Landslide Susceptibility GIS model of the SPC Region

University of Pittsburgh, Center for Impactful Resilient Infrastructure Science and Engineering

"Exploring Approaches to Managing Landslide Risks"
August 29, 2019

SPC

Ryan Gordon, MPA
Transportation Planner

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Hany Hassaballa (GISP, PE)
Sr. GIS Analyst

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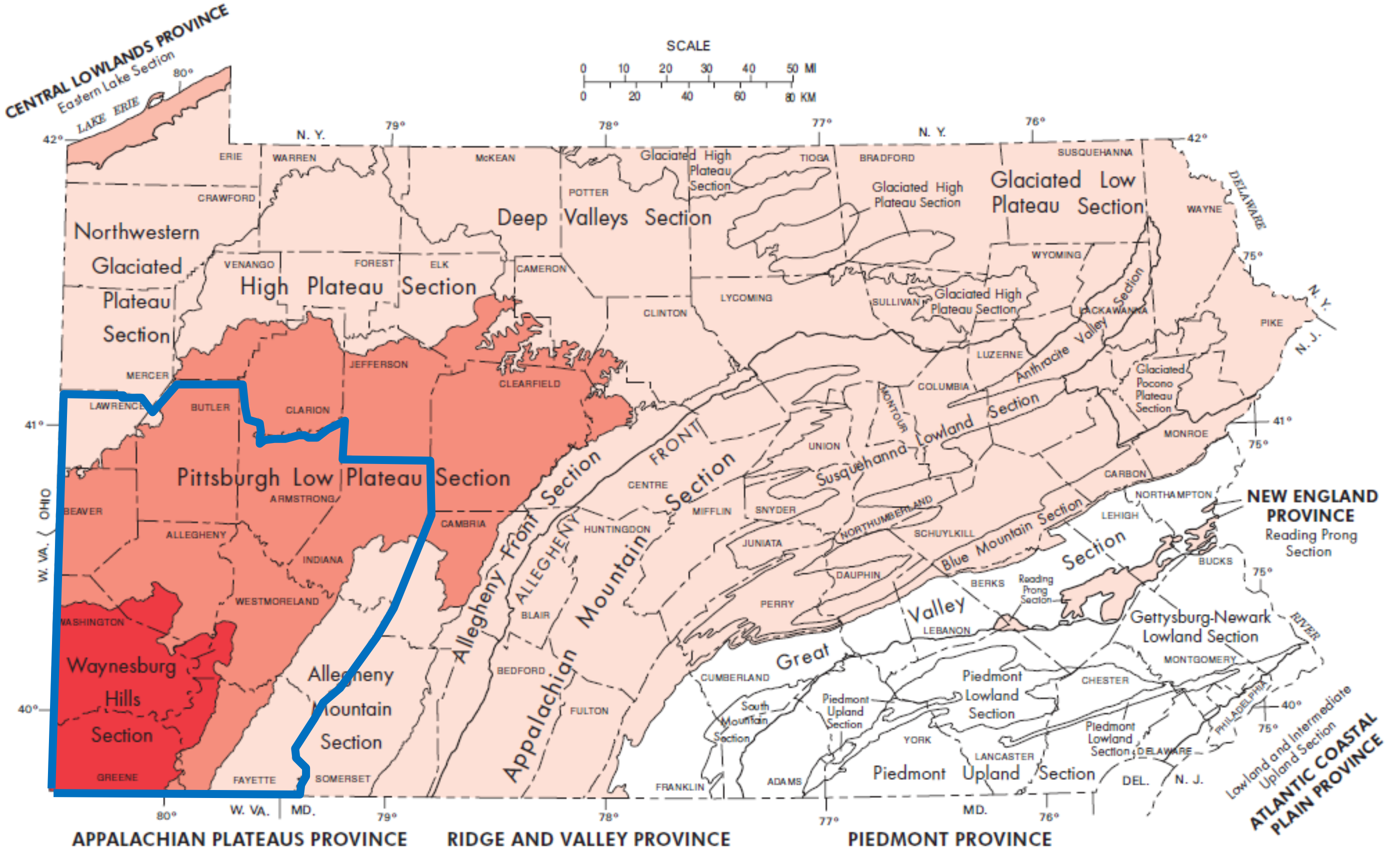
Landslides:

Impacts on Transportation Infrastructure



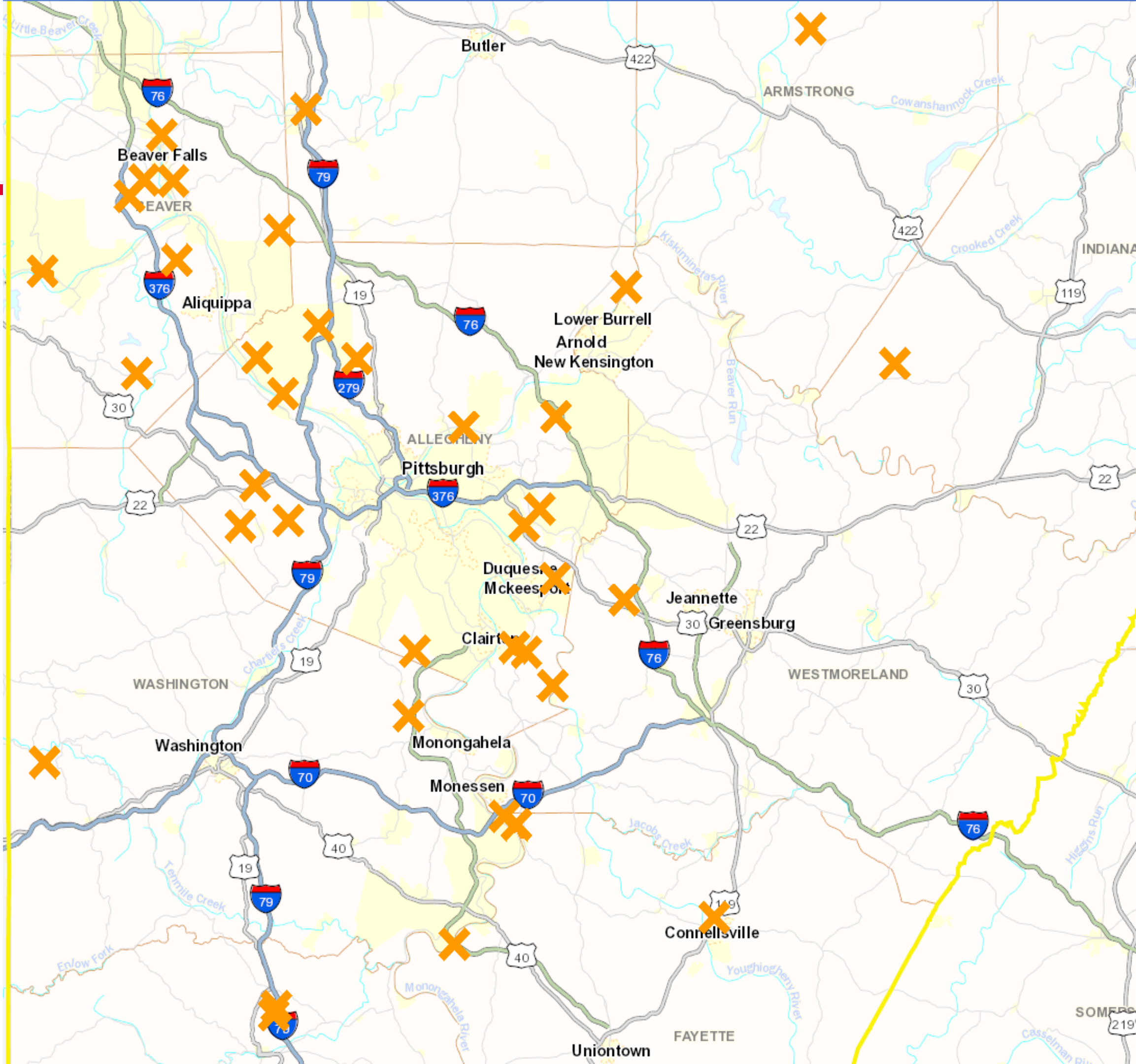
Highest
High to moderate
High along lake bluffs and stream banks
Generally low, but includes local areas of high to moderate
Generally low

