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Resilience and Durability to Extreme Weather Pilot Project: Pennsylvania Department of Transportation

Resilience and Durability Pilot Projects 2018 – 2020
The Federal Highway Administration (FHWA) partnered with eleven pilot project teams to assess and deploy resilience solutions. This case study is part of a series that summarizes the pilot projects and highlights transportation system resilience efforts at other agencies across the country. For more information, visit https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/extweatherpilot.cfm.

Summary
The Pennsylvania Department of Transportation (PennDOT) built upon prior research on extreme weather vulnerability and existing processes for hydrologic and hydraulic assessments to address impacts of more intense and frequent precipitation events under future climate scenarios.

Key Takeaways
- Evaluating climate models and future precipitation estimates allowed PennDOT to distill the scenarios most useful to inform the design process.
- PennDOT's pilot study highlighted the importance of conducting precipitation analysis on additional sites due to regional variability.
- PennDOT identified and fulfilled a need for a resilient design checklist and an adaptation strategy toolbox to help designers navigate challenging design processes.

Objectives

PennDOT conducted a pilot study to support the development of processes and procedures to assess potential flooding vulnerabilities and risks related to transportation infrastructure. The study evaluated possible methods for incorporating future precipitation scenarios into hydrologic and hydraulic (H&H) procedures as part of the PennDOT design process. The analyses conducted for the pilot study aimed to meet the following goals:

- Address climate change in H&H studies and evaluate use of ratios to increase existing precipitation to obtain future estimates. These precipitation ratios can also be thought of as adjustment factors or factors of safety.
- Evaluate the range of precipitation ratios that are reasonable and how they vary by region, as well as the impact of increased precipitation on H&H outputs.
- Evaluate if higher precipitation events result in changes to design and what additional adaptive design strategies may be needed to improve resiliency. Estimate the additional design costs.

Scope

PennDOT's study included expanded versions of the H&H assessments typically conducted to obtain environmental permits. The assessments went beyond existing PennDOT procedures to address the impacts of more intense and frequent precipitation events under future climate scenarios. Assessments were conducted at three sites in separate counties within Pennsylvania: Baker Road over Little Conewago Creek in York County, Streets Run Road / Baldwin Road along Streets Run in Allegheny County, and Station Road Bridge over East Branch of Chester Creek in Delaware County (Figure 1). The H&H assessments include existing hydraulic performance, future hydrology and hydraulic model results, resilient design options, and an economic analysis for the resilient design options, among other components.

Figure 1. From left to right: Baker Road in York County, Streets Run Road / Baldwin Road in Allegheny County, and Station Road Bridge in Delaware County. Source: PennDOT.

Approach

Evaluating Site Locations

PennDOT sought to select three sites from three separate counties to provide insights into the geographic differences of projected precipitation and land use changes. Regional metropolitan planning organizations and PennDOT District Offices identified candidate sites based on bridge and roadway locations that are generally seen as high risk for flooding as determined from PennDOT's 2017 Extreme Weather Vulnerability Study and local knowledge. Data were collected on all candidate sites and the sites were then prioritized based on a set of desirable characteristics, such as availability of existing hydraulic modeling and bridges with existing flood issues.

Analyzing Future Precipitation

Guided by recommended practices published by FHWA and the Transportation Research Board National Cooperative Highway Research Program, PennDOT analyzed future precipitation for 2050 and 2100 using two Representative Concentration Pathways (RCPs), which are scenarios that categorize a range of future greenhouse gas emissions; eight global climate models (GCMs); and the Localized Constructed Analogs dataset for downscaling the GCM outputs in a way that is useful for engineering and hydrologic analyses. PennDOT used RCP 4.5 and RCP 8.5 in the analysis. RCP 4.5 is a scenario with moderate emissions increases until 2080, after which emissions level off. RCP 8.5 is a scenario indicative of continued use of fossil fuels and a large increase in emissions.

Developing Precipitation Ratios

Using the datasets mentioned above, PennDOT conducted analyses at all three sites to obtain a ratio of future to historical daily precipitation that can be used to adjust existing conditions precipitation to future conditions. Ratios were calculated for annual exceedance probabilities (AEPs) ranging from 0.5 (2-year event) to 0.002 (500-year event). In addition to the three sites, PennDOT calculated precipitation ratios for an additional seven counties in different regions in Pennsylvania to gain a better understanding of how GCM results vary statewide.

Estimating Future Flood Discharges

Precipitation projections are used to estimate discharges that can inform the values of key hydraulic parameters needed for assessment of resiliency design options. For the three site analyses conducted for this study, PennDOT integrated future precipitation depths using the U.S. Army Corps of Engineers' Hydrologic Modeling System, HEC-HMS. The three analyses use the precipitation ratio for 0.10 AEP event for evaluating alternative adaptive options since it is more stable and reasonable across all GCMs and provides more reasonable estimates of future flood discharges.

Evaluating Impacts and Identifying Resilient Design Strategies

PennDOT used the HEC-RAS hydraulic model, also developed by the U.S. Army Corps of Engineers, to estimate flood elevations and velocities and evaluate the impacts on bridges and roadways. To assist in the evaluation of the need for various resilient design options for each site-specific analysis, PennDOT developed two resilient design checklists: one applicable to typical bridge projects and one applicable to roadways that parallel streams or rivers. Each checklist includes a "Potential for Resilient Design" column coded with low, medium, or high to indicate the level of potential for resilient design considerations.

