Urban Stream Design – How we Got to Now

Mary Powell, Corvus Environmental
Dave Skuodas, UDFCD


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EISENHOWER TUNNEL 1973


R442504


The Watershed
Standley Lake
72nd Avenue
Wadsworth Blvd
HWY 36
Federal Blvd
Sheridan Blvd
Clear Creek

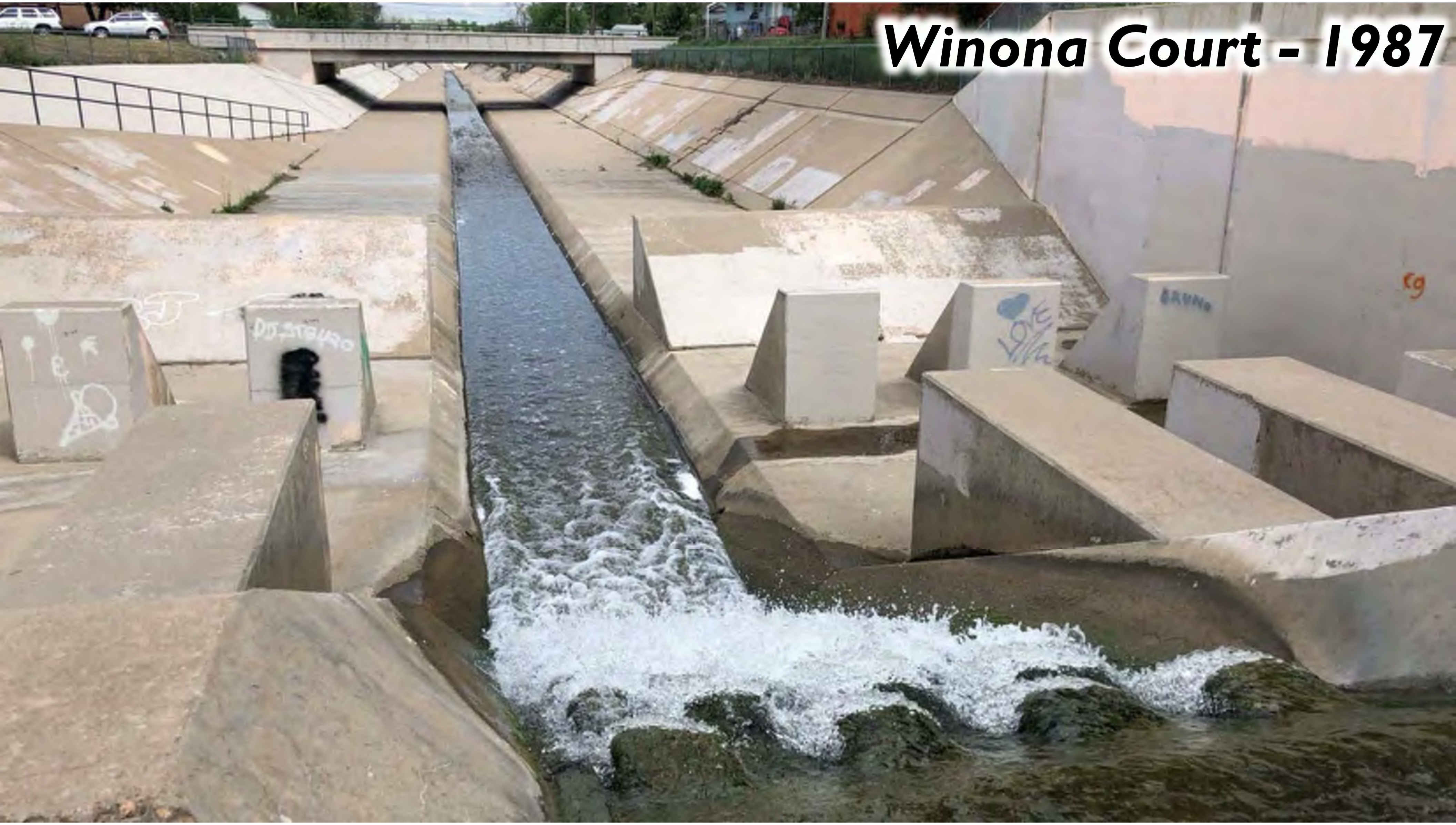
The Watershed
Standley Lake
72nd Avenue
Wadsworth Blvd
Sheridan Blvd
HWY 36
Federal Blvd
Clear Creek
Little Dry Creek (ADCO) Tributar
Little Dry Creek
Leyden Creek
Ralston Creek
Van Bibber Creek
Westminster
Arvada

The Watershed
Standley Lake
Wadsworth Blvd
HWY 36
Federal Blvd
72nd Avenue
Sheridan Blvd
Clear Creek


North of Raleigh Street - 1984


South of 76th Ave - 1986

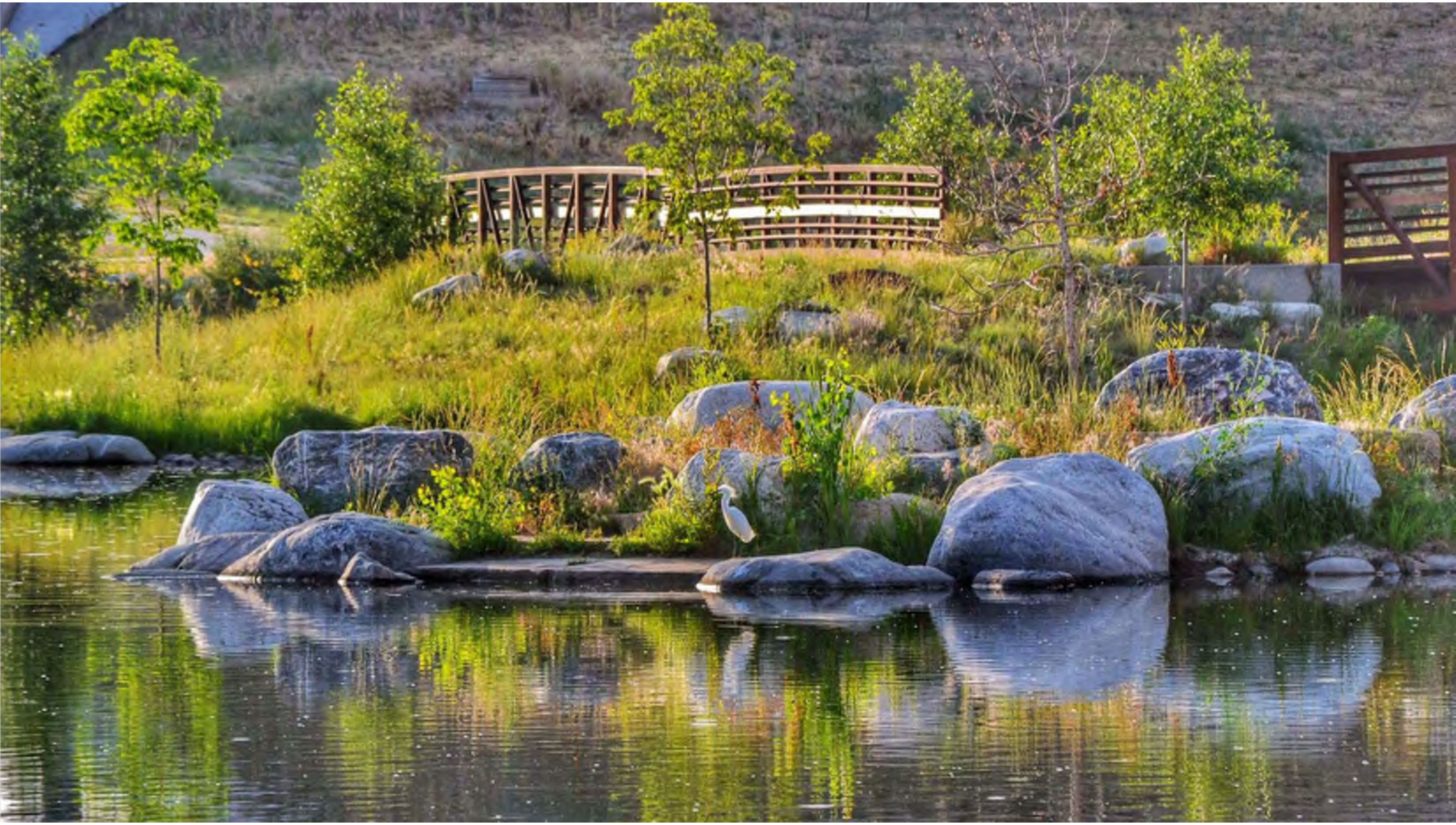

Utica Street - 1986


Winona Court - 1987


South of 75th Ave - 1987


West of Lowell Blvd - 1998


West of Lowell - 1998



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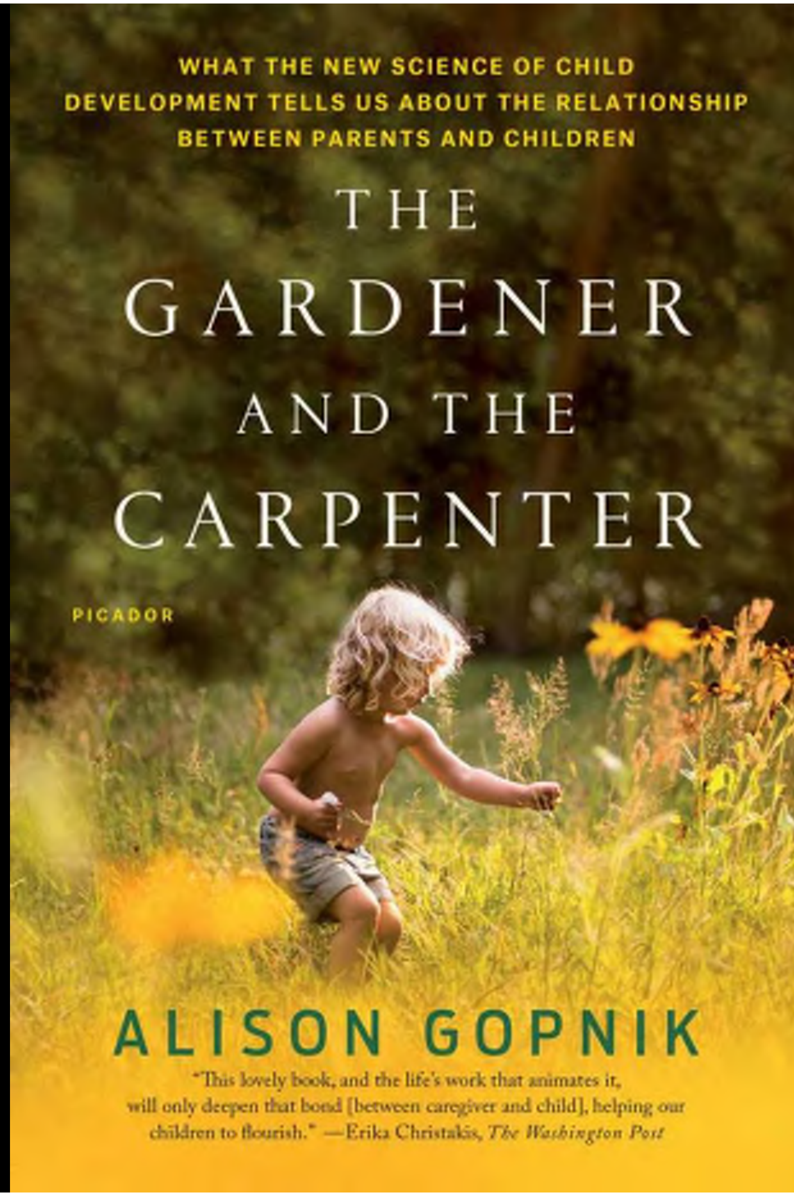
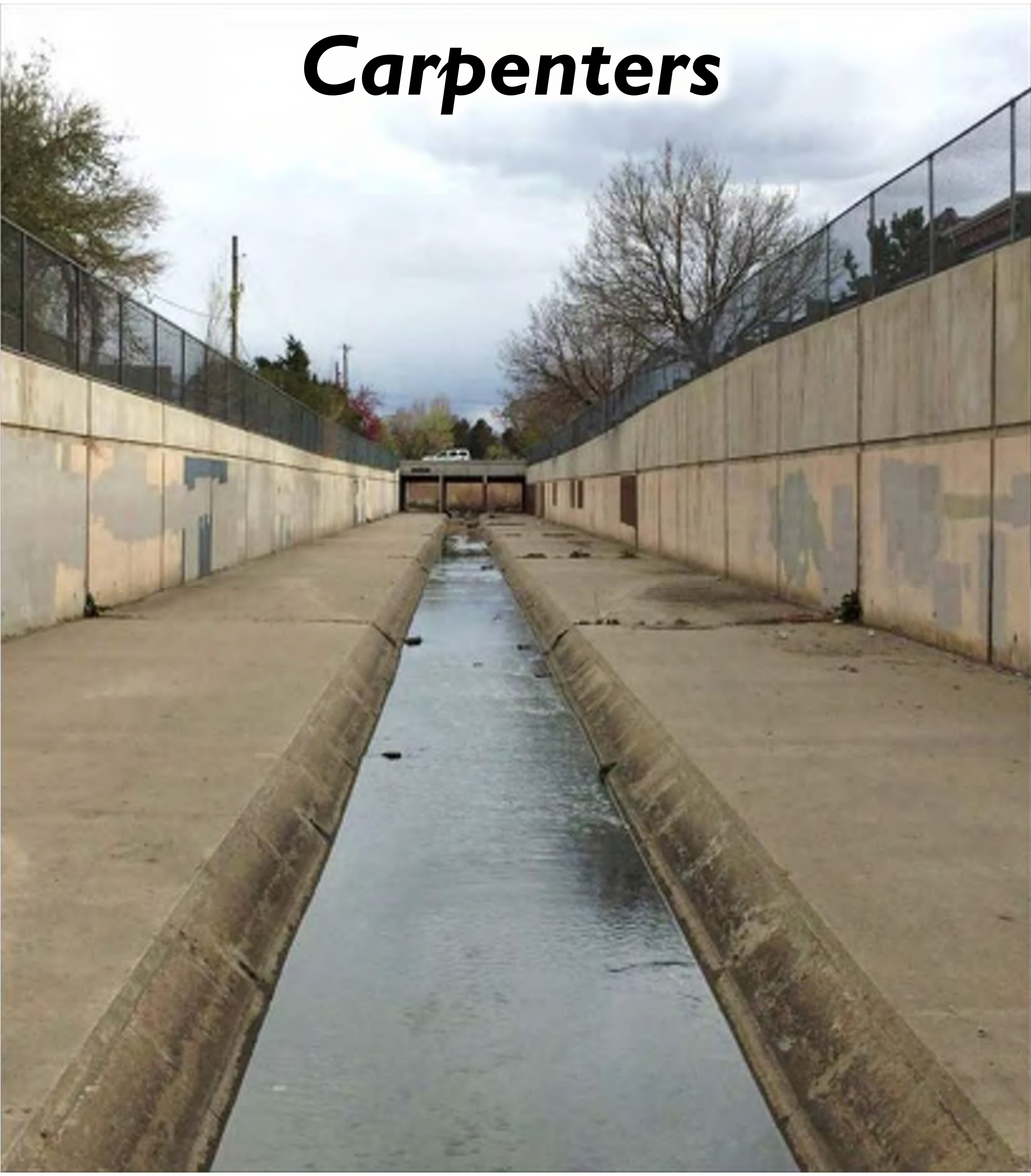
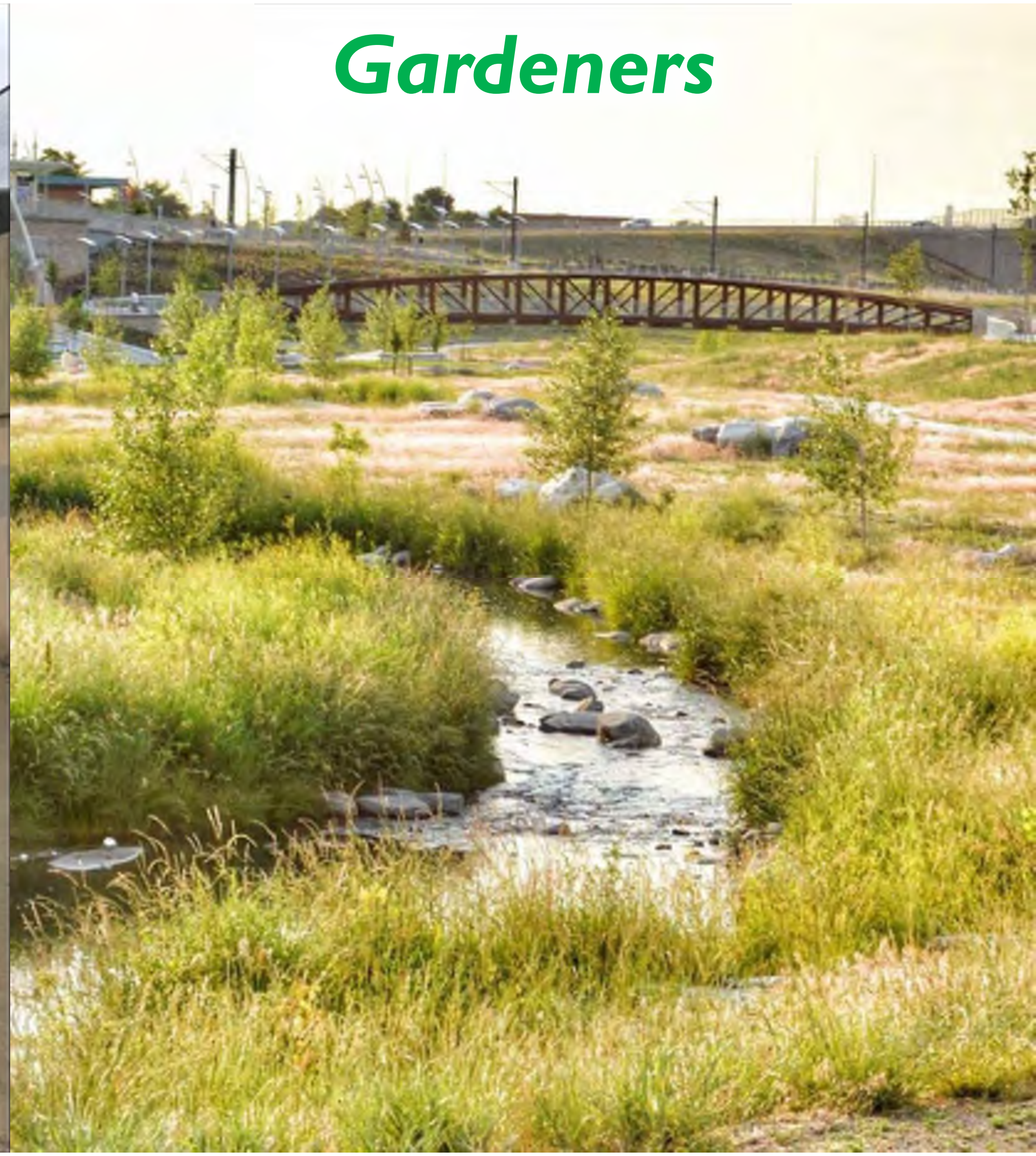

WHAT THE NEW SCIENCE OF CHILD DEVELOPMENT TELLS US ABOUT THE RELATIONSHIP BETWEEN PARENTS AND CHILDREN
THE GARDENER AND THE CARPENTER
PICADOR
ALISON GOPNIK
"This lovely book, and the life's work that animates it, will only deepen that bond [between caregiver and child], helping our children to flourish." —Erika Christakis, The Washington Post


ASTROPHYSICS


Carpenters

Gardeners


South Westminster
Lowell Blvd
75th Avenue
Sheridan Blvd
72nd Avenue
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Google Earth

75th Avenue
Lowell Blvd
Sheridan Blvd
72nd Avenue
South Westminster
Google Earth

Plan Form


Google Earth


Google Earth


Google Earth


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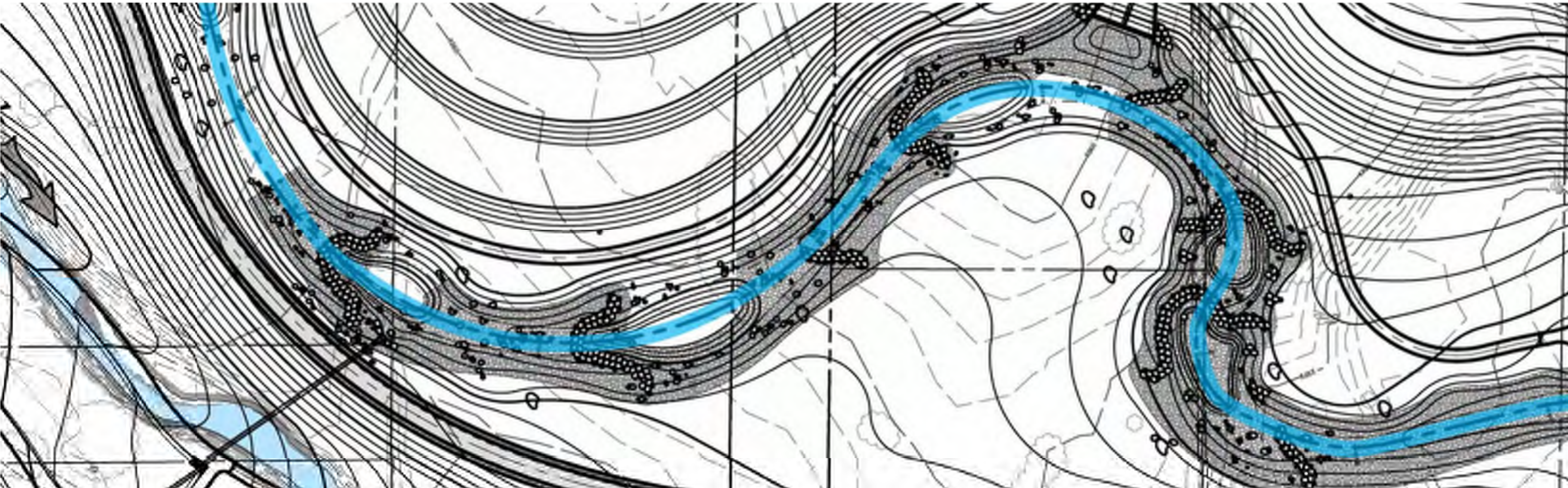
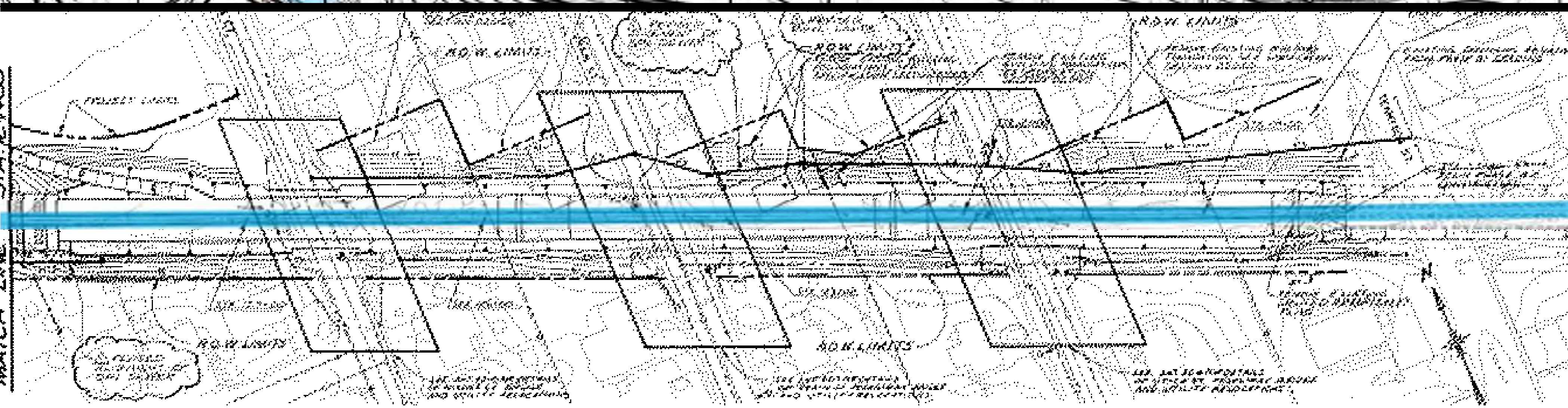



R.O.W. LIMITS

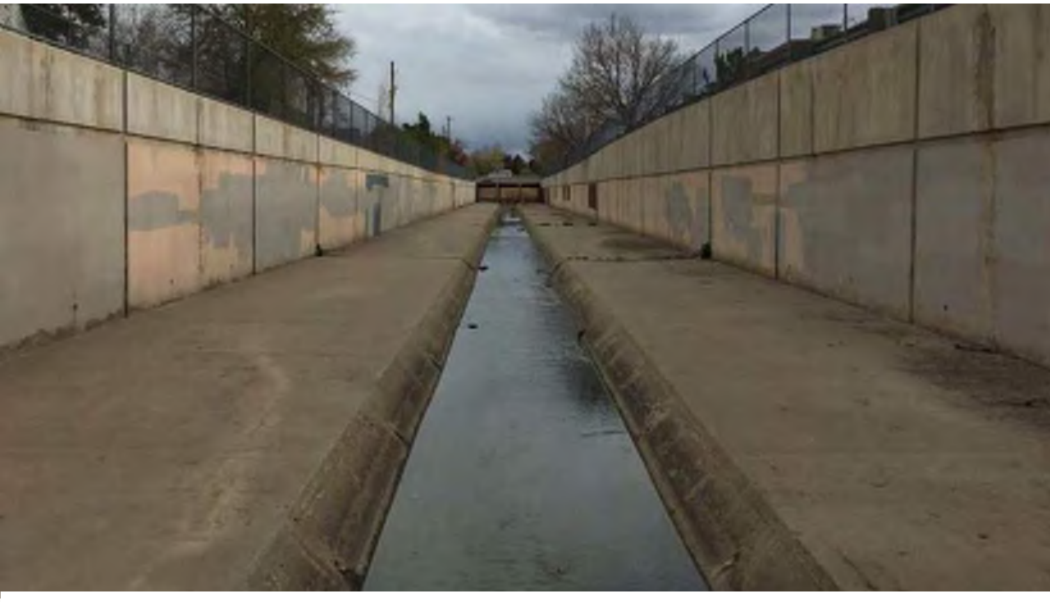

Google Earth

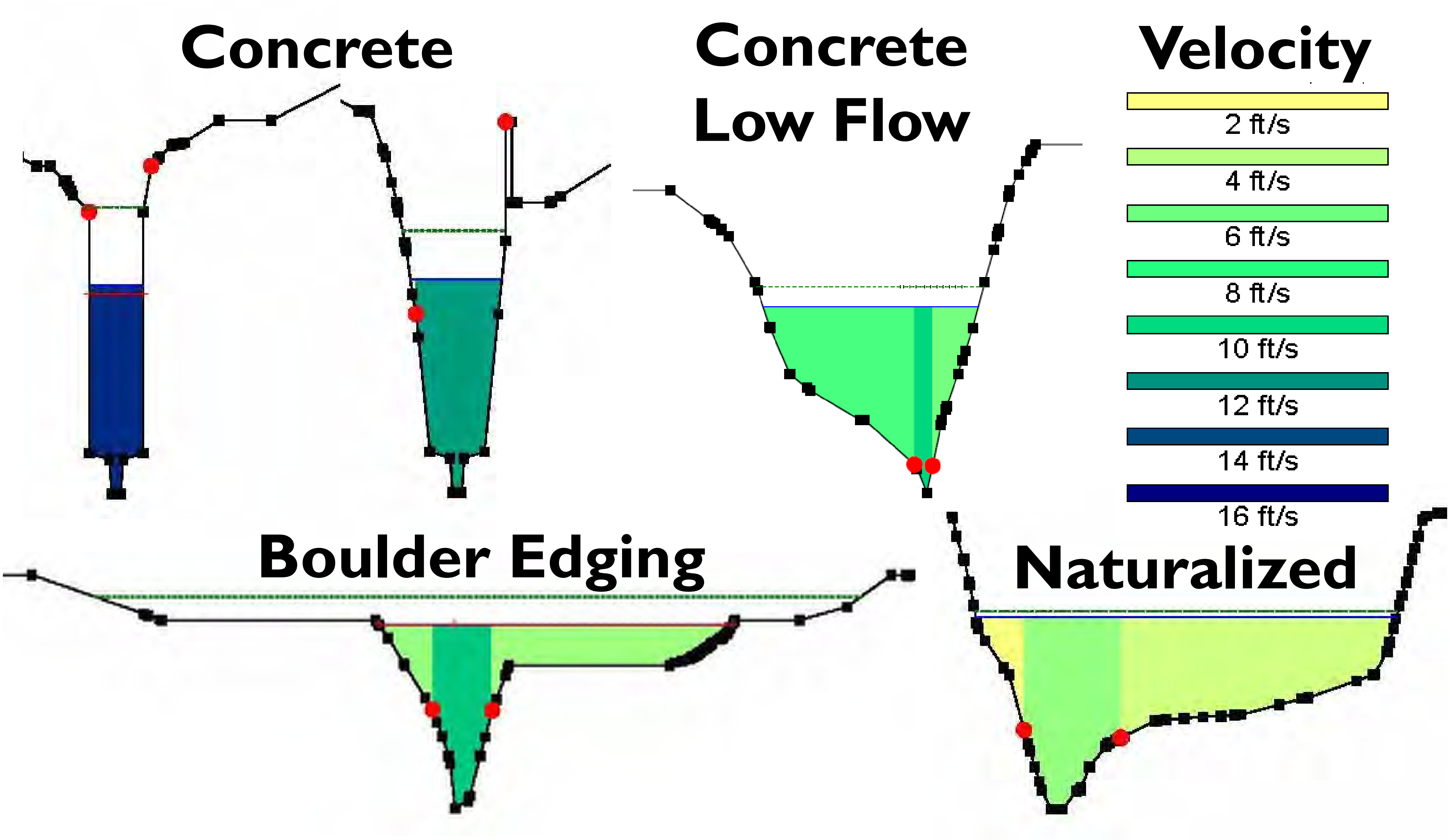

Google Earth


Lowell Blvd
Google Earth

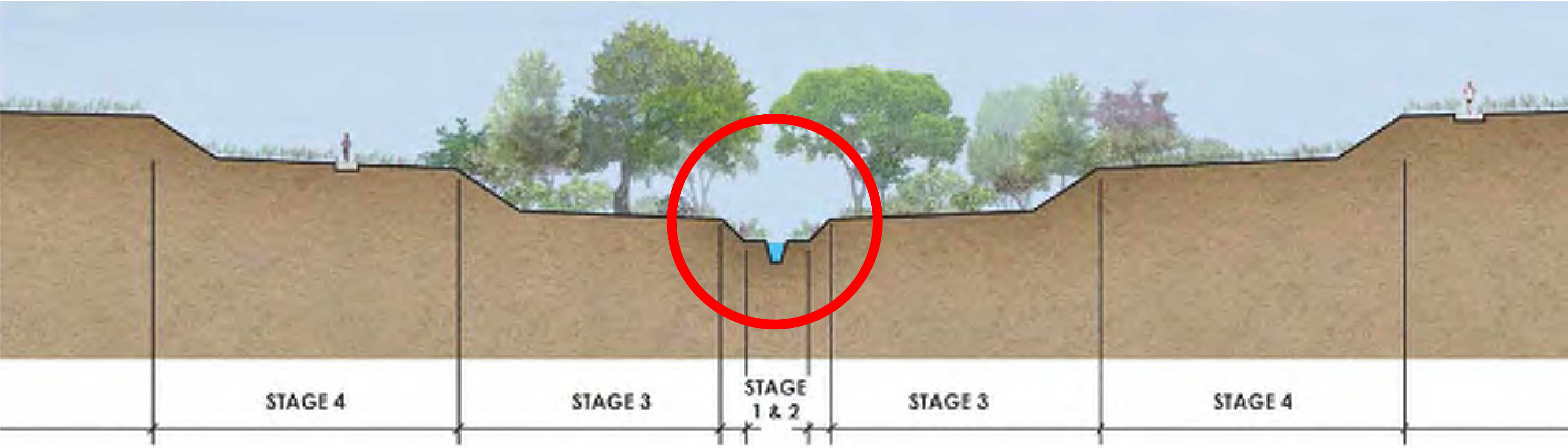

Federal Blvd
287
Google Earth

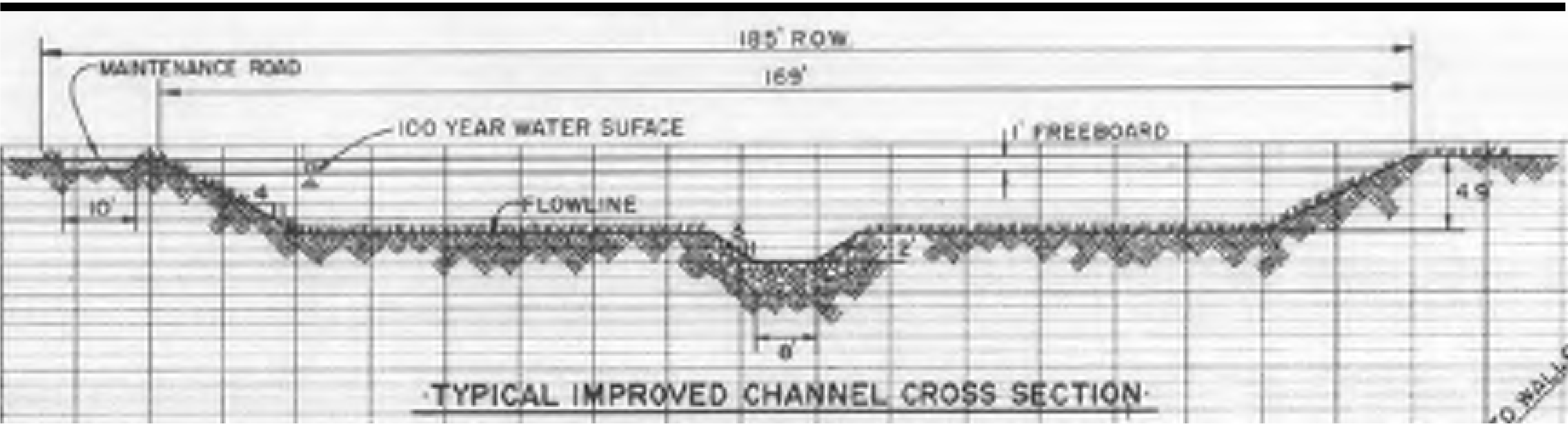
Cross Section



Concrete
Concrete
Low Flow
Velocity
2 ft/s
4 ft/s
6 ft/s
8 ft/s
10 ft/s
12 ft/s
14 ft/s
16 ft/s
Boulder Edging
Naturalized



STAGE 4
STAGE 3
STAGE 1 & 2
STAGE 3
STAGE 4

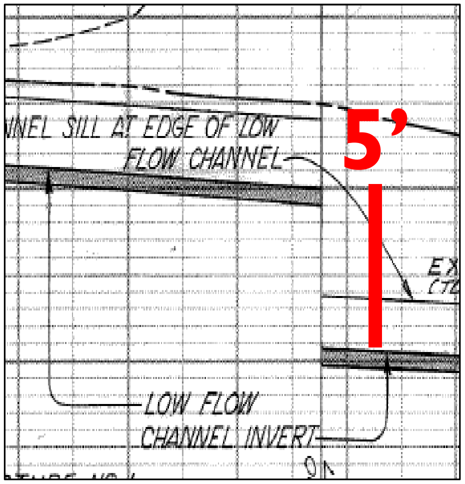

185' ROW
MAINTENANCE ROAD
169'
100 YEAR WATER SUFACE
1' FREEBOARD
10'
FLOWLINE
4.9'
8'
·TYPICAL IMPROVED CHANNEL CROSS SECTION·

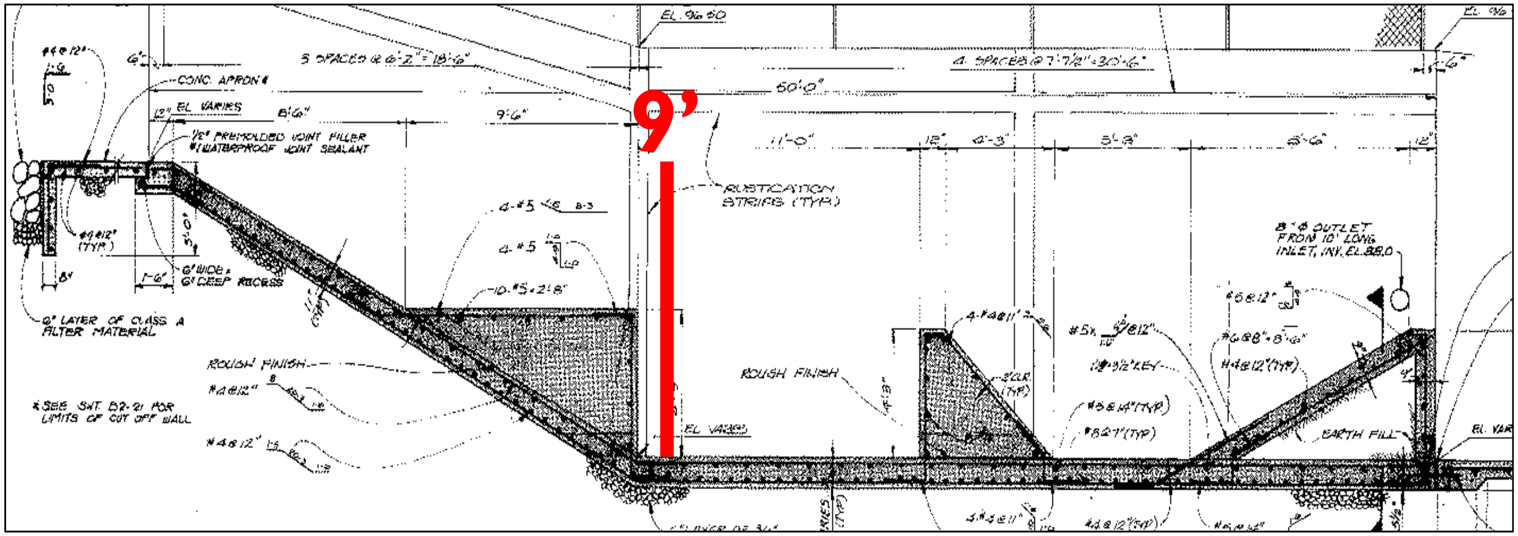
Grade Control

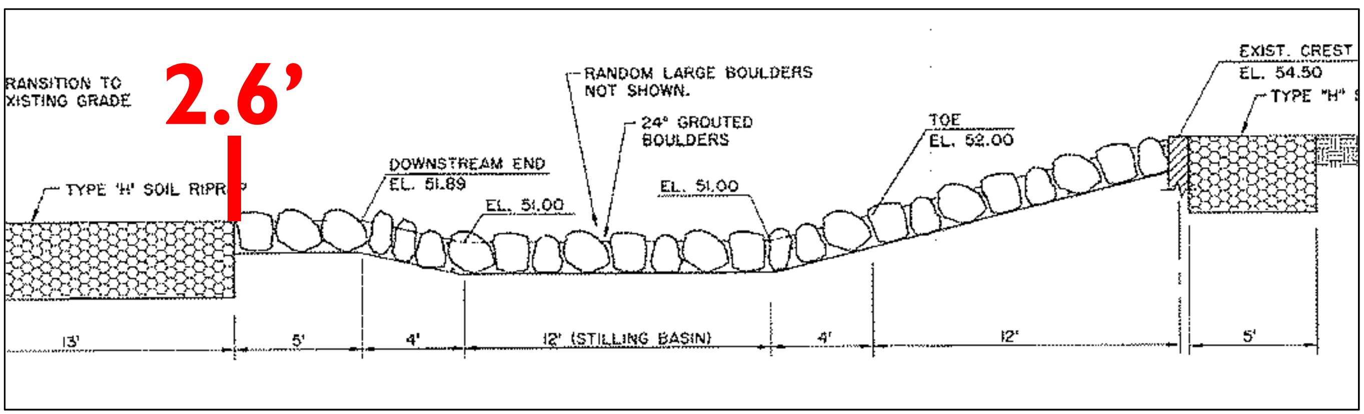


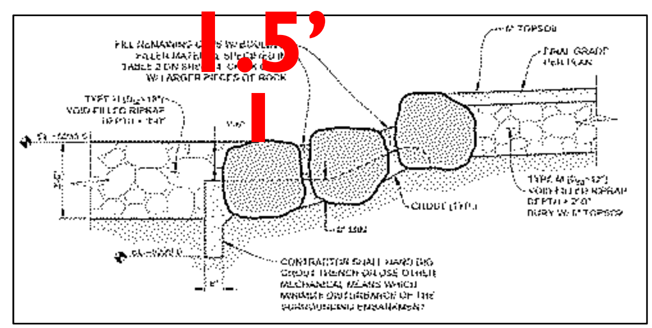


WESTMINSTER FOREIGN
AUTO PARTS


5’
NEL SILL AT EDGE OF LOW FLOW CHANNEL
LOW FLOW CHANNEL INVERT


9’
EL. 96.50
5 SPACES @ 6'-2" = 18'-6"
4 SPACES @ 7'-7/2" = 30'-6"
50'-0"
CONC. APRON
EL. VARIES
1/2" PREMOLDED JOINT FILLER
& WATERPROOF JOINT SEALANT
9'-6"
11'-0"
5'-8"
5'-6"
RUSTICATION STRIPS (TYP.)
8" Ø OUTLET FROM 10' LONG INLET, INV. EL. 88.0
6" WIDE x 6" DEEP RECESS
6" LAYER OF CLASS A FILTER MATERIAL
ROUGH FINISH
* SEE SHT. B2-21 FOR LIMITS OF CUT OFF WALL
EARTH FILL


2.6’
RANSITION TO
XISTING GRADE
TYPE 'H' SOIL RIPRAP
DOWNSTREAM END
EL. 51.89
EL. 51.00
RANDOM LARGE BOULDERS NOT SHOWN.
24" GROUTED BOULDERS
EL. 51.00
TOE
EL. 52.00
EXIST. CREST
EL. 54.50
TYPE "H"
13'
5'
4'
12' (STILLING BASIN)
4'
12'
5'


1.5’


Google Earth

Maintenance

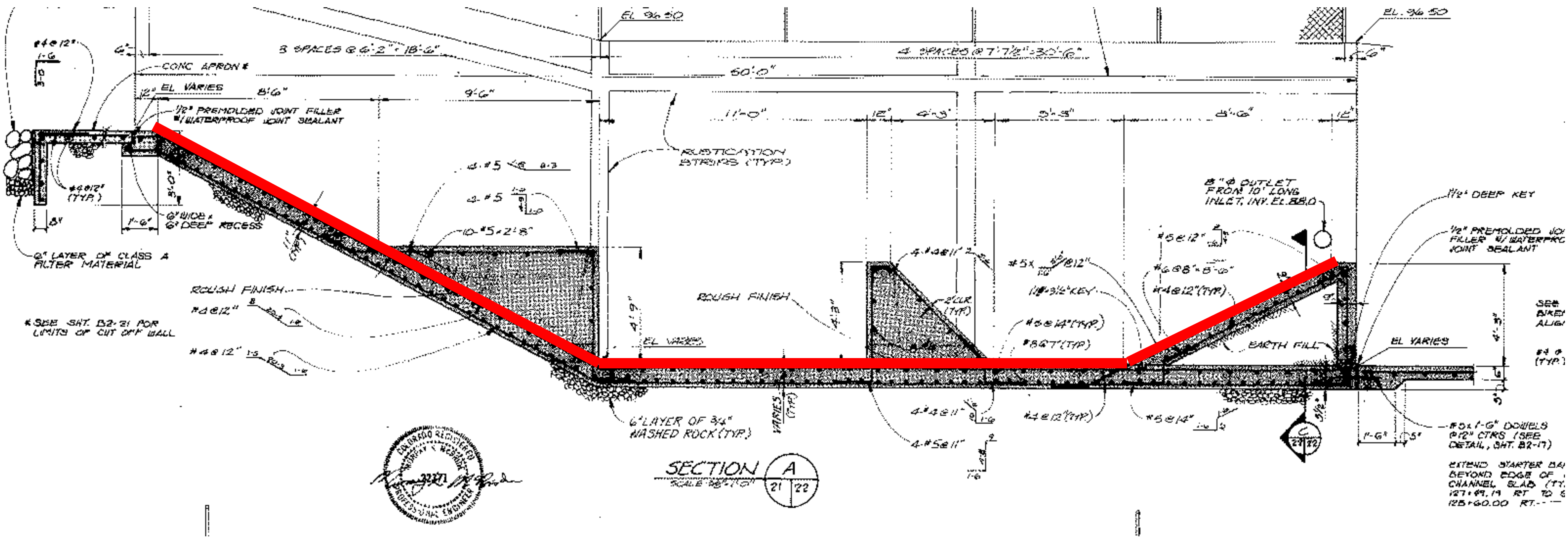

*This Photo not from Little Dry Creek

Uses


Trail

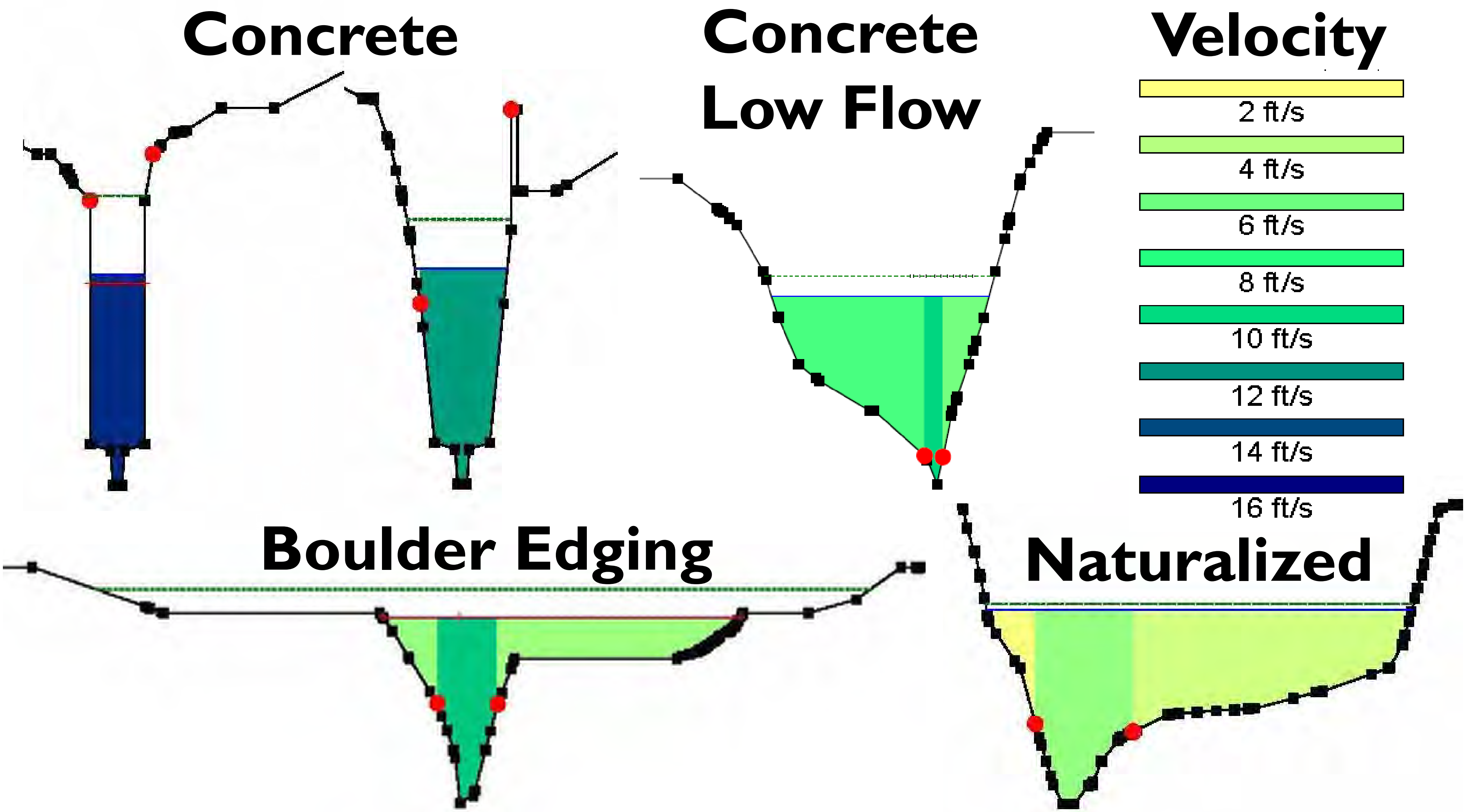

Trail

The "Winona Ditch Gap"


EL. 96.50
3 SPACES @ 6'-2" = 18'-6"
4 SPACES @ 7'-7 1/2" = 30'-6"
50'-0"
CONC APRON *
EL VARIES
8'-6"
9'-6"
11'-0"
4'-3"
5'-3"
8'-6"
1/2" PREMOLDED JOINT FILLER W/ WATERPROOF JOINT SEALANT
RUSTICATION STRIPS (TYP.)
6" WIDE x 6" DEEP RECESS
6" LAYER OF CLASS A FILTER MATERIAL
* SEE SHT. B2-21 FOR LIMITS OF CUT OFF WALL
ROUGH FINISH
EL VARIES
8" Φ OUTLET FROM 10' LONG INLET, INV. EL. 88.0
1 1/2" DEEP KEY
1/2" PREMOLDED JOINT FILLER W/ WATERPROOF JOINT SEALANT
EARTH FILL
6" LAYER OF 3/4" WASHED ROCK (TYP.)
#5 x 1'-6" DOWELS @ 12" CTRS (SEE DETAIL, SHT. B2-17)
SECTION A
21 22




[redacted]


Concrete
Concrete Low Flow
Velocity
2 ft/s
4 ft/s
6 ft/s
8 ft/s
10 ft/s
12 ft/s
14 ft/s
16 ft/s
Boulder Edging
Naturalized


WESTMINSTER FOREIGN
AUTO PARTS


Carpenters


Gardeners

Action & Reaction: Approaches for Understanding Sedimentation & Erosion

Matthew Johnson, PE, CFM
Brinton Swift, PE, CFM

01 Channel Stability Theory

02 Analysis Considerations

03 Simplified Sediment Approaches

04 Design Examples

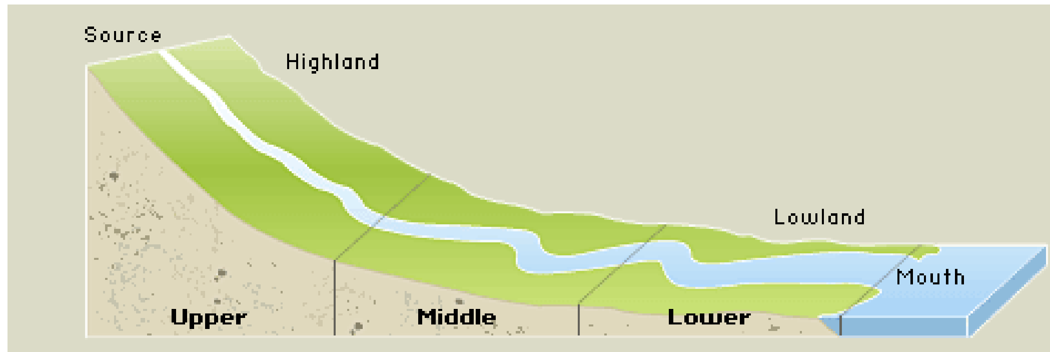
01

Channel Stability Theory

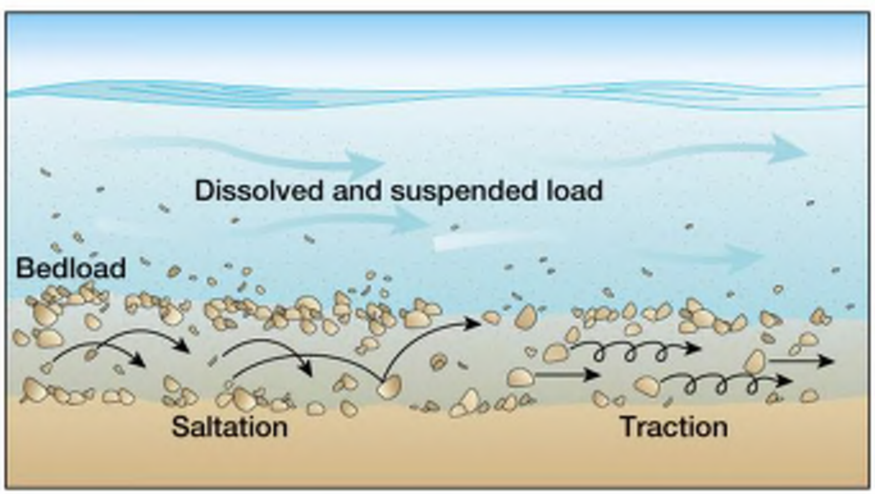
Channel Stability Theory

Q_w

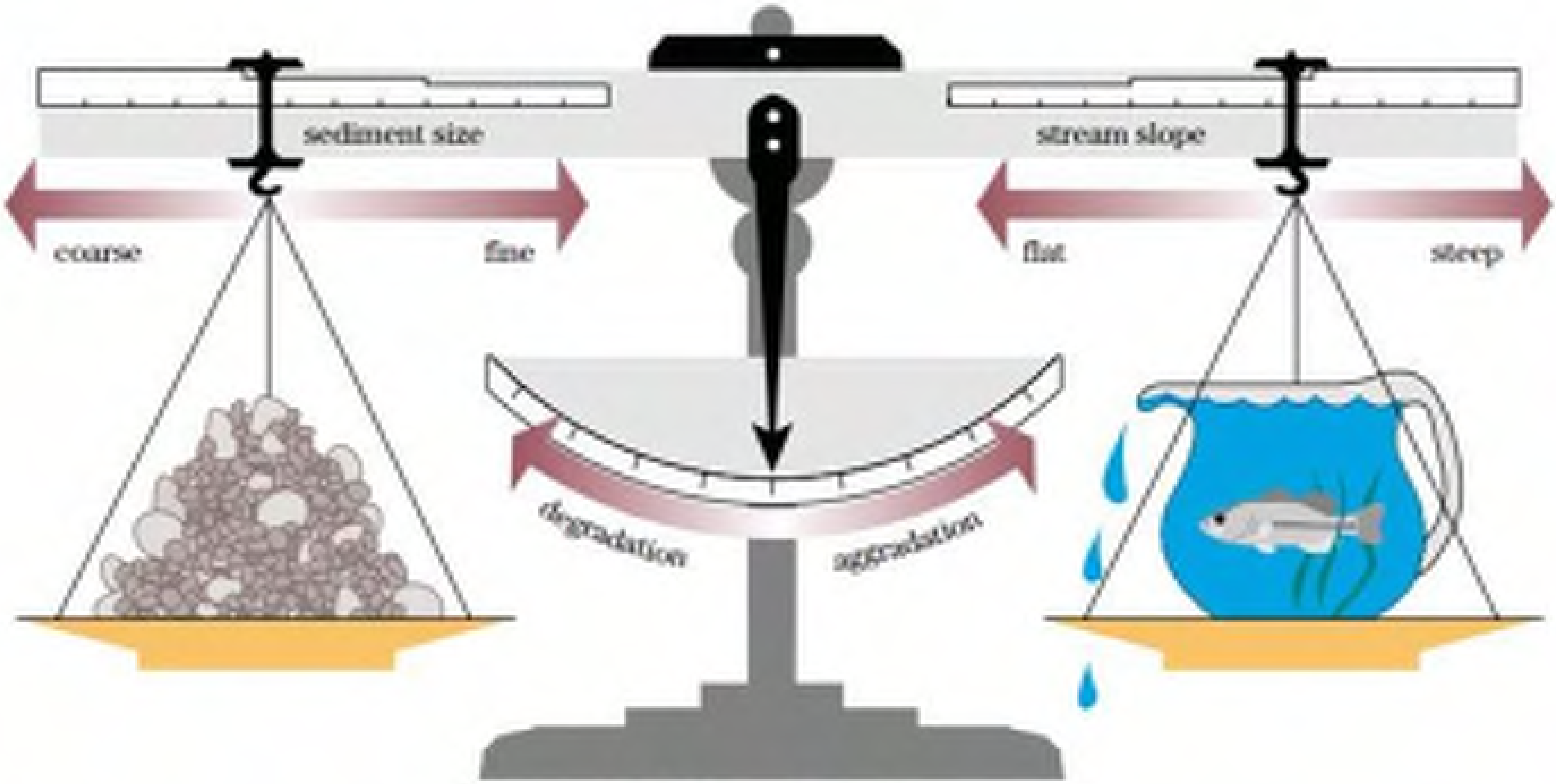
S



Q_s



D_{50}



$$Q_s \bullet D_{50} \propto Q_w \bullet S$$

From Rosgen (1996), from Lane, Proceedings, 1955.
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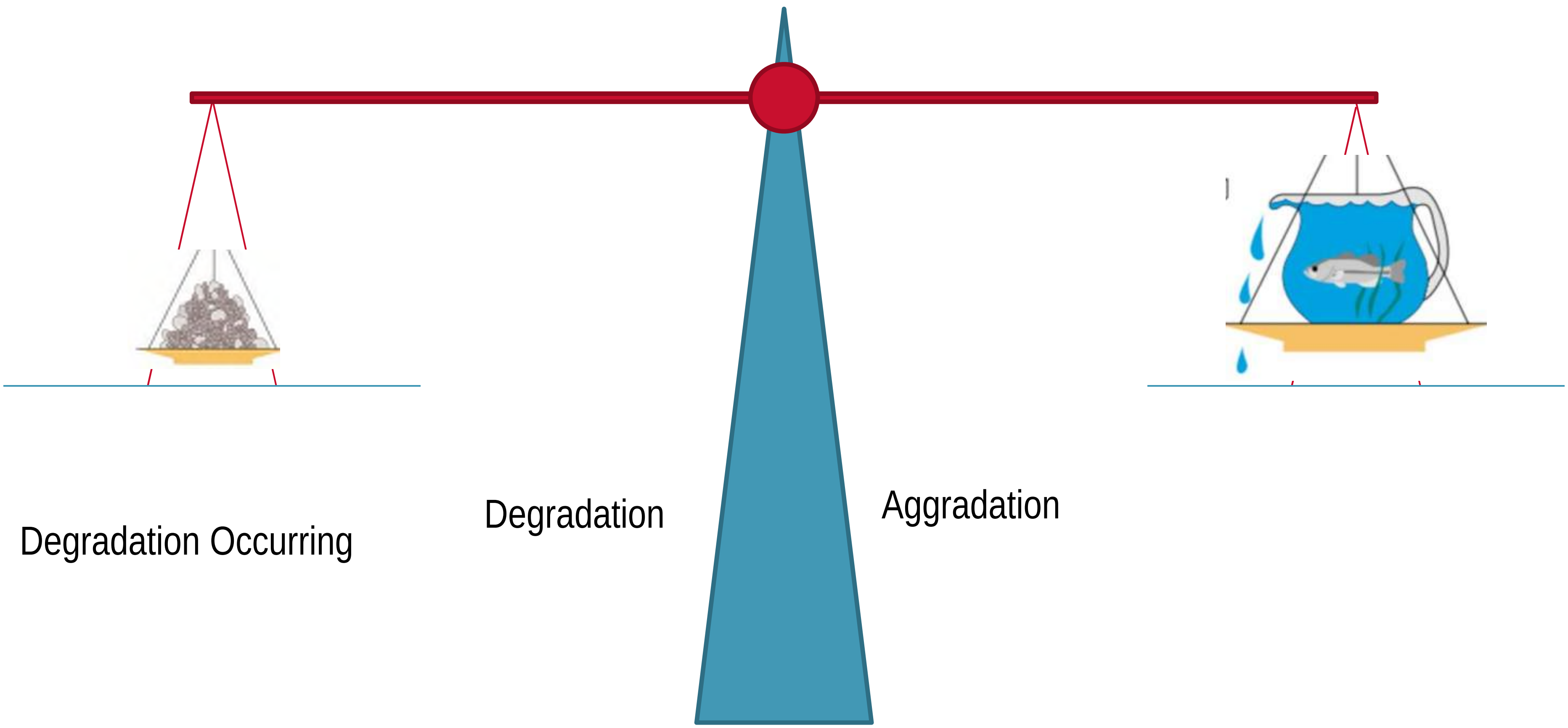
Lane' Balance



Sediment Supply, Capacity, and Transport

Sediment Supply – The amount of sediment conveyed into a reach for a given flow

Sediment Capacity – The amount of sediment that can be conveyed by a given flow in a reach

Sediment Transport – A comparison of sediment supply and sediment capacity to identify changes in bed and bank in a reach.

IN SIMPLE TERMS

Sediment Supply > Sediment Capacity = Aggredation

Sediment Supply < Sediment Capacity = Degradation

Stream Response Potential (SPR)

- *Design Hydrology for Stream Restoration and Channel Stability at Stream Crossings (Bledsoe, September 2016)*

Fine-bed river system have greater susceptibility to change with a greater range of flow regimes transporting sediment; high SPR

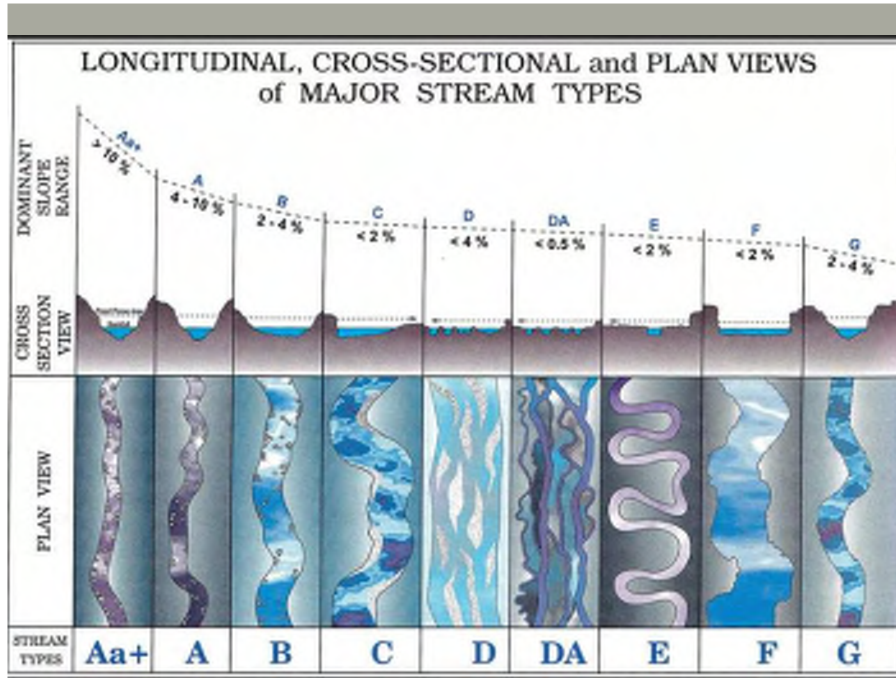
Coarse-bed river systems have lower variability with a small range of flow regimes transporting sediment; lower SPR

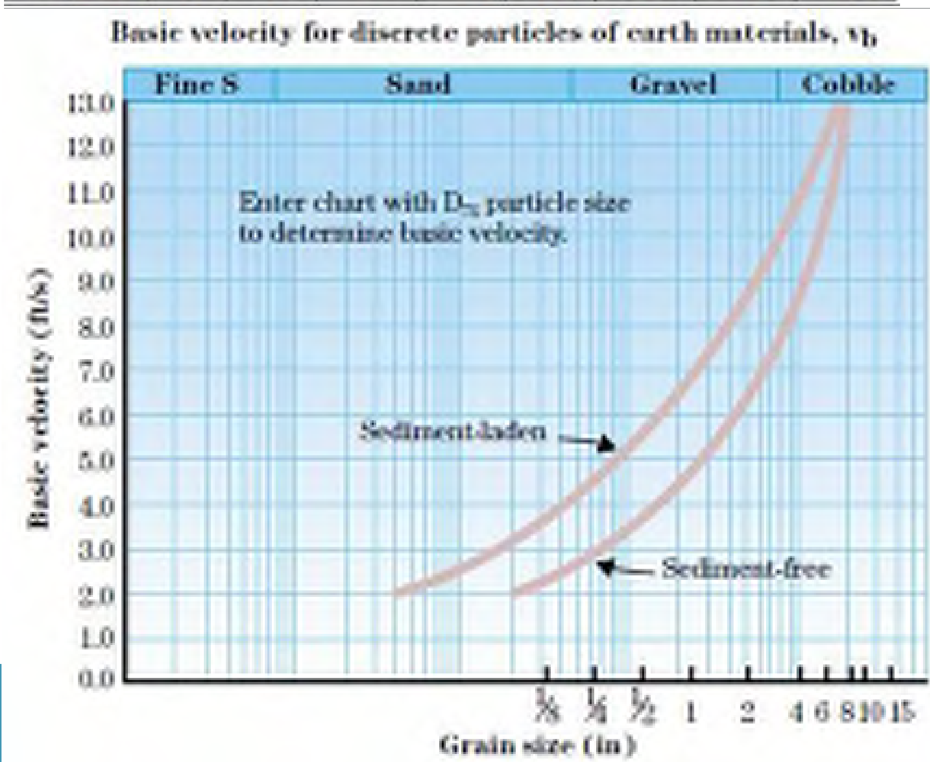
02

Analysis Considerations

Channel Stability Analysis

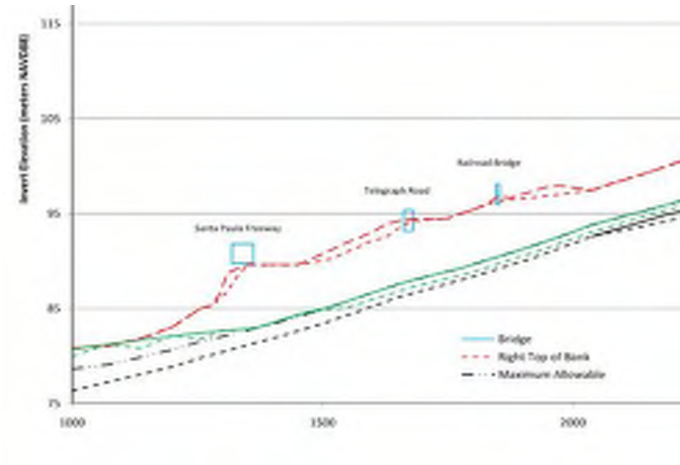
- Reference Channel Approaches
  - Comparison of similar channel properties (Rosgen)
- Historic Channel Behavior
  - Review of previous channel trends
- Channel Threshold Methods
  - Critical Shear Stress
  - Critical Velocities
- Empirical Channel Form Equations
  - Julien, etc.

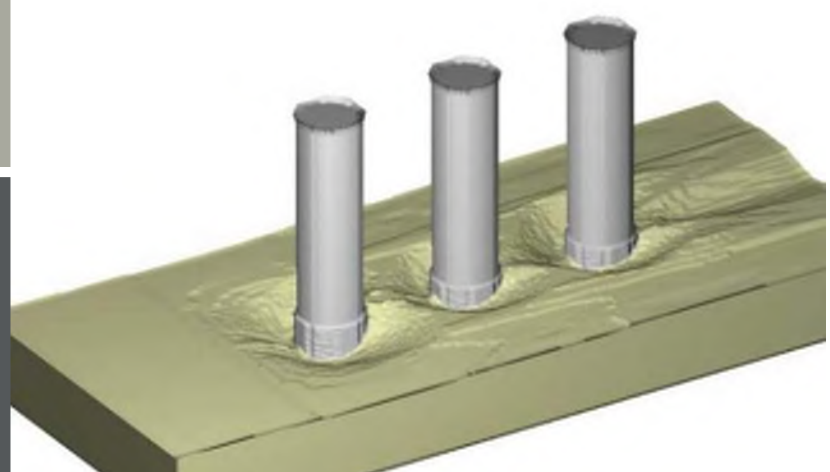




Channel Stability Analysis Methods

- Sediment Budget Analyses
  - Segmented sediment accounting
- Numerical Sediment Transport Models
  - HEC-RAS, SRH-2D, etc
- Computational Fluid Dynamic Models
  - FLOW3D, Fluent, etc
- Physical Models





Analysis Selection Considerations

Purpose of the Analysis

- Feasibility Studies
  - Coarser detail
  - General comparisons
  - Often qualitative
- Permitting Support
  - More detail
  - Stability trends
  - Comparative analyses
  - Qualitative or quantitative
- Design Support
  - Significant detail
  - Accurate quantitative

Analysis Selection Considerations

- Historical Data
  - Aerial Imagery
  - Previous hydrology, hydraulic, sediment, and geomorphic studies
- Topography/Bathymetry
- Hydrology
  - Previous Studies
  - Regression, Deterministic Models, Stochastic Models
  - Reservoir Operational Data
- Hydraulics
  - Normal Depth
  - Hydraulic Model
- Geotechnical/Sediment Information
  - Grain size distributions or Erosion Resistance
  - Geologic formations
  - Inflowing sediment/gradations
- Future Conditions
  - Land use
  - Geometry
  - Weather patterns

03 Simplified Sediment Approaches

Sediment Supply

- Equilibrium Load
  - Supply = Capacity
- Sediment Yield Calculations
- Gage Data
- Historical
- Upstream Supply Reach Capacity

Sediment Capacity

- Transport Equations
- Stable Slope
- Historical Behavior

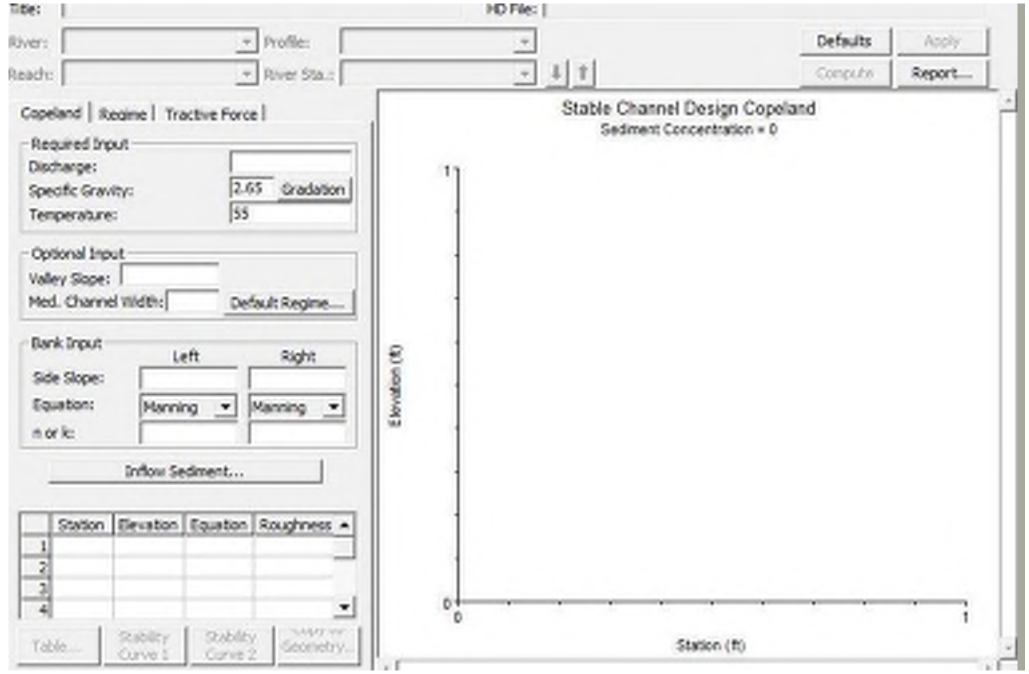
Stable Channel Design

Trends

- Use Copeland Method
  - Stability curve slope/width
  - Aggradation or degradation is expected
  - Based on supply reach

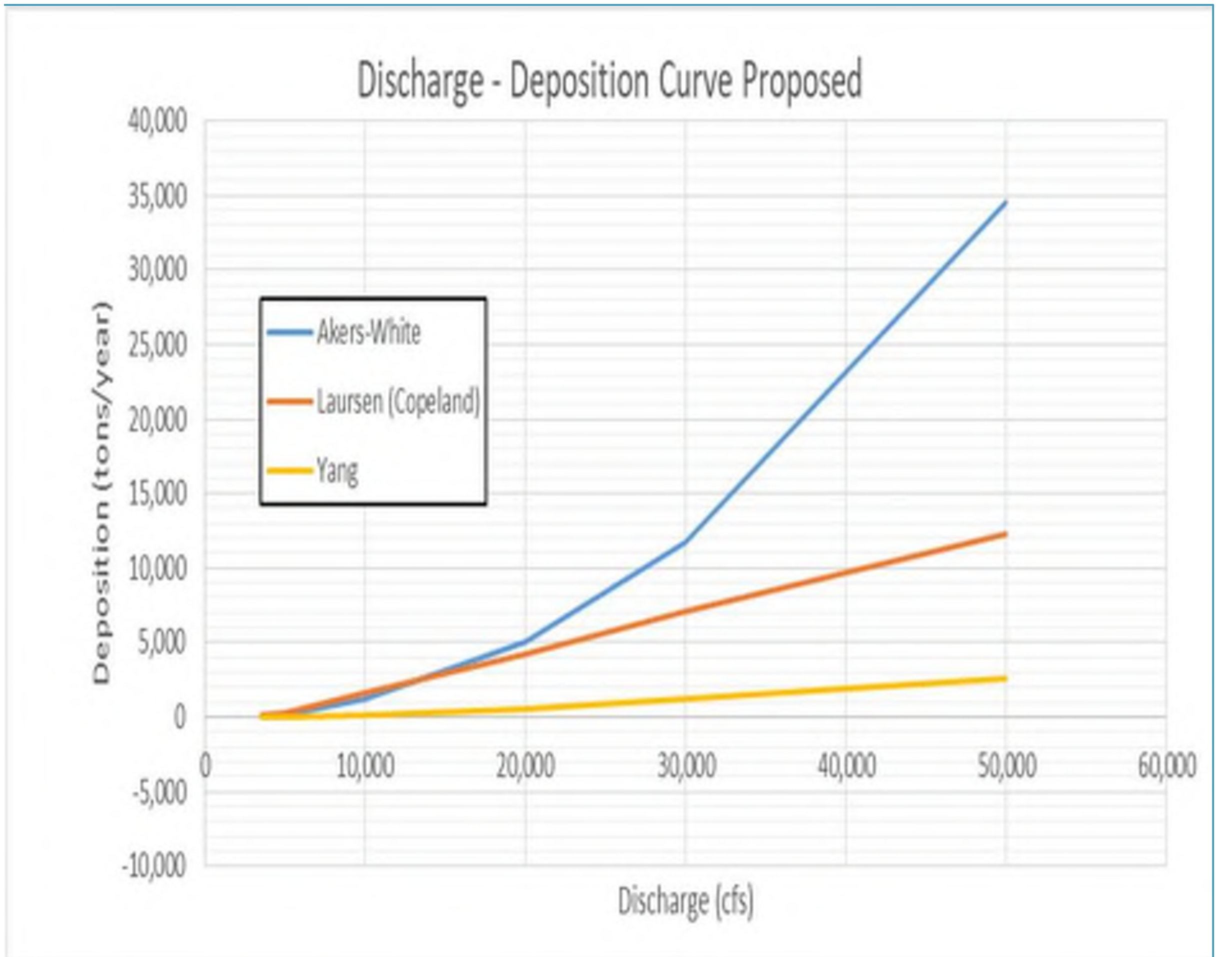
- Regime Method
  - Stable slope for a given geometry

- Tractive Force
  - Critical Shear vs Applied Shear



Sediment Transport Capacity

Quantity



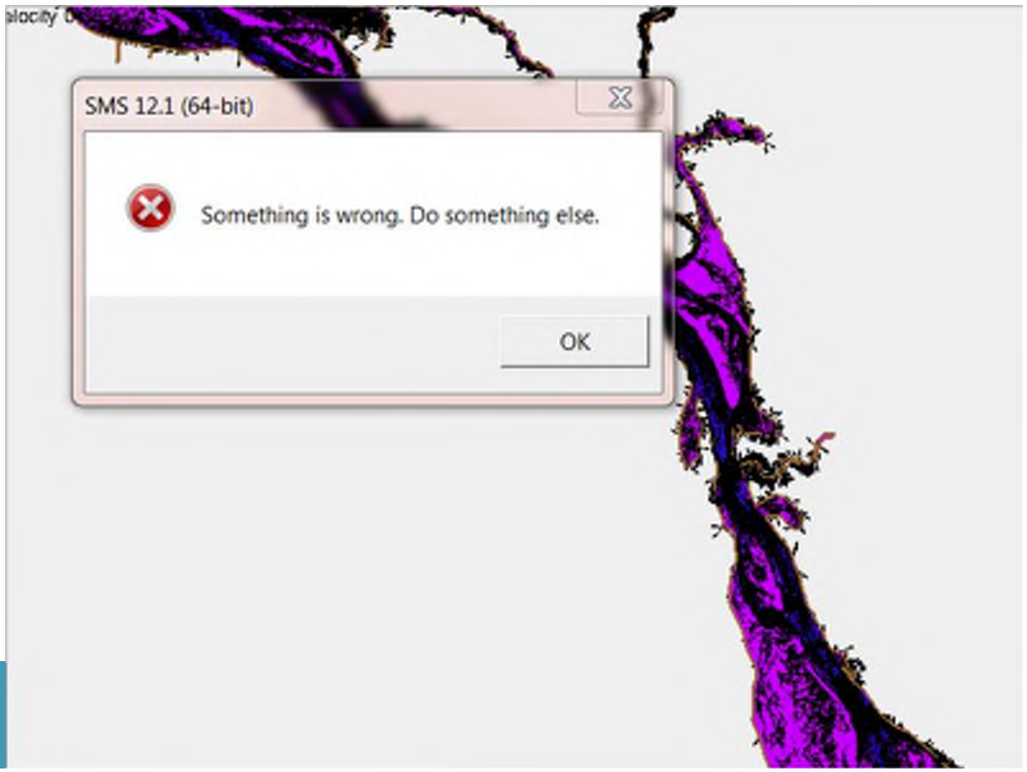
- Sediment Transport Capacity
  - Calculation of capacity of cross-section not actually sediment transported
- Compare ability of section to transport sediment between existing and proposed conditions
- Compare upstream, downstream, and design reaches

Sediment Transport Capacity

- Transport Equations
  - Ackers-White
  - Engelund-Hansen
  - Laursen
  - Meyer-Peter-Muller
  - Toffaleti
  - Yang
- Suspended Load
- Bed Load
- Wash Load

Table 12-8 Range of input values for sediment transport functions (Sam User's Manual, 1998)

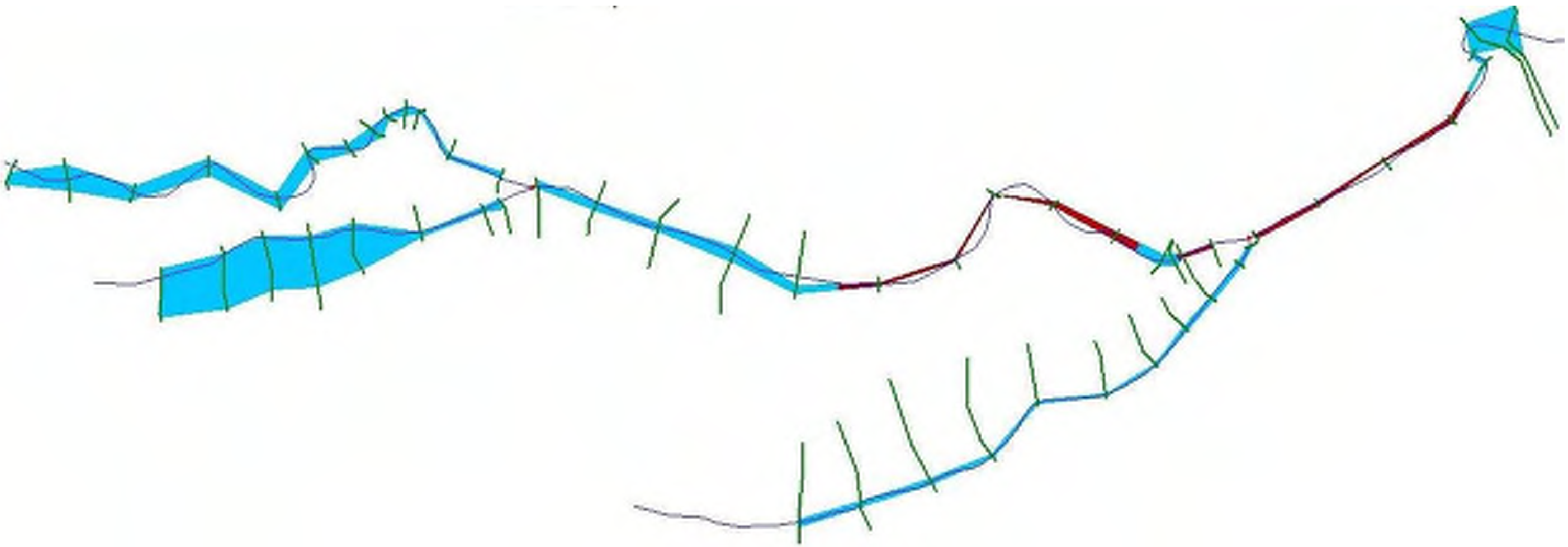
Function	d	d_m	s	V	D	S	W	T
Ackers-White (*flume*)	0.04 - 7.0	NA	1.0 - 2.7	0.07 - 7.1	0.01 - 1.4	0.00006 - 0.037	0.23 - 4.0	46 - 89
Englund-Hansen (*flume*)	NA	0.19 - 0.93	NA	0.65 – 6.34	0.19 – 1.33	0.000055 – 0.019	NA	45 - 93
Laursen (*field*)	NA	0.08– 0.7	NA	0.068 – 7.8	0.67 – 54	0.0000021 – 0.0018	63 – 3640	32 - 93
Laursen (*flume*)	NA	0.011 - 29	NA	0.7 - 9.4	0.03 – 3.6	0.00025 – 0.025	0.25 – 6.6	46 - 83
Meyer-Peter Muller (*flume*)	0.4 – 29	NA	1.25 – 4.0	1.2 – 9.4	0.03 – 3.9	0.0004 – 0.02	0.5 – 6.6	NA
Tofaletti (*field*)	0.062 – 4.0	0.095 – 0.76	NA	0.7 - 7.8	0.07 – 56.7 (R)	0.000002 – 0.0011	63 - 3640	32 – 93
Tofaletti (*flume*)	0.062 – 4.0	0.45 – 0.91	NA	0.7 - 6.3	0.07 – 1.1 (R)	0.00014 – 0.019	0.8 – 8	40 - 93
Yang (*field-sand*)	0.15 – 1.7	NA	NA	0.8 - 6.4	0.04 – 50	0.000043 – 0.028	0.44 – 1750	32 - 94
Yang (*field-gravel*)	2.5 – 7.0	NA	NA	1.4 - 5.1	0.08 – 0.72	0.0012 – 0.029	0.44 – 1750	32 - 94



Sediment Impact Analysis Methods (SIAM)

System Changes

- Sediment Budget Tool comparing annualized sediment reach transport capacities
- Indicates overall sediment surplus or budget
- Screening level tool



Limitations

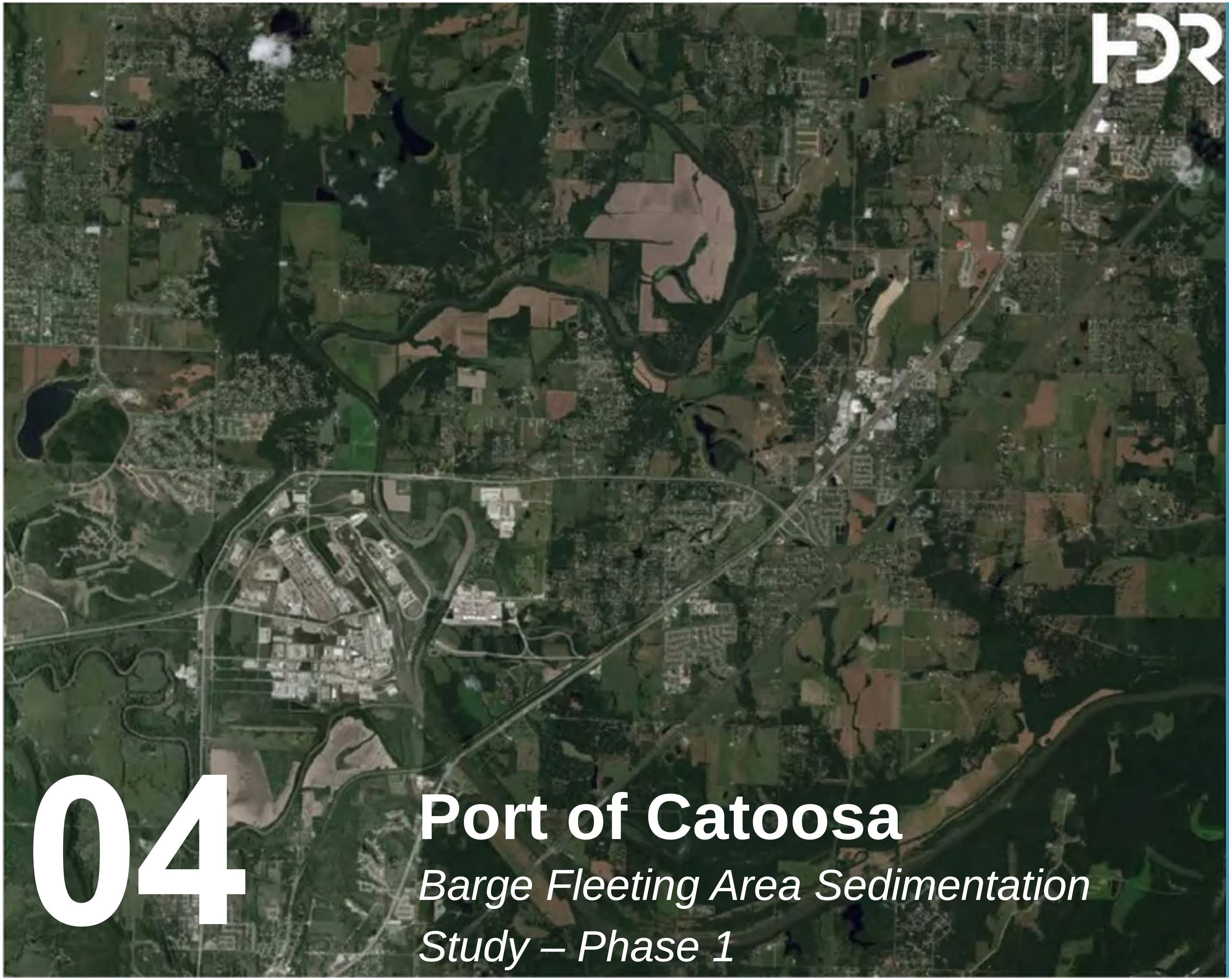
- Risk
- Complex Hydraulics
- Complex Geotechnical Conditions

Project Needs

Stable Channel = Trends

Sediment Transport Capacity = Quantity

SIAM = System Changes



04 Port of Catoosa

Barge Fleeting Area Sedimentation Study – Phase 1

Port of Catoosa Sedimentation Analysis

- Objectives
  - Screening Level Tool for Port Improvements
  - Dredging Requirements

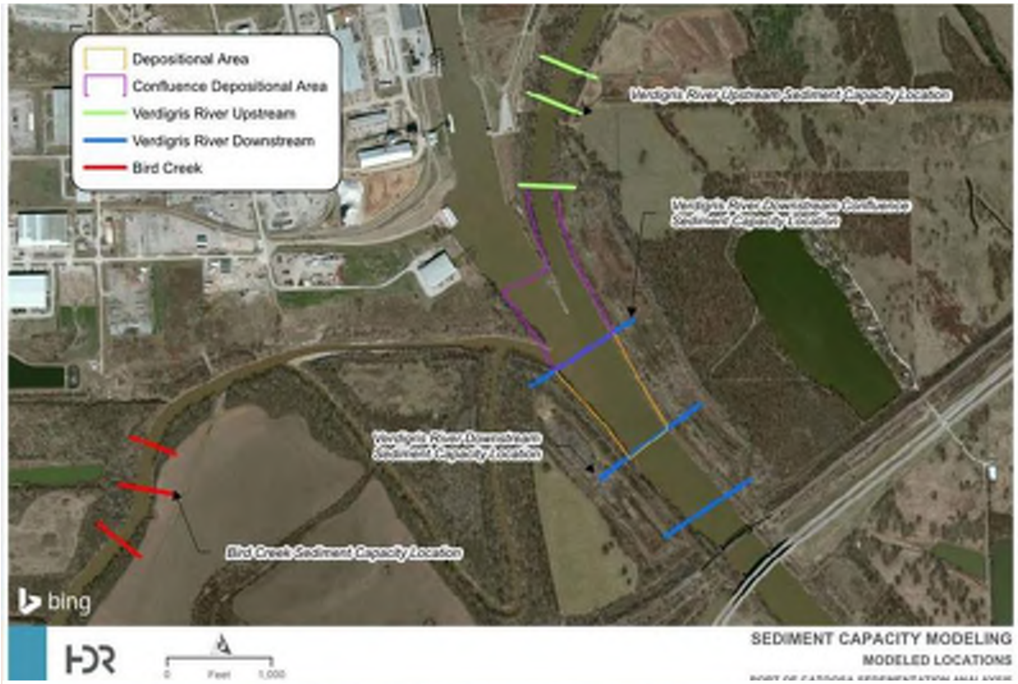
- Data
  - 2D Hydrodynamic Model
  - Geotechnical Gradations
  - Limited Dredging Information
  - Gage Data

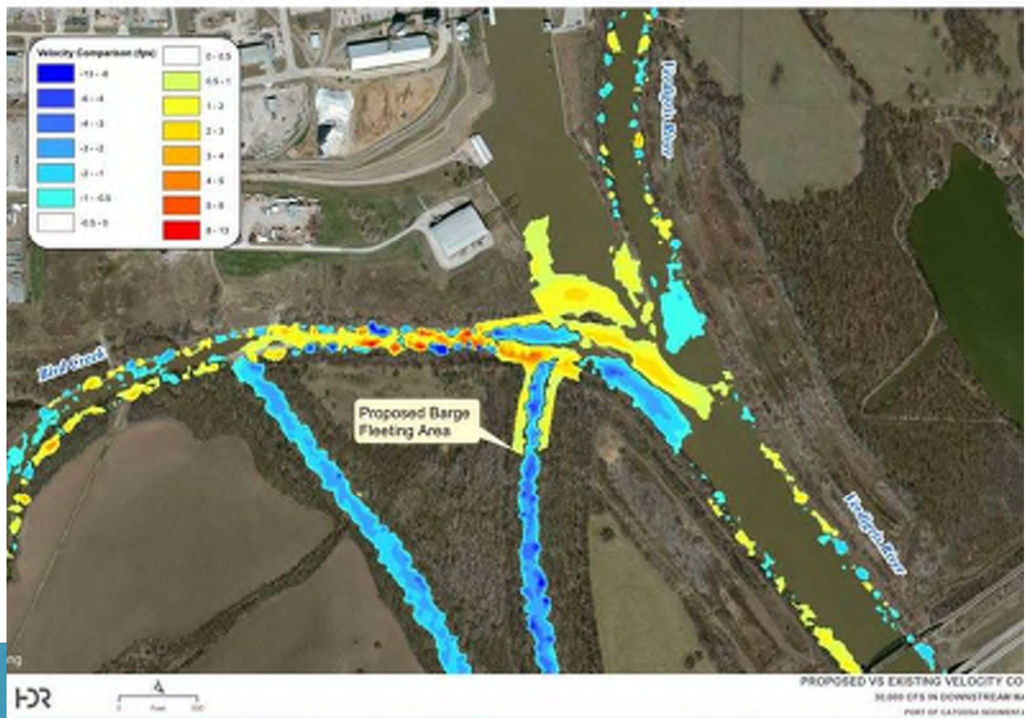
- Analysis
  - HEC-RAS Sediment Transport Capacity Comparison
  - 2D Hydrodynamic Model Velocity Comparison

Port of Catoosa Sedimentation Analysis

- Limitations
  - Limited Resolution
  - Relative Changes Only
  - No Calibration

- Benefits
  - High Level Screening Tool
  - Easy to Understand Results
  - Efficient Analysis

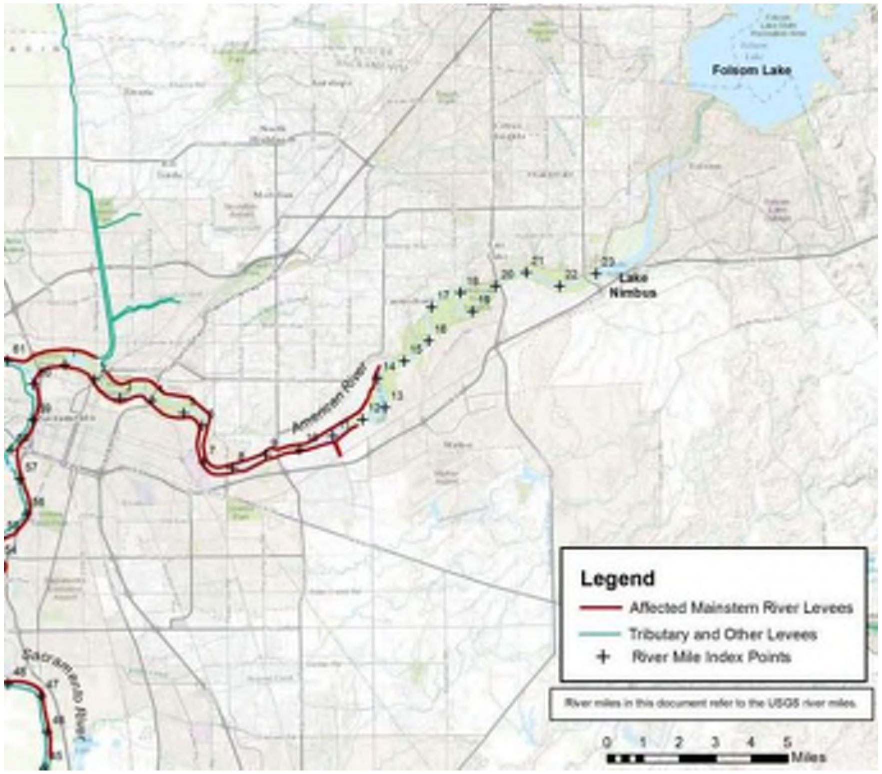


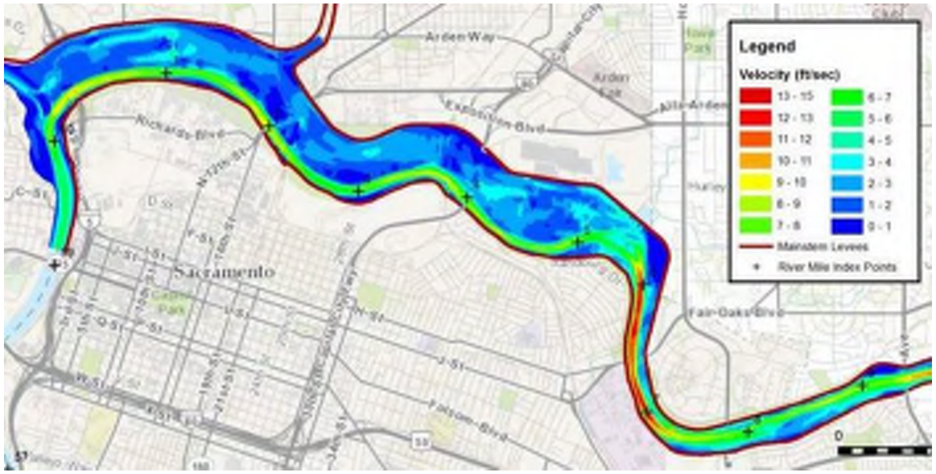


05 Folsom Dam Water Control Manual

Folsom Dam WCM

- Support Permitting of New Folsom Dam Gates
- Objectives
  - Understand Horizontal Stability
  - Understand Vertical Stability
  - Understand Gravel Habitat Mobility
- Challenges
  - 22-Mile Reach
  - Limited Bed Sediment Data
  - Highly Variable Bed Material
  - Long Term Reservoir Operations
- Analyses
  - HEC-RAS Hydraulic Model
  - Threshold Analysis





Folsom Dam WCM

- Support Permitting of New Folsom Dam Gates
- Approach for 6 Alternatives
  1. Identify Erosion Critical Sites
  2. HEC-RAS results (1930-2002)
  3. Critical Shear vs. Applied Shear
  4. Identify Periods of Erosion (1930-2002)
  5. Determine Overall Erosion Magnitude
  6. Compare Existing and Proposed Erosion

Site	J604 FLD Average Applied Shear Above Critical Shear (lb/ft^2)	J602F3 FLD Average Applied Shear Above Critical Shear (lb/ft^2)	Change in Average Shear Above Critical Shear (lb/ft^2)
Site 1	*	*	*
Site 3	*	*	*
Site 4a	*	*	*
Site 4b	*	*	*
Site 5	*	*	*
Site 6	*	*	*
Site 7	*	*	*
Site 8a	*	*	*
Site 8b	*	*	*
Site 9a	*	*	*
Site 9b	*	*	*
Site 10	0.20	0.20	0.0
Site 11a	*	*	*
Site 11b	*	*	*
Site 12	*	*	*
Site 13	0.20	0.21	0.01
Site 14	*	*	*

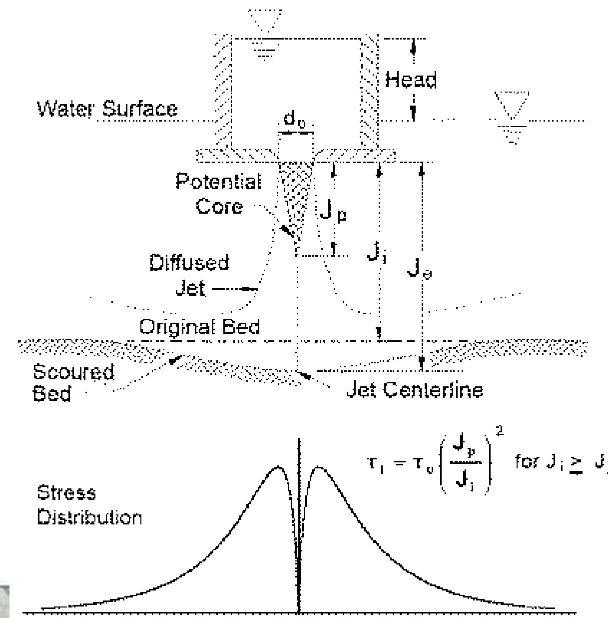
* Shear stresses would not exceed critical shear.
Negative values represent a reduction in average applied shear.

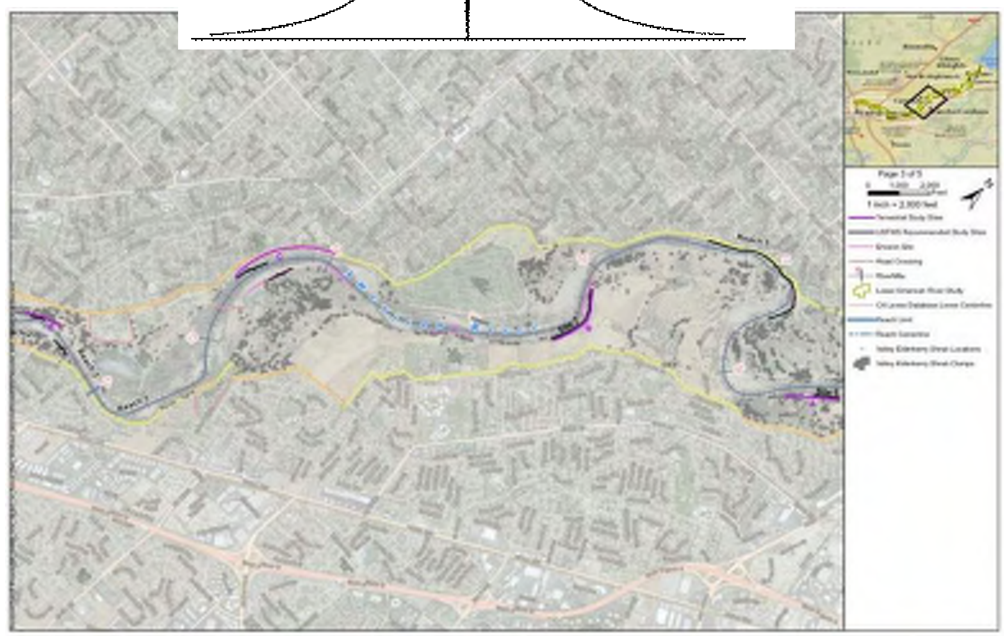
Comparison	Type of Analysis	Number of Sites where Average Shear is above Critical Shear	Increase or Decrease in Average Shear Stresses above Critical Shear	Maximum Total Change in Erosion Over Period of Record (ft)
E504 ELD vs J604 FLD	Horizontal Erosion Average overbank Shear	2	Decrease	0.13
E504 ELD vs J602p ELD	Horizontal Erosion Channel Shear	11	Increase	0.029 ft/day*
E504 ELD vs J602F3 ELD	Horizontal Erosion Average overbank Shear	2	No Change in Shear Stresses	0.5
J604 FLD vs J602p FLD	Horizontal Erosion Channel Shear	11	Increase	0.029 ft/day*
J604 FLD vs J602F3 FLD	Horizontal Erosion Average overbank Shear	2	Increase	0.27
E503p ELD vs J602F3 ELD	Horizontal Erosion Average overbank Shear	2	No Change in Shear Stresses	0.3

* Values are erosion rates

Folsom Dam WCM

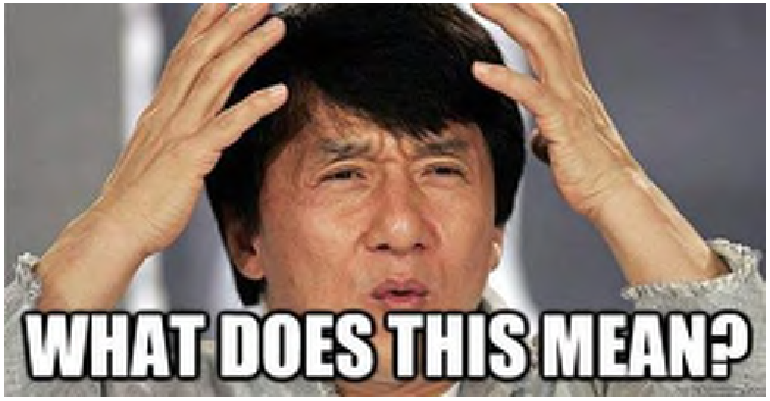
- Limitations
  - Generalized Bed Properties
  - Huge Variability in Erosion Rate Information
  - Average Shear From Model
  - Limited Resolution
- Benefits
  - Understanding of Huge Period of Flows
  - Repeatable Comparison of Alternatives
  - Easy to Understand Results
  - Easily Incorporated into Other Analyses
  - Efficient Analysis





Wrapping Up

Take Away



- Why is this important?
  - Much can be learned from even simple analyses with comprehensive sensitivities
  - You don't always need the most complicated analysis
  - All the information needed for a detailed analysis is not always available
  - Some analyses can be too complicated for general consumption
- However…
  - A combination of multiple approaches should always be considered
  - Detailed analyses are an essential tool for many designs
- Always…
  - Complete a sensitivity analysis.
  - Professional judgement and experience is the most important component of any analysis

Matthew Johnson, PE, CFM
matthew.a.Johnson@hdrinc.com

Brinton Swift, PE, CFM
Brinton.swift@hdrinc.com

Questions?

The Gunnison River and Riparian Habitat Rehabilitation Project

Local Partnerships at Work

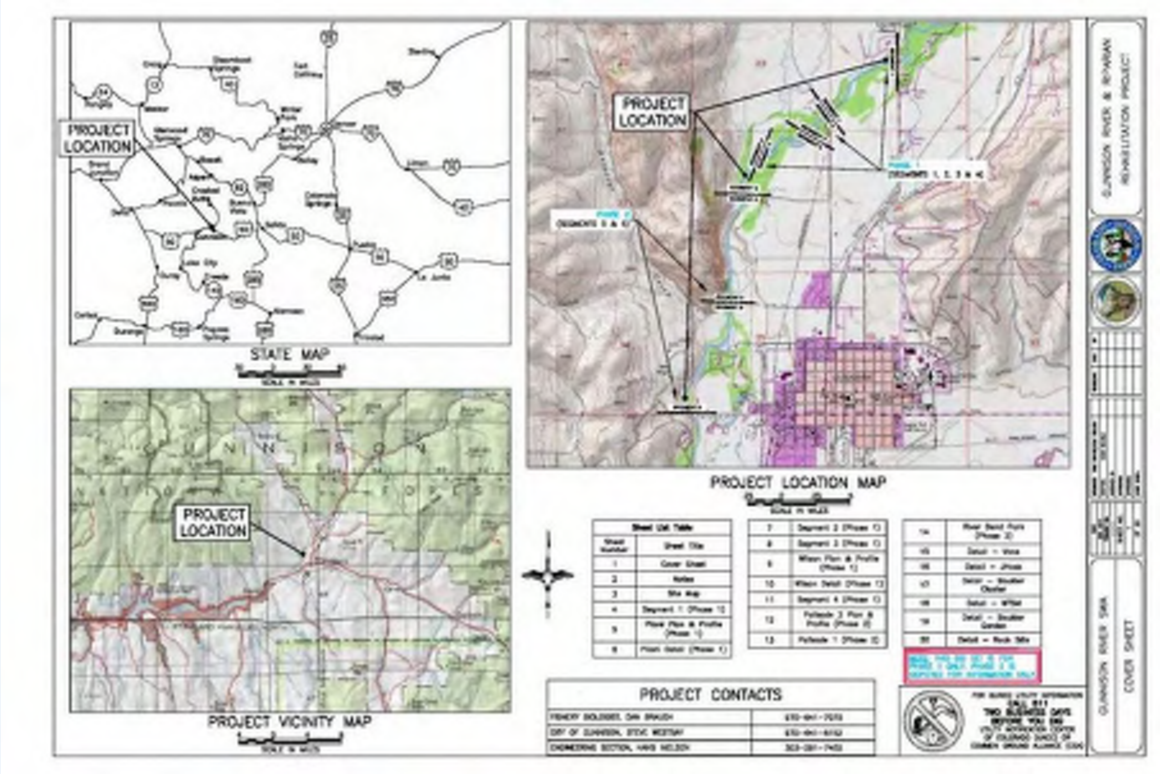
Dan Brauch – CPW Aquatic Biologist
Steve Westbay – City of Gunnison

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

COLORADO PARKS & WILDLIFE

CITY OF GUNNISON COLORADO

GUNNISON ANGLING SOCIETY
THE GUNNISON CHAPTER OF TROUT UNLIMITED



Goddard Ranch

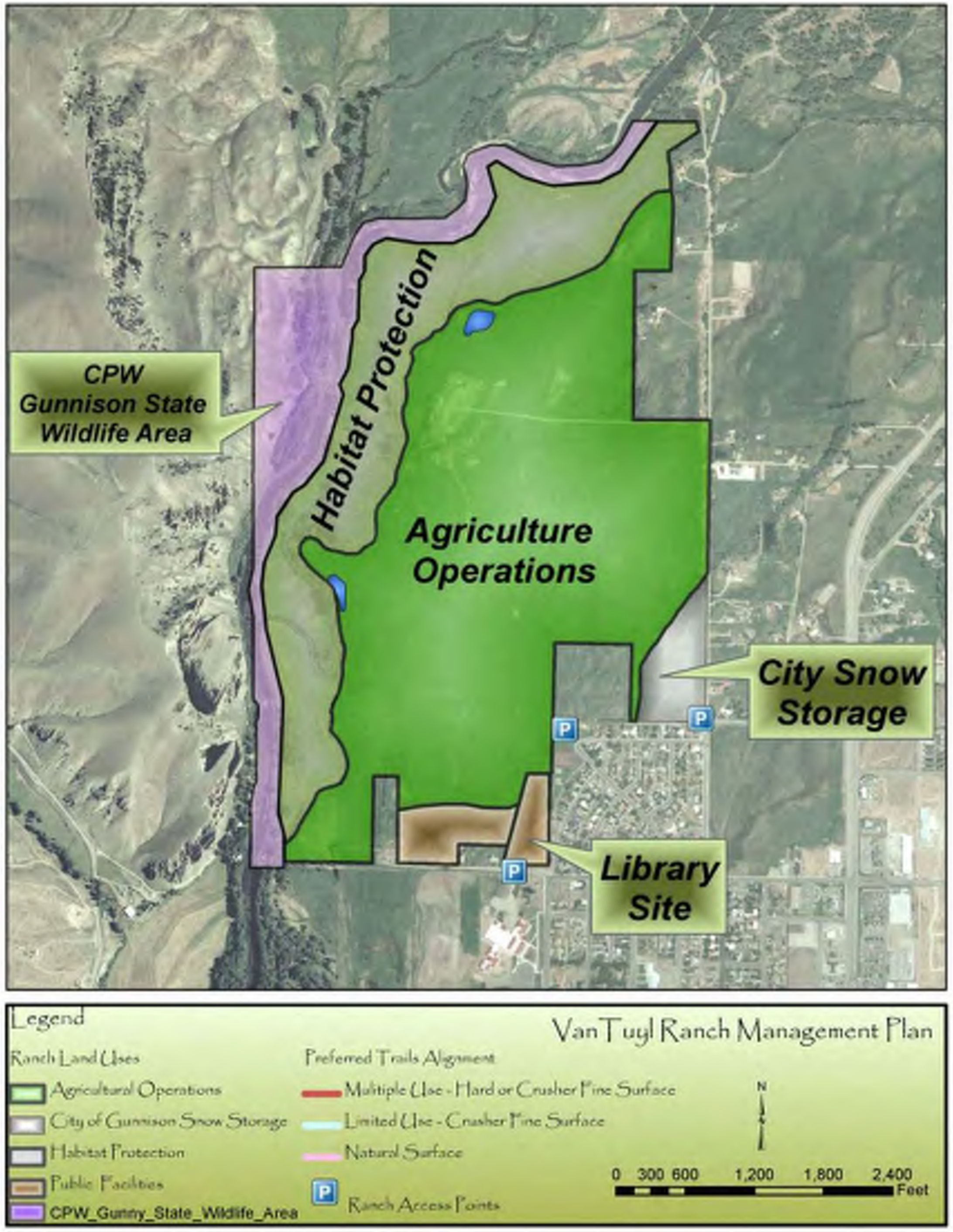
UPPER GUNNISON RIVER WATER CONSERVANCY DISTRICT 1959

LOR FOUNDATION

Background
VanTuyl Ranch & Gunnison River State Wildlife Area
A Project 25 Years in the Making

- Property purchased 1993 by the Trust for Public Lands
- Titles conveyed to Bureau of Reclamation (BOR) & the City
- State Wildlife Area deed transfer from BOR to CPW in 1994
- City took over ranch operations in 2008 after lifetime resident Ray VanTuyl passed away

- Ranch Annexed in 2011
  - Regulated by an *Adaptive Resource Management Plan*
  - Alluvial Aquifer Recharge – City domestic water source
  - Watershed Protection – Septic system proliferation
  - Prescribed Agricultural Operations & community garden
  - Public Open Space – 5K trail system
  - Flood Control
  - Habitat Protection



Rehabilitation Project - It Starts with an IDEA in 2001

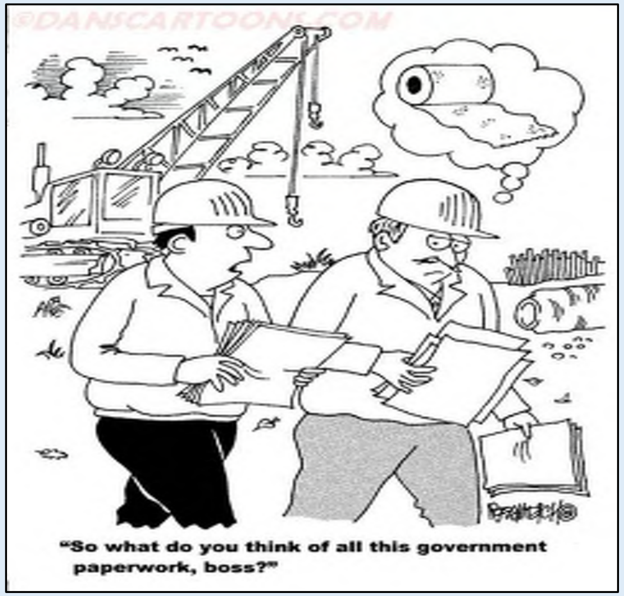
- *Fluvial Morphology & River Restoration Assessment*,2001
- Partners: CWCB, Trout Unlimited, UGRWCD, CPW, City, 2012
- Championing the Cause: CPW & City, 2012
- Funding: 2014 CWCB Grant ($440K); Private Donations ($150K)
- Design Programming 2014 through 2017
- Scope Modification 2016 – Project Cost Overruns
- Permitting: ACOE 404; Fish & Wildlife Service 2017
- Project Bid Award September 2017 & Construction through May 2018

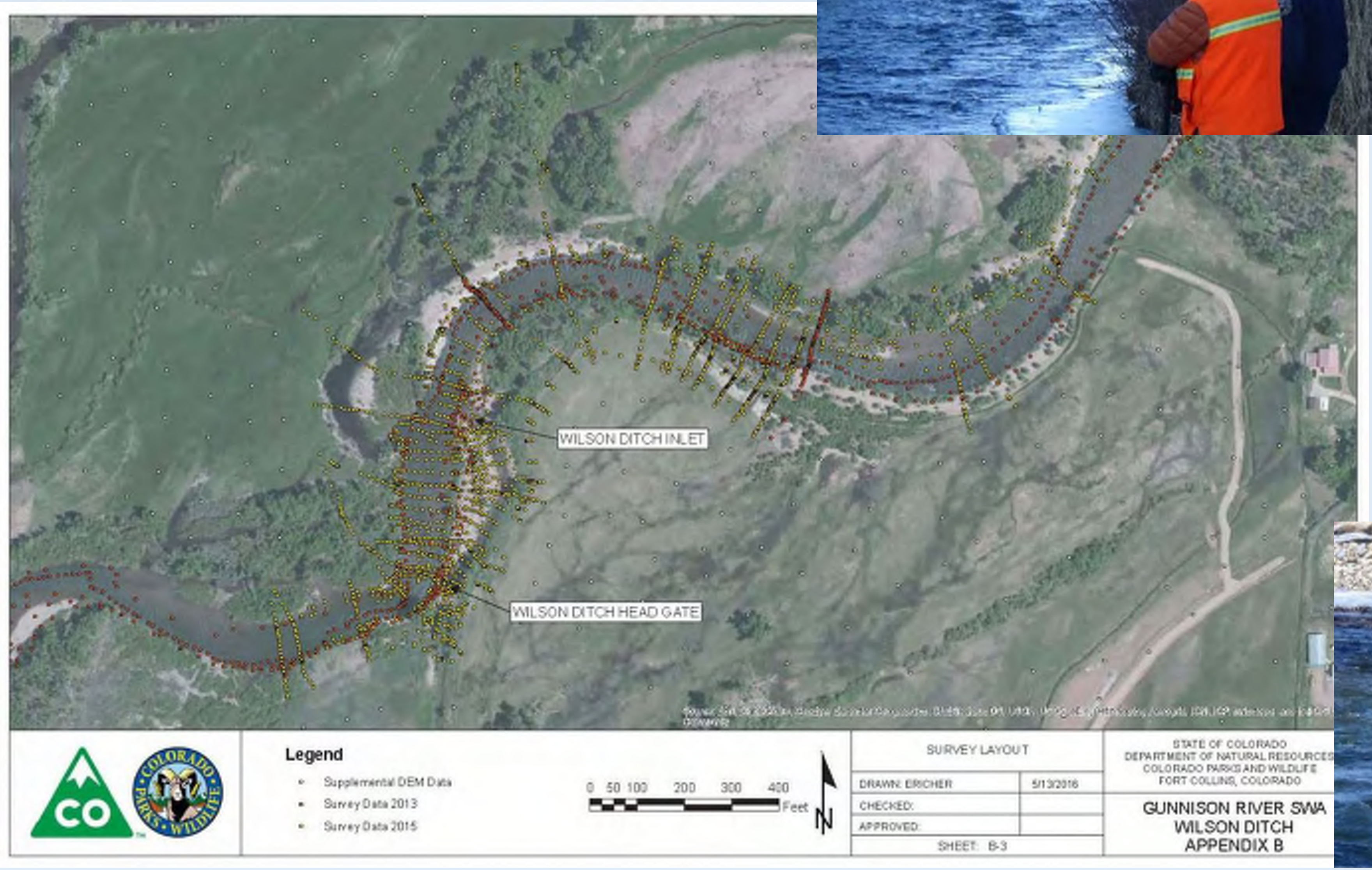
PROJECT GOALS

- Improve diversions- H2O rights due diligence
- Reconnect floodplains
- Improve channel habitat
- Increase trout biomass
- Improve trout size
- Improve riparian habitat
- Improve public river access

Permitting Overview

- Gunnison Sage-grouse Listing Decision November 12, 2014 - US Fish and Wildlife Service
- ACOE Nationwide Permit 33:*Temporary Access Construction and Dewatering – agricultural diversions*
- ACOE Regional General Permit 12: *Aquatic Habitat Improvement for Stream Channels in Colorado*
- Endangered Species Act, Section 7 Consultation, ACOE/FWS
  - *Cultural Resource Inventory*
  - *Wetland Inventory*
  - *ESA Gunnison Sage-grouse Critical Habitat Biological Assessment*
  - *Special Conditions for season of operations, equipment access, et AL*
- Coordination & Approvals from the Bureau of Reclamation
- County Flood Hazard Application



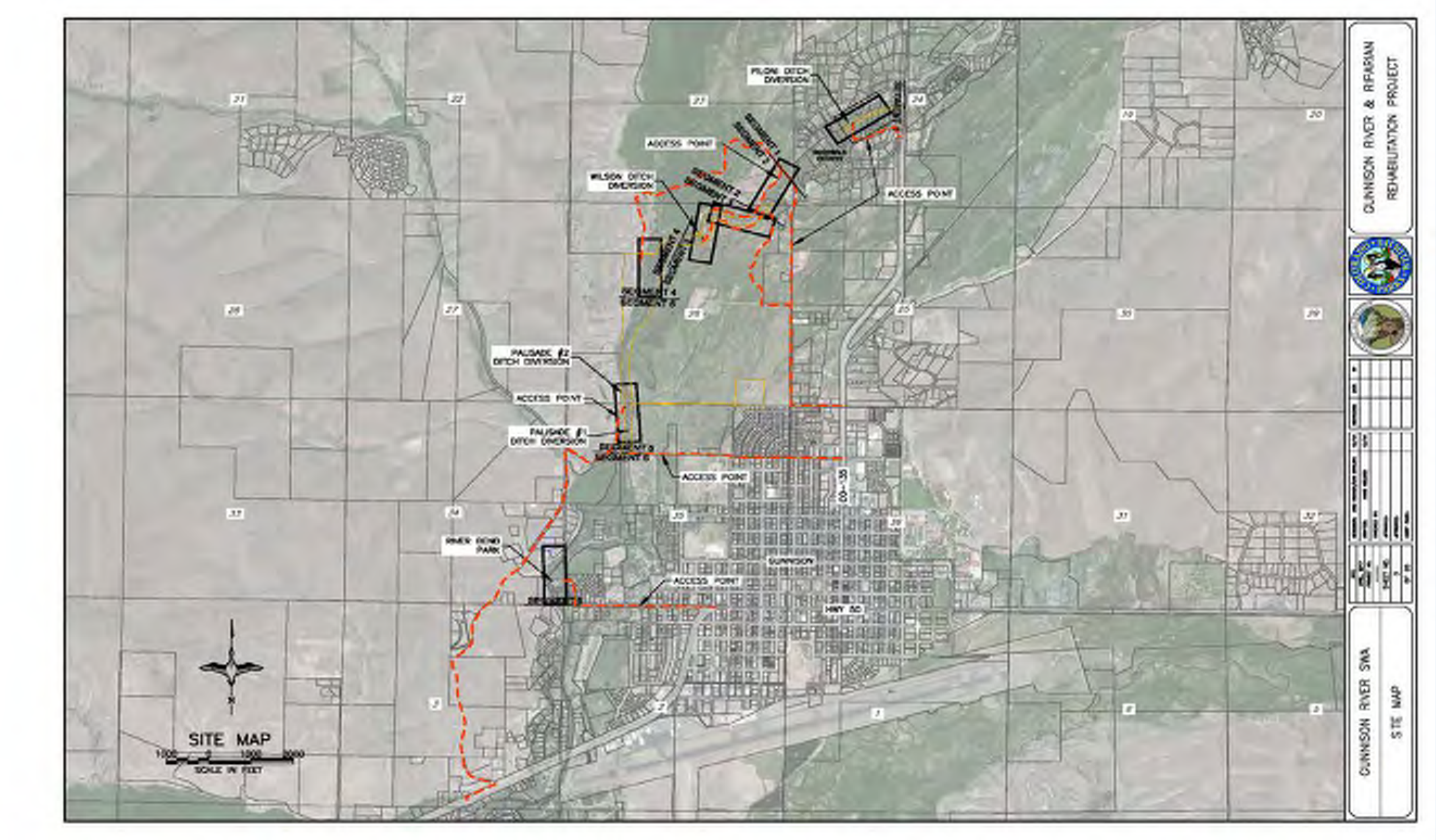


Project engineering and design was done by the CPW's engineering staff. These in kind design services, along with permit administration by local agencies added significant project value.