Figure 1. The physiographic provinces and sections of Pennsylvania, and landslide susceptibility.

Financial Impact of Landslides on Transportation in the Region

- 2019 (current TIP) has $70 million in slide remediation projects and line items.
- 250 active slides in the District 12. Estimated repair cost exceeds $100 million
- 123 active slides in District 11. Estimated repair cost exceeds $91 million.
- In the 2019 Long Range plan we show several landslide reserves totaling $275 million for the life of the plan

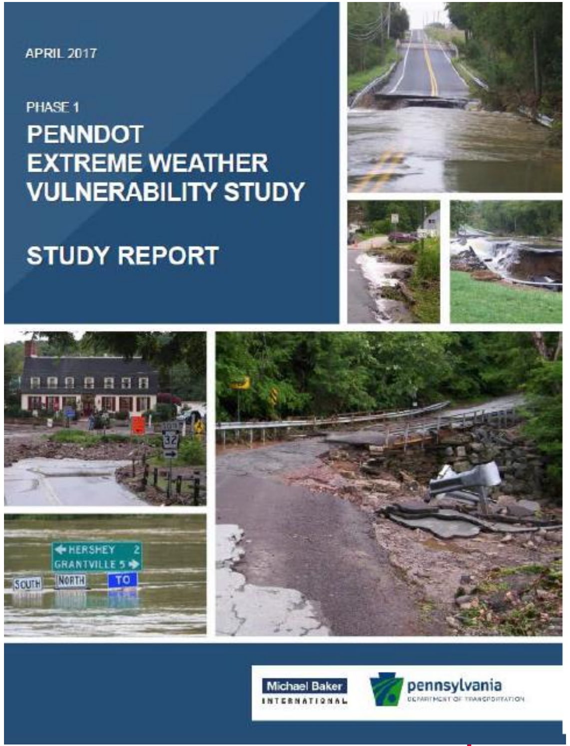
Current TIP
Slide Remediation Projects



Emphasis on Resiliency at Federal and State Level

- New Federal Transportation Planning Factor that MPOs shall consider and implement
  - "Improve resiliency and reliability of the transportation system and reduce or mitigate stormwater impacts of surface transportation"

- Metropolitan Transportation Planning (Section 1201):
  - Purpose statement for MPO Planning adds "Take into consideration resiliency needs"



SmartMoves
For a Changing Region

Resilient Communities

The revitalization of our communities will make us a magnet for new investment. Intensive investments in connectivity, walkable neighborhoods, and green infrastructure will attract business and residents to newer and older communities alike.

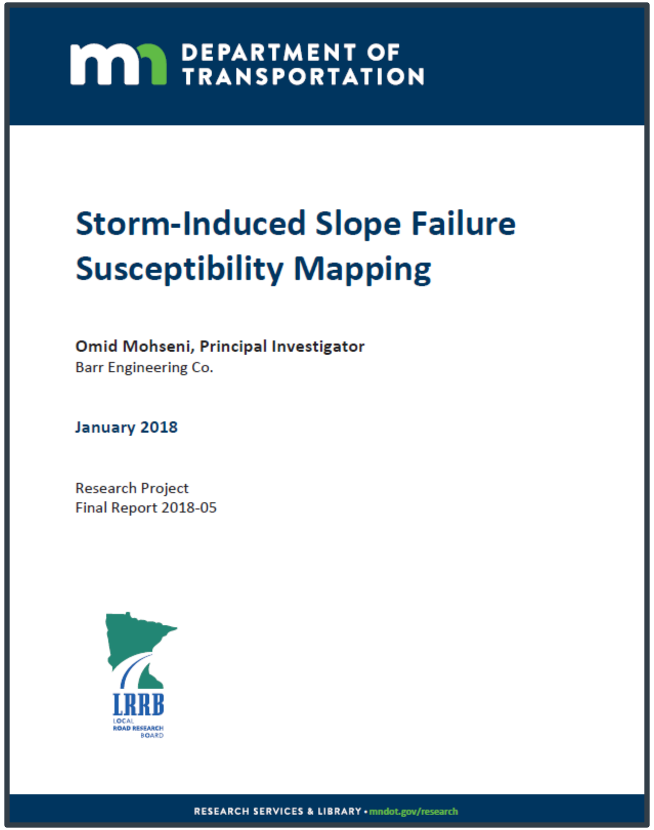
Resilient Communities – Elevate Community

- Promote institutional investment in older communities, repurposing versus demolition, and ensure that affordable housing is retained utilizing best practice models in the region for land use, vacant properties, and environmental strategies.
- Provide municipal education on land use best practices, "Smart Growth" principles, community development, transportation planning, and on existing mechanisms to leverage private sector development.
- Promote strategic infrastructure investment in communities that reduces physical exposure and vulnerability from natural hazards, including flooding and landslides.
- Embrace emerging infrastructure innovations & technologies including planning, design, materials and construction processes for an adaptable and resilient built environment.

Tackle Climate Change, Air & Water – The Earth Sustains Us

- Invest in strategies that adapt to and decelerate the impacts of climate change. This includes investment in disaster preparedness, response, and recovery, as well as, creating awareness about climate change, its projected impacts, and regional strategies.
- Conservation of the region's natural resource assets & key tracts of land that enhance environmental quality, natural land connectivity, habitat corridors, agricultural lands preservation & provides recreational opportunities for residents and tourists.
- Promote and support sustainable regional water resource management and planning for water topics, such as, stormwater, flooding, water quantity, water quality, and infrastructure systems.
- Support and encourage transportation projects or programs that will contribute to attainment or maintenance of the national ambient air quality standards (NAAQS) for ozone, carbon monoxide (CO), and particulate matter (PM).

