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Flood Resiliency, Aquatic Organism Passage, Critical Infrastructure, and Economics
A Case for Stream Simulation Design and ERFO Policy Changes

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- Amy Singler, Eileen Fretz, American Rivers
- Alison Bowden, Jessica Levine, The Nature Conservancy

Discussion Topics

- Define terms
- Why does this matter
- Why& how structures fail
- Stream Sim design methodology
- Upper White River case study and hydraulic results
- Cost Comparisons
- Policy recommendations

Why does this matter?

CLIMATE CHANGE HAS ARRIVED AND WE ARE GOING BROKE CONTINUALLY FIXING UNDERSIZED STRUCTURES WITH UNDERSIZED STRUCTURES!

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Definitions

- **Flood Resiliency** – A road crossing structure that is capable of surviving a flow greater than the design flood with minimal maintenance required

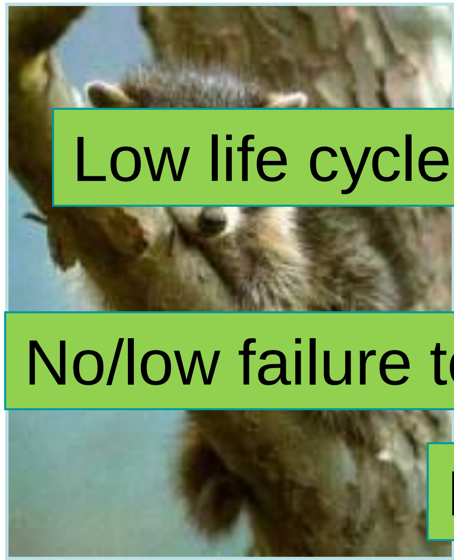
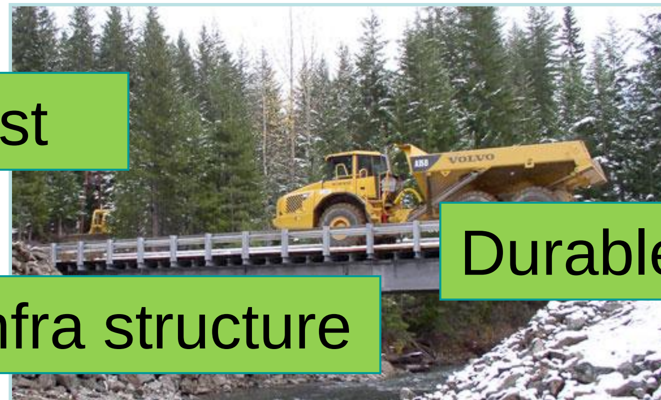
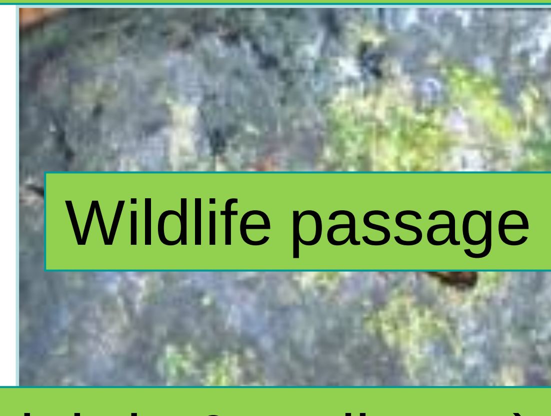
- **AOP** (Aquatic Organism Passage) – A road crossing structure that allows passage of aquatic organisms of all species and life stages in addition to other terrestrial, amphibian, reptile species of importance.

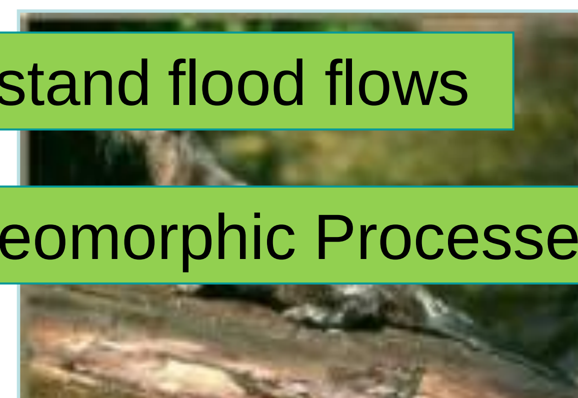
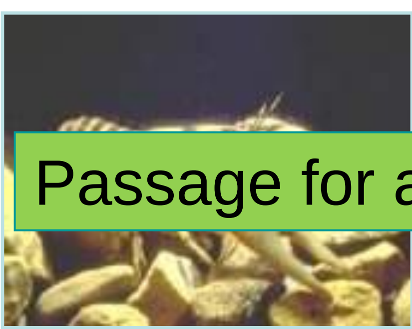
Definitions

- **Critical infrastructure** – Road crossing of importance where loss can have dramatic impacts on public safety, emergency management, and commerce.

- **Economics** – The true cost of structures and how we pay for it all

What Should Road Crossing Do ?
Produce Designs That:

- Ensures public safety
- Low life cycle cost
- Durable
- Wildlife passage
- No/low failure to infra structure
- Passes watershed products (debris & sediment)
- Provides Ecological Connectivity
- Withstand flood flows
- Maintains Geomorphic Processes
- Passage for all aquatic organisms
- Doesn’t need maintenance