KEY DESIGN CONSIDERATIONS

Design Improvements on 7 Channel Segments along a 3.75 mile reach

- Abate historic channelization where practical
- Reestablish morphological function
- Improving fish habitat
- Emphasize low profile channel features
- Improve Riparian Function w/ vegetation treatment
- Reconnect floodplains where possible
- Use native vegetation: willow transplants; sod mat

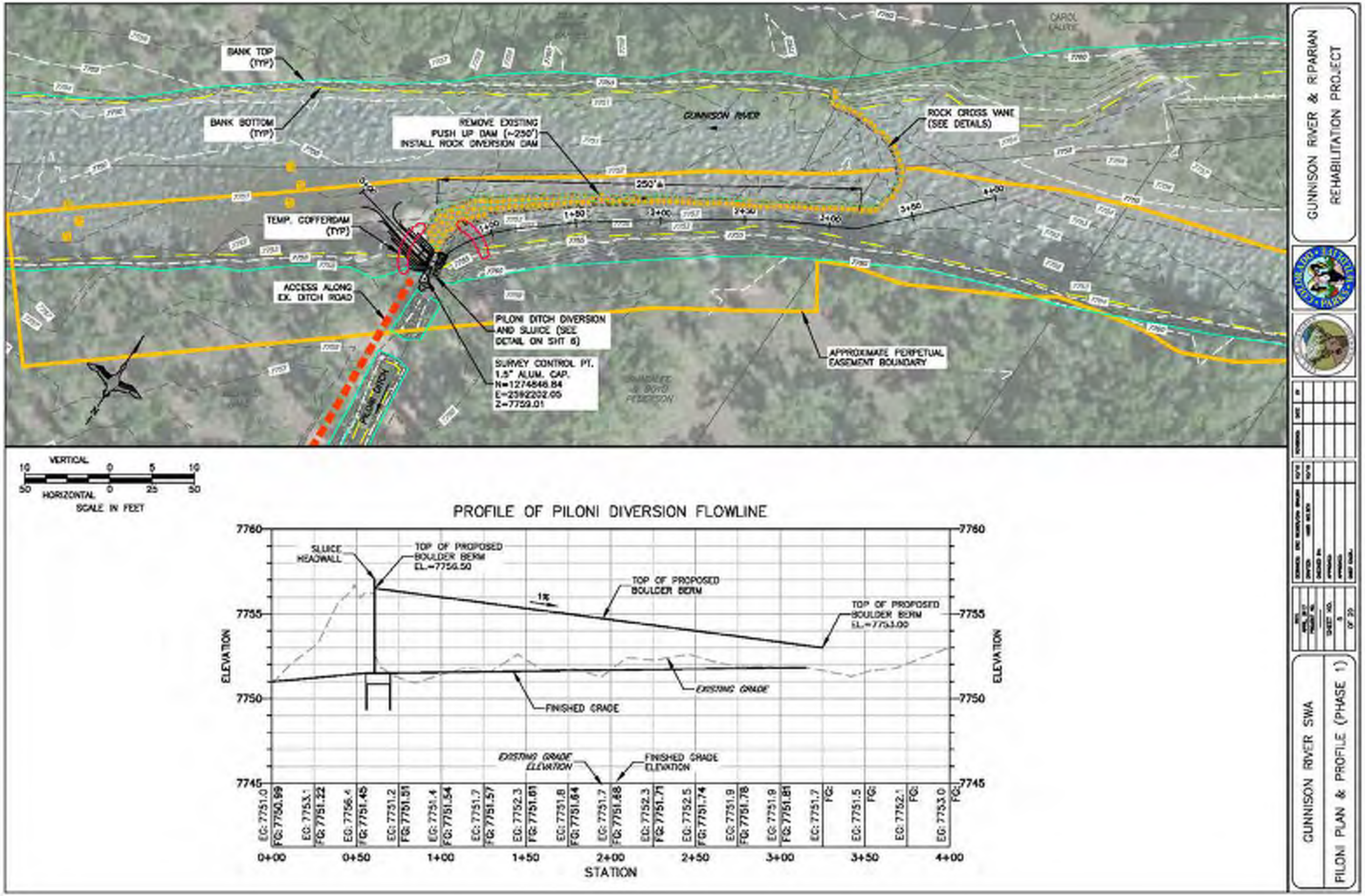


Pre-Construction Conditions – Hydraulic Modelling

Hydraulic modeling indicated that the initial designs of one channel feature would cause flood elevation rise & final design alterations were made to ensure no-rise would occur.

Elevation grade change between the head gates and diversion points were critical functions of the final design to ensure adequate water delivery and sediment control.

Piloni Ditch Diversion



Piloni Ditch – Major Diversion & Habitat Improvements

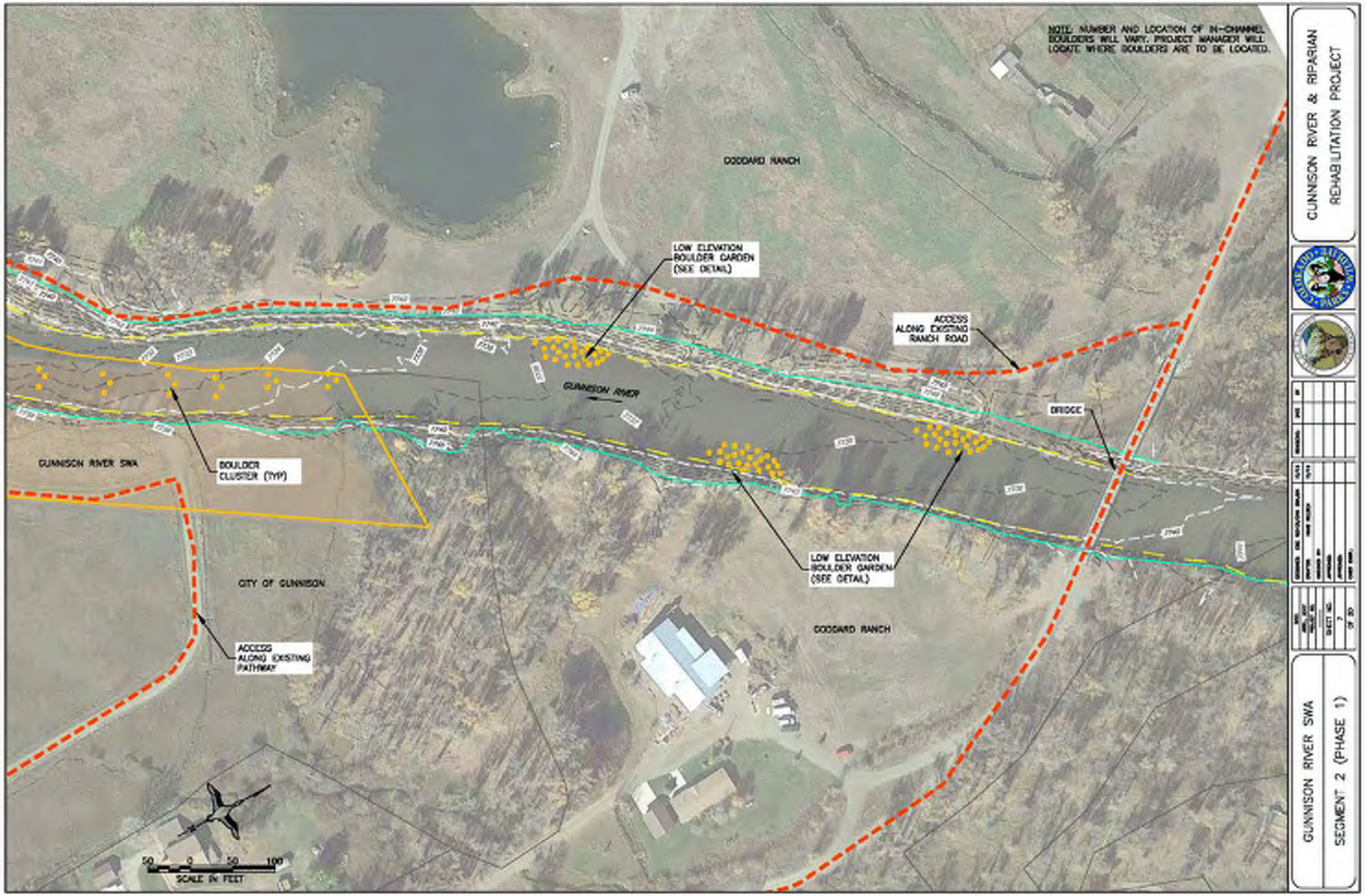
Frozen soil conditions experienced in early January 2018 finally chased the crew off for the season. Construction began again the past week – estimated completion date May 2018.

A $100,000 grant from the LOR Foundation allowed for constructing a new headworks on the Piloni Ditch & the construction of additional fish habitat structures in all reaches of the river project area.

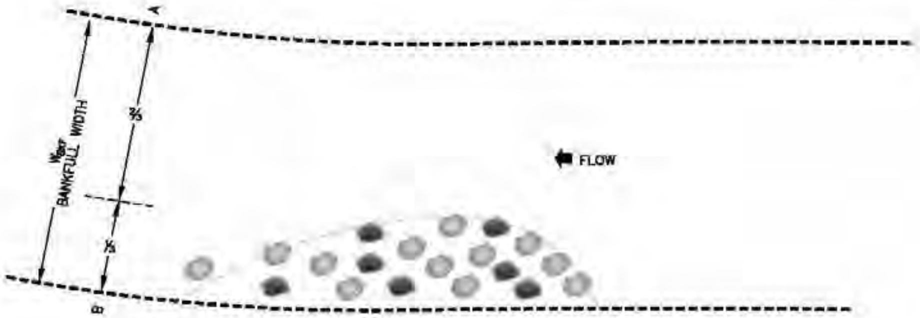
Piloni Ditch – March 27, 2018

Ongoing Construction

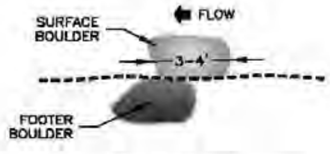
Typical Fish Habit Channel Features



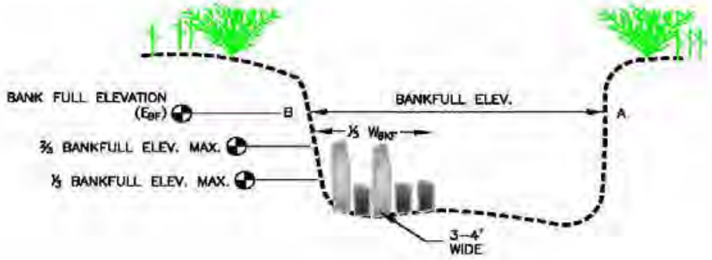
Boulder Garden Details



PLAN VIEW
NTS



BOULDER PROFILE VIEW
NTS



CROSS-SECTION VIEW
NTS

CONSTRUCTION NOTES:

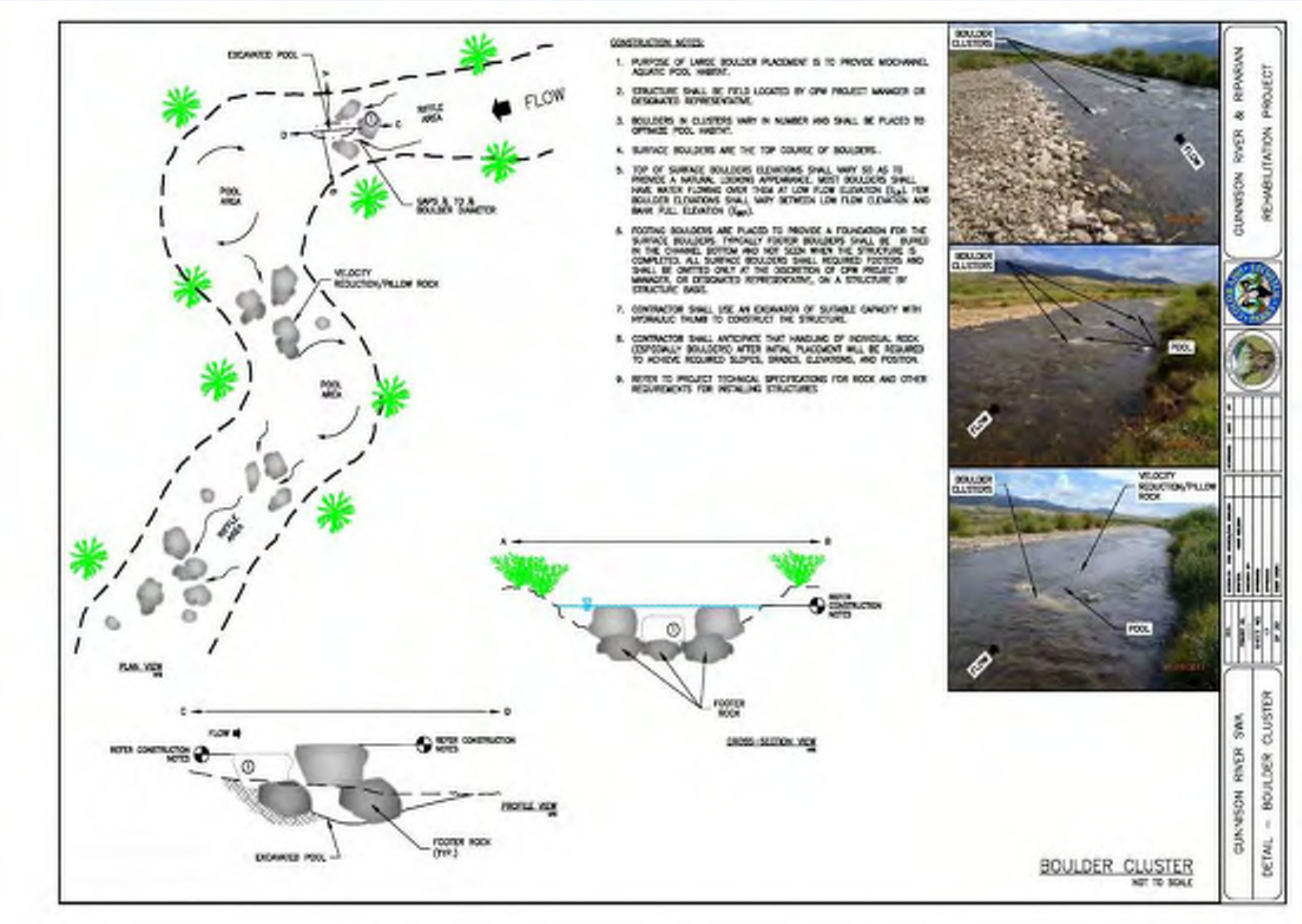
1. STRUCTURE SHALL BE FIELD LOCATED BY CPW PROJECT MANAGER OR DESIGNATED REPRESENTATIVE.
2. SURFACE BOULDERS ARE THE TOP COURSE OF BOULDERS. SURFACE BOULDERS SHALL VARY IN DEPTH BETWEEN 1/3 BANK FULL DEPTH AND 2/3 BANK FULL DEPTH.
3. FOOTING BOULDERS ARE PLACED TO PROVIDE A FOUNDATION FOR THE SURFACE BOULDERS. TYPICALLY FOOTER BOULDERS SHALL BE BURIED IN THE CHANNEL BOTTOM AND NOT SEEN WHEN THE STRUCTURE IS COMPLETED. ALL SURFACE BOULDERS SHALL REQUIRED FOOTERS AND SHALL BE OMITTED ONLY AT THE DISCRETION OF CPW PROJECT MANAGER, OR DESIGNATED REPRESENTATIVE, ON A STRUCTURE BY STRUCTURE BASIS.
4. BOULDERS SHALL BE PLACED AT AN IRREGULAR SPACING.
5. BOULDERS SHALL BE PLACED APPROXIMATELY 2-4 x BOULDER DIAMETER APART.
6. CONTRACTOR SHALL USE AN EXCAVATOR OF SUITABLE CAPACITY WITH HYDRAULIC THUMB TO CONSTRUCT THE STRUCTURE.
7. CONTRACTOR SHALL ANTICIPATE THAT HANDLING OF INDIVIDUAL ROCK (ESPECIALLY BOULDERS) AFTER INITIAL PLACEMENT WILL BE REQUIRED TO ACHIEVE REQUIRED SLOPES, GRADES, ELEVATIONS, AND POSITION.
8. REFER TO PROJECT TECHNICAL SPECIFICATIONS FOR ROCK AND OTHER REQUIREMENTS FOR INSTALLING STRUCTURES

BOULDER GARDEN
NOT TO SCALE

GUNNISON RIVER & RIPARIAN REHABILITATION PROJECT

GUNNISON RIVER SWA
DETAIL - BOULDER GARDEN

Fishery habitat improvements include construction boulder gardens and boulder clusters on all project area river reaches.



Low Profile Boulders Clusters at Work

Channelization Challenges
Establishing Thalweg & Sinuosity

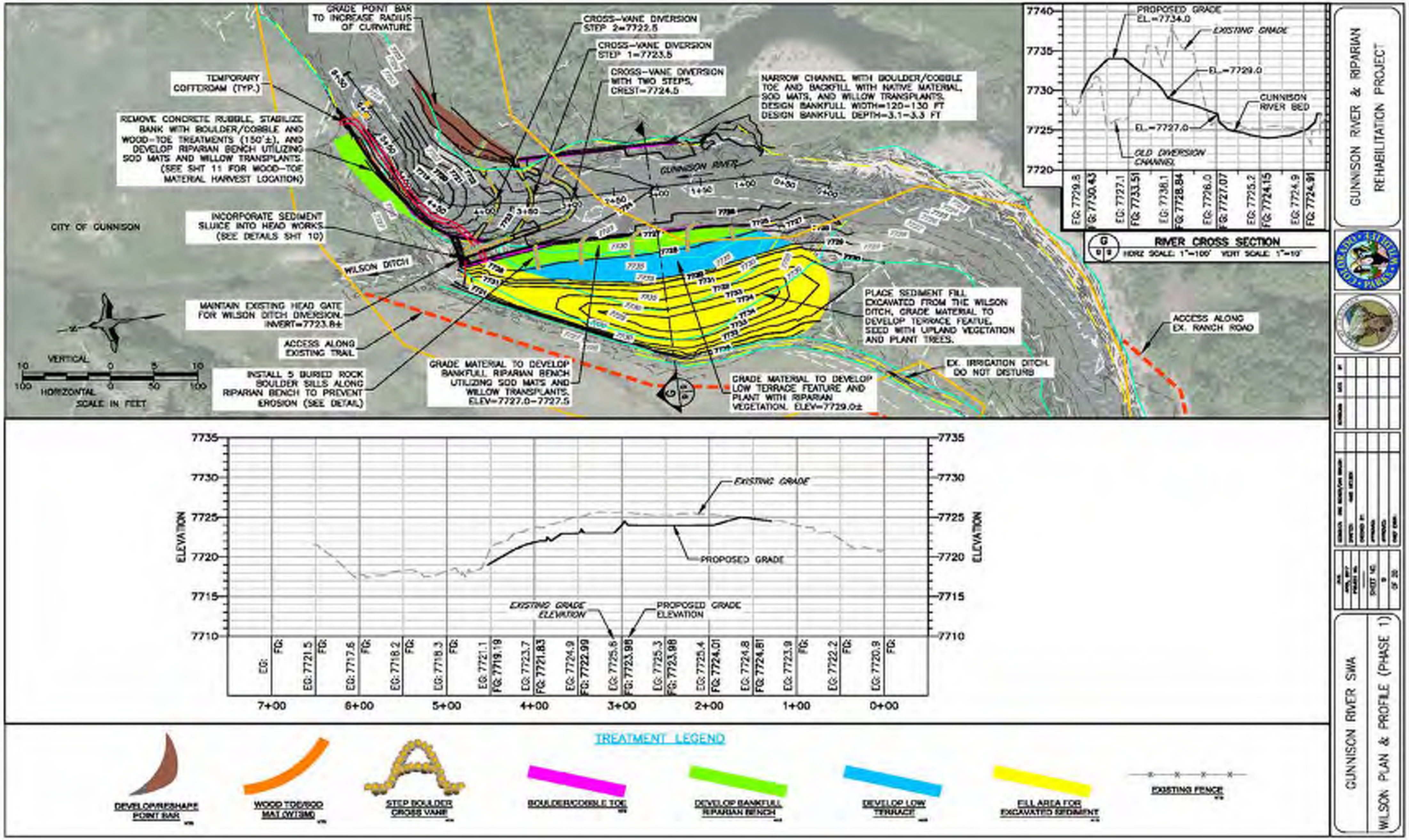
Thalweg & Sinuosity- Boulder Gardens in lieu of point bars

Wilson Diversion Pre-Construction Conditions

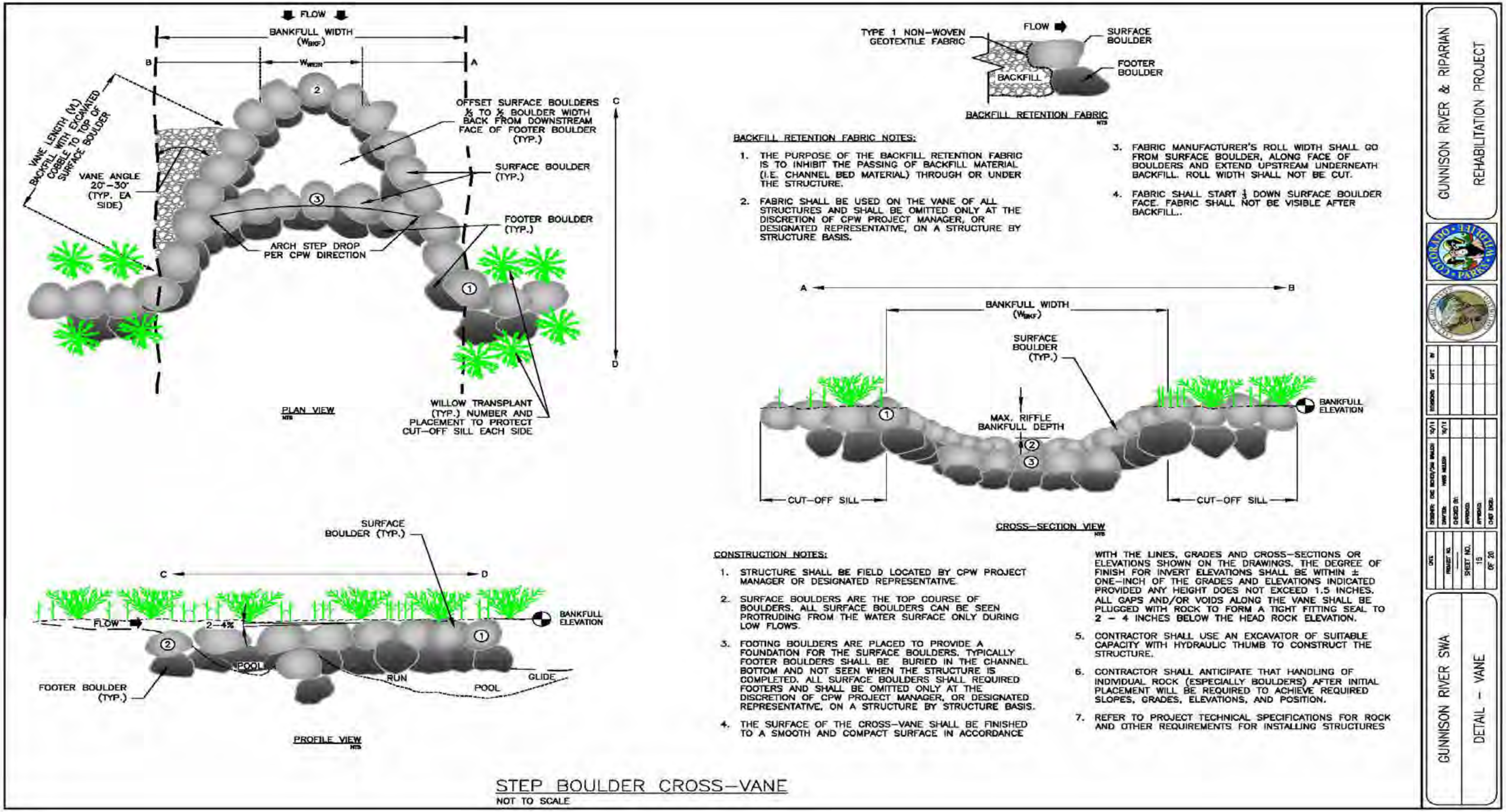
Significant design & construction challenges

Wilson Diversion Pre-Construction Conditions

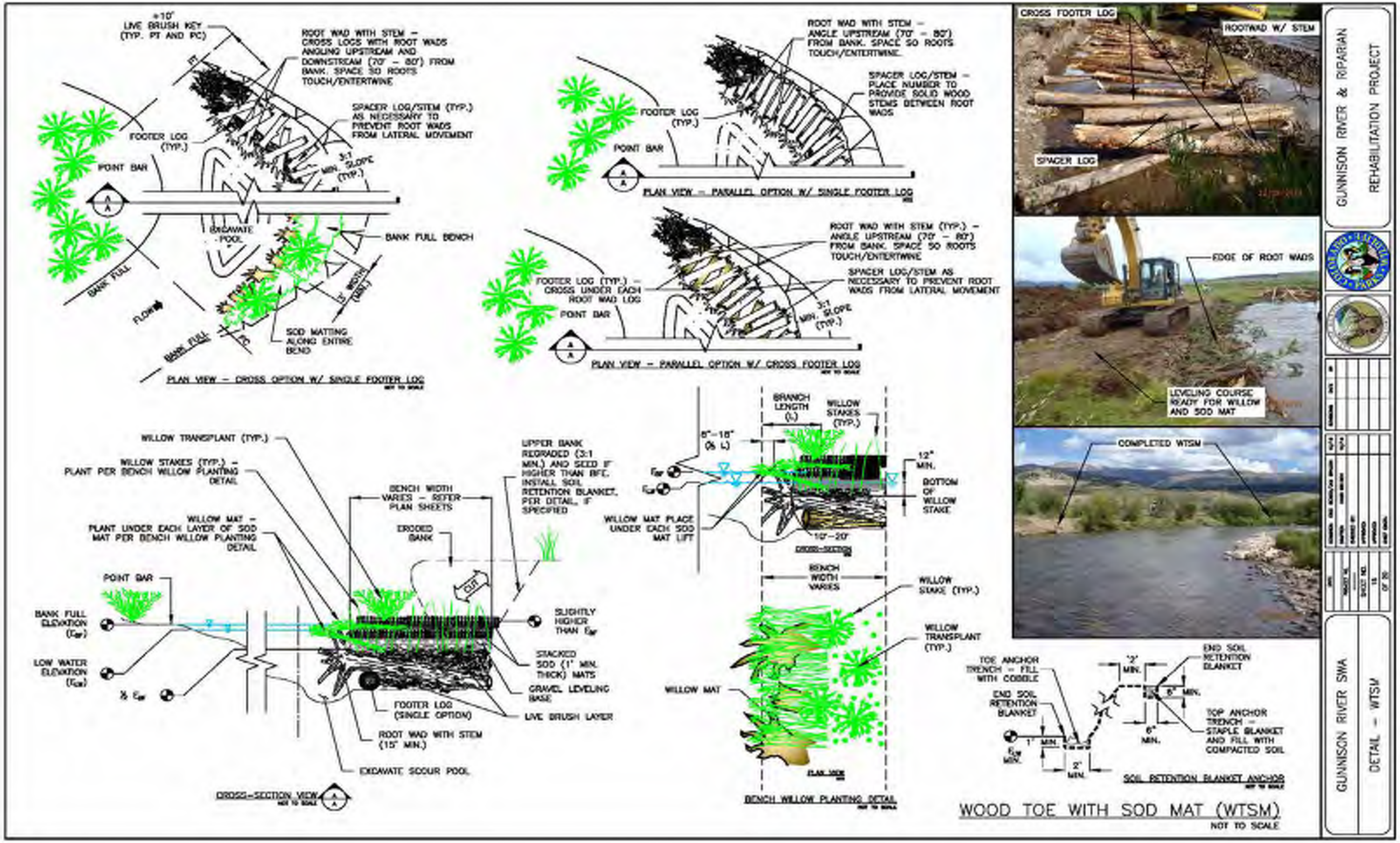
Wilson Diversion Plan and Profile



Low Profile Cross Vanes



Wood Toe and Sod Mat Details



Local contactor Spallone Construction was awarded the Bid in August 2017. CSI Concrete was a subcontractor for the project.

Work on the Wilson diversion began in late October 2017. Favorable weather conditions allowed for completion of all rock structures & concrete work. The majority of vegetation work was also complete during the warm fall season.

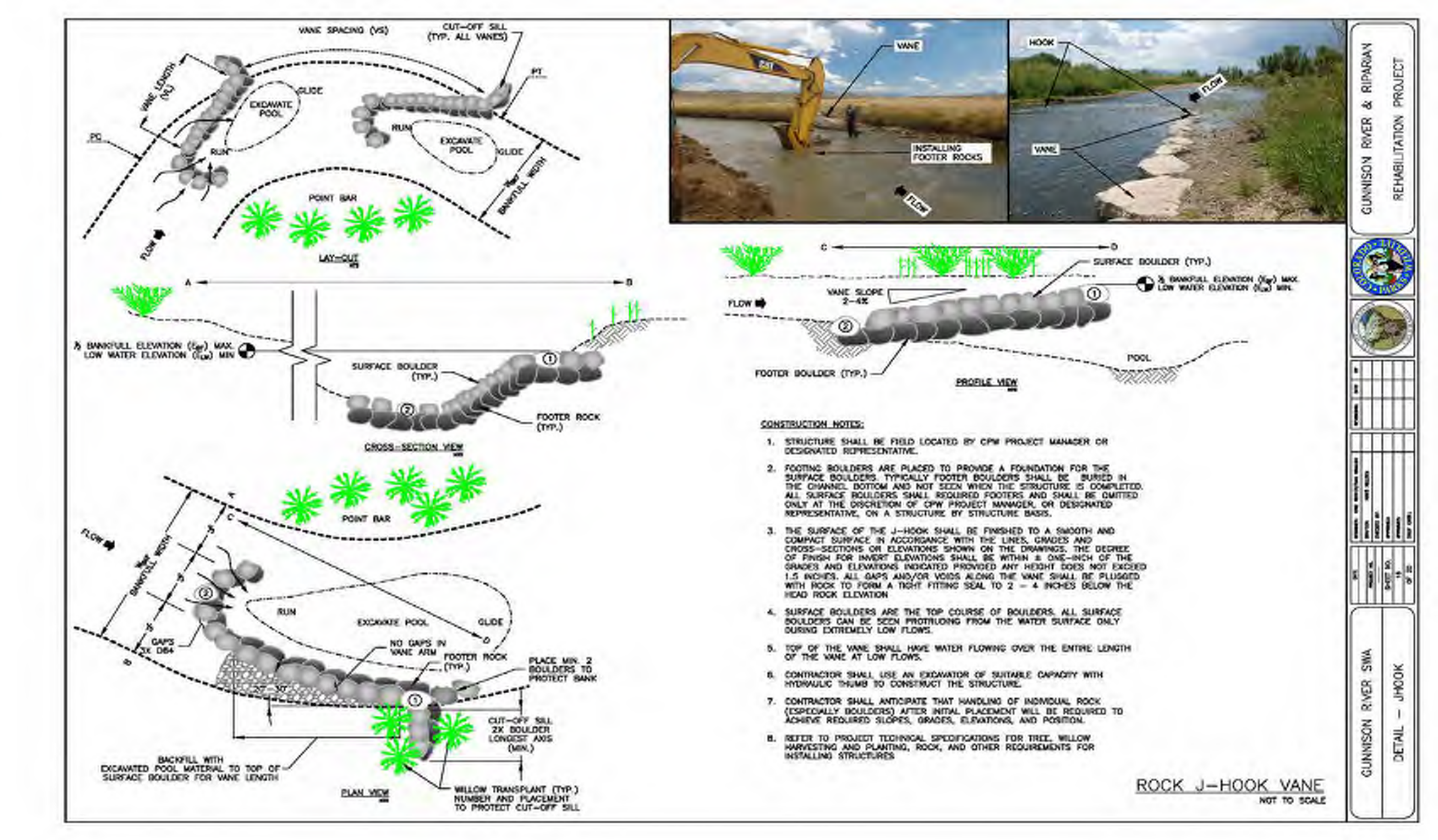
Riparian Habitat Treatments

Bank stabilization, willow transplanting & other work will improve riparian habitat. Reconnection of the floodplain, where appropriate, was also a project goal

Floodplain Connection

Terrace & Floodplain Riparian Habitat Treatment

J-Hook Design Details

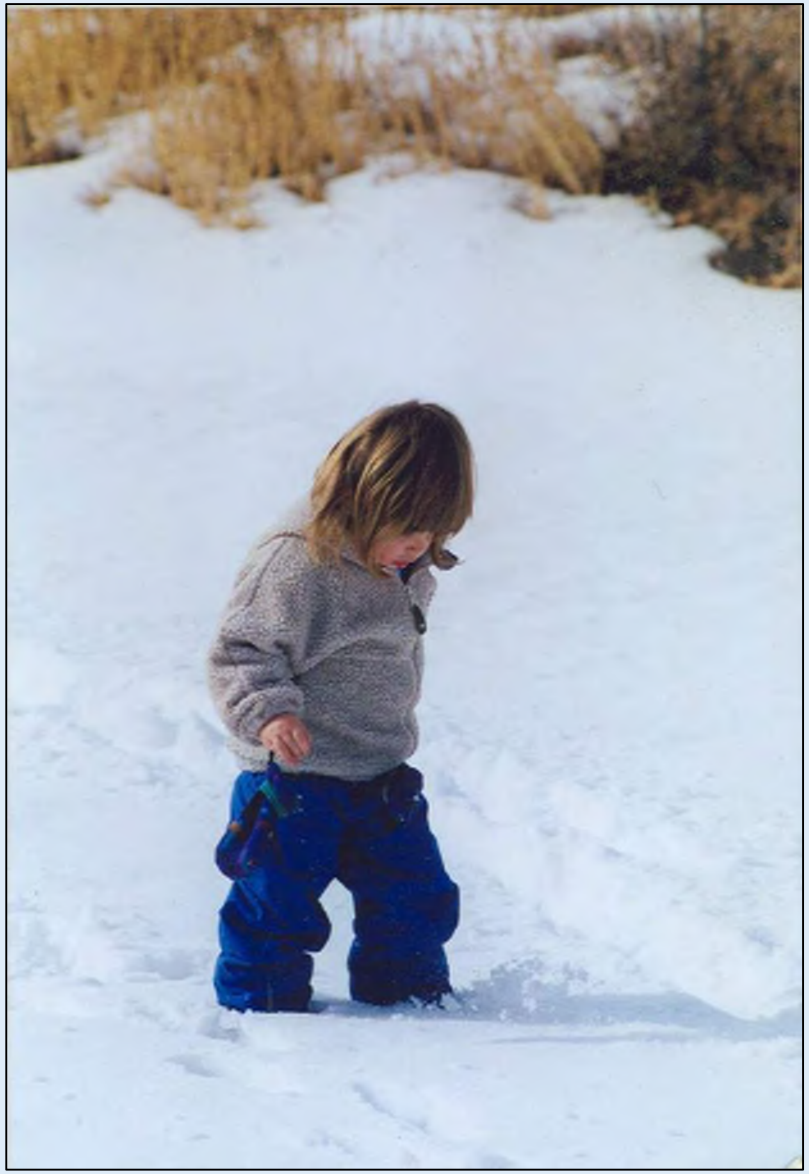


While equipment was staged at the Wilson Diversion, work to stabilize the Ohio Creek/Gunnison confluence was accomplished.

A J-Hook structure and boulder cluster habitat features were constructed at the confluence.

Observations – Lessons Learned

- Develop partnerships & allies - focus on possible stakeholders
- Be a champion of Great Projects
- Good ideas take time – do not loose focus
- Be a steward of natural resources – it is what *sustainability* requires



'A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.'

Aldo Leopold

Drone Based Riprap Imaging and Gradation Measurement

LeAndra Nelson, PE – Kiewit Engineering Group

Kiewit Engineering Group

- 1,400 Engineers
  - Construction Engineering Services
  - Permanent Design Services
- Power & Energy
- Roadway
- Railway
- Structures
- Hydraulics
- Geotechnical

Purpose

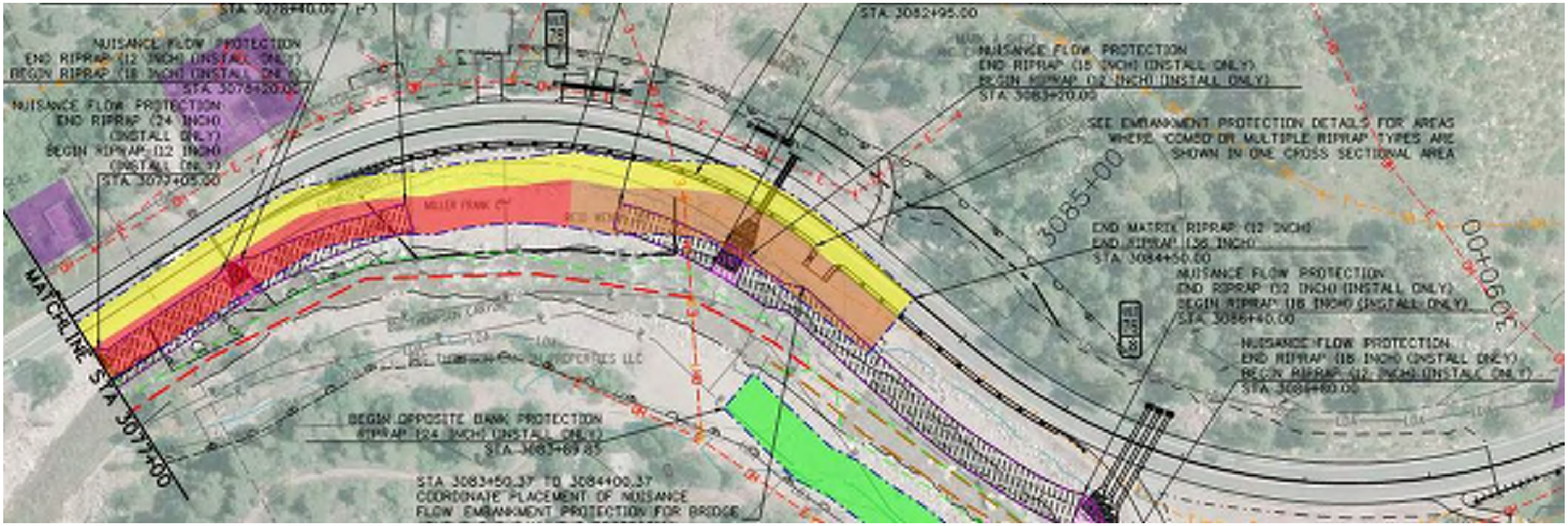
- Limited processes for measuring rock gradation
- Build on use of drones
- Independent quality check

US-34 Permanent Repair Project

An Opportunity for Innovation

State-of-the-Industry Geomatics

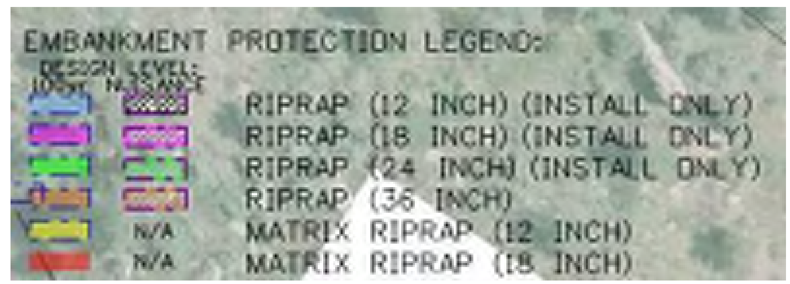
- GPS Coverage
- RTK Equipped Survey Crews
- Machine Control
- Drone Based Remote Sensing
  - Topographic Models
  - Construction Work Planning
  - Quantity Determination



*Plans Provided Courtesy of CDOT

Embankment Protection

- Challenging River Hydraulics
- Environmental Requirements
- Varying size/type of riprap



Quality Concerns

- 100,000 CY riprap placed
- Difficult placement
- Varying gradations
- Potential to fail inspection
- QC Methods

Accepted Quality Methods

Visual Inspection

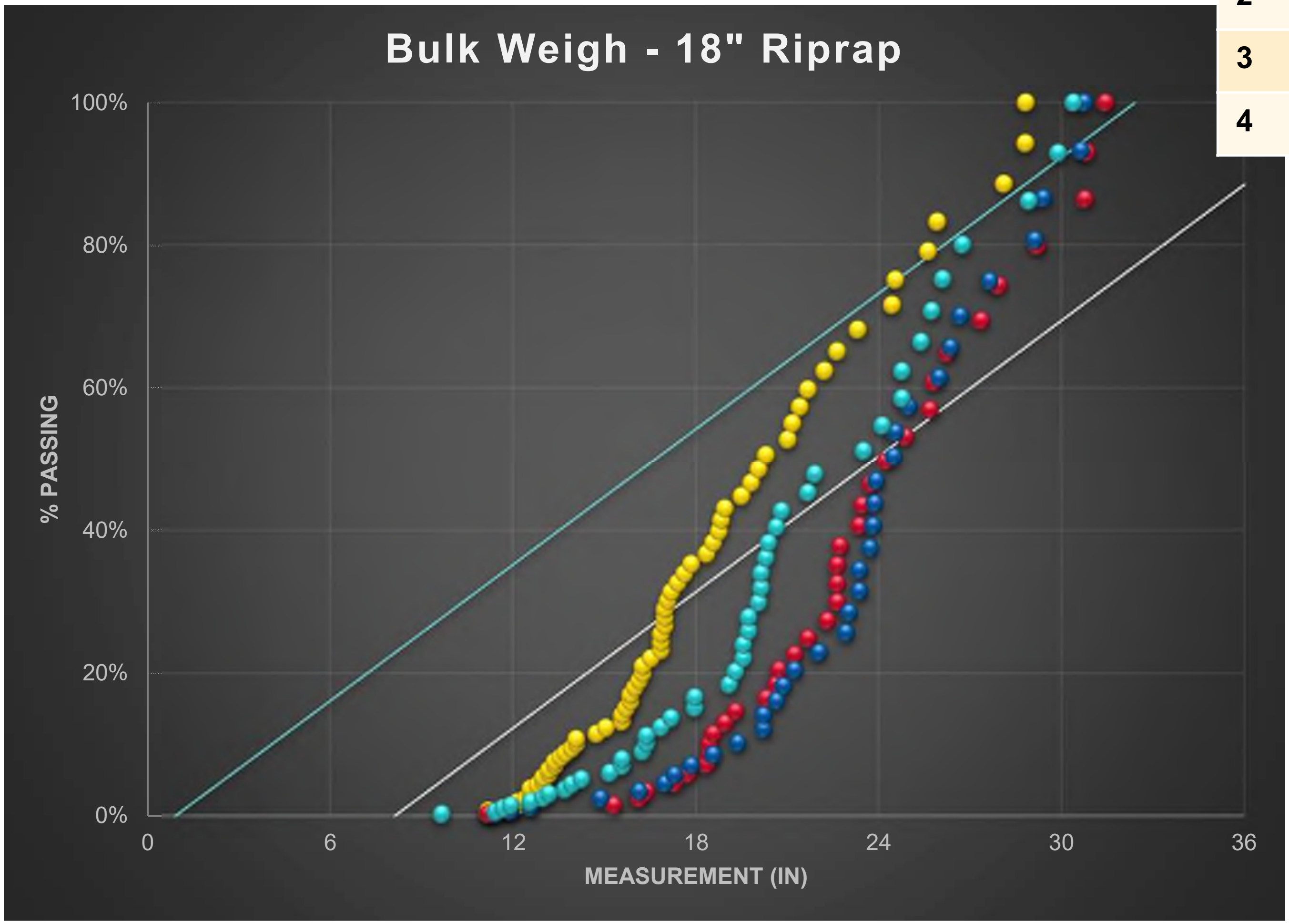
Bulk Weigh

Random Sampling

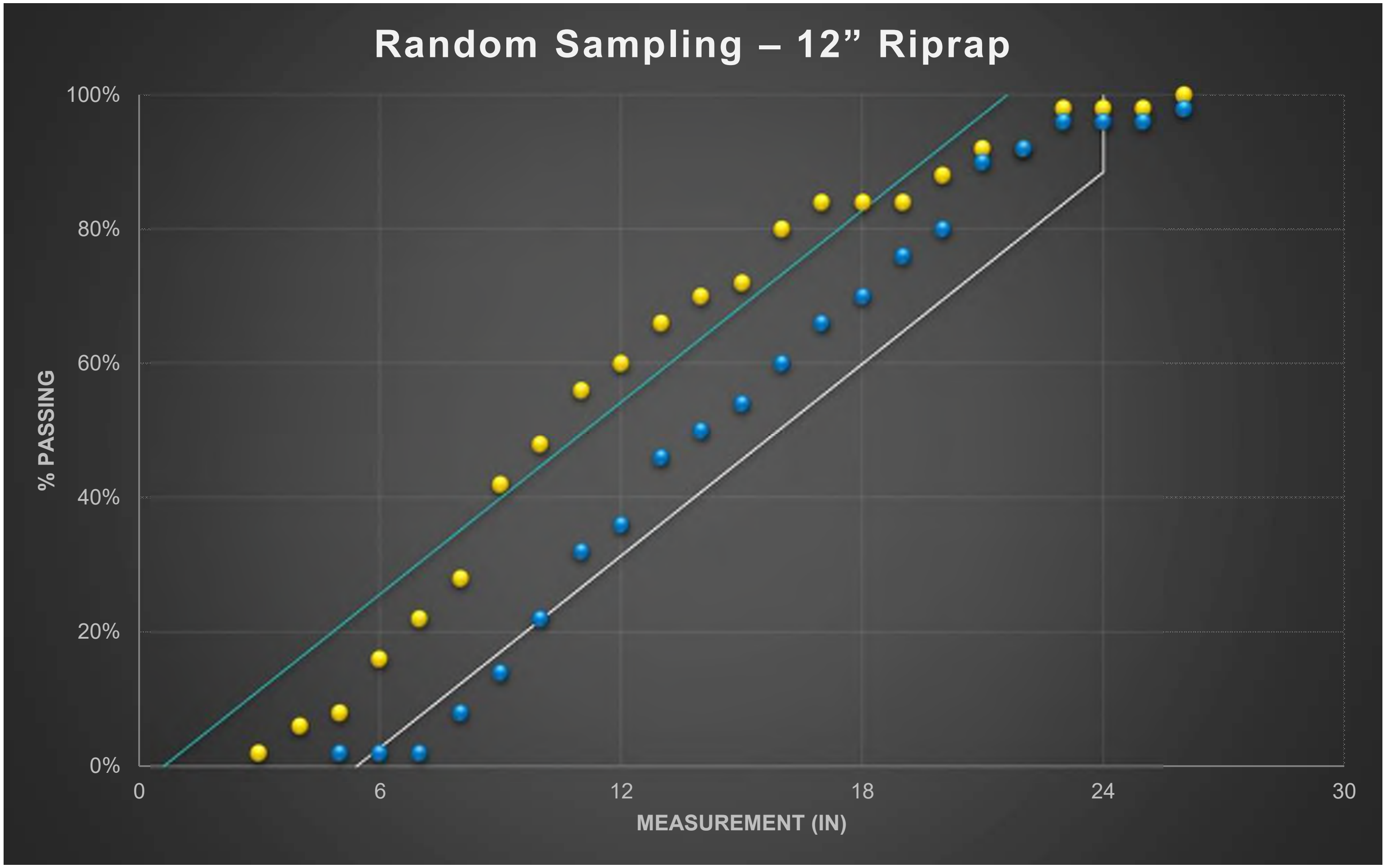
Visual Inspection

Bulk Weigh

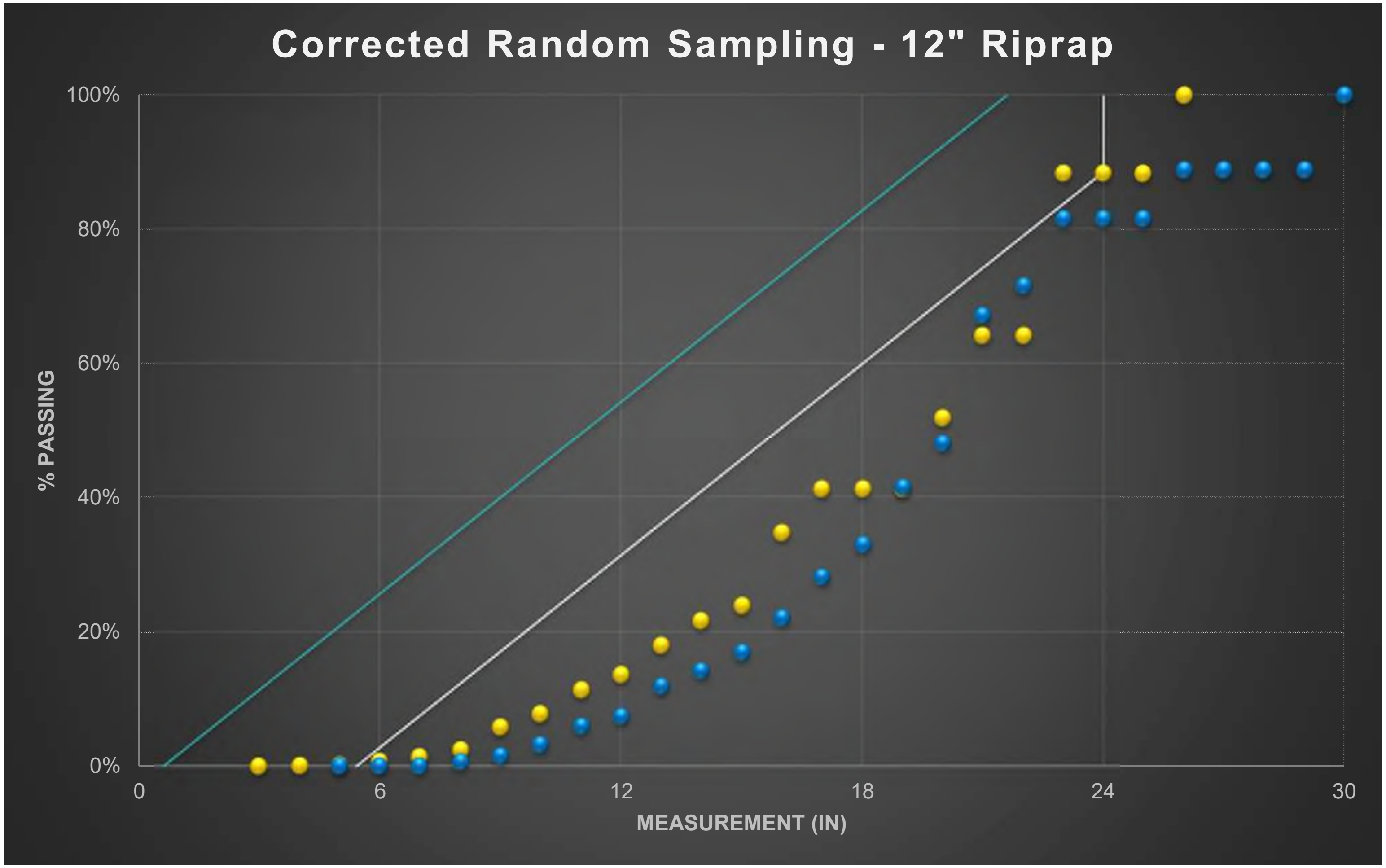
Sample	No. Stones	Stones > 30”
1	67	0
2	47	3
3	36	2
4	46	1



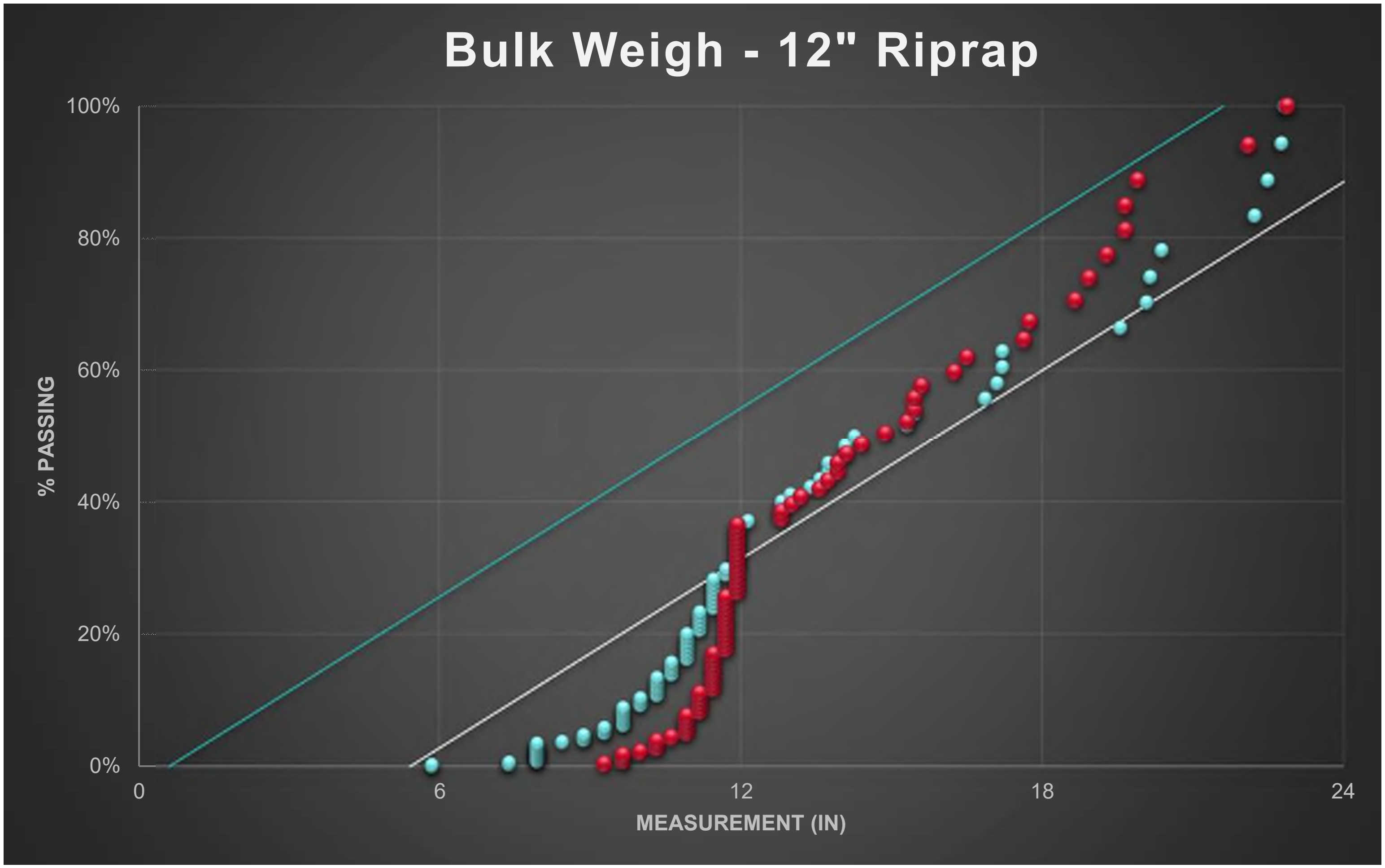
Random Sampling



Random Sampling



Random Sampling vs. Bulk Weigh



Current Quality Method Drawbacks

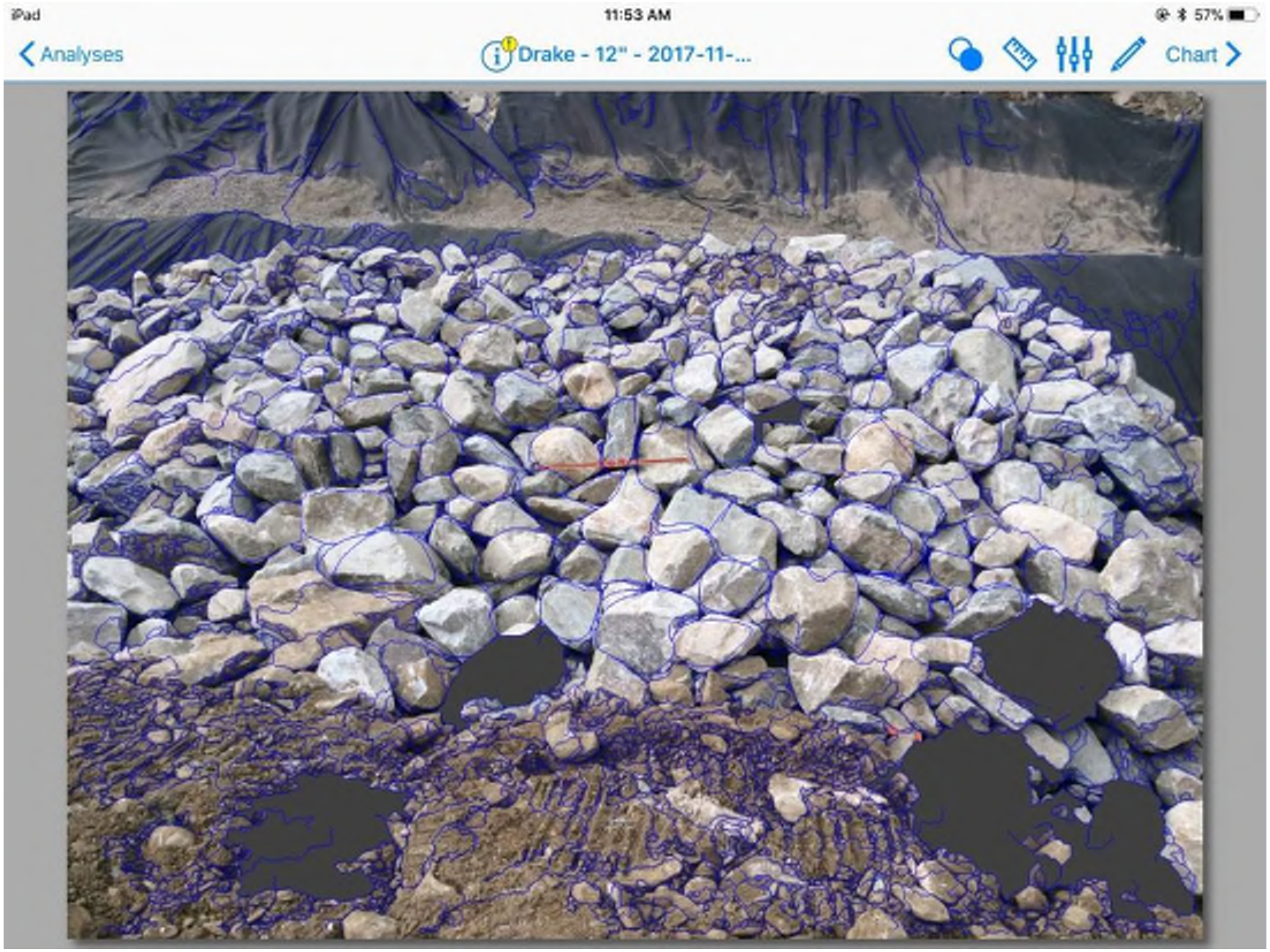
Method	Drawbacks
Visual Inspection	• Requires experienced inspector • Subjective
Mass Weigh	• Time consuming • Large mass • Sample size too small
Random Sampling	• Volumetric correction • Sample size too small

Independent Quality Methods

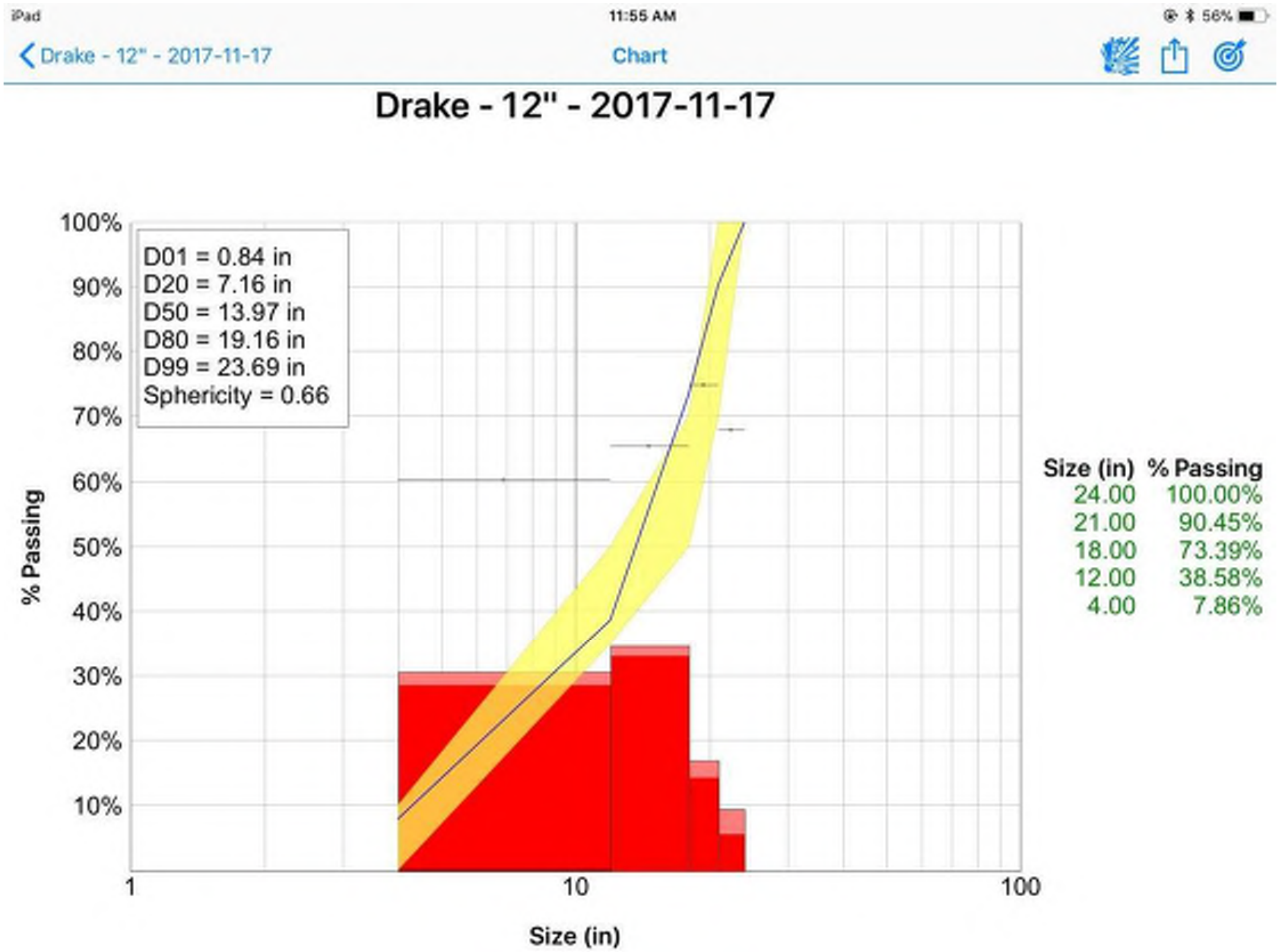
Ground Level Image Segmentation

Drone Image Segmentation

Ground Level Image Segmentation

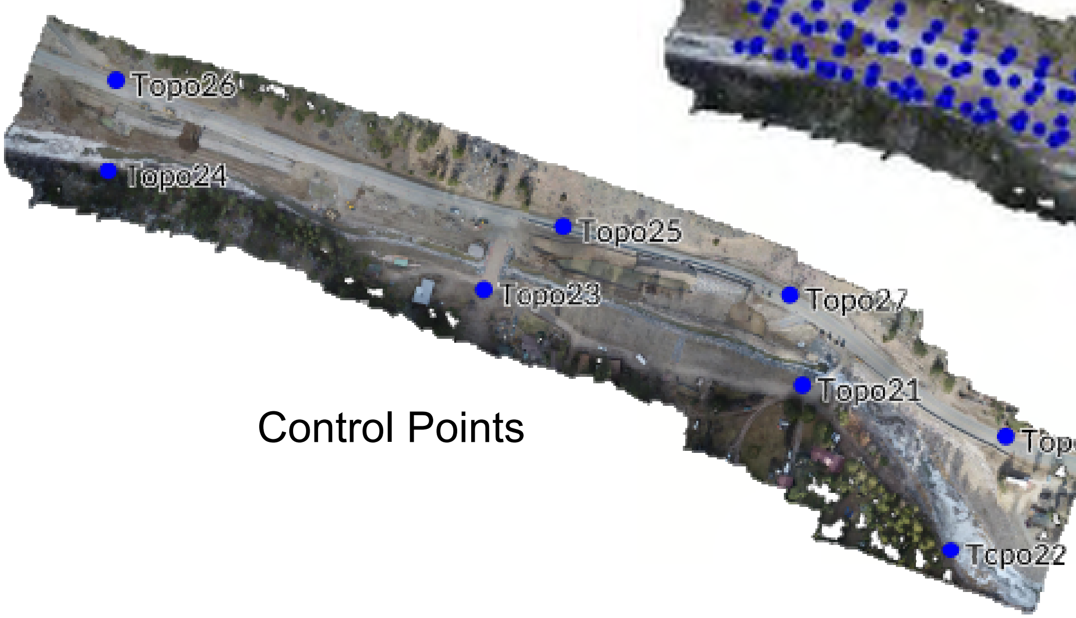


Ground Level Image Segmentation

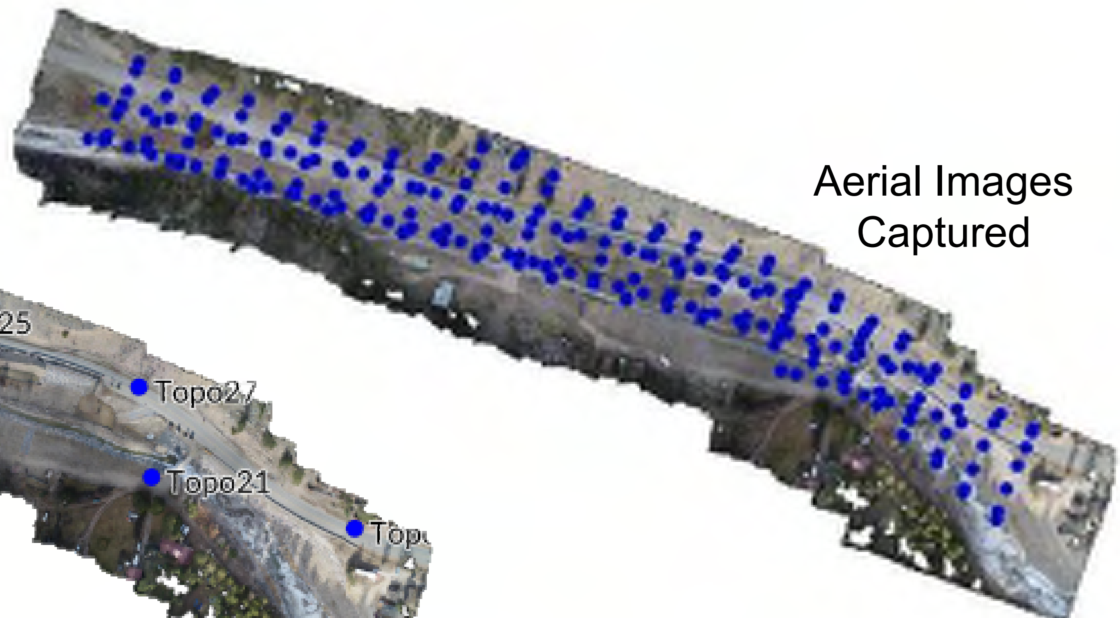


Drone Image Segmentation

- Comprehensive GPS network
- Controlled drone flights
- Automated photogrammetric processing



Control Points



Aerial Images Captured

Drone Tasking

- Typical flight height
  - 80 meters (250 feet)
  - 120 meters (400 feet)

40 m Flight Height

80 m Flight Height

120 m Flight Height

Drone Tasking

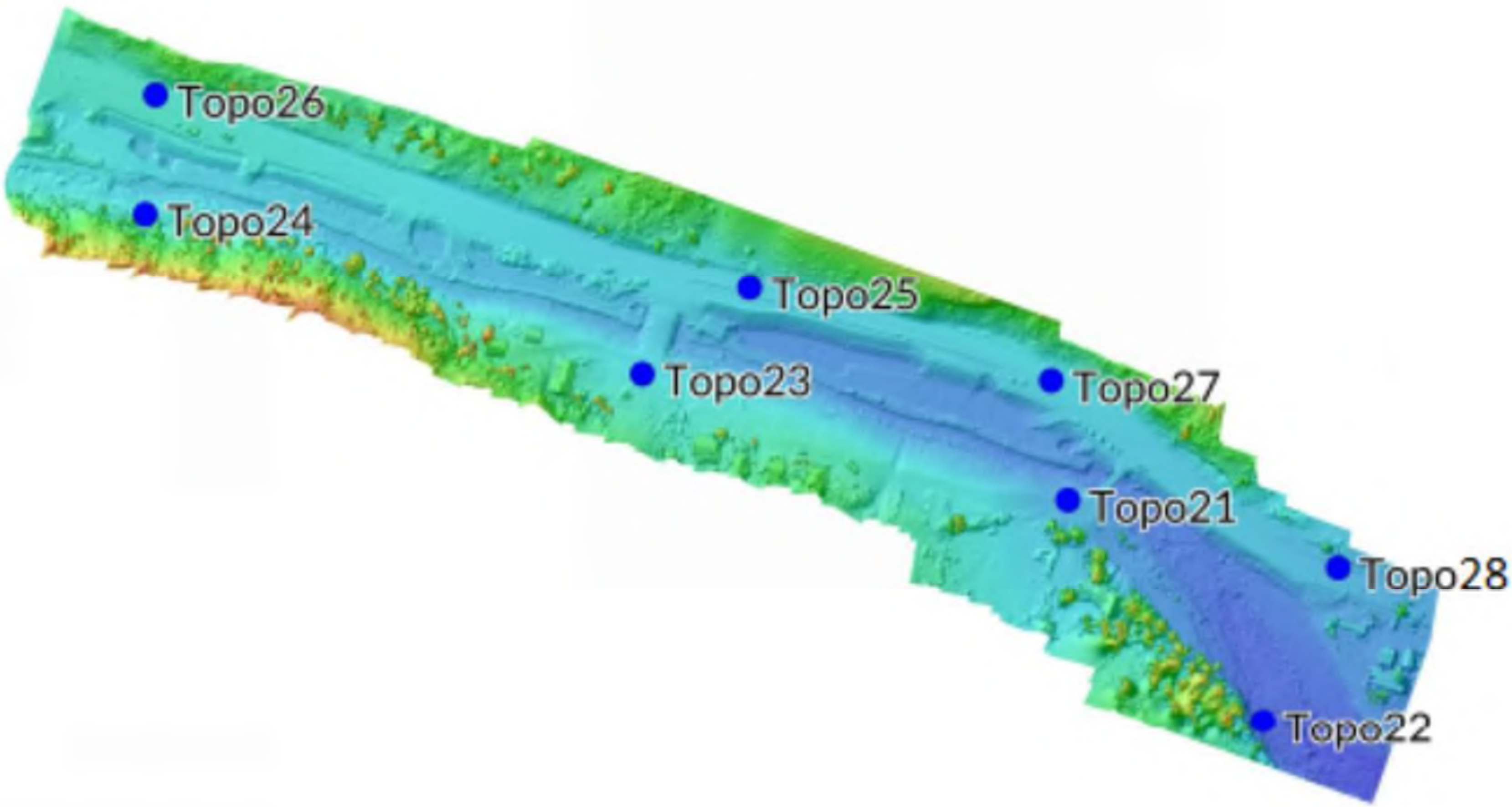
- Constraints
    - Operator with surveying background
    - 3” – 4” Accuracy
    - FAA licensed pilot
    - Light and weather conditions
    - Flight lines and programming
    - Overlapping images
    - Ground Control

From Riprap Quantity to Gradation Quality

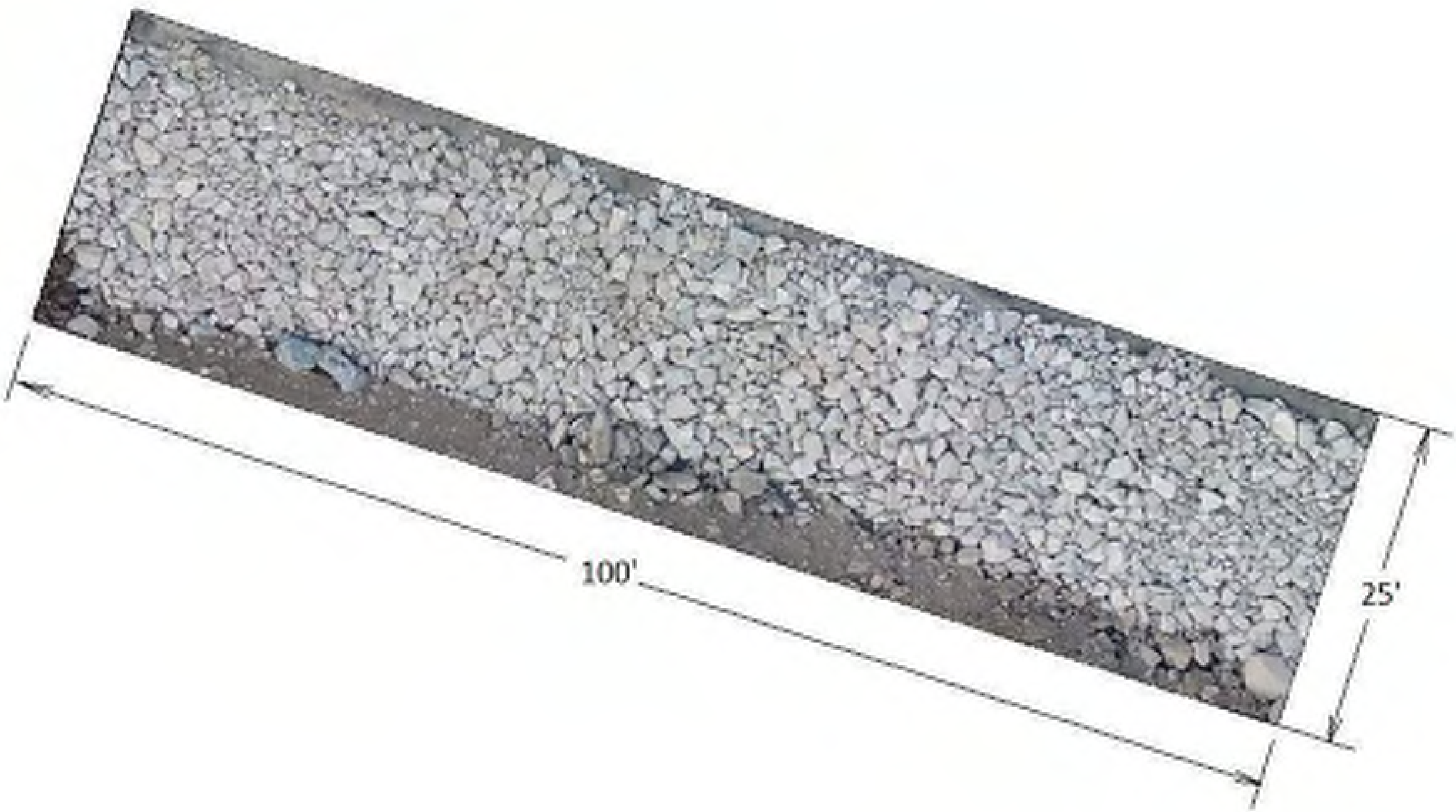
- Photogrammetric processing results
- Gradation Classes

Photogrammetric Processing Report

Photogrammetric Processing Report

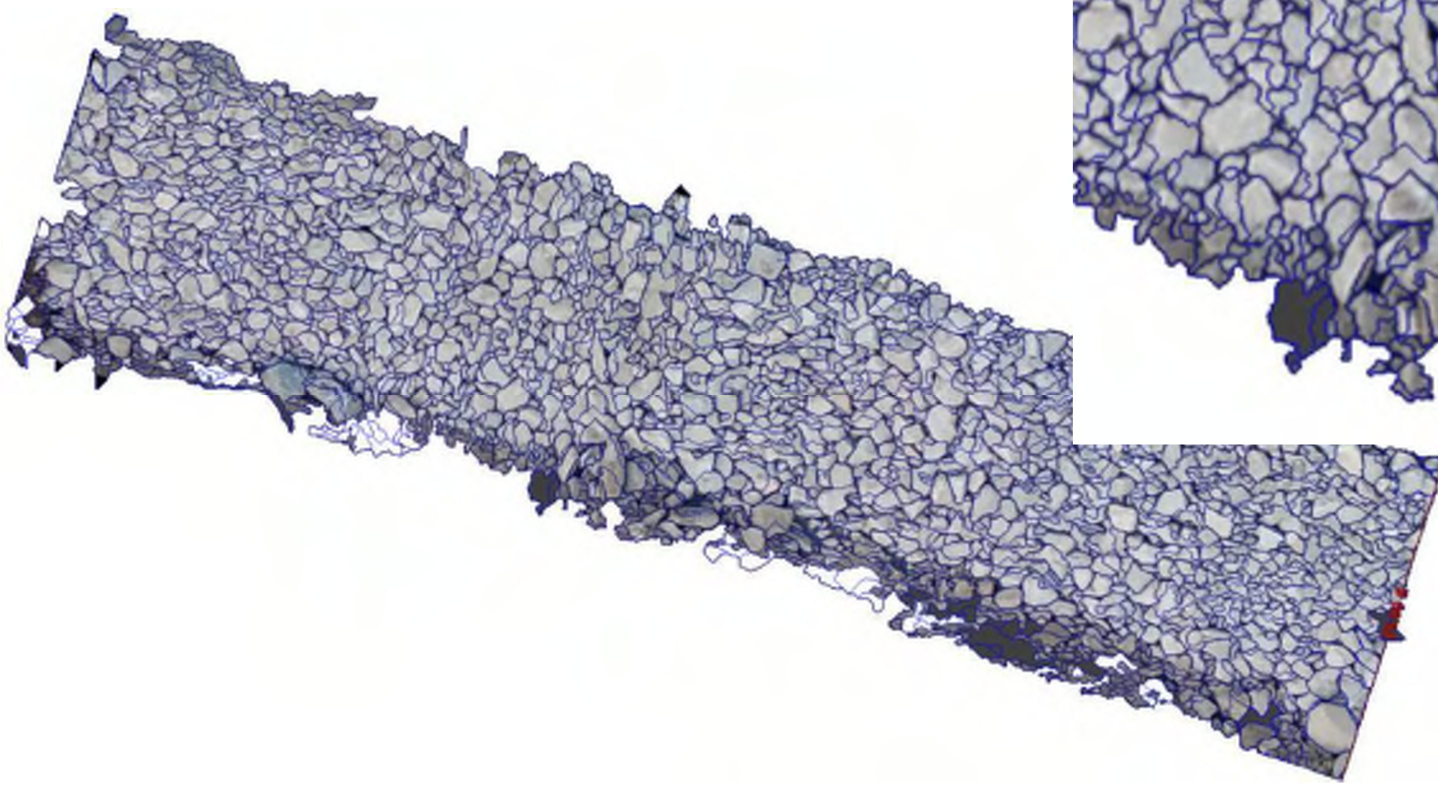


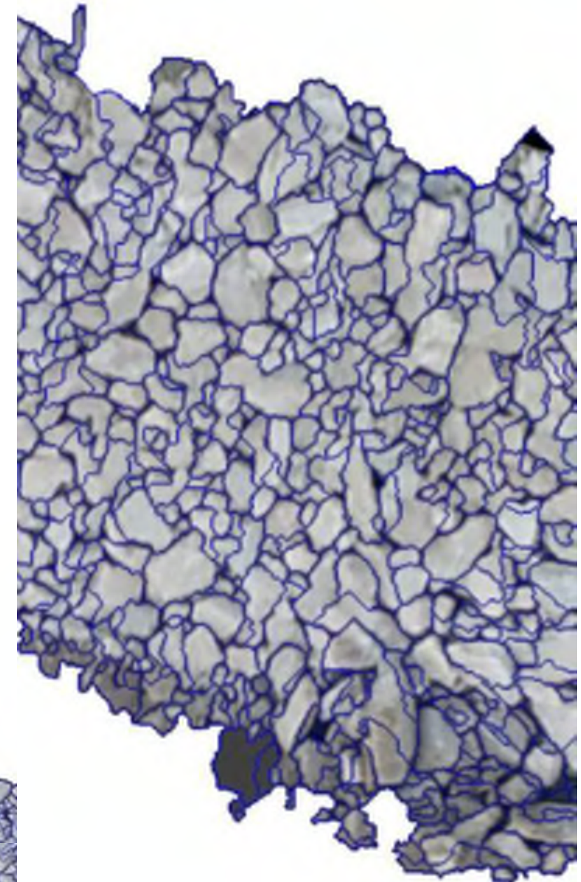
Photogrammetric Processing Report



Drone Image Segmentation

- 2,500 sq. ft Sample Area (100’ x 25’)
- Contains over 1,000 stones

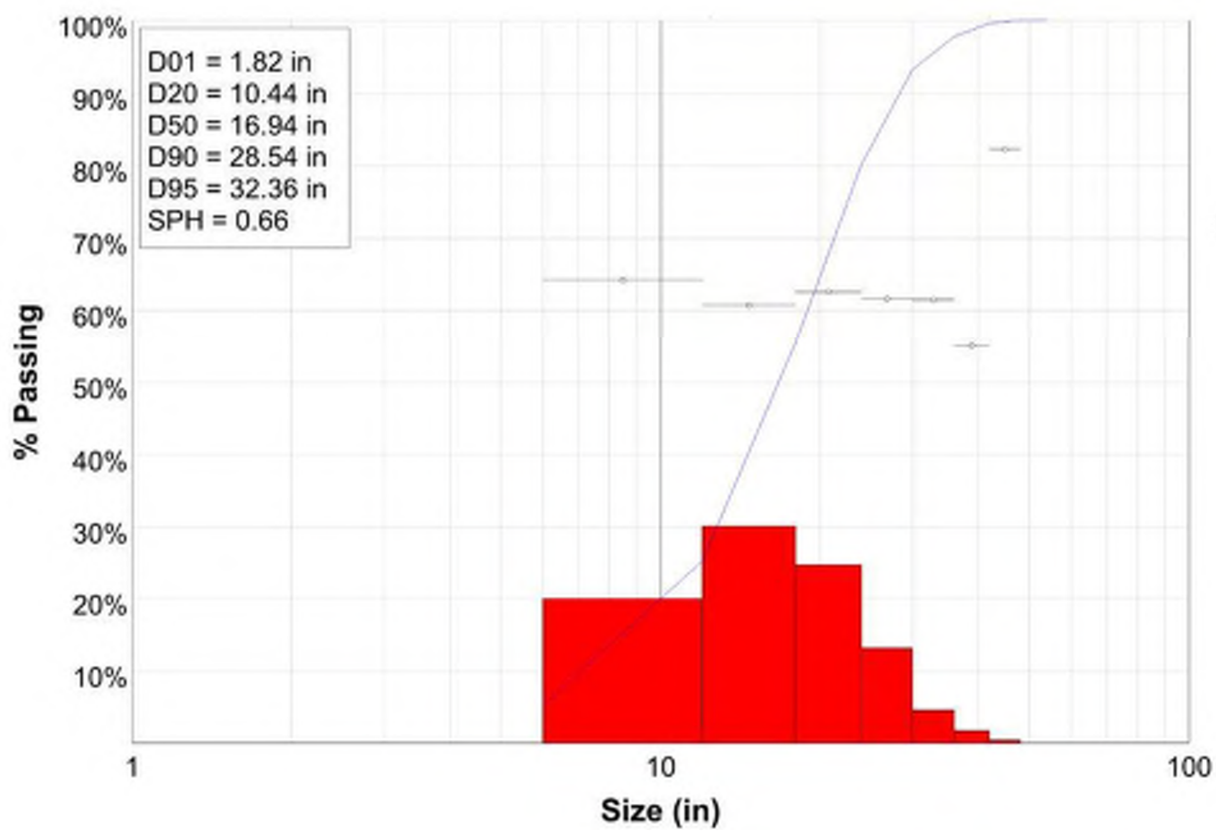




Gradation Analysis

- 18” Riprap Gradation

Moodie East



Size (in)	% Passing
54	100.00%
48	100.00%
42	99.54%
36	97.76%
30	93.21%
24	80.02%
18	55.32%
12	25.21%
6	5.16%

KieTrac Documentation Form

US-34 Rock Riprap Gradation Report

US 34 Big Thompson

Site ID: Moodie **Engineer:** A. Stainbrook **Date:** 2018-01-20

Weather Conditions: Clear Skies, Mid-Afternoon

US-34 Station: 3080+00.00 to 3081+00.00 **Highway Side:** N ☐ S ☒

Plan D: 18 **Slope Angle:** 4:1 H:V degree

Reason for Inspection: Field Gradation Measurement

Test	Performed	Pass	Fail	D	D	D
Random Sampling	☐	☐	☐			
Bulk Weigh	☐	☐	☐			
Image Segmentation	☒	☒	☐	8.94	16.94	26.27

Inspection Summary

List potential issues and hazards:

Matches visual inspection, passes specification

Test Report By:

Name: Andy Stainbrook

Title: QC Manager

Signature:

Report Reviewed By:

Name: LeAndra Nelson

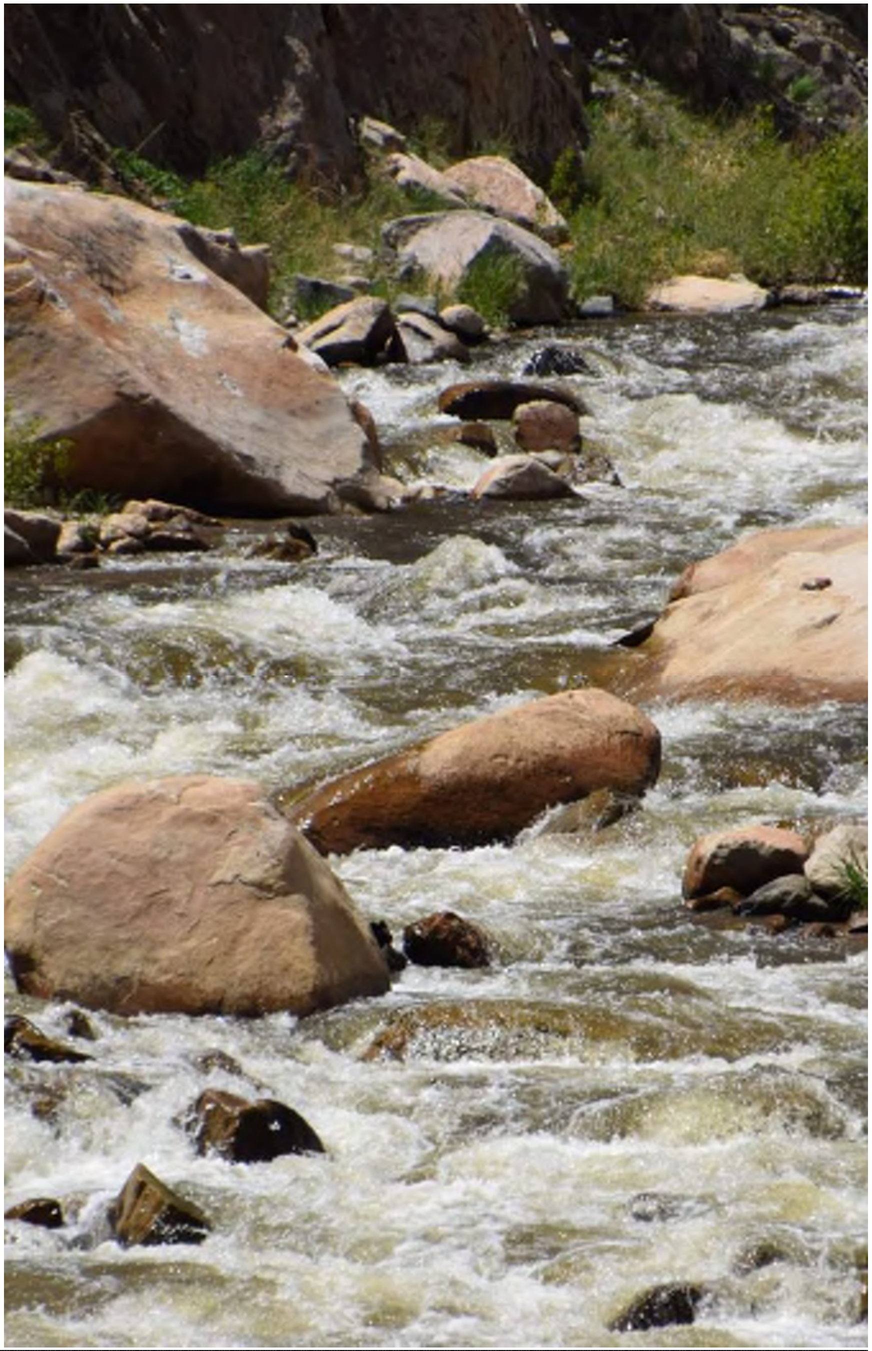
Title: Hydraulic Engineer

Signature:

Page 1

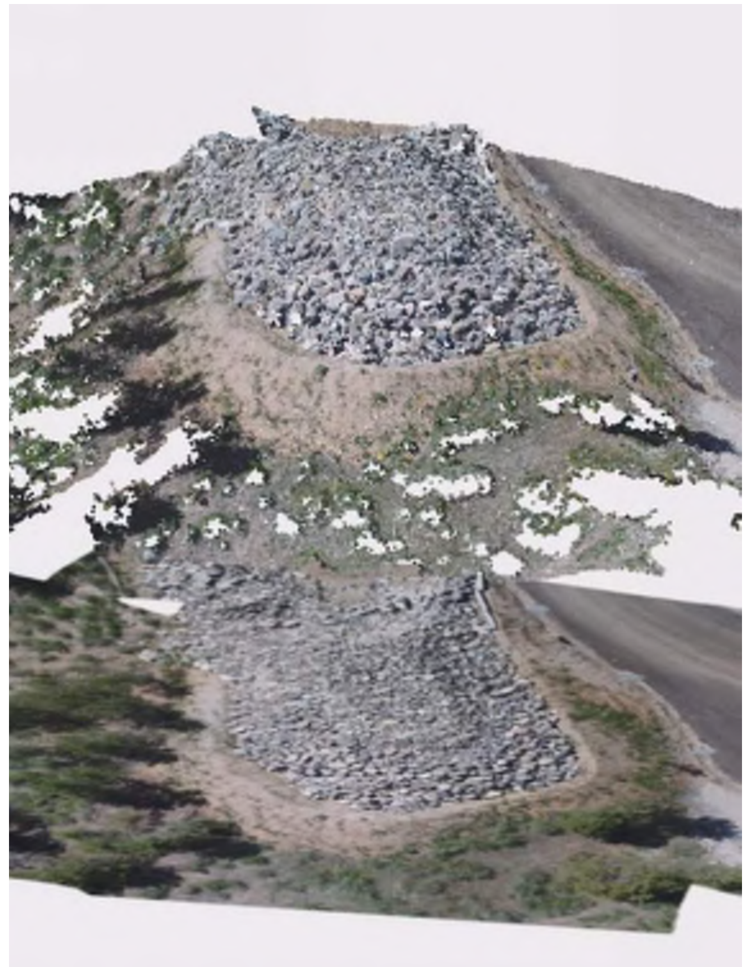
Image Segmentation Conclusions

- Larger sample size
- Better gradation analysis
- Easy to integrate with drone survey
- Independent QC met
- Build right the first time
- Reduce risk
- Safety



Point Cloud Applications

- Quantity take-off
- Quality assurance
- Work planning
- Bridge clearances
- Automatic object identification



“Growth and improvement are not likely to occur unless we are willing to try something we have not done before. Sometimes the effort fails – but it is the reaching, the striving, the divine discontent that builds confidence and generates greater strength and knowledge.”

Peter Kiewit

Acknowledgements

- George Cotton, PE – Kiewit Engineering Group / Chief Hydraulic Engineer
- Ben Constable – Kiewit Engineering Group / VDC Coordination Manager
- Jim Brinkman – Kiewit Engineering Group / VDC Civil Designer
- Karl Pearson – Kiewit Central District / US-34 Survey Chief

Questions?

CASFM 2018 Annual Conference

Technical Modeling Sessions:

Session1: Regulating 2d Models & Tools for Planning

Isaac Allen (AECOM)

Session2: How to be Less Wrong – Errors & Uncertainty in Hydraulic Modeling

Ryan Carroll & Andrew Friend (Michael Baker International)

Tools to Stay Ahead of the Storm

Dana McGlone (Dewberry Consultants), Kevin Stewart (UDFCD), Kevin Houck (CWCB)

Bendway Weirs and 2D Modeling: An Innovative Stream Design

Aaron Sutherlin & Drake Ludwig (Matrix Design Group)

Quantifying Climate Change Impacts on Flood Hydrology using Global Climate Models to Adjust NOAA Atlas 14 Precipitation Depths

Derek Rapp & Jim Wulliman (Muller Engineering), Brian K. Varrella (CDOT)

Evolution of the 2-D Base Level Engineering Across FEMA Reion VIII and a Case Study from Garfield County, Colorado

Eli Gruber, Garrett Sprouse, & David Sutley (CDM Smith)

Regulating 2D Models & Tools for Planning

Isaac Allen

CASFM 2018

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Colorado Water Conservation Board
Department of Natural Resources

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Purpose of this Presentation

1

Share some lessons learned and discussion points raised from CHAMP program on the use of 2D models for regulatory purposes

2

Highlight important items communities should consider when working with 2D models

Current FEMA Regulations

- FEMA regulations allow for use of 2D models, but regulations were created with 1D analyses in mind

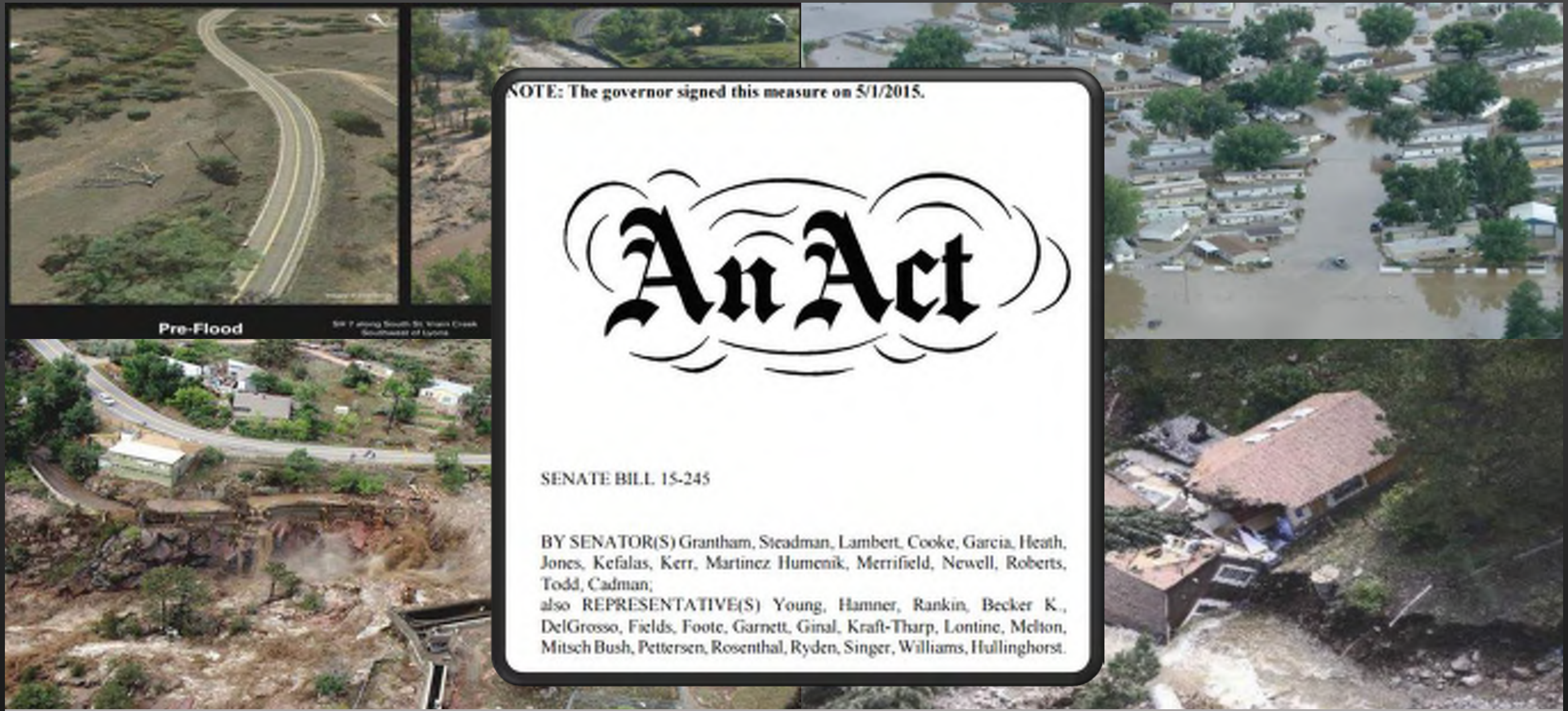
- Difficult to conform 2D results to 1D based formats, also some regulations require additional clarification for 2D analyses

SID 78 — *The water-surface profiles of different flood frequencies must not cross one another*

- Some regulations not conducive for beneficial information that can be generated from 2D models

SID 70 — *Floodway surcharge values must be between zero and 1.0 ft.*

CHAMP Overview



Led by the CWCB, CHAMP was established after the 2013 floods to help communities become more resilient through comprehensive mapping of floodplains and other natural hazards.

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Department of Natural Resources

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Regulating 2D Models & Tools for Planning

1D/2D and 2D Regulatory Products

FW 1D/2D and 2D Floodways

LOMCs and Other Regulatory Processes

Next Steps

Questions

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

AECOM

1D/2D and 2D Regulatory Products

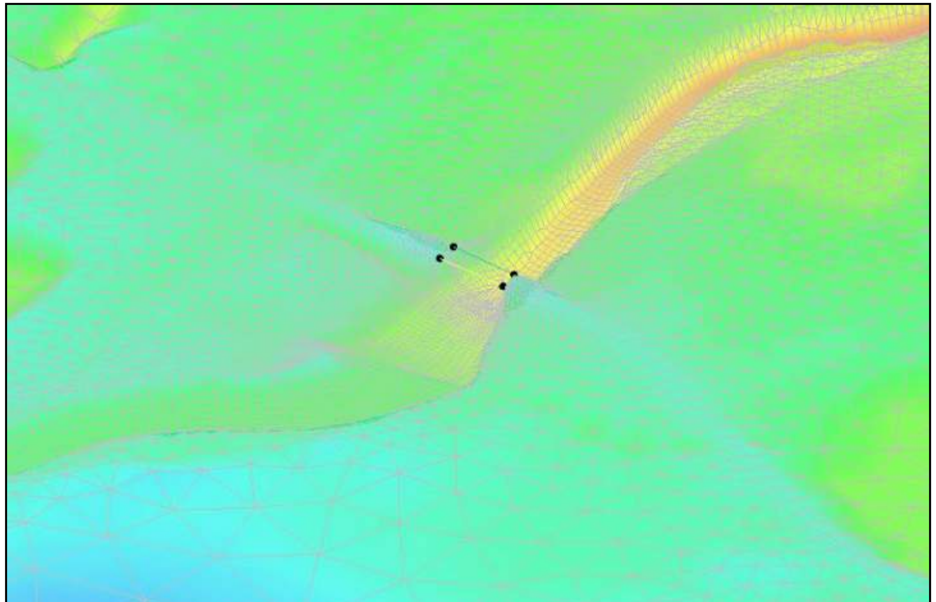
FW

FW

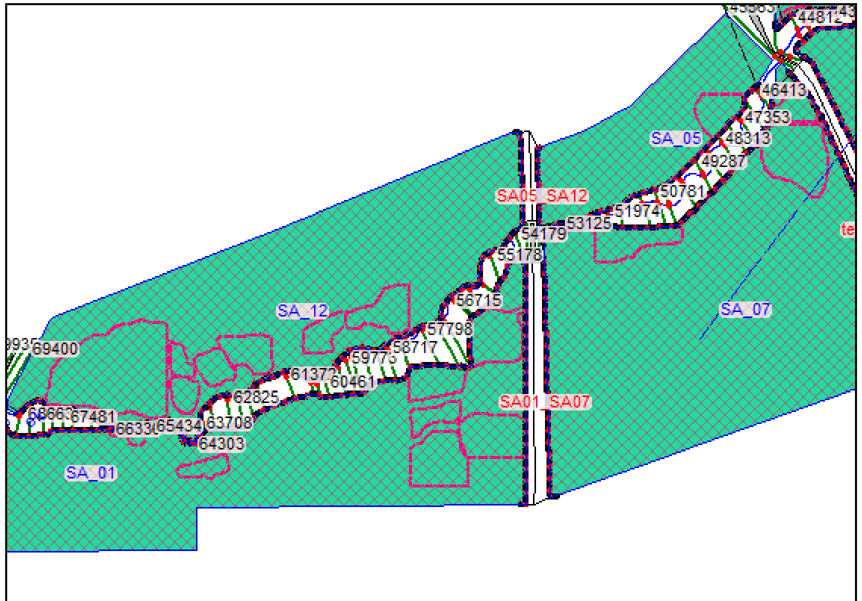
CHAMP 2D

- Recent Colorado CTP work
  - (2) 1D/2D combined analyses completed in HEC-RAS Version 5.0.3
  - (2) 2D analyses completed in SRH-2D

- 2D models were used because of:
  - Increase in regulatory flow rates in heavily developed town
  - Request by community to complete a 2D analysis to utilize previous 2D work
  - Handle complex flow scenarios after preliminary 1D evaluation



Example SRH-2D Mesh Grid



Example HEC-RAS 1D/2D Geometry

2D Developments

- Through Colorado CTP Program, worked with FEMA to develop approved approach for some regulatory items

- FEMA guidance indicates floodways using unsteady flow need to be coordinated with project officers

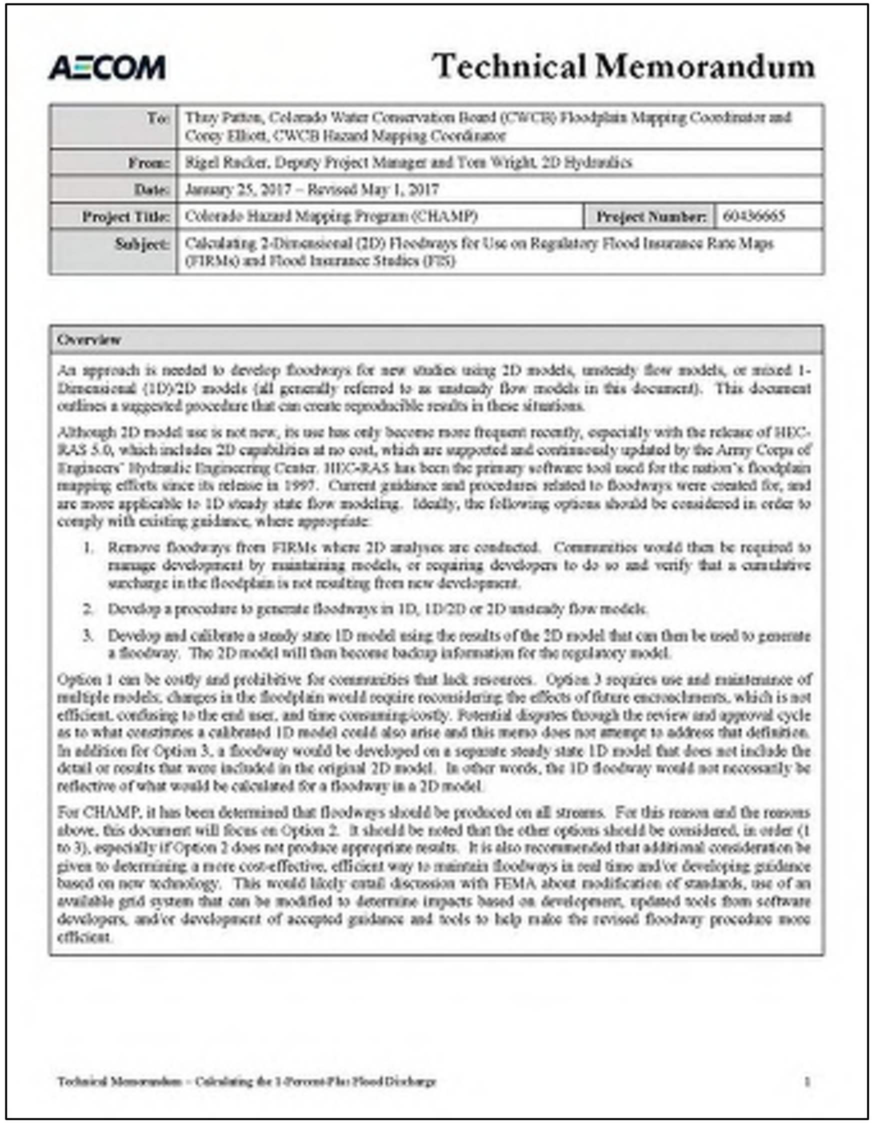
- Developed process for evaluating 2D floodways, which included:
  - Creating Floodway Data Tables
  - Creating Flood Profiles

- Information is available on CHAMP website:

http://coloradohazardmapping.com/

BUT

- Approaches are just a temporary fix to conform 2D results to 1D based standards



AECOM **Technical Memorandum**

To:	Thuy Patton, Colorado Water Conservation Board (CWCB) Floodplain Mapping Coordinator and Corey Elliott, CWCB Hazard Mapping Coordinator		
From:	Rigel Rucker, Deputy Project Manager and Tom Wright, 2D Hydraulics		
Date:	January 25, 2017 – Revised May 1, 2017		
Project Title:	Colorado Hazard Mapping Program (CHAMP)	**Project Number:**	60436665
Subject:	Calculating 2-Dimensional (2D) Floodways for Use on Regulatory Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies (FIS)		

Overview

An approach is needed to develop floodways for new studies using 2D models, unsteady flow models, or mixed 1-Dimensional (1D)/2D models (all generally referred to as unsteady flow models in this document). This document outlines a suggested procedure that can create reproducible results in these situations.

Although 2D model use is not new, its use has only become more frequent recently, especially with the release of HEC-RAS 5.0, which includes 2D capabilities at no cost, which are supported and continuously updated by the Army Corps of Engineers' Hydraulic Engineering Center. HEC-RAS has been the primary software tool used for the nation's floodplain mapping efforts since its release in 1997. Current guidance and procedures related to floodways were created for, and are more applicable to 1D steady state flow modeling. Ideally, the following options should be considered in order to comply with existing guidance, where appropriate:

1. Remove floodways from FIRMs where 2D analyses are conducted. Communities would then be required to manage development by maintaining models, or requiring developers to do so and verify that a cumulative surcharge in the floodplain is not resulting from new development.
2. Develop a procedure to generate floodways in 1D, 1D/2D or 2D unsteady flow models.
3. Develop and calibrate a steady state 1D model using the results of the 2D model that can then be used to generate a floodway. The 2D model will then become backup information for the regulatory model.

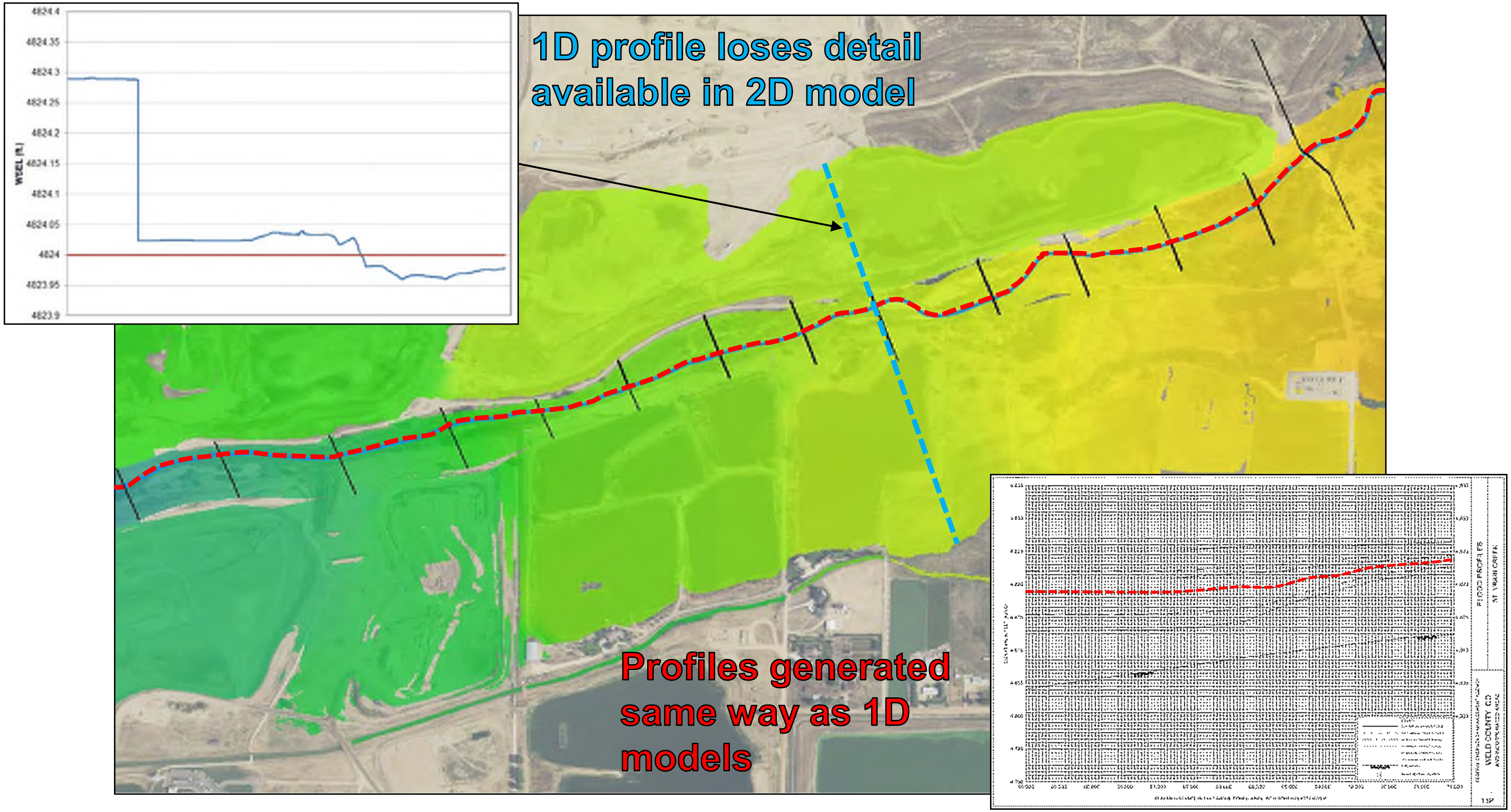
Option 1 can be costly and prohibitive for communities that lack resources. Option 3 requires use and maintenance of multiple models, changes in the floodplain would require reconsidering the effects of future encroachments, which is not efficient, confusing to the end user, and time consuming/costly. Potential disputes through the review and approval cycle as to what constitutes a calibrated 1D model could also arise and this memo does not attempt to address that definition. In addition for Option 3, a floodway would be developed on a separate steady state 1D model that does not include the detail or results that were included in the original 2D model. In other words, the 1D floodway would not necessarily be reflective of what would be calculated for a floodway in a 2D model.

For CHAMP, it has been determined that floodways should be produced on all streams. For this reason and the reasons above, this document will focus on Option 2. It should be noted that the other options should be considered, in order (1 to 3), especially if Option 2 does not produce appropriate results. It is also recommended that additional consideration be given to determining a more cost-effective, efficient way to maintain floodways in real time and/or developing guidance based on new technology. This would likely entail discussion with FEMA about modification of standards, use of an available grid system that can be modified to determine impacts based on development, updated tools from software developers, and/or development of accepted guidance and tools to help make the revised floodway procedure more efficient.