Strategy Implementation – Landslide Susceptibility Mapping


DEPARTMENT OF TRANSPORTATION

Storm-Induced Slope Failure Susceptibility Mapping

Omid Mohseni, Principal Investigator
Barr Engineering Co.

January 2018

Research Project
Final Report 2018-05

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Advantages of the Methodology

- Significant time savings
- Applicable to a regional or county level
- Utilized existing datasets
- Previously utilized in a very similar way by MNDOT

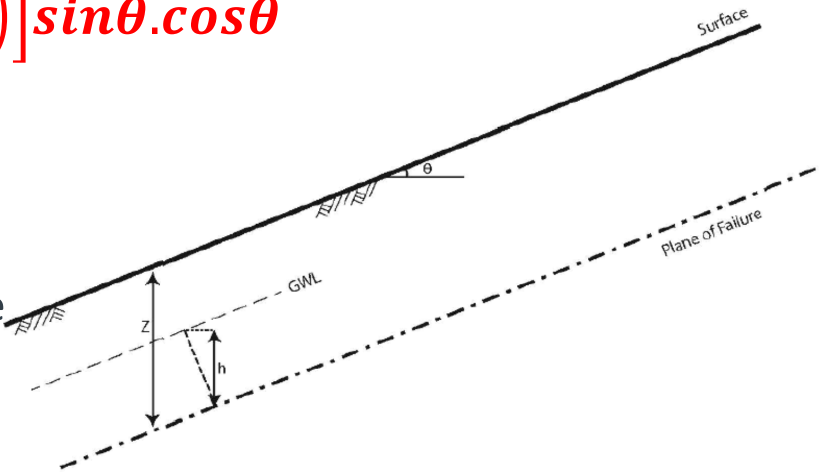
SPC Applications of the Landslide Susceptibility Model

- Help assess vulnerability of the current transportation network and anticipate potential impacts.
- Integrating resiliency elements into our TIP development process, assessing our TIP Candidate projects against the landslide model.
- Identify opportunities and adaptation strategies - May be able to address some slide-prone areas proactively where we have projects.

Applying Coulomb's Law of Friction to Soil Stability

$$FS = \frac{\hat{C} + [(\gamma_{sat} - \gamma_w) h / \cos^2\theta + \gamma(Z - h / \cos^2\theta)] \cos^2\theta . \tan\hat{\varphi}}{\left[\frac{\gamma_{sat} h}{\cos^2\theta} + \gamma\left(Z - \frac{h}{\cos^2\theta}\right)\right] \sin\theta . \cos\theta}$$

h is the level of water which can be used estimate amount of precipitation that can cause soil instability



Where:

FS= factor of safety

H= ground water level

γ_{sat} = is the specific weight of saturated soil

$\hat{\varphi}$=effective internal angle of friction

Ĉ=Apparent cohesion

γ=unit weight of soil under normal condition

γ_w=the specific weight of water

θ=the slope angel

Calculating Critical Head of Water

$$\mathrm{Hcr} = \frac{\dfrac{\hat{C}}{\gamma_w} - SG.Z.\cos^2\theta(\tan\theta - \tan\hat{\varphi}\Big)}{\cos^2\theta\big[(SG_{sat} - SG\big)(\tan\theta - \tan\hat{\varphi}) + \tan\hat{\varphi}\big]}$$

Derived by Okimura 1985 *Natural Disaster Science Magazine*

Where:

1. θ=the slope angel

2. $\hat{\varphi}$=effective internal angle of friction

3. $\hat{C}$=Apparent cohesion

4. SG= Specific gravity of soil

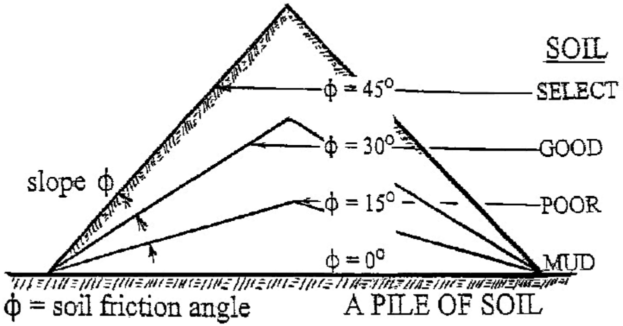
5. SG_{sat} =Saturated specific gravity of soil

6. Z= Soil Layer Depth

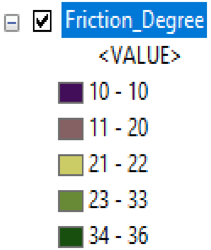
Internal Friction Angle

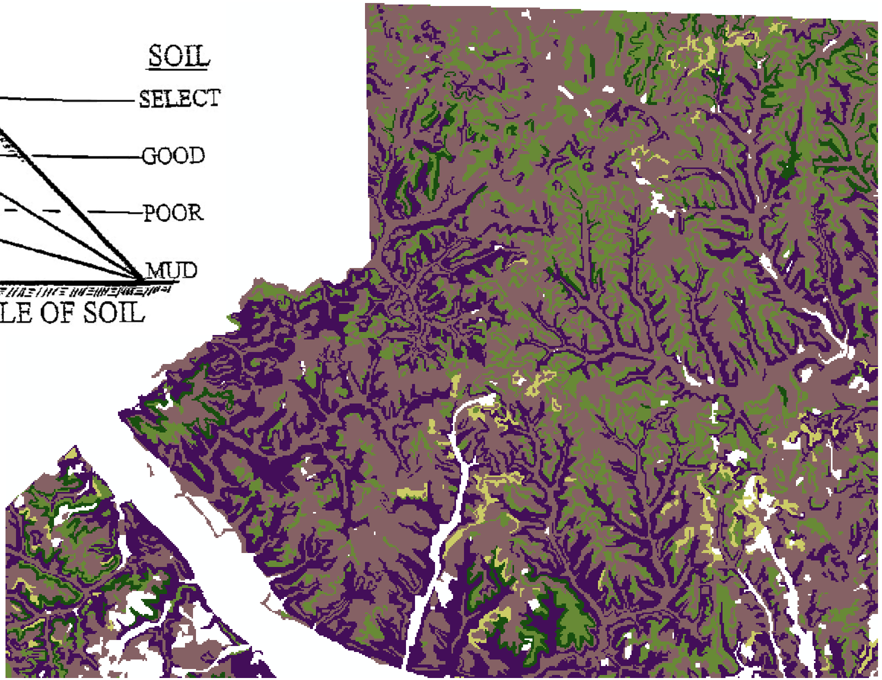
Friction Angle is one of two Factors that gives the soil its shear strength. This strength is due to friction between soil particles

$$Hcr = \frac{\dfrac{\overset{3}{\hat{C}}}{\gamma_w} - \overset{6}{SG}.Z.\cos^2\theta(\tan\overset{1}{\theta} - \tan\overset{2}{\hat{\varphi}})}{\cos^2\theta\left[(\underset{5}{SG_{sat}} - \underset{4}{SG})(\tan\theta - \tan\hat{\varphi}) + \tan\hat{\varphi}\right]}$$



