



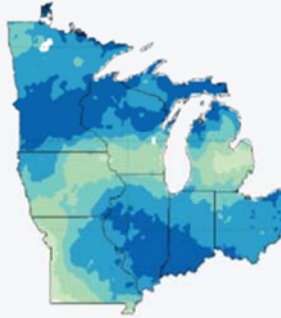
FINAL REPORT

OHIO DOT INFRASTRUCTURE RESILIENCY PLAN

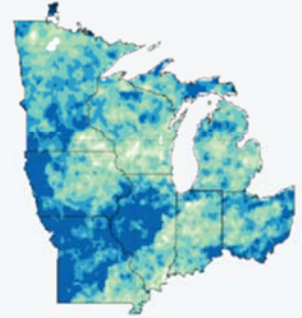
5.6.2016



Annual Average Precipitation



Heavy Precipitation



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OHIO DEPARTMENT OF TRANSPORTATION

SUBMITTED BY:
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EXECUTIVE SUMMARY

The key objective of this study is to identify the vulnerability of ODOT's transportation infrastructure to climate change effects and extreme weather events. The analysis includes a discussion and analysis of the type of transportation assets vulnerable, the degree of exposure, sensitivity, adaptive capacity, and the potential approaches to adapt to these changes.

The work completed with this study includes:

- Understanding the vulnerability of ODOT's overall transportation system to climate change;
- Determining potential consequences from a broad range of potential climate impacts;
- Identifying facilities at risk to climate change impacts within Ohio by type;
- Identify range of adaptation and/or sustainability options (activities) that ODOT should consider in detail in future adaptation studies
- Providing the foundation for ODOT to integrate the results of this vulnerability assessment into future decision making processes and future adaptation/resiliency studies.

The core project team for this study includes ODOT Office of Environmental Services staff and RSG, ODOT's contractor. Over the course of the study, numerous ODOT staff were consulted (see Appendix A), as were several state and national experts in the climate change field:

- ODOT's Office of Tech Services, Office of Systems Planning and the Office of Statewide Planning to assess ODOT's long-range planning and GIS assets available.
- ODOT's maintenance staff in each of ODOT's 12 Districts to identify transportation assets impact areas and focus areas for the future.
- ODOT's design teams (e.g. structural, hydraulic, geotechnical, pavement) to identify sensitivity of infrastructure to climate impacts and ideas/costs for adaptation solutions.
- MPOs (Columbus and Cincinnati) within Ohio who have already conducted some level of climate change analysis.

Utilizing ODOT's existing GIS systems, the project team developed additional GIS mapping and analytics to evaluate the vulnerability of ODOT's infrastructure to climate change effects. This effort determined that the primary climate change effect of concern is the increased incidence of heavy precipitation events, which will impair the functioning of core assets -- highways, bridges, and culverts.

A set of adaptive responses are described that will need to be further detailed by an ongoing effort within ODOT. **A key action item of this study is the designation of a specialist within ODOT to manage a divisional cross-cutting effort to maintain the Department's focus on**

vulnerability to climate change impacts to core infrastructure. A summary of this study's recommendations is below:

1. Identify lead office within ODOT-Office of Planning.
2. Annual Tasks of the Resiliency Lead (selected items):
 - a. Issues, data collection and analysis that need to be monitored on an ongoing basis, as part of input to ODOT's transportation planning function.
 - b. What climate stressors will affect the proposed facility either directly or through effects on the surrounding ecology?
 - c. What are the impacts of these stressors on the affected environment for the facility (and to what extent is any proposed facility in an area vulnerable to climate change)?
 - d. What are the recommended strategies for protecting the function and purpose of the proposed facility?
 1. Ongoing weather data analytics to understand the geographic location and severity of the emergency declarations and the amount of funds provided for emergency relief.
 2. Improve data collection for weather-related hazard events. Include "Prior flood hazard" as a data element within the department's GIS system. Assign responsibility for updating the data on a regular basis.
3. Ongoing refinement of VAST model for the 3 asset types (highways, bridges, culverts):
 - a. Initial refinement of scales and weights in VAST model based on input from Districts.
 - b. Annual inspection visit to the top ranked vulnerable assets in each asset class. Revise VAST model as necessary to conform to best data/knowledge from USGS and from field inspections.
 - c. Update list of critical facilities, re run VAST to determine whether there is a different prioritization of assets. Critical facilities, in the current model, consist solely of regional medical centers. Traffic operations centers, ODOT regional maintenance facilities, and emergency response system components (e.g. fire, EMS, and police) could be added to the vulnerability assessment model.
 - d. Expand the VAST model to other facilities.
4. Interagency Coordination:
 - a. Coordinate with ODOT Emergency Transportation Operations
 - b. Follow-up with districts which expressed a potential for improvement in each of the topic areas surveyed, in order to understand what can and should be done in light of this information.



- c. Implementation of formal “after action” reviews as an essential component of the continuous improvement philosophy under the Incident Command Structure (ICS) / Continuity of Operations / Continuity Program Management Cycle (<https://www.fema.gov/continuity-operations>)
- d. Coordinate with ODOT Asset Management,
- e. Develop advisory team of ODOT and extra-ODOT, including climate scientists from USGS/NWS.





OHIO DOT INFRASTRUCTURE RESILIENCY PLAN

PREPARED FOR:
OHIO DEPARTMENT OF TRANSPORTATION

CONTENTS

INTRODUCTION TO THE OHIO DOT INFRASTRUCTURE RESILIENCY PLAN	1
Framework of the Vulnerability Study	2
PREDOMINANT CLIMATE CHANGE TRENDS	3
Global Processes Driving Climate Change	3
Recent Climate Changes in Ohio	4
Projected Climate Effects in Ohio	8
Warming Trends in Ohio	10
Precipitation Trends in Ohio	15
Lake Erie Water Level	16
How is Climate Change Affecting Different Parts of Ohio?	18
Potential for Climate Change Impacts in Other Parts of the Country to Impact Ohio	19
IMPACTS TO TRANSPORTATION ASSETS	20
Impacts of Rising Temperatures	20
Impacts of Increasing Heavy Precipitation Events	21
Impacts of Drought	23
Impacts to Lake Erie	23
Potential Beneficial Impacts of Climate Change Effects in Ohio	24
Other Impacts or Responses	24
TYPES OF INFRASTRUCTURE ASSETS VULNERABLE TO KEY CLIMATE CHANGE EFFECTS	25
Point Assets	26
Fixed Route Assets	26



Risk Assessment	27
Climate Change Effects: Gradual or Event Driven	28
Short-Term Climate Change Impacts on ODOT Assets (2015-2050)	28
Long-Term Climate Change Impacts on ODOT Assets (2050-2080)	31
Conclusion of the Risk Assessment	39
VULNERABILITY ASSEMENT	40
The Vulnerability Assessment Screening Tool.....	40
Bridge and Culvert Vulnerability	41
National Bridge Inventory	41
Ohio Bridge Inventory	42
Future Precipitation and Stream Flow Changes	43
Distance to Nearest Hospital	44
Watershed Characteristics.....	44
Previous Flooding Locations.....	45
Results of Vulnerability analysis for Bridges.....	47
Results of Vulnerability analysis for Culverts.....	49
Stormwater Management Facilities	52
Vulnerability Assessment of Highways.....	53
Ohio Pavement Condition Inventory	54
Strategic Transportation System	54
Future Precipitation and Stream Flow Changes	54
Distance to Nearest Hospital	55
Watershed Characteristics.....	55
Previous Flooding Locations.....	55
Erosion Risk.....	56
Results of Vulnerability Analysis for Highway Segments.....	57
ADAPTIVE RESPONSES TO INFRASTRUCTURE VULNERABILITY	63
Types of Adaptive Responses	63
Extreme Weather Adaptation / Emergency Transportation Operations (ETO)	67
ODOT Survey Assessment.....	67
Standing call out lists and written procedures for emergency deployment to other districts:	69
Access to the equipment, back up communications, and power:	72

Supplies and materials:	73
Training and Cross training:	74
Stand-by Contractors:.....	75
Damage assessment teams per FHWA Emergency Relief (ER):	77
Relationships with Federal, State and local officials:	78
What about Emergency Transportation Operations (ETO) keeps you up at night?.....	78
ODOT Emergency Transportation Operations - Comments and Recommendations.....	80
CLIMATE RESILIENCE - SPECIAL TOPICS	81
Pavement Performance.....	81
Discussion of Literature Sources Reviewed	82
Expert Outreach.....	85
Key Findings and Future Analysis	87
Air Quality	87
Potential Air Quality Impacts.....	88
Potential Regulatory Compliance Issues	88
Ohio Ambient Air Quality.....	89
EPA Ambient Air Monitoring data	90
Mobile Source Emissions Outlook	93
Key Findings	94
Potential Impacts of the Northwest Passage.....	95
Key Findings and Future Analysis	102
RECOMMENDATIONS FOR ADVANCING THE RESILIENCY PLAN	103
Appendix A: ODOT Staff Consulted in development of Resiliency Plan	106
Appendix B: Experts Consulted in Development of Resiliency Plan	106
Appendix C: Research Literature.....	107
 FIGURE 1: TOTAL ANNUAL GLOBAL CO₂ EMISSIONS FROM ALL SOURCES, 1990-2100, BY IPCC EMISSION SCENARIO ...	4
FIGURE 2: INCREASING TEMPERATURES IN THE MIDWEST, 1895-2000 (FROM NCA 2013)	5
FIGURE 3: GREAT LAKES ICE COVERAGE, AND PHOTOGRAPH OF LAKE ERIE ICE 2008 (LEFT) AND 2012 (RIGHT)(NCA 2013).....	5
FIGURE 4: PERCENTAGE CHANGE IN HEAVY PRECIPITATION, 1958-2007.....	6
FIGURE 5: PHOTO OF SEVERE FLOODING IN FINDLAY, OHIO	7
FIGURE 6: FEDERAL EMERGENCY DECLARATIONS IN OHIO, 1956-2013	8
FIGURE 7: MAP OF OHIO SHOWING THE SUSTAINING SCIOTO STUDY AREA.....	9

FIGURE 8: PROJECTED TEMPERATURE CHANGE (DEGREES F) FROM 1961-1979 BASELINE, MID-CENTURY (LEFT) AND END OF CENTURY (RIGHT), IPCC EMISSIONS SCENARIO A2	11
FIGURE 9: PROJECTED TEMPERATURE CHANGE (DEGREES F) FROM 1961-1979 BASELINE, MID-CENTURY (LEFT) AND END OF CENTURY (RIGHT), IPCC EMISSIONS SCENARIO B1	12
FIGURE 10: PROJECTED CHANGES TO ANNUAL TEMPERATURES FOR THE MIDWEST BY MID-CENTURY (2041-2070) AS COMPARED TO RECENT HISTORY (1971-2000) (NCA 2013)	13
FIGURE 11: PROJECTED CHANGES IN PRECIPITATION PATTERNS, 2041-2070 RELATIVE TO 1971-2000 (NCA 2013)	15
FIGURE 12: HISTORIC AND PROJECTED CHANGES IN LAKE LEVELS FOR THE GREAT LAKES	17
FIGURE 13: STRUCTURAL DAMAGE IN PORT WING, WI.....	18
FIGURE 14: PROJECTED TEMPERATURE CHANGE (°F) FROM 1961-1979 BASELINE, MID-CENTURY (LEFT) AND END OF CENTURY (RIGHT), IPCC EMISSIONS SCENARIO A2	20
FIGURE 15: PROJECTED CHANGES IN PRECIPITATION PATTERNS, 2041-2070 RELATIVE TO 1971-2000	22
FIGURE 16: OHIO'S STRATEGIC TRANSPORTATION SYSTEM (FROM ACCESS OHIO 2040)	25
FIGURE 17: RAINFALL INTENSITY MAP OF OHIO	36
FIGURE 18: REVISED IDF CURVES BASED ON MOST RECENT NOAA DATA	37
FIGURE 19: PRELIMINARY REDEFINED RAINFALL INTENSITY ZONES FOR OHIO BASED ON MOST RECENT IDF CURVES	38
FIGURE 20. ILLUSTRATION OF THE VAST VULNERABILITY SCORING APPROACH	41
FIGURE 21. SUB-REGIONS OF OHIO FOR CLIMATE PREDICTIONS.....	44
FIGURE 22: LOCATION OF THE 10 MOST VULNERABLE BRIDGES	48
FIGURE 23: LOCATIONS OF THE 20 MOST VULNERABLE CULVERTS	51
FIGURE 24: MOST VULNERABLE CULVERTS IN NORTHEASTERN OHIO	51
FIGURE 25. ILLUSTRATION OF THE VAST VULNERABILITY SCORING APPROACH	54
FIGURE 26. TEN MOST VULNERABLE HIGHWAYS SEGMENTS	58
FIGURE 27: HIGHLY VULNERABLE HIGHWAY SEGMENTS (RANK 1-4)	59
FIGURE 28: HIGHLY VULNERABLE HIGHWAY SEGMENTS (RANK 5-10)	60
FIGURE 29: FEDERAL FUNDS PROVIDED FOR EMERGENCY DISASTER RELIEF TO OHIO COUNTIES, 1973-2013	67
FIGURE 30: STATISTICAL CONSIDERATIONS FOR CLIMATE CHANGE	82
FIGURE 31: MAP OF OZONE ATTAINMENT AND NON-ATTAINMENT AREAS IN OHIO	89
FIGURE 32: MAP OF PM 2.5 ATTAINMENT AND NON-ATTAINMENT AREAS IN OHIO (24-HOUR AND ANNUAL STANDARDS)	90
FIGURE 33: CONCENTRATIONS OF OZONE IN OHIO METRO AREAS	91
FIGURE 34: CONCENTRATIONS OF VOLATILE ORGANICS IN OHIO METRO AREAS.....	92
FIGURE 35: CONCENTRATION OF NITROGEN DIOXIDE IN OHIO METRO AREAS	92
FIGURE 36: CONCENTRAIONS OF PM-2.5 IN OHIO METRO AREAS	93
FIGURE 37: NATIONAL MSAT EMISSIONS TRENDS 2010 – 2050 FOR VEHICLES OPERATING ON ROADWAYS USING EPA'S MOVES2010B MODEL.....	94
FIGURE 38: THE NORDIC ORION'S ROUTE, SEPTEMBER 2013.....	96
FIGURE 39: THE NORTHWEST PASSAGE AND RUSSIA'S NORTHERN SEA ROUTE (NSR)	97
FIGURE 40: AVERAGE MONTHLY ARCTIC SEA ICE EXTENT FROM JULY 1979 - 2013	98
FIGURE 41: RUSSIAN LK-60 ICEBREAKER	99
FIGURE 42: GLSLB CAPACITY CONSTRAINTS.....	100

TABLE 1: IPCC EMISSION SCENARIOS AND DRIVING FACTORS	3
TABLE 2: RANGES OF PROJECTED AVERAGE ANNUAL TEMPERATURE INCREASES FOR OHIO UNDER 2 IPCC EMISSIONS SCENARIOS.....	14
TABLE 3: RANGES OF PROJECTED AVERAGE ANNUAL TEMPERATURE INCREASES FOR OHIO IPCC EMISSIONS SCENARIO A2	21
TABLE 4: LIKELIHOOD-SEVERITY MATRIX FOR A QUALITATIVE ASSESSMENT OF CLIMATE CHANGE EFFECTS.....	27
TABLE 5: CATEGORIZATION OF KEY CLIMATE CHANGE EFFECTS IN OHIO	28
TABLE 6: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING TEMPERATURE (SHORT- TERM)	28
TABLE 7: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING HEAVY PRECIPITATION EVENTS (SHORT- TERM).....	29
TABLE 8: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING FREQUENCY/SEVERITY OF DROUGHT EVENTS (SHORT- TERM)	30
TABLE 9: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF LAKE LEVEL DECLINE (SHORT-TERM).....	31
TABLE 10: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING TEMPERATURE (LONG- TERM)	31
TABLE 11: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING HEAVY PRECIPITATION EVENTS (LONG- TERM).....	32
TABLE 12: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING FREQUENCY/SEVERITY OF DROUGHT EVENTS (LONG- TERM)	33
TABLE 13: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF LAKE LEVEL DECLINE (LONG-TERM)	33
TABLE 14. VULNERABILITY CALCULATION APPROACH.....	46
TABLE 15. FINAL RESULTS, TEN MOST VULNERABLE BRIDGES	48
TABLE 16: REVISED RESULTS, TEN MOST VULNERABLE BRIDGES.....	49
TABLE 17: FINAL RESULTS, 20 MOST VULNERABLE CULVERTS	50
TABLE 18: REVISED RESULTS, 20 MOST VULNERABLE CULVERTS	52
TABLE 19. VULNERABILITY CALCULATION APPROACH.....	56
TABLE 20: REVISED RESULTS, 20 MOST VULNERABLE HIGHWAY SEGMENTS.....	62
TABLE 21: CHANGES IN MEAN AND VARIANCE FOR TEMPERATURE AND PRECIPITATION	83
TABLE 22: MEPDG MODELING RESULTS	84

INTRODUCTION TO THE OHIO DOT INFRASTRUCTURE RESILIENCY PLAN

The key objective of this study is to identify the vulnerability of ODOT's transportation infrastructure to climate change effects and extreme weather events. The analysis includes a discussion and analysis of the type of transportation assets vulnerable, the degree of exposure, sensitivity, adaptive capacity, and the consequences of impact. The periods of interest are "Short-term" (2015-2050) and "Long-term (2050-2099).

The work completed with this study includes:

- Understanding the vulnerability of ODOT's overall transportation system to climate change;
- Determining potential consequences from a broad range of potential climate impacts;
- Identifying segments or facilities at risk to climate change impacts within Ohio by region or type;
- Determine a possible range, scale, and cost of climate impacts;
- Identify range of adaptation and/or sustainability options (activities) that ODOT should consider in detail in future adaptation studies
- Providing the foundation for ODOT to integrate the results of this vulnerability assessment into future decision making processes and future adaptation/resiliency studies.

The core project team for this study includes ODOT Office of Environmental Services staff and RSG, ODOT's contractor. Over the course of the study, numerous ODOT staff were consulted (see Appendix A), as were several state and national experts in the climate change field:

- ODOT's Office of Tech Services, Office of Systems Planning and the Office of Statewide Planning to assess ODOT's long-range planning and GIS assets available.
- ODOT's maintenance staff in each of ODOT's 12 Districts to identify transportation assets impact areas and focus areas for the future.
- ODOT's design teams (e.g. structural, hydraulic, geotechnical, pavement) to identify sensitivity of infrastructure to climate impacts and ideas/costs for adaptation solutions.
- MPOs (Columbus and Cincinnati) within Ohio who have already conducted some level of climate change analysis.

Utilizing ODOT's existing GIS systems, the project team developed additional GIS mapping and analytics to evaluate the vulnerability of ODOT's infrastructure to climate change effects. Transportation assets have been categorized assets into groups:

- Assets that have a low likelihood of being impacted by a future climate condition and a low consequence of being impacted by that condition,
- Assets that have a low likelihood of being impacted by a future climate condition and a high consequence of being impacted by that condition,

- Assets that have a high likelihood of being impacted by a future climate condition and a low consequence of being impacted by that condition, and Assets that have a high likelihood of being impacted by a future climate condition and a high consequence of being impacted by that condition.

FRAMEWORK OF THE VULNERABILITY STUDY

NCHRP Report 750 describes a framework for conducting an asset vulnerability and adaptation assessment for State DOTs. The Ohio DOT Resiliency Plan has largely followed these steps:

1. Identify Predominant Climate Change Trends in Ohio
2. Define Asset Types that Will Receive Adaptation Consideration
3. Assess Asset Vulnerabilities
4. Conduct Risk Appraisal of Assets
5. Identify Adaptation Options for High Risk Assets
6. Identify Adaptive Responses
7. Provide the foundation for ODOT to integrate the results of this vulnerability assessment into future

The vulnerability assessment approach used in this project effectively combines Steps 3 and 4 in one integrated framework, VAST, standing for Vulnerability Assessment Screening Tool. VAST is a tool developed by FHWA for use by State DOTs in conducting asset vulnerability assessments. For this project, RSG operationalized the VAST model as a software application ODOT can use on an ongoing basis to refine and improve the prioritization of vulnerable assets.

PREDOMINANT CLIMATE CHANGE TRENDS

This chapter presents research on climate change and extreme weather in Ohio to identify the major climate change effects and to project changes over the next 100 years. This synthesis of research provides the foundation for determining the range, scale and cost of climate change impacts are assessed.