Technical Memorandum – Calculating the 1-Percent-Plus Flood Discharge 1

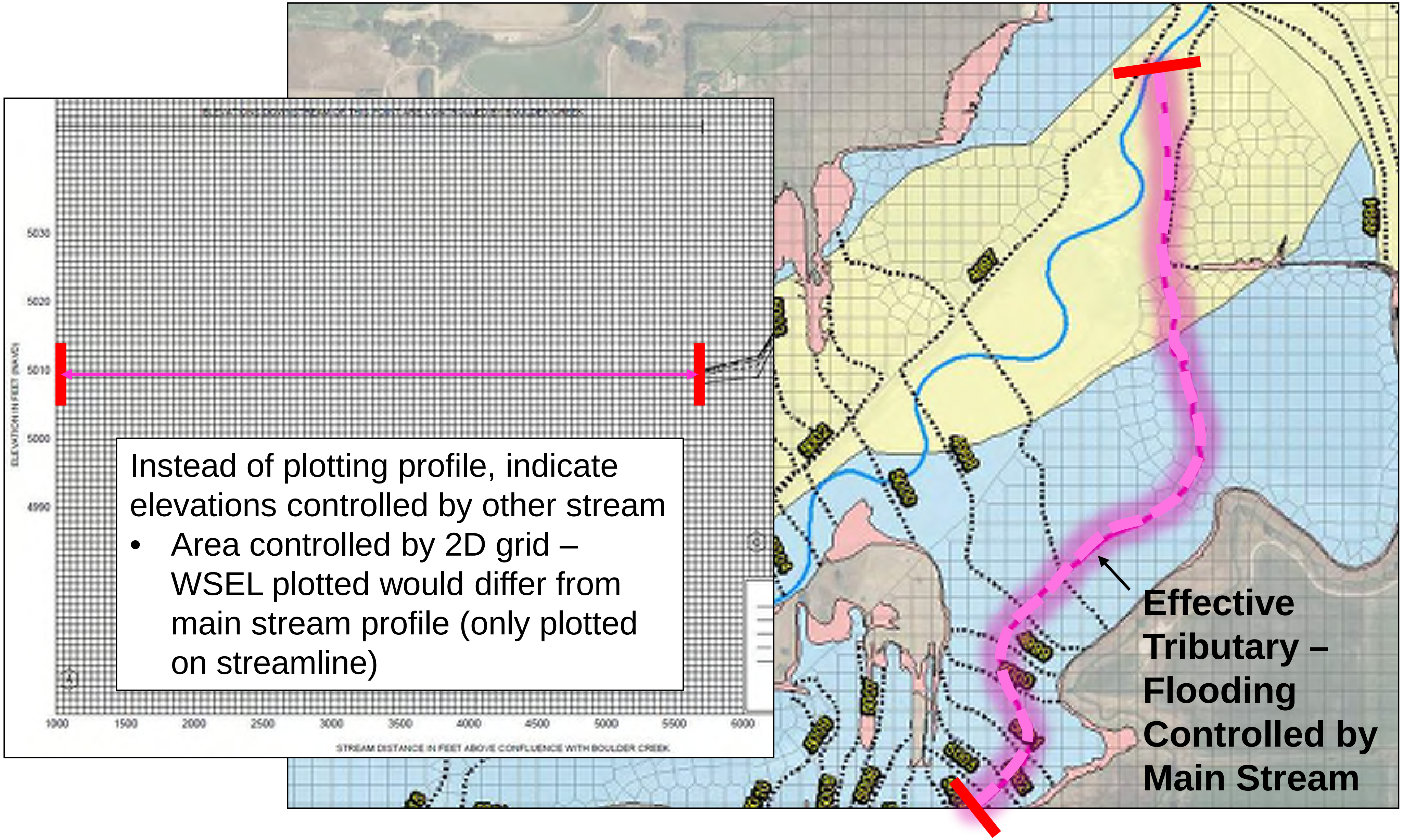
References
1. http://coloradohazardmapping.com/hazardMapping/floodplainMapping/Documents

Profiles


1D profile loses detail available in 2D model
Profiles generated same way as 1D models
WSEL (ft)
4824.4
4824.35
4824.3
4824.25
4824.2
4824.15
4824.1
4824.05
4824
4823.95
4823.9

FW

Profile Tie-ins

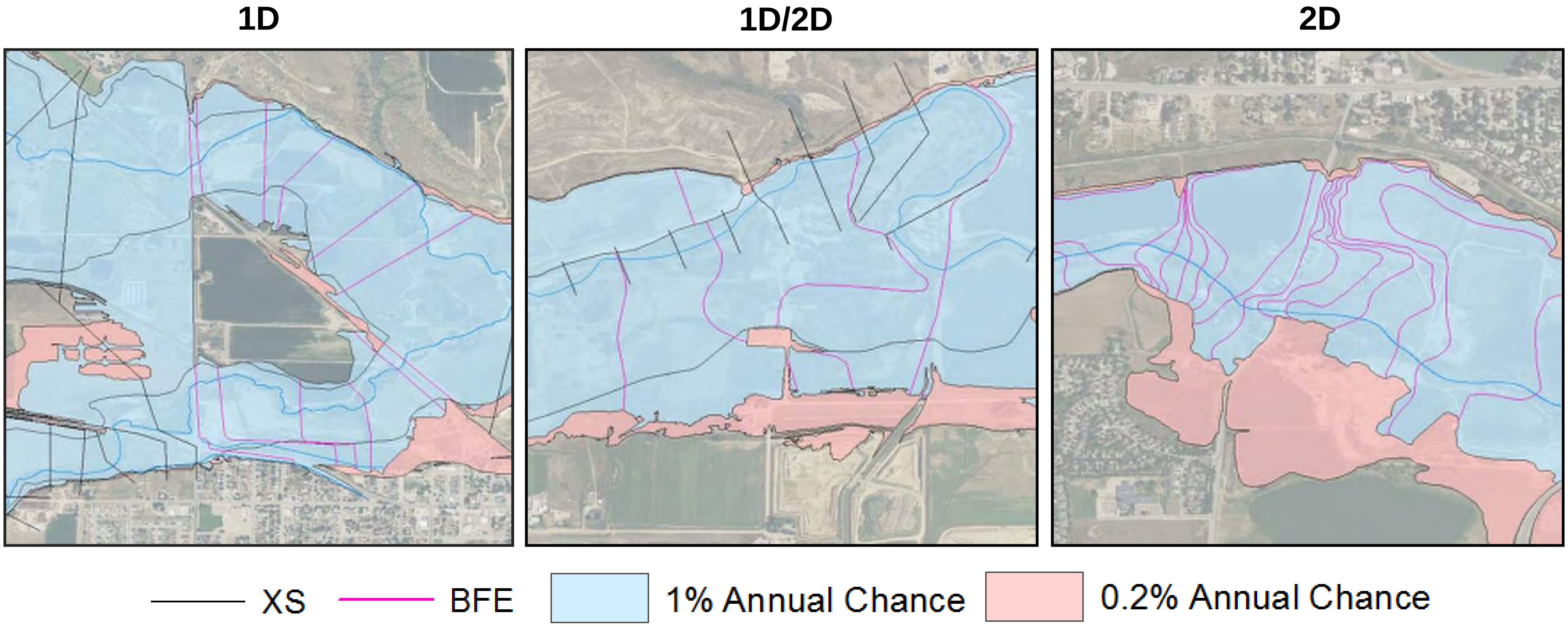


Instead of plotting profile, indicate elevations controlled by other stream

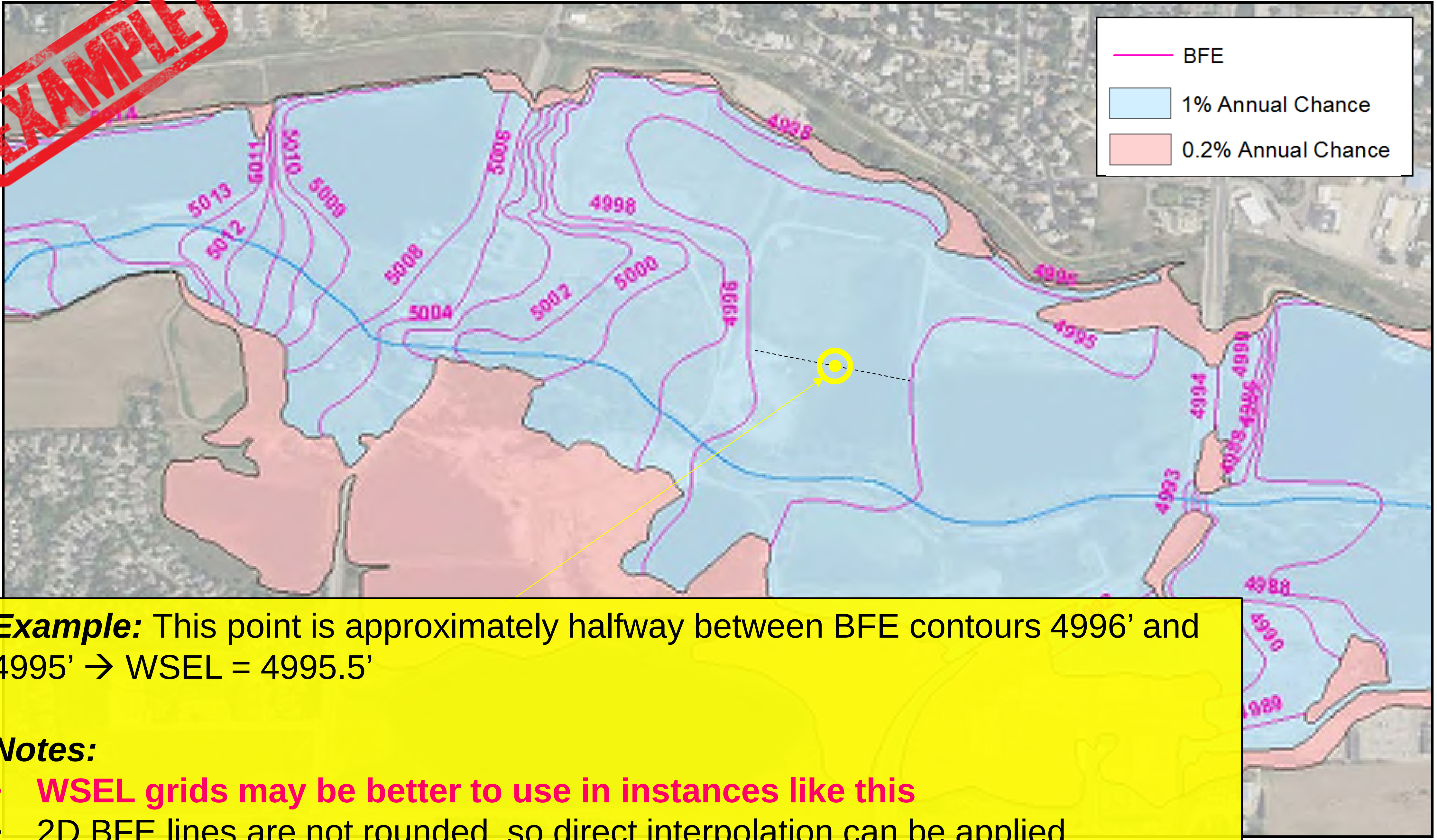
- Area controlled by 2D grid – WSEL plotted would differ from main stream profile (only plotted on streamline)

BFE Lines

Based on current standards, Base Flood Elevation (BFE) lines for 1D models are used only at confluences and to show backwater elevation. Otherwise, 1D cross sections report WSELs. BFEs for 1D/2D and 2D models are contoured from the WSEL grid. EXAMPLE



FW



Example: This point is approximately halfway between BFE contours 4996’ and 4995’ → WSEL = 4995.5’

Notes:

- **WSEL grids may be better to use in instances like this**
- 2D BFE lines are not rounded, so direct interpolation can be applied

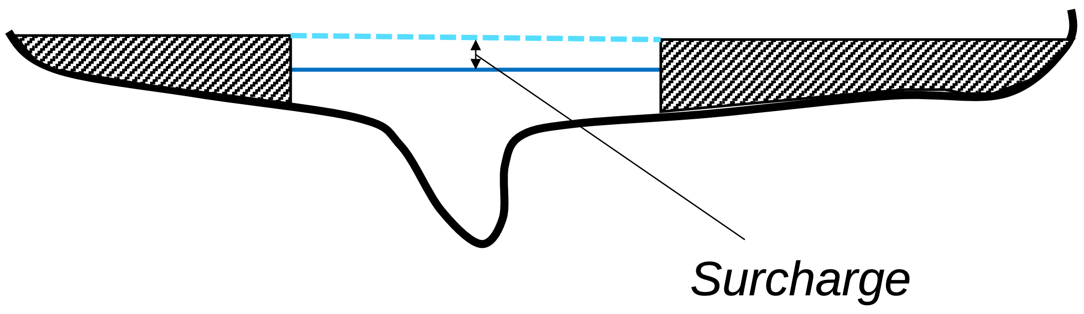
1D vs. 2D Floodways

- Major difference between a 1D and 2D floodway is that the surcharge in a 1D model is averaged across the entire cross section, whereas surcharges in 1D/2D and 2D floodways are evaluated at each computational cell

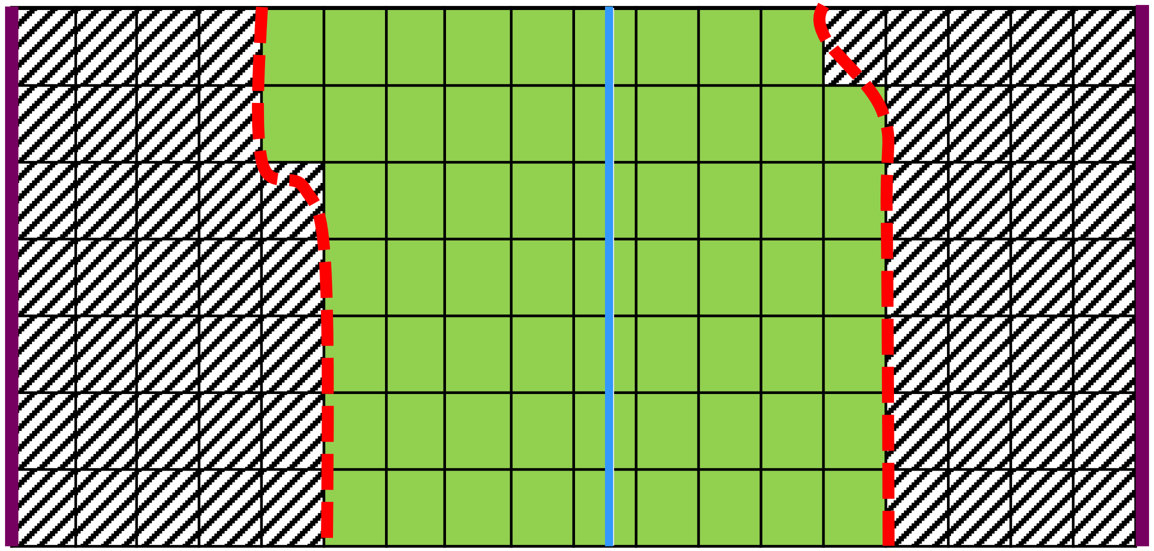
So what does that mean?

- **1D/2D and 2D floodways tend to be much wider because each cell must fall within the surcharge range**. In a 1D/2D or 2D model there are 10,000s of locations that must satisfy the surcharge standard versus in a 1D model where there are 10s or 100s. EXAMPLE

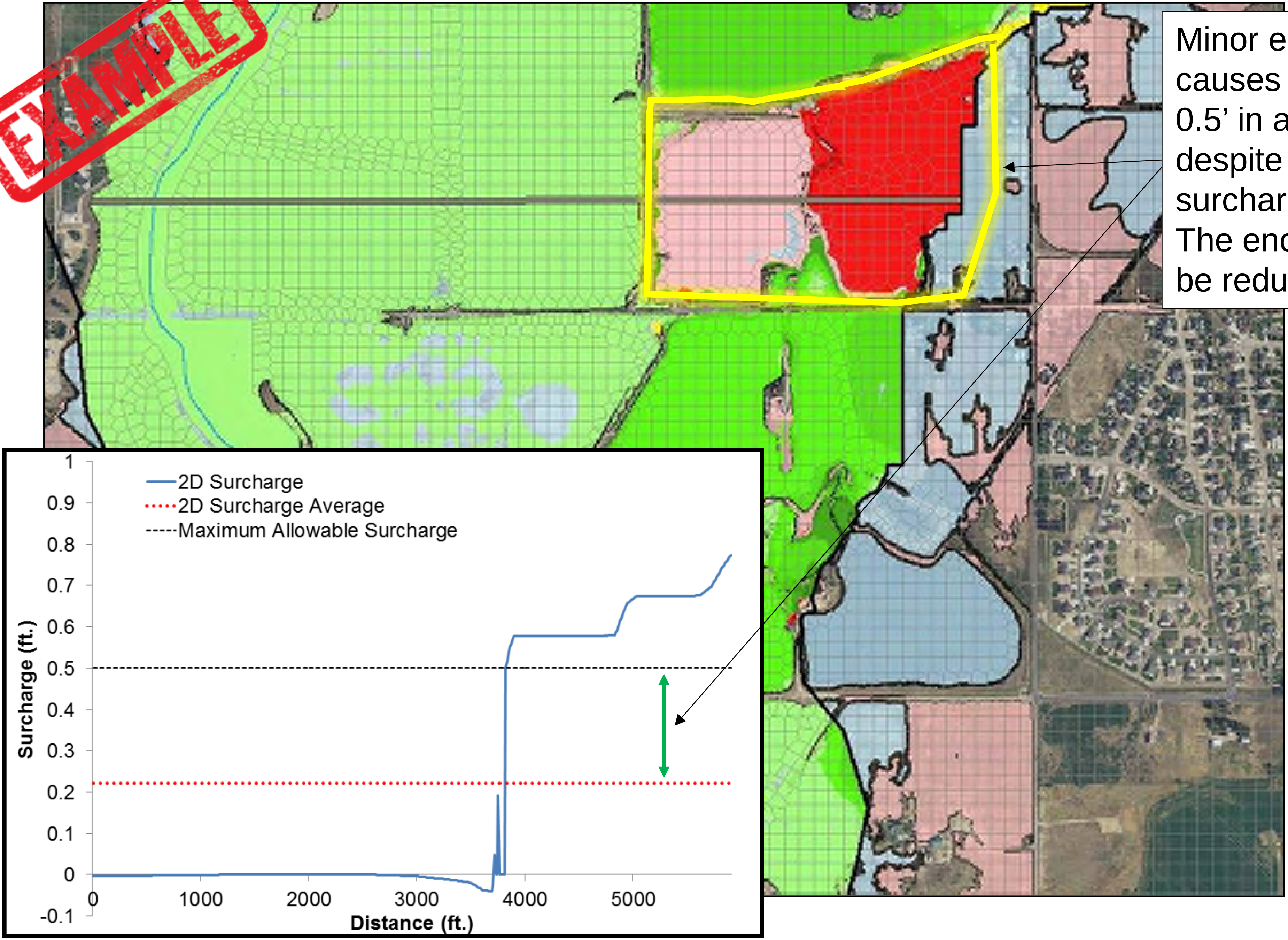
1D Floodway



2D Floodway



Minor encroachment causes surcharges above 0.5’ in a localized area, despite having an average surcharge well below 0.5’. The encroachment must be reduced.



Encroachment

2D Cell

Surcharge (ft.)

- < -0.1
- -0.1 - 0
- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6
- > 0.6

Floodway Products

- The tools available for managing a 1D/2D or 2D floodway are the same as those available for typical 1D models, including:

Floodway Data Table EXAMPLE

Table 24: Floodway Data

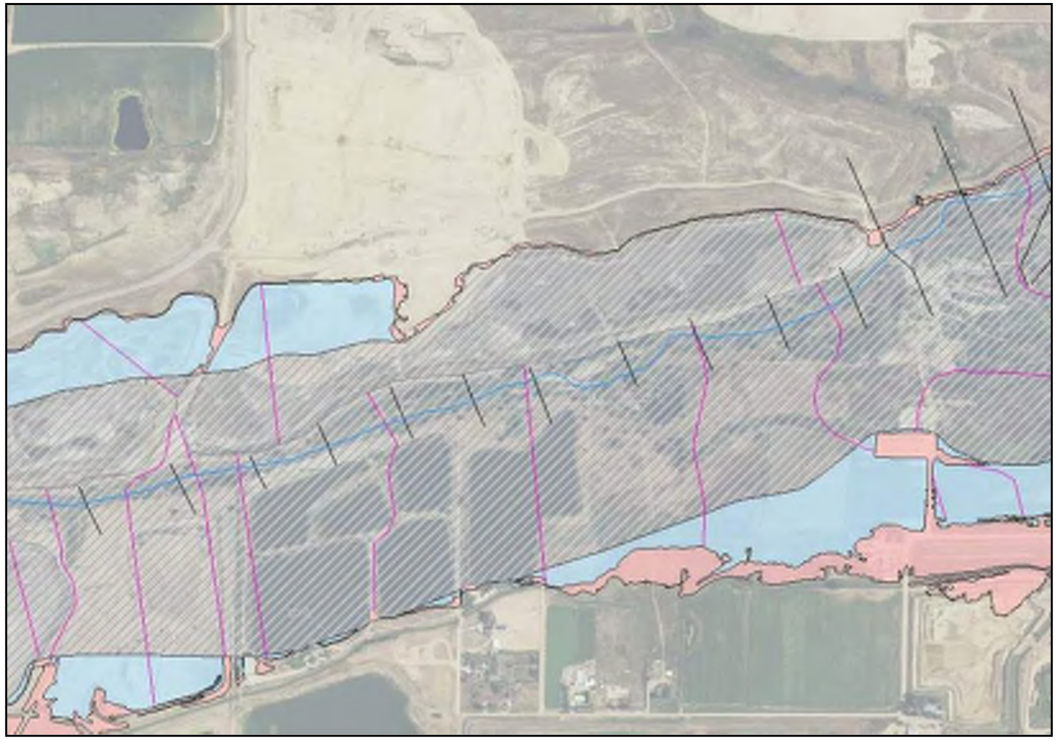
LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/ SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
*2	33,345	1,539	*	7.4	4,955.0	4,955.0	4,955.2	0.2
*2	35,685	2,770	*	5.9	4,964.0	4,964.0	4,964.0	0.0
*2	37,219	3,197	*	10.3	4,966.0	4,966.0	4,966.1	0.1
*2	38,593	1,649	*	7.1	4,971.0	4,971.0	4,971.0	0.0
*2	39,818	1,392	*	6.7	4,974.0	4,974.0	4,974.0	0.0
*2	41,855	2,161	*	7.3	4,980.0	4,980.0	4,980.0	0.0
*2	42,716	3,100	*	5.7	4,983.0	4,983.0	4,983.1	0.1
*2	44,365	2,917	*	7.0	4,989.0	4,989.0	4,989.1	0.1
*2	45,454	2,143	*	4.6	4,994.0	4,994.0	4,994.0	0.0
Station 45,563 - 96,222**								

[1]Feet above confluence with St. Vrain Creek
[2]Values computed using a 2D model. Locations are represented by BFEs on the FIRMs. Additional information is available to help determine floodway information including depth and velocity grids. Contact the Boulder County Floodplain Administrator for more information.
*Data not available
**Administrative floodway. Model results not available. Contact the Boulder County Floodplain Administrator for more information.

TABLE 24	FEDERAL EMERGENCY MANAGEMENT AGENCY BOULDER COUNTY, CO AND INCORPORATED AREAS	FLOODWAY DATA FLOODING SOURCE: BOULDER CREEK

59

Mapped Floodway



- But, the information provided within the tools is slightly different and there is additional information aside from those tools that can help with floodway management.

EXAMPLE

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/ SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
CI	150,199	115	497	10.1	6,074.7	6,074.7	6,074.8	0.1
CJ	151,524	49	339	14.8	6,105.8	6,105.8	6,106.0	0.2
CK	152,663	50	347	14.5	6,133.9	6,133.9	6,133.9	0.0
CL	153,337	36	328	15.3	6,162.1	6,162.1	6,162.5	0.4
CM	154,170	80	404	12.5	6,187.3	6,187.3	6,187.3	0.0
CN	155,171	40	318	15.6	6,225.0	6,225.0	6,225.0	0.0
CO	156,199	43	327	15.4	6,252.3	6,252.3	6,252.4	0.1
CP	156,899	97	821	6.1	6,280.4	6,280.4	6,280.5	0.1
CQ	158,224	46	344	14.5	6,318.7	6,318.7	6,318.7	0.0
CR	159,109	58	365	13.7	6,342.8	6,342.8	6,342.8	0.0
CS	160,194	44	326	15.4	6,382.1	6,382.1	6,382.4	0.3
CT	160,599	64	662	7.6	6,401.1	6,401.1	6,401.4	0.3
CU	161,186	36	304	16.4	6,418.8	6,418.8	6,419.0	0.2
CV	162,141	49	363	13.8	6,478.9	6,478.9	6,478.9	0.0
CW	162,910	32	295	16.9	6,537.3	6,537.3	6,537.5	0.2
CX	163,833	34	299	16.8	6,608.6	6,608.6	6,608.8	0.2
CY	165,200	34	304	16.5	6,679.2	6,679.2	6,679.2	0.0
CZ	166,325	50	340	14.7	6,743.3	6,743.3	6,743.5	
DA	167,215	67	410	12.2	6,793.8	6,793.8	6,794.2	
DB	168,176	53	346	14.4	6,843.8	6,843.8	6,843.9	
DC	168,874	45	336	14.9	6,876.1	6,876.1	6,876.1	

[1]Feet above confluence with St. Vrain Creek

TABLE 24

FEDERAL EMERGENCY MANAGEMENT AGENCY

BOULDER COUNTY, CO

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: BOULDER C

Cross Sections

No cross sections are reported for 1D/2D and 2D floodways. Instead, information is referenced to BFE lines.

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/ SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
*[2]	33,346	1,539	*	7.4	4,955.0	4,955.0	4,955.2	0.2
*[2]	35,685	2,770	*	6.9	4,964.0	4,964.0	4,964.0	0.0
*[2]	37,219	3,197	*	10.3	4,966.0	4,966.0	4,966.1	0.1
*[2]	38,893	1,649	*	7.1	4,971.0	4,971.0	4,971.0	0.0
*[2]	39,818	1,392	*	6.7	4,974.0	4,974.0	4,974.0	0.0
*[2]	41,855	2,161	*	7.3	4,980.0	4,980.0	4,980.0	0.0
*[2]	42,716	3,100	*	5.7	4,983.0	4,983.0	4,983.1	0.1
*[2]	44,385	2,917	*	7.0	4,989.0	4,989.0	4,989.1	0.1
*[2]	45,454	2,143	*	4.6	4,994.0	4,994.0	4,994.0	0.0
Station 45,563-56,222**								

[1]Feet above confluence with St. Vrain Creek
[2]Values computed using a 2D model. Locations are represented by BFEs on the FIRMs. Additional information is available to help determine floodway information including depth and velocity grids. Contact the Boulder County Floodplain Administrator for more information.
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**Administrative floodway. Model results not available. Contact the Boulder County Floodplain Administrator for more information.

TABLE 24

FEDERAL EMERGENCY MANAGEMENT AGENCY

BOULDER COUNTY, CO

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: BOULDER CREEK

EXAMPLE

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
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CQ	158,224	46	344	14.5	6,318.7	6,318.7	6,318.7	0.0
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CS	160,194	44	326	15.4	6,382.1	6,382.1	6,382.4	0.3
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CY	165,200	34	304	16.5	6,679.2	6,679.2	6,679.2	0.0
CZ	166,325	50	340	14.7	6,743.3	6,743.3	6,743.5	[illegible]
DA	167,215	67	410	12.2	6,793.8	6,793.8	6,794.2	[illegible]
DB	168,176	53	346	14.4	6,843.8	6,843.8	6,843.9	[illegible]
DC	168,874	45	336	14.9	6,876.1	6,876.1	6,876.1	[illegible]

[1]Feet above confluence with St. Vrain Creek

TABLE 24

FEDERAL EMERGENCY MANAGEMENT AGENCY

BOULDER COUNTY, CO

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: BOULDER C

Data

Data (width, mean velocity, etc.) presented in the 2D FWDT is not comprehensive. To get data for any other location in the floodway, the WSEL, velocity, and depth grids should be used.

LOCATION		FLOODWAY			1% ANNUAL CHANCE FLOOD WATER SURFACE ELEVATION (FEET NAVD88)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQ. FEET)	MEAN VELOCITY (FEET/ SEC)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
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*[2]	37,219	3,197	*	10.3	4,966.0	4,966.0	4,966.1	0.1
*[2]	38,893	1,649	*	7.1	4,971.0	4,971.0	4,971.0	0.0
*[2]	39,818	1,392	*	6.7	4,974.0	4,974.0	4,974.0	0.0
*[2]	41,855	2,161	*	7.3	4,980.0	4,980.0	4,980.0	0.0
*[2]	42,716	3,100	*	5.7	4,983.0	4,983.0	4,983.1	0.1
*[2]	44,385	2,917	*	7.0	4,989.0	4,989.0	4,989.1	0.1
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Station 45,563-56,222**								

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**Administrative floodway. Model results not available. Contact the Boulder County Floodplain Administrator for more information.

TABLE 24

FEDERAL EMERGENCY MANAGEMENT AGENCY

BOULDER COUNTY, CO

AND INCORPORATED AREAS

FLOODWAY DATA

FLOODING SOURCE: BOULDER CREEK

Additional Information for 2D Floodways

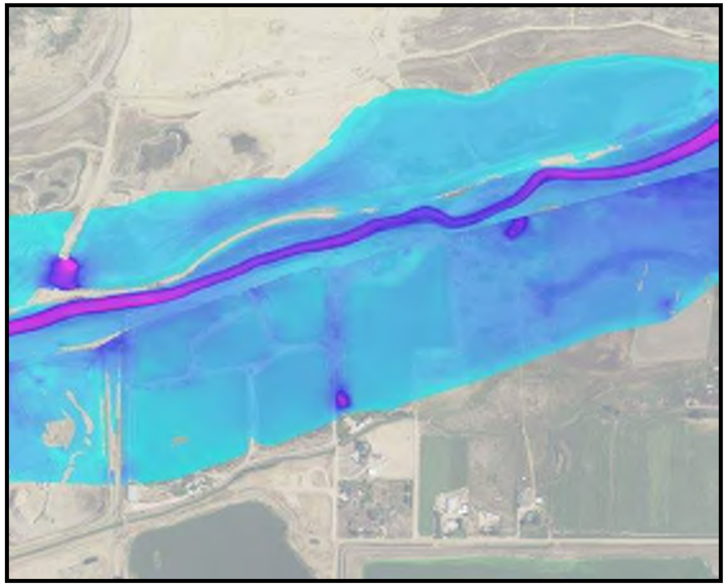
- 1D/2D and 2D FWDT only report information at select locations. To find detailed information about specific locations, the surcharge, WSEL, depth, and velocity grids should be used

Surcharge

Uses

- Shows the WSEL for the encroached floodplain
- Used to evaluate surcharge at individual properties

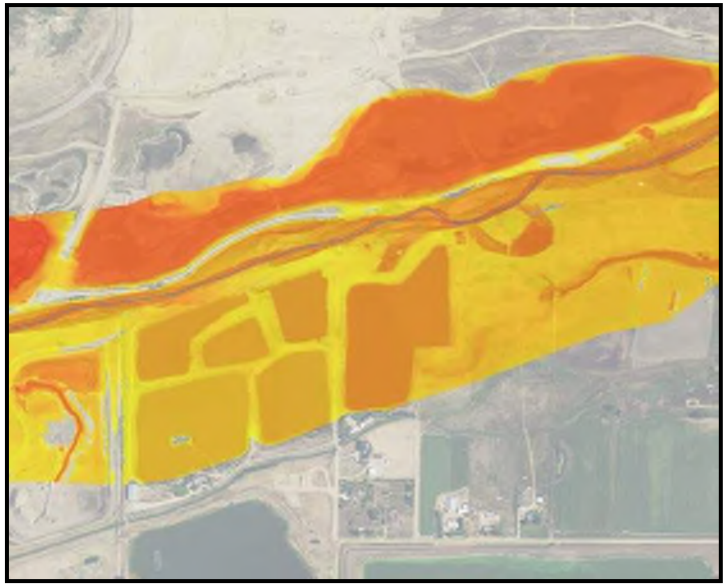
Velocity



Uses

- Supplement for “Mean Velocity’ column in FWDT

Depth



Uses

- Can be used to communicate a depth of floodway at a specific property

FW

1D/2D and 2D Floodways

Purpose of the Floodway

- The **floodway represents the "full build" or "ultimate" condition** that can occur without creating a surcharge greater than the designated height. The benefit of the floodway is that as development occurs, a new engineering study is not required to determine whether the development will cause a surcharge over the designated height

- Floodways make the job of a Floodplain Manager easier. However, with the introduction of 1D/2D and 2D models there are some additional things to consider:

  1) Floodway standards and guidance were established for 1D analyses – application to 2D can be:

Time Intensive

Difficult

  2) Applying 1D floodway principles to 1D/2D and 2D models may result in a more restrictive floodway because of the resolution of the model results.

So with that in mind….

Floodway Options

- Decision on floodway development needs to be made with community input

OPTION	PROS	CONS
Generate 2D Floodway under Current Standards	• Floodway management is very similar to 1D • Addtn'l info to help with regulation	• Time intensive • Tend to be wider, limiting potential for development
Calibrate 1D model to 2D model, Create Floodway from 1D	• Keep existing practices	• 2 models to update • Lose some detail from 2D model
Manage without a Floodway	• Manage development on case by case basis	• Must track cumulative impacts of development • Maintain "living" model
Alternate method for 2D Floodway (D x V, Full Conveyance, etc.)	**?**	**?**

EXAMPLE

To demonstrate the **difference between managing a floodplain with and without a floodway**, consider the hypothetical case. Floodtown, USA has adopted a 0.5 foot surcharge standard. Floodtown, USA had a floodway delineated on the previous set of effective FIRM maps.

Scenario 1: Floodtown, USA elects to have a 2D floodway delineated on the revised FIRM maps.

Scenario 2: Floodtown, USA does not have a floodway on the new FIRMs due to creation of the new regulatory 2D model.

Consider three events:

- **Event 1**: Release of the new Floodtown, USA FIRM Panels and FIS
- **Event 2**: Construction plans for a new shopping center submitted by Development Co.
- **Event 3**: Submittal of a building permit by Resident A to construct a new porch for their house

EXAMPLE

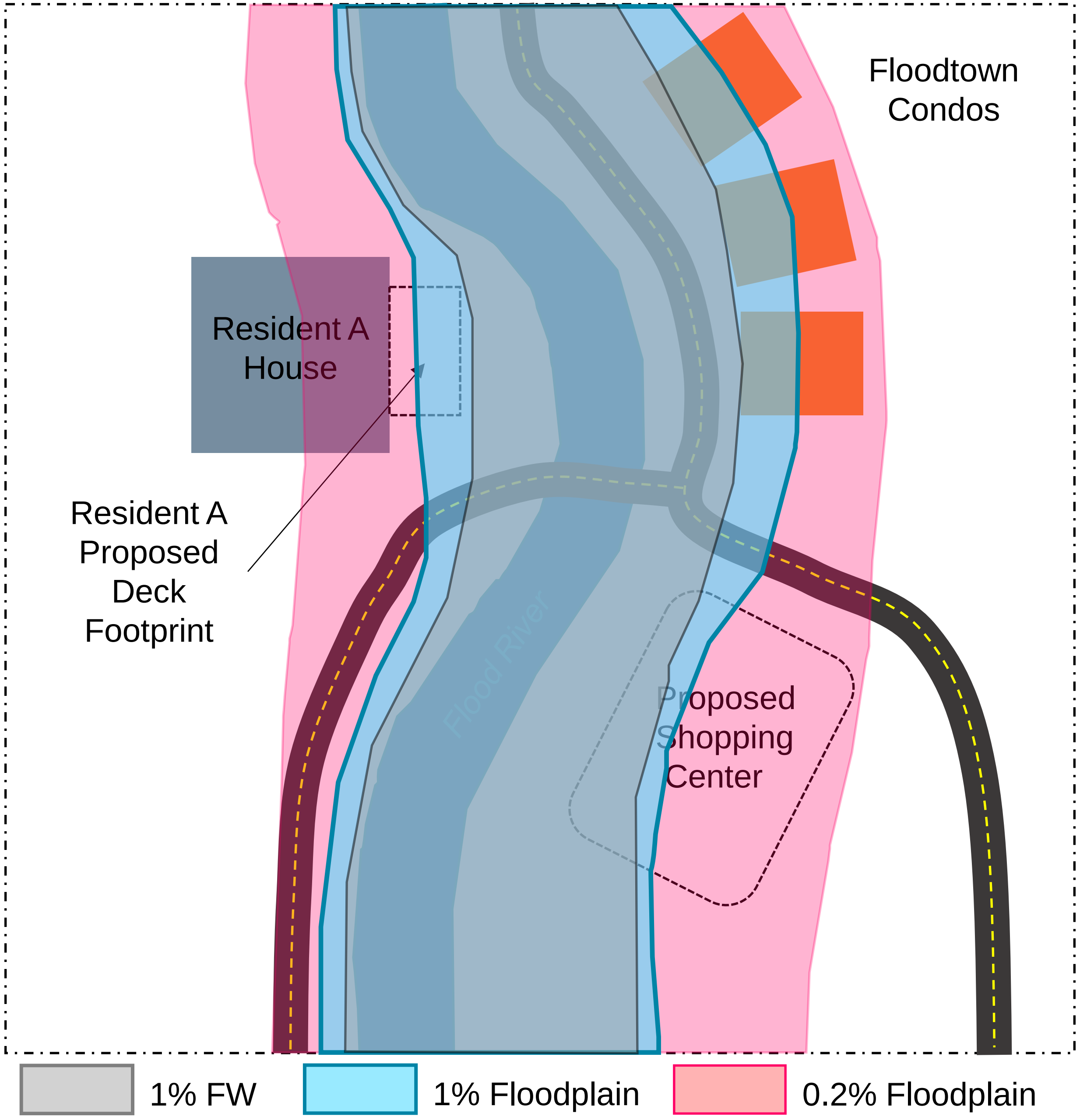
Scenario 1: A 2D Floodway is Delineated on the Revised FIRM Maps

EXAMPLE

Event 1: Release of the new Floodtown, USA FIRM Panels and FIS

Description:
Floodtown, USA's new floodplains just became effective. Included with the floodplains are WSEL, surcharge, depth, and velocity grids generated from the 2D model, as well as a 2D floodway. Development is managed similar to the way it was prior to release of the new FIRMs.

Floodtown, USA

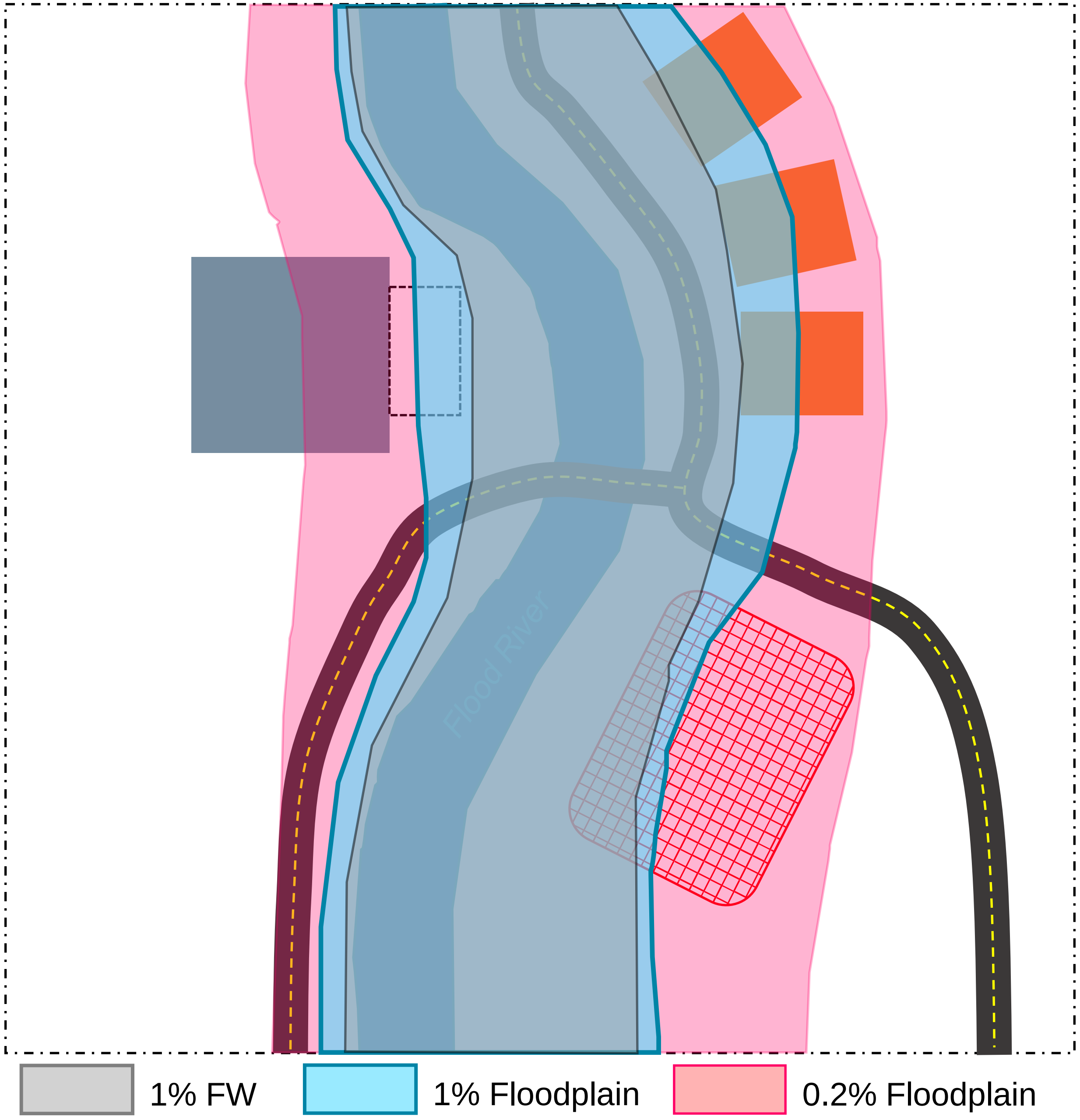


EXAMPLE

Event 2: Construction plans for a new shopping center submitted by Development Co.

Description:
Plans are submitted by Development Co. for construction of a shopping center. The Floodtown, USA Floodplain Manager sees that the proposed footprint of the shopping center development is within the delineated floodway so they tell Development Co. **they must prove a no-rise or development cannot occur**. Development Co. is not able to prove a no-rise so a permit is not issued.

Floodtown, USA

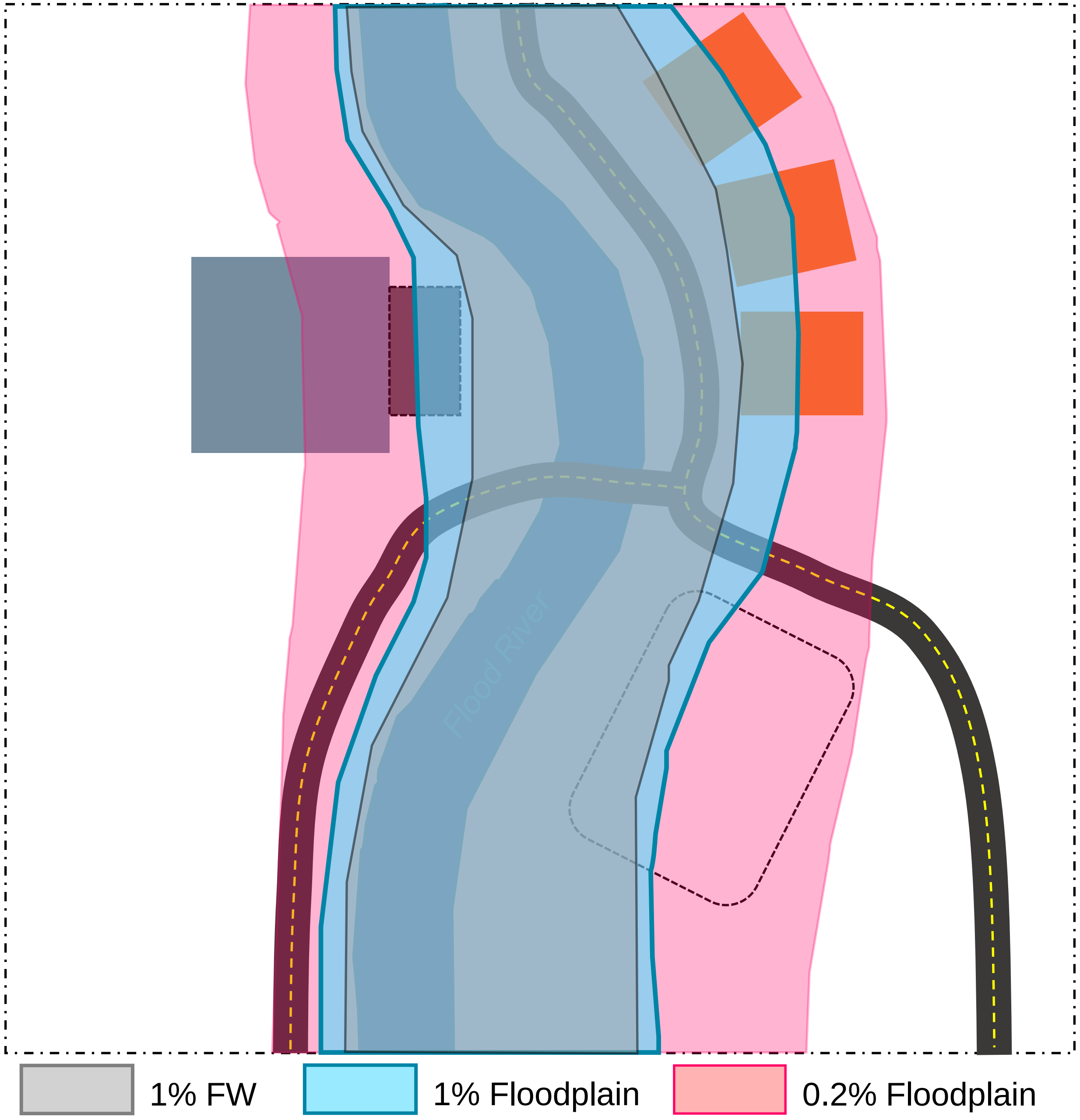


EXAMPLE

Event 3: Submittal of a building permit by Resident A to construct a new porch for their house.

Description:
Resident A submits an application to construct a porch. The Floodtown, USA Floodplain Manager sees that the proposed footprint of the porch is outside of the floodway. As a result, a permit is issued and Resident A proceeds with construction of their porch.

Floodtown, USA



EXAMPLE

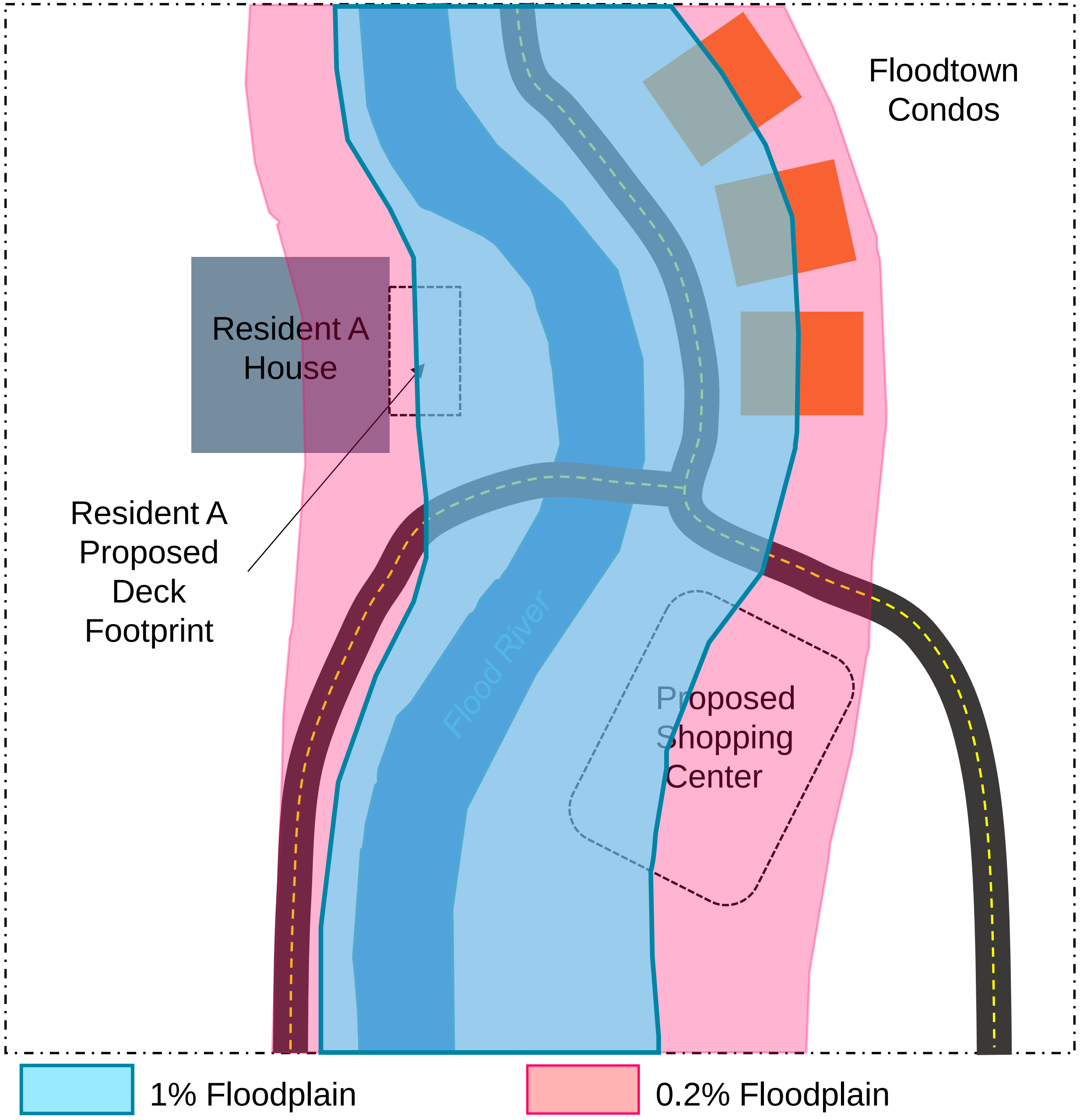
Scenario 2: A 2D Floodway is **not** delineated on the Revised FIRM Maps

EXAMPLE

Event 1: Release of the new Floodtown, USA FIRM Panels and FIS

Description:
Floodtown, USA's new floodplains just became effective. Included with the floodplains are WSEL, surcharge, depth, and velocity grids generated from the 2D model. The WSEL grid generated is now the baseline for all future floodplain development in Floodtown, USA.

Floodtown, USA

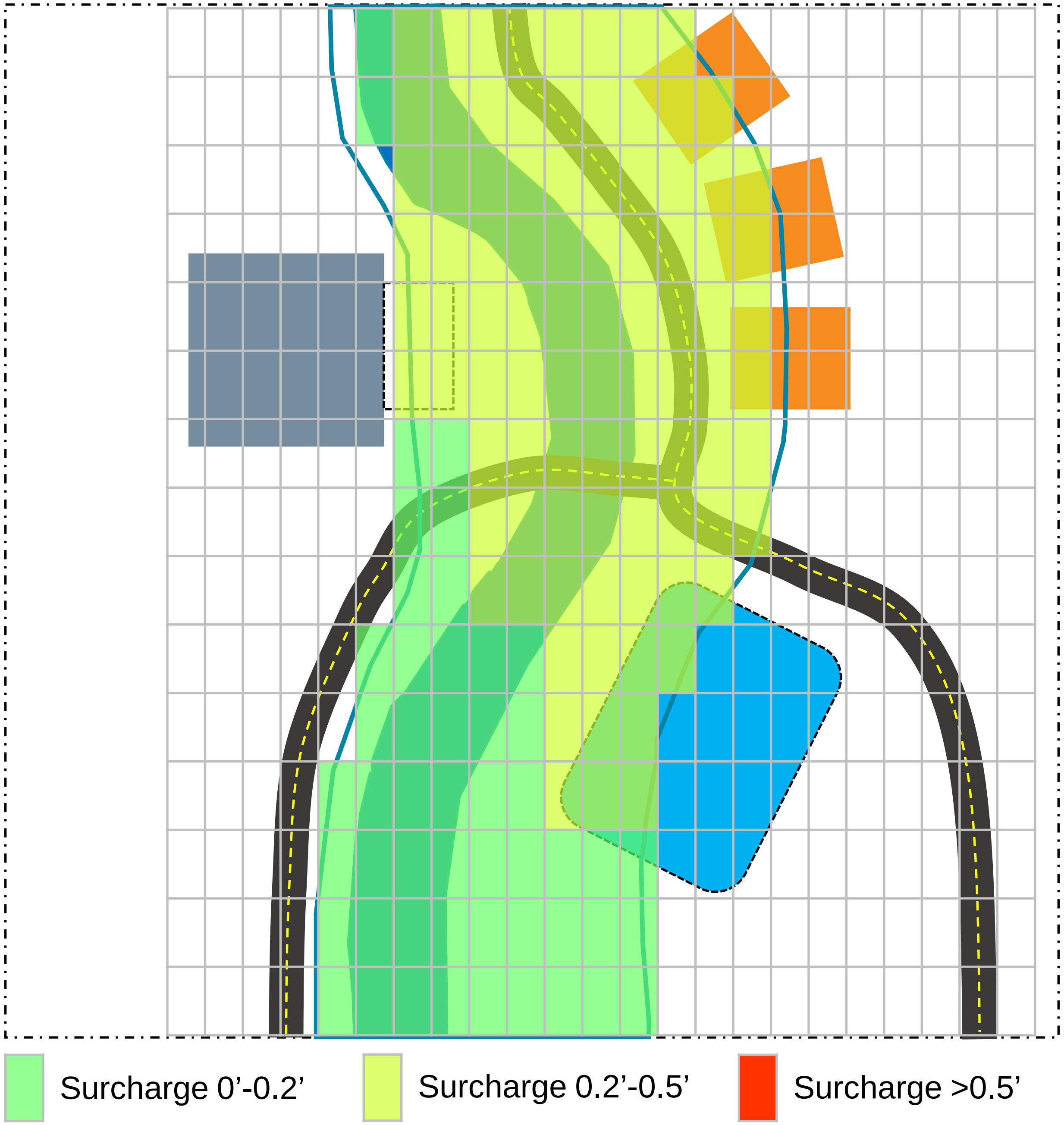


EXAMPLE

Event 2:Construction plans for a new shopping center submitted by Development Co.

Description:
Floodtown Engineering Co. is contracted to study the impacts of the shopping center construction. They find that when compared to the *effective WSEL*, the shopping center does not cause an increase in the WSELs above 0.5 foot and does not cause a shift in the floodplain extents. As a result, the shopping center receives an approved floodplain permit and is constructed.

Floodtown, USA

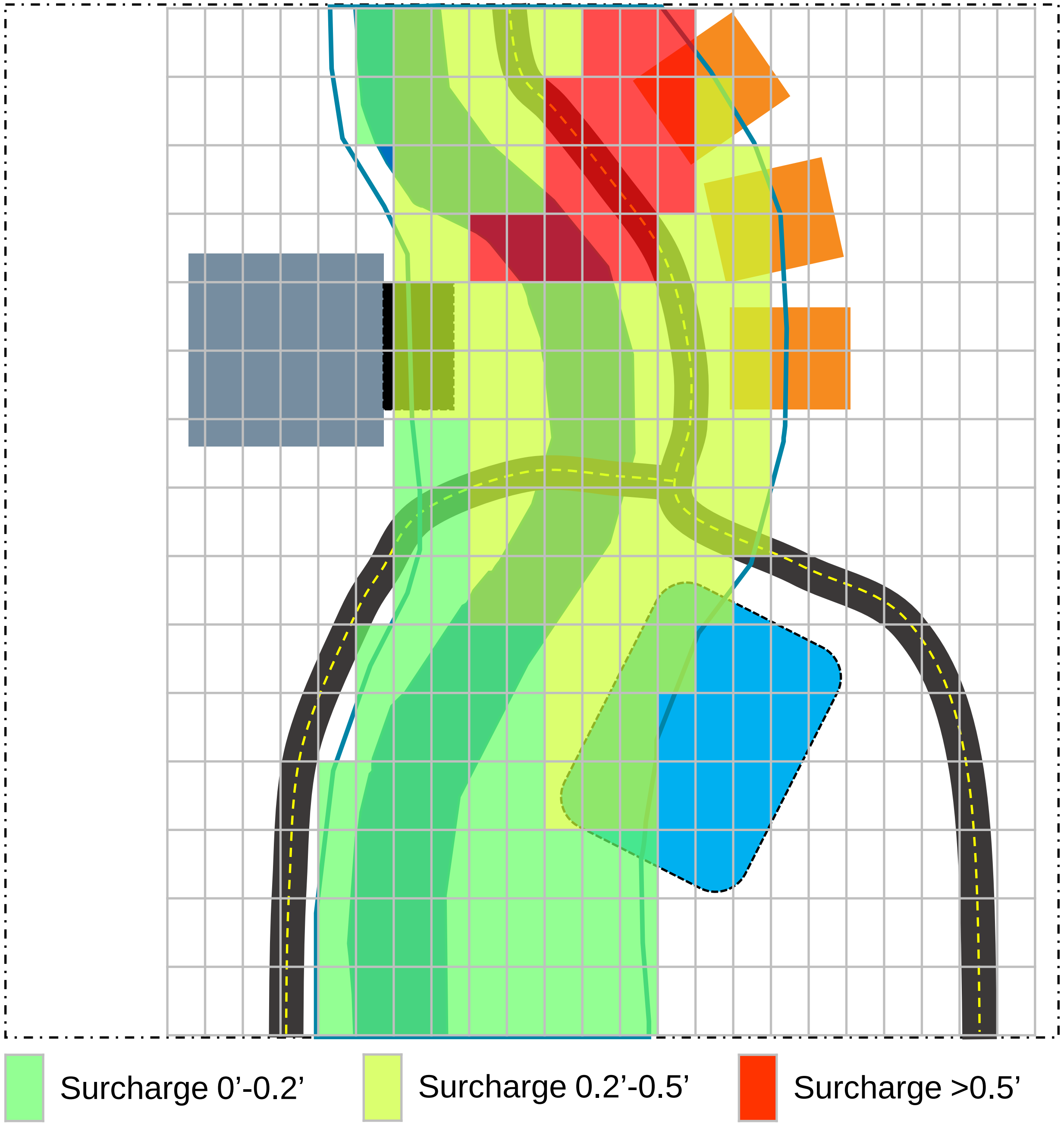


EXAMPLE

Event 3: Submittal of a building permit by Resident A to construct a new porch for their house.

Description:
Floodtown Engineering Co. is hired by Resident A to study the impacts of constructing a porch. The study accounts for the cumulative development, that is the proposed porch design plus any change caused by the shopping center construction. They find that compared to the effective WSEL, the deck ***does*** cause an increase in the WSEL above 0.5 foot from the ***effective WSEL grid***. As a result, Resident A's floodplain permit is denied on the basis that it causes an adverse condition downstream.

Floodtown, USA



FW

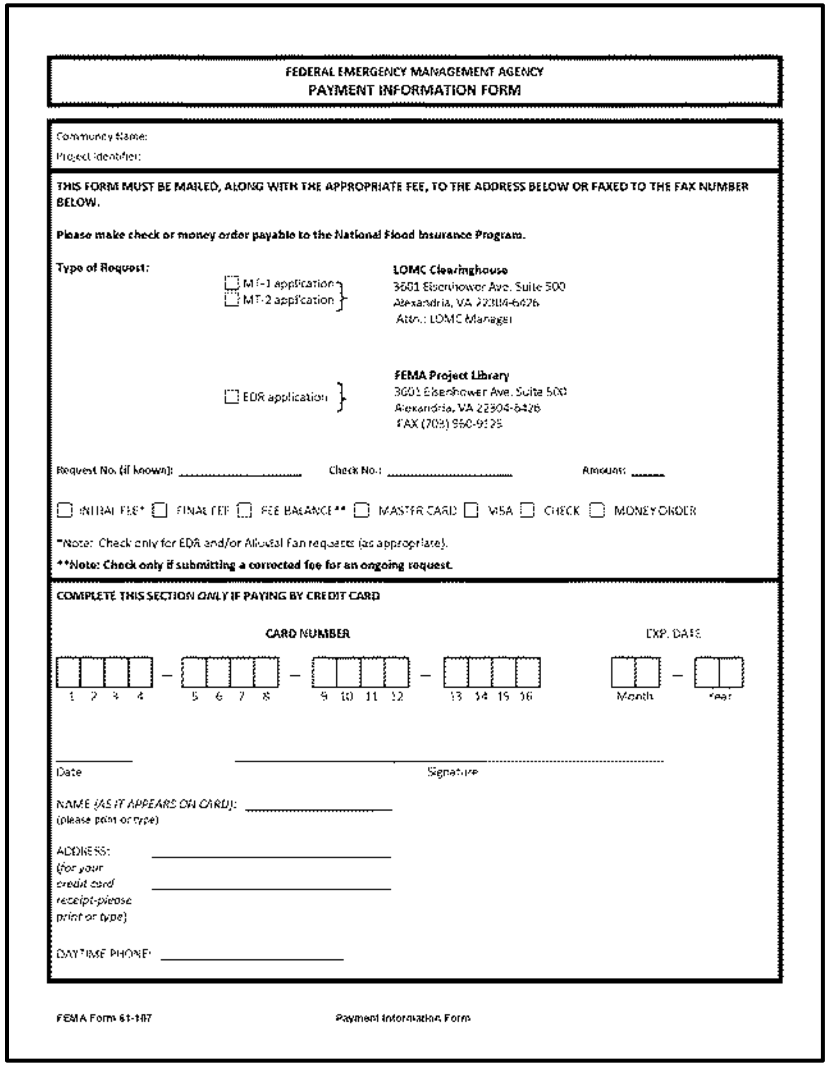
LOMCs and Other Regulatory Processes

CLOMR/LOMR

- The CLOMR/LOMR process is the same for either a 1D, 1D/2D, or 2D model.
  - Still follow MT-2 procedures
  - Same fees

- CLOMR/LOMR can be completed using various modeling techniques as long as the CLOMR/LOMR ties-in with the effective data (i.e. 1D CLOMR/LOMR completed in area with 2D model); however, **communities should strive to maintain a continuous model.**

- CLOMRs/LOMRs may be required more often when using 1D/2D or 2D models because the models show more detail.



FEDERAL EMERGENCY MANAGEMENT AGENCY
PAYMENT INFORMATION FORM

Community Name:
Project Identifier:

THIS FORM MUST BE MAILED, ALONG WITH THE APPROPRIATE FEE, TO THE ADDRESS BELOW OR FAXED TO THE FAX NUMBER BELOW.

Please make check or money order payable to the National Flood Insurance Program.

Type of Request:

☐ MT-1 application
☐ MT-2 application

LOMC Clearinghouse
3601 Eisenhower Ave. Suite 500
Alexandria, VA 22304-6426
Attn.: LOMC Manager

☐ EDR application

FEMA Project Library
3601 Eisenhower Ave. Suite 500
Alexandria, VA 22304-6426
FAX (703) 960-9125

Request No. (if known): ________ Check No.: ________ Amount: ______

☐ INITIAL FEE* ☐ FINAL FEE ☐ FEE BALANCE** ☐ MASTER CARD ☐ VISA ☐ CHECK ☐ MONEY ORDER

*Note: Check only for EDR and/or Alluvial Fan requests (as appropriate).

****Note: Check only if submitting a corrected fee for an ongoing request.**

COMPLETE THIS SECTION *ONLY* IF PAYING BY CREDIT CARD

CARD NUMBER EXP. DATE

1 2 3 4 – 5 6 7 8 – 9 10 11 12 – 13 14 15 16   Month – Year

Date ________ Signature ________

NAME *(AS IT APPEARS ON CARD)*: ________
(please print or type)

ADDRESS: ________
(for your credit card receipt-please print or type) ________

DAYTIME PHONE: ________

FEMA Form 61-107   Payment Information Form

No-Rise Certifications

- No-Rise conditions are more difficult to prove when referenced to 1D/2D or 2D models.

- Similar to the discussion of 2D floodways, each cell must meet the no-rise criteria, as opposed to 1D models where the no-rise criteria only needs to be satisfied at each cross section. In a typical 1D/2D or 2D model, there are 10,000s of locations that must satisfy the no-rise standard versus a 1D model where there are 10s or 100s.

- Needs engineering judgement

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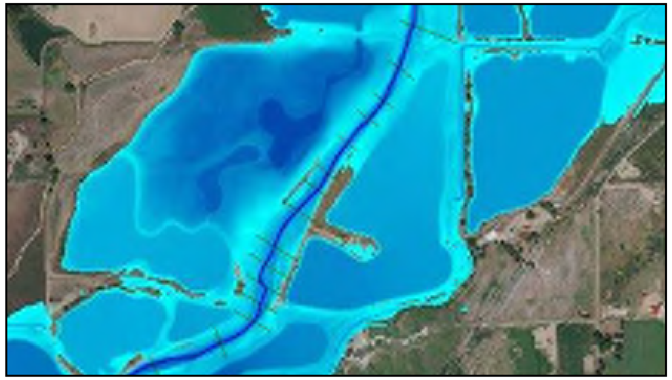
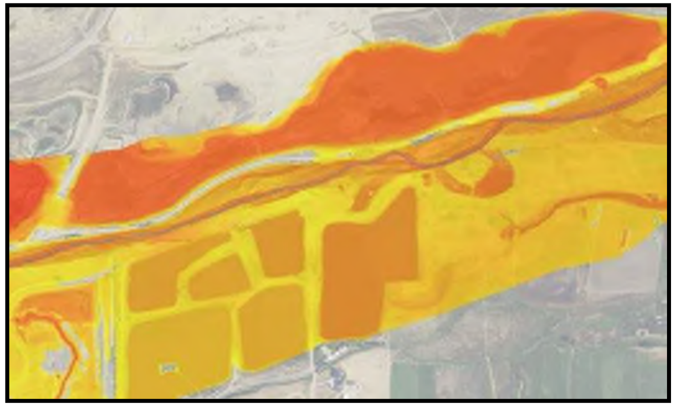
Next Steps

Revisiting Old Concepts

- Depending on local capabilities:

1. Use water surface elevation grids to determine base flood elevations. More accurate than BFEs and profiles





2. Use depth and velocity grids to evaluate specific impacts at locations/structures of interest

3. Use online resources to publish results

Regulating 2D Models & Tools for Planning

FW

Next Steps

What's Next?

- CWCB looking to test web applications for 2D results
- CWCB looking to add trainings and guides
- Discussion on federal guidance and how it could be revised to incorporate 2D capabilities

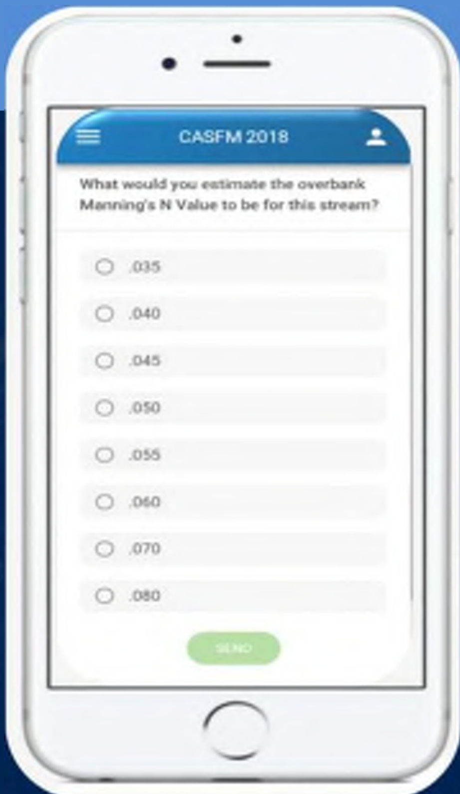
FW

Questions

Questions?

Isaac Allen
Project Engineer
isaac.allen@aecom.com

On your Smartphone or laptop, go to www.slido.com
Enter event code: 4040



What would YOU estimate as a Manning's N Value for this overbank?

Choose your answer (multiple choice)

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NATIONAL FLOOD INSURANCE PROGRAM
Celebrating 50 Years

CASFM

How to be Less Wrong- Errors & Uncertainty in Hydraulic Modeling

Ryan Carroll, CFM
Andrew Friend, PE


BFE

How uncertain are we?

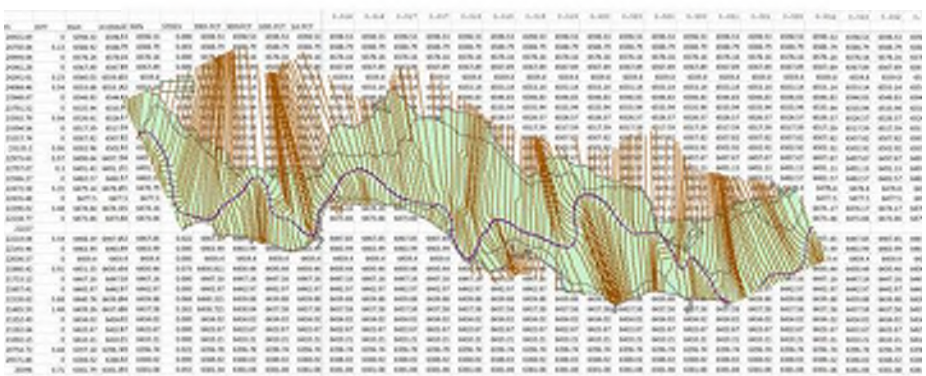
- ‘Flaw’ of Averages
- Better Data = Better Decisions!
- Do communities understand the uncertainty?
  - Terrain Data & Survey
  - Hydrology
  - Other model inputs

https://wall2.sli.do/event/kqnvgwas

- Effects of Data Errors on Computed Steady-Flow Profiles (ASCE members Burnham & Davis- USACE, 1990)
  - 80 USACE Engineers estimating Manning’s n values for 10 streams.
  - Average standard deviation of their estimates was 25%

Our Approach

- 3 Variables
  - Manning's N Roughness Values
  - Discharges
  - Cross-section placement/geometries
  - Combined
- 2 Streams- Steep and Flat gradients
- Sensitivity Analysis using HEC-RAS
- 500 model iterations per variable, per stream



Our Approach

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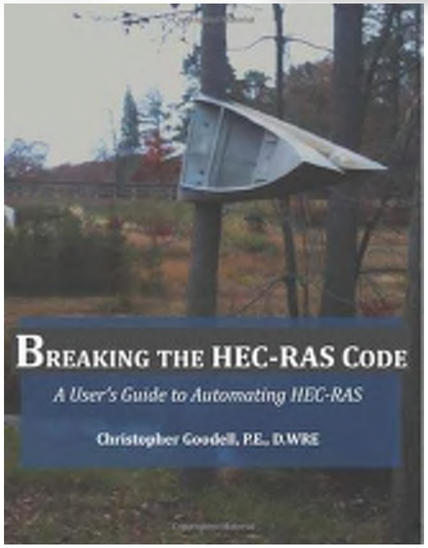
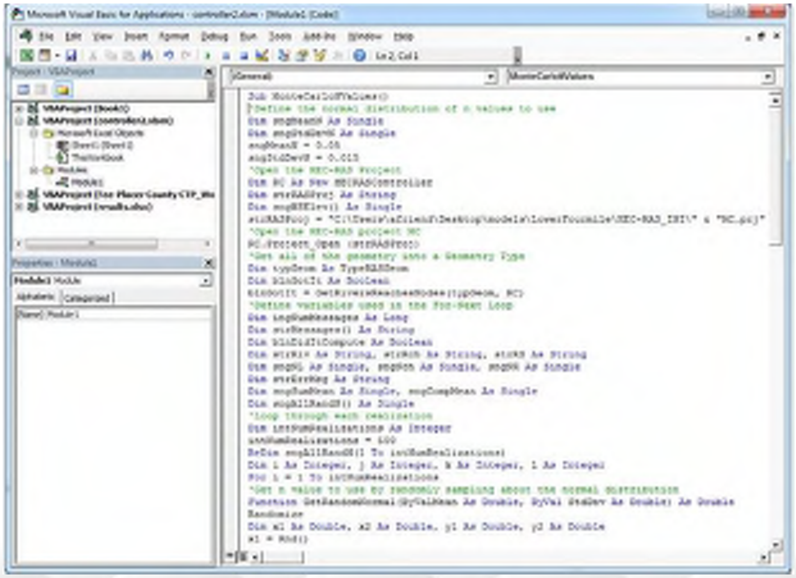
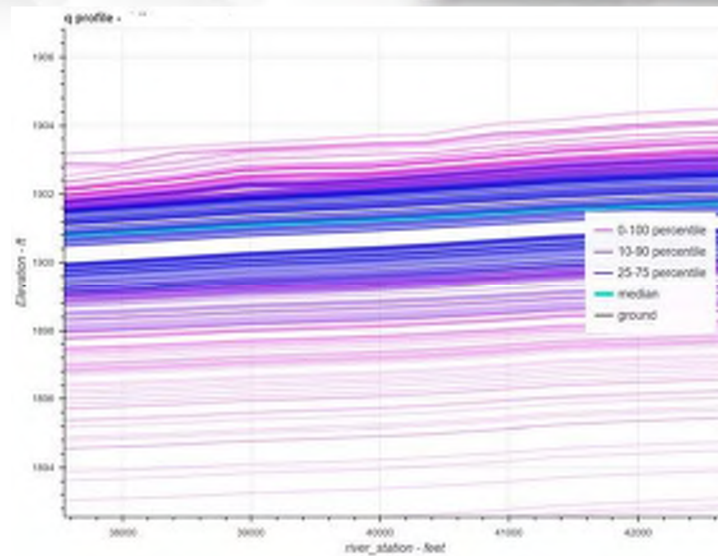
- Iterative modeling performed using HEC-RAS Controller
  - Allows automation and control of HEC-RAS through an API
  - User writes commands in Visual Basic – can be done within Excel
  - Monte Carlo simulations using random values with set parameters





Our Approach

- N Values
  - Estimation of roughness for entire cross-section (Natural Channel & Floodplain)
  - Mean N of 0.050 (25% error)
  - Values ranged from 0.016 to 0.084
- Discharges
  - Steep Stream- Regression (36% error)
  - Flat Stream- Gage Analysis (30% error)
- Cross-section Placement
  - 5 different layouts
  - 40 foot shift for each iteration
  - 200 foot XS spacing



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Results- Manning's n Values

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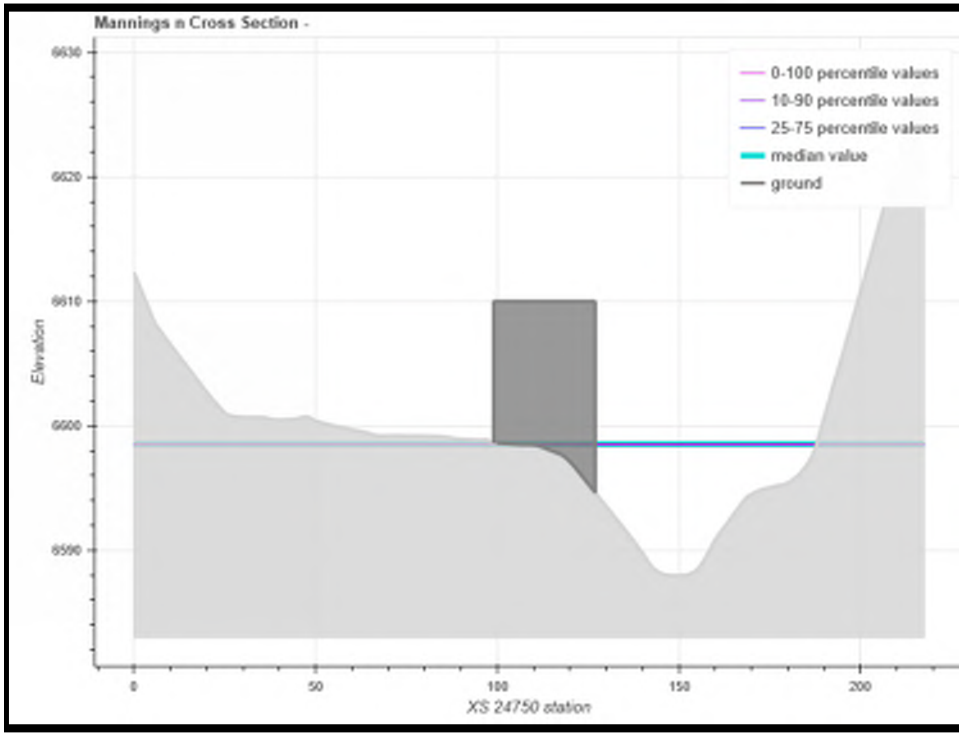
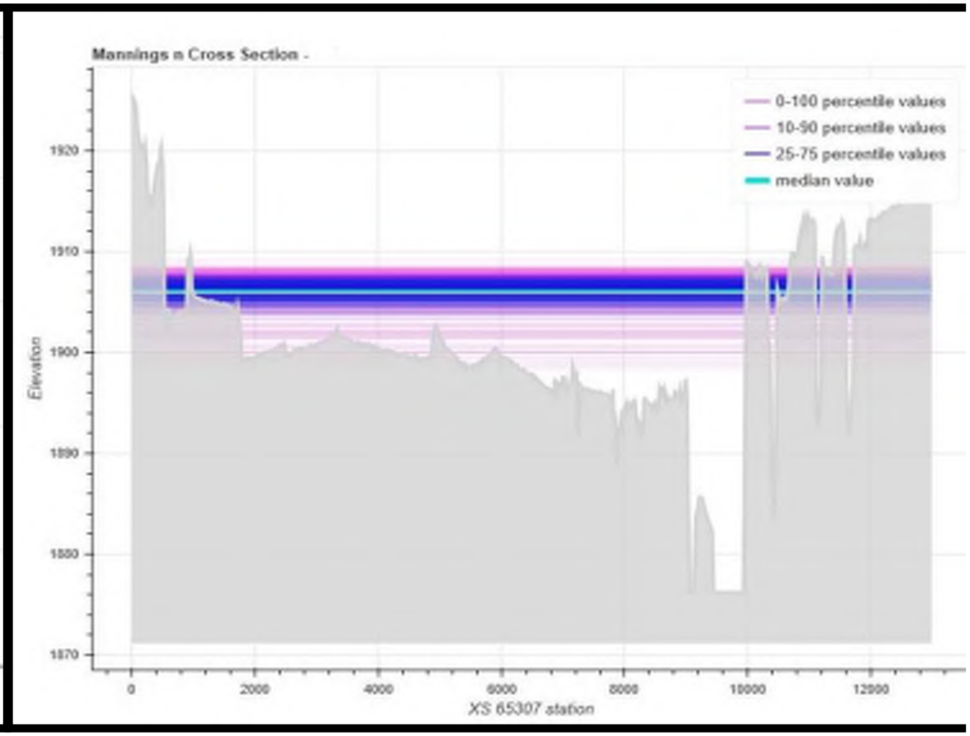
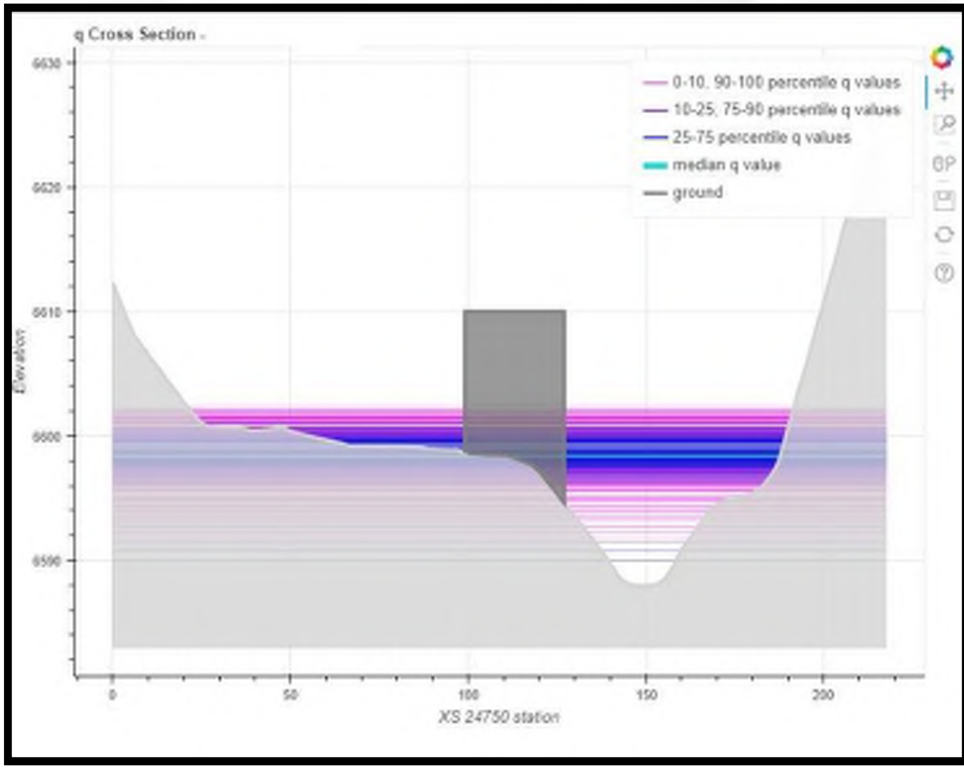




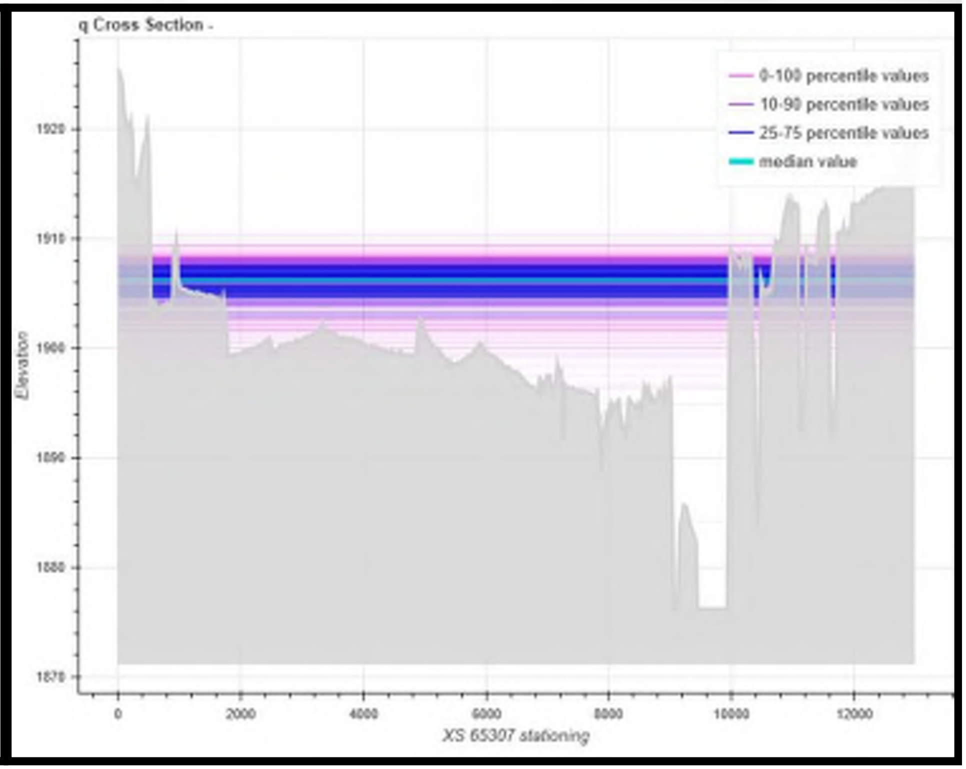
Steep Terrain

Flat Terrain

Results- Discharges

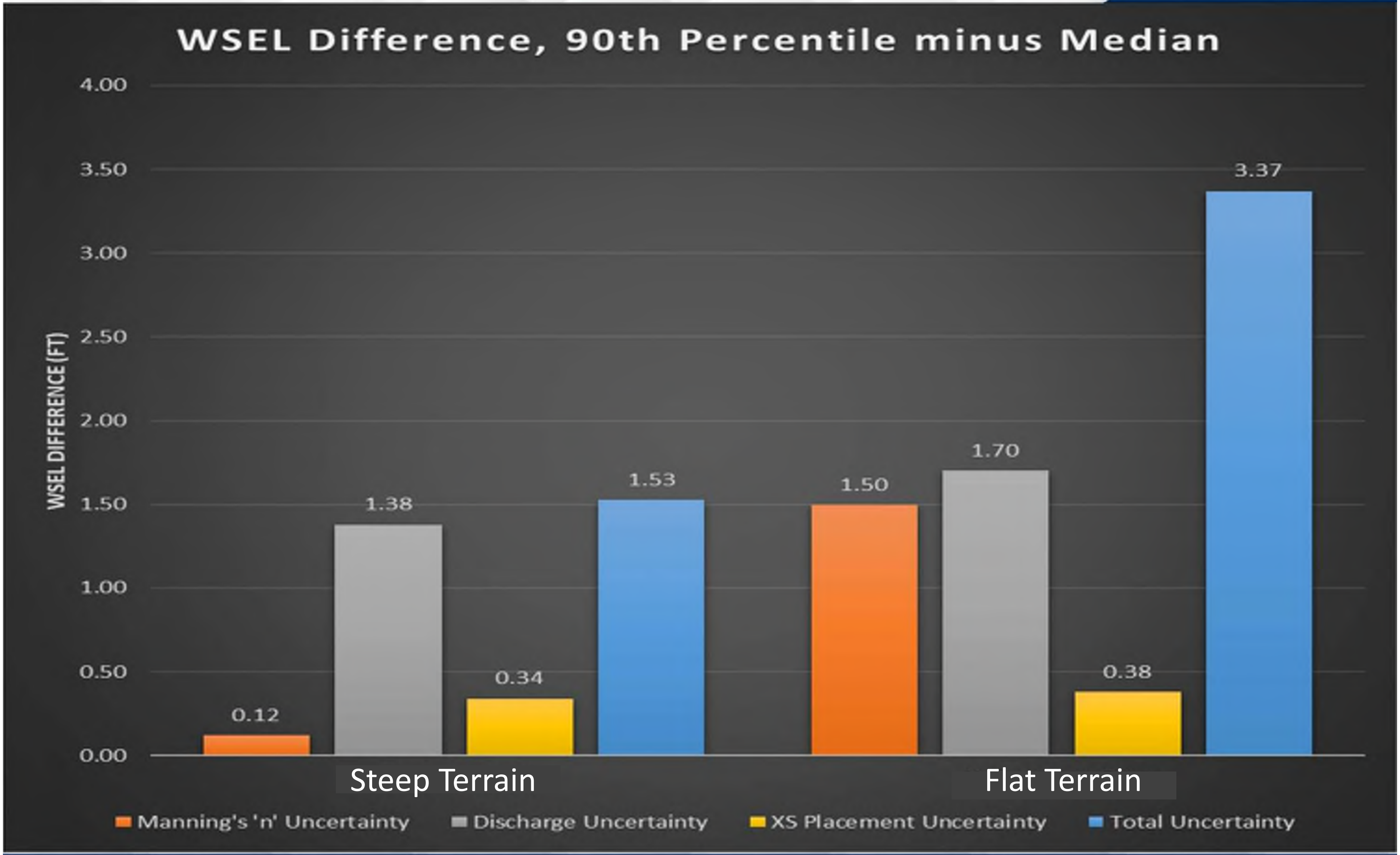


Steep Terrain
(Regression)



Flat Terrain
(Gage Analysis)

Results


WSEL Difference, 90th Percentile minus Median
WSEL DIFFERENCE (FT)
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.12
1.38
0.34
1.53
1.50
1.70
0.38
3.37
Steep Terrain
Flat Terrain
Manning's 'n' Uncertainty
Discharge Uncertainty
XS Placement Uncertainty
Total Uncertainty

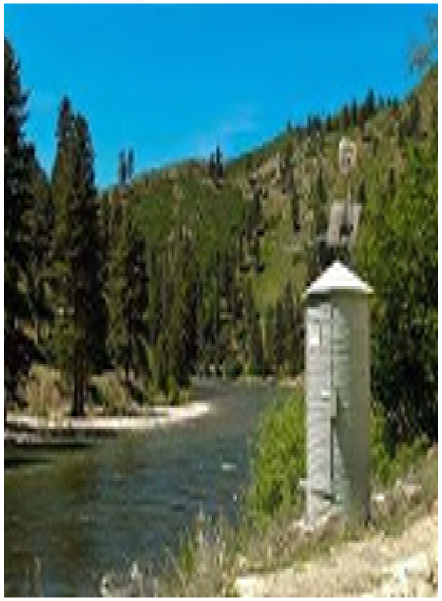
Takeaways

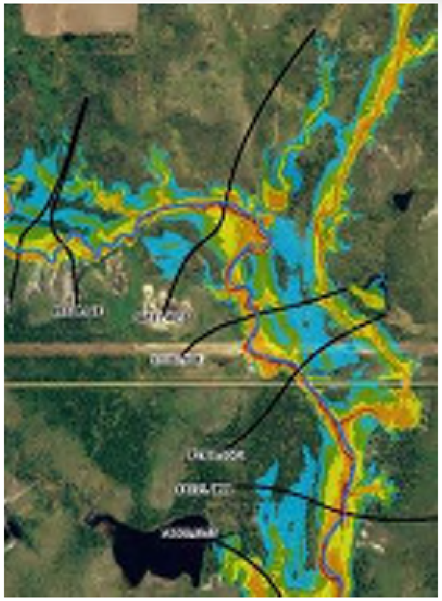
	WSEL Difference, 90th Percentile minus Median (ft)	
Uncertainty Source	Steep Terrain	Flat Terrain
Manning's 'n' Uncertainty	0.12	1.50
Discharge Uncertainty	1.38	1.70
XS Placement Uncertainty	0.34	0.38
Total Uncertainty	1.53	3.37

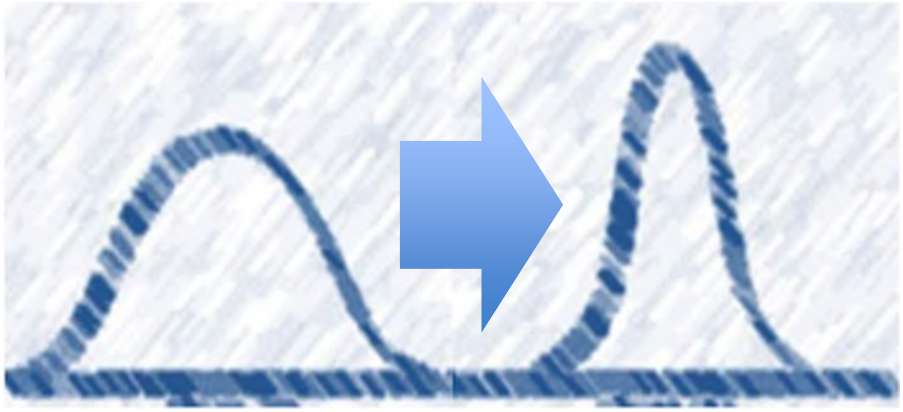
- Mannings n Values
  - There's potential for greater uncertainty in flat terrain; less so in steep terrain.
  - Spend more time on field data collection and calibration in flat terrain
  - Spend less time reviewing n values for models in steep terrain
- Discharges
  - Uncertainty can be impacted by type of study. Method selection is key .
  - Calibrate!
  - Investing more heavily in hydrology can increase reliability and validity of flows.
- Cross Section Placement
  - Appropriate spacing helps to reduce uncertainty associated with placement
- Addressing uncertainty in any of these areas will impact your overall model reliability.

Takeaways- engineers

- Other variables at play: time/schedule, cost, weather, study size, years of record, development.
- Stakeholders rely on engineers to develop data they can use, for:
  - Floodplain management
  - Building codes
  - Emergency management, planning, etc.
- Pay attention where it matters. Shrink the margin of error. Narrow the distribution.
- Better data = better decision making





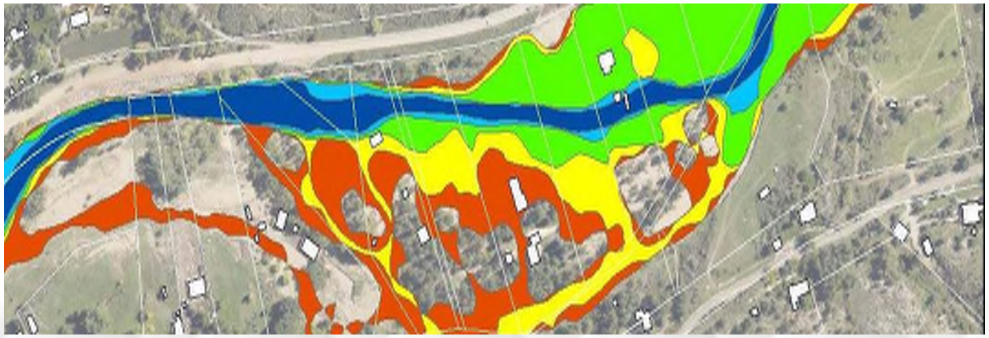


Takeaways- Communities

- Understand the uncertainty that exists and focus efforts to reduce it.
- What types of rivers and streams do you have?
- Hydrologic method can be considered in local regulation- methods/basins with less confidence/higher uncertainty could be regulated differently.
- Consider using FEMA's **1% Plus** values in regulation

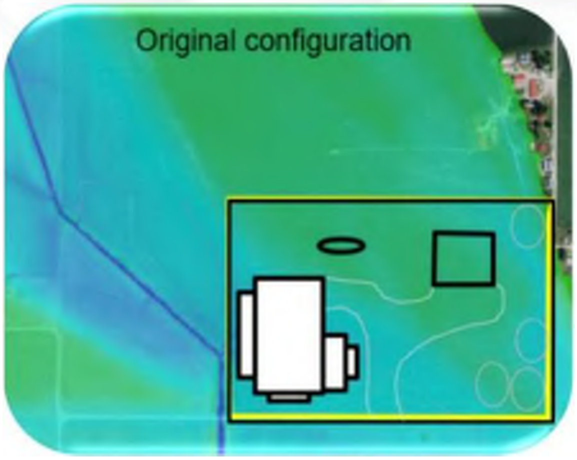


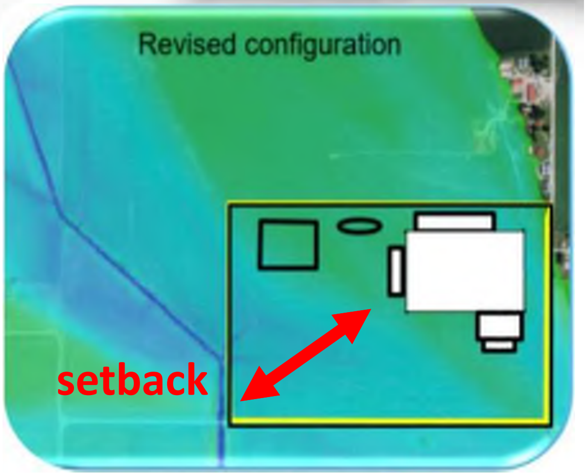


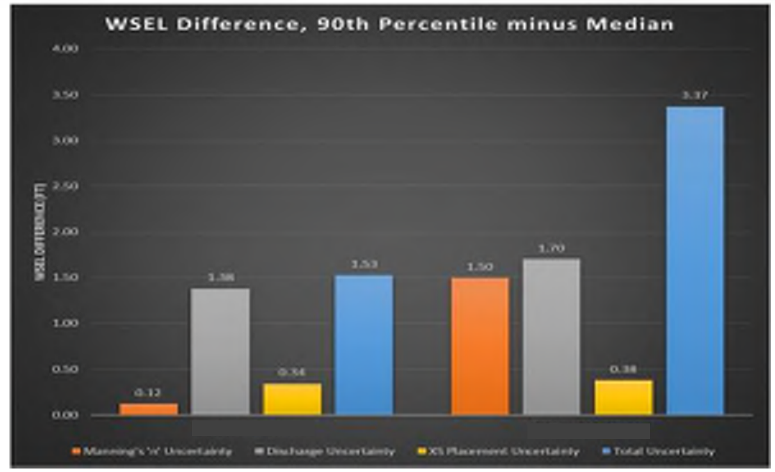
Takeaways- Communities

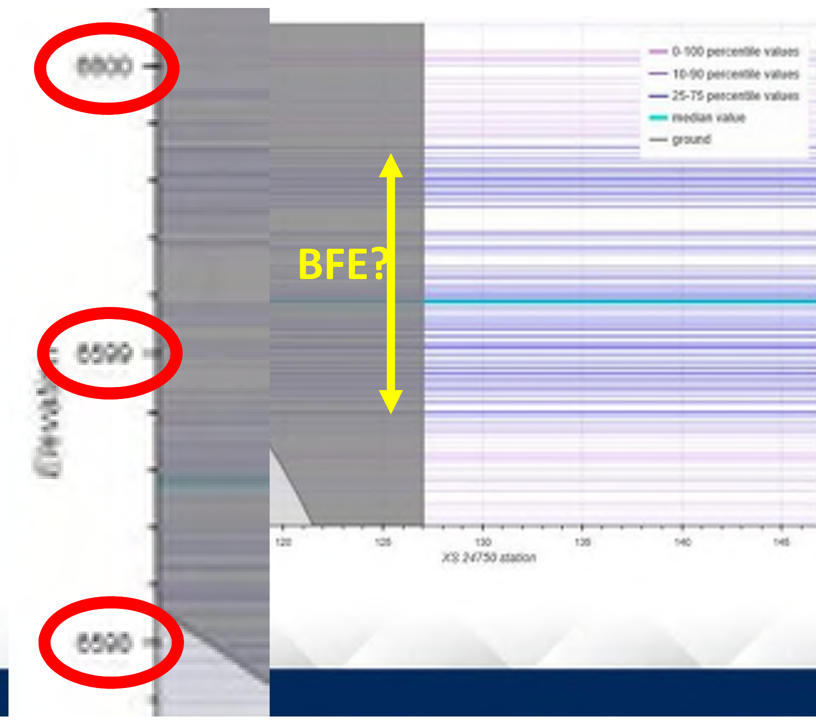
- Enact policies, plans, and code that account for the uncertainty that exists:
  - Buffers & Setbacks
  - Overlay zoning
  - Adoption of a 1% Plus Floodplain
  - Additional regulations in the 500-year floodplain
  - Hazard Mitigation Planning
  - Other planning tools





- Enact policies and code that account for the uncertainty that exists:
  - Freeboard





Next Steps

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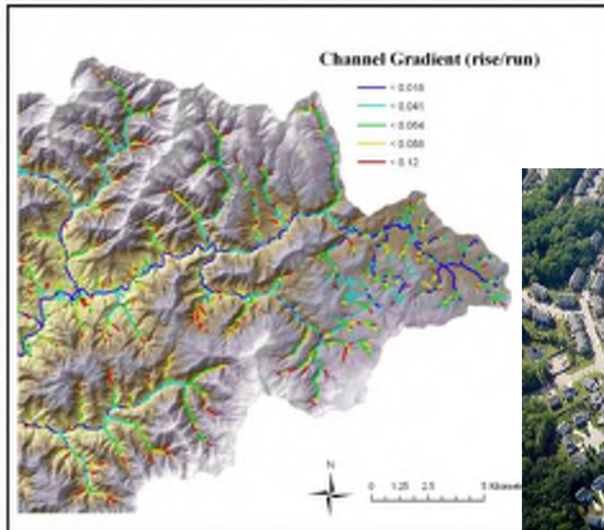
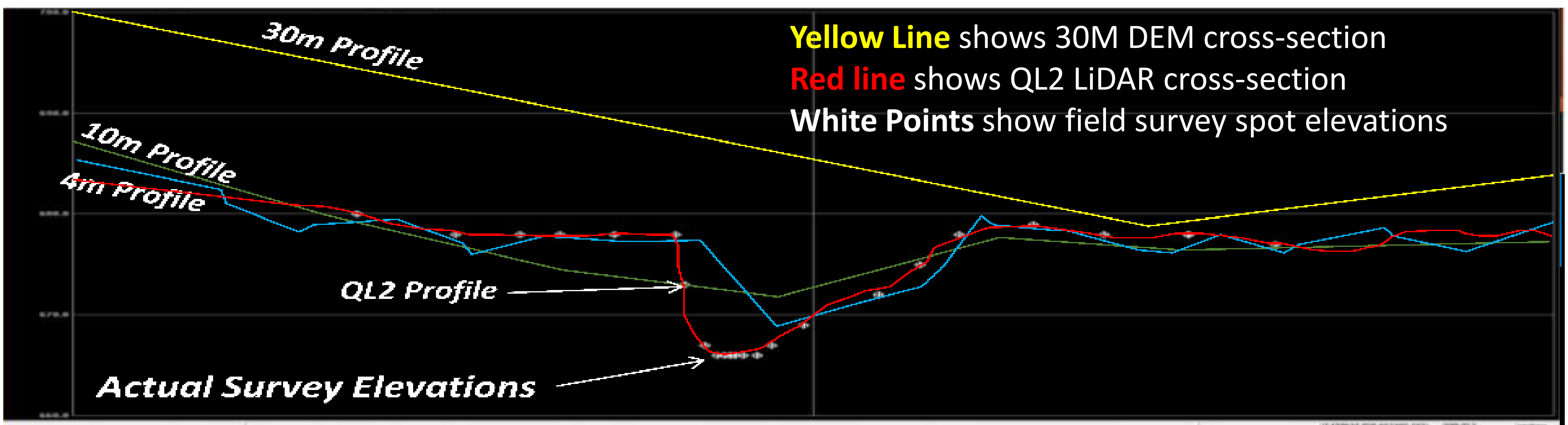
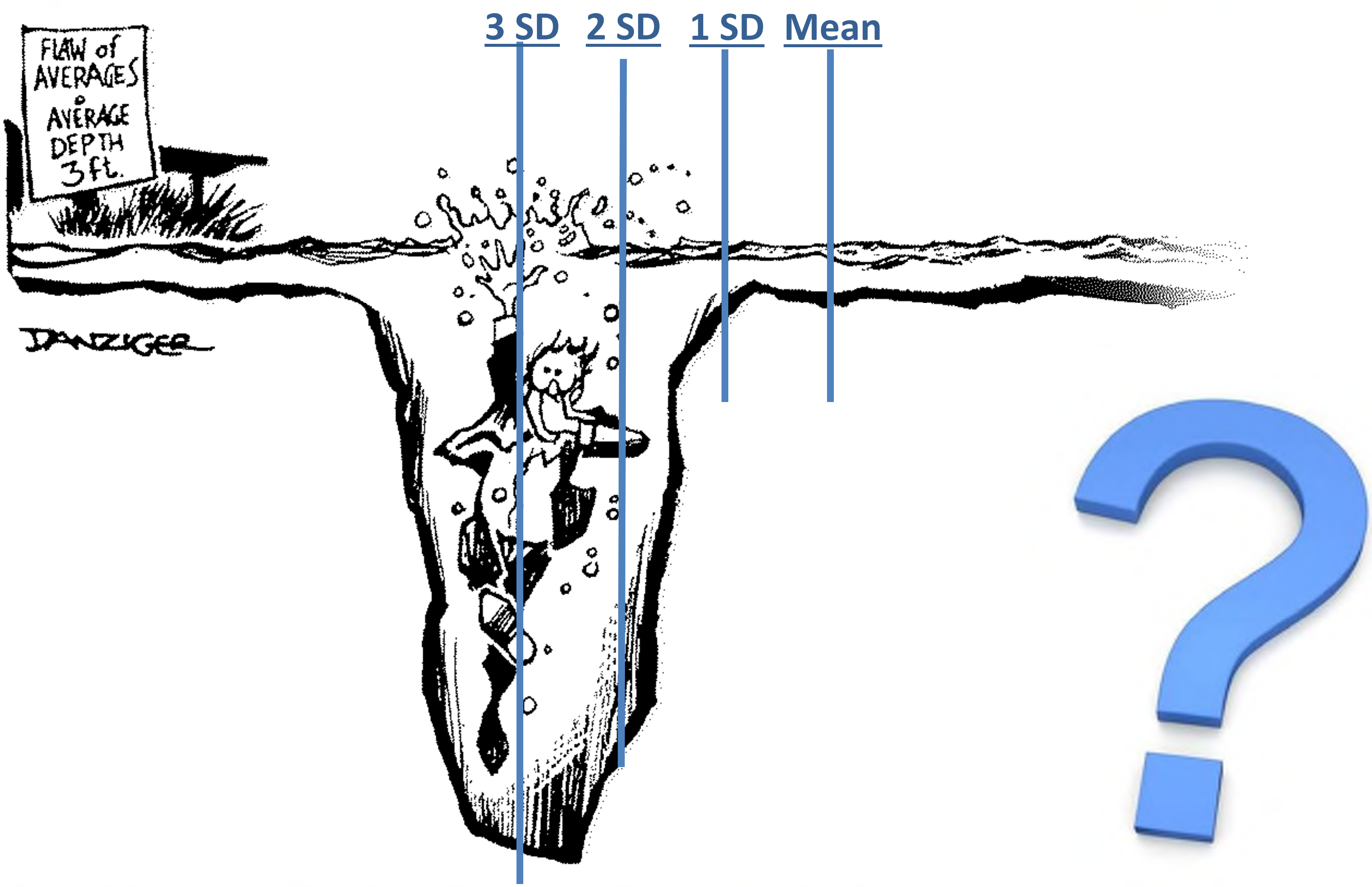
- A work in progress!
- Refine the assessment
  - Additional stream simulations
    - Are the results repeatable on other streams with similar slopes/characteristics?
    - What about other channel gradients?
  - Additional variables
    - Development
    - Hydraulic structures
    - LIDAR vs. field survey





Questions?


3 SD
2 SD
1 SD
Mean
FLAW of AVERAGES
AVERAGE DEPTH 3ft.
DANZIGER

Highway 115 at Pathfinder Park in Florence, CO
July 23, 2018

Tools to Stay Ahead of the Storm

Dana McGlone[1]; Kevin Stewart[2], PE, Kevin Houck[3], PE
[1]Dewberry Consultants, [2]UDFCD, [3]CWCB

2018 CASFM Annual Meeting

Tools to Stay Ahead of the Storm

- Early detection
- Municipalities
  - Mobilizing people and resources
- Project managers
  - Protection of project sites
- Understanding heavy rainfall thresholds
  - Impervious areas, nature of the threat

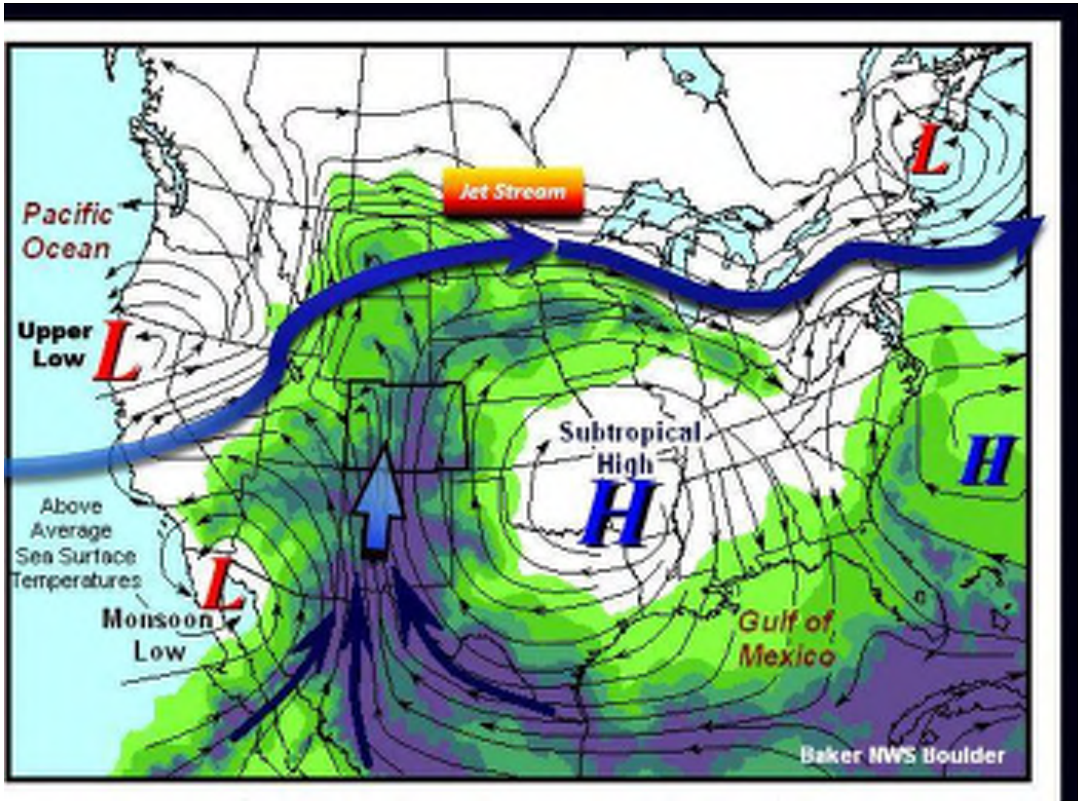
What is QPF?

Quantitative **P**recipitation **F**orecast:

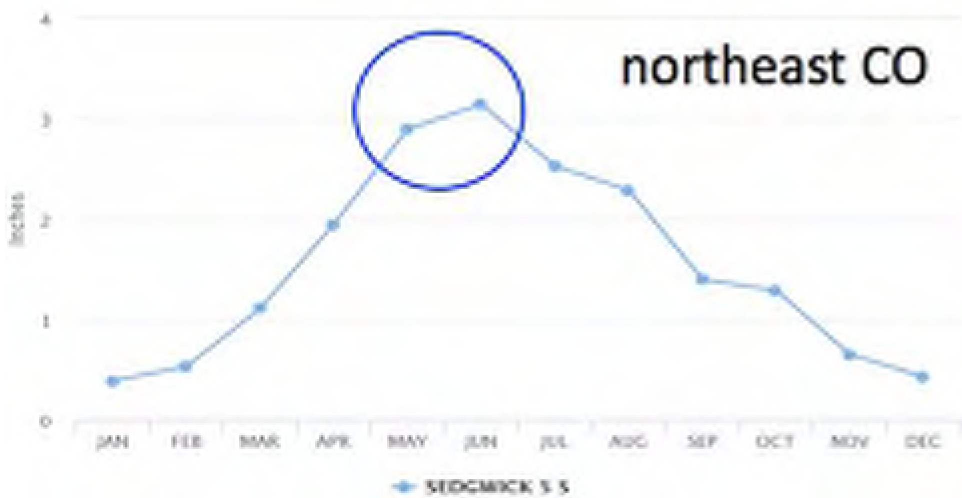
- A deterministic estimate of **how much** precipitation will accumulate at a **given location** over a **given amount of time**
- Typically deduced from atmospheric model
- Extremely difficult to accurately and precisely predict, especially for thunderstorm type rainfall
- Key input for many decision making systems
- Key input into many H&H prediction systems

North American Monsoon (NAM)

- Monsoon = seasonal shift in the wind pattern
- Gulf of California and Gulf of Mexico combine in "monsoon surge" with this upper-atmospheric pattern
- Typically ramps up in July and persists through August



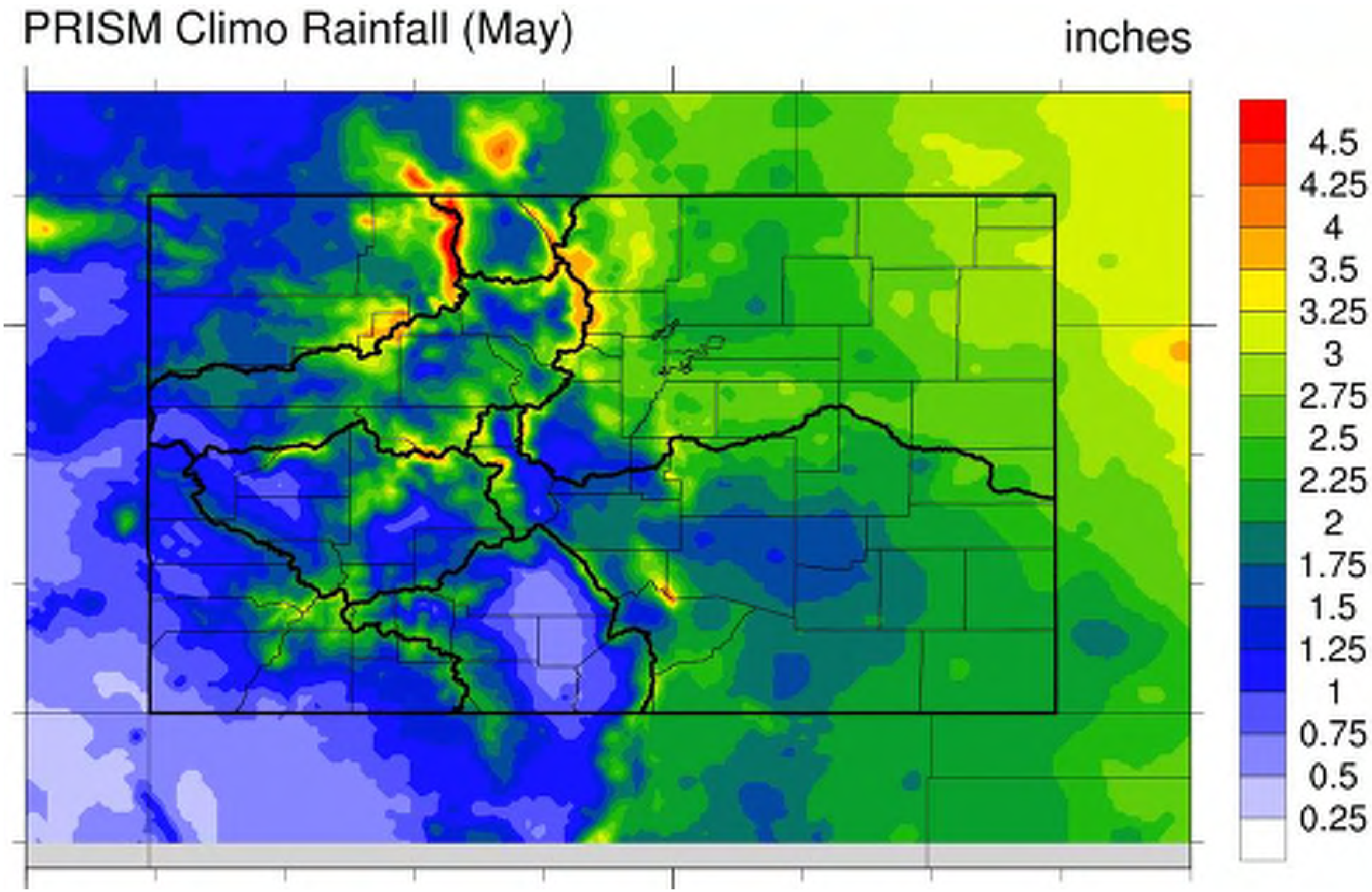
Dewberry



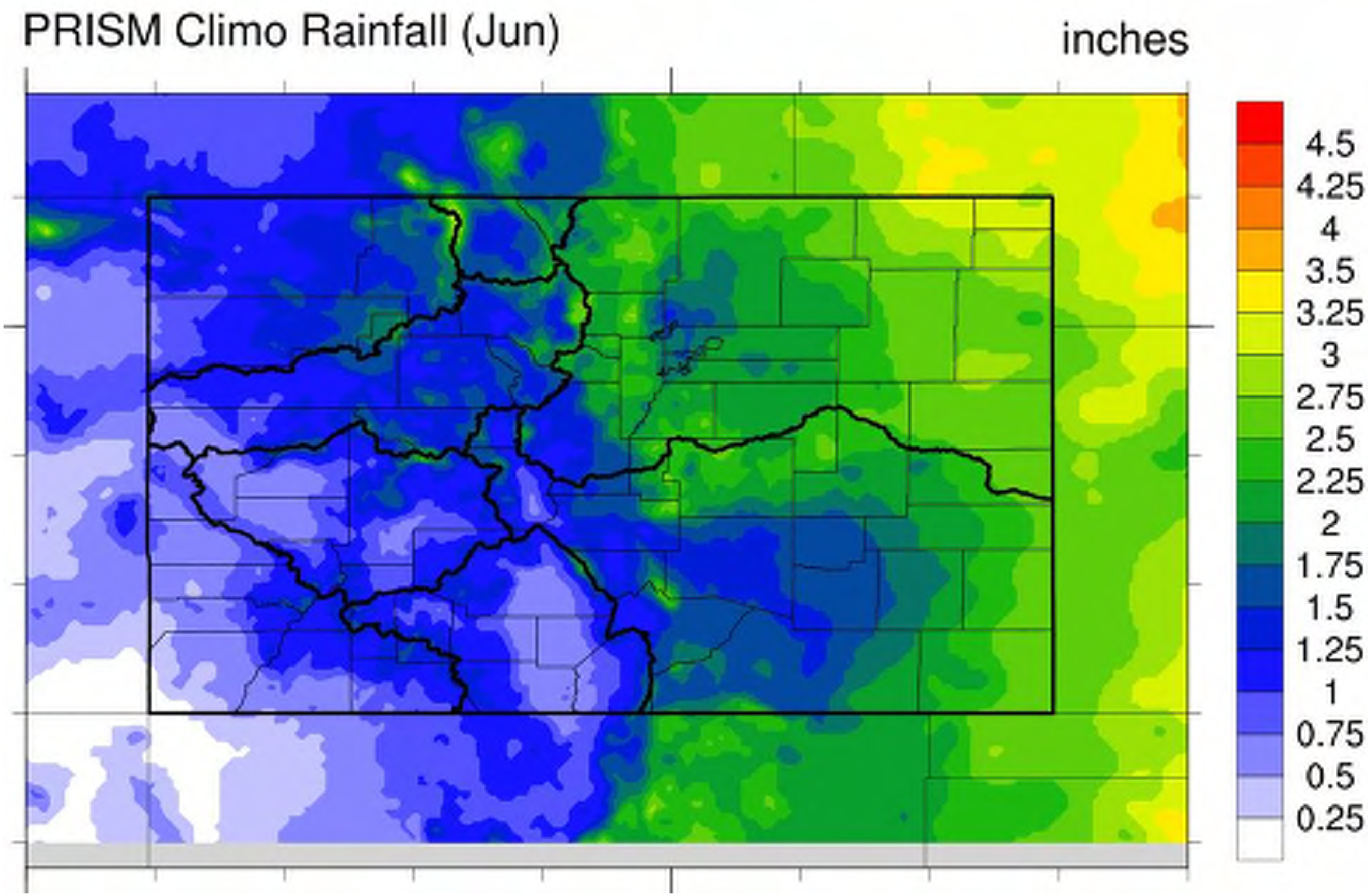
Source: Colorado Climate Center

Proof in the Peak (1981-2010)

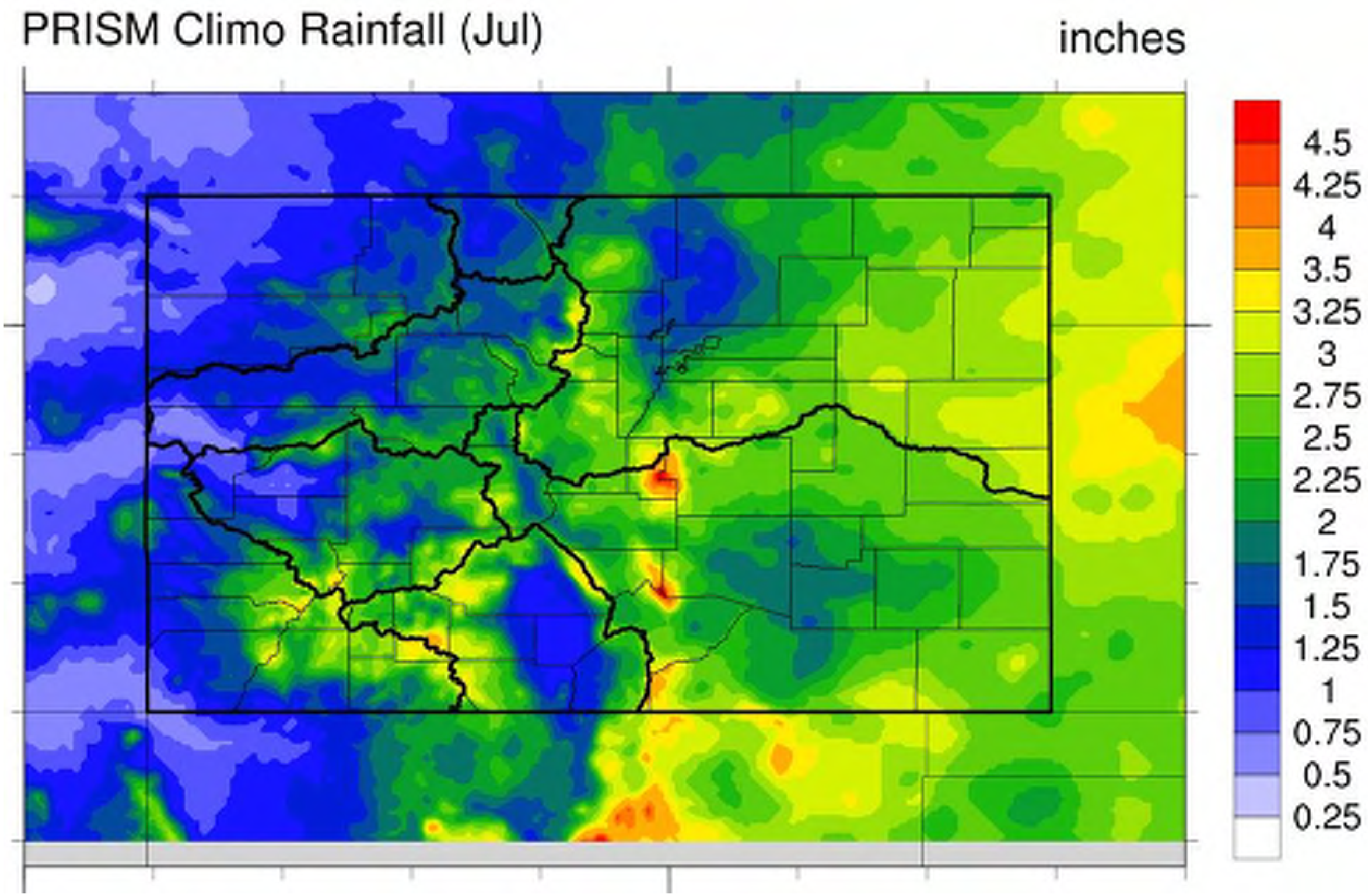
Monthly Variability of Rainfall



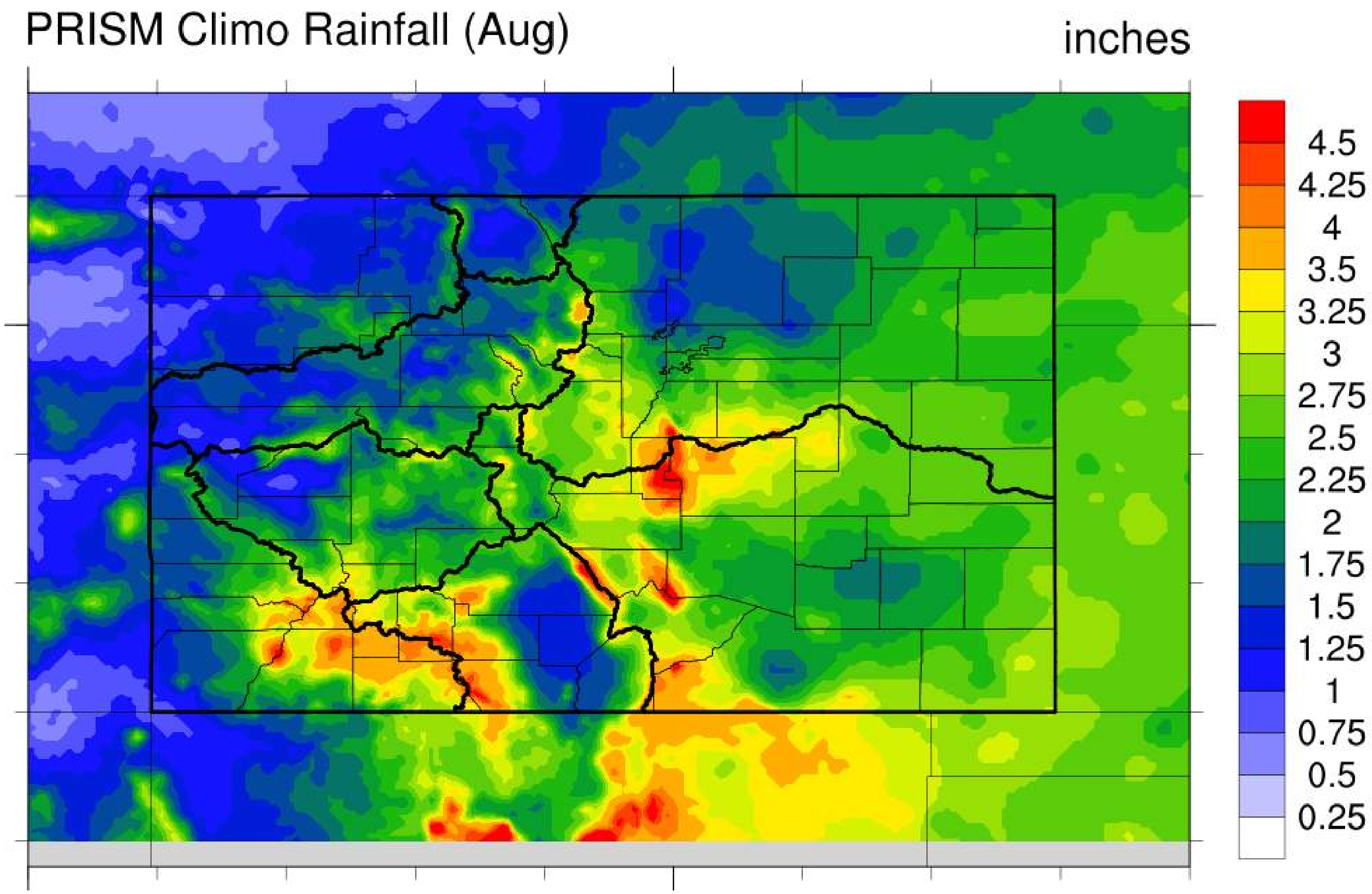
Monthly Variability of Rainfall



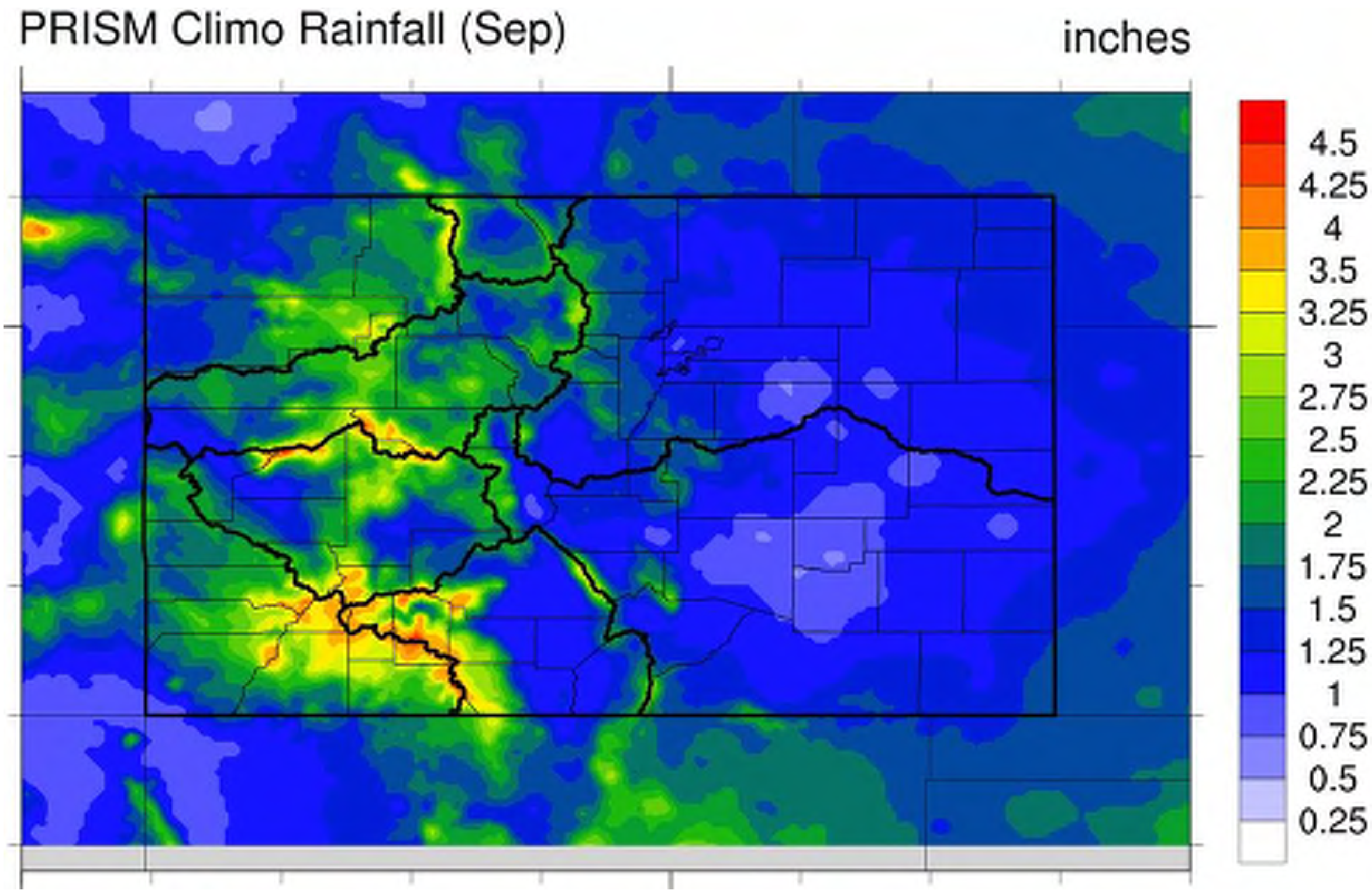
Monthly Variability of Rainfall



Monthly Variability of Rainfall



Monthly Variability of Rainfall

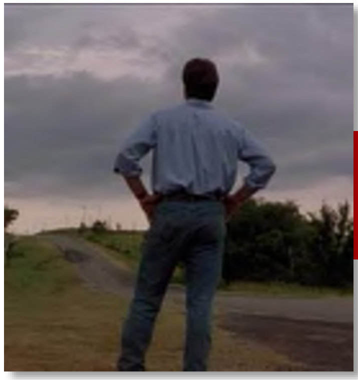


Objective versus subjective forecasts

PROS

- More easily QC'd
- More flexible

- Consistency & reproducibility
- Easier to improve



Subjective — Objective

- Labor intensive
- May have constraint on skill

- Not always intuitive
- Maintenance

CONS

What are we doing to stay ahead?