Key Results & Findings

Precipitation Ratios

Ratios were estimated for both 2050 and 2100 and for RCP 4.5 and RCP 8.5. For some GCMs, precipitation ratios were higher for 2050 than 2100 and higher for RCP 4.5 than RCP 8.5, which PennDOT determined to be unrealistic. Therefore, the precipitation data for 2050 and RCP 4.5 were not used in evaluating adaptive design options for any of the sites. The variation is attributed to model uncertainty and the fact that the emission scenarios do not differ much at 2050. Figure 2 shows the average precipitation ratios generated by all GCMs at the study sites for the RCP 8.5 2100 scenario. Ratios higher than 1.0 imply increased future precipitation.

In addition to the three sites, precipitation ratios were obtained for an additional seven counties in different regions of Pennsylvania using the same procedures. The average precipitation ratios for the additional counties were not sufficient to define a regional trend. However, the average precipitation ratios for the more extreme events (0.01 and 0.002 AEP) appear to be highest in the central and northeastern parts of the State that include York, Cambria, Clearfield, Northumberland and Wayne Counties. Additional data and further analyses are recommended to determine if the precipitation ratios vary with topographic and/or climatic characteristics.

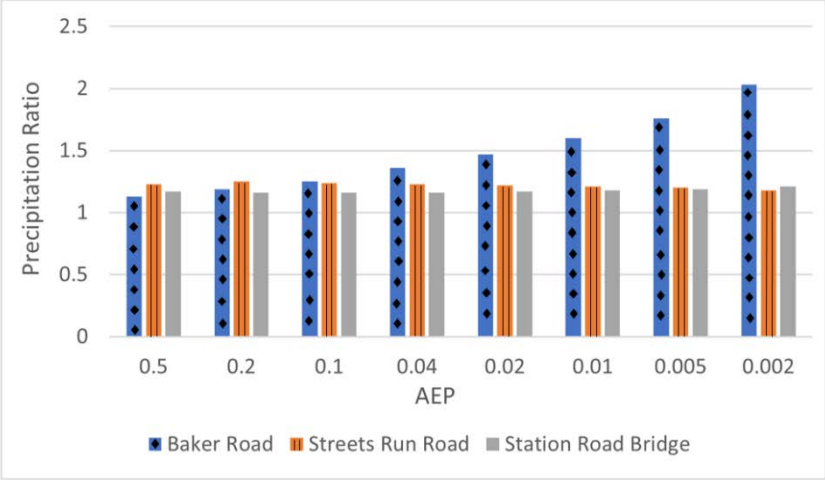

Figure 2. Precipitation ratios at study sites for the RCP 8.5 2100 scenario. Source: PennDOT.

Individual Site Analyses

PennDOT completed H&H assessments for the three sites to illustrate the application of projected precipitation ratios and to evaluate adaptation options. The assessments apply the concepts and results provided in the previous sections using the HEC-HMS and HEC-RAS modeling software. For all three sites, water surface elevations and channel velocities are projected to increase in future conditions. Frequency and extent of overtopping is also projected to increase in future conditions. For each site, resilient design checklists provided options to address identified issues and a preliminary economic analysis was conducted to estimate cost of implementation. The complete assessments are part of PennDOT's Final Pilot Report, available at https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/.

Lessons Learned

The pilot study's research into the potential application of future precipitation to PennDOT's H&H analyses process resulted in several lessons learned for PennDOT:

- PennDOT found significant variability of GCM models across individual models, areas within the State, RCP scenarios, and analysis years, and determined the RCP 4.5 and 2050 scenarios not to be useful for the alternative adaptive design options for the three pilot sites.
- PennDOT determined that applying the results of GCM precipitation forecasts to the design process requires careful consideration. Directly applying GCM results for low probability precipitation events could result in very high design stream discharges requiring expensive or unreasonable resiliency improvement actions to address.
- Identifying cost-effective adaptation strategies for individual sites is a difficult process requiring expertise from technical staff across multiple disciplines. Designers may benefit from an adaptation strategy toolbox with successfully implemented strategies and potential costs and considerations.
- Each project site will have its own specific issues and must be assessed individually. A risk-based approach should be considered wherein factors such as potential loss of life, length of detour if road is closed, and potential for overtopping to cause significant erosion are considered when prioritizing resilient design options.
- Precipitation ratios, or "factors of safety," can be applied to precipitation analyses used for infrastructure design to reflect future increases in peak flows at high risk locations. While sample values were estimated for three study areas, the results may be applicable for other areas in Pennsylvania.
- A resilient design checklist is recommended to assist in the evaluation of site-specific resilient design options. It consists of hydraulic parameters compared between existing and future conditions to determine if the site will be more vulnerable to issues such as scour, stability, and roadway overtopping.

Next Steps

To build on the pilot study, PennDOT identified the following next steps:

- PennDOT recommends future precipitation analyses be conducted for at least 15 more sites in addition to the 10 sites analyzed in this study to better define regional trends.
- U.S. Geological Survey regression equations for Pennsylvania cannot be used to predict future discharges due to a lack of a statistically significant precipitation variable for the defined hydrologic regions, but approaches could be explored to evaluate application of precipitation projections into regression equations.
- PennDOT's Extreme Weather Vulnerability Study identified example adaptation strategies and an associated toolbox as a starting point for improving resilience of Pennsylvania's transportation system, but additional steps are needed to review and assess viable strategies.

For More Information

Resources

PennDOT Final Pilot Report:
https://www.fhwa.dot.gov/environment/sustainability/resilience/pilots/

PennDOT Extreme Weather Vulnerability Study:
https://www.penndot.gov/ProjectAndPrograms/Planning/Pages/default.aspx

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