Climate change trends in Ohio have been obtained from a review of recent research from published or presented national and regional sources, and from telephone interviews with identified experts in the climate change field. This synthesis begins with a general perspective on climate change and progresses to information pertaining to Ohio specifically.

This chapter has the following sections:

- Discussion of Global Processes Driving Climate Change
- Climate Change in Ohio-Recent Trends and Projected Changes
- Impacts to Transportation

A listing of the resources reviewed and the experts interviewed for this research scan are in Appendix C.

GLOBAL PROCESSES DRIVING CLIMATE CHANGE

The standard reference work on global climate change is from the International Panel on Climate Change (IPCC)¹, an international forum of climate change experts. The IPCC Greenhouse Gas Emission Scenarios provide a general background to the trends in heat trapping gases over the 100-year time frame of interest.

The IPCC emission scenarios were first introduced in 1992 and have been updated periodically since then. The results are reported in the Special Report on Emissions Scenarios (SRES). Each scenario represents a variety of interactions between population growth, economic development, adoption of new technologies, and land use. To this end, four emission scenarios have been established, which are described in Table 1.

The IPCC does not assign a probability to any one emission scenario versus another. Instead, they describe 4 emission scenarios that effectively establish a range of futures for the generation of greenhouse gases. **Error! Reference source not found.** displays projected trendlines in global CO₂ emissions, 1990-2100, associated with each of the four IPCC scenario.

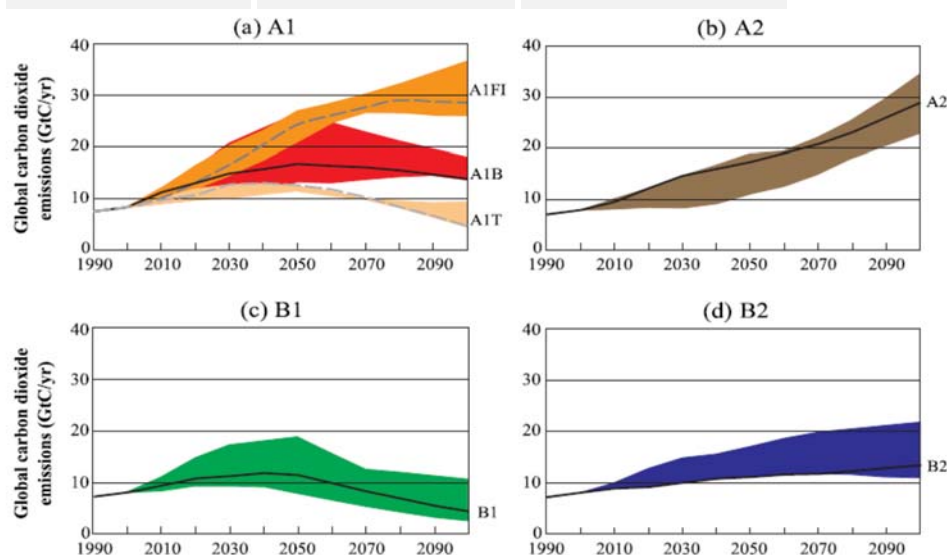
TABLE 1: IPCC EMISSION SCENARIOS AND DRIVING FACTORS

Scenario	Population	Economic Development	Technological Change
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¹ IPCC was jointly established by the World Meteorological Organization and the United Nations Environment Program.

A1	Peaks mid-century	Rapid economic growth	Rapid adoption of new technologies
A2	High growth	Intermediate growth	Slow adoption of new technologies
B1	Peaks mid-century	Intermediate growth	Rapid adoption of new technologies
B2	High growth	Intermediate growth	Slow adoption of new technologies

**FIGURE 1:
TOTAL
ANNUAL
GLOBAL CO₂
EMISSIONS
FROM ALL
SOURCES,
1990-2100, BY
IPCC
EMISSION
SCENARIO**



The IPCC emission scenarios provide inputs to several Global Circulation Models included within the IPCC's Coupled Model Intercomparison Project (CMIP3). An important climate change impact initiative occurring currently in Ohio is the Sustaining Scioto project, to which USGS is partner. USGS has adapted 4 CMIP3 Global Circulation Models to use for developing climate forecasts for central Ohio. The downscaled climate models use 2 IPCC emission scenarios: A1B (balanced technological approach) and A2, representing the moderate and high ranges of carbon generation.

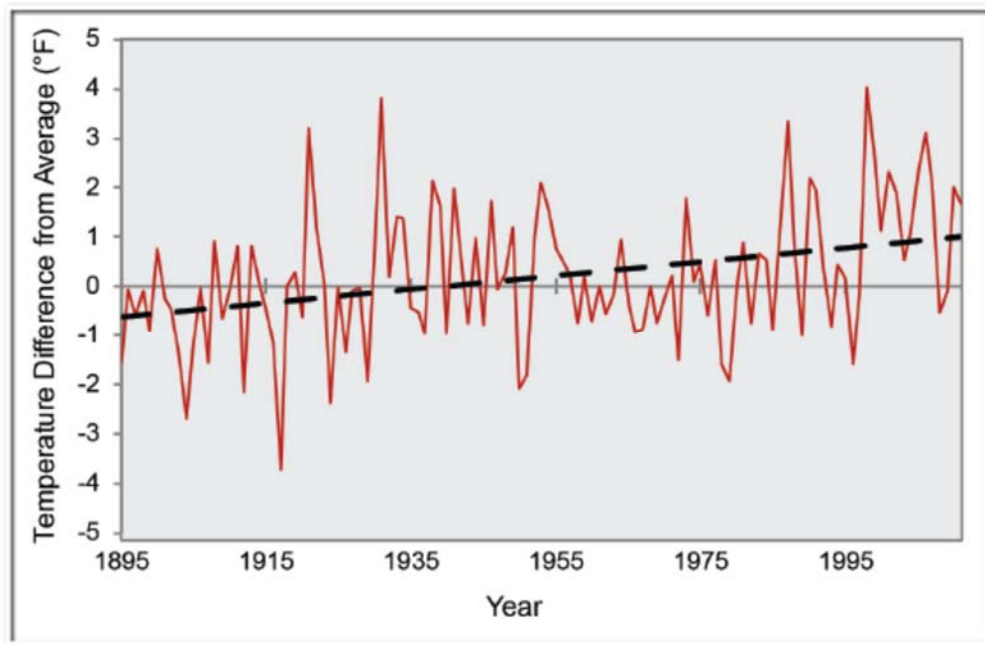
In considering climate change impacts on ODOT's assets it is relevant to consider the IPCC emissions scenarios and what these mean for the potential range of climate impacts in Ohio over the 21st century.

RECENT CLIMATE CHANGES IN OHIO

US and Midwest average temperatures have increased by approximately 1.5 °F since 1895 with more than 80% of this occurring since 1980. Most US regions are experiencing warming, but the effects are not uniform.

Figure 2, from the 2013 National Climate Assessment, shows the trend in average annual temperatures for the Midwest.

FIGURE 2: INCREASING TEMPERATURES IN THE MIDWEST, 1895-2000 (FROM NCA 2013)



Globally, the warmest 13 years since the 1860s have occurred since 1990². These trends have been experienced in Ohio as well, according to State Climatologist Jeffry Rogers³.

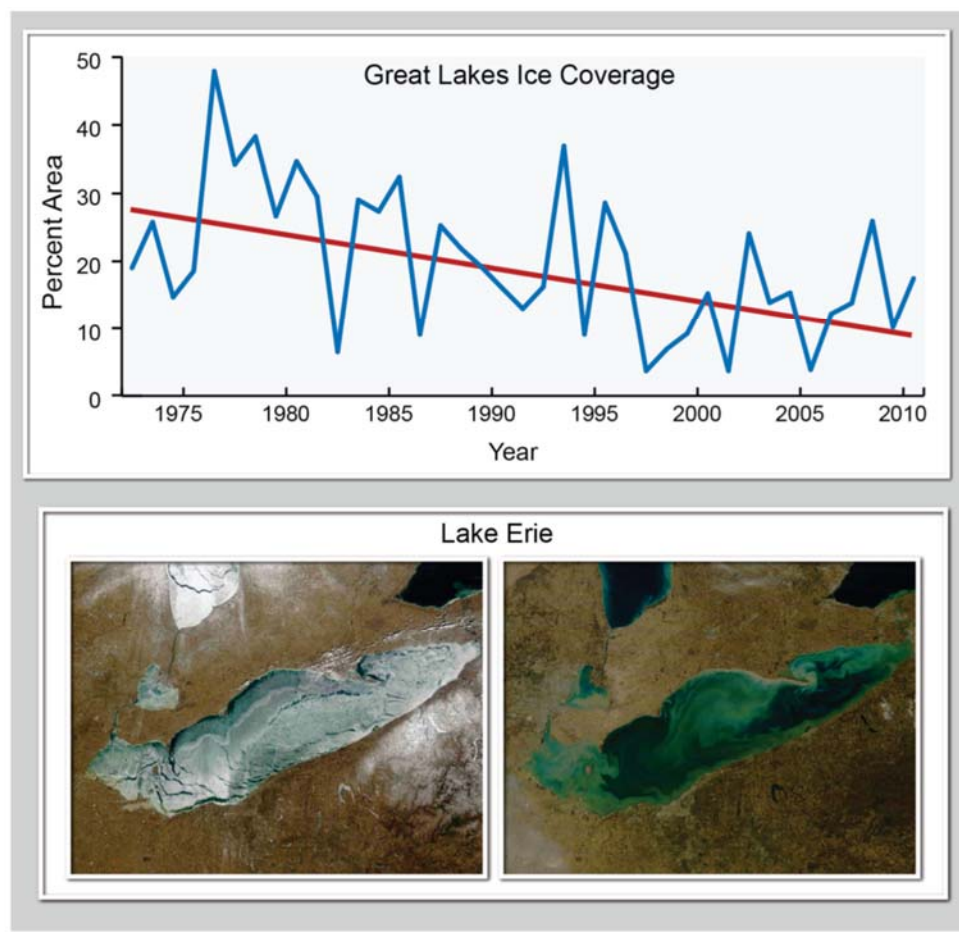
A consequence higher air temperatures is less ice coverage for surface water.

Figure 3 shows the trend in Great Lakes ice coverage, 1975-2010.

FIGURE 3: GREAT LAKES ICE COVERAGE, AND PHOTOGRAPH OF LAKE ERIE ICE 2008 (LEFT) AND 2012 (RIGHT)(NCA 2013)

² In descending order these years are: 2010, 1998, 2005, 2003, 2002, 2004, 2006, 2001, 1997, 1995, 1999, 1990, 2000.

³ Jeffry Rogers. Personal communication 10/29/13.

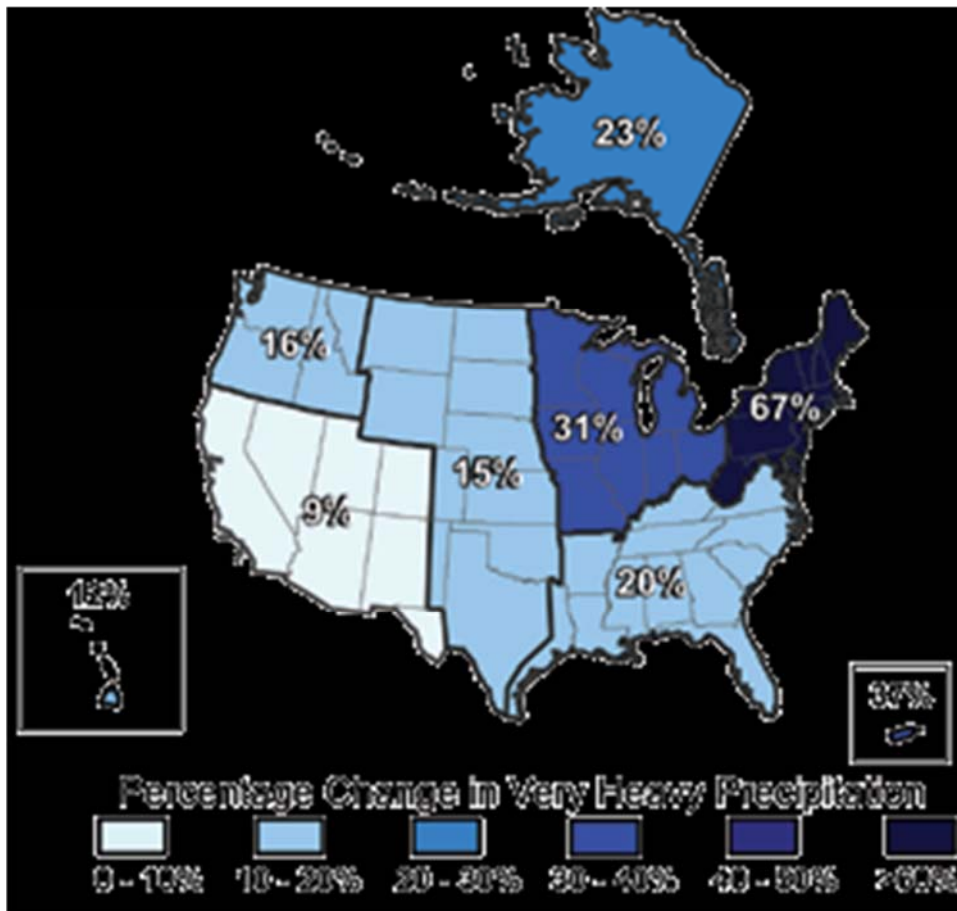


Lake Erie’s water level dropped 3.5 feet since 1997 due to unusual warming years.

Since 1900 average annual rainfall in Ohio has increased from 37” to 40”, an increase of approximately 8%, roughly in line with the increase of humidity in the atmosphere. While Ohio has seen an increase in precipitation, a significant portion of the precipitation increase has occurred in extreme events (“100-year storms”, Figure 4).

FIGURE 4: PERCENTAGE CHANGE IN HEAVY PRECIPITATION, 1958-2007⁴

⁴ Data are from James Noel, NOAA and represent the increase in 100-year storm events over the recent historic time frame. The graphic is taken from a August 16, 2012 presentation by James Noel on the Ohio River Basin Climate Change Project, used with permission by the author.



An example of an extreme rainfall event in recent years occurred in August 2007, where heavy rains in northwestern and north-central Ohio caused widespread flooding and damage. Rainfall totals for the flooded areas were 3-5 inches with some locations reporting 8-10 inches. National Weather Service gages in the area indicated a rainfall recurrence of greater than 1,000 years. Figure 5 shows a photo of flooding from August 2007 in Findlay, Ohio.

FIGURE 5: PHOTO OF SEVERE FLOODING IN FINDLAY, OHIO

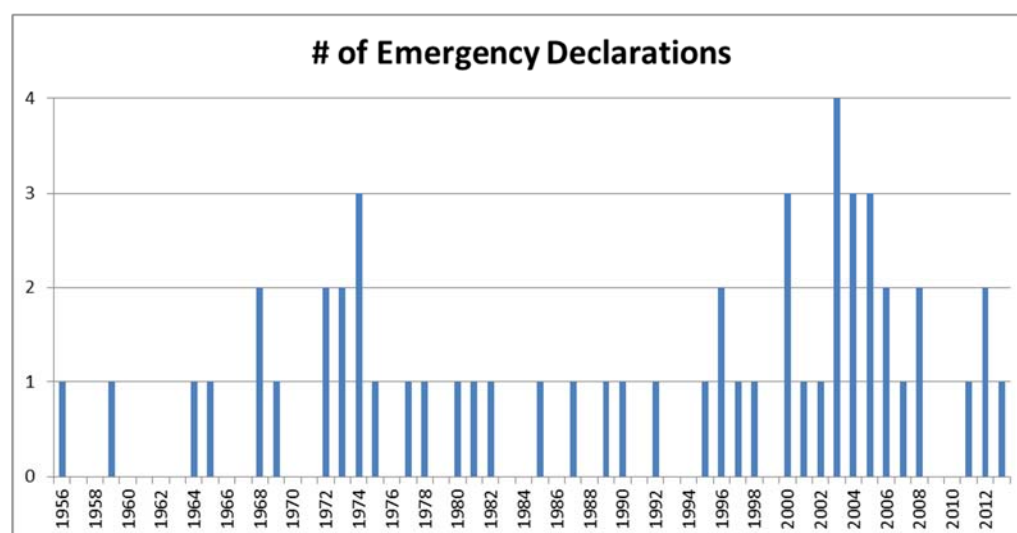


Photos by Mary Terry, courtesy of City of Findlay Engineer's Office.

Findlay, OH - August 2007

Extreme weather events are one indicator of climate change in Ohio. Figure 6 is based on data from the Ohio Emergency Management Agency and shows the number of federal emergency declarations in Ohio since 1956. The data indicate greater number and frequency of emergency declarations in the state in the last decade.

FIGURE 6: FEDERAL EMERGENCY DECLARATIONS IN OHIO, 1956-2013



PROJECTED CLIMATE EFFECTS IN OHIO

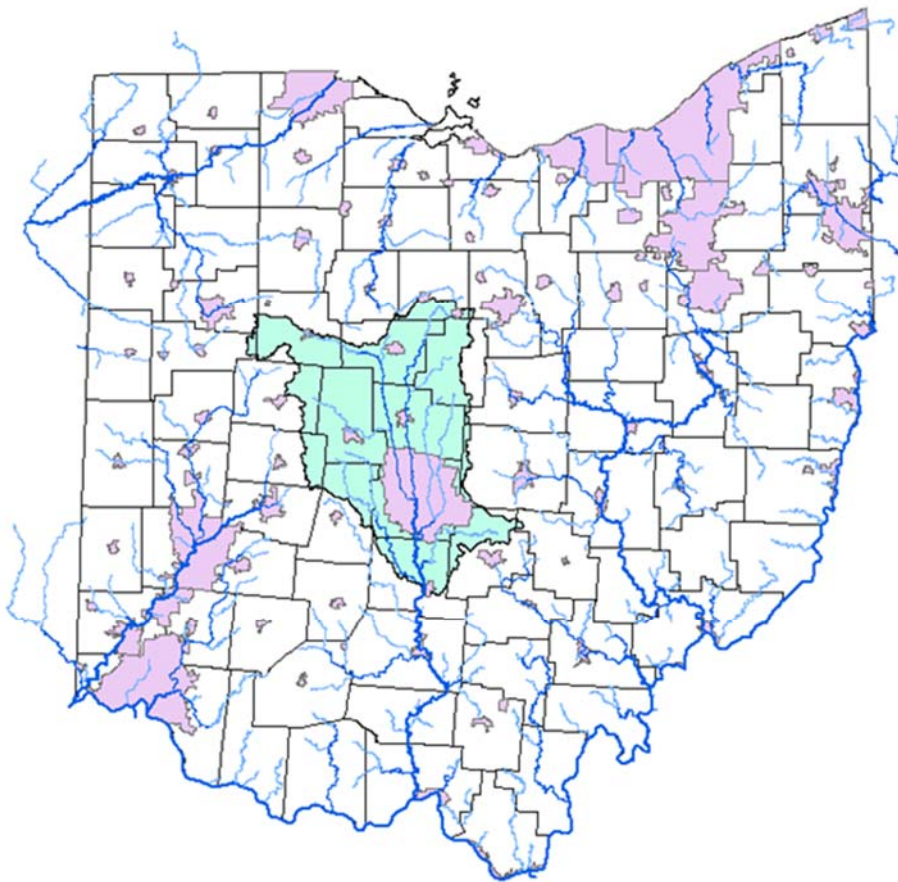
A common theme in climate change research is the challenge of projecting climate changes for smaller geographic areas, referred to as downscaling. As discussed above, most climate

science is supported by Global Circulation Models. Downscaling the results of these models to smaller geographic areas is more challenging and subject to greater uncertainty.

There are 3 key sources that provide information on climate change in Ohio:

- The National Climate Assessment—information for this report is from a Draft January 2013 report.
- National Oceanographic and Atmospheric Administration (NOAA) is conducting an Ohio River Basin Climate Change Project. NOAA's Jim Noel has presented on historic and projected climate for the Ohio River Basin Climate Change project.
- The Sustaining Scioto (discussed above) project area encompasses a large portion of central Ohio and is therefore an indicator of potential climate change for the state as a whole. The Sustaining Scioto project area is shown in Figure 7.