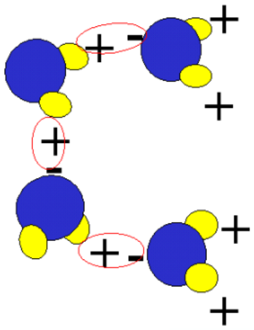
Soil Types	Soil Cohesion (kPa)	Angle of Internal friction (min)	Angle of Internal friction (max)	Porosity
Sand	0	30	35	0.43
Silty Loam	21	30	40	0.48
Loam	23	30	40	0.43
Silty Clay Loam	15	15	30	0.43
Clay	13.5	20	30	0.38
Talus	0	45	45	0.1

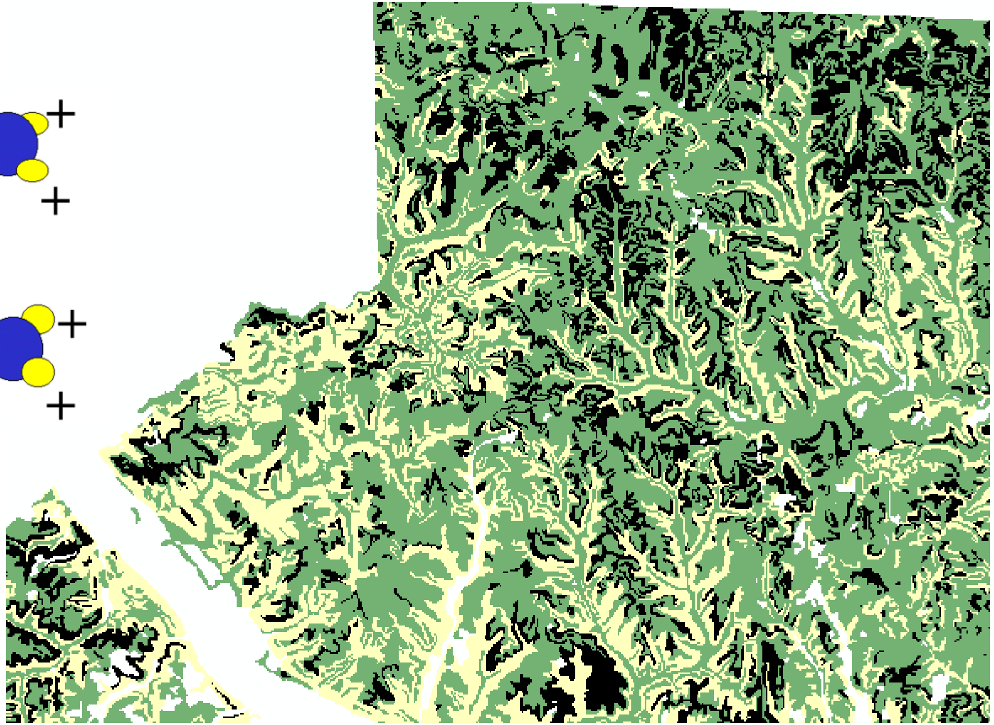




Cohesion

Cohesion is one of two factors that gives the soil its shear strength. It is due to Electrostatic attraction between fine soil particle.





$$Hcr = \frac{\frac{\hat{C}}{\gamma_w} - SG.Z.\cos^2\theta(\tan\theta - \tan\hat{\varphi})}{\cos^2\theta[(SG_{sat} - SG)(\tan\theta - \tan\hat{\varphi}) + \tan\hat{\varphi}]}$$

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Soil Specific Gravity & Saturated Specific Gravity

Specific Gravity of soil is Ratio between the density of soil and the density of Water:

$$Hcr = \frac{\frac{\hat{C}}{\gamma_w} - SG.Z.\cos^2\theta(\tan\theta - \tan\hat{\varphi})}{\cos^2\theta\left[(SG_{sat} - SG)(\tan\theta - \tan\hat{\varphi}) + \tan\hat{\varphi}\right]}$$

From SSURGO Database

$$\textit{Specific Gravity} = \frac{\textit{density of the object}}{\textit{density of water}} = \frac{\rho_{object}}{\rho_{H_2O}}$$

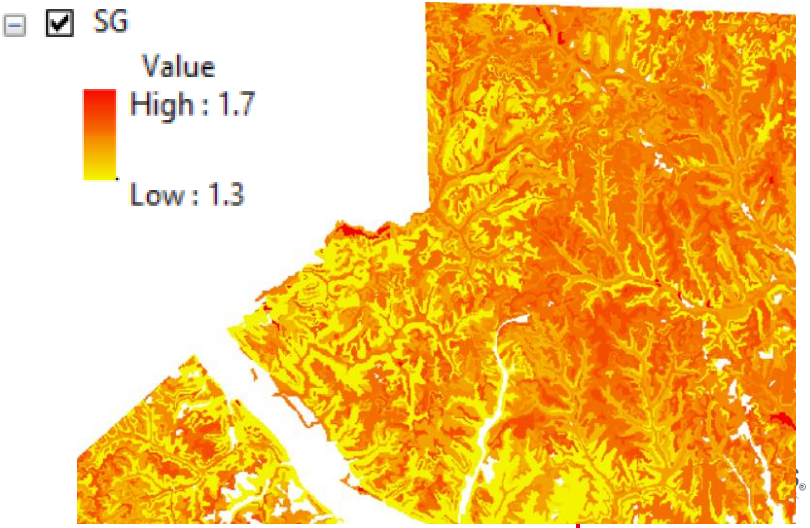
$$SG_{sat} = SG + (\eta - \vartheta_{FC})$$