Failure Mechanism During Floods

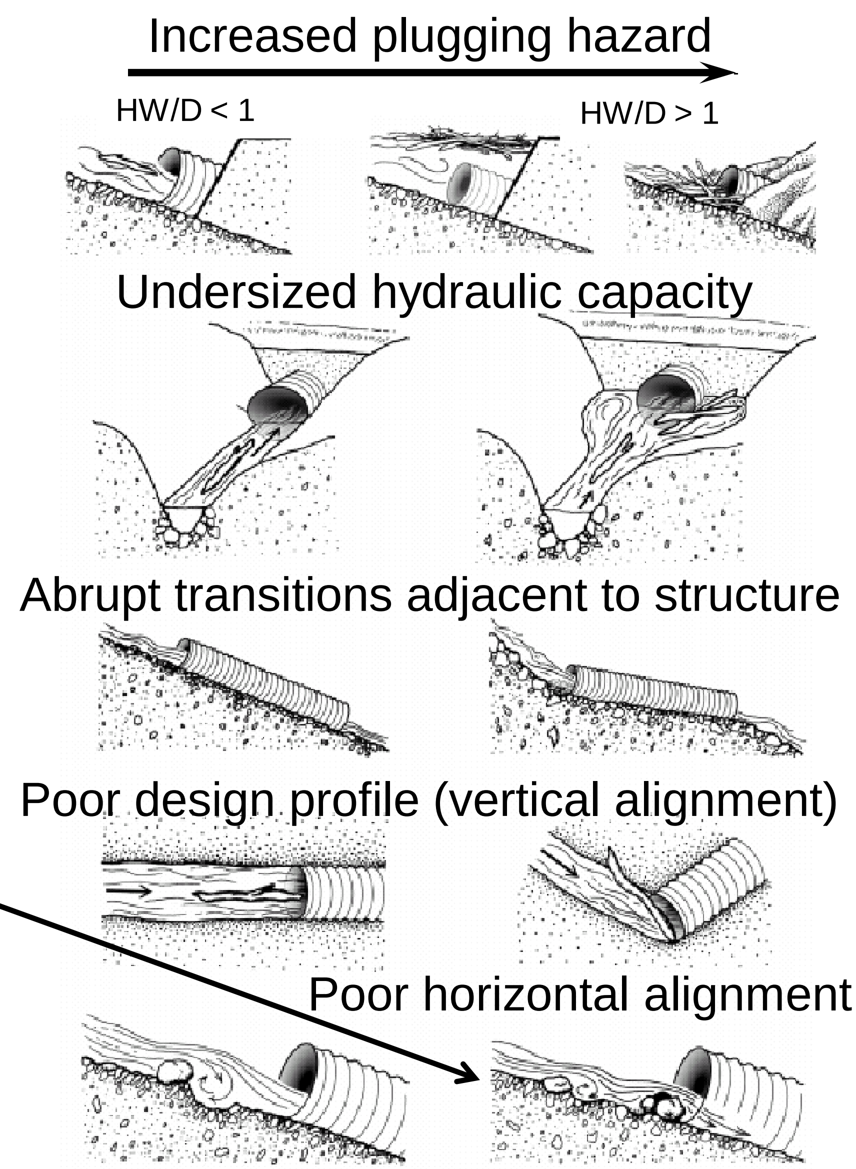
Failure Mechanism

- Hydraulic Exceedance (capacity)
- Sediment "Slug"
- Woody Debris Lodgment (slower by collection of woody debris and sediment buildup)
- Debris flow (Large / catastrophic -Natural or from upstream crossing failure)

How and Why do Structures Fail (In Floods)

Plugging Hazard Mechanism

- Design flood overtops structure (hydraulic capacity exceeded)
- Abrupt Transitions
- Poor vertical alignment with channel)
- Poor stream to structure geometry (skewed)
- Structure and geometry disrupt sediment transport
- ***Poor geomorphic location***

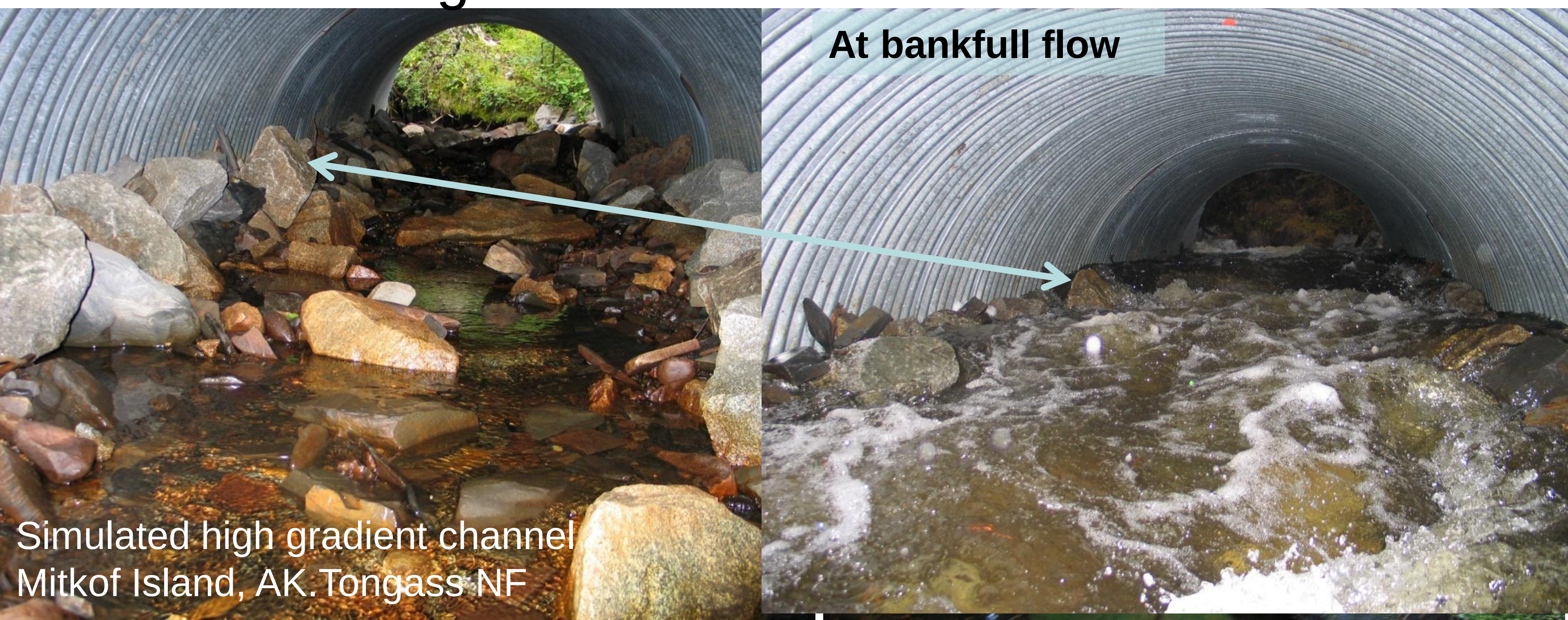


Furniss et al 1998

?How Do We Achieve Flood Resiliency and AOP?