FIGURE 7: MAP OF OHIO SHOWING THE SUSTAINING SCIOTO STUDY AREA



The IPCC has established terminology to describe uncertainty, or the probability of an occurrence:

- Virtually certain >99%
- Extremely likely >95%

- Very likely >90%
- Likely >66%
- More likely than not >50%
- Unlikely <33%
- Very unlikely <10%
- Extremely unlikely <5%

The TRB Special Report 290 uses these probabilities and assigns them to key climate change effects as follows:

- Increases in very hot days and heat waves – very likely (>90%)
- Rising sea levels –virtually certain (>99%)
- Increases in Arctic temperature – virtually certain (>99%)
- Increases in intense precipitation events – very likely (>90%)
- Increases in hurricane intensity -- likely (>66%)

Of the key climate change effects listed above, two are directly relevant to Ohio, namely: increases in very hot days and heat waves, and increases in intense precipitation events.

1. Warming trends -- higher average temperatures, continuing to increase over the 21st century.
2. Precipitation trends –
 - increase in extreme rainfall events
 - increase in the frequency and duration of drought conditions.

General warming and the trends for precipitation -- describe general conditions that will affect the state. These projected impacts mirror the climate changes described for the recent past.

Another special issue – declining Lake Erie water levels – is a more specific effect that may result from a combination of climate-induced factors such as increases in evaporation and decreases in snowfall. There is not general scientific agreement that the changes being observed for Lake Erie are being caused by climate change. However, the lake's importance to Ohio's transportation system warrants its special treatment in this project.

WARMING TRENDS IN OHIO

For the Midwest region, the National Climate Assessment (NCA) projects increased heat wave intensity and frequency. A sampling of findings from recent research includes:

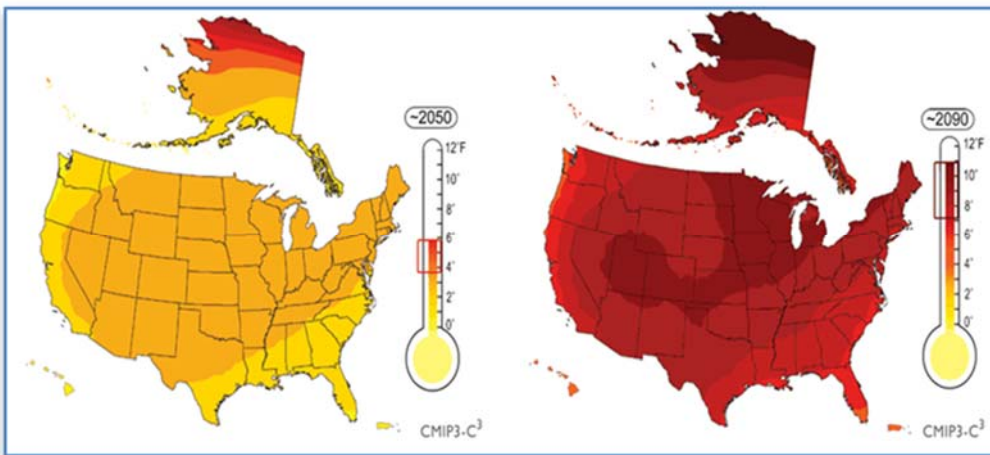
1. All seasons are experiencing temperature increases with the most rapid increases occurring in the springtime and winter. There have been 45 new daytime highs recorded since 2000, many of which are in the March 15-April 19 period. Seasonal warm temperatures are also in evidence as 5 of the 12 warmest summers since 1895 have occurred since 2000.
2. There are longer frost-free periods.

3. Several places in Ohio are showing increases in the number of days with high temperatures exceeding 95 degrees F.

Temperature increases are occurring faster during nighttime periods due to an increase in humidity in the atmosphere.

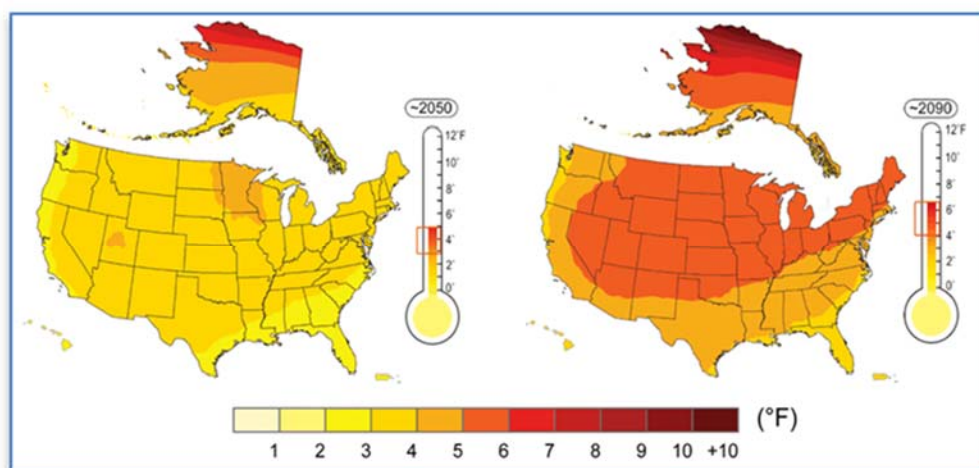
Figure 9 show projections from several CMIP3 climate models, under 2 IPCC emission scenarios (A2 and B1)⁵. Under the A2 emission scenario, average annual temperatures are projected to increase 4-6 degrees F by mid-century and by 7-10 degrees by end of century. Under the low emissions B2 scenario, projected average temperature changes are 2-5 degrees F by mid-century and 4-7 degrees F by end of century. The brackets on the temperature scales in the figures present the likely range of projections.

FIGURE 8: PROJECTED TEMPERATURE CHANGE (DEGREES F) FROM 1961-1979 BASELINE, MID-CENTURY (LEFT) AND END OF CENTURY (RIGHT), IPCC EMISSIONS SCENARIO A2



⁵From August 16, 2012 powerpoint presentation by Jim Noel, Service Coordination Hydrologist for NOAA/NWS Ohio River Forecast Center. "Ohio River Basin Climate Change Project".

FIGURE 9: PROJECTED TEMPERATURE CHANGE (DEGREES F) FROM 1961-1979 BASELINE, MID-CENTURY (LEFT) AND END OF CENTURY (RIGHT), IPCC EMISSIONS SCENARIO B1

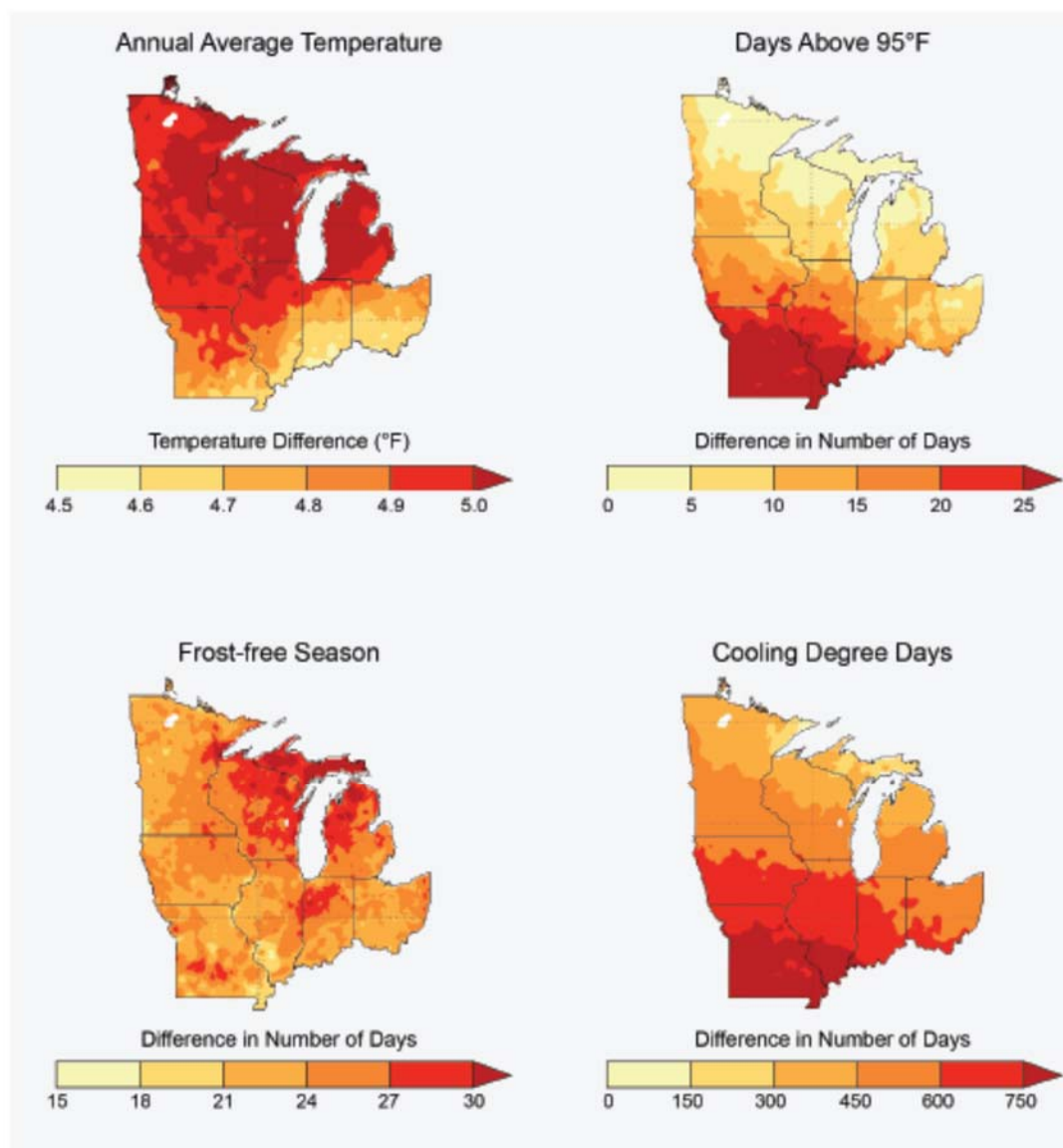


It is anticipated that Ohio will warm another 2-4 degrees F over next few decades. The largest impact of warming is anticipated to be to the agricultural sector, though it is assumed to be relatively resilient to gradual warming. Greater disruptions will occur to all sectors due to extreme heat, drought, and heavy downpours.

FIGURE 10

Figure 10, from the 2013 National Climate Assessment, focuses on a set of projected temperature changes for the Midwest region by mid-century.

FIGURE 10: PROJECTED CHANGES TO ANNUAL TEMPERATURES FOR THE MIDWEST BY MID-CENTURY (2041-2070) AS COMPARED TO RECENT HISTORY (1971-2000) (NCA 2013)



NCA projections on future warming depend on projections of increased concentrations of heat trapping gases from the IPCC emission scenarios. For mid-century, projections for regionally averaged temperature increases for the Midwest are increases of 3.8 F (low emissions scenario, B1) and 4.9 F for high emissions scenario (A2).

TABLE 2: RANGES OF PROJECTED AVERAGE ANNUAL TEMPERATURE INCREASES FOR OHIO UNDER 2 IPCC EMISSIONS SCENARIOS

	IPCC Scenario A1B (Mid-Level GHG Emissions)		IPCC Scenario A1B (High GHG Emissions)	
	Low	High	Low	High
+50 Years	2.5	5.0	3.0	5.5
+100 Years	4.5	7.0	5.5	7.0

PRECIPITATION TRENDS IN OHIO

Relative to the general agreement regarding warming trends globally and in Ohio, there is generally less consensus on how precipitation will change in the future. Much of this lack of consensus stems from the greater variability of projections from the CMIP3 Global Circulation Models. However, there is agreement among them that the frequency and intensity of storm events will increase in the future (Bergeron and Clark, 2010).

What is projected to occur in Ohio is consistent with the atmosphere increasing in humidity. There are notable seasonal patterns to precipitation changes:

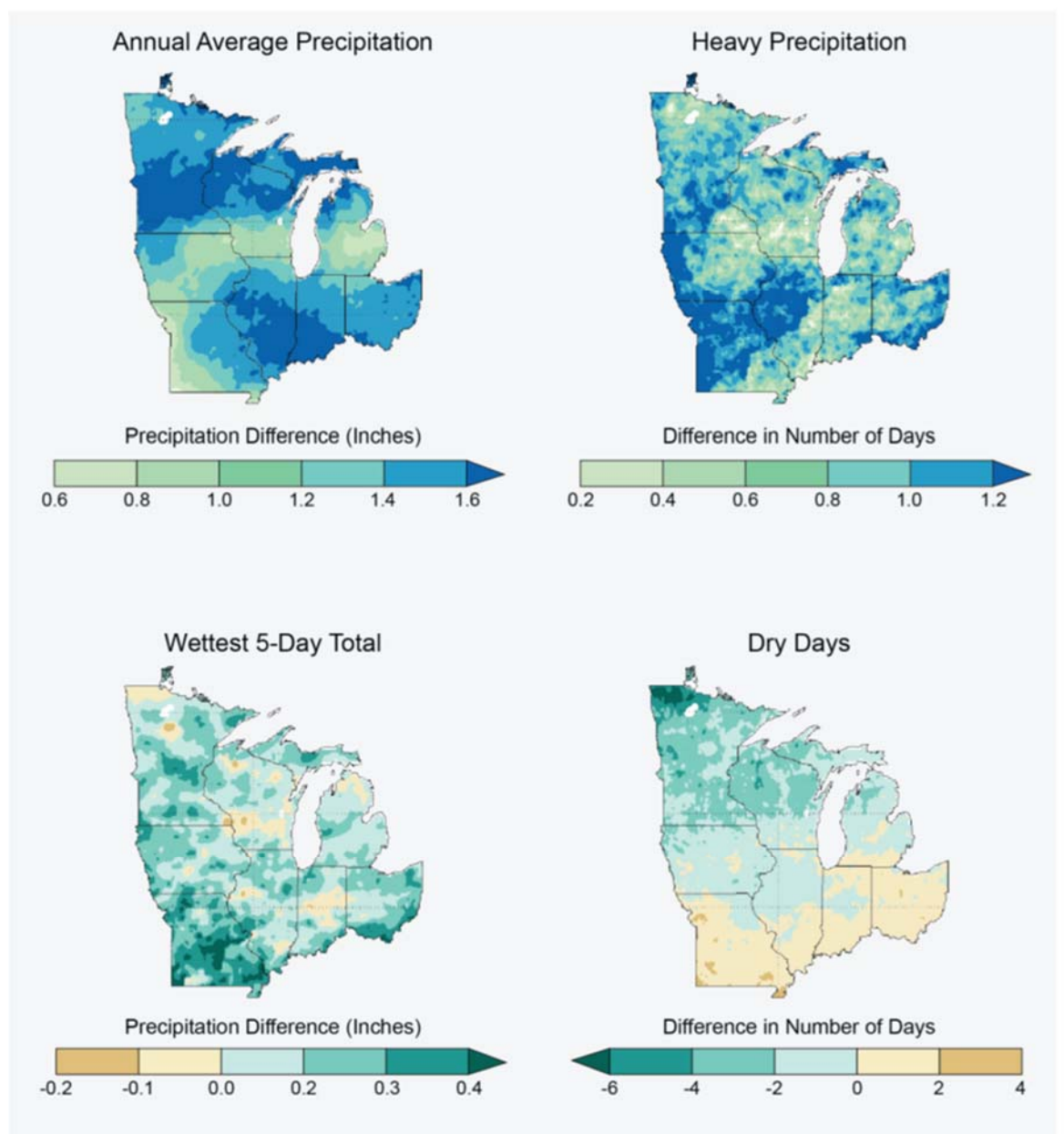
- Autumn is experiencing the greatest increase in precipitation.
- Winter precipitation is not increasing as much as in other seasons. Lake effect snowstorms are becoming less frequent and are more likely to turn into rain as the atmosphere heats up.
- There is significant consensus that extreme rainfall events and resulting flooding will increase in frequency and intensity. Recent weather patterns in Ohio are consistent with these characteristics:
 - “Heavy” rainfall events (>1 ” over a 24-hour period) have gone up while “Non-heavy” rainfall events ($<.1$ ” over a 24-hour period) have decreased⁶.
 - Minimum and median streamflows are up in 3 of 4 seasons.

A challenging case in the area of precipitation is the fact that extreme precipitation events are projected to occur along with greater frequency of sustained drought -- longer dry spells, punctuated with extreme rains. Further, sustained droughty conditions can exacerbate flooding through greater soil compaction, reduced soil permeability, and higher runoff volume.

The recent National Climate Assessment provides the data shown in Figure 11. These data are from Global Circulation Models and support the general findings that extended droughts are projected to occur along with more intense precipitation events.

FIGURE 11: PROJECTED CHANGES IN PRECIPITATION PATTERNS, 2041-2070 RELATIVE TO 1971-2000 (NCA 2013)

⁶ Phone Interview with Dev Noyogi, Indiana State Climatologist. 7 November 2013.



According to Jeffry Rogers, Ohio State Climatologist, Ohio is buffered from extreme duration drought, such as is experienced in the Great Plains or southwestern US, because it is on the fringes of the high pressure dome that sets up over the middle of the country. Ohio is on a storm track that draws weather toward the Great Lakes. As a result, Ohio has access to weather systems that ultimately cause changes to weather in the state.

LAKE ERIE WATER LEVEL

Lake Erie is the 10th largest lake in the world and is the shallowest of the Great Lakes. The lake is collectively managed by the U.S. and Canada. There is not a firm understanding of the

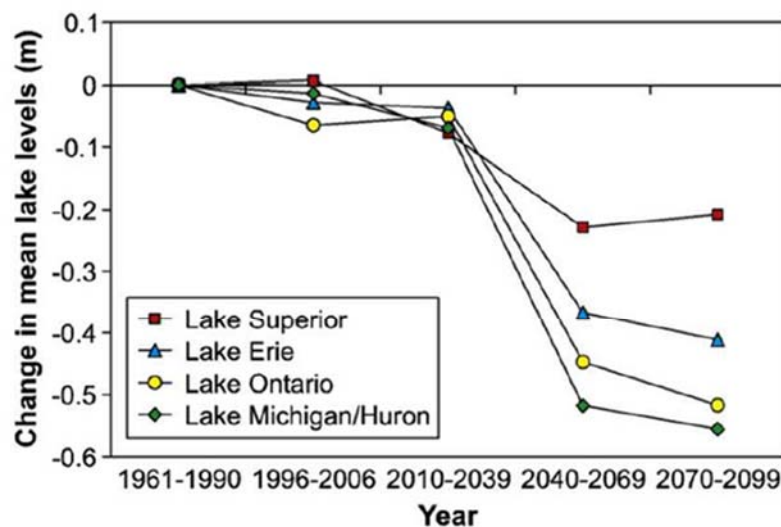
underlying causes of lake level drop and it is difficult to attribute the drop in lake level to climate change.

A sampling of findings from recent research includes:

- With higher temperatures, there is greater evaporation that has not been offset by inflows due to precipitation.
- The National Climate Assessment also projects a variety of changes and risks for the Great Lakes. There are some beneficial changes, such as projected declines in ice cover that will lengthen the commercial navigation season. On the negative side, there is consensus on a continuing reduction in lake levels for Lake Erie poses economic risks to shipping.
- A water level forecast provided in Hayhoe, et al. (2010) predicts approximately 0.45 meter (1.5 foot) decline in Lake Erie by 2040 (Gronewold, 2011).

TRB Special Report 290 predicts lower lake levels for the Great Lakes and St. Lawrence Seaway. Reduction in Great Lakes water levels will reduce shipping capacity. This will be partially offset by a longer shipping season.

FIGURE 12: HISTORIC AND PROJECTED CHANGES IN LAKE LEVELS FOR THE GREAT LAKES



From: Hayhoe, et al., (2010)



Lake level decline has also been addressed for the Lake Michigan-Huron system, whose level is cited in 2008 as declining for the past 33 years (Sellinger et al., 2008).

Hydrological models have been used to predict impacts of extreme weather events on lake levels. From the TRB Special Report 290, increased precipitation events over inland areas are

likely to occur, causing catastrophic flooding. At the same time, persistent drought conditions are also likely to become more common, causing more lock downtime and reducing vessel carrying capacity through the St. Lawrence Seaway.

