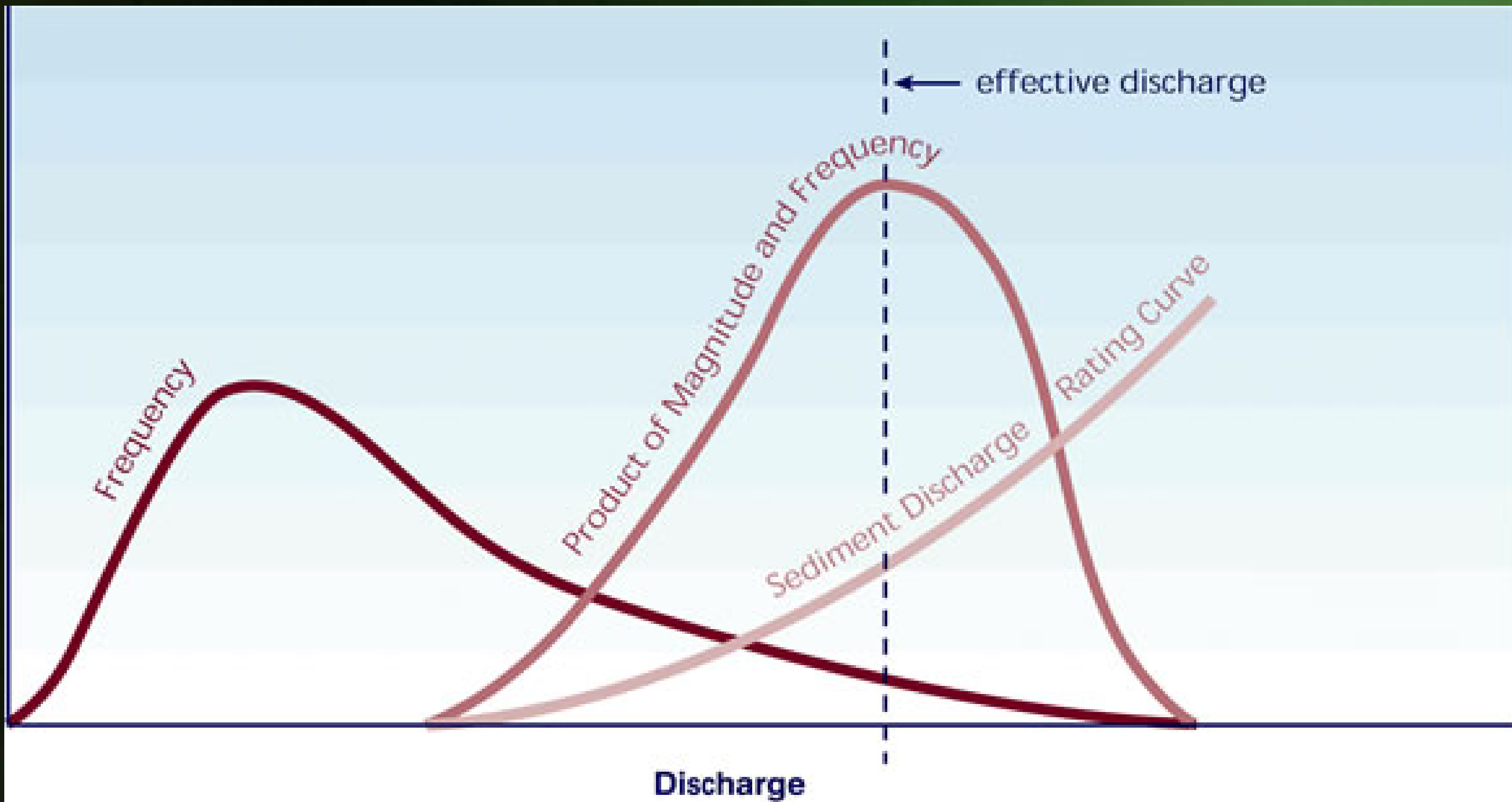


Figure 8.7 Comparison of field-determined bankfull discharge with discharge of 1.5-year recurrence interval for 4 regions in the United States.

Effective Discharge



From Wolman and Miller, 1960.

Fig. 7.5 -- Effective discharge determination from sediment rating and flow duration curves.
In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98.
Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US).

"If you don't know bankfull, you don't know S**T!"

- Dave Rosgen

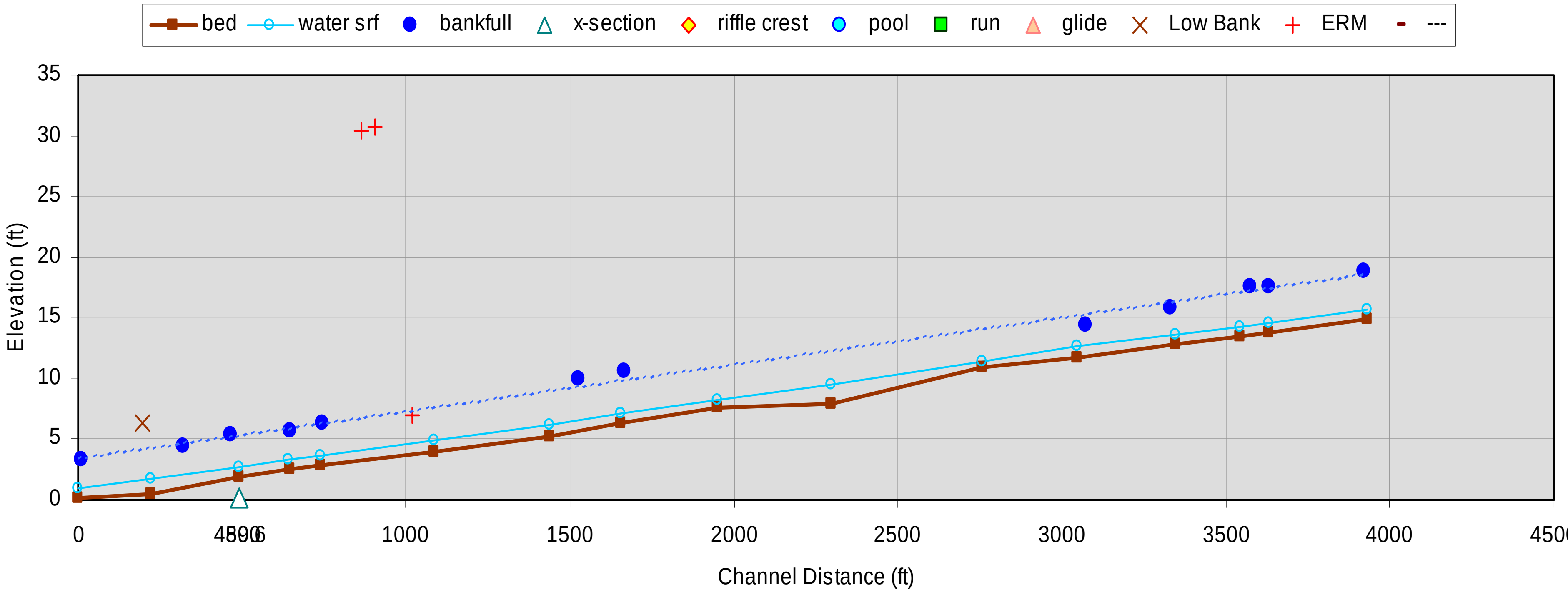
References

Data collection efforts

- Summary of field survey
- Bankfull field indicators
- Other data sources and references

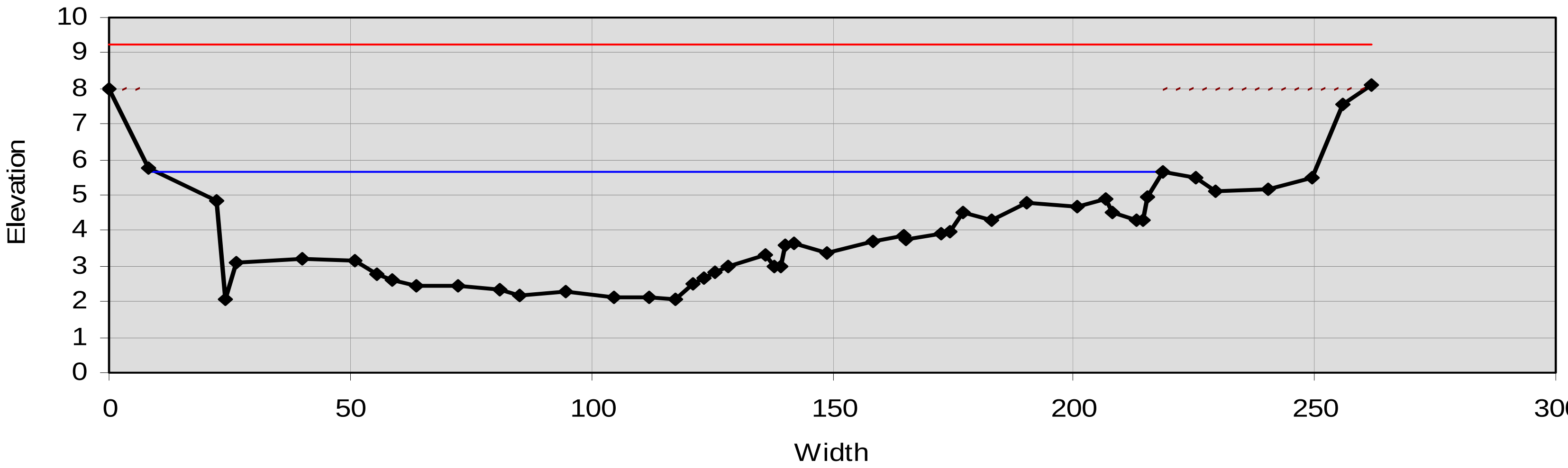
Bankfull Discharge

Fountain Creek @ Fountain



Cross Section 1

4 + 89.6 Fountain Creek @ Fountain, Riffle



Bankfull Dimensions

477.7	x-section area (ft.sq.)
208.9	width (ft)
2.3	mean depth (ft)
3.6	max depth (ft)
211.4	wetted parimeter (ft)
2.3	hyd radi (ft)
91.3	width-depth ratio

Flood Dimensions

---	W flood prone area (ft)
---	entrenchment ratio
5.9	low bank height (ft)
1.6	low bank height ratio

Materials

4.9	D50 Riffle (mm)
18	D84 Riffle (mm)
26	threshold grain size (mm):

Bankfull Flow

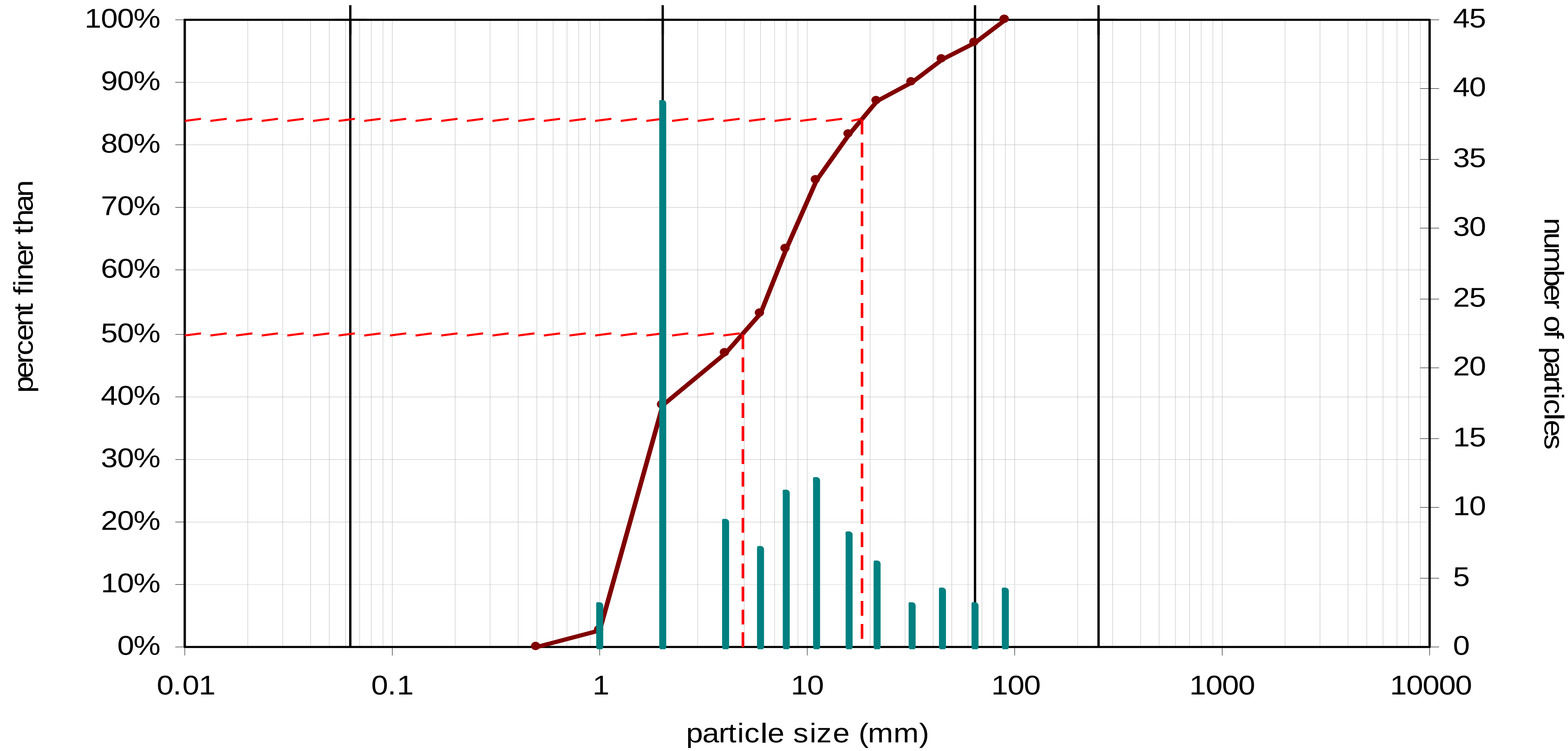
6.5	velocity (ft/s)
3104.9	discharge rate (cfs)
0.76	Froude number

Flow Resistance

0.024	Manning's roughness
0.05	D'Arcy-Weisbach fric.
12.3	resistance factor u/u*
38.7	relative roughness

Forces & Power

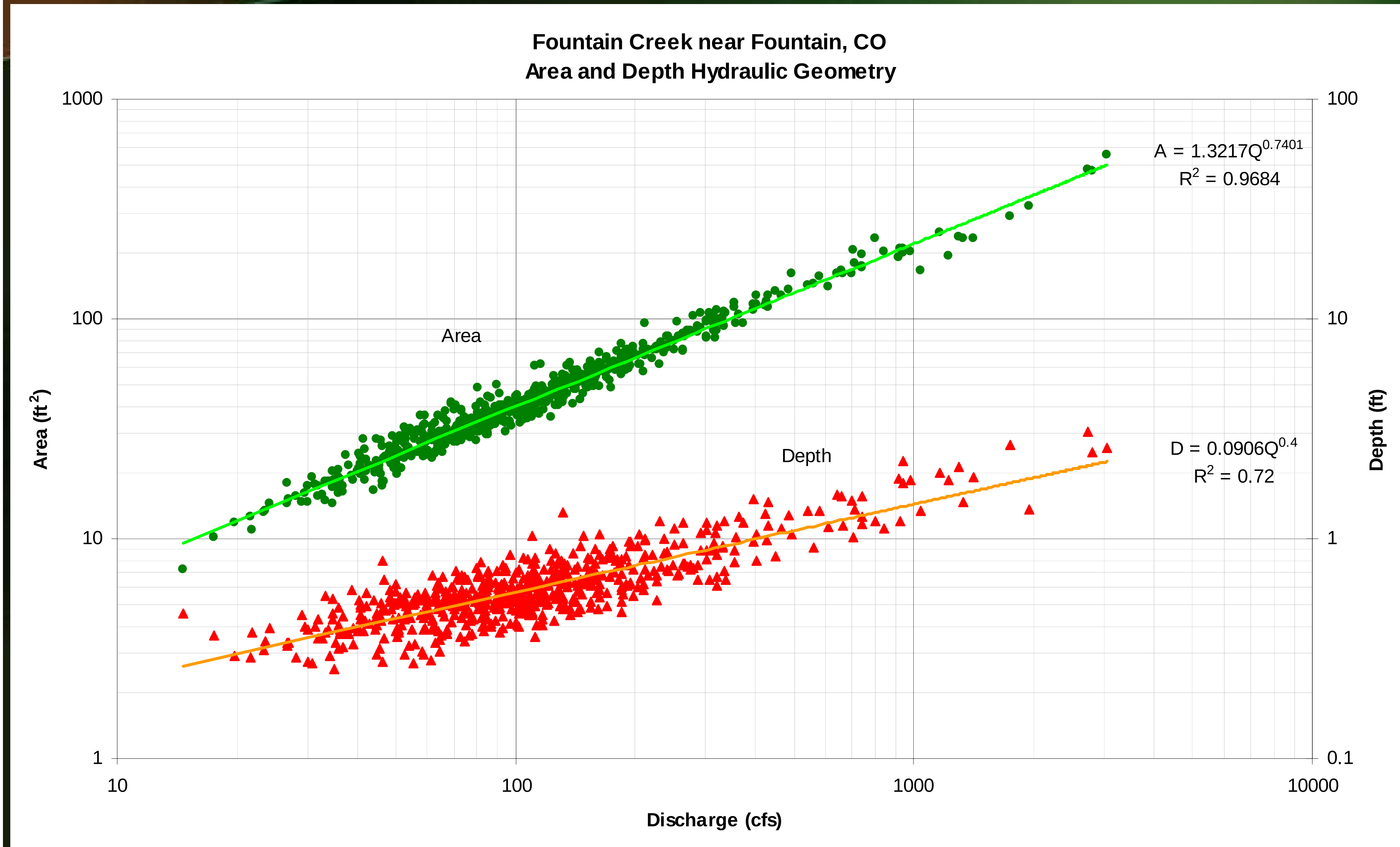
0.37	channel slope (%)
0.52	shear stress (lb/sq.ft.)
0.52	shear velocity (ft/s)
3.4	unit strm power (lb/ft/s)



Size (mm)	
D16	1.3
D35	1.9
D50	4.9
D65	8.4
D84	18

Size Distribution	
mean	4.8
dispersion	3.7
skewness	-0.01

Type	
silt/clay	0%
sand	39%
gravel	58%
cobble	4%
boulder	0%



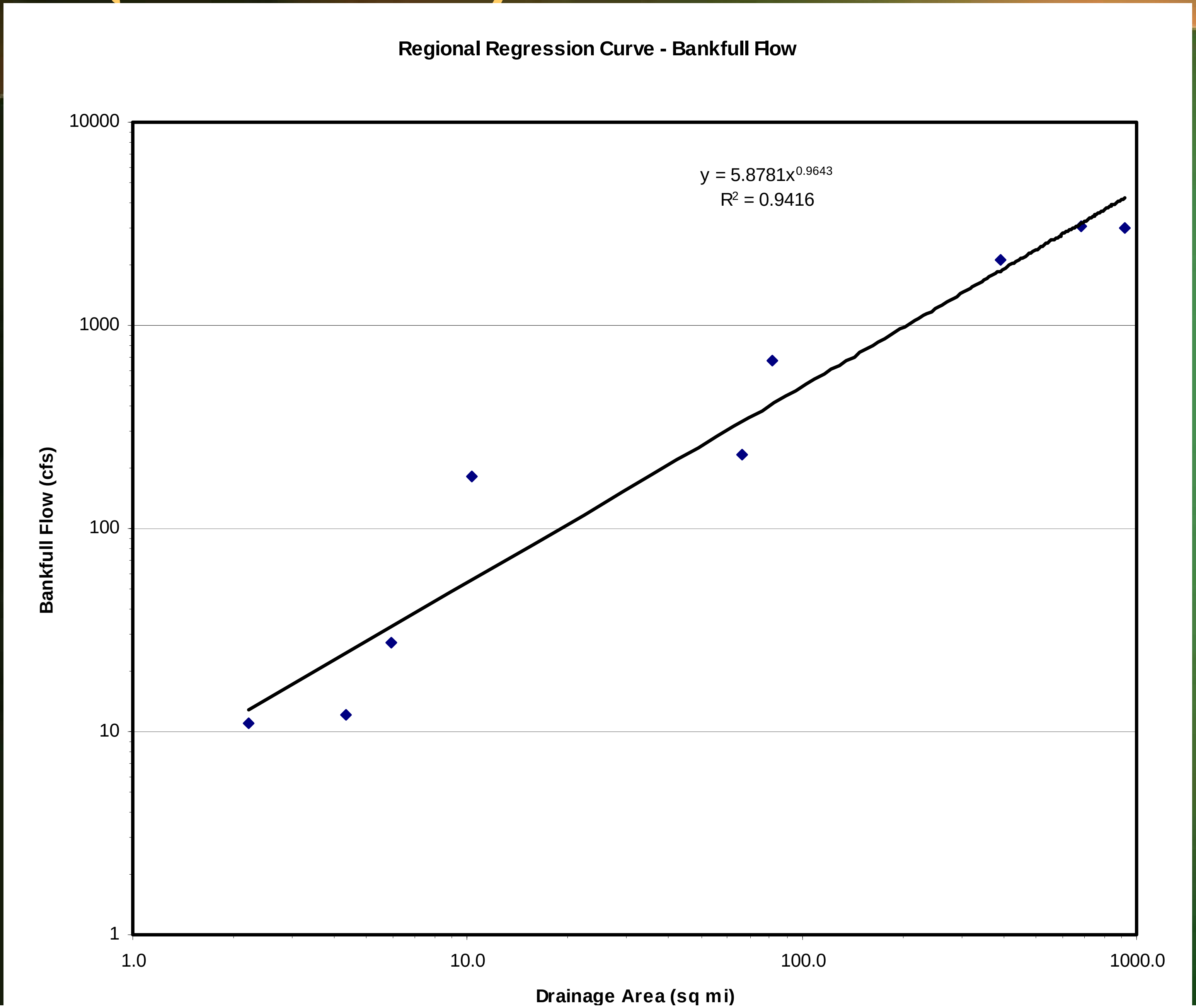
Fountain Creek near Fountain, CO
Area and Depth Hydraulic Geometry
Area
Depth
A = 1.3217Q^0.7401
R^2 = 0.9684
D = 0.0906Q^0.4
R^2 = 0.72
Area (ft^2)
Depth (ft)
Discharge (cfs)
1000
100
10
1
0.1
10000

Gage Station	DA (mi^2)	Q (cfs)	A (ft^2)	W (ft)	D (ft)	W/d Ratio	Rosgen Stream Type	Return Interval
Monument Creek @Northgate	82	73	18	18	1.1	16.6	C4	1.33
Fountain Ck @Colorado Springs	392	2,130	256	61	4.2	14.4	C4	1.25
Fountain Ck @Fountain	681	3,100	478	209	2.3	91	C4	1.25
Fountain Creek @Pueblo	926	2,990	309	159	1.9	81.5	C4	1.43
Jimmy Camp Creek at Fountain	66	229	45	29	1.5	18.8	C4	1.42
Cottonwood Creek @Woodmen	10	180	28	27	1.0	25.2	F4	1.19

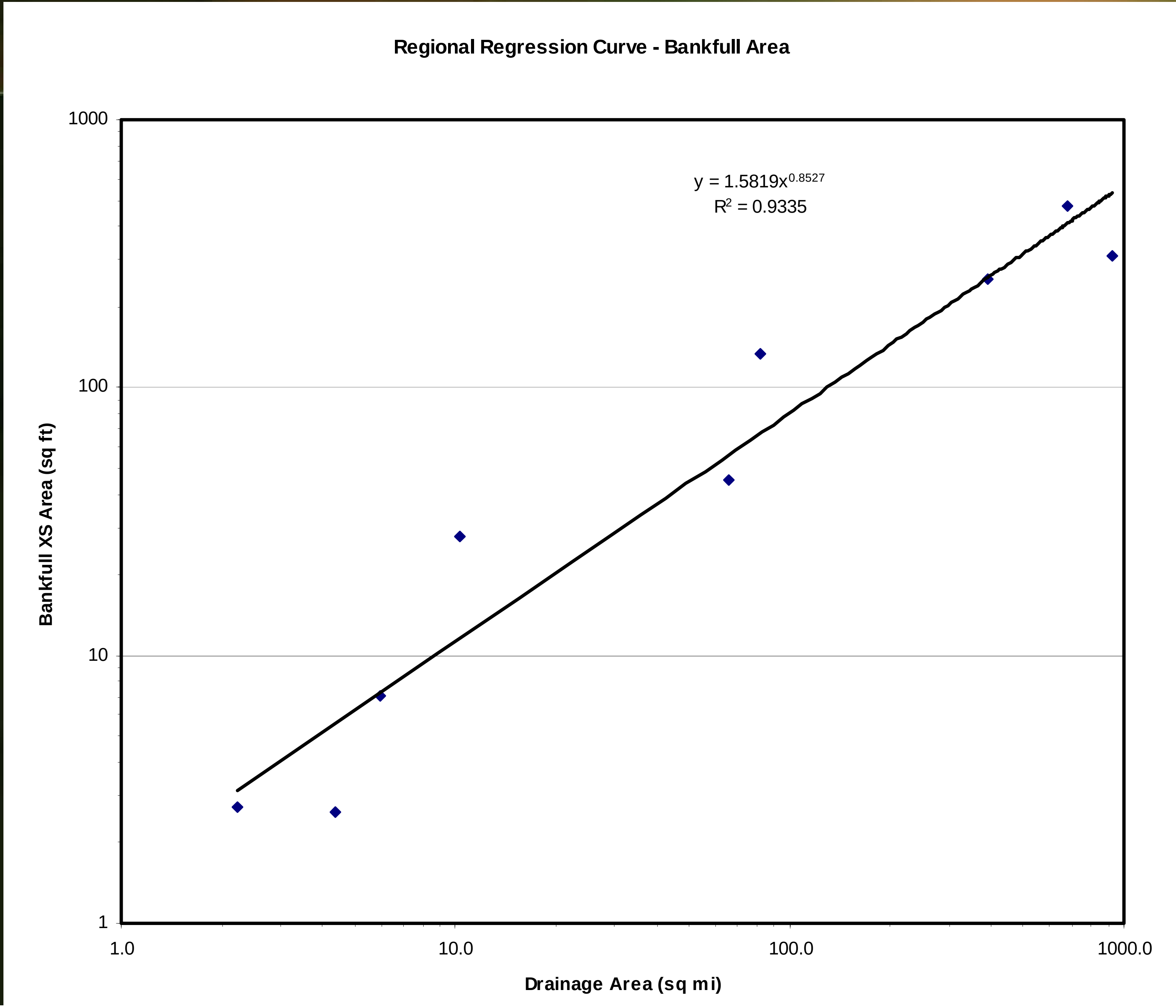
Regression Results

- Function of drainage area
- Log-log plots
- Power function
- Data correlation

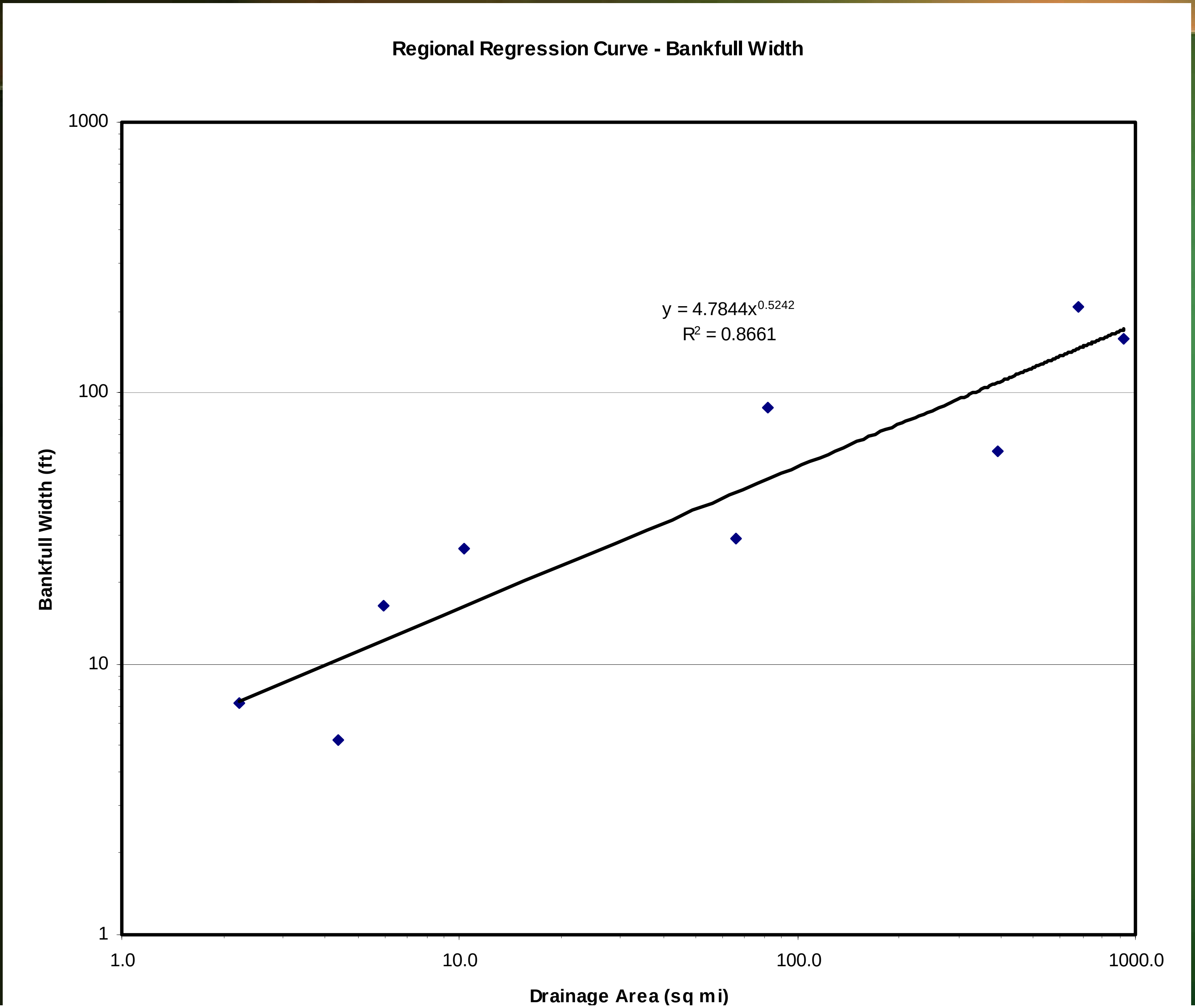
Bankfull Discharge



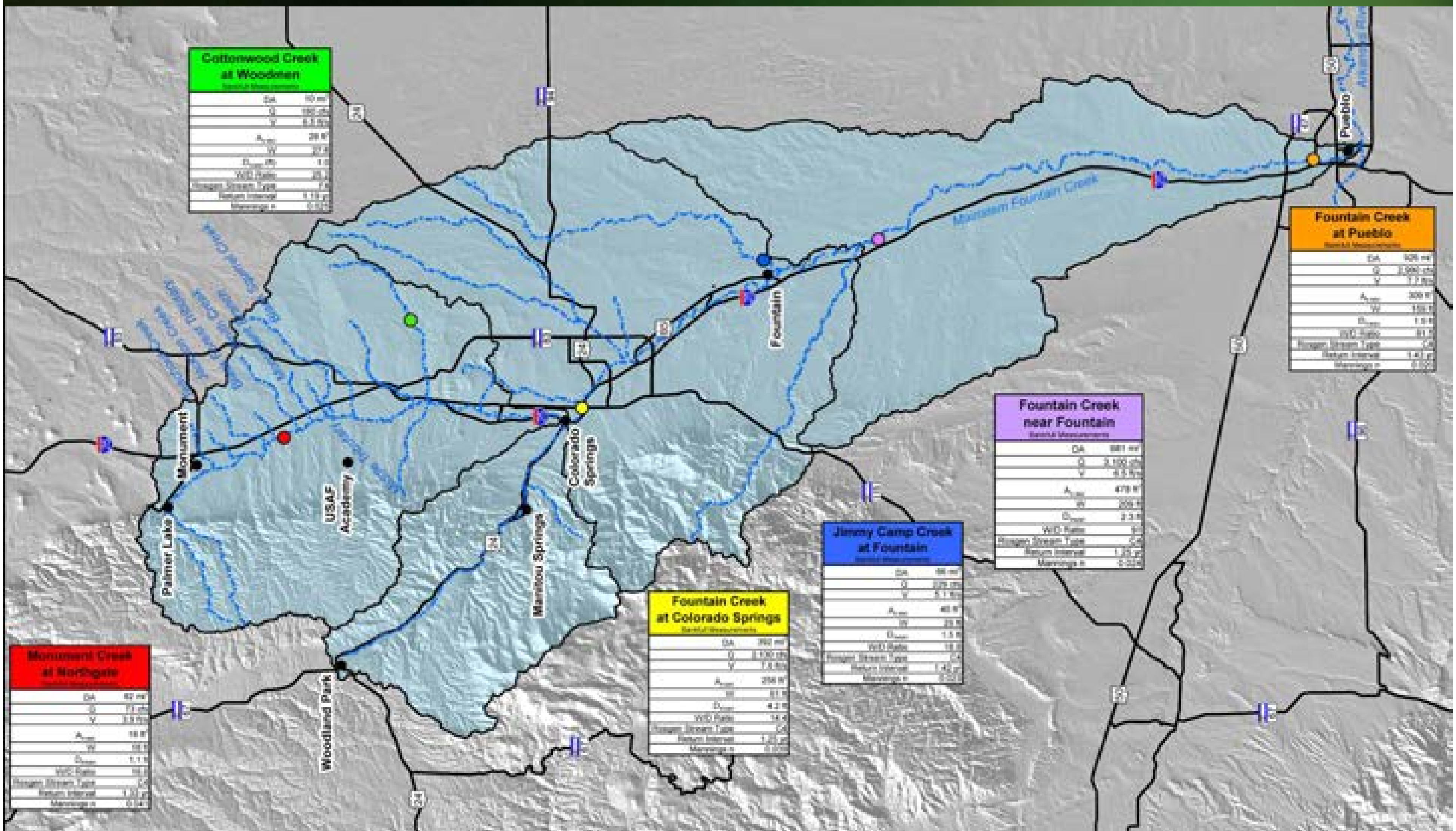
Channel Cross-sectional Area



Channel Width



Fountain Creek Bankfull Flows



By the numbers…

- 1999 flood flow was approx. 20,000 cfs
- Bankfull discharge is approx. 2,000 cfs
- Bankfull agrees with recurrence interval
  - 1.25 years
- Effective discharge is approx. 200 cfs
- Baseflow?

Applications

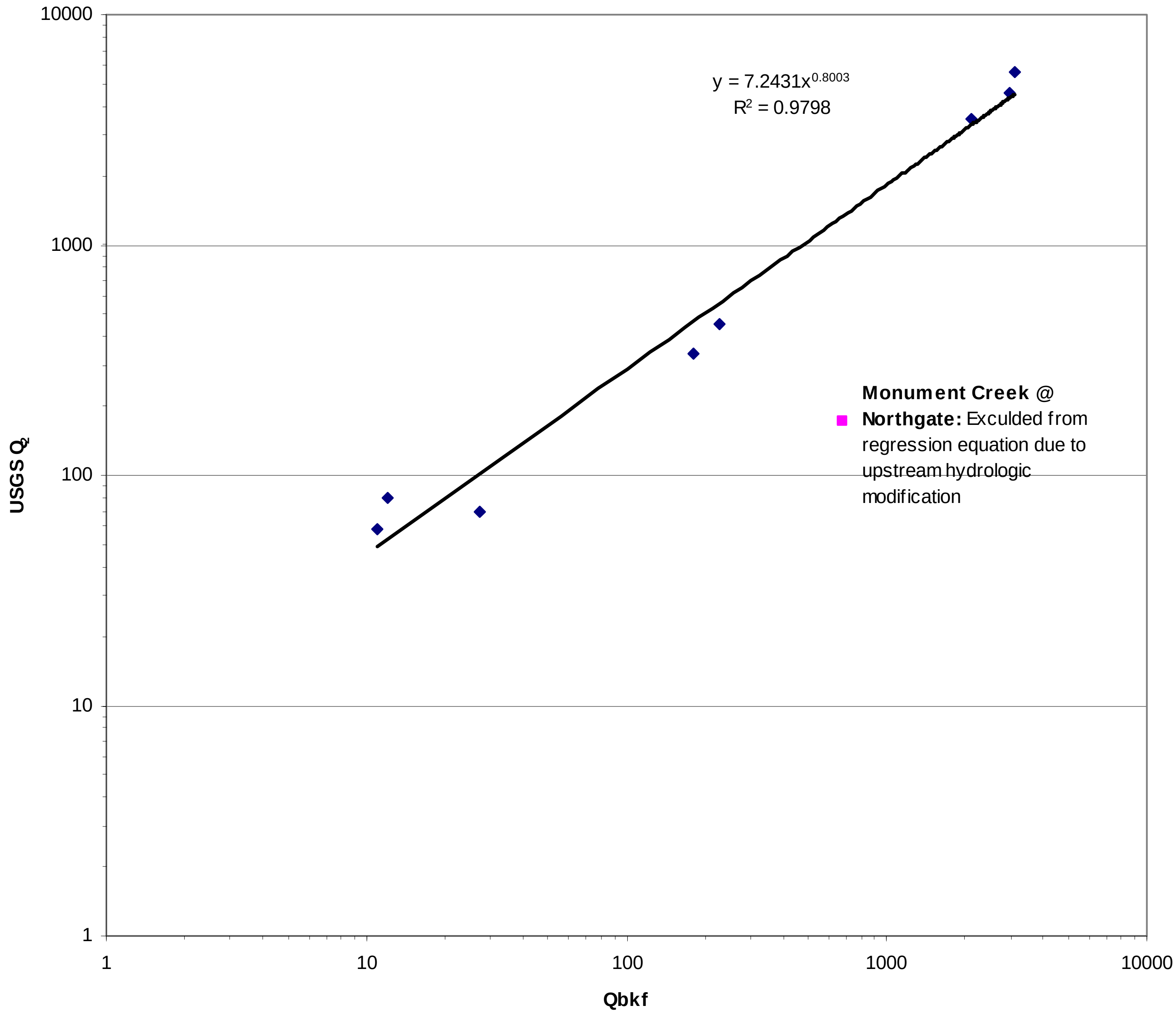
"The concept of channel-forming or dominant discharge is now a cornerstone of river channel restoration design"

(Channel-Forming Discharge Selection in River Restoration Journal of Hydraulic Engineering Volume 133, Issue 7, pp. 831-837 July 2007)

Applications

- design and planning tool for stream restoration
- stability assessment
- road crossings
- hydrology model calibration

Bankfull Flow vs. 2-year Flood



Limitations

- Short comings
- Future data needs

THANK YOU!

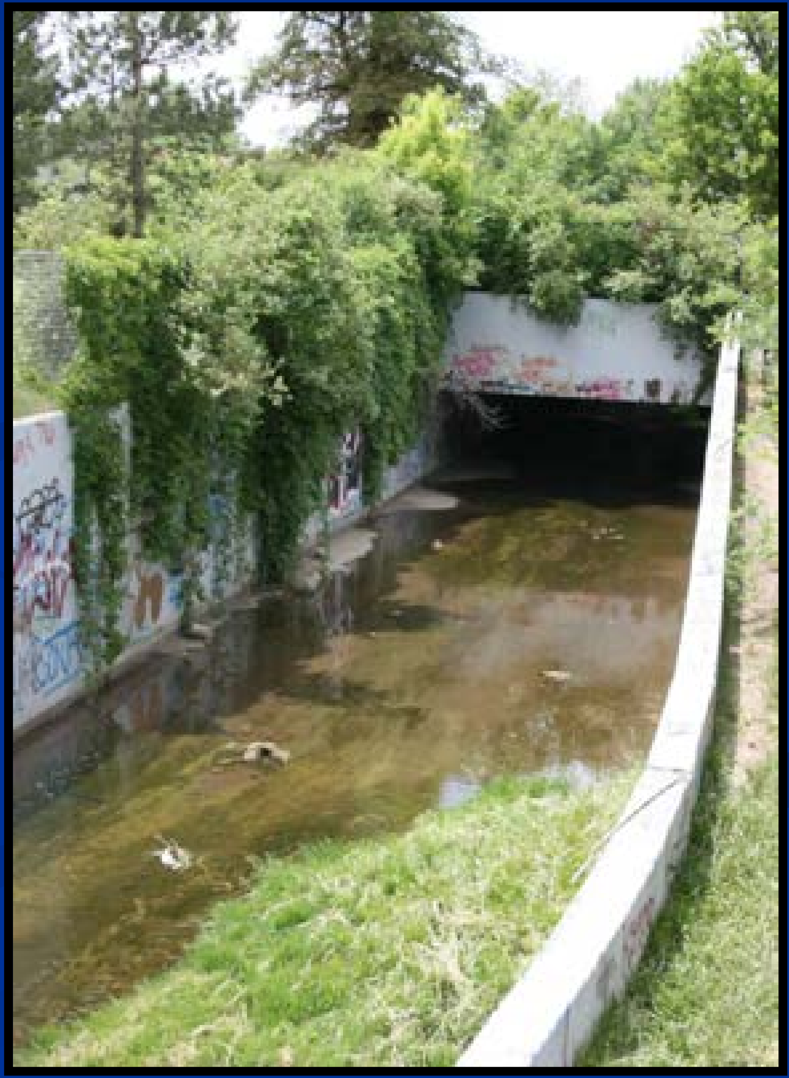
Contact Information

- Graham Thompson
  - 719.575.0100
  - graham_thompson @matrixdesigngroup.com

FLOODPLAIN ENCROACHMENT

THIS IS WHY WE HAVE A JOB!

- What did Denver look like prior to development?
- Should there be criteria for 100-year capacity for all drainageways?
- How does floodplain management factor into land use decisions?
- What about safety and flood hazard reduction?



FLOODPLAIN ENCROACHMENT

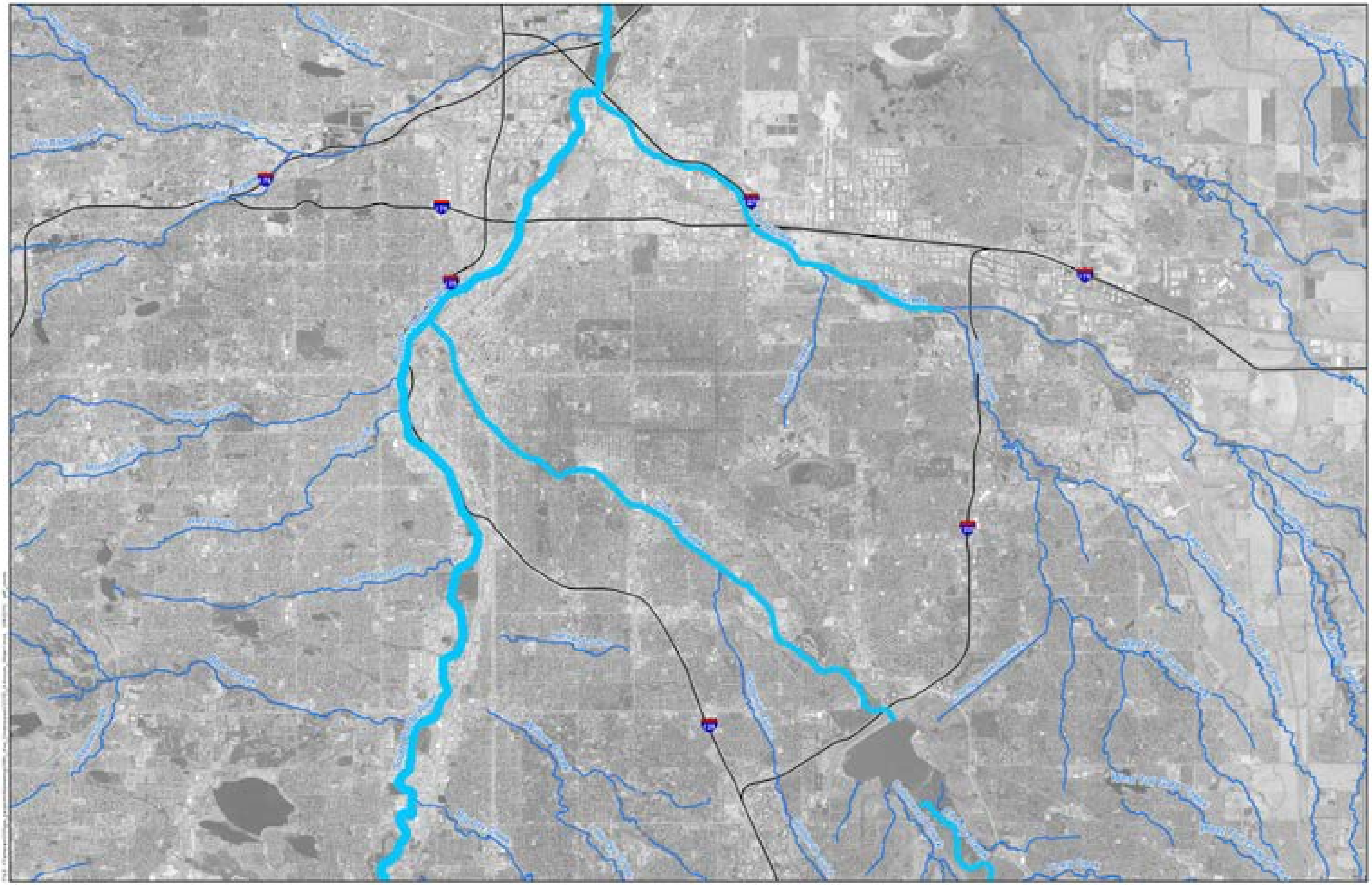
THIS IS WHY WE HAVE A JOB!

- Where can we put drainageways underground?
- Which pipes need 100-year capacity?
- It is cost effective to pipe the 100-year event?

