



NCD For Extreme Event Restoration- Improved Resilience

Thomas Graupensperger

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Getting the Best Bang for the Buck!

Added Benefits of Natural Channel Design(NCD)

- Municipal Separate Storm Sewer System(MS4) Stream Restoration and Floodplain Reconnection for optimized Total Maximum Daily Load (TMDL) credit
- Joint Gray Infrastructure Rehabilitation and Natural Nature Based Features (NNBF); Natural Channel Design (NCD) Restoration
- Improved : Resilience, Sustainability, Ecologic Uplift and Effective Hyporheic Zone (EHZ) Function & Flood Hazard Mitigation
- Reduced Maintenance, Long-Term Pollutant Reduction TMDLs for Terrestrial-Riparian-Aquatic Habitat and Benefits



Improving Resiliency & Sustainability of Vulnerable Infrastructure – NCD Restoration Case Studies



Common Reach Characteristics & Vulnerabilities to Extreme Rainfall Events

Confined Valley: Post-Extreme Event Below

- Confined Valley Floodplain-Floodprone Reach w/ Low Sinuosity
- Infrastructure- Roadway Embankment Encroachments present along Confined Valley Channel
- Reaches Typically Discharge to Receiving Stream Channel Confluence or its Floodplain
- Downstream Receiving Reach Characteristically Lower Gradient Channel Slope and/or Wider Level Floodplain Area
- Lower Gradient Results in Downstream Receiving Confluence Zone Transitional-Depositional Reach
- Bridges, Culverts and Roadways- Along or Across Channel Lacking Capacity-Result in Scour & Aggraded/Depositional Zones
- Long-Term Historical use of Adjacent Roadway and Bridge Crossings Typically Areas of Multiple Prior Replacements
- Diminished Capacity of Structure Crossing Results in Increased Maintenance(Debris-Sediment Removal) Following Flood Events



Unstable-Impaired-Disconnected Stream Channels

Historic Prior Fill Placed in Left Bank

Pond Embankment Right Bank



NCD Stream Restoration – Bankfull Bench & Floodplain Reconnection

*Provides: Outfall Step-Pool Stability / Storm-Flood Hazard Mitigation / Sediment Retention- TMDLs
Treats 1st -3rd Order Stream Channels, Riparian Restoration, Reduced Velocity: Scour and Shear: Erosion*



Integrated Gray Infrastructure with Green/Natural Nature-Based Infrastructure/ Ecosystem & Water Quality Restoration

Upstream Culvert and Highway Construction

NCD Downstream One Year Later (2017)



Stream Restoration (11-2018) Extreme Event Impacts

*2018 into Early 2019 : 12 Rainfall Events greater than 1" in 24 Hours- Many 0.25-0.5 iph
(Central PA 2018 Rainfall 67"+ / Average Annual Rainfall is 42")*



Stream Repairs - Bankfull Bench Restored May 2020

Post 2018 PA Rainfall 67"+ Multiple Extreme Events (Average Annual 42")



Stream Restoration: Post-Ida Repairs Resulting From Upstream Embankment Failure

Restored Area Downstream Deposition
September 1, 2021 Tropical Storm Ida 5"+ Rainfall in 17 Hours (2 Periods @ 0.92 iph)



Bridge Scour Assessment for Sediment Load and Risk Reduction

2014 Statistic- Bridge foundation scour greater w/ recent increase in events

Natural Channel Design (NCD) Restoration:

- **Improves Water Quality, Mitigates Flood Hazard and Promotes Resiliency** during bridge replacement and highway reconstruction



Scour undermines bridges and may cause bridge failures due to structural instability. **In the last 30 years, more than 1,000 bridges collapsed in the U.S. and about 60% of the failures are related to the scour of bridge foundations.**

Reference: FHWA/LA.10/535

Extreme Weather Event Impacts

Infrastructure, Vulnerability, Risk and Resilience

Regulatory Compliance and Permitting

- Environmental Regulations – CWA-NPDES
- Integrated Watershed/Landuse Master Planning
- MS4 Stormwater Runoff Pollution TMDL Pollutant Reductions

Extreme Weather Event Vulnerability

- Asset Inventory, Vulnerability Assessment, Risk Management, Prioritization-Criticality and Adaptation
- Storm-Flood Hazard Impact Identification
- Transportation Safety- hazard warning
- Resilient and Adaptive Design-Construction