Lake level declines coupled with larger waves, larger storm surges, and more dramatic seiches can have an array of impacts⁷. These include the damaging of “entrance structures” and “interior harbor structures” as well as previously dredged areas, which must be re-dredged (Bergeron and Clark, 2010, see Figure 13).

FIGURE 13: STRUCTURAL DAMAGE IN PORT WING, WI



Water level forecasts for the SRES A1 high emissions scenario shows a slightly greater than one foot drop in Lake Erie’s water level starting in approximately 2040 and remaining that low at/beyond 2100 (Gronewold, 2011).

A water level forecast provided in Hayhoe, et al. (2010) predicts approximately somewhat greater than 0.5 meter (1.6+ foot) decline in Lake Erie by 2070 (Gronewold, 2011).

HOW IS CLIMATE CHANGE AFFECTING DIFFERENT PARTS OF OHIO?

Some differences in climate change effects throughout Ohio can be seen in Figure 10 and Figure 11. As described earlier climate change is understood with greatest confidence as a global or continental phenomenon. There is significantly less confidence with a more focused geography, such as a region (“the Midwest”), state, or sub-state. For this reason

⁷ A seiche is a lake wave.

there are few research studies addressing differences in climate change effects for different regions of Ohio.

The TRB Special Report 290 highlights evacuation routes for all types of weather events as being likely candidates for a “climate proofing” analysis. For Ohio, evacuations due to flooding and strong wind events (i.e. tornadoes) are projected to increase, focusing resiliency planning on evacuation routes.

Areas in Ohio with clay soils, such as the southeast area near Marietta, will have greater challenges with heavy precipitation events. Clay soils are less permeable generally and so may not be able to absorb the increased heavy precipitation events that are forecast for the state as a whole. Consequences include increased surface runoff and slope slumping. These impacts will be particularly pronounced in the hillier southeastern section of the state.

POTENTIAL FOR CLIMATE CHANGE IMPACTS IN OTHER PARTS OF THE COUNTRY TO IMPACT OHIO

The resources and experts consulted for this project did not include much information on this topic. For many scientists, these types of impacts are highly speculative and, as a result, do not receive serious consideration. However, there are some impacts from recent severe weather events that provide some indication of what could happen to Ohio from extreme weather events elsewhere.

For example, from the TRB Special Report 290, the 1988 drought stranded more than 4000 barges on the Mississippi and resulted in a massive shifting freight to other modes, particularly railroad. As Ohio is part of a regional Great Lakes transportation system where freight is shipped from west to east and vice versa through the Great Lakes and its connecting waterways there could be increased demand for access to Ohio harbors when extreme weather impacts harbors and access in other Great Lakes states. Therefore some consideration should be given to the need to accommodate increases in boat traffic through Ohio waterways and harbors in the event a key port is damaged in another Great Lakes state. Consideration should also be given to accommodating increases overland truck traffic if water-based travel is not available due to the temporary or permanent closure of a harbor or channel in a neighboring state.

Seelinger, et al (2008) reported that lake level declines in Lake Michigan and Huron could result in lower permitted ship weight limits. Since 1997, Lakes Michigan and Huron have dropped 1.1 meters which could result in greater ship traffic or shifting of shipping to trucking or rail modes.

Brent Sohngen, an Environmental Economist at OSU, has speculated that Ohio could receive population increases from immigration of coastal populations moving inland as a result of sea level rise. Professor Sohngen has submitted grant proposals to study these potential impacts but these proposals have not been funded to date.

IMPACTS TO TRANSPORTATION ASSETS

This section presents a list of potential impacts of climate change on transportation assets in Ohio. This information was gleaned from the research scan and expert interviews. As described above, there are 4 key climate effects that should be planned for by transportation planners:

1. Increasing average temperatures
2. Increasing heavy storm events
3. Increasing frequency and duration of droughts
4. Declining Lake Erie water levels

IMPACTS OF RISING TEMPERATURES

Most of Ohio is projected to have a higher number of days with high temperatures exceeding 95 degrees F. Figure 8 shows projections from several CMIP3 climate models, under IPCC emission scenario A2⁸. Under the A2 emission scenario, average annual temperatures are projected to increase 3.0-5.5 degrees F by mid-century and by 5.5-7.0 degrees by end of century. Temperature projections by the 2013 National Climate Assessment support these projections.

FIGURE 14: PROJECTED TEMPERATURE CHANGE (°F) FROM 1961-1979 BASELINE, MID-CENTURY (LEFT) AND END OF CENTURY (RIGHT), IPCC EMISSIONS SCENARIO A2

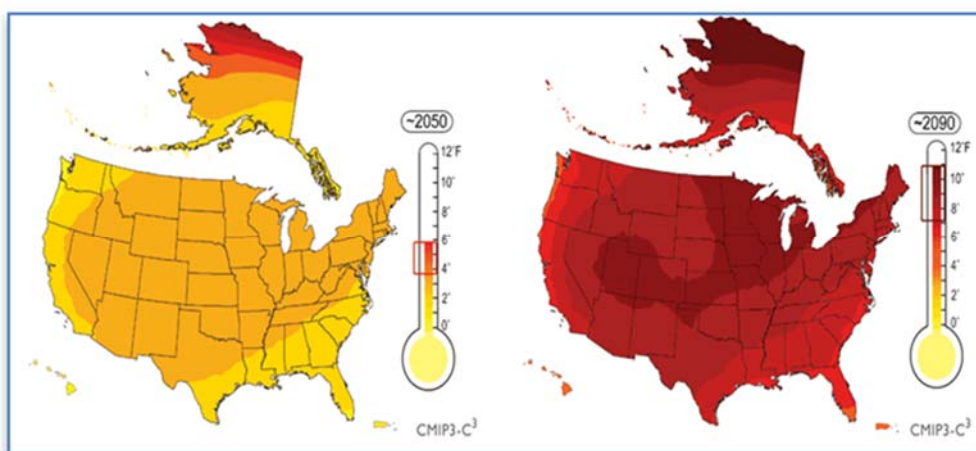


Table 3 Table 3 provides a range of temperature changes for Ohio.

⁸From August 16, 2012 powerpoint presentation by Jim Noel, Service Coordination Hydrologist for NOAA/NWS Ohio River Forecast Center. "Ohio River Basin Climate Change Project".

TABLE 3: RANGES OF PROJECTED AVERAGE ANNUAL TEMPERATURE INCREASES FOR OHIO IPCC EMISSIONS SCENARIO A2

IPCC Scenario A2 (High GHG Emissions)		
	Low	High
+ 50 Years	3.0	5.5
+ 100 Years	5.5	7.5

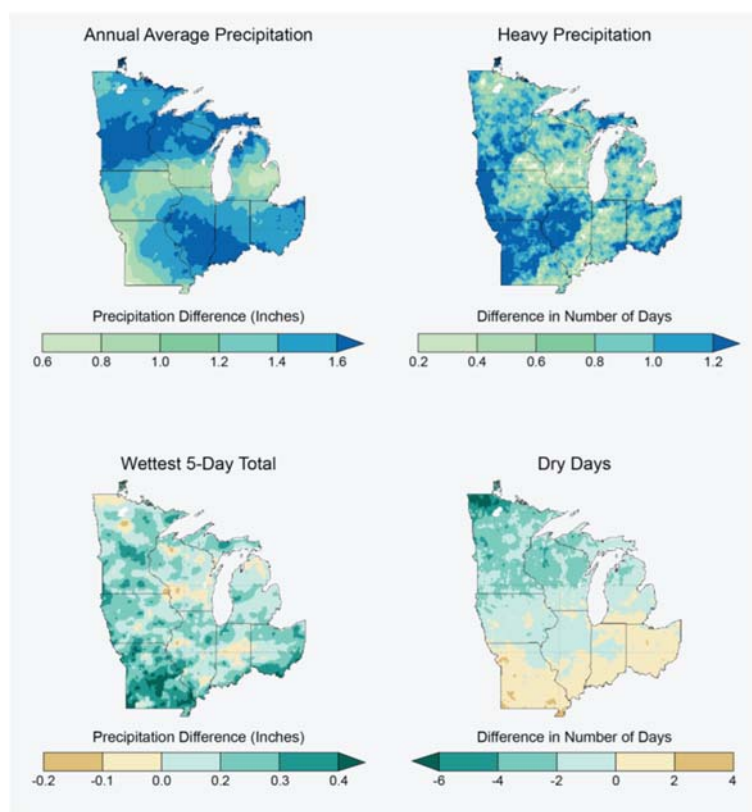
Increasing average temperatures can have following general impacts to transportation:

1. compromise pavement integrity in some cases;
2. certain areas may experience cost savings in roadway maintenance (i.e. longer lasting roadways);
3. buckling of airstrips;
4. thermal expansion in bridge joints;
5. reduced soil permeability, increasing surface runoff;
6. increasing freeze-thaw cycling;
7. lengthening construction season, but offset with cessation of daytime construction activity due to extreme heat, increase of night-time construction activity.
8. reductions in snow and ice removal, lessening wintertime maintenance costs and the use of salt and chemicals on roads;
9. worsening of summertime air quality issues, particularly for ground level ozone, one of the NAAQS criteria pollutants. There are currently three 8-hour ozone nonattainment areas in Ohio under the 2008 standard:
 - Cincinnati-Hamilton
 - Cleveland-Akron-Lorain
 - Columbus

IMPACTS OF INCREASING HEAVY PRECIPITATION EVENTS

Relative to the consensus on increasing average temperatures in Ohio there is generally less consensus on how precipitation will change over the next 100 years. Part of this lack of consensus relates to the increased frequency of extreme precipitation events coupled with longer duration droughts. The 2013 National Climate Assessment projects more frequent droughts occurring along with more intense precipitation events in Ohio over the next century (Figure 11).

FIGURE 15: PROJECTED CHANGES IN PRECIPITATION PATTERNS, 2041-2070 RELATIVE TO 1971-2000



Since 1970 “Heavy” rainfall events (>1 ” over a 24-hour period) have increased while “Non-heavy” rainfall events ($<.1$ ” over a 24-hour period) have decreased⁹. Thus, there is a tendency for longer dry spells, punctuated with extreme rains. Droughty conditions can exacerbate flooding conditions by reducing soil permeability leading to greater runoff.

Increased frequency of heavy rain events can flood assets, including roads and bridges, and have other related impacts as well:

- slope erosion, slumping of ditches, backfilled areas;
- increased soil moisture causing increased hydrostatic pressure behind retaining walls and abutments, and reduced pavement subgrades stability;
- overcapacity stormwater systems, including combined sewer systems leading to declining surface water quality;
- increased runoff from heavy storms leads to heavier sediment loading with potential adverse impacts on bridge foundations;

⁹ Phone Interview with Dev Noyogi, Indiana State Climatologist. 7 November 2013.

- increased scour action at bridge piers and abutments;
- watercourse migration at bridge crossings and adjacent to highways;
- destabilization of stream/wetland mitigation areas which could compromise project permitting; and,
- Potential compromising of pavement integrity on roads constructed on expandable clay soils.

IMPACTS OF DROUGHT

According to the 2013 National Climate Assessment, almost the entire state of Ohio is projected to have an increased in the number of dry days, defined as days with less than 0.10” of precipitation.

Due to weather systems attracted by the Great Lakes, Ohio is buffered by persistent drought conditions such that occur in the U.S. Southwest. High-pressure systems can temporarily disrupt this weather pattern causing dry air masses to settle over the state, resulting in drought-like conditions. The increasing occurrence of these conditions offset with large precipitation events creates a “one-two” punch: drought conditions reduce soil permeability, which exacerbate surface runoff when heavy precipitation occurs. Heavy precipitation, in turn, can break down soil components that facilitate water absorption. Thus, increasing drought can be an amplifier of other climate change problems such as heavy precipitation.

Drought-like conditions may also impair wetland mitigation areas that have been established to permit ODOT projects and for which ODOT is responsible for maintenance.

Finally, extended droughts can affect the navigability of waterways such as the Ohio River and, potentially, access to water ports on Lake Erie.

IMPACTS TO LAKE ERIE

The water level of Lake Erie is projected to decline by 1.5 feet by mid-century. There are potentially many causes of this impact, including increased evaporation due to higher air temperatures. Increased drought conditions may also contribute but this effect may be offset by the more frequent periodic heavy precipitation events. The key transportation impacts include reduced depth of navigation channels, stranded docks and barriers, and potentially reduced access to lakefront, harbors, marinas.

Projected declines in water levels of Lake Erie could require additional harbor dredging related to Lake Erie water ports. A rule of thumb value of \$5/cubic yard for dredging. Illustrative costs for dredging the Port of Toledo #1 slip were estimated to be \$0.88-\$2.6 million. To dredge the entire port of Toledo Authorized Federal Harbor Channel was estimated to be approximately \$90 million¹⁰.

¹⁰ “Port Asset Values and Economic Impacts” -- July-September, 2010 issue of *Great Lakes Seaway Review*. Authors: Dale Bergeron (University of Minnesota) and Gene Clark (University of Wisconsin). <http://changingclimate.osu.edu/assets/pubs/sr-port-asset-2010.pdf>

TRB Special Report 290 cites a statistic from the Lake Carriers Association—a typical St. Lawrence Seaway oceangoing vessel loses 100 tons of capacity for each one-inch loss of draft.

POTENTIAL BENEFICIAL IMPACTS OF CLIMATE CHANGE EFFECTS IN OHIO

The climate change research scan identified four potential beneficial impacts of Climate Change on ODOT operations and assets:

- certain areas of the state may experience cost savings in roadway maintenance (i.e. longer lasting roadways) due to the reduction of freeze-thaw cycling, snow removal, and salt usage;
- lengthening construction season;
- reductions in snow and ice removal, reducing wintertime maintenance costs and the use of salt and chemicals on roads;
- potentially greater shipping traffic on Lake Erie (water side shipping) and in Ohio (land side shipping) due to climate impacts elsewhere.

OTHER IMPACTS OR RESPONSES

1. A beneficial impact of climate change could stem from the potential regulation of greenhouse gas emissions by the EPA, leading to shifting to more energy efficient modes of transport.
2. Related to the above is an array of potential air quality impacts, including increases in the formation of ground level ozone due to higher summertime temperatures, and the potential increase in PM2.5 due to fugitive dust from droughty soils.
3. Classes of climate change response:
 - Changes in design -- the past is not a good predictor of future conditions. Expected changes in climate extremes, such as more extreme temperatures, more intense precipitation, and more intense storms, could push environmental conditions outside the range for which the system was designed.
 - Changes in materials.
 - Changes in construction methods-- Increased flooding from more intense storms could require changes in physical improvements (increase culvert sizes, increased height of bridges) and operational measures (evacuation planning, real time information systems).
 - Changes in Operations & Maintenance practices.

TYPES OF INFRASTRUCTURE ASSETS VULNERABLE TO KEY CLIMATE CHANGE EFFECTS

ODOT's Long-Range Transportation Plan, Access Ohio 2040, describes the range and types of infrastructure assets managed by the Department (Figure 16).

FIGURE 16: OHIO'S STRATEGIC TRANSPORTATION SYSTEM (FROM ACCESS OHIO 2040)



The asset classes listed below are referred to in evaluation of the Likelihood and Severity of climate change effects on ODOT's asset classes:

POINT ASSETS

- Airports (104)
- Culverts/Drains/Outfalls
- Bridges
- Water Ports (8 on Lake Erie, 3 on Ohio River)
- Passenger Terminals
- Freight Terminals
- Transit Stops

FIXED ROUTE ASSETS

- Roads (43,211 lane miles)
- Marine Highways (716 miles), M70 (parallel to Interstate 79) and M90 (parallel to Interstate 90)
- Waterways
- Railways
- Bikeways (4,207 lane miles)
- Pedestrian Facilities
- Stormwater Management Systems

Other types of assets should be considered in a Vulnerability Assessment such as:

- Evacuation Routes
- Maintenance and Operations Facilities
- Traffic Signals and Traffic Control Centers
- Emergency Operating Systems
- Back-up power
- Communications
- Fueling
- Other Intelligent Transportation Systems
- Telecommunication Corridors
- Ecosystems that Complement or Mitigate Transportation Systems – wetlands, floodplains, roadside vegetation, areas of rock fall, and mitigation areas.

The U.S. Army Corps of Engineers manages the locks and dams on the Ohio River and its tributaries. The Ohio River Basin Alliance is conducting a parallel effort to understand the effects of climate change on these transportation assets. RSG has reached out to professionals in the Alliance to share information and will maintain communication with this group through the duration of the project.

Each of these asset classes will be evaluated for their vulnerability to the 4 key climate change effects. The qualitative Risk Assessment, presented below, is a combination of the Likelihood of an impact from climate change and the Severity of the impact (low, moderate, high). As this project progresses into the formal Vulnerability Assessment, greater

geographic resolution will be applied so that the vulnerability of specific assets in specific parts of Ohio can be addressed.

RISK ASSESSMENT

The Risk Assessment method is based on the qualitative assessment suggested by the Federal Highway Administration (FHWA).¹¹ In the context of climate change **Risk** is a combination of two elements: the likelihood of an event occurring and (2) the consequence of such an event ($R = L \times C$).

The primary elements of a qualitative risk assessment include:

- projecting climate-related effects and determining how these effects impact infrastructure; and,
- identifying and evaluating the likelihood and severity of climate-related impacts in order to characterize risks in the planning context (conducted qualitatively in this section);

The evaluation of the likelihood and consequence of climate-related impacts provides policymakers with some guidance on the level of risk and may be based upon a literature review or expert survey such as the research scan conducted for this project. The risk can be determined for a given system or program and focuses on identified climate change effects.

Another approach to Risk Assessment suggested in NCHRP Report 750 relates to the consequences of an asset being disrupted by a climate event. In this approach, the following factors are considered:

- Direct agency costs of restoring service.
- Direct user costs associated with a lack of service.
- Indirect costs associated with broader economic repercussions.
- Safety to the public caused by lack of service.
- Environmental impact due to lack of service.
- Reputation of the agency, or the public's confidence in the agency's ability to deal with emergency services.

Table 4 describes a qualitative approach of assessing risk of hazardous events and describes how risk associated is categorized (adapted from the FHWA website).

TABLE 4: LIKELIHOOD-SEVERITY MATRIX FOR A QUALITATIVE ASSESSMENT OF CLIMATE CHANGE EFFECTS

Likelihood/Severity	Low	Moderate	High
Low (<35%)			
Moderate (35-75%)			
High (>75%)			

¹¹ See:

http://www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/vulnerability_assessment/index.cfm#Toc236233838

For example, an event that is very likely to occur and produce catastrophic consequences has a high level of risk associated with it (described in a red-colored cell in the matrix).

Alternatively, an event that is not likely to occur or, if it were to occur, would produce very little damage, would be considered a very low risk (described in a green-colored cell in the matrix). Finally, risks are assessed for short-term (2013-2050) and long-term (2050-2080) time frames.

CLIMATE CHANGE EFFECTS: GRADUAL OR EVENT DRIVEN

Climate change effects can be gradual or event-driven. If anticipated, gradual effects can be planned for in a systematic manner, providing Adaptive Capacity to ODOT. Event-driven impacts, such as flooding from a heavy storm event, initially require operational procedures to manage emergency conditions. Over the long term, however, event-driven events may necessitate fundamental changes to the design of the affected infrastructure.

The key climate change effects projected for Ohio are categorized in Table 5.

TABLE 5: CATEGORIZATION OF KEY CLIMATE CHANGE EFFECTS IN OHIO

	Gradual	Event-Driven
Increasing Average Temperatures	x	
Increasing Frequency of Heavy Precipitation Events		x
Increased Drought Duration	x	
Reduced Lake Erie Water Levels	x	

SHORT-TERM CLIMATE CHANGE IMPACTS ON ODOT ASSETS (2015-2050)

Impact of Higher Temperatures

There is widespread agreement among climate scientists that average temperatures in Ohio will increase to 2050. In recent years there has been research on the impact of higher temperatures on transportation assets such as pavements. In most cases, the severity is considered to be low (Table 6).

TABLE 6: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING TEMPERATURE (SHORT- TERM)

Likelihood/Severity	Low	Moderate	High
High (>75%)	Most point assets, Roads, Airports, Railways, Bikeways, Pedestrian Facilities, Stormwater Management Systems, Other Assets	Bridges, Worsening summertime air quality impacts	

	(Telecommunications, ITS, etc.)		
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Impact of Increased Heavy Precipitation Events

Table 7 provides a Risk Assessment for increasing heavy precipitation events, which is judged to have a high likelihood in the short-term.