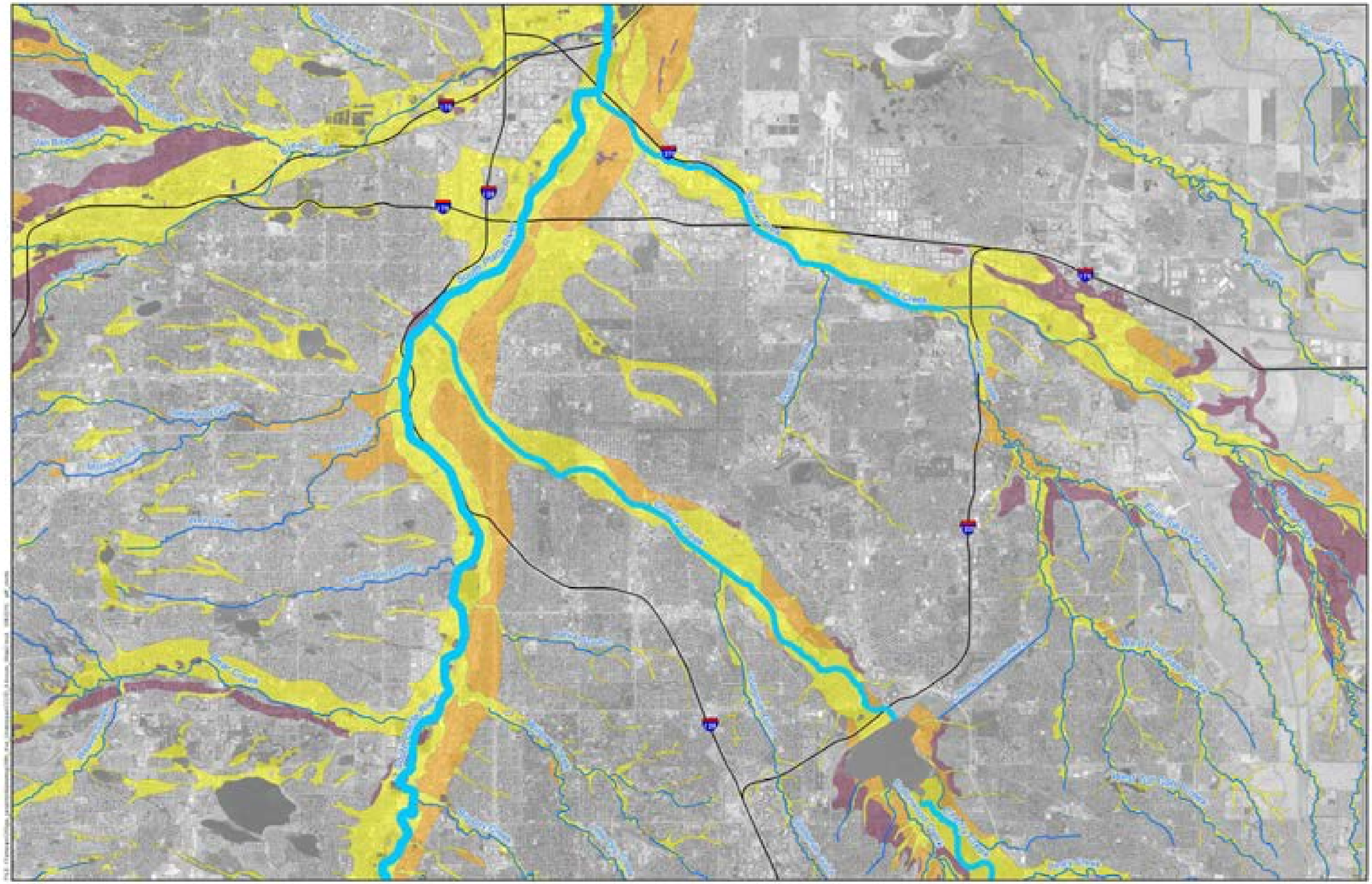
Case Studies

- Montclair outfall
- Park Hill outfall
- West Speer outfall (Tucker Creek)
- Westerly Creek
- Harvard Gulch

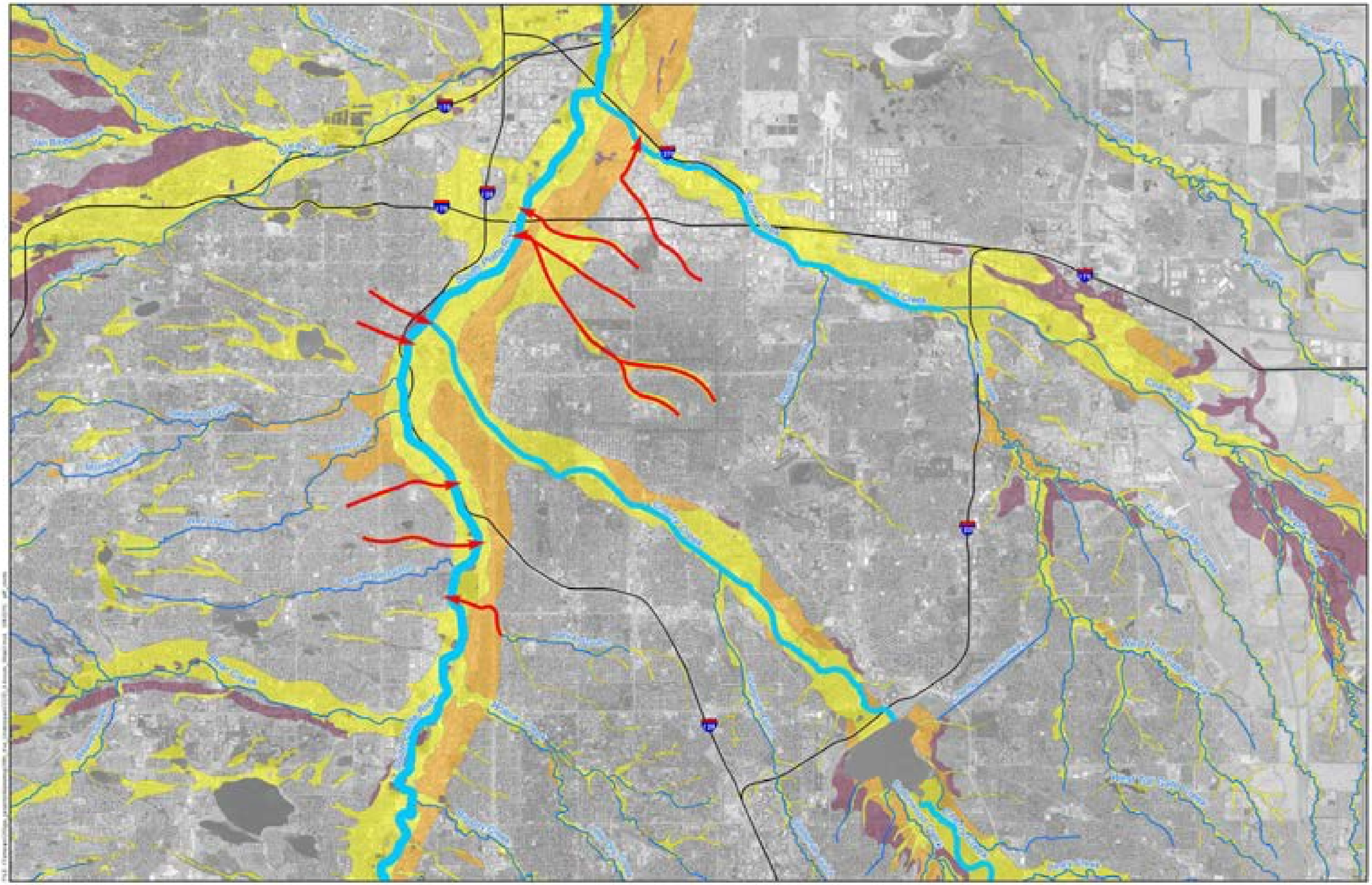
Denver Today



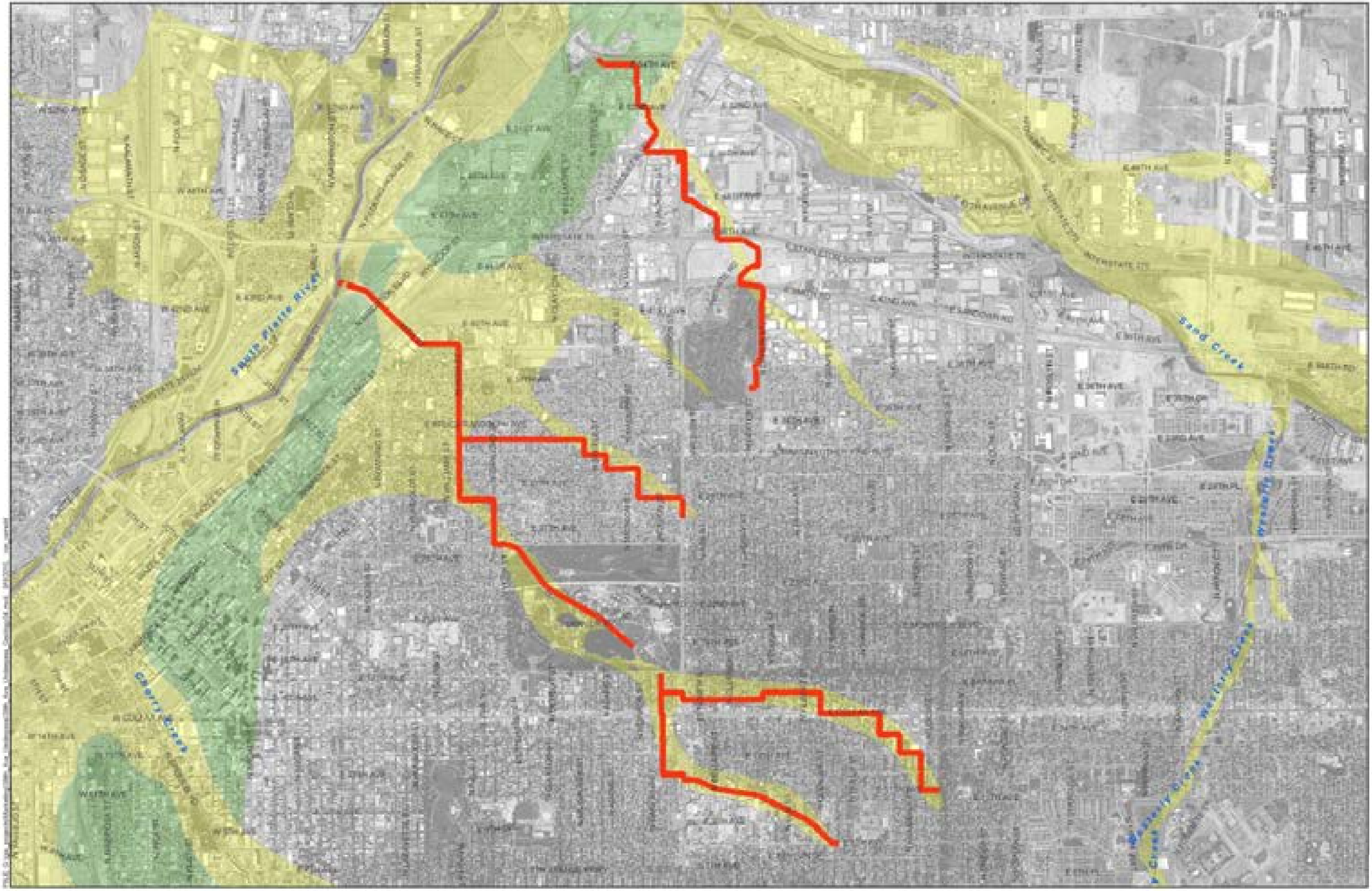
Geologic Overlay



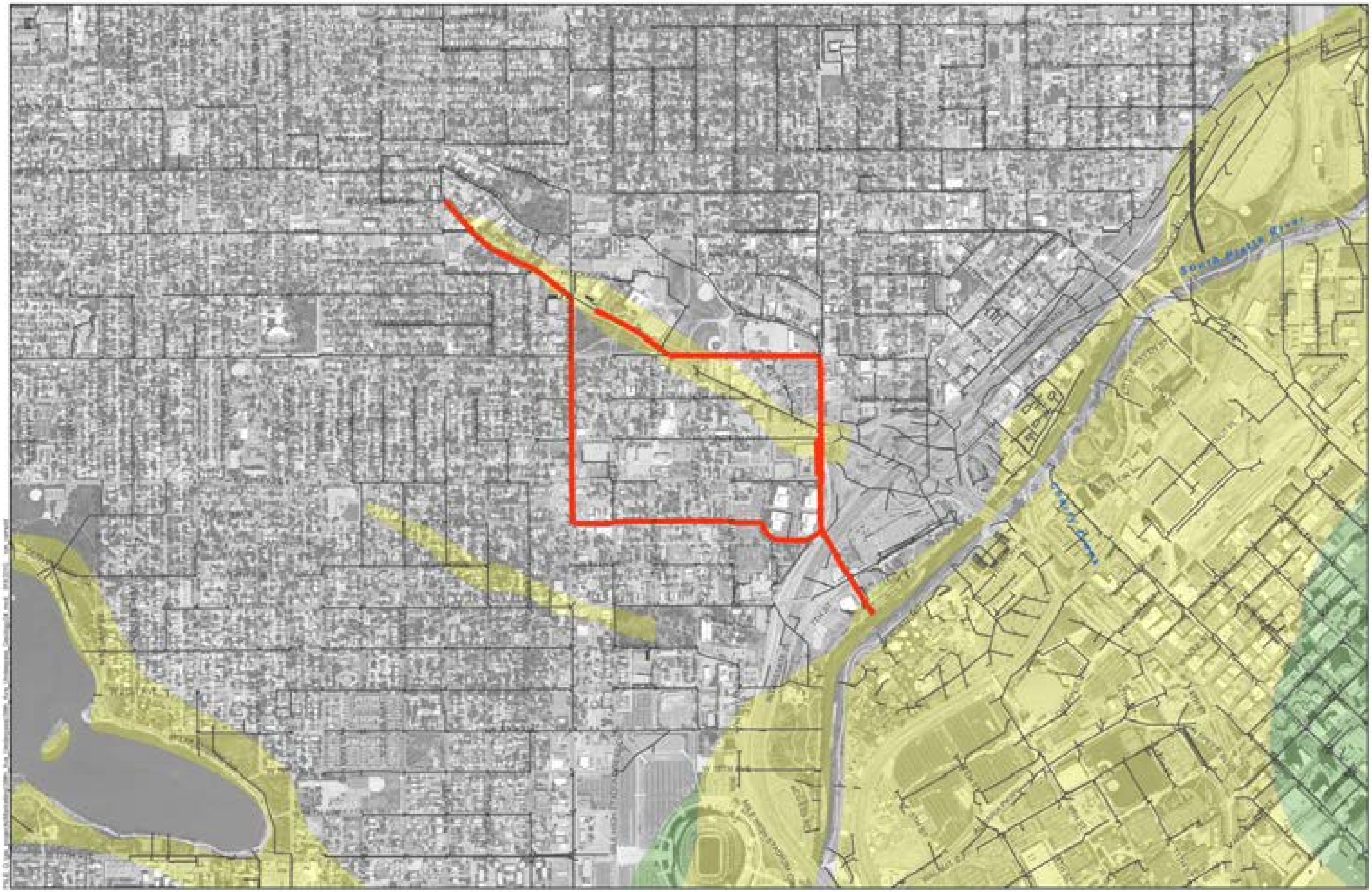
New Streams



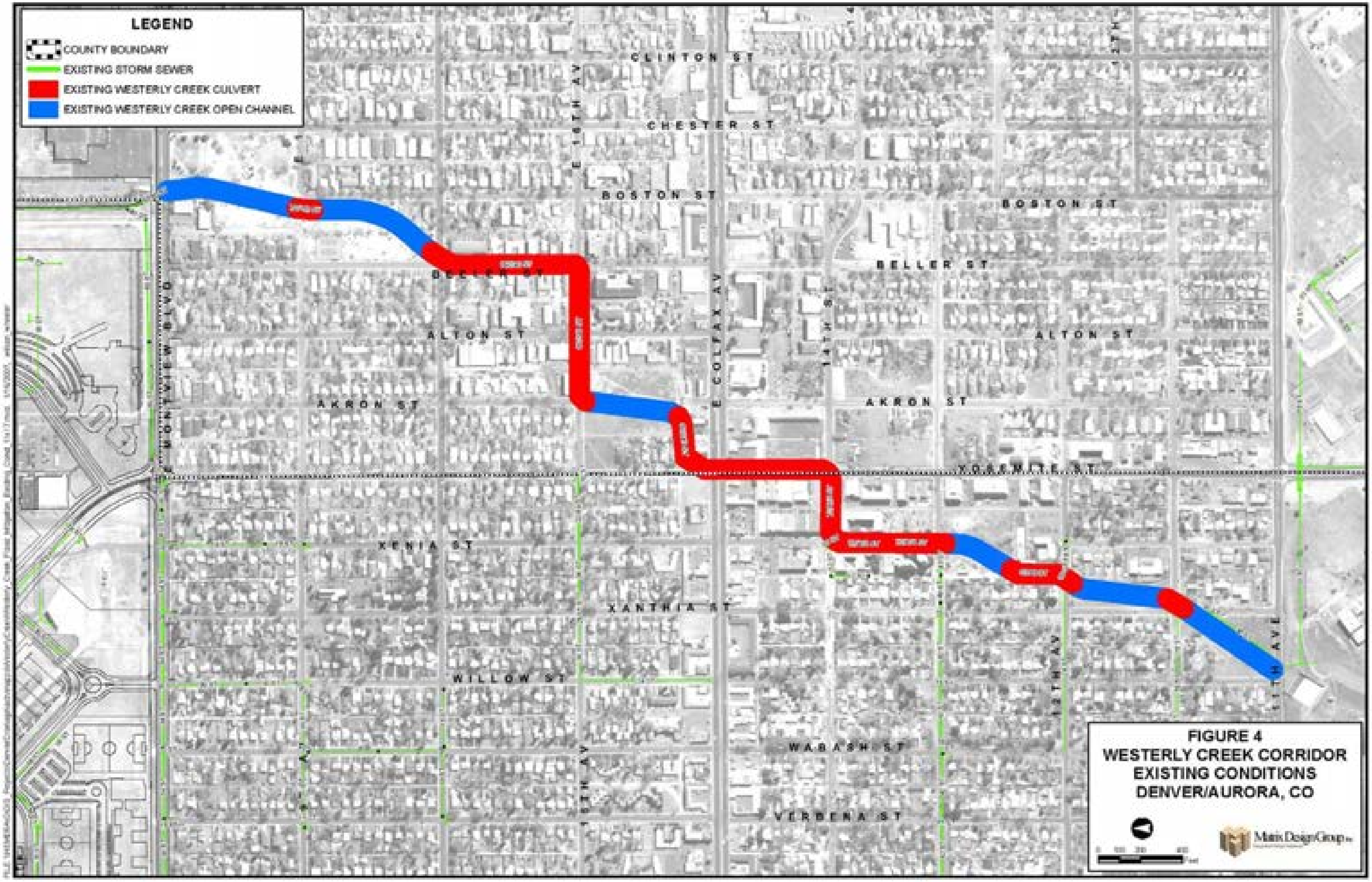
Montclair and Park Hill Outfalls



West Speer Outfall



Westerly Creek

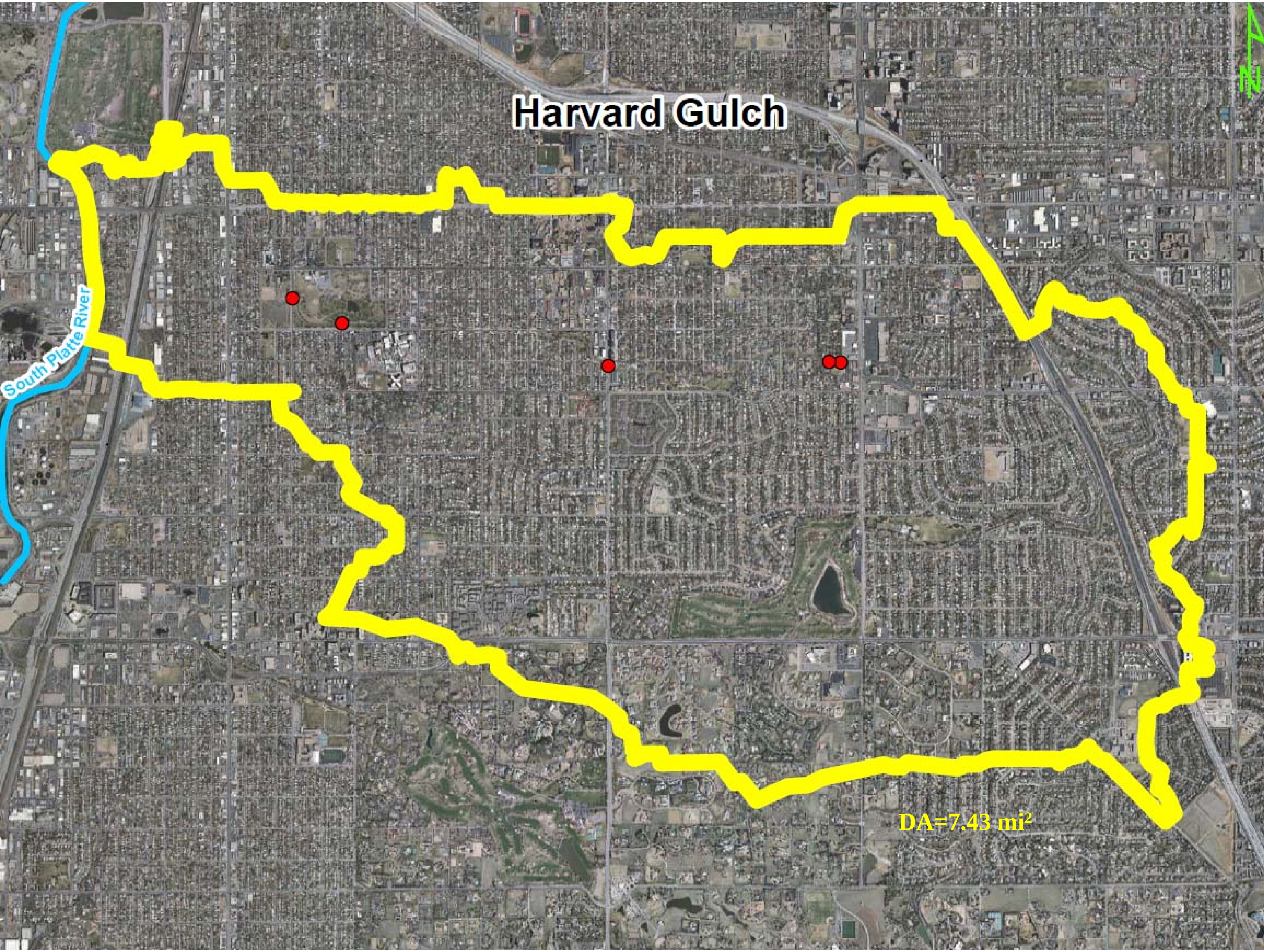


Westerly Creek

Westerly Creek

- In 1980, a 10-year pipe was constructed to reduce frequent flooding
- In 1991, Westerly Creek Dam was constructed
- What is the incentive to reduce the floodplain?
- Should the 10-year system be replaced with an open channel?
- Are there other benefits to an open channel, and are these considered in a Benefit/Cost analysis?

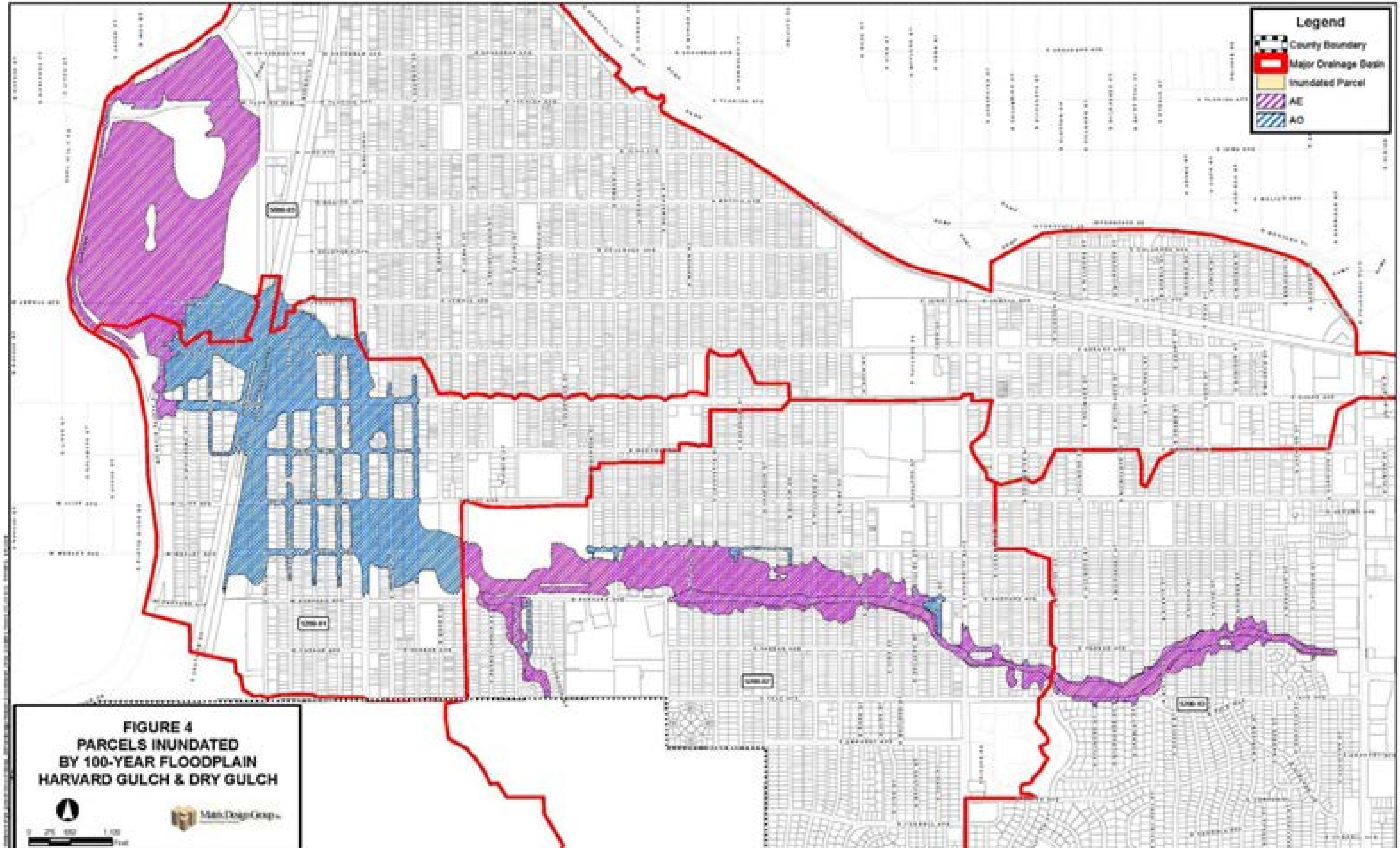
Harvard Gulch at Logan Street

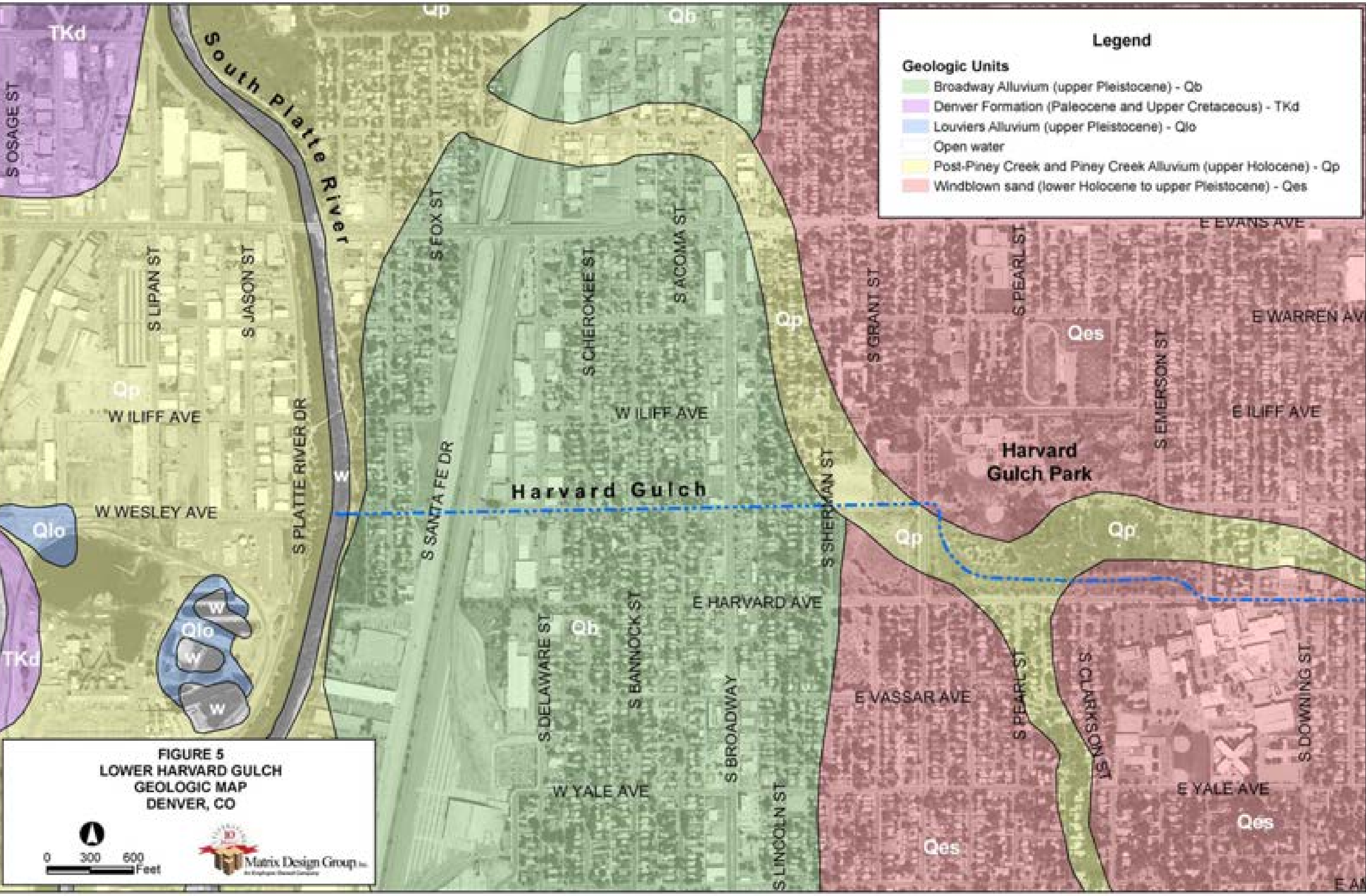


Harvard Gulch
South Platte River
DA=7.43 mi²
N

Harvard Gulch

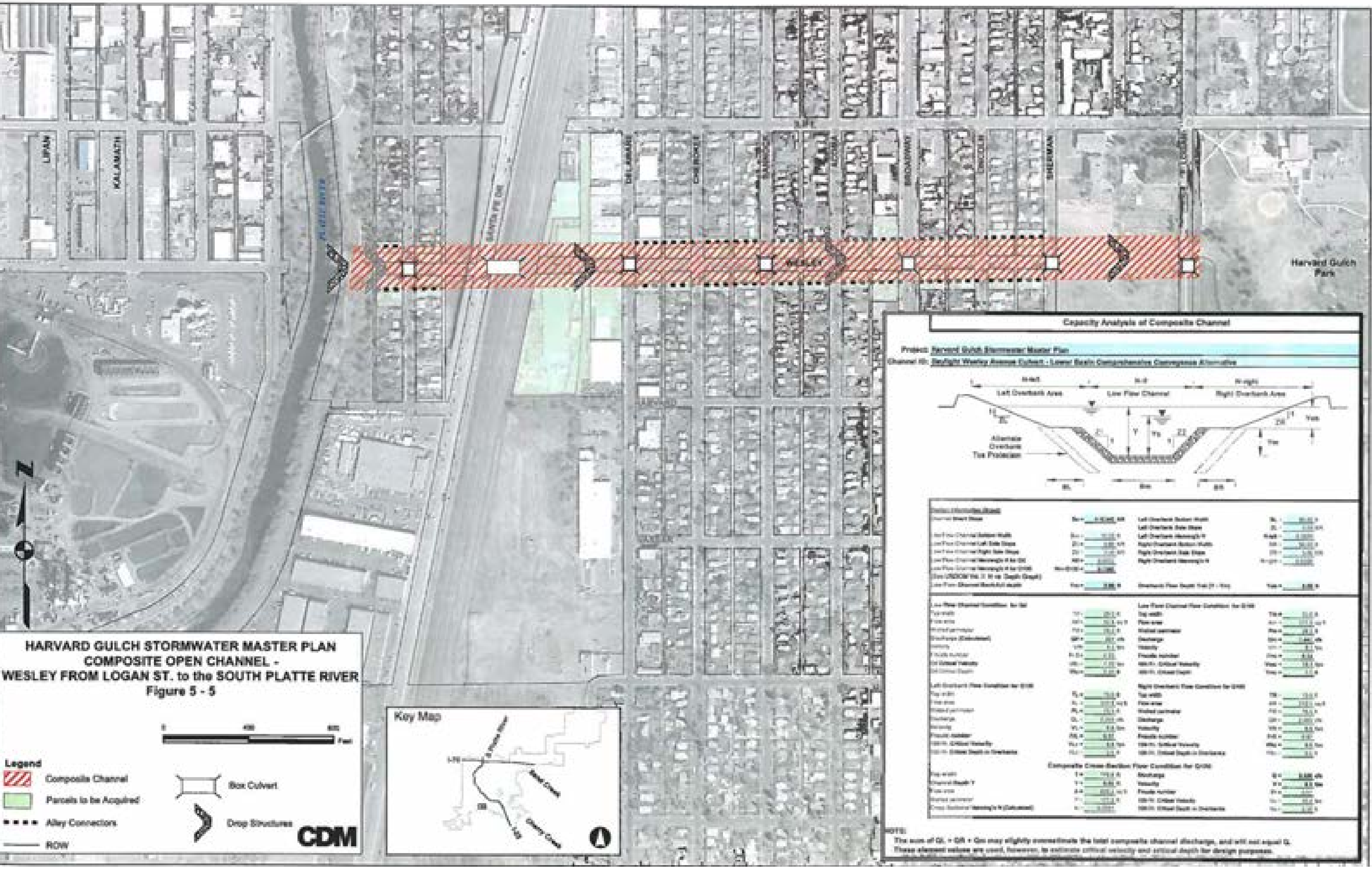
Harvard Gulch Floodplain





Legend
Geologic Units
Broadway Alluvium (upper Pleistocene) - Qb
Denver Formation (Paleocene and Upper Cretaceous) - TKd
Louviers Alluvium (upper Pleistocene) - Qlo
Open water
Post-Piney Creek and Piney Creek Alluvium (upper Holocene) - Qp
Windblown sand (lower Holocene to upper Pleistocene) - Qes
FIGURE 5
LOWER HARVARD GULCH
GEOLOGIC MAP
DENVER, CO
0 300 600
Feet
Matrix Design Group
South Platte River
Harvard Gulch
Harvard Gulch Park
TKd
Qp
Qb
Qes
Qlo
w
S OSAGE ST
S LIPAN ST
S JASON ST
S FOX ST
S CHEROKEE ST
S ACOMA ST
S GRANT ST
S PEARL ST
S EMERSON ST
E EVANS AVE
E WARREN AVE
W ILIFF AVE
E ILIFF AVE
S PLATTE RIVER DR
S SANTA FE DR
S SHERMAN ST
W WESLEY AVE
E HARVARD AVE
S DELAWARE ST
S BANNOCK ST
S BROADWAY
S LINCOLN ST
S CLARKSON ST
S DOWNING ST
E VASSAR AVE
W YALE AVE
E YALE AVE

Harvard Gulch – Open Channel



science for a changing world

Water-Data Report 2008

06711575 HARVARD GULCH AT HARVARD PARK AT DENVER, CO

South Platte Basin
Upper South Platte Subbasin

LOCATION (REVISED).--Lat 39°40'18.20", long 104°58'37.30" referenced to North American Datum of 1983, in NW ¼ SW ¼ sec 26, T.4 S., R.68 W., D County, CO, Hydrologic Unit 10190002, on right bank 125 ft north of East Harvard Avenue, 300 ft west of South Ogden Street, and directly north c Porter Memorial Hospital, in Denver.

DRAINAGE AREA.--Not determined.

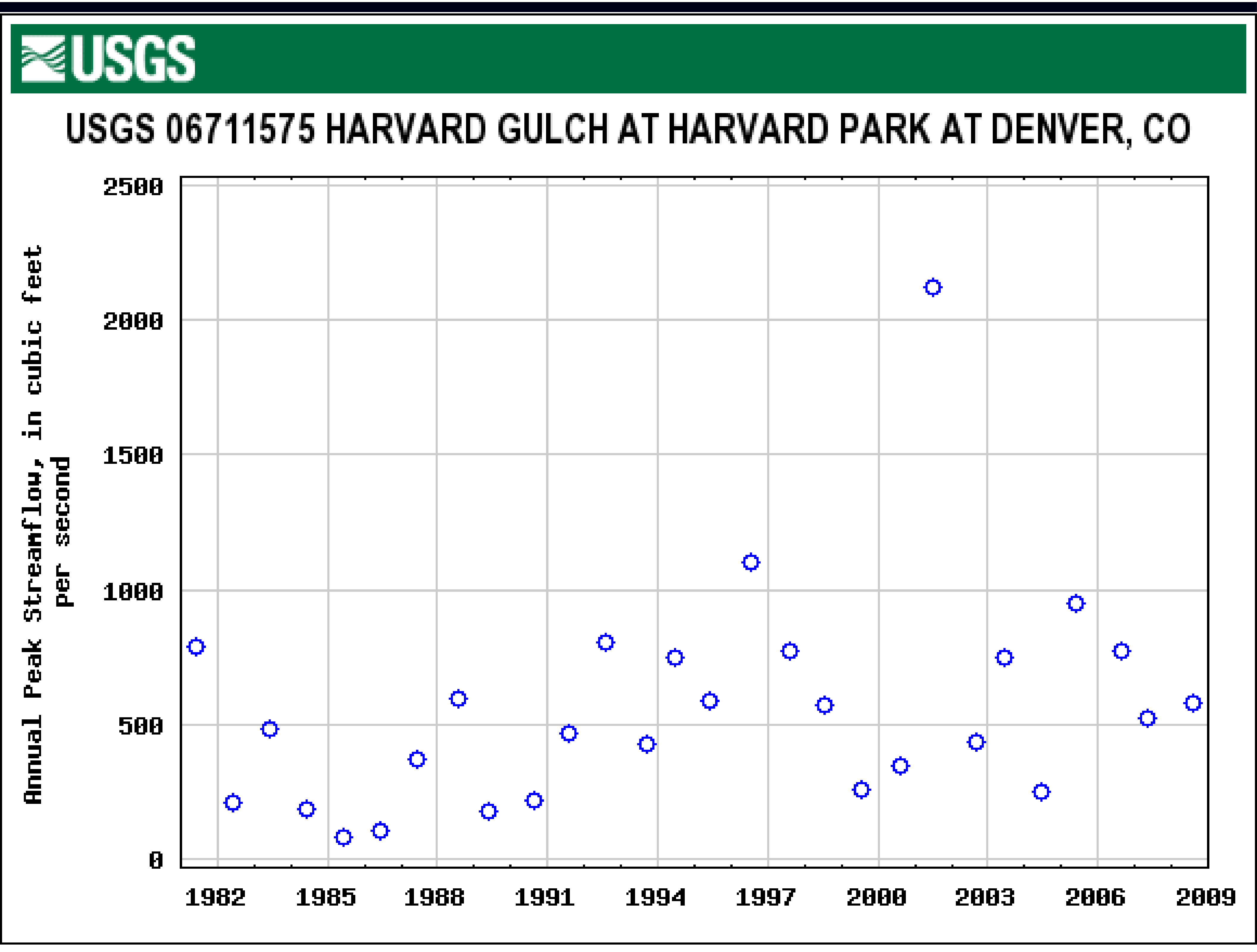
SURFACE-WATER RECORDS

PERIOD OF RECORD.--August 1979 to current year (annual seasonal-maximum only).

GAGE.--Nonrecording gage and crest-stage gage. Elevation of gage is 5,320 ft above NGVD of 1929, from topographic map. Supplementary water-sta recorder used for storm events.

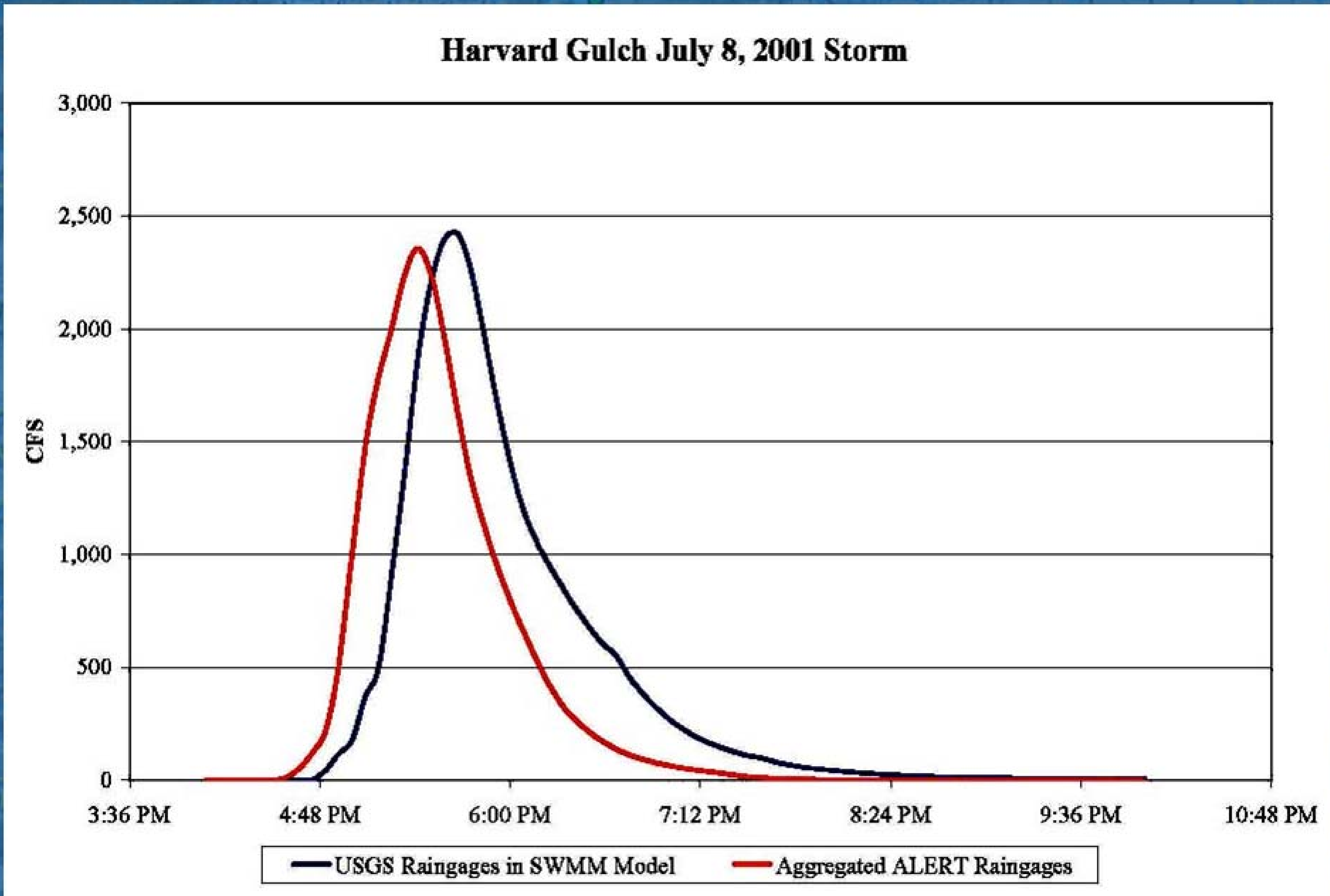
REMARKS.--Gage operated seasonally, April through September.

EXTREMES FOR PERIOD OF RECORD (REVISED).--(seasonal only) Maximum discharge, 2,120 ft^3/s, July 8, 2001, gage height, 17.44 ft, from rating curv extended above 95 ft^3/s on basis of slope-area measurements at gage heights 14.88 ft and 15.62 ft, and flow-over-weir measurement of right ov bank flow at the peak. The water year 2001 maximum discharge was previously published as "not determined".

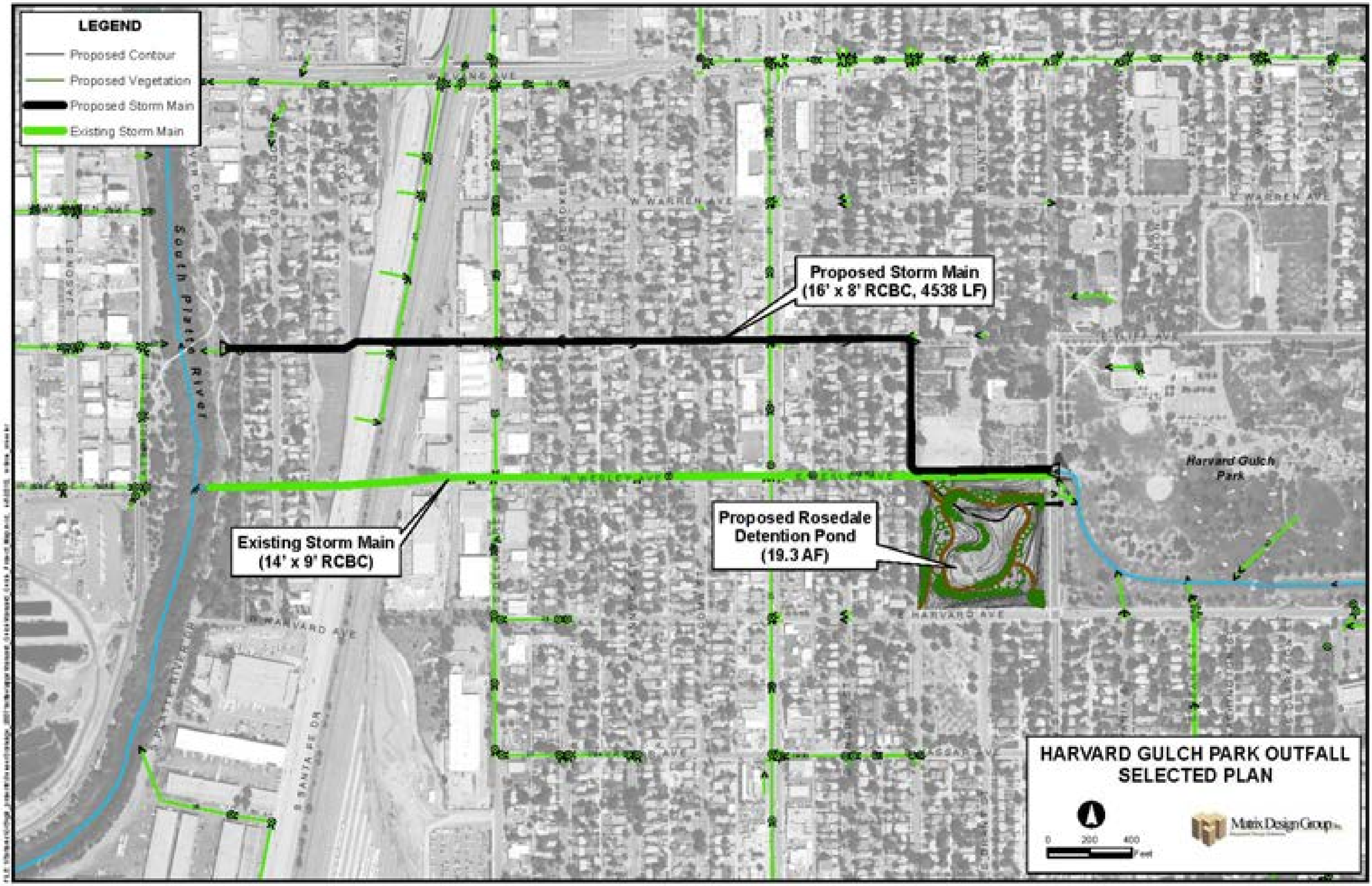

USGS
USGS 06711575 HARVARD GULCH AT HARVARD PARK AT DENVER, CO
Annual Peak Streamflow, in cubic feet per second
0
500
1000
1500
2000
2500
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009

Harvard Gulch…July 8, 2001

Harvard Gulch…July 8, 2001



Harvard Gulch Outfall



Harvard Gulch Outfall

- Should Denver spend $20 million to increase the capacity of the existing outfall that has not failed?
- What incentive is there to provide flood control?
- How is such a project justified?
- How much confidence do we have in the hydrology from 1965?
- Do we have an obligation to reduce flood hazards?

Recommendations

- Criteria should require 100-year capacity for "major drainageways"
- Benefit/cost analyses will usually not support 100-year design projects
- Flood hazard reduction, community redevelopment, open space corridors, trails and wildlife habitat benefit from 100-year outfalls
- If major outfalls had 100-year capacity, would we be out of a job?

CERTIFICATION OF THE TEMPLETON GAP LEVEE IN COLORADO SPRINGS, CO

Mark K. Kempton, P.E., C.F.M.

Anderson Consulting Engineers, Inc.

Fort Collins, CO

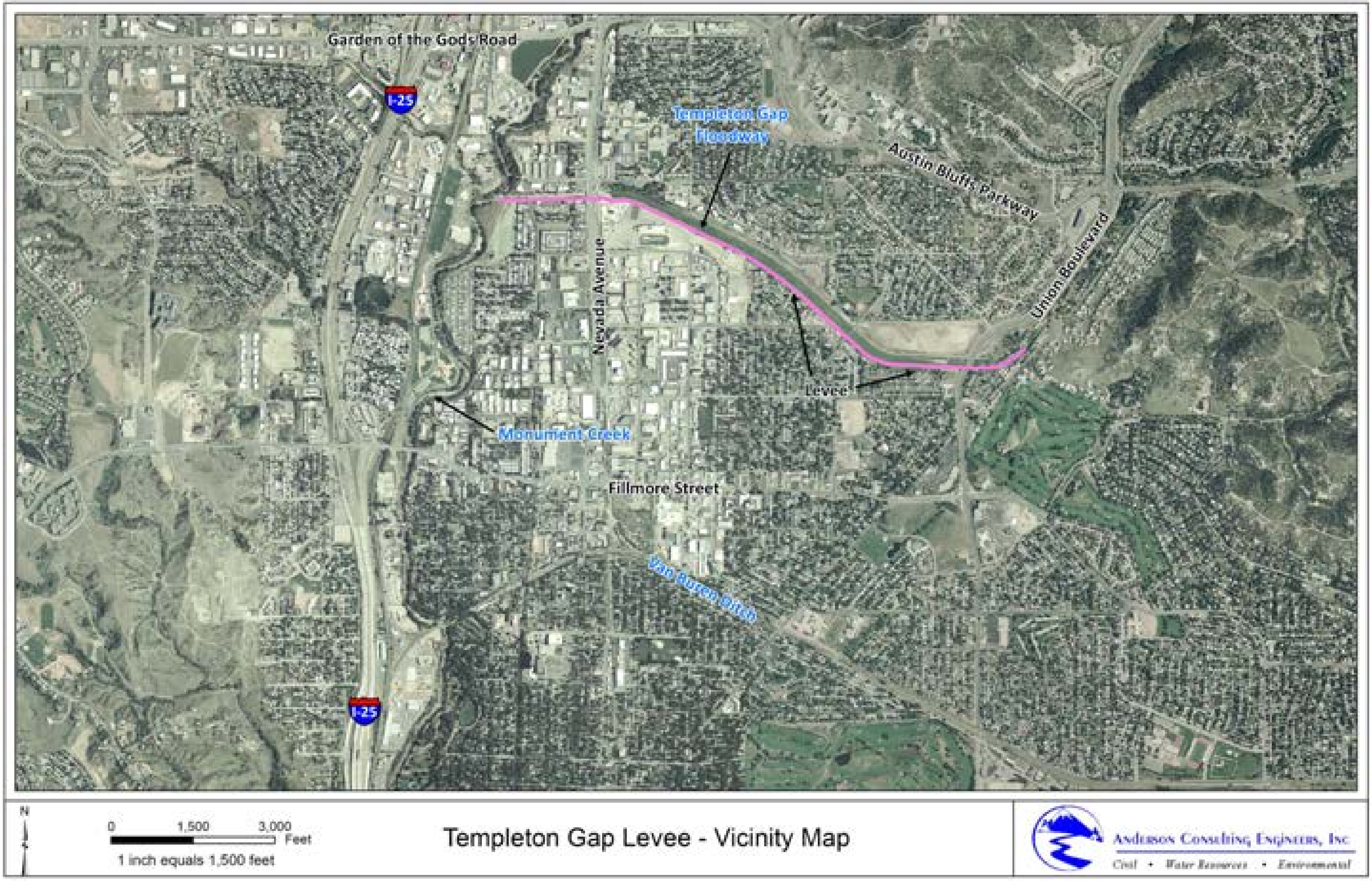
Anderson Consulting Engineers, Inc.