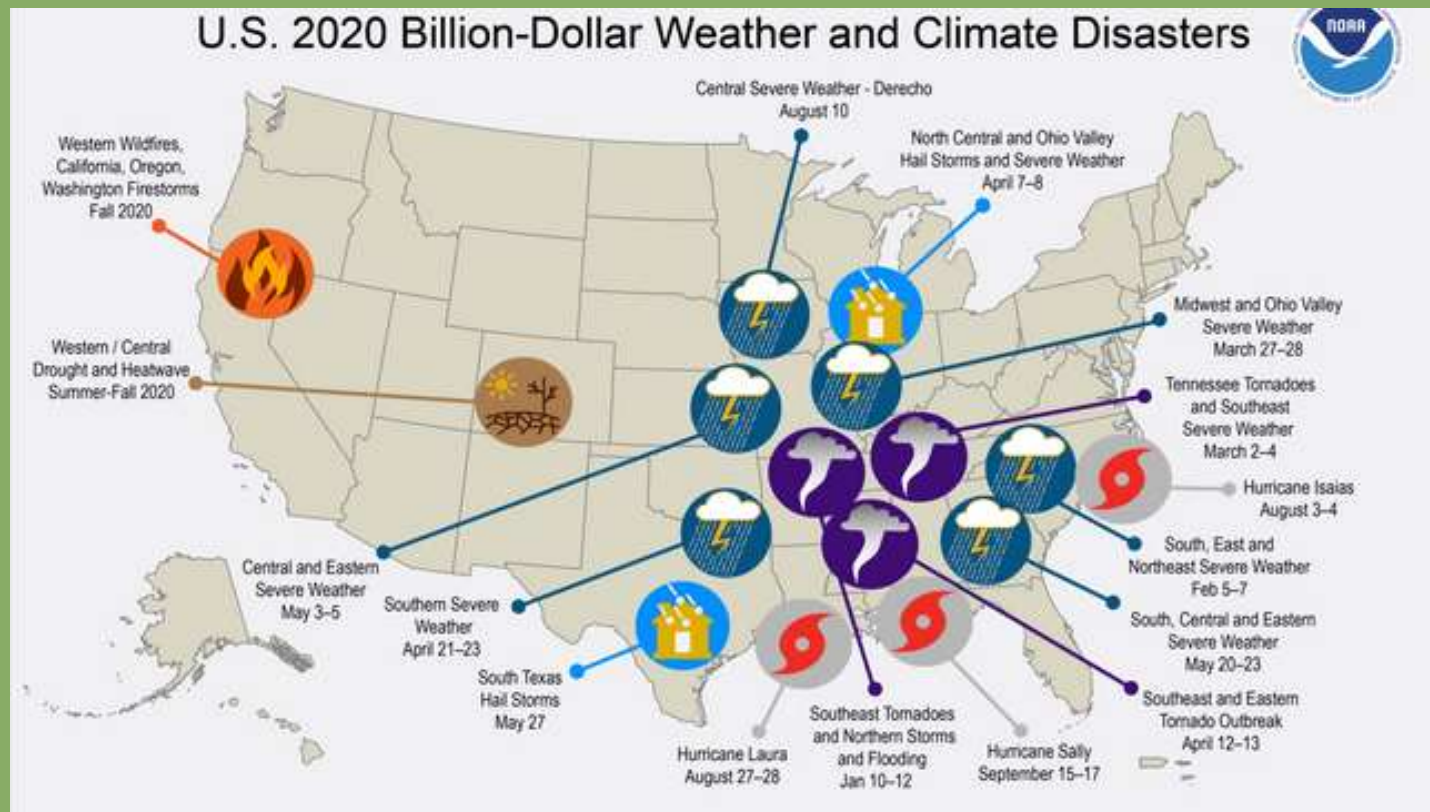


Plan-Design for Extreme Events to Improve Resilience

2020 : 16 Billion-Dollar Events **To Date End of June 2022: \$9 Billion**

Adaptation, Preparedness, and Resilience for Extreme Weather Events

More numerous and more intense extremes = increased vulnerability/risk

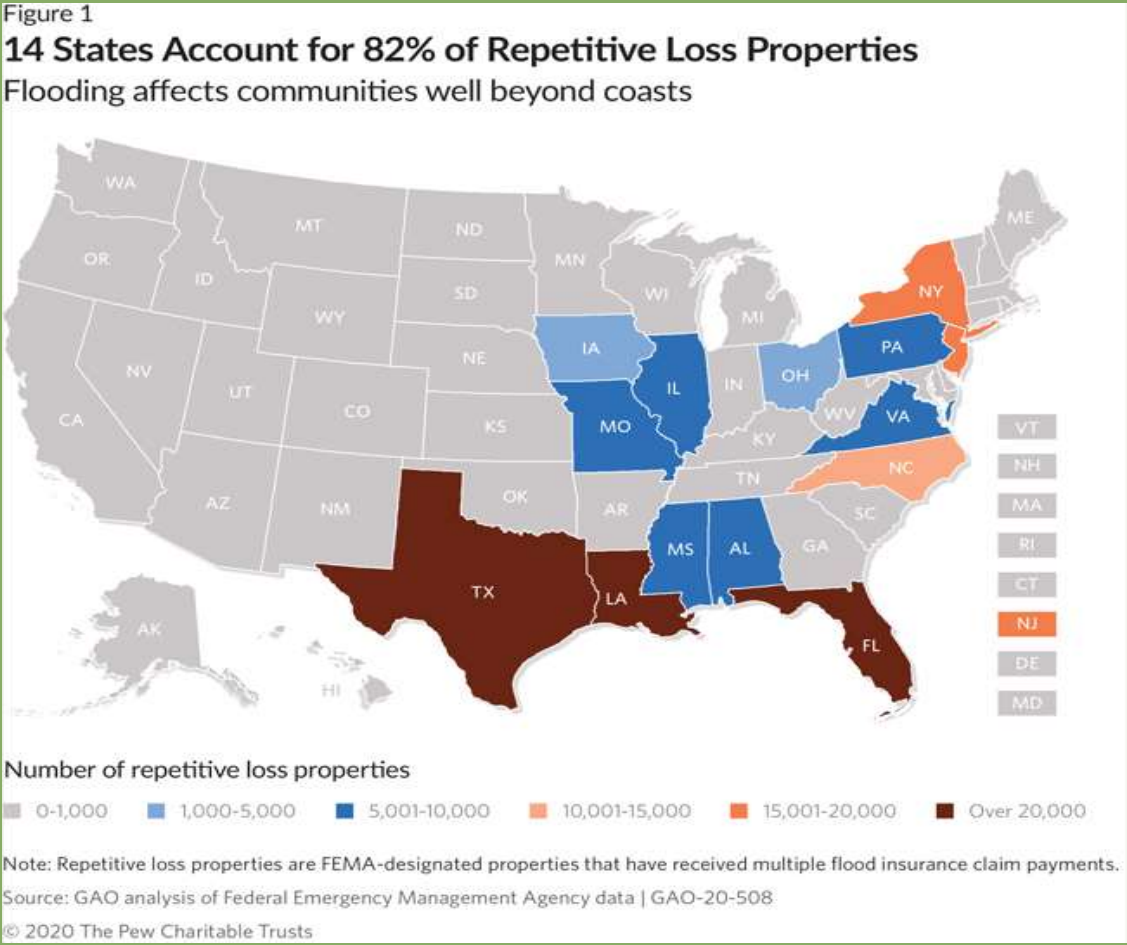