TABLE 7: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING HEAVY PRECIPITATION EVENTS (SHORT- TERM)

Likelihood/Severity	Low	Moderate	High
High (>75%)	Non-Flood-Prone Assets	Non-Flood Prone Assets Vulnerable to Severe Runoff	Stormwater management systems; Flood-prone assets (bridges, highways, ports, intermodal facilities); Emergency support systems; Evacuation routes

Many of ODOT's assets are vulnerable to heavy precipitation (>1" over 24 hours) events currently. Increasing frequency of these events will affect the same assets more frequently.

The increased severity of these events will affect more sections of ODOT highways and a greater number of bridges. In addition to flooding, heavy soil water saturation, in combination with increasing drought severity, can compromise pavement and bridge foundations due to extreme soil moisture fluctuation. Impacts to wetland mitigation areas might also be anticipated, in addition to the potential for stream migration. Superimposed on these impacts are the impacts on stormwater management systems in both urban and rural areas.

Impact of Increased Incidence of Drought

As discussed, projected increasing drought-like conditions are an amplifier to other climate change impacts such as increasing heavy precipitation events. Table 8 provides a Risk Assessment for increasing frequency and severity of drought, which is rated as having a Moderate Likelihood.

TABLE 8: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING FREQUENCY/SEVERITY OF DROUGHT EVENTS (SHORT- TERM)

Likelihood/Severity	Low	Moderate	High
Moderate (35-75%)	Airports; Passenger Terminals; Freight Terminals; Transit Stops; Roads; Bridges; Railways; Bikeways; Pedestrian Facilities; Stormwater Management Systems; Other Assets	Waterways, Water Ports, Lake Erie Intermodal Facilities	

For most of ODOT's assets, drought will have an indirect impact. We consider the impacts of drought to have a Moderate likelihood due to the relative lower consensus that longer duration droughts will occur from experts such as the Ohio State Climatologist.

For many of ODOT's key assets – roads and bridges – increasing duration of drought is not projected to have a major impact. Two of the most critical impacts related to drought identified in other climate vulnerability studies are:

1. the reduction of soil permeability leading to higher runoff events during heavy storms.
2. increasing fluctuation in wet-dry soil moisture regimes causes soil movement and structure fatigue.

The Severity of increased drought frequency is rated as Moderate for waterways and to Lake Erie water ports because the adaptation costs can be expensive to address (e.g. dredging to overcome shallower channels). Adaptive responses may involve new regulations to regulate ship weight/carrying capacity which, in turn, could be expensive to promulgate and enforce.

Table 9 provides a Risk Assessment for the declining Lake Erie water level. The research scan indicated variability of opinion on the water level trend for Lake Erie. For this reason, it is rated as having a Moderate Likelihood of occurring.

TABLE 9: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF LAKE LEVEL DECLINE (SHORT-TERM)

Likelihood/Severity	Low	Moderate	High
Moderate (35-75%)	Most point assets, except freight terminals on Lake Erie; most fixed-route assets except those immediately proximate to Lake Erie; Other assets.	Potential impacts to lakeside roads and bridges; Potential impacts to lakeside port facility infrastructure such as cranes, freight terminals, pipelines, etc.	

There is more widespread agreement that the costs associated with declining water levels would be high due to reduced navigability and increased shipping costs. Mitigation costs such as dredging would also be high. However, ODOT is not responsible for maintaining the navigability of the Great Lakes, which is the responsibility of the US Army Corps of Engineers. ODOT does have some port-related assets on the Lake Erie shoreline which are potentially affected by declining water levels.

LONG-TERM CLIMATE CHANGE IMPACTS ON ODOT ASSETS (2050-2080)

Most impacts described under Short-Term impacts are projected to become more acute in the long-term (2050-2080).

TABLE 10: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING TEMPERATURE (LONG- TERM)

Likelihood/Severity	Low	Moderate	High
High (>75%)	Most point assets ¹² , Roads, Airports, Railways, Bikeways, Pedestrian Facilities, Stormwater Management Systems, Other Assets	Roads (more expensive pavement mix, more frequent pavement maint.), Bridges,	Worsening Summertime Air Quality Impacts

¹² Examples of “point assets” are intermodal facilities, maintenance facilities, operations centers, transit centers, and port facilities.

	(Telecommunications, ITS, etc.)	Airports, Railways;	
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As noted above, ODOT should be able to adapt to accelerated pavement deterioration over time by monitoring pavement conditions and adapting pavement mixes as necessary. This will result in higher relative pavement management costs to the Department.

TABLE 11: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING HEAVY PRECIPITATION EVENTS (LONG- TERM)

Likelihood/Severity	Low	Moderate	High
High (>75%)	Non-Flood-Prone Assets— Point assets (airports, terminals, etc.); Fixed-Route Assets		Stormwater management systems; Flood-prone assets (wash-outs of bridges, highways, ports, intermodal facilities); Slope erosion; Waterways; Emergency operating systems; Evacuation routes; Non-Flood Prone Assets Vulnerable to Severe Runoff

TABLE 12: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF INCREASING FREQUENCY/SEVERITY OF DROUGHT EVENTS (LONG- TERM)

Likelihood/Severity	Low	Moderate	High
High (>75%)	Airports; Passenger Terminals; Freight Terminals; Transit Stops; Roads; Bridges; Railways; Bikeways; Pedestrian Facilities; Stormwater Management Systems; Other Assets	Waterways, Water Ports, Lake Erie Intermodal Facilities	

TABLE 13: LIKELIHOOD/SEVERITY TABLE FOR THE EFFECTS OF LAKE LEVEL DECLINE (LONG-TERM)

Likelihood/Severity	Low	Moderate	High
Moderate (35-75%)	Most point assets, except freight terminals on Lake Erie; most fixed-route assets except those immediately proximate to Lake Erie; Other assets.		Potential impacts to lakeside roads and bridges; Potential impacts to lakeside port facility infrastructure such as cranes, freight terminals, pipelines, etc.

IMPACTS TO PAVEMENTS

In the short term, the research scan suggests that rising average temperatures of 2-4°F should not cause significant pavement degradation. ODOT therefore has time to plan to adapt to pavement degradation. RSG consulted with Aric Morse of ODOT's Office of

Pavement Engineering to obtain more information on the potential vulnerability of pavements to increasing temperatures. Mr. Morse stated: “I don’t think we know exactly what temperature increase will begin to start causing pavement performance problems for our current specifications and design variables....There are many places all over the world that deal with much hotter temperatures than 4 degrees. Pavement design can accommodate these differences. The gradual change should not really be an issue.”

However, some recent research contrasts with this viewpoint. For example, a 2008 study for the UK Department of Transport indicated that higher average temperatures can have several effects on asphalt pavements¹³:

- Hardening of the bitumen leading to increased brittleness, surface cracking, and fretting (loss of surface depth).
- Higher incidence of surface rutting allowing for surface water ponding on roads and presenting a safety concern.
- Reduced skid resistance.

As temperatures increase over time, changes to the asphalt mix to adapt to higher temperatures will be necessary. Changes to the asphalt mix could result in a more expensive mix, requiring increasing budgetary support.

Temperature increases above the projected 2-4°F level could require more significant response by ODOT. However, due to the gradual onset of rising temperatures, ODOT should be able to adapt by modifying pavement mixes over time. In the short-term potential exceptions to this, highlighted in Table 6, are bridge joints which, due to their critical importance in bridge sufficiency, may fatigue sooner than their projected design life.

The most commonly cited concern related to rising temperatures relates to pavement deterioration. RSG consulted with ODOT pavement engineer Aric Morse, who provided this information:

- Hot Mix Asphalt pavements really are not sensitive to a climate change of only a few degrees over a 50 year period, ODOT resurfaces every 10 -14 years and any climate changes would be adapted to with specification updates as they notice changes in performance.
- The idea of needing to replace pavement due a few degree change over a period of 50 years is not likely. Lower layers are not as sensitive to temperature as the surface.
- Under an assumption of a larger temperature change (e.g.10 degrees over a shorter period), this could require a greater amount of polymer be combined with liquid asphalt for our surface course. To increase asphalt cement by 2 grades of polymer, would result in about a 15% increase in the cost of asphalt cement. Asphalt cement costs approximately 50% of the cost of a ton of asphalt concrete.

¹³ From: The Effects of Climate Change on Highway Pavements and How to Minimize Them. Published Project Report PPR 184. TRL Limited for the UK Department of Transport. October 2008

The conclusion of this research is that climate change will not affect pavement related costs to any degree that is measurable. The variability in oil costs are a larger component of overall costs and dwarf any increase in re-paving due to the reformulation of the pavement mix. There is a process in place for monitoring pavement response and plenty of time to adapt.

IMPACTS TO AIR QUALITY

One element of the Likelihood-Severity matrix for increasing average temperatures relates to summertime air quality impacts. These impacts to public health, experienced primarily in existing urban NAAQS (ozone) non-attainment areas¹⁴, could be significant. Other implications of non-attainment area designation include increased difficulty in implementing the State Implementation Plan (SIP) for achieving attainment with the NAAQS.

Jacob and Winner researched the impact of climate change on air quality¹⁵ and state: “It emerges from the state of current knowledge that climate change represents a significant penalty for air quality managers toward the achievement of ozone air quality goals...(t)he climate penalty for ozone air quality implies the need for more stringent emission controls to attain a given air quality objective.”

In turn, the air quality impacts could increase the geographic extent of existing nonattainment areas, or result in the designation of new nonattainment areas. It will become more difficult to demonstrate progress toward meeting federal air quality standards. For the purposes of this evaluation, the impacts are considered moderate in the short-term but are assumed to increase in severity in the long-term.

IMPACTS OF INCREASING HEAVY PRECIPITATION EVENTS

RSG consulted with The Office of Hydraulic Engineering (OHE) administrator, Jeff Syar to obtain background information regarding climate change and the impact on hydraulic structures. The OHE has already responded to changes in precipitation patterns in Ohio through data that impacts design calculations.

Hydraulic structures for highways are designed using return period years, which represent the average time between the occurrence of storms or floods of a given magnitude. The return period year represents the probability of exceedence for the event in a given year. In simplistic terms, a 100 year return period represents a 0.01 probability of exceedence (1 percent) of the event occurring in any one year while a 2 year return period represents a 0.50 probability of exceedence (50 percent) of the event occurring in any one year. The equation for the return period year is:

$$\text{Return Period Year} = \frac{1}{\text{Probability}}$$

¹⁴ There are currently three 8-hour ozone nonattainment areas in Ohio under the 2008 standard: Cincinnati-Hamilton, Cleveland-Akron-Lorain, and Columbus.

¹⁵ Jacob, Daniel J. and Darrell A. Winner. “Effect of Climate Change on Air Quality”. *Atmospheric Environment*. Volume 43, Issue 1. January 2009. Pages 51-63.

ODOT's Location and Design, Volume 2, Drainage Design Manual (L&D, Vol. 2) includes specific information for the hydrology and hydraulic design of highways, culverts, and bridges. The majority of the culverts and bridges use a peak discharge design, utilizing higher return period year events, which have a low probability of exceedence while other roadway hydraulic structures use a lower return period year with a higher probability of exceedence.

Hydraulic structures designed using a higher return period year includes culverts and bridges. These types of structures are typically designed using regression equations developed from the United States Geological Survey (USGS) using stream gauge data. The data are periodically updated approximately every 10 years. The next update will be in 2016.

Hydraulic structures designed using a lower return period year include storm sewers and catchment/inlet spacing. These types of structures utilize the Rational Equation to estimate stormwater runoff discharge (cubic feet per second) based upon the Drainage Area (acres), Amount of surface imperviousness (unit-less ratio), and the storm intensity (inches/hour) from Intensity Duration Frequency (IDF) curves.

IDF curves are found in the L&D, Vol. 2 Manual, which are believed to have been developed from historical precipitation data from Technical Paper 40, Rainfall Atlas Frequency of The United States, which can be found at:

http://www.nws.noaa.gov/oh/hdsc/PF_documents/TechnicalPaper_No40.pdf.

These IDF curves have been in use at ODOT for a minimum of 20 years. The exact date of origin is unknown by current staff at ODOT. The State was broken up into four regions that have different IDF curves in a simplistic manner (Figure 17).

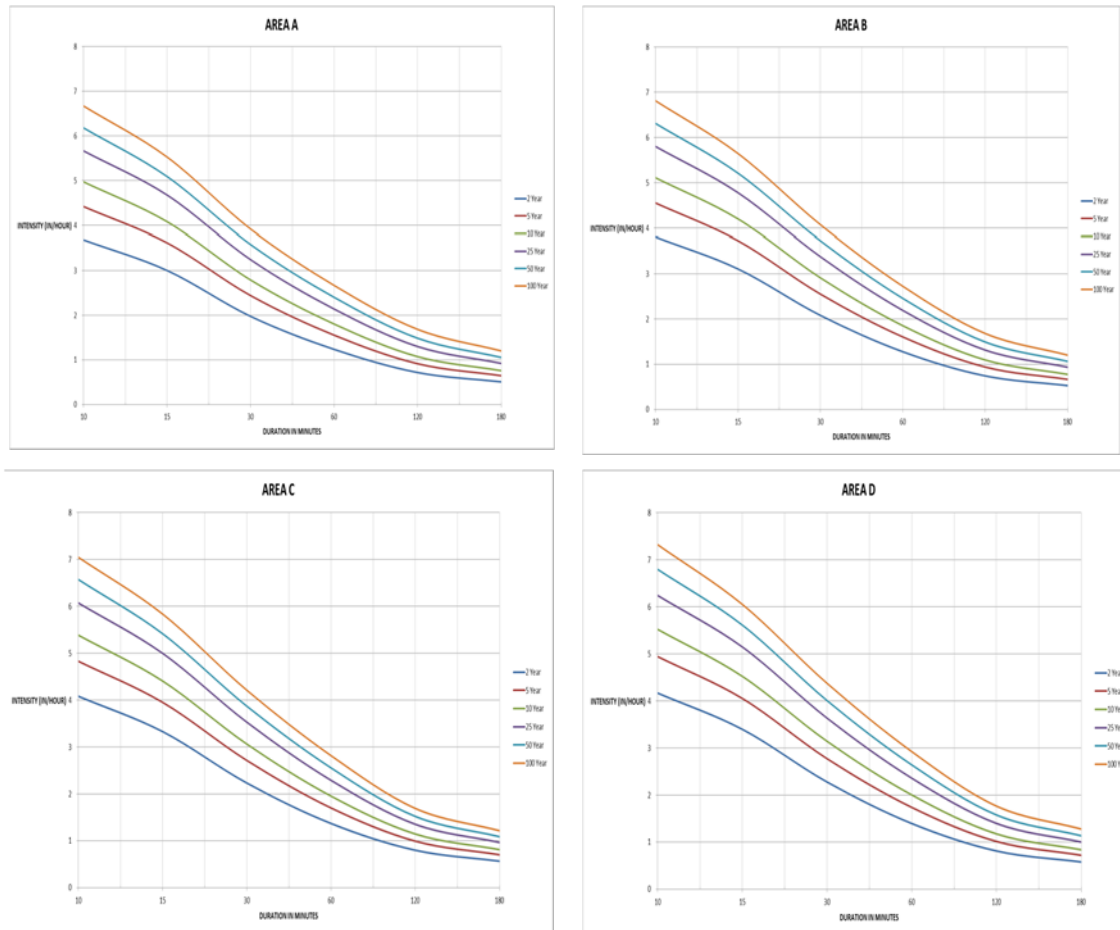
FIGURE 17: RAINFALL INTENSITY MAP OF OHIO

RAINFALL INTENSITY ZONE MAP	1101-3
	REFERENCE SECTION 1101.2.4



OHE recently developed revised IDF curves with data obtained from the National Oceanic and Atmospheric Administration (NOAA) webpage:
<http://dipper.nws.noaa.gov/hdsc/pfds/> (Figure 18).

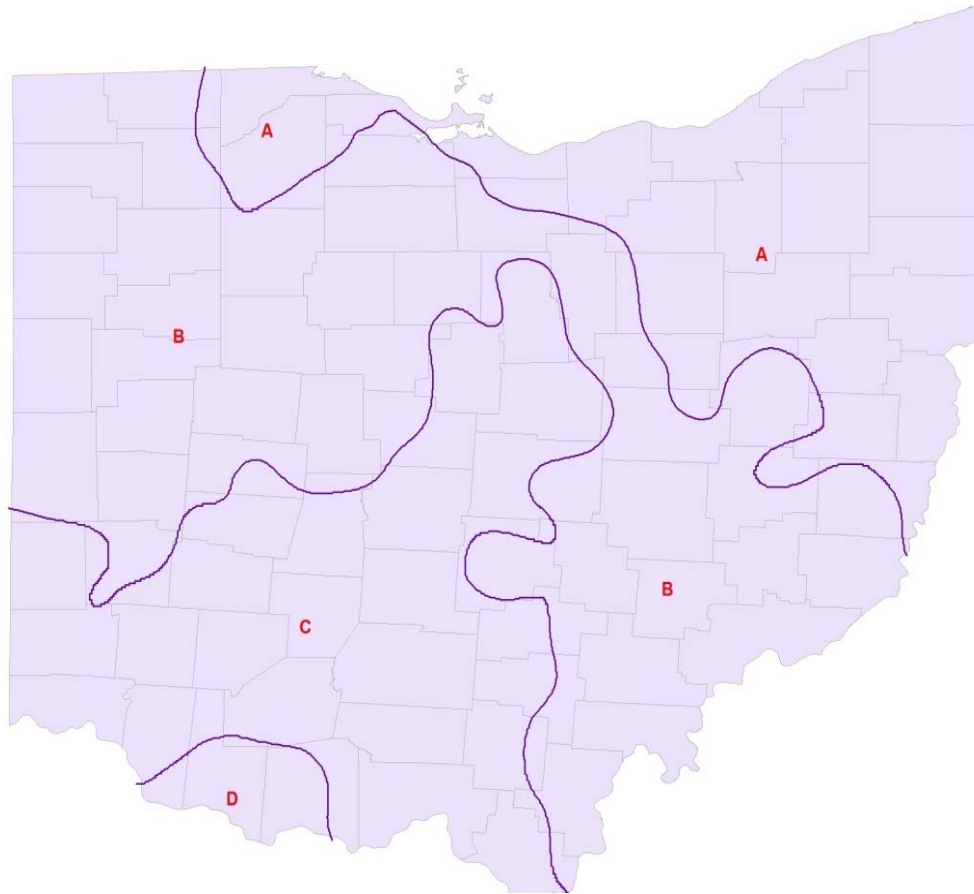
FIGURE 18: REVISED IDF CURES BASED ON MOST RECENT NOAA DATA



Preliminary findings indicated the following:

- Defined regions are different from existing regions (Figure 19). In general, rainfall intensity increases towards the southern portion of the state.
- Lower return period events yielded higher storm intensities than those listed in the L&D, Vol. 2 Manual
- The 10-year return period event appeared to be approximately the same between or with very little difference than the values in the L&D, Vol. 2 Manual and the newly created values.
- Higher return period events yielded lower storm intensities than those listed in the L&D, Vol. 2 Manual

FIGURE 19: PRELIMINARY REDEFINED RAINFALL INTENSITY ZONES FOR OHIO BASED ON MOST RECENT IDF CURVES



The vast majority of hydraulic structures designed by ODOT use a 10-year return period or higher. This would indicate that a conservative design would be created and that new IDF information wouldn't necessarily yield a flooding risk due to climate change.

Hydraulic design that utilizes the 2 or 5 year return period would be items that may have a heightened level of risk due to the increased intensity from the new IDF curves. Included items are: Bicycle Pathways (culverts), Maintenance of Traffic Drainage, ditch depth of flow and protection for roadways with and ADT of 2,000 or less, and pavement or bridge deck drainage to determine catchment spacing for all roadways except for freeways.

A cursory review of the new IDF curve information and resulting surface water runoff was evaluated for several scenarios for the impacted structure types. The results were not deemed significant enough to warrant a change in the existing IDF curves at this time. However, further review of the new IDF curve intensities is ongoing.

In addition, ODOT has not experienced significant or increased levels of flooding of these types of hydraulic structures and the Rational Equation is known to yield conservative estimates of surface water discharge, especially when the drainage area increases.