Civil • Water Resources • Environmental

Acknowledgements

- Dan Bare, City of Colorado Springs, City Engineering/Stormwater Division
- Thuy Patton, Colorado Water Conservation Board
- Dawn Gladwell, FEMA Region VIII
- Chris Pauley, Anderson Consulting Engineers, Inc.
- Dave Jula, Baker – FEMA PTS Contractor
- Lymann Henn, Inc., Denver – Geotechnical Consultants

Templeton Gap – Vicinity Map



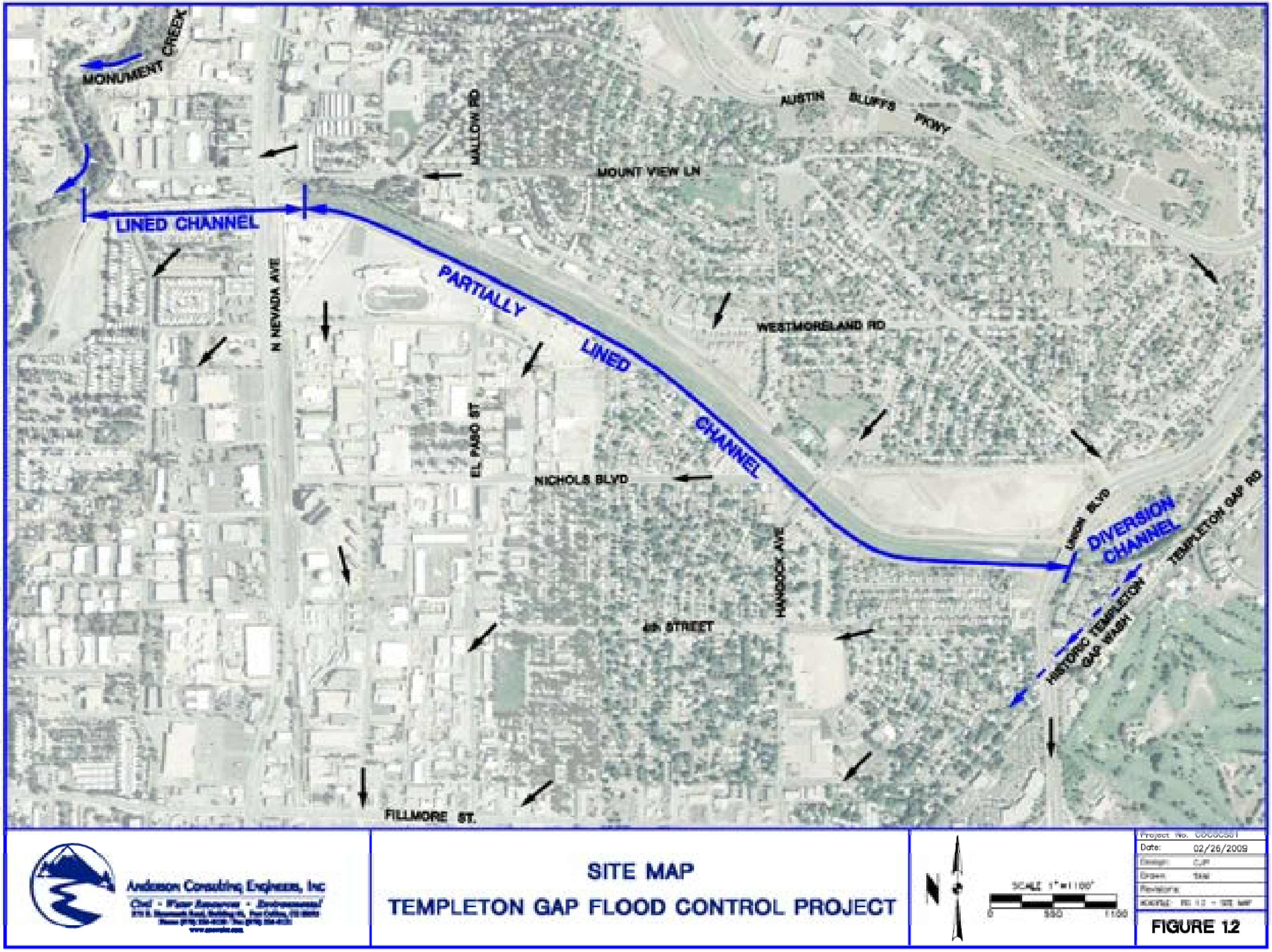
History of the Floodway

- Templeton Gap Wash prior to 1952
- Templeton Gap Wash floods occurred in 1855, 1886, 1922, 1929, 1932 and 1935
- Templeton Gap Wash was a tributary to Shooks Run, which flows through downtown Colorado Springs south to Fountain Creek
- Army Corps of Engineers re-routed the Wash westward to Monument Creek to alleviate flooding
- Floodway channel and levee constructed between 1948 and 1952 by the U.S. Army Corps of Engineers

History of the Floodway

- Colorado Springs took ownership of the levee in 1952
- Levee is in the Corps Inspection of Completed Works (ICW) program
- Inspected every 2 years by the Corps
- Levee has had maintenance issues over the years
- Sedimentation, trees, shrubs growing on the levee
- Several property encroachments on the levee right-of-way over the last 60 years

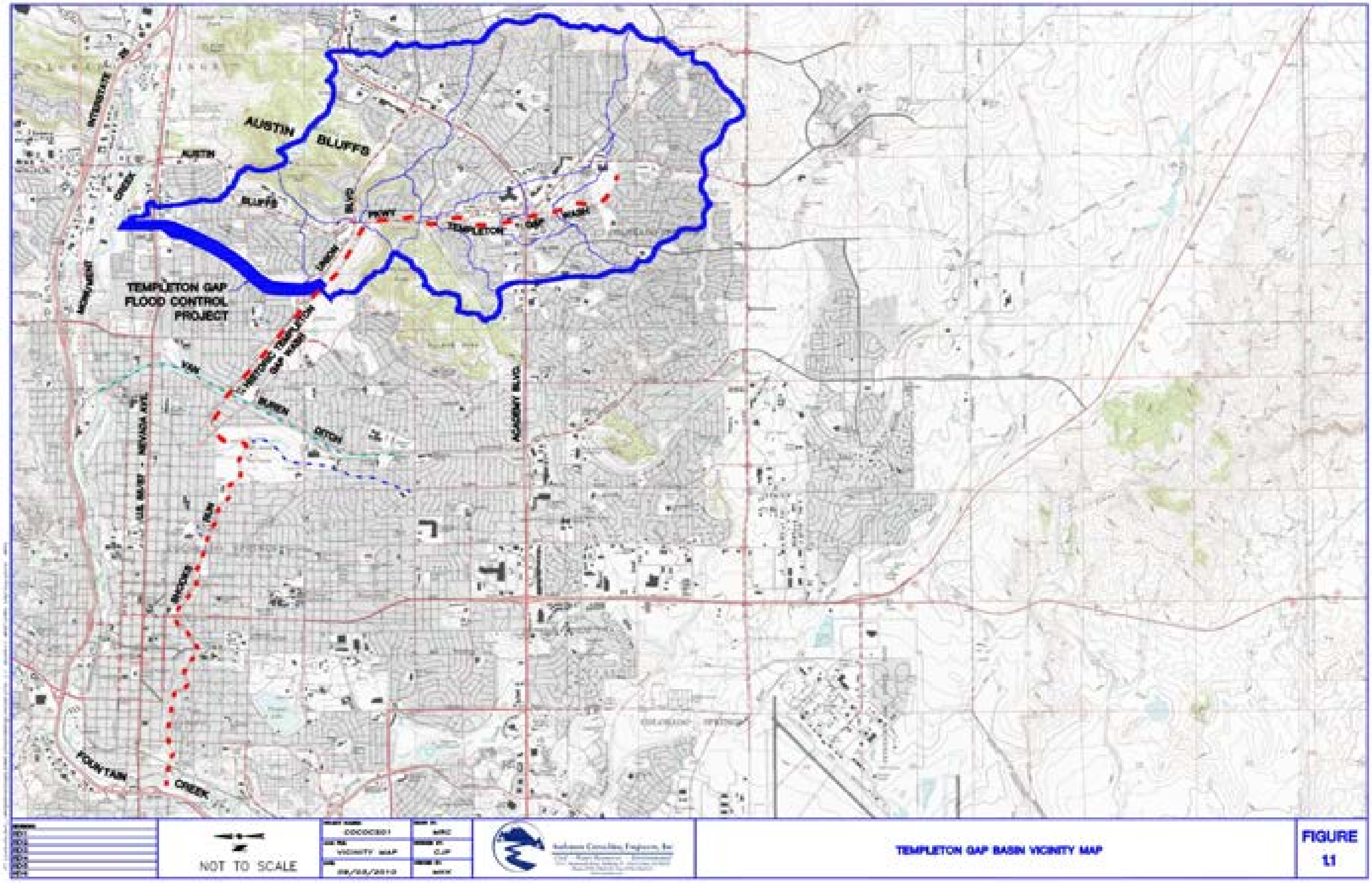
Historic T. Gap Wash Alignment



Hydrology

- Maximum estimated discharge = approx. 9,700 cfs in 1932
- Maximum 1-day precipitation = 4.3” in September 2008
- 8.5 square mile drainage basin
- Fully developed (with no detention) between 1965 and 1975
- 10-year discharge = 6,490 cfs
- Levee design Q_{100} in 1949 = 14,000 cfs
- New HEC-HMS hydrologic study Q_{100} = 13,490 cfs

T. Gap Drainage Basin – 8.5 mi²



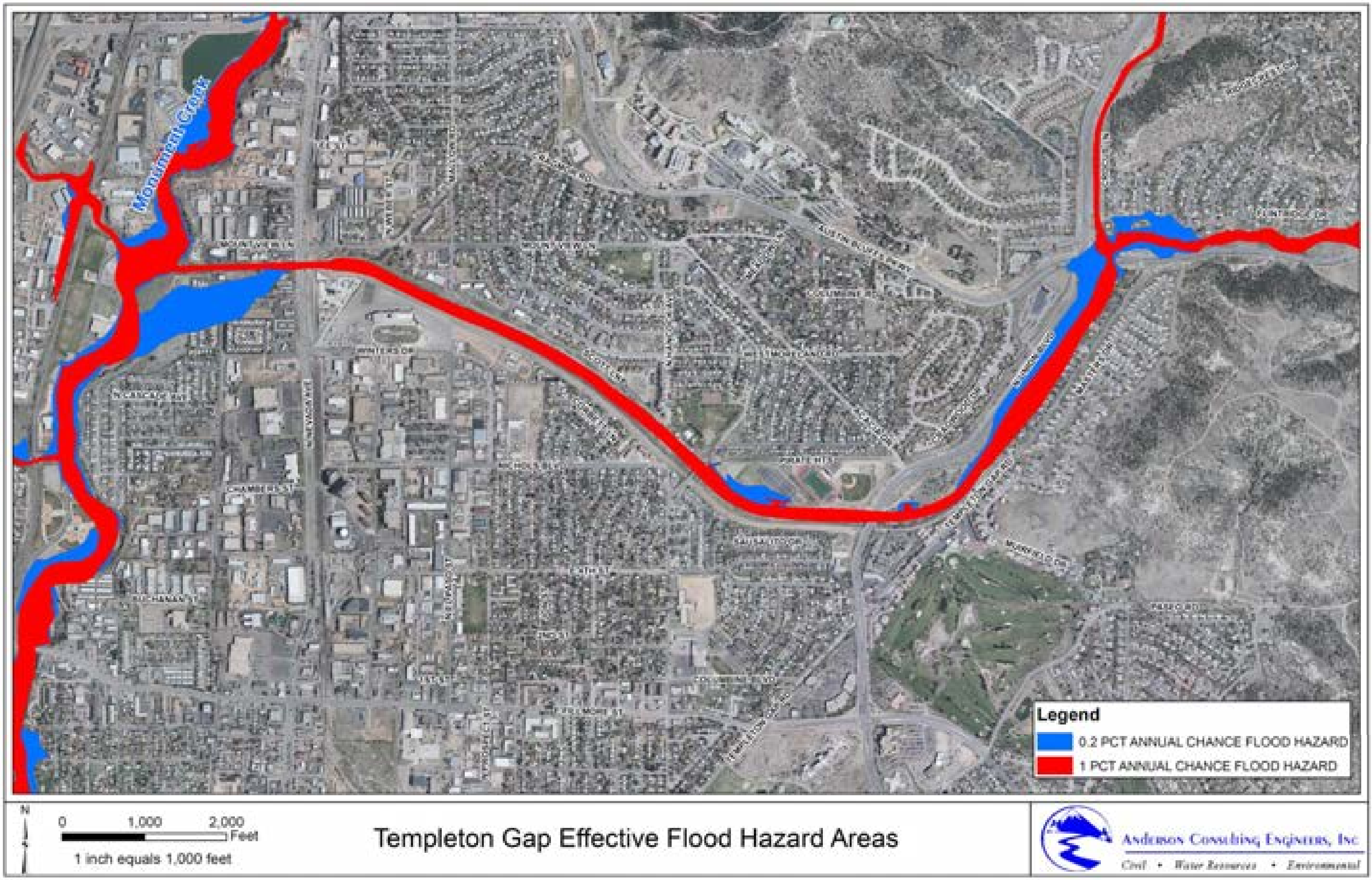
How Are Levees Evaluated?

- Prior to 1980, no evaluation was required for FEMA maps
- After 1986, all levees required to conform to Section 65.10 of the National Flood Insurance Program (NFIP) regulations
- City of Colorado Springs owns and maintains the Templeton Gap Levee

El Paso County DFIRM

- Levee has to be re-certified for the El Paso County DFIRM project
- Levee needs to meet requirements of Section 65.10 of the Code of Federal Regulations (CFR)
- Levee currently shown as providing flood protection on El Paso County FIRM panel
- Effective floodplain mapped in 1982

Effective Floodplains– 1982 study



What Does Section 65.10 Require?

A levee must meet the following criteria before being certified or re-certified and shown on a DFIRM.

- Minimum 3 to 4 feet of **freeboard** above the 100-year event
- **Structural design** of all closures, embankment protection, embankment and foundation stability, seepage and settlement analyses
- Analysis of **interior drainage** including storage areas and gravity outlets
- A documented and executed **O&M plan**

Section 65.10 (Continued)

- Levee should be **owned**, **operated** and **maintained** by a Federal or State created entity.
- The requirements of 65.10 may be waived if certification of the levee system can be provided by another **Federal** agency responsible for flood control activities, such as the U.S. Army Corps of Engineers.

Requirements for Levee Re-Certification

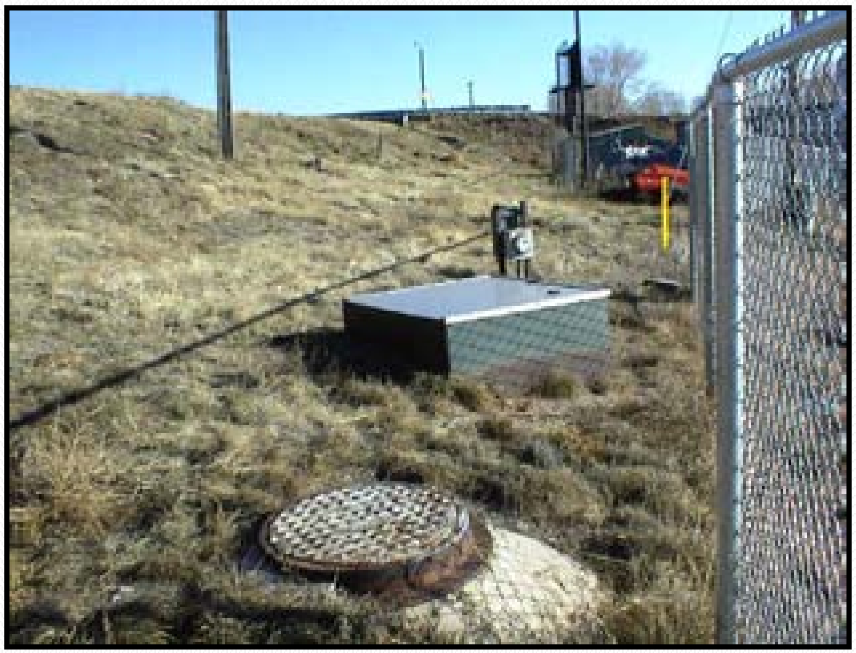
- Hydrologic and hydraulic analyses to show 3 to 4 feet of freeboard along the levee in the 100-year event
- Boreholes along specific reaches or all of the levee to perform seepage and stability analyses
- Preparation of an O&M Plan that describes regular maintenance and the operation of any closure devices

Templeton Gap Levee, Colorado Springs, CO-Certification Issues

- Inadequate freeboard due to sedimentation – sediment is 3 to 4 feet deep in some areas
- Levee overtops some sections during 100-year event
- Several utilities crossing the channel under the levee – cable TV, 2 sanitary sewer lines, 3 water lines, gas line
- Utilities installed deep in relation to existing invert - too shallow in relation to original channel invert
- Coordinate with utility owners to relocate/lower utilities

Templeton Gap Levee, Colorado Springs, CO- Certification Issues

- Several encroachments on Levee ROW
- Previous lawsuits regarding ROW along levee

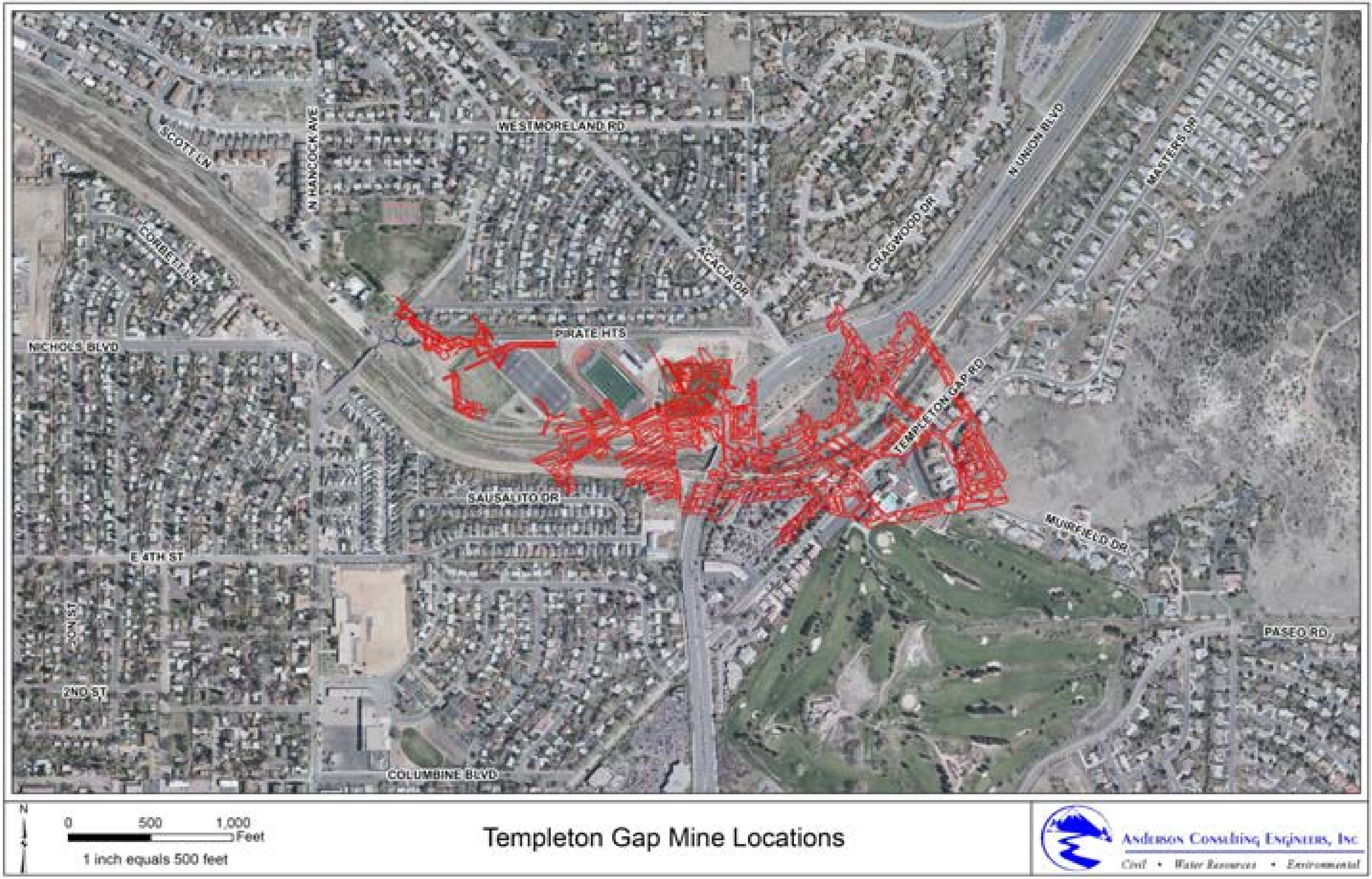


Levee Certification Issues

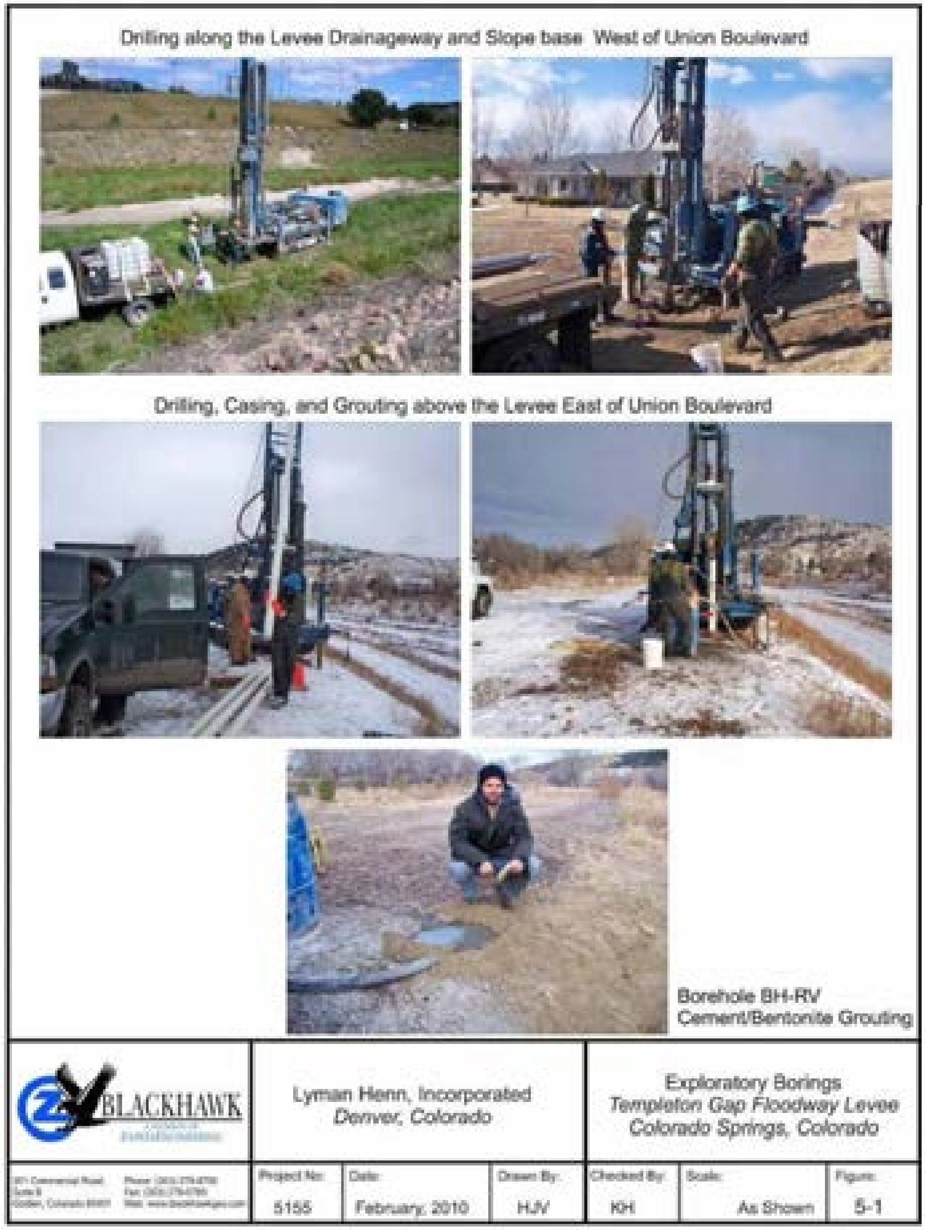
- Part of levee built over inactive coal mine – possible subsidence
- Failing rock drop structure – needs to be replaced – too close to levee and bend in channel

BH-1 – Sand collapse near surface

Coal Mine Layout Map



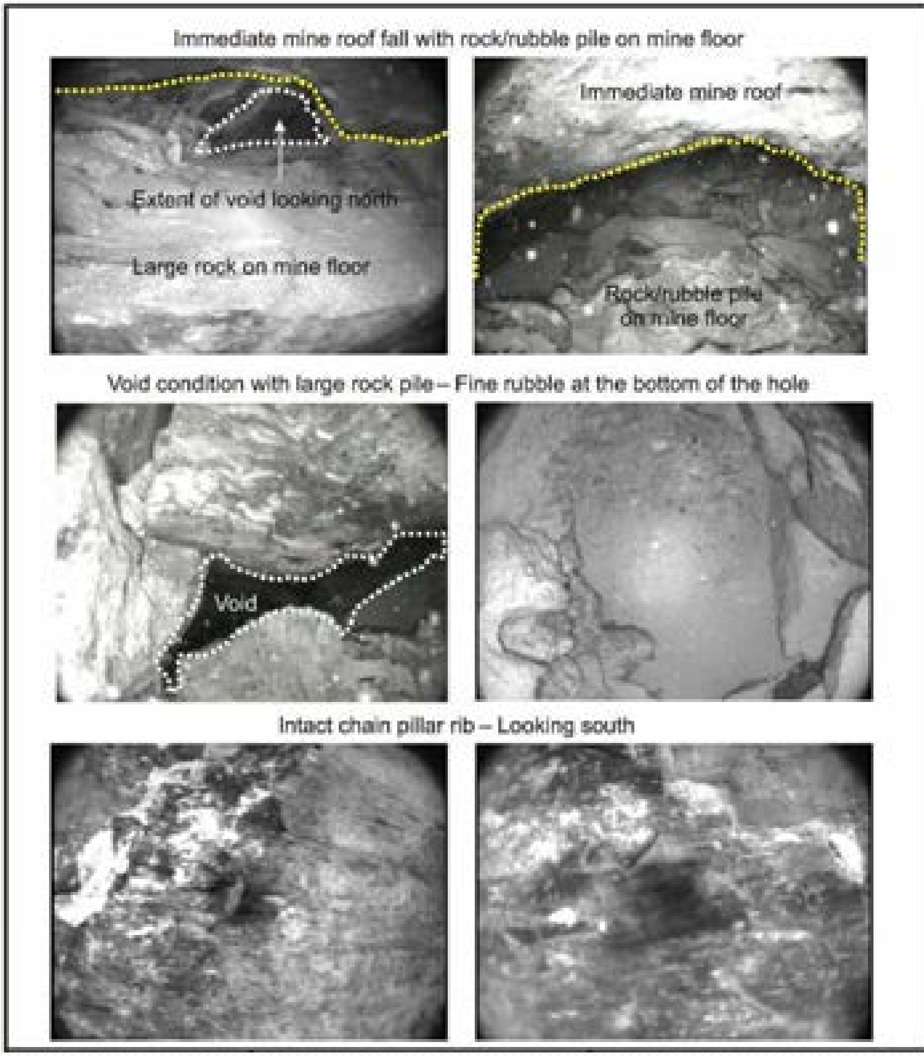
Geotechnical/Mine Investigations

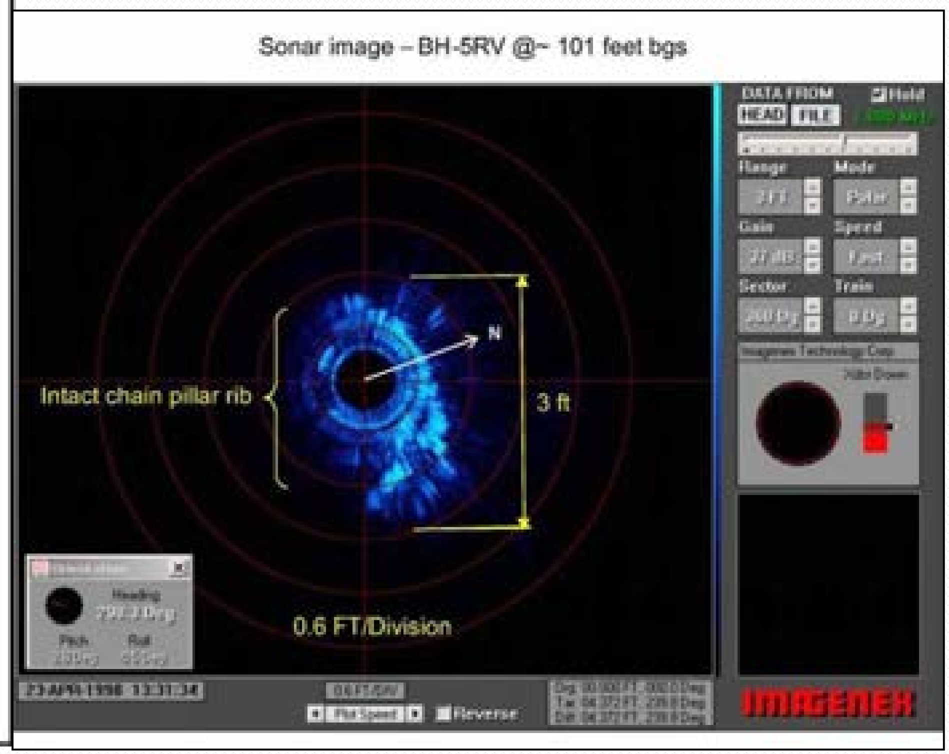


Video Camera and Sonar Images

Void 7 ft high @ depth between 99-106 ft bgs

Images @ ~ 101 ft bgs





Levee Certification Issues

- Union Blvd. culvert crossing built in 1980 – invert 3 feet above original channel invert
- Multiple trees growing in levee – City removed trees in 2009 - root systems to be removed as part of improvement project

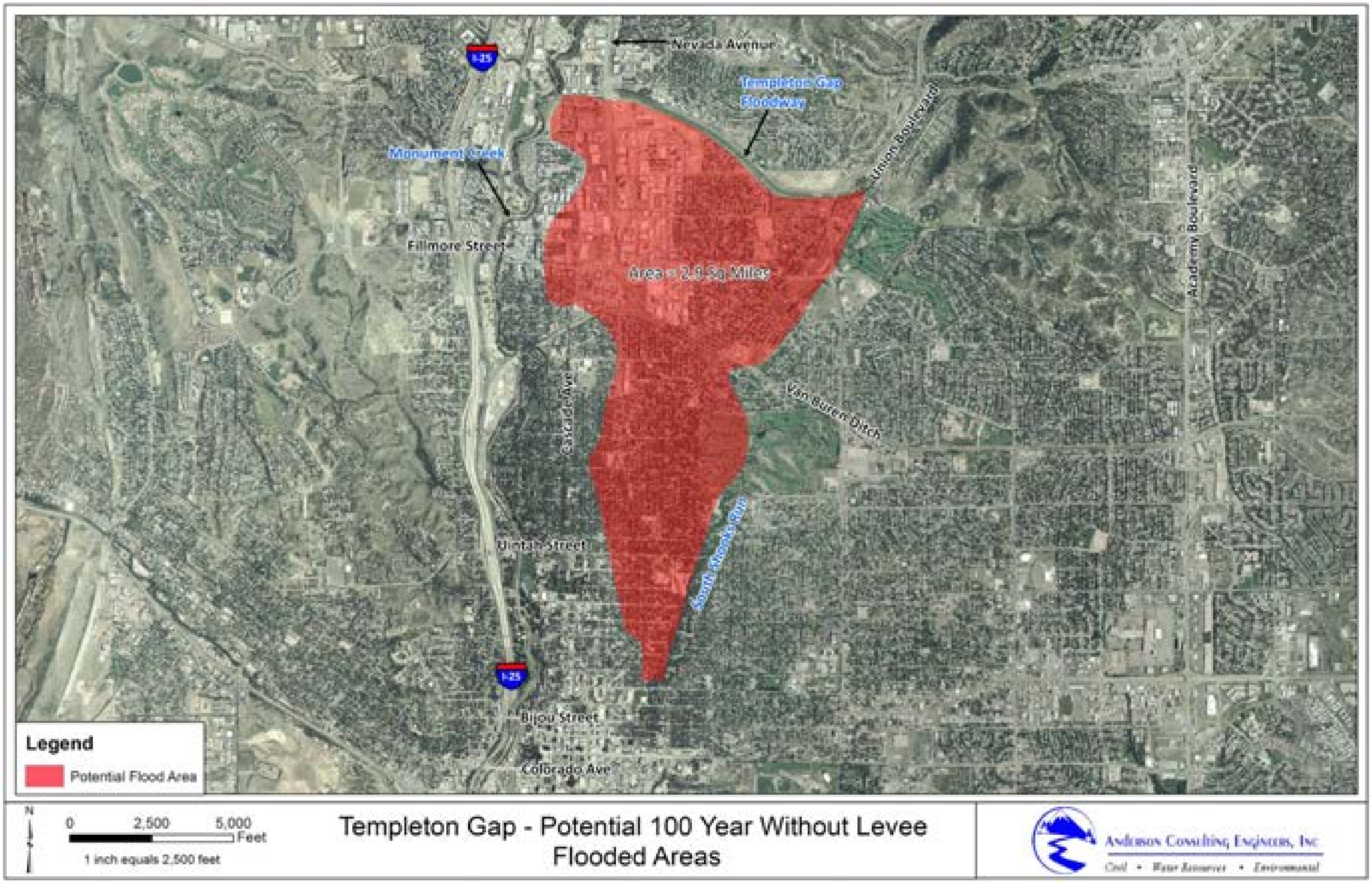
Levee Certification Issues

- Replacement of Hancock Road Bridge
- Coordinating bridge design with levee design to satisfy local floodplain and Section 65.10 criteria

Hydraulics and Floodplain Mapping

- Prepared new HEC-RAS “with-levee” hydraulic model of floodway from Austin Bluffs Parkway to Monument Creek
- Prepared 2-dimensional FLO-2D “without-levee” model of areas protected by the levee
- Even distribution of 100-year discharge along 3 separate levee sections
- Mapping and combining 3 separate without-levee floodplains
- Estimate that 2.9 square miles of residential/commercial areas are protected from lower return period events

Potential Floodplain for Without-Levee 2-D Analysis



Structures Affected by Without-Levee Floodplain

Zone AE 100-year Floodplain

- 2,000 to 3,000 Residential structures*
- 200 to 300 Commercial structures*

Zone X Floodplain (less than 1-foot depth)

- 2,000 to 3,000 Residential structures*
- 50 to 150 Commercial structures*

* ***<u>Preliminary Estimates</u>***

Templeton Gap Levee – Steps to Certification

ACE has performed the following services to certify the levee to FEMA

- Investigation of the existing hydraulic and geotechnical properties of the levee system
- Developed alternatives to mitigate lack of freeboard, utility crossing issues, and sedimentation issues
- Preparing construction plans and specifications to
  - dredge the channel ;
  - raise the levee;
  - repair drop structures; and
  - move sediment through the levee system.

Templeton Gap Levee – Steps to Certification

- Possible mitigation of potential mine subsidence by filling mines with a grout/cellular foam mixture – still under investigation
- Prepare a CLOMR to have FEMA approve the rehabilitation methodology
- 404 permit application
- Floodplain use permit
- Army Corps approval of design
- When construction is complete - prepare a LOMR to certify the levee as providing 100-year flood protection

Future of the Levee Certification Project

- Public passed ballot Issue 300 in November 2009
- City eliminated Stormwater Enterprise fees in December 2009
- Remaining Enterprise funds not sufficient to construct the project
- Without adequate funding – levee will be de-certified on the El Paso DFIRM
- Residential stormwater fees = approx. $4 per month
- Flood Insurance = approx. $125 per month
- "You're saving yourself a few bucks a year," City Councilor Scott Hente said last fall, "to incur the luxury of spending $1,000 a year on flood insurance."[1]

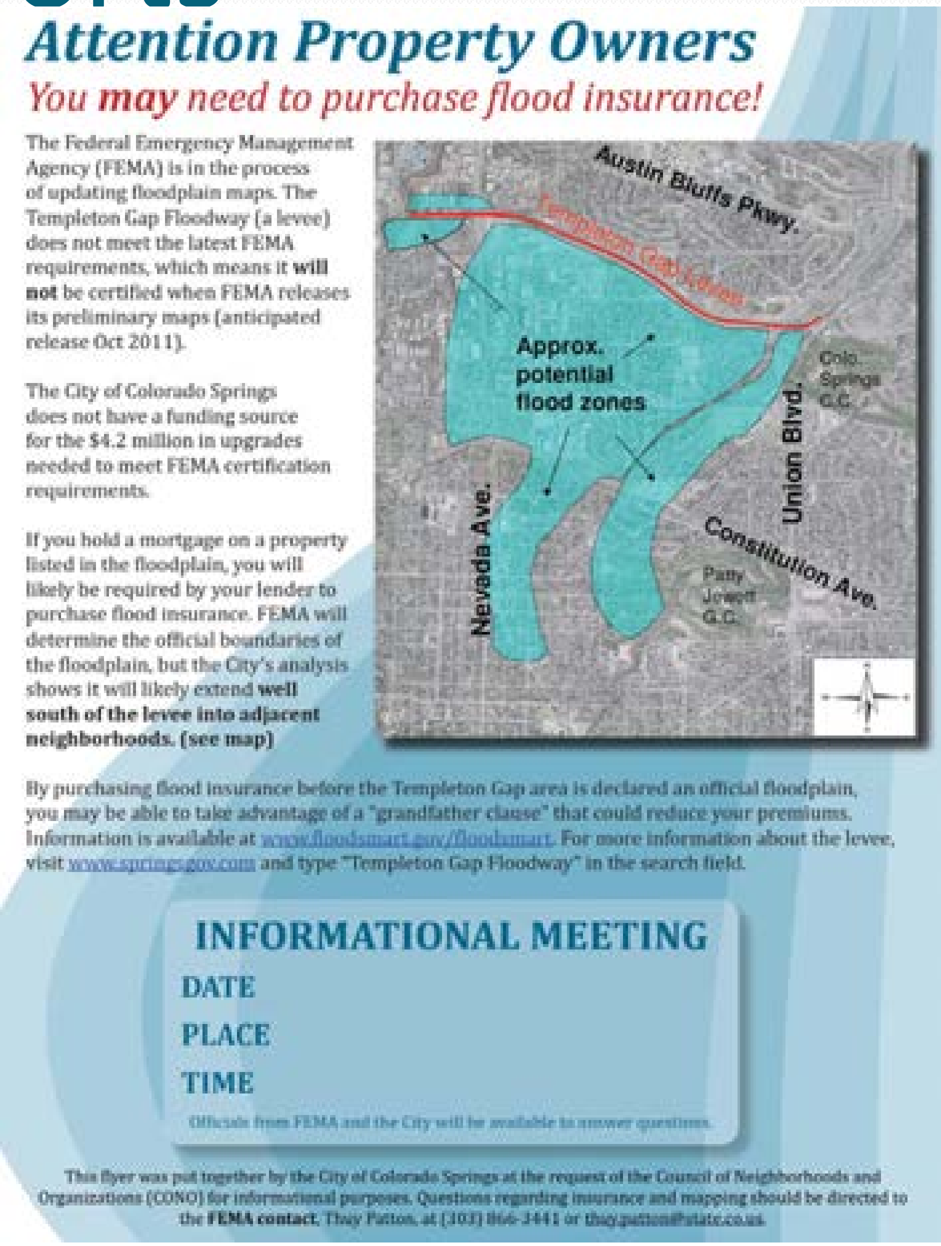
[1] Colorado Springs Independent website

Future of the Levee Certification Project

- City still looking into alternatives to fund the levee improvements
- Flood insurance for all affected properties is estimated to be $3 million ***per year***
- ***One time cost*** to rehabilitate levee and mitigate mine subsidence = approximately $4.2 million
- B/C ratio over 50 years = ???

City Outreach Efforts

- $4.2 million cost of improvements
- Unknown when or if the levee/mine improvements will be made



Attention Property Owners

*You **may** need to purchase flood insurance!*

The Federal Emergency Management Agency (FEMA) is in the process of updating floodplain maps. The Templeton Gap Floodway (a levee) does not meet the latest FEMA requirements, which means it **will not** be certified when FEMA releases its preliminary maps (anticipated release Oct 2011).

The City of Colorado Springs does not have a funding source for the $4.2 million in upgrades needed to meet FEMA certification requirements.

If you hold a mortgage on a property listed in the floodplain, you will likely be required by your lender to purchase flood insurance. FEMA will determine the official boundaries of the floodplain, but the City's analysis shows it will likely extend **well south of the levee into adjacent neighborhoods. (see map)**

By purchasing flood insurance before the Templeton Gap area is declared an official floodplain, you may be able to take advantage of a "grandfather clause" that could reduce your premiums. Information is available at www.floodsmart.gov/floodsmart. For more information about the levee, visit www.springsgov.com and type "Templeton Gap Floodway" in the search field.

INFORMATIONAL MEETING

DATE

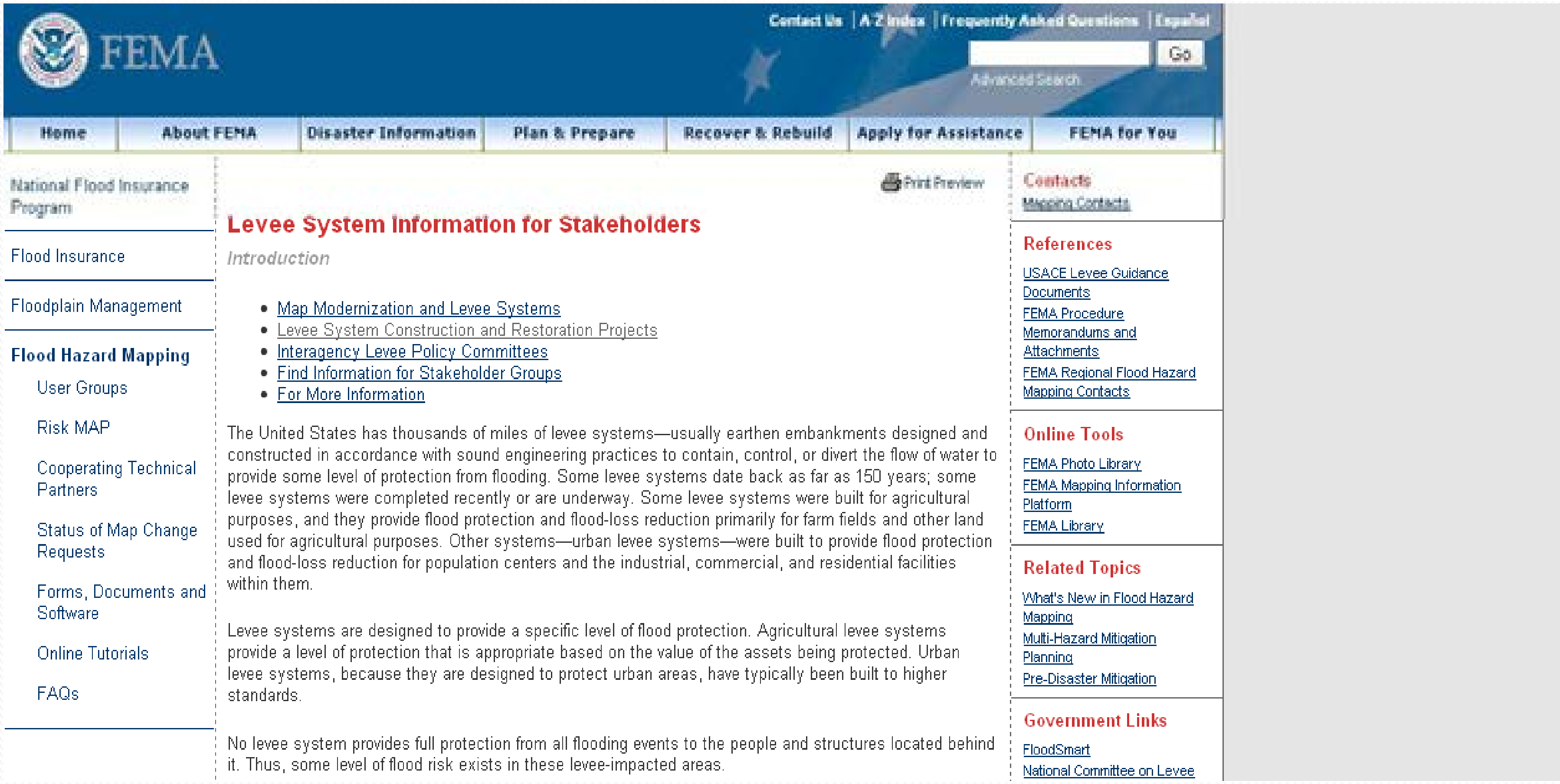
PLACE

TIME

Officials from FEMA and the City will be available to answer questions.

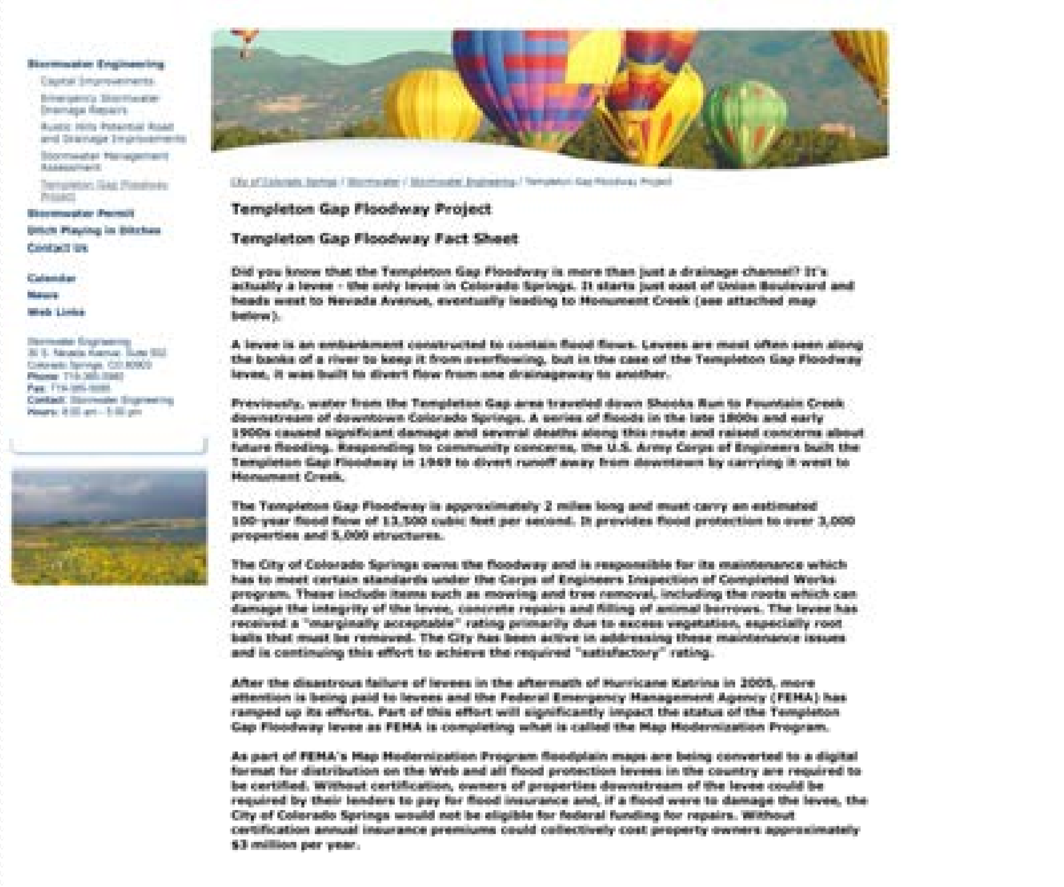
This flyer was put together by the City of Colorado Springs at the request of the Council of Neighborhoods and Organizations (CONO) for informational purposes. Questions regarding insurance and mapping should be directed to the **FEMA contact**, Thuy Patton, at (303) 866-3441 or thuy.patton@state.co.us.

DFIRM Requirements For Mapping The Effects Of Levees



http://www.fema.gov/plan/prevent/fhm/lv_intro.shtm

Colorado Springs Templeton Gap Floodway Fact Sheet



Stormwater Engineering
Capital Improvements
Emergency Stormwater Drainage Repairs
Stormwater Management Assessment
Templeton Gap Floodway Project
Stormwater Permit
Contact Us
Calendar
News
Web Links

City of Colorado Springs / Stormwater / Stormwater Engineering / Templeton Gap Floodway Project

Templeton Gap Floodway Project

Templeton Gap Floodway Fact Sheet

Did you know that the Templeton Gap Floodway is more than just a drainage channel? It's actually a levee - the only levee in Colorado Springs. It starts just east of Union Boulevard and heads west to Nevada Avenue, eventually leading to Monument Creek (see attached map below).

A levee is an embankment constructed to contain flood flows. Levees are most often seen along the banks of a river to keep it from overflowing, but in the case of the Templeton Gap Floodway levee, it was built to divert flow from one drainageway to another.

Previously, water from the Templeton Gap area traveled down Shooks Run to Fountain Creek downstream of downtown Colorado Springs. A series of floods in the late 1800s and early 1900s caused significant damage and several deaths along this route and raised concerns about future flooding. Responding to community concerns, the U.S. Army Corps of Engineers built the Templeton Gap Floodway in 1949 to divert runoff away from downtown by carrying it west to Monument Creek.

The Templeton Gap Floodway is approximately 2 miles long and must carry an estimated 100-year flood flow of 13,500 cubic feet per second. It provides flood protection to over 3,000 properties and 5,000 structures.

The City of Colorado Springs owns the floodway and is responsible for its maintenance which has to meet certain standards under the Corps of Engineers Inspection of Completed Works program. These include items such as mowing and tree removal, including the roots which can damage the integrity of the levee, concrete repairs and filling of animal borrows. The levee has received a "marginally acceptable" rating primarily due to excess vegetation, especially root balls that must be removed. The City has been active in addressing these maintenance issues and is continuing this effort to achieve the required "satisfactory" rating.

After the disastrous failure of levees in the aftermath of Hurricane Katrina in 2005, more attention is being paid to levees and the Federal Emergency Management Agency (FEMA) has ramped up its efforts. Part of this effort will significantly impact the status of the Templeton Gap Floodway levee as FEMA is completing what is called the Map Modernization Program.

