Watershed and Road-Stream Crossing Responses to Extreme Rainfall: Lessons in Adaptation

Dale Higgins
Retired, Hydrologist
Chequamegon-Nicolet NF

Objectives

- Culvert Design
- Quantify Extreme
- Watershed Responses
- What Failed? Why?
- What Survived? Why?
- Lessons for Adaptation

Traditional Hydrology & Hydraulics (H&H)
Culvert Design

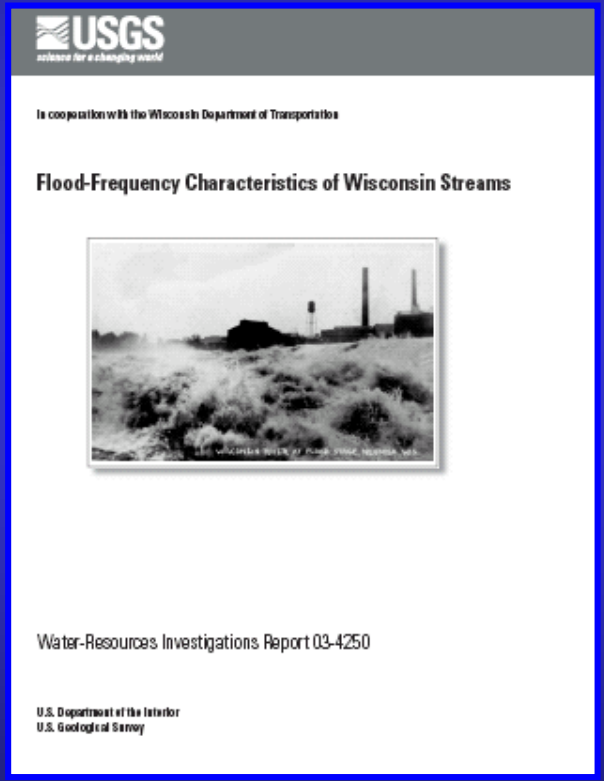
- Squeeze as much “clear” water through the pipe as possible
- Minimize installation cost
- Infrastructure problems: scour, debris, abrasion, reduced life span, failures
- Environmental problems: restricts AOP, upstream aggradation, downstream scour, erosion, sedimentation

Stream Simulation

Culvert Design

- Mimics the stream: bankfull width
- Minimizes environmental impacts
- Infrastructure benefits: reduced maintenance, flood resilience, increased life span
- Environmental benefits: AOP, restore channel morphology, natural transport of sediment and wood