The NOAA webpage provides IDF information for a specific geospatial location by positioning a pointer on a map, which would be the preferred method of producing IDF curve information for any future changes. This would ensure that the most recent rainfall data is incorporated into the estimated stormwater runoff equation (Rational Equation) and it would be specific to the location. However, current software used by ODOT does not have this capability. OHE will be pursuing this methodology in the future.

Other Midwestern States, such as Wisconsin, have pointed out that stormwater design criteria are designed to withstand the historical range of weather variability, but there is a question as to how appropriate the historical climate data are for long-term assets such as stormwater facilities.

CONCLUSION OF THE RISK ASSESSMENT

A key conclusion of the Risk Assessment is that most of ODOT's core infrastructure facilities -- highways, bridges, and culverts -- are primarily vulnerable to increasing heavy precipitation events. As discussed above, small changes to hydraulic design parameters have already been made by the Office of Hydraulic Engineering based on the most recent data on precipitation and stream flow.

Therefore, the Vulnerability Assessment will focus on the vulnerability to extreme precipitation and flooding.

VULNERABILITY ASSESSMENT

This project considers a special challenge that ODOT must address when working to provide an efficient transportation system. That challenge is the increasing frequency of extreme weather, which has the potential to degrade system performance and reliability. A well-defined and internally supported vulnerability assessment will provide concrete guidance to ODOT on how to maximize system performance considering the potential for increased extreme weather events.

The Federal Highway Administration has advanced a process for assessing vulnerable assets called the Vulnerability Assessment Screening Tool, or VAST. The VAST approach has been used by other Midwestern DOTs such as Minnesota and Michigan to point to specific assets that may be vulnerable to extreme weather events, primarily heavy storm events.

THE VULNERABILITY ASSESSMENT SCREENING TOOL

In applying the VAST analysis to Ohio, RSG has reviewed recent practical applications of vulnerability assessments for other State DOTs. We also held several meetings with subject matter experts within ODOT, including facility planners, hydraulic engineers, and bridge engineers to gain their input and help refine the vulnerability assessment approach.

The results are a prioritized list by asset type, prioritized by vulnerability and system importance. Having a prioritized list of vulnerable assets will then enable the consideration of adaptation responses, which may range from reconstruction to changes in design standards to programmatic changes.

VAST relies on two main ideas:

1. The vulnerability of a particular asset is composed of the sensitivity, adaptive capacity, and exposure of that asset, which are defined as follows:
 - a. Exposure - the level of intensity of a climate effect that is experienced by a particular asset;
 - b. Sensitivity - the susceptibility of an asset to being damaged by a climate effect;
 - c. Adaptive Capacity - the ability of the transportation system to continue functioning after an asset is damaged.
2. Sensitivity, adaptive capacity, and exposure of a particular asset can be approximated using appropriate indicators.

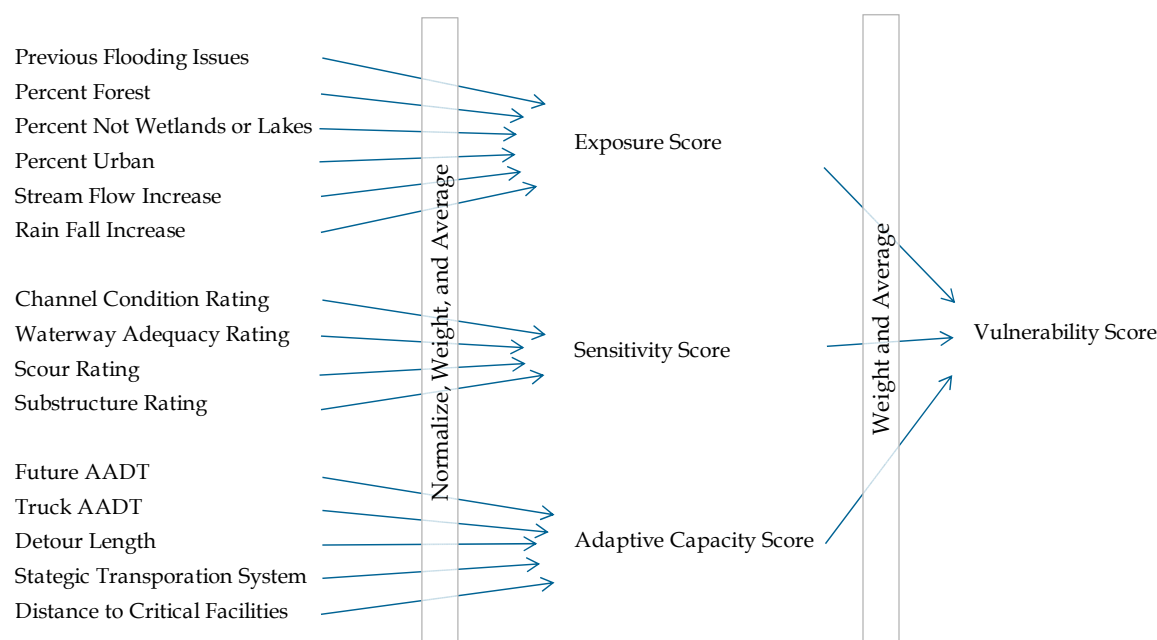
To illustrate for culverts, one indicator for adaptive capacity might be the detour distance in the event that the culvert is destroyed leading to a road closure. Within VAST, indicators can be normalized to give a score between 1 and 4, and then scores for all indicators are averaged together using user-specified weights. The average score would then be the adaptive capacity component of vulnerability.

A similar process is followed for the other two components, exposure and sensitivity. The indicators for sensitivity might be culvert condition rating and channel condition rating. For

exposure, the indicators might be change in maximum stream flow. Once the three component scores are calculated, they are averaged together, again using user-specified weights, to produce the final vulnerability score. This entire process is repeated for each bridge and culvert, after which they are prioritized based on the vulnerability score.

Figure 20 illustrates the bridge vulnerability scoring approach for this analysis.

FIGURE 20. ILLUSTRATION OF THE VAST VULNERABILITY SCORING APPROACH



For the ODOT Resiliency Plan, 3 asset types are analyzed for vulnerability using the VAST framework: bridges, culverts, and highways. In all three cases, vulnerability is related to flooding, high precipitation events, or high streamflow.

BRIDGE AND CULVERT VULNERABILITY

The analysis process starts with assembling bridge and culvert datasets. The core information for these datasets comes from the National Bridge Inventory and the Ohio Bridge Inventory, which were joined together to create the starting point for the datasets. That table was then augmented with data from specialized spatial analysis.

NATIONAL BRIDGE INVENTORY

The NBI is compiled and maintained by the FHWA based on reports from each state. It includes all bridges and culverts that have a span of at least 20 feet, and is updated on an annual basis. For this analysis, the 2014 inventory for Ohio was downloaded from the NBI website¹⁶. It included approximately 27,000 structures.

The NBI provided data for the following data fields in the final analysis data set:

¹⁶ <http://www.fhwa.dot.gov/bridge/nbi/ascii.cfm>

- Channel Condition Rating
- Culvert Condition Rating
- Detour Length

The channel and culvert ratings are codes on an ordinal scale ranging from 9 to 0. The codes are a qualitative measure of the general conditions. For channel condition, 9 means “There are no noticeable or noteworthy deficiencies which affect the condition of the channel”, while 0 means “bridge closed because of channel failure”. The codes are defined and described in the NBI coding guide¹⁷.

The detour length is the additional travel distance required if the bridge were impassable. It is recorded in the NBI for each bridge with units of kilometers.

OHIO BRIDGE INVENTORY

The Ohio Bridge Inventory (OBI) was used to add additional data fields to the analysis dataset. The OBI is very similar to the NBI, but includes smaller bridges and culverts down to a 10-foot span. It also includes additional fields that are not in the NBI, and is generally more up-to-date than the NBI. The OBI was downloaded from the ODOT TIMS website¹⁸

The OBI provided the following data fields for the final analysis dataset:

- Waterway Adequacy Rating (adequacy of the water way opening with respect to passage of flow)
- Scour Critical Rating (vulnerability to scour)
- Substructure Condition Rating (physical condition of piers, abutments, piles, footings, etc.)
- Future Average Daily Traffic
- Average Daily Truck Traffic
- Strategic Highway Network Designation (whether the structure is on the Strategic Transportation System, STS)

The waterway adequacy, scour critical, and substructure condition are very similar to the channel and culvert ratings from the NBI; they all use an ordinal scale from 9 to 0 to indicate the general condition of the structure. The daily traffic fields give the number of vehicles passing over the bridge. The strategic highway field indicates whether the bridge is on the strategic highway network.

An additional dataset is the Ohio Culvert Inventory (OCI), which contains approximately 80,000 culverts. All of the culverts in the OCI have a span of 10 feet or less. The OCI does

¹⁷ Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation’s Bridges, <http://www.fhwa.dot.gov/bridge/mtguide.pdf>

¹⁸ <http://gis.dot.state.oh.us/tims/Data/Download>

not have culvert condition ratings as part of the dataset, so it was not used as part of this analysis.

FUTURE PRECIPITATION AND STREAM FLOW CHANGES

Four custom spatial analyses were used to add additional fields to the analysis dataset. The first of these analyses was conducted to determine predicted future changes in precipitation and stream flow.

The core data for the analysis came from the Ohio River Basin Climate Change Project conducted by the National Oceanic and Atmospheric Agency/National Weather Service Ohio River Forecast Center¹⁹ for the U.S. Army Corps of Engineers. The project used global climate change models and geographic downscaling, along with hydrologic modeling to predict changes in precipitation and stream flow through the end of the century for sub-regions of Ohio.

These results were used to add four fields to the analysis data set:

- Relative change in stream flow from 2010 to 2050
- Relative change in rain fall from 2010 to 2050
- Relative change in stream flow from 2010 to 2099
- Relative change in rain fall from 2010 to 2099

These values were based on predicted annual rainfall or stream flows, and each bridge was assigned values based on the sub-region it fell within. Figure 21 shows the climate change prediction sub-regions.

¹⁹ <http://216.68.102.178/commish/2014/febtech/agendaitem16.pdf>

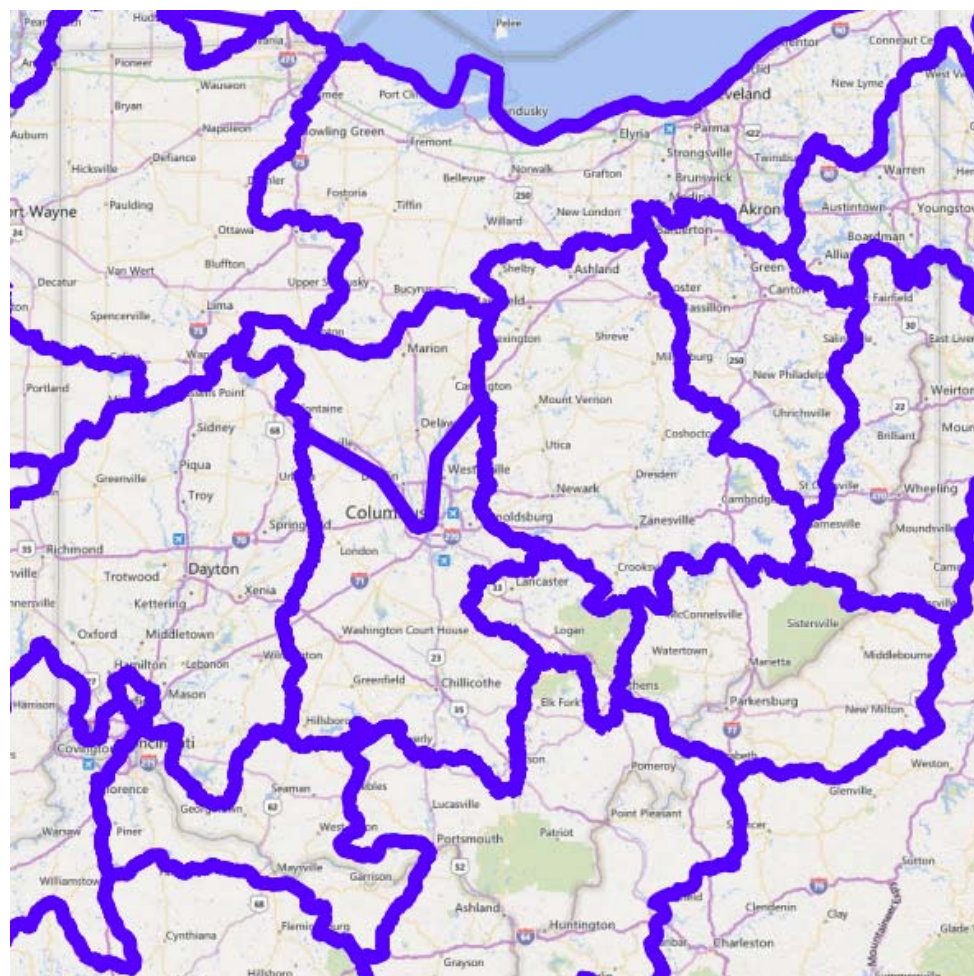


FIGURE 21. SUB-REGIONS OF OHIO FOR CLIMATE PREDICTIONS

DISTANCE TO NEAREST HOSPITAL

The second spatial analysis calculated the on-network distance from each bridge or culvert to the nearest hospital. Bridges that were near a hospital were considered important for providing emergency access. The distance was calculated by constructing a network model of the roadways in Ohio, and generating paths between each bridge and hospital. The path lengths were then used as the distance to the nearest hospital.

This indicator could be expanded to include other “Centers of Regional Importance”, which could include major employers or emergency response centers. RSG inquired about these types of data but has not located a central data set.

WATERSHED CHARACTERISTICS

The third spatial analysis determined the characteristics of the watershed associated with each bridge and culvert. The fields provided by this analysis were:

- percent urban land cover in the watershed

- percent forested land cover in the watershed
- percent not lake or watershed land cover in the watershed

The values for these fields were calculated by first determining the watershed for each bridge using hydrologic analysis, and then using land cover data from the USGS to determine the percent of each kind of land cover in the watershed.

PREVIOUS FLOODING LOCATIONS

The previous flooding locations were provided by Thomas Lyden, ODOT Administrator of Maintenance Operations, in an Excel report giving the route and mile markers for the locations. A spatial analysis was used to digitize this information in GIS. Previously flooded locations were mapped in order to determine proximity of bridges or culverts.

Data Filtering

The data assembly process involved several steps to filter the data down to only those assets that were pertinent to the analysis. The dataset started with the NBI, which contained 26,986 records. It was filtered to include only bridges over waterways, which left 14,774 records. Then the OBI was joined to the NBI, and 12,854 records matched between the two datasets.

The dataset was then filtered to include only those bridges on state-maintained routes, which left 5,375 records. Then the dataset was split into two datasets for culverts and bridges. The final number of records for each was:

- Bridges: 5444
- Culverts: 3527

Vulnerability Calculation for Bridges and Culverts

The analysis data set provided the basis for calculating the vulnerability score for each bridge or culvert. Each field in the data set was used as an indicator to calculate the exposure, sensitivity, and adaptive capacity scores. The three component scores were then averaged together to produce the final vulnerability score.

Table 14 summarizes the indicators that were used for the bridges and culverts vulnerability calculations. It also gives the rationale for each indicator, and the weight for each indicator. For this version of the analysis, every indicator is given the same weight. Refinements of the approach will give greater weight to those indicators that are important for determining vulnerability.

Each indicator has a specific approach to transform the indicator raw value to a score between 1 and 4.

TABLE 14. VULNERABILITY CALCULATION APPROACH

Indicator	Rationale	Weight	Bridges	Culverts
Exposure Indicators		4.0		
Previous Flooding Issues	Structures that have previous flooding issues will probably flood again	4.0	X	X
Percent Forest	Woody debris can obstruct culverts or cause impact damage in extreme events	1.0	X	X
Percent Not Wetlands or Lakes	Lakes and wetlands attenuate extreme rainfall events	1.0	X	X
Percent Urban	Urban land cover worsens flooding events	1.0	X	X
Stream Flow Increase	Increased stream flow causes more frequent overtopping	4.0	X	X
Rain Fall Increase	Increased rain fall causes more frequent over topping	4.0	X	X
Sensitivity Indicators		1.0		
Channel Condition Rating	Channels in poor condition will suffer further damage in more extreme events	1.0	X	X
Waterway Adequacy Rating	An inadequate water way is not capable of handling higher stream flows	1.0	X	X
Scour Rating	Increasing flooding events will only	1.0	X	

	exacerbate any existing scour problems			
Substructure Rating	Bridges with distressed substructures are susceptible to additional damage with more frequent flooding	1.0	X	
Culvert Condition Rating	More extreme flooding events will damage any poor-condition culverts	1.0		X
Adaptive Capacity Indicators		3.0		
Future AADT	Structures with higher ADT are more important to the overall transportation network	1.0	X	X
Truck AADT	Structures with higher truck volumes carry more high-value trips	1.0	X	X
Detour Length	A longer detour length means a more costly recovery period when a structure is damaged	1.0	X	X
Strategic Transportation System	Structures on the strategic transportation system are important to the wider network	1.0	X	X
Distance to Critical Facilities	Structures near hospitals are important links for emergency services	1.0	X	X

RESULTS OF VULNERABILITY ANALYSIS FOR BRIDGES

The vulnerability calculation approach was used to determine a vulnerability score for each bridge. Based on input from ODOT staff, it was determined that the Exposure indicators should be weighted most heavily in the analysis. The assets are ranked according to score to determine which are the most vulnerable. Table 10 lists the 10 most vulnerable bridges using the basic approach of vulnerability assessment where all factors are weighted equally.

Table 15 shows the locations of the ten most vulnerable bridges based on this analysis.

TABLE 15. FINAL RESULTS, TEN MOST VULNERABLE BRIDGES

Asset ID	Bridge Location Description	Score (Rank#)
4822	NB I 75 (RILEY CREEK)	2.64 (1)
4823	SB I 75 (RILEY CREEK)	2.64 (2)
2228	I.R.475 00475 (OTTAWA RIVER)	2.62 (3)
4056	US 62 3.09 MI W OF SR 165 (BR MAHONING RIVER)	2.5 (4)
2144	US 224 0.70 MI E OF SR 625 (MILL CREEK)	2.48 (5)
2132	US 62 0.47 MI W OF SR 289 (SR 289 MAH R & CSX&NS RR)	2.45 (6)
2143	US 224 0.80 MI E OF SR 625 (MILL CREEK)	2.44 (7)
785	US 62 4.13 MI E OF SR 173 (OVR SR183 RR CRK&GASKILL)	2.43 (8)
786	US 62 4.13 MI E OF SR 173 (OVR SR183 RR CRK&GASKILL)	2.42 (9)
751	SR 619 2.24 MI W OF SR 183 (LITTLE BEECH CREEK)	2.42 (10)

Figure 22 shows the location of the 10 most vulnerable bridges ranked by this method. The top two most vulnerable bridges are located on I75 Northbound, over Riley Creek outside of Bluffton, Ohio. The third most vulnerable bridge according to this model is on I-475 over the Ottawa River west of Toledo. The seven other bridges in the top 10 are concentrated in the northeastern part of Ohio near Youngstown, Canfield, and Alliance.

FIGURE 22: LOCATION OF THE 10 MOST VULNERABLE BRIDGES

Most Vulnerable Assets



number of assets: 5608
with valid scores: 5444
shown here: top 10

To demonstrate the use of the VAST model, the Bridge Vulnerability Rankings will shift based on the relative weighting of the three indicator groups. If, for example, the weighting

for Exposure were kept at 4.0, but the weighting for Adaptive Capacity was reduced to 1.0, the ranking of vulnerable bridges would change. Table 16 shows the revised rankings and compares them to the rankings accomplished using the model weightings that produced Table 15.