As part of FEMA's Map Modernization Program floodplain maps are being converted to a digital format for distribution on the Web and all flood protection levees in the country are required to be certified. Without certification, owners of properties downstream of the levee could be required by their lenders to pay for flood insurance and, if a flood were to damage the levee, the City of Colorado Springs would not be eligible for federal funding for repairs. Without certification annual insurance premiums could collectively cost property owners approximately $3 million per year.

http://www.springsgov.com/page.aspx?navid=2743

Templeton Gap Levee Certification

Question or Comments?

ANDERSON CONSULTING ENGINEERS, INC.

Civil • Water Resources • Environmental

Abstract

The Templeton Gap Levee was constructed in Colorado Springs, CO in 1950 by the U.S. Army Corps of Engineers as part of the Templeton Gap Flood Control Project (TGFCP). The levee and the associated canal-like channel were constructed to alleviate flooding on the Templeton Gap Wash which originates in the Austin Bluffs section of Colorado Springs. Runoff that is intercepted by the TGFCP historically flowed to the southwest to its confluence with Shooks Run, near the area of present day downtown Colorado Springs. Flooding from the Templeton Gap Wash caused severe flooding in the downtown Colorado Springs area in 1855, 1886, 1922, 1929, and 1932. The TGFCP rerouted the historic Templeton Gap Wash to its current left bank confluence with Monument Creek approximately 6 miles upstream of the Shooks Run confluence with Fountain Creek.

To meet the levee certification requirements of the El Paso County DFIRM project, the City of Colorado Springs selected Anderson Consulting Engineers, Inc. (ACE) to assess the condition of the existing levee, and to provide the necessary documentation to improve the levee and subsequently have the levee accredited to be shown on the El Paso County DFIRM as providing 100-year flood protection.

This presentation will highlight the procedures that ACE followed to assess the existing condition of the levee system, outline the alternative evaluations performed by ACE to mitigate the various deficiencies of the levee system, and also highlight the unique challenges associated with the certification of this particular levee system. The presentation will also outline the hydraulic analyses and floodplain mapping efforts associated with the Templeton Gap Floodway channel, and the without-levee floodplain mapping required by FEMA as part of the DFIRM process.

The presentation will highlight the following;

- Freeboard for the 100-year flood event;
- Sedimentation issues within the channel;
- Road crossing issues;
- Utility crossings through the channel and the levee;
- Potential mine subsidence in the area of the levee;
- 1- and 2-dimensional hydraulic modeling and floodplain mapping;
- Levee certification and the DFIRM timeline;
- Potential de-certification of the levee on the DFIRM; and
- Flood insurance impacts to the approximately 5,000 structures protected by the levee.

Author Information;

Mark K. Kempton, P.E., CFM

Anderson Consulting Engineers, Inc.

375 East Horsetooth Road, Building 5

Fort Collins, CO 80525

(970) 226-0120

mkkempton@acewater.com

One Thing Is CLEAR

Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

2010 CASFM Conference

Snow Mass, CO September 21-24, 2010

REACHING THE MASSES FOR STORMWATER QUALITY

A presentation on the

ONE THING IS CLEAR

PUBLIC OUTREACH CAMPAIGN

Douglas County, Colorado

J. DAVID VAN DELLEN, Town of Castle Rock

WARD MAHANKE, City of Lone Tree

One Thing Is CLEAR
Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

Who is One Thing Is CLEAR?

- CLEAR is the expanded communication and information vision of the Douglas County Stormwater Co-op Group made up of the following members:

Castle Pines Metro District	Douglas County	Southeast Metro SW Authority
Castle Pines North Metro District	Douglas County School District	SPLASH
Cherry Creek Steward Partners	Heritage Hills Metro District	Stonegate Village Metro District
City of Lone Tree	Highlands Ranch Metro District	Town of Castle Rock
City of Castle Pines North	Lincoln Park Metro District	Town of Parker

Our creeks, rivers & lakes depend on you.

What is One Thing Is CLEAR?

- CLEAR is a public outreach campaign promoted through:
  - Local newspaper advertisements
  - OneThingIsClear.org website
  - Promotional materials and give-a-ways
- CLEAR stands for Cooperative for Local Environmental Awareness & Responsibility.

One Thing Is CLEAR

Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

C is for Cooperative

- The Co-op is an unfunded volunteer partnership made up of local agencies in and around Douglas County
    - Primarily Phase II MS4 permit holders
    - Shares resources and ideas related to MS4 Permit
- CLEAR is a product of the co-op that:
    - Reduced public outreach costs to individual members
    - Created a unified voice to the public
    - Developed almost entirely using in-house staff and resources

Our creeks, rivers & lakes depend on you.

L is for Local

- CLEAR targets local audiences through the community newspaper
- CLEAR uses real photos within Douglas County to keep the message close to home
- CLEAR targets local pollutant issues within our watersheds
  - Sediment from construction sites
  - Nutrients such as phosphorus and nitrogen
  - Nonpoint source pollutants common to urbanized areas

One Thing Is CLEAR
Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

EA is for Environmental Awareness

- CLEAR believes that behavior change can happen when people are presented with a frequent, consistent and simple message of awareness.
- We promote public understanding of stormwater quality issues by:
    - Highlighting common behaviors that impact water quality
    - Explaining the direct connection of urban areas to our waterways
    - Simplifying the message into common language
    - Sending the same message using several difference media sources

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Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

R is for Responsibility

- CLEAR promotes and understands that our waterways are dependent on people choosing to do the right thing in protecting water quality.
- We promote active protection of stormwater quality by:
  - Providing practical recommendations to homeowners and businesses
  - Providing a way to report spills and get involved at a local level
  - Focusing on choices down to the smallest cigarette butt

One Thing Is CLEAR

Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

Newspaper Advertisements

- Our Newspaper ads are the primary means of reaching the public on a regular basis
  - Ads run in nine local Colorado Community Newspapers
  - Covering Douglas County and portions of five surrounding Counties
  - With a circulation of over <u>90,500</u> homes or <u>226,300</u> readers
  - Ads have a new message each month fitting to that time of year

One Thing Is CLEAR

Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

Evolution of Advertising Campaign

- Co-op partners with Colorado Community Newspapers to begin monthly ads in 2007
    - Ads unify the message across Douglas County but there is no common link to point to.
- Co-op develops DCStormwater.org to link ads to a common website in 2008
    - Website provides central location for County-wide initiatives but there is still no name for the campaign
- Co-op develops One Thing Is CLEAR branding and changes website in 2010
    - CLEAR captures the link and vision for all outreach initiatives

Ad prior to CLEAR

It's not good for our water... either.

Whenever you are outside and you notice a piece of trash, please stop and dispose of it properly. Your rivers, creeks and lakes depend on you. What isn't collected today is picked up in the next rainstorm and sent directly to the nearest creek. From the moment this small piece of trash enters our waterways, it is responsible for a tremendous amount of damage.

Local stormwater agencies, including participants of the Douglas County Stormwater Co-op Group, SPLASH and SEMSWA, are teaming together to bring you this message. We take this so seriously that we posted this ad rather than send you more garbage in the mail. Together, with your help, we can make a difference in keeping our waterways clean. Look for this ad in coming months for more ways you can get involved.

THIS MESSAGE BROUGHT TO YOU BY

Castle Pines Metropolitan District
303.688.8330

Castle Pines North Metro District
303.688.8550
www.cpnmd.org

Cherry Creek Stewardship Partners
303.345.1675
www.cherry-creek.org

City of Lone Tree
303.662.8112
www.cityoflonetree.com

Douglas County
303.663.6181
www.douglas.co.us/publicworks/stormwater

Douglas County School District
303.387.0027
www.dcsdk12.org

Heritage Hills Metro District
303.792.7357
www.heritagehillshoa.org

Highlands Ranch Metro District
303.791.0430
www.highlandsranch.org

Lincoln Park Metro District
303.779.4252

Southeast Metro Stormwater Authority
303.858.8844
www.semswa.org

SPLASH
303.967.0244
www.splashco.org

Stonegate Village Metro District
303.858.9909
www.svmd.org

Town of Castle Rock
720.733.2235
www.crgov.com/utilities

Town of Parker
303.840.9546
www.parkeronline.org

Please report accidental and illegal dumping to your local agency.

ADOPT A HIGHWAY

Creek and highway cleanup efforts help offset pollution from our major transportation corridors.
Contact your local agency to find out how you can get involved.

Ad with CLEAR

HOUSEHOLD CHEMICAL WARNING:
Thins paint, kills wildlife.

When using hazardous chemicals, store and dispose of containers responsibly, and clean up spills promptly according to manufacturer instructions. Your rivers, creeks and lakes depend on you. Harmful chemicals left on outdoor surfaces are picked up in the next rainstorm and sent directly to the nearest creek. Once these chemicals reach our waterways, they pose a threat to fish, wildlife, recreation and drinking water supplies.

Local stormwater agencies, including participants of the Douglas County Stormwater Co-op Group, SPLASH and SEMSWA, are teaming together to bring you this message. We take this so seriously that we posted this ad rather than send you more garbage in the mail.
One thing is clear: our creeks, rivers and lakes depend on you.

THIS STORMWATER MESSAGE BROUGHT TO YOU BY

One Thing Is CLEAR
Cooperative for Local Environmental Awareness & Responsibility
onethingisclear.org

Visit www.onethingisclear.org to:

- **Report accidental and illegal dumping to your local agency**
- **Search local volunteer events**
- **Find more helpful tips**

For information about household chemical disposal services in your area, contact the Tri-County Health Department at www.tchd.org/householdchemical.htm

Colorado Community Newspapers agree: Please recycle this newspaper responsibly and partner with our communities for a better tomorrow.

Ad campaign creative donated by the Town of Castle Rock Utilities Department, Stormwater Division.

Photo taken along East Plum Creek in Castle Rock

It's clear this stream is grateful

Our streams want to say thanks for giving them a gift this year. Your actions made a difference for keeping our water clean. You chose to properly dispose of household chemicals, pet waste and trash. You used fertilizers appropriately and kept harmful material out of runoff's path. You volunteered at local events to preserve our waterways. Keep up the good work.

Local stormwater agencies, including participants of the Douglas County Stormwater Co-op Group, SPLASH and SEMSWA, are teaming together to bring you this message. We take this so seriously that we posted this ad rather than send you more garbage in the mail. One thing is clear: our creeks, rivers and lakes depend on you.

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One Thing Is CLEAR
Cooperative for Local Environmental Awareness & Responsibility
onethingisclear.org

Visit www.onethingisclear.org to:

- **Report accidental and illegal dumping to your local agency**
- **Search local volunteer events**
- **Find more helpful tips**

Make your New Year's Resolution now; get involved. Contact your local agency for upcoming events.

Colorado Community Newspapers agree: Please recycle this newspaper responsibly and partner with our communities for a better tomorrow.

Ad campaign creative donated by the Town of Castle Rock Utilities Department, Stormwater Division.

One Thing Is CLEAR

Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

Looking Forward

- CLEAR provides the means to expand the campaign into other initiatives linked with the common message
    - Creating a “Thank you” message on garbage and pet waste stations
    - Finding public advertising venues such as buses, billboards, etc.
    - Linking with local volunteer events to reinforce the message

CLEAR T-Shirts used at Creek cleanup events

One Thing Is CLEAR
Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

OneThingIsClear.org Website

- The website serves the following core functions:
  - Provide stormwater hotline contacts for all participating MS4s
  - Provide maps for users to find their respective MS4 contact
  - Provide educational and volunteer opportunities
  - Provide helpful and practical tips for protecting water quality
  - Provide campaign resources for local agencies

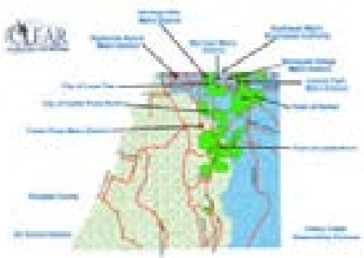
One Thing Is CLEAR

Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

Contact Us

Please reference our map to determine which authority is responsible for stormwater management in your area.



CLEAR MEMBER ROSTER

Permit Holder	Phone	Web Site
Castle Pines Metro District	303-688-8330	www.castlepinesmetro.com
City of Castle Pines North	303-705-0200	www.cpngov.com
Castle Pines North Metro District	303-688-8550	www.cpnmd.org
Town of Castle Rock	720-733-2235	www.CRgov.com/utilities
Cherry Creek Stewardship Partners	303-345-1675	www.cherry-creek.org
Douglas County	303-663-6181	www.douglas.co.us/stormwater
Douglas County School District	303-387-0027	www.dcsdk12.org
Heritage Hills Metro District	303-792-7357	www.heritagehillshoa.org
Highlands Ranch Metro District	303-791-0430	www.highlandsranch.org
Lincoln Park Metro District	303-779-4252	
City of Lone Tree	303-662-8112	www.cityoflonetree.com
Meridian Metro District	303-790-0345	www.dtcmeridian.com
Town of Parker	303-840-9546	www.parkeronline.org
Southeast Metro Stormwater Authority	303-858-8844	www.semswa.org
SPLASH	303-858-8844	www.splashco.org
Stonegate Village Metro District	303-858-9909	www.svmd.org

One Thing Is CLEAR
Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

So what does it cost us?

- 15 members share equally in the costs of the campaign and website
- Website Costs
    - Total Cost to develop OneThingIsCLEAR.org $4,475

Cost per Member $298

One Thing Is CLEAR
Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

Ad Costs

- Annual cost for the ad campaign and website maintenance:
  - Annual website cost $1,200
  - Total Cost for Ads $24,500
  - <u>Matching funds from CCN ($12,225)</u>
  - Total Cost to CLEAR $13,425
  - Cost per Member $895

One Thing Is CLEAR
Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

Cost comparison to traditional outreach materials

Agency	Circulation	Description	Total Cost	Comparison
Town of Castle Rock	15,000	Print and mail brochure	$5,500	8 newspaper ads for cost of 1 utility insert -or- 7 years of ads for cost of 1 mailer
	15,000	Ad as Utility bill insert	$552	
	90,500	One Half-page Newspaper ad	$68	
Unincorporated Douglas County	¼ unincorporated Douglas County over 4 years and all commercial	Print and mail brochure	$6,000	
	90,500	One Half-page Newspaper ad	$68	

One Thing Is CLEAR
Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

Looking outward

- CLEAR provides the means for the campaign to expand beyond Douglas County
  - Join the website to post stormwater hotline for your area
  - Use ads in your local newspaper or other advertising venue
  - Access the ads through OneThingIsClear.org
  - Ad Campaign Style Guide defines identity and image standards for uses

One Thing Is CLEAR

Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

Can we make a difference for water quality?

- We believe we can, but change starts with us.
- CLEAR is one way we can make a difference.
- As seen in our ads: “We take this so seriously that we posted this ad rather than send you more garbage in the mail.”
- It ends with the masses. People are catching the vision and…
- One thing is clear, our streams are grateful!

One Thing Is CLEAR
Cooperative for Local Environmental Awareness & Responsibility

Our creeks, rivers & lakes depend on you.

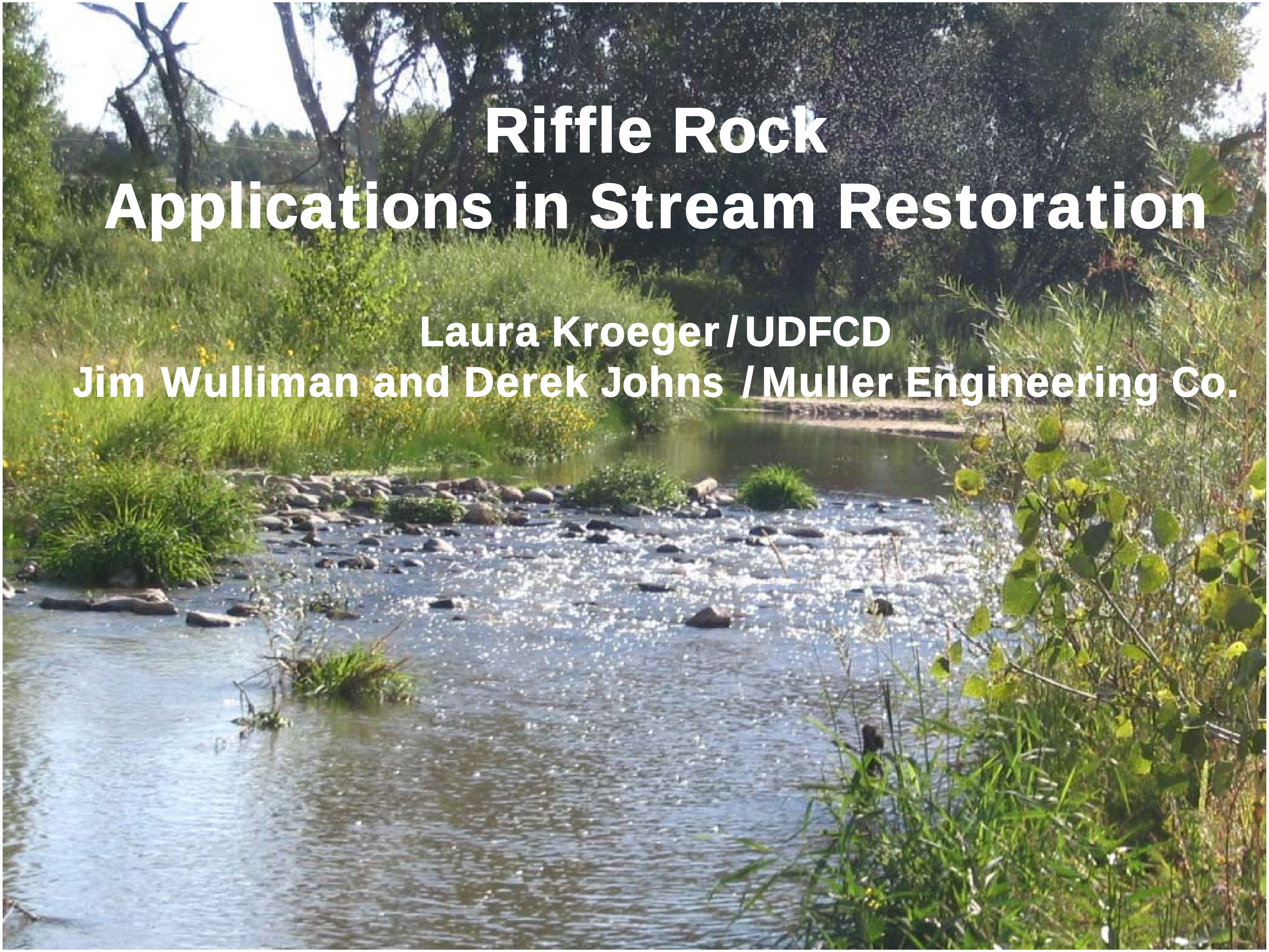
Thanks and Questions

THIS STORMWATER MESSAGE BROUGHT TO YOU BY

Castle Pines Metro District	Douglas County	Southeast Metro SW Authority
Castle Pines North Metro District	Douglas County School District	SPLASH
Cherry Creek Steward Partners	Heritage Hills Metro District	Stonegate Village Metro District
City of Lone Tree	Highlands Ranch Metro District	Town of Castle Rock
City of Castle Pines North	Lincoln Park Metro District	Town of Parker

Riffle Rock
Applications in Stream Restoration

Laura Kroeger / UDFCD
Jim Wulliman and Derek Johns / Muller Engineering Co.




Cherry Creek at 17 Mile House


Cherry Creek at Stroh Ranch


Cherry Creek at Hess Road


Cherry Creek at Pine Lane


Upper Marcy Gulch


Shea Homes BackCountry


Cottonwood Creek at Cherry Creek State Park

UDFCD Perspective

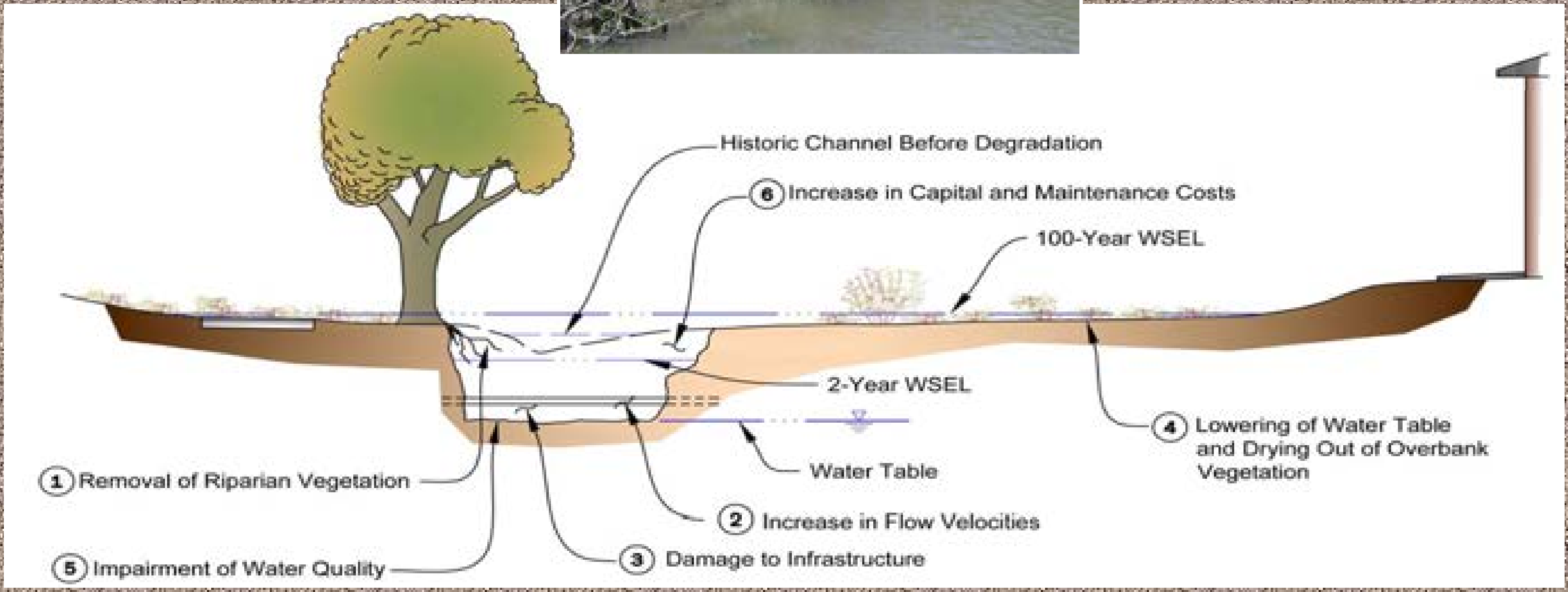
- Recognize benefits of riffle rock, but...
- Recognize limitations and complexities, too.
- Sponsoring "white paper" to discuss background, design guidelines, and cautions.

UDFCD "White Paper"

- Development of riffle rock during Cottonwood Creek Reclamation Project
- Case studies for riffle drops and rock lining.
- Design guidance.
- Construction guidance.

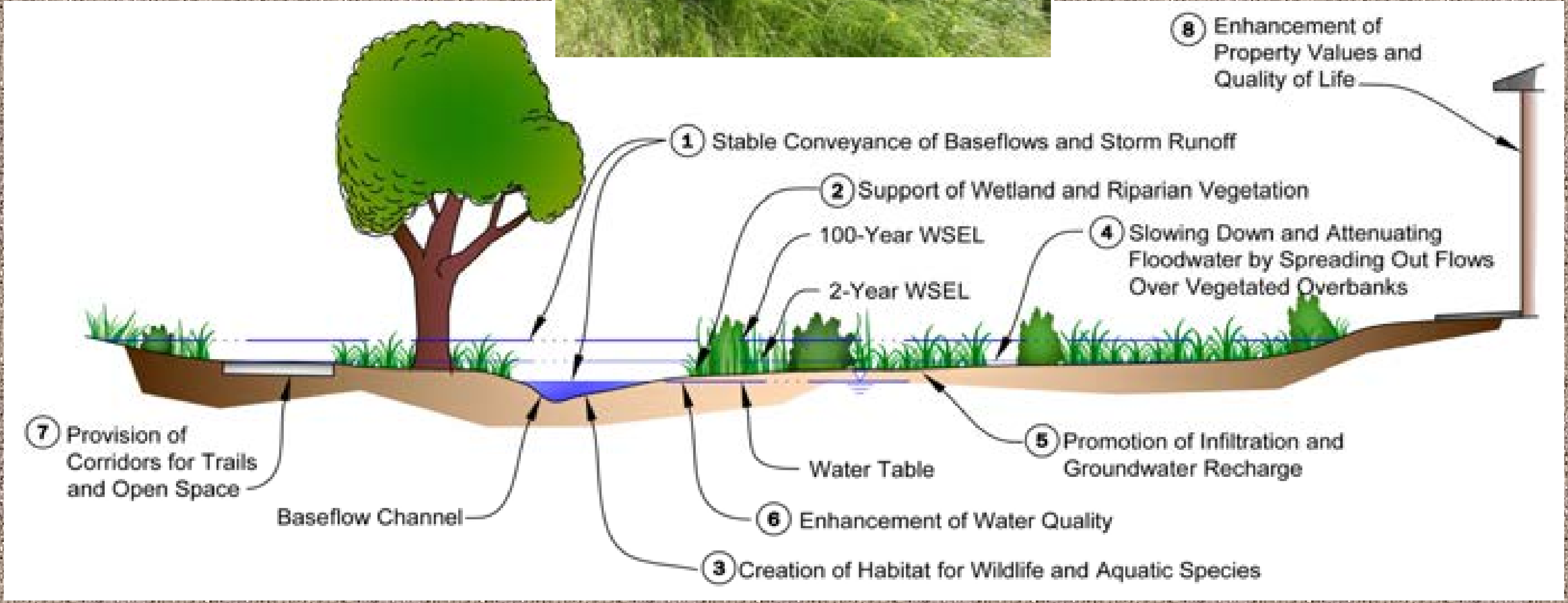
Cottonwood Creek Reclamation Project

Degraded Stream: Eroding, incised channel with dried-out, fragile overbanks.



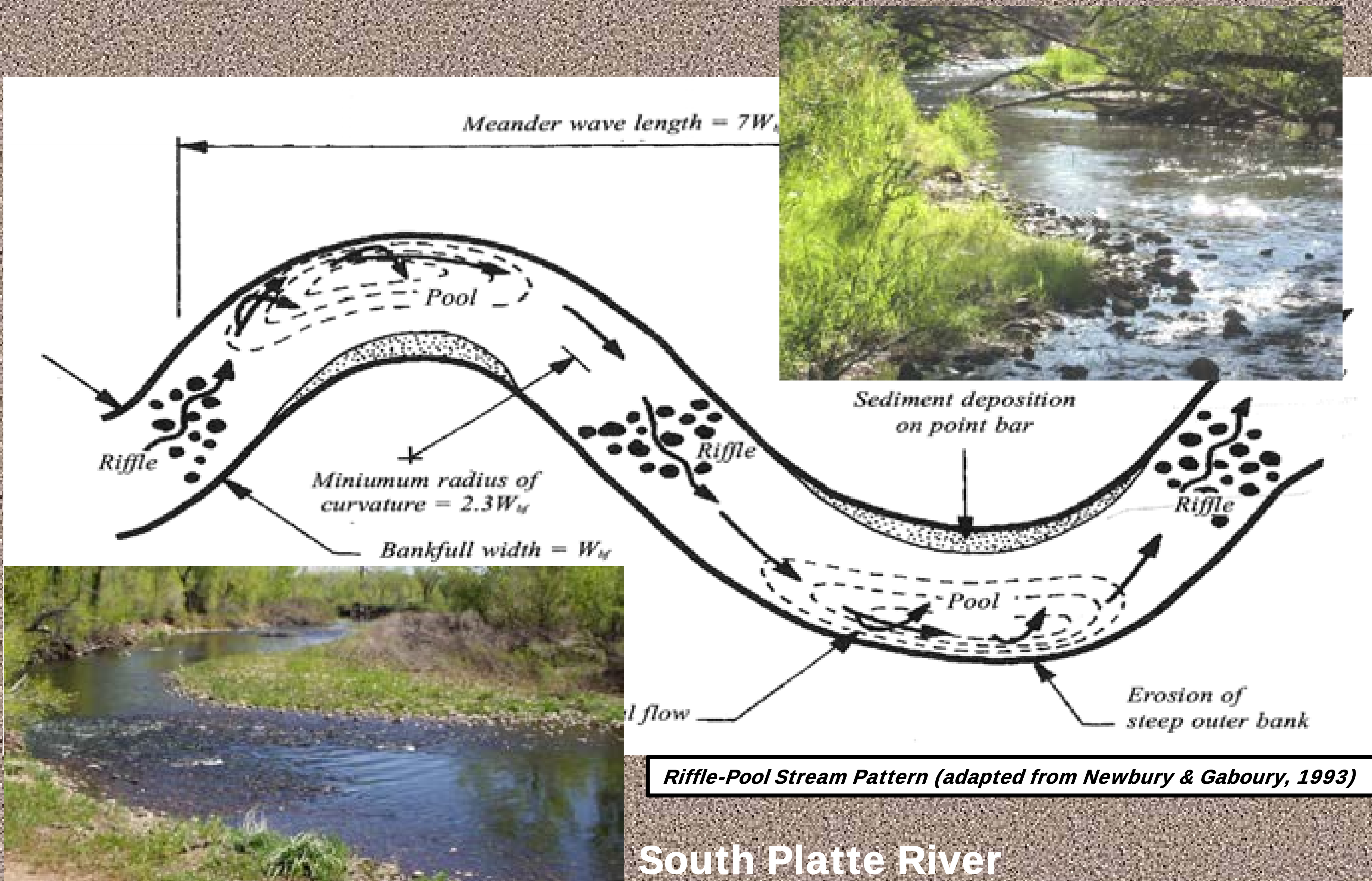
Healthy Riparian Corridor:

Shallow baseflow channel with storm flows spilling into wide, well vegetated overbanks.



Riffle-pool Stream Form

Bear Creek



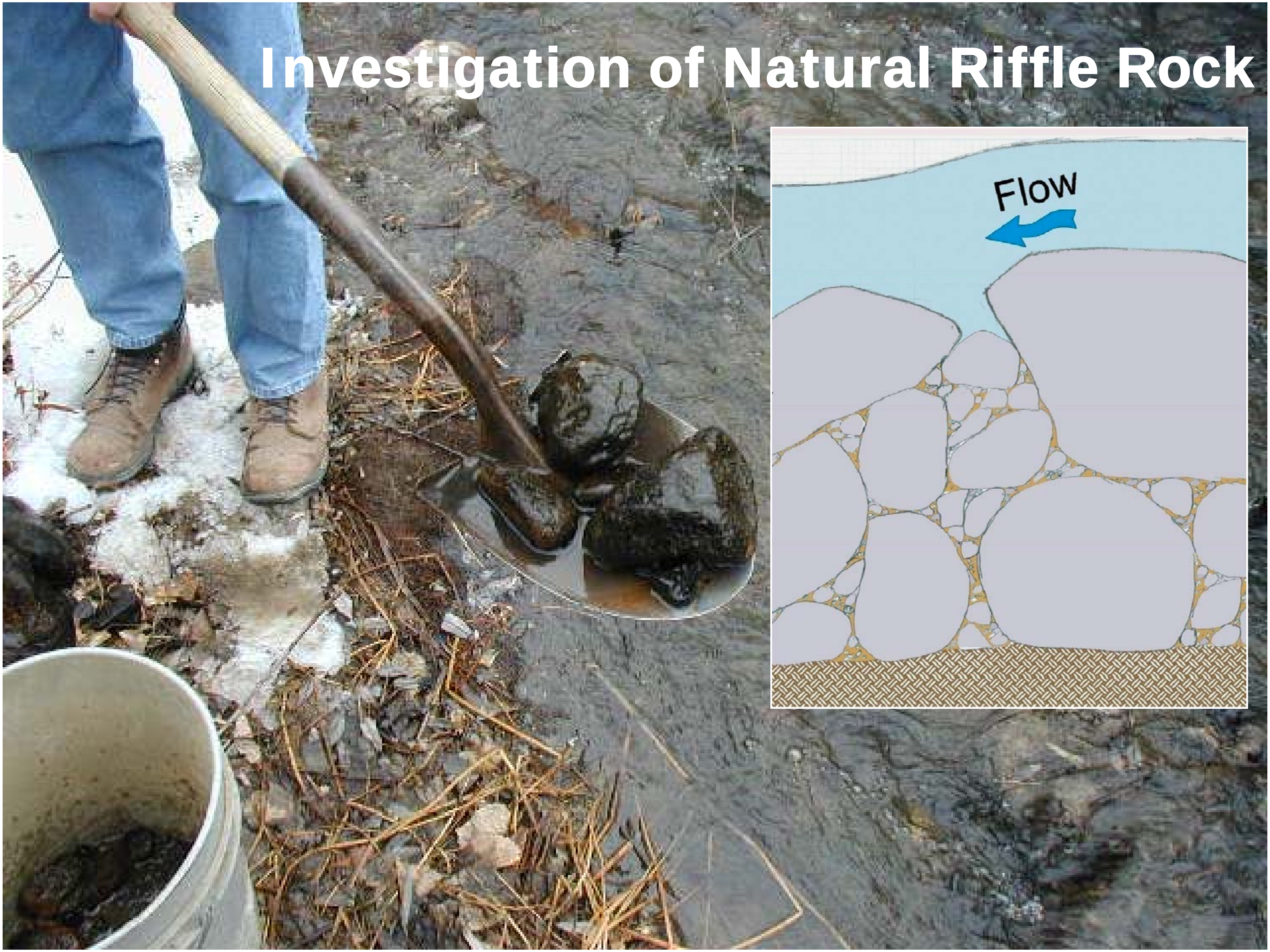
Riffle-Pool Stream Pattern (adapted from Newbury & Gaboury, 1993)

South Platte River

Cottonwood Creek Reclamation Plan

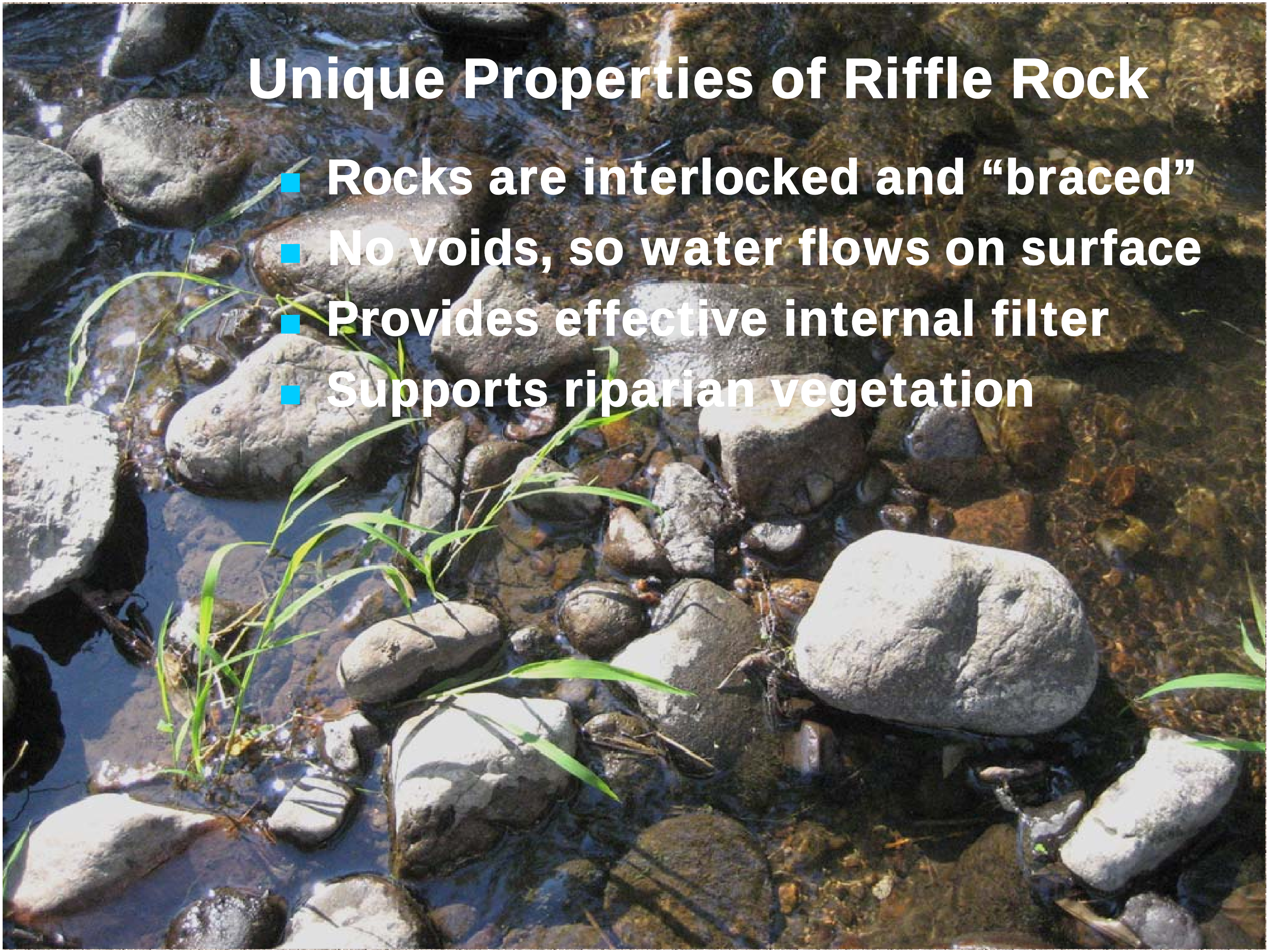

Investigation of Natural Riffle Rock
Bear Creek

Investigation of Natural Riffle Rock

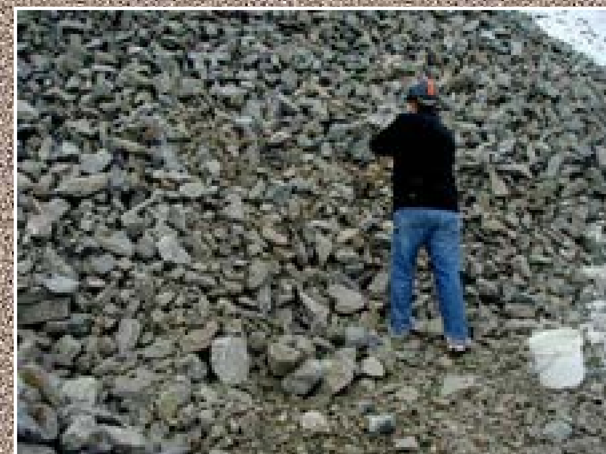


Unique Properties of Riffle Rock

- Rocks are interlocked and “braced”
- No voids, so water flows on surface
- Provides effective internal filter
- Supports riparian vegetation



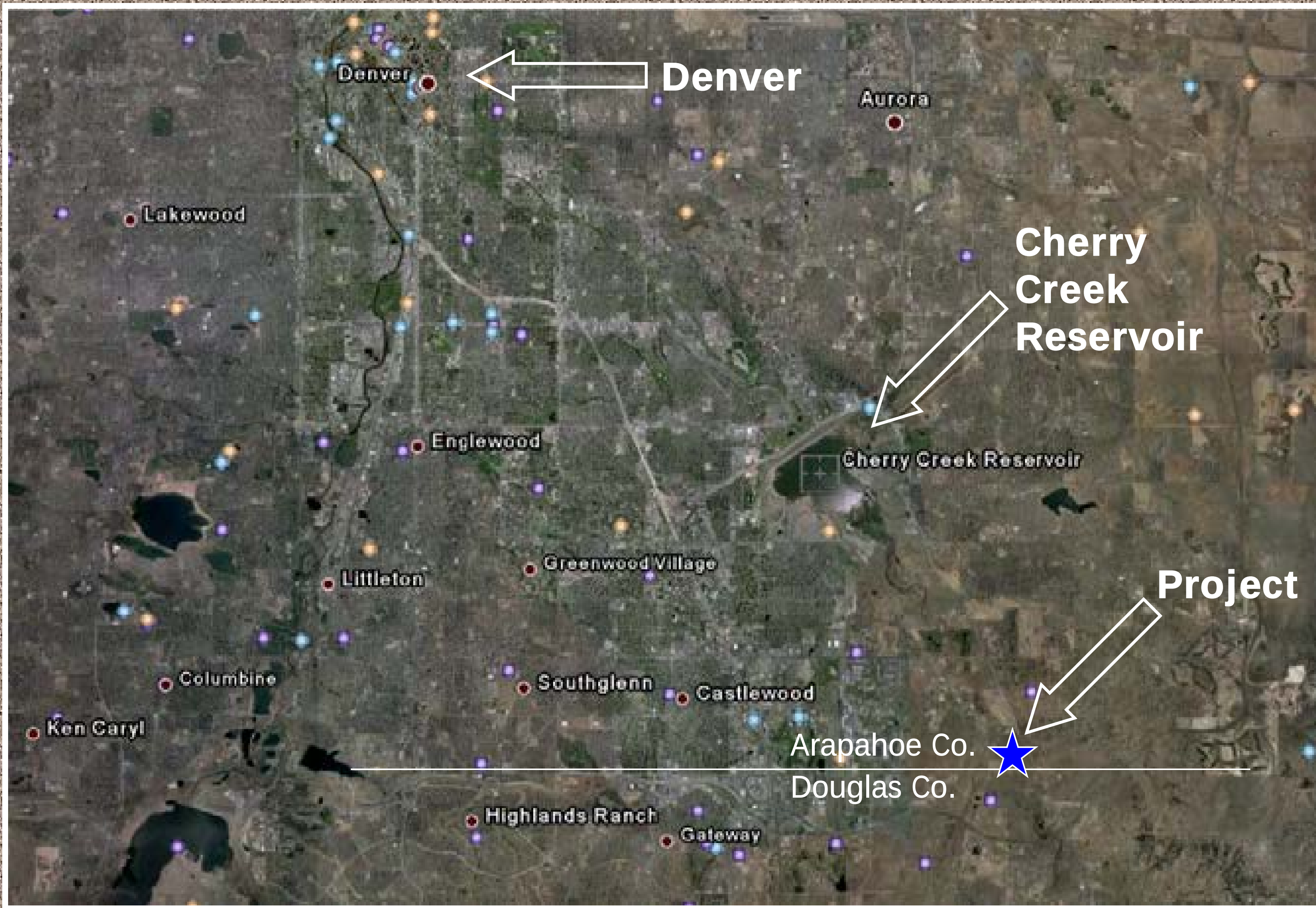
Riffle Rock Ingredients



Mixed Riffle Rock

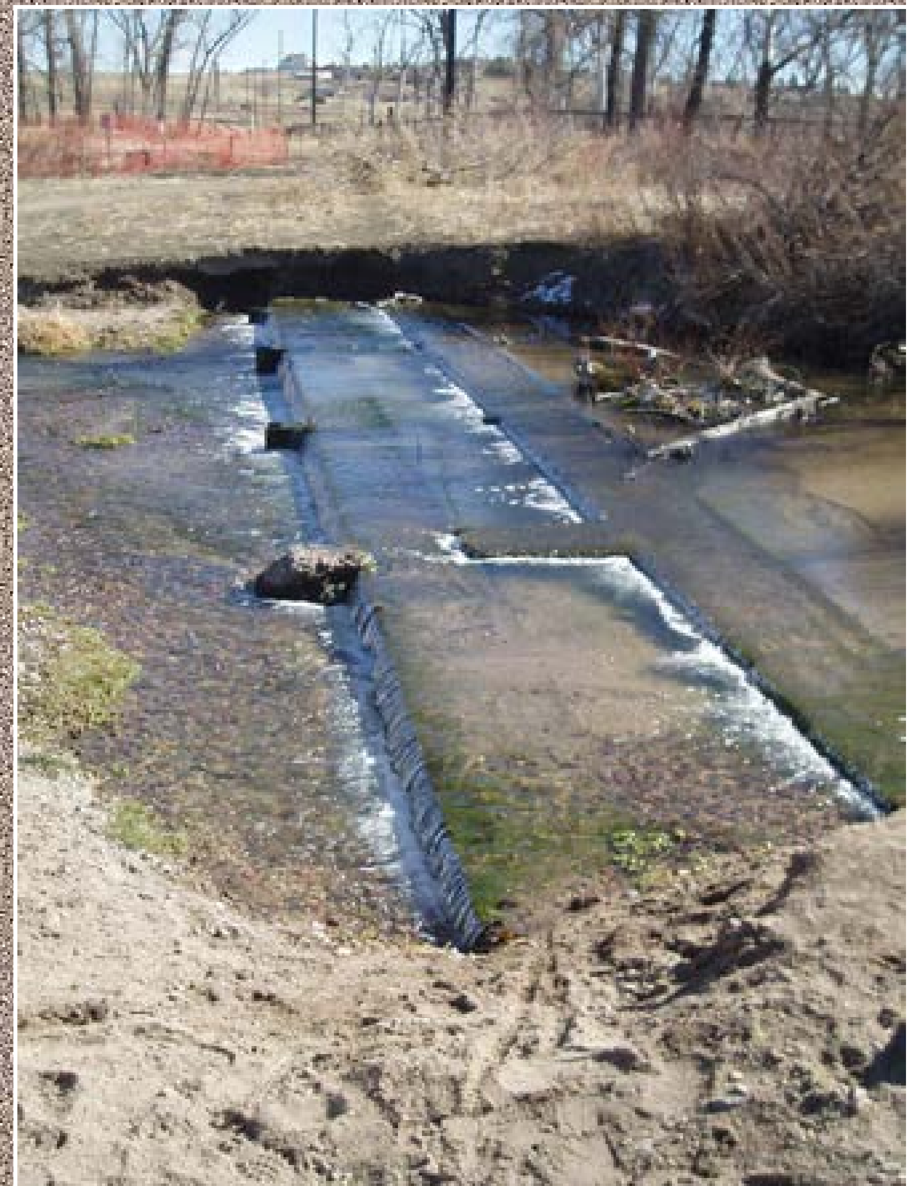

After Placement and Compaction

Cherry Creek Open Space Restoration



Pre-Project Conditions

Upper Reach



Middle Reach

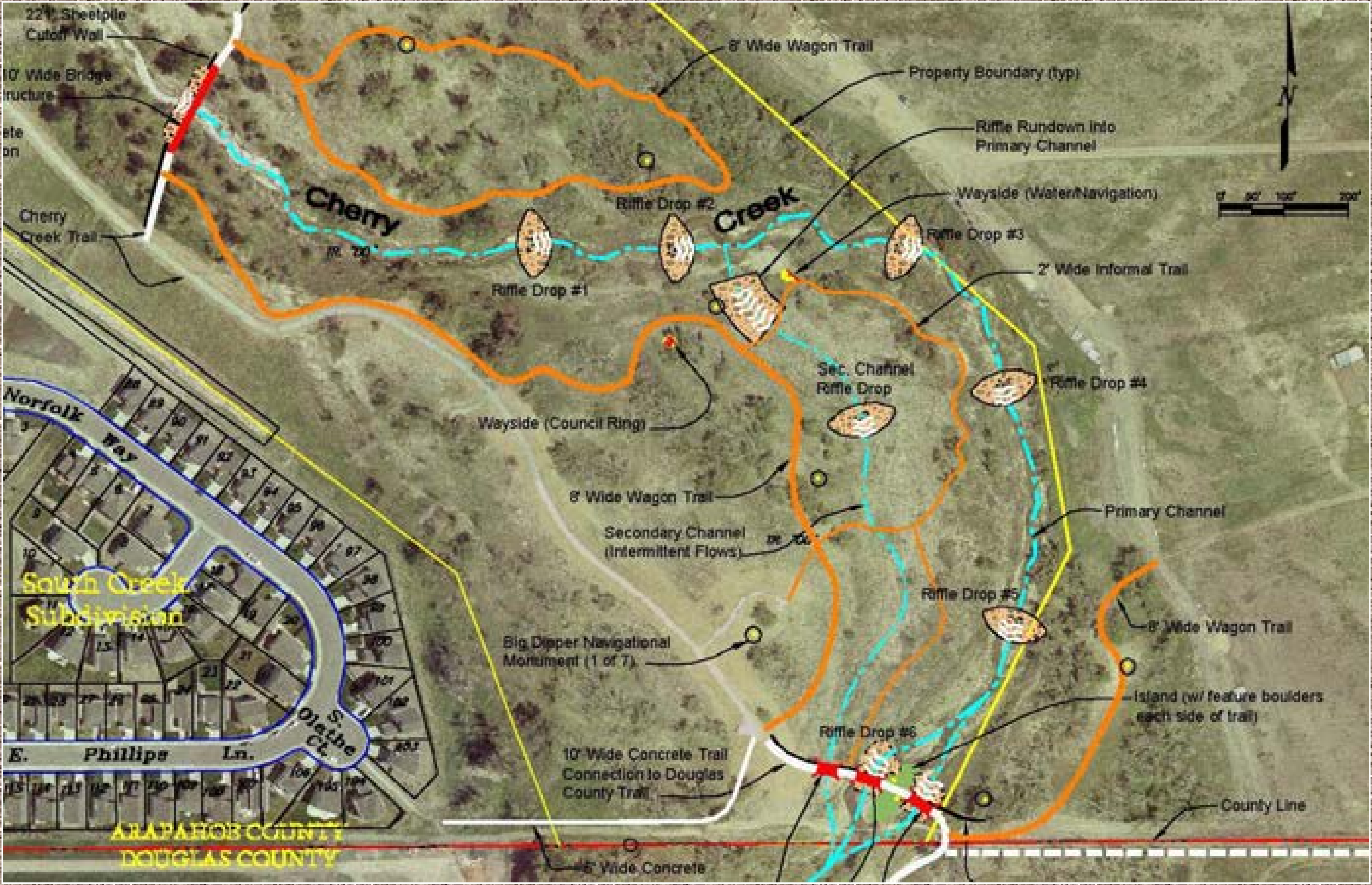
Lower Reach

Project Vision

- Goal was not just stabilization, but *restoration* of natural stream processes.
- Preserve the Cherry Creek “sponge effect”.
- Create a model project for environmental permitting.
- Pursue opportunities for multi-function open space enhancements.
- Bring the community to the creek

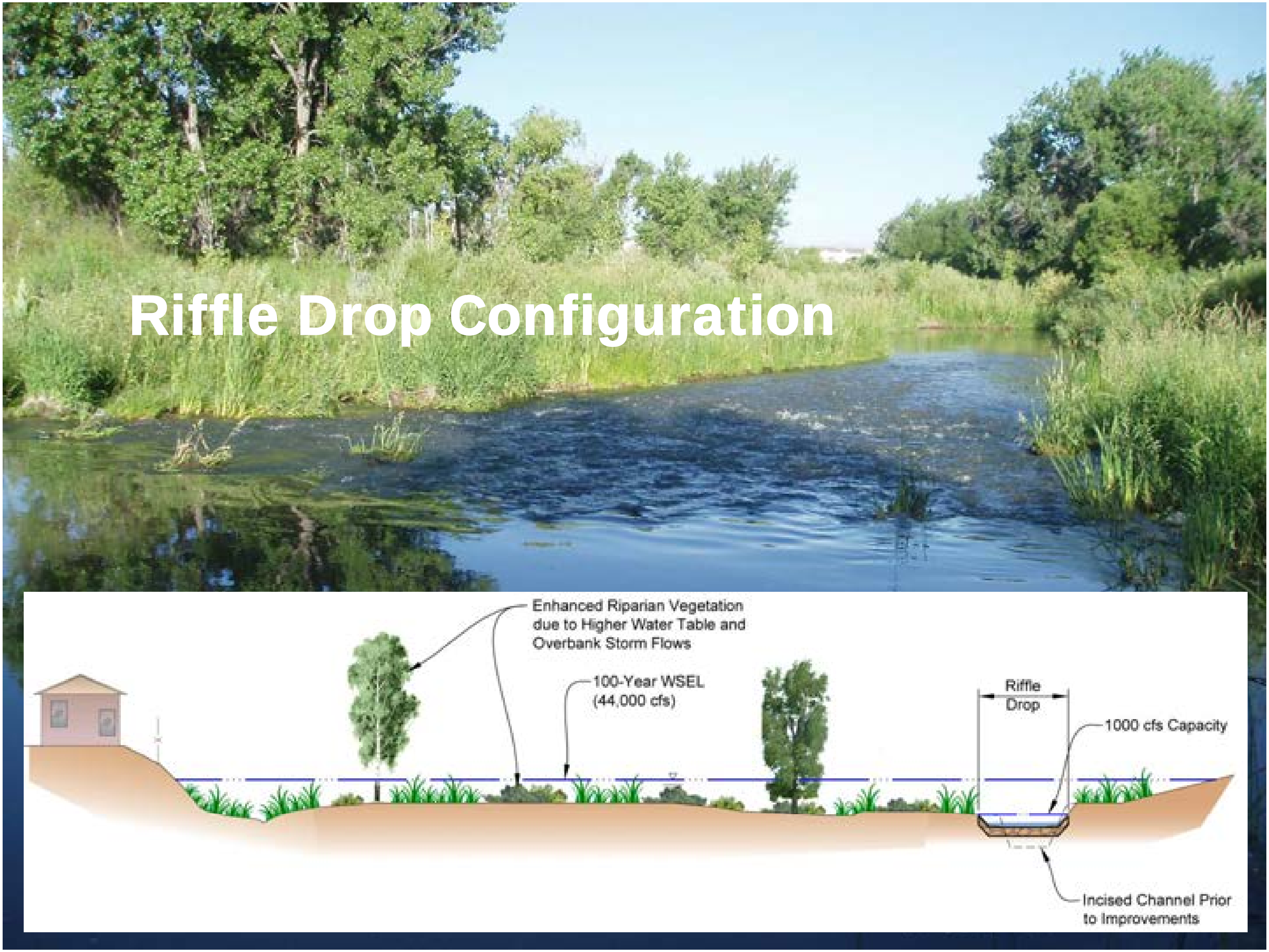
Restoration of Cherry Creek

Redistributed Flows and Riffle Drop Grade Control




Riffle Drop Advantages
Maintains shallow baseflow channel and high water table.
Low height and gentle slope allows drop to drown out.
Cost effective.
Supports riparian revegetation.
Enables fish passage
Natural appearance and function.
Acceptance by regulatory agencies.