Or Can We Have Our Cake And Eat It Too!

Stream Simulation Design: A channel that simulates characteristics of the adjacent natural channel (reference reach), will present no more of a challenge to movement of organisms than the natural channel.



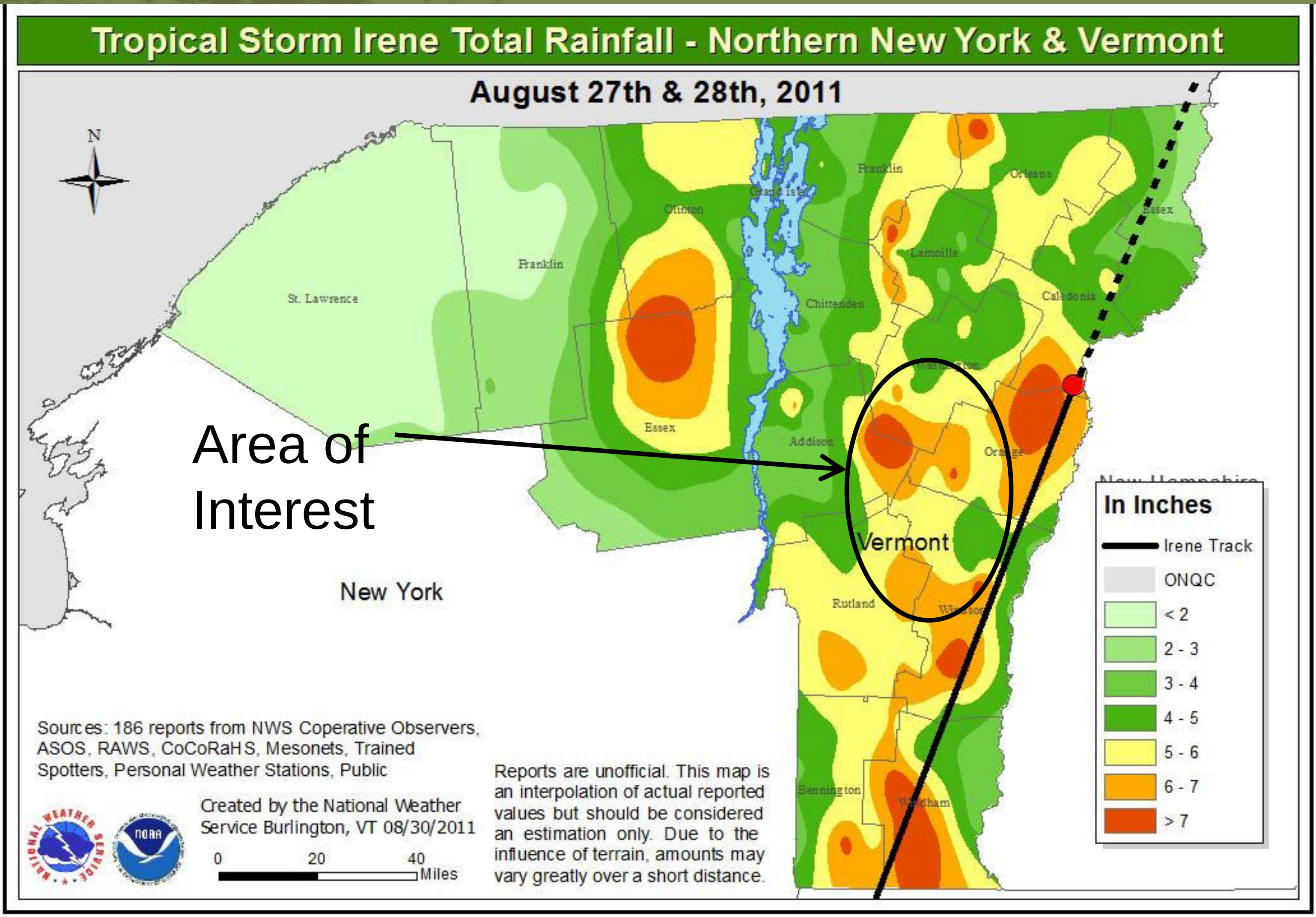
Analytically Driven Stream Simulation Design

Design the channel (shapes, banks, bed, bedforms) considering risk, long term changes and engineering constraints then wrap the structure around it. The reference reach provides the standards (range of allowable measurements for cross section dimension, extra width is derived by analysis)