Hydrology
Culvert Design

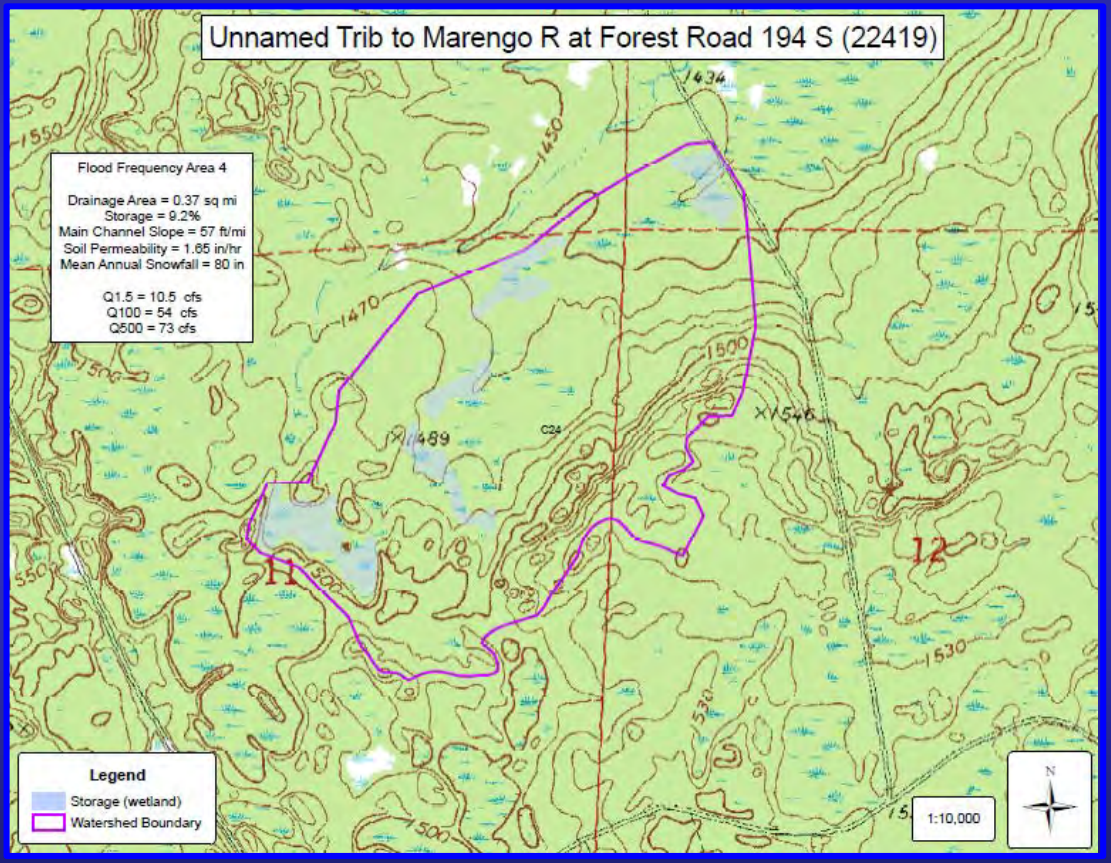

USGS
science for a changing world

In cooperation with the Wisconsin Department of Transportation

Flood-Frequency Characteristics of Wisconsin Streams

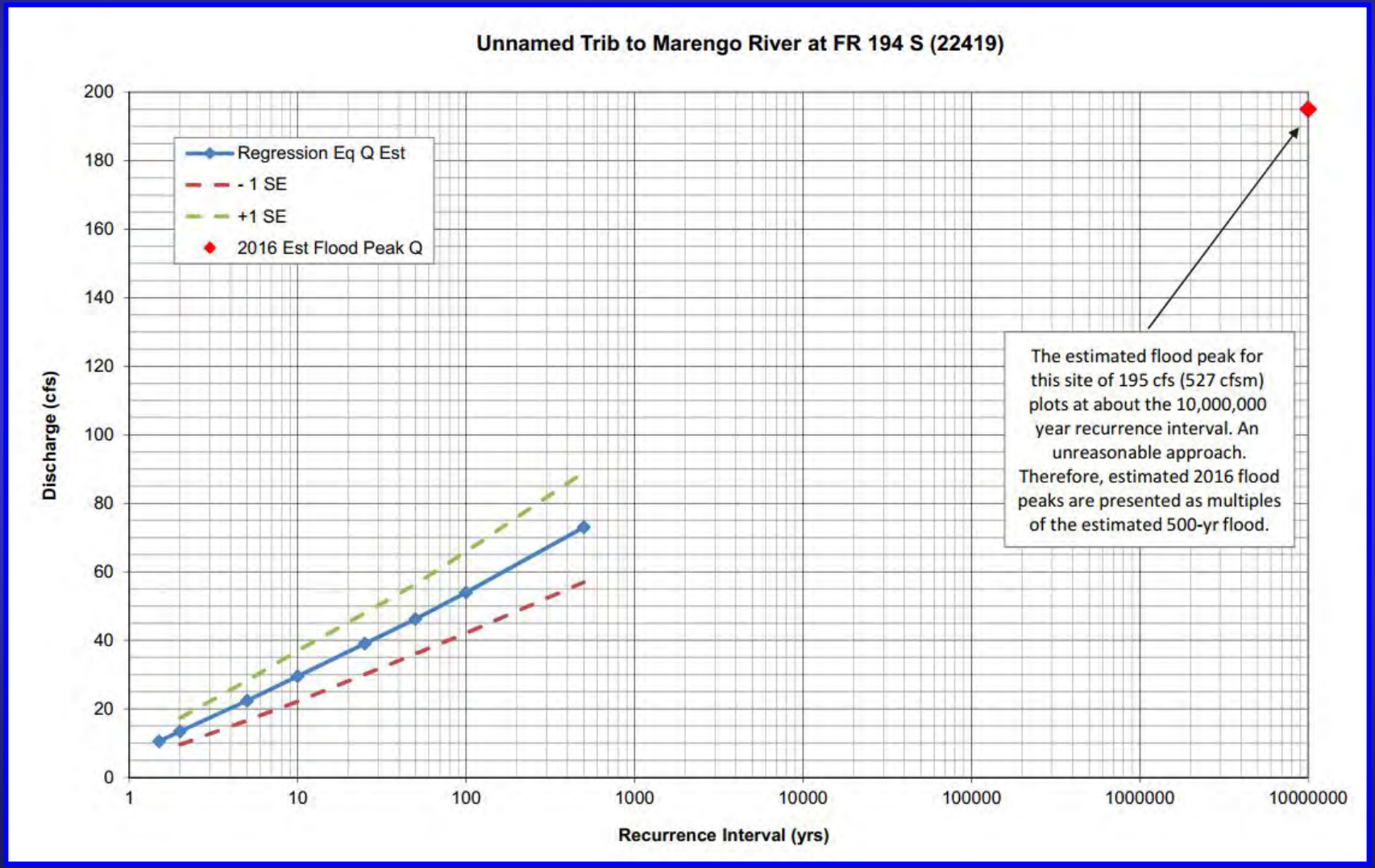
Water-Resources Investigations Report 03-4250

U.S. Department of the Interior
U.S. Geological Survey

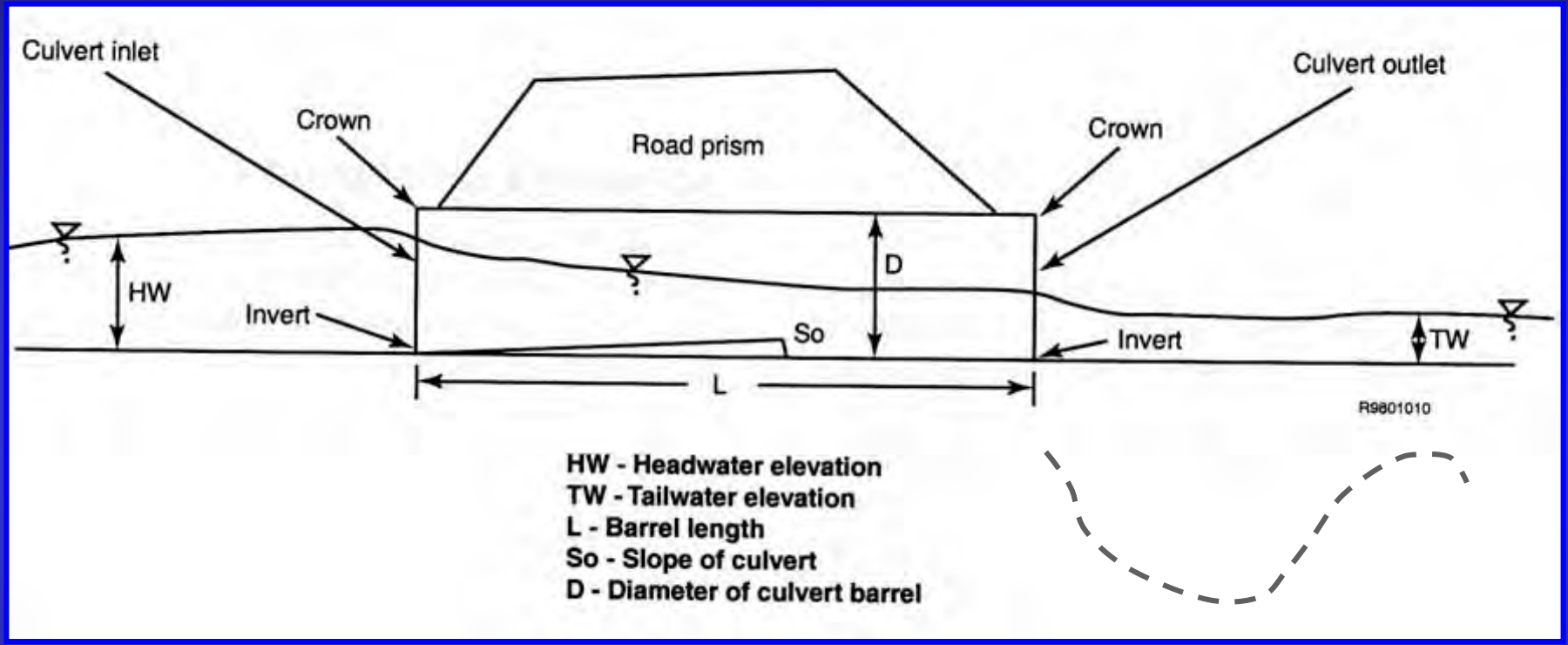


WI regression equations used to estimate flood flows and recurrence intervals for ungaged sites.