Riffle Drop Configuration




Riffle Drop Configuration


Completed Project


Upper Marcy Gulch
“Before” Condition

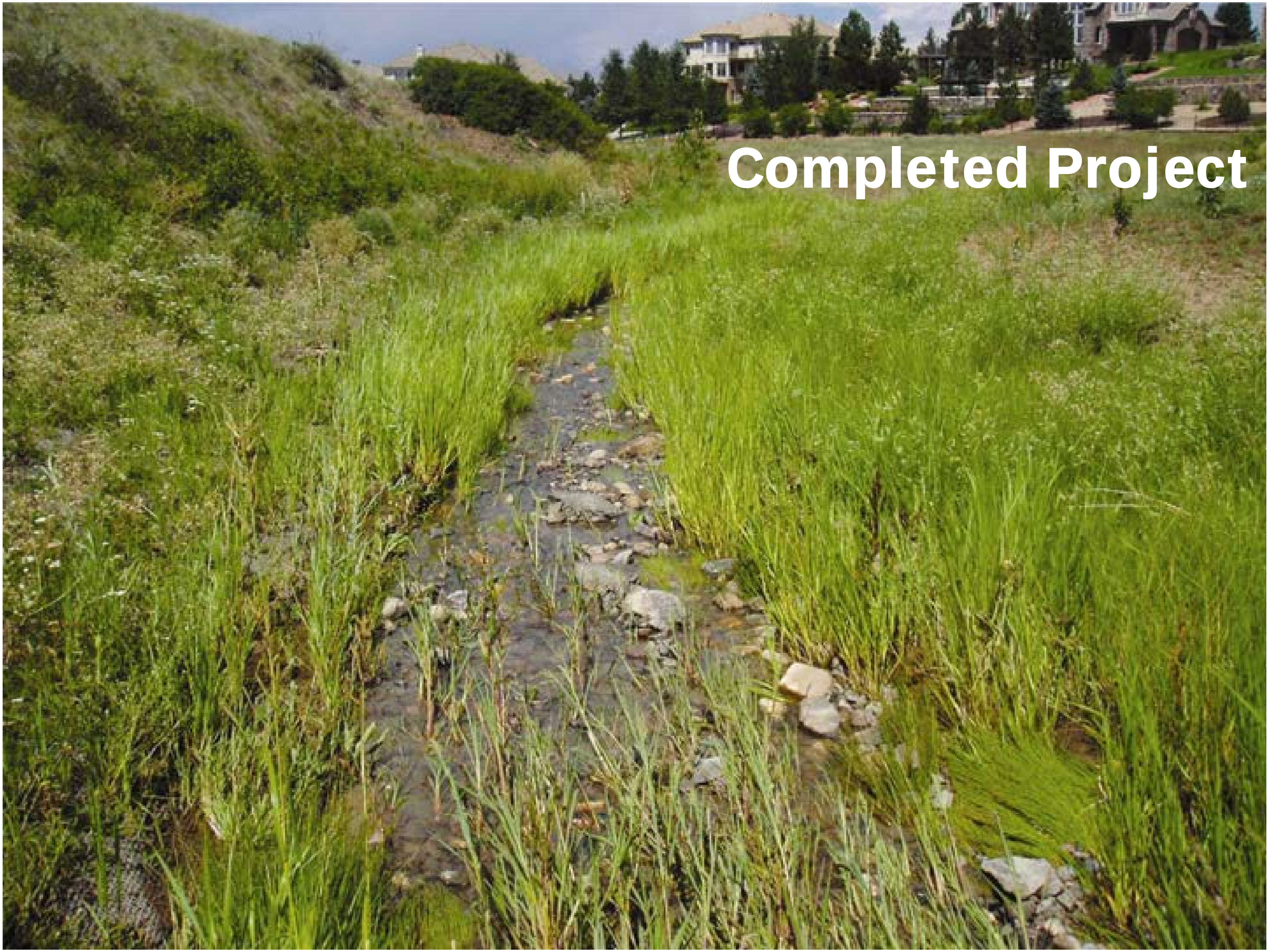

Upper Marcy Gulch
“Before” Condition

During Construction


During Construction


Riffle Rock Lining and
Boulder Drop


Ability of Riffle Rock to
Support Riparian Vegetation


Completed Project

Suitable Conditions for Riffle Drops

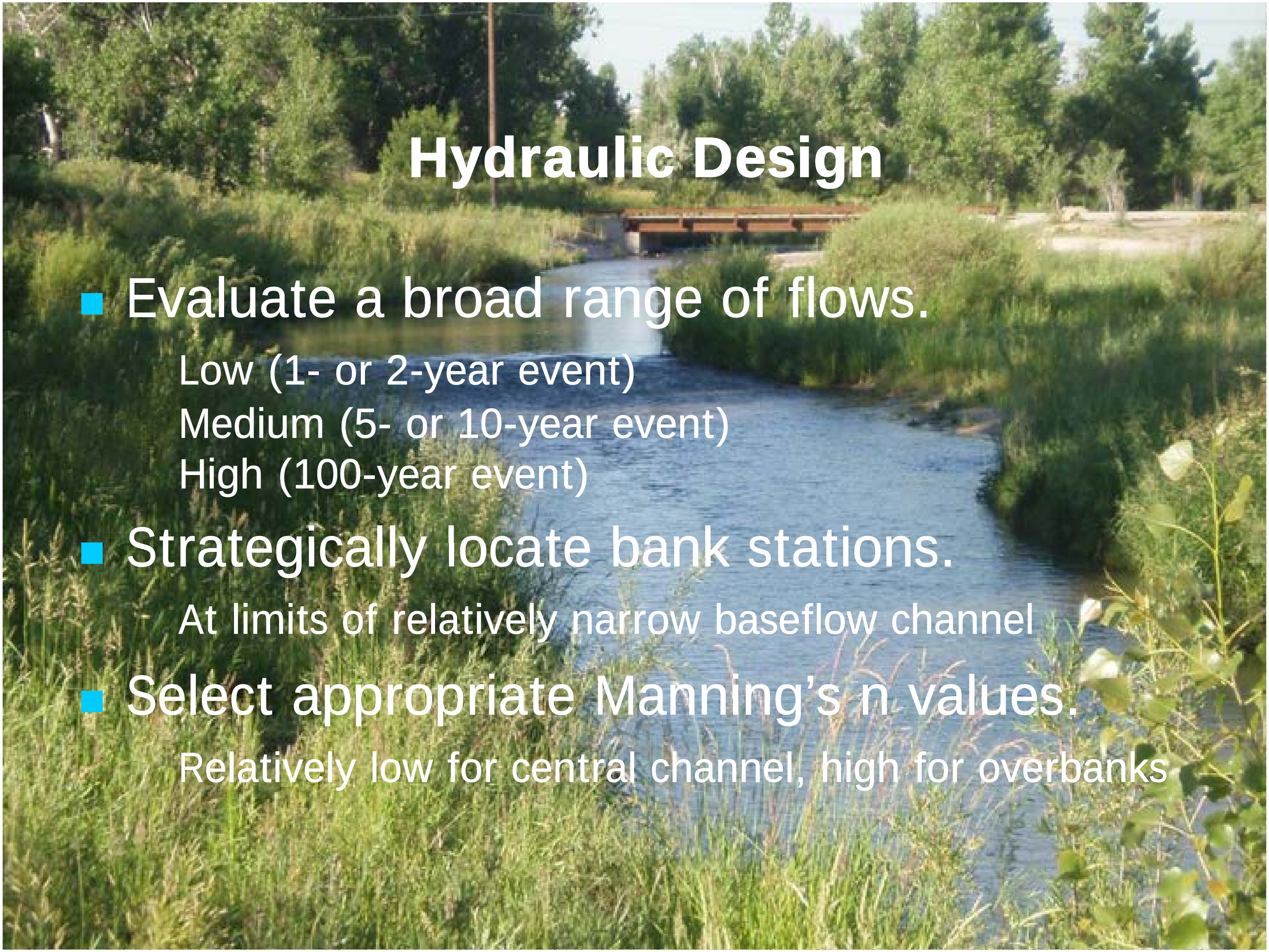
- Wide, flat floodplains with shallow active channels.
- Low gradient streams where riffle drops can “drown out”.
- Vegetated overbanks that can handle periodic flooding.
- Locations where only a small drop height (approximately 1-foot) is desired.

Limitations Regarding Riffle Drops

- Requires thorough hydraulic analysis and knowledgeable interpretation.
- Riffle drops are very installation-sensitive, requiring attention during construction.
- Requires preservation and enhancement of overbank vegetation.
- Not a “hard point”, so rock may move.

Riffle Drop Layout

- Longitudinal slope of 20:1 (5-percent) or flatter.
- Continue at least 1-foot below channel invert.
- Base on conservative long-term equilibrium slope.
- Crest width equal to baseflow channel, side slopes < 8:1 carried up 1.5 to 3 feet.
- Rock thickness at least 2 times D50.
- Additional rock thickness at upstream end or provide cutoff.
- D50 range 6 to 18-inches.


Hydraulic Design
Evaluate a broad range of flows.
Low (1- or 2-year event)
Medium (5- or 10-year event)
High (100-year event)
Strategically locate bank stations.
At limits of relatively narrow baseflow channel
Select appropriate Manning’s n values.
Relatively low for central channel, high for overbanks

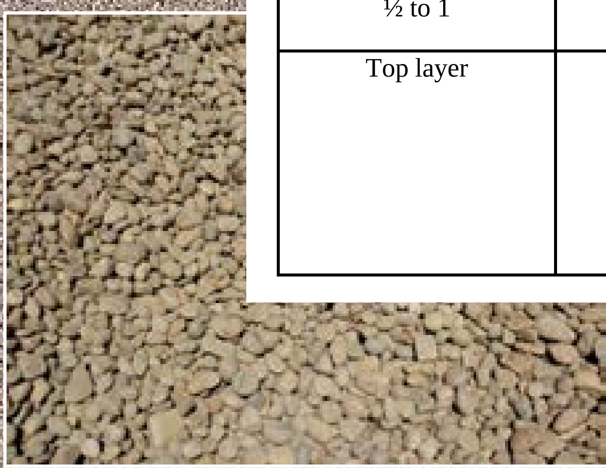
Rock Sizing Methods

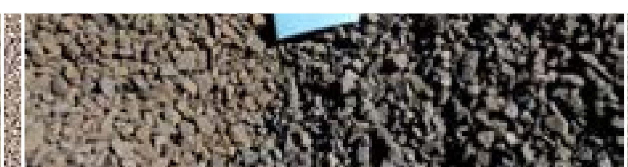
- Steep slope conditions.
  - CSU equation (Abt, et al, 1988)
  - USDA equations (Robinson, et al, 1998)
  - COE equation (EM1110-2-1601, 1991)
- Mild slope conditions.
  - UDFCD equation (Volume 1, 2001)
  - COE Equation (EM1110-2-1601, 1991)
- Design safety factor.

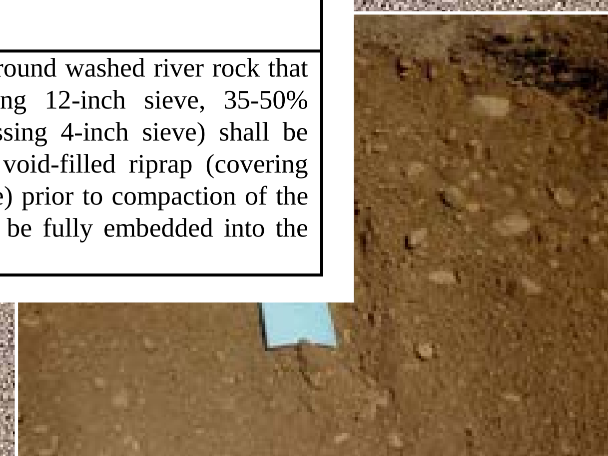
Specifying a Riffle Rock Mix

Specifying a Riffle Rock Mix

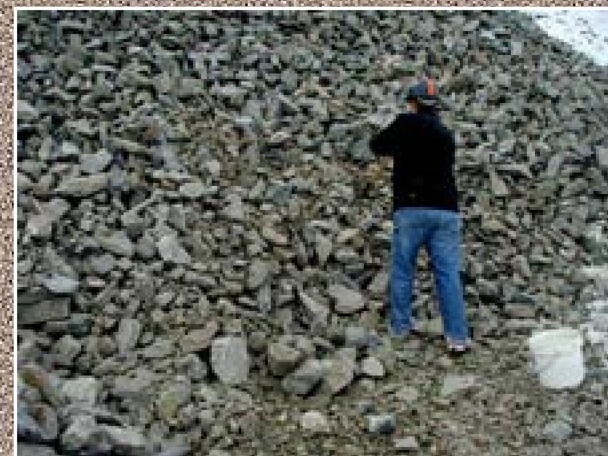
Approximate Proportions (loader buckets)	Material Type	Material Description
6	Riprap	D50=18-inch (Type H)
3	Void-fill material	7-inch minus crushed rock surge (100% passing 7-inch sieve, 80-100% passing 6-inch sieve, 35-50% passing 3-inch sieve, 10-20% passing 1.5-inch sieve)
1	Void-fill material	2 to 4-inch cobble (round washed river rock that is well-graded, 100% passing 6-inch sieve, 35-50% passing 3-inch sieve, 5-20% passing 2-inch sieve)
1	Void-fill material	4-inch minus pit run surge (round river rock and sand, well graded, 90-100% passing 4-inch sieve, 70-80% passing 1.5-inch sieve, 40-60% passing 3/8-inch sieve, 10-30% passing #16 sieve).
1	Void-fill material	Type II bedding
½ to 1	Void-fill material	Native topsoil
Top layer	Top dressing	Additional 4 to 12-inch cobbles (round washed river rock that is well graded, 80-100% passing 12-inch sieve, 35-50% passing 6-inch sieve, 5-20% passing 4-inch sieve) shall be mixed in on the surface of the void-filled riprap (covering approximately 30% of the surface) prior to compaction of the void-filled riprap. Cobbles shall be fully embedded into the mass of the void-filled riprap.







Construction Guidance



Construction Guidance

Mixing Riffle Rock

Construction Guidance

Placing Riffle Rock

Construction Guidance

Grading and Compacting Riffle Rock

Construction Guidance

Backfilling side slopes

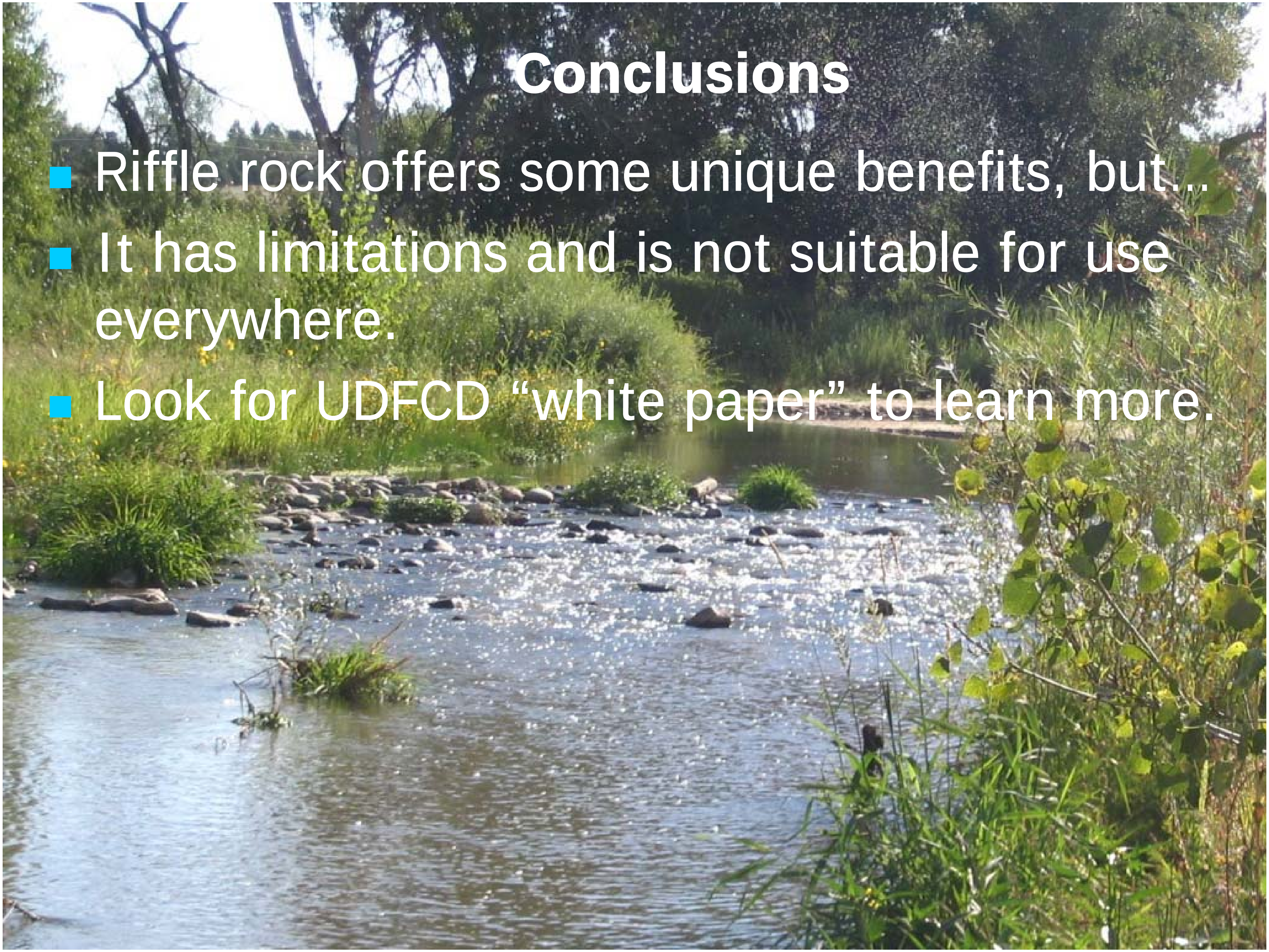
Construction Guidance

Revegetating


Completed Drop

Conclusions

- Riffle rock offers some unique benefits, but…
- It has limitations and is not suitable for use everywhere.
- Look for UDFCD "white paper" to learn more.



The New USDCM Volume 3

CASFM 2010

Holly Piza, P.E., UDFCD
and
T. Andrew Earles, Ph.D., P.E., D.WRE,
Wright Water Engineers, Inc.

WRIGHT WATER ENGINEERS, INC.

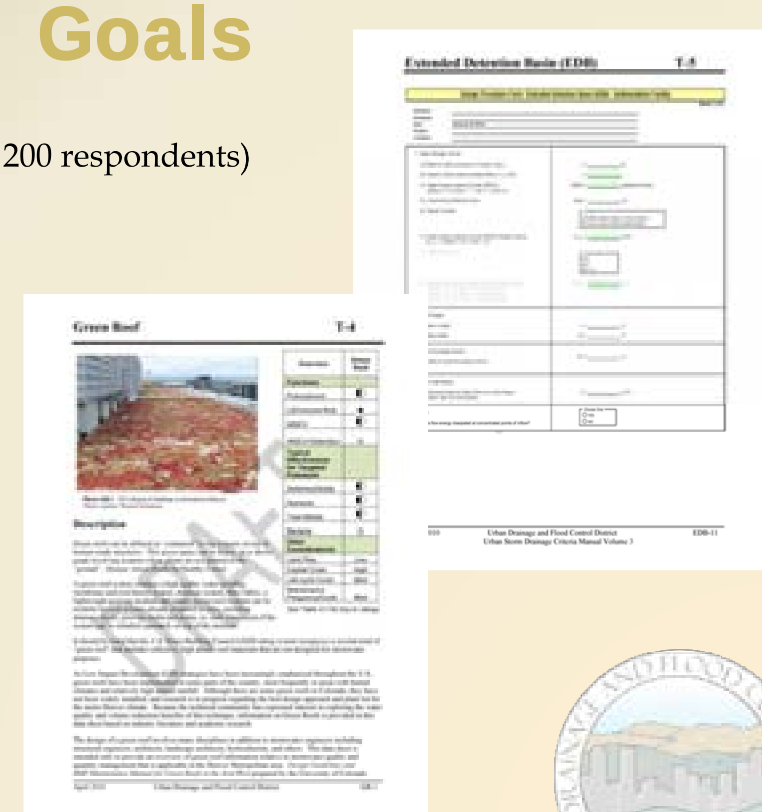
Agenda

- Overview of Rewrite
- BMP Selection
- Quantifying Volume Reduction
- Treatment BMPs

Goals

(Based on a survey of over 200 respondents)

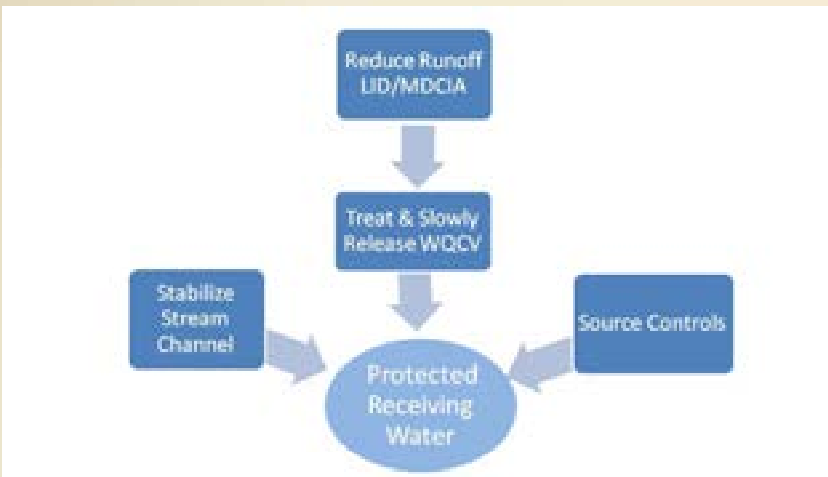
- Format
- Content
- Software


Extended Detention Basin (EDB) T-5

Green Roof T-4

USDCM Volume 3 History and Fundamentals

- First Release in 1992
- No Change in Concept



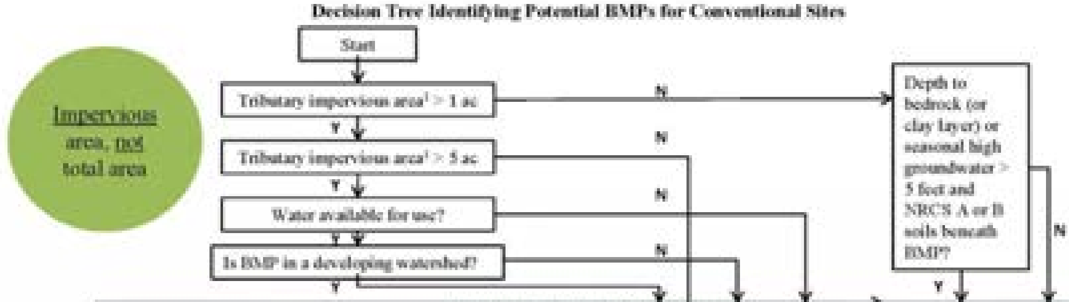
The Four Step Process

Overview of Manual

1. Stormwater Management and Planning
2. BMP Selection
3. WQCV and Runoff Volume Reduction
4. Treatment BMPs
5. Source Control BMPs
6. Construction BMPs
7. BMP Maintenance

Treatment BMPs	Source Control BMPs	Construction BMPs
• Grass Swales • Sand Filter • EDB • (*and so on*)	• Covering Storage & Handling Areas • Disposal of Household Waste • (*and so on*)	• Inlet Protection • Stockpile Storage • Sediment Basins • (*and so on*)

Decision Tree Identifying Potential BMPs for Conventional Sites

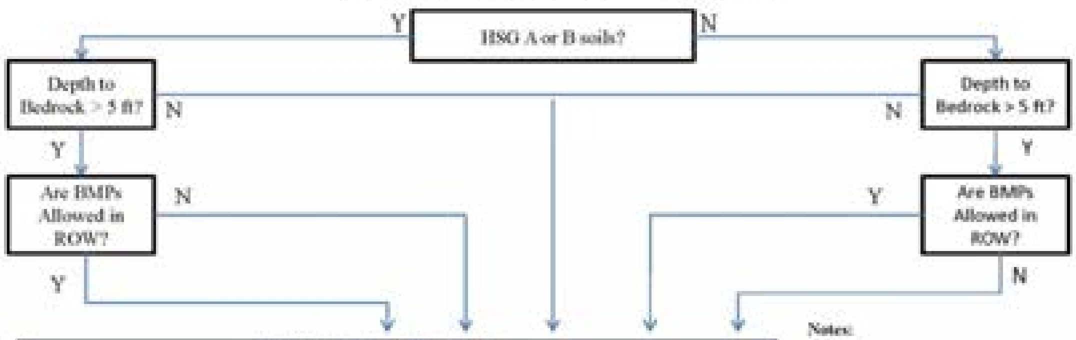


Step 1—Runoff Reduction Practices						
Grass Swale	●	●	●	●	●	●
Grass Buffer					●	●
Constructed Wetland Channel[2]	●[2]	●[2]	●[2]	●[2]	●[2]	●[2]
Permeable Pavement—Full Infiltration[5]					●	
Permeable Pavement—No or Partial Infiltration[5]						●
Green Roof					●[3]	●[3]
Step 2—Provide WQCV with Slow Release						
Permeable Pavement — Full Infiltration[5]					●	
Permeable Pavement – No or Partial Infiltration[5]						●
Bioretention—Full Infiltration[5]					●	
Bioretention—No or Partial Infiltration[5]						●
Extended Dry Detention Basin	●	●	●	●		
Constructed Wetland Basin[2]	●	●				
Retention Pond	●	●				
Sand Filter Extended Detention		●	●	●	●	●
Green Roof					●[3]	●[3]
Regional Water Quality Treatment	●[4]	●[4]	●[4]	●[4]	●[4]	●[4]

Notes

[1] "Tributary impervious area" refers to the impervious area draining to the BMP, not the total area of the project site.
[2] For a successful wetland channel or basin, a water source (groundwater or baseflow) will be required.
[3] In the Front Range of Colorado, irrigation, at least periodically in dry times, will be required to sustain a green roof.
[4] If a regional facility will be used to provide the WQCV, some degree of onsite treatment/MDCIA will still likely be required.
[5] No Infiltration = underdrain and liner, Partial Infiltration = underdrain and no liner, Full Infiltration = no underdrain and no liner

BMP Selection Flow Chart for Highly Urbanized Sites



Step 1—Runoff Reduction Practices					
Permeable Pavement—Full Infiltration[4]	●	●			
Permeable Pavement—Partial or No Infiltration[4]			●	●	●
Green Roof	●	●[1]	●[1]	●[1]	●[1]
Step 2—Provide WQCV with Slow Release					
Permeable Pavement—Full Infiltration[4]	●	●			
Permeable Pavement—Partial or No Infiltration[4]			●	●	●
Bioretention—Full Infiltration[4]	●	●			
Bioretention—Partial or No Infiltration[4]			●	●	●
Green Roof with Full WQCV	●[1]	●[1]	●[1]	●[1]	●[1]
Underground BMPs with Full WQCV		●[2]			●[2]
Regional Water Quality Treatment	●[3]	●[3]	●[3]	●[3]	●[3]

Notes:

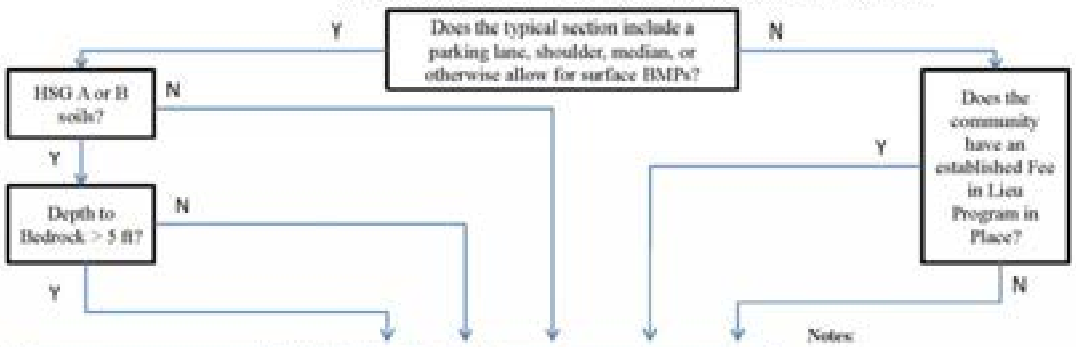
[1] In the Front Range of Colorado, irrigation, at least periodically in dry times, will be required to sustain a green roof.

[2] Underground BMPs should only be considered when surface-based BMPs are not practicable and only when approved by the local jurisdiction. See the Underground BMP Fact Sheet for additional restrictions on use.

[3] If a regional facility will be used to provide the WQCV, some degree of onsite treatment/MDCIA will still likely be required.

[4] No Infiltration = underdrain and liner
Partial Infiltration = underdrain and no liner
Full Infiltration = no underdrain and no liner

BMP Selection Flow Chart for Linear Construction in Urbanized Areas



Step 1—Runoff Reduction Practices					
Permeable Pavement—Full Infiltration[3]	●				
Permeable Pavement—Partial or No Infiltration[3]		●	●		
Biofiltration Tree Planter				●	●
Step 2—Provide WQCV with Slow Release					
Permeable Pavement—Full Infiltration[3]	●				
Permeable Pavement –Partial or No Infiltration[3]		●	●		
Bioretention—Full Infiltration[3]	●				
Bioretention—Partial or No Infiltration[3]		●	●		
Fee in Lieu/Offsite Mitigation				●[4]	
Underground BMPs with Full WQCV				●[1]	●[1]
Regional Water Quality Treatment	●[2]	●[2]	●[2]	●[2]	●[2]

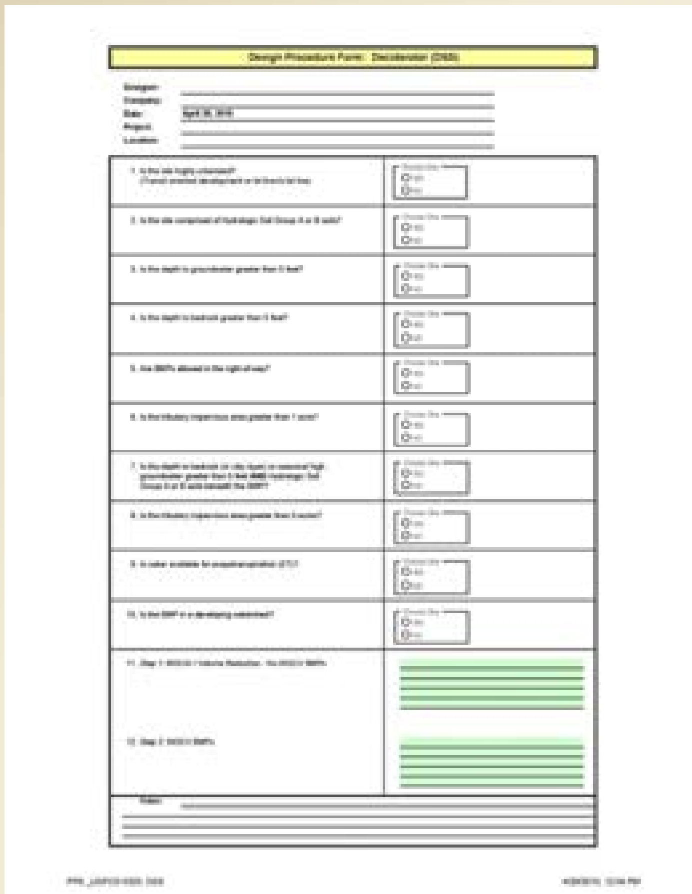
Notes:

[1] Underground BMPs should only be considered when surface-based BMPs are not practicable and only when approved by the local jurisdiction. See the Underground BMP Fact Sheet for additional restrictions on use.

[2] If a regional facility will be used to provide the WQCV, some degree of onsite treatment/MDCIA will still likely be required.

[3] No Infiltration = underdrain and liner
Partial Infiltration = underdrain and no liner
Full Infiltration = no underdrain and no liner

[4] Only recommended when the community has an established program for "Fee in Lieu"



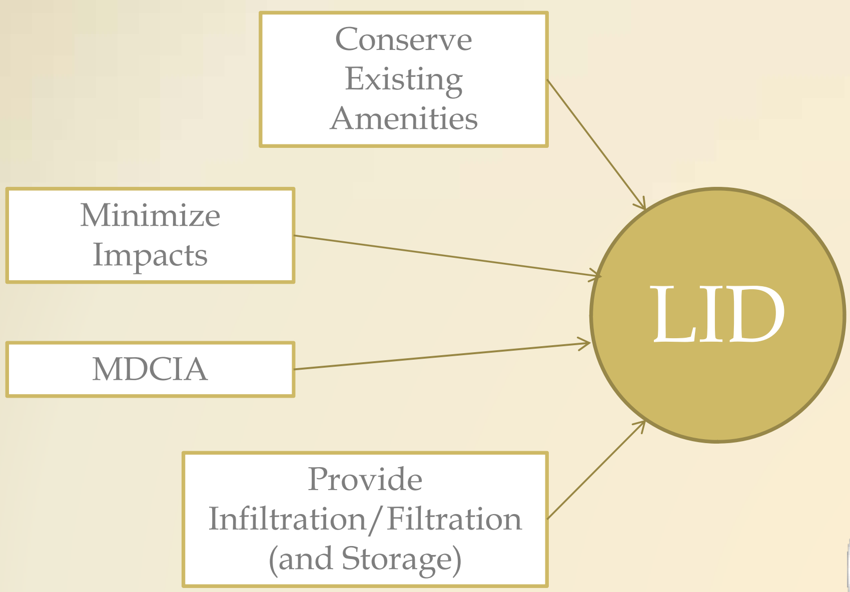
BMP Selection

Site Conditions
- Size
- Soils
- Contributing Drainage Area
- Groundwater
- Base flows
- Watershed Development Activities

Treatment Processes
- Sedimentation
- Straining
- Infiltration or filtration
- Evapotranspiration
- Biological Uptake

Land Use
- Ultra Urban
- High Density Mixed Used
- Campus
- Industrial
- Low Density Mixed Use
- Residential
- Parks and Open Space

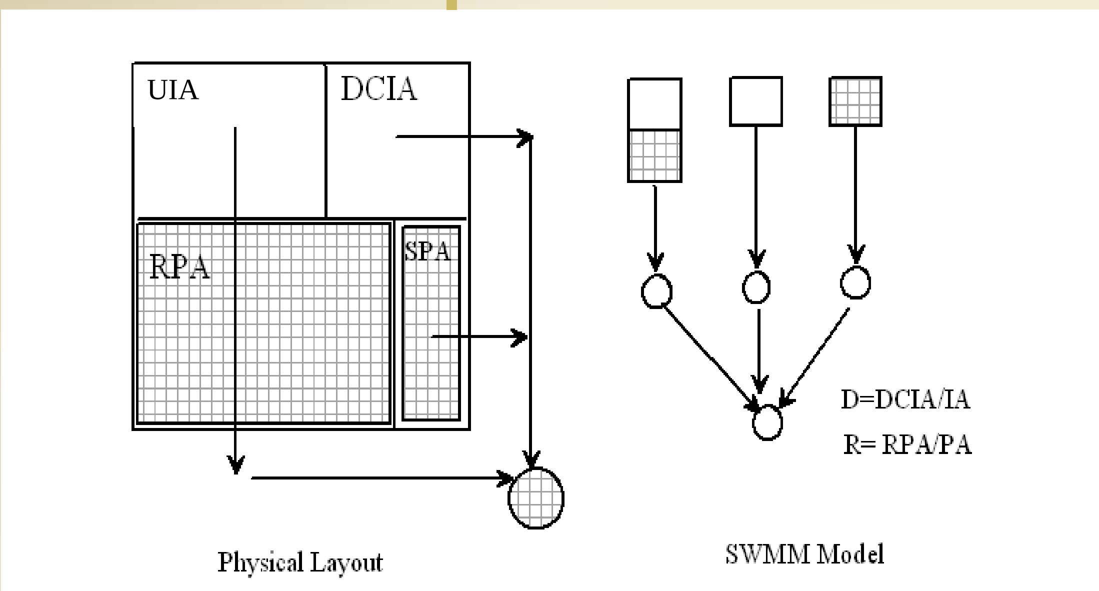
Effective Impervious Calculations and LID



Volume Reduction

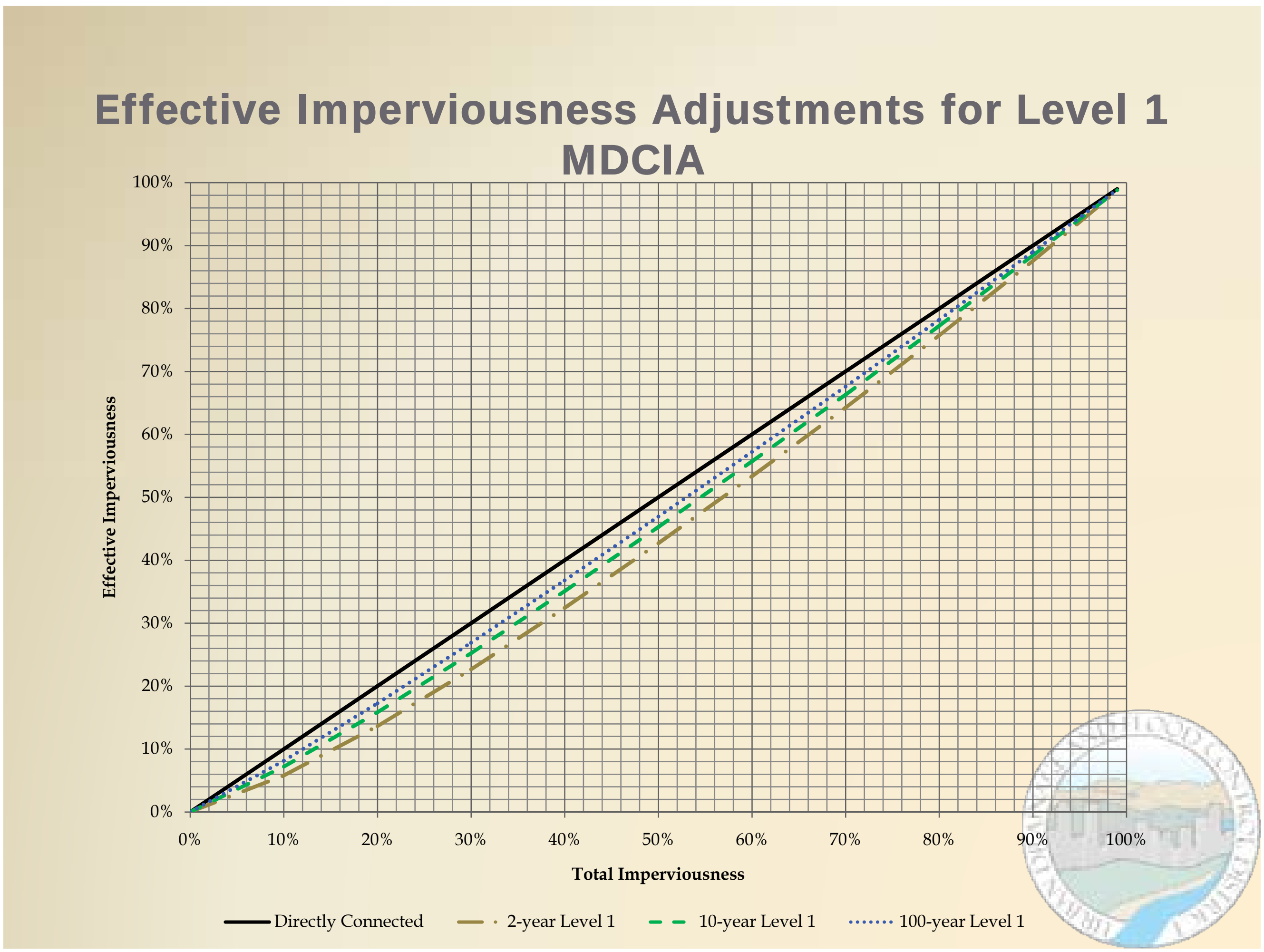
- Minimization of Directly Connect Impervious Area (MDCIA)
- Infiltration-based BMPs
- Master planning level versus site level

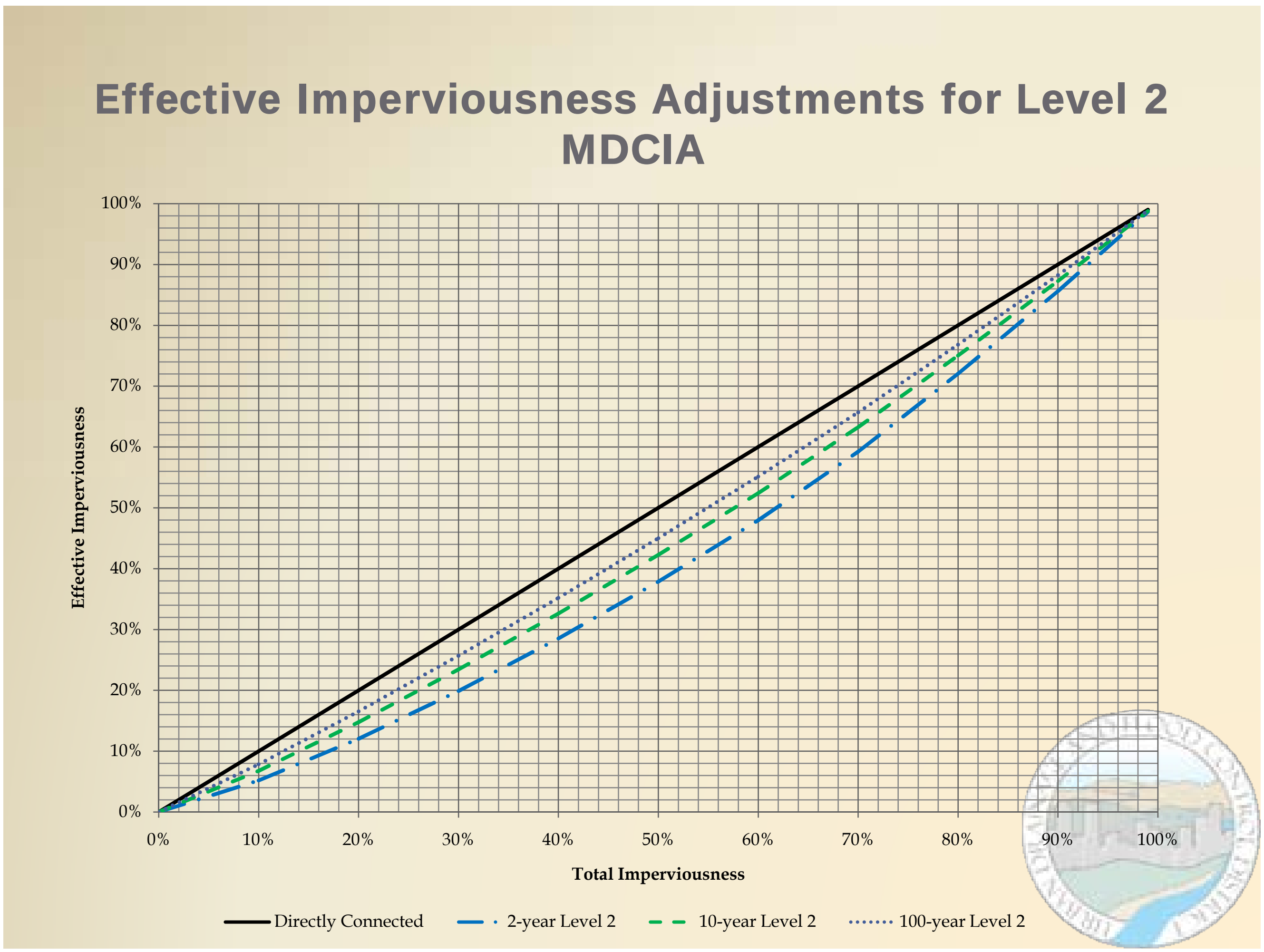
Conceptual Model



UIA = Unconnected Impervious Area
DCIA = Directly Connected Impervious Area

RPA = Receiving Pervious Area
SPA = Separate Pervious Area

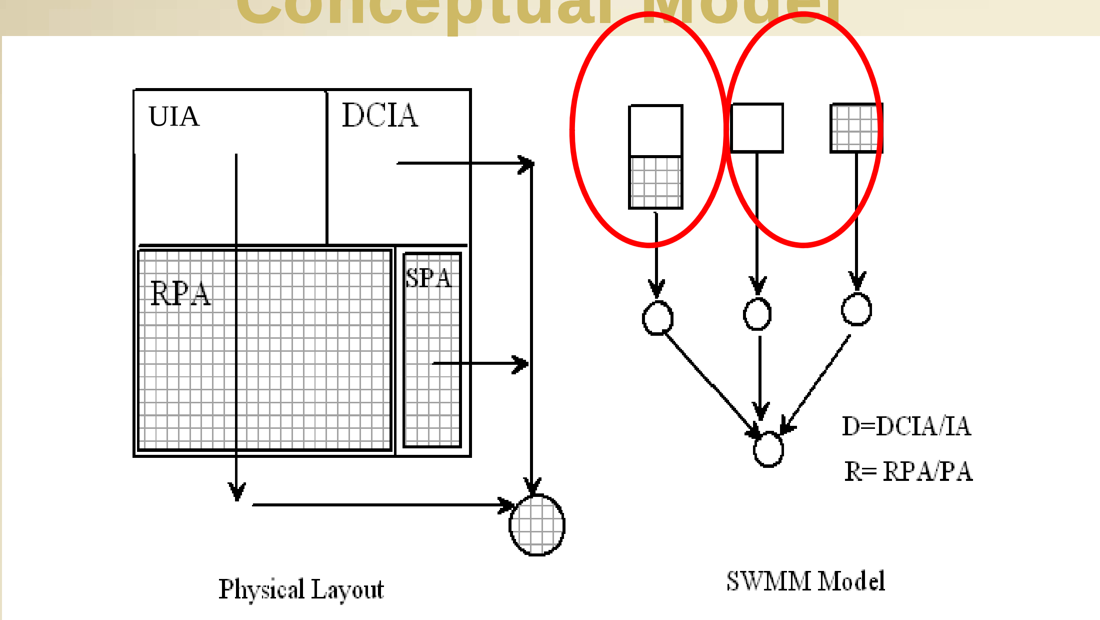

Effective Imperviousness Adjustments for Level 1 MDCIA
Effective Imperviousness
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Total Imperviousness
Directly Connected
2-year Level 1
10-year Level 1
100-year Level 1


Effective Imperviousness Adjustments for Level 2 MDCIA
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Effective Imperviousness
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Total Imperviousness
Directly Connected
2-year Level 2
10-year Level 2
100-year Level 2

SWMM Modeling Using Cascading Planes

- Conceptualize sub-watersheds as UIA, DCIA, SPA, RPA. Two approaches:
  - Two SWMM sub-catchments for each sub-watershed UIA + RPA and DCIA + SPA
  - Single SWMM sub-catchment with internal routing
- Rainfall distribution input to SWMM. Alternative: Use CUHP and specify D and R values.
- Parameters for infiltration, depression storage and other input parameters from *Runoff* chapter of UDFCD Manual.
- Two options for WQCV:
  - Pervious area depression storage
  - Storage unit with an outlet in SWMM.