Based on soil surface texture

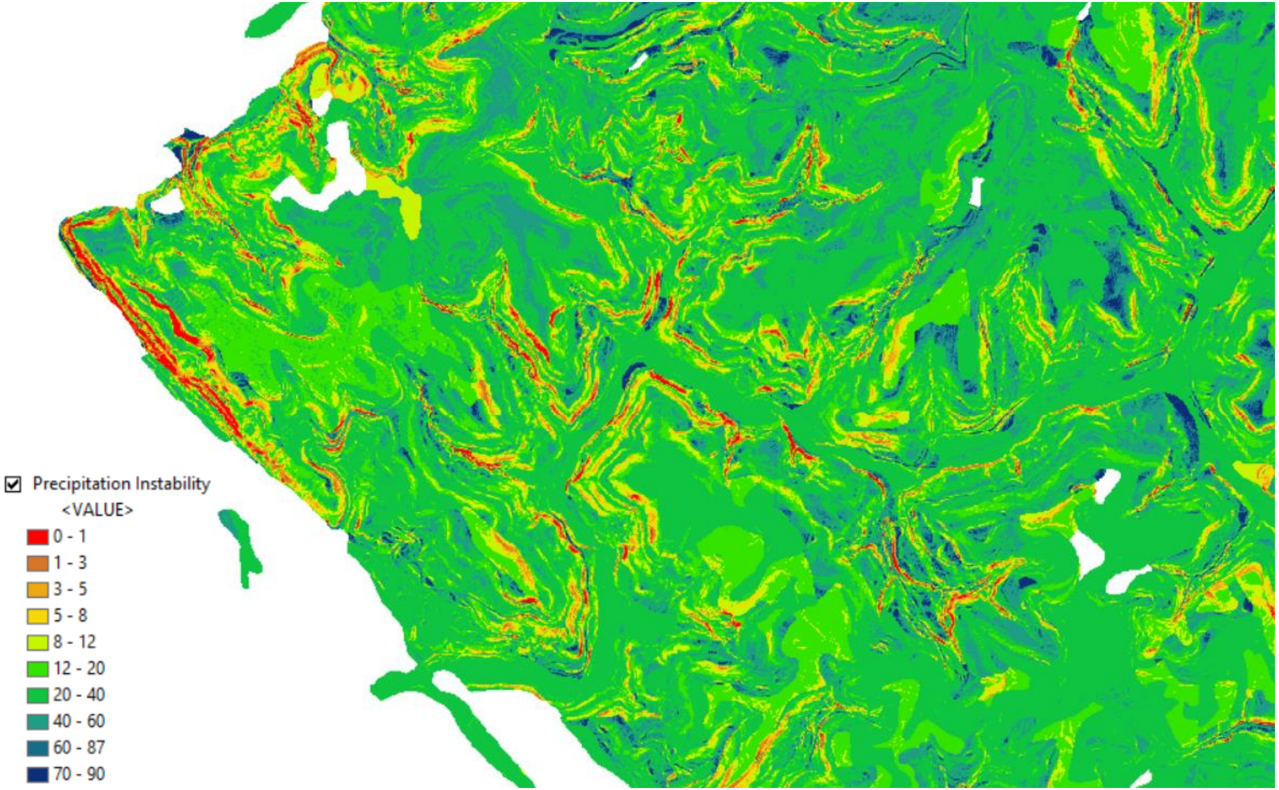
$$\eta = 1 - \frac{SG}{2.65}$$

Z = 6 FT

More realistic results than other values



Calculating Critical Head of water Hcr & F (Rain Infiltration)



$$Hcr = \frac{\frac{\hat{C}}{\gamma_w} - SG.Z.\cos^2\theta(\tan\theta - \tan\hat{\varphi})}{\cos^2\theta[(SG_{sat} - SG)(\tan\theta - \tan\hat{\varphi}) + \tan\hat{\varphi}]}$$

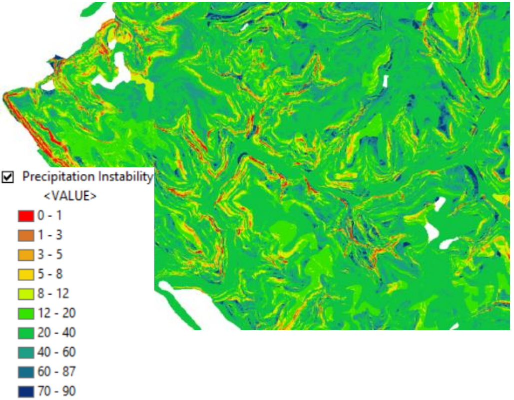
3 6 1 2 5 4

$$F = H_{cr}\cos^2\theta\underbrace{(\eta - \boldsymbol{\vartheta}_{FC})}$$

Take into consideration field capacity status of soil

Comparing storm precipitation to maximum water Infiltration

$$Hcr - Storm\ Precipitation\ (in\ inches)$$



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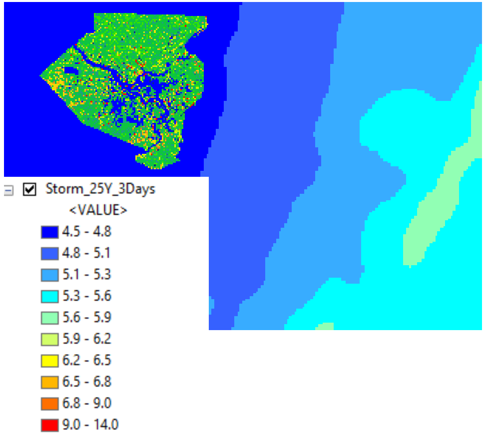

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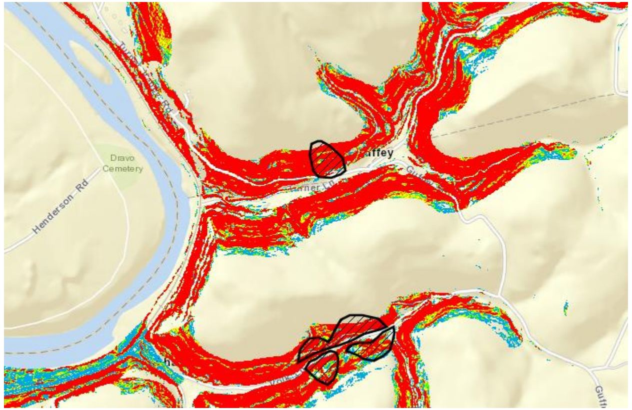

Create surfaces for

- 25 Year Strom (inches) → Very High Susceptibility
- 50 Year Strom (inches) → High Susceptibility
- 100 Year Strom (inches) → Moderate Susceptibility
- 200 Year Strom (inches) → Low Susceptibility
- 1000 Year Strom (inches) → Very Low Susceptibility