TABLE 16: REVISED RESULTS, TEN MOST VULNERABLE BRIDGES

Asset ID	Bridge	Score (Rank#)	
		Exposure Weight = 4.0 Adaptive Capacity Weight = 1.0	Exposure Weight = 4.0 Adaptive Capacity Weight = 3.0
2144	US 224 0.70 MI E OF SR 625 (MILL CREEK)	2.84 (1)	2.48 (5)
4056	US 62 3.09 MI W OF SR 165 (BR MAHONING RIVER)	2.78 (2)	2.5 (4)
2143	US 224 0.80 MI E OF SR 625 (MILL CREEK)	2.78 (3)	2.44 (7)
751	SR 619 2.24 MI W OF SR 183 (LITTLE BEECH CREEK)	2.77 (4)	2.42 (10)
672	SR 7 0.45 MI N OF SR 88 (MILL CREEK)	2.74 (5)	2.31 (36)
1270	US 224 1.32 MI E OF SR 225 (WILLOW CREEK)	2.74 (6)	2.32 (33)
785	US 62 4.13 MI E OF SR 173 (OVR SR183 RR CRK&GASKILL)	2.74 (7)	2.43 (8)
786	US 62 4.13 MI E OF SR 173 (OVR SR183 RR CRK&GASKILL)	2.74 (8)	2.42 (9)
2132	US 62 0.47 MI W OF SR 289 (SR 289 MAH R & CSX&NS RR)	2.72 (9)	2.45 (6)
4822	NB I 75 (RILEY CREEK)	2.7 (10)	2.64 (1)

The results show that most of the top rated bridges still rank highly, though the bridge ranked as most vulnerable in Table 15 is the tenth most vulnerable using the revised weighting scheme. Of greater interest is the fact that two bridges not previously ranked in the top 10 (#672 and #1270) move up to the fourth and fifth positions, respectively.

The point of this exercise is to show the flexibility of the model. The model is sensitive to the weightings applied by the user. To make the model truly useful for ODOT planning, Subject Area Specialists should be convened to review the results of alternative weighting schemes, and make appropriate adjustments to the model such that the results meet the collective expectations of an expert group.

RESULTS OF VULNERABILITY ANALYSIS FOR CULVERTS

As discussed, a similar modeling approach is used to determine the vulnerability of culverts. The indices for culverts are identical to those for bridges with the exception of the Culvert Condition Rating (bridges have scour rating).

shows the 20 highest ranked culverts in terms of vulnerability to flooding using this analysis.

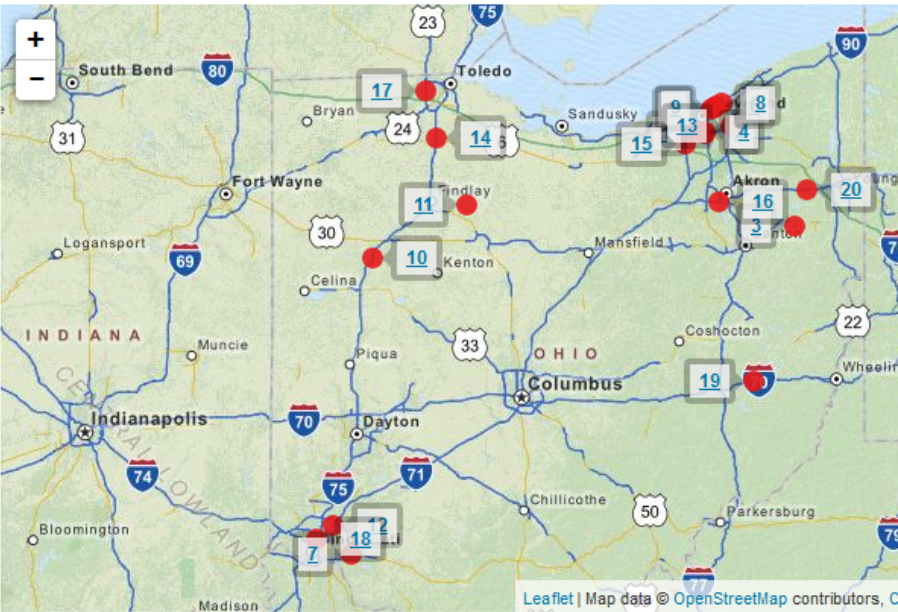
TABLE 17: FINAL RESULTS, 20 MOST VULNERABLE CULVERTS

Asset ID	Culvert Location Description	Score (Rank#)
362	I-480 .68 MI. E. OF JCT. SR-17 (WEST CREEK)	2.55 (1)
361	I-480 .73 MI. E. OF JCT. US-42 (STICKNEY CREEK)	2.52 (2)
383	US 62 1.73 MI W OF SR 165 (BR MAHONING RIVER)	2.51 (3)
368	IR90 .51 MI E OF JCT SR283DA (DOAN CREEK CULVERT)	2.43 (4)
366	I 90 0.40 MI E EDDY ROAD (NINE MILE RUN @ MM 179.2)	2.42 (5)
405	SR32 2.9 MI EAST OF I275 (TRIBUTARY SHAYLER RUN)	2.41 (6)
365	IR90 2.96 MI W OF SR175 (EUCLID CREEK CULVERT)	2.4 (7)
367	I 90 1.4 MI W SR 283 (DUGWAY BROOK)	2.4 (8)
461	I 75 .08 MILE N OF SR 309 (LOST CREEK)	2.38 (9)
75	HIGHWAY 00023 (THE OUTLET BRANCH)	2.38 (10)
290	IR 71 1.3 MI N OF SR 126-COOPER (TRIB N BR SYCAMORE CREEK)	2.37 (11)
12	HIGHWAY 1 (POE DITCH)	2.36 (12)
373	I-71 .15 MI.S. OF JCT. US-42 (BALDWIN CREEK)	2.35 (13)
59	I.R. 76 JCT SR 619 AND IR 76 (MUD RUN)	2.35 (14)
208	HIGHWAY 00475 (HELDMAN DITCH)	2.34 (15)
288	IR 75 .1 MI S OF SR 562 (ROSS RUN)	2.34 (16)
202	I.R. 76 0.69 MI E OF SR 534 (DUCK CREEK)	2.33 (17)
211	I80 TPK 4.3MI EAST OF EXIT 8 (RIDGEWAY DITCH MP1498)	2.32 (18)
287	IR 75 .3 MI N OF IR 275 (TRIBUTARY MILL CREEK)	2.32 (19)
369	I-90 .04 MI W. CLAGUE RD INTER (SPERRY CREEK)	2.32 (20)

Figure 23 shows the locations of the 20 highest ranked culverts for vulnerability. As with bridges, there are several located in the northeastern part of Ohio, near Canfield, Boardman, and Alliance, and an additional 3 culverts, ranked 4, 7, and 11, are along Highway 7 in Ashtabula County.

FIGURE 23: LOCATIONS OF THE 20 MOST VULNERABLE CULVERTS

Most Vulnerable Assets

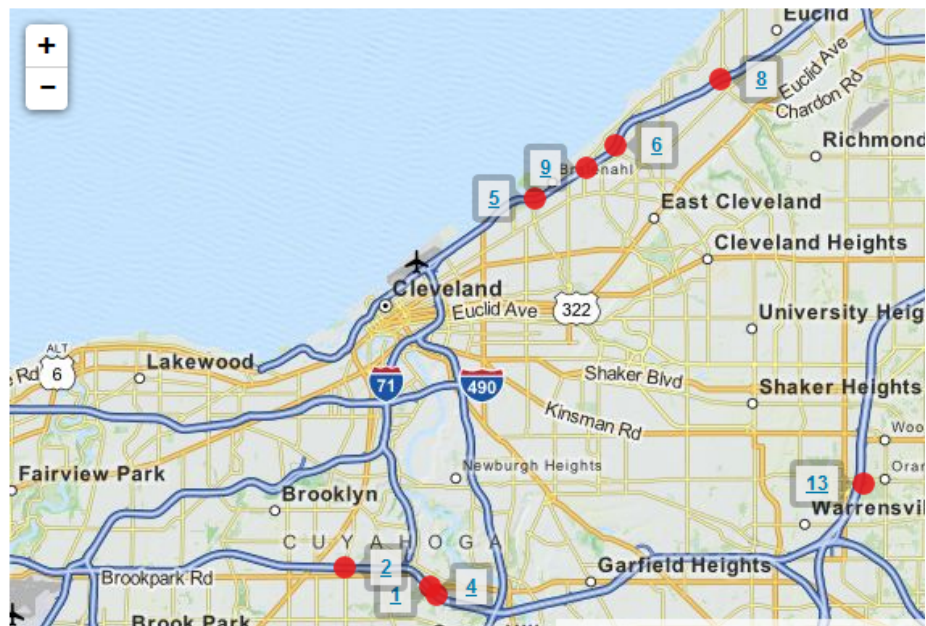


number of assets: 3620
with valid scores: 3527
shown here: top 20

Eight of the 20 most vulnerable culverts are in northeastern Ohio, several of which are located on I-90, east of Cleveland (Figure 24).

FIGURE 24: MOST VULNERABLE CULVERTS IN NORTHEASTERN OHIO

Most Vulnerable Assets



As with bridges, we can demonstrate the flexibility of the model by comparing the ranking of vulnerable culverts if weights are changed. Making the same adjustment as for bridges, namely, keeping Exposure at 4.0 weighting and reducing Adaptive Capacity to a 1.0 weighting, produces a revised priority list (Table 18), substantially different than the one shown in Table 17.

TABLE 18: REVISED RESULTS, 20 MOST VULNERABLE CULVERTS

Asset ID	Culvert	Exposure Weight = 4.0 Adaptive Capacity Weight = 1.0	Exposure Weight = 4.0 Adaptive Capacity Weight = 3.0
383	US 62 1.73 MI W OF SR 165 (BR MAHONING RIVER)	2.83 (1)	2.51 (3)
75	HIGHWAY 00023 (THE OUTLET BRANCH)	2.63 (2)	2.38 (10)
351	SR 37 0.93 MI W OF SR257 (SMITH RUN)	2.62 (3)	2.3 (24)
31	S.R. 7 2.4M S OF JCT SR550 (SUGAR RUN)	2.55 (4)	2.26 (32)
27	S.R. 60 0.02M N OF JCT SR821 (SECOND CREEK)	2.54 (5)	2.3 (22)
189	USR-33 JCT. SR-707 (DENNISON RUN)	2.53 (6)	2.17 (54)
145	SR 555 7.2 M N OF MORGAN CO LINE (OVER BR BRUSH CREEK)	2.53 (7)	2.19 (46)
30	S.R. 7 0.09M S OF JCT SR550 (MILE RUN)	2.51 (8)	2.26 (31)
144	I.R.77 3.6M N WASH. CO. LINE (STREAM)	2.5 (9)	2.31 (21)
146	SR 376 .5 MI S OF JCT SR 60 (SR376 OVER RIFFLE RUN)	2.5 (10)	2.13 (72)
153	S.R. 60 0.3M S JCT SR376 (STREAM)	2.49 (11)	2.14 (70)
405	SR32 2.9 MI EAST OF I275 (TRIBUTARY SHAYLER RUN)	2.48 (12)	2.41 (6)
327	S.R. 7 0.35M N OF JCT SR218 (LONG RUN)	2.48 (13)	2.16 (55)
32	S.R. 7 4.62M S OF JCT SR550 (STREAM)	2.47 (14)	2.16 (57)
178	SR 7 0.26 MI S. JCT SR 255 (PATTON RUN)	2.46 (15)	2.12 (75)
142	SR 146 3.2 MI. E OF SR 147 (UNKNOWN STREAM)	2.46 (16)	2.12 (74)
138	SR 821 0.18M N WASH. CO. LINE (STREAM)	2.46 (17)	2.12 (77)
136	SR. 821 1.92M S OF JCT SR78 (STREAM)	2.45 (18)	2.11 (81)
262	US 62 2.60 MI. W OF SR206 (BR NEGRO RUN)	2.45 (19)	2.12 (73)
266	S.R. 328 5.09M N OF JCT SR56 (SIMPLE CREEK)	2.43 (20)	2.13 (71)

STORMWATER MANAGEMENT FACILITIES

In addition to conducting the VAST analysis for culverts, the project team met multiple times in person and via teleconference with ODOT Hydraulics engineers Jeff Syar, Becky Humphries, and David Ryley.

The Office of Hydraulics Engineering has recently developed new Intensity-Duration-Frequency (IDF) curves with the most recent data obtained from NOAA Precipitation-Frequency data available online (<http://dipper.nws.noaa.gov/hdsc/pfds/>).

IDF curves are used to obtain inputs to the Rational Equation used in the hydraulic design of infrastructure utilizing precipitation return periods of less than 10 years (i.e. higher frequency/probability rainfall events). ODOT assets that may have a heightened level of risk associated with increased rainfall intensity include:

- Culverts for bicycle pathways;
- Maintenance of Traffic drainage;
- ditch depth of flow

- stormwater protection for low volume roadways (AADT \geq 2,000); and
- pavement or bridge deck drainage to determine catchment spacing for all roadways except for freeways.

OHE's findings indicated the following:

- Based on the most recent NOAA Precipitation-Frequency data, rainfall intensity regions within the ODOT L&D Manual are different from existing regions. In general, rainfall intensity increases towards the southern portion of the state.
- Lower return period events (<10 years) yielded higher storm intensities than those listed in the L&D, Vol. 2 Manual. However, as mentioned, these types of structures are designed using the Rational Equation, which is acknowledged to yield conservative estimates of surface water discharge. Further, ODOT has not experienced significant or increased levels of flooding of these types of hydraulic structures. Nevertheless, ODOT could benefit from incorporating the most recent rainfall data (from NOAA) and the current software ODOT uses does not have this capability.
- The 10-year return period event appeared to be approximately the same between or with very little difference than the values in the L&D, Vol. 2 Manual and the newly created values.
- Higher return period events yielded lower storm intensities than those listed in the L&D, Vol. 2 Manual. Higher return periods are used for the design of highways, highway culverts, and bridges.

VULNERABILITY ASSESSMENT OF HIGHWAYS

To illustrate the vulnerability assessment approach for highway segments, one indicator for adaptive capacity might be the AADT on the highway segment. Within VAST indicators can be normalized to give a score between 1 and 4, and then scores for all indicators would be averaged together using user-specified weights. The average score would then be the adaptive capacity component of vulnerability.

A similar process would be followed for the other two components, exposure and sensitivity. An indicator for sensitivity might be pavement condition rating. For exposure, the indicators might include change in maximum stream flow for a parallel stream. Once the three component scores are calculated, they are averaged together, again using user-specified weights, to produce the final vulnerability score. This entire process is repeated for each highway segment, after which they are prioritized based on the vulnerability score.

Figure 20 below illustrates the highway segment vulnerability scoring approach for this analysis. Additional details on the highway segment vulnerability scoring approach are given in the following sections.

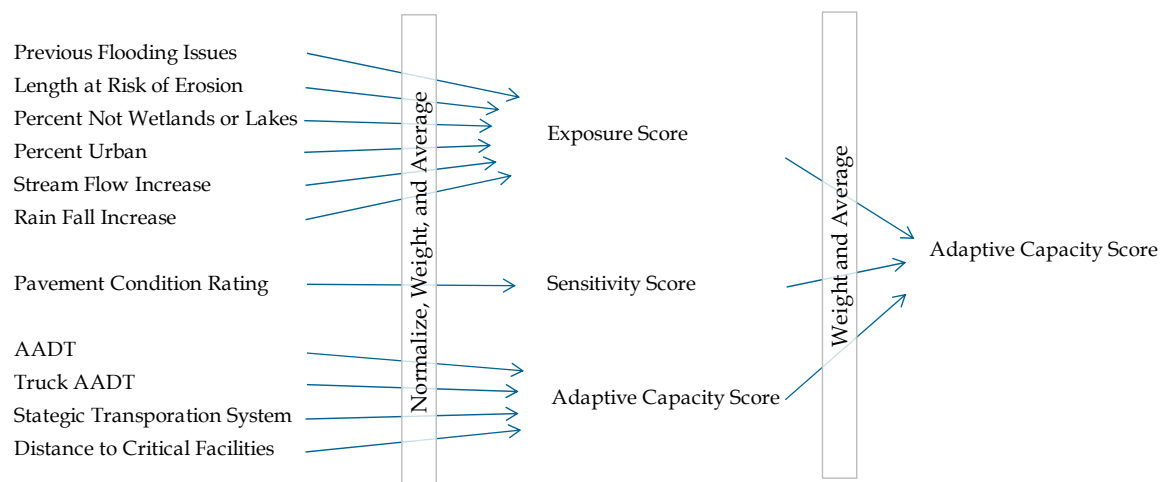


FIGURE 25. ILLUSTRATION OF THE VAST VULNERABILITY SCORING APPROACH

The analysis process started with assembling the highway dataset. The core information for this dataset came from the Ohio Pavement Condition Inventory. That table was then augmented with data from specialized spatial analysis.

OHIO PAVEMENT CONDITION INVENTORY

The Ohio pavement condition inventory is compiled and maintained by the Ohio DOT. It includes spatial and pavement condition data for roadway segments maintained by the state. It also includes information on AADT. The inventory provides the data for the following indicators.

- AADT
- Truck AADT
- Pavement Condition Rating

STRATEGIC TRANSPORTATION SYSTEM

The Strategic Transportation System (STS) dataset gives the highway segments that are important to statewide mobility. The dataset was used to determine which of the segments from the pavement condition inventory are on the strategic highway network.

FUTURE PRECIPITATION AND STREAM FLOW CHANGES

Five custom spatial analyses were used to add additional fields to the analysis dataset. The first of these analyses was conducted to determine predicted future changes in precipitation and stream flow. The core data for the analysis came from the Ohio River Basin Climate Change Project conducted by the National Oceanic and Atmospheric Agency/National Weather Service Ohio River Forecast Center²⁰ for the U.S. Army Corps of Engineers. The project used global climate change models and geographic downscaling, along with

²⁰ <http://216.68.102.178/commish/2014/febtech/agendaitem16.pdf>

hydrologic modeling to predict changes in precipitation and stream flow through the end of the century for sub-regions of Ohio. These results were used to add four fields to the analysis data set:

- Relative change in stream flow from 2010 to 2050
- Relative change in rain fall from 2010 to 2050
- Relative change in stream flow from 2010 to 2099
- Relative change in rain fall from 2010 to 2099

These values were based on predicted annual rainfall or stream flows, and each highway segment was assigned values based on the sub-region it fell within. Figure 21 shows the climate change prediction sub-regions.

DISTANCE TO NEAREST HOSPITAL

The second spatial analysis was to calculate the on-network distance from each highway segment to the nearest hospital. Highway segments that were near a hospital were considered important for providing emergency access. The distance was calculated by constructing a network model of the roadways in Ohio, and generating paths between each highway segment and hospital. The path lengths were then used as the distance to the nearest hospital.

This indicator could be expanded to include other “Centers of Regional Importance”, which could include major employers or emergency response centers. RSG has inquired about these type of data but has not located a central data set.

WATERSHED CHARACTERISTICS

The third spatial analysis determined the characteristics of the watershed associated with each highway segment. The fields provided by this analysis were:

- percent urban land cover in the watershed
- percent not lake or watershed land cover in the watershed

The values for these fields were calculated by first determining the watershed for each highway segment using hydrologic analysis, and then using land cover data from the USGS to determine the percent of each kind of land cover in the watershed.

PREVIOUS FLOODING LOCATIONS

The fourth spatial analysis was used to determine if the highway segment was in a frequent flooding location based on field experience²¹. The previous flooding locations were provided in an Excel report giving the route and mile markers for the locations. This was used to map the locations, and then determine if each highway segment was within one of the locations.

²¹ These data were supplied by Thomas Lyden, ODOT Administrator of Maintenance Operations.

EROSION RISK

The fourth spatial analysis determined the length of each highway segment that is within 200 feet of the paralleling stream or river bank. This length was used to indicate the risk of roadway damage from flooding and erosion. The buffer dimension, 200 feet, was selected as a conservative buffer that would appropriately account for variations in impacts

Data Filtering

The data assembly process involved several steps to filter the data down to only those assets that were pertinent to the analysis. The dataset started with the Ohio pavement condition inventory, which included only state-maintained highway segments. This original dataset contained 96,462 records. The dataset was then filtered to include only those highway segments that have at least a 0.25-mile contiguous section with the FEMA 100-year flood plain. It was also filtered to exclude highway segments that were already analyzed as part of a separate bridges and culverts analysis. This filtering step eliminated highway segments built on structures. The final number of highway segments analyzed for vulnerability is 1,195.

Vulnerability Calculation for Highways

The analysis data set provided the basis for calculating the vulnerability score for each highway segment. Each field in the data set was used as an indicator to calculate the exposure, sensitivity, and adaptive capacity scores. The three component scores were then averaged together to produce the final vulnerability score.

Table 14 summarizes the indicators that were used for the highway segment vulnerability calculations. It also gives the rationale for each indicator, and the weight for each indicator. For this version of the analysis, every indicator is given the same weight. Refinements of the approach will give greater weight to those indicators that are important for determining vulnerability.