Conceptual Model



UIA = Unconnected Impervious Area
DCIA = Directly Connected Impervious Area

RPA = Receiving Pervious Area
SPA = Separate Pervious Area

Dimensionless Analysis

- Conveyance-based BMPs:

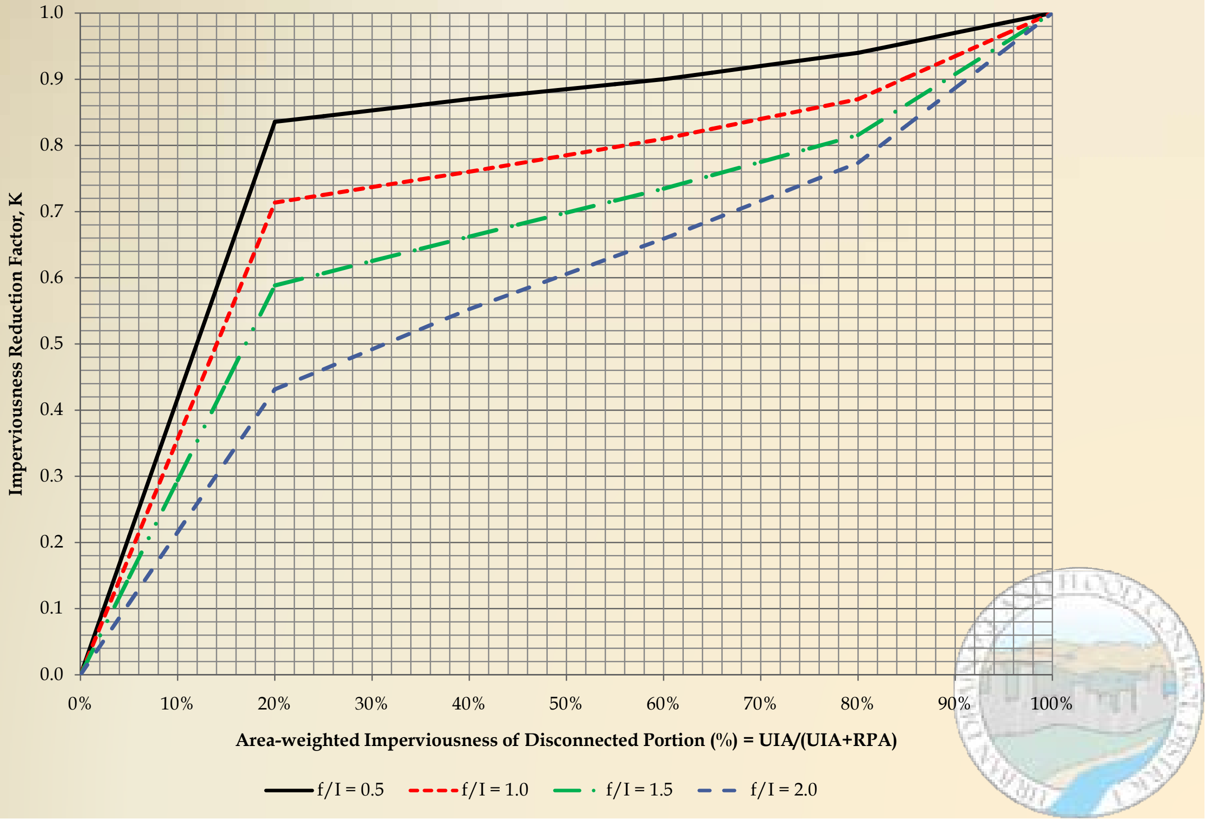
$$K = Fct(\frac{F_d}{P}, A_r) = Fct(\frac{f}{I}, A_r)$$

- Storage-based BMPs:

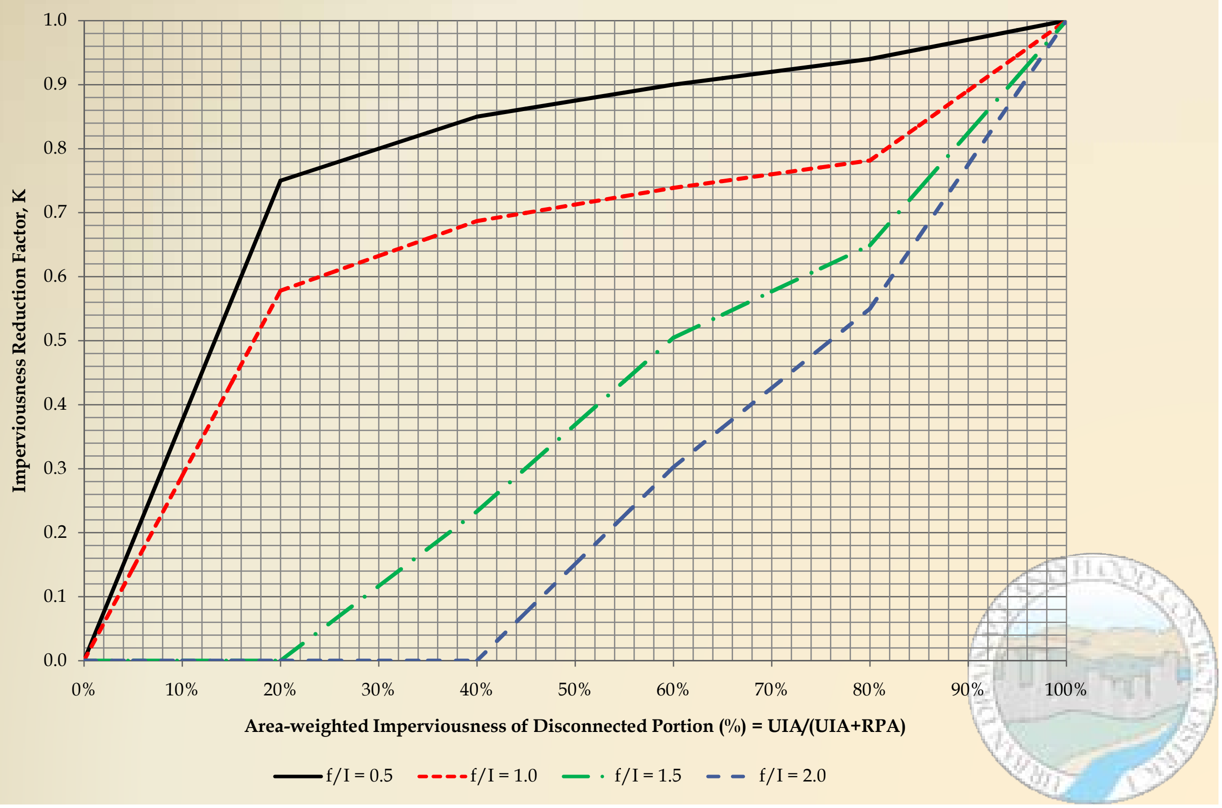
$$K = Fct(\frac{F_d}{P}, A_r, A_d \frac{WQCV}{P})$$

K = Imperviousness reduction factor
F_d = Pervious area infiltration loss (in)
f = Pervious area infiltration rate (in/hr) corresponding to saturated hydraulic conductivity
P = Design rainfall depth (in)
I = Rainfall intensity (in/hr)
A_r = RPA/UIA
A_d = RPA

Conveyance-based Imperviousness Reduction Factor



Storage-based Imperviousness Reduction Factor



Examples

Chapter 4, Treatment BMPs

Overview	Grass Swale	Grass Buffer	Constructed Wetland Channel	Permeable Pavement	Bioretention (Rain Garden)	Extended Detention Basin	Sand Filter	Retention Pond	Constructed Wetland Basin	Green Roof	Underground BMPs
Functions											
LID/Volume Red.	Yes	Yes	Somewhat	Yes	Yes	Somewhat	Yes	Somewhat	Somewhat	Yes	No
WQCV Capture	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Variable
WQCV+Flood Control	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Variable
Typical Effectiveness for Targeted Pollutants[3]											
Sediment/Solids	Good	Good	Unknown	Very Good[1]	Very Good[1]	Good	Very Good[1]	Very Good	Very Good	Unknown	Variable
Nutrients	Moderate	Moderate	Unknown	Good	Moderate	Moderate	Good	Moderate	Moderate	Unknown	Variable
Total Metals	Good	Good	Unknown	Good	Good	Moderate	Good	Moderate	Good	Unknown	Variable
Bacteria	Poor	Poor	Moderate	Poor	Moderate	Poor	Poor	Poor	Poor	Poor	Variable
Other Considerations											
Life-cycle Costs[4]	Low	Low	Low	High[2]	Moderate	Moderate	Moderate	Moderate	Moderate	Unknown	Moderate

[1] Not reccomended for watersheds with high sediment yields (unless pretreatment is provided).

[2] Does not consider the life cycle cost of the conventional pavement that it replaces.

[3] Based primarily on data from the International BMP Database (www.bmpdatabase.org).

[4] Based on BMP-REALCOST available at www.udfcd.org.

Grass Swale

Grass Swale	
Functions	
LID/Volume Red.	Yes
WQCV Capture	No
WQCV+Flood Control	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs[4]	Low

[3] Based primarily on data from the International BMP Database (www.bmpdatabase.org).

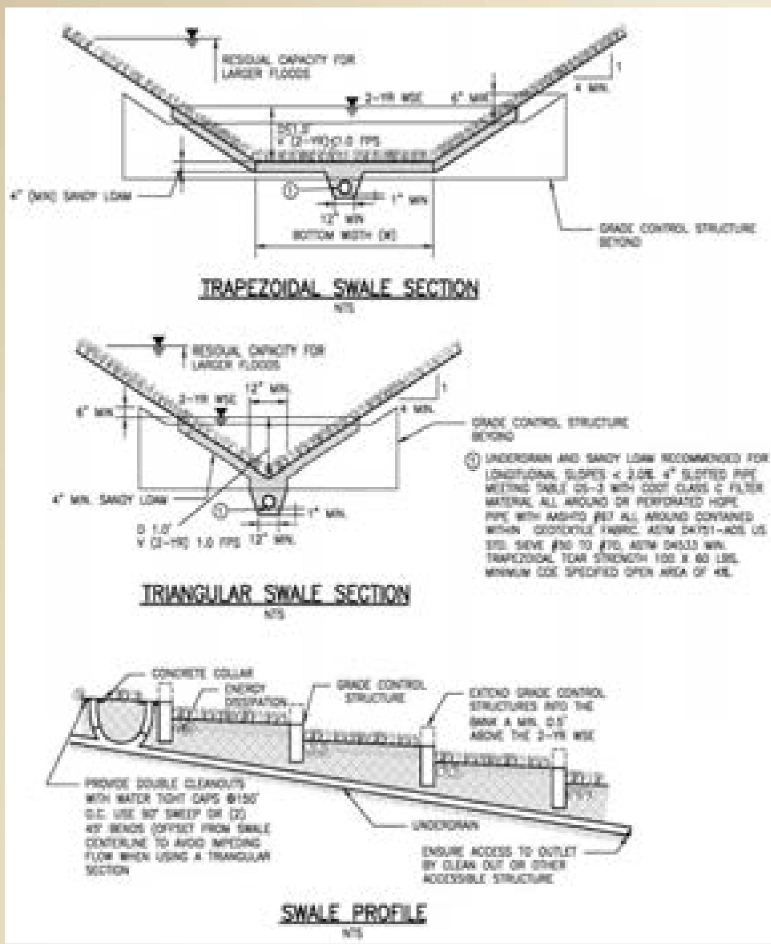
[4] Based on BMP-REALCOST available at www.udfcd.org.

- Removal of sediment and associated constituents through filtering (straining)
- Reduction of storm sewer systems in the upper portions of a watershed
- A less expensive and more attractive conveyance element

Grass Swale

Design Flow	Maximum Froude Number	Maximum Velocity	Maximum Flow Depth
2-year event	0.5	1 fps	1 foot

Grass Swale


RESIDUAL CAPACITY FOR LARGER FLOODS
2-YR WSE
4" (MIN) SANDY LOAM
1" MIN
12" MIN
BOTTOM WIDTH (B)
GRADE CONTROL STRUCTURE BEYOND
TRAPEZOIDAL SWALE SECTION
RESIDUAL CAPACITY FOR LARGER FLOODS
2-YR WSE
12" MIN
GRADE CONTROL STRUCTURE BEYOND
4" MIN. SANDY LOAM
1" MIN
12" MIN
TRIANGULAR SWALE SECTION
CONCRETE COLLAR
GRADE CONTROL STRUCTURE
UNDERDRAIN
SWALE PROFILE

Grass Buffer

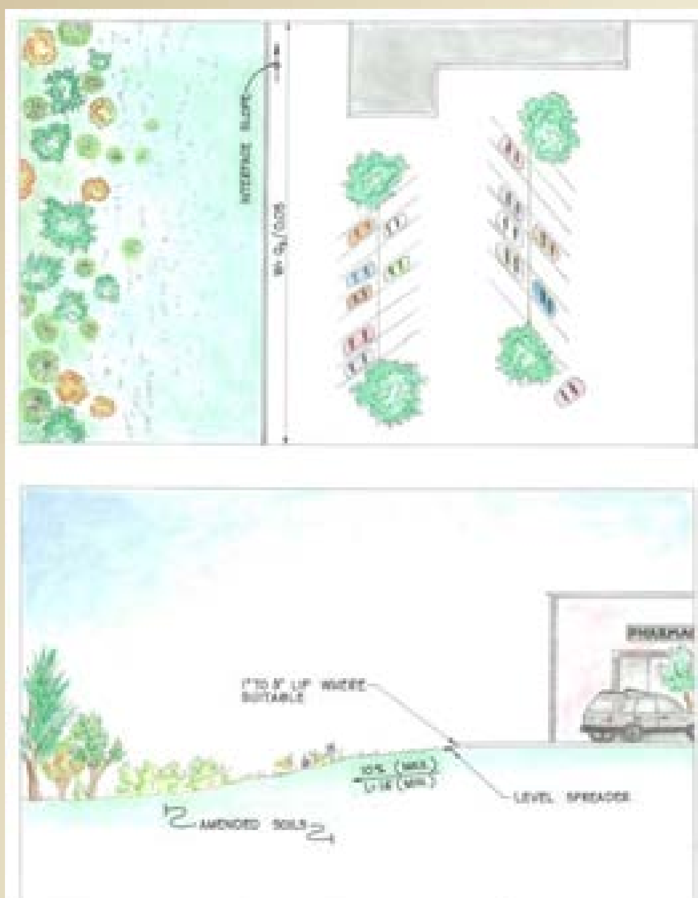
Photo Courtesy Muller Engineering

Grass Buffer	
	Functions
LID/Volume Red.	Yes
WQCV Capture	No
WQCV+Flood Control	No
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Good
Nutrients	Moderate
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs[4]	Low

[3] Based primarily on data from the International BMP Database (www.bmpdatabase.org).

[4] Based on BMP-REALCOST available at www.udfcd.org.

- Filters (strains) sediment and trash.
- Reduces directly connected impervious area.
- Can easily be incorporated into a treatment train approach.
- Provides green space available for multiple uses including recreation and snow storage.
- Straightforward maintenance requirements when the buffer is protected from vehicular traffic.



Grass Buffer

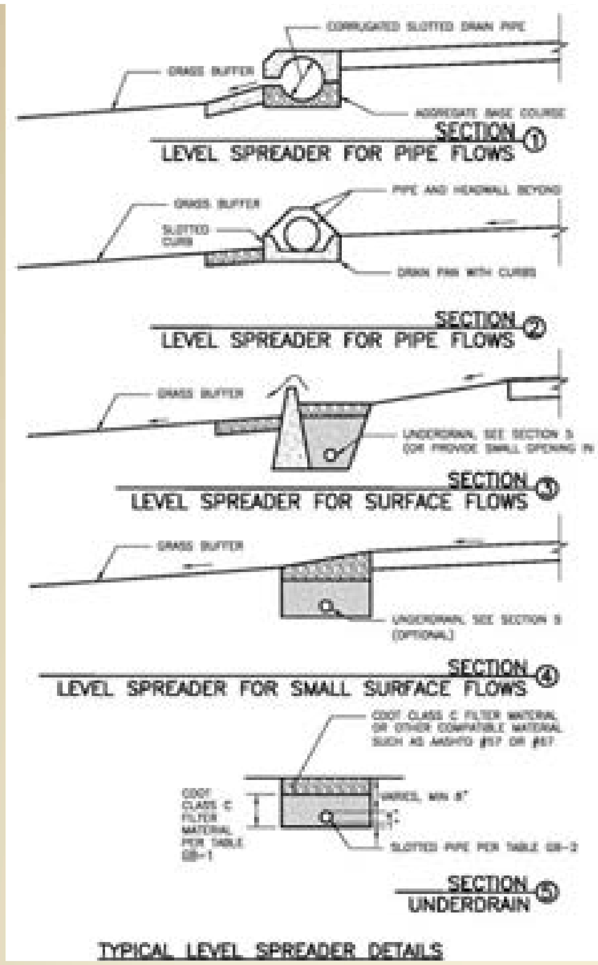
Sheet Flow: FL × SI ≤ 1

Concentrated Flow: LT × SI > 1

Where:
FL = watershed flow length (ft)
SI = interface slope (normal to flow) (ft/ft)

Example:
12′ travel lane +4′ shoulder
LT=16′
SI=5%
FL x SI = 0.8, sheet flow

24′ travel lanes = 4′ shoulder
LT=28′
SI=5%
FL x SI = 1.4, concentrated flow



Grass Buffer

Photo Courtesy Bill Wenk

Permeable Pavement Systems

Photo Courtesy SEH

- Provides capture and slow release of the WQCV, providing water quality treatment in an area that serves more than one purpose.
- Can be used to reduce effective imperviousness or alleviate nuisance drainage problems
- Benefit tree health by providing additional air and water to nearby roots.
- Less likely to form ice on the surface than conventional pavements.
- Some can be used to achieve LEED credits.

Permeable Pavement	
Functions	
LID/Volume Red.	Yes
WQCV	Yes
WQCV+Flood Control	Yes
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good[1]
Nutrients	Good
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs[4]	High[2]

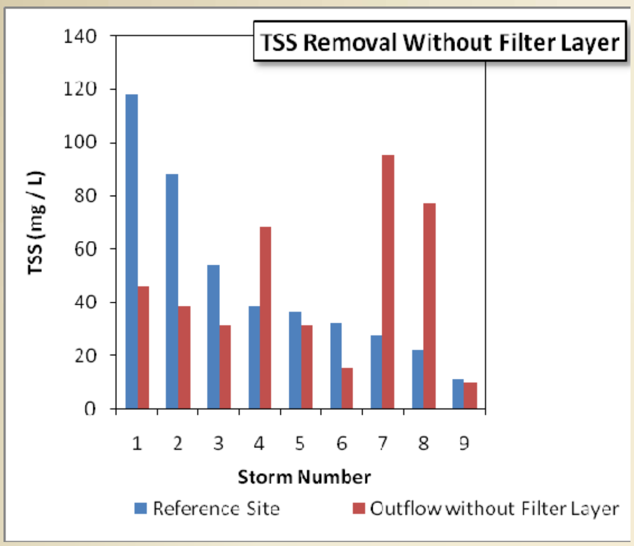
[1] Not recommended for watersheds with high sediment yields (unless pretreatment is provided.

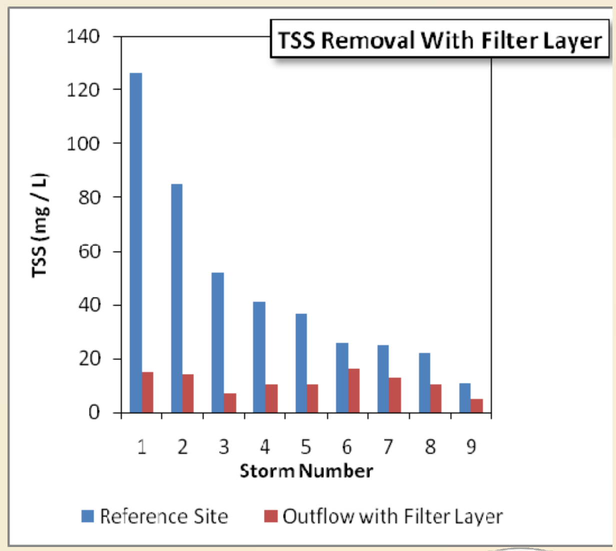
[2] Does not consider the life cycle cost of the conventional pavement that it replaces.

[3] Based primarily on data from the International BMP Database (www.bmpdatabase.org).

[4] Based on BMP-REALCOST available at www.udfcd.org.

Permeable Pavement Systems





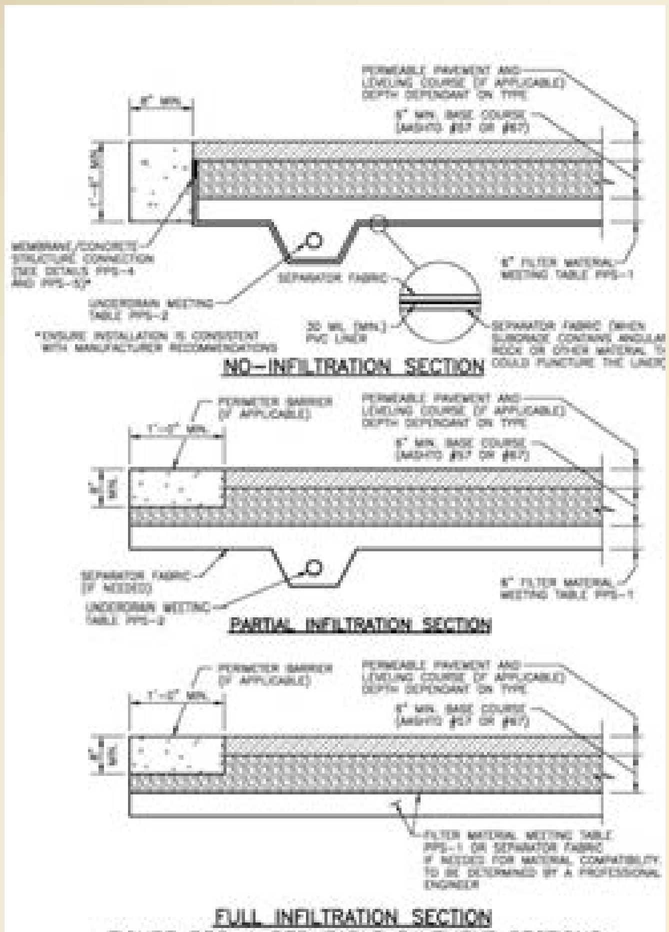


FIGURE PPS-1 PERMEABLE PAVEMENT SECTIONS

Filter and Drain Design

Class C Filter Material

Sieve Size	Mass Percent Passing Square Mesh Sieves
19.0 mm (3/4")	100
4.75 mm (No. 4)	60 – 100
300 µm (No. 50)	10 – 30
150 µm (No. 100)	0 – 10
75 µm (No. 200)	0 - 3

Slotted Pipe Dimensions

Pipe Size	Slot Length	Slot Width	Slot Centers	Open Area
4"	1-1/16"	.031"	.413"	1.90
6"	1-3/8"	.031"	.516"	1.98

Filter and Drain Design

U.S. Army et al (1971)

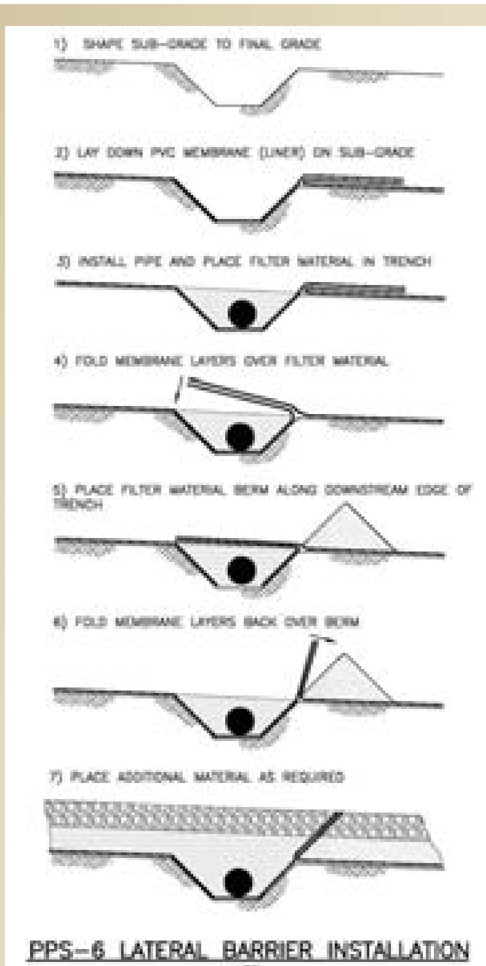
$$\frac{D85}{Slot\ Width} > 1.2$$

U.S. Bureau of Reclamation (1973)

$$\frac{D85}{Slot\ Width} > 2$$

Class C Filter Material
D85 (min) = 2.60 mm
D85 (max) = 11.00 mm

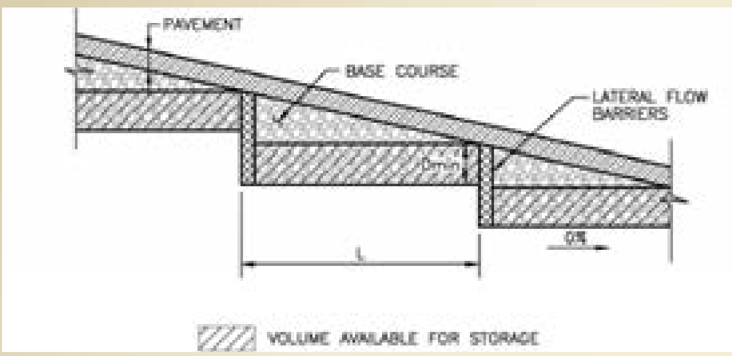
Maximum acceptable slot width based on U.S. Reclamation criteria is 0.051″



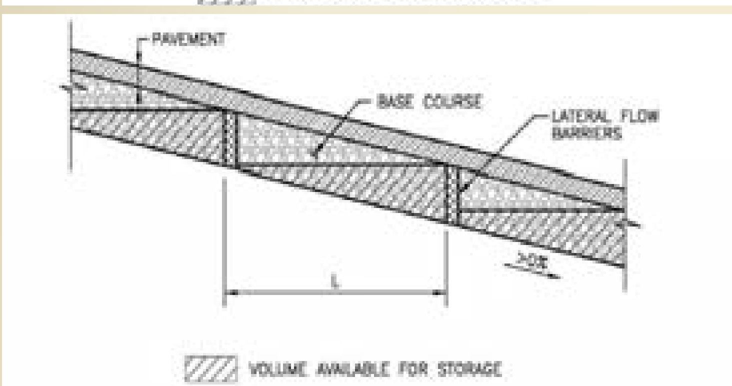
Permeable Pavement Systems

Lateral Barriers

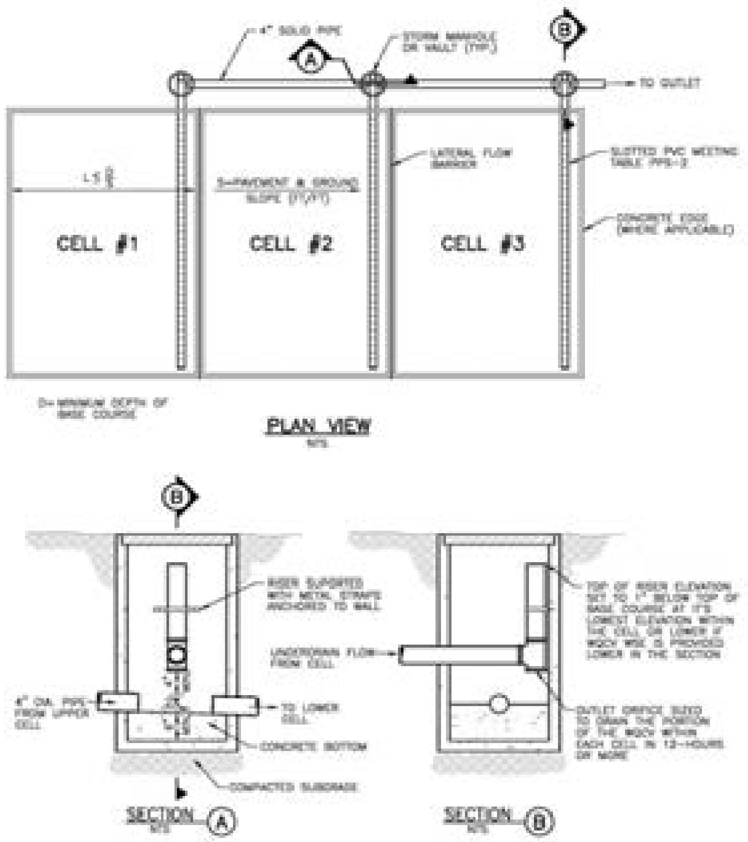
Stepped or Sloped Installation



$$V = 0.40\ D\ \text{Area}$$



$$V = 0.40\left[\frac{D + (D - sL)}{2}\right] Area$$



Permeable Pavement Systems

Separate Cells

12-Hour Drain Time for Infiltrating BMPs

$$\text{Diameter}_{(12\text{ hour drain time})} = \sqrt{\frac{\text{Volume}}{1414\, y^{0.41}}}$$

Where:

Diameter = orifice diameter (in)
y = distance from the lowest elevation of the storage volume (ft)
(i.e. surface of the filter) to the center of the orifice.
Volume = volume to drain in 12-hours (WQCV) (ft^3)

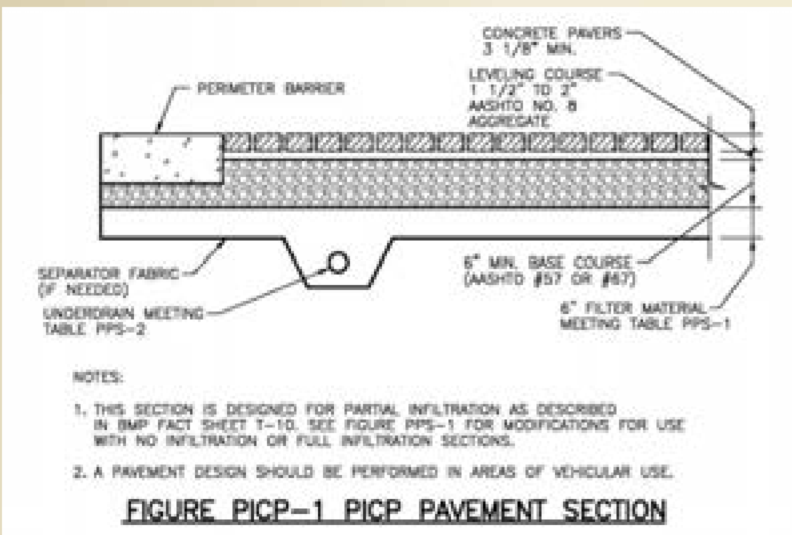
Permeable Pavement Systems

Example Construction Drawings Notes

- Excavation of subgrade shall not commence until after the preconstruction meeting.
- Subgrade shall be excavated using low ground pressure (LGP) track equipment to minimize over compaction of the subgrade [1].
- Grading and compaction equipment used in the area of the permeable pavement should be approved by the engineer prior to use.
- Loose materials shall not be stored on the permeable pavement area.
- The contractor shall, at all times during and after system installation, prevent sediment, debris, and dirt from any source from entering the permeable pavement system.
- Placement of the wearing course shall not begin until fine grading and landscaping in adjacent areas is complete.

[1] For partial and full infiltration sections, see Design Procedure.

Permeable Interlocking Pavement (PICP)



- Can be used for traffic calming
- Can be used in intersections
- Can be placed back if utility cuts or other patches are required.
- Maintains infiltration rates well.
- Provides flexibility in design options such as color and patterns.
- LEED credits

PICP

- Use the herring bone pattern with an overall length to thickness (aspect) ratio of three or less for vehicular applications.
- Select units with a maximum opening of 0.5 inches (measured from the chamfers) where needed to satisfy ADA requirements.
- Ensure all pavers are at least 40% of the original size.

Photo Courtesy SEH

PICP

- Ensure all pavers are at least 40% of the original size.
- Provide a sailor or soldier course at all edges

PICP

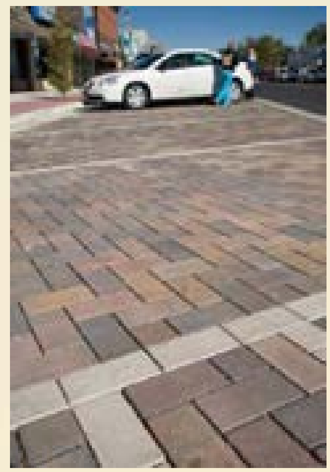
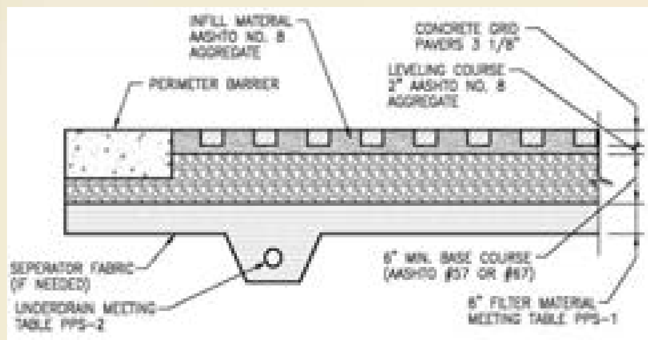


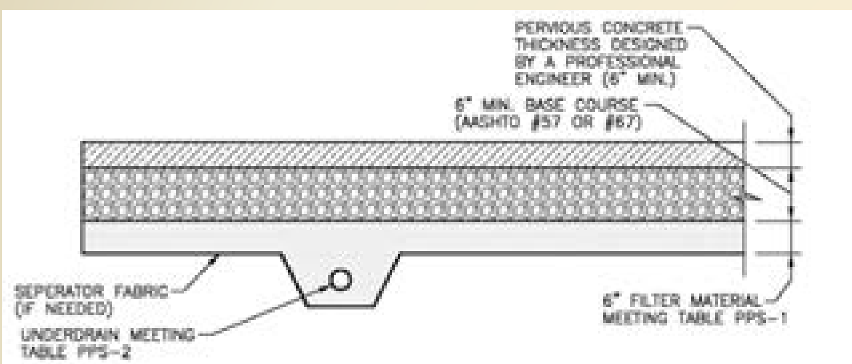
Photo Courtesy SEH

Photo Courtesy SEH

Concrete Grid Pavement



Pervious Concrete



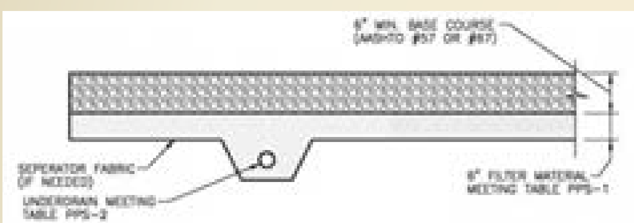
Pervious Concrete

- Provide adequate joints
- Use the *Specifier's Guide for Pervious Concrete Pavement Design*
- Select a contractor with prior experience in successful pervious concrete installation
- Mix, transport and discharged within one hour of the introduction of mixture water to the cement.
- Compaction of pervious concrete is achieved by rolling. Cross rolling should be performed using the minimum number of passes required to achieve an acceptable surface.

Pervious Concrete

- Joints should be formed by rolled using a "pizza cutter roller." Joints should never be cut.
- Place between April 1 and November 1 and when the ambient temperature is between 40° and 90° Fahrenheit.
- Mixture water quantity is critical. The correct quantity has been achieved when the concrete has a wet metallic sheen.
- Add an air entraining agent.
- The pavement surface must be covered with a six-mil thick polyethylene sheet. The sheet should remain secure and in place until the concrete has reached a maturity equivalent to 14 days of curing at 70° Fahrenheit at 95% relative humidity. No vehicular traffic should be permitted during this time.
- Fogging should begin once the concrete has been placed and should continue until the polyethylene curing cover is secured.

Porous Gravel



Sand Filters


Photo Courtesy Fred Bromberger

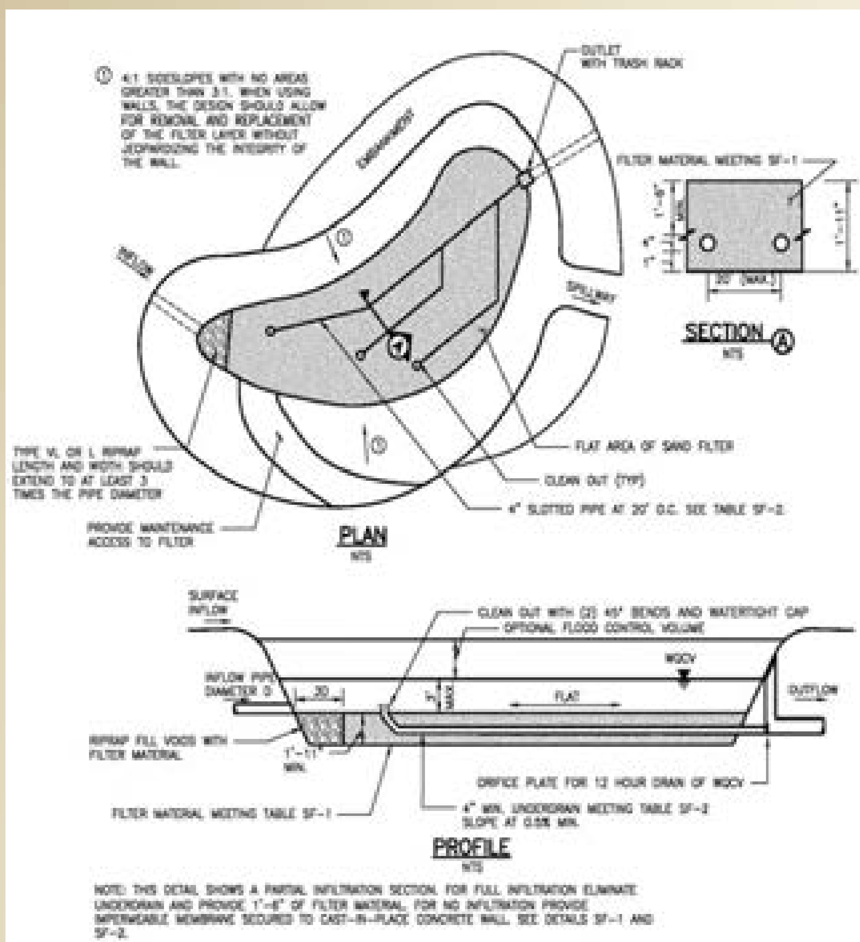
Sand/Media Filter	
Functions	
LID/Volume Red.	Yes
WQCV Capture	Yes
WQCV+Flood Control	Yes
Typical Effectiveness for Targeted Pollutants[3]	
Sediment/Solids	Very Good[1]
Nutrients	Good
Total Metals	Good
Bacteria	Poor
Other Considerations	
Life-cycle Costs[4]	Moderate

[1] Not recommended for watersheds with high sediment yields (unless pretreatment is provided).

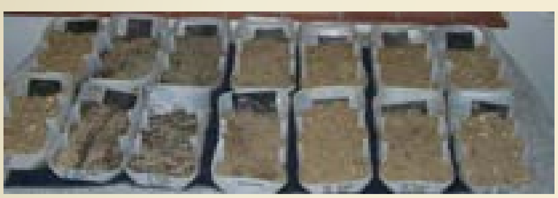
[3] Based primarily on data from the International BMP Database (www.bmpdatabase.org).

[4] Based on BMP-REALCOST available at www.udfcd.org.

Sand Filters



Bioretention (Rain Gardens or PLDs)



Bioretention

Why not Peat?

- Environmental Impacts
- Peat is not produced in Colorado

Why Paper?

- Compost alone leaches more nutrients than desired
- Paper captures nutrients from the compost for slow release to roots
- Paper temporarily slows the infiltration rate of the media and retains moisture

Extended Detention Basin (EDB)

- Expand criteria for various size EDBs
  - Primarily related to forebay size, depth and outlet into the trickle channel
- Include guidance on Full Spectrum Detention
  - Includes integration with UD-BMP
- Increase Flexibility
  - Guidance on Soft Bottom Trickle Channels and Micropools

Extended Detention Basin (EDB)

Most Common Mistakes

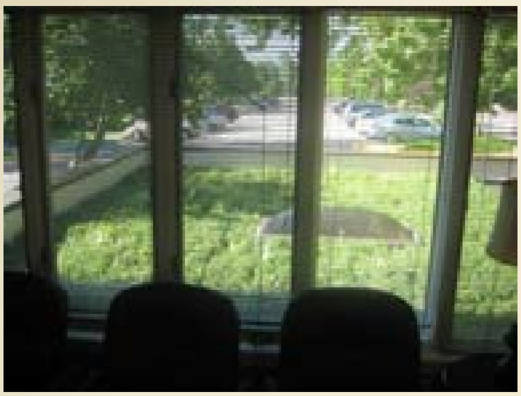
- No micropool
- Well Screen does not extend into the micropool
- No bottom Stage (initial surcharge volume)

Full Spectrum Detention

Most Common Misconceptions

- Does not result in a larger pond
- UDFCD does not recommend adding part or all of the WQCV (or the EURV) to the 100-yr detention volume
- Recommended drain times are approximate
- Specific design for metering other storm events is not necessary

Green Roofs



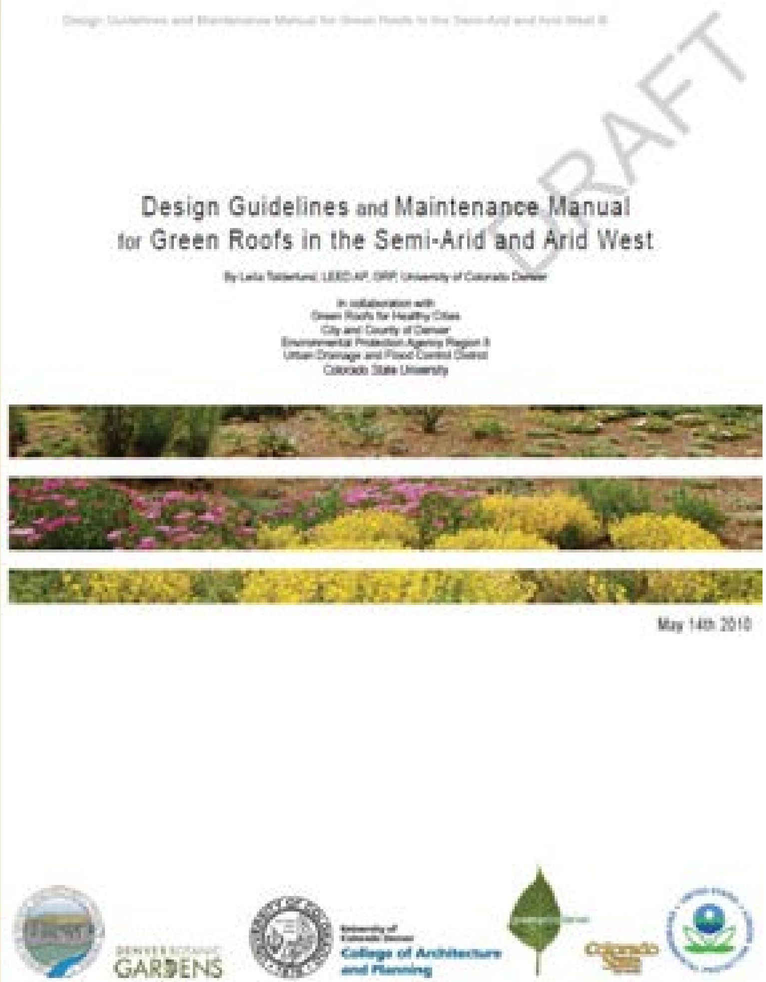

Green Roofs

Design and Maintenance Guidelines for Green Roofs in the Arid and Semi-Arid West

Includes a quote from EPA, Region 8 on using green roofs to satisfy capture of the WQCV

Contains over a dozen Denver area green roofs case studies including:

- Residential (SF and MF)
- Commercial
- Municipal
- Federal



Underground BMPs

- Not all BMPs are created equal
- Why underground BMPs have not previously been included
- When should underground BMPs be considered
- Guidance on evaluating data
  - TARP Tier 2 (field data)
  - What's included:

Monitoring Plan Element
Number of storm events
Parameters
Quality Assurance/Quality Control (QA/QC)—monitoring plan
QA/QC—laboratory analyses
Representativeness—sampling method
Representativeness—storm characteristics
Representativeness—precipitation depth
Representativeness—antecedent dry period
Data Analysis

Thank you!

Q&A

Welcome!

Emergency Management for Floodplain Managers: What Happens When It Actually Floods?