Hydrology
Culvert Design

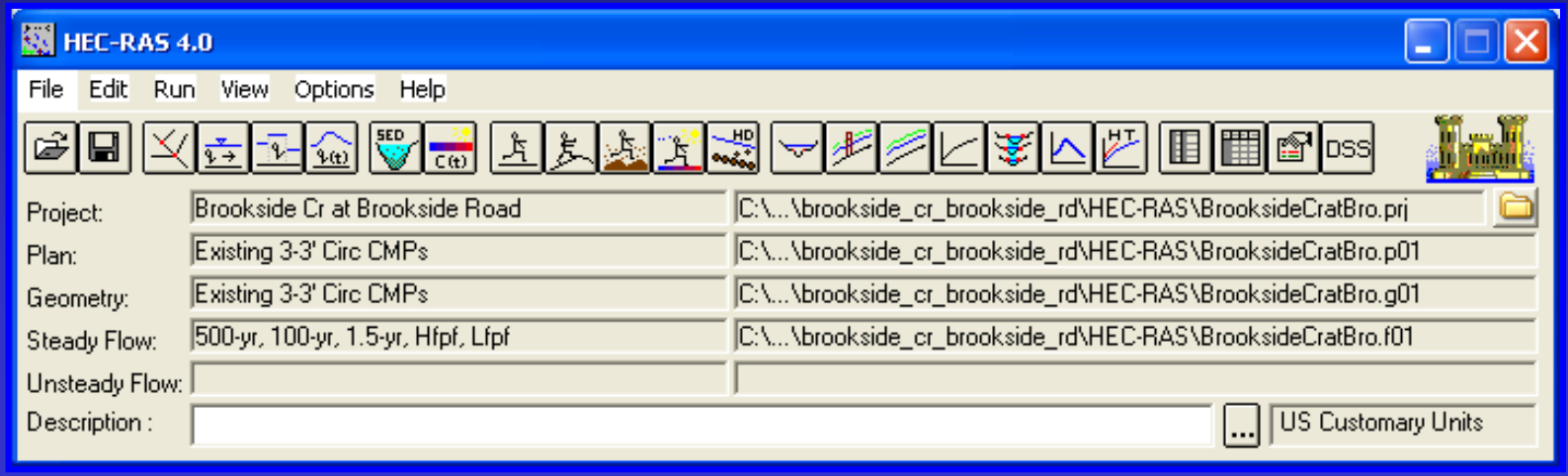


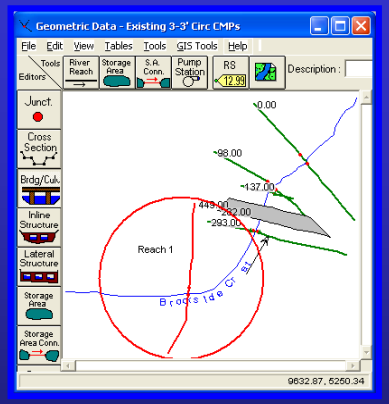
Hydraulics (H&H)
Culvert Design

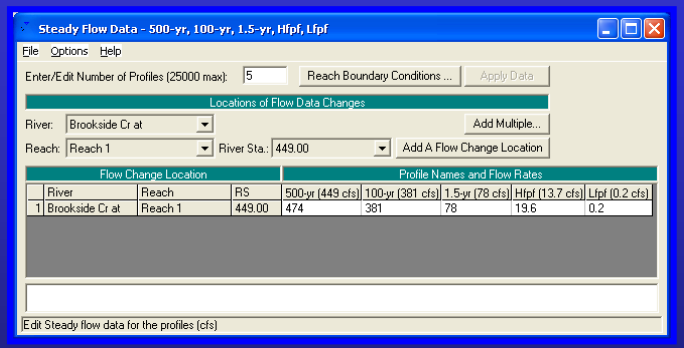


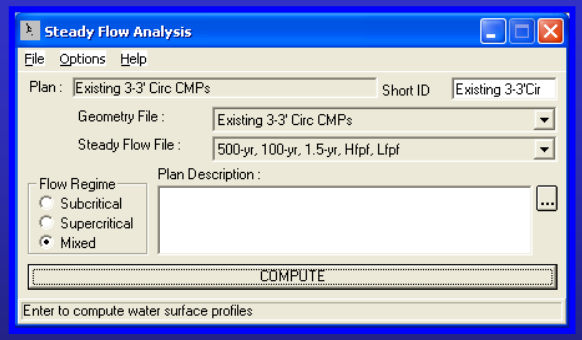
Stream simulation improves flood resiliency: bankfull width provides greater waterway area, HW and TW rise at a more natural level, HW/D<0.8 at Q_{100} provides freeboard and prevents pressurize flow, both provide debris passage