Source: NYC's High Performance Infrastructure Guidelines

Regions With More Frequent Storm-Flood Impact-Damages

Gulf Coast / Mid-West / East Coast : Frontal Systems, Tropical Storms & Hurricanes

Number of Repetitive Loss Properties

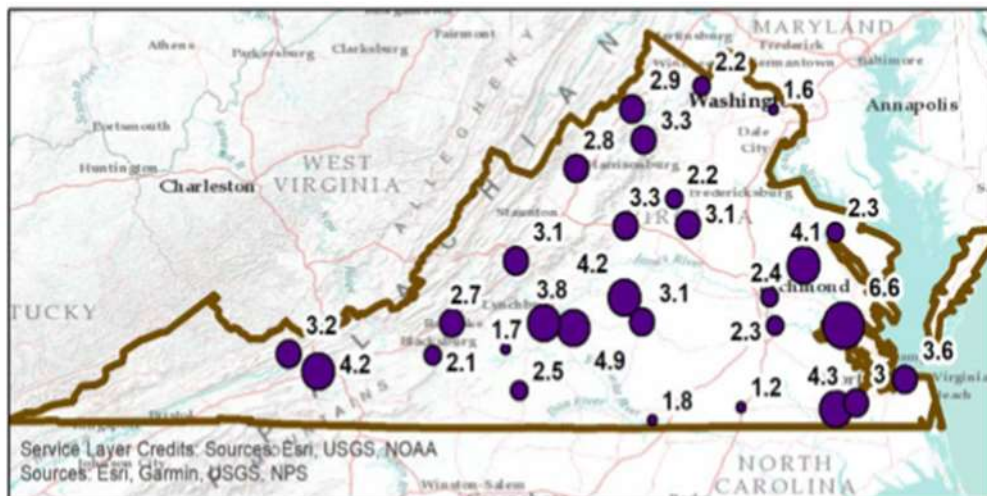


Climate Migration Impacts- Design Criteria for Future Events

Extreme Storm-Flood Events vs. Design Life?