A Workshop to Better Prepare Local Floodplain Managers for Actual Flood Events

CASFM Annual Conference
September 2010
Snowmass, CO

amec

Workshop Goals

- Introduce local floodplain managers to emergency management
- Define local floodplain management roles and responsibilities before and after a flood
- Identify preparedness and mitigation actions to be take now that will assist the local floodplain manager before and after a flood

Workshop Agenda

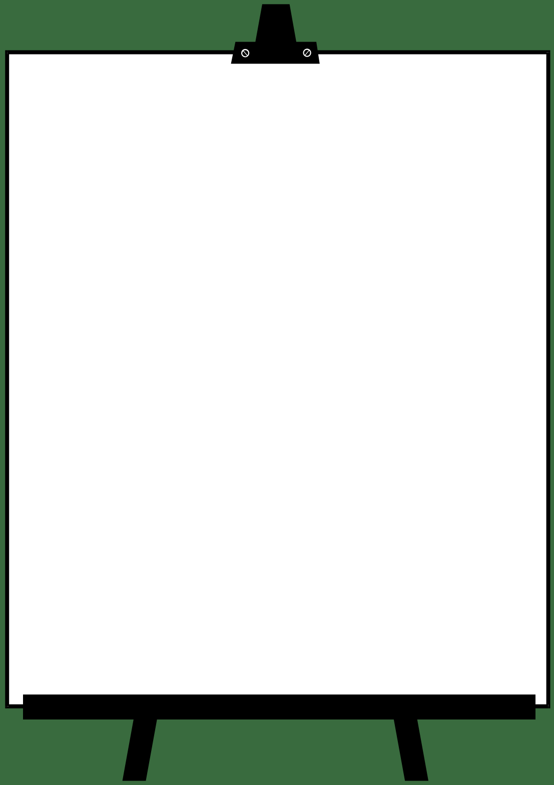
- Introduction to Workshop
- Group Activity #1: Flood Response
- Group Activity #2: Flood Recovery
- What Can You Do Now? Flood Preparedness and Mitigation Actions

Introductions

- Jeff Brislawn, CFM
- Hillary King

Workshop Materials

- Handouts
- Take-away
- Follow-up

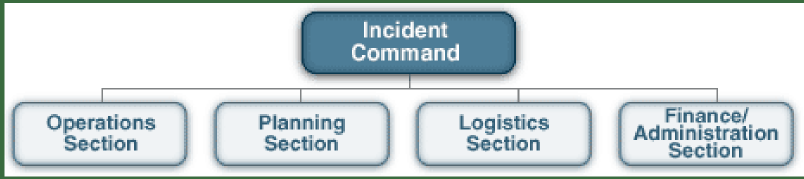


The Emergency Management Cycle

Event

Emergency Management Issues

- Interagency Coordination
  - NIMS/ICS
  - Terminology & Acronyms!
  - The EOC
  - Public Information
  - The Media
- Post-Disaster Decision Making
- Non-flood issues



ESF #1 Transportation
ESF #2 Communications
ESF #3 Public Works & Engineering
ESF #4 Firefighting
ESF #5 Emergency Management
ESF #6 Mass Care and Housing Annex
ESF #7 Resource Support
ESF #8 Public Health and Medical
ESF #9 Urban Search and Rescue
ESF #10 Oil and Hazardous Materials Response
ESF #11 Food, Water & Natural Resources
ESF #12 Energy
ESF #13 Public Safety & Security
ESF #14 Long-term Community Recovery & Mitigation
ESF #15 Public Information

Group Activities

- I. Flood Response Scenario
- II. Flood Recovery Scenario

What Can You Do Now? Preparedness and Mitigation Actions

- Communication and Coordination
- Training and Exercises
- Planning
- Documentation and Mapping
- Mitigation Policies and Projects
- Public Information

What Can You Do Now?
Communication and Coordination

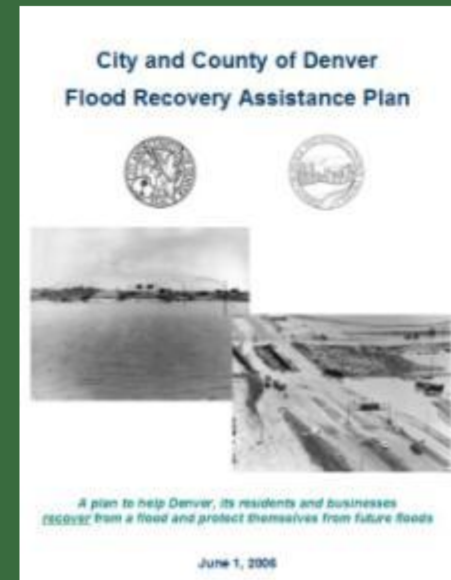
- Know your local players
  - Emergency manager, PIO, IT staff , and others
  - Use mitigation planning process
- Know your state/federal players
  - Be familiar with assistance programs/contacts
  - Take advantage of workshops offered
- Educate your elected officials
  - Use HAZUS, tabletop exercises
- Have media ready materials (programs, common terms)

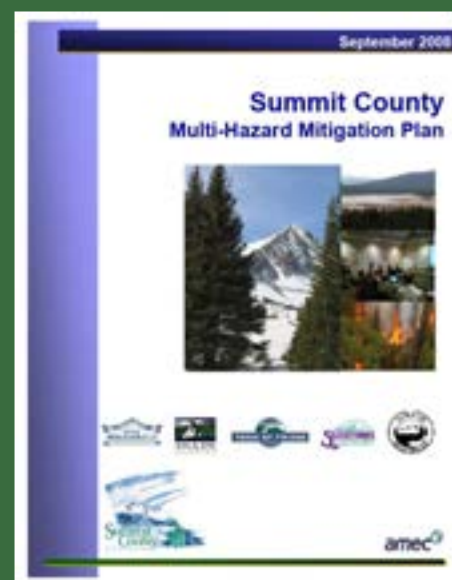
What Can You Do Now?
Training and Exercises

- Damage Assessment Team
- RSDE & ICC
- Benefit-Cost Analysis
- ICS/NIMS
- The retrofit course
- Lenders and agents workshops
- Managing Flood-Prone Development through NFIP

What Can You Do Now?
Planning

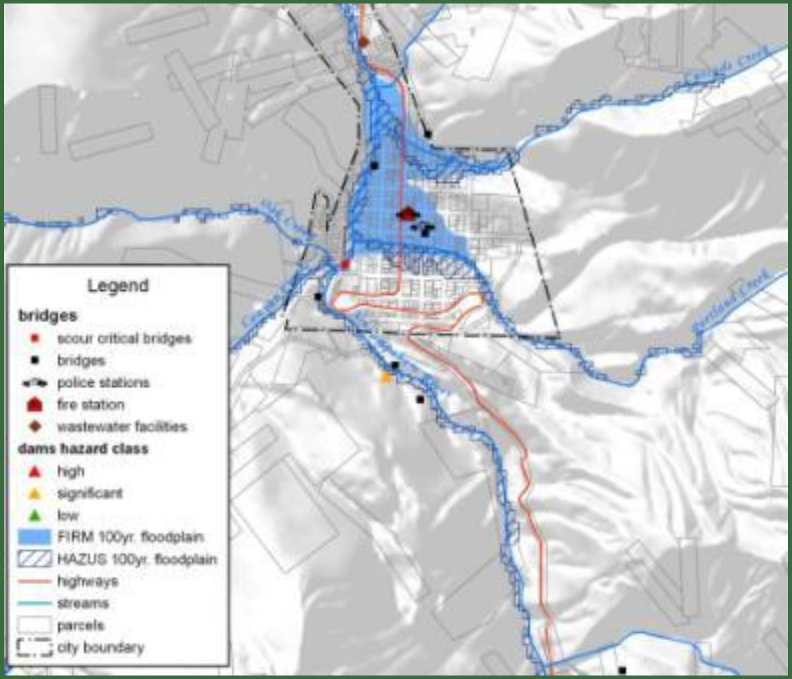
- Floodplain Management Plans (FMA, CRS, SRL)
- Mitigation Plans (DMA, PDM)
- Emergency Operations Plans
- Recovery Plan
- Other Community Plans (Master, CIP, Transportation)
- Plans of state/feds for your community
- Family preparedness plans
- Information on emergency/disaster declarations in ordinance





What Can You Do Now?
Documentation and Mapping

- Map repetitive losses, hazardous materials, critical facilities, historic buildings, mitigation projects
- Document variances issued, road/bridge elevations, CAVs, public works maintenance data, stream gage data, high water mark collection procedures
- Protect information - off-site storage, Go Box



What Can You Do Now?
Mitigation Policies and Projects

- National Flood Insurance Program
  - Beyond minimum standards
  - Repetitive losses
  - Protect critical facilities
  - Community Rating System
- No Adverse Impact
- Management of natural floodplain functions and resources
- Regulate to future conditions

What Can You Do Now?
Public Information

- Team Flood Smart Outreach Toolkits
- Warning and evacuation
- NOAA Weather Radios
- StormReady Certification
- Mitigation Open House
- Business Continuity Planning
- Citizens Guide to Flood Awareness
- NFIP materials/forms at front office (CRS credit)

NFIP/CRS

StormReady

Workshop Conclusion: Goals Check

- Introduce floodplain managers to emergency management
- Define floodplain management roles and responsibilities before and after a flood
- Identify preparedness and mitigation actions to be take now that will assist the local floodplain manager before and after a flood

Workshop Conclusion

- Questions?
- Take Home Packets

Thank You!

Emergency Management for Floodplain Managers: What Happens When It Actually Floods?

A Workshop to Better Prepare Local Floodplain Managers for Actual Flood Events

CASFM Annual Conference
September 2010
Snowmass, CO

amec

CASFM CONFERENCE – 2010
THE PLANNING PROCESS FROM INCEPTION THROUGH IMPLEMENTATION

PRESENTED BY APA COLORADO
Steve Westbay AICP, CFM
Community Development Director – City of Gunnison

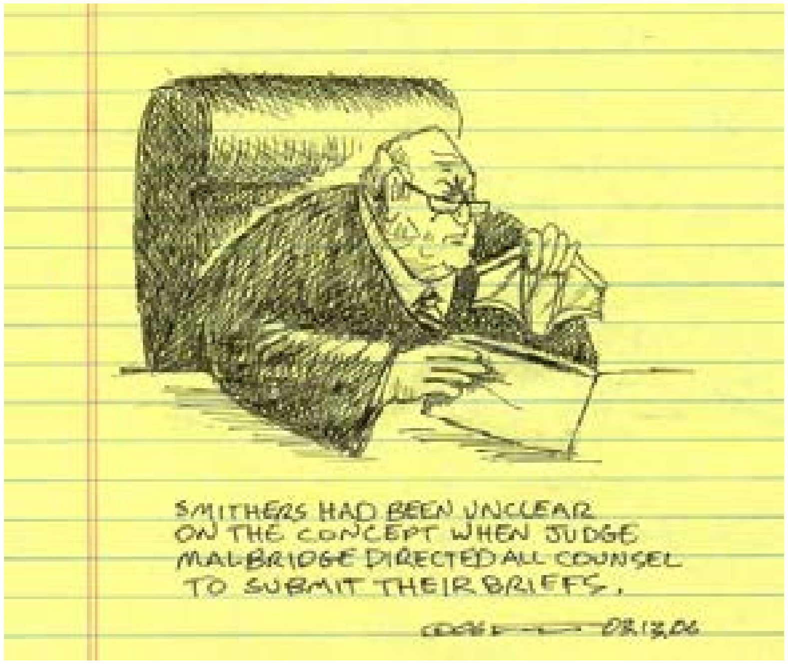
swestbay@cityofgunnison-co.gov
phone #: 970-641-0558

I. Planning and Development Process – Colorado Planning Law

Reader Note: The majority of this information presented in Section 1 is derived from *Colorado Land Planning and Development Law* (5th Addition, published by APA Colorado). Other sources are referenced when applicable.

A. LOCAL GOVERNMENT – HOME RULE & STATUTORY DEGINATIONS

1. **General.** Under the *Colorado Constitution*, local jurisdictions may become a home rule government by the creation of its own charter.



2. **Statutory Powers.** Statutory jurisdictions only have the powers explicitly given to them by state statutes. If there is no explicit grant of power provided by state statutes, a statutory government cannot engage in the activity.
   - Planning practitioners in statutory jurisdictions should ask …Where in the state statutes does it say or imply that local government can act in a certain manner?

3. **Home Rule Powers**. Home Rule jurisdictions have the power to create ordinances and laws to extend to all governmental matters include subdivision and zoning. However, there are limitations to the home rule powers and these limitations pertain to *matters of state interest*, restrictions related to the TABOR and Gallagher Amendments, and other specific state and federal laws.

- Planning practitioners in Home Rule jurisdictions should ask …Where in the Charter or Municipal Code does it say or imply that local government can act in a certain manner?

4. **Appeals from Local Decisions.** Appeals may be brought forth by citizens, applicants, the local government or other government agencies for either denials or approvals.
   - The appeal of Legislative Acts (new ordinance regulations, et al), are reviewed under the *Colorado Rules of Civil Procedures*. For example, a new land use code could be appealed on the premise that it does not allow for due process in zoning amendments. The court is usually asked to provide a Declaratory Judgment, which allows citizens to obtain a determination of validity under prevailing case law, state statutes or the *Constitution*.

- The appeal of Quasi-Judicial Acts (affecting individual land use rights), are reviewed under the *Colorado Rules of Civil Procedures*, which address protocol for civil law cases, and may allow for punitive or compensatory damages.

B. LAND USE PLANNING – THE COMPREHENSIVE PLAN

"They've raised the standard."

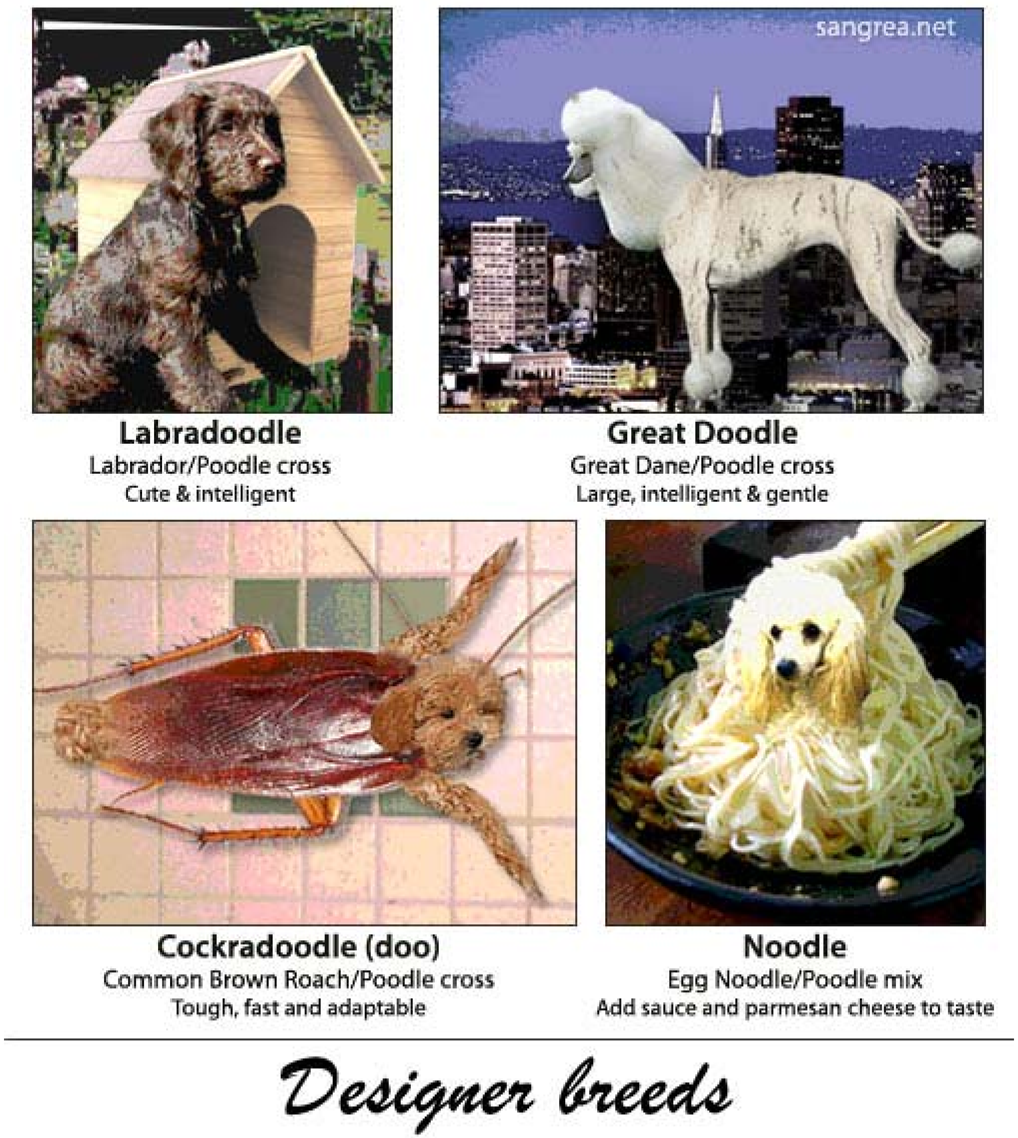
1. **General.** The act of land use planning is separate and distinct from the act of zoning. The land use plan (Comprehensive or Master Plan) sets forth the most desirable land uses based on community perspective. Zoning provides a detailed means for giving legal effect to the plan's policies.

2. **Advisory Context.** Colorado case law provides that adopted land use plans are advisory only and do not bind the discretion of a jurisdiction in regard to specific subdivision or zoning decisions.

3. **Mandatory Context.** Home Rule jurisdictions may require zoning and subdivision proposals to be established in accordance with jurisdiction's comprehensive plan, and this policing power has been upheld by the Colorado Supreme Court. However, the comprehensive plans must be sufficiently detailed.

4. **Three Mile Plans.** The Colorado Revised Statutes, §31-12-105 (1)(e) requires that there be a plan in place for an area extending three miles beyond a municipality's boundaries prior to the annexation of territory into the municipality. Additionally, state statutes give municipalities express authority to enter into agreements with adjoining counties for joint participation in land use planning, subdivision procedures and zoning for specific areas designated in the Intergovernmental Agreement (IGA). Generally, policing powers are not extended through the IGA.

5. **Regional Councils**. Many states empower regional councils of government to regulate planning. Regional councils of government were enacted by the General Assembly in 1972 in order to provide structure to governmental functions transcending local government boundaries. However, the regional councils in Colorado have no policing powers. Established regional councils include:
   - Denver Regional Council of Governments
   - Northwest Regional Council of Governments
   - Pikes Peak Area Council of Governments
   - Pueblo Area Council of Governments
   - Region 10 (West Central Colorado)
   - South Central Council of Governments



6. **State Level Planning.** Several administrative branches of Colorado state government address planning as part of their respective duties.
   - **Colorado Department of Local Affairs (DOLA) – Division of Local Government**. Acts as a liaison between state and local governmental entities. Budget restrictions severally limit the assistance provided by DOLA.

- **Colorado Land Use Commission**. This Commission was created by the General Assembly in 1970 to formulate land use planning program at the state level. This commission was specifically directed to synthesize existing land use programs at federal, state and local levels. The General Assembly has not appropriated significant money to the Commission and this body only acts to fulfill responsibilities required by statute.
- **Colorado State Land Board**. This is a five member board appointed by the Governor. The Board serves as the trustee for school trust lands. The Board also manages the Stewardship Trust, consisting of about 300,000 acres of school trust lands, which are to be protected due to beauty, natural values, open space and wildlife habitat.
- **1041 Regulations – Activities of Statewide Interest.** Statutory provisions (§24-65.1-101 through 502), which are commonly referred to as 1041 Regulations, define a specific types of development that may impact the state. They also define criteria to be used by local governments in planning of such projects, and allow local jurisdictions additional regulatory powers. Defined areas of state interest include the following.
  1. Mineral Resource Areas
  2. Natural Hazard Areas
  3. Certain areas containing historical, natural or archeological resources.
  4. Airports, highways, major public utilities, mass transit terminals and other key facilities.

C. LOCAL GOVERNMENT LAND USE CONTROL ENABLE ACT—CRS §29-20-102

1. **Enabling Legislation**. In 1974, the General Assembly enacting the *Land Use Enabling Act, H.B. 1034*, which conferred broad authority for local government planning and regulation of land use, and the *Areas and Activities of State Interest Act, H.B. 1041*, which allowed local government to designate matters of statewide interest for regulation through a permit system. The *Land Use Enabling Act* grants broad authority to local governments to plan for and regulate the use of land within their respective jurisdictions. The act enables local government the ability to conduct comprehensive plans, and to establish zoning, subdivision, and development regulations.
2. **Zoning History**. In 1926 the United States Supreme Court herd *Village of Euclid v. Ambler Realty*, and the court

determined that zoning is a legitimate exercise of local government police powers. Statutory jurisdictions only have the zoning powers allowed by state statutes (CRS §31-23-301 through 312; §31-15-401 and §31-15-50). Police powers allow local jurisdiction to regulate types of uses, dimensional standards (height, setback lot size, etc), regulate hillside development impacts, define street configurations and enhance the aesthetic values of the community.

3. **Legislative and Quasi-Judicial Actions.** The initial enactment and subsequent amendments of development standards and zoning maps are designated as legislative actions. While rezoning applications, conditional uses, variances and subdivision actions are quasi-judicial actions.

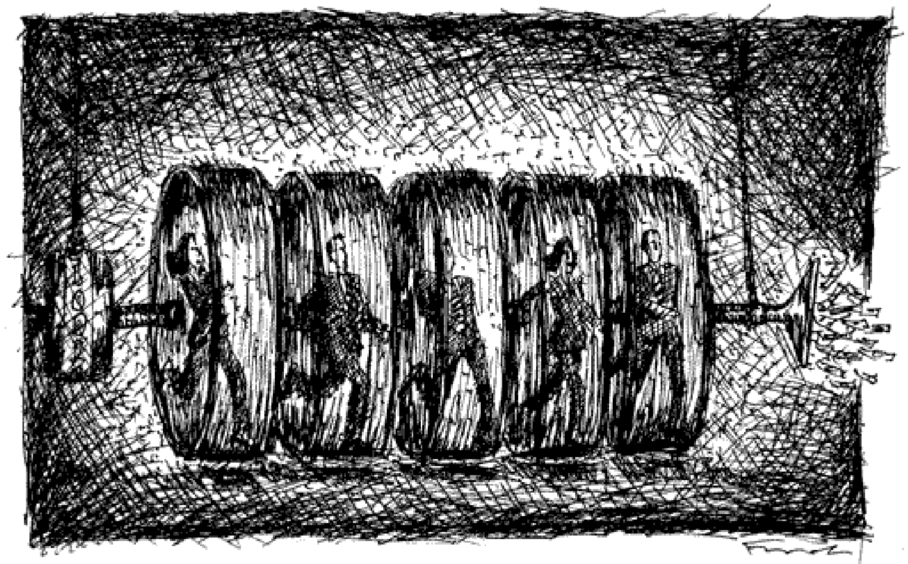
4. **Areas of State Interest**. The General Assembly has declared several areas of statewide concern that limit the general granting of zoning powers to local jurisdictions.
   - Zoning ordinances must accommodate group homes for the aged and home for persons with mental illness as residential uses.
   - Development standards cannot prohibit manufactured homes that meet the basic standards of the local building code. However, manufactured housing is subject to the local jurisdiction's building codes addressing unique public safety matters such as snow load, wind shear, seismic design and energy conservation (CRS §30-28-115(3)).
   - The imposition of rental control on private residential housing is a matter of state interest and local jurisdictions cannot establish regulations directed at rent control.
   - Local zoning ordinances cannot create limitations or restrictions based on race or color.
   - Jurisdictions with populations greater than 65,000 are required to adopt a plan for the extraction of commercial mineral deposits.
   - Counties are required to establish procedures for locating and designating solid waste facilities.

5. **Rezoning – Map Amendments.** Local government is empowered by Enabling Legislation to establish specific districts and regulate land uses through various provisions within the zoning code. Zoning district boundaries are established by the Zoning Map. Within related jurisdictional boundaries rezoning applications can be initiated by City Councils, County Commissioners, Planning and Zoning Commissions and local property owners.

- Local jurisdictions may initiate comprehensive rezoning of large areas. These types of rezoning acts are generally initiated to fulfill the objectives of the comprehensive plan. These comprehensive rezoning processes are treated as legislative acts and are accompanied by the adoption of a new zoning map.
- Rezoning of individual areas is more common, and they are usually requested by property owners. Rezoning requests are usually subject to compliance with standardized criteria statements contained in the local land development codes.
- Spot Zoning is not defined by legislation, but is a colloquialism describing the application of a specific zoning district classification to a small area which is surrounded by a larger different (usually less intense) zone district (Craig Hullinger & Chuck Eckenstahler 2004, Planning.blogst.com). There are often logical reasons to zone small parcels in a unique manner such as a corner lot that provides services to a local neighborhood. Good planning practices will prevent the appearance of spot zoning. The key is to adhere to established criteria statements for rezoning and ensure the application request conforms to an up-to-date comprehensive plan.

6. **Planned Unit Developments**. Planned Unit Developments (PUDs) are a unique form of zoning that provides flexible alternatives to the common zoning regulations. PUDs allow local jurisdictions wide discretion to negotiate almost every aspect of the proposed development and in return the developer is granted great flexibility in use designations, dimensional standards, and design.
   - PUDs are a negotiated process and neither party is forced to accept the propositions.
   - PUDs are authorized by state statutes (CRS §24-67-101 through 108).
   - The statutes require that PUDs conform to the comprehensive plan.
   - PUDs are required to follow a written guide that establishes the standards, conditions and provisions directing the development of the PUD.
   - PUDs may contemplate one or several zoned districts, which are subject to formal review and approval. They are also subject to municipal provisions for subdivision.

7. **Essential Nexus**. Zoning regulations must bear a reasonable relationship (nexus) to some legitimate government interest such as protecting the health, safety or welfare of the public. This nexus between zoning and the public welfare provides the basis for the constitutionality of land use regulations.
   - A regulation as applied to specific property must not create an unreasonable burden on the owner, even if the regulation is reasonably related to a legitimate government interest.
   - A land owner is not entitled to the most profitable or best use of their property. A zoning regulation will generally be upheld if the land owner has not been deprived of all reasonable economic use of private property.



Hourly-Billing Lawyer Cages...Patent Pending.

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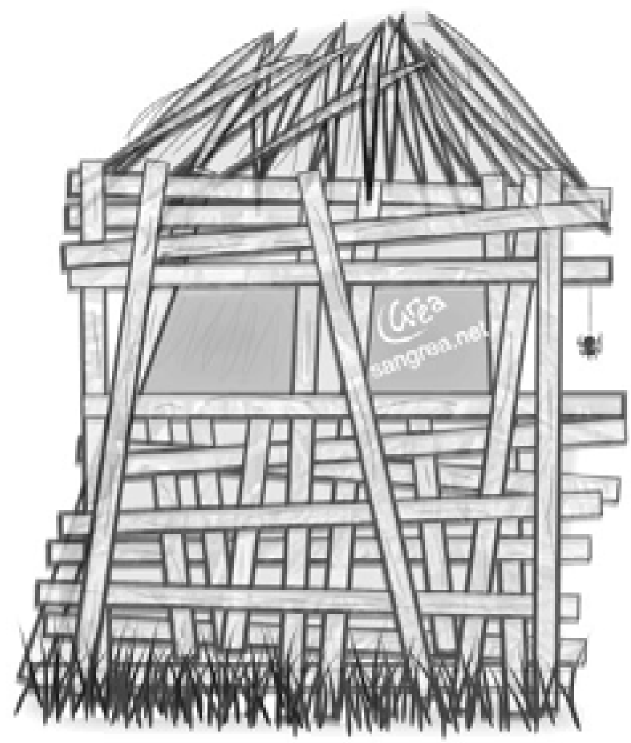
8. **Dedications, Exactions & Impact Fees.** Development regulations may impose exactions, impact fees, land dedications or require certain improvements in relation to a subdivision or development application. However, such exactions may be challenged as exceeding police powers or that they constitute an invalid tax; and the exactions may be challenged as a "taking" of private property rights.

- *Colorado Revised Statutes* provides broad authority to jurisdictions and statutes anticipate exactions as a valid power of local government.
- In 1994 the U.S. Supreme Court decided Dolan v. City of Tigard, which specified how exactions of real property are to be measured. While the court did not require mathematic precision, the ruling requires that local government quantify the impacts created by the development and then document how the exaction will alleviate the related impact. The Supreme Court found that the exaction must be ***roughly proportional*** to the impact created.

9. **Nonconforming Uses.** A nonconforming use is a pre-existing lawful use that becomes prohibited as a result of a new code adoption. Zoning Codes often grant the right to continue that use as a ***legal nonconforming use***. This grandfathering is not absolute and the zoning code may require the removal of the use over time.
   - The Colorado Supreme Court has stated that zoning provisions allowing nonconforming uses should be strictly applied by the jurisdiction because such uses can depress property values, contribute to urban blight and may present life-safety issues.
   - Nonconforming uses are banned from expanding, additional nonconforming uses and if structures are destroyed they cannot be replaced. Restarting a nonconforming use after it ceases for a certain period of time is prohibited.

10. **Nonconforming Structures.** Nonconforming structures are generally in conflict with dimensional standards such as height, setback, or percent coverage. Nonconforming structures are treated similar to nonconforming uses. The landowner is entitled to maintain the structure subject to reasonable limitations. The owner cannot alter the structure in a manner that expands the nonconforming structure. If the nonconforming structure is destroyed, it cannot be rebuilt in a nonconforming manner. However, variances may be granted in situations where a "hardship" is demonstrated. Variances are heard by the local Zoning Board of Adjustments and Appeals.



When lousy renovations meets postmodernism

11. **Conditional Uses.** A conditional use is generally compatible with the permitted uses in a particular zone district, but which

can be denied if it does not fit in with the specific surroundings. These uses usually have inherent impacts such as increased traffic, noise, or odor. Mitigation measures are often applied to the proposed use through conditions limiting the hours of operation, requiring that activities be conducted within structures that reduce noise, or by applying other conditions.

D. SUBDIVISION

"So what do you think of all this government paperwork, boss?"

1. **Subdivision Intent**. A subdivision plat is a map showing how a given piece of property is to be divided into lots and blocks, and identifying streets, easements, parks and other land intended to be dedicated to the public. The plat provides the necessary survey details to legally describe individual parcels; it ensures that lots are appropriate sizes and have adequate frontage; it serves to verify that utilities extensions are manageable, and it ensures that all lots have legal access.

2. **Plat Details**. Subdivision plats contain several statements, signature blocks, and other necessary details necessary for proper execution. Based on statutory requirements, most municipalities require that plats contain a legal opinion ensuring that land title is not encumbered, a surveyor statement ensuring surveyor accuracy, a description of the basis for bearing used by the surveyor, a dedication statement ensuring legal dedication of public spaces, acceptance signatures by the mayor, and includes County Clerk and Recorder information.

3. **Review Process**. Subdivisions are often reviewed in three phases including a sketch plan, preliminary plan, and final plan. Sketch plan reviews define the concept of the subdivision without providing any engineering plan detail. The preliminary plan is a very detailed process requiring the submittal of preliminary engineering designs for streets, water, sewer, electrical system, and stormwater and irrigation utilities. The final plan concentrates on the legal details of the subdivision including review of the plat language, improvement agreements, and final engineer plans. Generally, final plats should not be approved with conditions, because all related issues should be addressed before that point of the process.

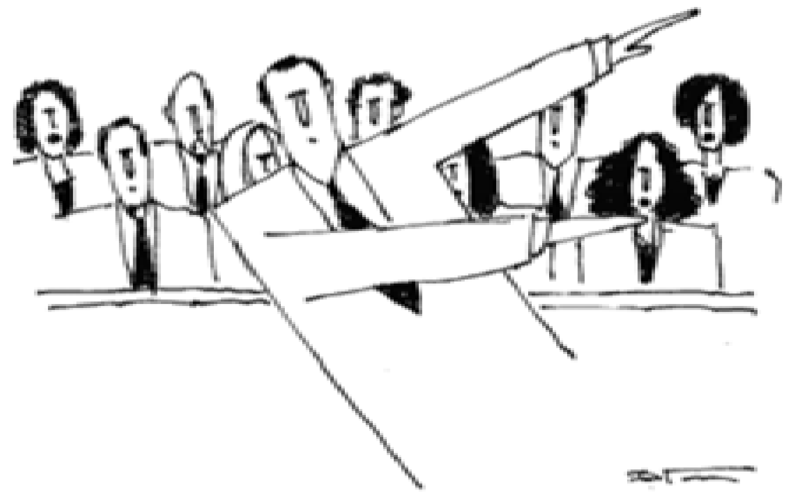
4. **Common Interest Communities.** Under statutory definitions, a subdivision includes any parcel of land used for condominiums, apartments or other multiple dwelling units or which divides a single parcel into two or more parcels, separate interest, or interest in common. Common interest communities establish either fee-simple ownership, which is commonly a house with a yard area (townhomes), or an airspace unit where multi-family units are contained in a single structure.

E. DUE PROCESS (Source: Hayes, Phillips & Maloney, P.C., Attorneys at Law, Rocky Mountain Land Use Institute Presentation, 2001).

1. Any applicant appearing before a local body requesting a decision of that local body when acting within the scope of its powers is entitled to receive due process of law.

2. Due process is guaranteed by the *United States Constitution (USC).*

- Amendment 5 provides that no person shall "be deprived of life, liberty, or property, without due process of law;" Article 14, Section 1 provides "Nor shall any state deprive any person of life, liberty or property without due process of law…"
- A similar provision exists in the *Colorado Constitution* at Article II, Section 25. "No person shall be deprived of life, liberty or property without due process of law."



Counsel's opening was so slanted he struggled to maintain his balance.

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- In the land use context, because property rights are at issue, the provisions of each of the constitutional sections cited above, together with 42 USC. §1983 are applicable.

3. Legislative vs. Quasi-Judicial Actions - The level of due process required to be afforded depends upon whether the action of the governing body is legislative or quasi-judicial in nature.

   - Legislative action is usually reflective of some public policy relating to matters of a permanent or general character, is not normally restricted to identifiable persons or groups, and is usually prospective in nature. Quasi-judicial action, on the other hand, generally involves a determination of the rights, duties, or obligations of specific individuals on the basis of the application of presently existing legal standards or policy considerations to past or present facts developed at a hearing conducted for the purpose of resolving the particular interests in question. This type of decision-making is designated "quasi-judicial" precisely because it bears similarities to the adjudicatory function performed by courts. If a statute or ordinance authorizes the exercise of quasi-judicial authority but does not provide for notice and hearing, these basic requirements may properly be implied as a matter of fundamental fairness to those persons whose protected interests are likely to be affected by the government decision.
   - The leading case on what makes a matter quasi-judicial is Snyder v. City of Lakewood, 542 P.2d 371 (Colo. 1975). In Snyder the Court identified three criteria for identifying a matter as quasi-judicial, which are: (1) a state or local law requiring that the body give adequate notice to the community before acting; (2) a state or local law requiring that the body conduct a public hearing, pursuant to notice, at which time concerned citizens must be given an opportunity to be heard and present evidence; and, (3) a state or local law requiring the body to make a determination by applying the facts of a specific case to certain criteria established by law.

Defense counsel tries to minimize damages.

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4. Elements which must be present in a hearing.
   - The first element of fundamental fairness is "adequate notice" to place all parties in interest on

notice that a hearing is to be held, and giving fair notice as to what will be the scope and requested outcome of that hearing. Failure to give adequate notice may void any action taken at the hearing.

- **Level of Formality**. The level of formality to be afforded at the hearing is essentially a question of local preference, so long as adequate opportunity is afforded for all viewpoints which are relevant to the application to be aired.
- **Necessity of Findings.** In order to comply with due process requirements, and to insulate the decision made from successful judicial attack, findings must be made by the legislative body (findings are always better put in writing), which relate both to the evidence presented and to the criteria which exist and which are applicable to the application being heard. Bauer v. City of Wheat Ridge, 513 P.2d 203.
- **Impartial Decision-making Panel**. Applicants are entitled to an impartial panel. Any evidence of a pre-decision, or decision based on matters other than those appearing in the record, potentially subjects the decision-makers to liability to the application for violation of the applicant's due process rights.

F. ANNEXATION

1. **Legislative Intent.** The Municipal Annexation Act of 1965 is that portion of the *Colorado Revised Statutes* found at CRS 31-12-101 through 123. The policy intent is to encourage natural and orderly development of municipalities. Annexations are initiated by the submittal of a petition to the municipality. The petition must contain signatures from 50% of the affected land owners and those signers must own more than 50% of the land area.

2. **Municipal Annexation Policies.** Municipalities may adopt policies, and submittal data requirements either by ordinances, resolutions or provisions of their comprehensive plan. Because the process is legislative, the municipalities may require exactions, as part of the negotiation, that are not afforded under subdivision or other land use review processes.

3. **Annexation Eligibility (CRS 31-12-104).**
   - Not less than 1/6 of the proposed annexation perimeter area is contiguous with the

annexing municipality boundary.

- A community interest exists – the area is integrated with, or is capability of being integrated with, the annexing municipality.
- The annexation boundary does not extend more than three miles from the city boundary.

4. **Annexation Limitation (CRS 31-12-105).**
   - Annexation boundaries cannot divide and individual's real property without written consent.
   - The proposed annexation boundaries cannot cover an area encompassing a separate annexation petition submitted to another municipality.
   - Annexation boundaries cannot detach a school district boundary unless it is allowed by the affected school district.
   - A municipality cannot deny reasonable access to landowners adjoining a platted street or alley being annexed.

5. **Annexation of Enclaves (CRS 31-12-106)**
   - Enclaves are unincorporated areas of land entirely contained within the outer boundaries of the annexing municipality.
   - If an enclave has existed for more than three years after an annexation, the municipality may annex the land area without complying with the Limitation Provisions (31-12-105).

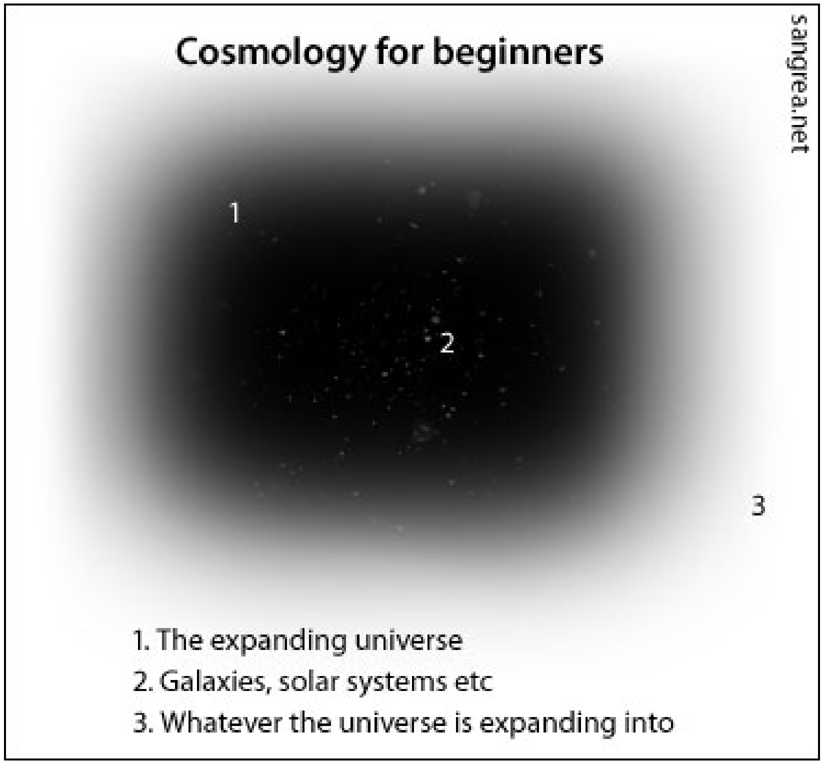
6. **Petitions for Annexation 31-12-107**
   - An annexation petition must contain several elements including allegations that the Eligibility and Limitation provisions of the *State Statutes* have been met, a legal description of the proposed, and a boundary map.
   - Many municipalities require additional information in conjunction with the petition submittal. For example many municipalities require land use and utility master plans, a fiscal impact report, and other similar data to help assess development feasibility.

II. *New Planning Paradigms*

A. URBAN MIGRATION and DEMOGRAPHIC TRENDS

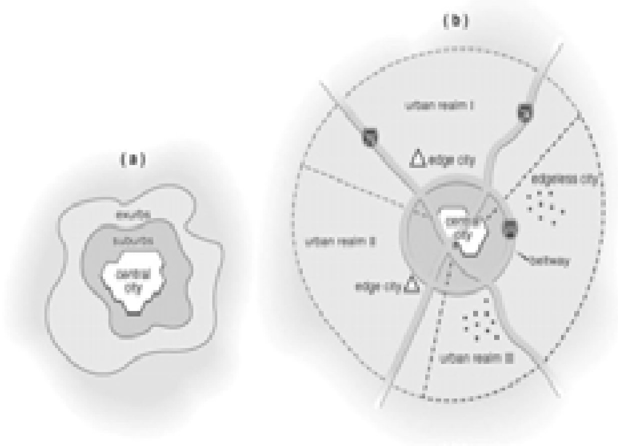
In 2006 the United States population reached 300 million and this figure is anticipated to increase to 400 million before the mid-century mark (2050). The growth rate is attributed in some part to natural growth (birth/death ratio), but 60 percent of the growth will be attributed to migration. Eastern and western European countries and Japan are projected to have falling populations in the future. The U.S. population projections exceed those for China and only lag behind growth rates of India.

1. **US Growth Rate Projections.** America adds 100 million people faster than any other nation except India and Pakistan – but *faster* than China. *Source*: Arthur C. Nelson, Metropolitan Institute at Virginia Tech.
   - 200 million in 1968
   - 300 million in 2006
   - 400 million in 2032
   - 500 million in 2050

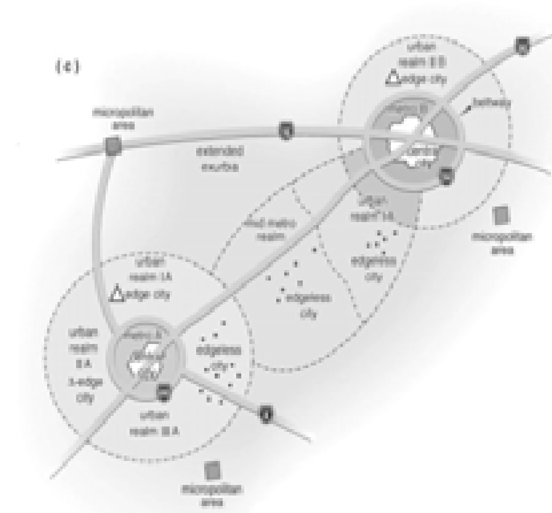


2. **Future Building Construction Trends.** Expanding population trends in the USA are a reality. The real questions related to planning are founded in contemplating the geographic distribution and extent of capital development required to accommodate this growth. Joel Kotkin (*The Next Hundred Million: America in 2050*, Penguin Press, 2010), suggests that growth will be accommodated in mixed use villages, and that small to mid-sized cities in the Mid-West and Rust Belt will see a significant resurgence, but he does not refer to this growth as a suburbanization land use.

   Dr. Arthur C. Nelson suggests a somewhat differing view of the growth distribution. Dr. Nelson maintains that growth will be concentrated in merged metropolitan areas, creating megapolitan areas. Dr. Nelson's report titled *Toward a New Metropolis: The Opportunity to Rebuild America*, (Brookings Institute, December 2004), provides the following building construction projections:



20th Century Metorpoltan Form



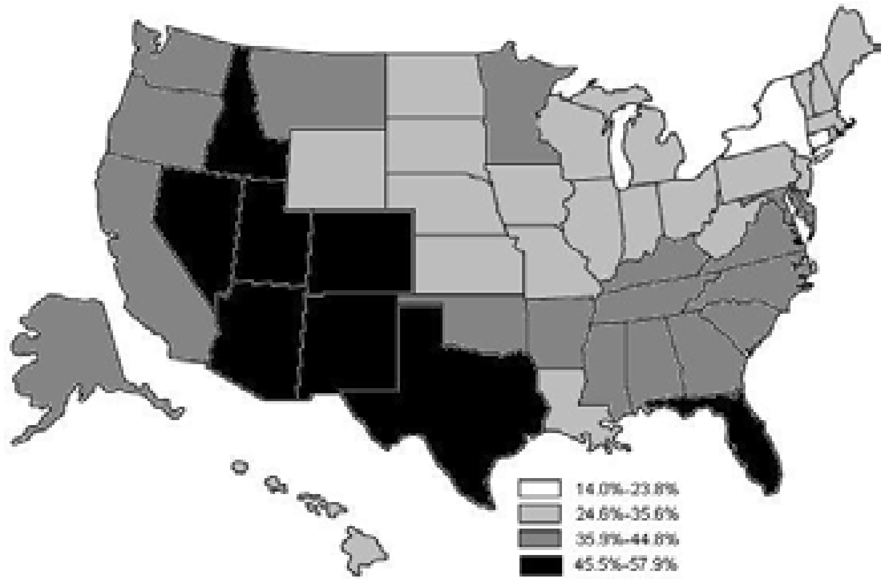
21st Century Megapolitan Form

- The nation had about 300 billion square feet of built space in 2000. By 2030, about 427 billion square feet of built space will be needed to accommodate growth projections. About 82 billion of that will be from replacement of existing space and 131 will be new space. Thus, 50 percent of that 427 billion will have to be constructed between now and 2030.

- Most of the space built between 2000 and 2030 will be residential space. The largest component of this space will be homes. Over 100 billion square feet of new residential space will be needed by 2030. However, percentage-wise, the commercial and industrial sectors will have the most new space with over 60 percent of the space in 2030 less than 30 years old.

Household Occupancy Trends –Traditional Occupancy on the Wayne			
Household Type	1960	2000	2040
Household with Children	48%	33%	27%
Single-Person Household	13%	27%	30%
Source: Census calculations by Arthur C. Nelson, Metropolitan Institute at Virginia Tech.			

- Overall, most new growth will occur in the South and the West. There is tremendous variation in the total amount of buildings to be built between regions. In the Northeast, for example, less than 50 percent of the space in 2030 will have been built since 2000, while in the West that figure is about 87 percent, a near doubling of built space. Fast growing southern and western places—states like Nevada and Florida and metropolitan areas like Austin and Raleigh—will see the most dramatic growth.



- Though a small component of overall growth, the projected demand for industrial space in the Midwest outpaces that of the other regions, unlike the other major land uses. States with a strong industrial presence will see the largest amount of growth in industrial space even though other areas may witness faster growth. After California, which far outpaces the nation in terms of absolute square feet of new industrial construction, the next four largest producers of industrial space are all Rust Belt states in the Midwest: Ohio, Michigan, Illinois, and Indiana. By 2030, 70% of the Midwest's industrial space will be less than 30 years old.

- While these projections may seem overwhelming, they also demonstrate that nearly half of what will be the built environment in 2030 doesn't even exist yet, giving the current generation a vital opportunity to reshape future development. Recent trends indicate that demand is increasing for more compact, walkable, and high quality living, entertainment, and work environments. The challenge for leaders is to create the right market, land use, and other regulatory climates to accommodate new growth in more sustainable ways.

- The challenges to accommodate future development vary by region of the country. In general, Western states—like California, Washington, and Oregon—have a strong history of growth management and will need to continue to find ways to improve upon and implement existing laws and approaches. However, neighboring states like Nevada and Arizona, where explosive growth is expected to occur, will need to find their own comprehensive solutions to manage the development boom, while facing limitations on land and water. Overall, the West will not see reduced growth pressures, and will need to find innovative ways to accommodate growth on existing land, in cities and suburban areas.

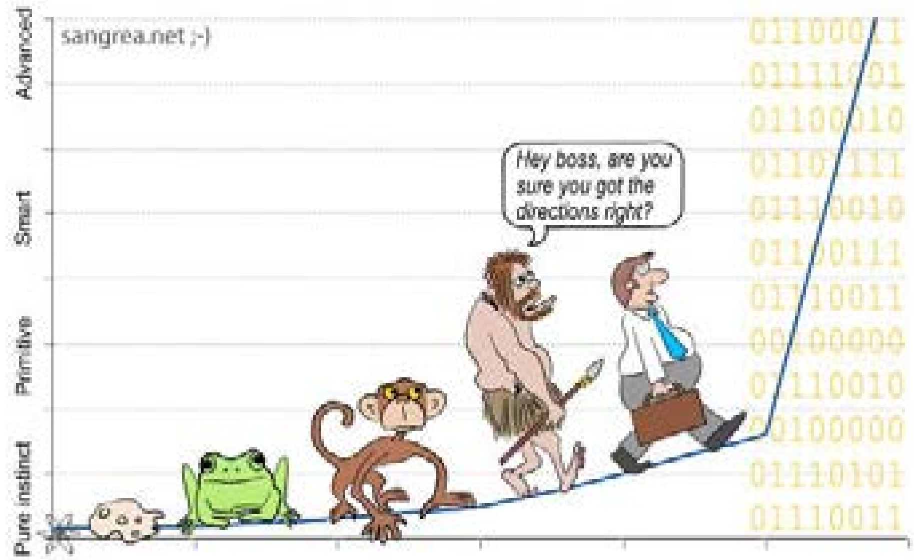
By contrast, the rapidly-growing South is more resistant to regulating growth and must make some important choices about the kind of economic and overall quality of life it hopes to achieve.

3. Colorado Population Trends

Location	Existing Population	Project Pop. 2035	5 Year Growth Rate	Average 25 Year Growth Rate
Colorado Total	5,171,798	7,699,126	1.7	1.5
Front Range	4,243,767	6,150,375	1.7	1.6
Denver	2,869,920	3,933,765	1.6	1.3
Northern Front Range	546,233	1,014,748	2.8	2.4
Colorado Springs	647,299	960,796	1.7	1.6
Pueblo	162,385	241,156	1.2	1.5
Western Slope	577,799	1,003,709	1.8	2.2
Central Mountains	131,609	229,791	0.8	1.7
Eastern Plains	163,289	247,909	0.3	1.2
Source: Colorado State Demographer				

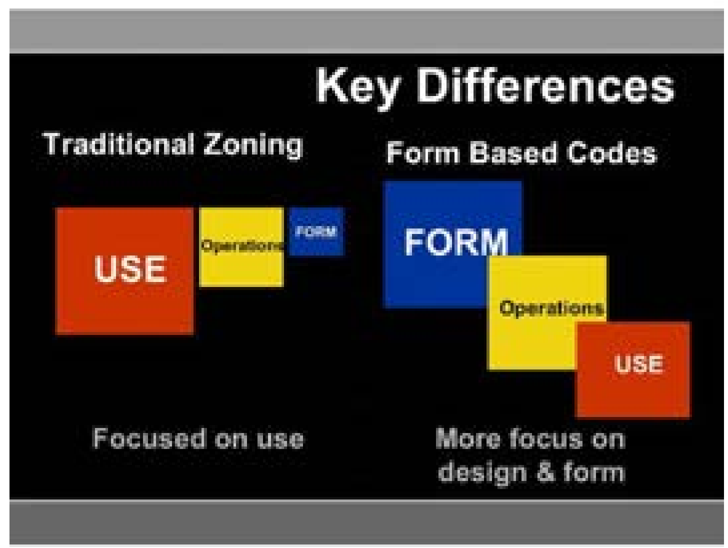
B. NEW URBANISM DEVELOPMENT

1. **Define New Urbanism Movement.** New Urbanism is an urban planning philosophy, promoting pedestrian-oriented neighborhoods, mixed housing and job types and quality streetscape and architectural design elements. This urban form, prevalent in European countries, was popularized in US in the early 1980s and continues to reform many aspects of American urban areas by promoting functional pedestrian oriented streetscape, energy efficient design (LEED concepts), and quality architectural design, using a transect definition of the community.



New Urbanism is predicated on strong urban design standards. These standards generally promote elements such as the traditional neighborhood design (TND) and transit-oriented development (TOD). The Congress for the New Urbanism is a central nonprofit organization promoting the new urbanism movement. This organization's mission is stated in the *Charter of the New Urbanism*, which says:

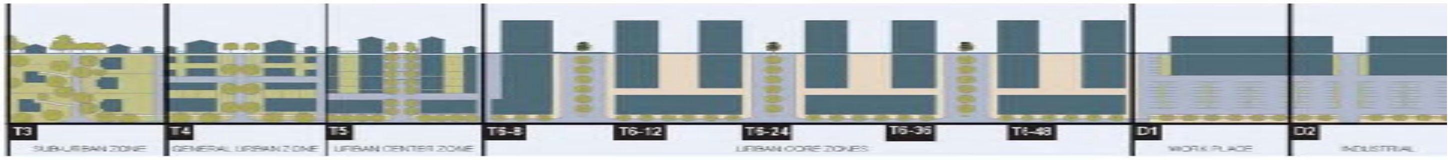
> "We advocate the restructuring of public policy and development practices to support the following principles: neighborhoods should be diverse in use and population; communities should be designed for the pedestrian and transit as well as the car; cities and towns should be shaped by physically defined and universally accessible public spaces and community institutions; urban places should be framed by architecture and landscape design that celebrate local history, climate, ecology, and building practice."



2. **Form Based Codes.** Form-based codes are intended to achieve a specific built form. They create a predictable public realm by controlling physical form primarily, with a lesser focus on land use. Generally, form-based codes address the relationship between building façades and the public realm or streetscape, the form and mass of buildings in relation to one another, and the scale and types of streets and blocks. Form-based codes guidelines correspond to an overall plan that designates the appropriate form and scale (and therefore, character) of development rather than only distinctions in land-use types. This is in contrast to conventional zoning's focus on the segregation of land uses, and the control of development intensity through dimensional standard (e.g., dwellings per acre, setbacks, parking ratios, and traffic Levels of Service (LOS). Form-based codes also sometimes include:

   - **Architectural Standards**. Regulations controlling external architectural materials and quality.
   - **Landscaping Standards.** Regulations controlling landscape design and plant materials on private property as they impact public spaces (e.g. regulations about parking lot screening and shading, maintaining sight lines, insuring unobstructed pedestrian movements, etc.).
   - **Signage Standards**. Regulations controlling allowable signage sizes, materials, illumination, and placement.
   - **Environmental Resource Standards.** Regulations controlling issues such as stormwater drainage and infiltration, development on slopes, tree protection, and solar access, etc.