Site Risks

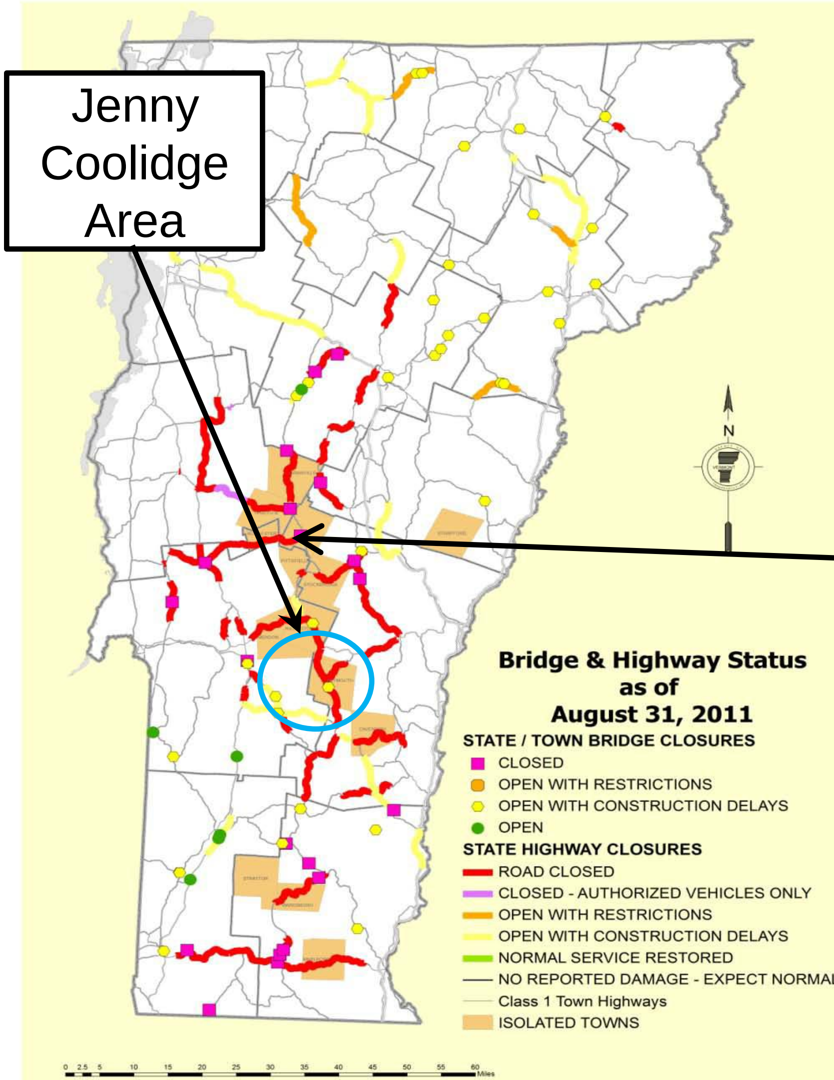
- ✓ **Channel Stability**
- ✓ **Vertical Adjustment Potential**
- ✓ **Headcut Potential**
- ✓ **Lateral Migration Potential**
- ✓ **Floodplain Conveyance /connectivity**

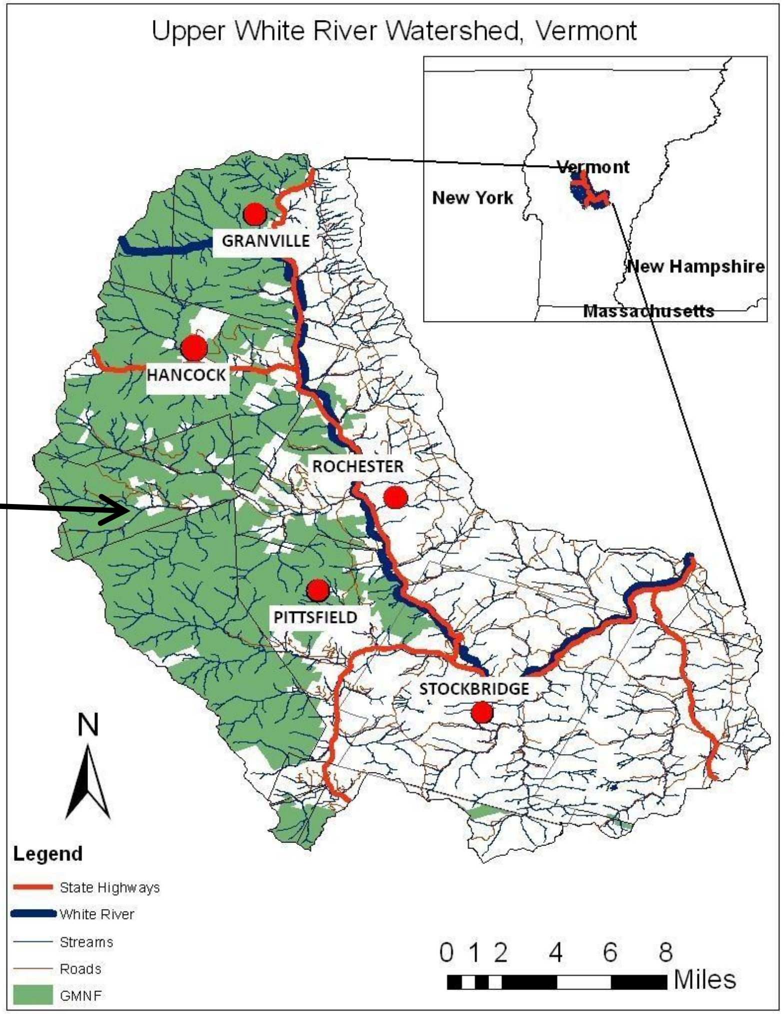
Tropical Storm Irene August 28, 2011



5 to 7+" of rainfall in less than 48 hours in steep mountainous terrain

Tropical Storm Irene Affected Structures





Economic Analysis Area

Upper White River Watershed

- **Town of Pittsfield, VT**
  - **10% of culverts replaced (25 of 237) following Irene**
  - **18 culverts were upgraded from 15” to 18” following Irene**
- **Town of Granville, VT**
  - **Replaced 18 culverts – total culverts in town unknown**
    - **13 replacements were 24” or smaller**
  - **Total replacement cost of Thatcher Brook/Town Line Rd**

  10’ x 7’ arch pipe = $50,600
- **Town of Rochester, VT**
  - **31 culverts damaged by Irene**
    - **15 were still unrepaired as of May 2012**

State wide 1,477 structure were damaged or destroyed

Damage on GMNF

- 24 Forest Service System Roads 21 miles
- Estimates repair costs = $6.4+ million
- $284,000 in trail damage