- Probabilistic approach – “ensemble of ensembles”
- Bias correction & post-processing
- Validation!!!

1. Urban Drainage and Flood Control District’s

Heavy Rainfall Guidance Tool: qpf.udfcd.org

2. Colorado Water Conservation Board’s

Colorado Flood Threat Bulletin: coloradofloodthreat.com

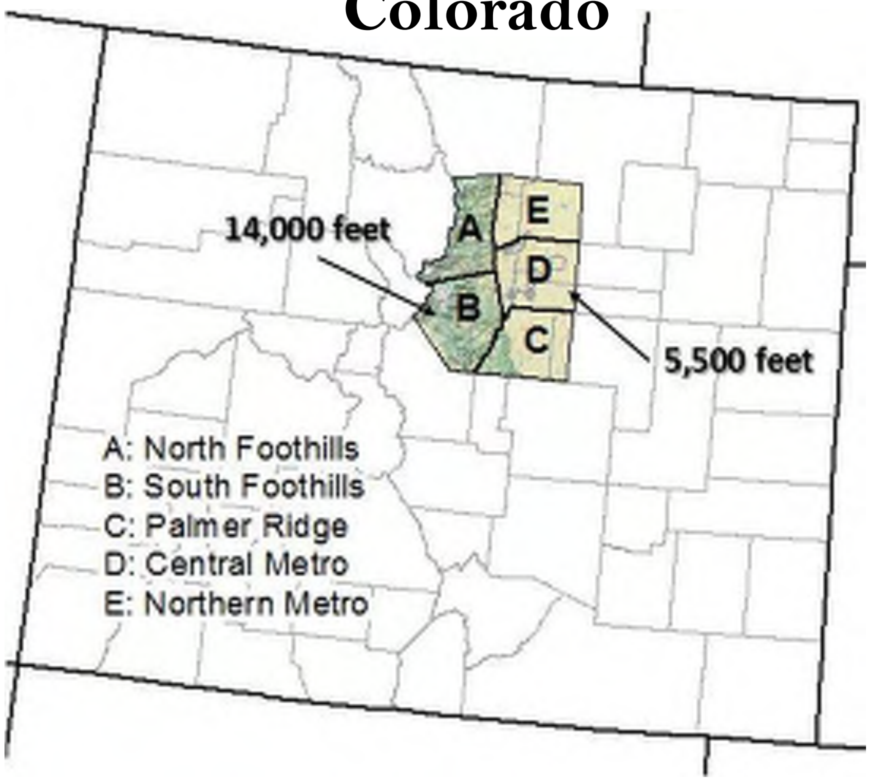
Objective Forecast

UDFCD Heavy Rainfall Guidance Tool

http://qpf.udfcd.org

- Objective: Increase lead time for anticipating heavy rainfall in the Denver metro area

Colorado

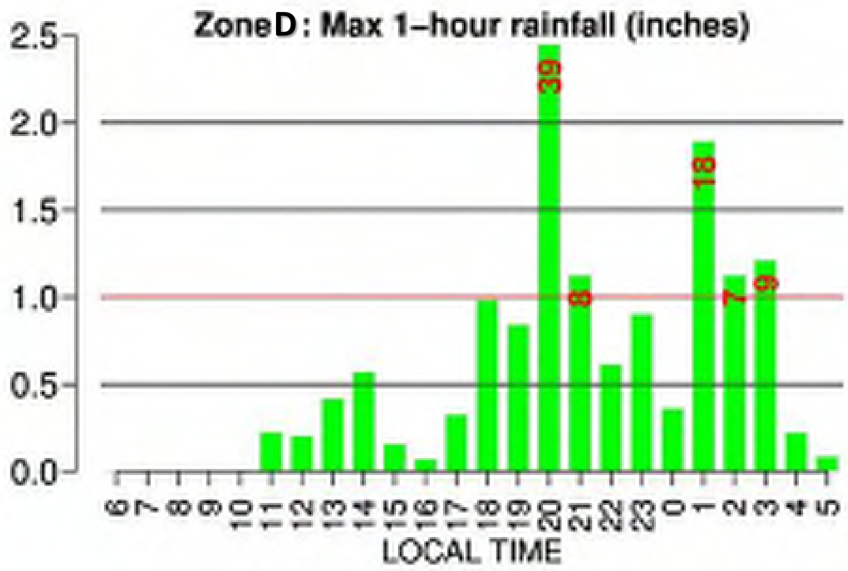


- 5 Forecast Zones covering ~6,000 mi^2
- Hourly output informs users on heavy rainfall:
  - timing
  - location
  - intensity
  - confidence

UDFCD Heavy Rainfall Guidance Tool

Zone D: Central Metro

ZONE F: Overall Threat	HIGH
% precipitation	85%
% exceeding 1in. per 1hr	45%
% exceeding 2.25in. per 3hr	7%
% exceeding 3.5in. per 6hr	<5%
% exceeding 4.5in. per 24hr	<5%
Primetime	20-4Wed



UDFCD Heavy Rainfall Guidance Tool

Daily Summary: June 17, 2018
Updated: N1

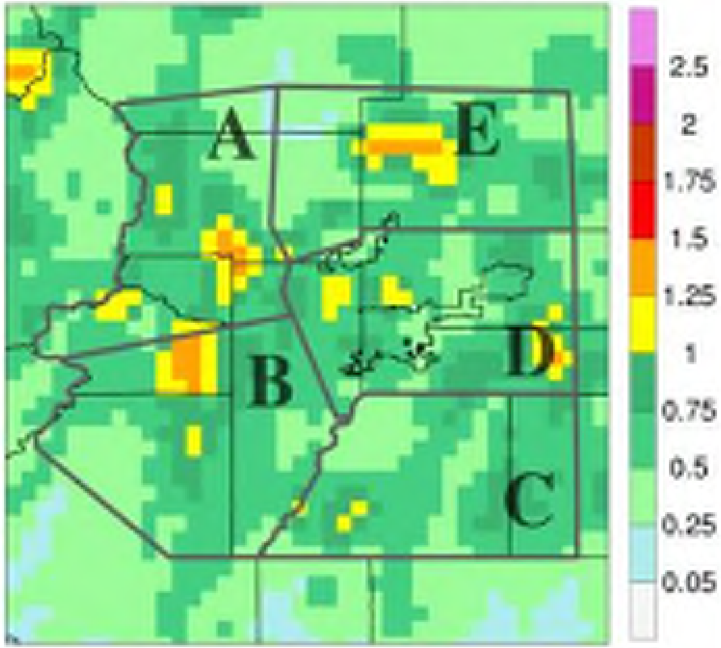
CAUTION: ARCHIVED FORECAST

	QPFMAX*	POP1**	Threat
All Zones	1.44 inches	59%	MOD

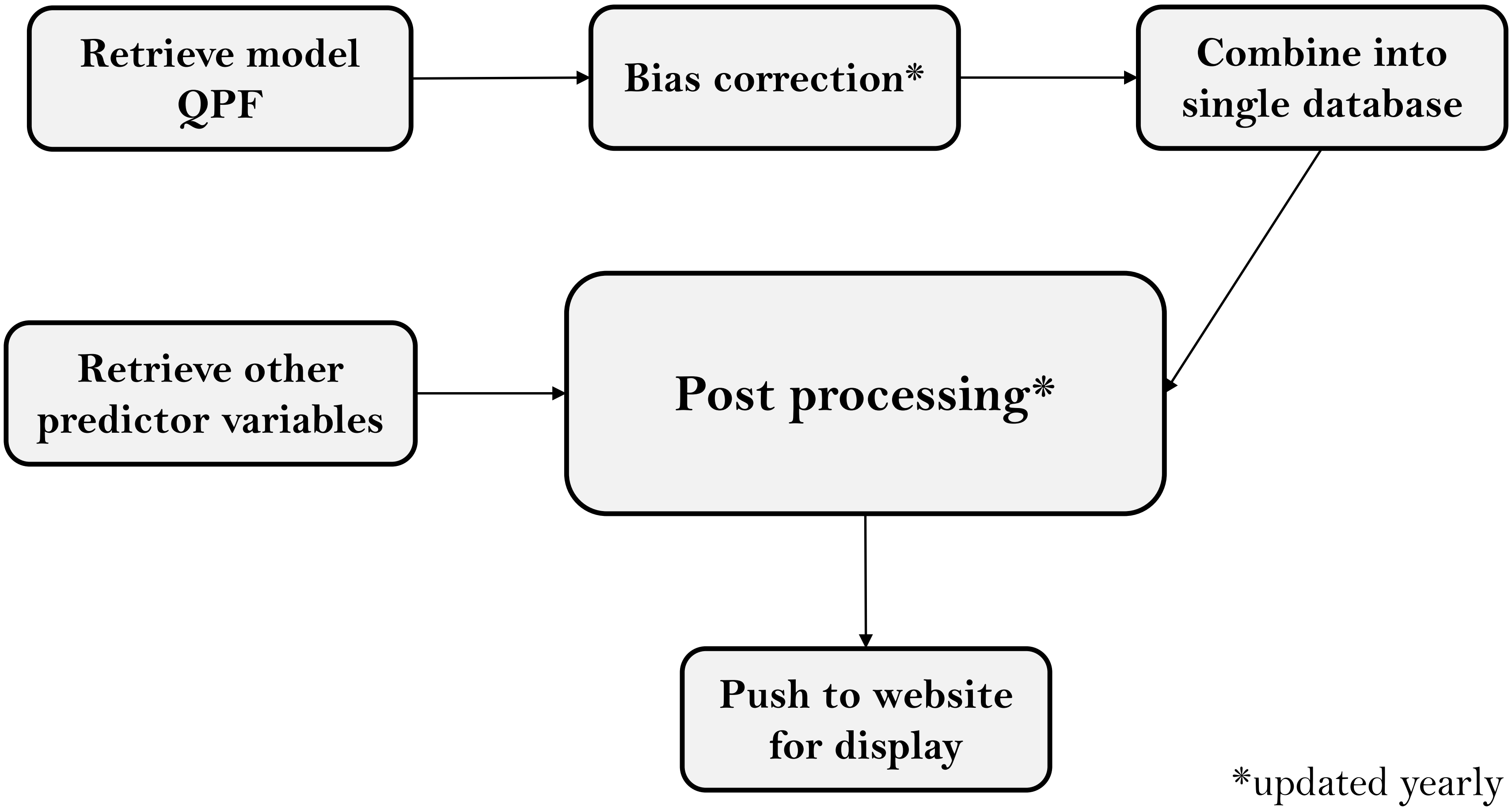
Zone	POP1**	Primetime	Threat
A	15%	14-16Sun	LOW
B	15%	15Sun	LOW
C	26%	13-20Sun	MOD
D	31%	14-18Sun	HIGH
E	14%	16-17Sun	LOW

QPFMAX*: Maximum 1-hour rainfall.
POP1**: Chance of exceeding 1 inch in 1-hour.

Maximum 1-hour rainfall



Operational Process Flow



*updated yearly

QPE/Rain Gage Data

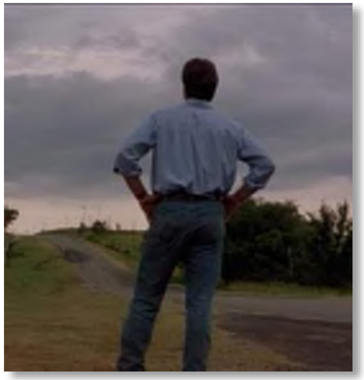
Objective: Estimate observed daily maximum 1-hour rainfall in each zone. **Value over 1 inch triggers “Flood Day” classification**.

Used the higher of:

- NOAA Stage IV hourly QPE
- UDFCD ALERT Rain Gage Network ~ 200 gages

Used CoCoRaHS (~300 rain gages) and hail reports for additional quality control.

Subjective Forecast

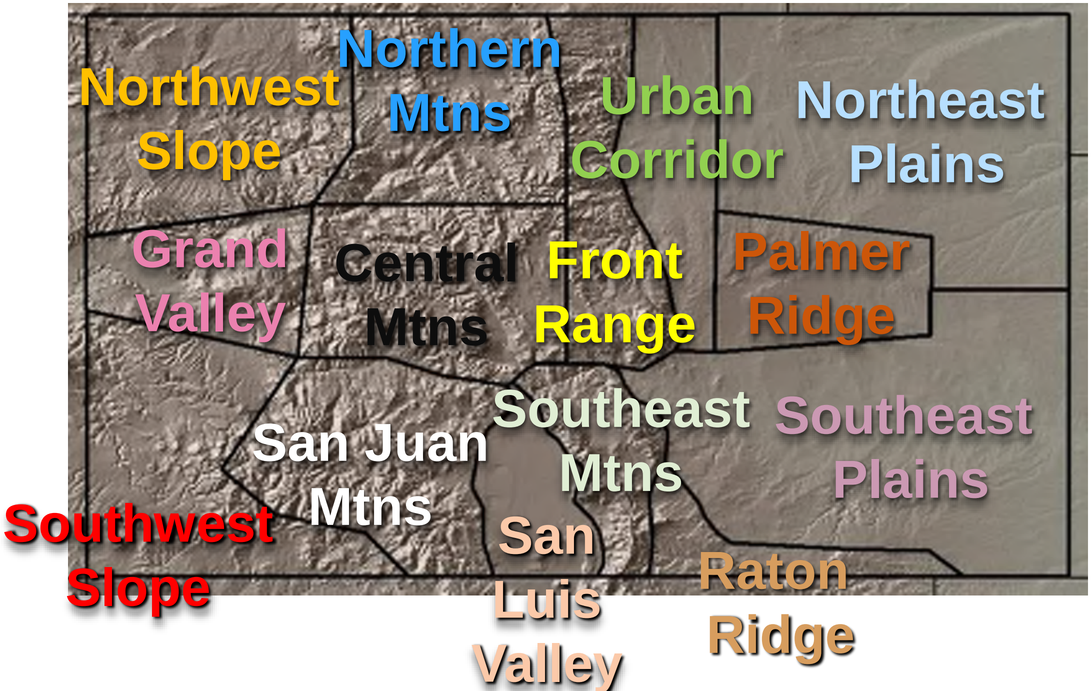


Colorado Flood Threat Bulletin

http://www.coloradofloodthreat.com

- Objective: Increase lead time for anticipating heavy rainfall over Colorado during the warm season

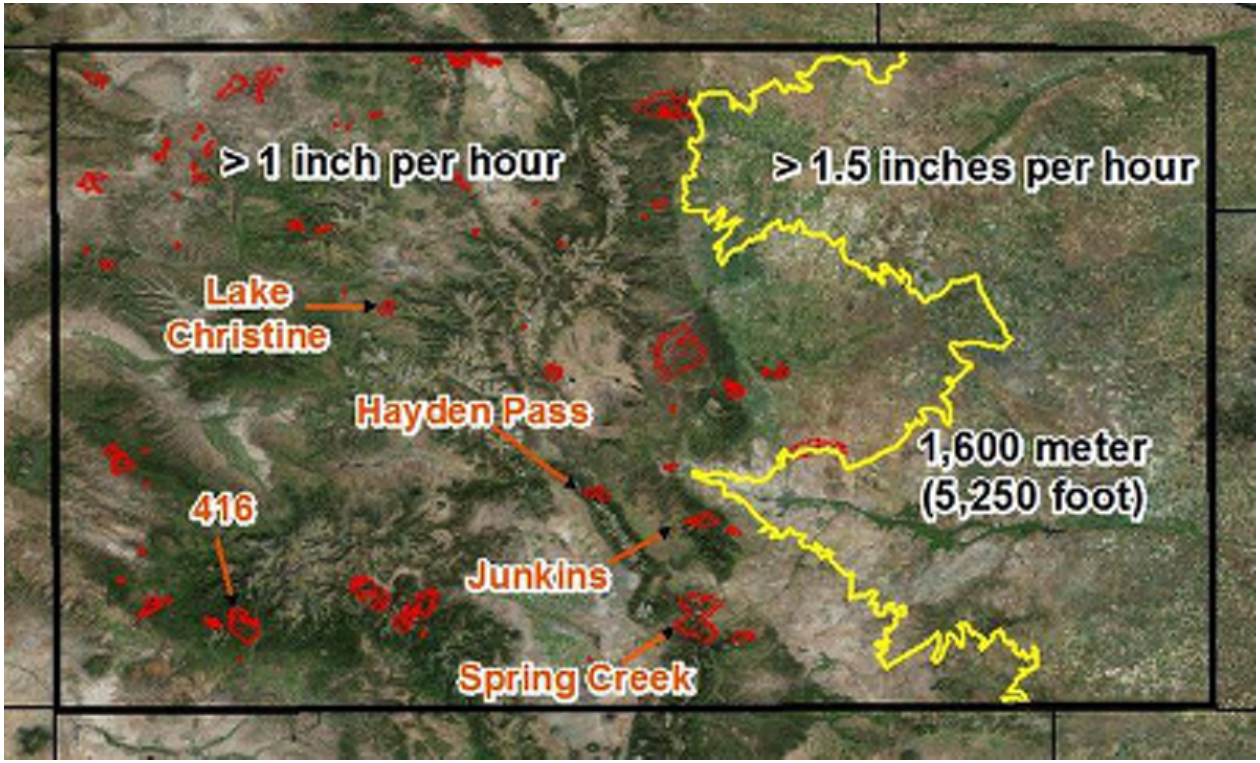
Colorado



- 14 Forecast Zones with a large range in topography
- Product informs users on heavy rainfall:
  - timing
  - location
  - intensity
  - confidence
  - nature of the threat

Motivation

- **Many heavy rainfall events occur with little to no lead time**
- **Can we estimate a daily “realistic” worst-case scenario?**
- **Can we develop a system that is reliable *and* discriminates between higher and lower threat days?**



Dewberry

Products

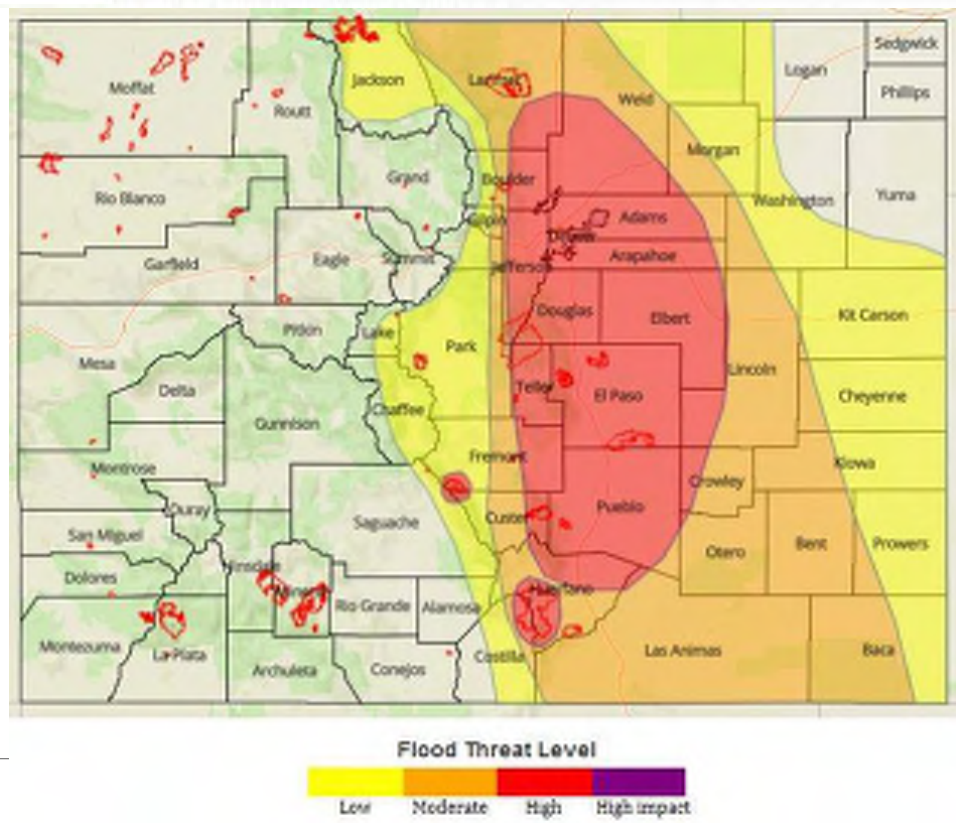
- Flood Threat Bulletin (FTB)
  - Issued by 11am daily
  - Identifies areas of flood risk for a 24-hr period
  - Possible PM updates

- State Precipitation Map (SPM)
  - Issued by 11am daily
  - Recaps the past 72-hours of hydrometeorolgical conditions
    - ✓ Rainfall totals, flooding, antecedent soil conditions

- Flood Threat Outlook (FTO)
  - Issued Monday and Thursday by 3PM
  - Outlook of threat and precipitation totals over the next 15 days
  - Rapid snowmelt, local heavy rainfall, drought development

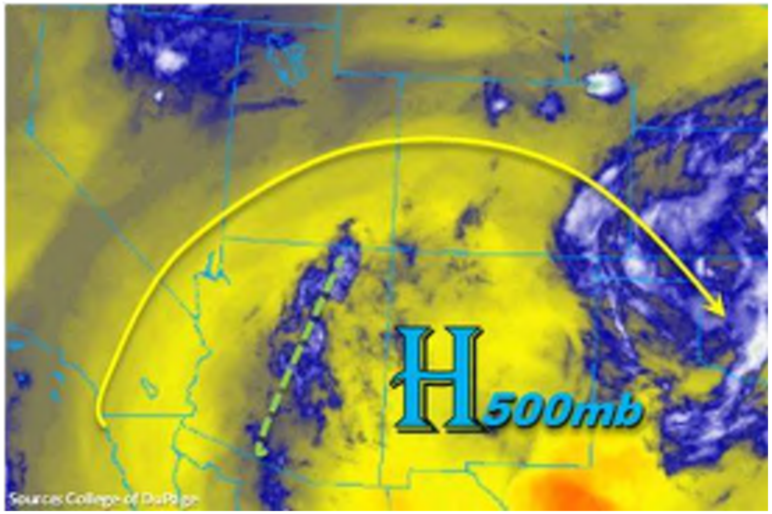
Flood Threat Bulletin (FTB)

THREAT	DESCRIPTION
NONE	No flood threat is expected.
LOW	Low probability (<50%) that isolated/widely scattered flooding will occur. If flooding occurs, low impact/severity flooding is anticipated.
MODERATE	Moderate probability (50-80%) of flooding occurring.
HIGH	High probability (>80%) of flooding occurring.
HIGH IMPACT	High probability (>80%) of *high-impact* flooding due to a combination of factors including, but not limited to: high population density, antecedent rainfall and/or long-term duration.



Flood Threat Map
July 23, 2018

Flood Threat Bulletin (FTB)



Discussion (not shown) with an image:

Zone-Specific Forecasts:

Front Range, Urban Corridor, Palmer Ridge, Southeast Plains, Northeast Plains, Southeast Mountains, Raton Ridge:

Very moist low-level will support heavy rainfall this afternoon. Showers and thunderstorms should kick off just after noon over the higher terrains. Over the higher terrains max 1-hour rain rates up to 1.25 inches are possible, which could trigger mud flows, debris slides and local stream flooding. Rain rates increase over the adjacent plains with 1-hour rain rates around 1.75 inches/hour. Localized 1-hour rain rates over 2 inches/hour are not out of the question in areas of the highest low-level moisture. A High flood threat has been issued for portions of these regions with the largest threat over the Urban Corridor, Palmer Ridge and Southeast Plains. A High flood threat has also been issued for all recent burn scars over the Southeast Mountains as storms could trigger debris slides and local stream flooding that track over these areas. Thunderstorms and showers will continue to rumble into the night, but the flood threat should decrease after midnight.

Primetime: 12PM to 7AM

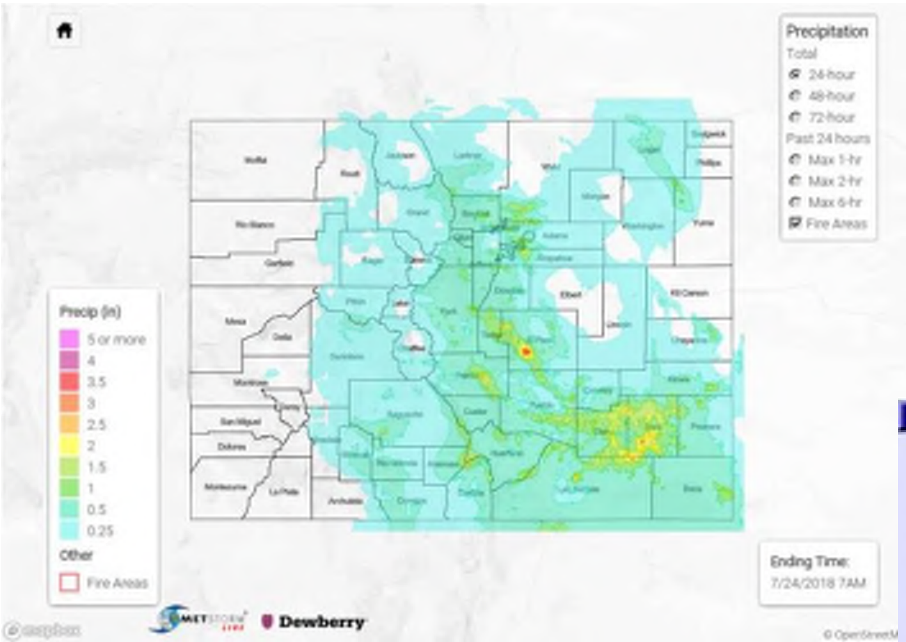
Southwest Slope, San Juan Mountains, San Luis Valley, Northern Mountains, Grand Valley, Central Mountains, Northwest Slope:

Low-level moisture won't be quite as high over western Colorado. Max 1-hour rain rates up to 0.4 inches/hour are possible over the higher terrain this afternoon. Upslope flow will be the main driver of thunderstorm development today, and with westerly winds, the rainfall should remain over the mountains with the greatest cover near the Continental Divide.

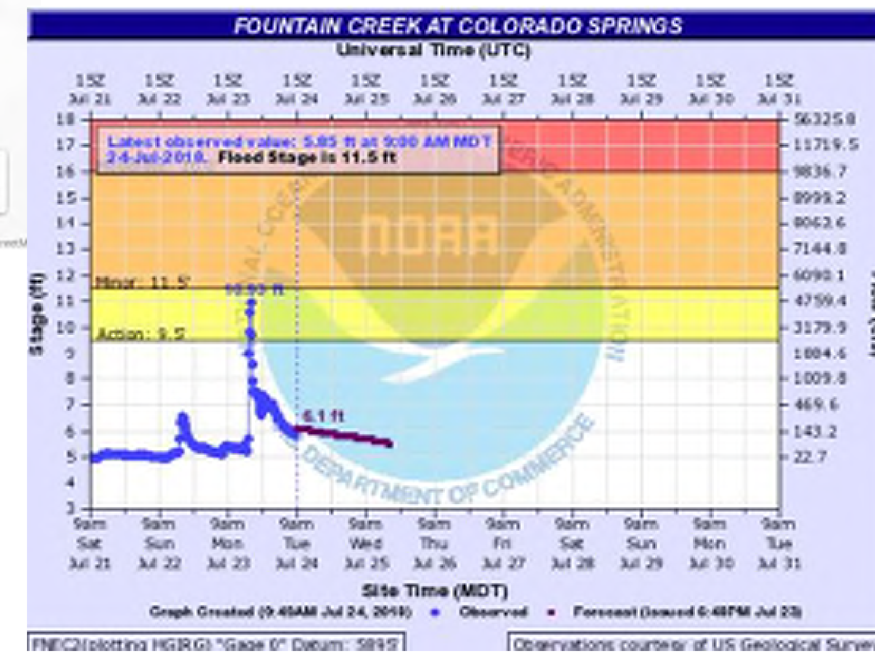
Primetime: 1PM to 8PM

State Precipitation Map (SPM)

SPM - July 24, 2018



Discussion (not shown) with relevant image:



- 4.12 inches north of Fountain
- 1.18 inches in 20min NW of CO Springs
- 2.76 inches at Aurora ALERT gage

Flood Threat Outlook (FTO)

Issue Date: Monday, July 17, 2017

Issue Time: 2:10PM MDT

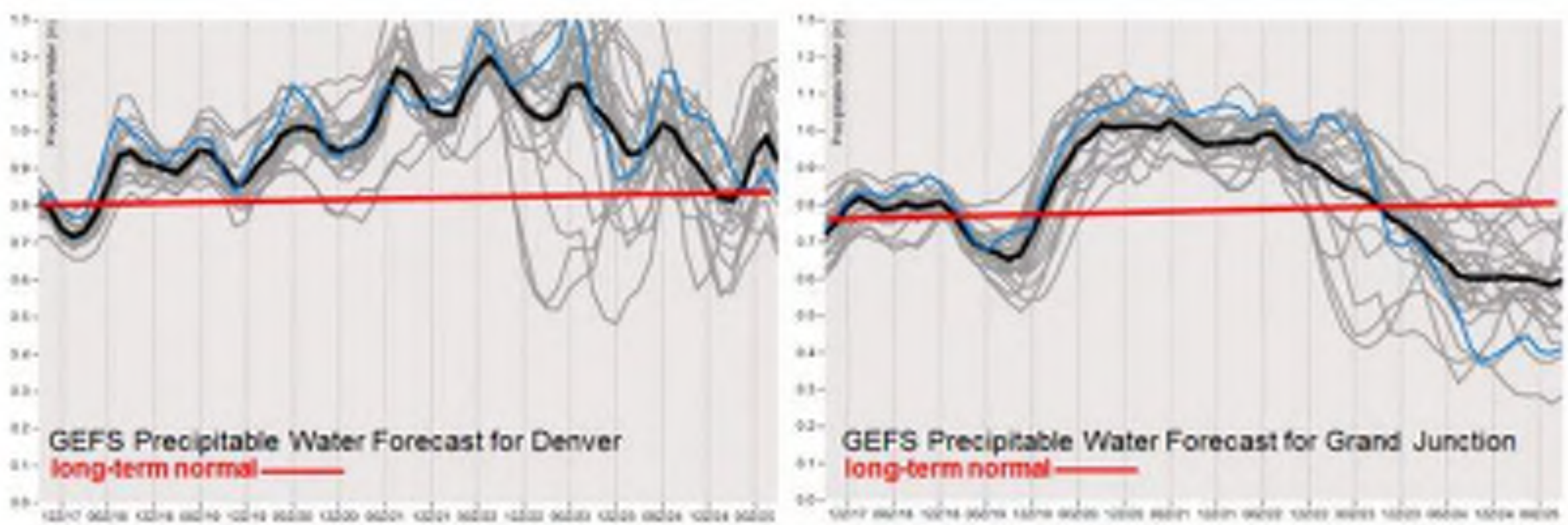
Valid Dates: 7/18 – 8/1

Next 15 Days	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue
	18-Jul	19-Jul	20-Jul	21-Jul	22-Jul	23-Jul	24-Jul	25-Jul	26-Jul	27-Jul	28-Jul	29-Jul	30-Jul	31-Jul	1-Aug
	Event #1				Event #2										

No Apparent Threat	Elevated Threat	High Threat

FLOOD THREAT LEGEND

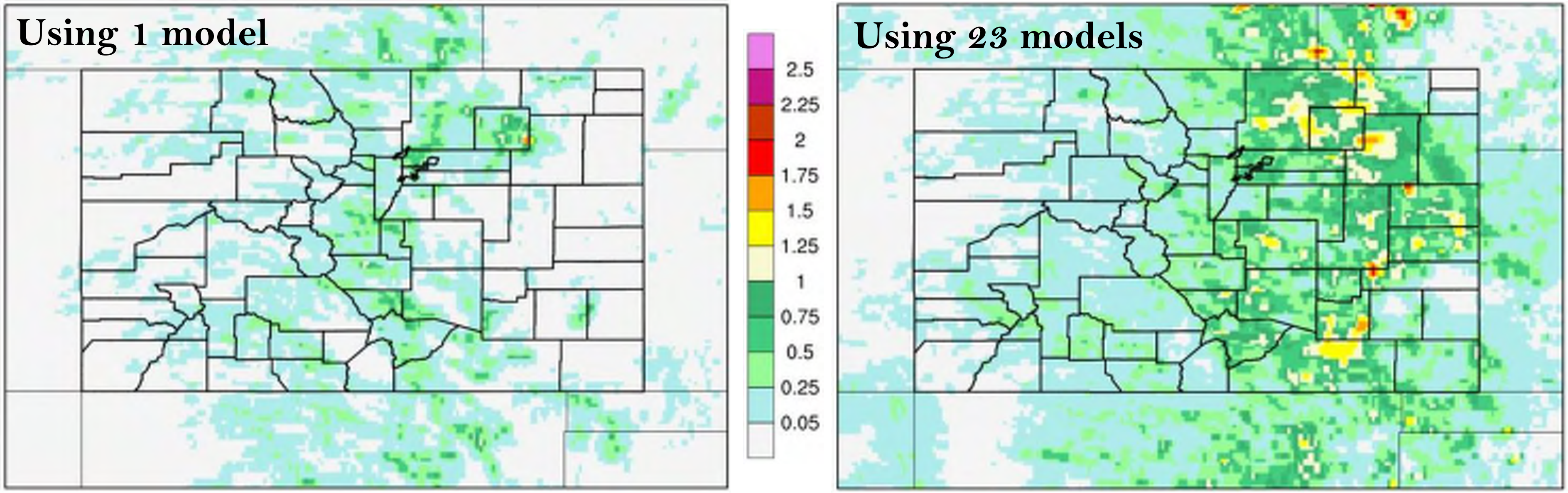
Discussion (not shown) with relevant images:



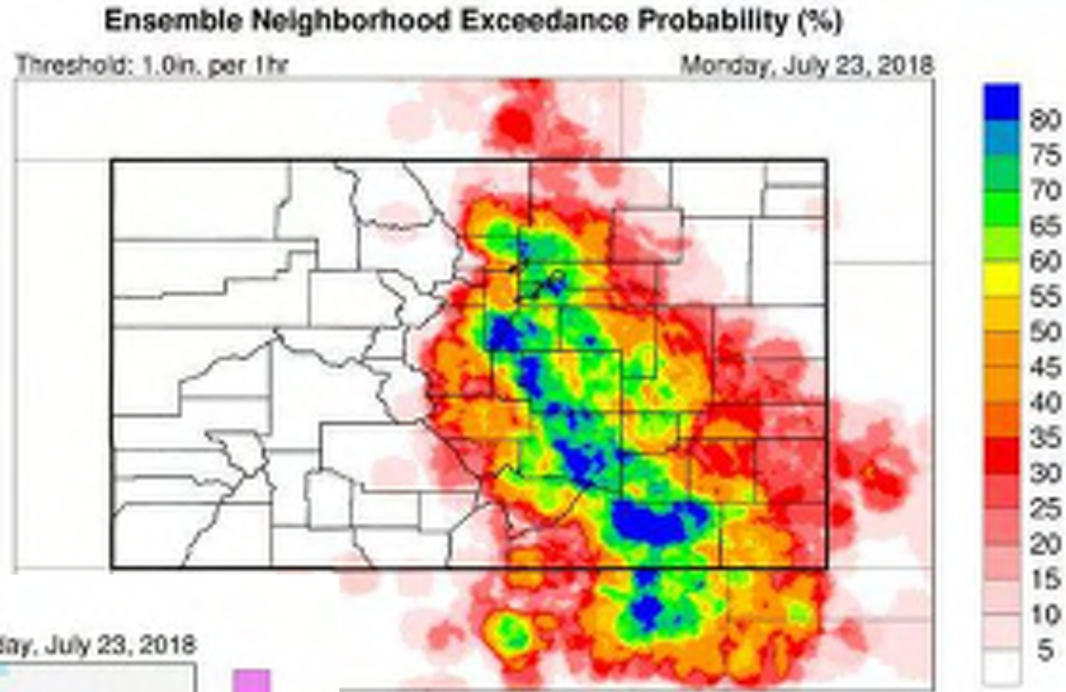
http://www.emc.ncep.noaa.gov/mmb/cguastin/gefs/EMCGEFSplumes.html

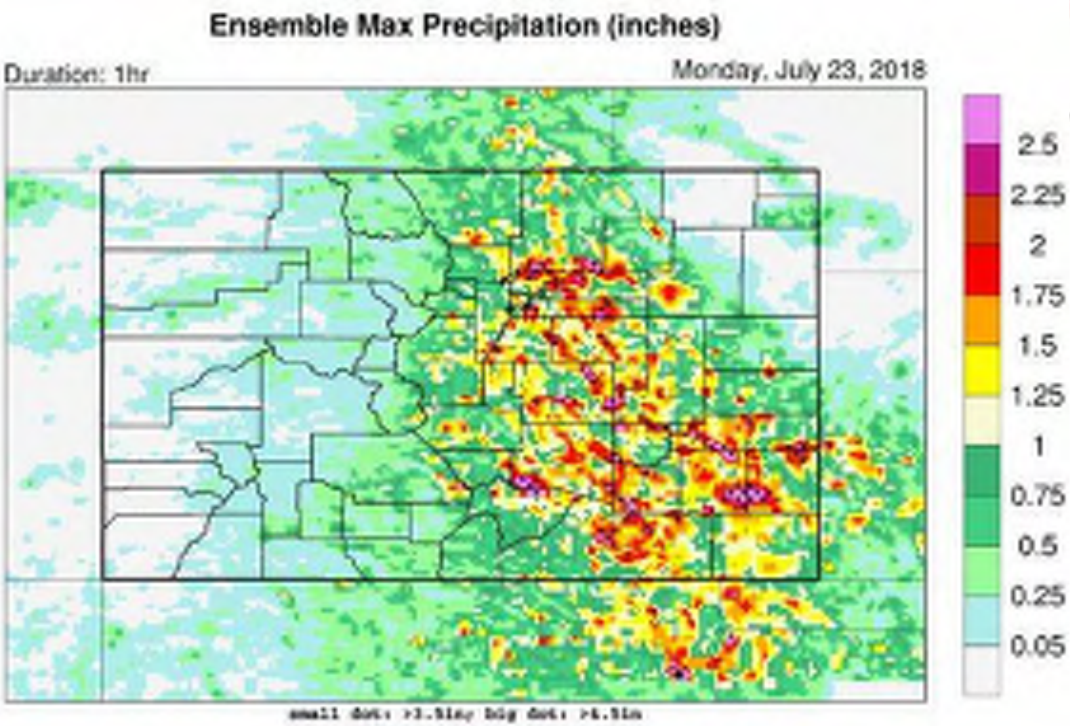
The benefit of an ensemble

Max 1-hour precipitation for 6/7/2017



The benefit of an ensemble





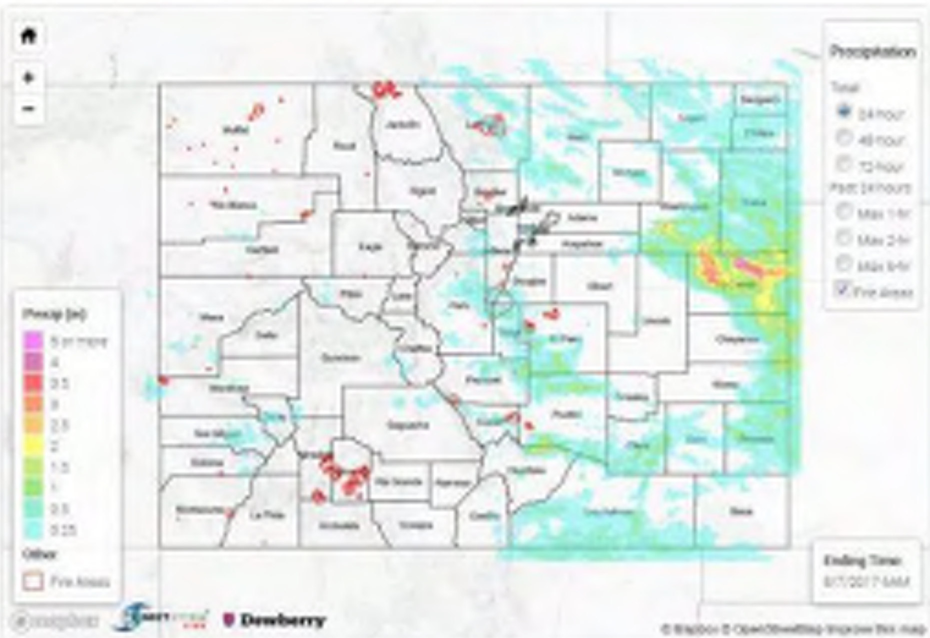
July 23, 2018

Twitter: @COFloodUpdates
Facebook: Colorado Flood Threat Bulletin

CO Flood Updates @COFloodUpdates · 7 Aug 2017

Replying to @COFloodUpdates

Check out full 24-hour rainfall summary and our new State Precipitation Map here: coloradofloodthreat.com/?cat=4 #cowx #coflood



1 2

CO Flood Updates @COFloodUpdates · 7 Aug 2017

Heavy rain for Eastern CO yesterday. A CoCoRaHS station in Kit Carson County recorded 6.2 inches, which is a 1 in 200-500 year event! #cowx

1 1 2

#COFlood
#COwx
#COFire

QPF-Max Application

- Kevin Stewart - UDFCD

Dewberry

UDFCD Heavy Rainfall Guidance Tool

Daily Summary: July 23, 2018
Updated: N1

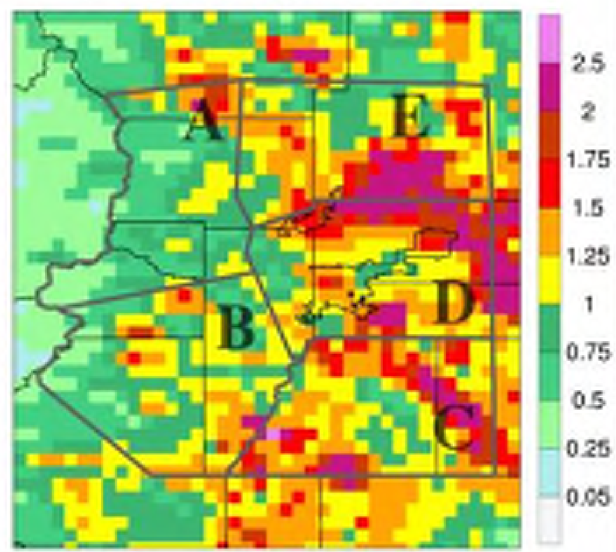
CAUTION: ARCHIVED FORECAST

	QPFMAX*	POP1**	Threat
All Zones	2.62 inches	>90%	VERY HIGH

Zone	POP1**	Primetime	Threat
A	30%	14-19Mon	HIGH
B	42%	11-20Mon	HIGH
C	41%	12-23Mon	VERY HIGH
D	20%	13-20Mon	VERY HIGH
E	17%	13-18Mon	HIGH

QPFMAX*: Maximum 1-hour rainfall.
POP1**: Chance of exceeding 1 inch in 1-hour.

Maximum 1-hour rainfall



Conclusions

- QPF reliability
- Climatology of warm season, heavy rainfall events in Colorado
- Objective vs subjective forecasts
- Heavy rainfall tools available to the public
- Applications for early detection of heavy rainfall events

For questions contact:
Dana McGlone
dmcglone@Dewberry.com

Bendway Weirs and 2D Modeling: An Innovative Stream Design

CASFM Annual Conference
Technical Modeling
September 26, 2018

Aaron Sutherlin, PE
Drake Ludwig, EI
Water Resources
Matrix Design Group, Inc.

Matrix
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- **Overview**
- History
- Approach
  - Morphology
  - Alternatives
  - Criteria
  - Modeling
- Construction
- Post-Construction

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Masciantonio Trust Bank Protection

Client

FOUNTAIN CREEK WATERSHED - FLOOD CONTROL & GREENWAY DISTRICT -

Design Team

Matrix DESIGN GROUP AN EMPLOYEE-OWNED COMPANY

THK associates, inc.

Construction

TEZAK HEAVY EQUIPMENT

Fountain Creek: A Perspective

- Plain bed gravel channel with sandy behaviors
- Over 5' of mobile bed
- 927 sq. mile drainage area
- ≈ 1,350' Drop from Col. Springs to Pueblo (44 miles)

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Fountain Creek: A Perspective

- June 17, 1965: 53 city blocks were inundated with water up to 8 feet deep, damaging 370 homes and 59 businesses. Damage estimated at $3.7 million. Peak flow of the flood was estimated at 47,000 cubic feet per second.
- June 11, 1864: Flow of 45,000 cfs. Waters rose 20-30 feet, sweeping away Colorado City.
- May 30, 1894: Flow of 40,000 cfs. Five lives lost and $2 million in property damage.
- May 30, 1935: Flow of 35,000 cfs. Damages in Colorado Springs were $1.8 million, and four people died. In Pueblo, damages were $500,000.
- June 3-4, 1921: Fountain Creek's flows were 34,000 cfs, adding to the worst flood in Pueblo history on the Arkansas River, where flows were 110,000 cfs. After the flood, 78 bodies were recovered. More than 500 homes and 100 commercial buildings were destroyed. Damage was more than $10 million.
- April 30, 1999: Peak flow of 18,900 cfs. A highway bridge at Pinon was swept away by the waters. Pueblo's Target store was threatened. Damages in Pueblo and El Paso County totaled more than $30 million. Extensive damage in North La Junta as well. By comparison, the most recent flood on Fountain Creek peaked at 13,800 cfs in Pueblo on June 16.

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Overview

History

Approach

Morphology

Alternatives

Criteria

Modeling

Construction

Post-Construction

Masciantonio Trust Bank Protection

Goals & Objectives

1. Land Protection / Recovery
2. Sediment Load Reduction
3. Water Quality Improvement

Solution

1. Stable Channel Dimension, Pattern, and Profile
2. Bendway Weirs

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Overview

History

Approach

Morphology

Alternatives

Criteria

Modeling

Construction

Post-Construction

October 27, 2011

November 2, 2015

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Masciantonio Trust Bank Protection

Overview

History

Approach

Morphology

Alternatives

Criteria

Modeling

Construction

Post-Construction

Matrix DESIGN GROUP
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Masciantonio Trust Bank Protection

- Overview
- History
- Approach
  - Morphology
  - Alternatives
  - Criteria
  - Modeling
- Construction
- Post-Construction

Matrix DESIGN GROUP
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Masciantonio Trust Bank Protection

- Overview
- History
- Approach
  - Morphology
  - Alternatives
  - Criteria
  - Modeling
- Construction
- Post-Construction

Matrix DESIGN GROUP
AN EMPLOYEE-OWNED COMPANY

Masciantonio Trust Bank Protection

- Overview
- History
- Approach
  - Morphology
  - Alternatives
  - Criteria
  - Modeling
- Construction
- Post-Construction

Matrix Design Group
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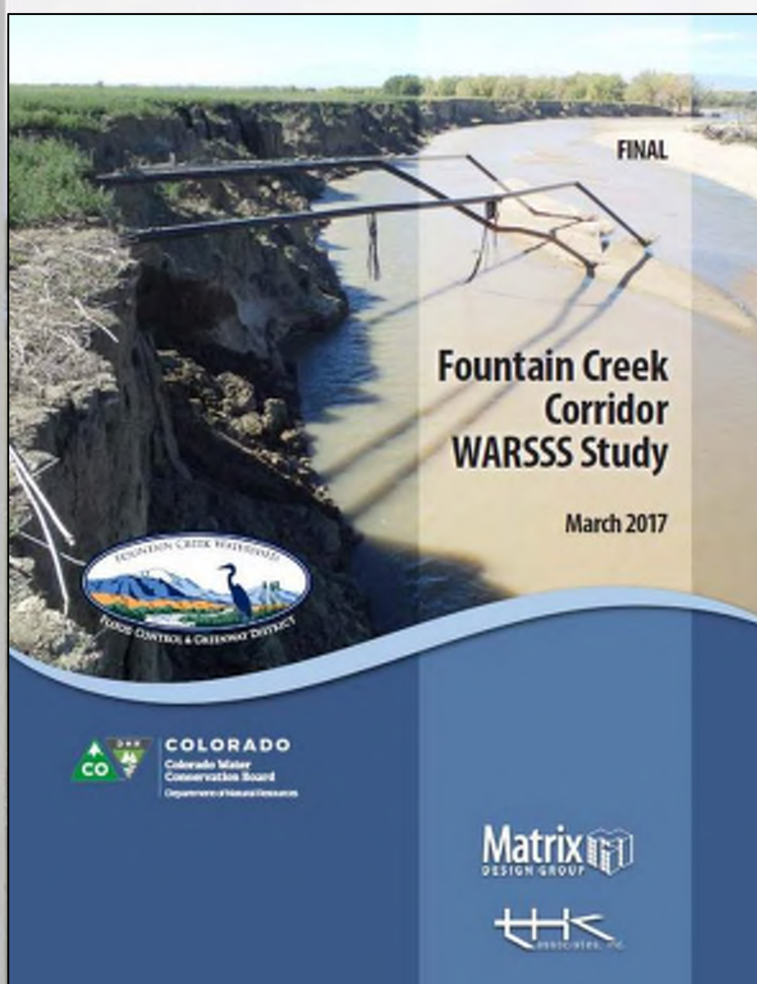
History

- Overview
- History
- Approach
  - Morphology
  - Alternatives
  - Criteria
  - Modeling
- Construction
- Post-Construction



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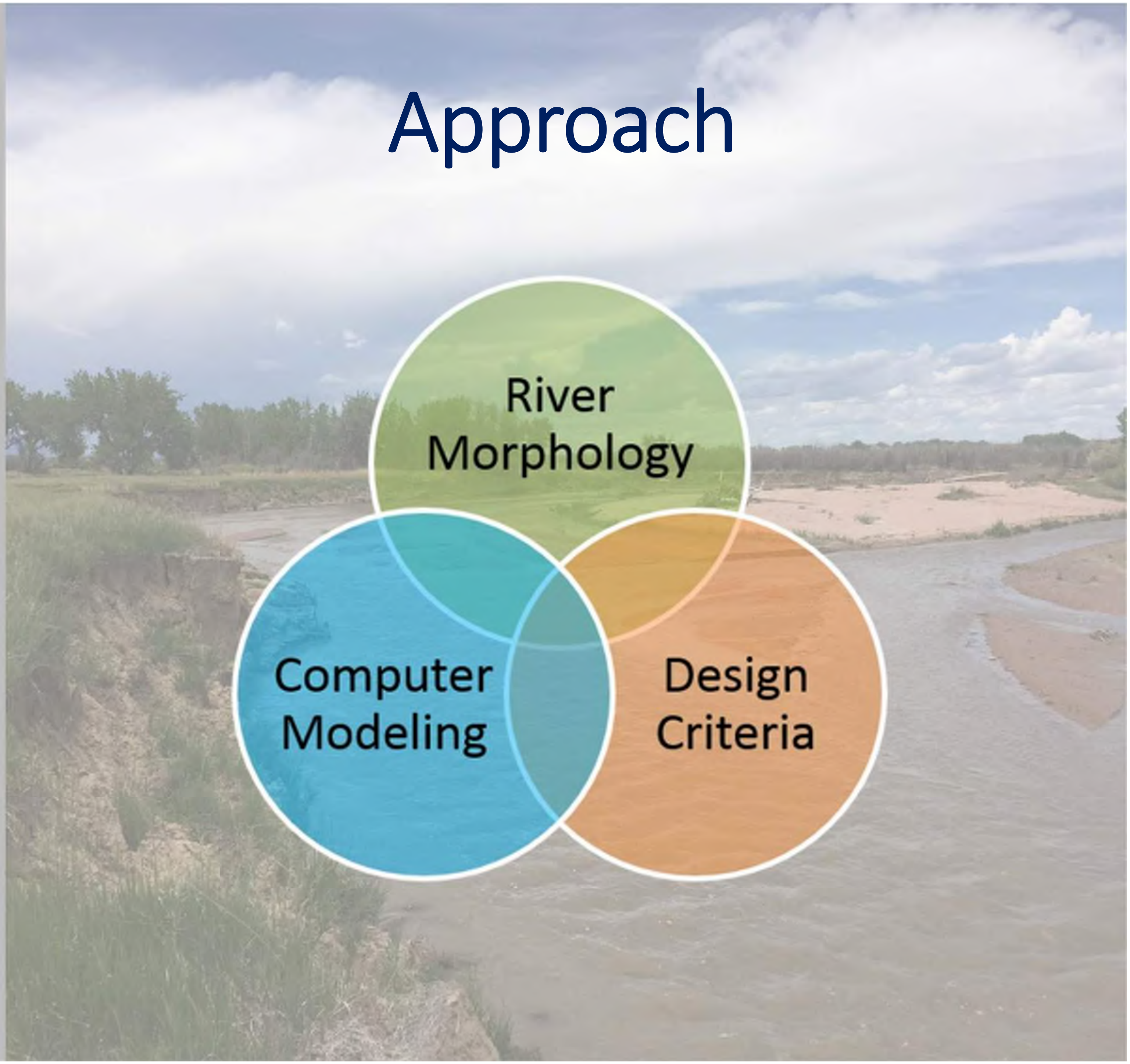
Approach

Overview
History
Approach
Morphology
Alternatives
Criteria
Modeling
Construction
Post-Construction

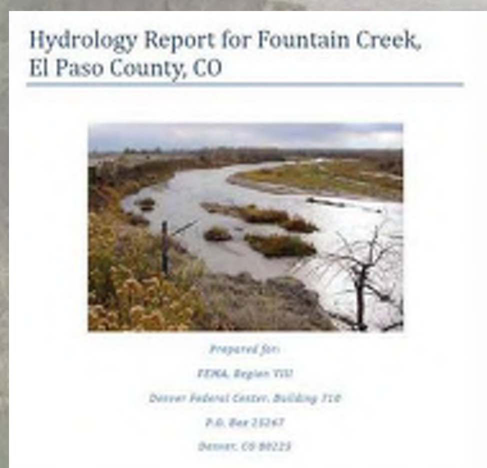


- Overview
- History
- **Approach**
  - Morphology
  - Alternatives
  - Criteria
  - Modeling
- Construction
- Post-Construction

Approach

Data Collection

- USGS Gage Data
- Fountain Creek Watershed Study
- Survey, LiDAR and Aerial Photos
- June 2015 Flood Event
- Young's Hollow


Hydrology Report for Fountain Creek, El Paso County, CO

Recurrence Interval	Mean Annual Flow	Bankfull Flow (Matrix)	2-Year	5-Year	10-Year	25-Year (June 16, 2015 Event)	50-Year	100-Year
Discharge (ft^3/s)	300	2,700	3,800	7,000	10,700	19,800	24,200	33,300

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Overview

History

Approach

Morphology

Alternatives

Criteria

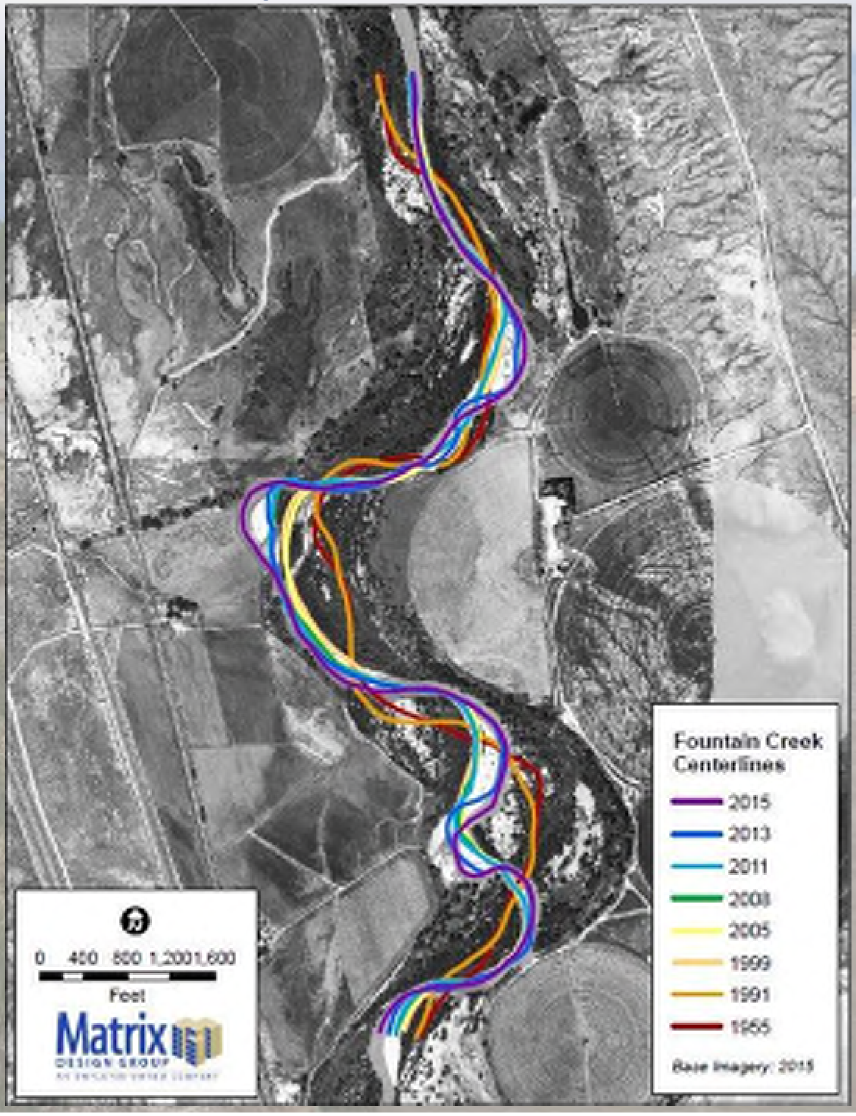
Modeling

Construction

Post-Construction

Morphology

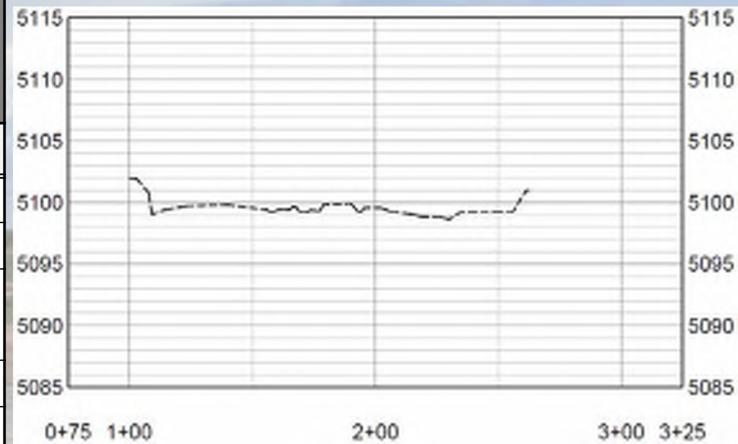
Impaired Reach

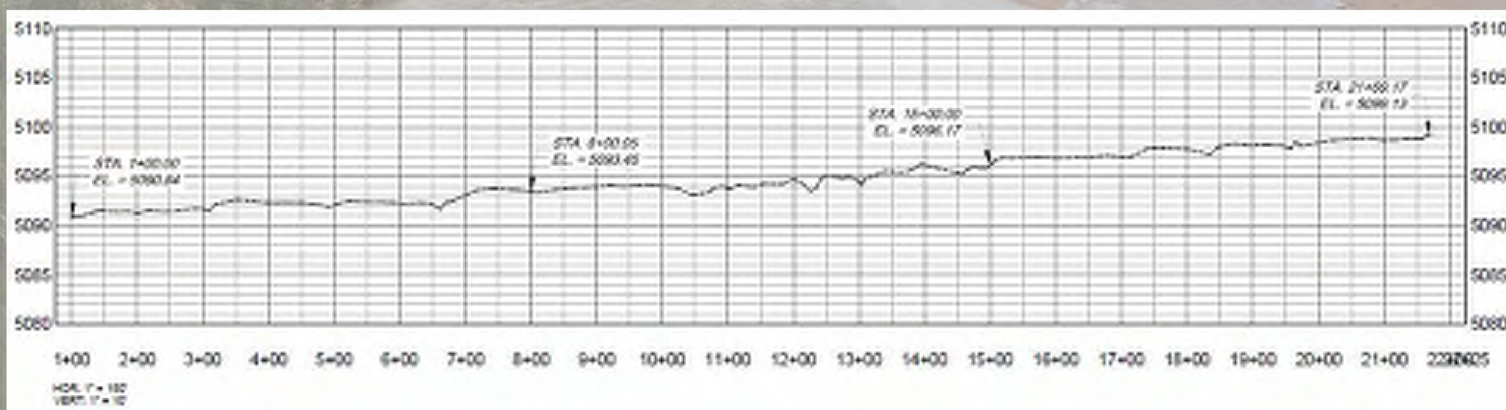


Morphology

Impaired Reach

IMPAIRED REACH EXISTING CONDITIONS	
DESCRIPTION	**VALUE**
TOTAL LENGTH	2,068 LF
BANKFULL WIDTH	161.4 LF
CROSS-SECTIONAL AREA	429.4 SQ FT
AVERAGE SLOPE	0.40%
AVULSION SLOPE	0.70%





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Morphology

Reference Reach

- Overview
- History
- Approach
- **Morphology**
- Alternatives
- Criteria
- Modeling
- Construction
- Post-Construction

Matrix DESIGN GROUP
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- Overview
- History
- Approach
- **Morphology**
- Alternatives
- Criteria
- Modeling
- Construction
- Post-Construction

Morphology

Departure Analysis

Dimension:

Parameter	Impaired Reach			Reference Reach		
	Min	Avg.	Max	Min	Avg.	Max
Area (ft.^{2})	380	389	398	431	505	639
Width (ft.)	163	188	213	145	157	178
Mean Depth (ft.)	1.8	2.2	2.5	2.5	3	4.4
Max Depth (ft.)	2.9	3.1	3.3	3.7	4	5.6
W/D (ft./ft.)	65	91.5	118	33	52	71

Pattern:

Parameter	Impaired Reach			Reference Reach		
	Min	Avg.	Max	Min	Avg.	Max
Radius of Curvature	375	375	375	520	522	524
Straight-way length	330	615	900	255	324	373
Sinuosity	1.7	1.7	1.7	1.2	1.2	1.2
Belt Width	960	960	960	760	760	760
Bend-way Length	850	850	850	664	794	923
Meander Wavelength	1996	1996	1996	1680	1680	1680
Bend to Bend	1400	1625	1850	1072	1072	1072

Profile:

Parameter	Impaired Reach	Reference Reach
Bankfull Slope (%)	0.4	0.3
Water Surface Slope (%)	0.4	0.3

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- Overview
- History
- Approach
  - Morphology
  - **Alternatives**
  - Criteria
  - Modeling
- Construction
- Post-Construction

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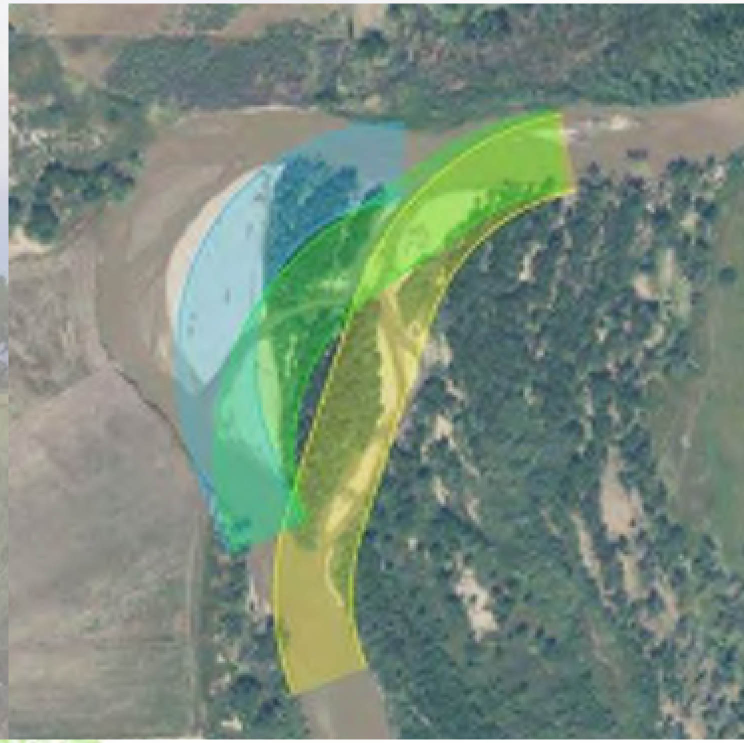
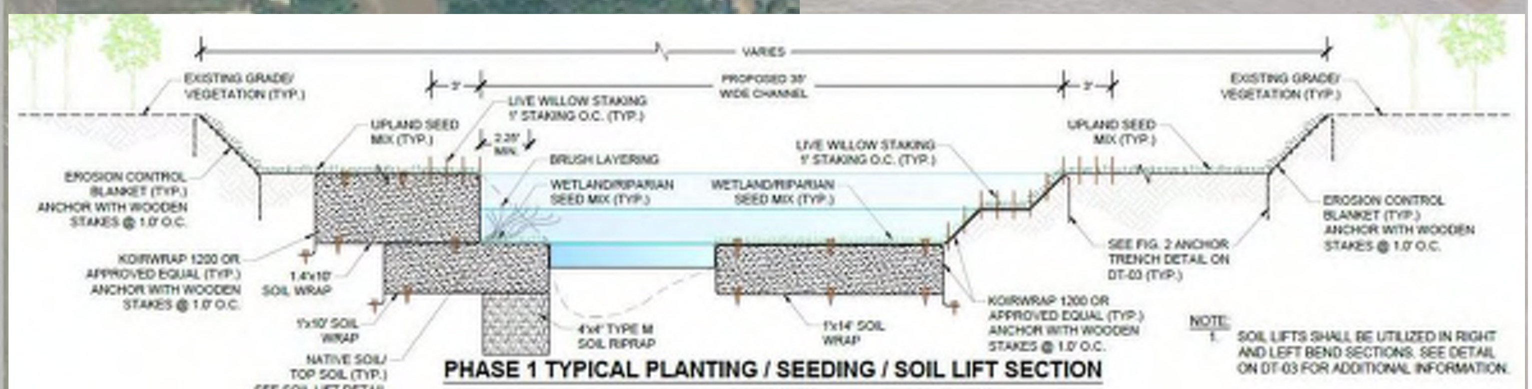
Alternatives



Design Considerations

- Creek Alignment
- Floodplain Grading

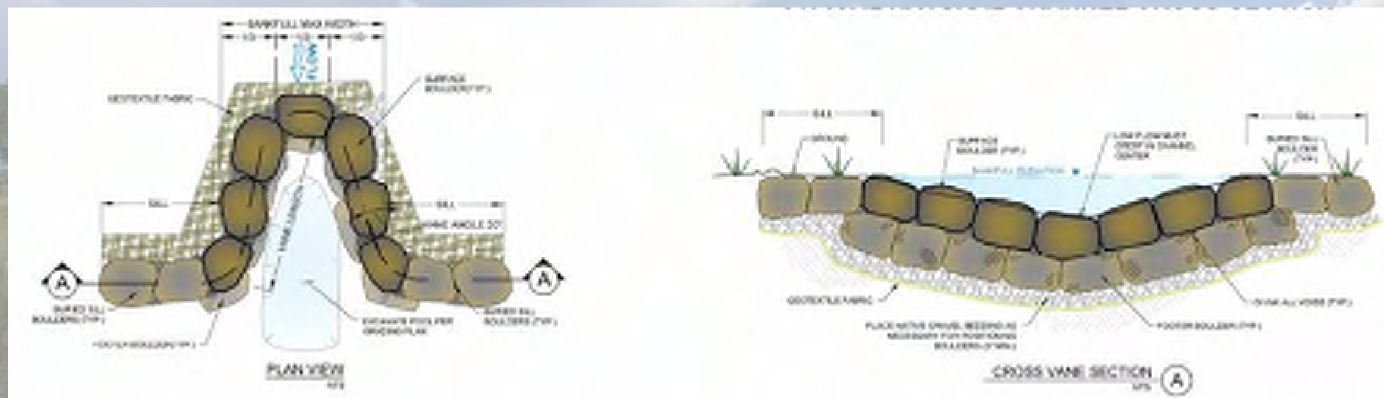


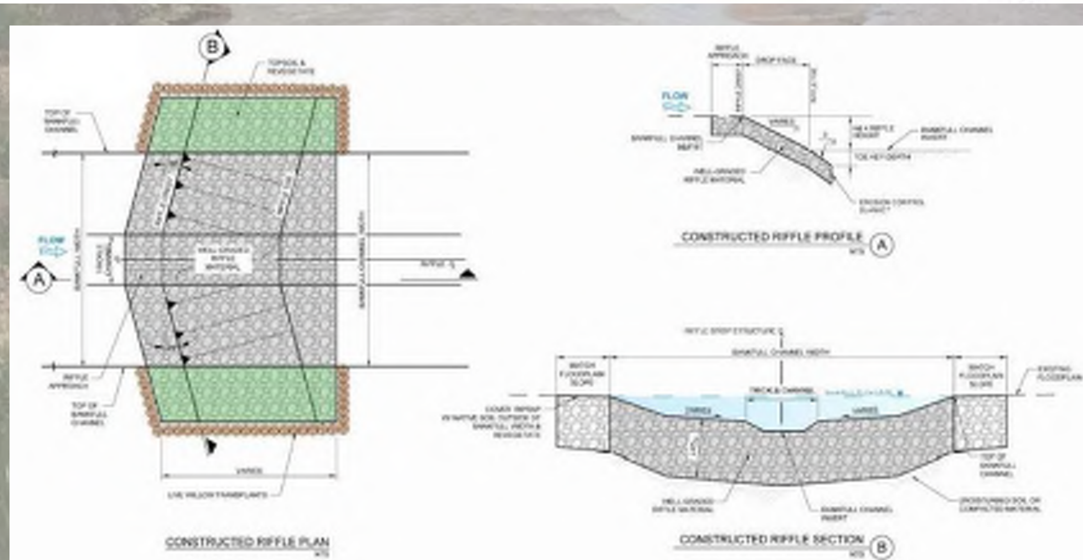
Overview
History
Approach
Morphology
Alternatives
Criteria
Modeling
Construction
Post-Construction

Alternatives

Design Considerations

- Grade Control





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Overview
History
Approach
Morphology
Alternatives
Criteria
Modeling
Construction
Post-Construction

Alternatives

Design Considerations

- Bank Protection
  - Bendway Weirs
  - Soil Riprap Toe
  - Grouted Boulder Toe
  - Debris Jams
  - Soil Cement
- Revegetation

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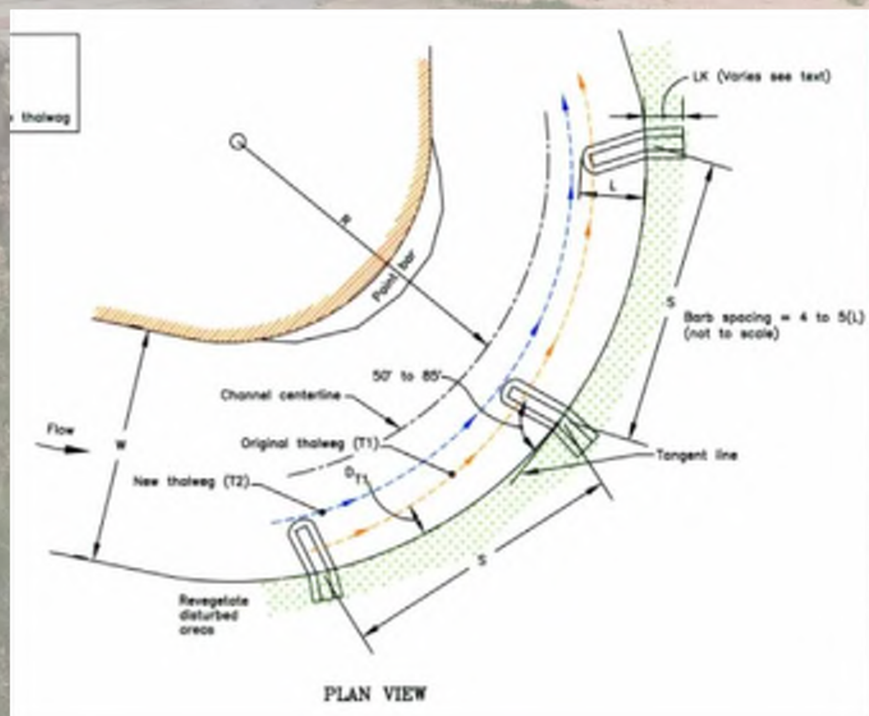
Alternatives

Selected Alternative

- Floodplain Grading and Bendway Weirs
- Bendway Weirs: low-elevation structures that are projected into the channel from a bank and angled upstream to redirect flow away from the bank and to control erosion. Typically constructed from rock, large woody debris or a combination of both.



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Overview

History

Approach

Morphology

Alternatives

Criteria

Modeling

Construction

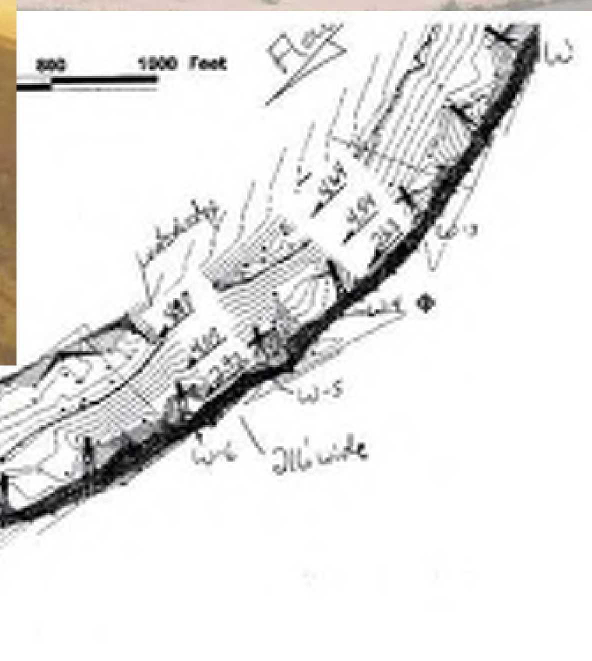
Post-Construction

Criteria

Bendway Weirs

- Numerous technical references

*Photo: Physical bendway weir model, Kinzli and Thornton (2009), CSU



*Sketch: Water velocities on Geffert River, Neosho River, KS, Balch, Derrick, and Emmert (2001)

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Criteria

Bendway Weirs

- Overview
- History
- Approach
  - Morphology
  - Alternatives
  - Criteria
  - Modeling
- Construction
- Post-Construction

- Wide range of design guidance parameters
  - Length
  - Height
  - Top Width
  - Spacing
  - Angle
  - Transverse Slope

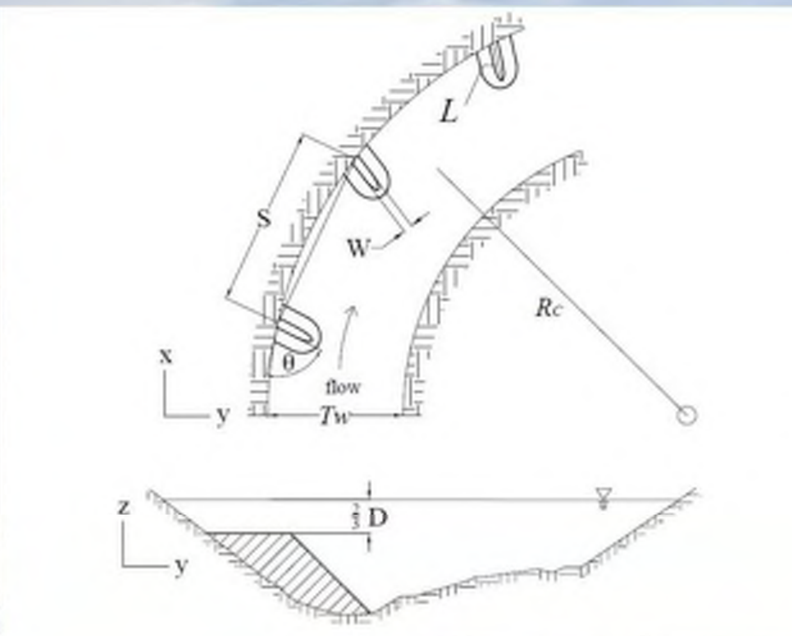

Table 1. Design guidelines for bendway weirs from literature (variables defined in Figure 1)

	Length		Height		Top width		Spacing		θ		Transverse slope	
Source	min	max	min	max	min	max	min	max	min	max	crest slope	transition
NCHRP Report 554, 2005	Tw/3	Tw/2	W/2	W	$2D_{100}$	$3D_{100}$	1.5L	1.5L	80	70	flat	flat
HEC-23, Design Guideline 1, 2009*	Tw/10*	Tw/3*	0.3 BF**	0.5 BF**	$2D_{100}$	$3D_{100}$	4L	5L	60	85	flat	1V:5H
Julien and Duncan, 2003	longer is better		max permitting navigation		none	none	2L	3L	60	60	none	none

**HEC-23 further recommends structure length to cross the stream thalweg

**HEC-23 further recommends structure height to fall between annual mean flow and annual low flow water surface elevations

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Modeling

Existing Hydraulics

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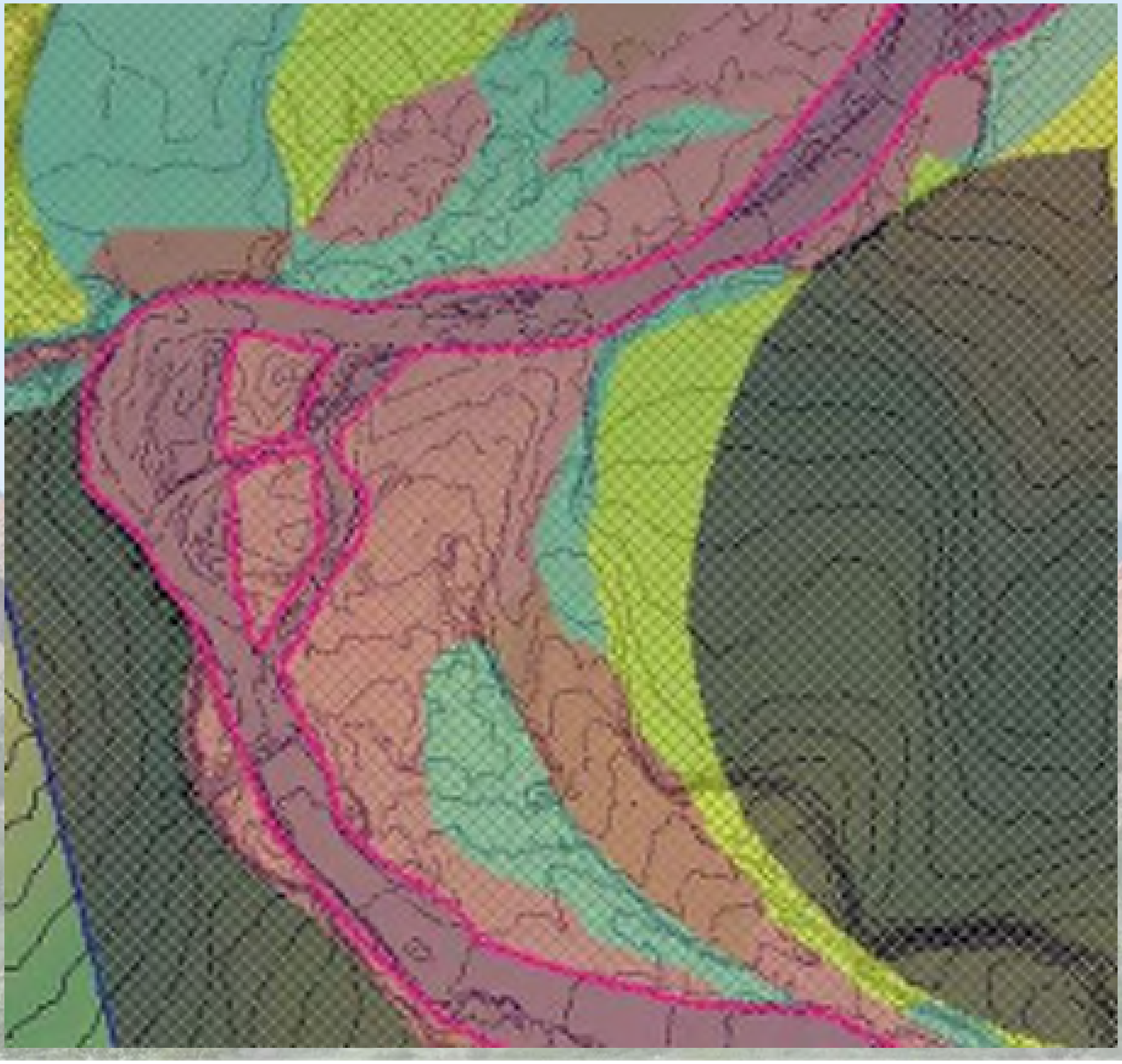
Modeling

Existing Hydraulics



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Overview

History

Approach

Morphology

Alternatives

Criteria

Modeling

Construction

Post-Construction

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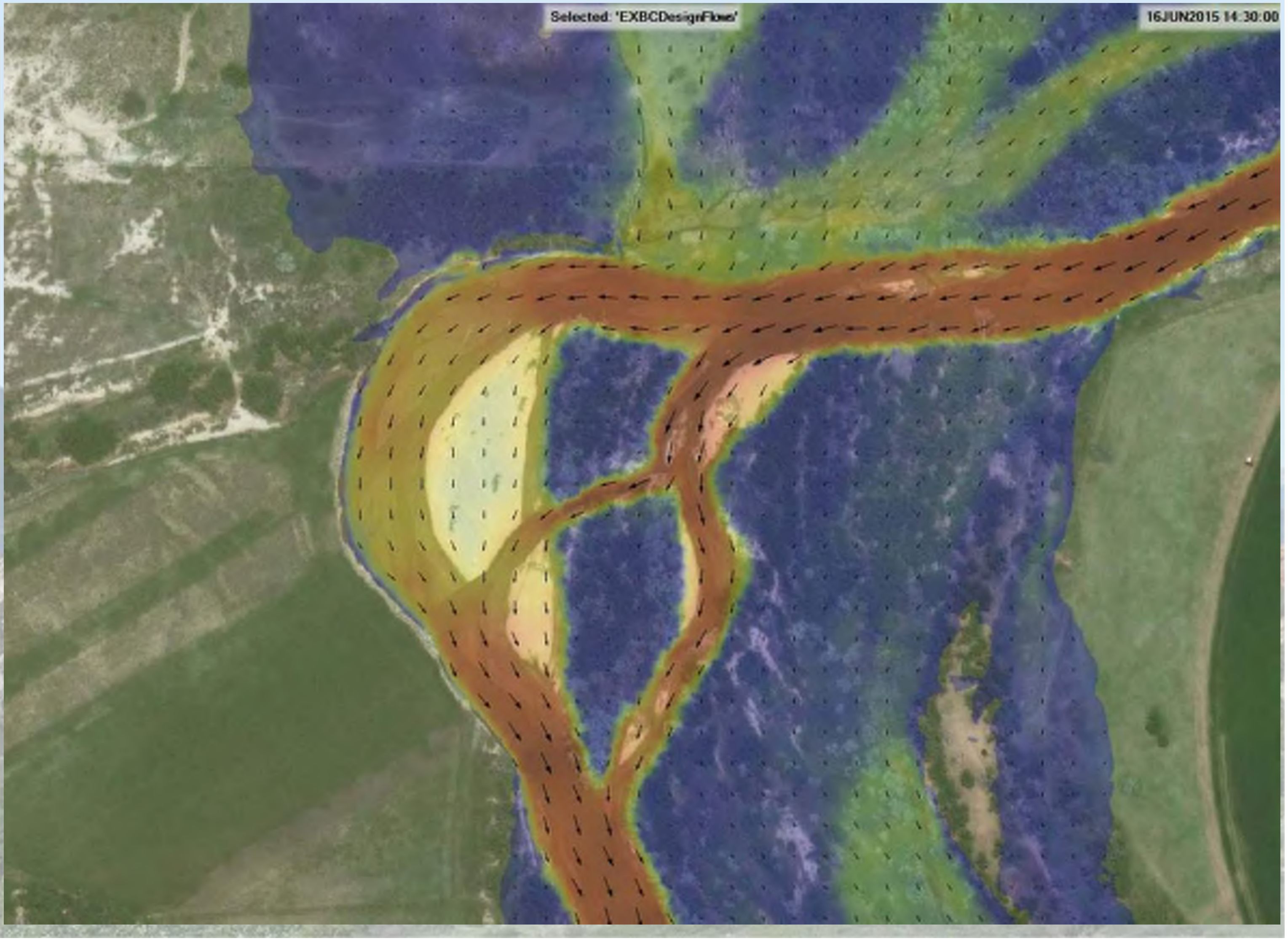
Modeling

Existing Hydraulics



Overview

History

Approach

Morphology

Alternatives

Criteria

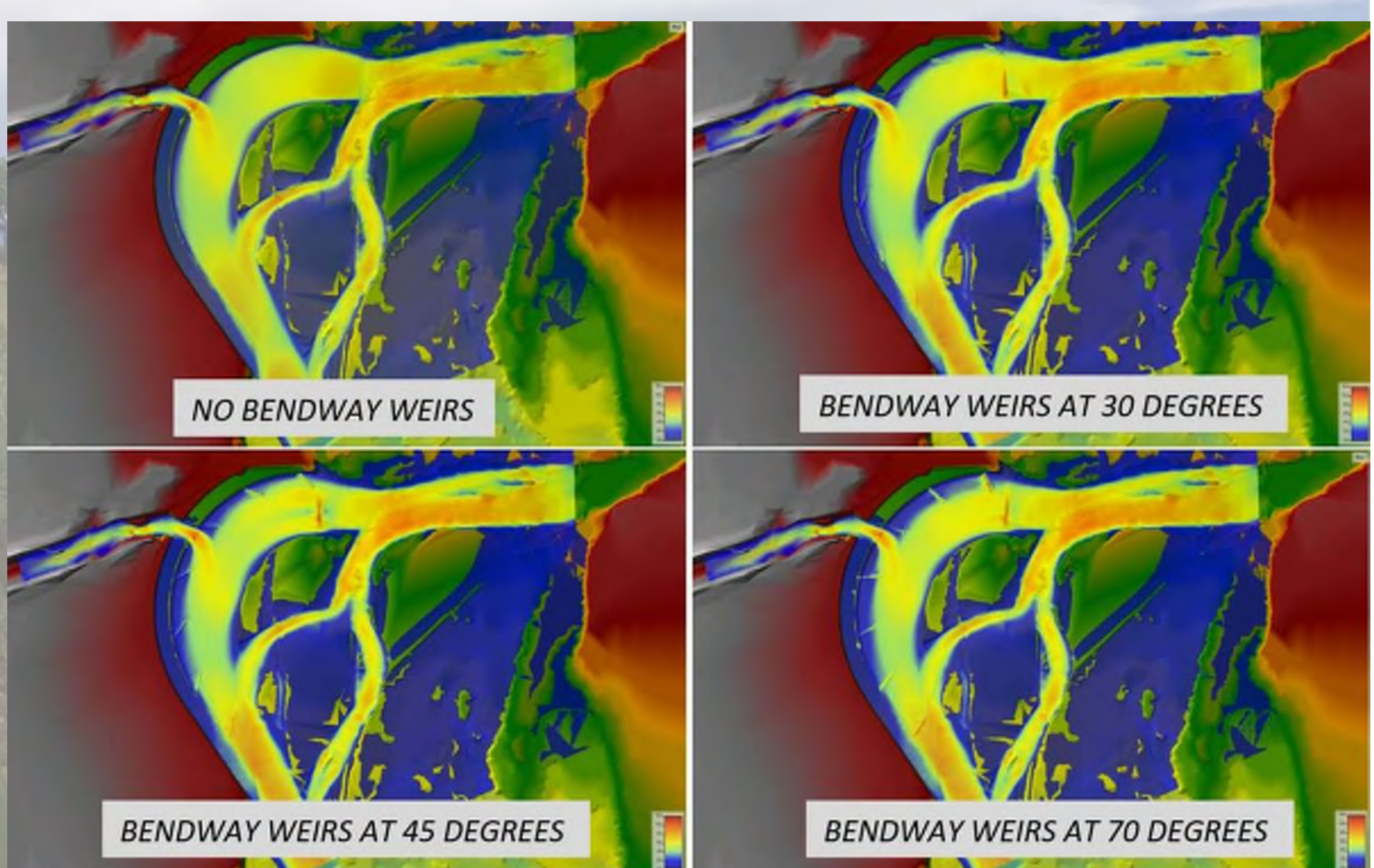
Modeling

Construction

Post-Construction

Modeling

Bendway Weir Analysis



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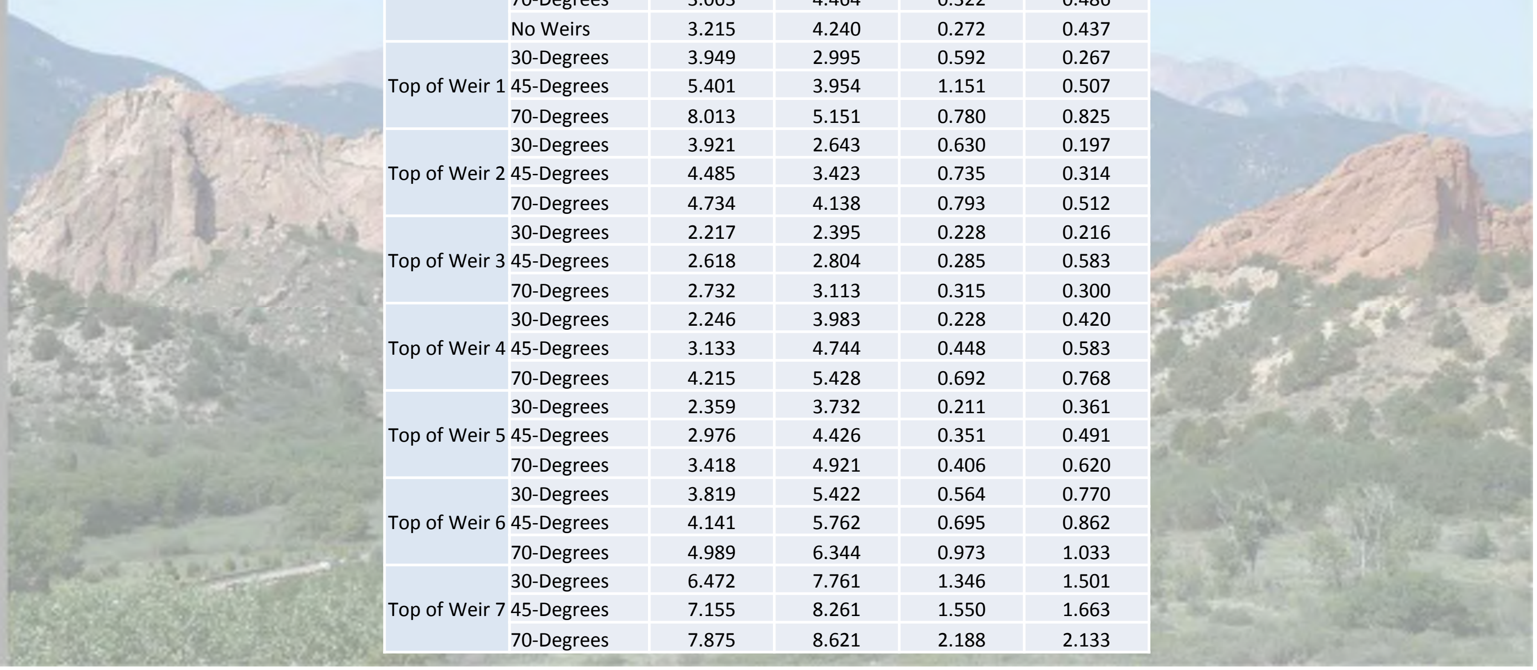
- Overview
- History
- Approach
  - Morphology
  - Alternatives
  - Criteria
  - **Modeling**
- Construction
- Post-Construction

Modeling

Bendway Weir Angle Analysis

Location	Weir Angle	Average Velocity (ft/s)		Average Shear Stress (lb/sq ft)	
		Storm Event		Storm Event	
		Bankfull	10-Year	Bankfull	10-Year
Toe of US Bank	30-Degrees	0.010	0.405	0.001	0.066
	45-Degrees	0.006	0.427	0.001	0.066
	70-Degrees	0.007	0.465	0.001	0.070
	No Weirs	0.002	0.451	0.000	0.045
Toe of DS Bank	30-Degrees	1.101	2.496	0.096	0.386
	45-Degrees	1.122	2.512	0.102	0.398
	70-Degrees	1.135	2.505	0.100	0.388
	No Weirs	0.355	3.008	0.063	0.418
Toe of Bench	30-Degrees	3.105	4.432	0.338	0.491
	45-Degrees	3.086	4.474	0.329	0.481
	70-Degrees	3.063	4.464	0.322	0.486
	No Weirs	3.215	4.240	0.272	0.437
Top of Weir 1	30-Degrees	3.949	2.995	0.592	0.267
	45-Degrees	5.401	3.954	1.151	0.507
	70-Degrees	8.013	5.151	0.780	0.825
Top of Weir 2	30-Degrees	3.921	2.643	0.630	0.197
	45-Degrees	4.485	3.423	0.735	0.314
	70-Degrees	4.734	4.138	0.793	0.512
Top of Weir 3	30-Degrees	2.217	2.395	0.228	0.216
	45-Degrees	2.618	2.804	0.285	0.583
	70-Degrees	2.732	3.113	0.315	0.300
Top of Weir 4	30-Degrees	2.246	3.983	0.228	0.420
	45-Degrees	3.133	4.744	0.448	0.583
	70-Degrees	4.215	5.428	0.692	0.768
Top of Weir 5	30-Degrees	2.359	3.732	0.211	0.361
	45-Degrees	2.976	4.426	0.351	0.491
	70-Degrees	3.418	4.921	0.406	0.620
Top of Weir 6	30-Degrees	3.819	5.422	0.564	0.770
	45-Degrees	4.141	5.762	0.695	0.862
	70-Degrees	4.989	6.344	0.973	1.033
Top of Weir 7	30-Degrees	6.472	7.761	1.346	1.501
	45-Degrees	7.155	8.261	1.550	1.663
	70-Degrees	7.875	8.621	2.188	2.133

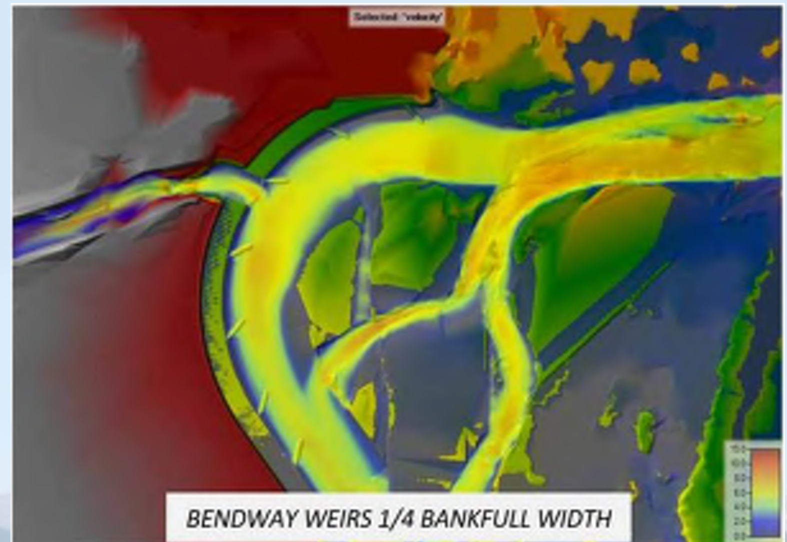


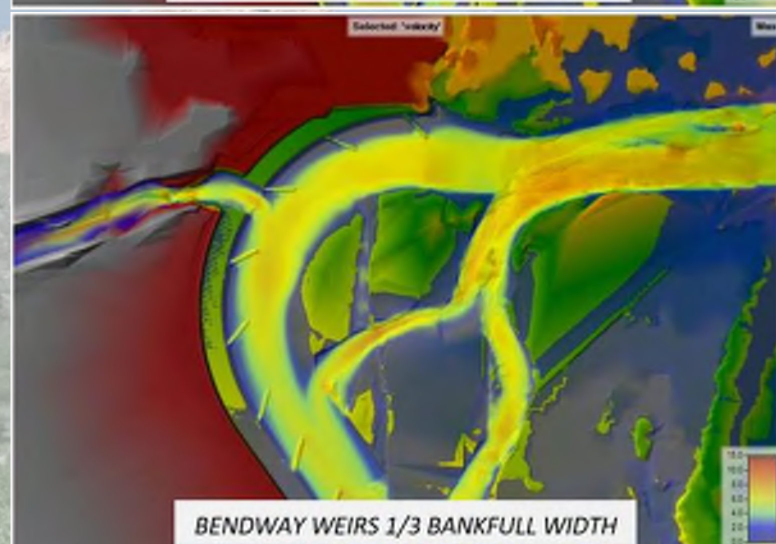
Matrix DESIGN GROUP
AN EMPLOYEE-OWNED COMPANY

Overview
History
Approach
Morphology
Alternatives
Criteria
Modeling
Construction
Post-Construction

Modeling

Bendway Weir Length Analysis





Overview

History

Approach

Morphology

Alternatives

Criteria

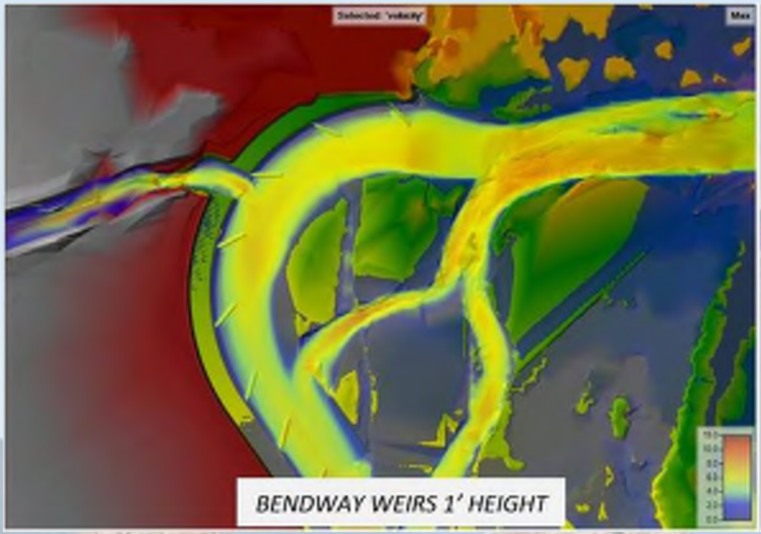
Modeling

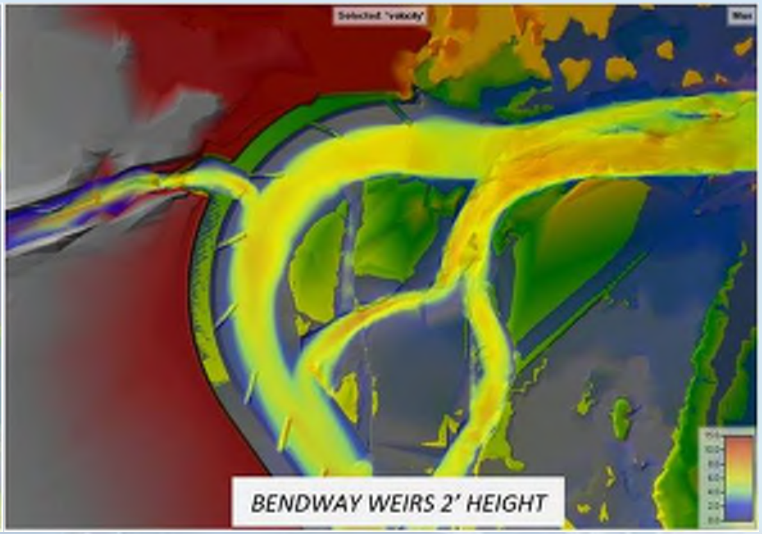
Construction

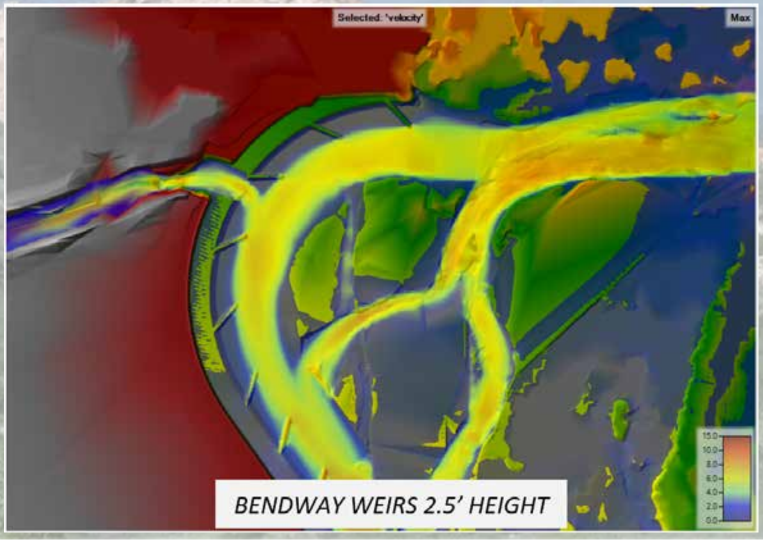
Post-Construction

Modeling

Bendway Weir Height Analysis







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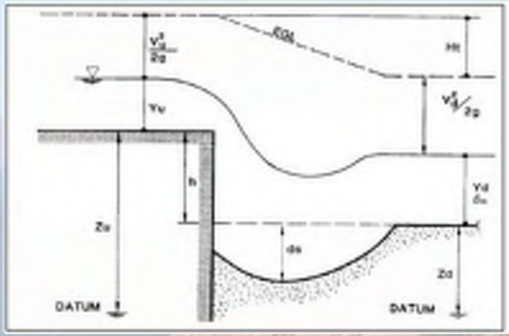
Modeling

Scour Analysis

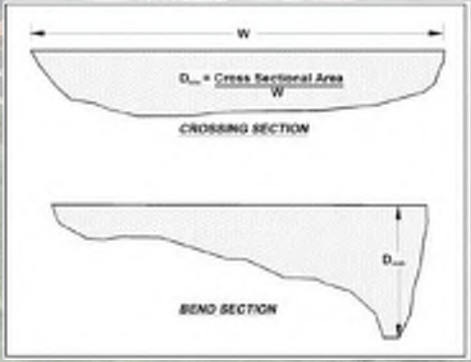
- Bedform Scour (Simons and Richardson 1966)
  - Max = 3.4ft

Figure 9. Bed form scour graphic

- Local Scour (Simons and Richardson 1966)
  - Max = 1.2ft



- Bendway Scour (HEC-23)
  - Max = 7.6ft
- Scour at Transverse Structures (HEC-23)
  - Max = 15.7ft



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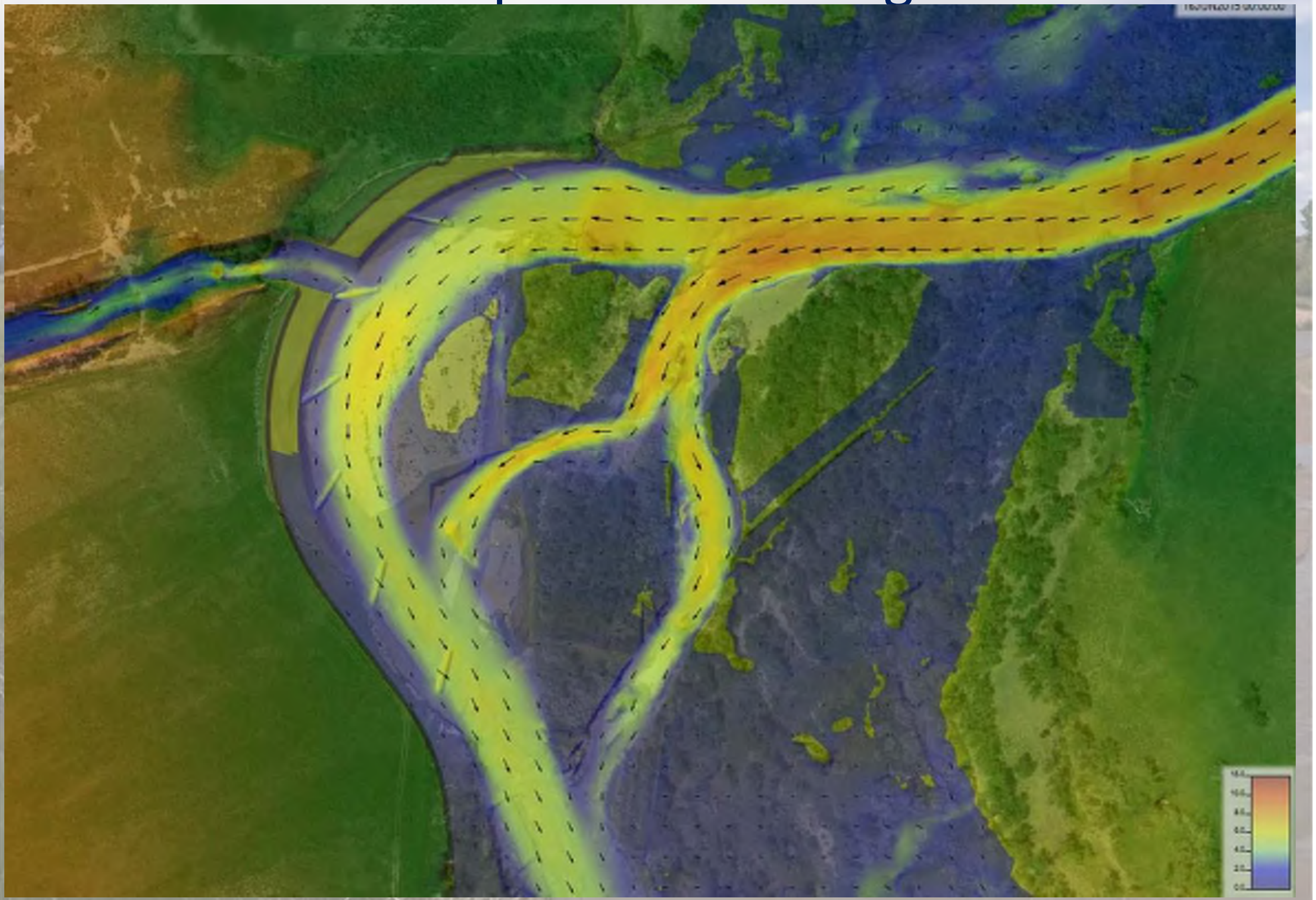
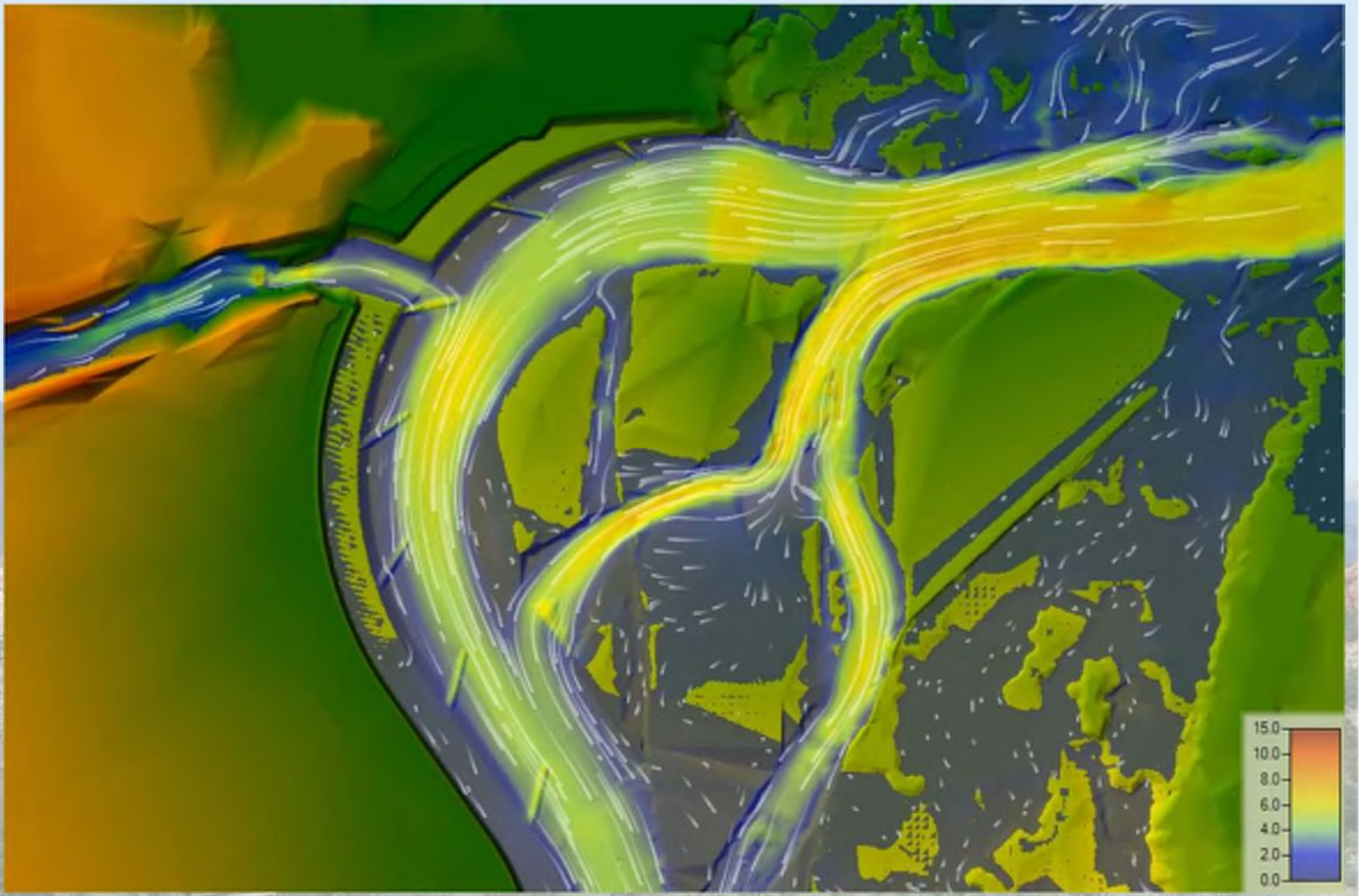
Modeling

Proposed Modeling



Modeling

Proposed Design



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- Overview
- History
- Approach
- Morphology
- Alternatives
- Criteria
- Modeling
- **Construction**
- Post-Construction

Matrix DESIGN GROUP
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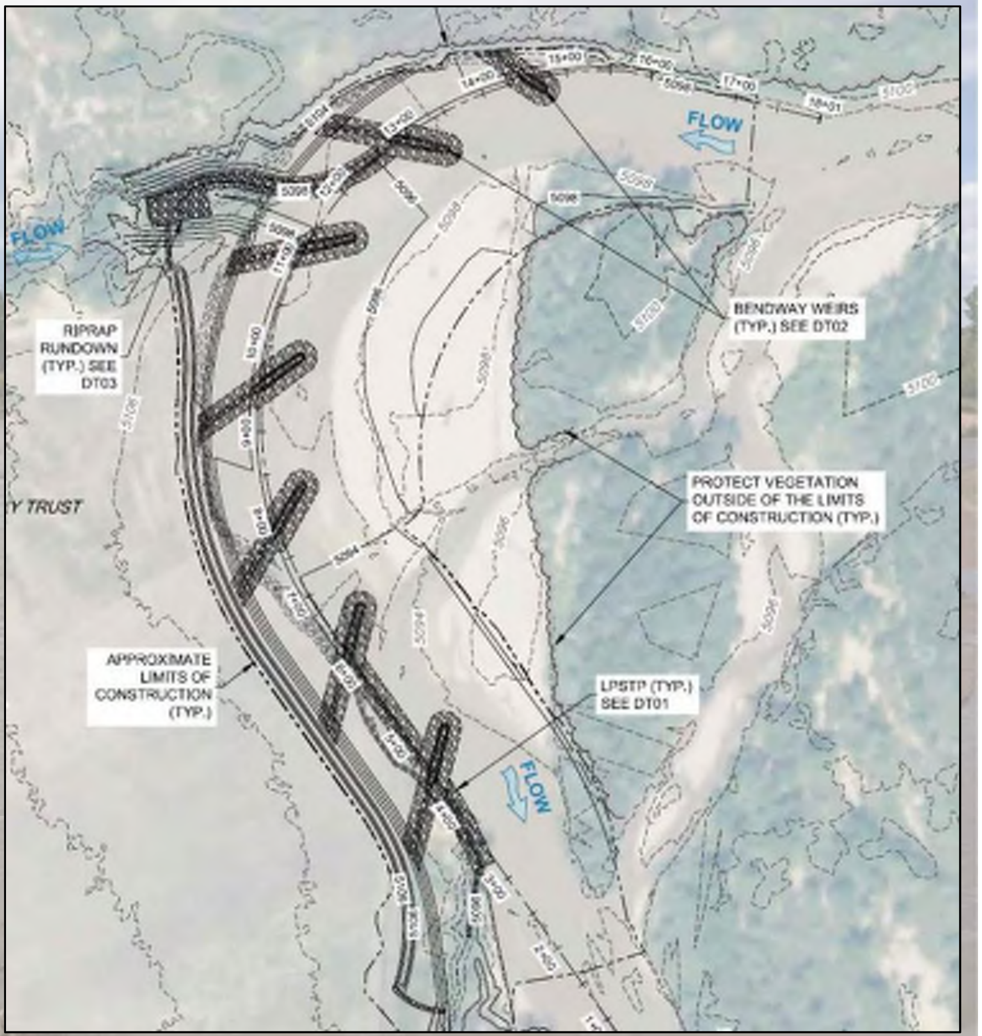
Final Design

Design Elements

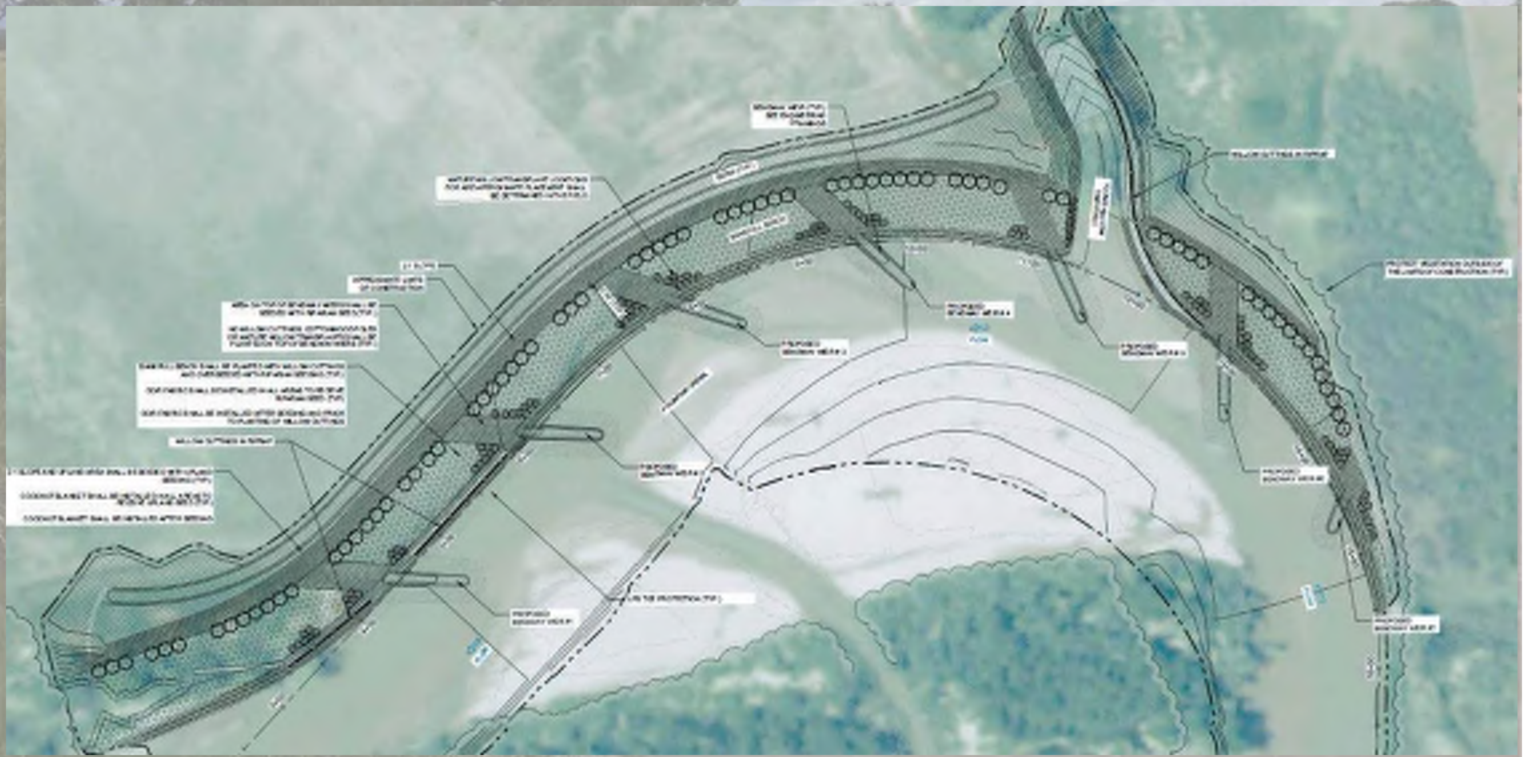
- Bendway Weirs
  - D50 = 36” Void Filled Riprap
  - Length = 70’
  - Top Width = 6’
  - Spacing = 170’
  - Angle = 50^{o}
  - Transverse Slope ~1.5%
  - Depth = 9’
- Bankfull Bench
- Longitudinal Peaked Stone Toe Protection



Final Design

Revegetation

- Willow Cuttings – 6,000
- Willow Transplants – 116
- Cottonwood Poles – 76
- Riparian Seeding – 1.4 acres
- Upland seeding – 1.13 acres



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Construction

Overview

- October 2017 through April 2018
- Total Cost: $1.7 million
- 10,900 Tons of Rock for the Weirs
- 5,300 Willows Planted

- Overview
- History
- Approach
  - Morphology
  - Alternatives
  - Criteria
  - Modeling
- Construction
- Post-Construction

Matrix DESIGN GROUP
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Construction

Matrix DESIGN GROUP
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Construction

Overview

History

Approach

Morphology

Alternatives

Criteria

Modeling

Construction

Post-Construction

Matrix DESIGN GROUP
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Construction

- Overview
- History
- Approach
  - Morphology
  - Alternatives
  - Criteria
  - Modeling
- **Construction**
- Post-Construction

Matrix DESIGN GROUP
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Construction

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Construction

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AN EMPLOYEE-OWNED COMPANY

Construction

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Construction

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Construction

Overview
History
Approach
Morphology
Alternatives
Criteria
Modeling
Construction
Post-Construction

Construction

Matrix DESIGN GROUP

AN EMPLOYEE-OWNED COMPANY

Construction

Post - Construction

Overview
History
Approach
Morphology
Alternatives
Criteria
Modeling
Construction
Post-Construction

Matrix DESIGN GROUP
AN EMPLOYEE-OWNED COMPANY

Post - Construction

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Post - Construction

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Post - Construction

Post - Construction

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Post - Construction

Post - Construction

Post - Construction

Overview

History

Approach

Morphology

Alternatives

Criteria

Modeling

Construction

Post-Construction

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Questions

COLORADO
Department of Transportation

Quantifying Climate Change Impacts on Flood Hydrology using Global Climate Models to Adjust NOAA Atlas 14 Precipitation Depths

CASFM Annual Conference
Snowmass Village, CO
September 25-28, 2018

Derek Rapp, P.E., CFM (*Muller Engineering, Project Mgr.*)

Jim Wulliman, P.E. (*Muller Engineering, Program Mgr.*)

Brian K. Varrella, P.E., CFM (*Colorado DOT Reg. 4 Hydraulics Lead*)

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Climate Change Impacts on Flood Hydrology

Disclaimer:

This information presented herein is preliminary, and has not been reviewed for quality assurance or control purposes by federal or state partners (Sept. 2018).