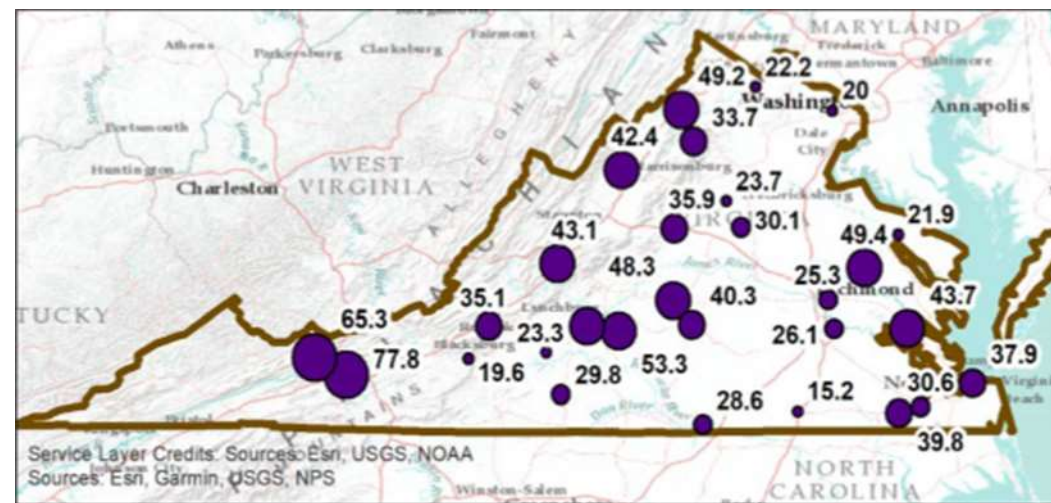
2085 100-YR Rainfall Increases: Coastal(+25-49%); Upper Piedmont(+20-40%) and Appalachian Mountain(+34-78%)

Adopted Design Capacity for Bridges ; Culverts: NOAA Atlas 14 –All Rainfall Return Periods: VA +20% ; NJ +25% (NCD Impacts?)



Rainfall increase in the 100-year event in inches across VA for year 2085 and the RCP 8.5 (Intergovernmental Panel on Climate Change:IPCC-high GH gas) emission scenario.

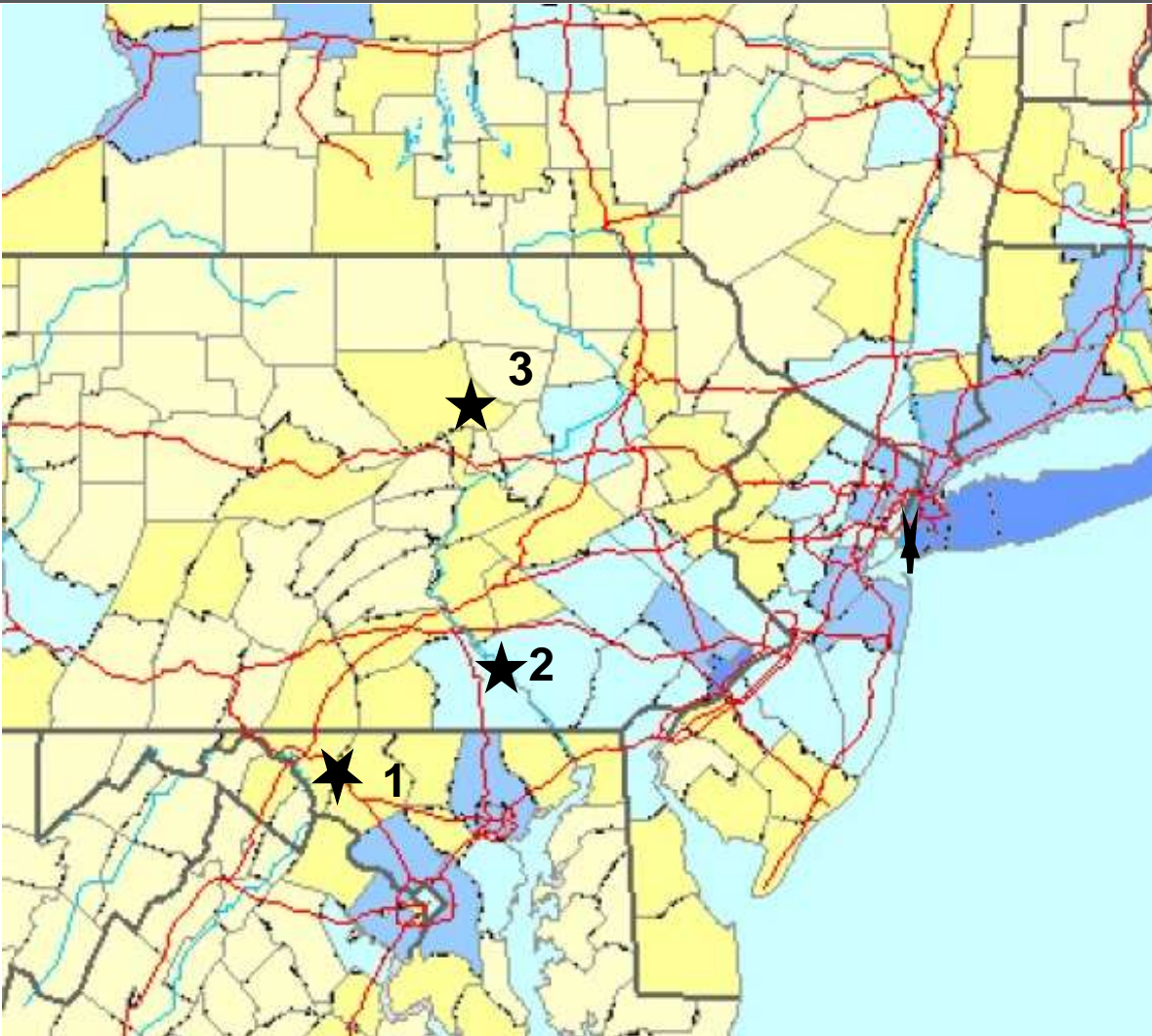
Source: "Incorporating Potential Climate Change Impacts in Bridge and Culvert Design" Virginia Transportation Research Council
http://www.virginiadot.org/vtrc/main/online_reports/pdf/20-r13.pdf