Forest Road 58 - $688,000

Kelley Stand Road System
$3,500,000

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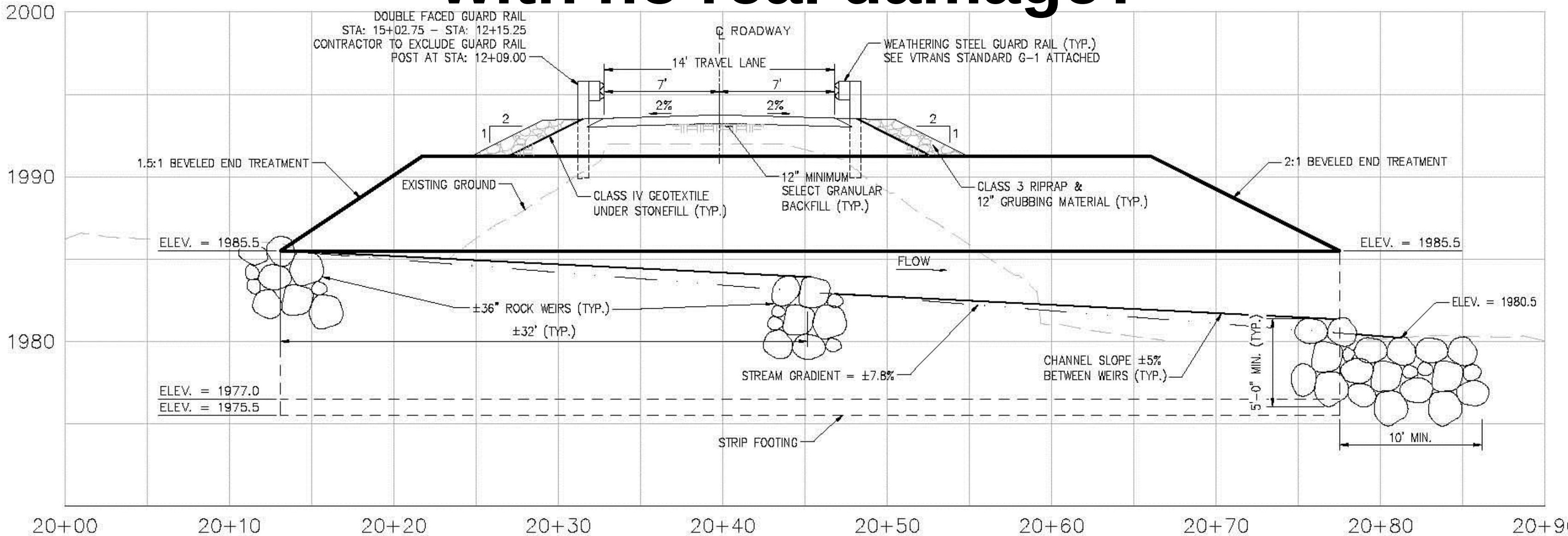
What structures survived the floods with no real damage?