Source:
Varrella, 2016

Climate Change Impacts on Flood Hydrology

Discussion Agenda:

1. ***CMIP Climate Projections***
2. Initial Results & Impressions
3. HEC-17 Guidance and Tool Development
4. CMIP Tool Results
5. Summary

Photo: Varrella, 2016

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CMIP Climate Projections

Before We Begin; *Initial Impressions*:

1. *Complex process!*
2. *Whole new language of terminology and acronyms*
3. *Research is truly international in scope*
4. *Incredible amount of information and different options to sort through*
5. *Results may generate more questions than answers*
6. *No definitive conclusions yet…*

CMIP Climate Projections

Objective:

The goal of this research project is to understand how to best utilize the climate projection datasets available online when evaluating potential impacts of climate change on infrastructure planning, design and construction. The US DOT CMIP Climate Data Processing Tool along with internally developed spreadsheets (based on HEC-17 guidance) are being used to extract raw climate projection data from various scenarios and to evaluate annual maximum precipitation depths. These results are then being compared with NOAA Atlas 14 point precipitation frequency estimates in an attempt to understand future trends relative to flood events.

CMIP Climate Projections

Acknowledgements:

We would like to acknowledge the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the World Climate Research Programme's (WCRP's) Working Group on Coupled Modelling (WGCM) for their roles in making available the WCRP's Coupled Model Intercomparison Project (CMIP) Phase 3 and Phase 5 multi-model datasets (CMIP3 and CMIP5). We also thank the climate modeling groups on the next slide for producing and making available their model output. For CMIP the U.S. Department of Energy's PCMDI office provides coordinating support and led the development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

The climate projection datasets were downloaded from the "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" archive at **http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/**.

CMIP Climate Projections

Acknowledgements: CMIP3 (14 International Models)

Climate Modeling Group
Bjerknes Centre for Climate Research, Norway
Canadian Centre for Climate Modeling and Analysis, Canada
Meteo-France/Centre National de Recherches Meteorologiques, France
Commonwealth Scientific and Industrial Research Organization, Atmospheric Research, Australia
U.S. Dept. of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory, USA
NASA/Goddard Institute for Space Studies, USA
Institute for Numerical Mathematics, Russia
Institut Pierre-Simon Laplace, France
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change, Japan
Meteorological Institute of the University of Bonn, Meteorological Research Institute of the Korean Meteorological Association, Germany/Korea
Max Planck Institute for Meteorology, Germany
Meteorological Research Institute, Japan
National Center for Atmospheric Research, USA
Hadley Centre for Climate Prediction and Research/Met Office UK

CMIP Climate Projections

Acknowledgements: CMIP5 (22 International Models)

Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology, Australia
Beijing Climate Center, China Meteorological Administration
College of Global Change and Earth System Science, Beijing Normal University
Canadian Centre for Climate Modeling and Analysis
National Center for Atmospheric Research
Community Earth System Model Contributors
Centro Euro-Mediterraneo per I Cambiamenti Climatici
Centre National de Recherches Meteorologiques/Centre Europeen de Recherche et Formation Avancee en Calcul Scientifique
Commonwealth Scientific and Industrial Research Organization, Queensland Climate Change Centre of Excellence
EC-Earth Consortium, representing 22 academic institutions and meterological services from 10 countries in Europe
Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences
The First Institute of Oceanography, State Oceanic Administration, China
NOAA Geophysical Fluid Dynamics Library
NASA/Goddard Institute for Space Studies, USA
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)
Institute for Numerical Mathematics
Institut Pierre-Simon Laplace
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
Max-Planck-Institut fur Meteorologie (Max-Plancke-Institute for Meteorology)
Meteorological Research Institute
Norwegian Climate Centre

CMIP Climate Projections

Background on Climate Projection Models:

- The online archive contains fine spatial resolution translations of climate projections over the U.S. developed using 3 downscaling techniques (monthly BCSD, daily BCCA, and daily LOCA).
- The archive is meant to provide access to climate projections at spatial and temporal scales relevant to watershed-scale decisions facing water resource managers and planners such as impacts of climate change on flood hydrology.

CMIP – Coupled Model Intercomparison Project

BCSD – Bias-Correction Spatial Disaggregation

BCCA – Bias-Correction Constructed Analogs

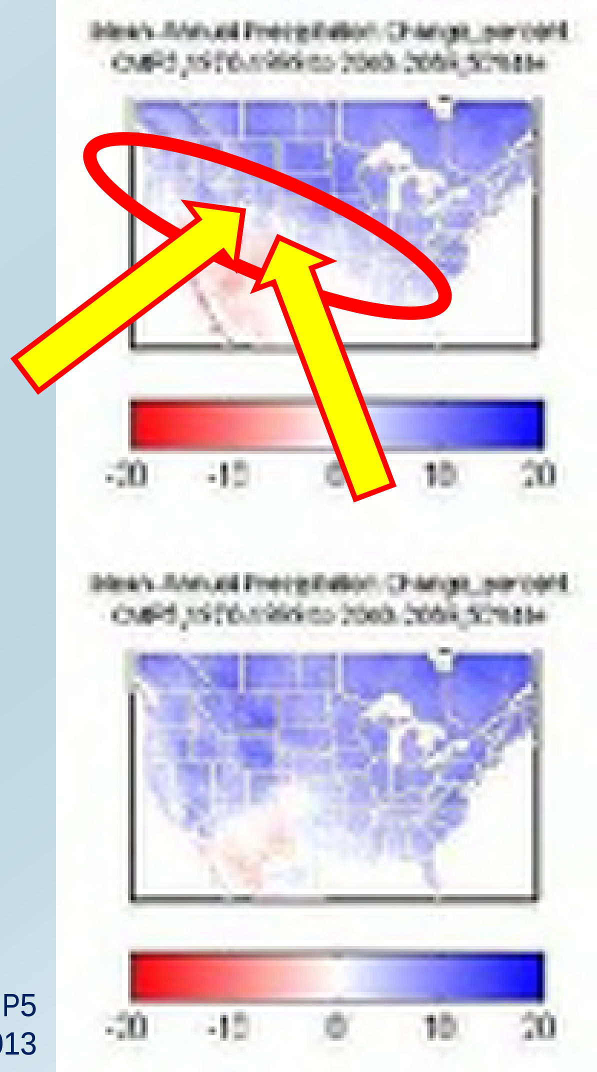
LOCA – Localized Constructed Analogs

CMIP Climate Projections

Mean Annual Precipitation

% change between observed and projected

- CMIP3 (Phase 3 – released 2007)
- CMIP5 (Phase 5 – released 2013)
- Observed Period (1970-1999)
- Projected Period (2040-2069)
- Southwest U.S. differs in Phases 3 and 5
- Colorado is on the boundary (white area)

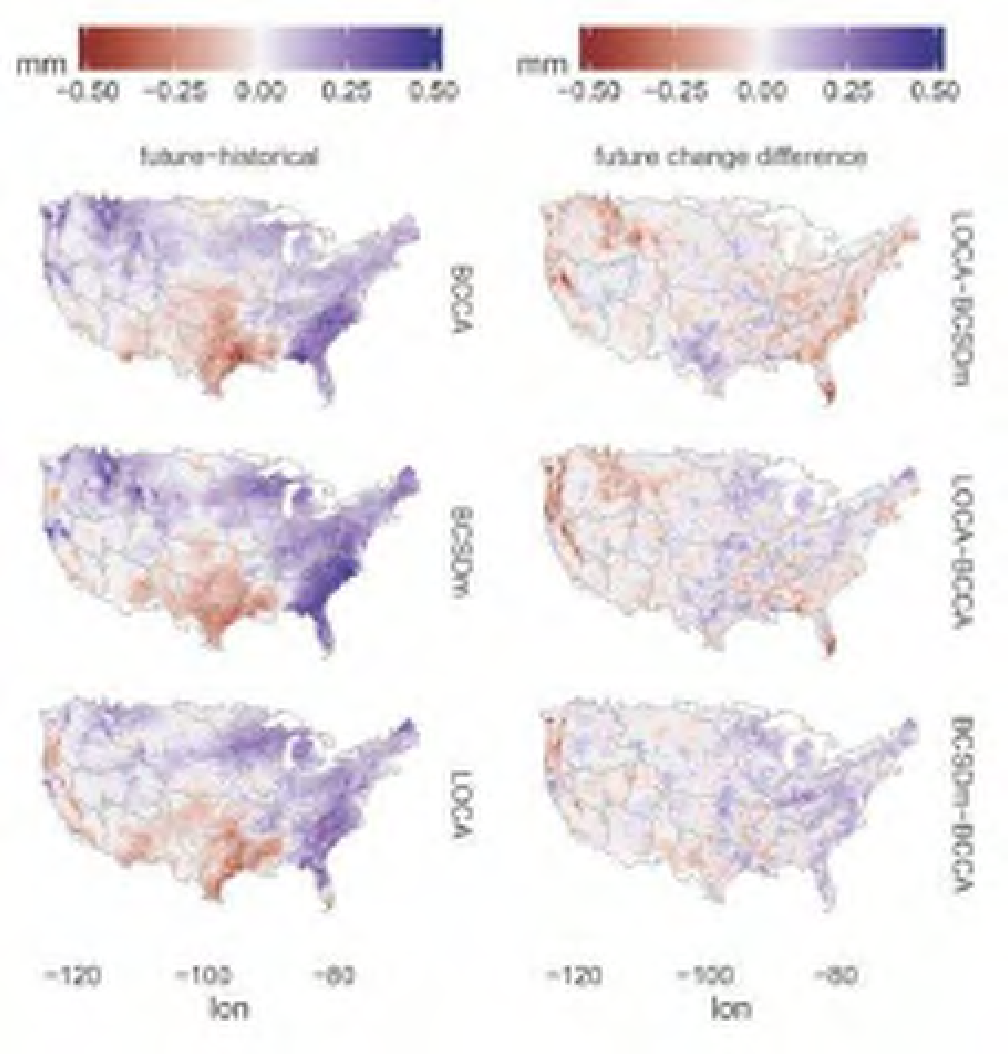


Bureau of Reclamation, Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections, *Tech rep.*, *May* 2013

CMIP Climate Projections

<u>Mean Daily Precipitation:</u>

- Observed Period (1970-1999)
- Projected Period (2040-2069)
- BCCA vs. BCSD vs. LOCA
- Slight variations throughout the country but Colorado is consistent in all projections.

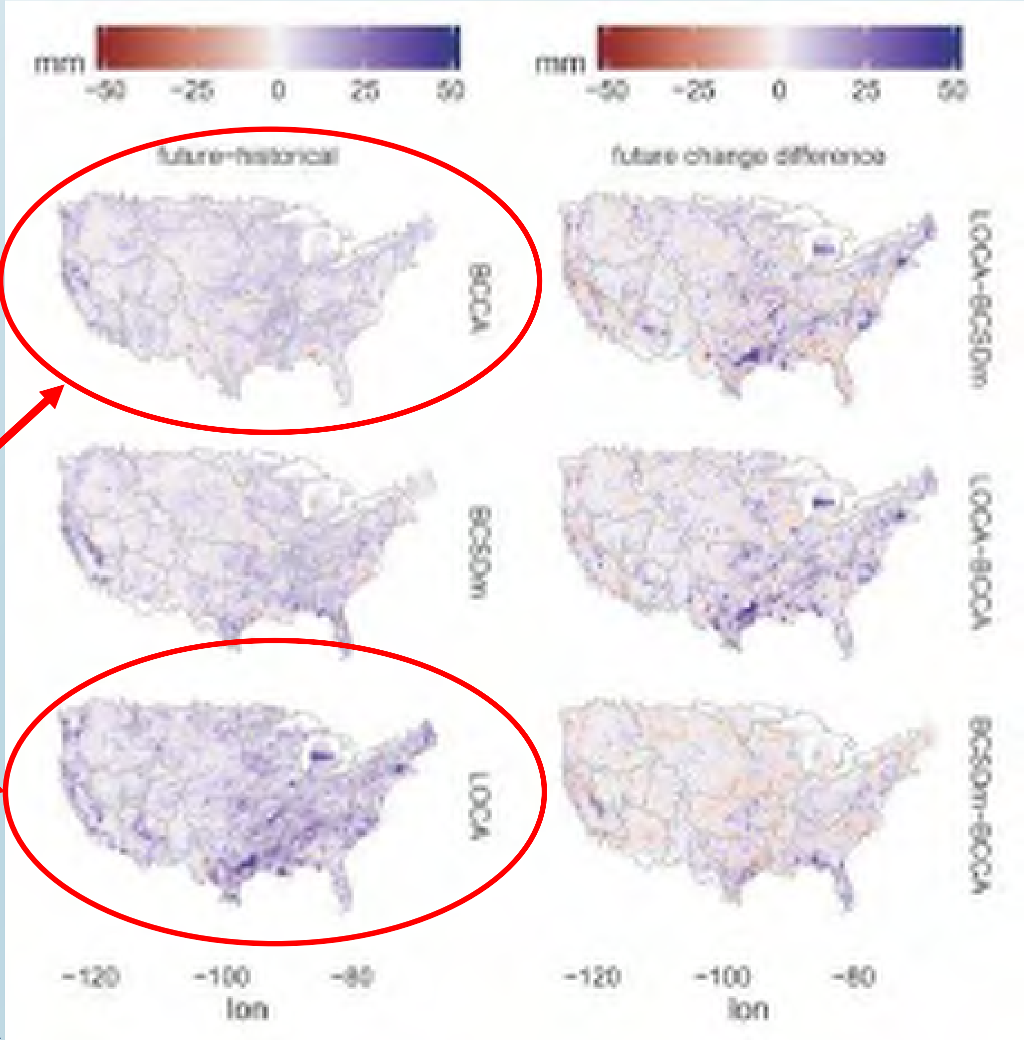


Bureau of Reclamation, Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections - Addendum, *Tech rep., Sept 2016*

CMIP Climate Projections

Maximum <u>Daily</u> Precipitation

- Observed Period (1970-1999)
- Projected Period (2040-2069)
- BCCA vs. BCSD vs. LOCA
- BCCA does not show much change in max depth
- LOCA able to project more extreme precipitation events.



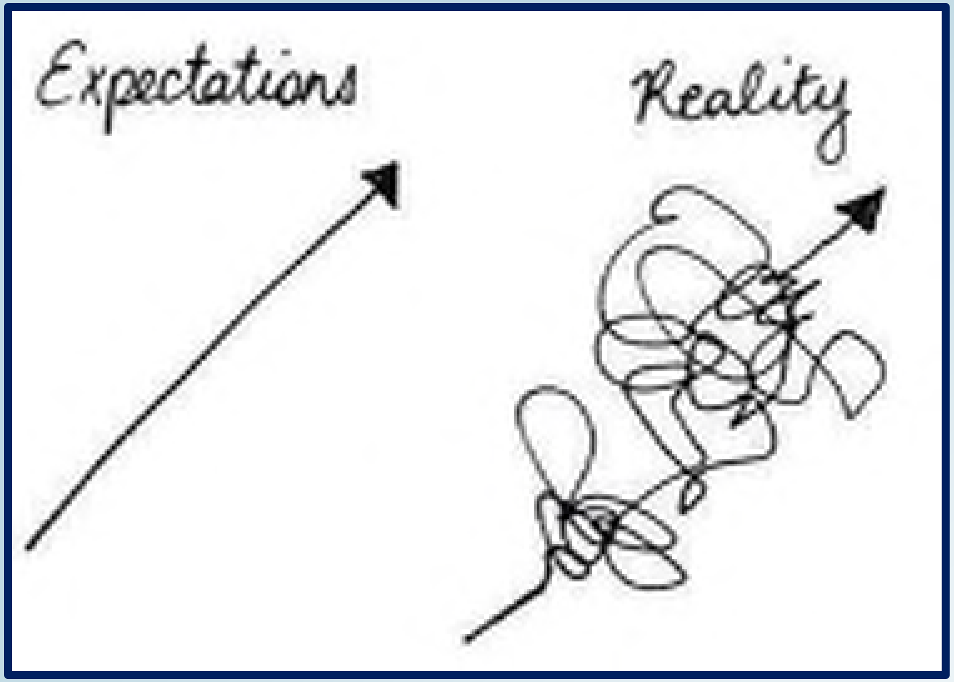
Bureau of Reclamation, Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections - Addendum, *Tech rep., Sept 2016*

Climate Change Impacts on Flood Hydrology

Discussion Agenda:

1. CMIP Climate Projections
2. ***Initial Results & Impressions***
3. HEC-17 Guidance and Tool Development
4. CMIP Tool Results
5. Summary

Doodle by Jessica Hagy, @JessicaHagy, 2014



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Initial Results & Impressions

- **New Acronyms and Terminology**

CMIP – Coupled Model Inter-comparison Project *(primary dataset)*

WGCM – Working Group on Coupled Modeling *(source of dataset)*

CDPT – Climate Data Processing Tool *(excel spreadsheet)*

BCSD – Bias-Correction Spatial Disaggregation *(monthly data – not used)*

BCCA – Bias-Correction Constructed Analogs *(daily data - CMIP3, CMIP5)*

CMIP3 - CMIP Phase 3 dataset *(released 2007, 14 international models)*

CMIP5 - CMIP Phase 5 dataset *(released 2013, 22 international models)*

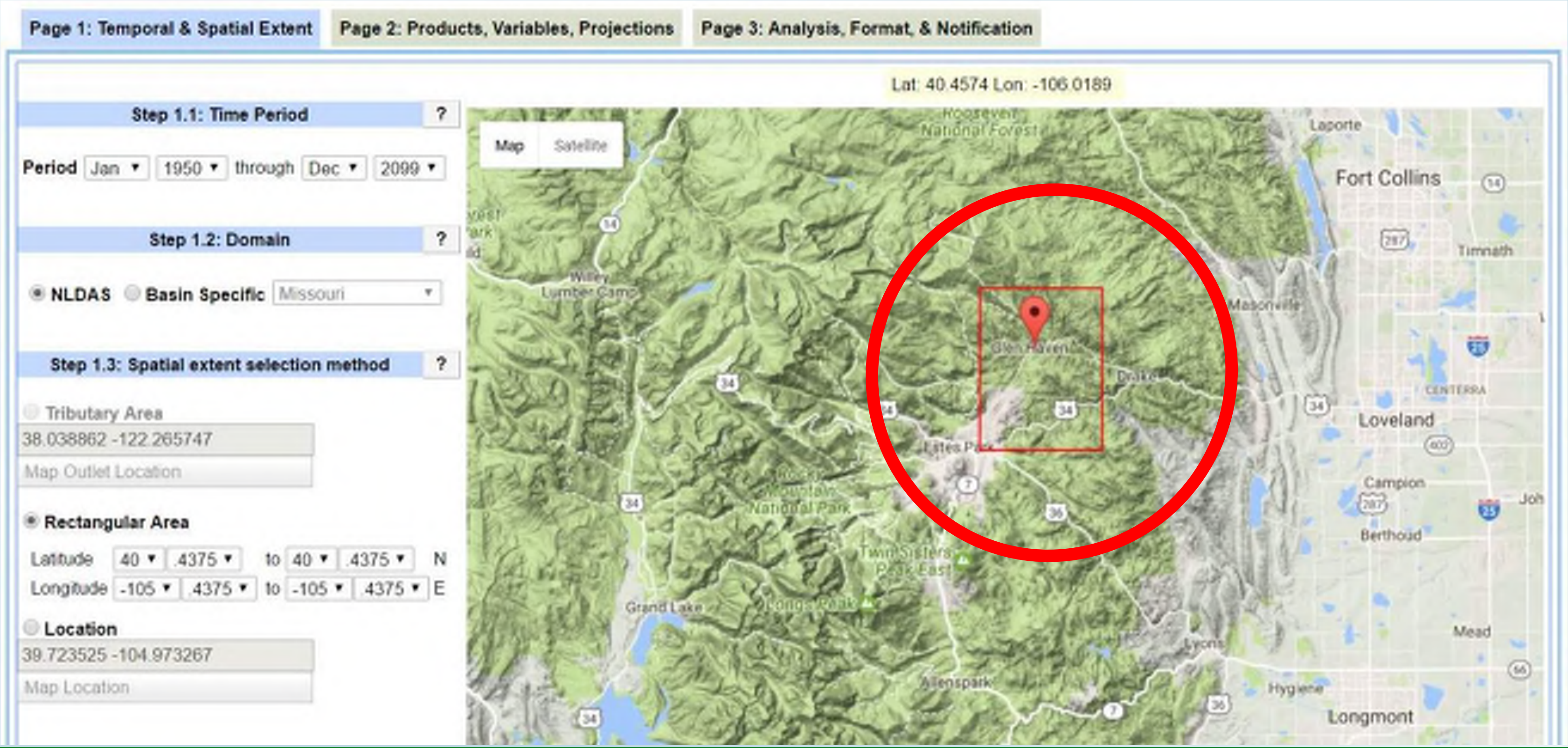
LOCA – Localized Constructed Analogs *(promising data, but can't import)*

RCP – Representative Concentration Pathways (emission scenarios)

Initial Results & Impressions

Request Process – *Select Location*

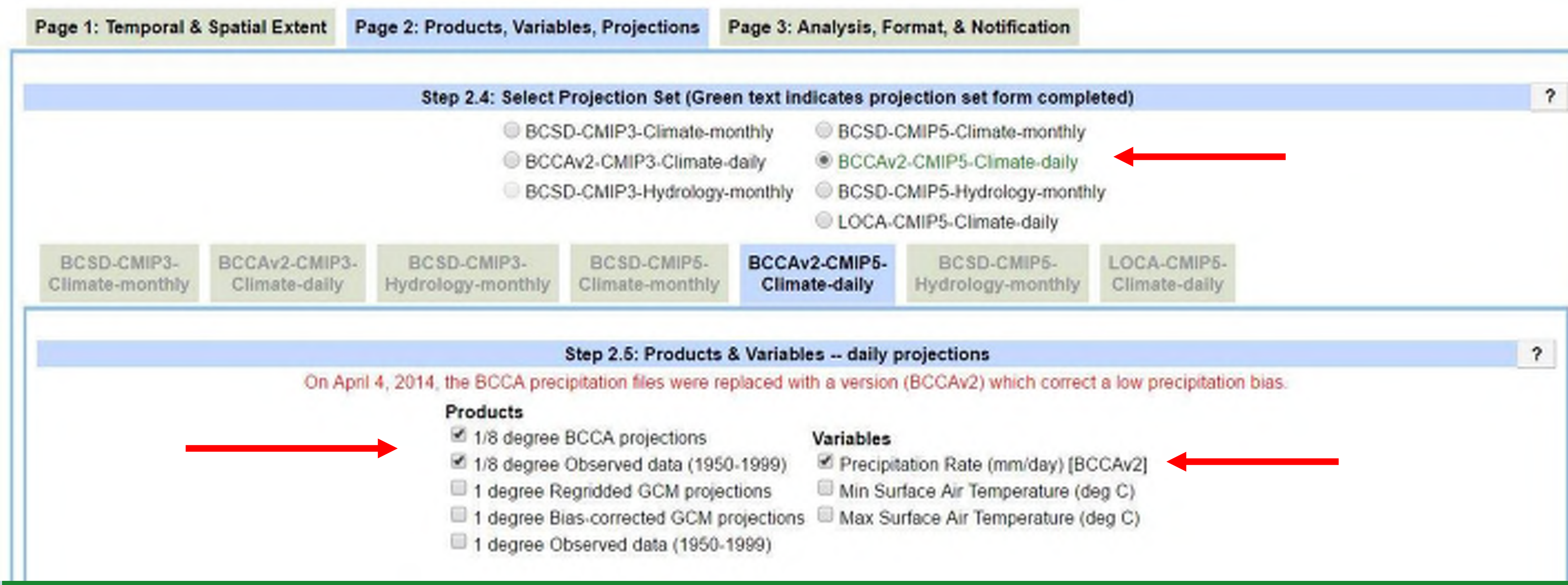
- Select location on 12 km X 12 km grid
- 1 grid per request only



Initial Results & Impressions

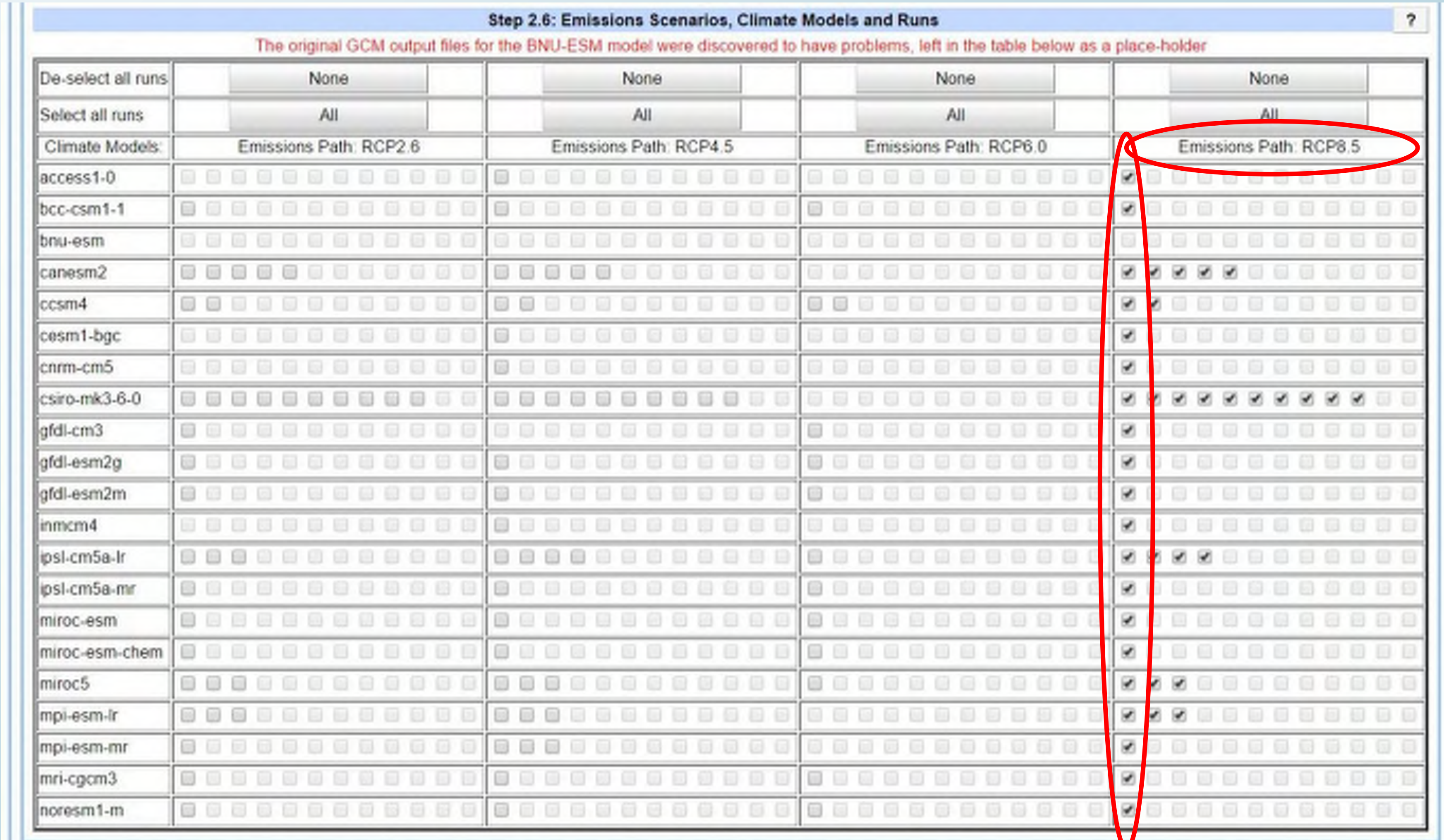
Request Process – *Select Projection Set (1 per Request)*

1. Select Phase - CMIP3 or CMIP5
2. Select Projection Set - BCSD (monthly), BCCA (daily), LOCA (daily)
3. Products - Observed and Projected, Precipitation and Temperature



Initial Results & Impressions

Select Emissions Scenario and Climate Model



Initial Results & Impressions

❑ Incredible breadth of data

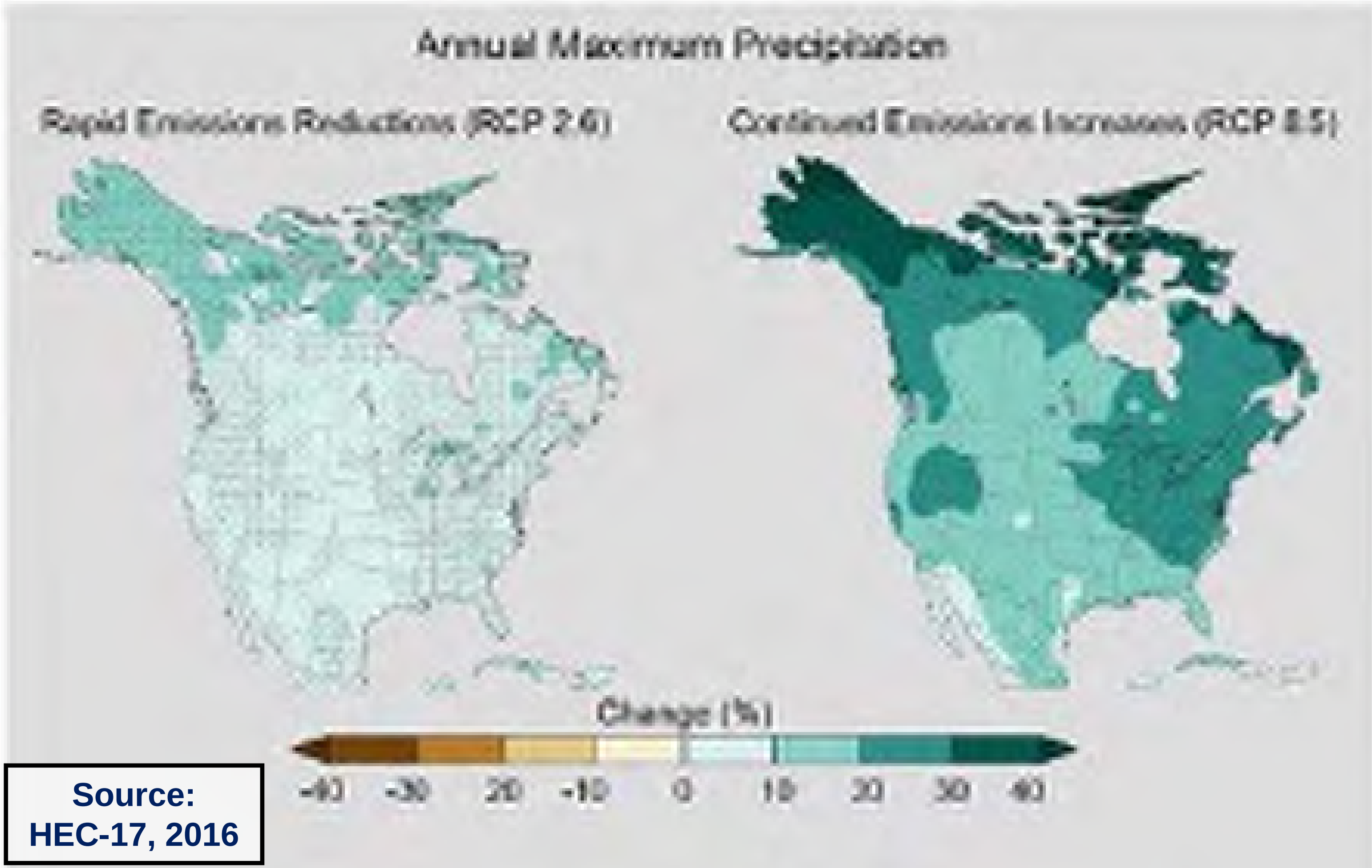
Emissions Scenario & Climate Model Selection:

- 3 Daily Projection Sets
- 2 to 4 Emissions Scenarios
- 8 to 32 Climate Models

ORGANIZE YOUR FILES!!

Phase	Projection Set	Emissions Scenario	Emissions Description	# of Climate Models
CMIP3	BCCA	B1	LOW, lower emissions technology, declining global population	9
		A1b	MEDIUM, rapid economic growth, declining global population	8
		A2	HIGH, slower technology change, high population growth	9
CMIP5	BCCA	2.6	LOW, substantial and sustained emissions reductions to 475 ppm CO_2	16
		4.5	MEDIUM-LOW Stabilized CO_2 at 630 ppm	19
		6.0	MEDIUM-HIGH Stabilized CO_2 at 800 ppm	12
		8.5	HIGH, high emissions continue 1313 ppm CO_2	20
CMIP5	LOCA	4.5	MEDIUM-LOW Stabilized CO_2 at 630 ppm	32
		8.5	HIGH, high emissions continue 1313 ppm CO_2	32

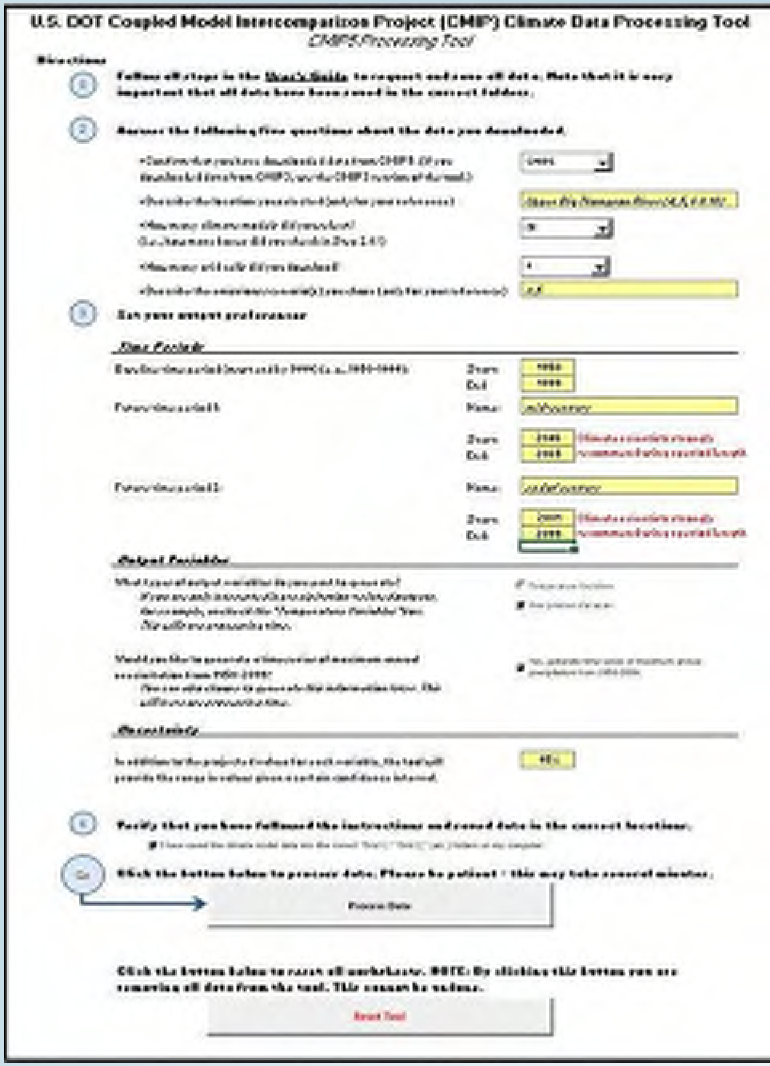
Initial Results & Impressions



Source: HEC-17, 2016

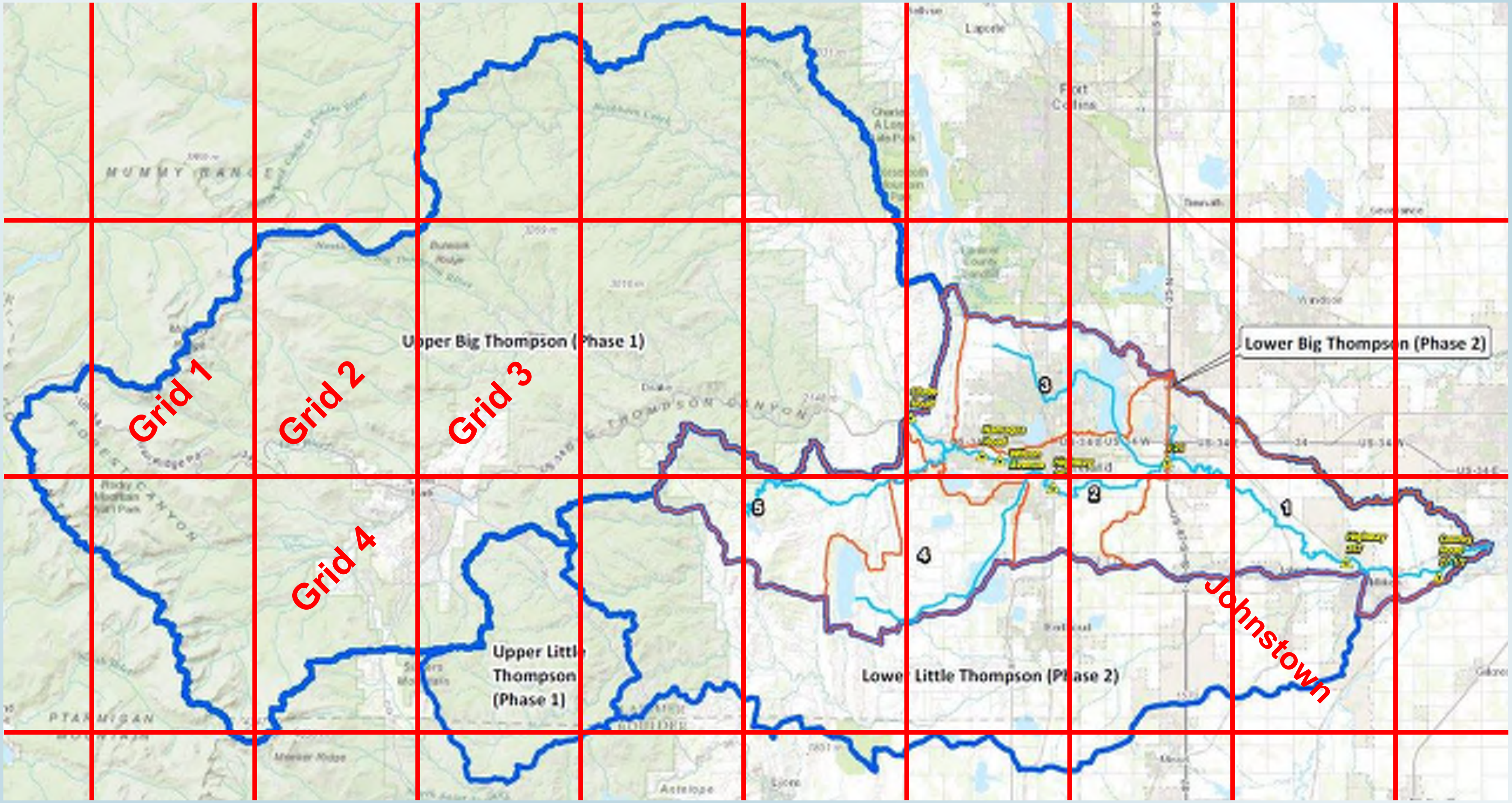
Initial Results & Impressions

- CMIP3 and CMIP5 Spreadsheet Tools developed by U.S. DOT
- Imports ASCII (.csv) files into Excel
- Can process up to 4 separate grids
- Determines Annual Maximum Time Series from daily data
- Currently not capable of processing LOCA datasets due to NetCDF file format



Initial Results & Impressions

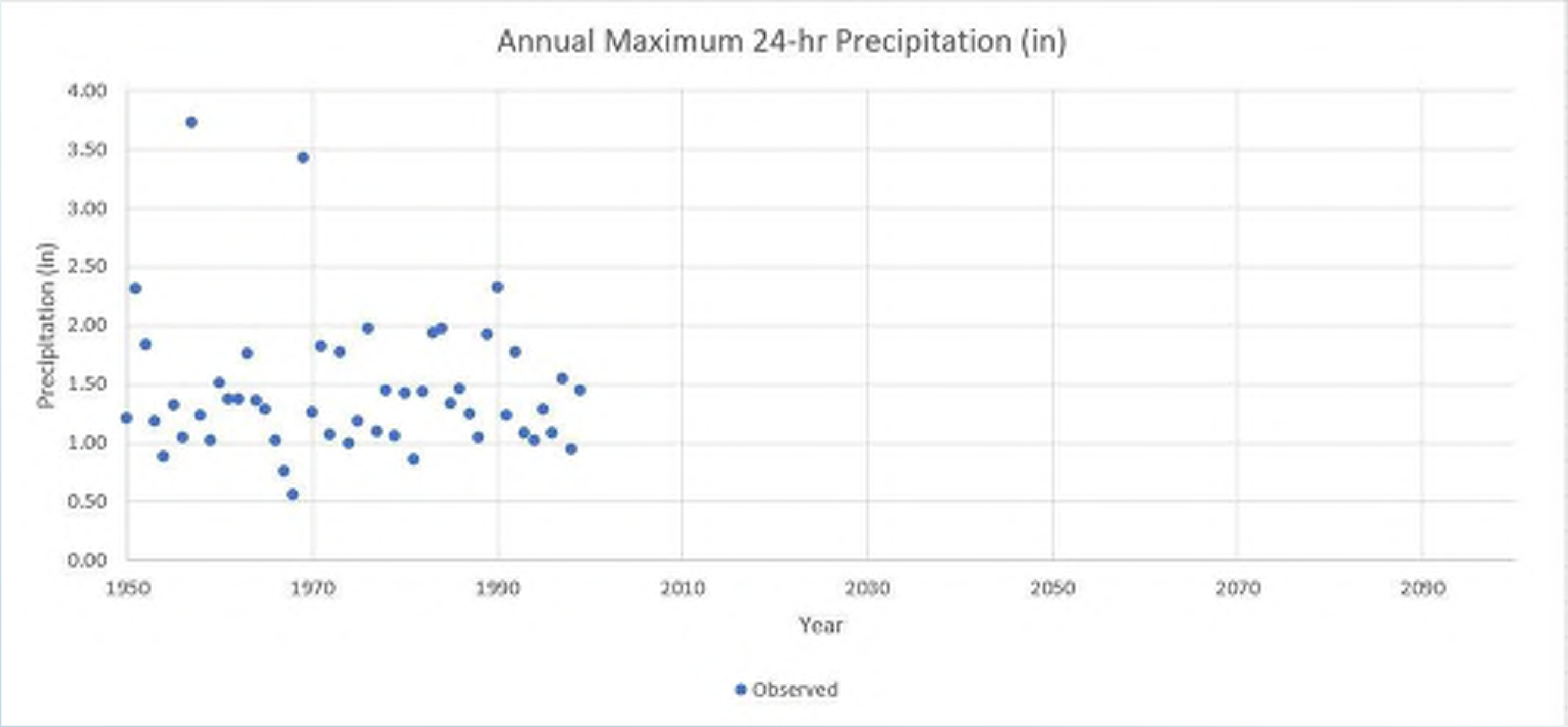
Colorado Test Case: Big Thompson River Watershed



Initial Results & Impressions

Observed Annual Max. Precip. (1950 – 2000)

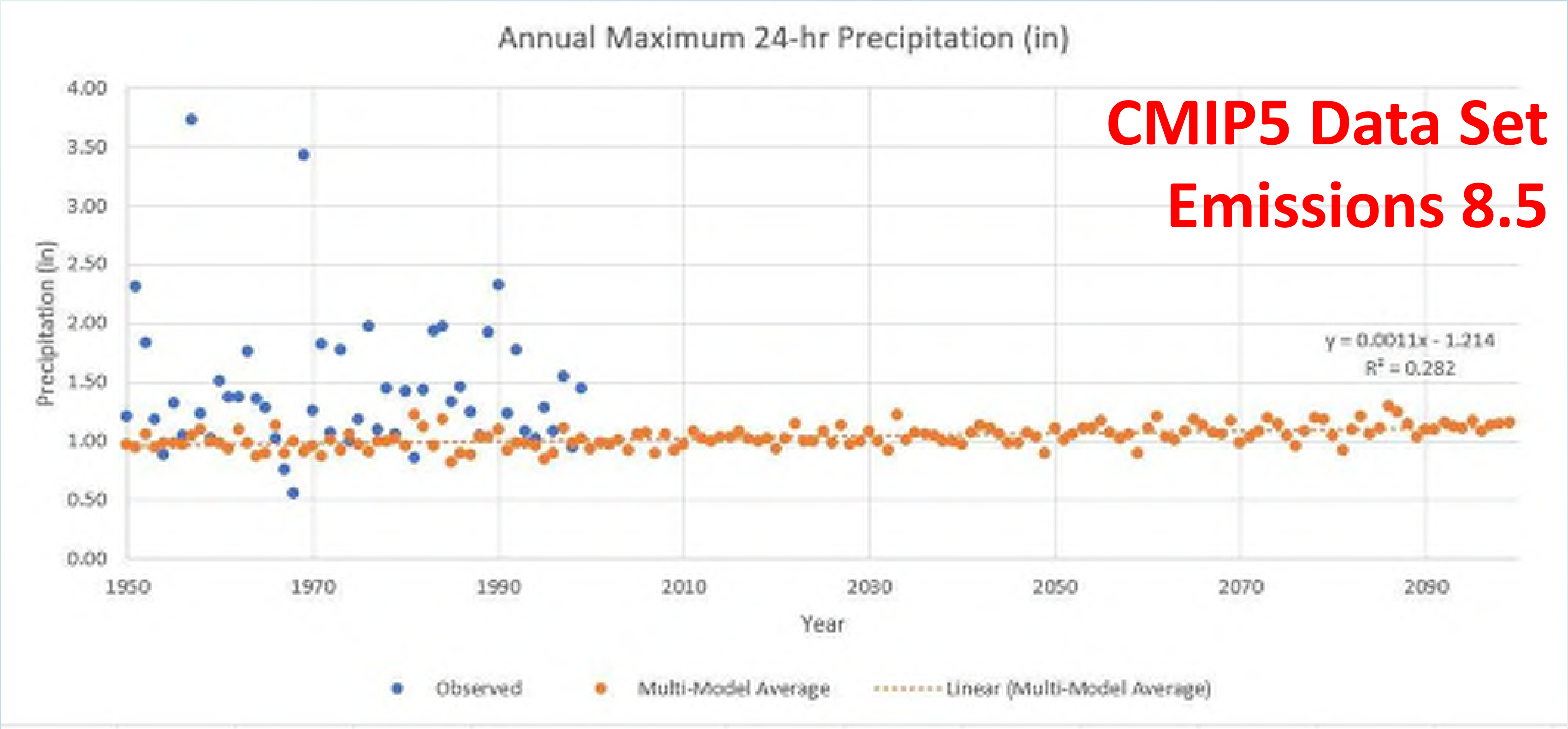
Average of 4 Grids



Initial Results & Impressions

Projected Annual Max. Precip. (1950-2100):

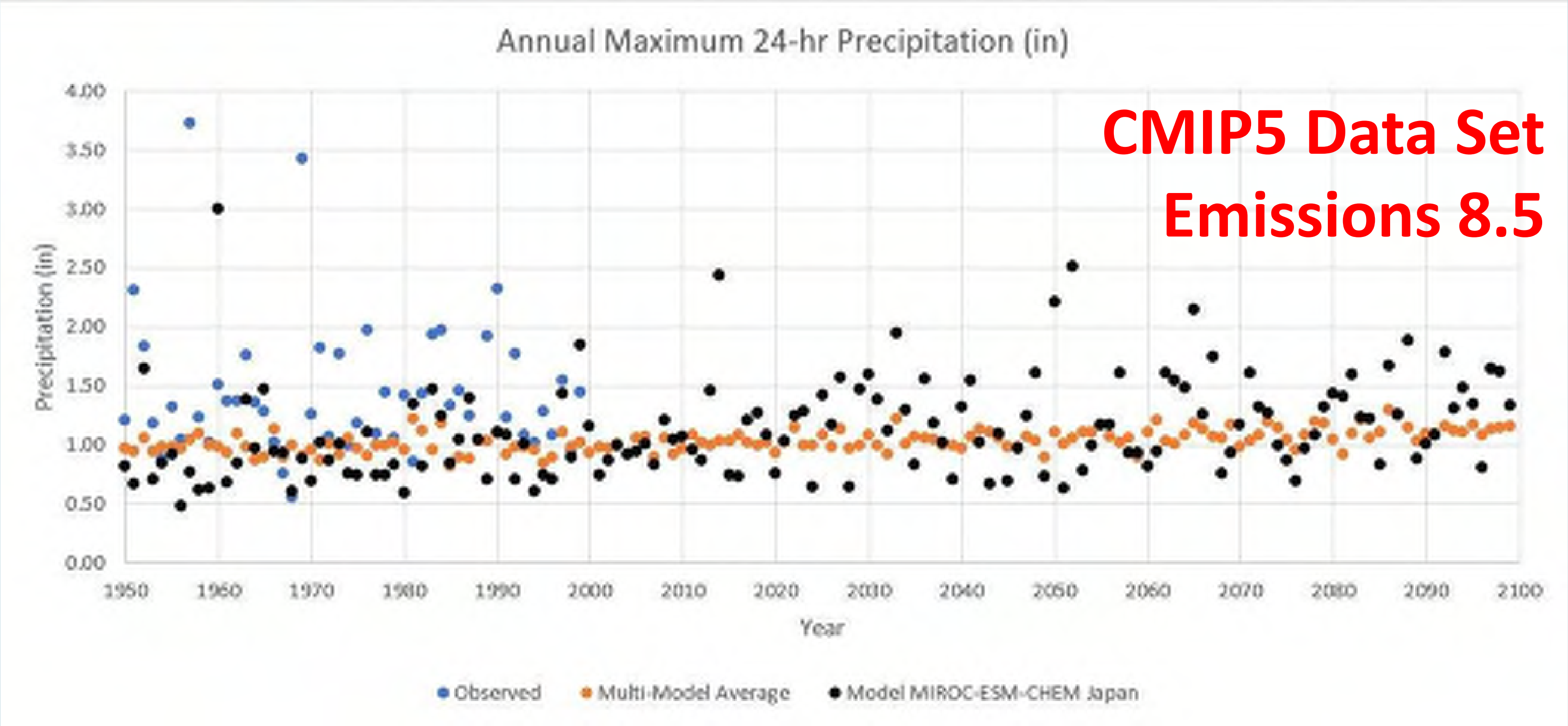
Multi-Model Average of 20 Climate Models



Initial Results & Impressions

Projected Annual Max. Precip. (1950-2100):

Model 15, MIROC-ESM-CHEM Japan

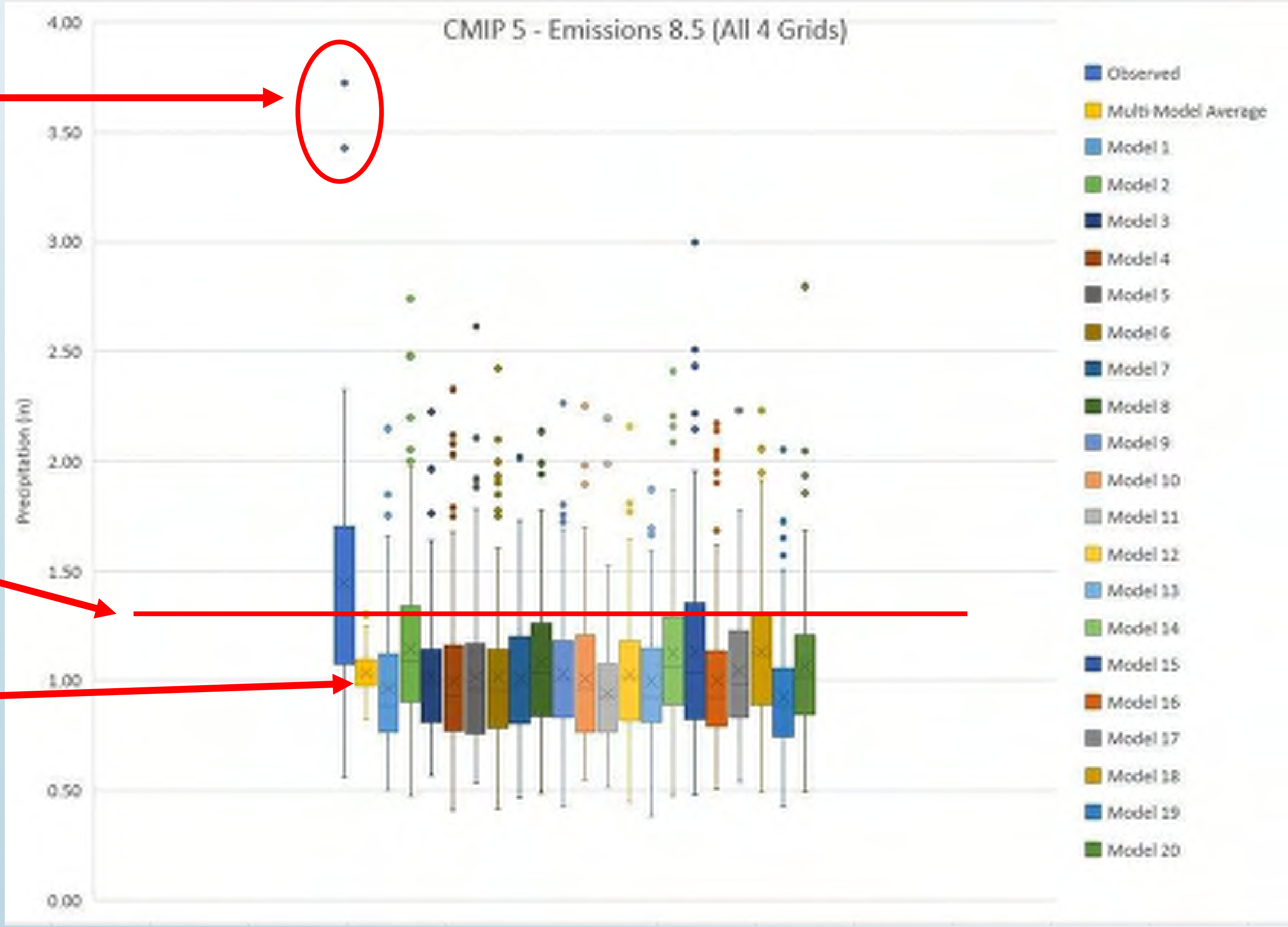


Initial Results & Impressions

Climate models unable to reproduce high observed values.

Observed median value is higher than Q3 for most models. High outlier for Multi-Model Average is equal to observed median.

Multi-Model Average dilutes out the high projections from the models since they occur in different years.



Climate Change Impacts on Flood Hydrology

Discussion Agenda:

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3. ***HEC-17 Guidance and Tool Development***
4. CMIP Tool Results
5. Summary

HEC-17 Guidance and Tool Development

Roger T. Kilgore, et al., Kilgore Consulting and Management

Hydraulic Engineering Circular Number 17, 2nd edition

Highways in the River Environment

Floodplains, Extreme Events, Risk, and Resilience

June 2016

Publication No. FHWA-HIF-16-018

- Ch. 4 – Nonstationarity and Climate Change
- Ch. 5 – Climate Modeling (Downscaling/Emission Scenarios)
- Ch. 7 – Analysis Framework (12 Step Procedure)

HEC-17 Guidance and Tool Development

HEC-17 Analysis Framework provides guidance for State DOTs when asked to consider extreme events and climate change.

Intended to help identify **data uncertainty** in climate models and hydrologic models by considering the resilience of designs over a range of potential peak discharges.

5 Levels of Analysis depending on the project service life and evaluation of risks (criticality, vulnerability, and cost).

HEC-17 Guidance and Tool Development

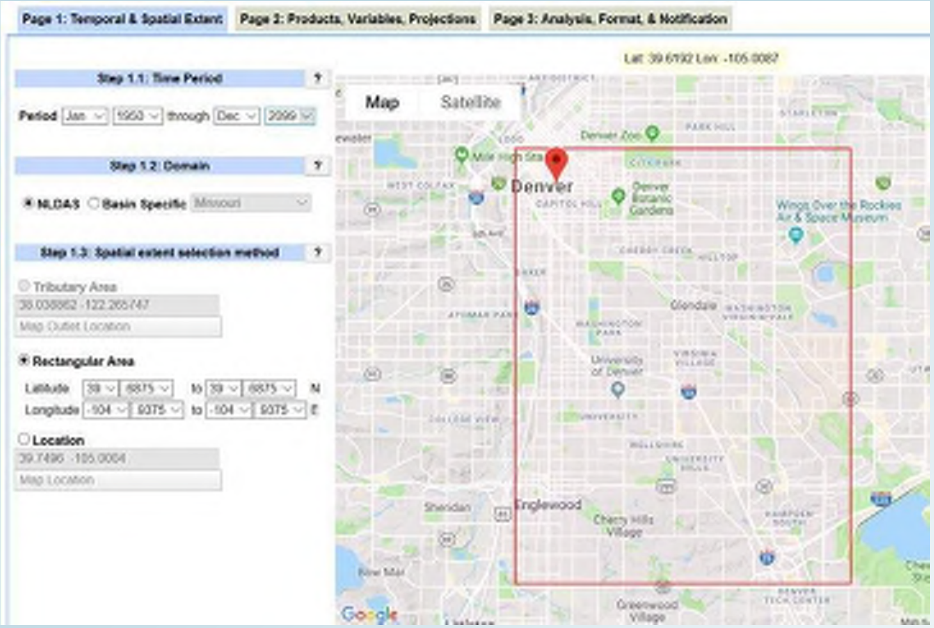
- Level 1 – standard model based on historical data
- Level 2 – standard model with additional evaluation of upper and lower confidence limits (LU, precip, discharge)
- Level 3 – Level 2 analysis plus incorporation of projected precipitation estimates
- Level 4 – Level 3 analysis plus evaluation of confidence limits on projected precipitation estimates.
- Level 5 – Involve expanded expertise from other fields.

HEC-17 Guidance and Tool Development

1. Obtain existing NOAA Atlas 14 Annual Maximum Series (AMS) Quantiles (e.g. 2yr-24hr through 500yr-24hr)

AMS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]									
Duration	Annual exceedance probability (1/years)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
24-hr	**1.61** (1.34-1.94)	**2.22** (1.83-2.68)	**2.71** (2.22-3.28)	**3.39** (2.70-4.24)	**3.93** (3.06-4.97)	**4.50** (3.38-5.80)	**5.10** (3.67-6.71)	**5.93** (4.10-7.96)	**6.58** (4.42-8.91)

2. Identify downscaled GCM grids to cover area of interest (recommend minimum of 3)



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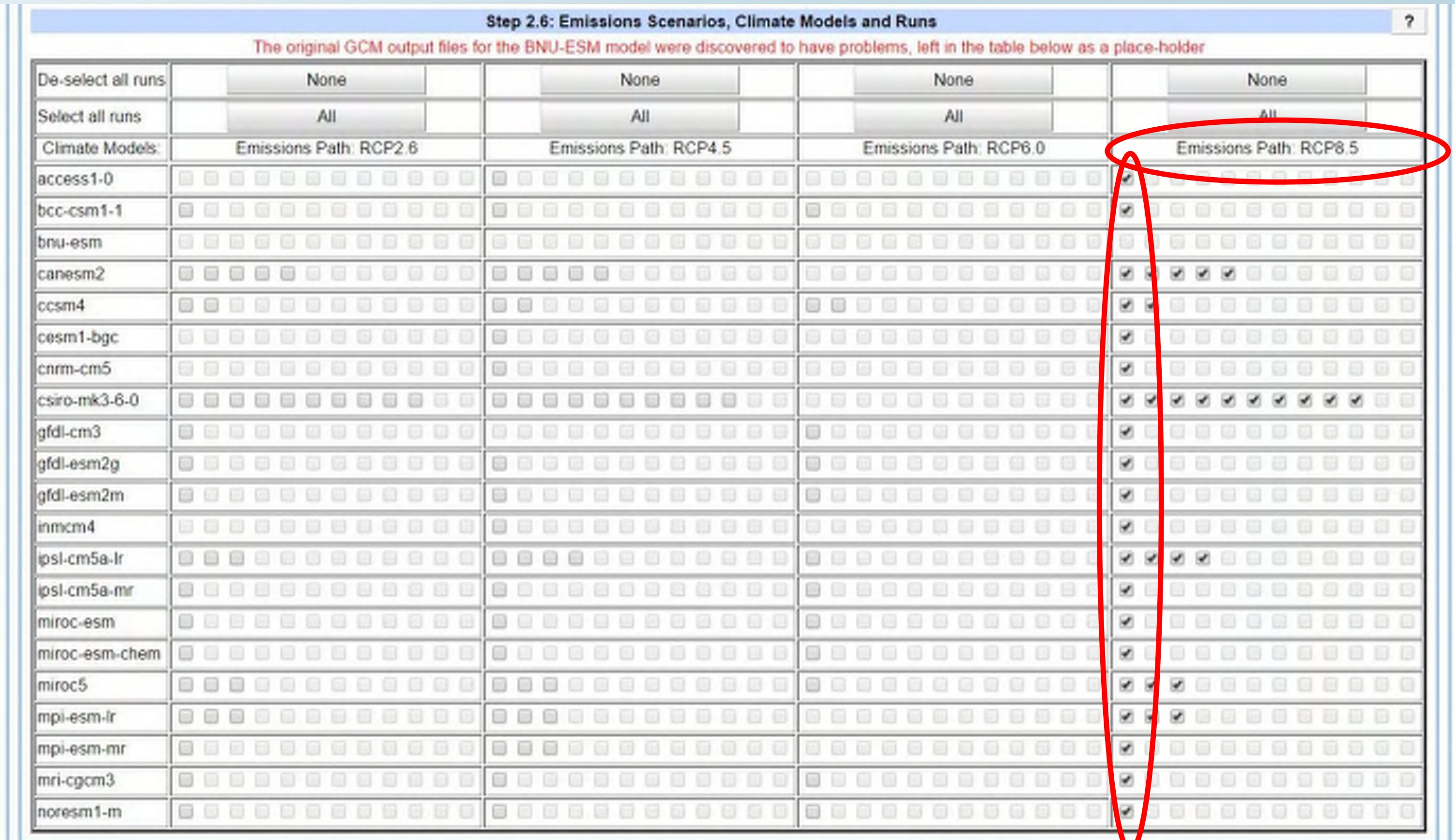
HEC-17 Guidance and Tool Development

3. Download CMIP precipitation for selected emission scenario and GCMs for each grid



HEC-17 Guidance and Tool Development

4. Extract AMS for each emission scenario, GCM and grid. Then adjust with point (1.04) and unconstrained 24-hr (1.12) correction factors

1950	1	1	0	0.014
1950	1	2	0.051	0
1950	1	3	0.072	0.009
1950	1	4	0	0.02
1950	1	5	0.008	[illegible]
1950	1	6	0	0
1950	1	7	0.002	0.266
1950	1	8	0	0
1950	1	9	0.019	0.065
1950	1	10	0.063	0

.csv file of daily precipitation (mm)

Emissions Scenario 8.5 - Grid 1

Observed Data			Model Projections						
Annual Maximum 24-hr Precipitation (in)			Annual Maximum 24-hr Precipitation (in)						
				Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Year	Observed		Year	ess1-0.1.rc	csm1-1.1.r	esm2.1.rc	sm4.1.rcp	ln1-bgc.1.r	m-cm5.1.rc
1950	1.67		1950	0.81	0.75	1.05	0.85	1.60	1.36
1951	1.63		1951	0.69	0.88	1.07	0.82	1.27	0.75
1952	1.40		1952	1.12	1.06	0.66	0.89	1.28	1.65
[illegible]	1.35		1953	1.47	1.51	0.87	0.99	0.94	1.61
1954	[illegible]		1954	0.82	0.86	0.57	0.70	0.71	0.82
1955	1.45		1955	0.46	0.97	1.76	1.10	0.80	1.25
1956	1.28		1956	0.79	1.07	0.51	1.71	0.89	1.34
1957	2.19		1957	0.92	1.61	1.32	1.28	0.90	0.97
1958	1.25		1958	0.81	1.52	0.51	1.49	0.64	0.93
1959	0.84		1959	0.69	0.57	0.84	0.89	1.20	0.85
1960	1.17		1960	0.91	0.80	1.11	0.60	0.40	0.83
1961	1.59		1961	0.82	1.29	1.07	0.52	1.40	1.06
1962	0.63		1962	0.69	0.90	0.58	0.91	1.30	0.64
1963	1.89		1963	1.00	0.45	1.14	0.92	0.48	1.48
1964	1.01		1964	0.45	0.92	1.52	0.77	0.73	0.80
1965	1.50		1965	0.63	0.88	1.38	0.85	0.90	0.85

Excel file of AMS, converted to inches, and adjusted for area/point and 24-hr period

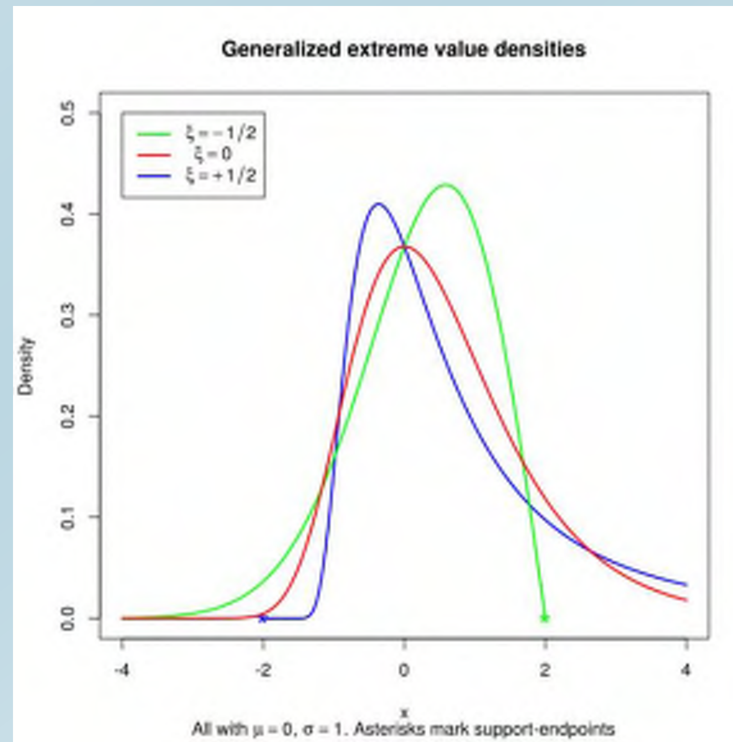
HEC-17 Guidance and Tool Development

5. Select <u>Baseline Period</u> for analysis (e.g. 1950-1999)
6. Select <u>Future Period</u> for analysis (e.g. 2020-2099)

Select Baseline and Future Time Periods

Baseline Period		**Future Period**	
Start Year	1950	Start Year	2020
End Year	1999	End Year	2099
(e.g. 1950 to 1999)		(e.g. 2020 to 2099)	

7. Extract Baseline Period AMS from Step 4 and compute <u>Baseline 10yr-24hr Quantile</u> by fitting GEV distribution



HEC-17 Guidance and Tool Development

8. Extract Future Period AMS from Step 4 and compute <u>Projected 10yr-24hr Quantile</u> by fitting GEV distribution

GEV Distribution (EasyFitXL)

Observed	Baseline Period (1950 - 1999)						
N/A	Model	1	2	3	4	5	6
-0.1679	GEV shape, k	0.1422	-0.0958	0.0468	0.1398	0.0517	-0.0147
0.4426	GEV Scale, σ	0.2645	0.2887	0.2915	0.2814	0.2816	0.2566
1.1874	GEV Location, μ	0.7611	0.9141	0.9029	0.8171	0.8121	0.8665
0.90	10-yr probability, P	0.90	0.90	0.90	0.90	0.90	0.90
2.02	10yr, 24hr Quantile	1.46	1.50	1.60	1.56	1.48	1.43

Future Period (2020 - 2099)						
Model	1	2	3	4	5	6
GEV shape, k	0.1131	-0.0398	0.1452	-0.0723	0.1037	0.1165
GEV Scale, σ	0.2511	0.3723	0.2759	0.2709	0.2879	0.2989
GEV Location, μ	0.8316	1.0179	0.8763	0.8184	0.8598	0.9045
10-yr probability, P	0.90	0.90	0.90	0.90	0.90	0.90
10yr, 24hr Quantile	1.47	1.82	1.61	1.38	1.59	1.68

10-yr, 24-hr RPB (Ratio of projected to baseline)						
Model	1	2	3	4	5	6
RPB (10yr,24hr)	1.01	1.21	1.01	0.88	1.07	1.17

9. Repeat Steps 3-8 for each GCM in emission scenario

CMIP Tool can handle all GCMs simultaneously

HEC-17 Guidance and Tool Development

10. Compute Ratio of Projected to Baseline (RPB) 10yr-24hr Quantiles and assess ratios

Select an Appropriate RPB for each Emission Scenario

Emission Scenario	RPB		
	Mean	Lower CL	Upper CL
2.6	1.02	0.81	1.28
4.5	1.03	0.83	1.28
6.0	1.03	0.89	1.20
8.5	1.04	0.87	1.24

90% Confidence Limits

MEAN	Lower CL	Upper CL
1.04	0.89	1.22
1.04	0.87	1.22
1.04	0.87	1.22
1.05	0.88	1.24
MEAN	Lower CL	Upper CL
1.04	0.87	1.24

10-yr, 24-hr Quantile for Baseline Period (1950 - 1999)

	1	2	3	4	5	6
Grid 1	1.46	1.50	1.60	1.56	1.48	1.43
Grid 2	1.53	1.57	1.73	1.61	1.55	1.50
Grid 3	1.43	1.47	1.52	1.53	1.43	1.38
Grid 4	1.44	1.54	1.59	1.52	1.47	1.39
MEAN	1.47	1.52	1.61	1.56	1.48	1.42

10-yr, 24-hr Quantile for Future Period (2020 - 2099)

	1	2	3	4	5	6
Grid 1	1.47	1.82	1.61	1.38	1.59	1.68
Grid 2	1.52	1.90	1.75	1.49	1.68	1.76
Grid 3	1.45	1.79	1.57	1.34	1.58	1.64
Grid 4	1.48	1.84	1.67	1.43	1.62	1.70
MEAN	1.48	1.84	1.65	1.41	1.62	1.70

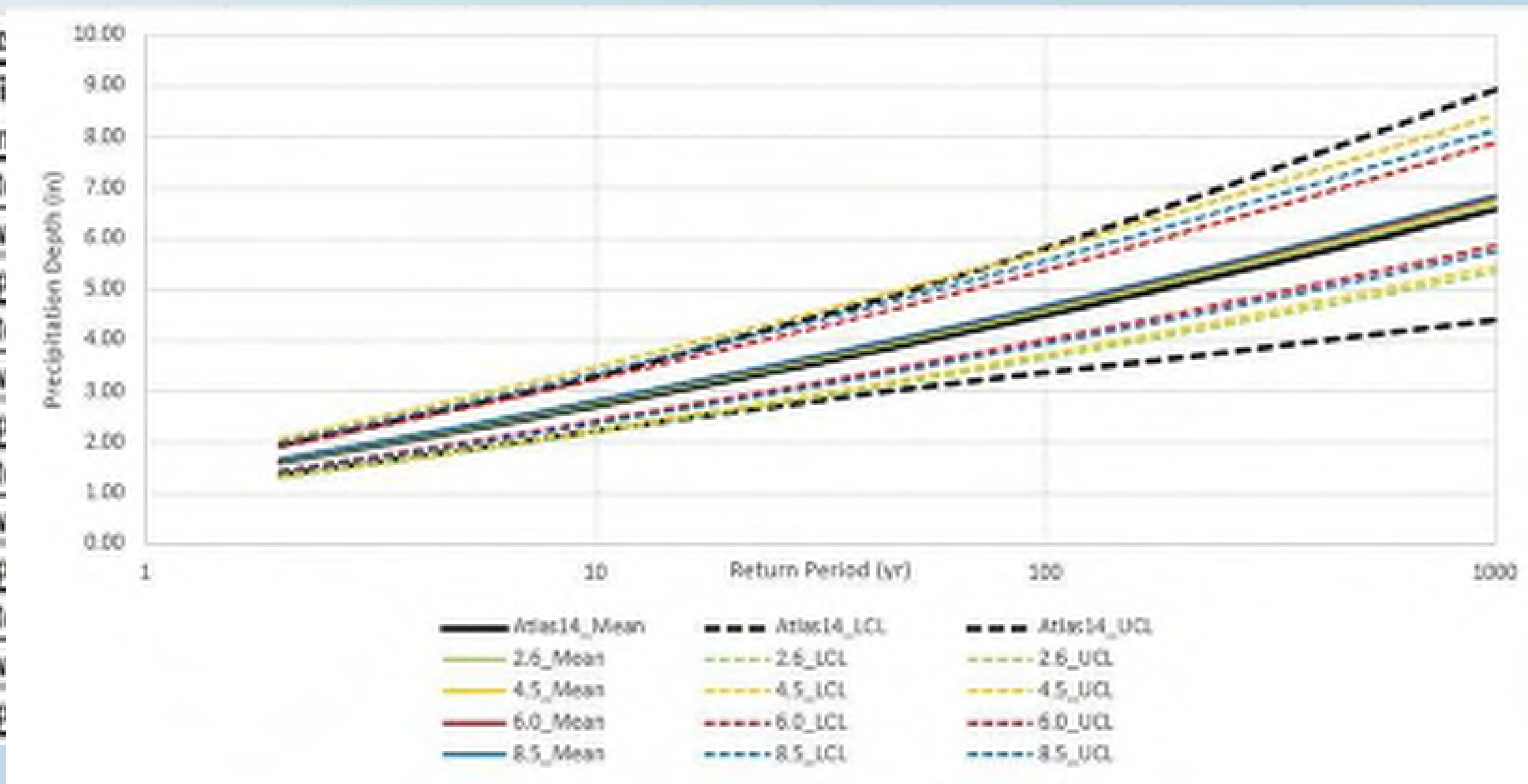
10-yr, 24-hr RPB (Ratio of Projected to Baseline)

	1	2	3	4	5	6
Grid 1	1.01	1.21	1.01	0.88	1.07	1.17
Grid 2	0.99	1.21	1.01	0.93	1.09	1.18
Grid 3	1.01	1.22	1.04	0.87	1.11	1.19
Grid 4	1.03	1.19	1.05	0.94	1.10	1.23
MEAN	1.01	1.21	1.03	0.91	1.09	1.19
Lower CL	0.99	1.19	1.01	0.87	1.07	1.17
Upper CL	1.02	1.22	1.05	0.94	1.11	1.22

HEC-17 Guidance and Tool Development

11. Adjust Atlas 14 Quantiles (Step 1) with selected RPBs to estimate <u>Projected Future Quantiles</u>

	Revic
Emission Scenario	Confi Lir
2.6	Mi
	Low
	Upp
4.5	Mi
	Low
	Upp
6.0	Mi
	Low
	Upp
8.5	Mi
	Low
	Upp



HEC-17 Guidance and Tool Development

12. Repeat Steps 3-11 for each future emissions scenario

CMIP Tool can handle all emission scenarios simultaneously

Evaluate Climate Change Indicator (CCI)

Review Climate Change Indicator (CCI)

Emission Scenario	Climate Change Indicator (CCI)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.08	0.08	0.08	0.07	0.06	0.06	0.05	0.05	0.05
4.5	0.15	0.15	0.15	0.12	0.12	0.11	0.10	0.09	0.09
6.0	0.16	0.16	0.16	0.13	0.13	0.12	0.11	0.10	0.09
8.5	0.20	0.20	0.20	0.17	0.16	0.14	0.13	0.12	0.12

CCI < 0.4 (Level 2 Analysis is sufficient)

0.4 < CCI < 0.8 (Design Team to determine appropriate level of analysis)

0.8 < CCI (Level 4 Analysis Recommended)

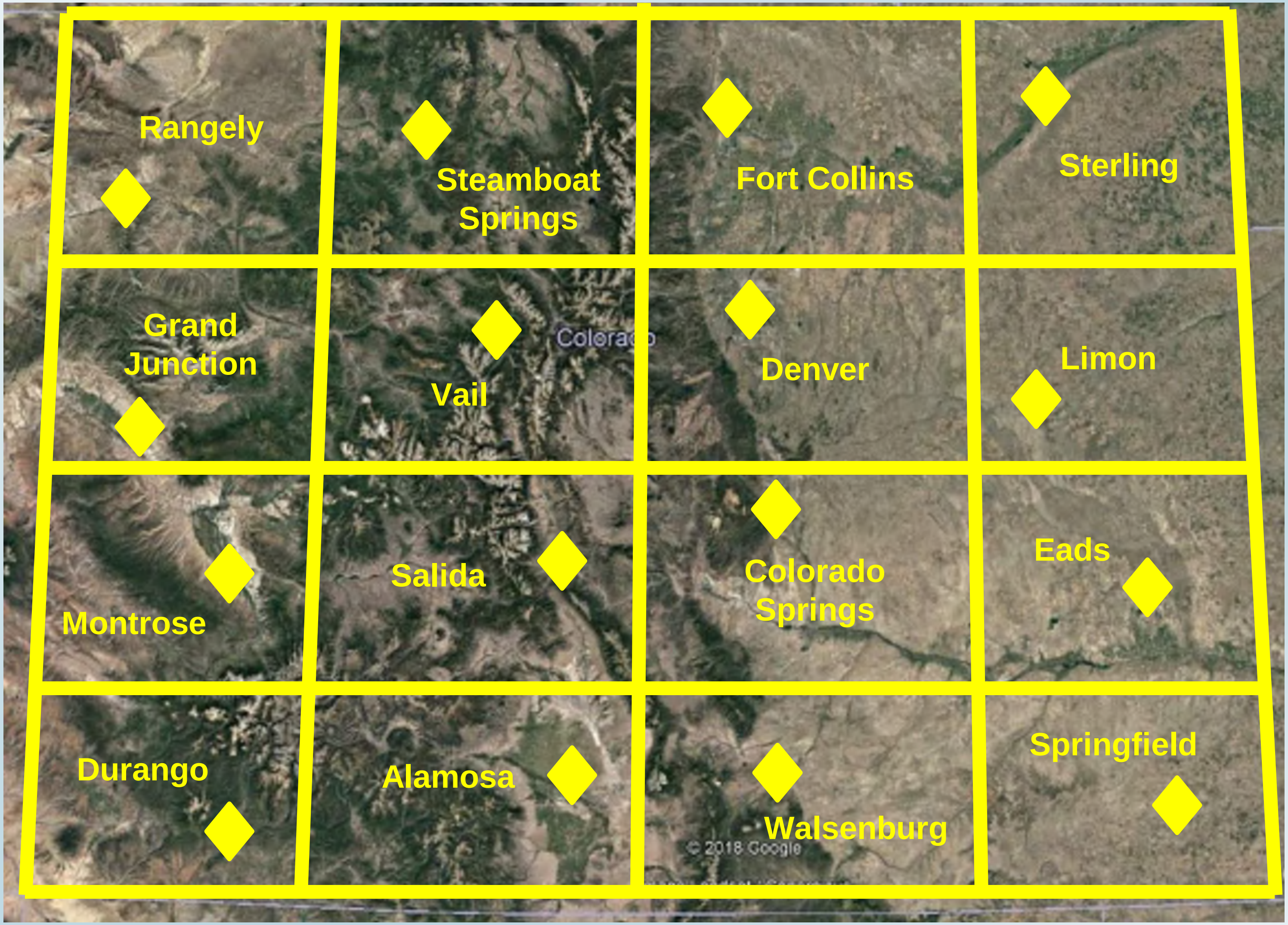
Climate Change Impacts on Flood Hydrology

Discussion Agenda:

1. CMIP Climate Projections
2. Initial Results & Impressions
3. HEC-17 Guidance and Tool Development
4. ***CMIP Tool Results***
5. Summary

Source: Rapp, 2008

CMIP Tool Results



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CMIP Tool Results

Eastern Plains

Mean RPB

Min 1.03
Max 1.11

4 Sterling

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.04	0.90	1.20
4.5	1.07	0.94	1.30
6.0	1.10	0.96	1.27
8.5	1.04	0.90	1.19

Emission Scenario	Climate Change Indicator (CCI)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.22	0.23	0.22	0.18	0.17	0.15	0.14	0.12	0.12
4.5	0.37	0.37	0.36	0.29	0.28	0.25	0.23	0.20	0.20
6.0	0.49	0.49	0.48	0.38	0.37	0.33	0.30	0.27	0.26
8.5	0.21	0.22	0.21	0.17	0.16	0.14	0.13	0.12	0.11

8 Limon

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.04	0.92	1.17
4.5	1.06	0.88	1.21
6.0	1.11	0.98	1.24
8.5	1.06	0.92	1.26

Emission Scenario	Climate Change Indicator (CCI)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.17	0.16	0.16	0.12	0.12	0.11	0.10	0.09	0.09
4.5	0.25	0.24	0.23	0.19	0.18	0.16	0.14	0.13	0.13
6.0	0.46	0.45	0.43	0.34	0.33	0.30	0.27	0.24	0.24
8.5	0.24	0.23	0.22	0.18	0.17	0.15	0.14	0.13	0.12

12 Eads

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.09	0.96	1.30
4.5	1.10	1.01	1.22
6.0	1.11	1.04	1.24
8.5	1.07	0.92	1.27

Emission Scenario	Climate Change Indicator (CCI)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.56	0.55	0.55	0.44	0.42	0.38	0.34	0.31	0.31
4.5	0.60	0.59	0.58	0.47	0.44	0.40	0.37	0.33	0.33
6.0	0.67	0.66	0.65	0.53	0.50	0.45	0.41	0.37	0.37
8.5	0.42	0.41	0.41	0.33	0.31	0.28	0.26	0.23	0.23

16 Springfield

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.06	0.94	1.20
4.5	1.05	0.98	1.22
6.0	1.03	0.89	1.20
8.5	1.07	0.93	1.19

Emission Scenario	Climate Change Indicator (CCI)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.27	0.26	0.26	0.20	0.19	0.17	0.16	0.14	0.14
4.5	0.22	0.21	0.21	0.16	0.16	0.14	0.13	0.12	0.12
6.0	0.14	0.13	0.13	0.10	0.10	0.09	0.08	0.07	0.07
8.5	0.30	0.29	0.28	0.22	0.21	0.19	0.17	0.16	0.16

CMIP Tool Results

Front Range

Mean RPB

Min 1.02
Max 1.08

3 Fort Collins

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.03	0.90	1.22
4.5	1.04	0.90	1.24
6.0	1.04	0.89	1.16
8.5	1.06	0.88	1.25

Emission Scenario	Climate Change Indicator (CCI) 1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.17	0.16	0.16	0.11	0.10	0.09	0.08	0.07	0.07
4.5	0.20	0.20	0.19	0.13	0.12	0.11	0.10	0.09	0.09
6.0	0.22	0.21	0.21	0.14	0.13	0.12	0.11	0.10	0.09
8.5	0.37	0.36	0.35	0.23	0.23	0.20	0.18	0.16	0.16

7 Denver

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.02	0.81	1.28
4.5	1.03	0.83	1.28
6.0	1.03	0.89	1.20
8.5	1.04	0.87	1.24

Emission Scenario	Climate Change Indicator (CCI) 1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.08	0.08	0.08	0.07	0.06	0.06	0.05	0.05	0.05
4.5	0.15	0.15	0.15	0.12	0.12	0.11	0.10	0.09	0.09
6.0	0.16	0.16	0.16	0.13	0.13	0.12	0.11	0.10	0.09
8.5	0.20	0.20	0.20	0.17	0.16	0.14	0.13	0.12	0.12

11 Colorado Springs

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.07	0.98	1.15
4.5	1.05	0.90	1.20
6.0	1.07	0.87	1.22
8.5	1.04	0.93	1.16

Emission Scenario	Climate Change Indicator (CCI) 1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.38	0.37	0.36	0.26	0.25	0.22	0.20	0.18	0.18
4.5	0.26	0.25	0.24	0.18	0.17	0.15	0.13	0.12	0.12
6.0	0.38	0.37	0.36	0.26	0.25	0.22	0.20	0.18	0.18
8.5	0.23	0.22	0.21	0.15	0.15	0.13	0.12	0.11	0.10

15 Walsenburg

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.08	0.99	1.20
4.5	1.06	0.97	1.21
6.0	1.06	0.95	1.23
8.5	1.06	0.97	1.24

Emission Scenario	Climate Change Indicator (CCI) 1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.44	0.42	0.40	0.29	0.27	0.23	0.20	0.18	0.17
4.5	0.36	0.34	0.32	0.23	0.22	0.19	0.16	0.14	0.13
6.0	0.35	0.33	0.31	0.23	0.21	0.18	0.16	0.14	0.13
8.5	0.36	0.34	0.33	0.23	0.22	0.19	0.16	0.14	0.14

CMIP Tool Results

High Mountains

Mean RPB

Min 1.05

Max 1.13

2 Steamboat Springs

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.08	0.99	1.16
4.5	1.06	0.95	1.15
6.0	1.10	1.00	1.19
8.5	1.13	0.97	1.26

Emission Scenario	Climate Change Indicator (CCI)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.39	0.38	0.37	0.28	0.26	0.23	0.20	0.18	0.17
4.5	0.27	0.27	0.26	0.20	0.18	0.16	0.14	0.13	0.12
6.0	0.45	0.45	0.44	0.32	0.31	0.27	0.24	0.21	0.20
8.5	0.60	0.59	0.58	0.43	0.40	0.36	0.31	0.28	0.27

6 Vail

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.08	0.94	1.19
4.5	1.05	0.94	1.16
6.0	1.09	0.95	1.22
8.5	1.11	0.96	1.25

Emission Scenario	Climate Change Indicator (CCI)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.28	0.28	0.27	0.21	0.20	0.18	0.16	0.15	0.14
4.5	0.19	0.19	0.18	0.14	0.14	0.12	0.11	0.10	0.10
6.0	0.34	0.34	0.32	0.26	0.24	0.22	0.19	0.18	0.17
8.5	0.43	0.42	0.40	0.32	0.30	0.27	0.24	0.22	0.22

10 Salida

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.08	0.94	1.23
4.5	1.06	0.90	1.17
6.0	1.07	0.96	1.22
8.5	1.09	0.96	1.24

Emission Scenario	Climate Change Indicator (CCI)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.37	0.35	0.35	0.28	0.27	0.24	0.21	0.19	0.18
4.5	0.28	0.27	0.26	0.21	0.20	0.18	0.16	0.14	0.14
6.0	0.32	0.31	0.30	0.25	0.23	0.21	0.18	0.16	0.16
8.5	0.43	0.42	0.41	0.33	0.31	0.28	0.25	0.22	0.21

14 Alamosa

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.09	0.93	1.24
4.5	1.05	0.89	1.23
6.0	1.08	0.94	1.28
8.5	1.08	0.93	1.24

Emission Scenario	Climate Change Indicator (CCI)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.53	0.52	0.50	0.43	0.38	0.34	0.31	0.27	0.26
4.5	0.32	0.31	0.30	0.26	0.23	0.21	0.19	0.16	0.16
6.0	0.50	0.49	0.47	0.41	0.36	0.32	0.29	0.25	0.24
8.5	0.51	0.50	0.48	0.42	0.37	0.33	0.30	0.26	0.25

CMIP Tool Results

Western Slope

Mean RPB

Min 1.08
Max 1.16

1 Rangely

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.15	0.95	1.34
4.5	1.13	0.94	1.31
6.0	1.13	1.00	1.30
8.5	1.15	0.95	1.28

Emission Scenario	Climate Change Indicator (CCI) 1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.71	0.69	0.66	0.55	0.51	0.45	0.40	0.36	0.34
4.5	0.61	0.59	0.57	0.48	0.44	0.39	0.35	0.31	0.29
6.0	0.64	0.61	0.59	0.50	0.46	0.40	0.36	0.32	0.30
8.5	0.72	0.70	0.67	0.56	0.52	0.46	0.41	0.36	0.35

5 Grand Junction

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.08	0.97	1.19
4.5	1.09	0.98	1.20
6.0	1.11	1.01	1.22
8.5	1.13	0.97	1.23

Emission Scenario	Climate Change Indicator (CCI) 1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.39	0.38	0.37	0.31	0.29	0.26	0.24	0.21	0.21
4.5	0.40	0.39	0.38	0.32	0.30	0.27	0.24	0.22	0.21
6.0	0.51	0.51	0.48	0.41	0.38	0.35	0.31	0.28	0.27
8.5	0.59	0.59	0.56	0.48	0.44	0.41	0.36	0.32	0.31

9 Montrose

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.12	1.02	1.28
4.5	1.10	1.01	1.21
6.0	1.13	1.00	1.26
8.5	1.14	1.00	1.28

Emission Scenario	Climate Change Indicator (CCI) 1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.55	0.55	0.52	0.43	0.39	0.34	0.30	0.27	0.25
4.5	0.49	0.49	0.47	0.39	0.35	0.31	0.27	0.24	0.22
6.0	0.62	0.62	0.59	0.49	0.45	0.38	0.34	0.30	0.28
8.5	0.66	0.66	0.63	0.52	0.48	0.41	0.36	0.32	0.30

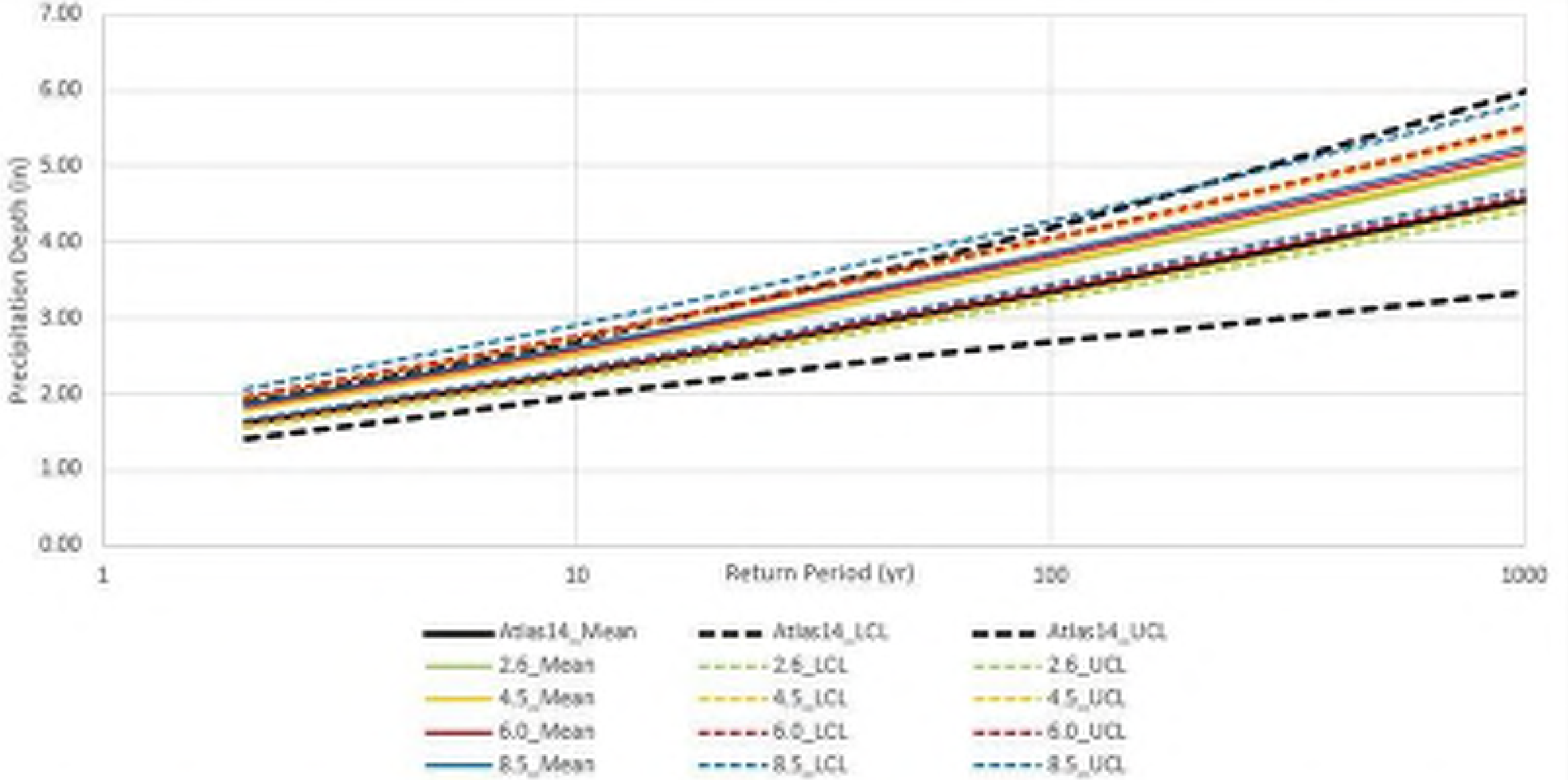
13 Durango

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL
2.6	1.10	0.97	1.22
4.5	1.11	0.98	1.20
6.0	1.14	1.01	1.21
8.5	1.16	1.03	1.28

Emission Scenario	Climate Change Indicator (CCI) 1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
2.6	0.59	0.58	0.56	0.48	0.46	0.41	0.37	0.34	0.33
4.5	0.65	0.64	0.61	0.52	0.50	0.45	0.41	0.37	0.36
6.0	0.80	0.78	0.75	0.64	0.61	0.55	0.50	0.46	0.44
8.5	0.89	0.88	0.84	0.72	0.69	0.62	0.56	0.51	0.49

CMIP Tool Results

Durango, CO



HEC-17 Guidance and Tool Development

1,491 Stations from the HCDN (1948-2007)

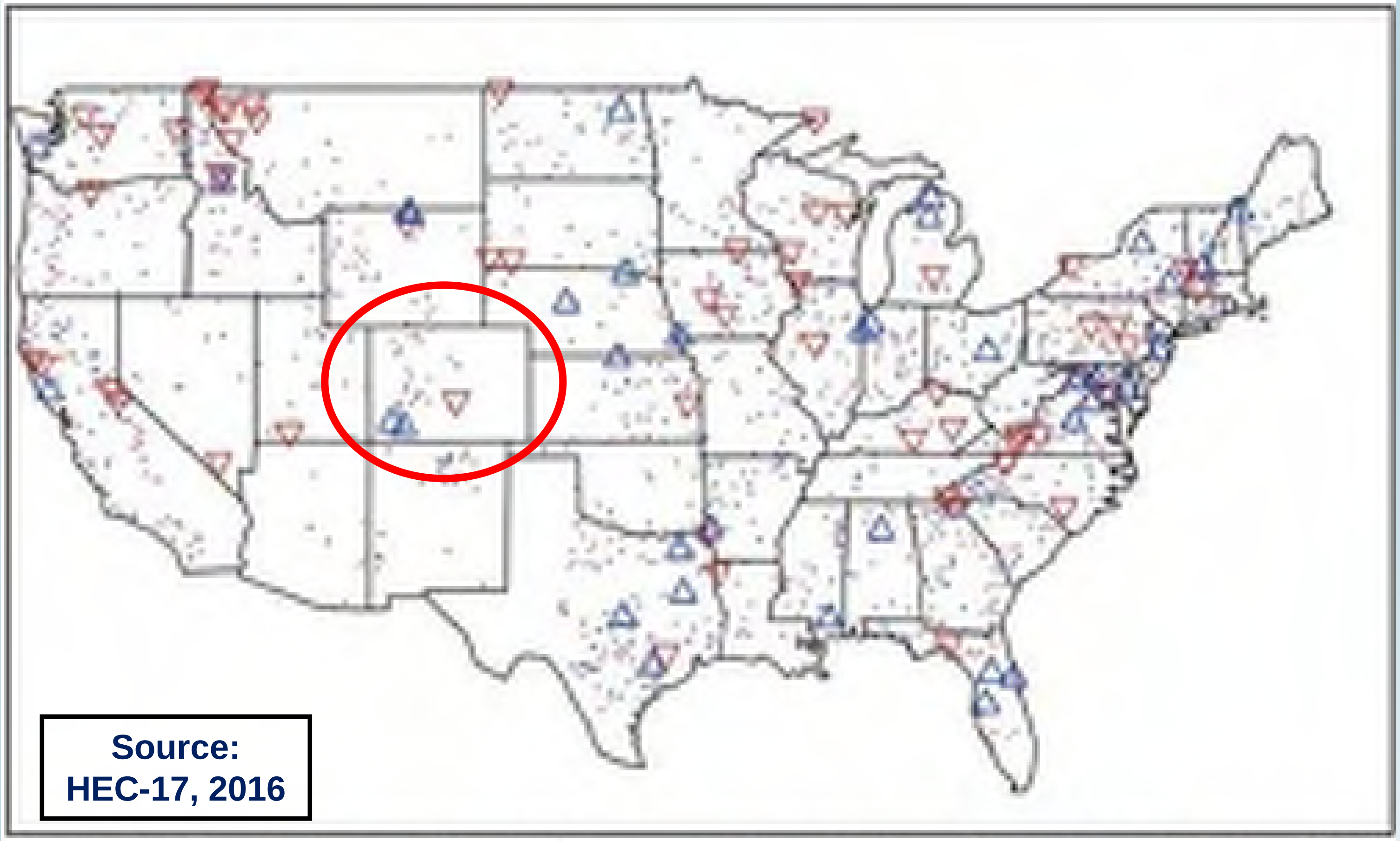


Figure 4.4. Trends in annual instantaneous peak streamflow (from Lins and Cohn, 2011).

CMIP Tool Results

Denver, CO (Average of All GCMs)

Select an Appropriate RPB for each Emission Scenario on the Quantile Summary worksheet

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL	Avg			Max			Min		
2.6	1.02	0.81	1.28	1.02	0.81	1.28	1.30	1.28	1.31	0.79	0.78	0.80
4.5	1.03	0.83	1.28	1.03	0.83	1.28	1.30	1.25	1.34	0.78	0.76	0.79
6.0	1.03	0.89	1.20	1.03	0.89	1.20	1.19	1.18	1.21	0.87	0.85	0.89
8.5	1.04	0.87	1.24	1.04	0.87	1.24	1.24	1.21	1.27	0.88	0.86	0.91

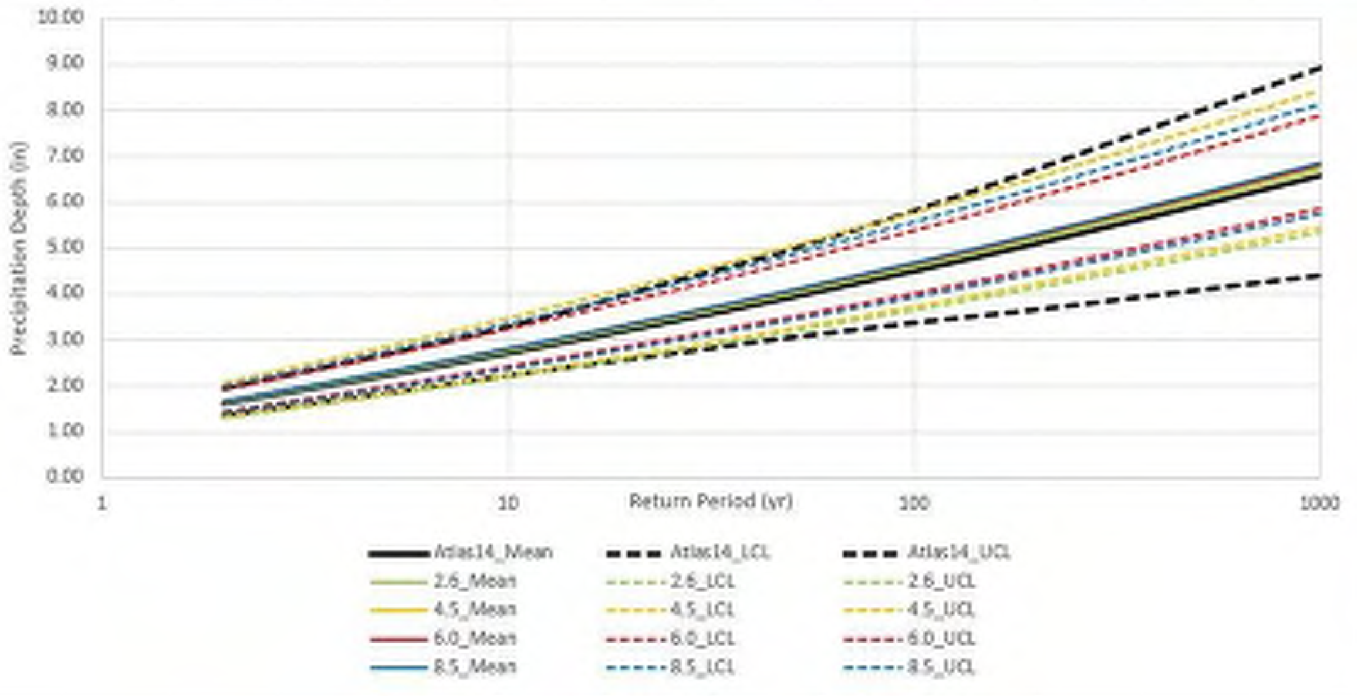
Review Climate Change Indicator

Emission Scenario	1/2	1/5
2.6	0.08	0.08
4.5	0.15	0.15
6.0	0.16	0.16
8.5	0.20	0.20

CCI < 0.4 (Level 2 Ana

0.4 < CCI < 0.8 (Design

0.8 < CCI (Level 4 Ana



CMIP Tool Results

Denver, CO (Minimum GCM)

Select an Appropriate RPB for each Emission Scenario on the Quantile Summary worksheet

Emission Scenario	RPB											
	Mean	Lower CL	Upper CL	Avg			Max			Min		
2.6	1.02	0.81	1.28	1.02	0.81	1.28	1.30	1.28	1.31	0.79	0.78	0.80
4.5	1.03	0.83	1.28	1.03	0.83	1.28	1.30	1.25	1.34	0.78	0.76	0.79
6.0	1.03	0.89	1.20	1.03	0.89	1.20	1.19	1.18	1.21	0.87	0.85	0.89
8.5	1.04	0.87	1.24	1.04	0.87	1.24	1.24	1.21	1.27	0.88	0.86	0.91

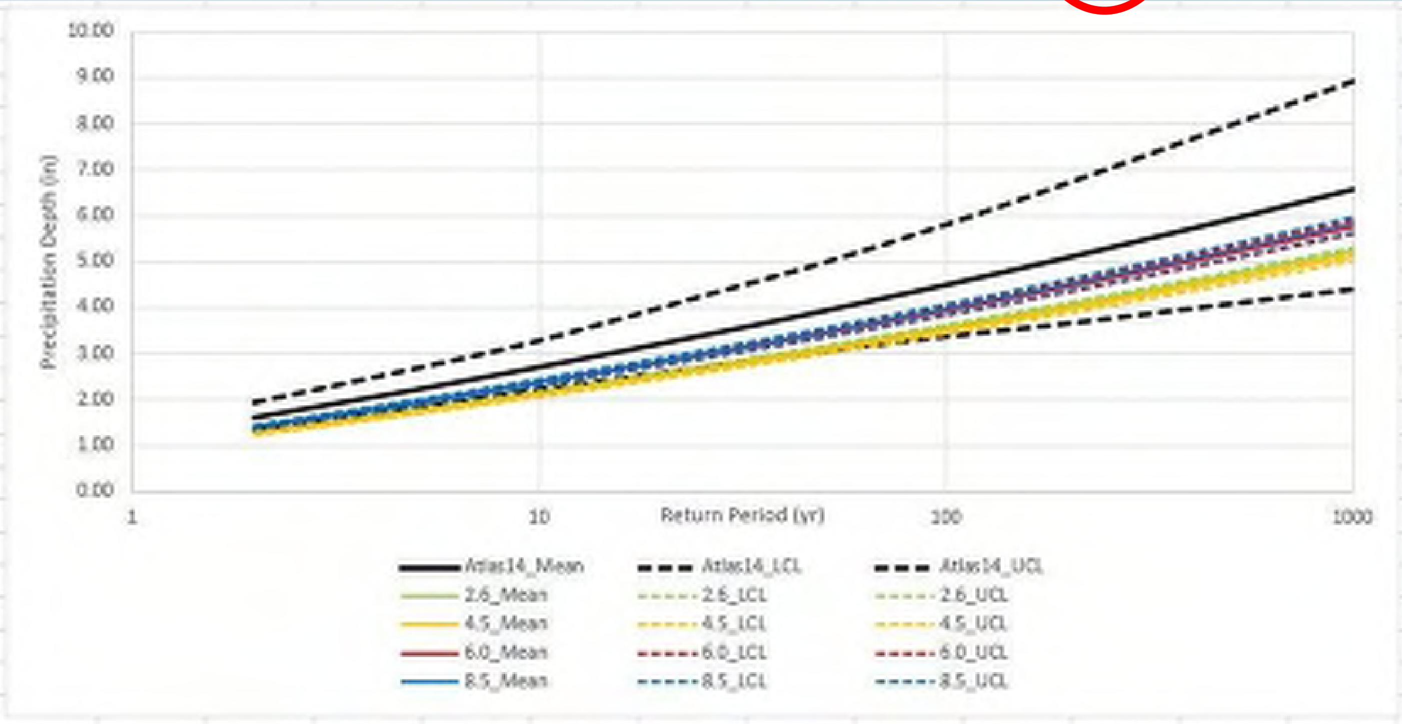
Review Climate Change Indicato

Emission Scenario		
	1/2	1/5
2.6	-1.01	-1.00
4.5	-1.07	-1.06
6.0	-0.62	-0.61
8.5	-0.58	-0.57

CCI < 0.4 (Level 2 An

0.4 < CCI < 0.8 (Desig

0.8 < CCI (Level 4 An



CMIP Tool Results

Denver, CO (Maximum GCM)

Select an Appropriate RPB for each Emission Scenario on the Quantile Summary worksheet

Emission Scenario	RPB Mean	RPB Lower CL	RPB Upper CL	Avg			Max			Min		
2.6	1.02	0.81	1.28	1.02	0.81	1.28	1.30	1.28	1.31	0.79	0.78	0.80
4.5	1.03	0.83	1.28	1.03	0.83	1.28	1.30	1.25	1.34	0.78	0.76	0.79
6.0	1.03	0.89	1.20	1.03	0.89	1.20	1.19	1.18	1.21	0.87	0.85	0.89
8.5	1.04	0.87	1.24	1.04	0.87	1.24	1.24	1.21	1.27	0.88	0.86	0.91

Review Climate Change Indicato

Emission Scenario	1/2	1/5
2.6	1.44	1.43
4.5	1.44	1.43
6.0	0.95	0.94
8.5	1.19	1.18

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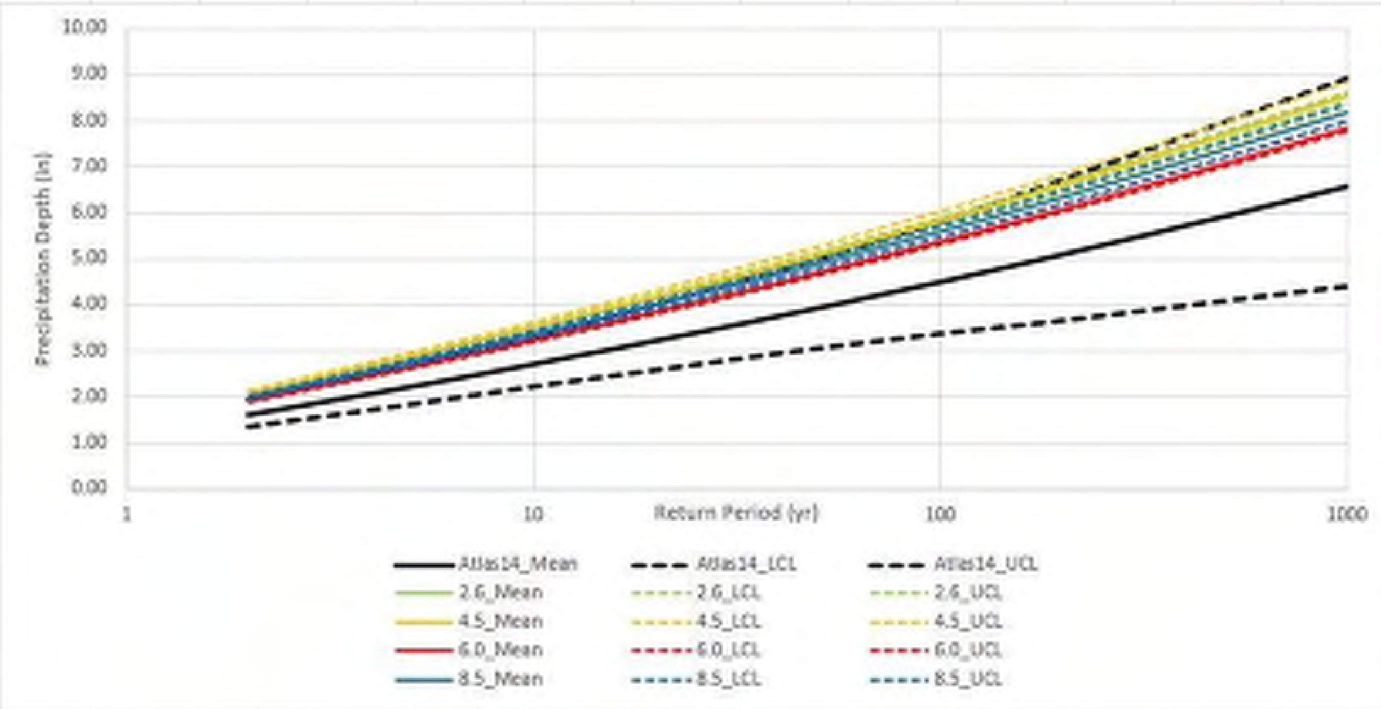
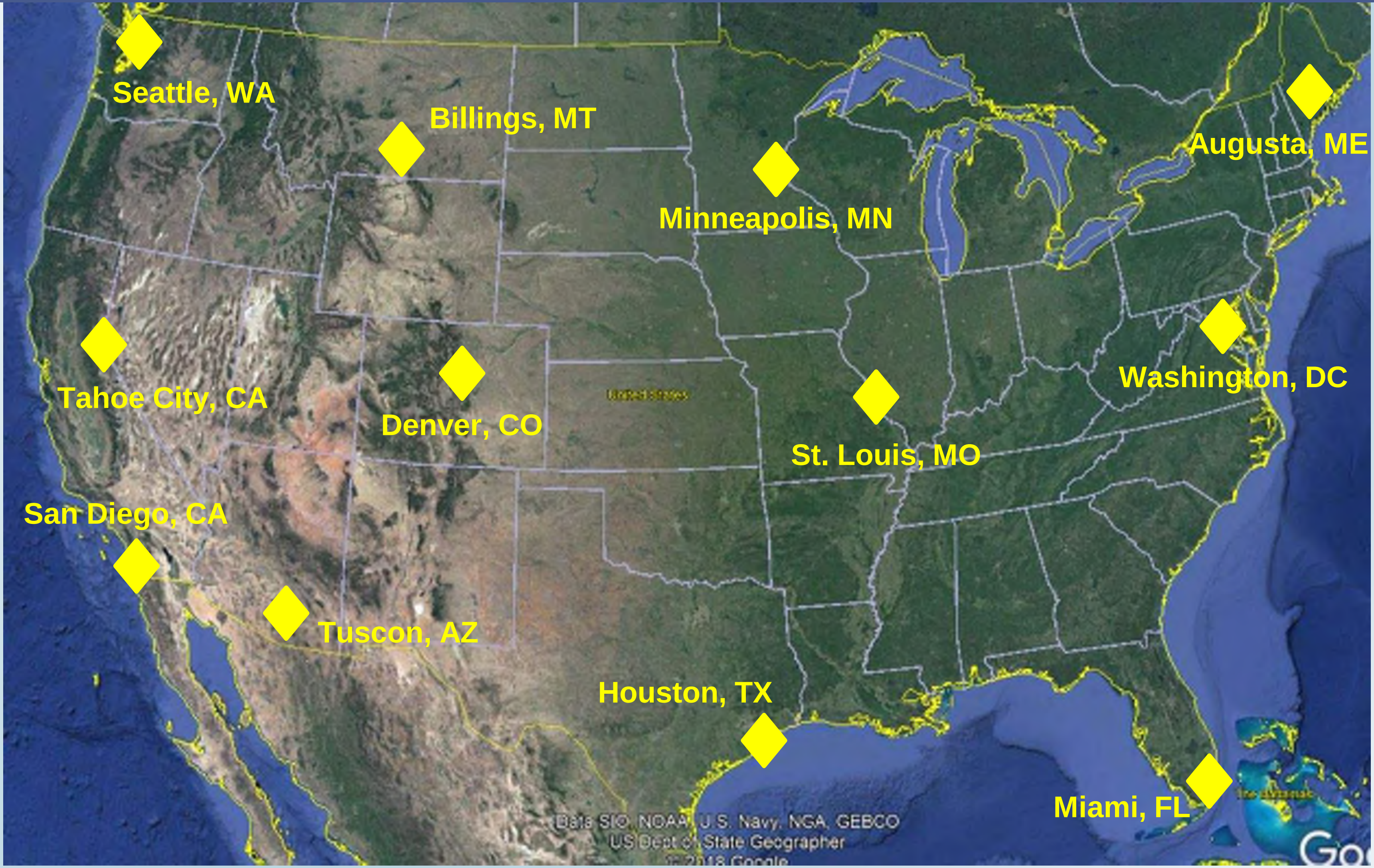


CMIP Tool Results



CMIP Tool Results

Ratio of Projected to Baseline (RPB)

Source: Varrella, 2012

Results below organized based on USA Map

Seattle	Billings	Minneapolis	Augusta
Tahoe City	Denver	St Louis	Washington
San Diego	Tuscon	Houston	Miami

Scenario 4.5 RPB Mean

1.13	1.11	1.12	1.10
1.09	1.03	1.10	1.10
1.07	1.11	1.04	1.06

Scenario 8.5 RPB Mean

1.17	1.18	1.11	1.13
1.17	1.04	1.14	1.06
1.13	1.13	1.06	1.09

Climate Change Impacts on Flood Hydrology

Discussion Agenda:

1. CMIP Climate Projections
2. Initial Results & Impressions
3. HEC-17 Guidance and Tool Development
4. CMIP Tool Results
5. ***Summary***

Source: "Hula Moose," Varrella, 2014

Summary

1. *Complex process!*
2. *New language of terms*
3. *International dataset*
4. *Myriad of info and options*
5. *Downscaling limitations and dampening of extremes (LOCA?)*
6. *Difficult to select appropriate GCMs without bias*
7. *Wide NOAA Atlas 14 Confidence limits often envelope results*
8. *No definitive conclusions – but will press on!*

Summary

Final Thought…

Climate-Modified Hydrology

Questions?