Percent increase in 100-year storm event across VA for year 2085 and the RCP 8.5 (high Greenhouse-GH gas) emission scenario.

Case Study Location Map :

Areas of Repeat Extreme Events: Trend Parallel to Coast, west of Chesapeake Bay and up Susquehanna River Valley. Southwest to Northeast Trending Atmospheric Rivers Contained by Appalachian Mountains, where Orographic Uplift of Storm Cells Occurs.



1. **MD 355 Urgent Needs** Roadway Embankment Scour, Frederick, MD
2. **State Route 2075, Muddy Creek,** Tributary to the Susquehanna River, York County, PA
3. **State Route 1003, Wallis Run,** Tributary to Loyalsock Creek, Lycoming County, PA

Improving Resiliency & Sustainability of Vulnerable Infrastructure – Natural Channel Design Restoration

MD355-UNT Monocacy R, Frederick Co. MD

SR2075-Muddy Creek, South York Co. PA

SR1003-Wallis Run, Lycoming Co. PA



NCD Stream Restoration Tributary to Monocacy River

- *Infrastructure Stabilization Alternates: Walls, Slope Trtmnts w/ NCD Restoration*
- *Hard Shale Channel in Confined Narrow Valley w/ Roadway Encroachment*
- *Multiple Repeat Extreme Events Followed by Required Maintenance Riprap*



Scour Prone Roadway Embankment Infrastructure Constraints & Constructability Issues (MD-355 Urgent Needs)

Post-2015, May 2018, May 2019 | Repeat Extreme Storm-Flood Events (4-5" in 2-4 hours)



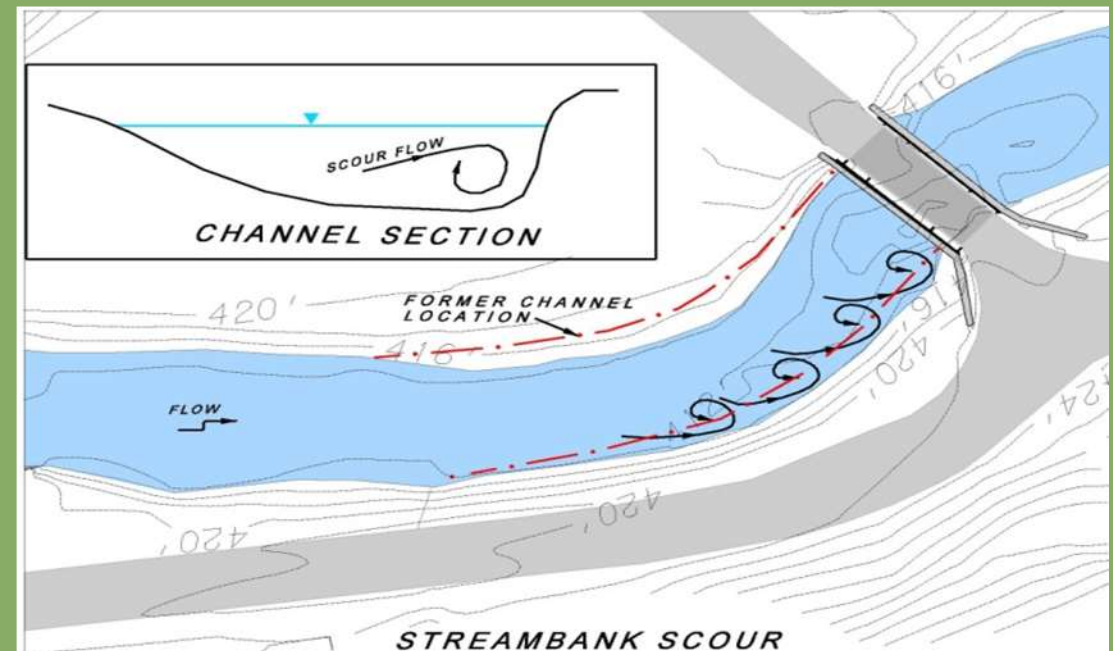
NCD Restoration Tributary to Monocacy River MD-355