Hydraulics
Culvert Design





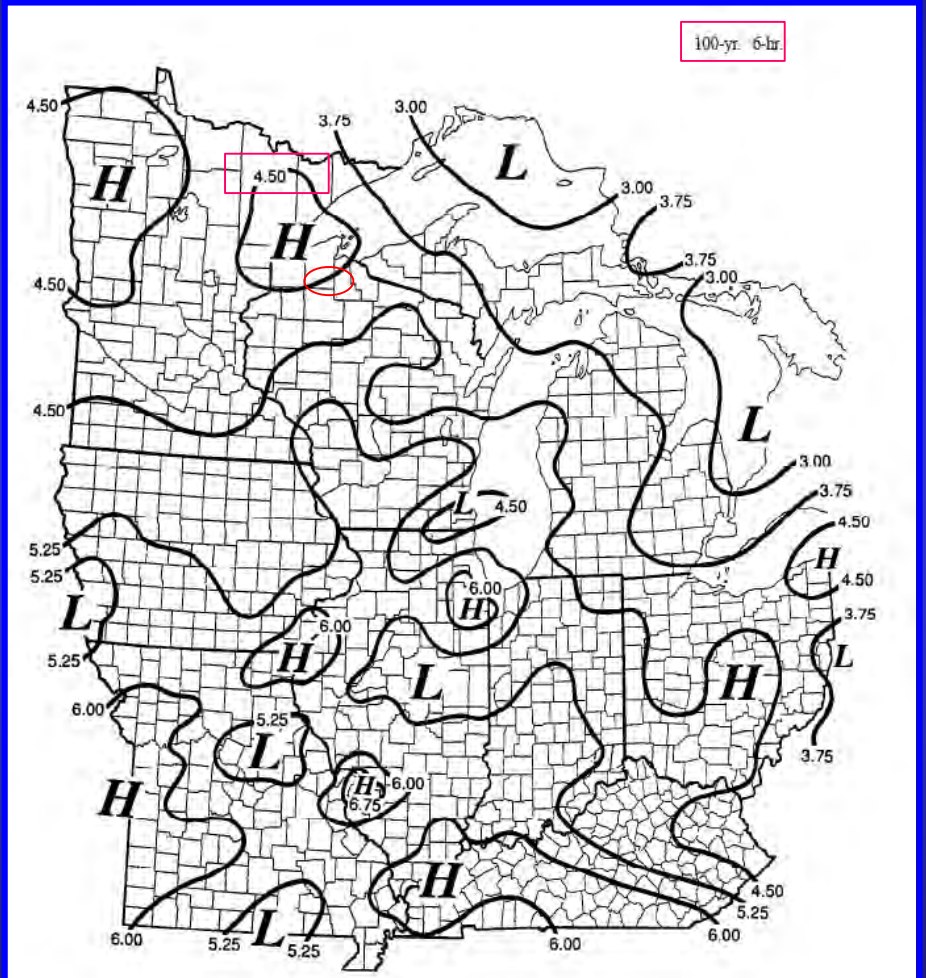




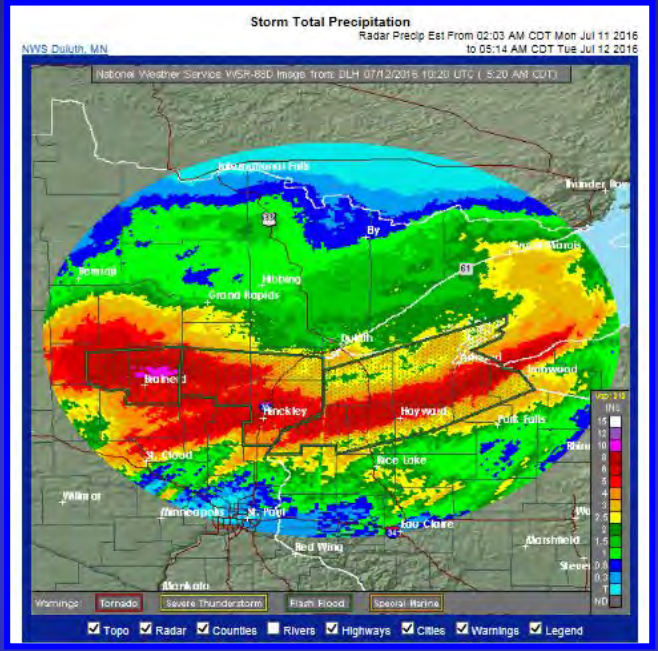
For most sites that survived the flood, peak discharge was estimated from high water marks and an existing hydraulic model from the original site design.

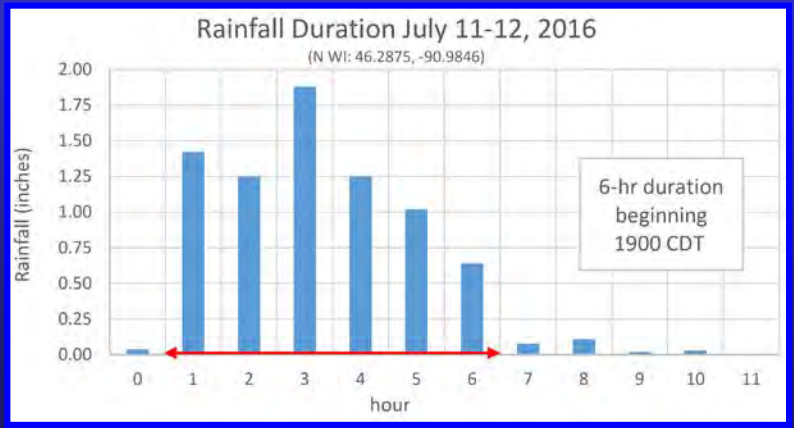
Quantifying Extreme: Rainfall

Chequamegon-Nicolet NF Example



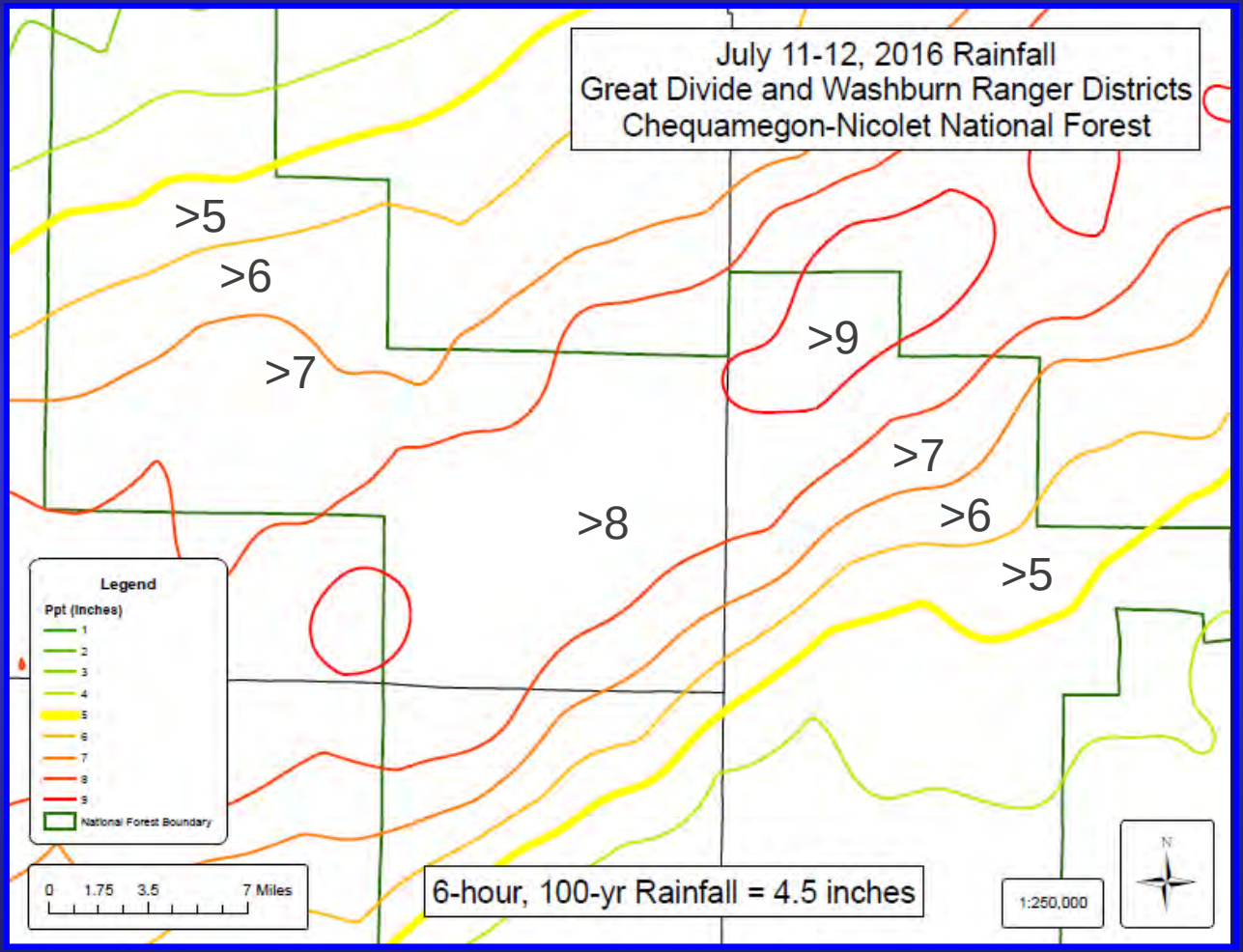
Reference: Huff, Floyd A., and James R. Angel. Rainfall Frequency Atlas of the Midwest. Illinois State Water Survey, Champaign, Bulletin 71, 1992.