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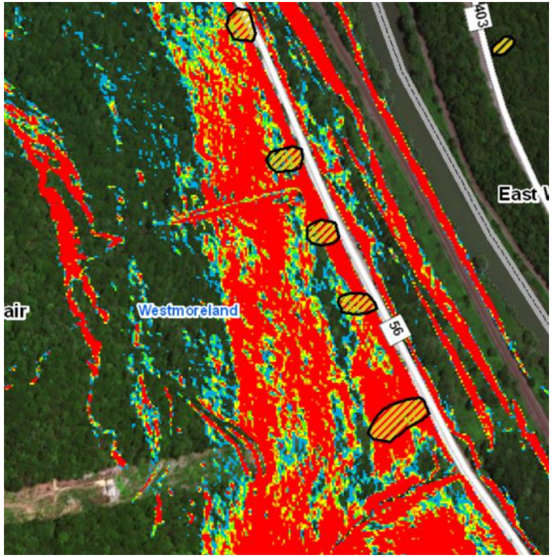
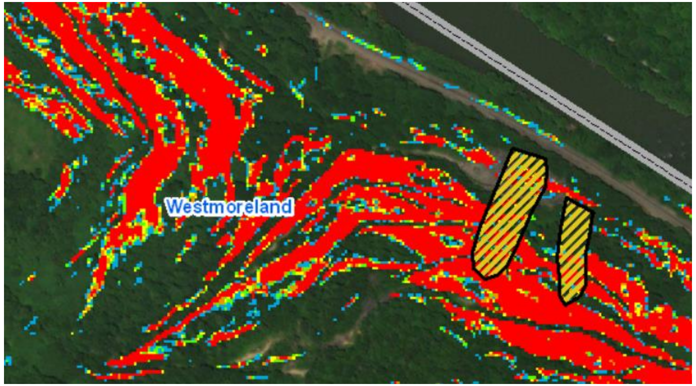
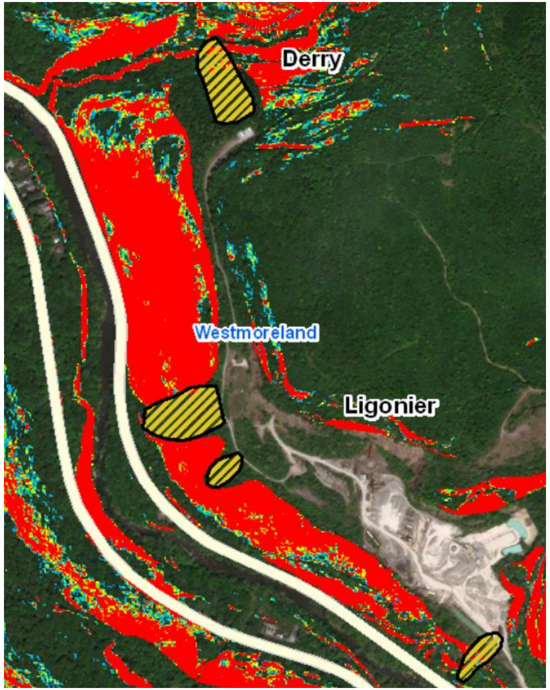
Example of Model Results

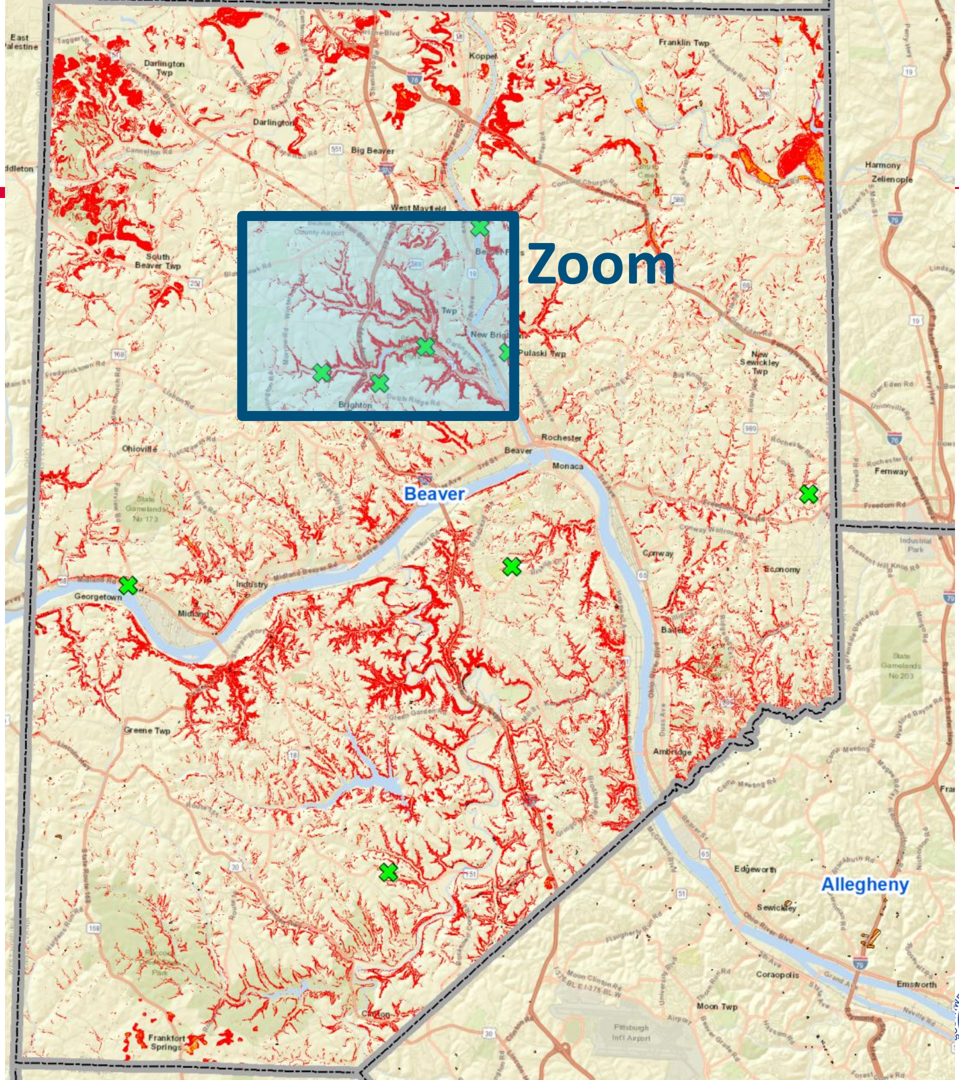






Current TIP Slide Remediation Projects

- Current Slide Remediation Projects in Beaver County on the current 2019 TIP
- 9 projects ($5.8 million)