*Infrastructure Stabilization- Restoration | Proprietary Wall, Imbricated or Rock Lined (NPS)
Scour Designed to Shear Stress Values: HEC-RAS Calibrated to D85%(20" Dia.) Particle Moved*



SR 2075 Bridge Replacement Over Muddy Creek, Tributary to the Susquehanna River

- Lower Piedmont, confined valley floodplain/deep alluvium/scour undercut right foundation
- Historic alterations- former railroad, RR bridge, RR station & roads
- Upper Chesapeake Bay area subject to frequent extreme events



SR 2075 Bridge Replacement Over Muddy Creek

Tributary to the Susquehanna River , Southern York County, PA

Isolated 7.5" Rainfall Event Over 4 Hours September 2001 & Again on August 31, 2018 – 8" Event in 3 Hours



BEFORE ABOVE



AFTER BELOW



Natural Stream Stabilization / Restoration at Structure Crossings

**Two Right Bank Rock J-Hook Vanes, Imbricated Rock Wall at Right Upstream Abutment with Downstream Bridge Cross-Vane*

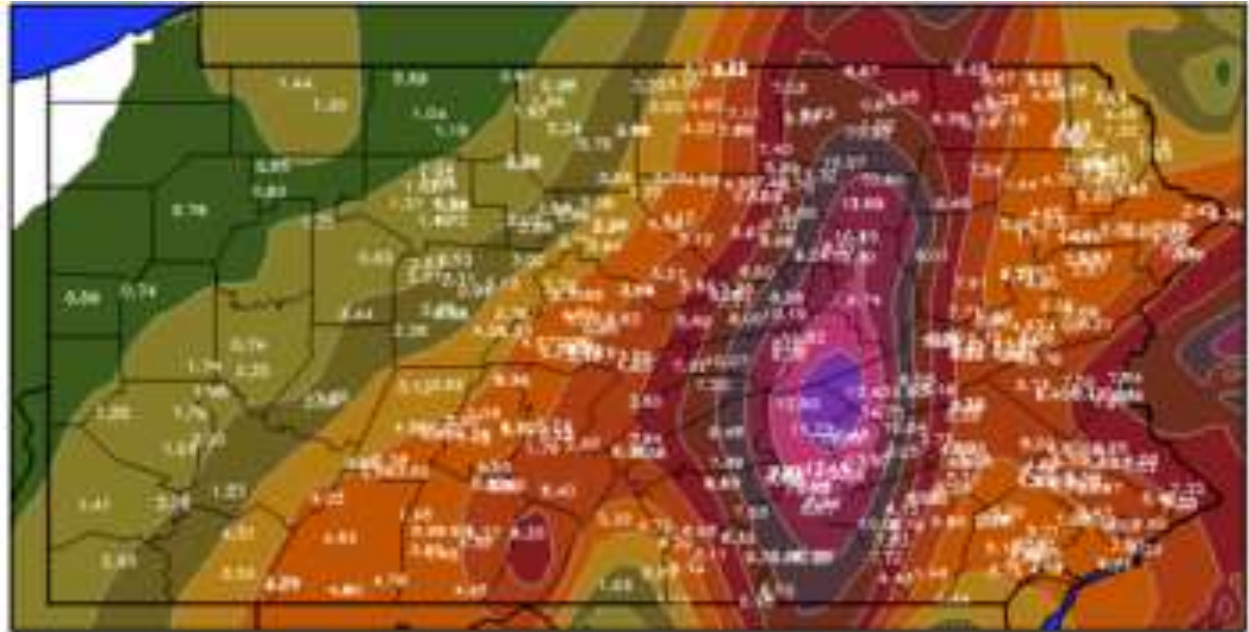
NCD – Stream Restoration Benefits:

- Reduced Sediment Discharge
- Stable Channels and Streams
- Scour Protected Bridges, Structures & Streambanks
- Stream Habitat and Fisheries Improvements
- **Improved Resiliency through Redundant Measures**



SR 1003, Bridge Replacement, Stream and Embankment Restoration, Wallis Run, Tributary to Loyalsock Creek

- Valley Ridge-Middle Section, Allegheny front, glacial outwash and terminal deposition
- **Confined hemlock forested valley, confluence grade flattening-deposition**
- Gas pipeline, 2-span bridge, road embankment infrastructure impacted
- **Prior damage, debris accumulation Tropical Storm Lee 8-9" September 8, 2011, (10 days post Irene) SHOWN**
- **Extreme Event S-N : October 21, 2016 : 8+" rainfall over 4.5 hours**



PA SR-1003 Over Wallis Run- Tributary to Loyalsock Creek

October 2016 Extreme Rainfall Event 8"+ 4.5 Hours, 36 SM DA: 1000-Yr Event
2-Span 20'X80' Bridge Deck Floated into Main Stem(See Top-Lower Left Image)



Stream Channel, Embankment, and Bridge Storm Damage(10-2016)

Loyalsock Creek, Lycoming County, PA

Opposing Loyalsock Bank Scoured 12-18' High

Deposits from 320' Long x 60-70' High Glacial Embankment Scoured by Event



Upstream Channel Restoration and Rock J-Vane Construction

*Rock J-Hook Vane designed to redirect flow away from embankment toe
Note Hemlock Debris & Snag in Tree – Level with track hoe arm- 16' flow depth*



- 3-5 ton rock vanes
- Constructed to bankfull elevation

Mid-Stream Restoration Embankment Reconstruction

Habitat Boulders Launched into Place after rolling downslope from Occasional Boulder Lost During Rock Embankment Construction



Bridge Replacement and Rock Cross Vane Completion

Scoured Bedrock-Right Bank / Point Bar on Glacial 60-feet+ to Rock- Left Bank



SR 1003 Bridge, Embankment, and Wallis Run Restoration

Completed September 2018



SR 1003 Wallis Run Restoration at Bridge Replacement

*Post-Construction September 2019- Repeat Extreme Event- Reconfigured Vane to J-Hook Vane
Greater Habitat-Flow Diversity Resulted on Wallis Run- Native Wild Trout Waters*



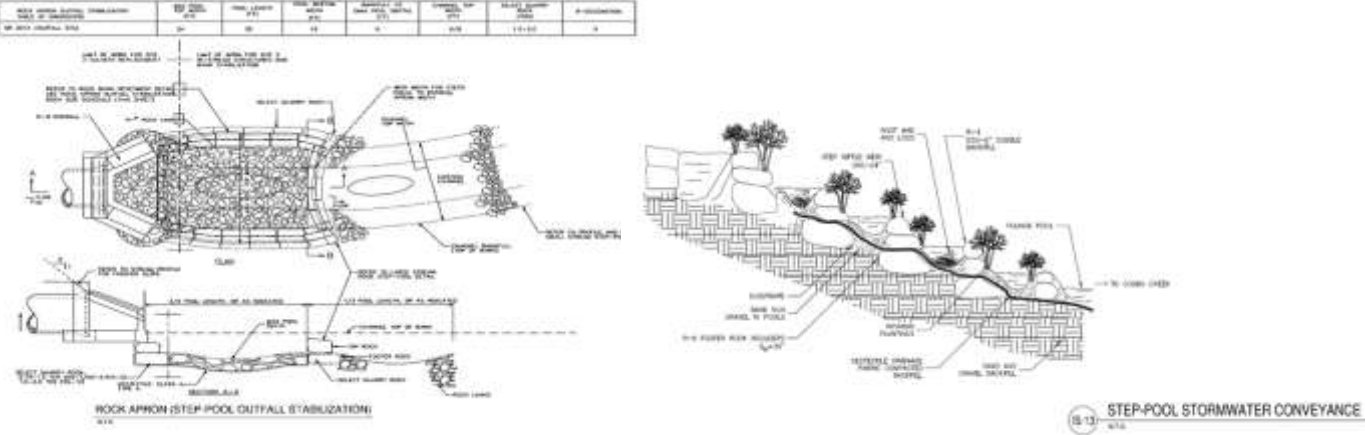
MS4 Stream Restoration TMDL Credit Examples