Quantifying Extreme: Rainfall

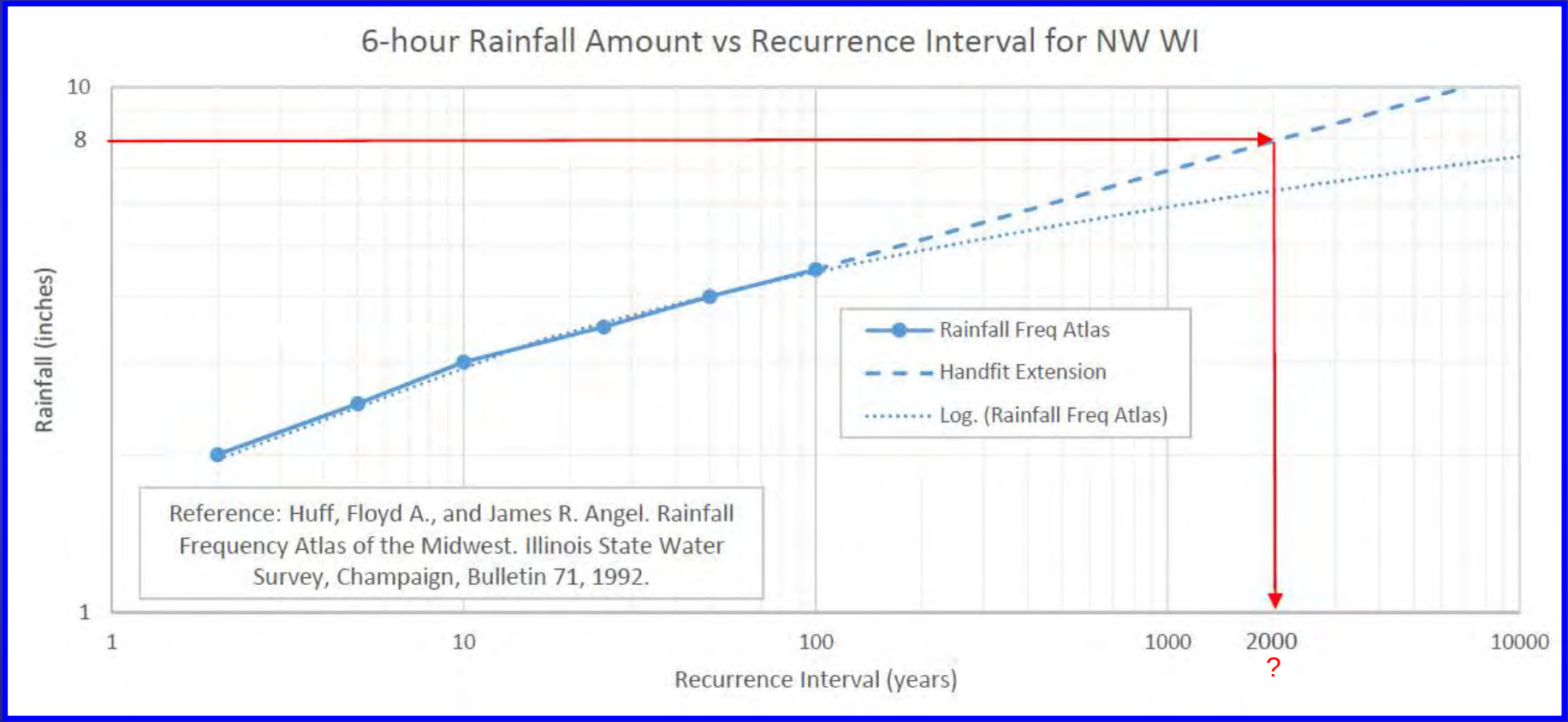
Chequamegon-Nicolet NF Example



(http://www.srh.noaa.gov/data/ridge2/Precip/qpehourlyshape)