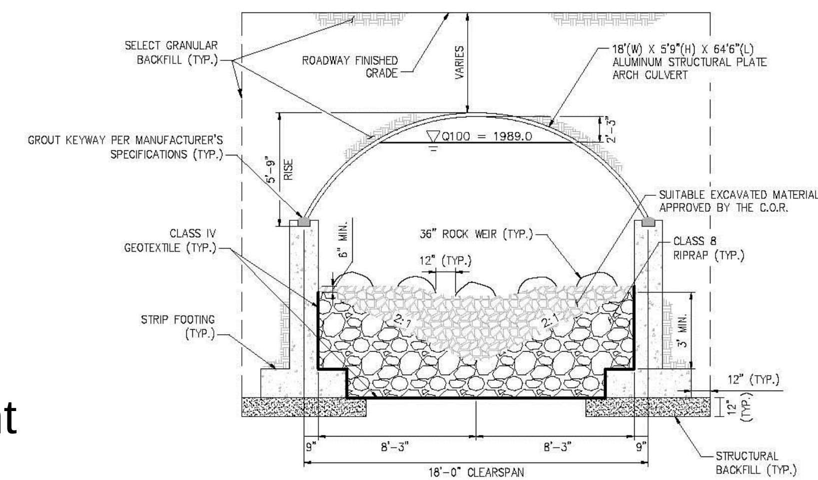
Stream Simulation Design Study Site

Jenny Coolidge Brook

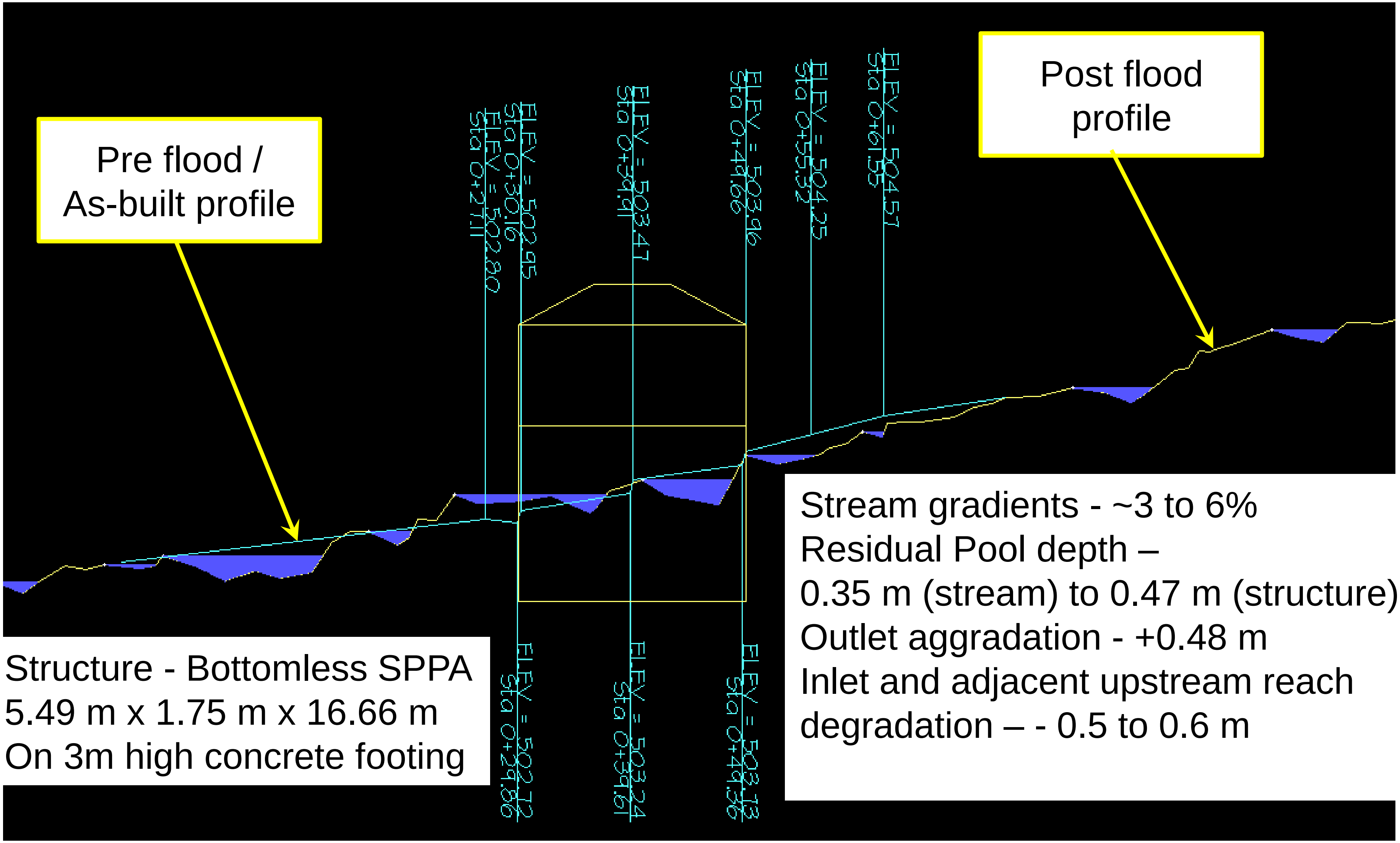
Structure - Bottomless SPPA

5.49 x 1.75 x 16.66 m @ 5.1% as built gradient

On 3m high concrete footing



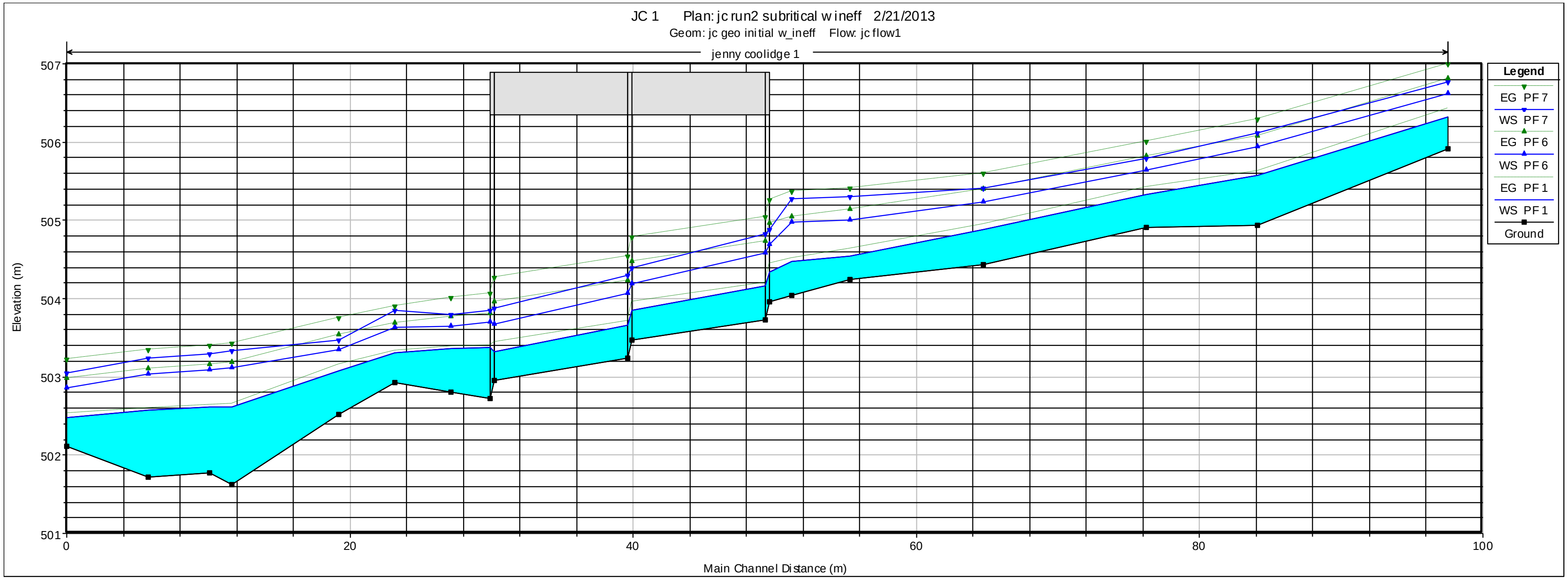
Jenny Coolidge Brook – Pre & Post Flood Profile



Structure - Bottomless SPPA
5.49 m x 1.75 m x 16.66 m
On 3m high concrete footing

Stream gradients - ~3 to 6%
Residual Pool depth –
0.35 m (stream) to 0.47 m (structure)
Outlet aggradation - +0.48 m
Inlet and adjacent upstream reach
degradation – - 0.5 to 0.6 m

Jenny Coolidge Brook
Preliminary Hydraulic Analysis



- Original As-Built conditions modeled
- Roughness determined by empirical methods (Limerinos & Jarrett method)
- Regression equations used to determine flows.
- Flood indicators surveyed in the field both up and downstream
- Modeled Q500 flow approximately matches flood indicators in several locations

Stream Simulation Flood Proof!