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Evolution of the 2-D Base Level Engineering Across FEMA Region VIII and a Case Study from Garfield County, Colorado

Eli Gruber, PE

Garrett Sprouse, EIT

David Sutley, PE

compass

Identify Hazards. Interpret Risks. Integrate Mitigation

CDM Smith

Project Acknowledgments

FEMA Region 8 Staff:

- David Sutley, PE
- Dawn Brabenec, PE

CWCB Staff:

- Thuy Patton, MPA, CFM

Anderson Consulting Engineers

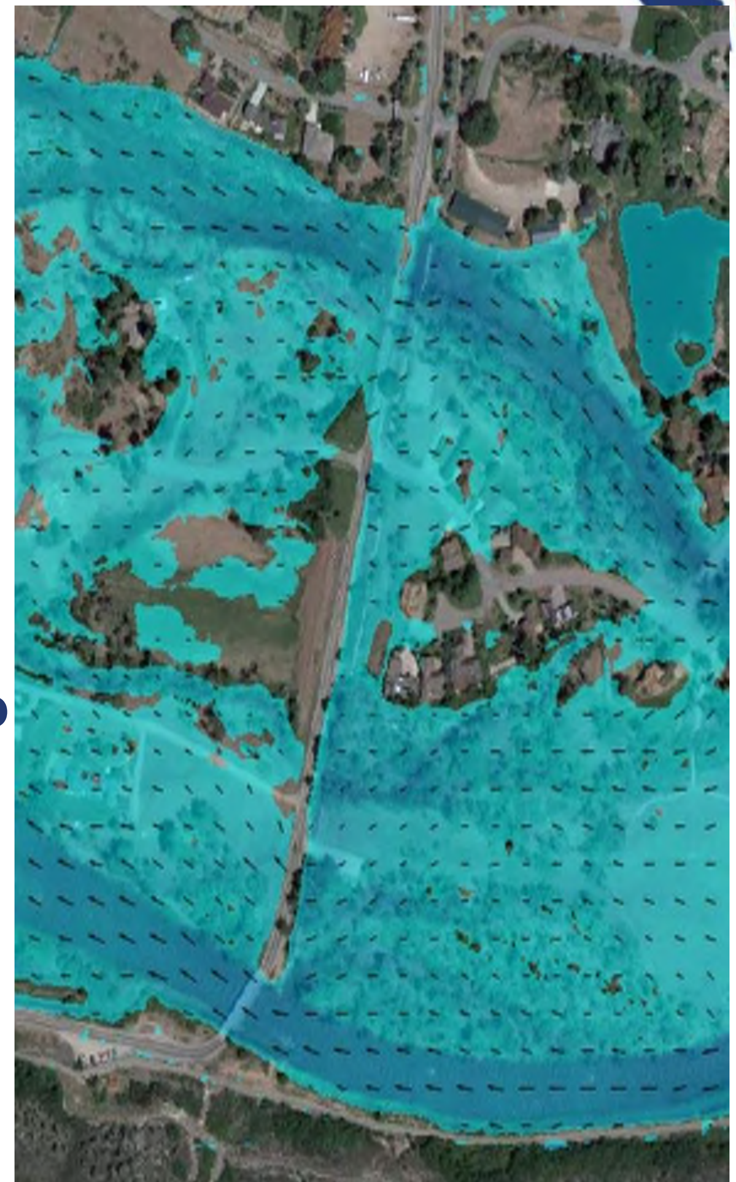
- Travis Rounsaville, PE
- Michelle Martin, PE

Terrain Data Sources:

- USGS - National Elevation Dataset
- CWCB - Colorado Hazard Mapping Program

Overview

- What is 2D Base Level Engineering (BLE)?
- Garfield County BLE
  - Process refinements
  - Issues and Limitations
- Where do we go from here?
- Research and Development



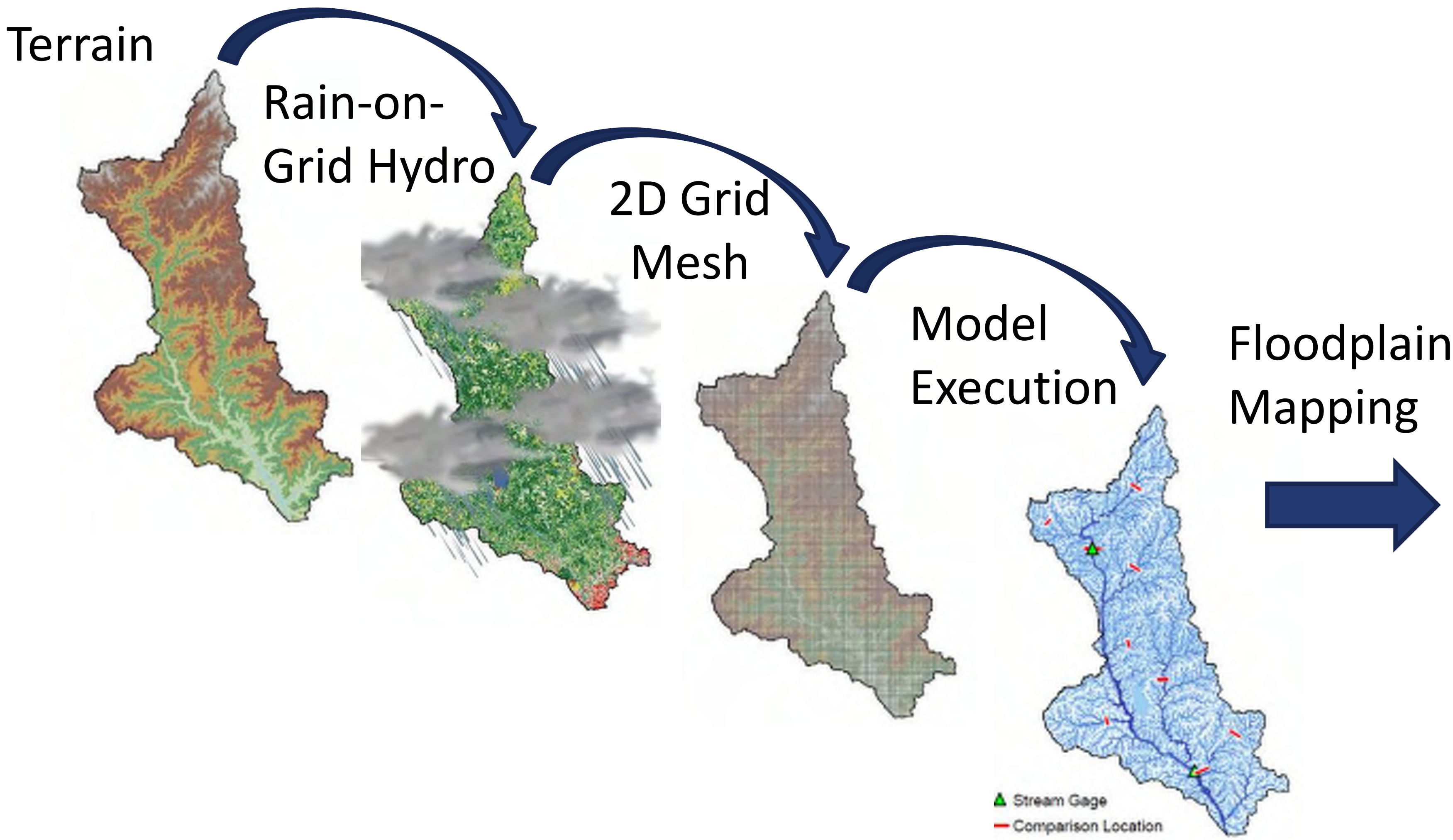
2D Base Level Engineering (BLE)

- What is 2D BLE?
  - Watershed-level hydraulic modeling and floodplain mapping
  - Automated processes
- HEC-RAS 5.0
- Produce results for previously unmapped areas and/or non-model backed SFHAs
- Help drive scoping decisions for future detailed studies (scalable)

Accuracy & Efficiency

Cost & Time

2D BLE Modeling Concepts



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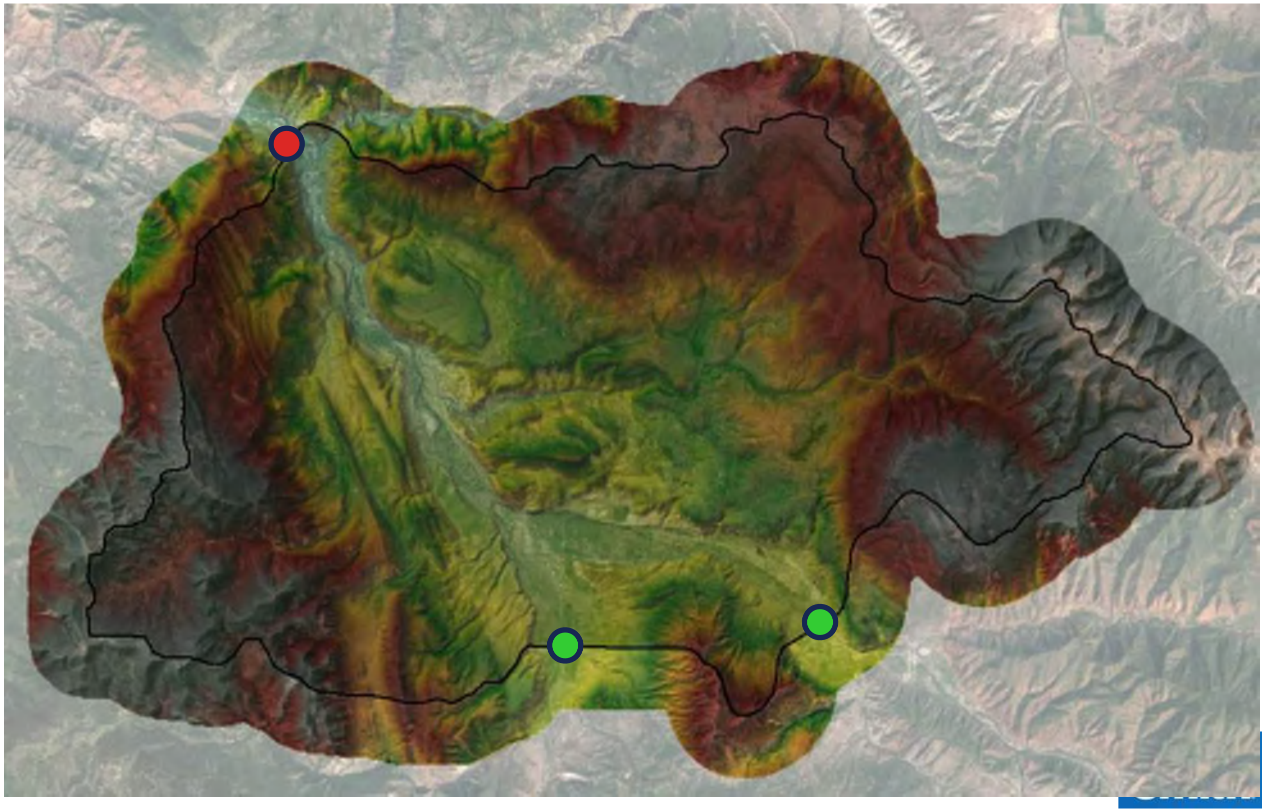
Identify, Interpret, Integrate

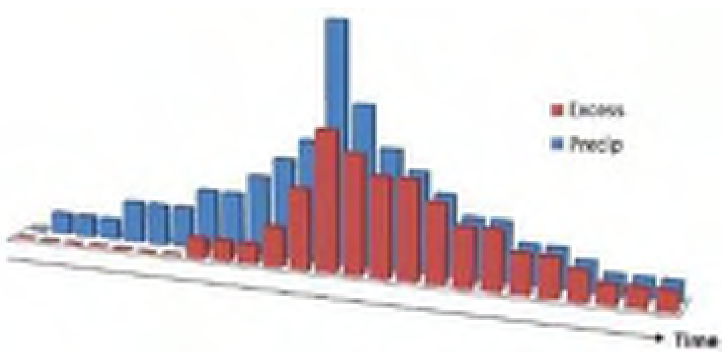
Model Area Delineation

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



BLE Rain-on-Grid Hydrology

- Applied directly to 2D Mesh
- No hydrologic losses in HEC-RAS 5.0
  - Simple HMS model
    - SCS CN Method – 24-hour storm
    - NOAA Atlas 14 precip raster
    - NRCS Soils + NLCD = Average CN
- Excess Precipitation Hyetograph



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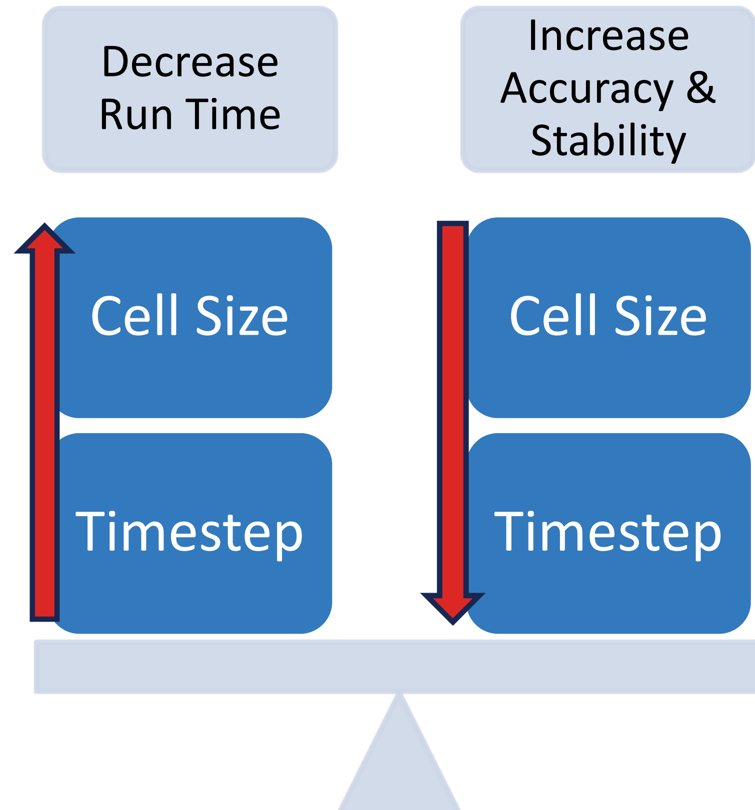
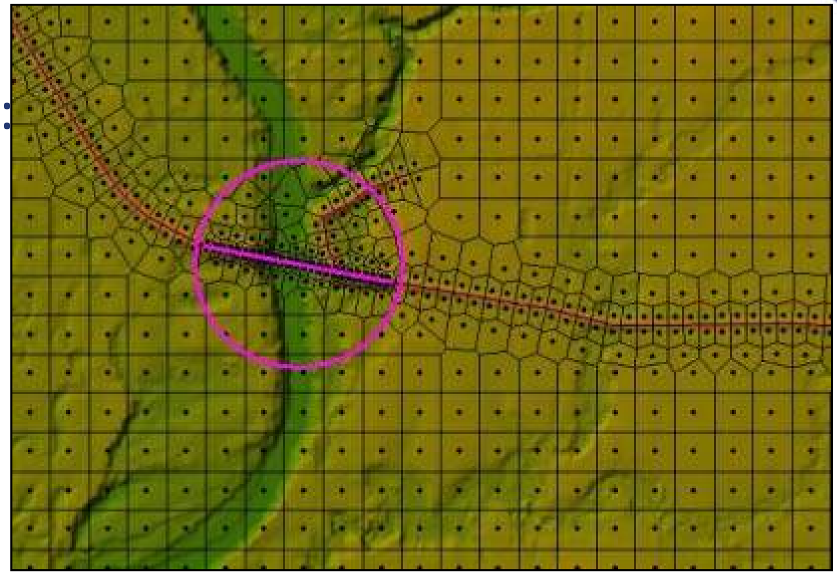
HEC-RAS 5.0 Hydraulic Parameters

- Grid cell mesh
  - 200-foot nominal cell size
- Manning's n
  - NLCD 2011 spatial coverage
- Boundary Conditions
- Computational options
  - Diffusion Wave Equation
  - Timestep options

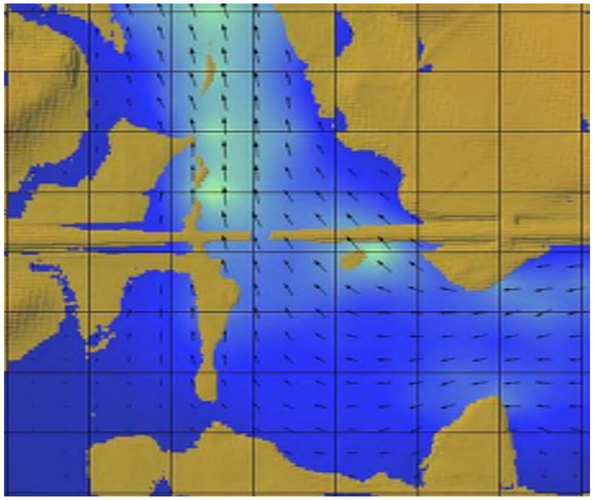


Breaklines

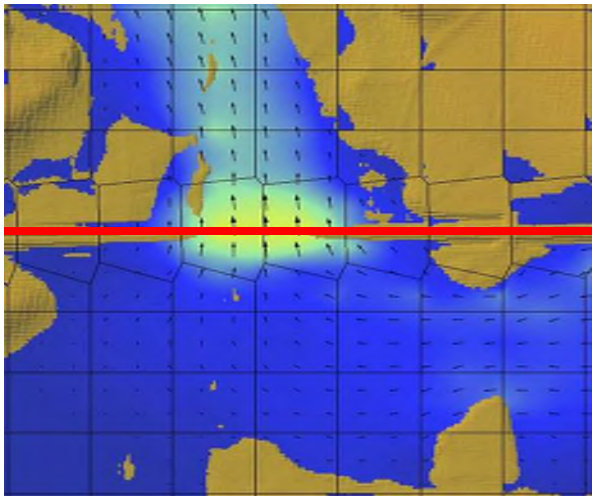
- Used to refine grid and represent:
  - Road embankments
  - Structures
  - Levees
  - Dams
  - Other Terrain Features



No Breakline



With Breakline



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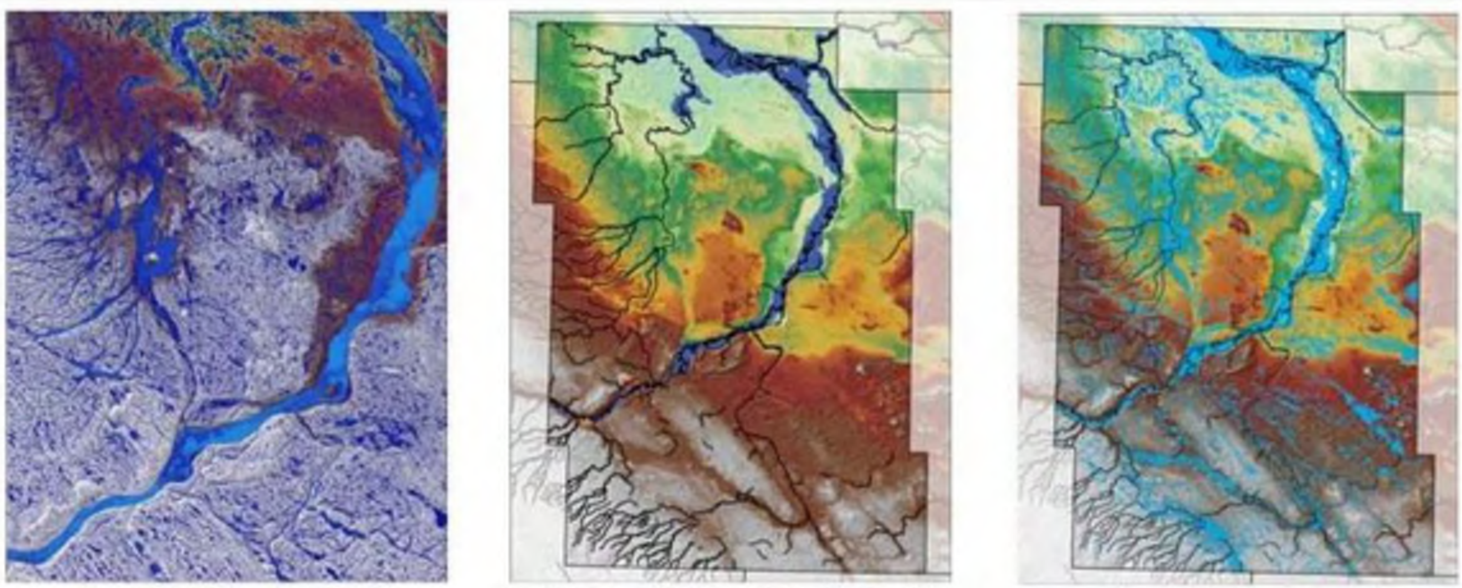
BLE Outputs

- Provide county-wide floodplain data for 7 recurrence intervals
- Mapped SFHA data for 1% and 0.2% ACE events
- Final BLE models and reports

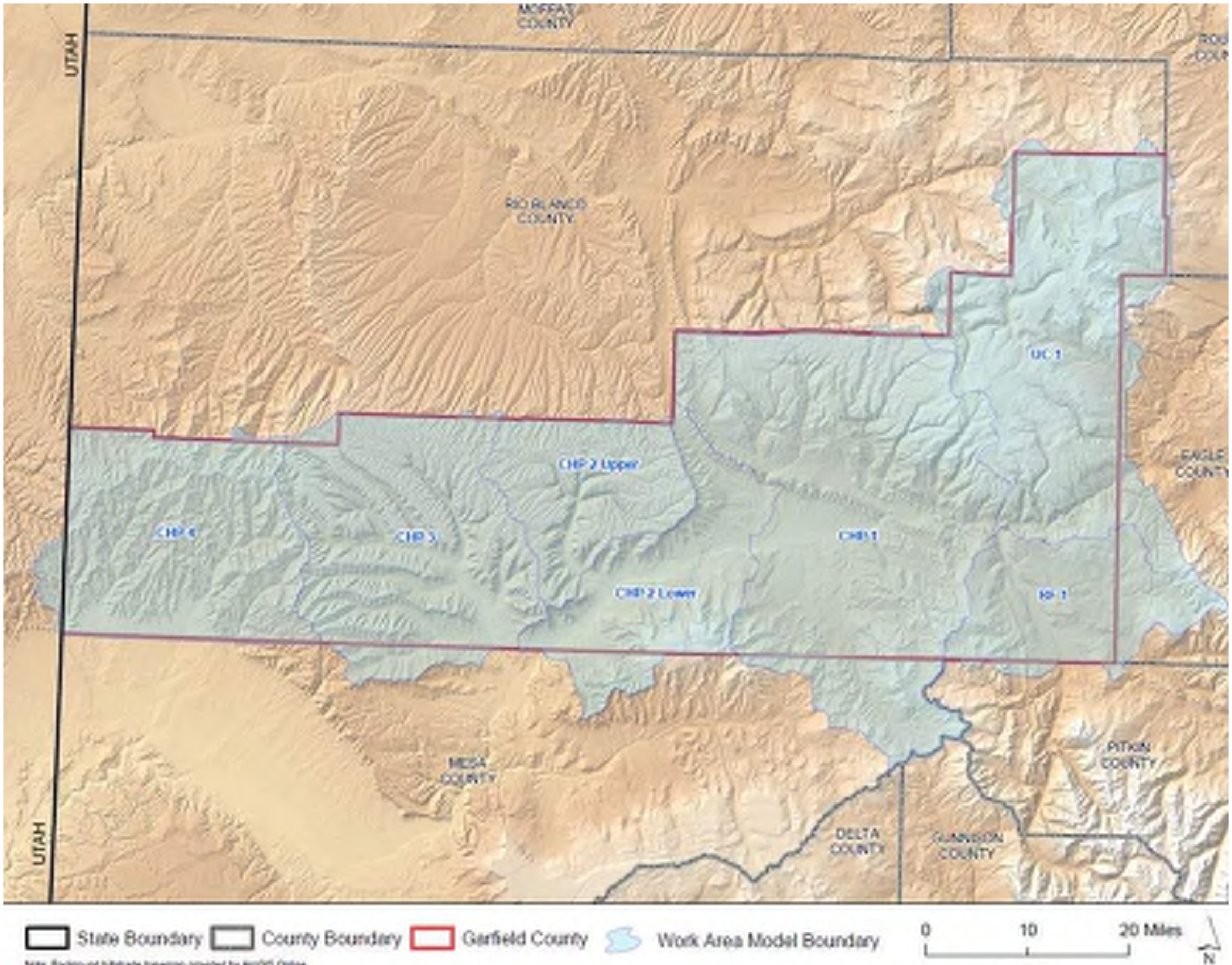
Annual Chance Exceedance	H&H Modeling	Floodplain Mapping
10%	☑	--
4%	☑	--
2%	☑	--
1%-minus	☑	--
1%-plus	☑	--
1%	☑	☑
0.20%	☑	☑



Raw Model Output Depth Grid   Identify County, CNMS and Effective Flood Zones   Floodplain Mapping Applied

CDM Smith ...pass Identify, Interpret, Integrate

Garfield County, CO 2D BLE



Garfield County Model Background

- LiDAR data from CWCB
- Produced floodplain data for full county
- Gage analysis for three major external inflows:
  - Colorado River
  - Roaring Fork
  - Crystal River
- Highly variable **terrain** and **hydrologic conditions**

Photo from Glenwood Springs Chamber of Commerce

Hydrologic Conditions

Challenge:

- Represent variable hydrologic conditions
  - Small streams and washes < 8,000’ controlled cloudburst rainfall events
  - Larger basins driven by snowmelt or rain-on-snow

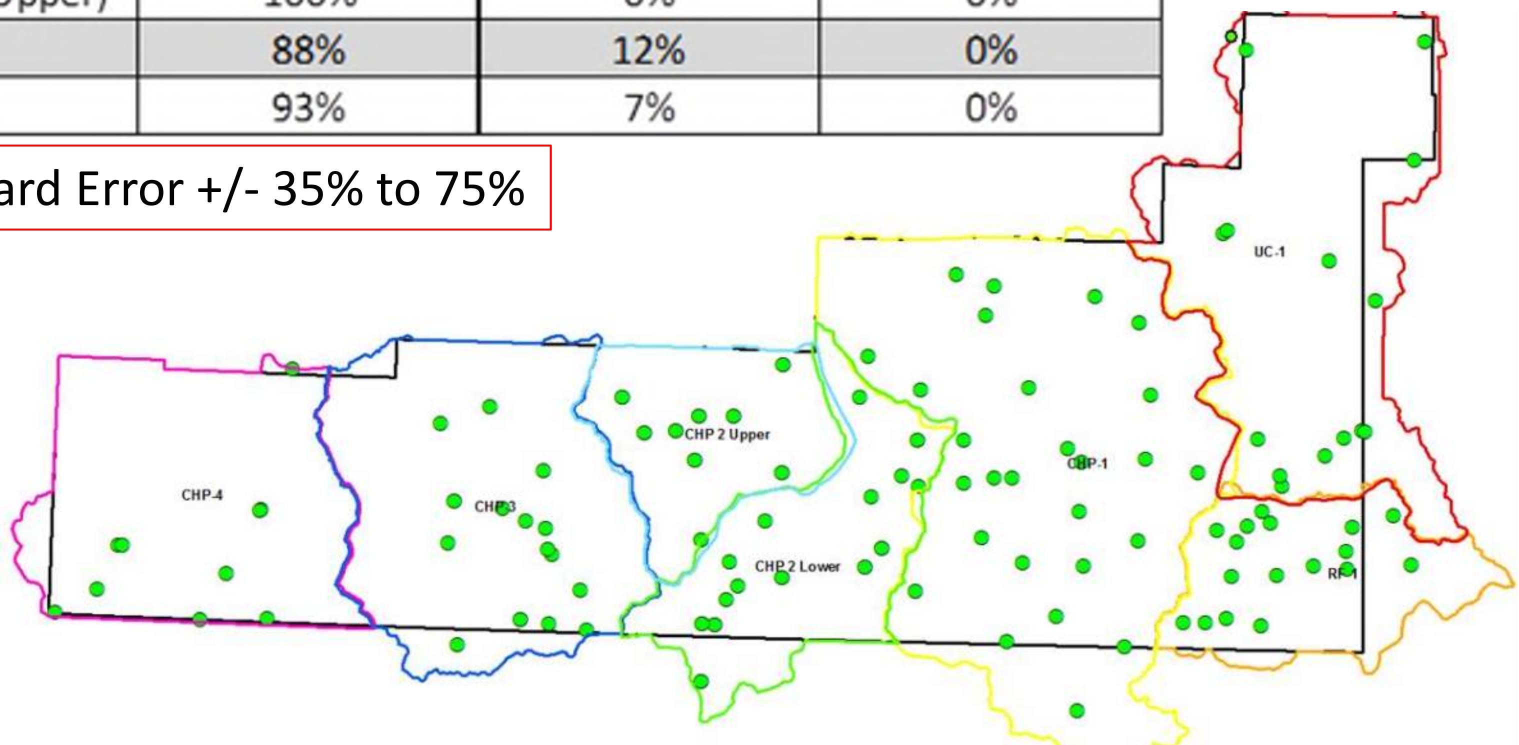
Solution:

- Model “calibration”
  - Calculate target 100-yr peak flows (gage or regional regression) at various points in model
  - Compare model values to target values
  - Adjust rain-on-grid hydrology and re-run model until best match at most points

“Calibration” Results

Model Area	Within 1-Sep	Within 2-Sep	Outside 2-Sep
UC-1	69%	31%	0%
RF-1	76%	24%	0%
CHP-1	81%	19%	0%
CHP-2 (Lower)	73%	27%	0%
CHP-2 (Upper)	100%	0%	0%
CHP-3	88%	12%	0%
CHP-4	93%	7%	0%

Standard Error +/- 35% to 75%



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Steep & Variable Channel Slopes

Challenge:

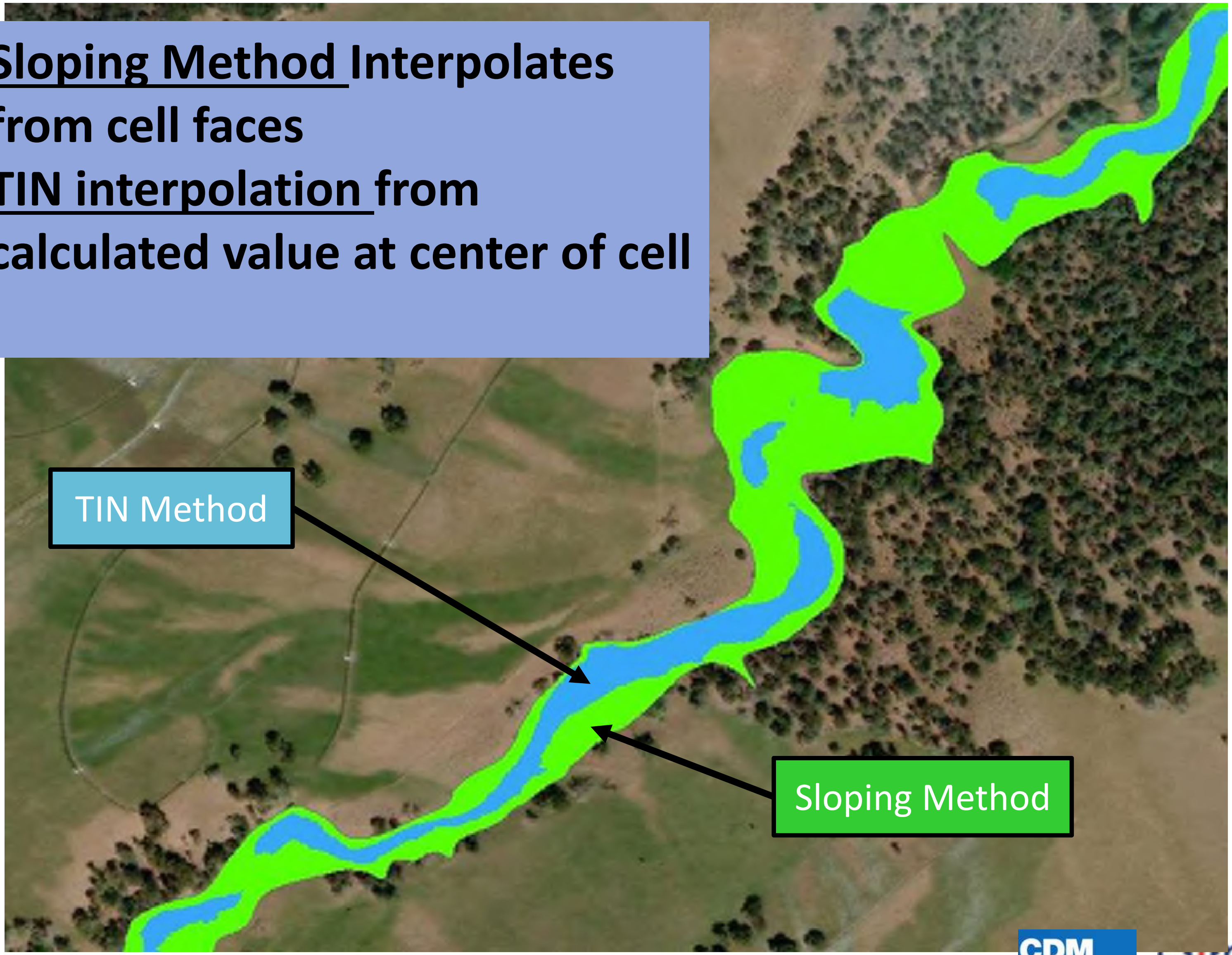
- Disconnected mapped floodplains
  - Map rendering issues in steep streams (>3%) with low discharge

Solution

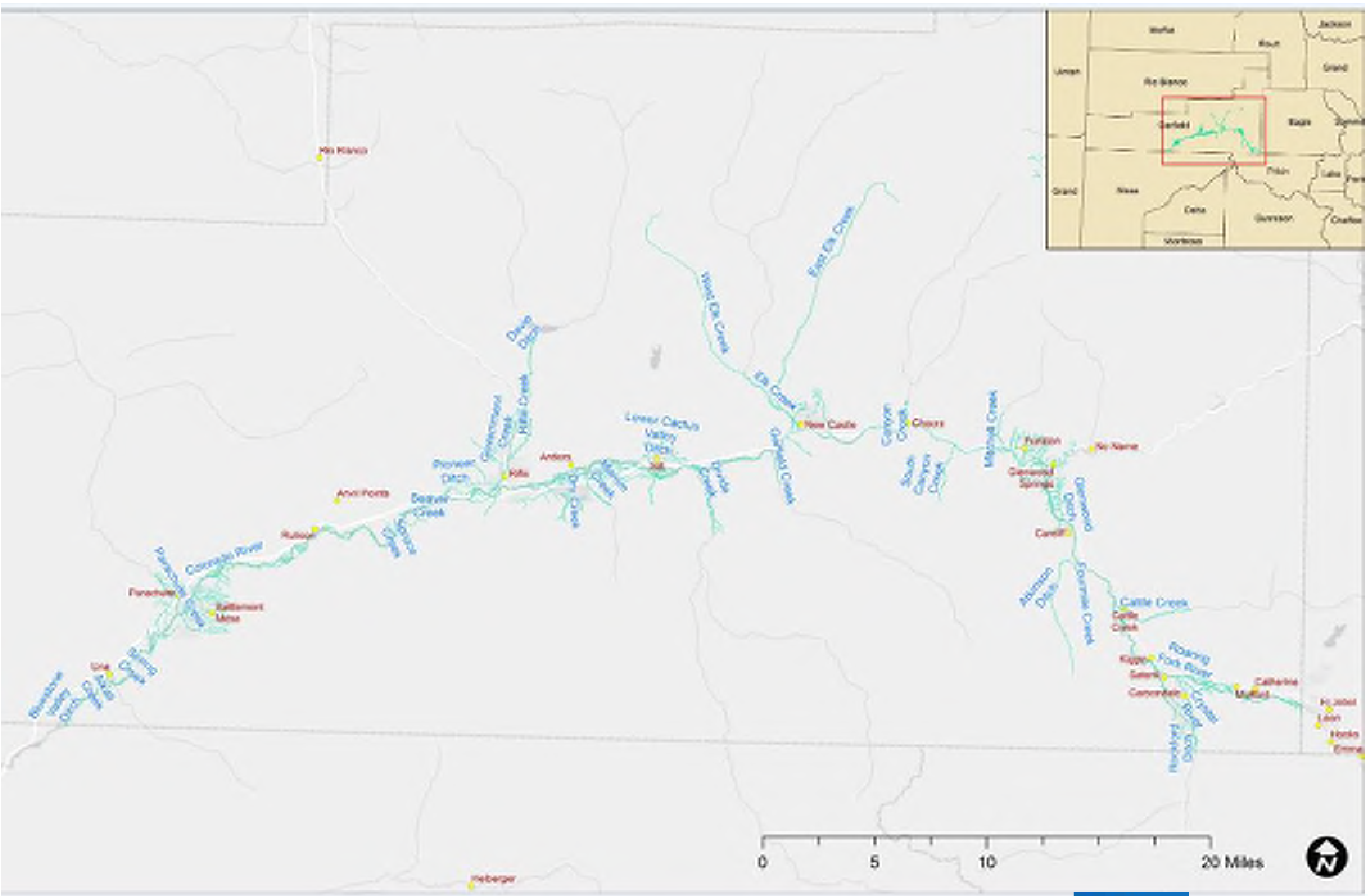
- Targeted grid cell mesh refinement
  - Streams with existing/prelim FEMA data and/or within municipal boundaries
  - Decrease cell size from 200ft to 40ft along stream centerline

Garfield Results Examples

1. Sloping Method Interpolates from cell faces
2. TIN interpolation from calculated value at center of cell

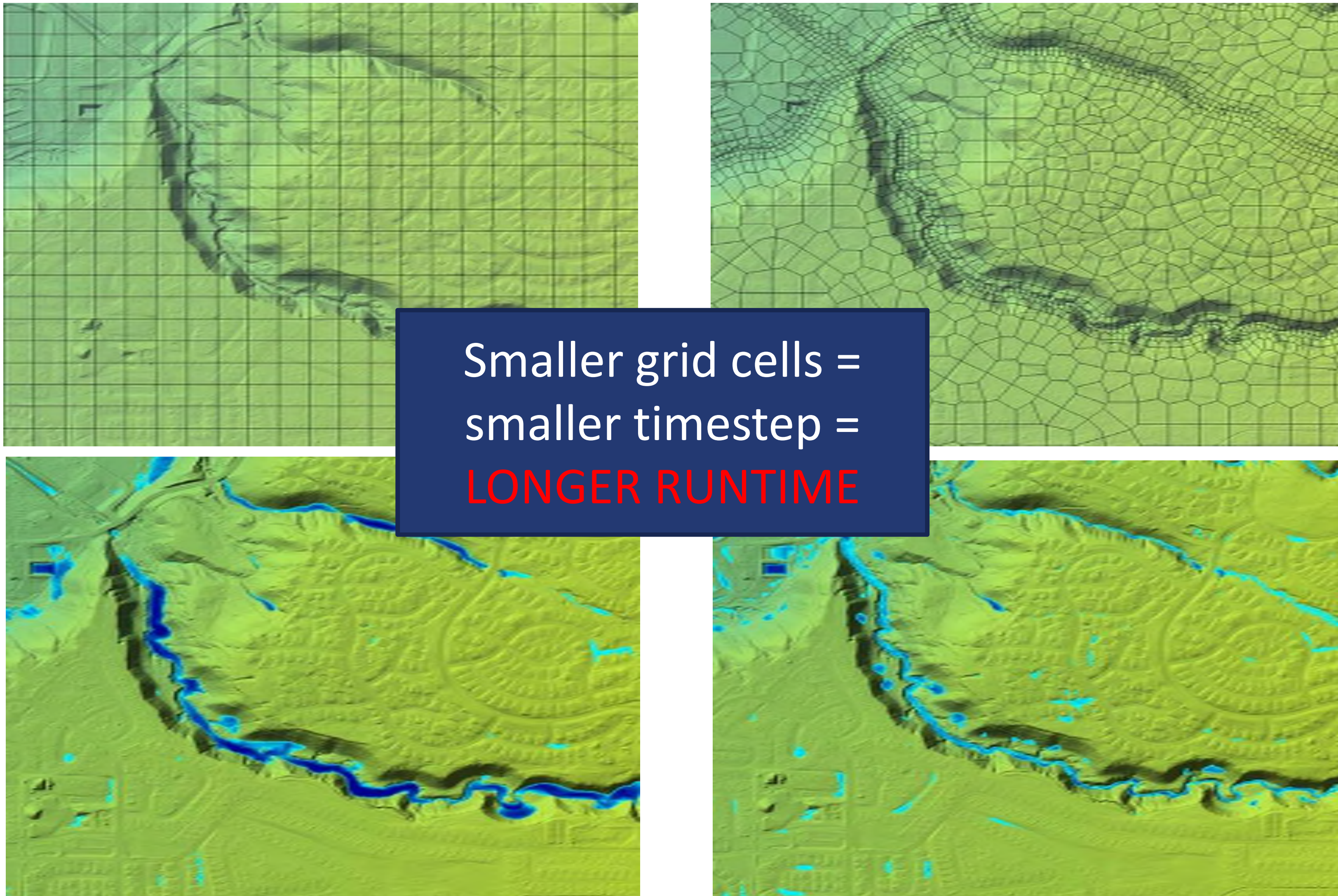


Refinement Areas



Mesh Refinement Results

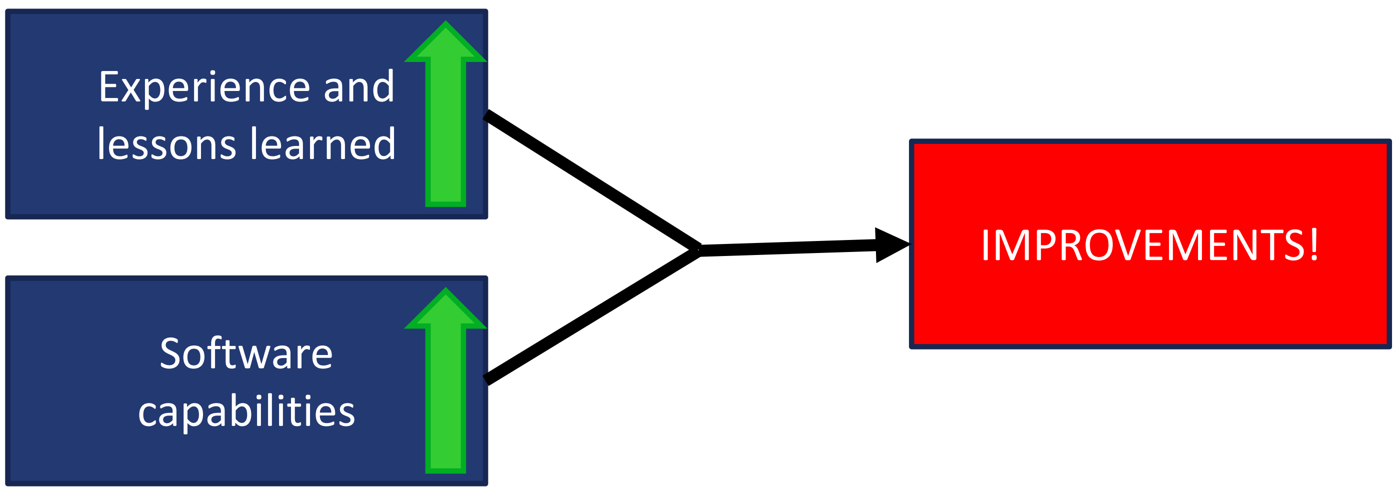
Before	After



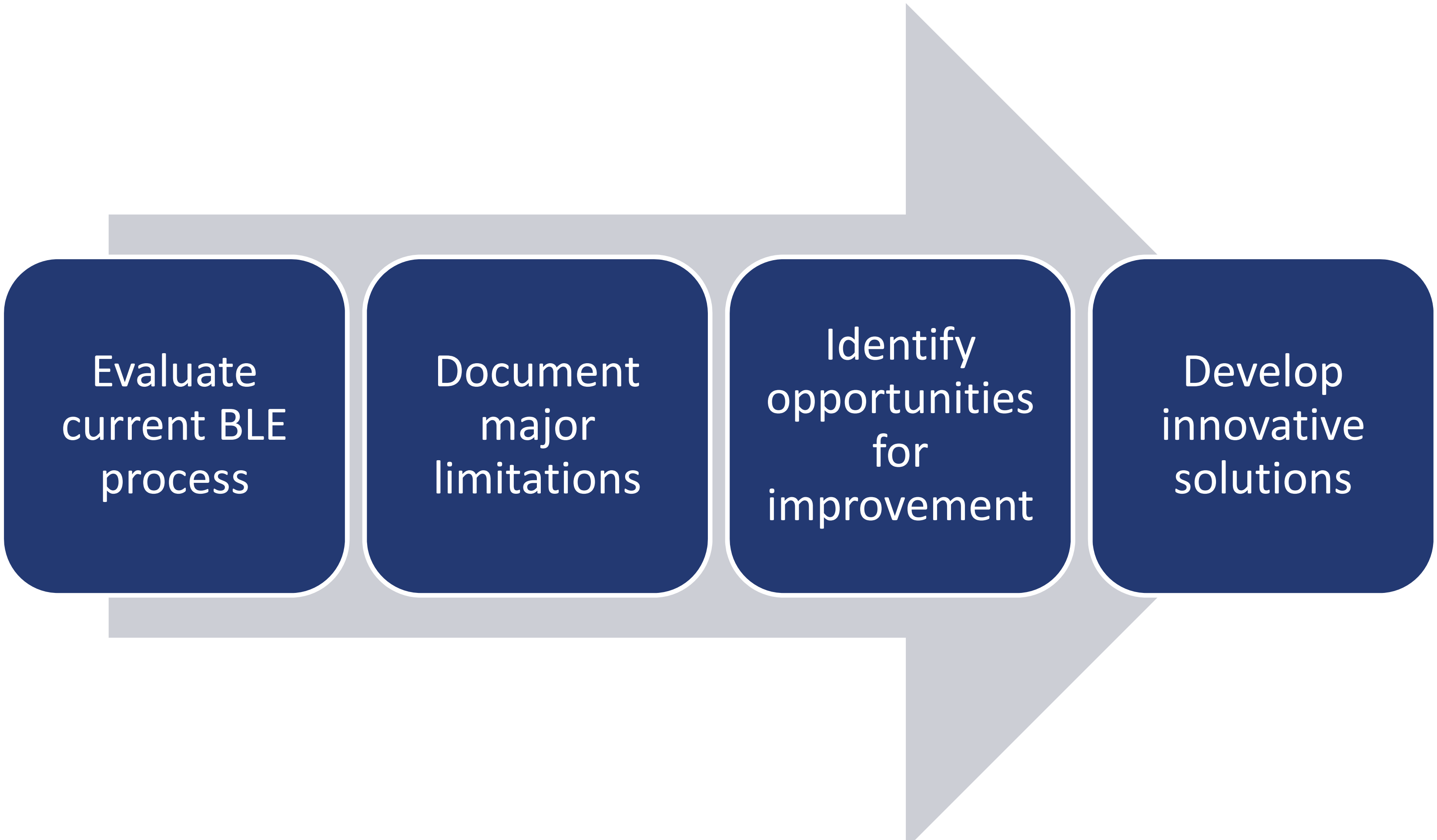
Smaller grid cells =
smaller timestep =
LONGER RUNTIME

Where do we go from here?

- 2D BLE process is capable of producing approximate Zone A floodplains in most areas
- Garfield County highlights some challenges to address



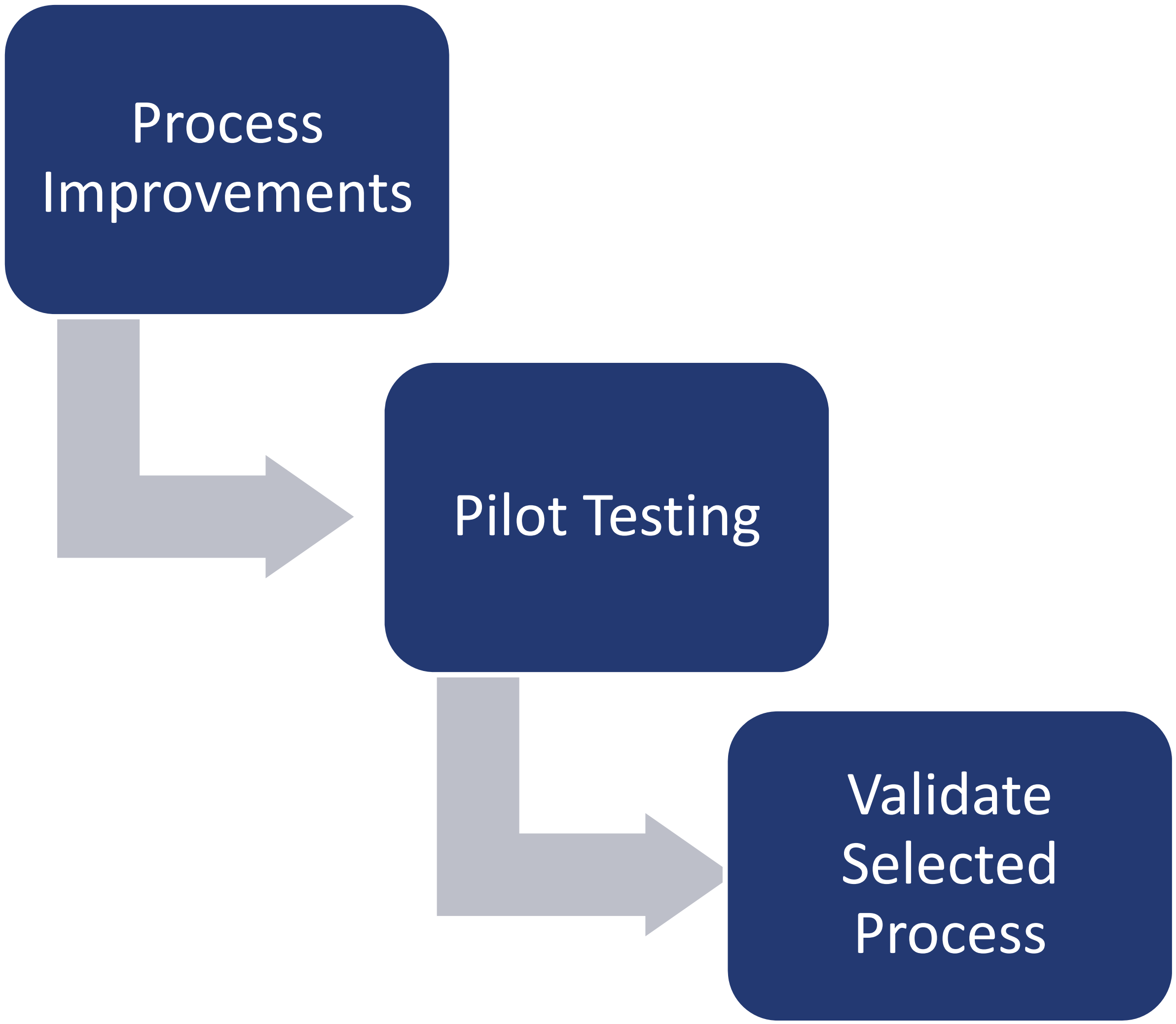
Ongoing Research & Development



Ongoing R&D Activities

- Pre-project watershed evaluation process
- Testing sensitivity to slope vs grid cell size vs discharge
- Sub-basin specific hydrologic parameters
  - Rainfall distribution/Precip/CN
- Methods for representing structures
- Improving results rendering and mapping

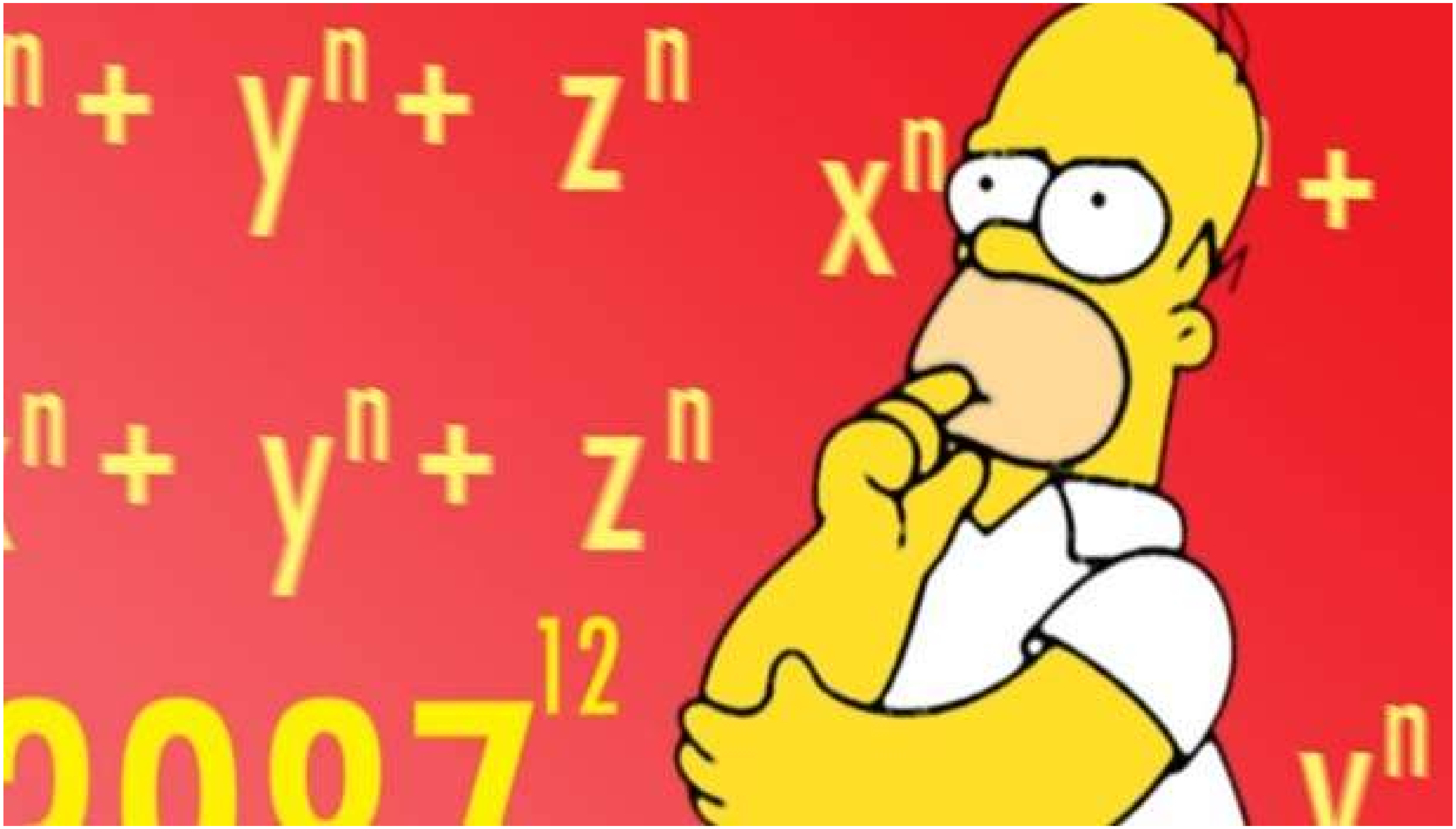
R&D Next Steps?



Key Takeaways

- 2D BLE is an efficient and (relatively) accurate method for producing floodplains
- Engineers should evaluate whether method can achieve desired project outcome
- Process limitations provide opportunities to improve....stay tuned!

Questions?




CERC
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staff
Compass
Contractor
Evaluation Factors
CTPs
Sub
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Provide
Contractor
LOCAL
Business
addition
products
Support
experience
RiskMAP
Partner
Government
Evaluate
Experience
Compliance
Map
Team Resources
Support
Projects
FLOOD
Technical
REGIONAL
proposed
Factor
Contractor
Proven
subcontracting
Hazard
Government
Providing
businesses
FEMA
Technical
Professional
Support
Control
HMTAP
Team
mitigation
regulatory management
TARC
Project
Ability
Key Personnel
Data
Technical Approach
information
factor
performance
Small Business
including
Building
Contract
development
PTS AE
FIMA
Operations
production
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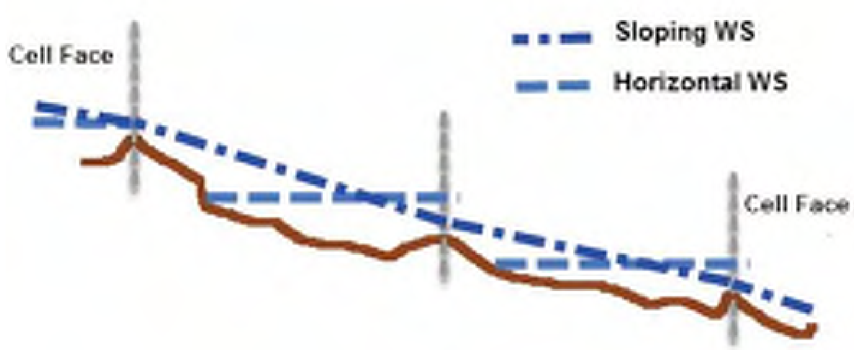
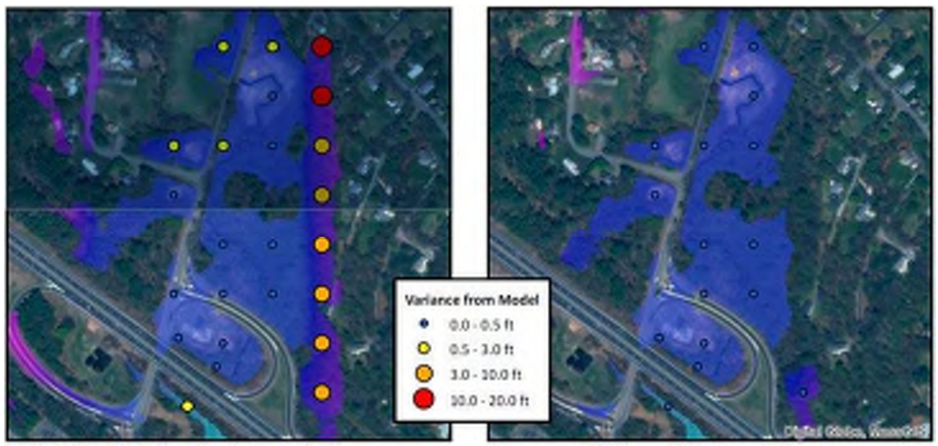
compass

Map Rendering Options

- **Sloping** – Interpolates from cell faces; tendency to overestimate

- **Compass TIN Method:** TIN interpolation from calculated value at center of cell





HEC-RAS 5.0.3 Sloping Interpolation

Compass TIN-based Interpolation

CDM Smith compass Identify, Interpret, Integrate

CASFM 2018 Annual Conference

Water Medley Sessions:

Session1: Oh No! We've got to go under it!

Becky Brock (Brierley Associates), Chris Knott (Btrenchless)

Session2: Planning and Siting of Recreational Whitewater Features

Brooke Seymour & Richard McLaughlin (UDCFD)

Nature Play Design Guidelines: Techniques for Including Nature Play within Floodplains

Cassie Kaslon & Susan Brown (Valerian), Frans Lambrechtsen (CH2M)

Oh No!

We've got to go under it!

2018 CASFM – Snowmass

BRIERLEY ASSOCIATES
Creating Space Underground
Becky Brock, PE
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BTrenchless
Chris Knott
chris.knott@btrenchless.com

Agenda

- Criteria for Stormwater Tunnels
- Subsurface Conditions
- Contracting Preferences
- Trenchless Comparisons
- Trenchless Methods
- Pipe Materials

Oh No! We've got to go under it!

BRIERLEY ASSOCIATES
Creating Space Underground

Stormwater Tunnels

Fixed Criteria:

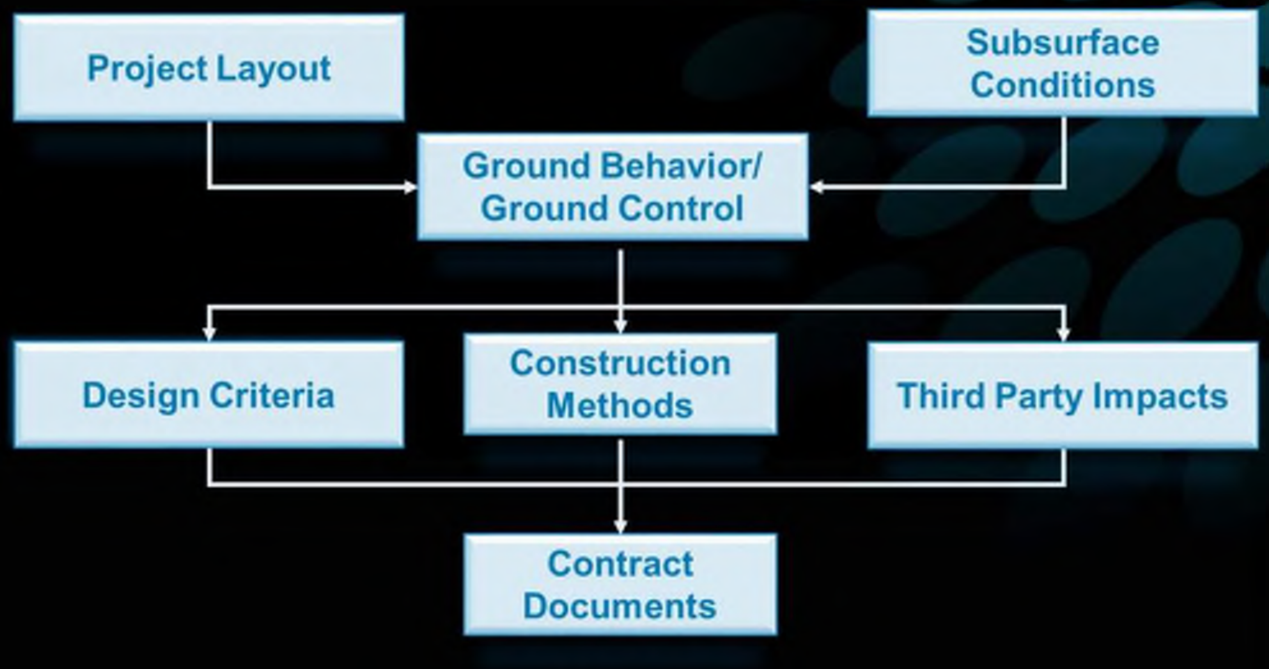
- Flow requirements:
  - Depth, length, diameter, and grade
  - Maintaining grade is critical for gravity flow
- Limited access / Impacts to 3rd parties
- Subsurface conditions

BTrenchless

BRIERLEY ASSOCIATES
Creating Space Underground

Subsurface Conditions

Design Approach:



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Creating Space Underground

Subsurface Conditions

Ground Behavior Dictates!!!

Subsurface Conditions

BTrenchless

Ground Behavior Dictates!!!

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Subsurface Conditions

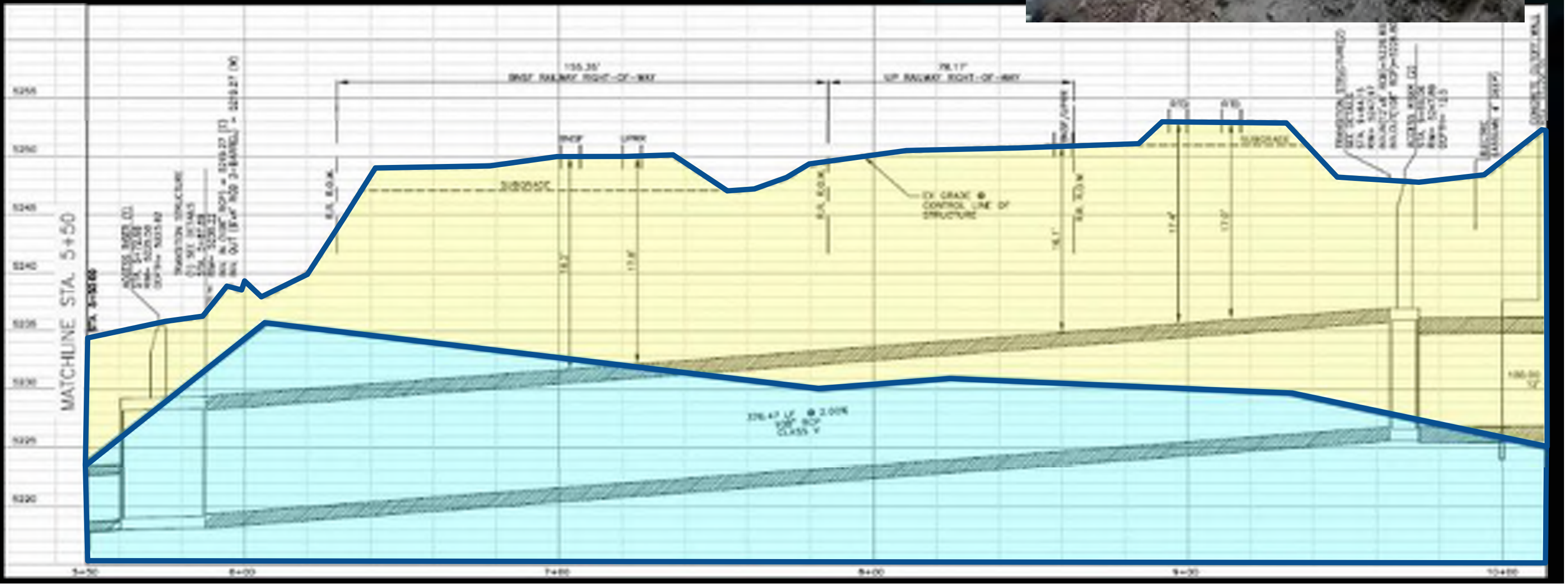
Subsurface Investigation:

- Crucial to project success
- Challenges of limited access
- Cost – Benefit ratio
- Quality investigation

Subsurface Conditions

Adverse Conditions:

- Difficult Steering
  - Mixed-face condition
  - Cobbles and boulders
- Settlement
  - Unstable soils
  - Shallow cover
- Utility conflicts / obstructions



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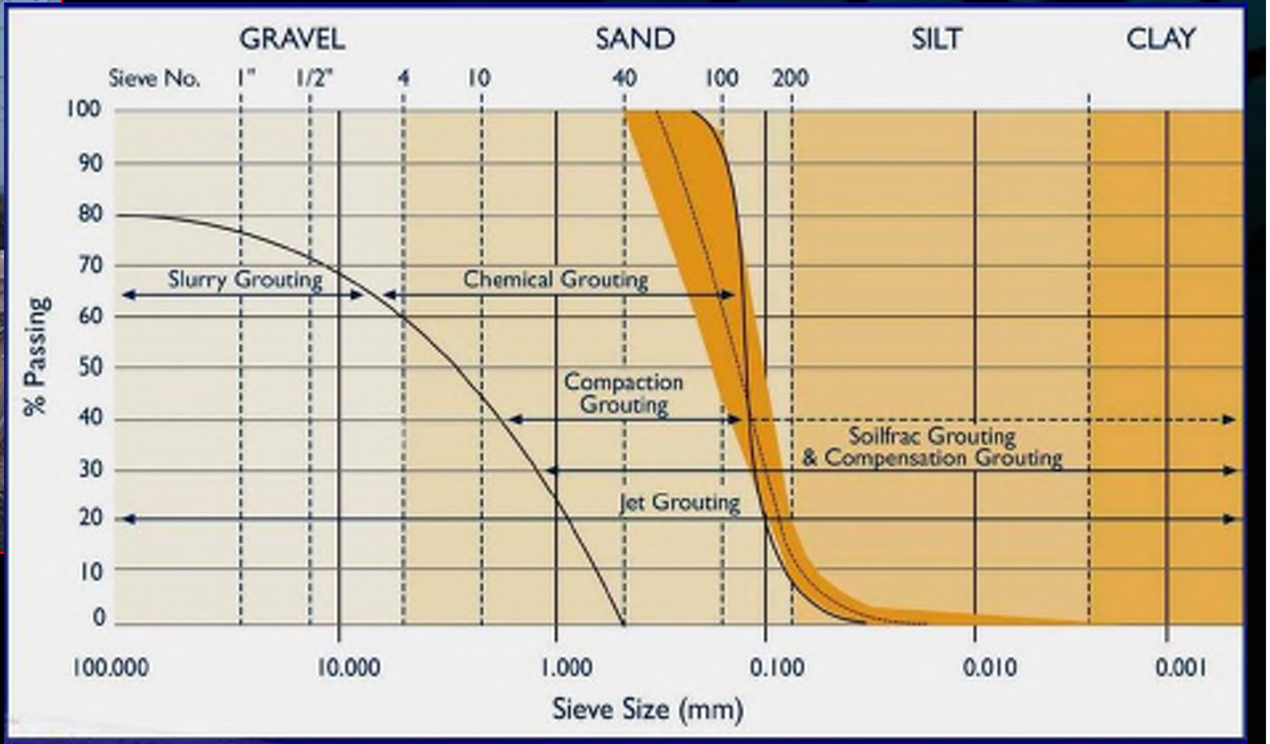
Subsurface Conditions

Mitigation Measures:

- Improves unfavorable ground conditions and reduce risk of damage
- Technique dependent on soil type and gradation



Source: HBI

BRIERLEY ASSOCIATES
Creating Space Underground

Contracting Preferences

The owner owns the ground:

- Contractor pre-qualification
- Geotechnical Baseline Report (GBR)
- Typical Specifications:
  - Trenchless Construction
  - Contact Grouting
  - Shaft Excavation and Support
  - Geotechnical Instrumentation and Monitoring

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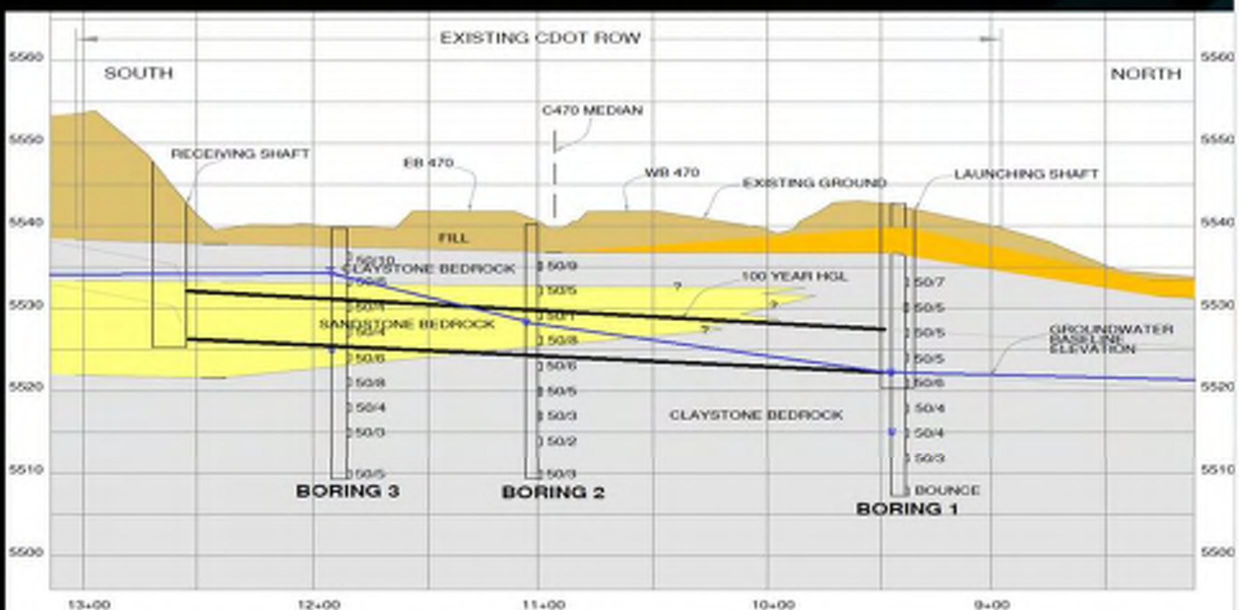
Creating Space Underground

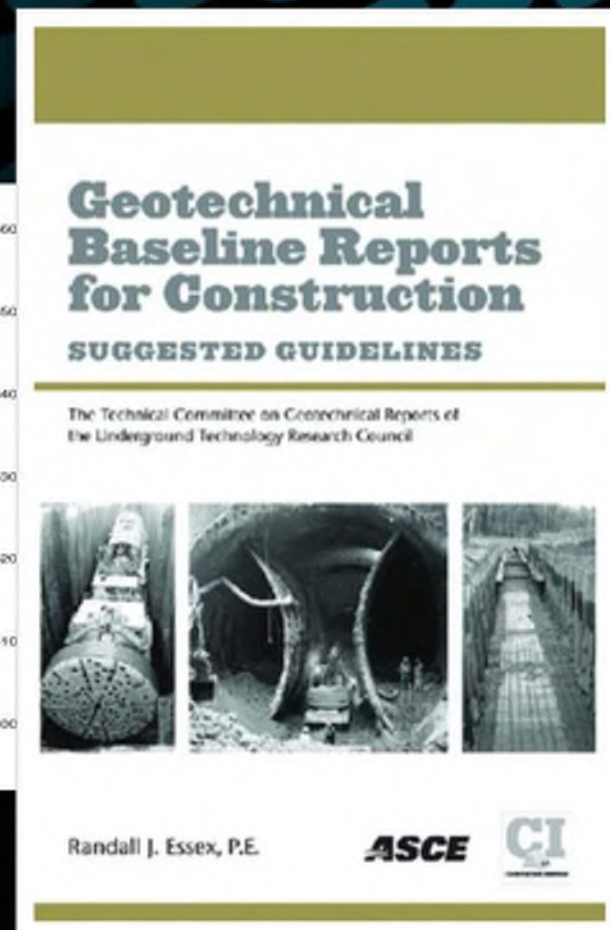
Contracting Preferences

BTrenchless

Geotechnical Baseline Report:

- Establishes a contractual baseline of subsurface conditions for bidding:
  - Baselines are contractual assumptions and not necessarily geotechnical fact
  - Anticipated physical and behavioral conditions
  - Included in the contract documents





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Creating Space Underground

Contracting Preferences

Geotechnical Baseline Report:

- Manages risk allocation
- Bids are comparable
- Provides a basis for DSC claims
- Commonly used in trenchless projects

WITHIN THE BASELINE	BEYOND THE BASELINE
CONTRACTOR'S RISK	OWNER'S RISK

BRIERLEY ASSOCIATES
Creating Space Underground

TRENCHLESS COMPARISONS

Method	Diameter (in)	Length (ft)	Usable Under Water?	Line & Grade Control	Cost
Auger Bore	8” - 72”	250’	N	Vertical	$
Pilot Tube	5”	500’	N	Y	$$
McLaughlin	20” – 48”	400’	N	Y	$$
Hand Tunnel	42” – 15’	100’ >	N	Y	$$$
Pipe Ramming	12” – 144”	400’	Y	N	$$$
TBM Pipe Jacking	51” – 129”	1000’	N	Y	$$$$
Microtunneling	36” – 96”	1000’	Y	Y	$$$$$

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Auger Bores

Advantages:

- Relatively inexpensive
- Suitable for a variety of soil types
- Drives up to 250 ft, capable of longer drives with reduced accuracy
- Wide range of sizes: 12” – 72” diameter casing – (non-welded casing option for larger diameters and bores with ground water)

BRIERLEY ASSOCIATES
Creating Space Underground

BTrenchless

Guided Boring Machine

Advantages:

- Grade and alignment precision
- Can increase the length and accuracy of other trenchless methods, such as Auger, Hand Tunnel and Hammer, for varying soil and grade concerns.

Creating Space Underground

McLaughlin Head

BTrenchless

Description:

McLaughlin steering head is used to install bore for drives up to 400 feet. Its guidance system is equipped with a water level for checking and maintaining grade, along with the ability to check and maintain the line throughout the bore with twin line projection halogen lights enclosed in the steering head.

The cutting path– grade and lateral movement of the steering head is controlled by hydraulic actuated flaps that open and close to keep the head on the intended path.

BRIERLEY ASSOCIATES
Creating Space Underground

Hand Tunnel

Description:

Utilizes manual labor for excavating material while hydraulic jacks advance the tunnel.

BRIERLEY ASSOCIATES
Creating Space Underground

Hammer or Pipe Ramming

Advantages:

- Well suited for cobbles and running sands
- Lowest probability of surface subsidence

BRIERLEY ASSOCIATES
Creating Space Underground

Pipe Jacking (TBM)

Advantages:

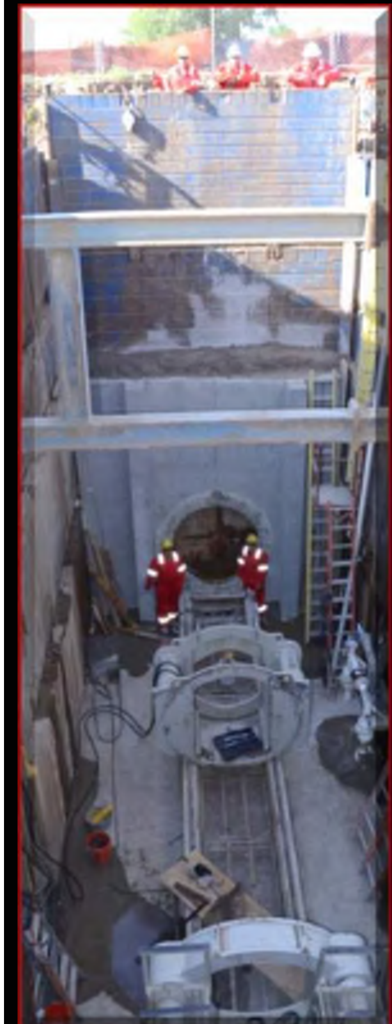
- Suitable for a wide variety of soil types
- Drives of over 1000 ft possible
- Allows for removal of obstructions
- Adaptable to changing soil conditions

Limitations:

- Ground water
- Cobble
- Minimum tunnel diameter of 51”

BRIERLEY ASSOCIATES
Creating Space Underground

Microtunnel



Advantages:

- Large Diameters (>36")
- All Ground Types
- Continuous Face Support
- Long Distances
- Above or Below Water Table
- EXTREMELY Accurate
- Can be used in areas with hazardous materials/soils with minimal exposure to personnel

BRIERLEY ASSOCIATES
Creating Space Underground

Microtunnel

Akkerman Jacking Frame

BRIERLEY ASSOCIATES
Creating Space Underground

Microtunnel

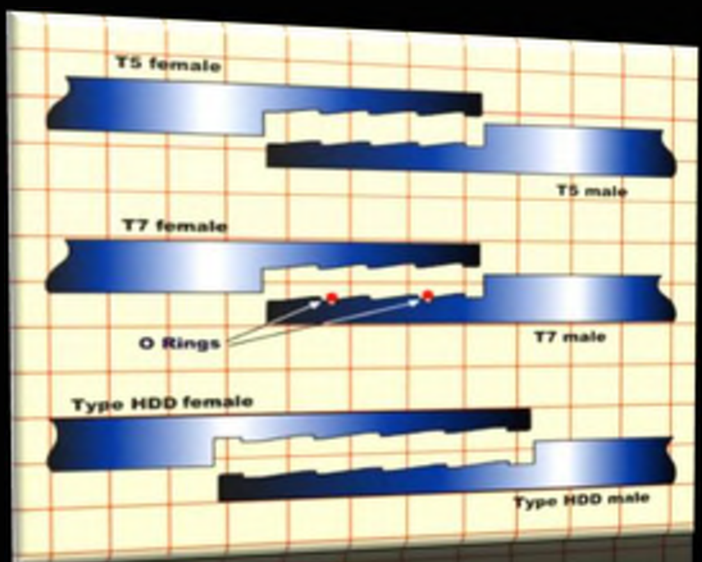
Slide Rail System

Exit / Entry Seal

BRIERLEY ASSOCIATES
Creating Space Underground

Permalok

The **Permalok** Interlocking Pipe Joining System features a precision machined joint connection which is completed in the field using the existing jacking frame on trenchless equipment or the force from the ramming machine. It eliminates the need for welding the steel pipe, and uses a time-saving 5-step installation process.



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HOBAS

HOBAS (CCFRPM) Pipes are centrifugally cast, glass-fiber-reinforced, polymer mortar.

These large diameter pipes are ideally suited for nearly all corrosive piping applications.

HOBAS pipes may be installed by a variety of installation methods. HOBAS pipes can be economically designed for non-pressure and pressure service by varying the quantity, placement, and orientation of the glass-fiber reinforcements.

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RCP (Reinforced Concrete Pipe)

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Creating Space Underground

Join Us!
Trenchless Elevated 2018

Date: November 1, 2018
Time: 7:30am – 5:00pm
Location: PPA Event Center - 2105 Decatur Street, Denver 80211

Who should attend?

Owners, utilities, municipalities, as well as engineers and contractors involved in the repair and replacement of aging underground infrastructure.

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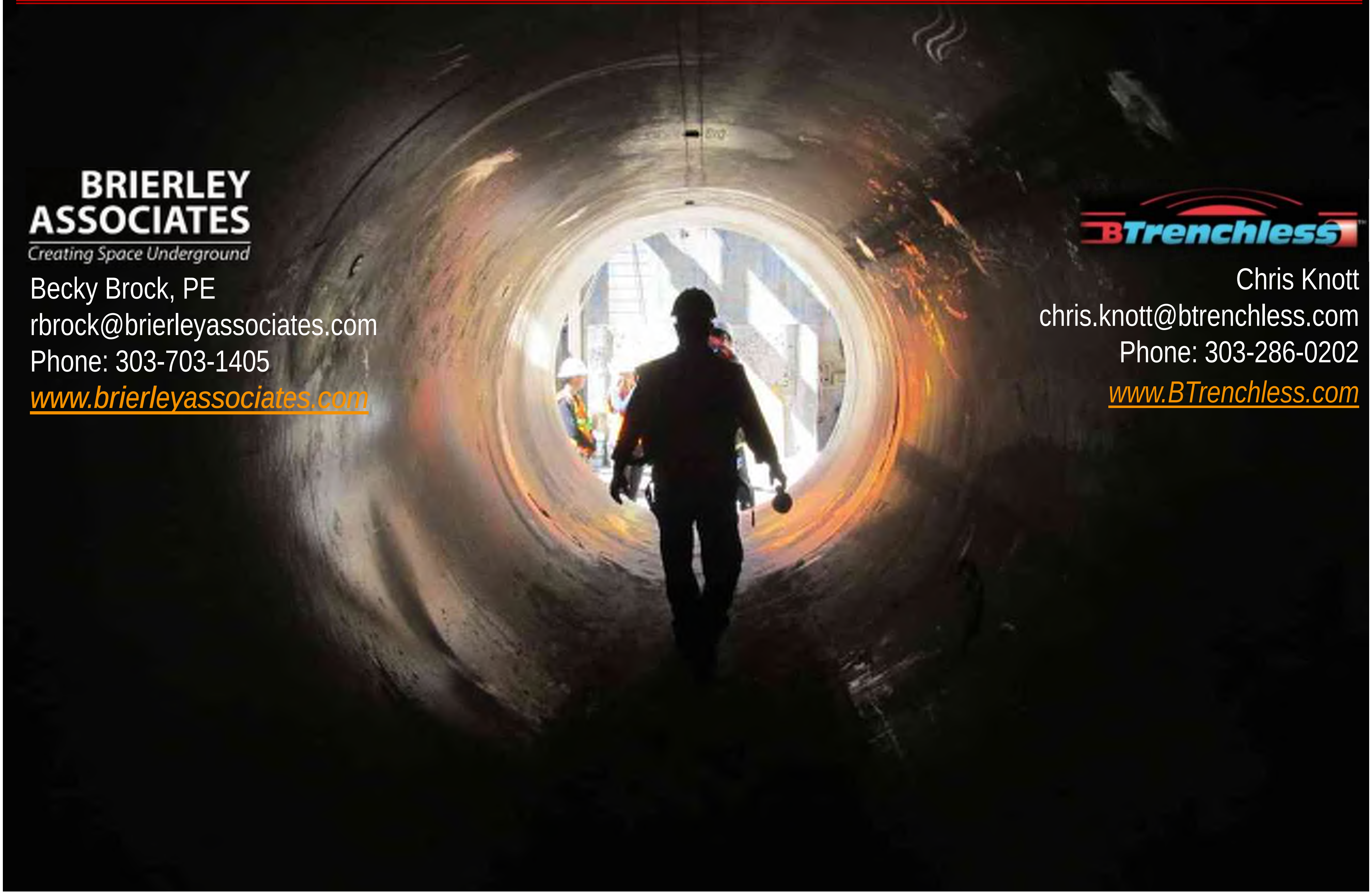
Questions?



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BTrenchless

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2018 CASFM CONFERENCE

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Planning and Siting of Recreational Whitewater Features

Presented to

CASFM

2018 Annual Conference

September 2018

Presentation Outline

1. Why Whitewater?
2. Planning
3. Design

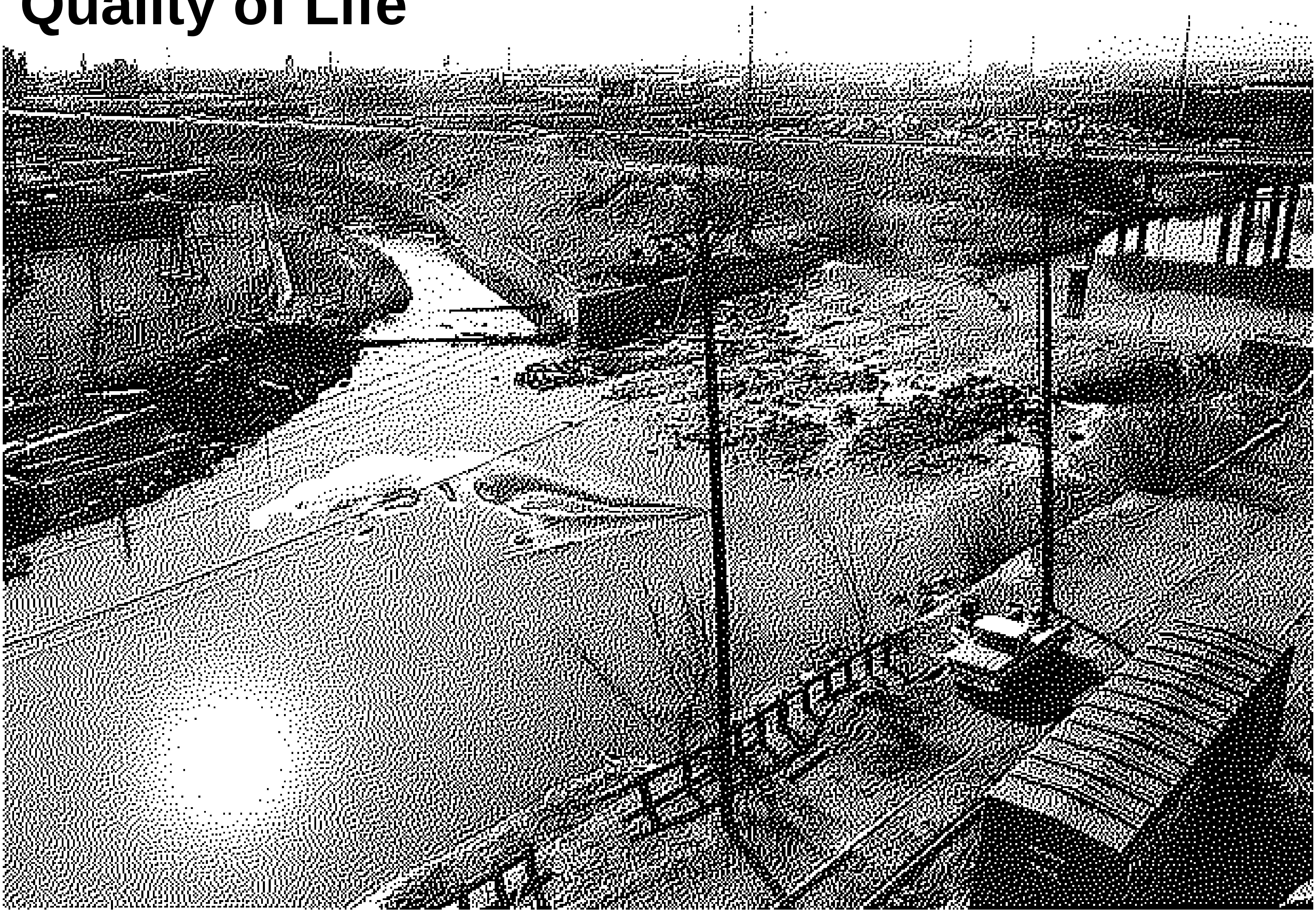
Why Whitewater

Quality of Life

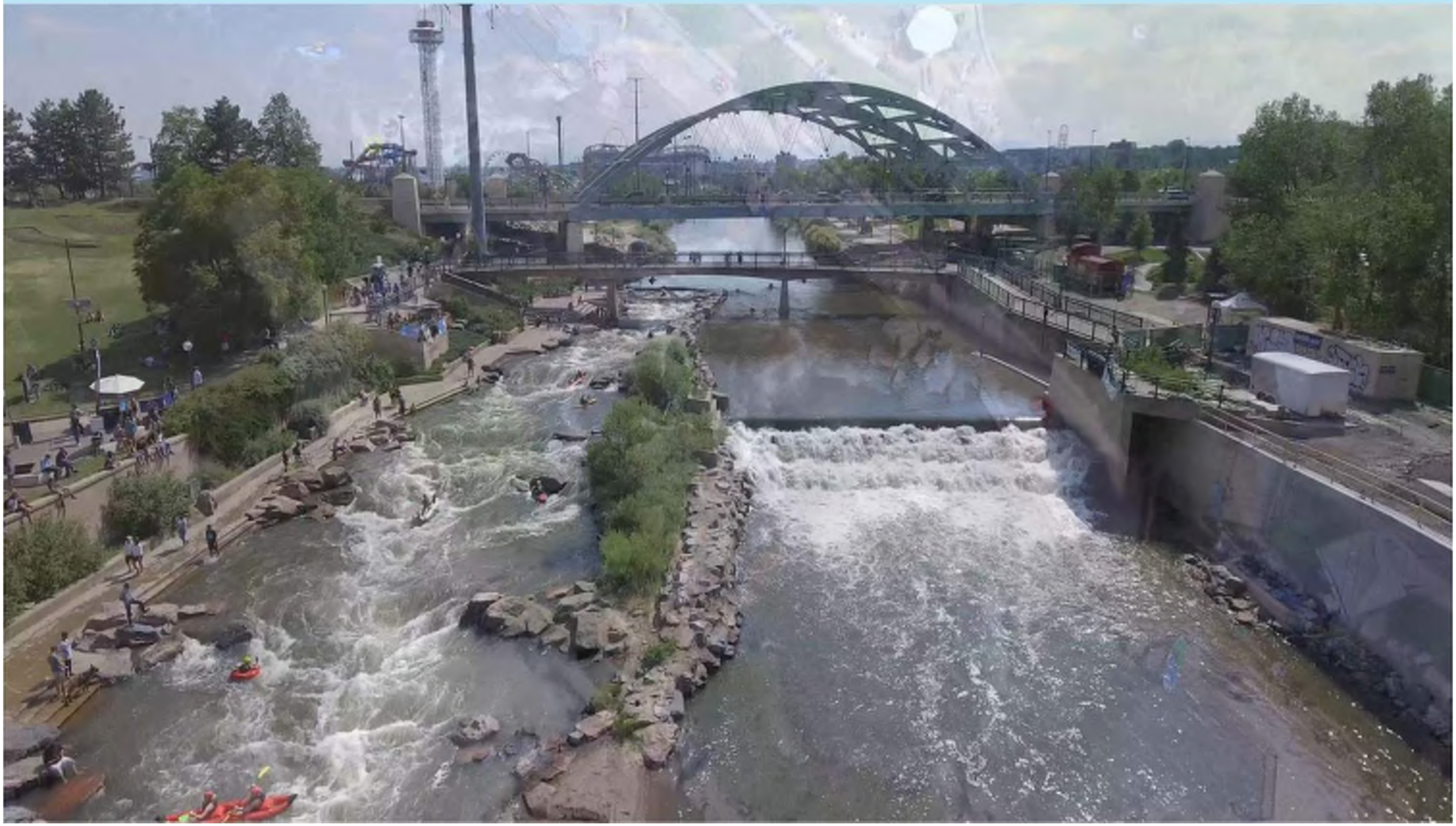
Economic Impact

Public Safety

Quality of Life



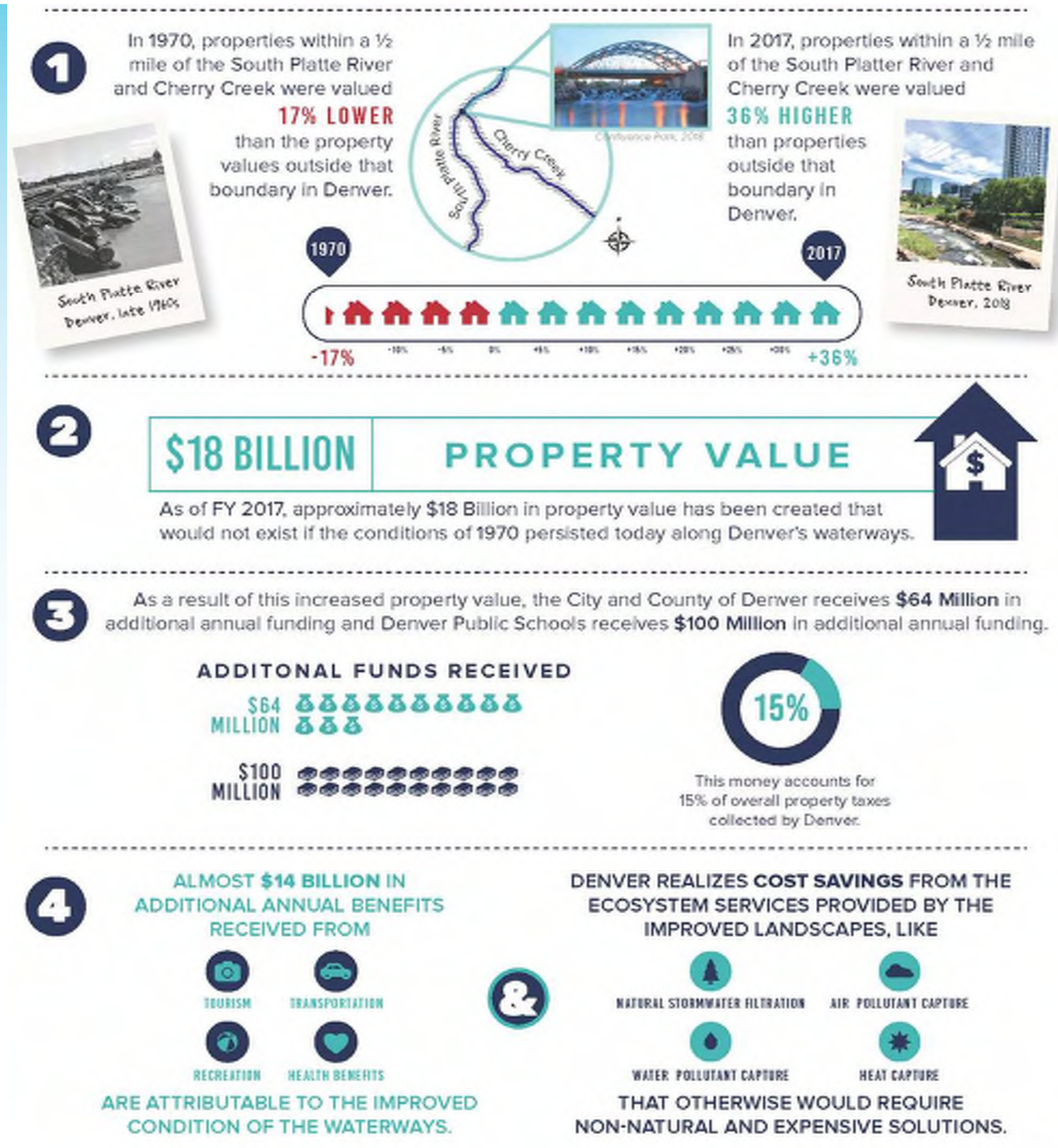
Quality of Life



Quality of Life

Economic Impacts

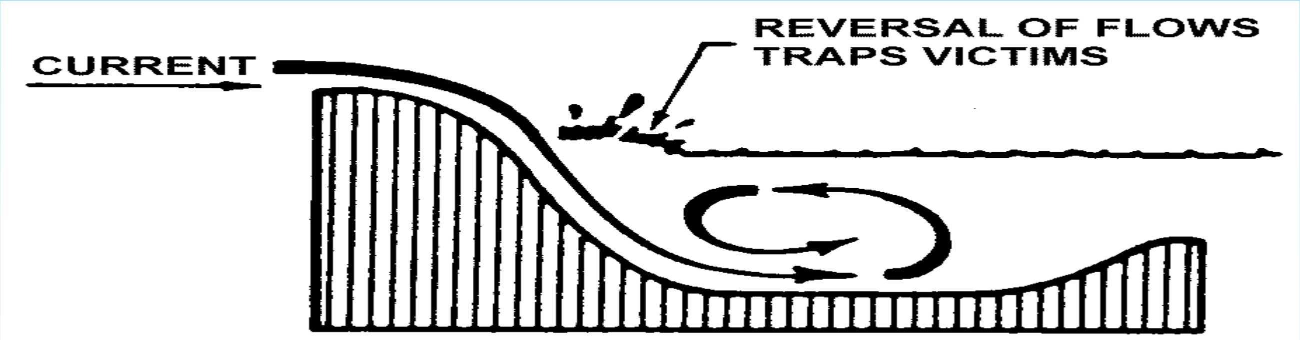
South Platte



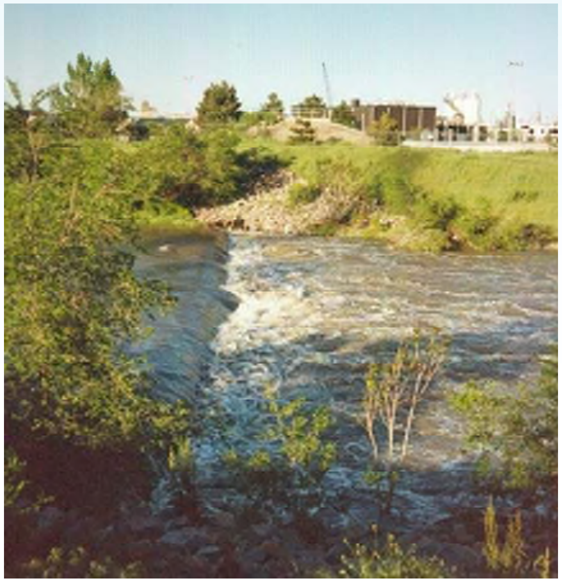
Economic Impacts
Chattahoochee River Restoration

- Economic Impact
  - 50,000 paying rafting customers and zip line customers a year
  - $74m in capital investment
  - 42 new businesses; several university extensions
  - $24m in gross revenues.
  - 400 new jobs
  - Gross tax receipts 2012 to 2017 up 45%.

Public Safety



Overly retentive hydraulics of a conventional dam



Clear Creek drop of 1.8 feet was proven fatal

Union Avenue Dam
Selected “milder” sloped proved hazardous

Presentation Outline

1. Why Whitewater
2. **Planning**
   - **Who are the Users**
   - **Site Factors**
   - **Recreational Intent**
3. Design

Who Uses Whitewater River Parks?

Cooling Off in Engineered River Parks
User Survey Results

Spectators

- ✓ Most visitors recreated on the streambanks (76%)

Children

- ✓ (43%) Recreating in the water compared to teens (27%), adults (20%), or seniors (4%)

Kayakers

- ✓ Represented **only 2%** of summer park activities

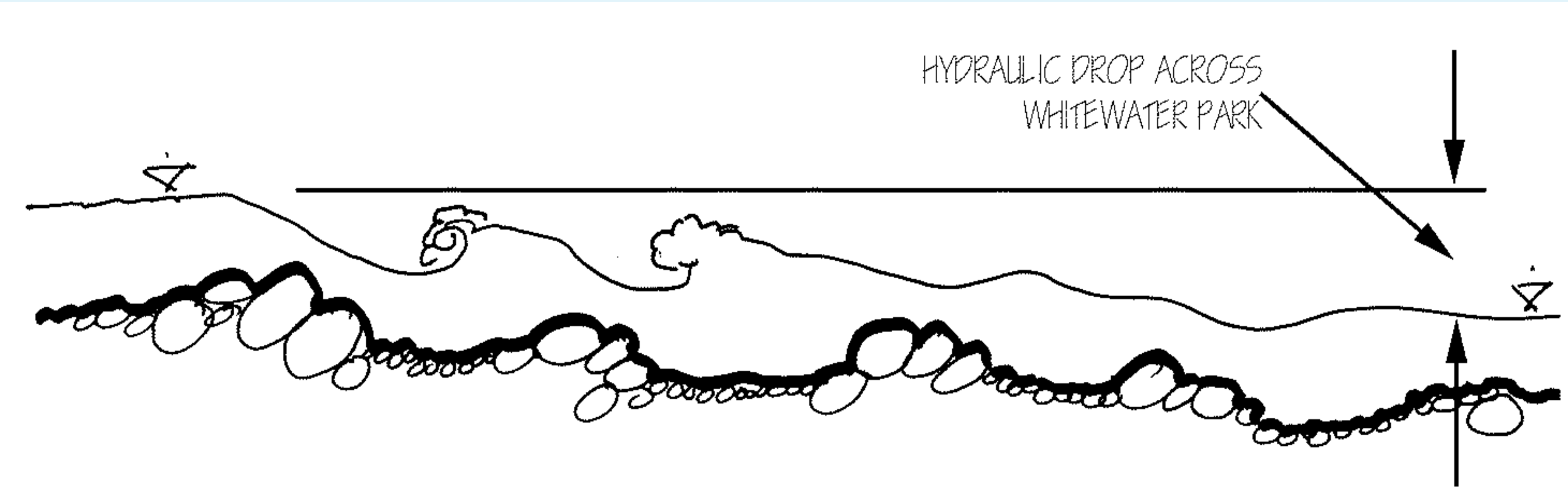
Site Evaluation or Site Factors

1. Available Flow
2. Vertical Drop
3. Adjacent Area/Access


Site Factor 1 - Flow

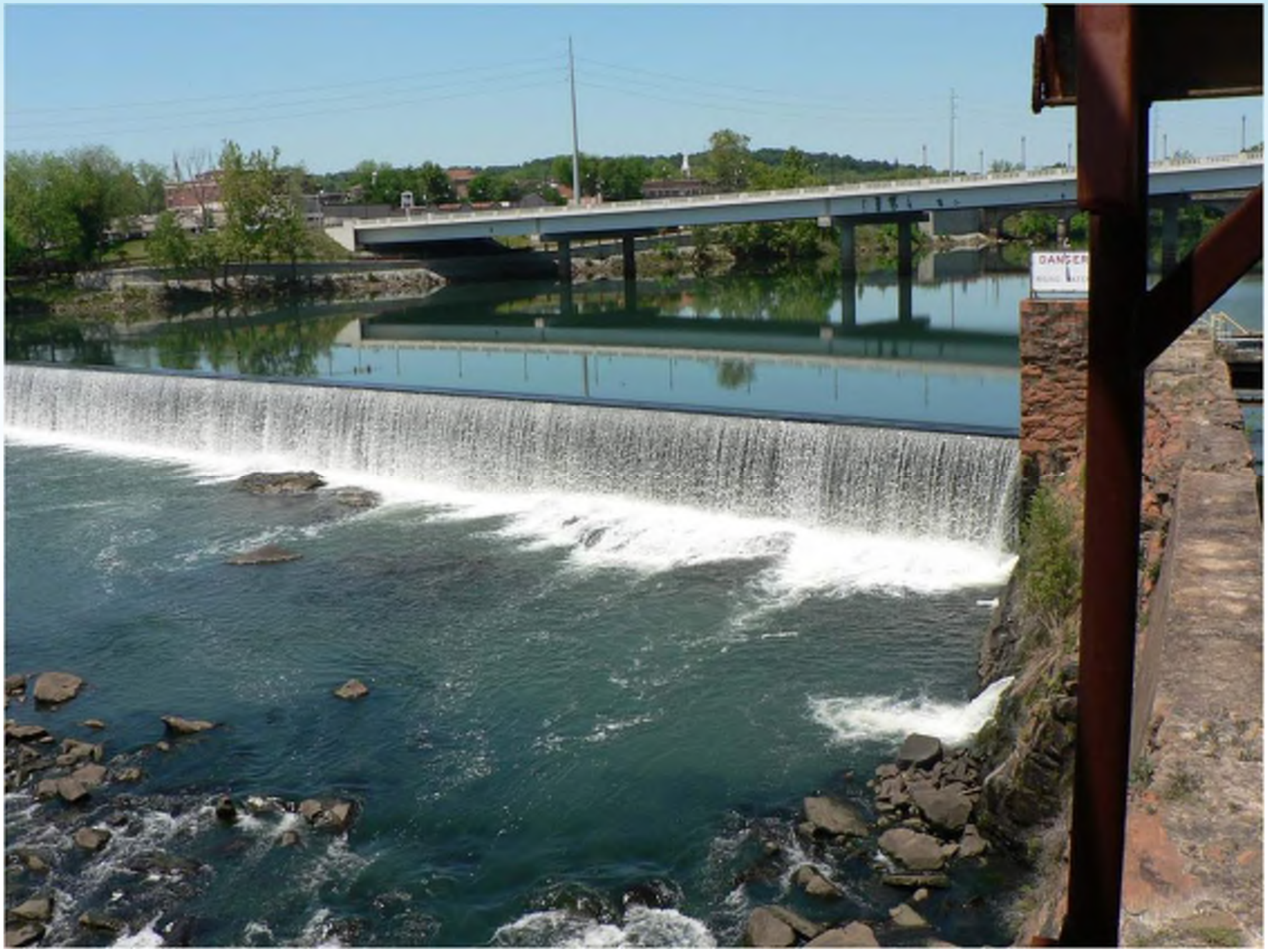
Site Factor 2 – Vertical Drop

Often conflict between developing the hydraulic drop and impacting the floodplain.

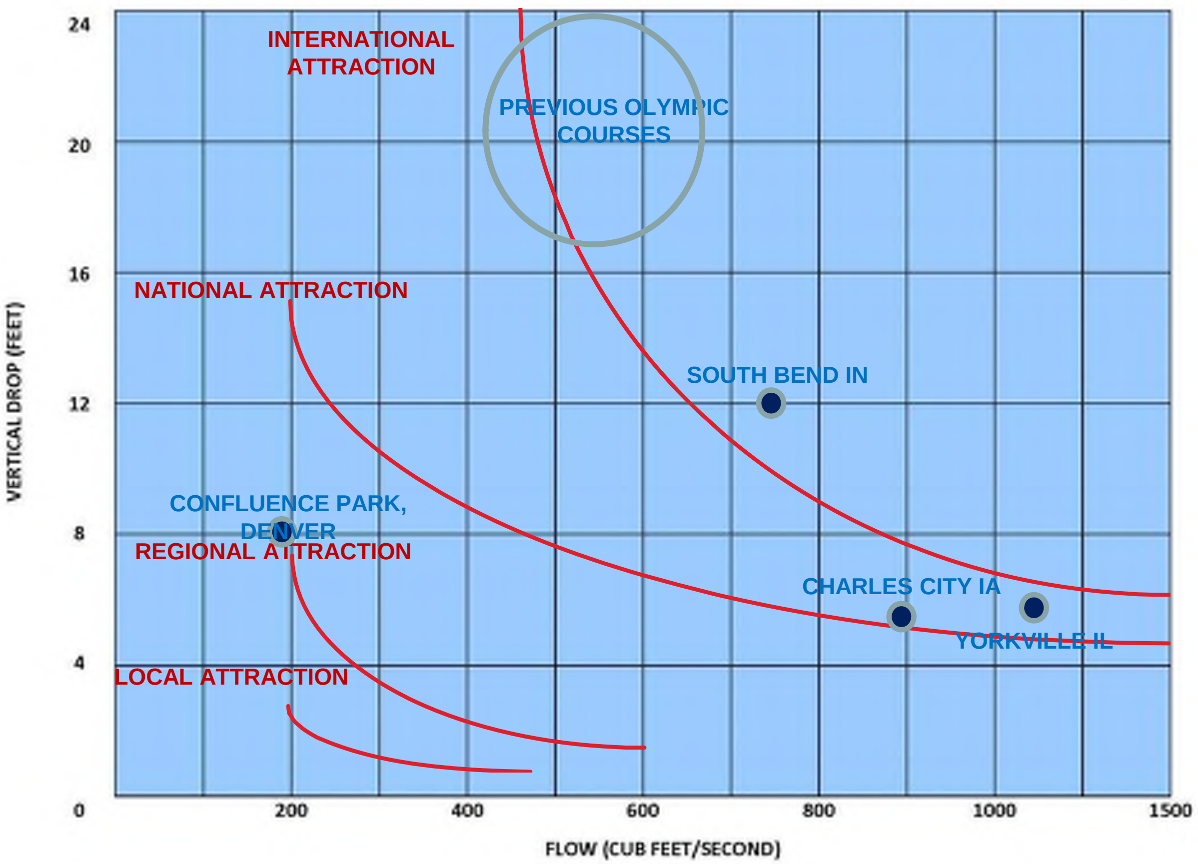


Site Factor 2 – Vertical Drop

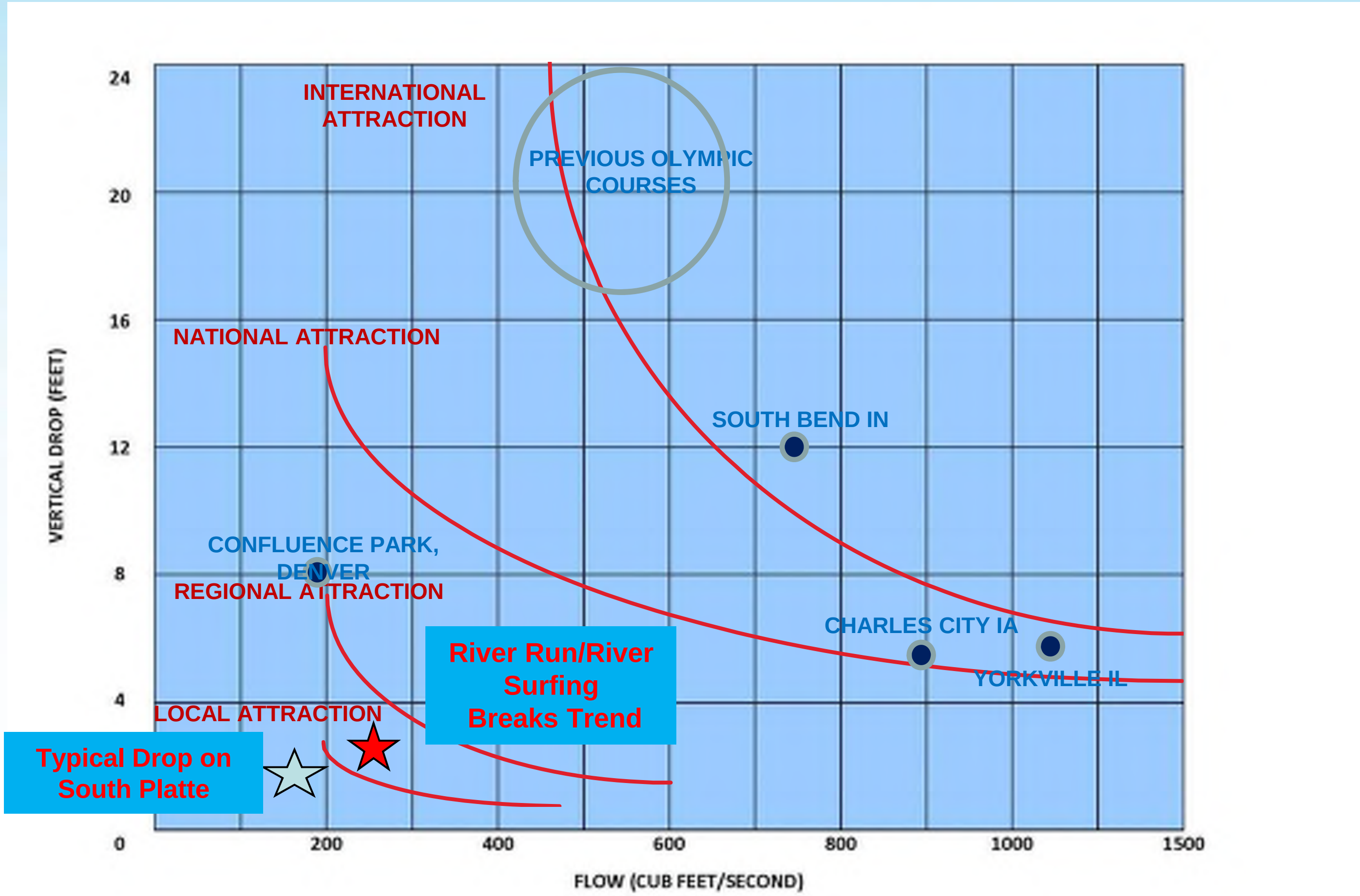
Look for existing dams, diversions, and drop structures.



Flow and Drop are Related



Flow and Drop are Related



Site Factor 3 – Adjacent Area/Access

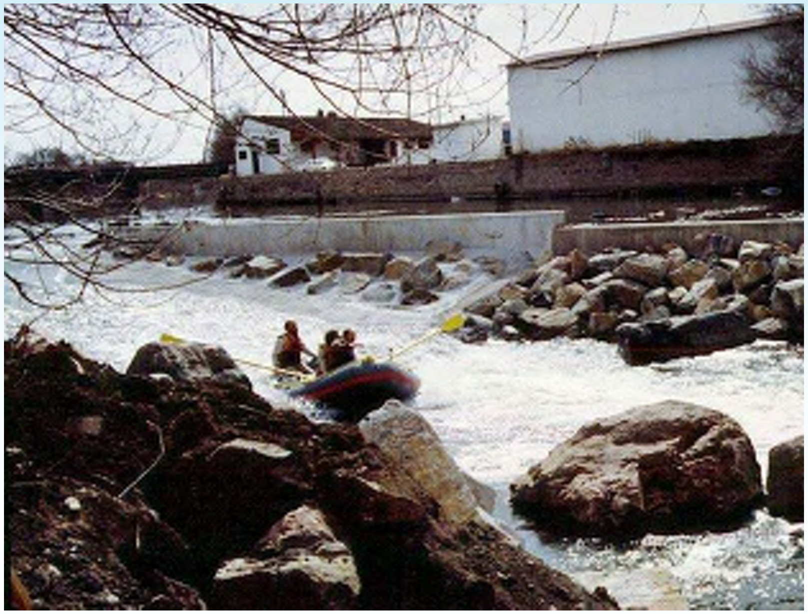
Whitewater parks are for spectators.

Site Factors - Others

- Floodplain
- River Morphology
- Fish Habitat and Passage
- Water Quality

Recreational Intent

Water trails



Creation of a Water Trail

Early Whitewater Bypasses, South Platte

Recreational Intent

Traditional

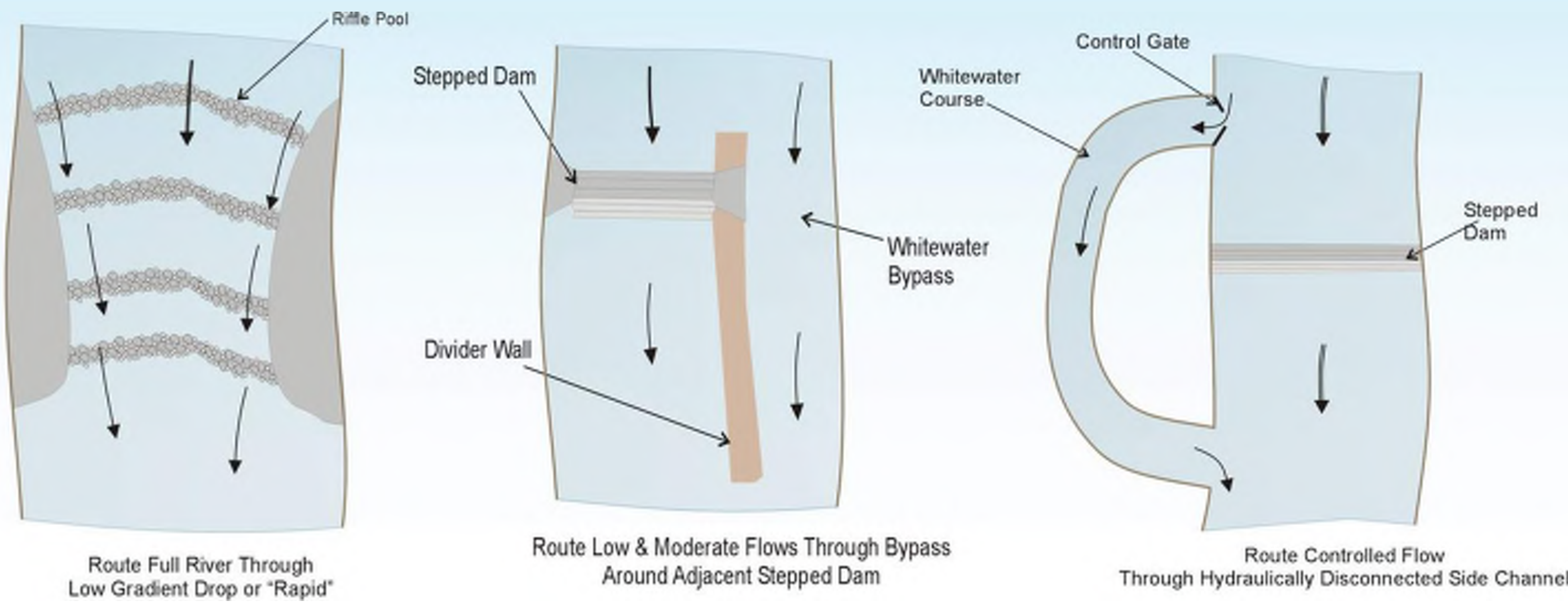
The Adventure Sports Course in Maryland has hosted both slalom and freestyle world cups yet is mostly enjoyed by the general public.