3. **Miami 21 - Form Based Code.** Miami is the first major metropolitan city in the nation to adopt a form-based code. *Miami 21* has been praised for the simplicity of zoning district standards and predictability. A property owner determines which zoning regulations apply to a parcel by locating the parcel in the Zoning Atlas which define the zoning area in a transect approach (rural to urban transition). An area may be rezoned only to a more intense district if the neighborhood abuts such a district (successional zoning).



DESCRIPTION						
Height	2 Story	3 Story	5 Story	8 Story +	1-8 Story	1-8 Story
Building Types	Detached Single-Family Dwelling	Party wall Residential, Live-Work	Residential, Commercial, Mixed-use	Residential, Commercial, Mixed-use	Workplace, Limited Residential Commercial	Industrial, Commercial
Density	18 du /acre	36 du /acre	65 du /acre	150 du /acre or as per Residential Density Increase Areas	9 du /acre	None

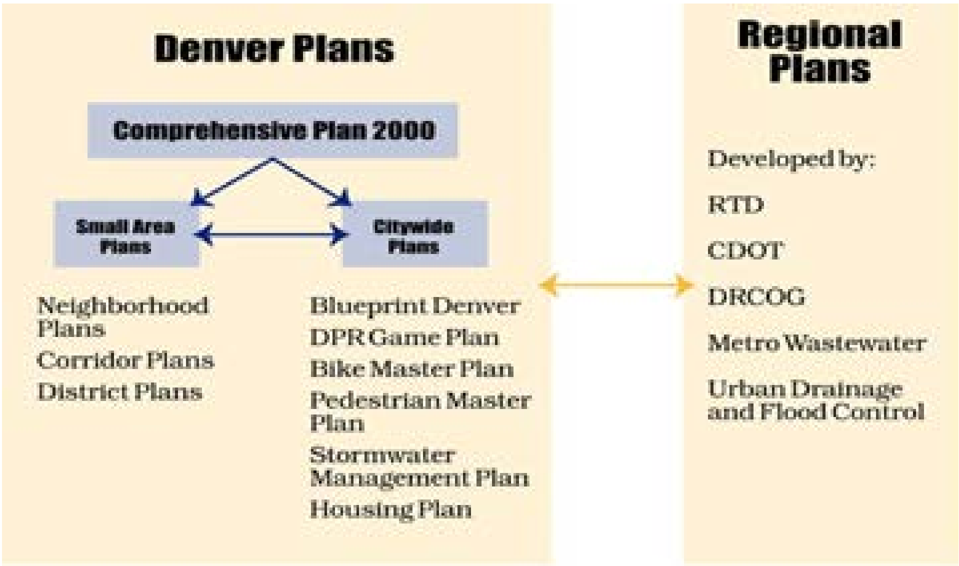
The *Miami 21* model is predicated upon public benefits and promotes pedestrian function rather than the automobile function. Guiding principles and public benefits include the following:

- contemporary urban streetscape design (wide sidewalks, narrow street, and street trees;
- active ground floors (large display windows & façade treatment, building mass, promote the front porch, prohibit snap-on garages;
- mixed uses (focus on architectural and streetscape design and deemphasize use restrictions;
- reduced infrastructure demand which is greater than City's capacity to provide them;
- affordable/workforce housing to support jobs base;
- waterfront access and parks to support the growing residential base;
- historic preservation of buildings and sites to support the unique character and touristic value;
- green building;
- brownfield redevelopment; and,
- civic and civil support spaces.

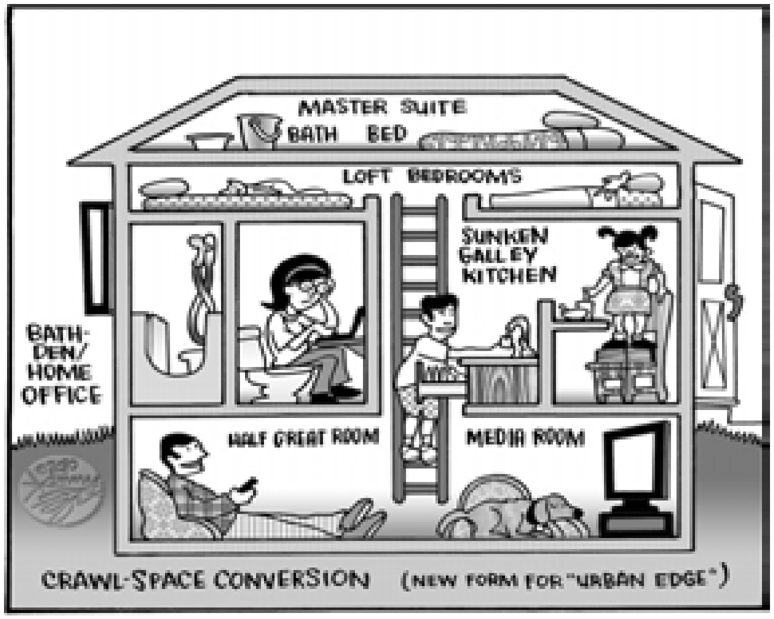
The risks identified by the Miami 21 model include:

- loss of development rights;
- the cost of public benefit programs;
- homogenized city form and stifled design creativity; and,
- vague provisions and unfamiliarity.

4. Denver Form Based Code. On June 30, 2010 the City of Denver adopted a new land development code, replacing a code that had been in place for over 50 years and was described as complicated, antiquated and inconsistent. The new code, which was an outgrowth of the *Comprehensive Plan* (2000) and *Blueprint Denver* (2005), contains seven zone districts, compared to over 59 different zone districts in the previous code.



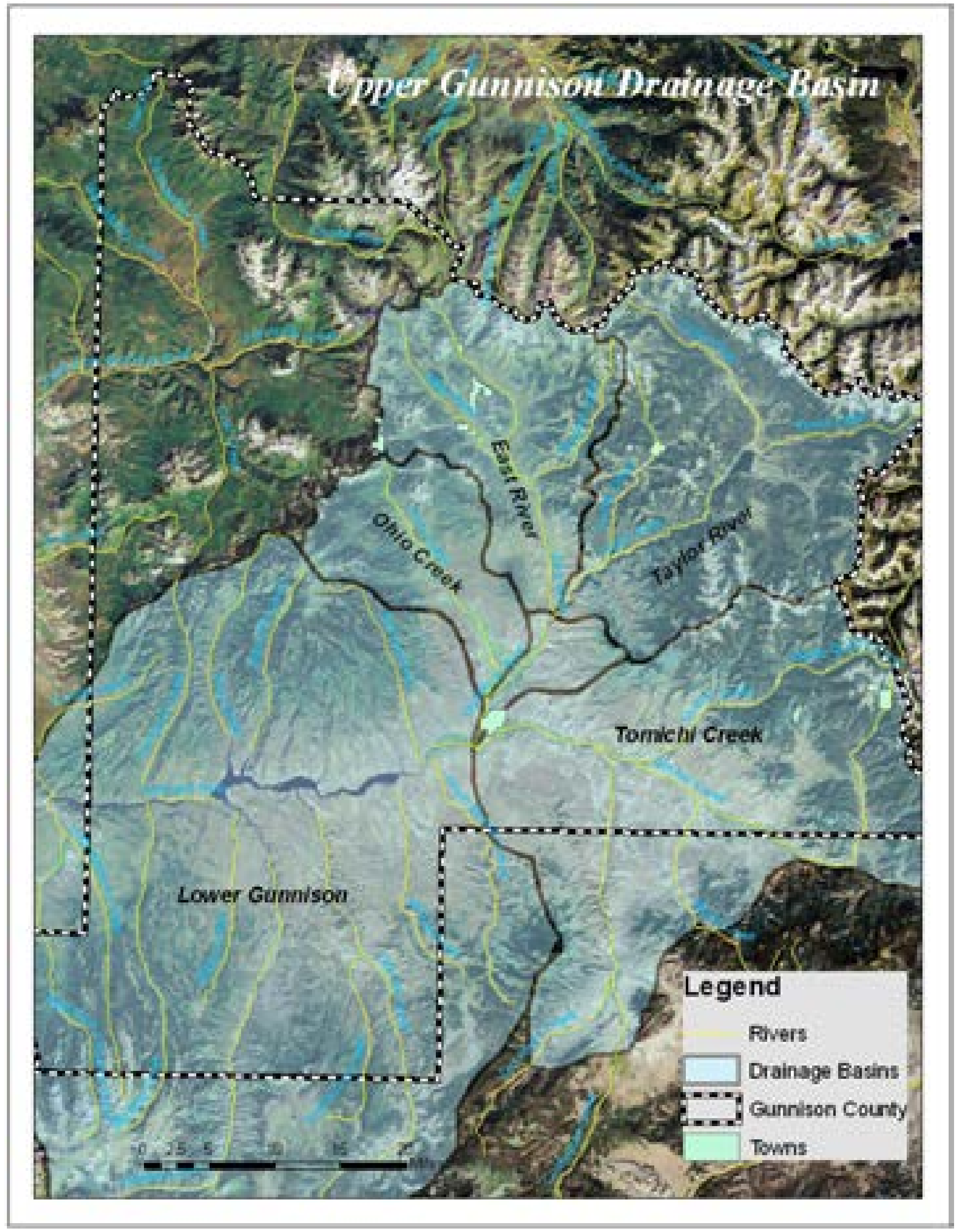
Denver's new code is not without its critics. In Kenny Be's *Denver Westword* article, Everybody Must Get Zoned, (1/7/2010), he described the new code stating *"…it is a control-freak fantasy with detailed rules for every aspect of city life*. One example is the transparency provisions for ground-floor retail in the urban district. Transparency will be used "…*To create rhythms and patterns on building facades that provide visual interest and reflect the uses within the building.*" The code also states that windows will occupy 30 percent of the ground floor wall-plan.



III. Planning Case Studies – Gunnison Basin

A. OVERVIEW OF THE GUNNISON BASIN

1. Gunnison is the fifth largest county area in the state, encompassing 3,260 square miles.
2. The average elevation is 9,500 feet.
3. Precipitation rates in the county are variable with Crested Butte averaging over 30 inches per year and Gunnison receiving about 10 inches annually.
4. The Upper Gunnison Drainage Basin covers approximately 6,330 square miles.
5. The County's population is approximately 15,000 with about 9,000 persons residing in the area of Gunnison.
6. Major employers include state and federal government, Western State College, mineral extraction, and the tourism service industry.
7 The County has five designated wilderness areas including the Maroon Bells, Fossil Ridge, and the Gunnison Gorge and one National Park; the Black Canyon of the Gunnison
8. Over 85 percent of the land area is managed by the federal government.
9. Highly charged issues in the County include:
   - Crested Butte Mountain Resort ski area expansion;
   - molybdenum on Mt. Emmons adjacent to Crested Butte;
   - the struggling economy and lack of economic diversity;
   - listing of the Gunnison Sage Grouse and Gunnison Prairie Dog;
   - geothermal energy resource production; and,
   - trans-mountain water diversion.

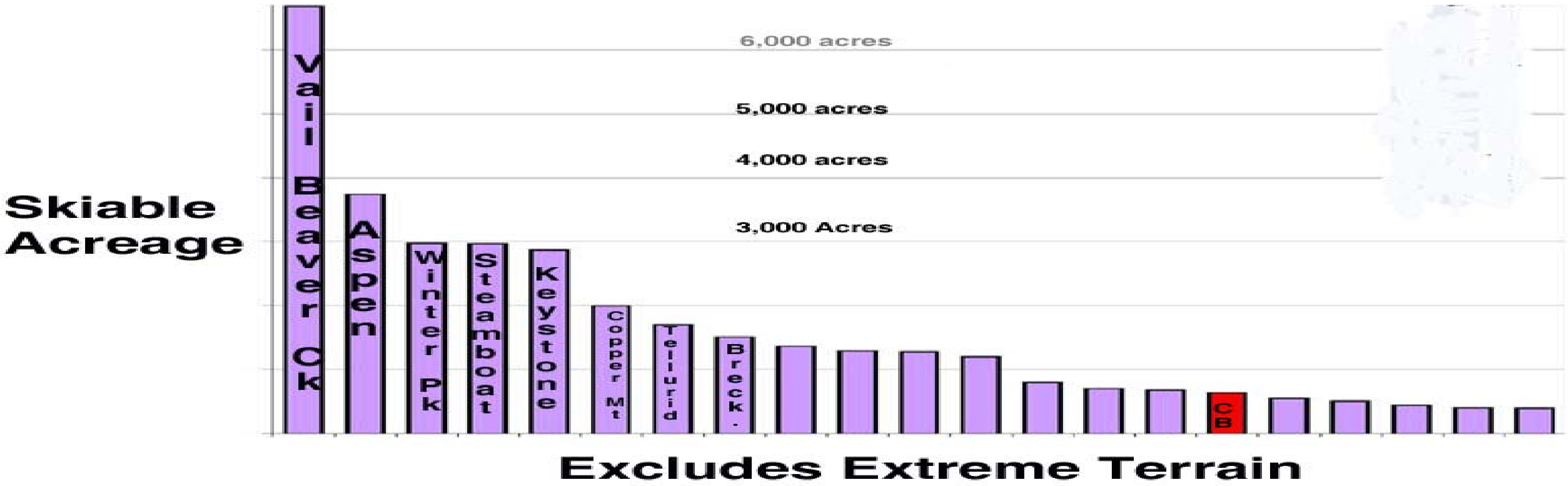


B. Mt Crested Butte—East Trade Parcel Annexation

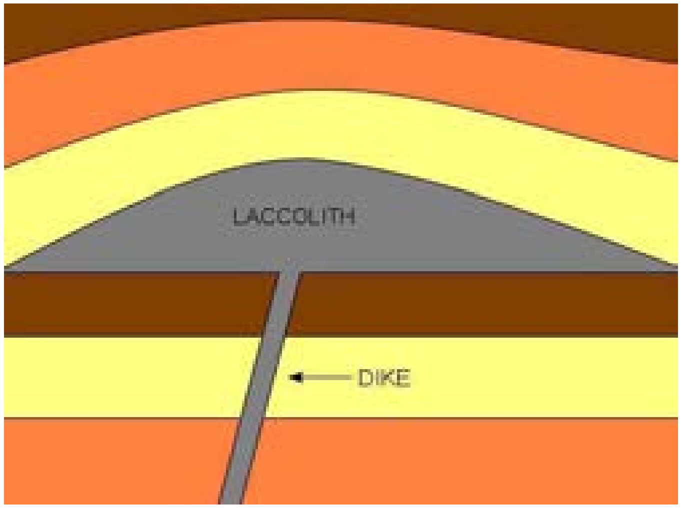
1. East Trade Parcel Background. In 1996 the US Forest Service (USFS), Colorado Land Board and Crested Butte Mountain Resort (CBMR) implemented a land exchange that garnered 4,000 acres of critical habitat, wilderness in-holdings and mining claims in the County; in return 600 acres of USFS land adjacent to Mt. Crested was deeded to CBMR. The land exchange included 640 acres within the Maroon Bells Wilderness area and a 3,000 acre ranch containing critical elk, deer, and sage grouse habitat.

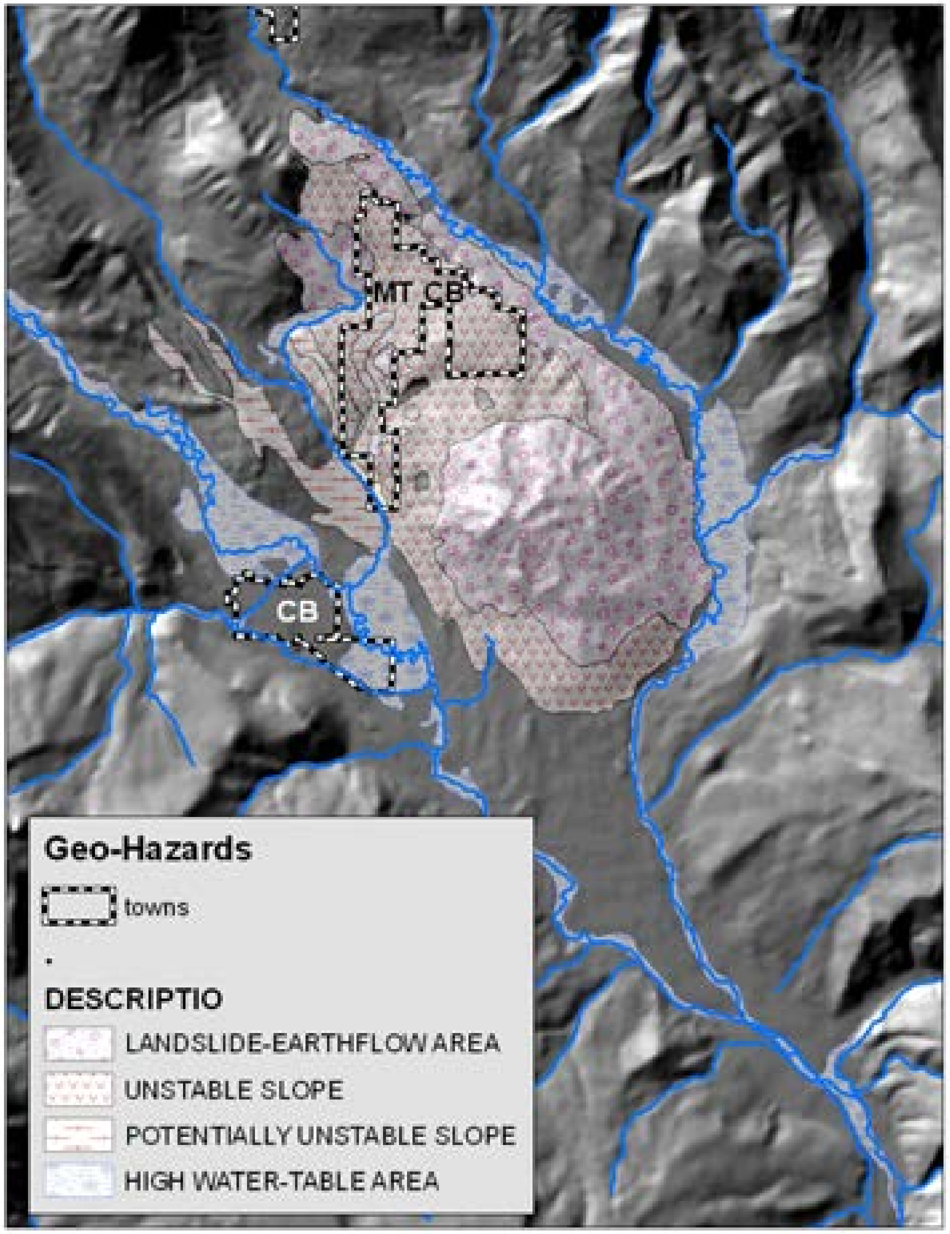
2. **East Trade Parcel Debate—Economics.** CBMR was the only privately-held major ski area in Colorado and was struggling in 1998.

- In the past two decades, the ski industry has enjoyed an enormous increase in terrain expansions, infrastructure improvements and real estate development, while during the same period; the number of ski areas operating in the U.S. decreased by 33% and total active skiers by 10%.
- Destination skier visits to Crested Butte have been on a steady downward trend for the past twenty years.
- CBMR's market share has decreased compared to other resorts.
- National skier demographics are changing; baby boomers are getting older and request intermediate and advanced terrain.
- CBMR lags in repeat visitors; only 54% return compared to 80% at Aspen or Vail.

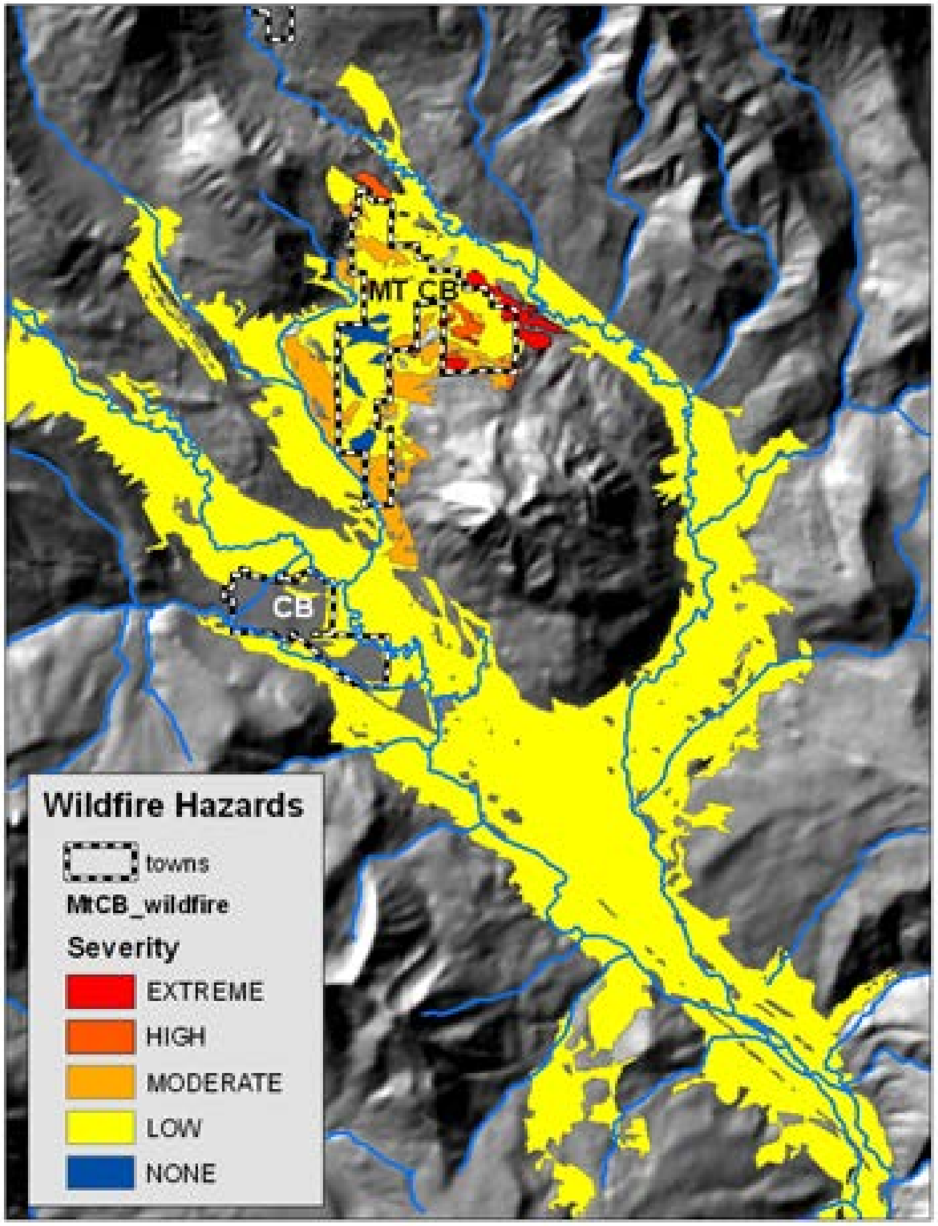


The East Trade Parcel Debate—Geologic Hazards. Mt. Crested Butte is known as a laccolith, an igneous intrusive injected into overlying rock beds. The Mt. Crested Butte laccolith was injected into the Mancos Formation, a Cretaceous age shale formation. The steep slopes and geologic structure create a diverse set of geologic hazards.

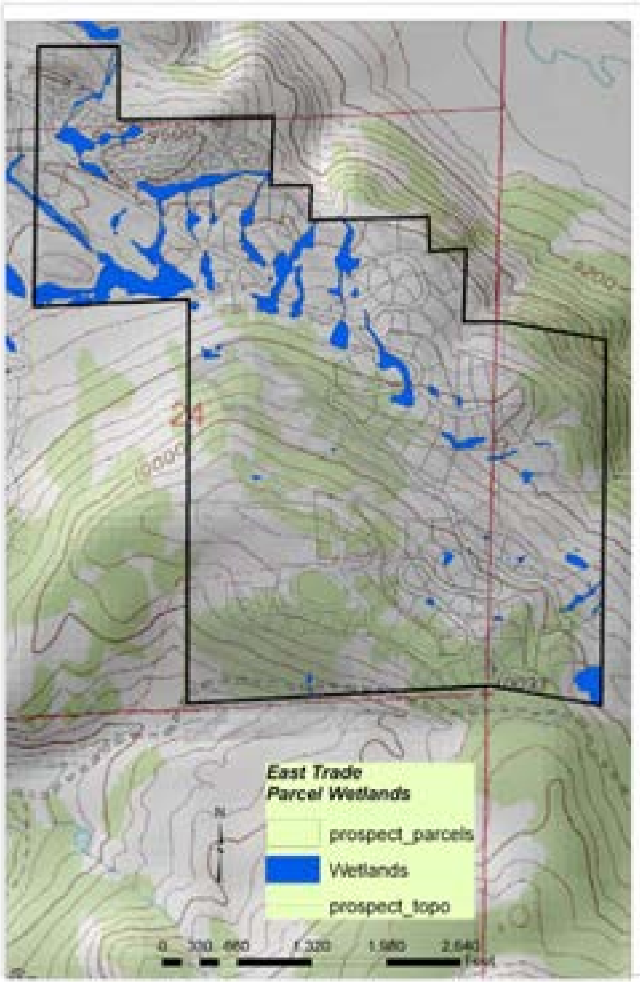


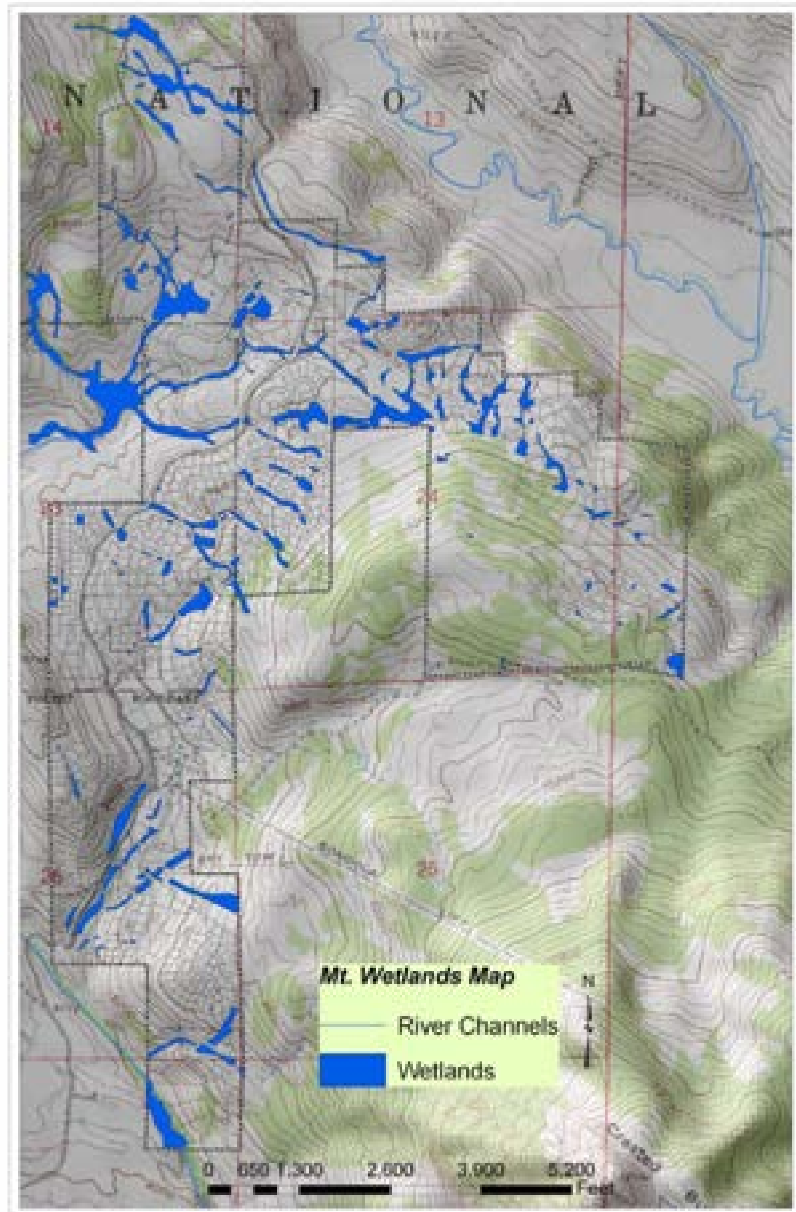


East Trade The East Trade Parcel Debate—Wildfire Hazards. In 1995 the County initiated a GIS model to define wildfire hazards. The model inputs include ladder fuel and forest density inventories along with slope and aspect GIS models to rank wildfire risks.

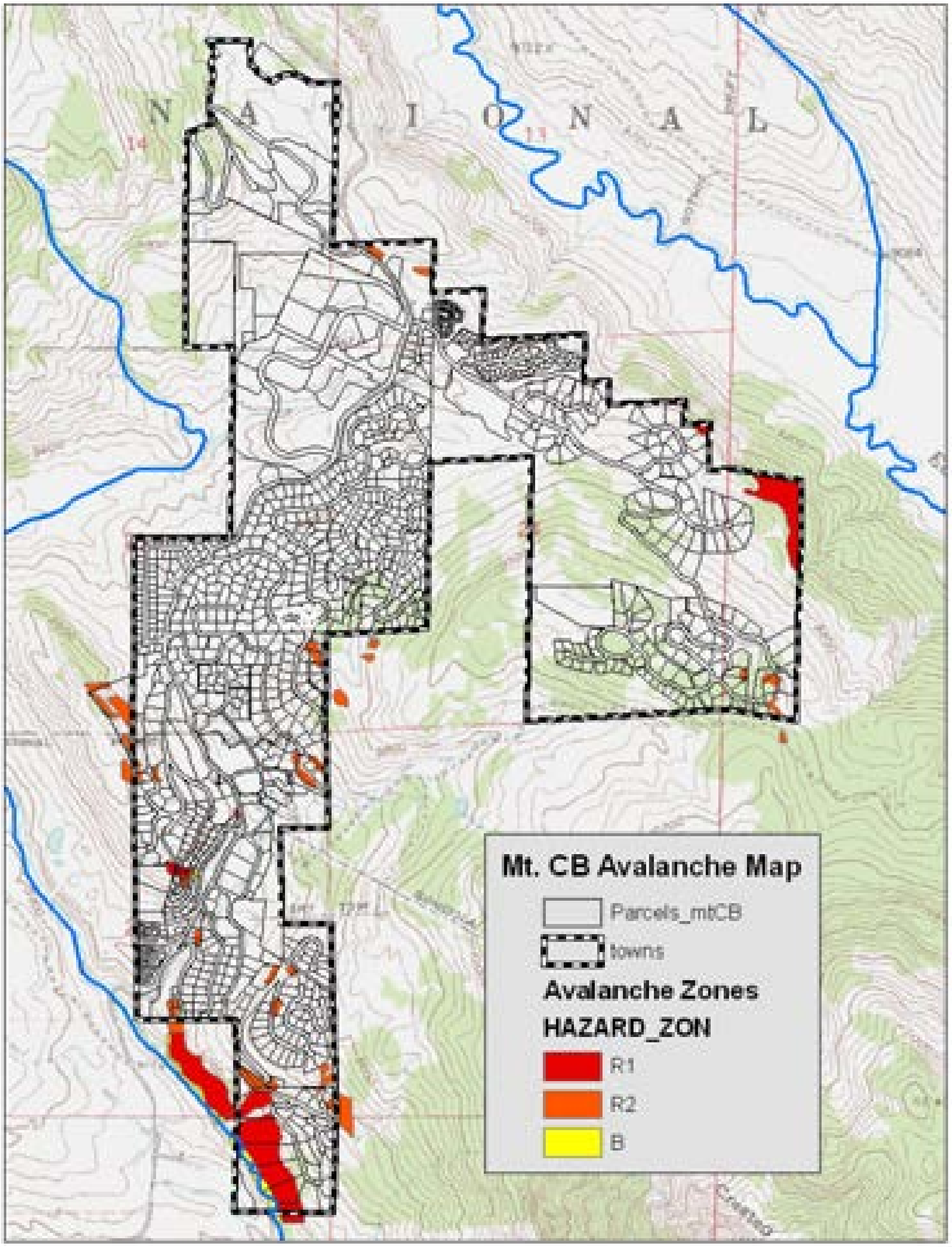


East Trade Parcel Debate—Wetlands and Water Quality. The *Annexation Petition* spawned a significant debate regarding environmental protection and sustainability. The Town completed a wetland inventory in 2000 and adopted wetland setback regulations. The East Trade Parcel annexation was subject to these new regulations. Wetland buffers measures are based on wetland function with a 100 foot setback required except from isolated wetland complexes.

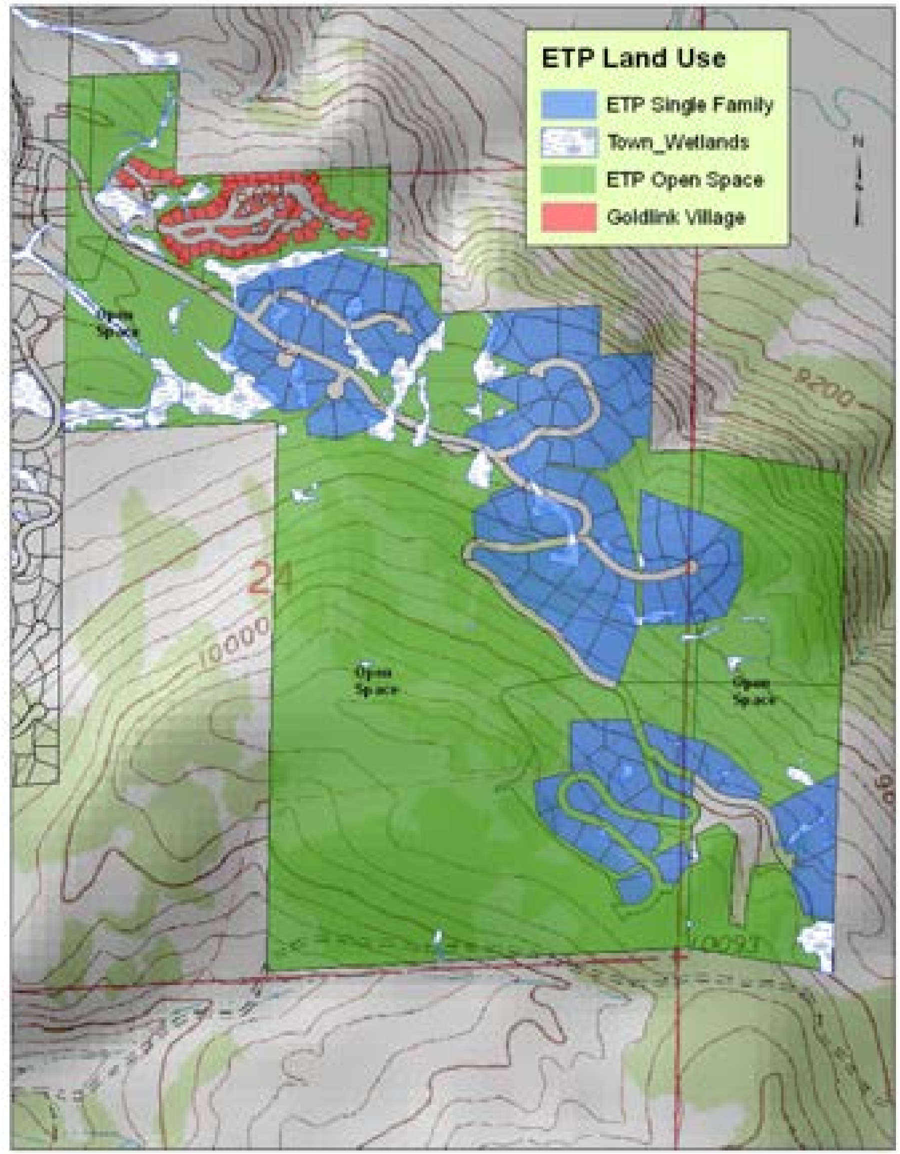




The East Trade Parcel Debate—Avalanche Hazards. In 1991 an avalanche on Sunlight Ridge buried the entire first floor of a condominium – fortunately there were no injuries. Two years later a child was killed in the condominium parking lot when an avalanche slid from Sunlight Ridge. This is one of the only non-skiing related deaths reported in any US municipality from an avalanche. Mt. Crested Butte responded by creating one of the first avalanche mitigation regulations in the nation.



3. East Trade Parcel Development Plans—Land Use. The East Trade Parcel is a planned unit development which at this point is designated exclusively for residential development. The plan also calls for development of approximately 80 affordable housing units. However, the initial zoning included a 180,000 sq. ft. commercial component including a hotel, restaurant and gondola. The commercial component was a designated hub between the existing mountain and the proposed Snodgrass ski area expansion. The land use plan contains 280 acres of open space and ski terrain and development of up to 300 dwelling units.



East Trade Parcel Development Plans—Geological & Geotechnical Summary. With the assistance of the Colorado Geological Survey an extensive set of site investigations were initiated on the East Trade Parcel. Testing included a series of drill borings and test pit, a matrix of piezometer wells and the installation of 4 inclinometers that were monitored for 18 months in conjunction with the piezometer wells. The major issue to answer was regarding the potential for massive slope failure. The bedrock Mancos Shale, which dips about 5^0 to the south, was found to be stable. Detritus material is saturated on a seasonal basis and requires engineered foundation design and special precautions for cut/fill placements.

GEOLOGIC HAZARDS AREN'T NECESSARILY ACTIVE ALL THE TIME

FIGURE 12.–North side of Crested Butte, Colorado, showing crest to southwest (right) and gravitational trenches northeast of crest (left from crest). Pronounced break in slope on east side (left) is approximate contact between porphyry and underlying Mancos Shale.

East Trade Parcel Development Plans—Site Grading Standards

- grading plans shall be prepared to conform to the master drainage plan;
- limit grading for walkout basements – 20' limit;
- all residential grading will occur in the building envelope, improvement corridor, and transition area;
- cut and fill erosion protection is required;
- dissipate runoff to soils;
- resulting slopes must not exceed 2:1 and wherever possible, natural slopes are to be used instead of structures;
- cut and fill slopes are to be stabilized using an approved seed mix with straw and tackifier upon completion but no later than October 15th of each year; and,
- site preparation, grading and utility installation shall occur in accordance with an approved *Erosion Control and Stormwater Management Plan*.

East Trade Parcel Development Plans
Development Standards—Wildfire Protection

Defensible Space

- All lots have a 50' defensible space zone.
- Dead branches on trees within the defensible space are trimmed or removed to minimize “ladder” fuel.
- Conifer trees in the defensible space shall be thinned to create 10' of separation between each crown.
- Conifer trees shall not be planted within 15' of a structure.
- Roof materials shall be non-flammable or have fire resistant rating.
- All chimneys shall be equipped with spark arresters.

East Trade Parcel Development Plans
Development Standards—Grading, Erosion Control & Storm Water Management

- The final site plan/grading plan shall be prepared to conform to the master drainage plan.
- Finished grading associated with a walkout basement shall be designed such that no flat area not natural to the site will extend beyond the building envelope or beyond twenty 20' feet of the foundation, whichever is more restrictive.
- All residential grading will occur in the building envelope, improvement corridor, and transition area.
- Newly graded areas shall be protected against erosion by appropriate retention fences or permanent erosion controls.
- Splash blocks, gravel foundation drainage beds, or trench drains and underground, perforated drain pipes shall be utilized to dissipate runoff.
- Finish site grading shall not produce runoff detrimental to adjacent properties and native wetland areas.
- Finish site grading shall be done to retain rainfall for maximum percolation in turf areas.
- No excavation may take place except as necessary for the construction of dwellings or improvements.
- Retaining walls shall appear to be extensions of existing natural land forms.
- Resulting slopes must not exceed 2:1 and wherever possible, natural slopes are to be used instead of structures.
- Cut and fill slopes are to be stabilized using an approved seed mix with straw and tackifier upon completion, but no later than October 15th of each year. Irrigation is not required until final grading and landscaping is in place.
- Site preparation, grading and utility installation shall occur in accordance with an *Erosion Control and Stormwater Management Plan* approved by the Planning Commission and will include the limitation on dates of disturbance.

East Trade Parcel Development Philosophy—Nature's Envelope. The East Trade Parcel was processed through preliminary subdivision for the entire master plan. Lot configurations were established in a manner to avoid wetlands, drainages, steep slopes and with consideration for aspect, building separation, skier access and other factors. Building envelopes are designed on the plat with the envelopes to preclude wetland encroachment, avoid slope stability hazards, or negatively affect the implementation of Best Management Practices. Outside the home site/building envelope; improvement corridor; and landscape and wildfire management zones, the site is to remain in an essentially natural condition, maintained to blend with all adjoining Nature's Envelopes.

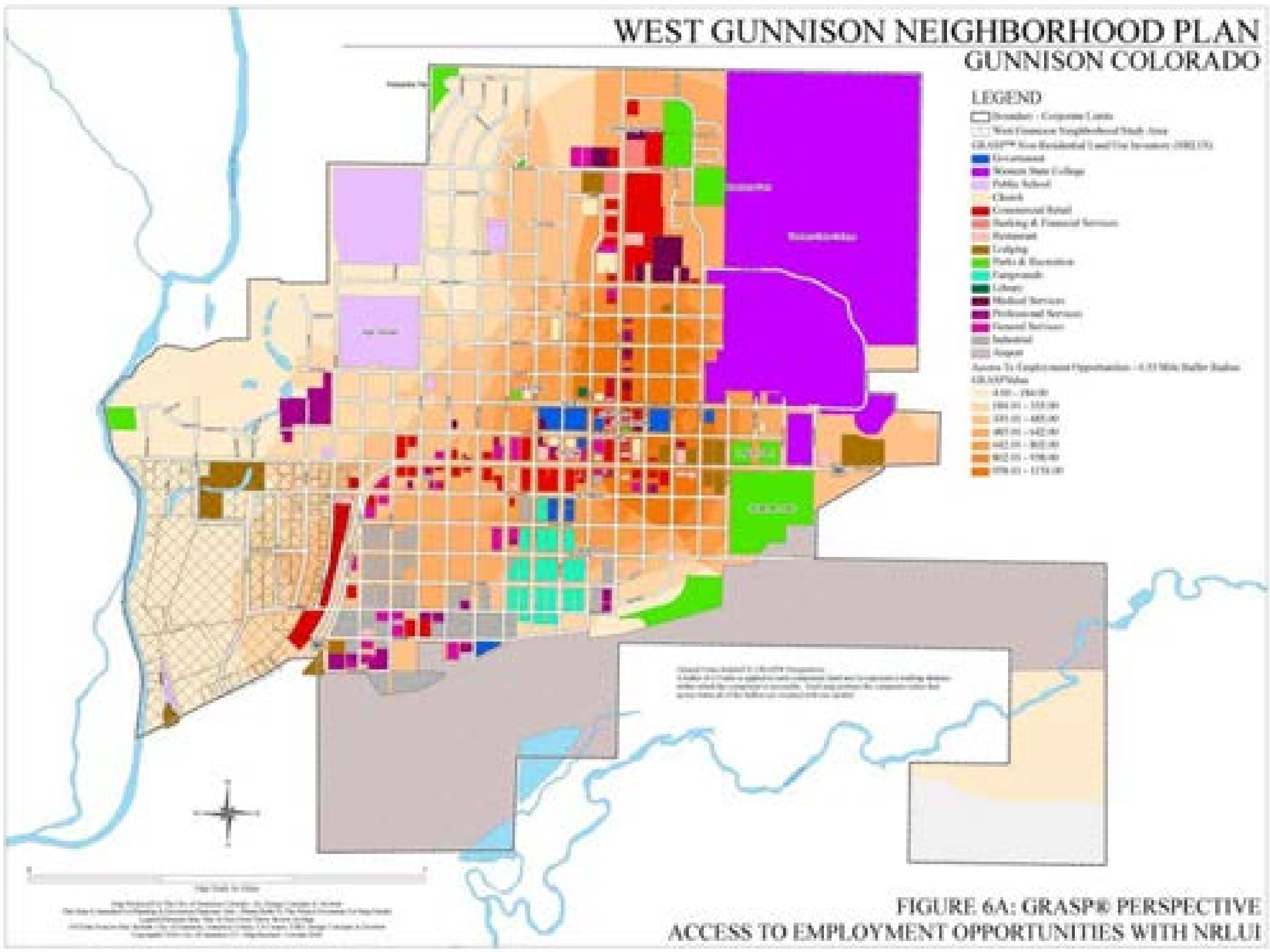
C. WEST GUNNISON NEIGHBORHOOD PLAN

1. Existing Neighborhood Conditions

- Approximately 200 acres.
- The majority of the land area is undeveloped and had no utility extension plan.
- The neighborhood is constrained by a limited number of access points.
- The neighborhood is predominately zoned for high density residential development. Underlying zoning would allow for the development of 2,100 units generating 15,000 to 20,000 vehicle trips per day.
- Jurisdictional wetlands and floodplains exist within the neighborhood.

2. West Gunnison—Neighborhood and Community Context

- limited access to the town center and employment facilities
- limited access to shopping and downtown
- opportunity to promote locations for profession/retail use
- opportunity to expand alternative travel modes

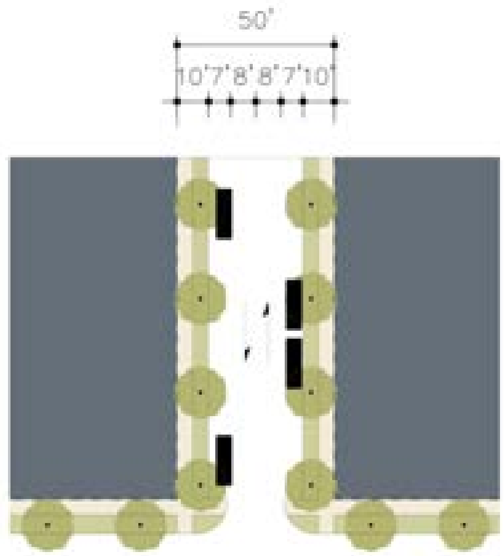


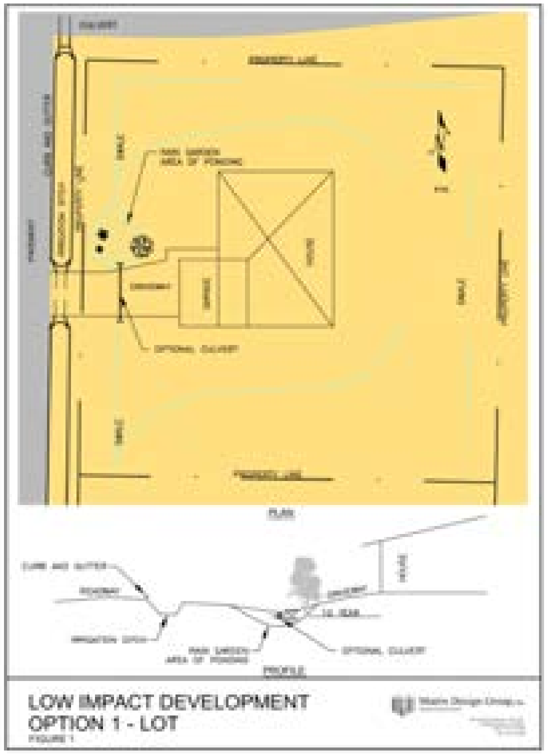
3. West Gunnison—Preferred Land Use

- 960 residential units anticipated and 150,000 square feet of professional office/retail
- limit development in the flood hazard zones
- three major highway intersections identified
- utility system sizing and extensions corridors identified
- public transit center is a permitted use
- Low Impact Design (LID) contemplated at varying scales

2. **West Gunnison – Low Impact Development**

- Currently a 10-year storm event generates essentially no runoff; any surface runoff flows into existing irrigation ditches.
- The City's standards require that post development maintain pre-development discharge.
- Low Impact Development practice.
- Regional detention systems will be designed to maintain a 100 year event
- LID concepts are defined for individual lots, a street block area, and neighborhood-wide venue.
- Street sections are significantly narrower than the traditions city streets.





CONCLUSION & COMMENTS

Legal Elements

- Know the general boundaries of the law and planning process – do not cross these bounds.
- Urban drainage and floodplain management often cross several different jurisdictional boundaries and it's incumbent upon the professionals to know the local zoning code.
- Be cognizant of the local jurisdiction status and whether it is a statutory or home rule jurisdiction.
- In order to avoid legal issues make sure to follow due process procedures set forth in local codes.
- Listen to your attorney and follow their opinion.

BOTTOM OF THE GENE POOL: SHORT-SIGHTED EAGLE

CONCLUSION & COMMENTS

Demographic Projections

- The next 30 years the United States will see significant population growth
- Major metropolitan areas will see significant growth with megapolitan regions being developed. The front-range corridor will form into a megapolitan region.
- Significant growth will occur in the western United States, and there are serious resources issues to be overcome.
- Growth management systems, permitted through state statutes will be the key element in directing and managing growth.
- Traditional industrial areas in the northeast will see a significant resurgence in industrial uses.
- Mass transit will play a critical role in growth distribution and accessibility – don't count on telecommuting to reduce commuting issues.
- Think about how your decisions affect the community's future.

CONCLUSION & COMMENTS

Smart Growth

- Smart growth starts with the comprehensive plan.
- Developers are buying into the concepts of traditional neighborhood development forms, which will help to provide in-fill and more dense development.
- Communities will need to place more focus on the pedestrian and less on the automobile.
- Economics will drive the need for local governments to focus on sustainable service extensions. Urban growth boundaries will be used to limit sprawl.
- Developing high density neighborhoods requires creative solutions for stormwater management, but smart growth requires that solutions be defined and implemented.
- In general, unincorporated jurisdictions should avoid getting into the urban services business – more often than not counties are not able to provide urban services.

CONCLUSION & COMMENTS

Development Processes

- Inventory natural resources before allowing the expansion of urban areas, and protect critical habitat and resources.
- Follow smart growth principles.
- Be aware of the true cost of growth – growth for the simple sake of growth is not economically sustainable.
- There is no perfect plan, but do not dance around issues.
- Be pragmatic in the development process, and provide necessary information and honest assessments to elected officials so that informed decisions can be made.

QUESTIONS