Green Mountain National Forest - FR17A - Bottomless Arch Outlet

Competed Construction 2010

Post TS Irene Sept. 2011

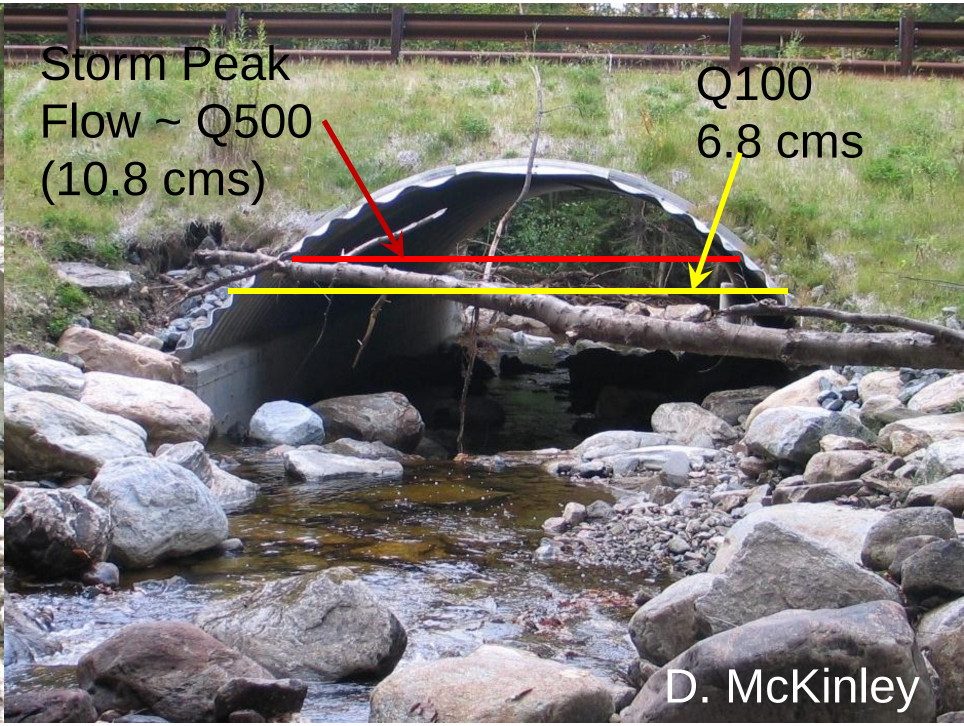
Lost largest boulders near outlet and some roughness along stem walls.
Structure and road undamaged and structure passes all aquatic organisms

Stream Simulation Flood Proof!

Green Mountain National Forest - FR17A - Bottomless Arch Inlet

Completed Construction 2010

Post TS Irene September 2011



Storm flows did not overtop the road. Minimal scour on left side of arch

Stream Simulation Design
Jenny Coolidge Brook

Post Irene Condition
Outlet

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Stream Simulation Design

Jenny Coolidge Brook

Bed degradation

Pre Irene Construction
Upstream of Structure

Post Irene Condition
Upstream of Structure

Stream Simulation Design

Jenny Coolidge Brook

Pre Irene Construction
Inside Structure

Post Irene Condition
Inside Structure

Economic Arguments for a New Approach
“Another reason bigger is sometimes better”

Example – Churchville Rd, Hancock, VT

- 12', Q25 steel pipe remained intact but washed out 1200 FT of Churchville Rd in August 2011
- As of April 2012, Churchville Rd is still closed
- An unmaintained road had to be upgraded so residents could continue to access Route 100, though less directly
- Town was **not eligible** for FEMA grant money to upgrade the culvert
- FEMA will pay for the replacement of the road at $1.1 million
- Tentative plans to install a bridge in 2013 at a cost of $200,000

Structure	Estimated Repair Cost
Culvert	$0 (no damage to culvert just plugged at inlet)
Churchville Rd	$1.1 million
Class 4 Road improvement	$84,000
Traffic Delay Costs	TBD (gas, lost work time, etc)
Total Cost of Failure	**$1,184,000 +**

Stream Simulation vs Traditional Hydraulic design Cost

	12' OBA	18' OBA
Foundation Fill	$4,000	+$2,000
Structural Excavation	$24,240	+$4,400
Constructed Steps	$1,280	+$480
Stream Sim Rock	$8,775	+$4,350
"Filler Material"	$400	+$200
Aggregate Surfacing	$1,480	+$80
Concrete Footings	$22,500	+$5,000
Reinforcing Steel	$2,200	+$43
Mobilization	$9,794	+$3,728
Open Btm Multi-plate	$33,060	+$15,040
Total Contract	**$107,729**	**+$35,361**

50% width increase ≈ 33% cost increase
Typical Range ~ 10 to 30% cost increase

Source: USDA-FS AOP Cadre 2011

Upper White River Basin – Culvert Costs

Road No./Name	Estimated Costs from DSR's			Actual Construction Cost	Actual % Increase for AOP Stream Sim.
	Traditional Culvert/ Replace in Kind	Betterment/AOP Stream Sim. Replacement	% Increase for AOP Stream Sim.		
FR42.05.0 over Bingo Road	$92.950.00	$142,050.00	53%	$113,738.00	**22%**
FR42B.00.0 over Bingo Brook	$112,175.00	$156,775.00	40%	Never Constructed-Decommissioned	N/A
FR49.00.5 over Boyden Brook	$93,800.00	$140,700.00	50%	Never Constructed	N/A
FR92.00.0 Over Goshen Brook	$106,635.00	$172,200.00	61%	$119,835.00	**12%**
FR92A.00.0 over Hale Brook	$104,700.00	$130,250.00	24%	$113,725.00	**9%**

Source: Green Mountain National Forest, 2008.