Recreational Intent
Surfing

Presentation Outline

1. Why Whitewater?
2. Planning
3. **Design**
   - **Types**
   - **Durability**
   - **Engineering Aspects**
   - **Safety Considerations**
   - **Costs**

Types of Whitewater Courses and Parks



Durability

Nantahala – 2013 World Cup Venue

Newly-changed Calgary weir still dangerous for rafters

Harvie Passage repair to cost millions | Alberta | News | Calgary Sun

SUN+

Harvie Passage repair to cost millions

Calgary's weir facing massive repair bill due to massive damage from high flood waters

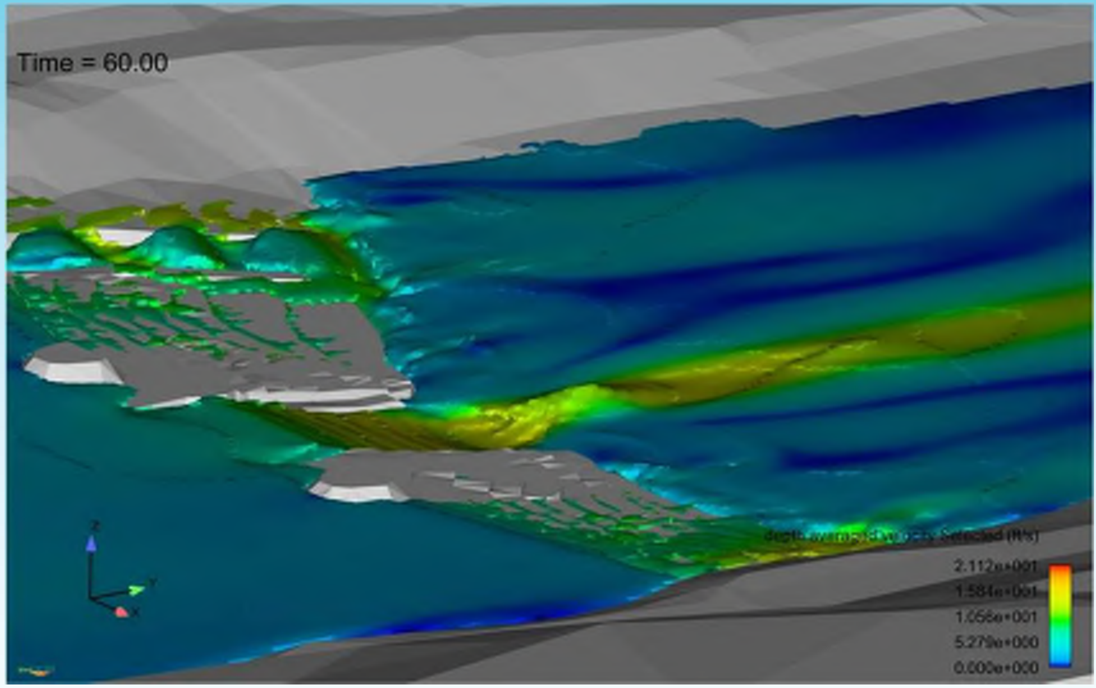
1996 Olympic Venue

Engineering Aspects

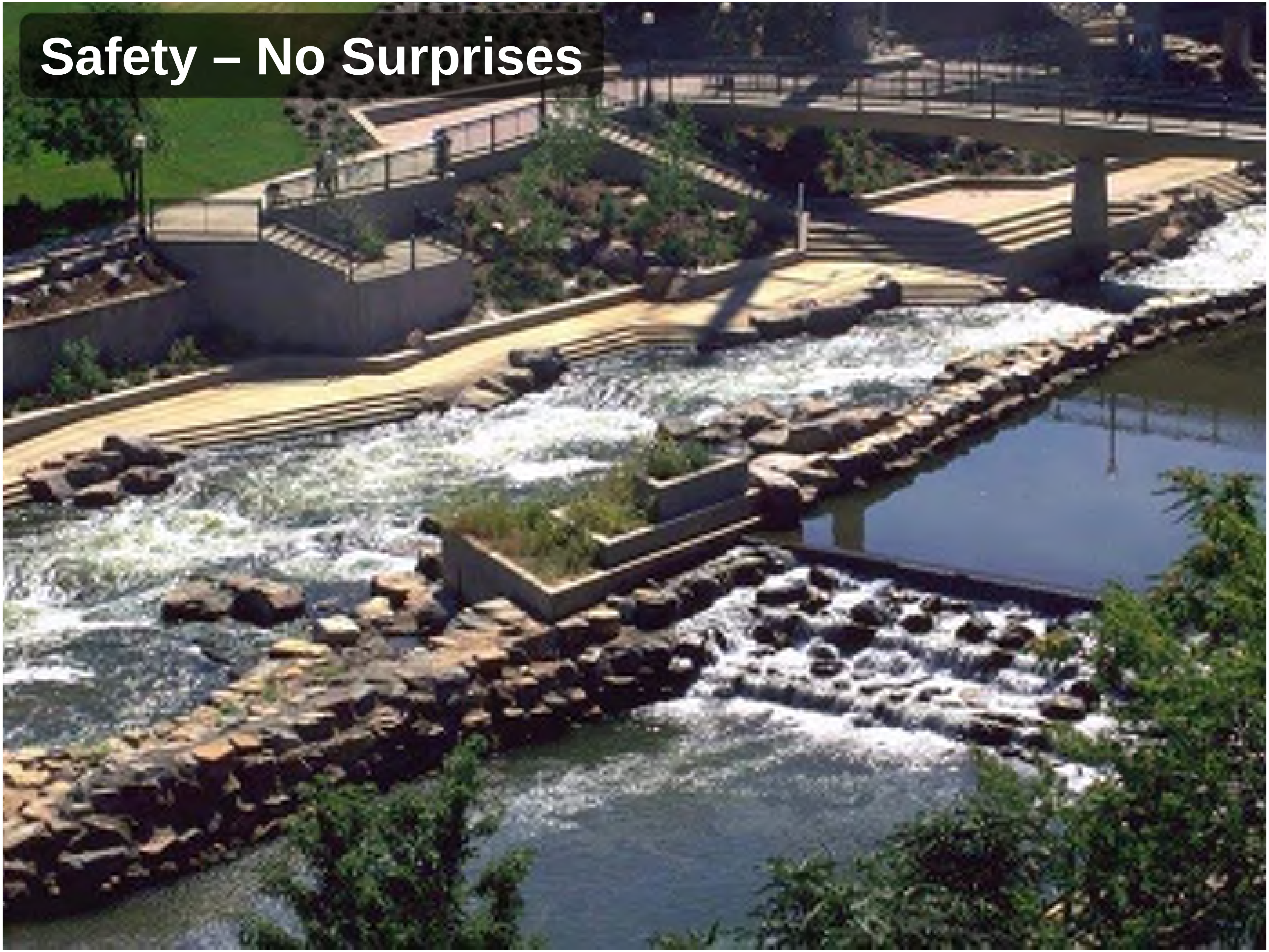
- Safety and Recreational Performance
- Floodplain Impacts and Conveyance
- Functioning of Integrated Purpose
- Structure Stability
- Lowest Life-Cycle Costs
- Permitting
- Fish Passage
- Natural Appearance

CFD Modeling

River Run Park



Safety – No Surprises



Costs

Estimated Percent Increase in Costs Related to Safety and Recreation*.

Scenario	Percentage Increase Based upon Entire Project Costs.
Conventional Drop (Hazardous Hydraulics)	Base
Low-Hazard Drop	10%
Recreational/Aesthetic Drop (River Run) – Non Adjustable	13%
WaveShaper Surf Feature	18%

**Based upon costs from River Run Project : 2017-2018, South Platte River.*

Thank You!

Misc slides

Site Factor 1 – Available Flow

Click to hide News Bulletins

- Please see news on new formats
- Full News

USGS Surface-Water Monthly Statistics for the Nation

The statistics generated from this site are based on approved daily-mean data and may not match those published by the USGS in official publications. The user is responsible for assessment and use of statistics from this site. For more details on why the statistics may not match, click here.

USGS 06710247 SOUTH PLATTE RIVER BELOW UNION AVE, AT ENGLEWOOD,C

Available data for this site | Time-series: Monthly statistics | GO

Arapahoe County, Colorado
Hydrologic Unit Code 10190002
Latitude 39°37'57", Longitude 105°00'52" NAD27
Drainage area 3,098 square miles
Gage datum 5,290 feet above NGVD29

Output formats
- HTML table of all data
- Tab-separated data
- Reselect output format

00060, Discharge, cubic feet per second,

Monthly mean in ft3/s (Calculation Period: 1996-03-01 -> 2017-04-30)

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996			27.1	103.8	157.9	205.1	212.7	107.0	80.8	30.5	57.0	23.5
1997	12.7	46.1	47.7	89.8	194.3	516.2	310.0	364.8	80.5	81.9	83.5	76.4
1998	73.6	66.6	111.7	402.8	931.8	346.5	490.4	463.7	96.0	111.3	28.5	14.7
1999	21.9	20.1	53.5	178.3	745.1	1,222	550.1	484.6	74.4	49.5	76.0	66.8
2000	64.2	57.6	76.6	146.6	259.5	248.4	171.5	107.5	41.7	42.4	33.8	39.5
2001	61.8	81.7	70.3	79.2	200.2	160.0	190.9	104.0	58.7	20.1	14.5	14.9
2002	19.2	31.7	60.2	23.4	45.0	70.6	22.4	10.8	19.6	21.7	9.95	9.67
2003	9.91	11.7	103.4	308.9	263.5	211.6	131.7	93.7	114.4	25.0	17.6	20.5
2004	23.4	38.7	27.6	132.2	143.5	142.1	288.2	191.3	58.3	58.1	59.6	26.9
2005	19.4	23.0	33.5	258.6	518.5	351.4	94.0	178.4	50.6	66.1	71.9	22.7
2006	14.3	29.0	38.7	47.9	138.6	134.6	333.9	245.5	109.6	161.5	56.6	26.4
2007	27.9	82.2	392.5	572.7	1,716	873.5	439.5	371.2	194.2	87.9	78.2	60.1
2008	32.2	69.2	134.3	192.2	258.5	345.2	376.7	213.9	88.8	40.2	17.1	22.0
2009	55.2	23.1	36.3	178.1	388.0	938.8	368.9	121.9	58.0	129.4	39.0	67.7
2010	56.8	61.7	92.6	374.3	461.0	389.7	149.0	302.0	28.7	31.0	53.8	43.7
2011	58.8	65.0	47.7	59.8	60.2	149.2	513.0	185.8	48.5	31.1	21.9	20.6
2012	55.0	60.9	58.7	48.6	39.7	47.6	44.6	25.5	35.7	29.3	17.4	15.0
2013	14.9	20.2	28.9	58.3	115.7	65.9	61.5	78.4	84.1	27.3	26.1	54.6
2014	43.9	51.0	62.1	186.0	198.5	695.5	324.5	200.6	63.0	91.4	67.0	65.7
2015	74.1	89.4	106.8	226.2	1,674	2,414	1,454	276.0	52.5	38.7	34.1	61.5
2016	61.7	80.0	112.9	536.0	1,028	564.7	248.6	119.5	47.9	22.5	32.0	41.5
2017	55.1	56.4	70.3	69.9								
Mean of monthly Discharge	41	51	82	194	454	481	323	202	71	57	43	38

** No Incomplete data have been used for statistical calculation

Who Uses Whitewater Parks –
New Trend……………..Surfing

WAVE SHAPER™

Safety

- Safety improvements – Union Avenue boat chutes; Sheridan, CO

Before

After

Recreational Intent

Performance & Engineering - Fun Equation

$$RE(fun) \propto f\,(SQ, \$, Power, Design)$$

RE= Quality of Recreational Experience

SQ= Site Quality = Access and Location

Power = Flow and Drop

$ = Life Cycle Costs


Nature Play Design Guidelines:
Techniques for Including Nature Play within Floodplains
CASFM 2018 Annual Conference Presentation

Cassie Kaslon

Managing Principal
Valerian

Susan Brown

Founding Principal
Valerian

Frans Lambrechtsen

Water Resource Engineer
Jacobs (CH2M)

bienenstock natural playgrounds

JACOBS

VALERIAN


NATURE PLAY
IN THE BUILT ENVIRONMENT
DESIGN STANDARDS AND GUIDELINES
PREPARED FOR:
DENVER
PARKS & RECREATION
URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

DENVER
PARKS & RECREATION

Design Guidelines

URBAN DRAINAGE AND FLOOD CONTROL DISTRICT

What's in the Guidelines

- Nature Play Benefits
- Site Selection
- Public Engagement
- Inclusion in Nature Play
- Design Development
- Construction Document Guidelines
- Project Construction Period
- Post Occupancy
- Case Studies

- Over 70 pages of riveting information!

Why Nature Play Matters

Recent findings from GOCO indicate that 80% of Denver Public School students have never been to the Rocky Mountains

Denver Office of Children's Affairs estimates that 54% of Denver's children live in families at or below poverty level

Benefits include:

- **Environmental Stewardship**
- **Socio Economic**
- **Developmental/Health**
- **Economic**

Why Nature Play Matters

The Denver Parks and Recreation Game Plan outlines the following key values for future park planning:

- **Sustainable Environments**
- **Equity**
- **Engagement**
- **Sound Economics**


I-270
PENA BLVD.
I-70
I-25
PLATTE RIVER
COLFAX AVE.
BROADWAY
UNIVERSITY BLVD.
COLORADO BLVD.
I-25
I-225


Globeville Landing Park
39th Ave GREENWAY
I-70
PENA BLVD.
ST.CHARLES PARK
CITY PARK
COLFAX AVE.
FIRST CREEK PARK
WESTWOOD PARK
JOHNSON HABITAT PARK
COLORADO BLVD.
PASQUINEL'S LANDING
GRANT FRONTIER PARK
I-225


I-270
PENA BLVD.
I-70
I-25
PLATTE RIVER
COLFAX AVE.
BROADWAY
UNIVERSITY BLVD.
COLORADO BLVD.
I-25
I-225
FIRST CREEK PARK

FIRST CREEK PARK


Site Selection

What Makes a Good Site

- Proximity to waterways/floodplains
- Existing mature vegetation
  - Shade trees – preserved and utilized
  - If removed, vegetation can be repurposed into seating and climbing features
- Plant inventory and weed management strategies

What Makes a Good Site

- **Existing landforms – hills and slopes should be preserved or developed**
  - **Embankment slides, caves, or climbing areas**
- **Accessible to multi-modal systems**
- **Proximity to regional trails**

What Makes a Good Site

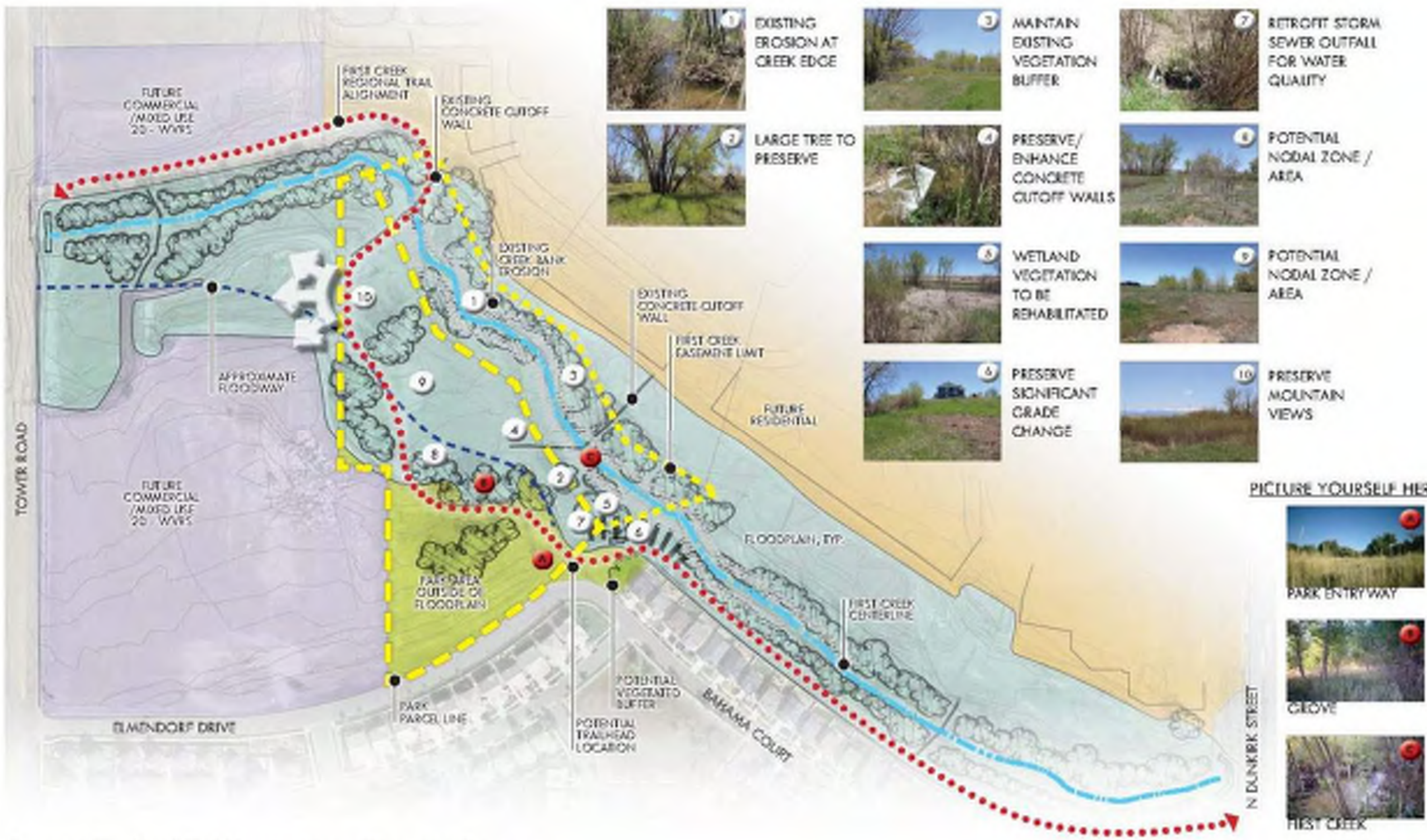


Figure 1.3: First Creek Park Opportunities and Constraints Diagram

Public Engagement Process

Community Context

Gather community input through creative measures.
Include hands on and collaborative activities: asset mapping, community commitment boards, sandbox charettes


Hidden
Elements of
Play

What You Wont See

- **Large Play Structures**
- **Play Features That Require Fall Zones and Safety Surfacing**

What You Wont See

- **Large Play Structures**
- **Play Features That Require Fall Zones and Safety Surfacing**

But You May See This!

- **Water**
- **Boulders**
- **Logs**
- **Plants**
- **Animals**
- **Dirt!**

Enhance the Existing

View the site from the eyes of the future user… children

Connect the element of fun into the existing site features

- **Landforms**
- **Vegetation**
- **Waterways**

Use The Trail System

Use Subtle Prompts

Use Landforms

Use Vegetation

Don’t Forget the Shade

Include All 5 Senses

Repurposing Material

Longevity and Maintenance

How to Make it Last (Longer)

Allegory of "The Car"

Two recent grads from a university just got their new "big boy (or girl)" job, and were buying new cars to go with their new jobs.

One grad did his *research* before buying the car, knew what *kind* of car, *how much* he was paying, *where* he was buying it, and created a *maintenance plan* for when to get it serviced.

The other grad did none of these things and bought the coolest imported car the salesman told him he should buy.

What happened?

Making it Last

1. **Develop a planting plan to withstand heavy use appropriate to the site**

• 2. **Educate users on how to use the space**

3. **Work with maintenance staff to develop a maintenance plan**

4. **Follow through after construction and make necessary changes**


Change Will
Happen

The Ideal Person Who Handles Change

The first person you think about who is great with change is an Engineer right?

How to Deal With Change?

1. **Know and expect change to happen**

2. **Identify what changes you can be okay with**

3. **Let change happen – the users will know, better than we will, how to use nature for play**

What Can and Can't Change

Things that CAN'T change

- Volume of the floodplain
- Locations of structures that cross the low flow channel
- Channel geometry

Things that CAN change

- Vegetation (within reason)
- Locations of nature play areas inside of the floodplain
- Alignments of secondary/tertiary trails

Educate Others

- **Engage the community in the discussion of the area**
- **Use signage to educate users on how the area may change over time – and that's OK**

More than A Fad

Please visit the following for additional resources:

www.valerianllc.com
www.naturalplaygrounds.ca
www.goco.org
www.thegreenwayfoundation.org
https://udfcd.org/

CASFM 2018 Annual Conference

Watershed Planning Sessions:

Session1: Welcome to The River Mile

Greg Murphy (Calibre Engineering), Chris Kroeger (Muller Engineering), Mike Galuzzi (Merrick & Company)

Session2: Planning for Recreation and Resilience on the Big Thompson River

Chris Carlson, Andrew Earles, Kevin Gingery, Kevin Shanks, Brandon Parsons, Shannon Tillack, Julia Traylor, Ellie Garza, & Scott Schreiber (City of Loveland)

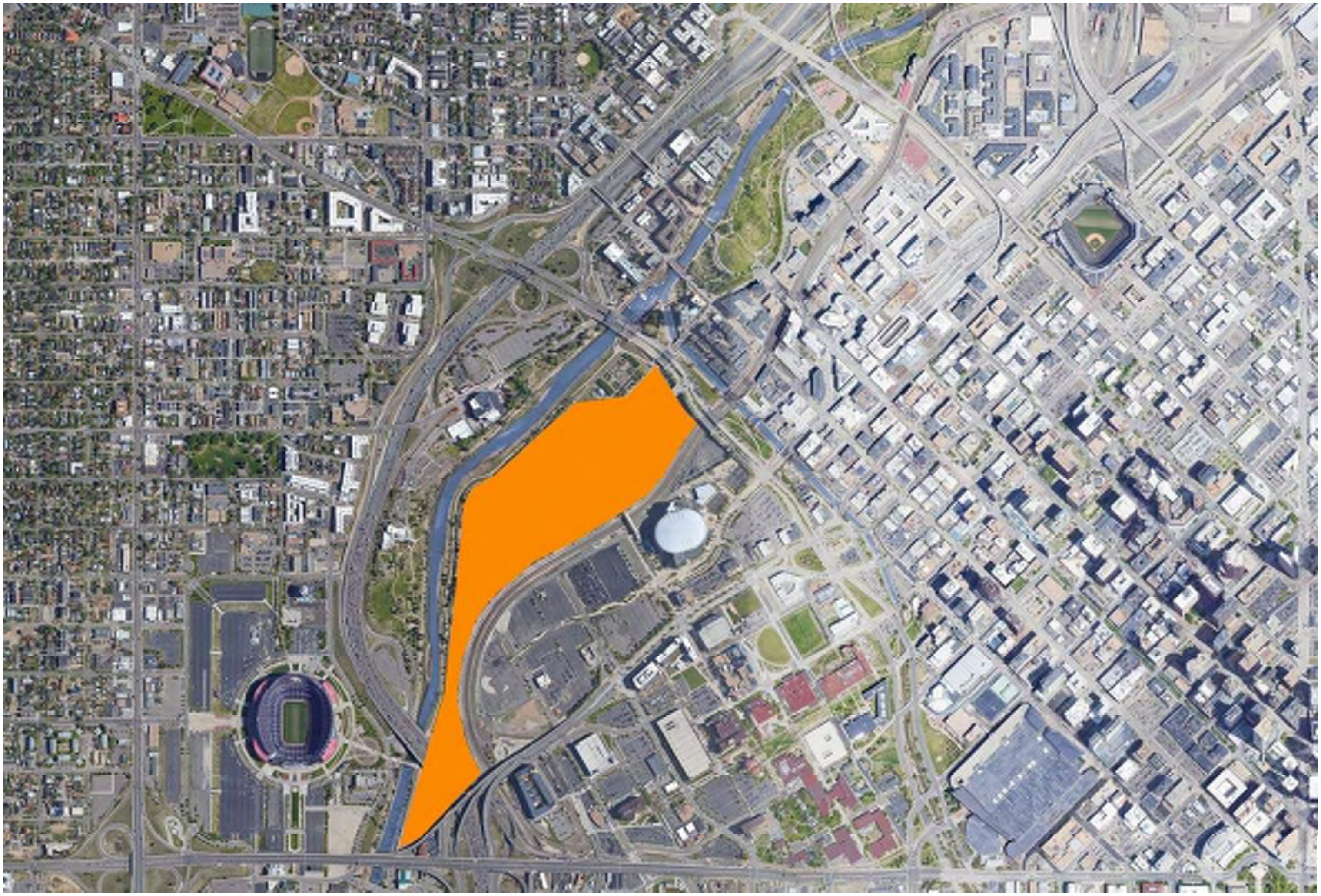
Watershed Framework: To Manage Runoff and Create Low Maintenance Stream – Stroh Tributary Case Study

Jacob James (Town of Parker), Barb Chongtoua (UDFCD), Jim Wulliman, Sara Johnson, Katy Shaneyfelt, & Sam Rogers (Muller Engineering Company), Andrew Earles & Brik Zivkovich (Wright Water Engineers)

Welcome to The River Mile

Greg Murphy, PE, ARCSA AP – Calibre Engineering
Chris Kroeger, PE – Muller Engineering
Mike Galuzzi, PE – Merrick & Company

Welcome to The River Mile



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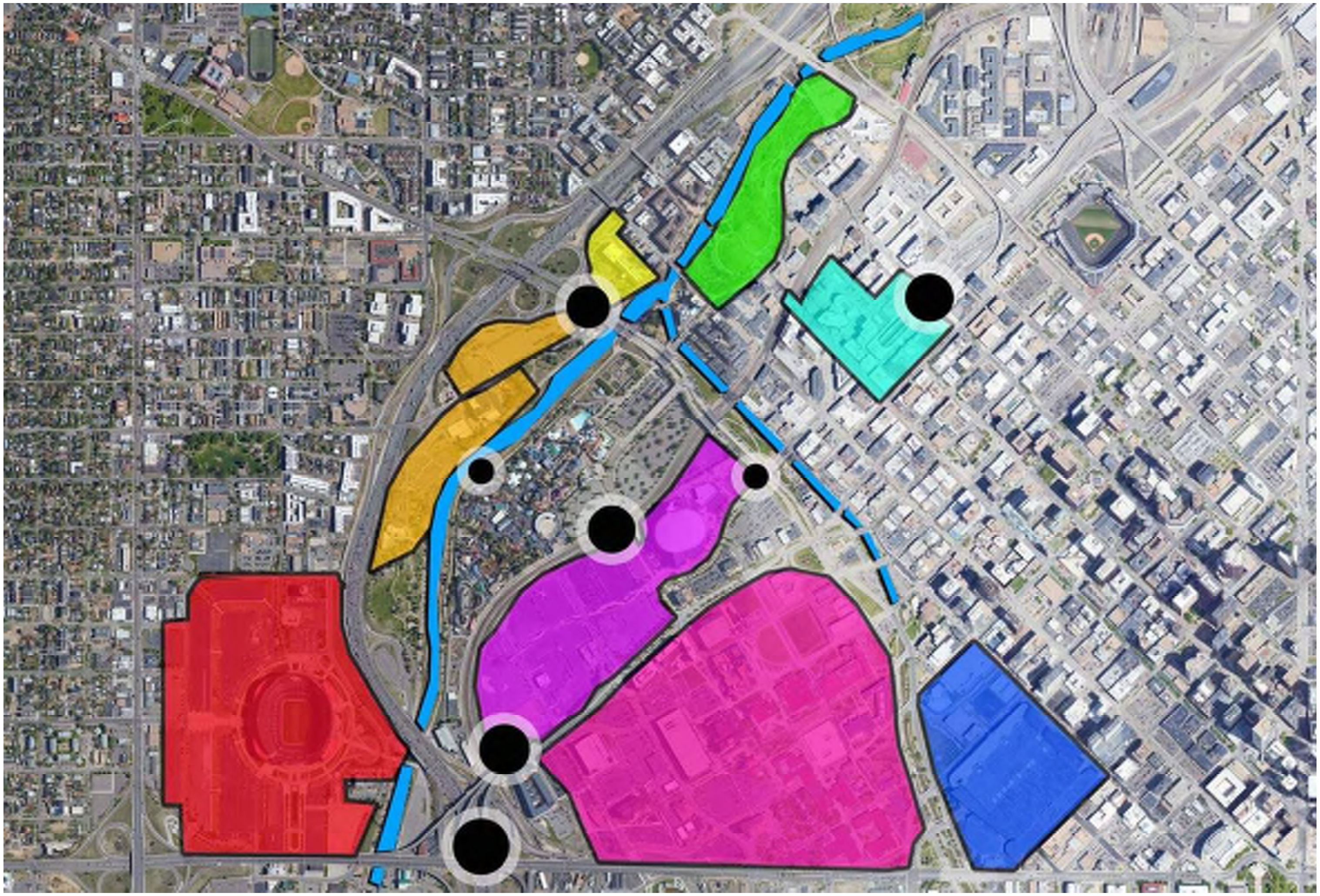

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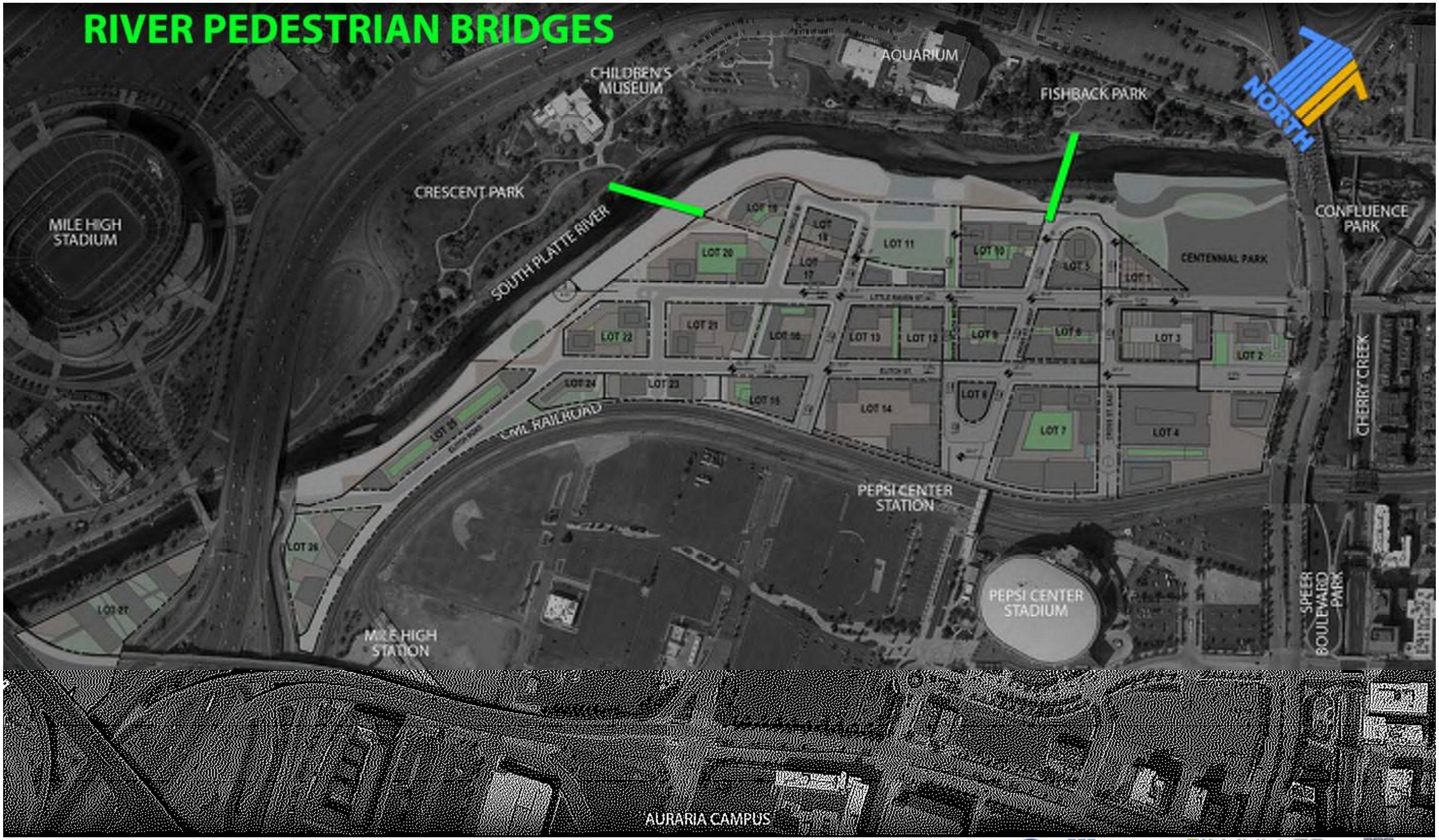

Calibre | MULLER ENGINEERING COMPANY | MERRICK

Welcome to The River Mile

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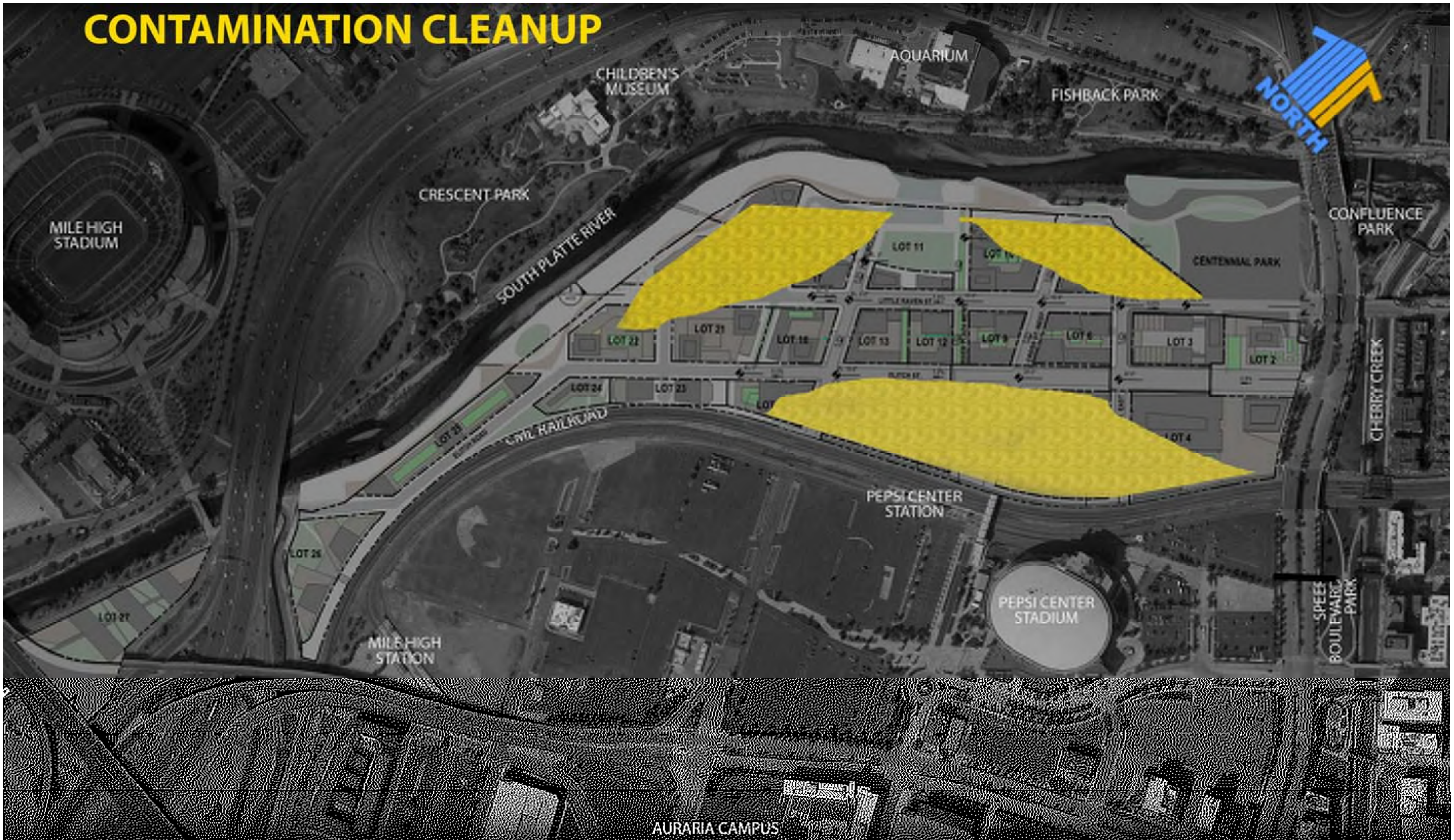

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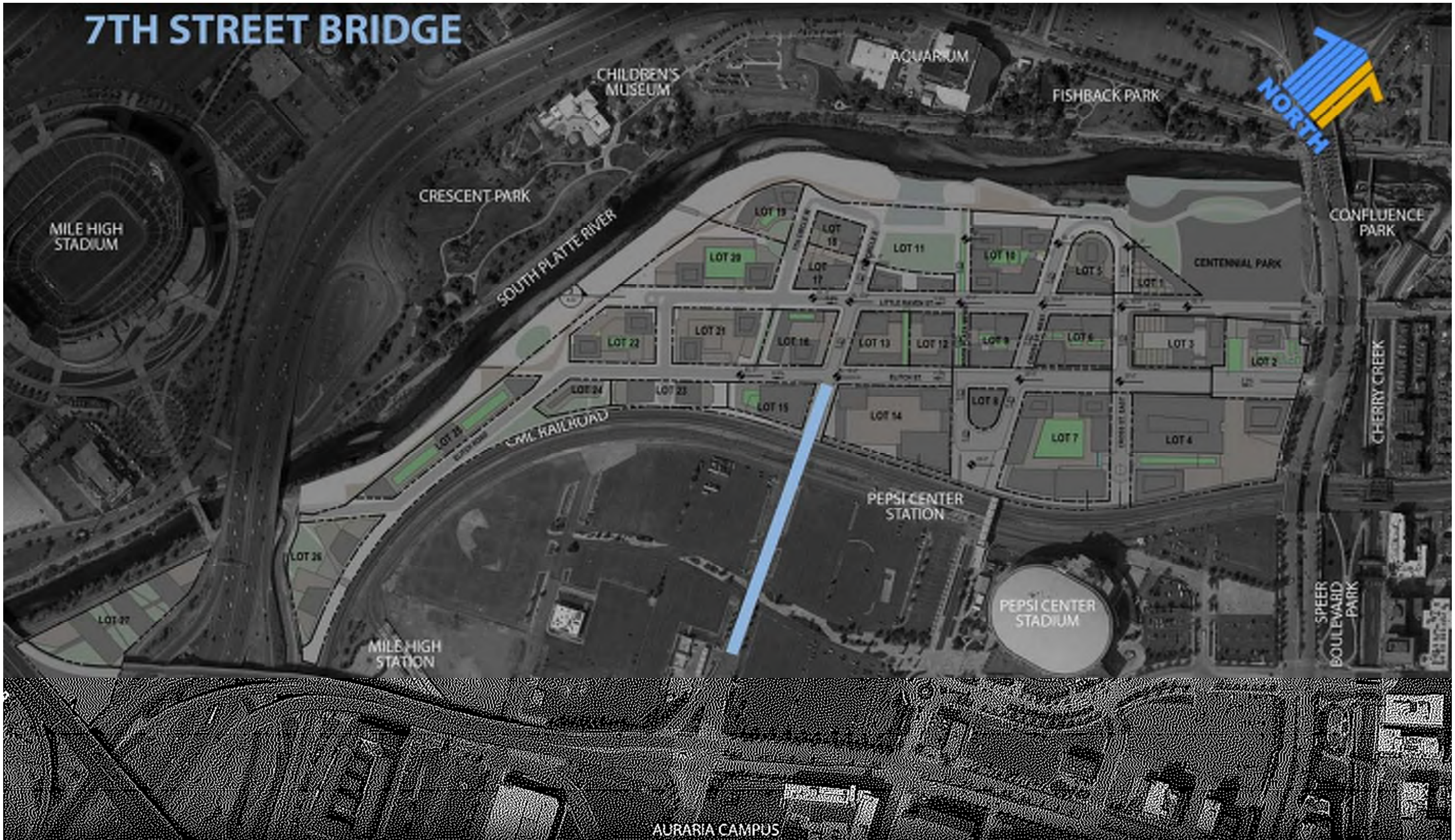

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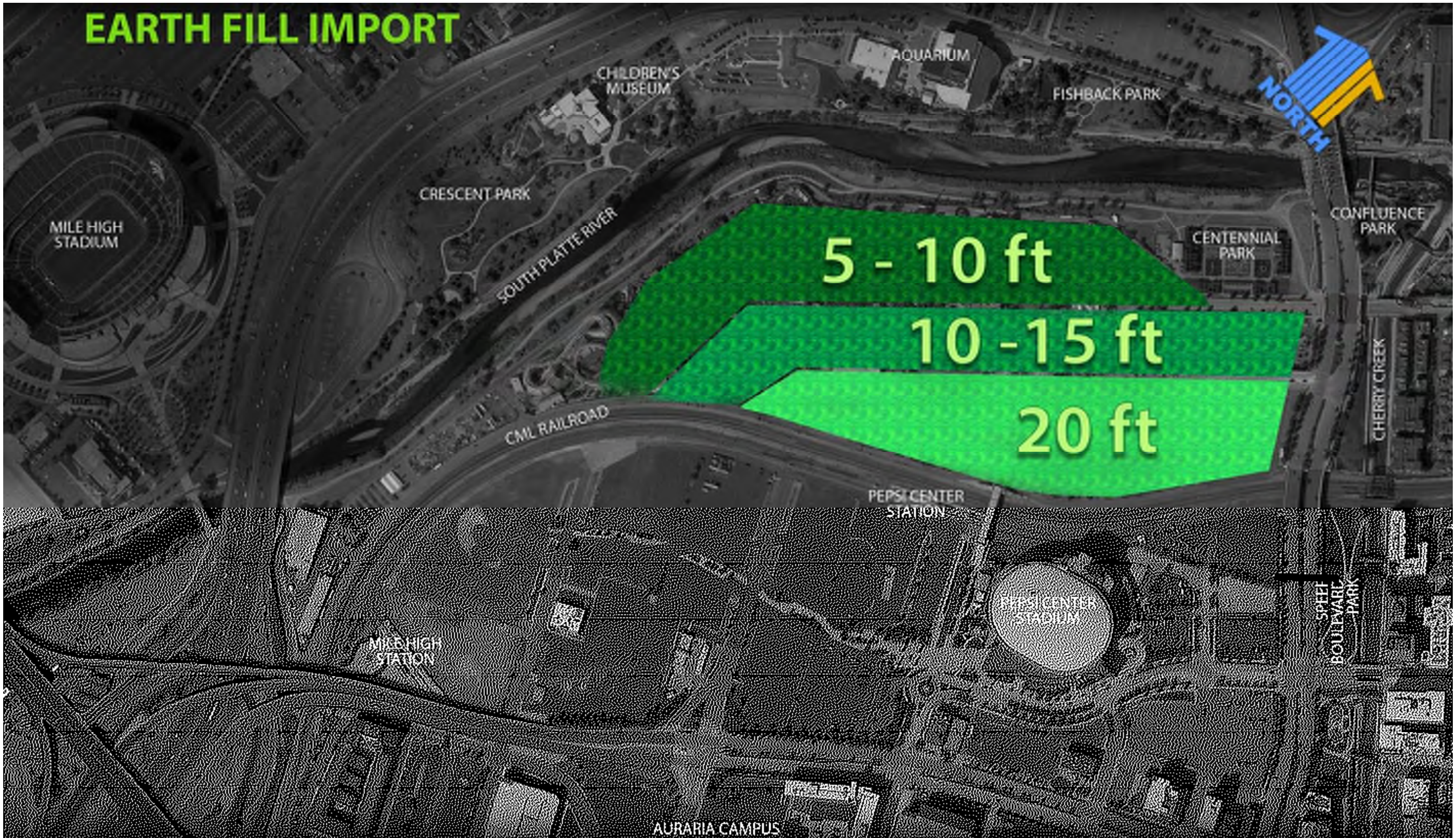

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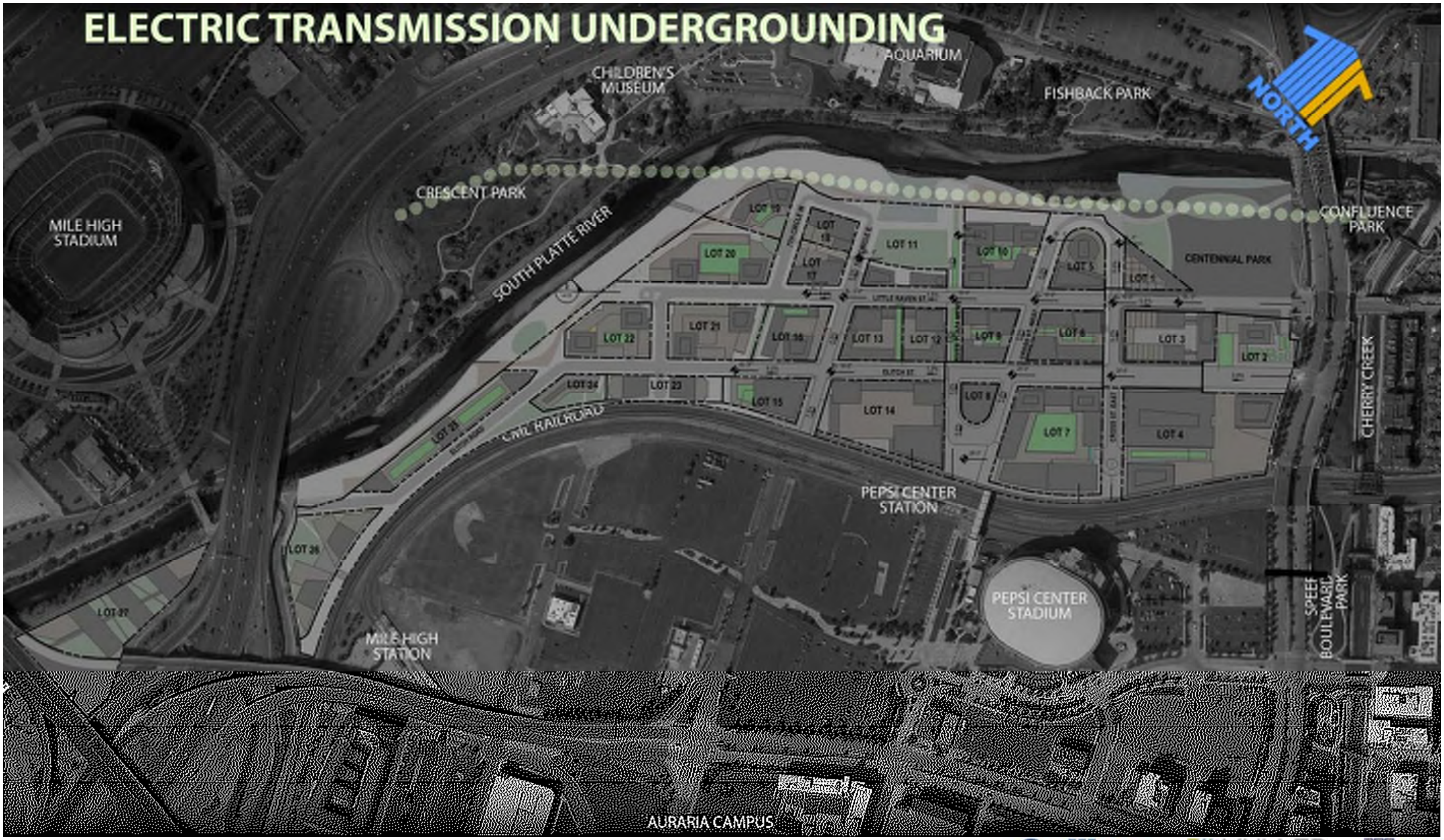

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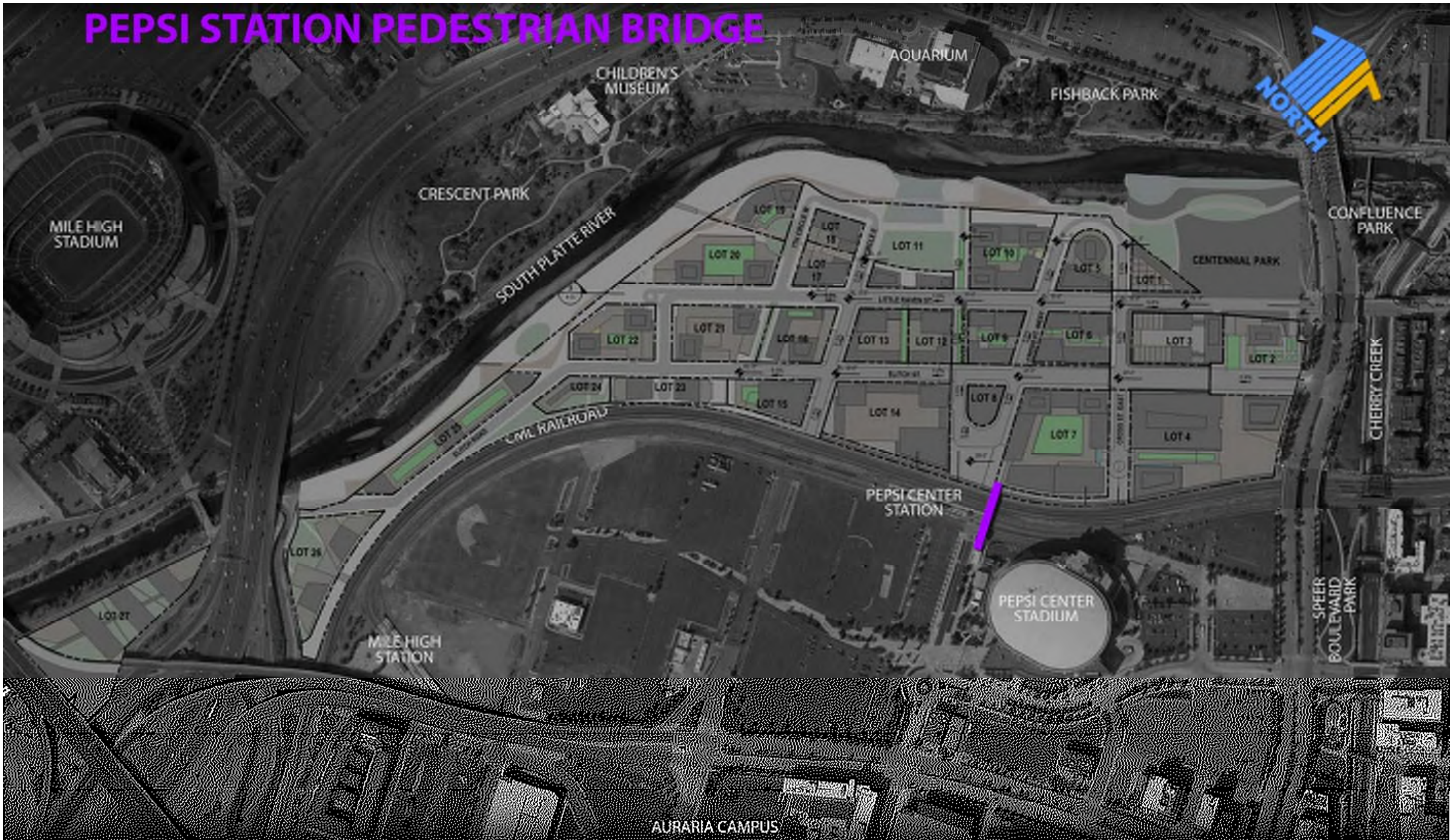

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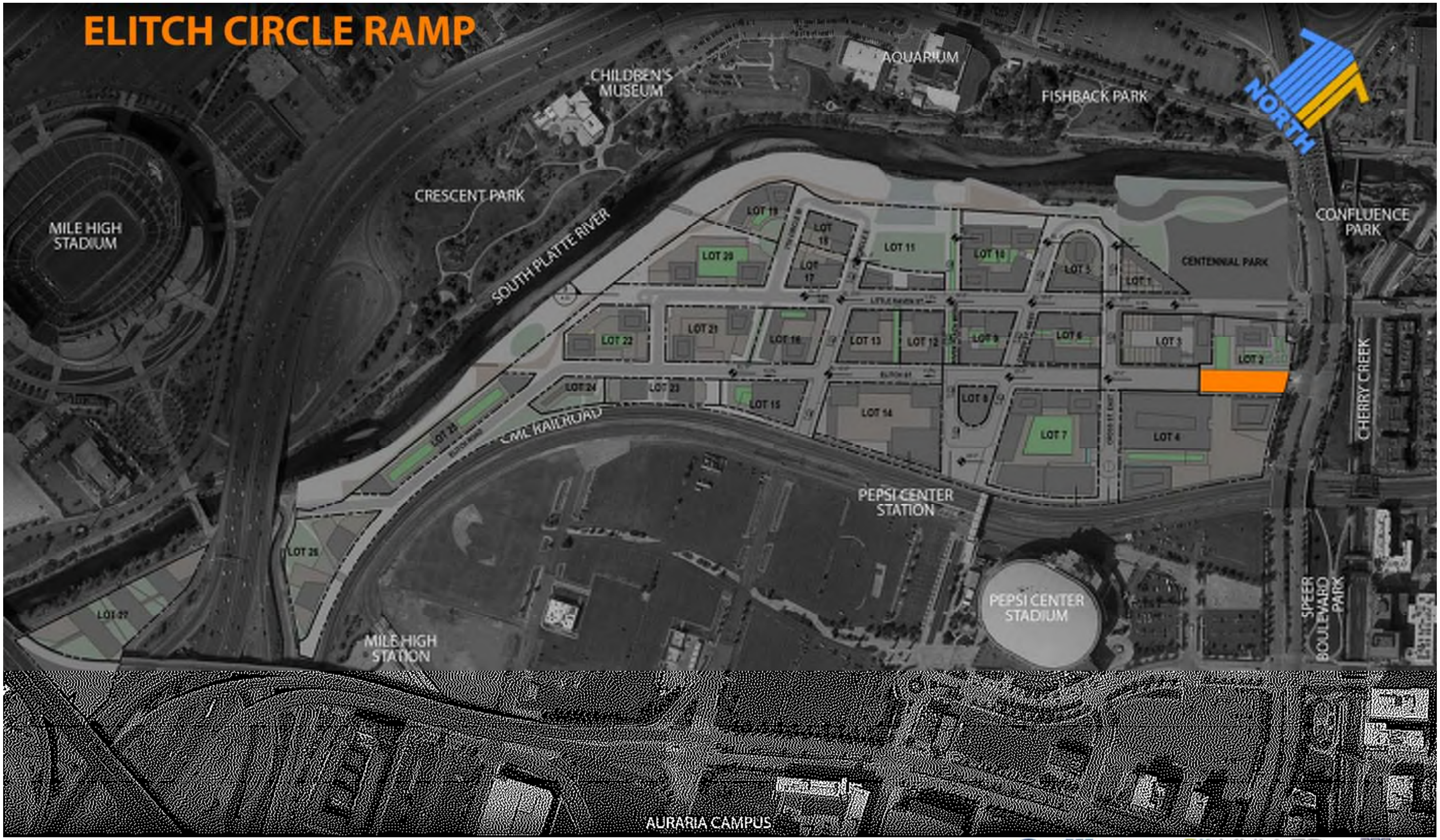

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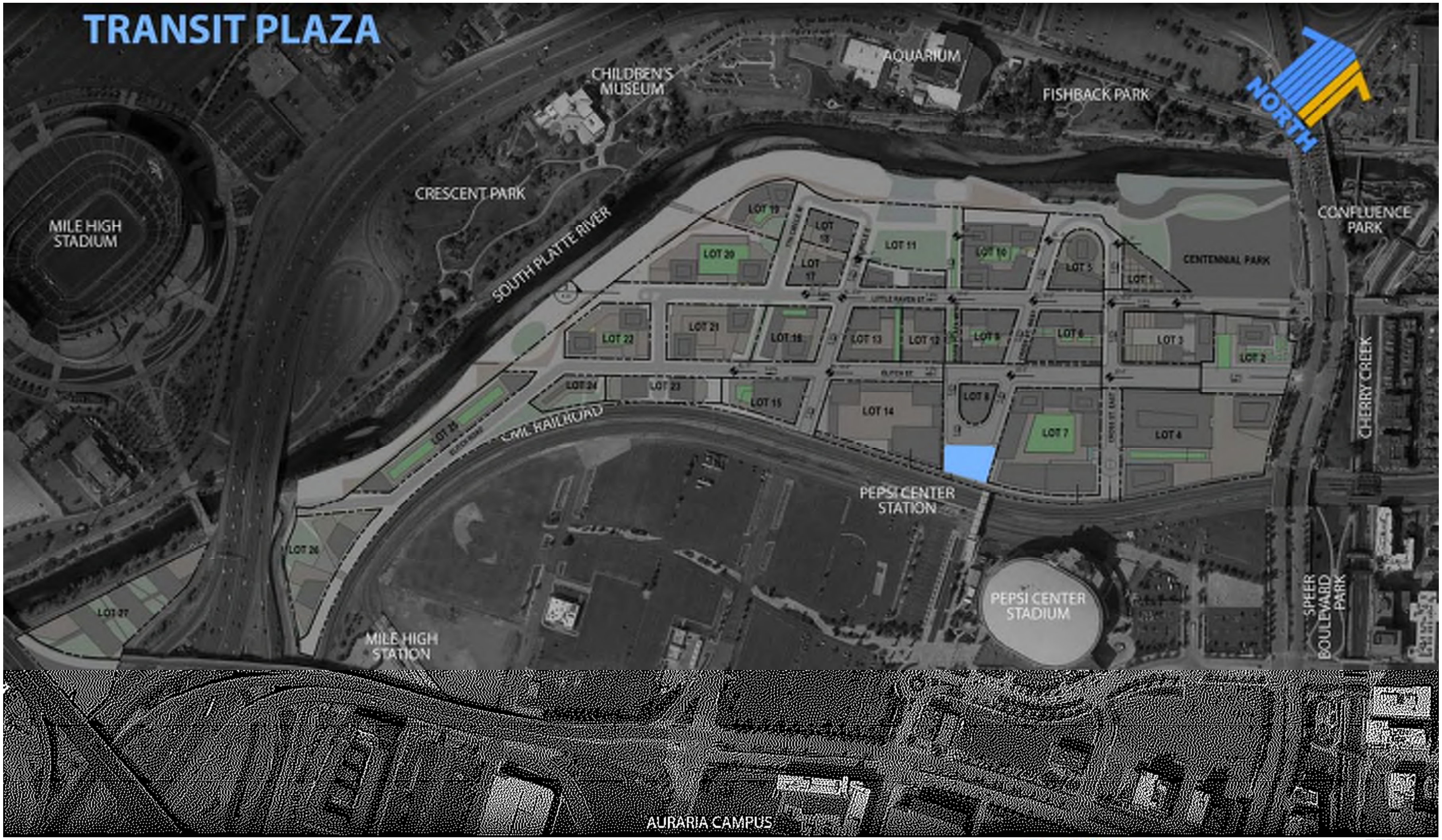

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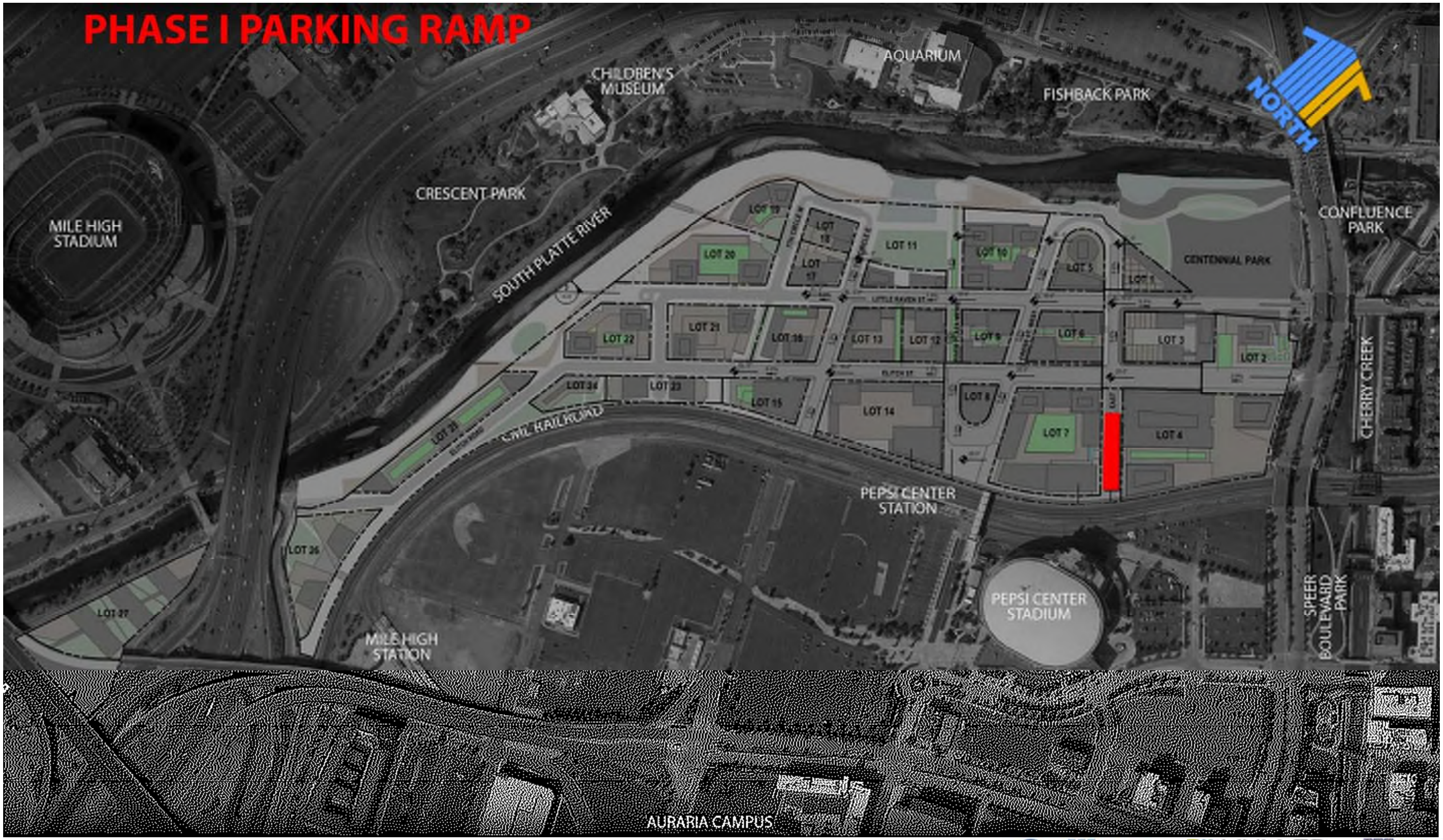

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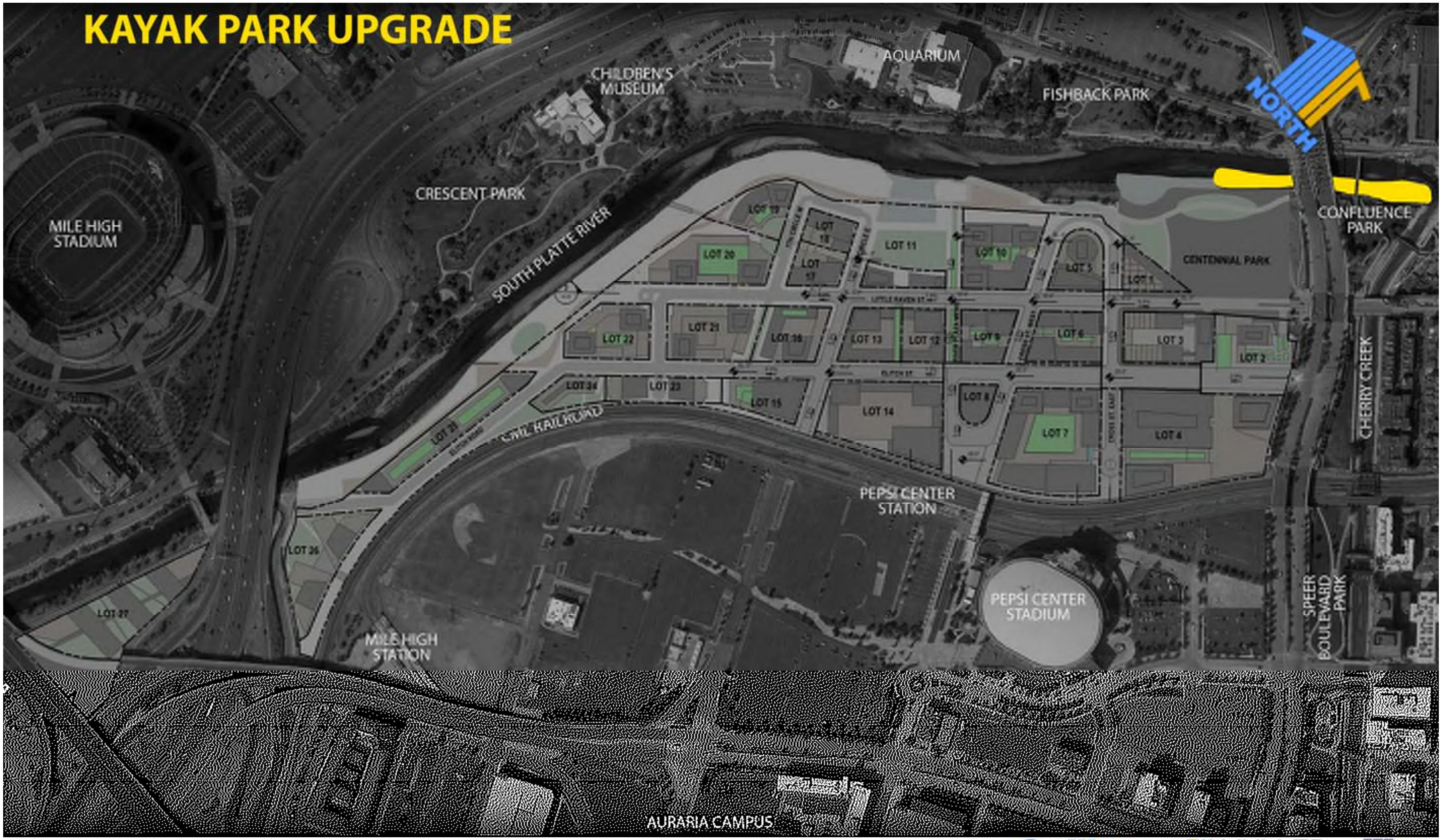

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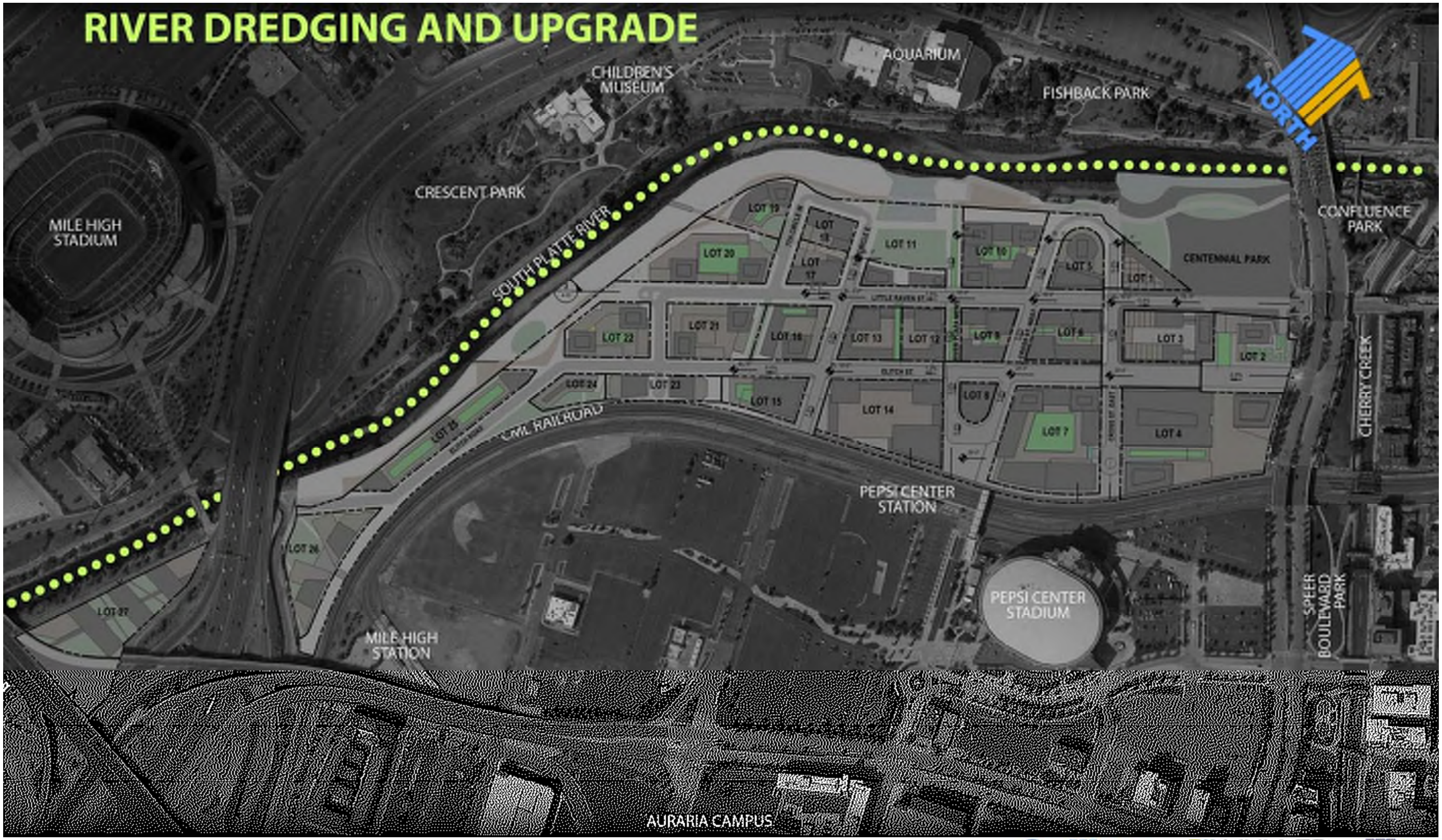

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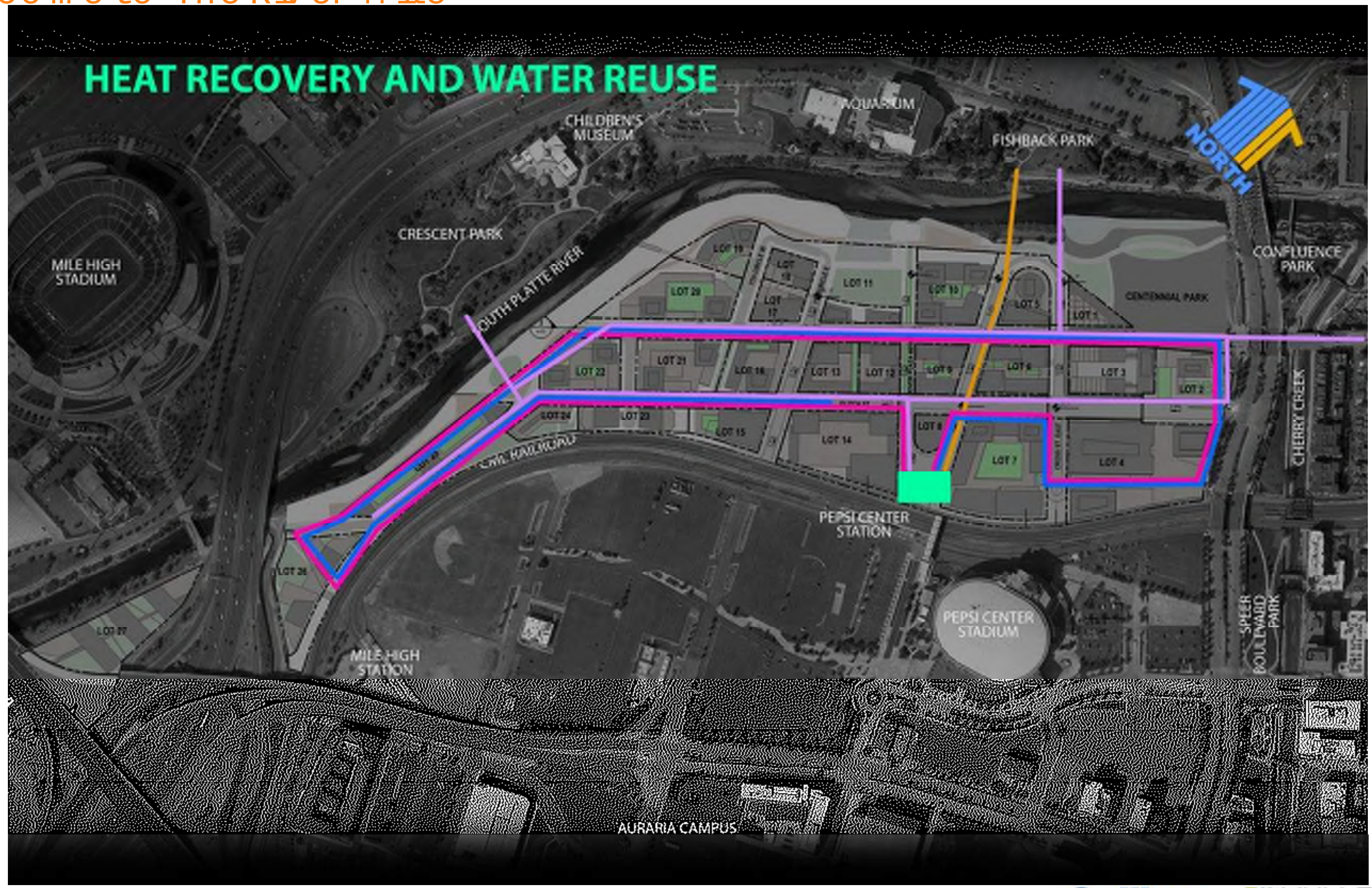

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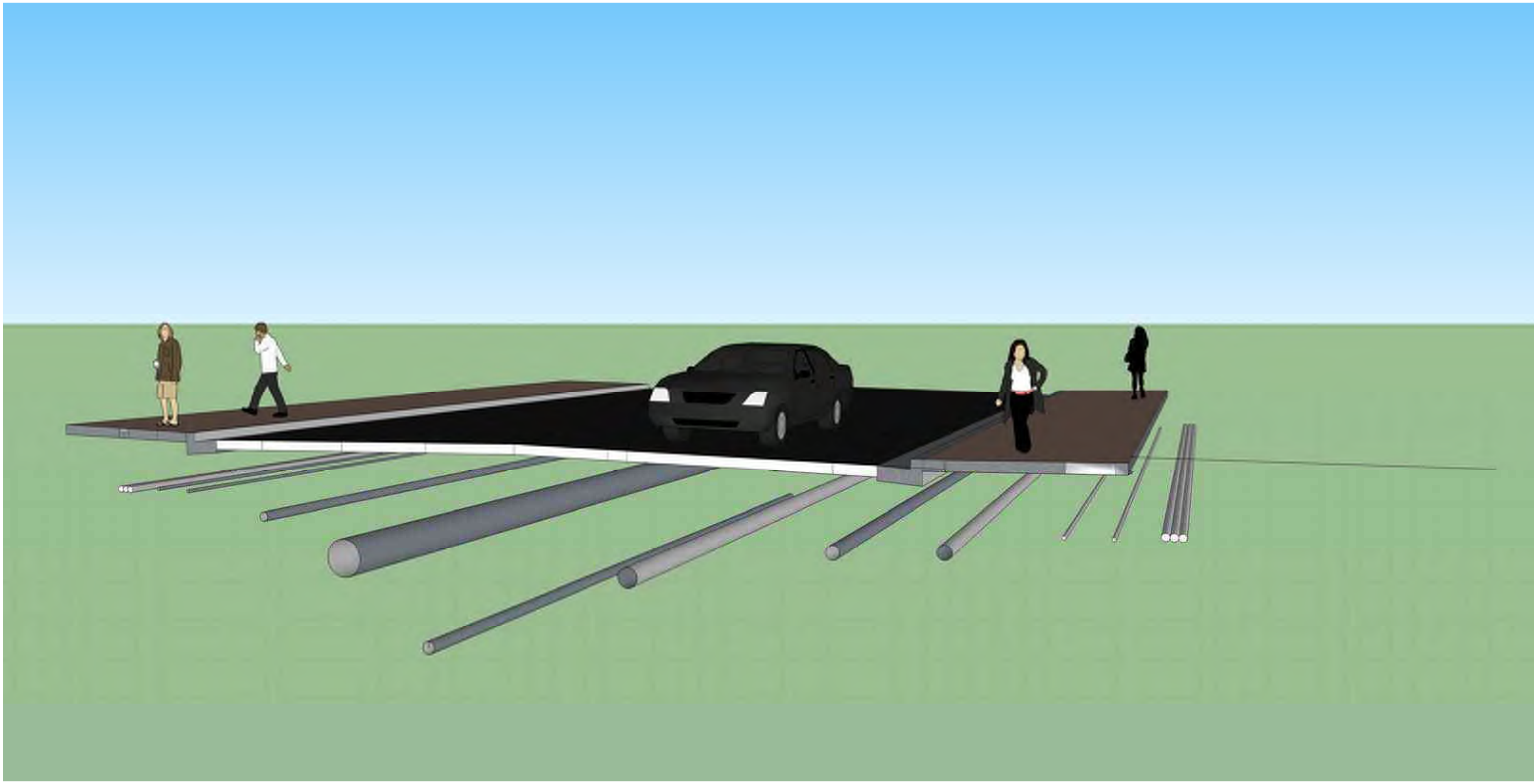

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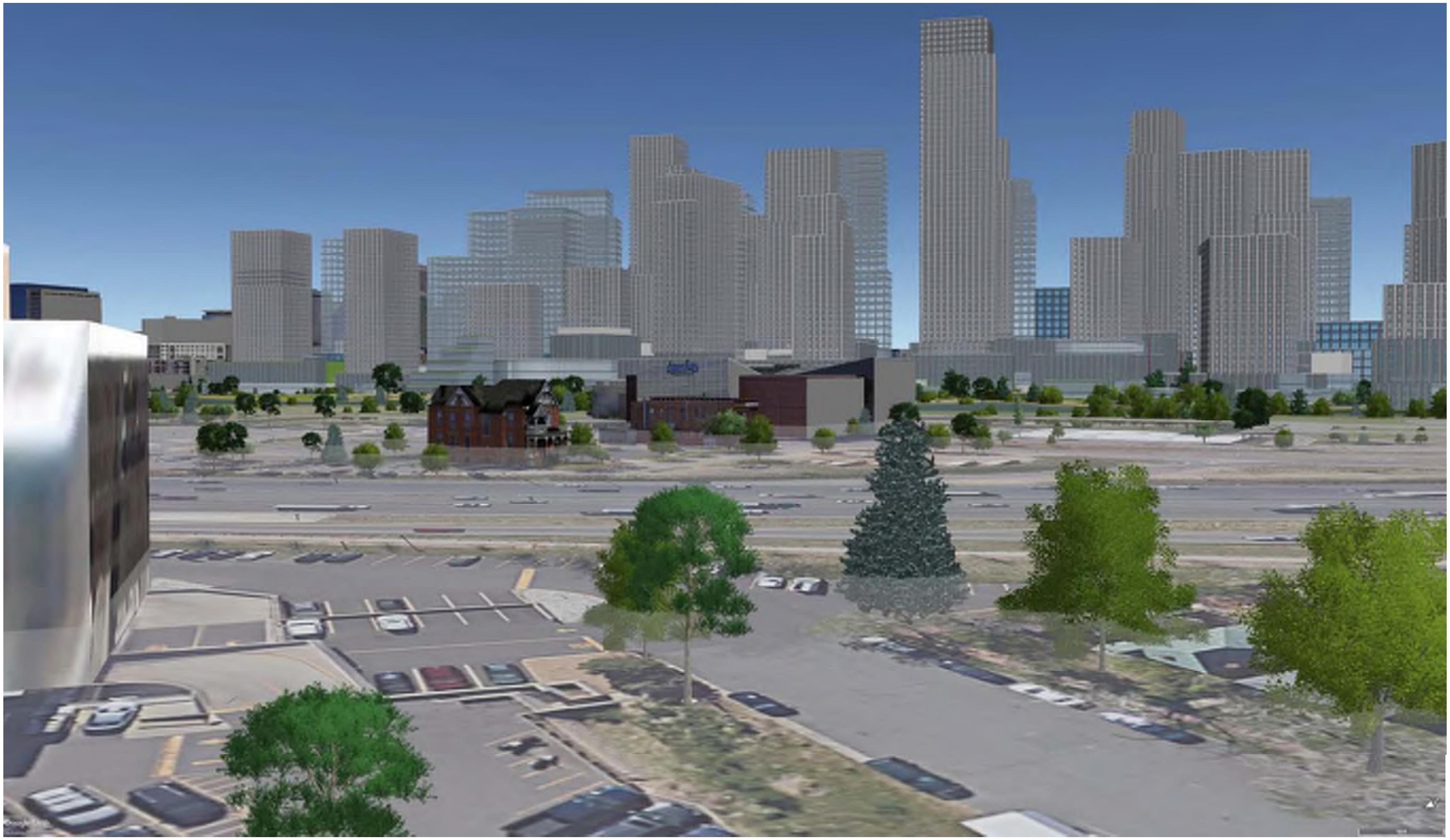

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Welcome to The River Mile

The story of this new urban district will be written around the rediscovery and revitalization of the South Platte. And the transformation of this stretch of the river into a mile-long social catalyst. The plan for this new urban district will unlock the waterfront as no other place in Denver does. Homes, restaurants, retail and entertainment offerings will open up to the river.

It will be one of the City's great places –

rivermiledenver.com

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Resources:

- UDFCD VOL. 3
- City and County of Denver ultra-urban green infrastructure guidelines
- City of Philadelphia green streets design manual
- District-scale green infrastructure scenarios for the Zidell development site, City of Portland

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Denver Green Roof Initiative

- Green (includes offsite financial contribution)
- Green + Energy
- Energy
- Certification

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Green Roofs

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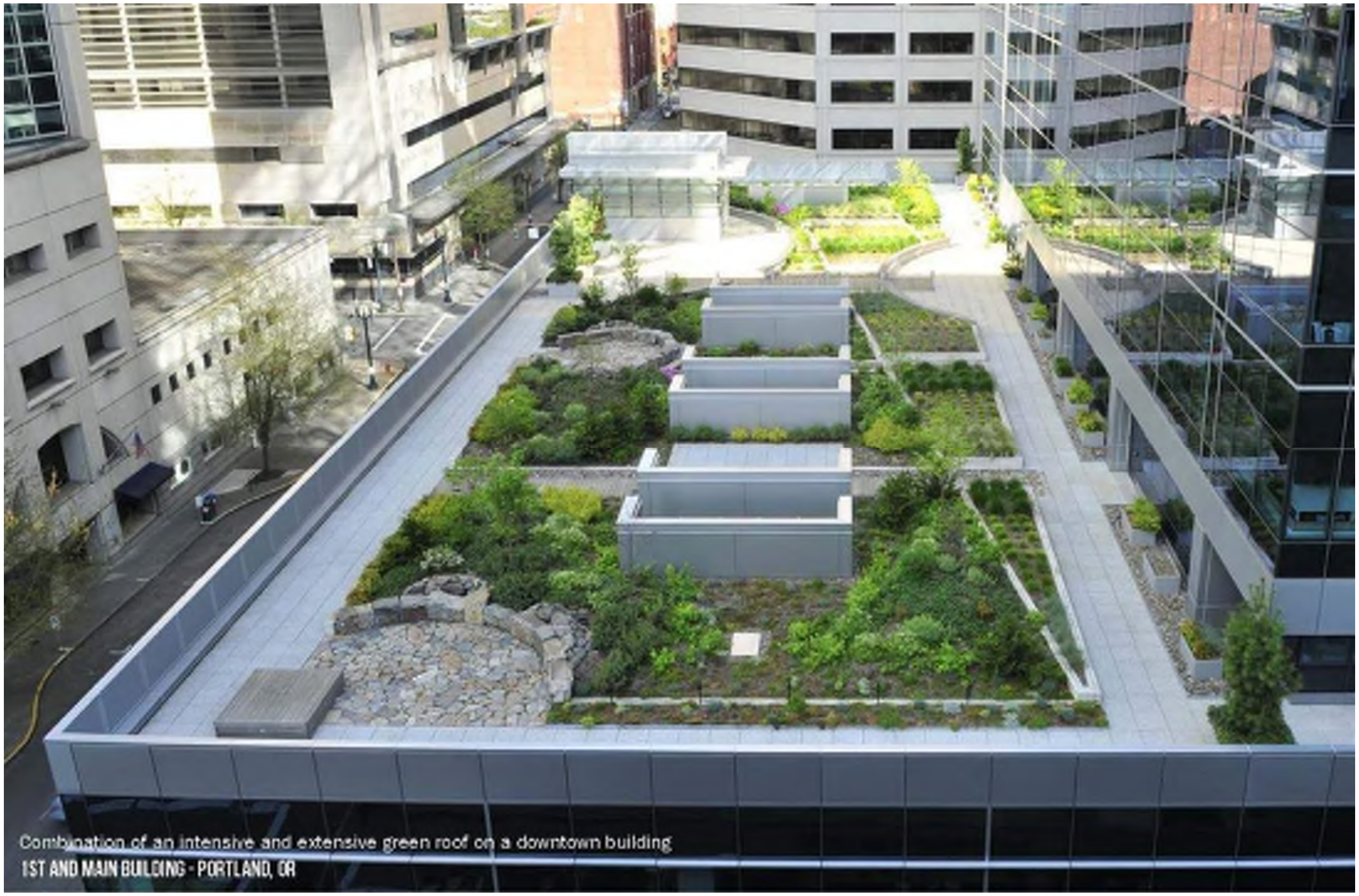

Beautiful as much as functional

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Social, quality of life, and economic opportunities

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- image from urban study by United Network Studio

Welcome to The River Mile

- image from urban study by United Network Studio

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Back of curb to building face

- Avoid overly dominant components
- Maximize pedestrian space and usability

Underground Treatment

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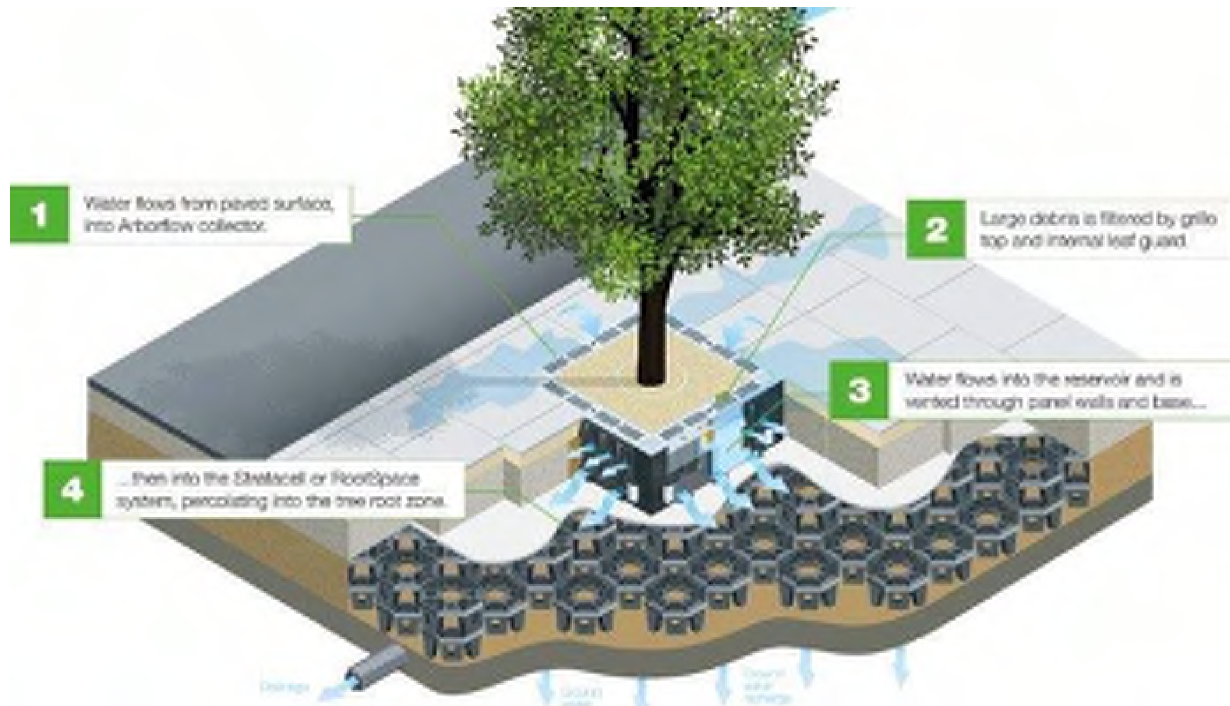
Underground Treatment

- Better multi-function use of Right of way
- Better for tree health
- Low maintenance
- Promotes infiltration
- Better runoff reduction



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Structural Support Systems

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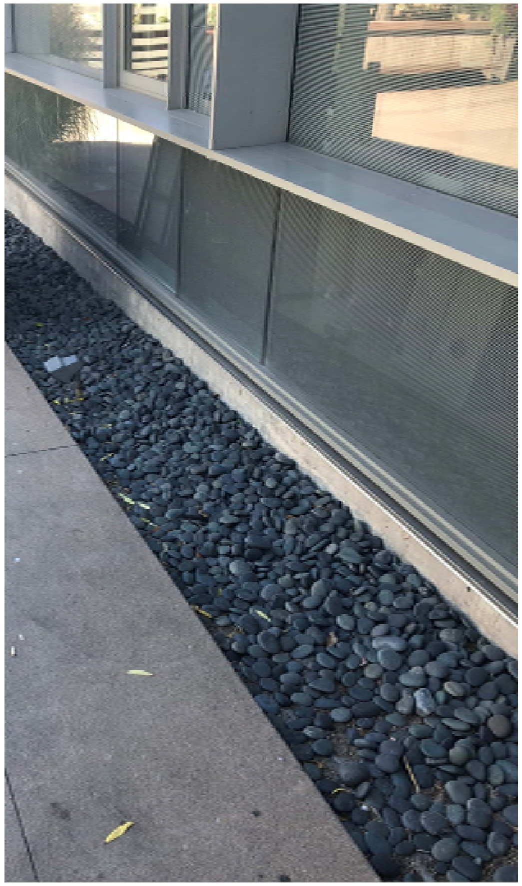

Roof drainage conveyance

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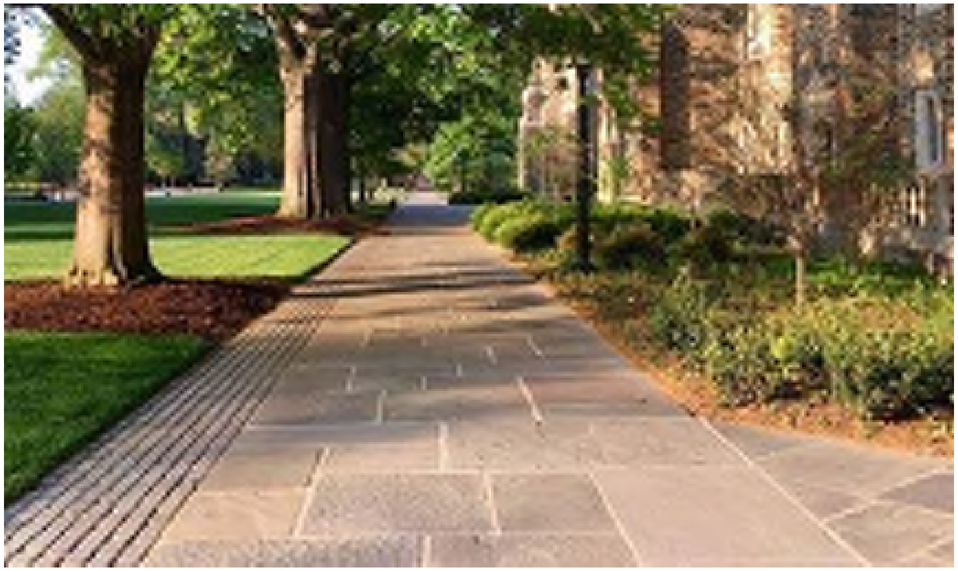

Surface treatment options

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Surface drains to convey stormwater below ground

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Tree Grates

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Purposeful, artistic, compatible with mobility goals

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Are we avoiding planter beds? NO

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Works here.

How about here?

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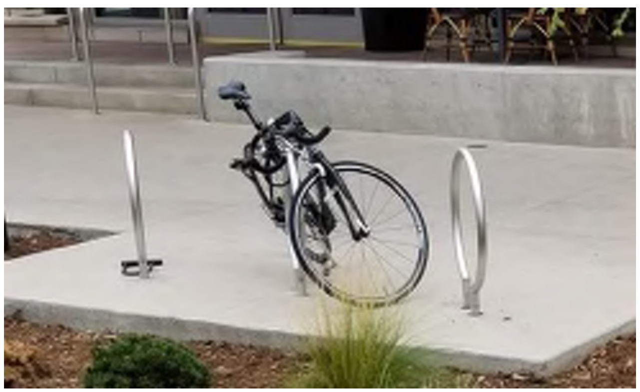

Provide room for the “Needs”

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Can't forget about the "Wants"

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Streets

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Curbless?

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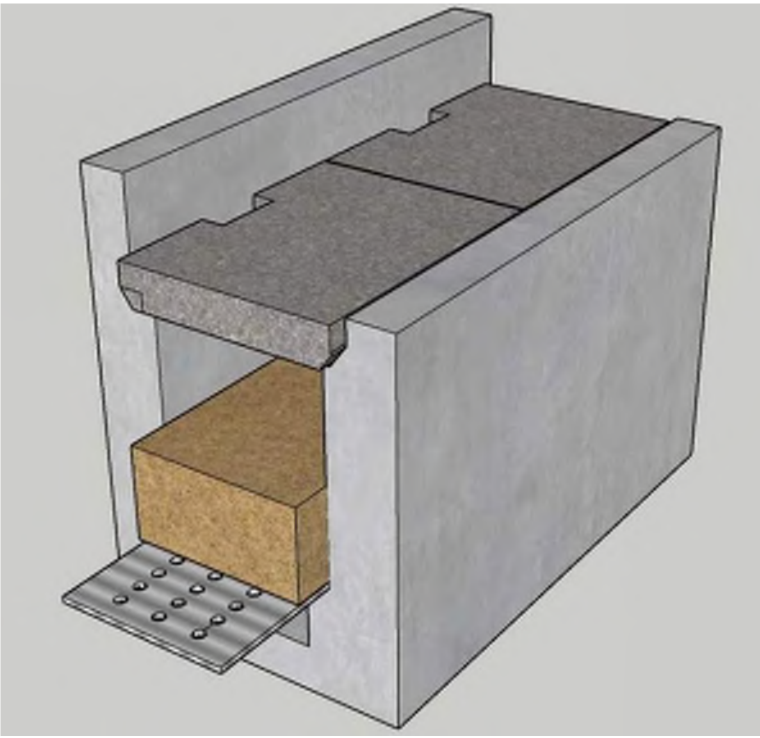

Inlet Options

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Inlet Options

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Plazas

Plazas

- Sunken water quality treatment

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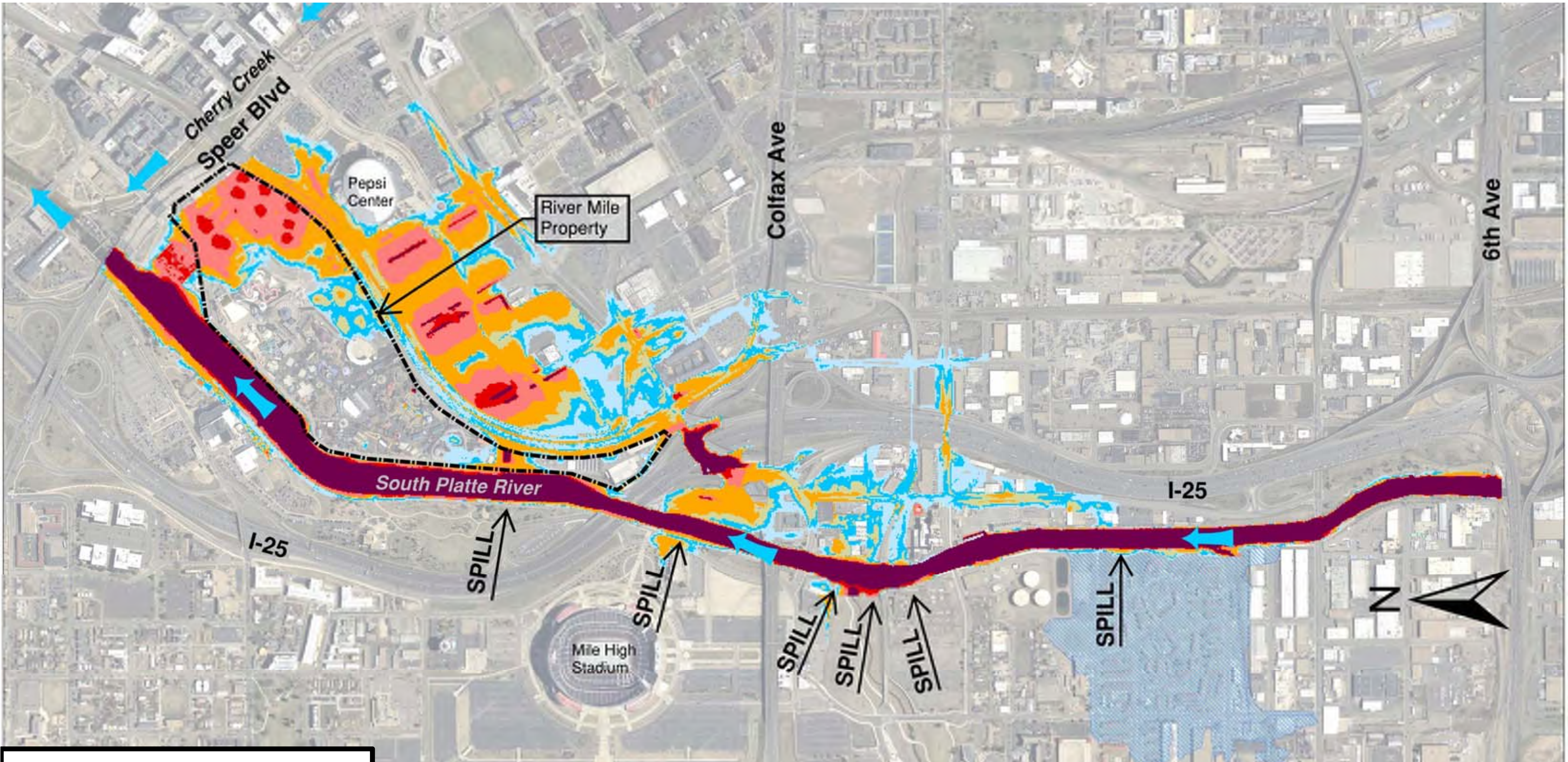

2-D FLOODPLAIN MODEL

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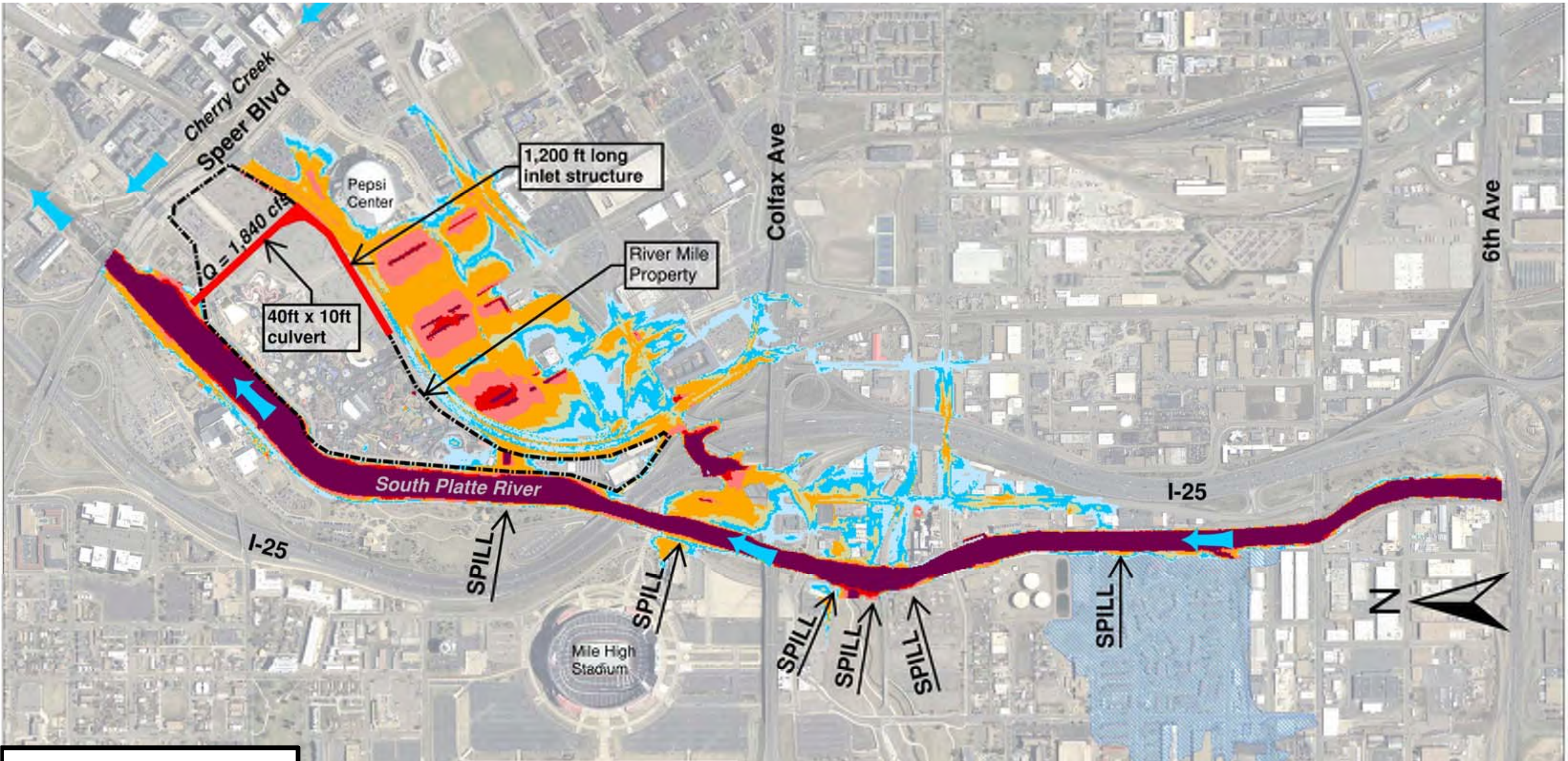

OPTION 1 - CULVERT

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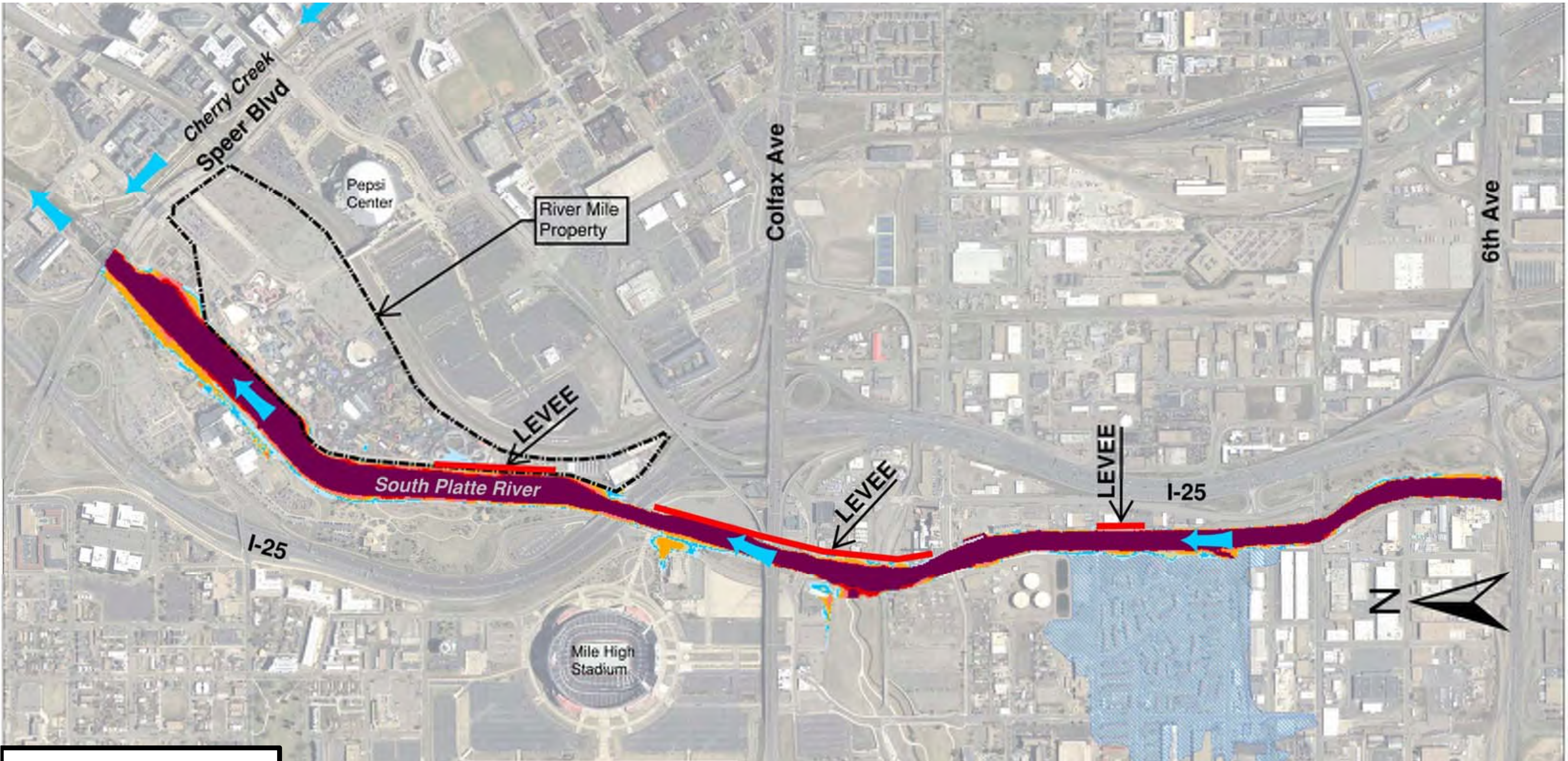

OPTION 2 - LEVEES

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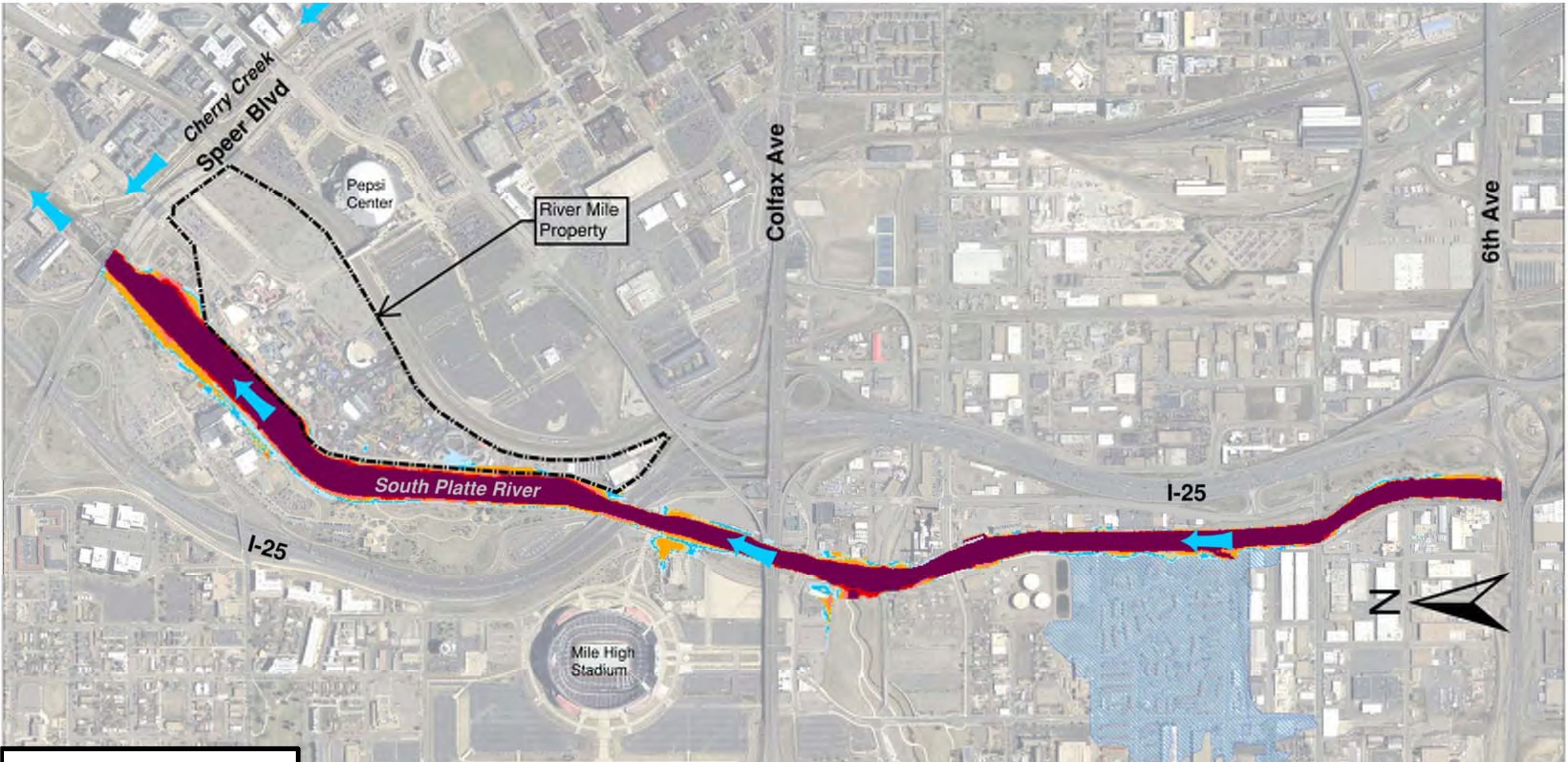

OPTION 3 – MODIFY RIVER

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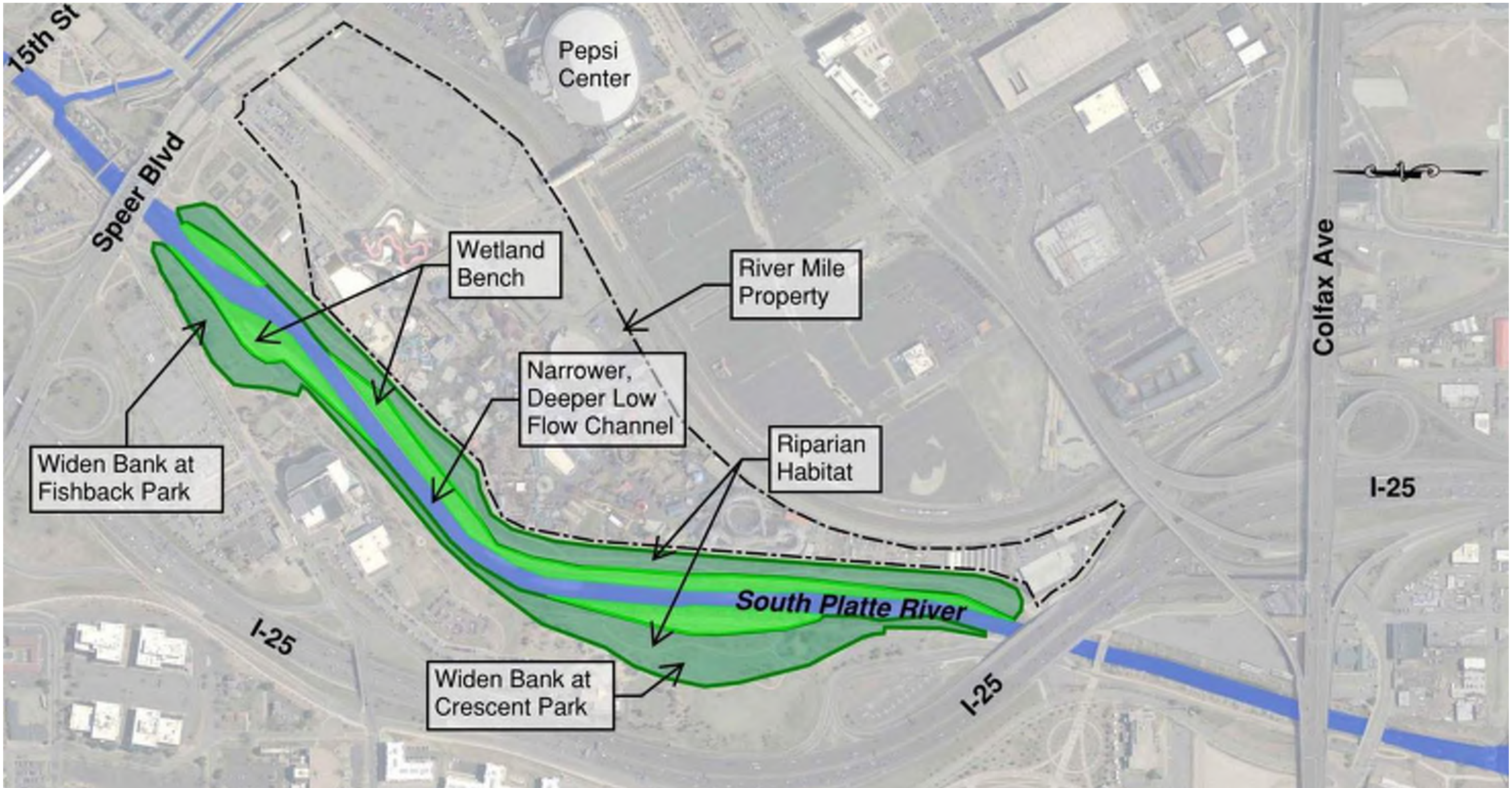

DENVER URBAN WATERWAYS RESTORATION STUDY

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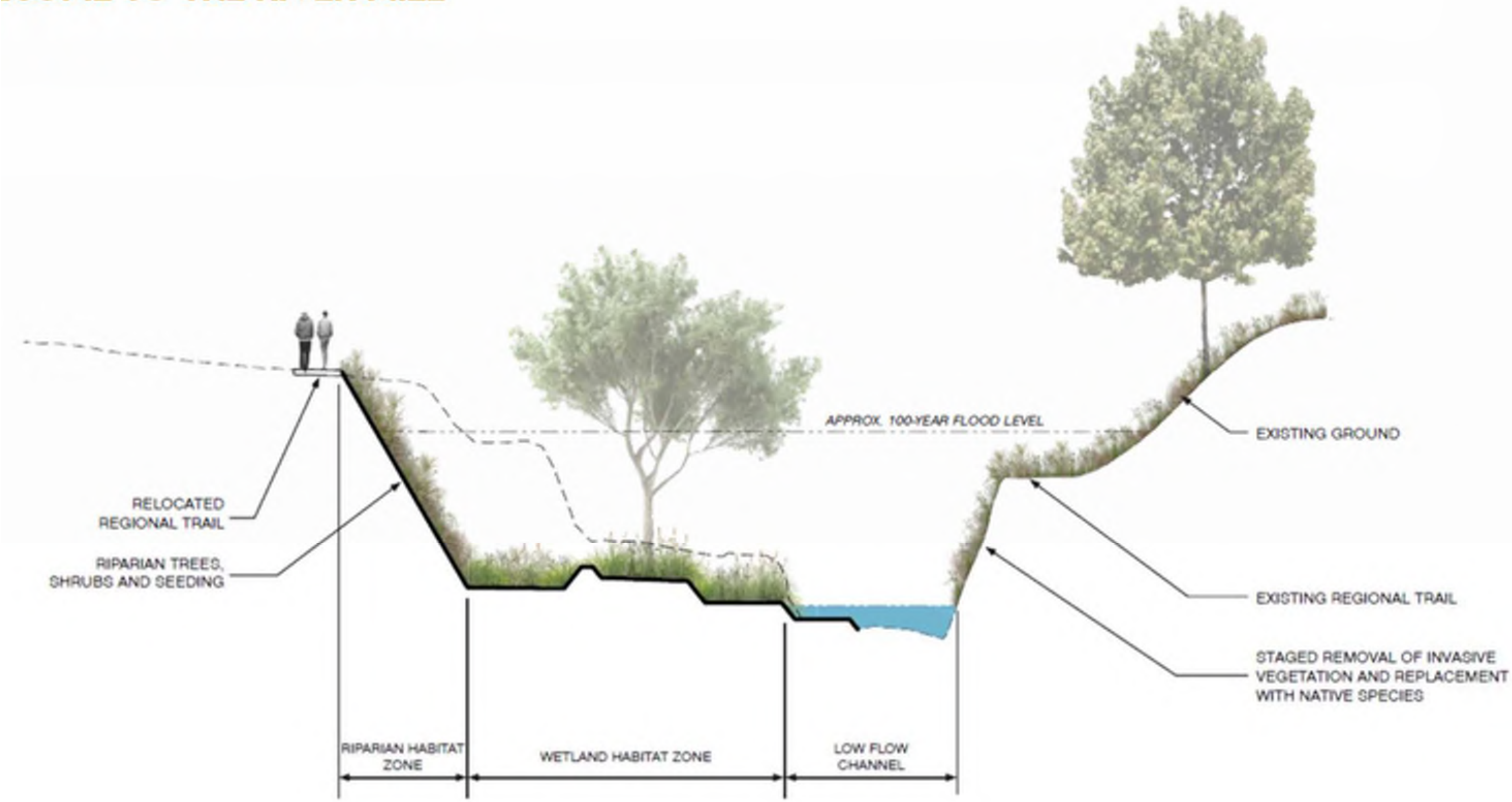

TYPICAL SECTION

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Riparian/Wetland Habitat

Aquatic Habitat/Fish

Trails/Paths

MULTIPLE USES

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River Access

Leisure

Boating

MULTIPLE USES

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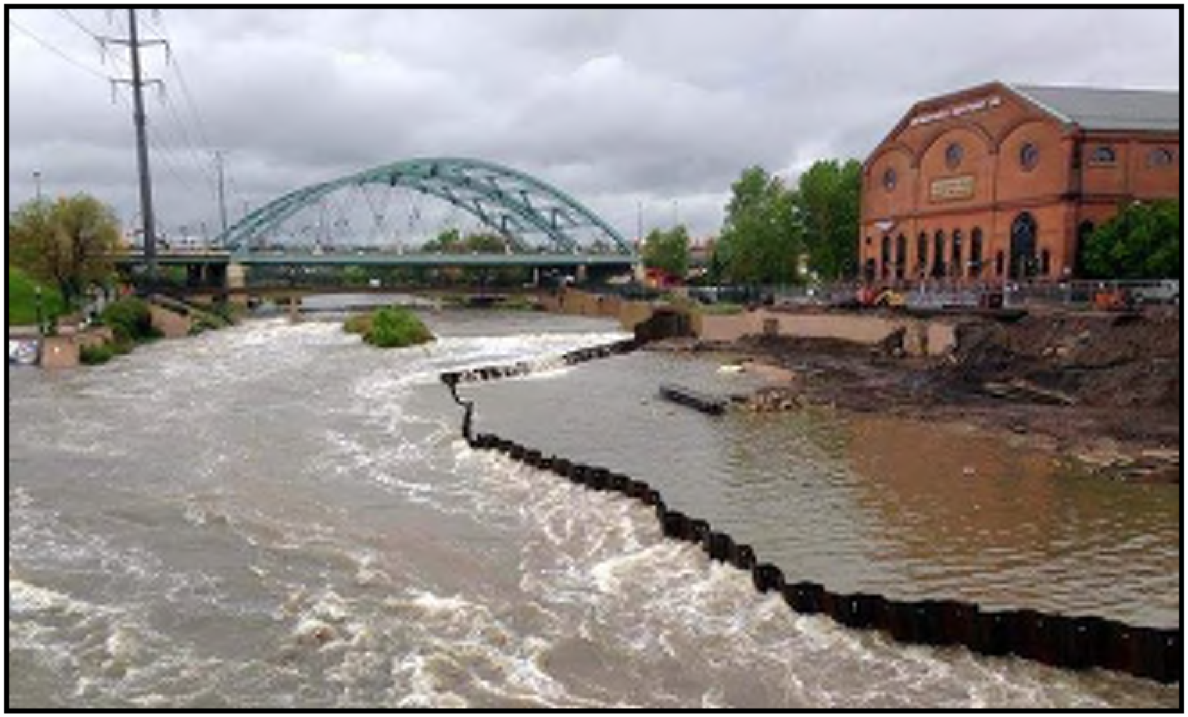
Flood Control



Swimming/Play

MULTIPLE USES

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River Surfing

RIVER RUN PARK,
Englewood, Co.