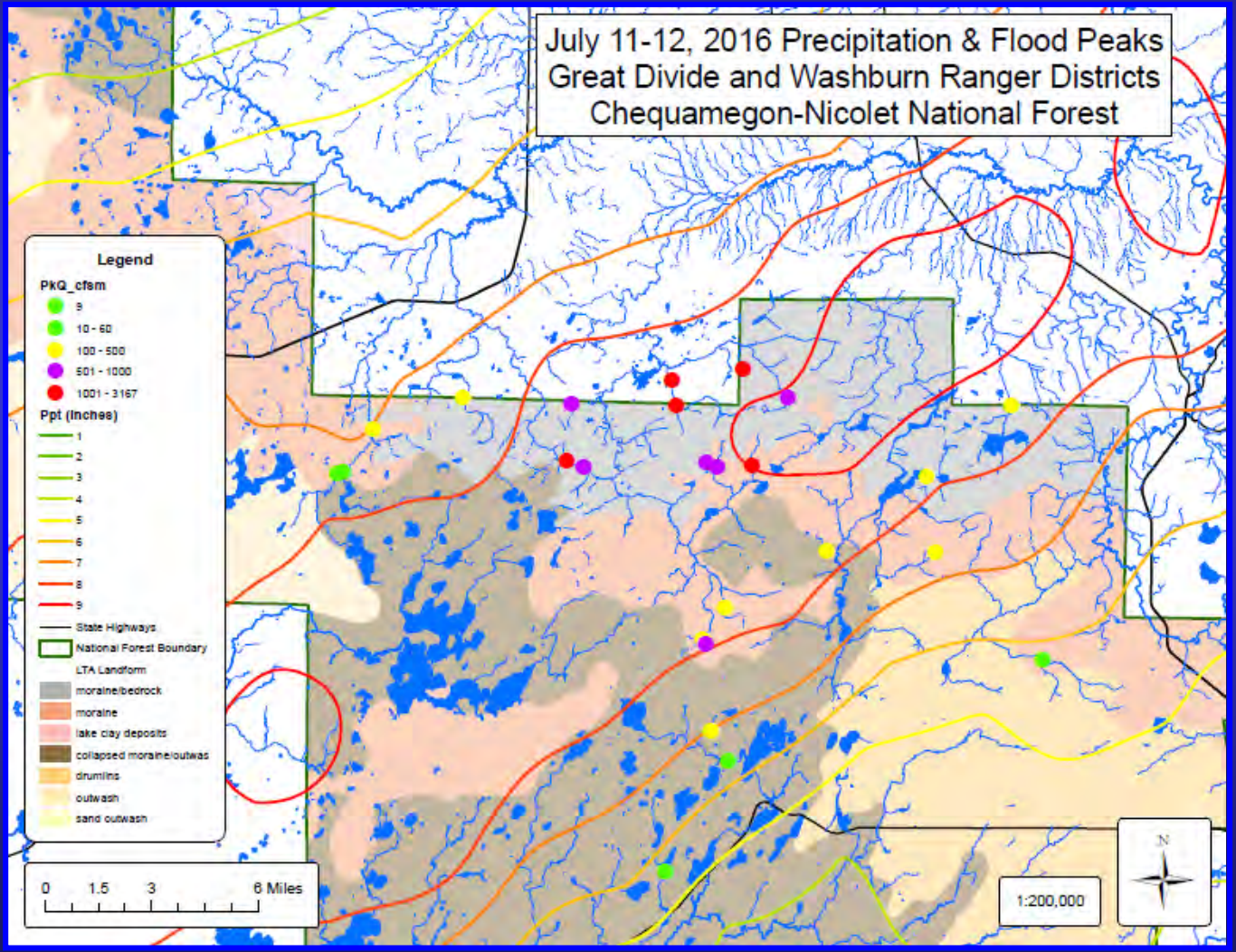
Quantifying Extreme: Rainfall

Chequamegon-Nicolet NF Example



Areas >6” generally exceeded the 500-yr recurrence interval.

Watershed Response Varied Substantially By Landform



Bedrock controlled:
500-3,000 cfsm
1-8 x Q_{500}
Moraines:
100-300 cfsm
1.1-2.9 x Q_{500}
Outwash/Sand:
10-60 cfsm
0.2-1.3 x Q_{500}

Runoff rates increased as relief increased and storage and soil permeability decreased.

What Failed? Why?

- Undersized: <bankfull width
- Extreme flood (>500-yr, <0.2%)
- Entrenched
- Poor alignment
- Debris?
- Poor condition

Undersized (<Bankfull Width)

What Failed? Why?

Seitz Cr at FR 150

Bankfull width = 8 ft

2-2.5’ circ. Culverts

Constriction ratio = 0.63

Unt 20 Mi Cr at FR 378

Bankfull width = 7 ft

3.5’x2.4’ culvert

Constriction ratio = 0.50

Extreme Flood, >500-yr

What Failed? Why?

- 20 Mi Cr at FR 377
- Bankfull width = 18 ft
- New bridge installed 2002
- Replaced 20 ft span
- Increased span to 28 ft
- 1.5 x bankfull width

Extreme Flood, >500-yr

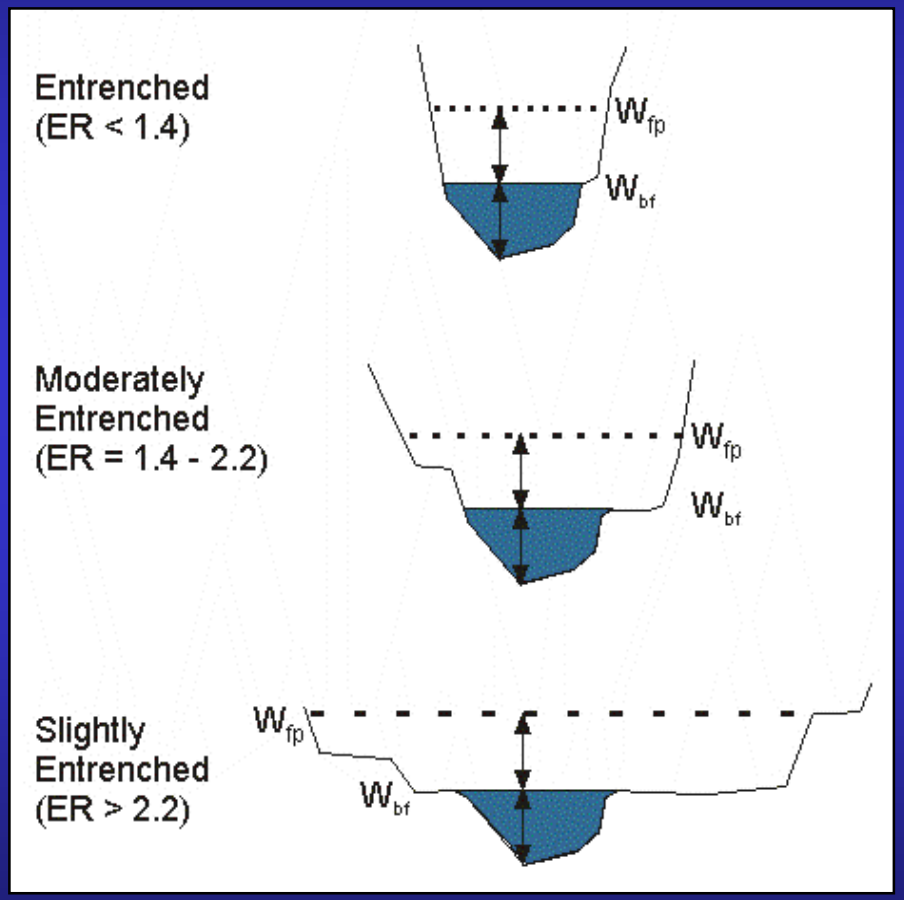
What Failed? Why?