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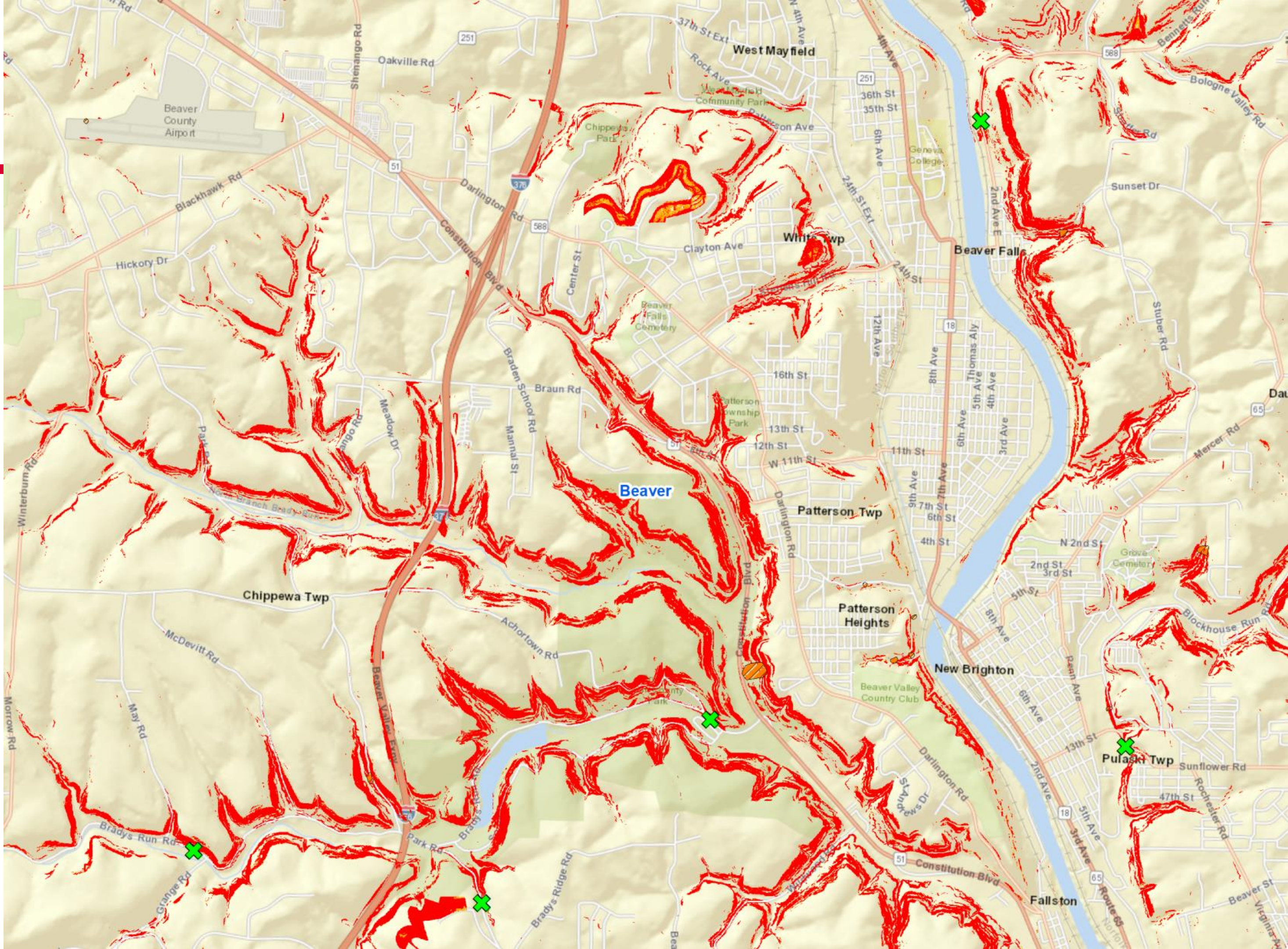
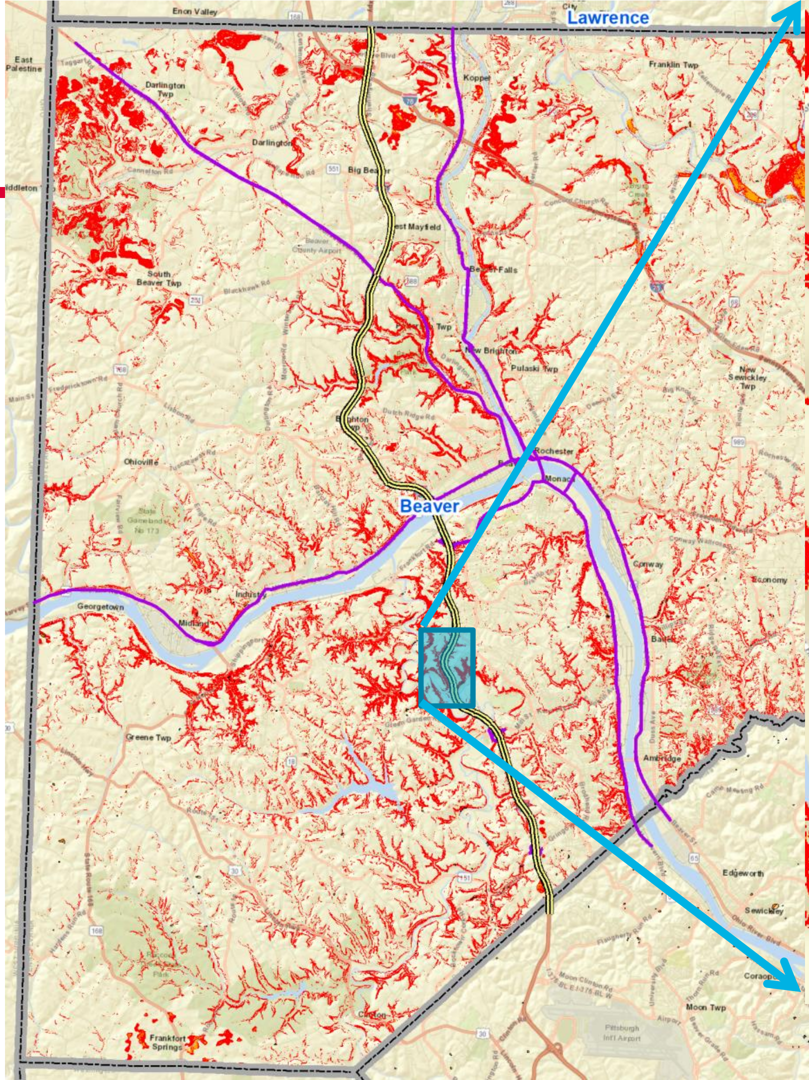
Zoom area

- Model predicting well where slides occurred.



Analysis of Potential Impact by Network (Interstate)

- What networks and corridors have the highest exposure and vulnerability to landslides?
- Where are the critical potential impact areas?
- Where do we need to possibly update detour routes and contingency plans.