Sediment Pollutant Reduction (TMDL) (2018- Extreme Events)



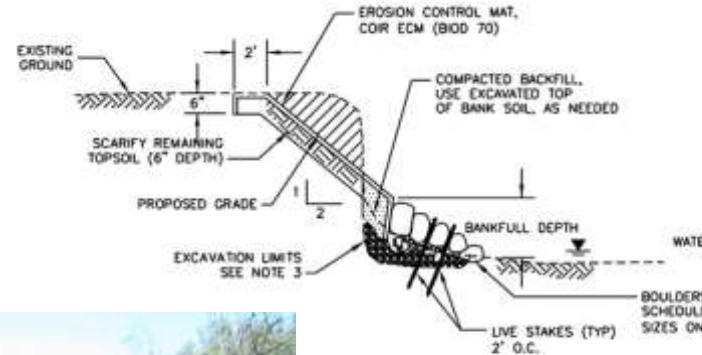
Priority 5: Outfall / Gully Step-Pool Restoration / Stabilization

- Potential locations within the RMS-BMS inventory system in each District
- MS4 Stream Restoration-Outfall Stabilization for Pollutant Reduction-TMDL Credits

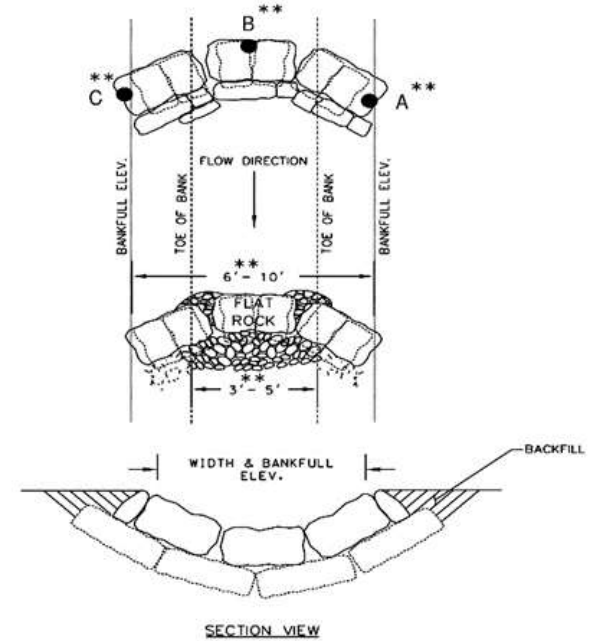


Channel Reconstruction Step-Pool Stabilization/Restoration

(Garland, TX Multiple Hurricanes & Extreme Weather Events-Infrastructure Impacts)



ROCK/BOULDER TOE BANK
N.T.S.



SECTION VIEW
SMALL STREAM TRIBUTARY ROCK STEP-POOL
N.T.S.

Source: Garland Texas Stream 2C (2019-11-23)

Extreme Storm – Flood & Scour Impacts to Local Infrastructure

Isolated Extreme Event- Upstream Rural Forested Watershed : Late May 2019



SR 2014 Over Bennetts Run

Fairfield Road - Montoursville, Lycoming County, PA

Sediment Impacted Small Drainage Area- Tributary WB Susquehanna River near Loyalsock Crk.



SR 2014 – Bennetts Run

2019 | July 30 Isolated Extreme Rainfall- Thunder Storm (1" in 15 minutes : 4"/ Hr Rate)

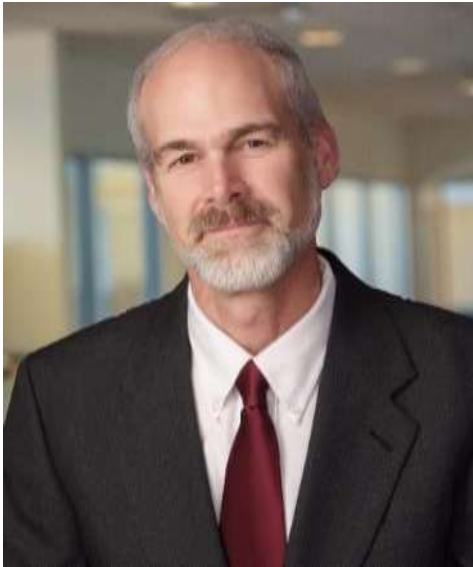


Warrensville Road Mill Creek, Lycoming County, PA

Extreme Storm – Flood Impacts, Upstream Embankment Toe Scour, Dry & Wet Slope-Landslides



Thank You for Attending & Please Reach Out with Questions!



Tom Graupensperger

Senior Scientist-NCD Restoration Designer

717.961.5098 / 717.576.8492

tgraupensperger@dewberry.com