We Need To Do A Better Job Determining Structures True Life Cycle Costs

- **Include long term maintenance cost (not normally included in cost computation!**
- A culvert failure can result in significant costs to state/towns including
  - Cost to replace the structure itself
  - Costs to replace other structures affected by the failure (homes, businesses, roads)
  - Delay costs from traffic disruption
- Emergency replacement costs are generally higher than normal replacement costs
- If a culvert remains undersized, these costs may be incurred multiple times during its life cycle

Source: (1)Perrin Jr., J and C. Jhaveri. "The Economic Costs of Culvert Failures." Jan 2004.

Information Gaps

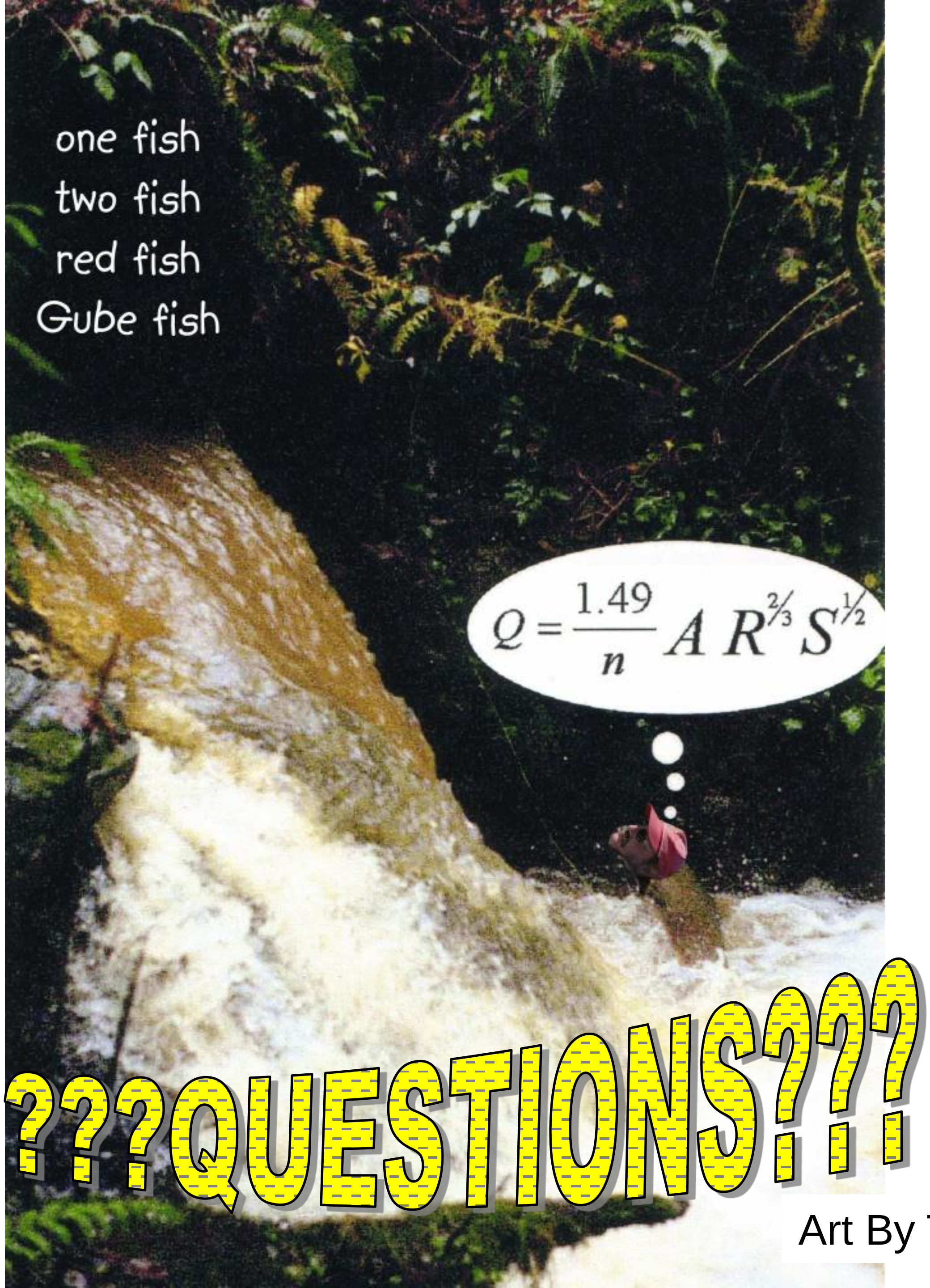
- Culvert inventory - State inventory completed in 2004/2005, but difficult to match with post-Irene town inventories.
- Records for maintenance and associated costs on structures and are minimal if they even exist!
- Repeat offenders – which culverts have failed multiple times during previous floods

Future Recommendations

- ✓ Incorporation of Stream Simulation ecologically-based stream crossing designs into state standards. Adopt consistent standards!
- ✓ Identify critical infrastructure (e.g. high volume traffic, major commuting delays, provision of critical emergency services, etc) and prioritize with at watershed scale with critical aquatic habitat
- ✓ Flexibility in FEMA and other funding sources to find ways to help towns invest in appropriate road-stream crossing designs. Remove the current "INCENTIVE" upgrade undersized structures
- ✓ Improved record-keeping and prioritization of "repeat offenders" for upgrades

Future Recommendations

- ✓ Adopt an Incident Command Structure (ICS) for flood-affected areas modeled after the National Incident Management System approach to wildfires and other disasters impacting communities and/or regions. Place high priority on deployment of an interagency flood response "Strike Team" compromised of fluvial restoration, engineering and fisheries experts to flood-affected regions immediately
- ✓ Educate engineers in improved design methods and real life cycle costs and politicians and the public on how rivers function and the real costs of cheap decisions in a riverine environment



Art By Tomas Dunklin