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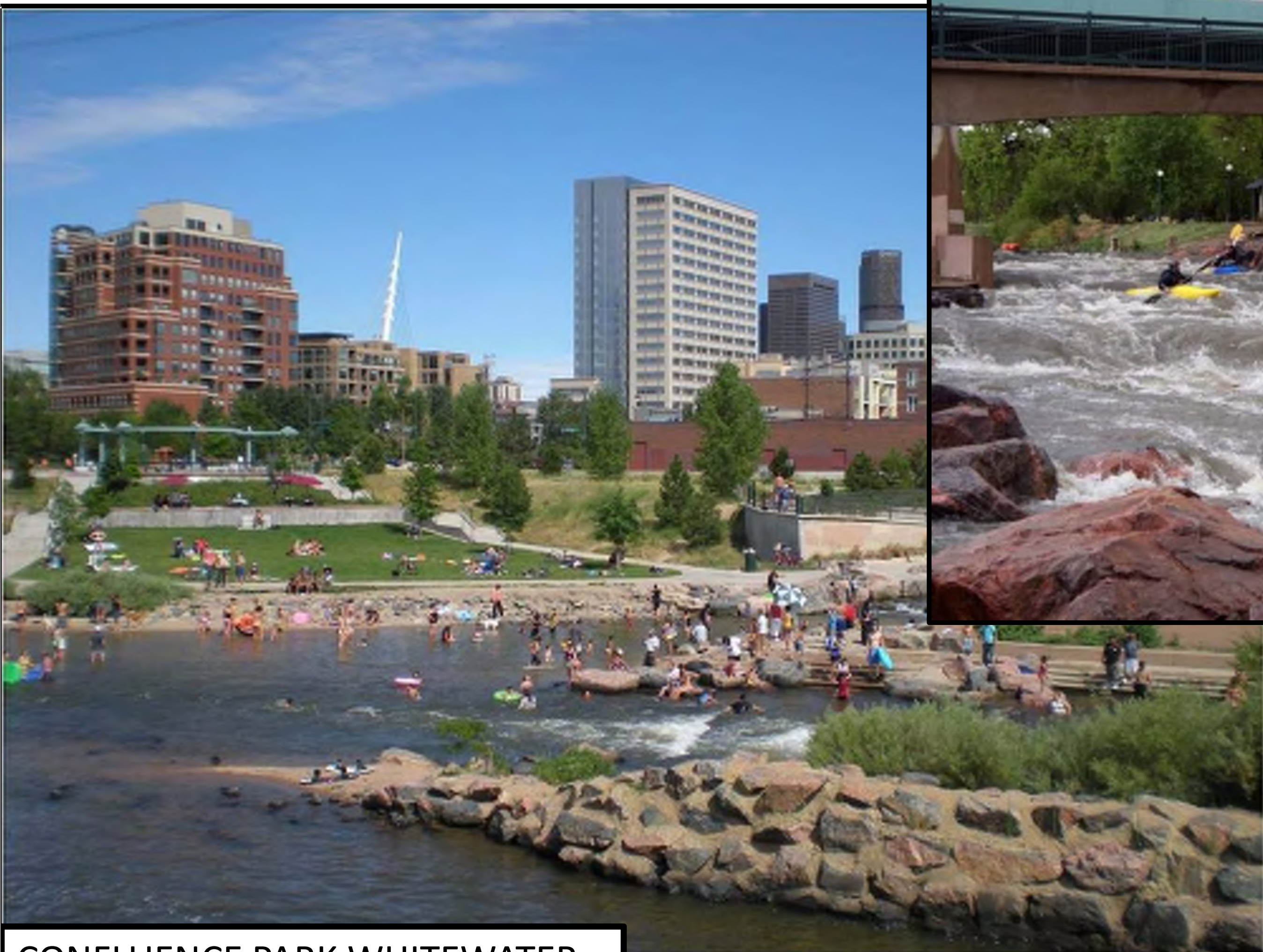
Welcome to The River Mile

River Surfing

RIVER RUN PARK,
Englewood, Co.

Calibre MULLER MERRICK

Welcome to The River Mile



CONFLUENCE PARK WHITEWATER COURSE, Denver

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SEDIMENT TRANSPORT

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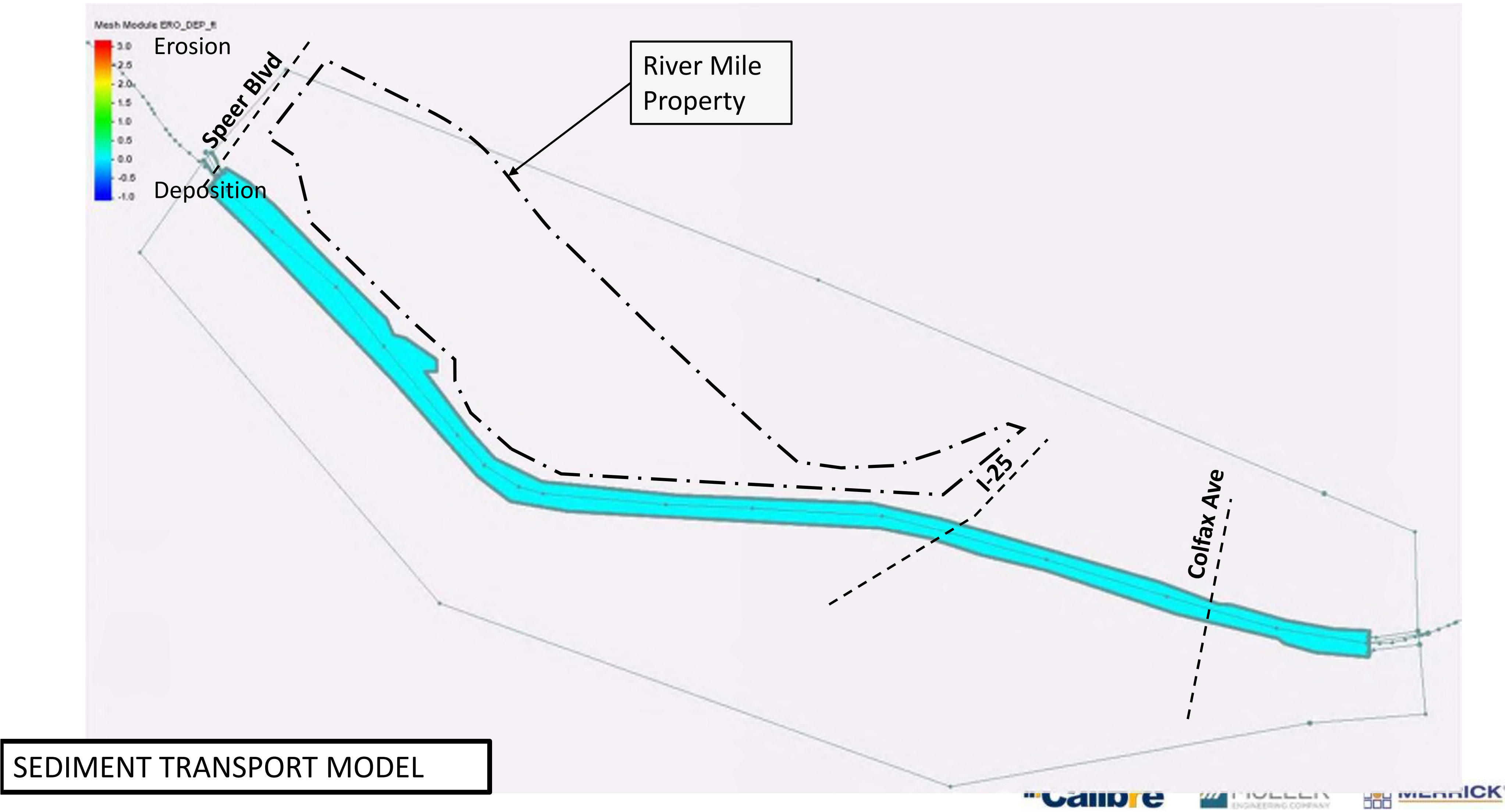



Questions
Greg Murphy, PE, ARCSA AP – Calibre Engineering
Chris Kroeger, PE – Muller Engineering
Mike Galuzzi, PE – Merrick & Company

Planning for Recreation and Resilience on the Big Thompson River

Chris Carlson, P.E., Andrew Earles, Ph.D., P.E., Kevin Gingery, P.E., Kevin Shanks, RLA, Brandon Parsons, Shannon Tillack, P.E., Julia Traylor, Ellie Garza & Scott Schreiber, P.E.

City of Loveland

WWE

associates, inc.

Matrix DESIGN GROUP

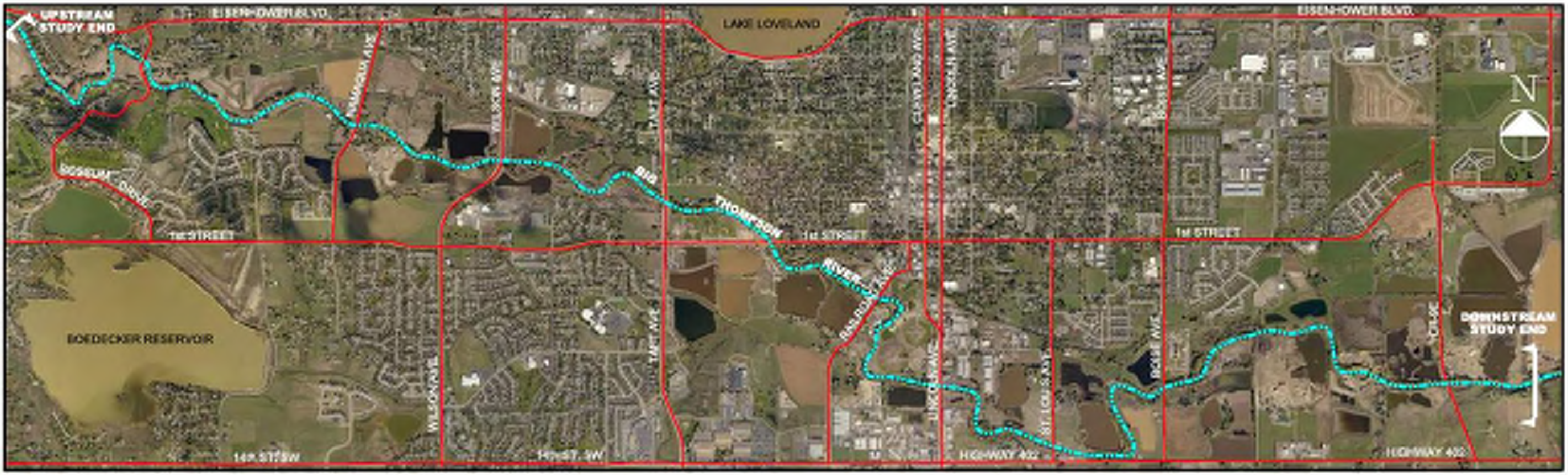
Colorado Association of Stormwater & Floodplain Managers (CASFM) Annual Conference
September 2018, Snowmass Village, Colorado

Overview of Presentation

- Need for Master Plan
- Unique Aspects of Project Approach
- Key Aspects of Master Plan
- Implementation

BIG THOMPSON RIVER CORRIDOR MASTER PLAN

Study Limits Map



Need for Big Thompson River Corridor Master Plan

Master Plan Objectives

- Capture a long term vision for the river corridor
- Recommend projects that mitigate flood hazards, restore the river's ecology, and meet multiple objectives
- Improve resiliency in the corridor
- Restore natural river & floodplain functions
- Recommend how the City can better capitalize on its river – recreation, trails, tourism, redevelopment, etc.
- Improve opportunities for public interaction
- Recommend how to manage & maintain the river corridor

Science Based, Community Driven

- Reach "Fact Sheets"
- Baseline resiliency score cards
- Field investigations
- Gap analysis
- Engineering & planning
  - Hydrology & hydraulics
  - Fish
  - Vegetation
  - Wildlife
  - Water quality
  - Irrigation diversions
  - Parks & recreation

- Trails
- Natural areas
- Bridges and roads
- Utilities
- Buildings
- Private property & infrastructure

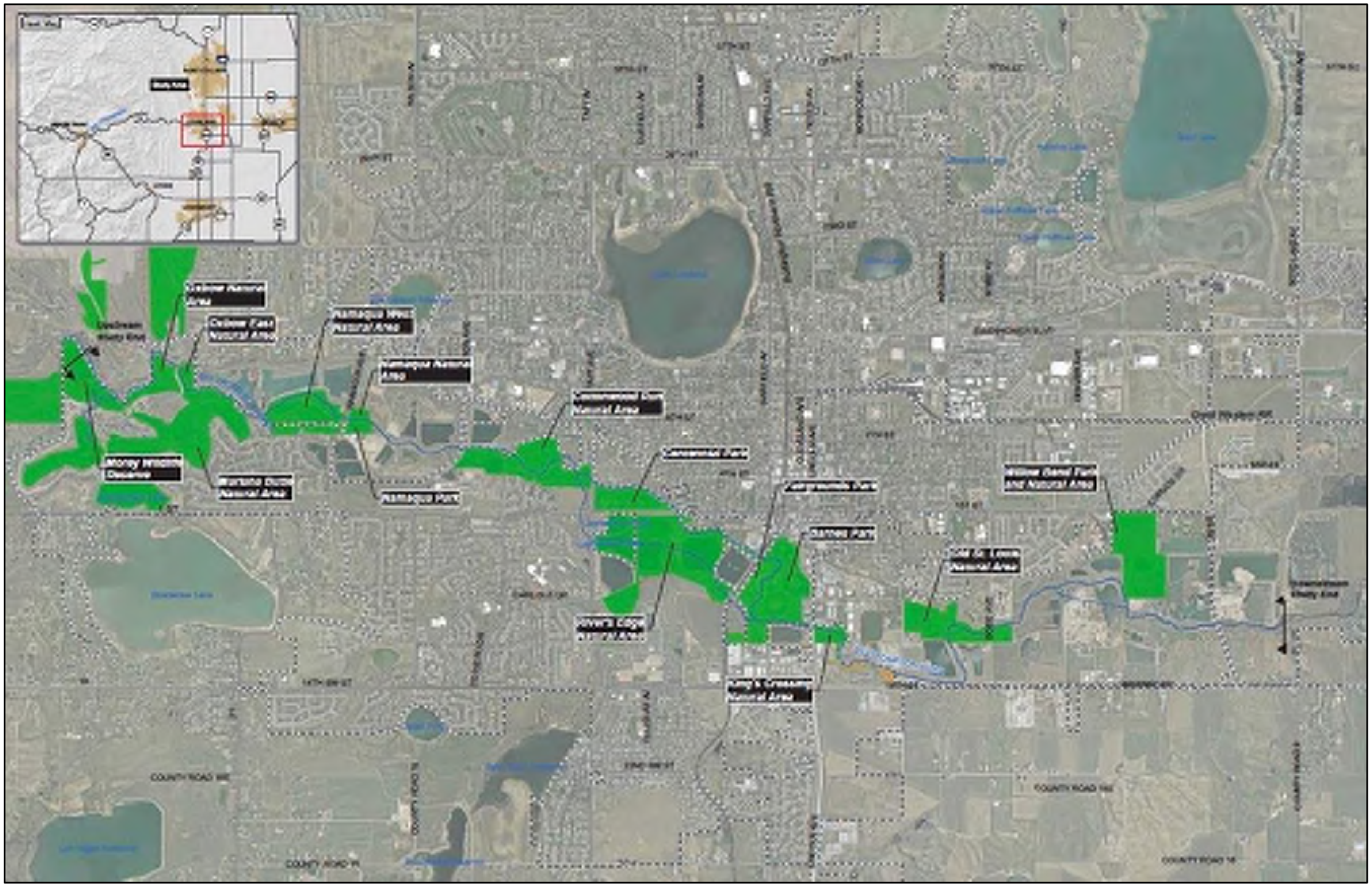
Vision for the Corridor

- A resilient, connected corridor
- Improve flood conveyance / reduce hazards
- Preserve ecological functions
- Urban fishery – improve fishing & access
- Continue open lands acquisition
- Improve river access & water-based recreation
- Regional corridor trail + trail connections
- Open land for wildlife & wildlife viewing

Vision for the Corridor

- Improve water quality
- Downtown access – trail/corridor connection
- Corridor access for future developments
- Redevelopment opportunities on Lincoln Avenue/Hwy. 287
- Comprehensive maintenance and management program
- Growing community involvement – waterway clean-ups, education, nature walks, community events

Open Lands & Natural Areas



Natural Areas

- Wildlife corridor - seating & wildlife viewing areas
- Weed and invasive species control; plant shrubs
- Cattail reduction/diversify wetland species
- River bank erosion protection
- Aquatic restoration & habitat – fishery enhancement
- Protect old gravel pit overtopping
- Water quality

Trails and Recreation

- Water recreation – tubing, fishing, swim/play
- Designated river access points & tubing route
- More trails – including soft surface trails and connections to neighborhoods
- Natural vs. manicured landscaping & appearance
- Trailhead improvements
- Natural play areas
- Bike skills/riding park

Transportation

- Currently 10 roadway crossings of the Big Thompson River within the study boundary
- Current crossing capacity (protection level) 5-50 year event
- Focus on Wilson, Lincoln, Railroad, and the future Boyd Lake Ave.
- Significant issues also at Hwy. 402/St. Louis, Taft & 1st

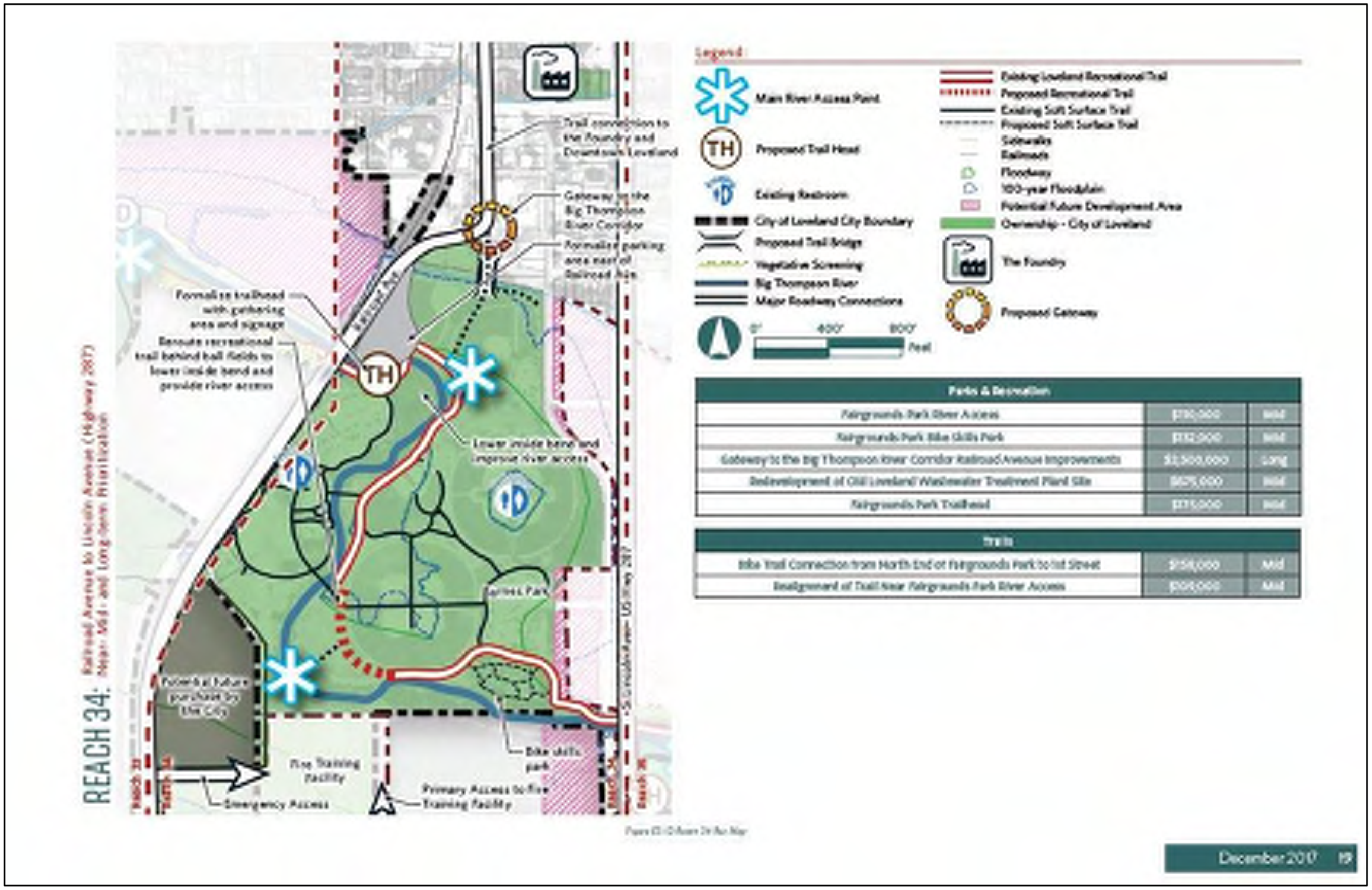
Resilience

Resilience Assessment Category	Reach 29: Morey-Rossum	Reach 30: Rossum-Namaqua	Reach 31: Namaqua-Wilson	Reach 32: Wilson-Taft	Reach 33: Taft-Railroad
Flood Hazards	18	18	21	17	17
Aquatic Habitat	5	4	5	5	8
Natural Areas/Open Space	11	8	8	11	12
Geomorphology	22	18	12	15	12
Parks and Recreation	5	2	3	5	9
Trails	3	3	3	8	10
Utilities	9	10	12	9	12
Water Quality	20	24	3	11	11
Gravel Pits	24	0	0	0	0
Land Use	13	7	9	11	14
Potential for Flood Damages to Urban Infrastructure/2013 Observations	25	25	30	25	10
Reach Total Score	70	53.9	48.1	53.8	52

Rank (Based on Highest Score)	Baseline Resilience Assessment Score	Reach
1	70	Reach 29: Morey - Rossum
2	69	Reach 38: CR 9E - D/S Limit
3	62	Reach 36: St. Louis - Boise
4	56	Reach 37: Boise - CR 9E
5	53.9	Reach 30: Rossum - Namaqua
6	53.8	Reach 32: Wilson - Taft
7	52	Reach 33: Taft - Railroad
8	48.4	Reach 35: Hwy 287 - St. Louis
9	48.1	Reach 31: Namaqua - Wilson
10	45	Reach 34: Railroad - Hwy 287

Unique Aspects of Project Approach

Balance of Planning & Engineering



Parks & Recreation		
Fairgrounds Park River Access	[illegible]	Mid
Fairgrounds Park Bike Skills Park	[illegible]	Mid
Gateway to the Big Thompson River Corridor Railroad Avenue Improvements	[illegible]	Long
Redevelopment of Old Loveland Wastewater Treatment Plant Site	[illegible]	Mid
Fairgrounds Park Trailhead	[illegible]	Mid

Trails		
Bike Trail Connection from North End of Fairgrounds Park to 1st Street	[illegible]	Mid
Realignment of Trail Near Fairgrounds Park River Access	[illegible]	Mid

Public Outreach

- Farmers Markets
- Summer Concerts
- Summer Festivals
- 2-day Workshop
- Project Website
- Open City Hall

Recreation

Stakeholders & Partners

Multiple concurrent, ongoing projects

- City of Loveland
  - Public Works
  - Parks & Recreation
  - Water & Power
  - Community& Strategic Planning
- Larimer County
- Big Thompson Watershed Coalition
- Big Thompson Water Quality Forum
- Colorado Department of Local Affairs

Key Aspects of Master Plan

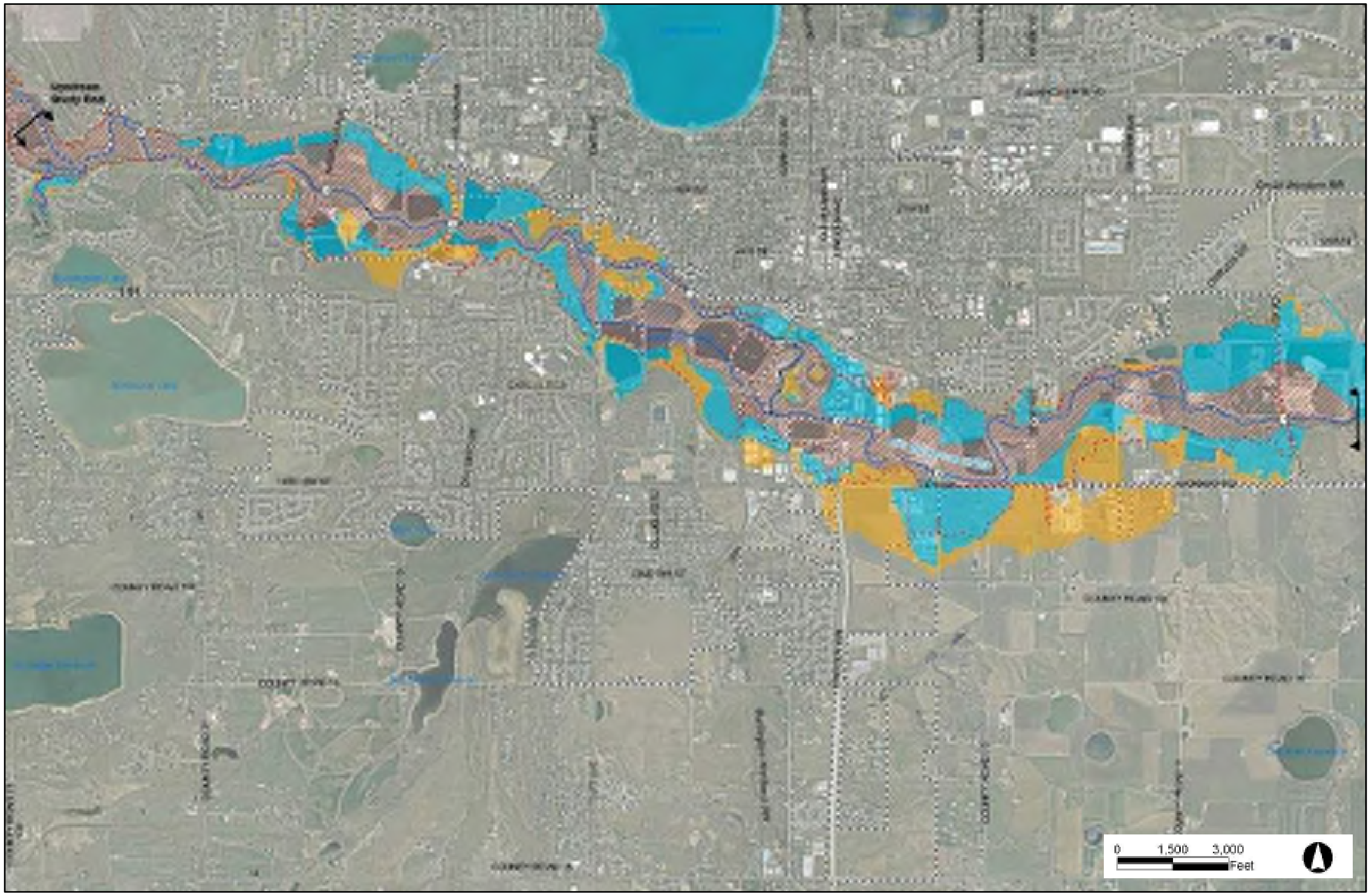
- Flood Hazard Reduction
- Gravel Pit Hazard Reduction
- Geomorphology
- Aquatic Habitat
- City Utilities
- Water Quality
- Natural Areas
- Parks, Recreation, Trails and Land Use
- Community Involvement Opportunities

Resilience

re·sil·ience /rəˈzilyəns/
noun

1. An ability to recover from or adjust easily to misfortune or change.

Floodplain Preservation



Balance of Recreational Access & Wildlife

Morey Wildlife Reserve – Passive Recreation and a Refuge for Wildlife

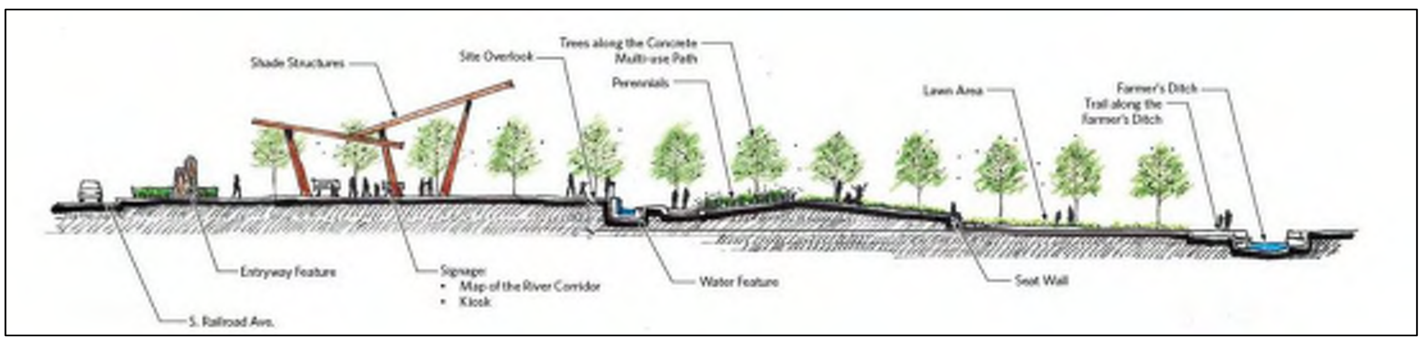
Balance of Recreational Access & Wildlife

Parks & Recreation		
Fairgrounds Park River Access	[illegible]	Mid
Fairgrounds Park Bike Skills Park	[illegible]	Mid
Gateway to the Big Thompson River Corridor Railroad Avenue Improvements	[illegible]	Long
Redevelopment of Old Loveland Wastewater Treatment Plant Site	[illegible]	Mid
Fairgrounds Park Trailhead	[illegible]	Mid

Trails		
Bike Trail Connection from North End of Fairgrounds Park to 1st Street	[illegible]	Mid
Realignment of Trail Near Fairgrounds Park River Access	[illegible]	Mid

Fairgrounds Park – Active Recreation and River Access

Connecting the River & Community



Implementation

Category & Cost												
Reach	Flood Hazard Reduction	Gravel Pits[2]	Aquatic Habitat	Geomorphology[2]	Natural Area/ Open Space	Parks & Recreation	Trails	Land Use	Utilities	Water Quality	Maintenance[4]	Total
29	$1,660,000		$1,81M - est. cost of Big Barnes diversion dam retrofit - not included in overall cost estimate since private dam		$100,000	$745,000	$1,083,000				$23,000	$3,590,000
30	$350,000[1]	----[3]	----[3]	----[3]	$100,000	$489,000	$368,000	$174,000			$26,000	$1,483,000
31	----[1]	----[3]	----[3]	----[3]		$43,000	$368,000	$14,000		$300,000	$16,000	$725,000
32				$1,430,000	$161,000	$162,000	$84,000		$111,000		$19,000	$2,473,000
33	----[1]	$2,450,000				$133,000	$123,000		$37,000		$24,000	$2,743,000
34	$16,900,000			$945,000		$4,792,000	$267,000		$74,000		$17,000	$22,970,000
35	$3,230,000	$675,000		$945,000	$24,000	$933,000	$811,000				$14,000	$6,620,000
36		$1,575,000		$790,000	$100,000	$578,000	$734,000				$20,000	$3,800,000
37		$2,625,000		$2,363,000	$136,000	$35,000	$1,493,000			$368,000	$34,000	$6,660,000
38	----[1]	$1,050,000		$473,000			$210,000				$10,000	$2,790,000
Totals	$21,790,000	$8,375,000	----[3]	$6,946,000	$621,000	$7,910,000	$5,541,000	$190,000	$220,000	$670,000	$203,000	$52,824,000

Implementation

Top 5 Priorities

1. Maintenance of River Corridor
2. River Coordinator
3. US 287 - Lincoln Avenue Conveyance Improvements
4. Wilson Avenue – Elevation of Approaches
5. Mariano Exchange Ditch Water Quality Evaluation

Maintenance

River Coordinator

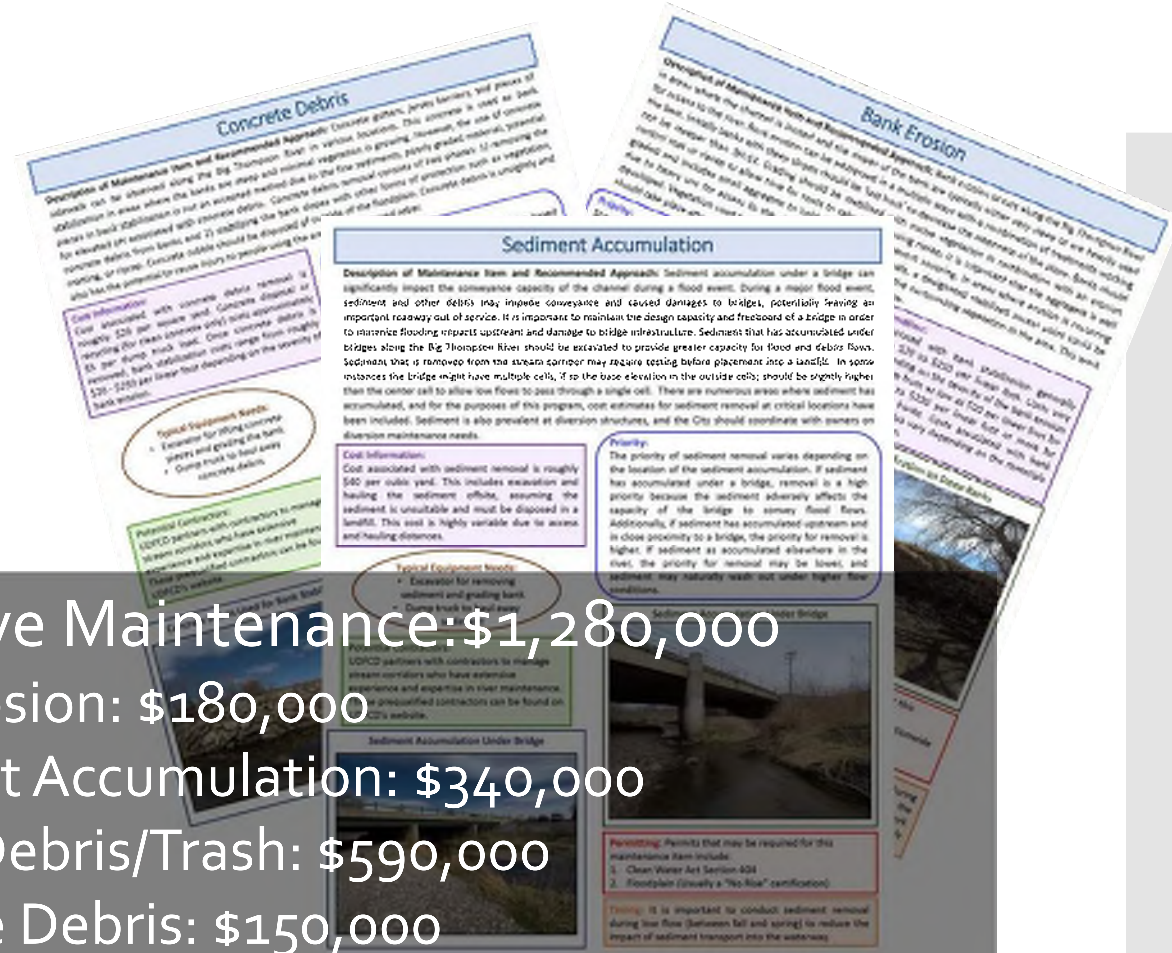
City of Loveland

- Bank Erosion
- Concrete Debris
- Sediment Accumulation
- Tree Removal
- Woody Debris
- Transient Settlements

Maintenance

Maintenance Types

Maintenance



Restorative Maintenance: $1,280,000

- Bank Erosion: $180,000
- Sediment Accumulation: $340,000
- Woody Debris/Trash: $590,000
- Concrete Debris: $150,000
- Hazardous Tree: $20,000

Questions

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WATERSHED FRAMEWORK: TO MANAGE RUNOFF AND CREATE LOW MAINTENANCE STREAM – STROH TRIBUTARY CASE STUDY

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September 26, 2018

2018 Colorado Association of Stormwater & Floodplain Managers, Snowmass Village, Colorado

Overview

- The Development Process - Seeking a Win-Win Approach
- Reducing Runoff and Laying Out the Land
- Costs of Development
- Modeling
- Lessons Learned and Technical Conclusions

Process of Development

- Stormwater Master Plan
- Annexation Agreements/ Pre-Development Agreements
- Subdivision/Site Layout
- Sketch Plan
- Preliminary Plan
- Final Plat
- Construction

Process of Development

Prior to development

- **Major Drainage Master Planning**
  - Based on assumptions of how watershed will develop
  - Future developed flows guide anticipated stabilization needs
  - Cannot be progressed beyond concept level due to unknowns

Stormwater Master Plan

Annexation Agreements/
Pre-Development Agreements

Subdivision/Site Layout

Sketch Plan

Preliminary Plan

Final Plat

Construction

Process of Development

Preparation for development

- **Annexation Agreements/Pre-Development Agreements**
  - Identifies development obligations to build infrastructure
  - Based on Master Plans and preliminary engineering reports
  - Timing of improvements
  - Constructed by developer or fee in lieu

- Stormwater Master Plan
- Annexation Agreements/ Pre-Development Agreements
- Subdivision/Site Layout
  - Sketch Plan
  - Preliminary Plan
  - Final Plat
- Construction

Process of Development

Active development stage

- **Subdivision/Site Planning**
  - Sketch 30%
    - Developers submit concept design documents
    - Obligations within annexation/pre-development agreements coordinated with early design documents

Process of Development

Active development stage

- **Subdivision/Site Planning**
  - Preliminary 70%
    - Developers submit preliminary design documents

Stormwater Master Plan

Annexation Agreements/ Pre-Development Agreements

Subdivision/Site Layout

Sketch Plan

Preliminary Plan

Final Plat

Construction

Process of Development

Active development stage

- **Subdivision/Site Planning**
  - Final Plat
    - Final design documents
    - Cost estimates are finalized for securities and/or fee in lieu obligations
    - Development agreements are finalized codifying obligations and triggers

Process of Development

Active development stage

- **Construction**
  - Inspection of public infrastructure during construction through final acceptance and transfer to municipality

Stormwater Master Plan

Annexation Agreements/ Pre-Development Agreements

Subdivision/Site Layout

Sketch Plan

Preliminary Plan

Final Plat

Construction

Challenges & Constraints

- Development obligations are determined well before understanding the true impact of development
- Stormwater master plans need to be updated and interpreted
- Development design can occur with limited communication; opportunities and critical information may be missed
- Submittal reviews may produce lengthy comments and design revisions

Stormwater Master Plan

Annexation Agreements/
Pre-Development Agreements

Subdivision/Site Layout

Sketch Plan

Preliminary Plan

Final Plat

Construction

Seeking a Win-Win

- Dynamic, concurrent stormwater planning
  - Stormwater design is incorporated throughout process
  - Efforts are collaborative
  - Feedback loop is continuous, reducing rework
  - Stormwater informs layout
  - Uses open spaces to reduce runoff and soften streams
  - Infrastructure costs are reduced
  - Long-term maintenance costs are reduced
  - Provides value to community

Seeking a Win-Win

- Dynamic, concurrent stormwater planning
  - Stormwater design is incorporated throughout process
  - Efforts are collaborative
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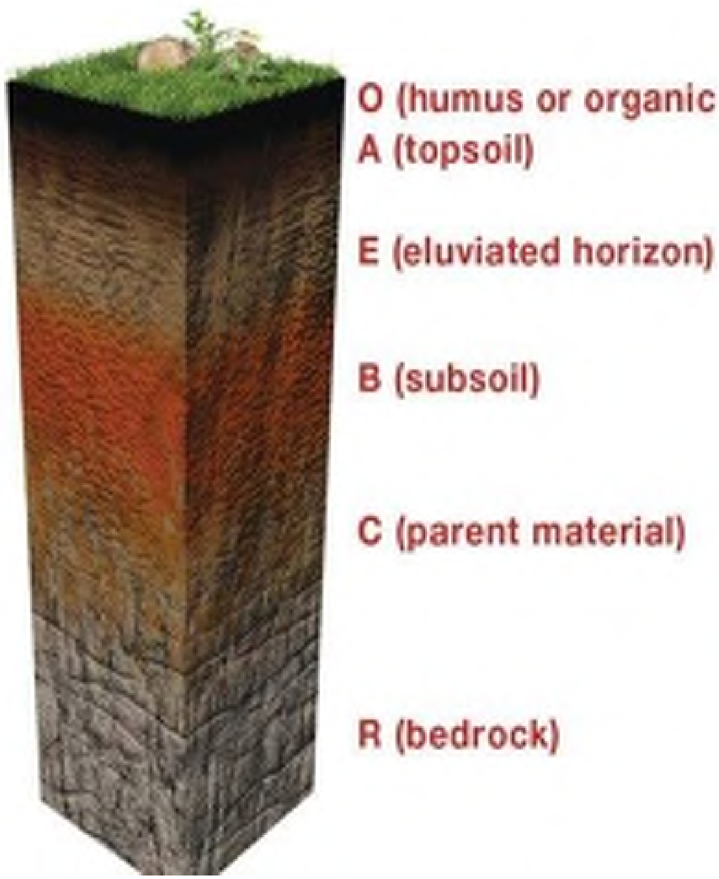
  - Stormwater informs layout
  - Uses open spaces to reduce runoff and soften streams
  - Infrastructure costs are reduced
  - Long-term maintenance costs are reduced
  - Provides value to community

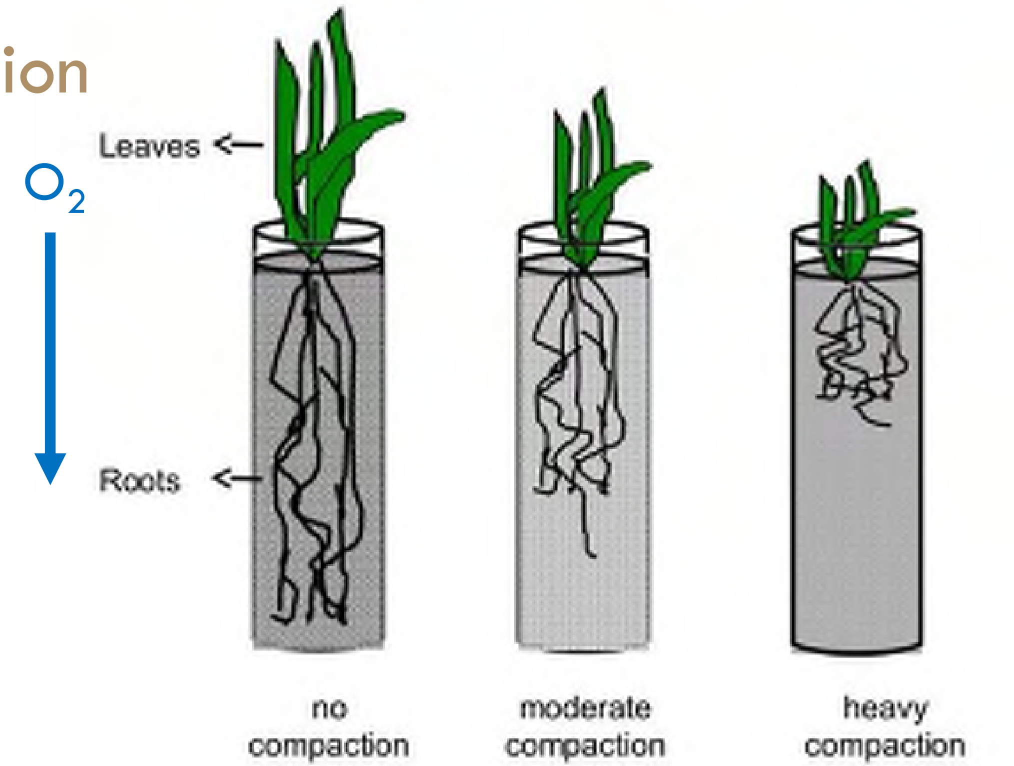
Reducing Runoff, Softening Streams

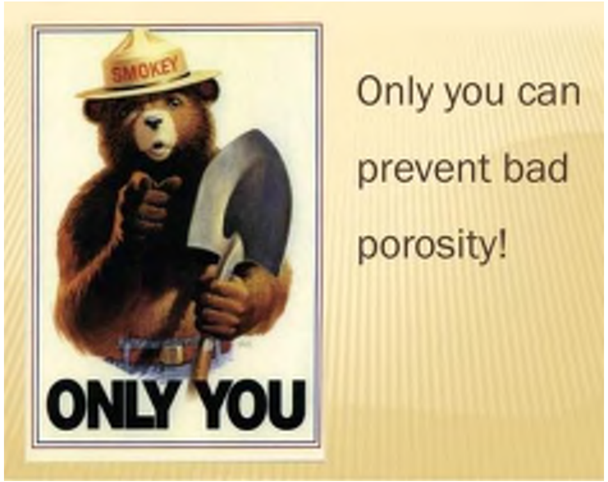
- Soil
  - Loamy texture
  - Organic
  - Low salts



Reducing Runoff, Softening Streams

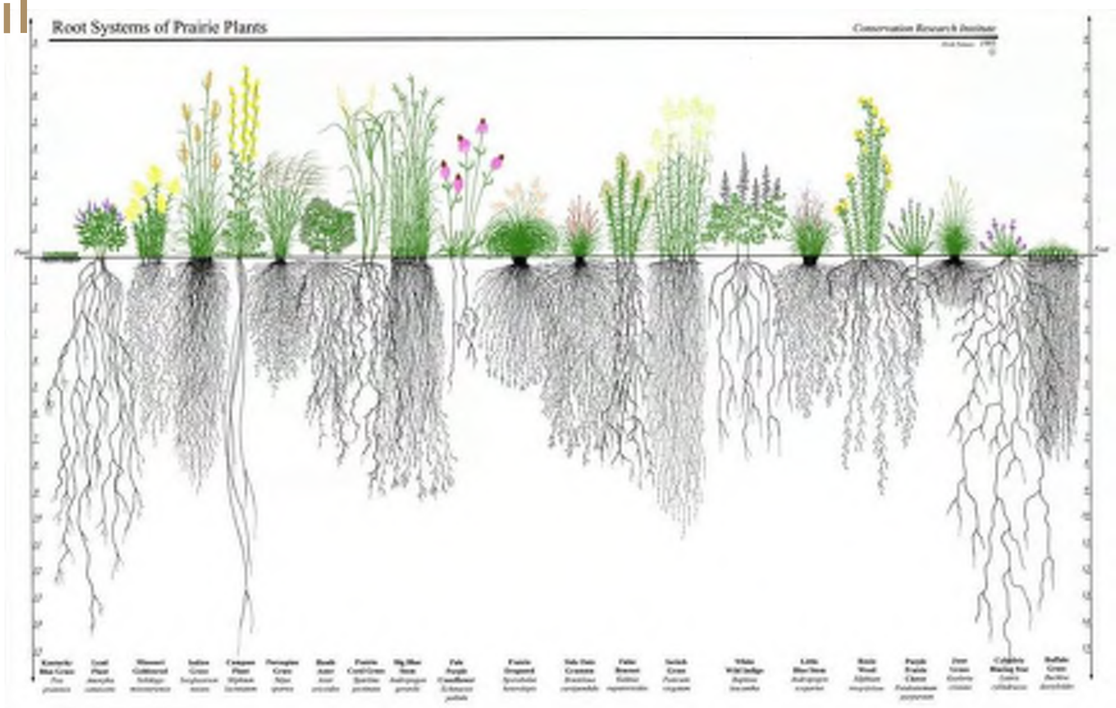
- Air
  - Avoid over-compaction
  - Rip, scarify, disc
  - Encourage root pathways





Reducing Runoff, Softening Streams

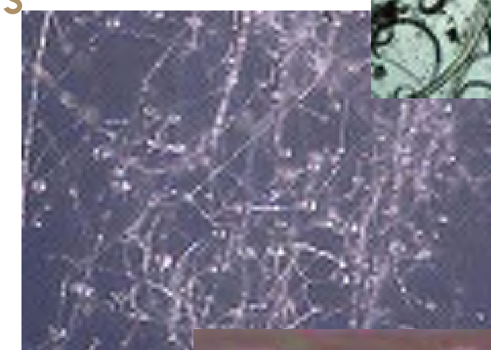
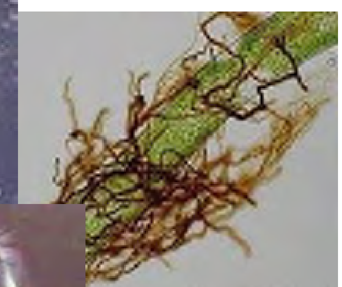
- Vegetation
  - Establish dense turf-forming grass for surface roughness
  - Consider native, deep rooted vegetation for pathways into soil



Reducing Runoff, Softening Streams

- Ecology
  - A cup of topsoil contain
    - 200 billion bacteria
    - 20 million bacteria species
    - 60 miles of fungi
    - 20 million protozoa
    - 100,000 nematodes
    - 50,000 arthropods
    - …and an earthworm




Reducing Runoff, Softening Streams

- Water
  - Distribute runoff over vegetated open spaces
  - Water sustains the life of the soil and vegetation
  - Runoff is reduced via
    - Interception
    - Infiltration
    - Evapotranspiration
    - Deep percolation

Reducing Runoff, Softening Streams

Soil,

Air,

Vegetation,

Ecology,

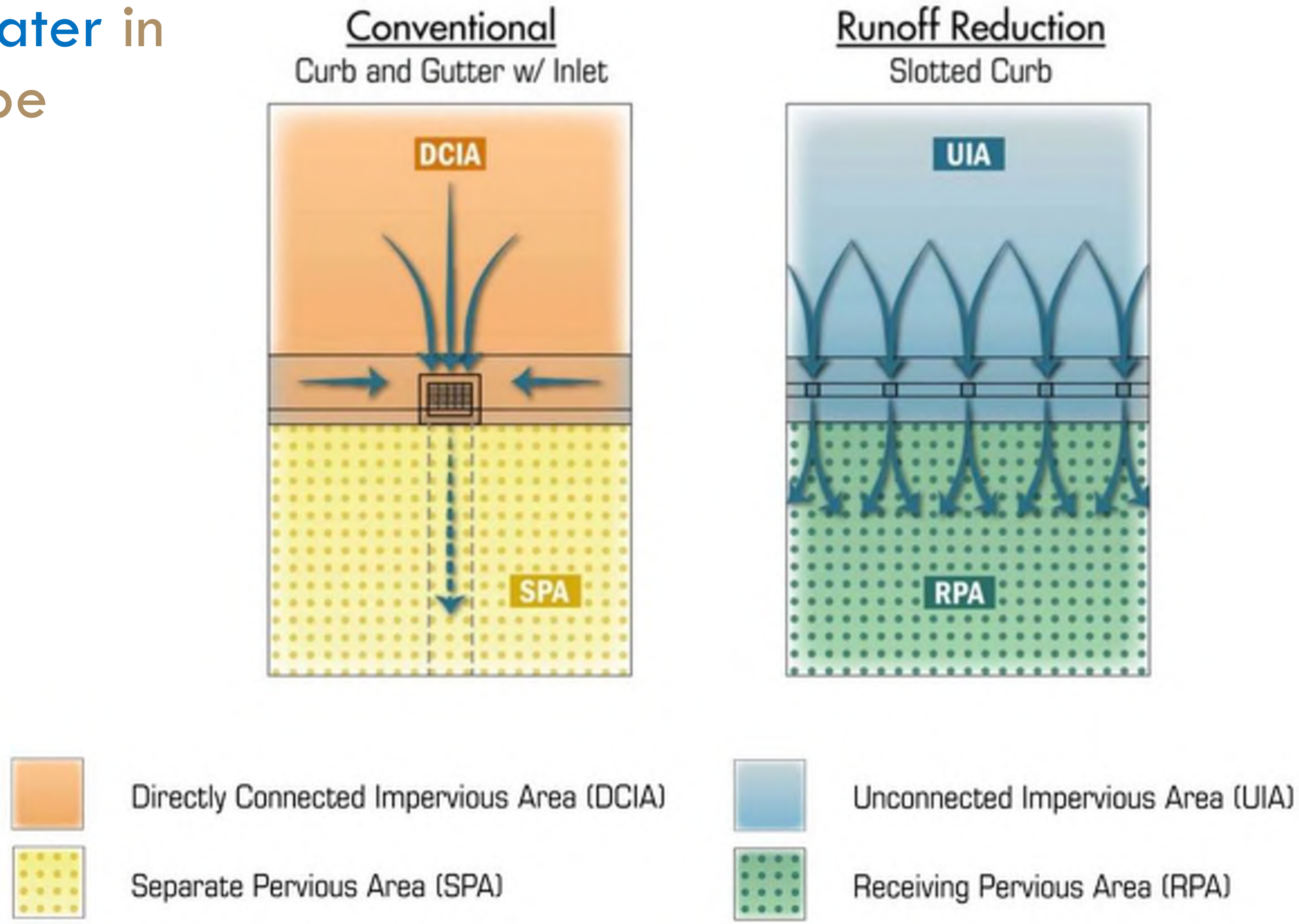
Water

Symbiosis between soil, air, vegetation, ecology, and water:

1. Saves water in the land to support life
2. Saves water courses
3. Saves water quality
4. Saves water supply

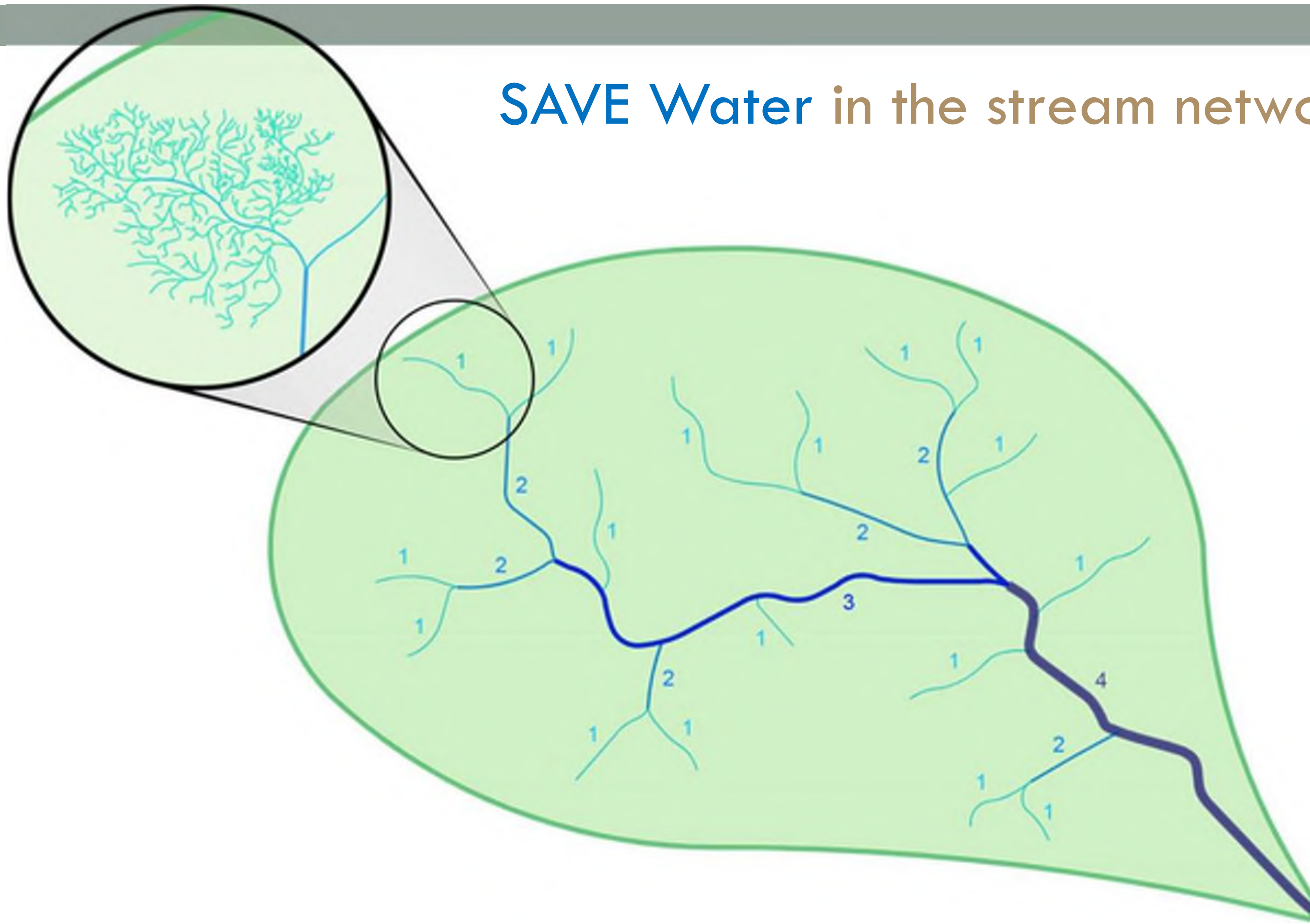
Reducing Runoff, Softening Streams

SAVE Water in landscape areas

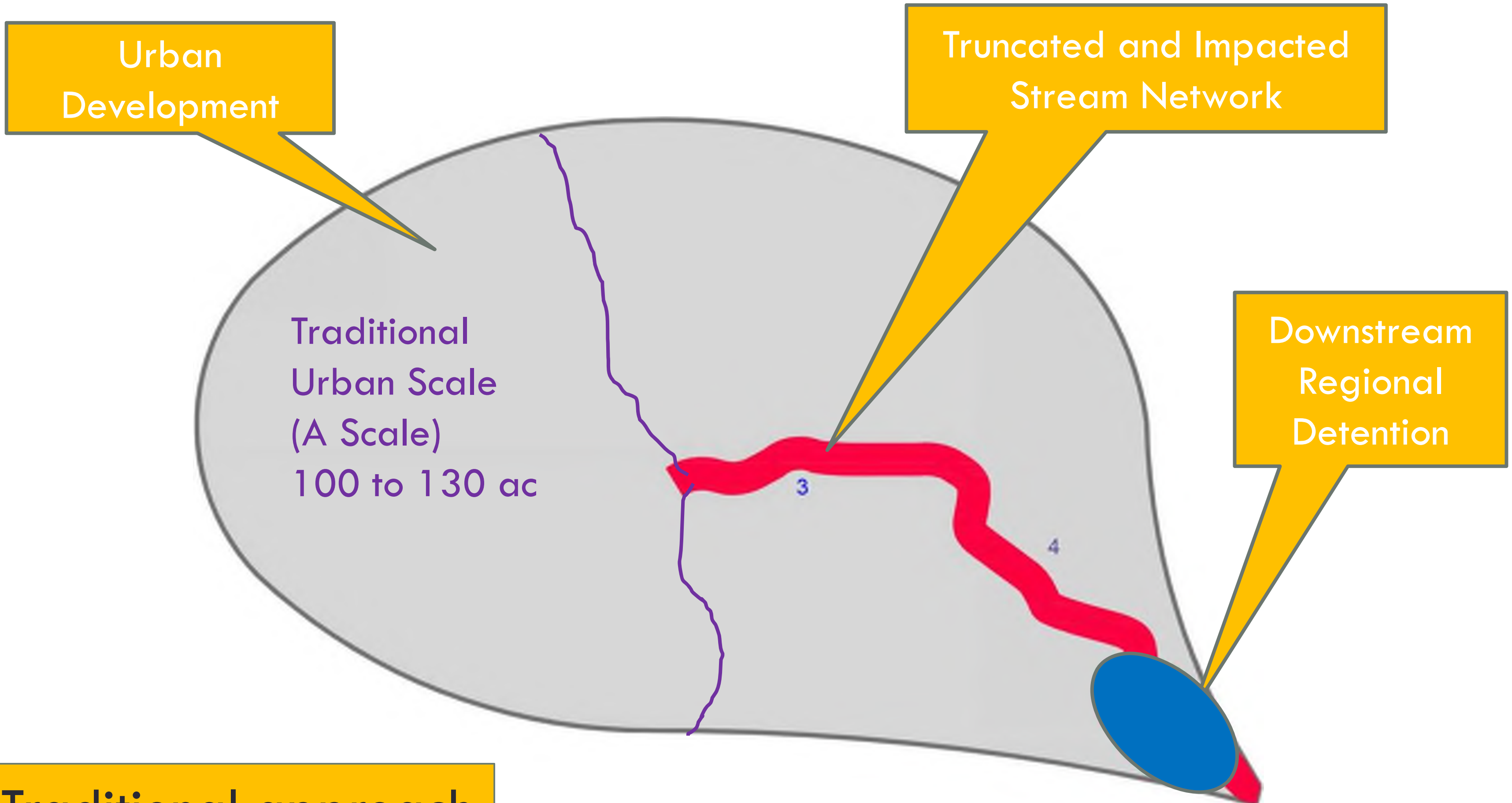


Laying Out the Land

SAVE Water in the stream network

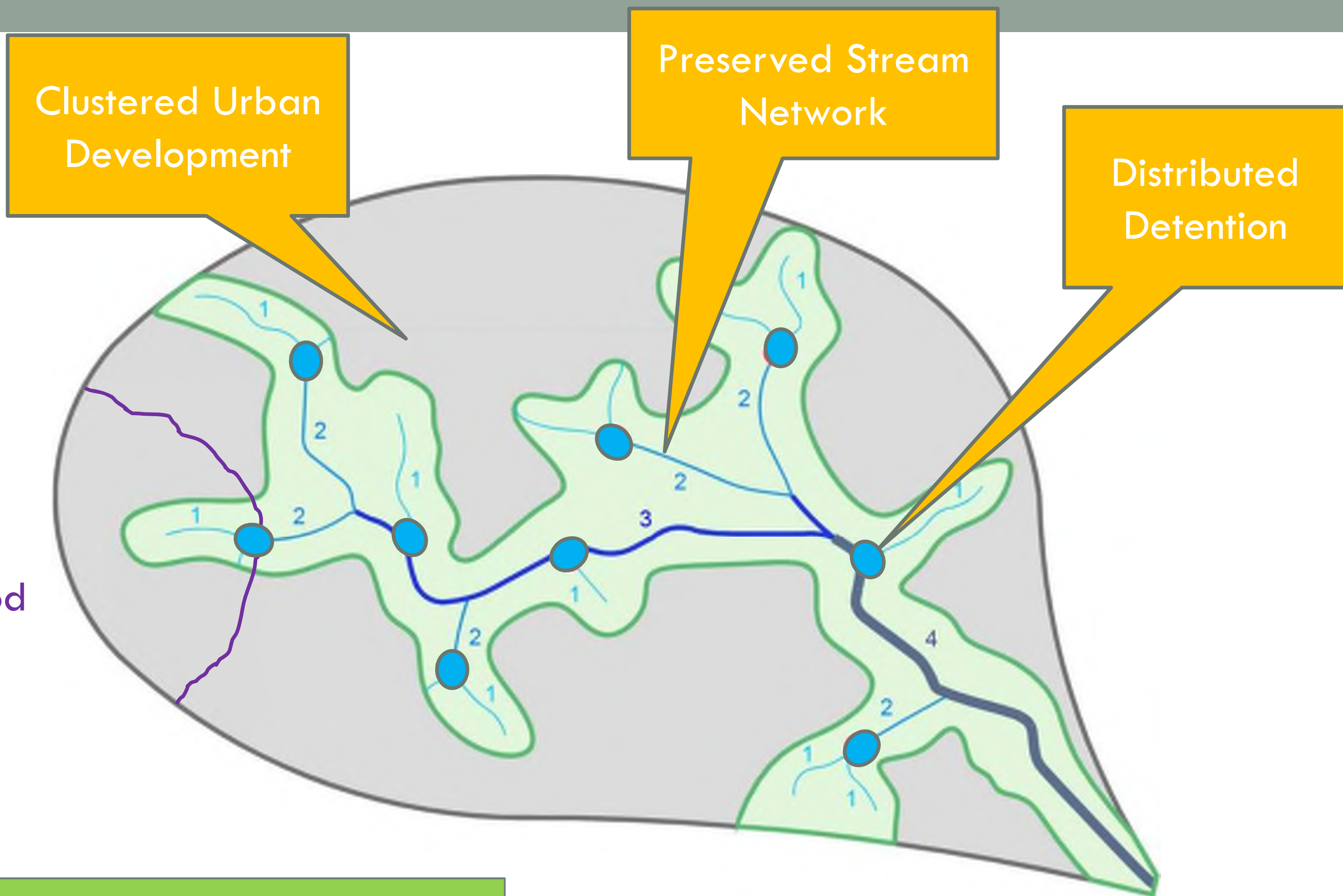


Laying Out the Land



Traditional approach

Laying Out the Land



Neighborhood Scale
(B Scale)
10 to 40 ac

Recommended approach

Laying Out the Land

Curb outfalls rather than inlets and laterals

Laying Out the Land

Grass swales rather than storm sewers

Laying Out the Land

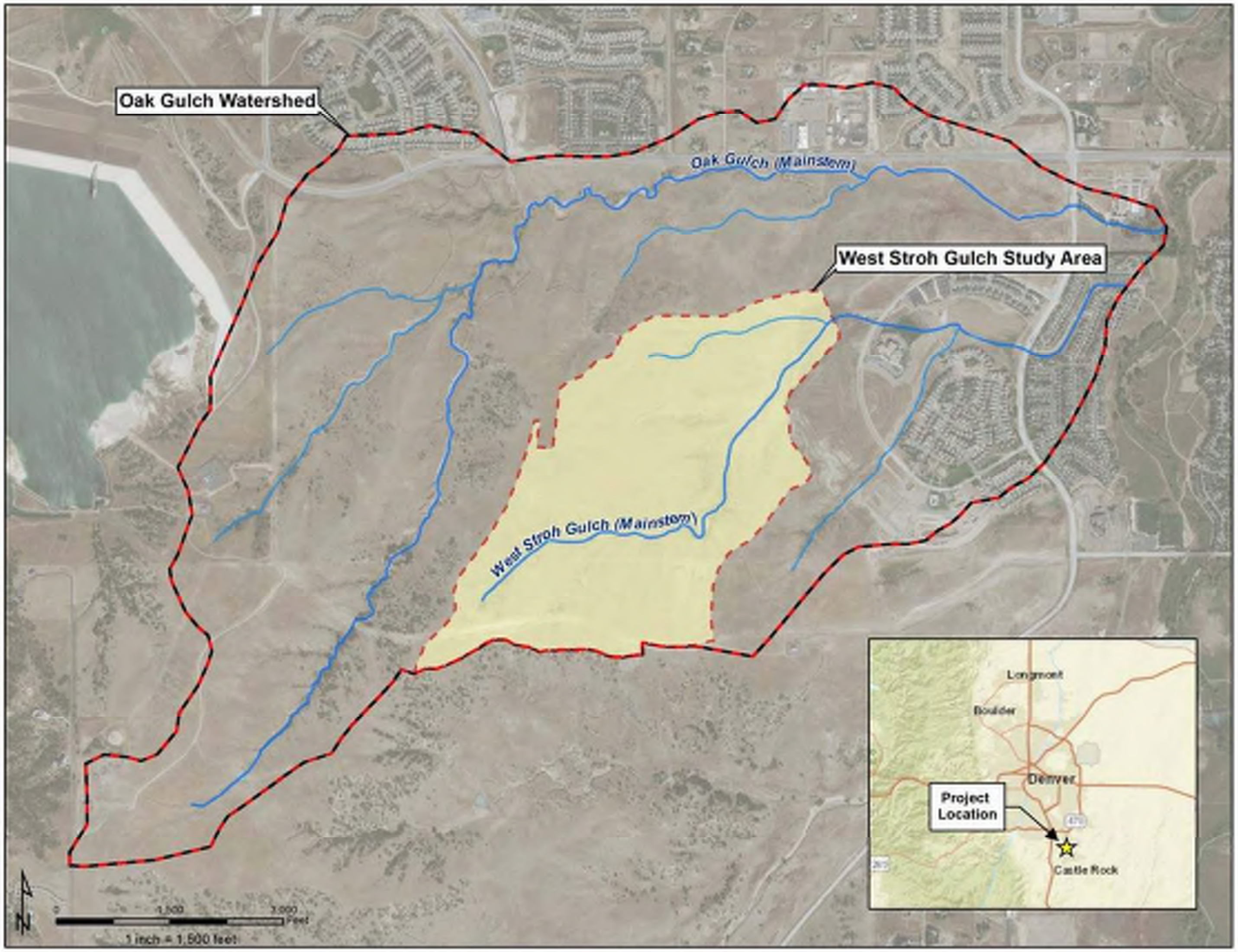
Distributed detention rather than downstream detention

Laying Out the Land

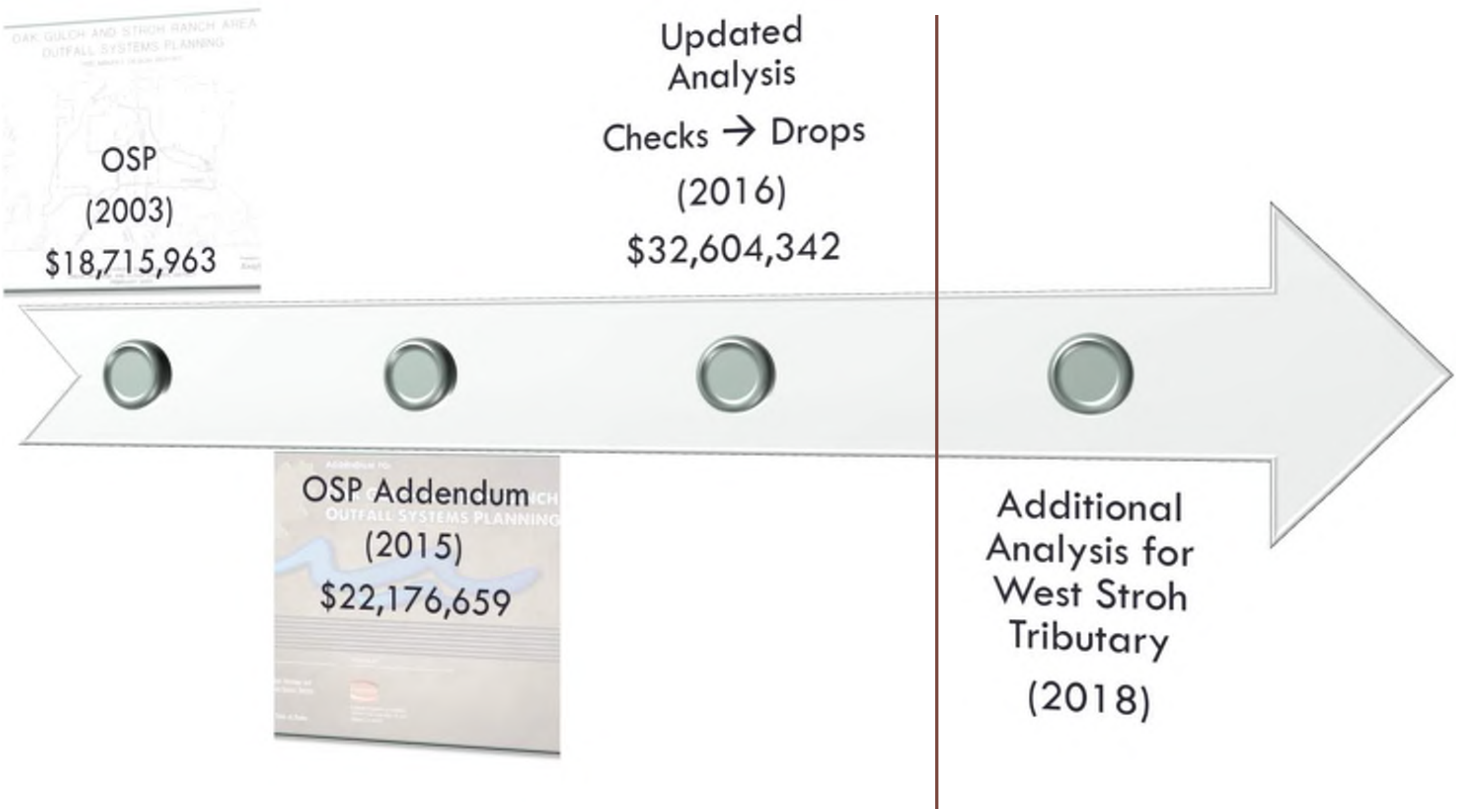
Soft streams rather than structural

Costs of Development

Oak Gulch Watershed



Oak Gulch Planning Timeline

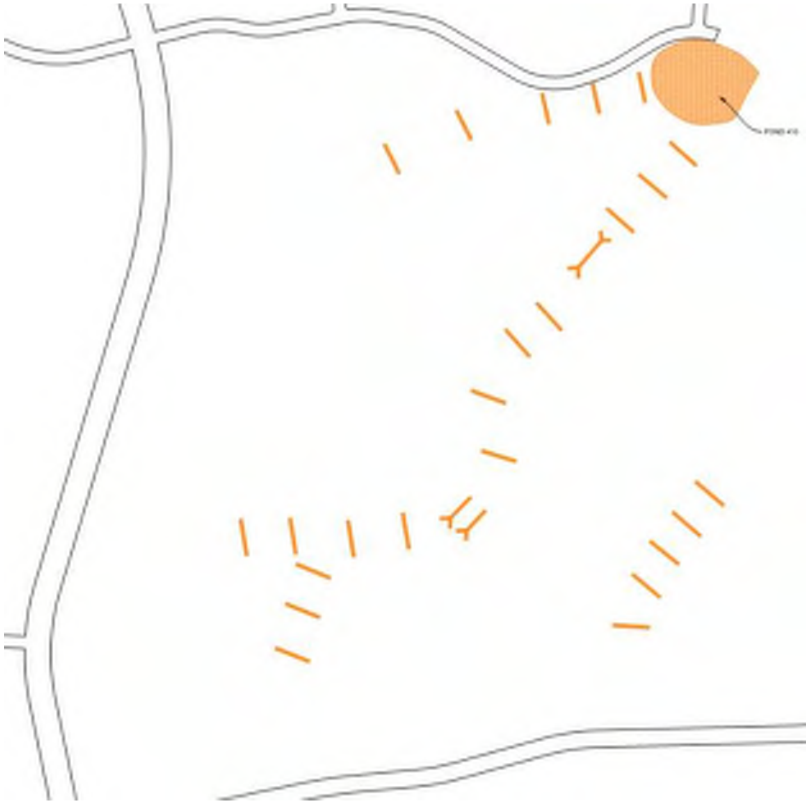


Lot Layout

Traditional

Low Maintenance Stream Distributed Detention

Stormwater Layout

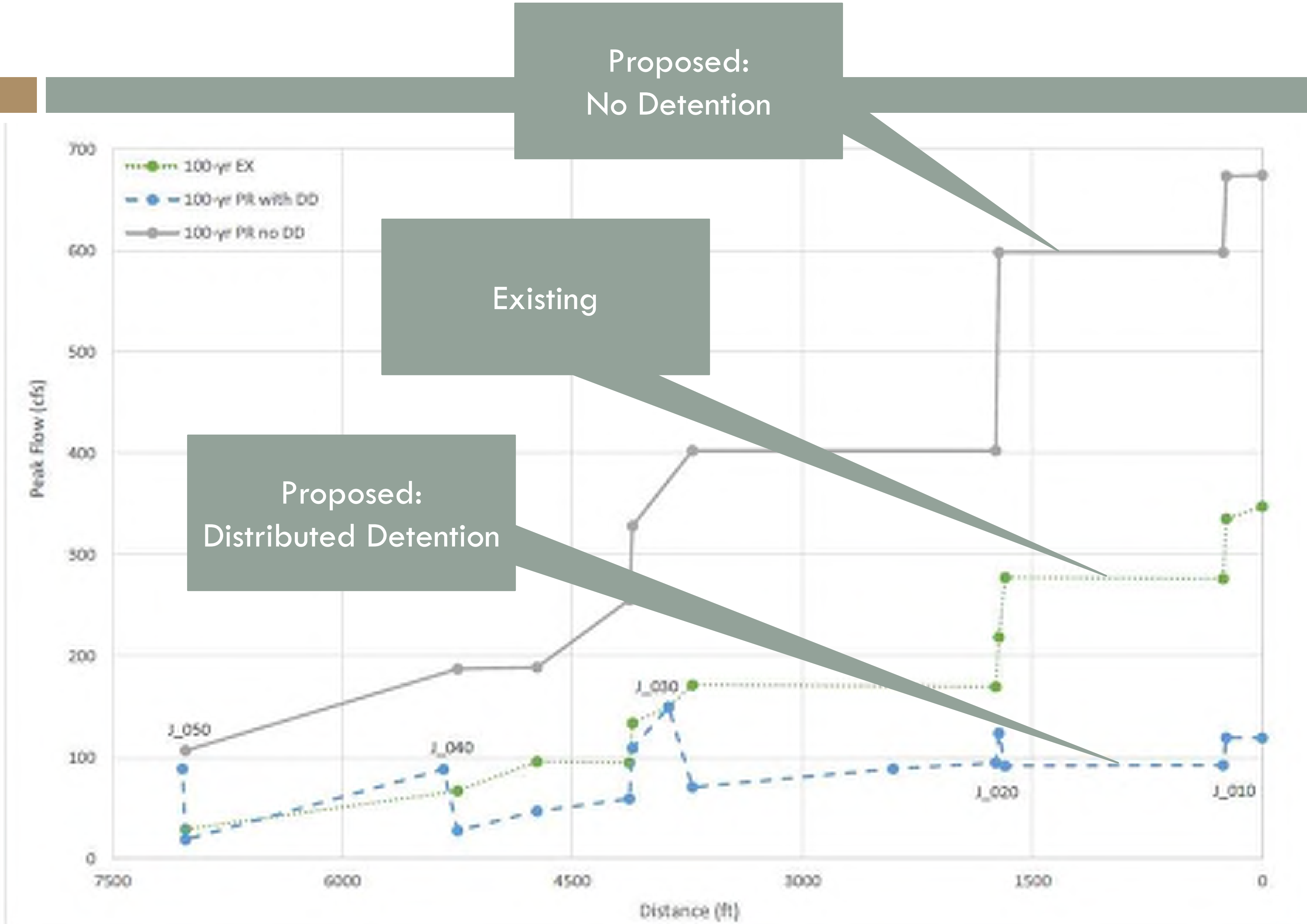
Traditional	Low Maintenance Stream Distributed Detention
	

Stormwater Layout

Traditional

Low Maintenance Stream (Distributed Detention)

West Stroh Hydraulic Profile – 100-yr Event

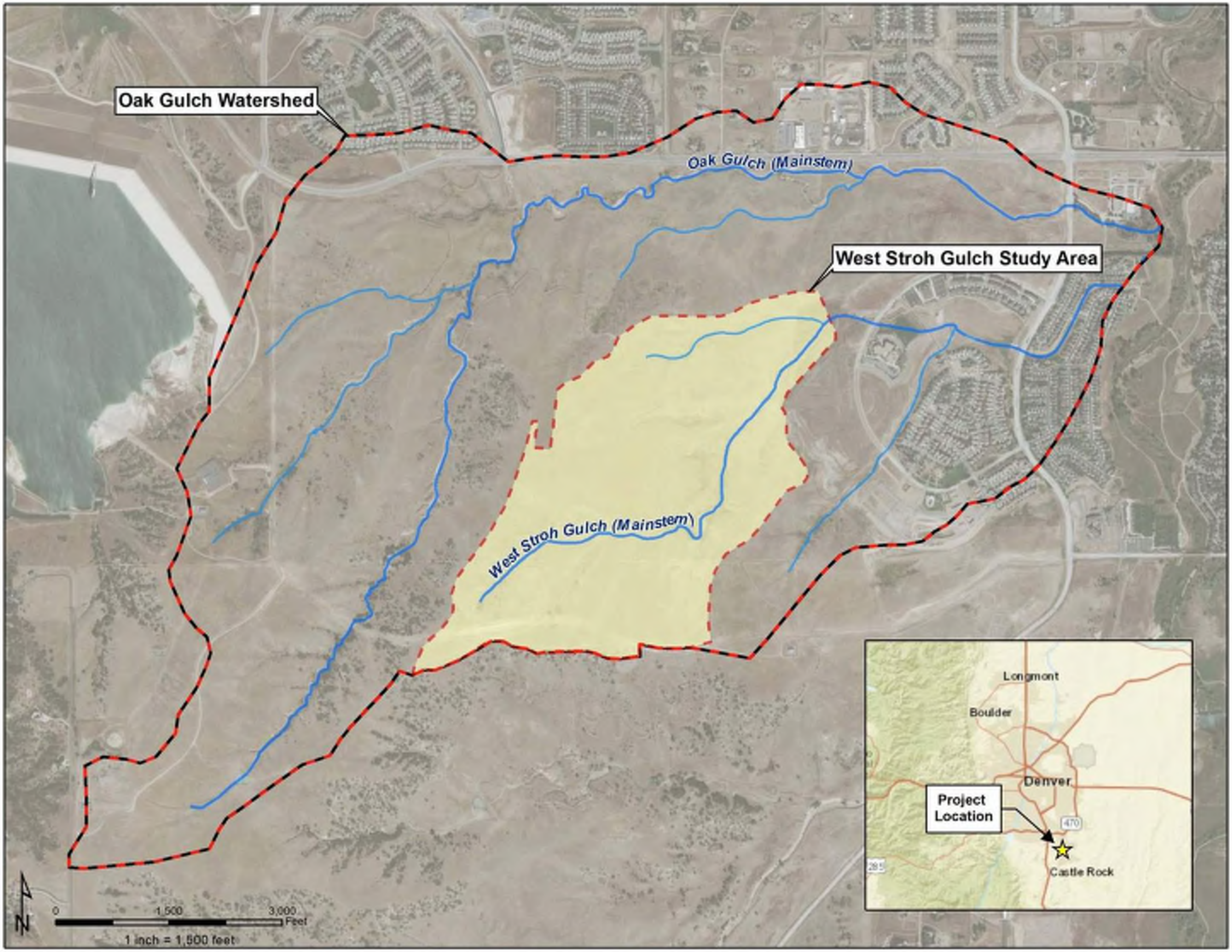


West Stroh Tributary Cost

Watershed Framework Stroh Ranch
Service Plan Cost Comparison

	Estimated Cost	
	Traditional Approach	Low Maintenance Stream Approach
Stream Restoration		
	$9,888,227	$5,778,192

Modeling

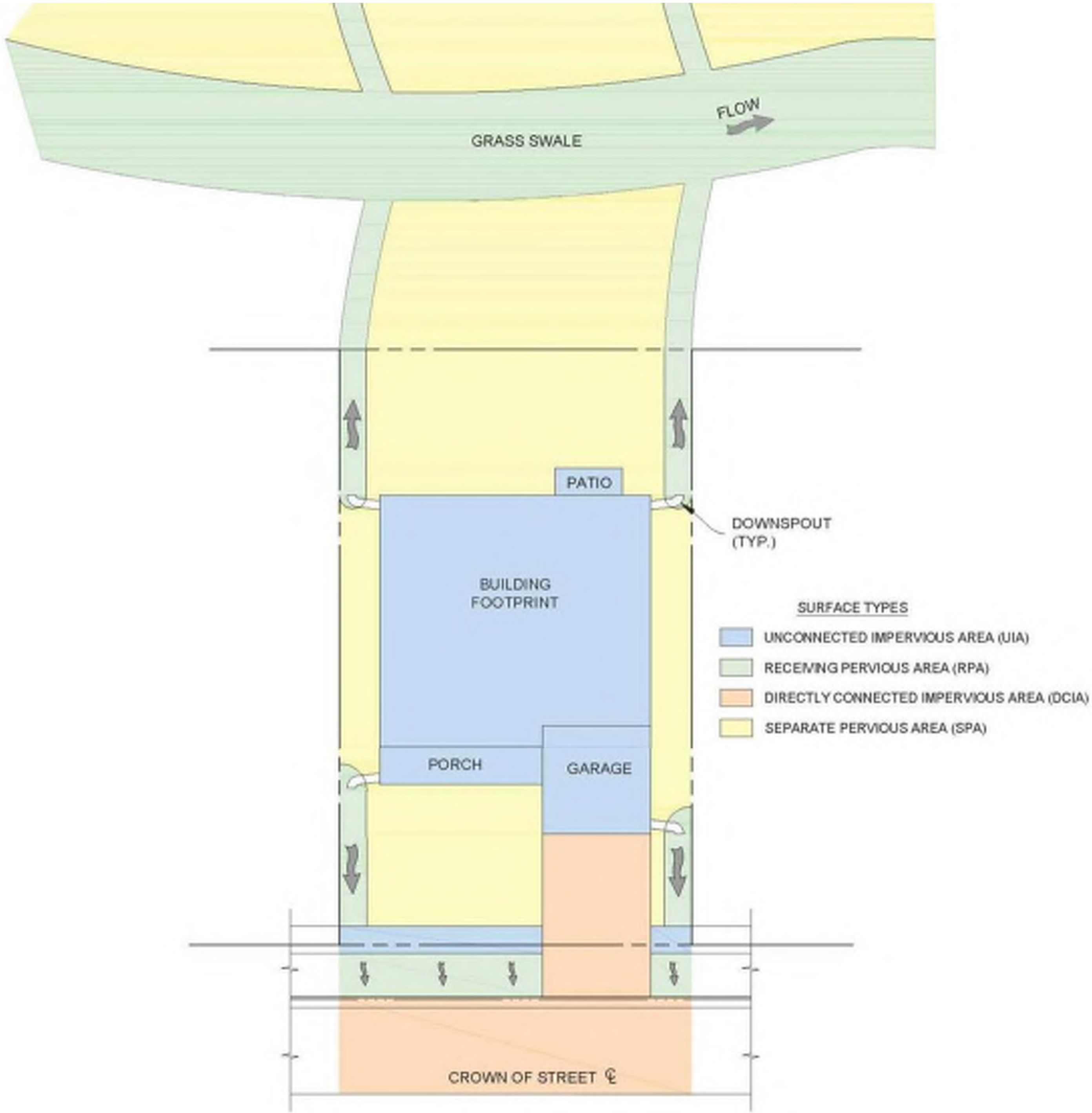


Oak Gulch Watershed
Oak Gulch (Mainstem)
West Stroh Gulch Study Area
West Stroh Gulch (Mainstem)
Longmont
Boulder
Denver
Project Location
470
285
Castle Rock
0
1,500
3,000
Feet
1 inch = 1,500 feet

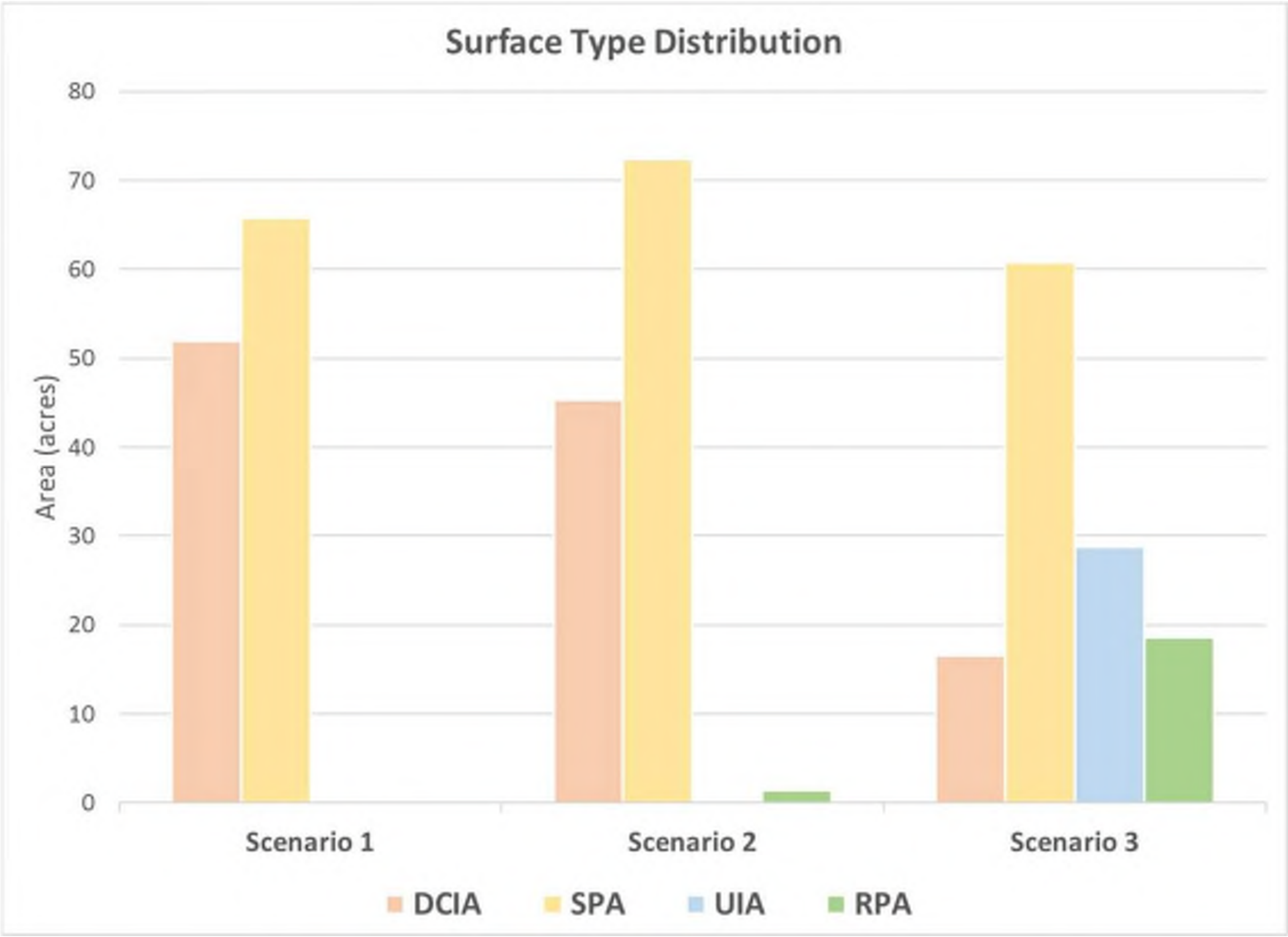
Scenario 1: A-Scale

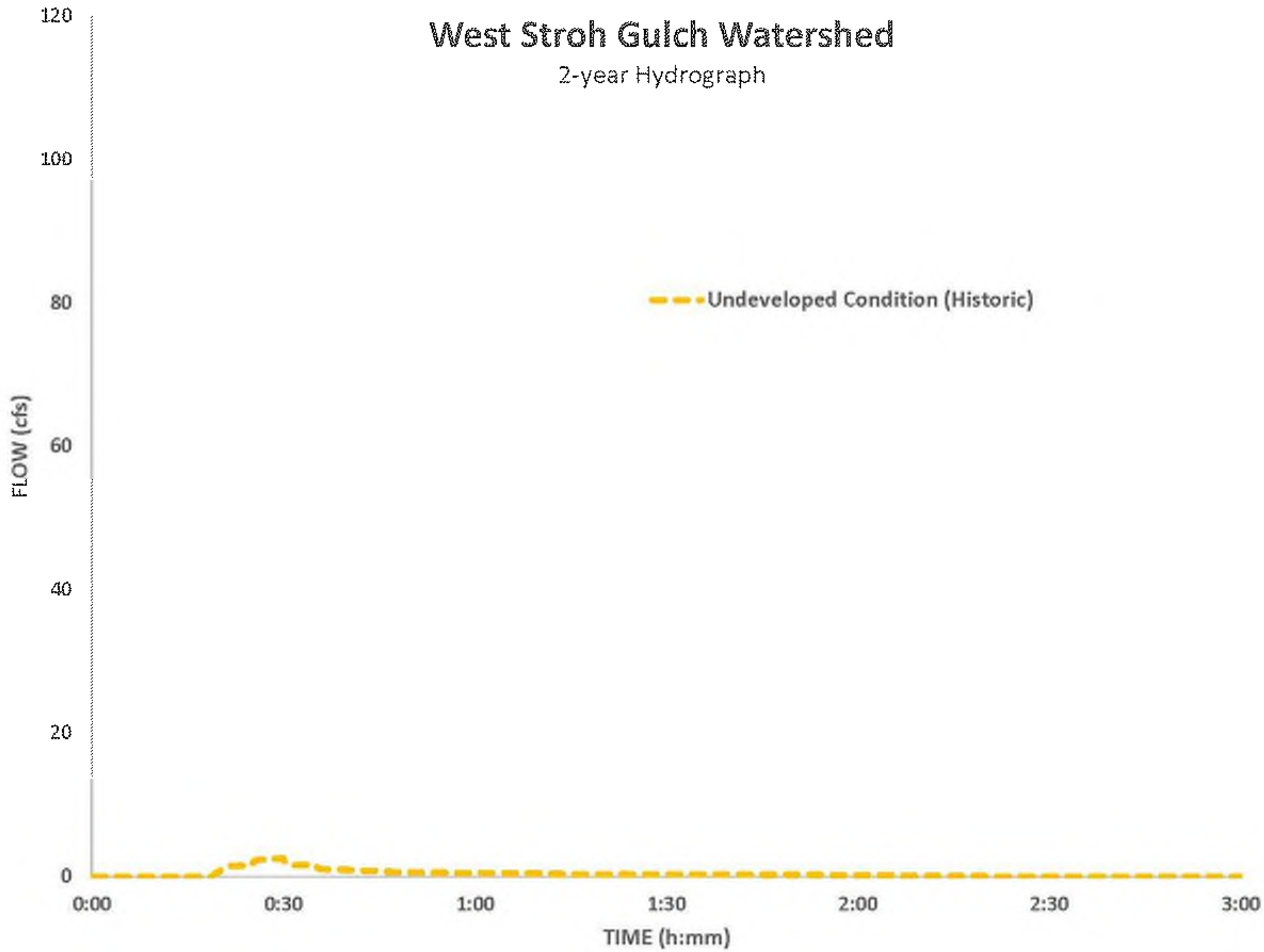
Scenario 2: B-Scale

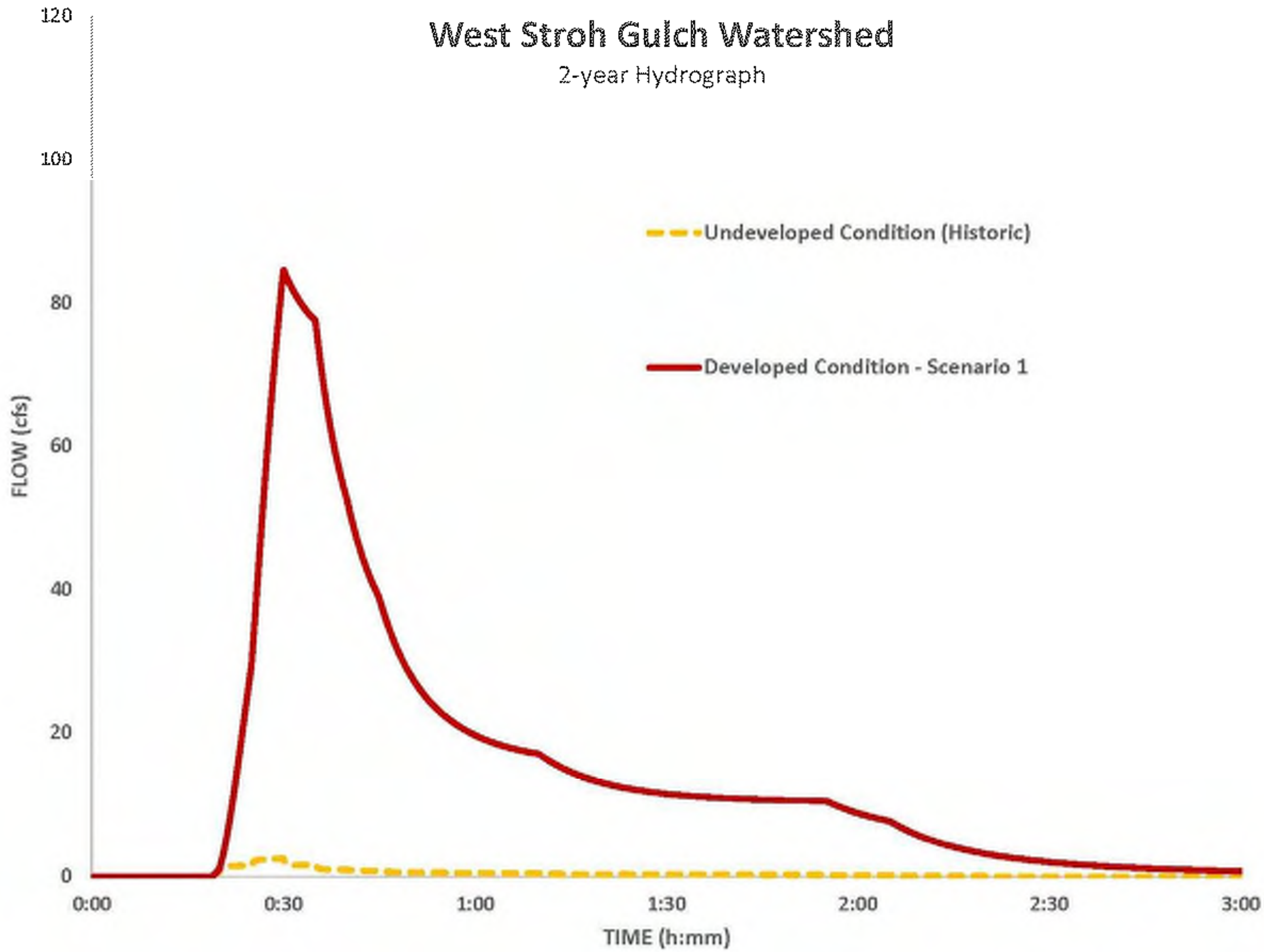
Scenario 3: C-Scale


GRASS SWALE
FLOW
PATIO
DOWNSPOUT
(TYP.)
BUILDING
FOOTPRINT
SURFACE TYPES
UNCONNECTED IMPERVIOUS AREA (UIA)
RECEIVING PERVIOUS AREA (RPA)
DIRECTLY CONNECTED IMPERVIOUS AREA (DCIA)
SEPARATE PERVIOUS AREA (SPA)
PORCH
GARAGE
CROWN OF STREET ℄

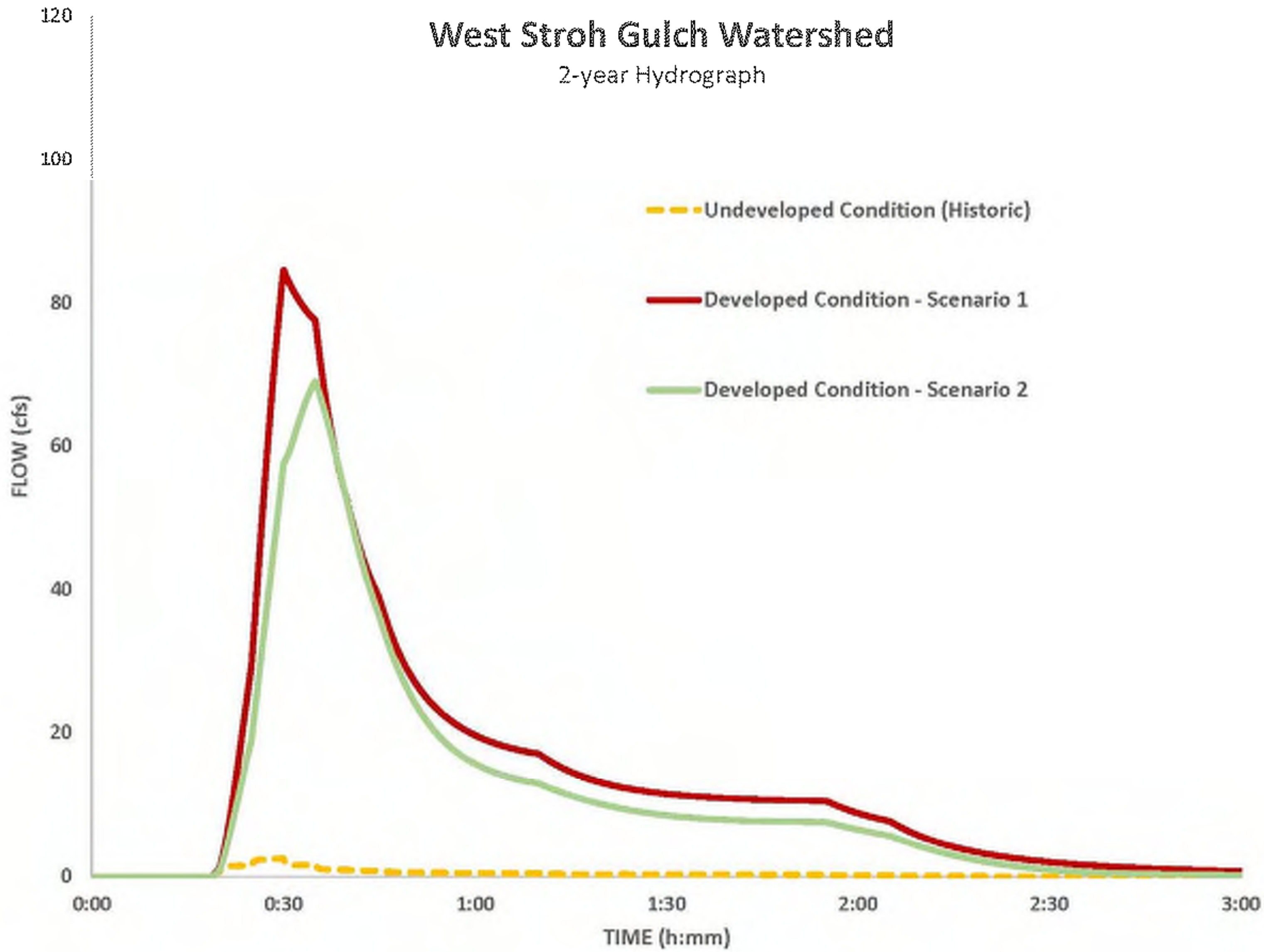
Cover-type Distribution

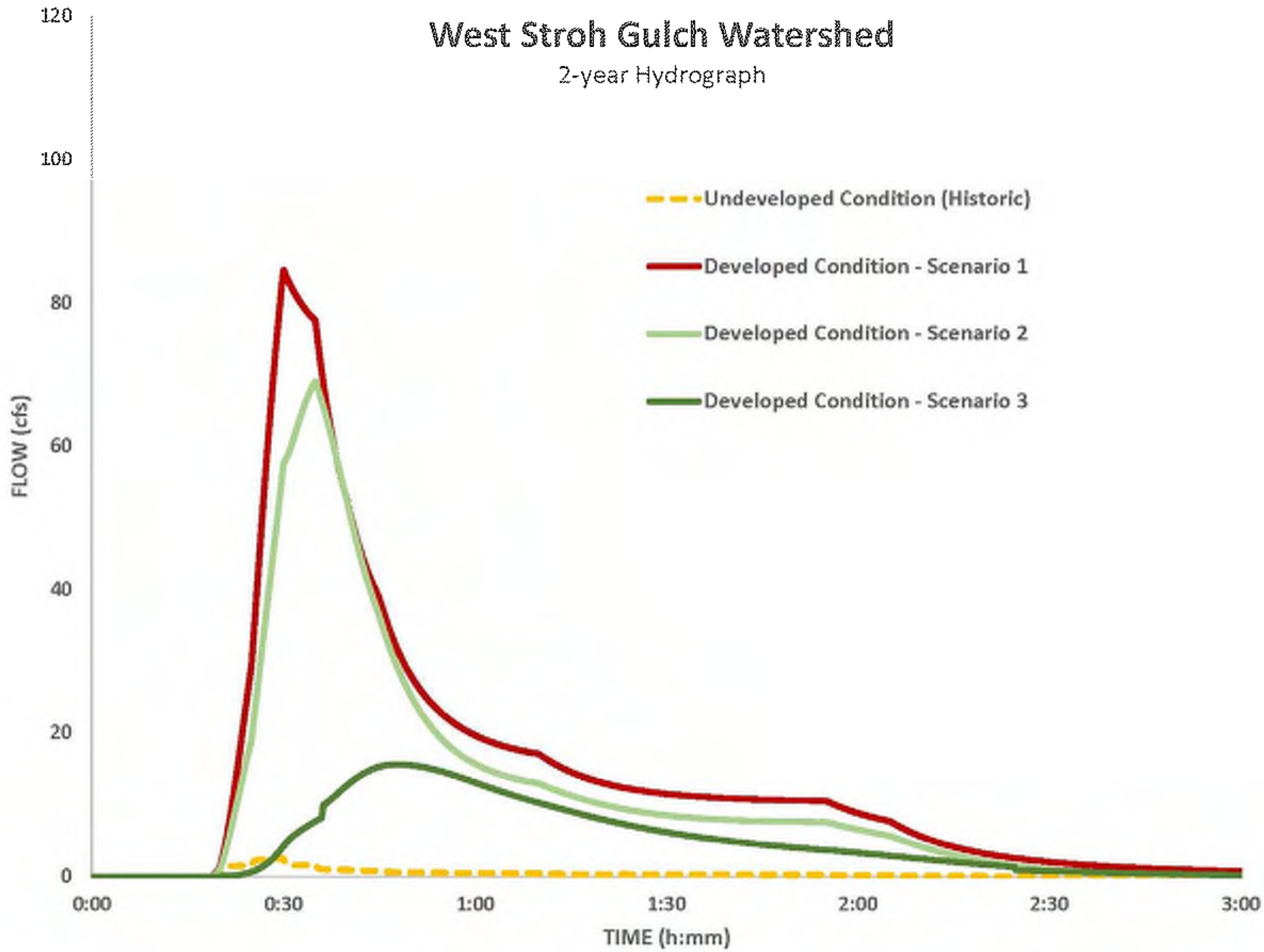



West Stroh Gulch Watershed
2-year Hydrograph
120
100
80
60
40
20
0
FLOW (cfs)
Undeveloped Condition (Historic)
0:00
0:30
1:00
1:30
2:00
2:30
3:00
TIME (h:mm)

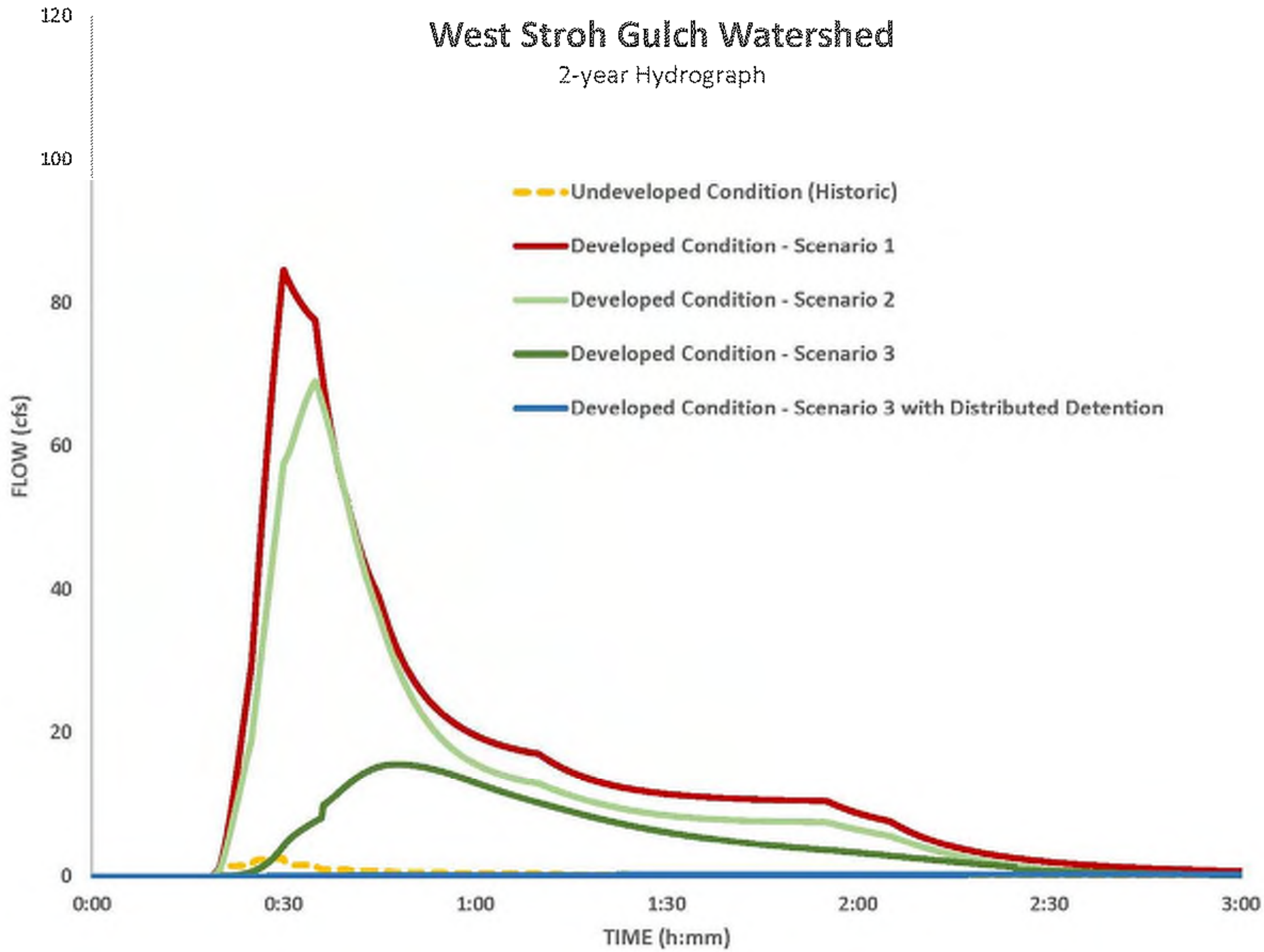


West Stroh Gulch Watershed
2-year Hydrograph
Undeveloped Condition (Historic)
Developed Condition - Scenario 1
FLOW (cfs)
120
100
80
60
40
20
0
0:00
0:30
1:00
1:30
2:00
2:30
3:00
TIME (h:mm)


West Stroh Gulch Watershed
2-year Hydrograph
Undeveloped Condition (Historic)
Developed Condition - Scenario 1
Developed Condition - Scenario 2
FLOW (cfs)
120
100
80
60
40
20
0
0:00
0:30
1:00
1:30
2:00
2:30
3:00
TIME (h:mm)



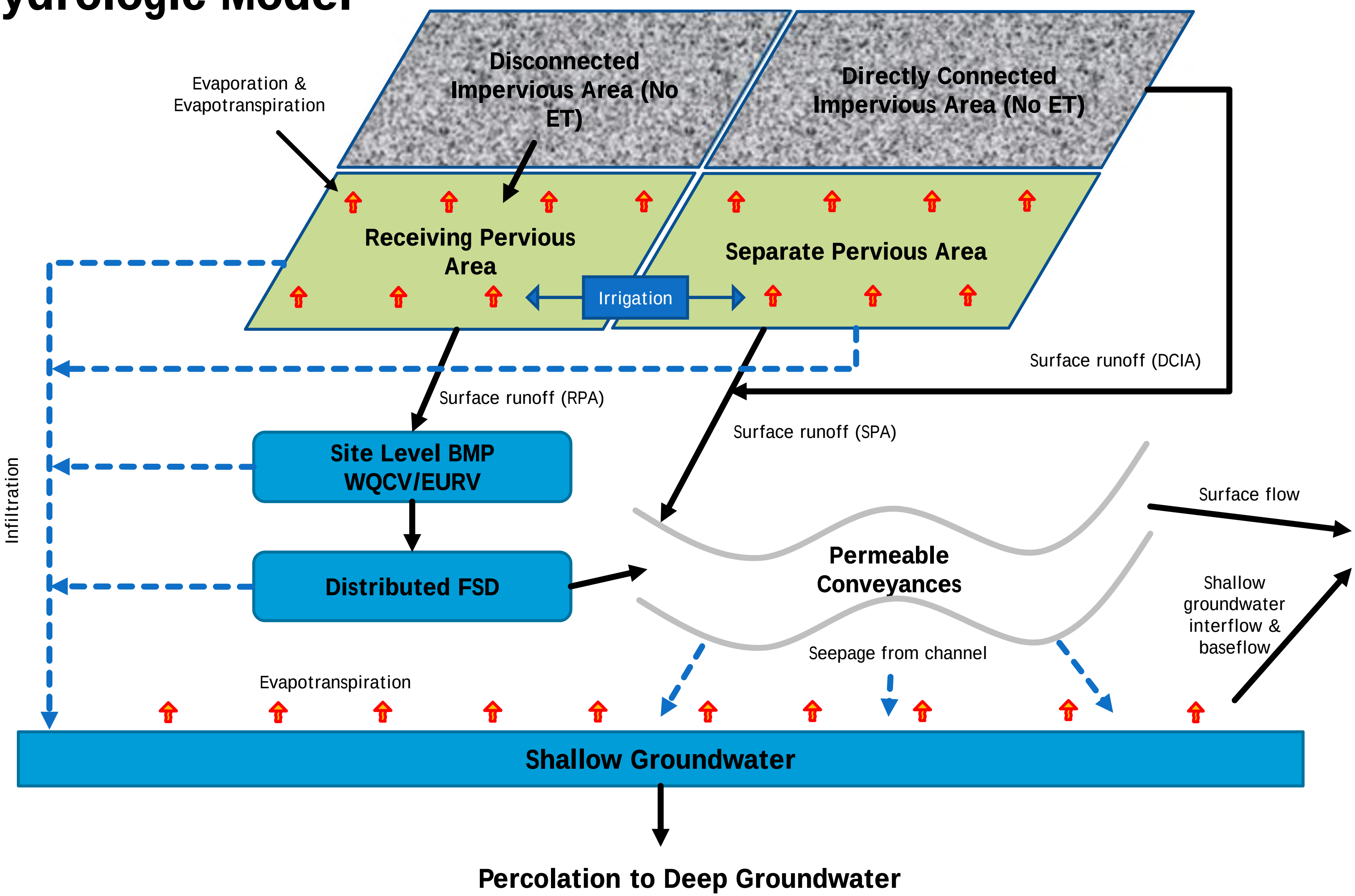
West Stroh Gulch Watershed
2-year Hydrograph
Undeveloped Condition (Historic)
Developed Condition - Scenario 1
Developed Condition - Scenario 2
Developed Condition - Scenario 3
FLOW (cfs)
120
100
80
60
40
20
0
0:00
0:30
1:00
1:30
2:00
2:30
3:00
TIME (h:mm)


West Stroh Gulch Watershed
2-year Hydrograph
Undeveloped Condition (Historic)
Developed Condition - Scenario 1
Developed Condition - Scenario 2
Developed Condition - Scenario 3
Developed Condition - Scenario 3 with Distributed Detention
FLOW (cfs)
120
100
80
60
40
20
0
0:00
0:30
1:00
1:30
2:00
2:30
3:00
TIME (h:mm)

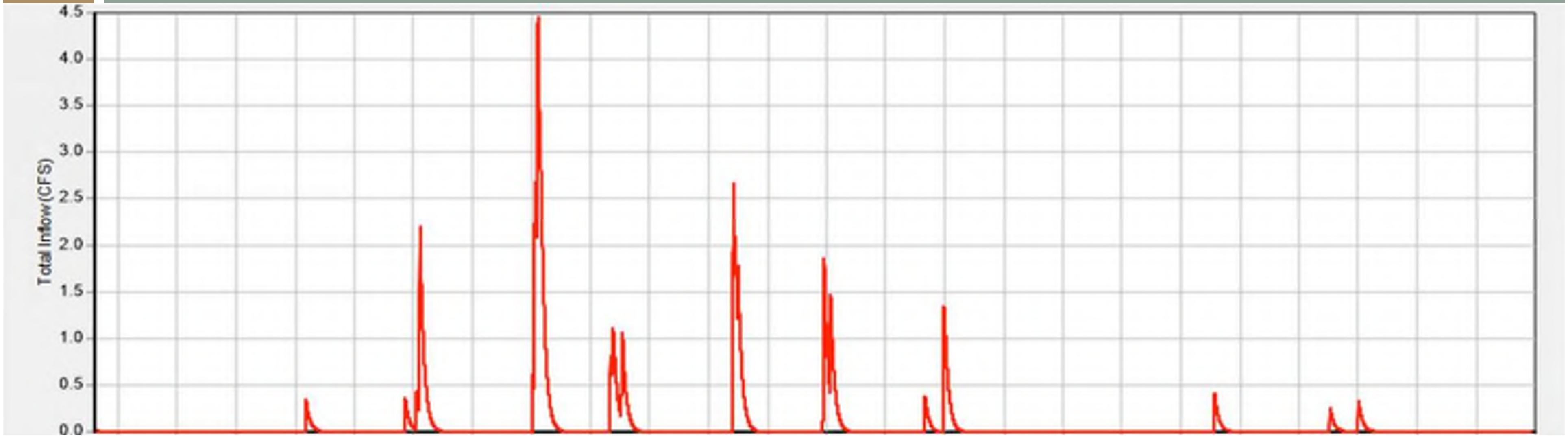
Continuous Simulation

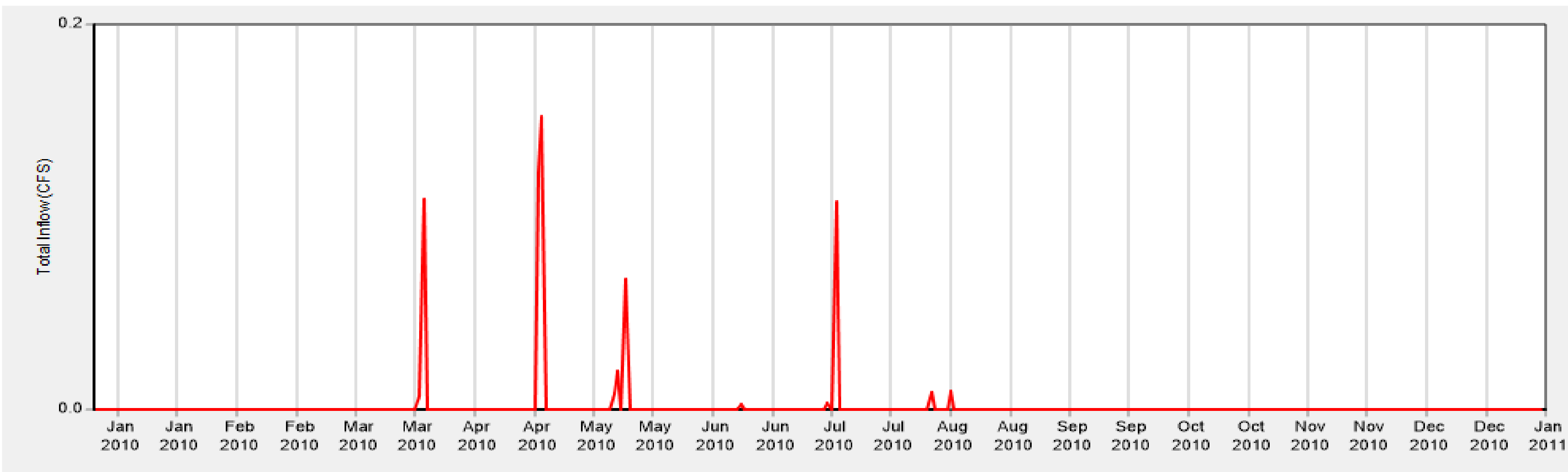
- Water budget analysis
- Rainfall time series
- Evapotranspiration & groundwater
- Accounting for irrigation
- Why do continuous simulation?

Conceptual Hydrologic Model



SWMM Hydrographs – Traditional versus Green





Technical Conclusions

- Traditional modeling practices for stormwater master planning are at a scale that fails to capture many watershed processes that affect infiltration.
- Often, the tributary network upstream of a regional detention facility is sacrificed for development.
- Using a distributed approach protects or recreates the functions of the lower order tributary network.
- Benefits reduce the peak rates and volumes of runoff for design events and help shift the water budget back toward a more natural condition.
- For the study area, the low-maintenance stream approach with distributed FSD results in infrastructure savings of approximately 20%, while providing a more aesthetic and environmentally sensitive approach to managing stormwater runoff.

Lessons Learned

- Early communication of expectations, minimize later costs and frustrations
- Understand which type of developer/landowner you are working with
- Development regulations vary between municipalities
- Incentives based on runoff reduction need to be clearly defined
- Requires close coordination with Planning Department, Developer, H&H modeler
- This pilot needs to culminate in documentation that is easy to understand and follow

Acknowledgements

- EWRI Task Committee - Implementing a Watershed Approach to Manage Stormwater as a Resource for Urban Stream Systems
- Project Collaborators – Harris Kocher Smith, Norris Design, Matrix Design Group, Redland Consulting, DTJ Design, and Stantec

Questions & Answers

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