- Morgan Falls Cr at FR 199
- Bankfull width = 10 ft
- New bridge installed 2006
- Increased span to 28 ft
- 2.8 x bankfull width
- Replaced 11’7”x 7.5” pipe

Entrenchment

What Failed? Why?

Entrenchment = FPW/BFW

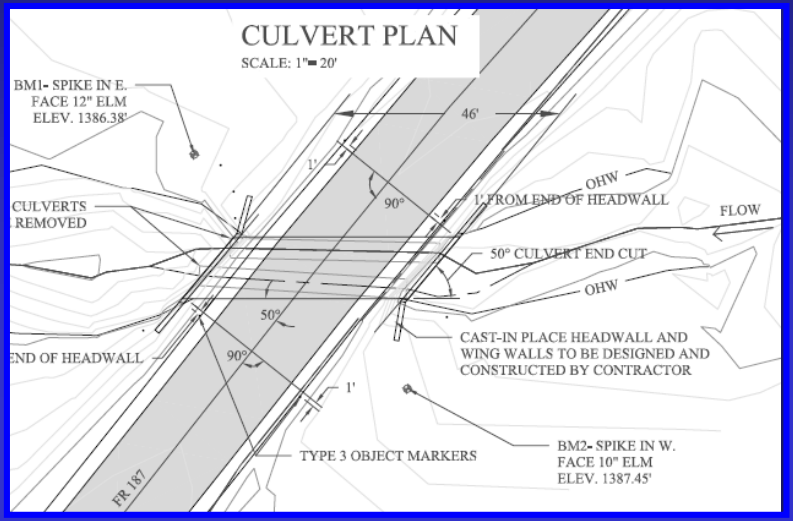


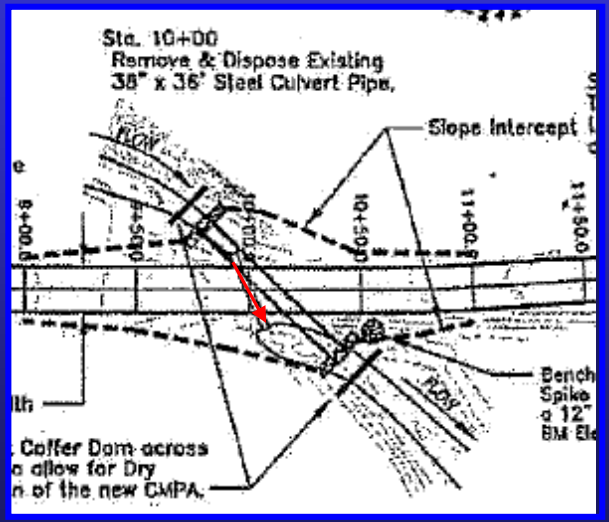
FPW = floodprone width

BFW = bankfull width

Alignment (when overtopped)

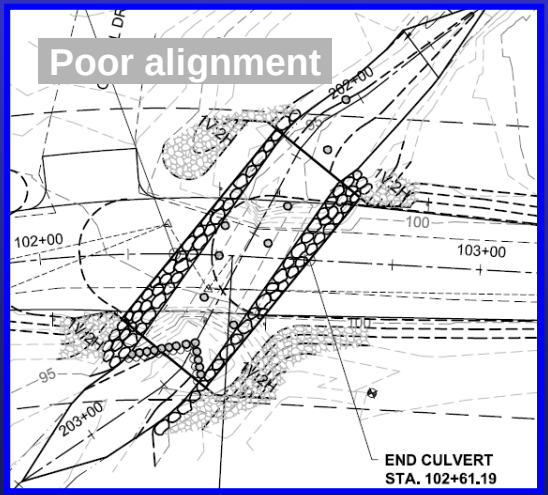
What Failed? Why?





Extreme Flood, Entrenched, Alignment, Structure

What Failed? Why?



What Survived? Why?

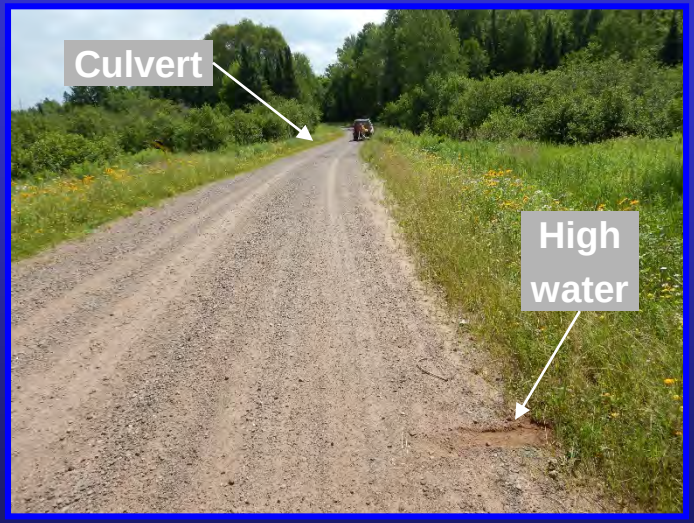
- ≥Bankfull Width
- Slight entrenchment with overflow
- Good alignment
- Stable side-slopes: riprap and vegetation
- Large key pcs
- Concrete

>Bankfull Width

What Survived? Why?

Slight Entrenchment w/Overflow

What Survived? Why?