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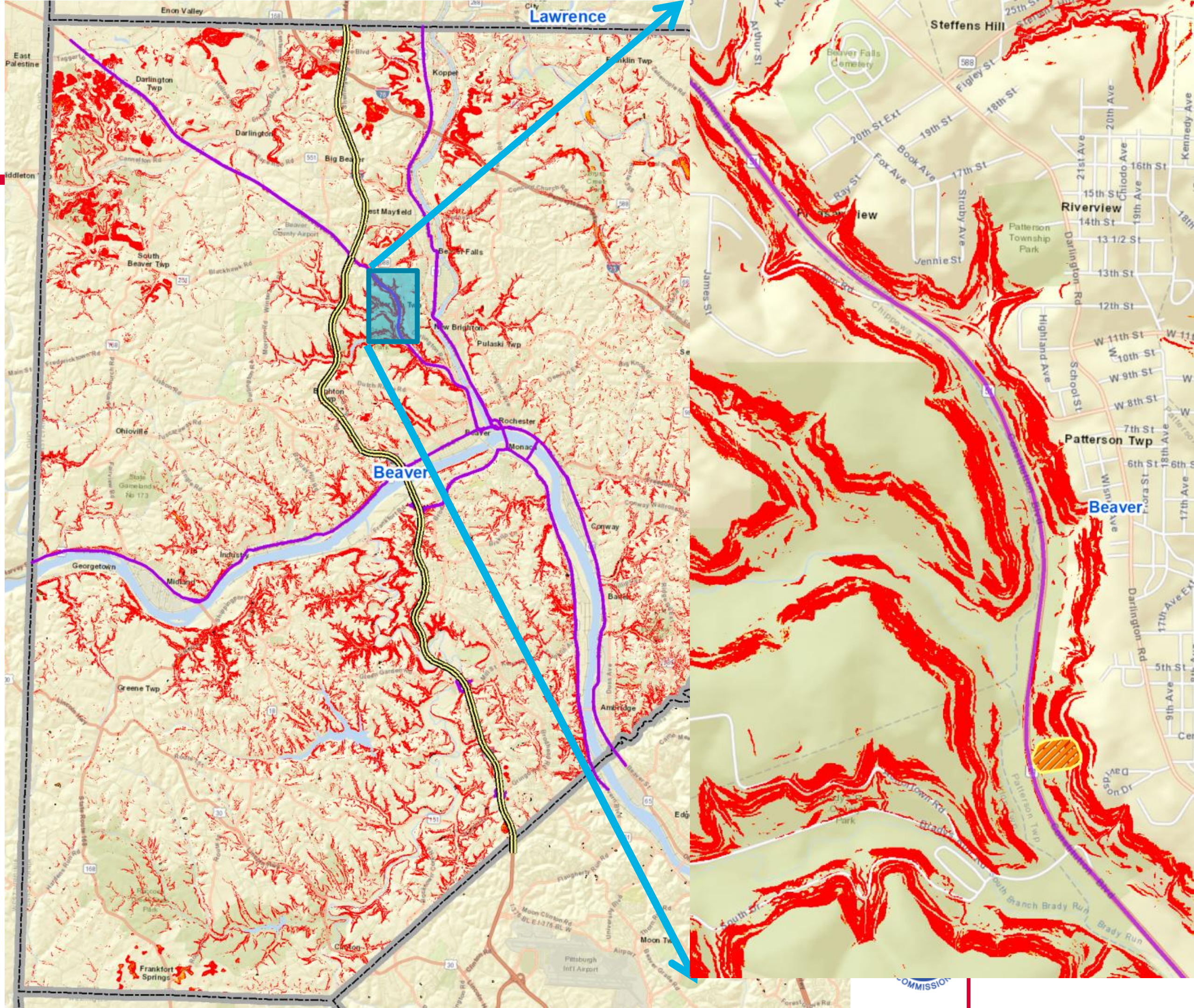
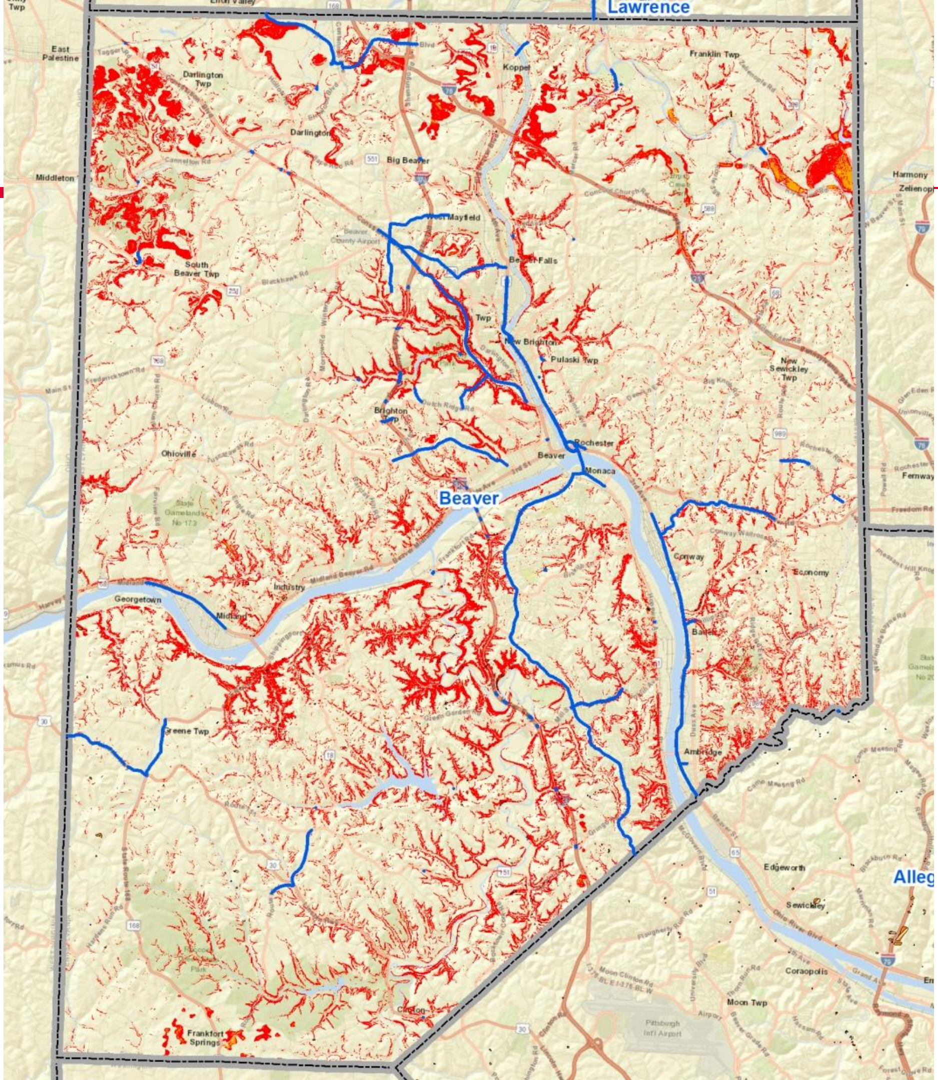
Analysis of Potential Impact by Network (NHS)

- What networks and corridors have the highest exposure and vulnerability to landslides?
- Where are the critical potential impact areas?
- Where do we need to possibly update detour routes and contingency plans.



12-Year Program Projects

- Looking at mid-range program of planned projects. Do we have any upcoming projects in our most critical vulnerable areas?
- What upcoming projects have the best prospects for implementing adaptation strategies in to the project scope.
- Where is the best place to invest in any proactive adaptation measures.
- TIP candidate projects where project scopes and costs may need to be modified.



Other Potential Applications

Sharing this data and collaborating with our PennDOT districts and our member planning departments for assistance in:

- Landslide data portals (Allegheny)
- Hazard Mitigation Planning
- Development review
- Comprehensive Planning
- Detour preparedness and evaluation
- Identifying areas for more in-depth prioritizing/mitigation.

Thank You