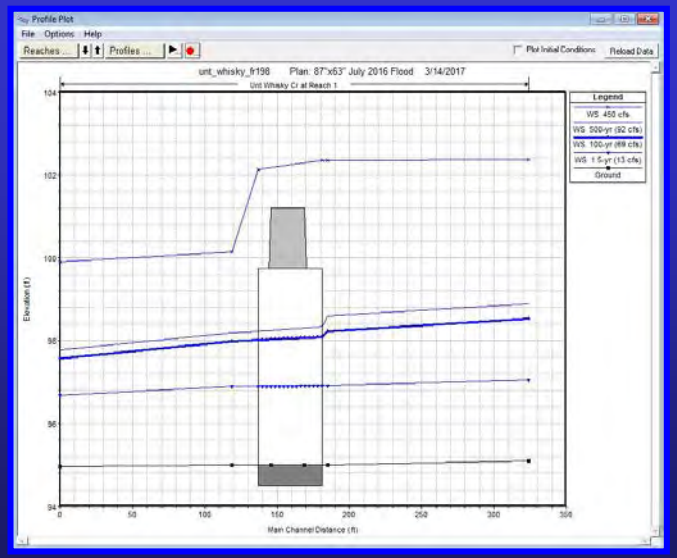


Marengo Trib N at FR 194

McCarthy Trib at FR 184

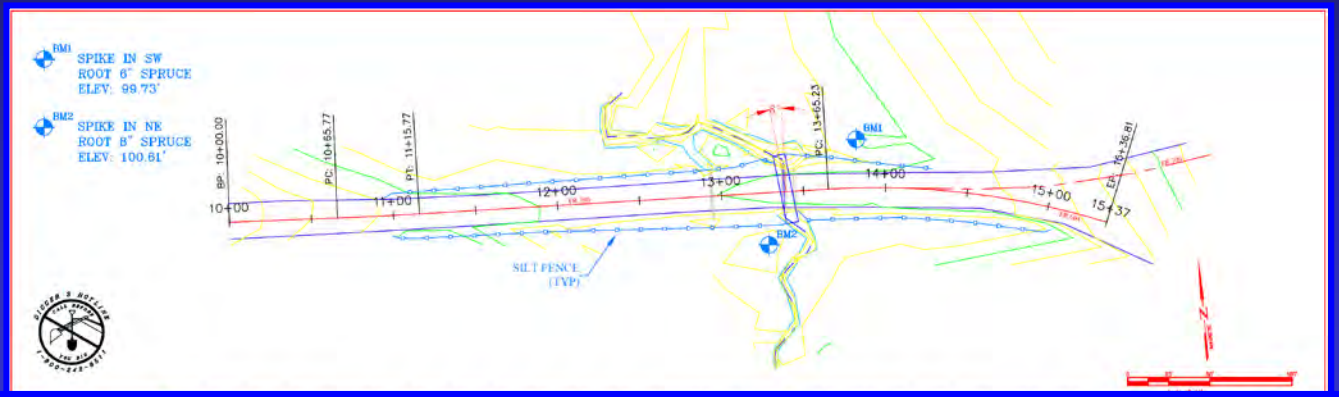
Slight Entrenchment w/Overflow

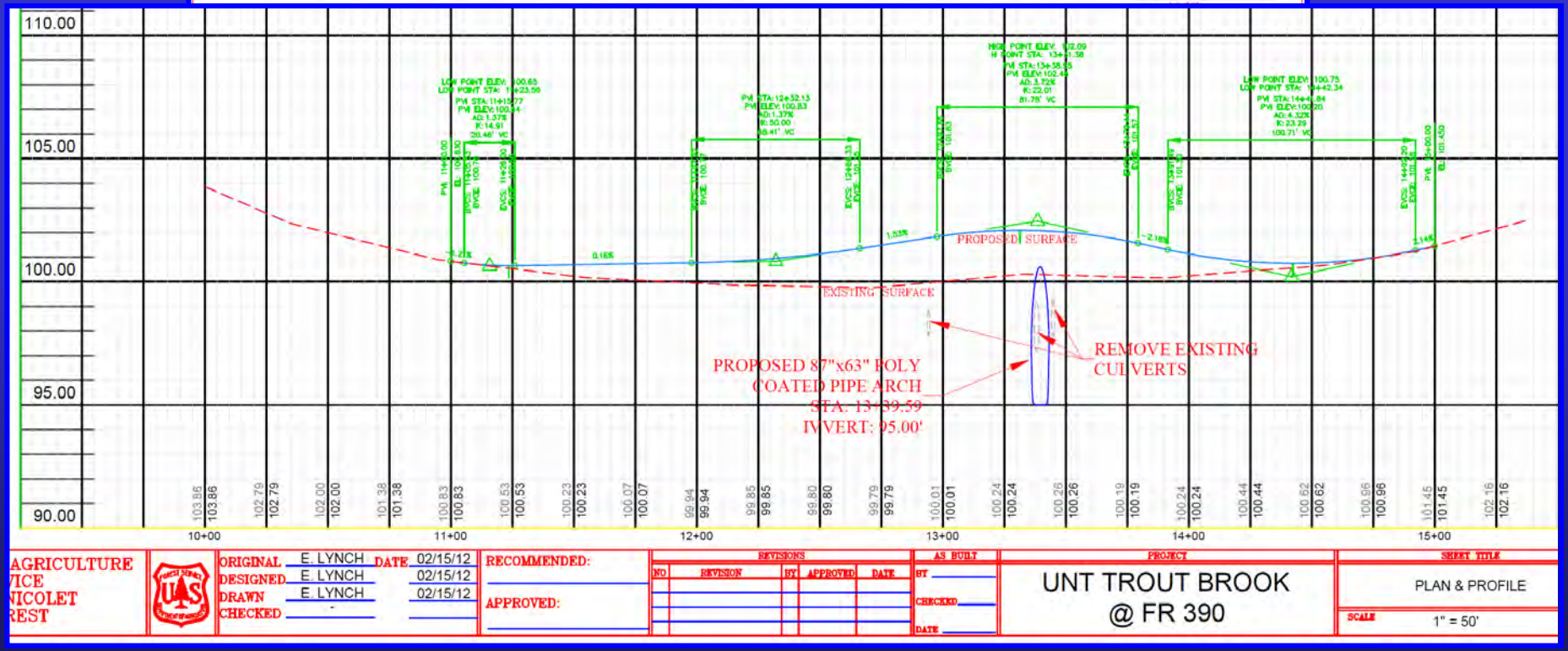
What Survived? Why?



Slight Entrenchment w/Overflow

What Survived? Why?





Stable Side Slopes: Riprap and Vegetation

What Survived? Why?

Hawkins Trib at FR 383

Brunsweiler Trib at FR 387

Concrete Structures

What Survived? Why?

Marengo R at FR 196

Trout Cr at FR 390

Large Key Pieces – Stream Simulation

What Survived? Why?

Lessons

- Stream simulation provides enhanced flood resiliency
  - >bankfull width minimizes HW depth & debris jambs
  - embedded structure
  - freeboard in design (HW/D<0.8)

- Rainfall likely to cause future increases of extreme floods
  - snowmelt causes many N WI annual floods
  - intense rainfall exceeds snowmelt rates
  - Intense rainfall is predicted to increase

- Watershed characteristics affect vulnerability and resilience to flood increases from more intense rainfall
  - lower soil permeability increases vulnerability
  - lower storage increases vulnerability
  - greater relief increases vulnerability

Lessons

- Site characteristics can increase vulnerability
  - greater entrenchment and stream slope
  - poor stream-road alignment
  - greater fill height

- Design options to improve resilience at vulnerable sites
  - minimize fill height
  - provide overflow areas to one or both sides
  - increase opening size
  - large riprap
  - dense vegetation
  - concrete structures