Each indicator has a specific approach to transform the indicator raw value to a score between 1 and 4. For details on the transformation methods, see the accompanying detailed report from the vulnerability calculation tool.

TABLE 19. VULNERABILITY CALCULATION APPROACH

Indicator	Rationale	Weight
Exposure Indicators		4.0
Previous Flooding Issues	Structures that have previous flooding issues will probably flood again	4.0

Length at Risk of Erosion	Highway segments that are closer to a stream or river are more likely to be damaged in a flood.	1.0
Percent Not Wetlands or Lakes	Lakes and wetlands attenuate extreme rainfall events	1.0
Percent Urban	Urban land cover worsens flooding events	1.0
Stream Flow Increase	Increased stream flow causes more frequent flooding	4.0
Rain Fall Increase	Increased rain fall causes more frequent flooding	4.0
Sensitivity Indicators		1.0
Pavement Condition Rating	Roadways with poor pavement condition are more likely to be damaged in a flood	1.0
Adaptive Capacity Indicators		3.0
AADT	Structures with higher ADT are more important to the overall transportation network	1.0
Truck AADT	Structures with higher truck volumes carry more high-value trips	1.0
Strategic Transportation System	Structures on the strategic transportation system are important to the wider network	1.0
Distance to Critical Facilities	Structures near hospitals are important links for emergency services	1.0

RESULTS OF VULNERABILITY ANALYSIS FOR HIGHWAY SEGMENTS

The vulnerability calculation approach was used to determine a vulnerability score for each highway segment. The assets were then ranked according to score to determine which are the most vulnerable. Figure 26 shows the 10 highest ranked highway segments for vulnerability.

FIGURE 26. TEN MOST VULNERABLE HIGHWAYS SEGMENTS

Most Vulnerable Assets

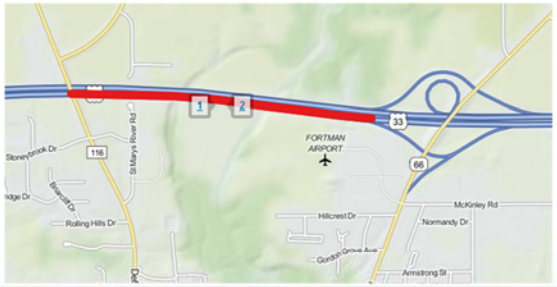



number of assets: 1195
with valid scores: 1173
shown here: top 10

FIGURE 27 AND





Figure 28 provide close up map images of each of the vulnerable highway segments. Not surprisingly, there are clusters of vulnerable segments on Highway 33 near St. Mary's (#1 and #2), Highway 7 in Martins Ferry (#3 and #4), and on Highway 50, east of Athens (#5, #6, #7, and #9).

FIGURE 27: HIGHLY VULNERABLE HIGHWAY SEGMENTS (RANK 1-4)

Asset ID	Rank	Highway Segment Vulnerability	Location Description	Map Image
115	1	2.75	Highway 33, St. Mary's, OH	
102	2	2.74	Highway 33, St. Mary's, OH	
106	3	2.55	Highway 7, Martins Ferry, OH	
121	4	2.55	Highway 7, Martins Ferry, OH	

The next section discusses general adaptation responses for assets generally. Adaptation responses include specific review of assets in the field, and longer term agency-wide commitments to consider vulnerability during planning and design.

FIGURE 28: HIGHLY VULNERABLE HIGHWAY SEGMENTS (RANK 5-10)

Asset ID	Rank	Highway Segment Vulnerability	Location Description	Map Image
50	5	2.54	Highway 50 (Appalachian Hwy), east of Athens	
45	6	2.52	Highway 50 (Appalachian Hwy), east of Athens	
21	7	2.5	Highway 50 (Appalachian Hwy), east of Athens	
312	8	2.49	Highway 33, Long Street, north of Scioto River	
79	9	2.48	Highway 50 (Appalachian Hwy), east of Athens	shown above with #6 and #7
605	10	2.48	I-280, southeast of Toledo	

AS WITH BRIDGES AND CULVERTS, THE REVISED RESULTS USING AN ADAPTIVE CAPACITY WEIGHTING OF 1.0 ARE SHOWN IN

Table 20.

TABLE 20: REVISED RESULTS, 20 MOST VULNERABLE HIGHWAY SEGMENTS

Asset ID	Exposure Weight = 4.0 Adaptive Capacity Weight = 1.0	Exposure Weight = 4.0 Adaptive Capacity Weight = 3.0
115	<u>2.83 (1)</u>	<u>2.75 (1)</u>
102	<u>2.82 (2)</u>	<u>2.74 (2)</u>
312	<u>2.74 (3)</u>	<u>2.49 (8)</u>
469	<u>2.68 (4)</u>	<u>2.26 (84)</u>
53	<u>2.67 (5)</u>	<u>2.54 (5)</u>
45	<u>2.67 (6)</u>	<u>2.52 (6)</u>
741	<u>2.66 (7)</u>	<u>2.44 (17)</u>
70	<u>2.64 (8)</u>	<u>2.45 (14)</u>
86	<u>2.64 (9)</u>	<u>2.46 (13)</u>
47	<u>2.62 (10)</u>	<u>2.41 (24)</u>

A key action item from this study is to carry forward the VAST analysis through vetting the results with substantive area experts (e.g. bridge and hydraulic engineers) and with District engineers who are most familiar with each asset. The VAST model is flexible, which means that the weightings and scaling of each indicator can be adjusted to better reflect the expert judgement of ODOT's engineers and planners.

After the VAST model vetting process, more specific adaptation responses, including retrofits or reconstruction, can be considered among the longer term-agency-wide responses (e.g. incorporating considerations of climate change into facility planning; modifying design standards, etc.).

ADAPTIVE RESPONSES TO INFRASTRUCTURE VULNERABILITY

In NCHRP Report 750, the Transportation Research Board (TRB) defines the adaptation of transportation systems to climate change as consisting of

“actions to reduce the vulnerability of natural and human systems or to increase system resiliency in light of expected climate change or extreme weather events”.²²

The actions described in this report are categorized as **avoiding/reducing** risk by making planning decisions that account for the potential climate impacts, **withstanding** the unavoidable changes in the environment with modifications to infrastructure, and **taking advantage** of potential climate variability and impacts by designing transportation systems that are equipped to benefit from future climate scenarios.

TYPES OF ADAPTIVE RESPONSES

There are several vital areas of adaptive responses to climate change that can be applied to managing vulnerability. The following section describes these areas in general. It is important to note that the sequence of this list does not indicate a hierarchical order to the overall process of adaptive response. Each area may have a profound effect on later stages of the development of strategies for transportation asset management.

Climate modeling will improve in accuracy over the coming decades, which will mean greater accuracy at smaller levels of geographic resolution. This, in turn, will mean an increase in the number and accessibility of climate modeling professionals who can inform ODOT decision making. The combination of better climate tools and climate modeling professional talent will enable ODOT to monitor climate changes and receive advance warning of potential failures from conditions such as rising surface water levels.



1. Planning

Adaptive responses begin with planning for ways to avoid/reduce the risk to transportation infrastructure. This is developing an adaptive systems management approach to transportation infrastructure management.²³ This approach has the potential to provide a long-term management framework that can evolve in light of new information about local/regional climate impacts that are observed over time versus modeled/predicted climate impacts. Infrastructure designed for long service lives (40 years and greater) may benefit the most from this approach as appropriate adjustments in design, construction, operation, and maintenance practices can be effectively implemented over time.²³

²² Transportation Research Board. “What is Adaptation?” NCHRP Report 750: Strategic Issues Facing Transportation, Volume 2, Part I, Chapter 1. 2013.

²³ Transportation Research Board. “What Are the Steps for Adaptation Planning?” NCHRP Report 750: Strategic Issues Facing Transportation, Volume 2, Part I, Chapter 2. 2013.

This adaptive planning approach should be applied system-wide regardless of the planned service life of an infrastructure system, though infrastructure designed for shorter service life has a greater potential to be adapted and replaced with a changing environment.

Included within the category of Planning responses are regulatory responses, including:

- potentially tightening NAAQS air quality standards and/or regulation of greenhouse gas emissions;
- development of institutional arrangements such as cross-agency collaboration to coordinate State response to climate change and/or extreme weather events;
- potential changes to FEMA maps to reflect revised floodplain designations;
- changes to land use ordinances to help conserve natural resource areas that provide stormwater/floodwater storage and mitigation;
- new regulation of shipping on Lake Erie governing the size (draft) of ships allowed in Lake Erie ports.



2. Environmental Analysis

Understanding the range and severity of potential extreme weather and climate impacts is of primary concern in determining the appropriate adaptive response.²⁴ According to the 2014 FHWA Climate Adaptation Plan, “Scientists have concluded that some level of climate change is already occurring. Weather patterns are changing, and these changes are expected to continue or accelerate in the future.” Planning for future climate impacts is not a matter of waiting for them to occur, but instead a matter of determining how the climate will continue to change and designing the necessary flexibility in transportation systems to protect infrastructure investments.

The following questions can be used to guide decision-making in the stages of environmental analysis²⁵:

1. What climate stressors will affect the proposed action either directly or through effects on the surrounding ecology?
2. What are the impacts of these stressors on the affected environment for the action (and to what extent is any proposed action in an area vulnerable to climate change)?
3. What is the risk to the asset and to the affected environment given expected changing climatic conditions?
4. To what extent do these stressors influence the desired characteristics of the proposed action (e.g., efforts to avoid, minimize, or mitigate potential risks)?

²⁴ U.S. Department of Transportation Climate Adaptation Plan 2014: Ensuring Transportation Infrastructure and System Resilience. Chapter 2. 2014.

²⁵ Transportation Research Board. “Projected Changes in the Climate.” NCHRP Report 750: Strategic Issues Facing Transportation, Volume 2, Part I, Chapter 3. 2013.

5. What are the recommended strategies for protecting the function and purpose of the proposed action?



3. Design Standards & Initiatives

Once the ongoing and future impacts of climate change have been determined, transportation systems managers can begin to develop design standards and adaptation initiatives that implement planning strategies and incorporate the recommendations of environmental analyses. Adaptive design standards include upgraded, detailed engineering specifications regarding the performance of materials and structures for multiple climate impacts such as flooding, temperature, precipitation. Adaptive initiatives to consider include maintaining the viability of alternative routes around vulnerable infrastructure, developing contingency plans for multiple types of climate impacts, and creating systems for collecting and updating data on infrastructure for asset management.²⁶ The outcome of such initiatives should include increased quality of analytical tools such as flood models and asset life-cycle models as well as more up-to-date mapping and road condition data to assist in transportation operations management.

A valuable model for this type of initiative is the US EPA's Climate Change Impacts and Risk Analysis project (CIRA).²⁷ The infrastructure component of the CIRA project identifies inland bridges, roads, urban drainage, and coastal property in the contiguous U.S. that may be vulnerable to climate change and estimates the costs to adapt the at-risk infrastructure and the benefits of greenhouse gas mitigation.

Design changes could include:

- modification of hydraulic design standards that reflect drainage capacity of watersheds and highways;
- improving materials or developing new roadway materials (e.g. pavement composition);
- using alternative construction methods;
- retrofitting key assets (for example, flood-proofing); and,
- reconstructing key assets to higher design standards.



4. Infrastructure Retrofit/Maintenance.

Decisions to retrofit infrastructure for adaptive response to climate change should be based on the best practices generated by adaptive response design standards and initiatives. However, these decisions should only be made after larger decisions on whether to protect,

²⁶ Transportation Research Board. "Adaptation Strategies." NCHRP Report 750: Strategic Issues Facing Transportation, Volume 2, Part II, Chapter 5.4. 2013.

²⁷ US EPA. "Infrastructure." Climate Change in the United States: Benefits of Global Action. Chapter 4, Section 7. 2014.

relocate, or abandon the infrastructure have been made.²⁶ Once the need for retrofitting has been established, additional decisions should be made in regard to whether the retrofit should include restoring any natural process that could mitigate the need for future upgrades (e.g., restoring barrier islands, flood plains, and shorelines).²⁶

Simultaneously, maintenance procedures should be developed and implemented to reduce future costs of managing transportation assets. A well-integrated maintenance program would be a direct outcome of an adaptive response initiative to improve data collection on vulnerable transportation assets.



5. Operations

While less common among adaptive response plans, developing specific procedures for the management of transportation operations in response to climate impacts is of vital importance.^{26 above} Individual climate impacts such as major storms, floods, and air quality events require unique responses that should be addressed in the planning stages of transportation asset management.

In its 2013 report, The Federal Highway Administration provides guidelines for developing an adaptive response plan for maintaining transportation operations.²⁸ This report emphasizes the dependence on a well-planned and maintained transportation infrastructure to provide sufficient system resiliency and/or redundancy for responding to climate impacts such as extreme weather events. Therefore, all of the areas of adaptive response are involved when considering disaster relief and emergency events.

Operational changes could include:

- the timing and type of maintenance;
- improved and more extensive monitoring of conditions (both climatic and infrastructure conditions);
- modifying procedures for emergency management;
- altering construction schedules;
- updates to evacuation planning for areas determined to be at risk, identification of alternative routes; and,
- development and ongoing support for real-time traveler information systems.



6. Public Outreach/Communications

Public outreach deserves special consideration as an adaptive response to extreme weather and climate change. Conveying information to the public about actions that can be taken in

²⁸ Federal Highway Administration (FHWA), Office of Operations, March 2013. Planning for Systems Management and Operations as Part Climate Change Adaptation.

response to extreme weather events has the potential to mitigate much of the risk to public safety and infrastructure during such events.

Improving communication links to the public could include installing additional road weather information systems, improving access to 511 systems, installing rapid stream gauge information systems, or generally informing the public on an ongoing basis on that types of impacts extreme weather can have on the transportation system. In short, public outreach should act as both a real-time information system about particular weather and climate impact events and as an on-going dialog meant to assist the public in understanding the motivations and goals of adaptive response strategies that protect both public safety and

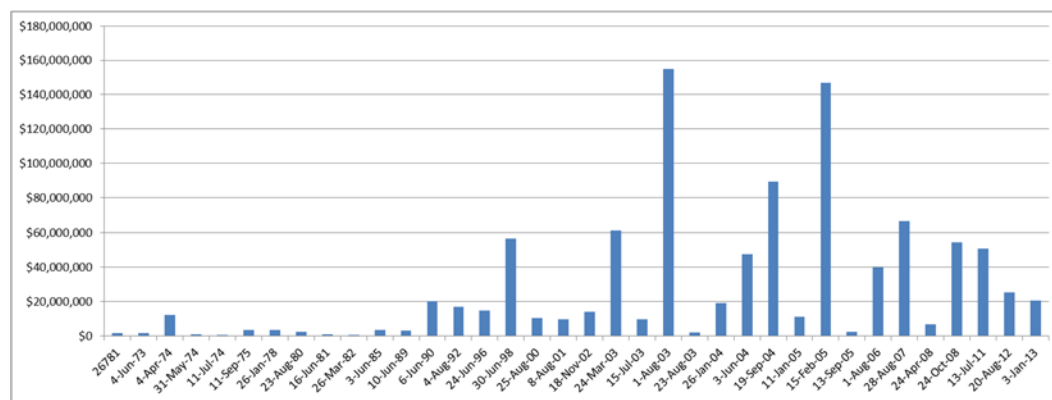
EXTREME WEATHER ADAPTATION / EMERGENCY TRANSPORTATION OPERATIONS (ETO)

The following survey analysis was done in conjunction with an extreme weather Resiliency Plan for ODOT by RSG. While a key focus of the Resiliency Plan is to determine which assets are vulnerable, the timing, location, and impact of extreme weather events can never be precisely predicted or prevented. Thus, it becomes important to address Emergency Transportation Operations (ETO) as a part of this effort.

Supporting this approach, information from FEMA was obtained to convey an idea of the cost of disaster relief for extreme weather events, shown in Figure 29. Since 1973 there have been 38 cases where federal disaster areas have been declared in Ohio. The total amount provided for all 38 incidents was \$984 million, averaging nearly \$26 million each incident.

The largest damage incident (\$155 million) occurred as a result of a July 2003 storm caused by a tornado with extreme rains and flooding. The second largest damage incident (\$146 million) was related to severe winter storms, ice, and mudslides.

FIGURE 29: FEDERAL FUNDS PROVIDED FOR EMERGENCY DISASTER RELIEF TO OHIO COUNTIES, 1973-2013

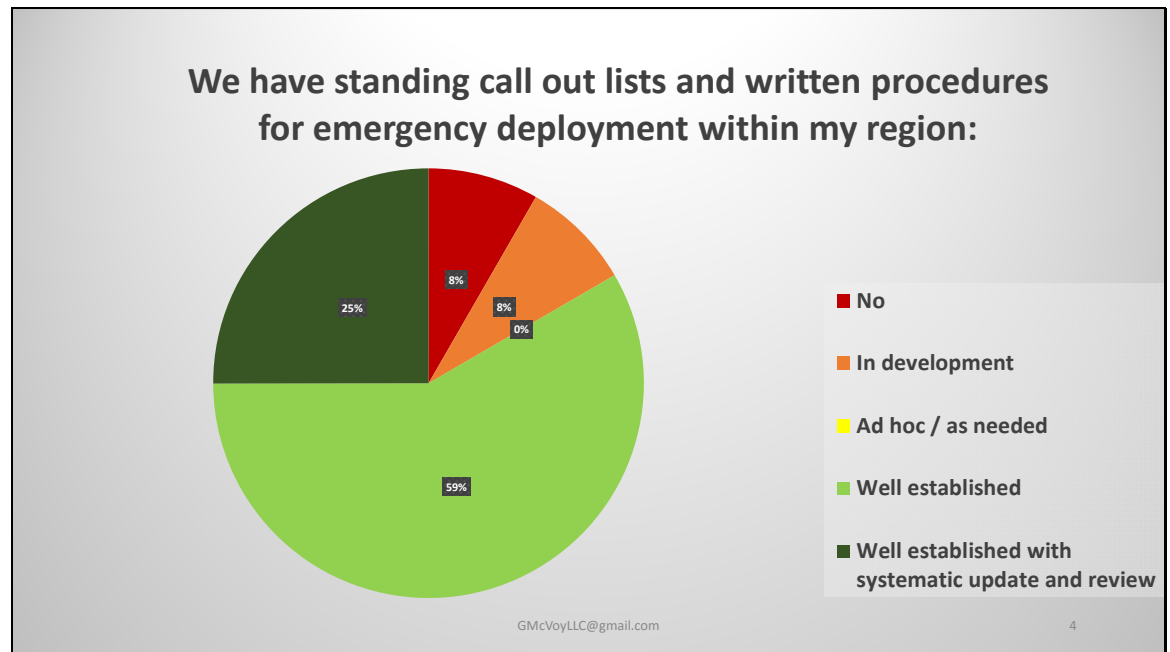


ODOT SURVEY ASSESSMENT

The following questions were asked of each of the twelve ODOT Districts using the survey instrument contained in Appendix A, to help establish a benchmark on ODOT extreme weather response readiness, and to inform additional analysis and discussion.

The survey was circulated by Administrator Thomas M. Lyden, P.E. following a March 18, 2015 Statewide meeting with District Highway Management Administrators (HMAs). Survey results from all twelve districts were initially discussed with Emergency Operation Coordinator, Carl Merckle, in preparation for a more general webinar discussion with the HMAs at their May 27, 2015 Statewide meeting. Notes from this meeting along with survey results by question, are presented herein together with some more general findings and recommendations.

STANDING CALL OUT LISTS AND WRITTEN PROCEDURES FOR EMERGENCY DEPLOYMENT WITHIN DISTRICT:



District survey commentary:

- “Only a few top level people in the District designated for emergencies.”
- Our District 08 Emergency Coordinator will notify and update the counties on any impending weather events and will help to coordinate a response either for ODOT facilities or requests for assistance through the Ohio Emergency Management Agency. He will act as the District liaison between the District counties and the State ODOT Emergency Coordinator.
- “District 08 Counties do have plans in place for getting crews together, addressing ODOT right of way and preparing for any requests for assistance which may come from OEMA. These plans are not written but are discussed at the county level.
- “All performed as per OCSEA Contract provisions (overtime).”
- “. . . for usual snow & ice, accidents, flooding, etc. Not well established for unusual”

May 27, 2015 Statewide discussion notes:

The districts have traditionally been responsible for updating the Blue Book, info (phone numbers, etc.) – but the Central Office has assumed that responsibility. Having a hard copy,

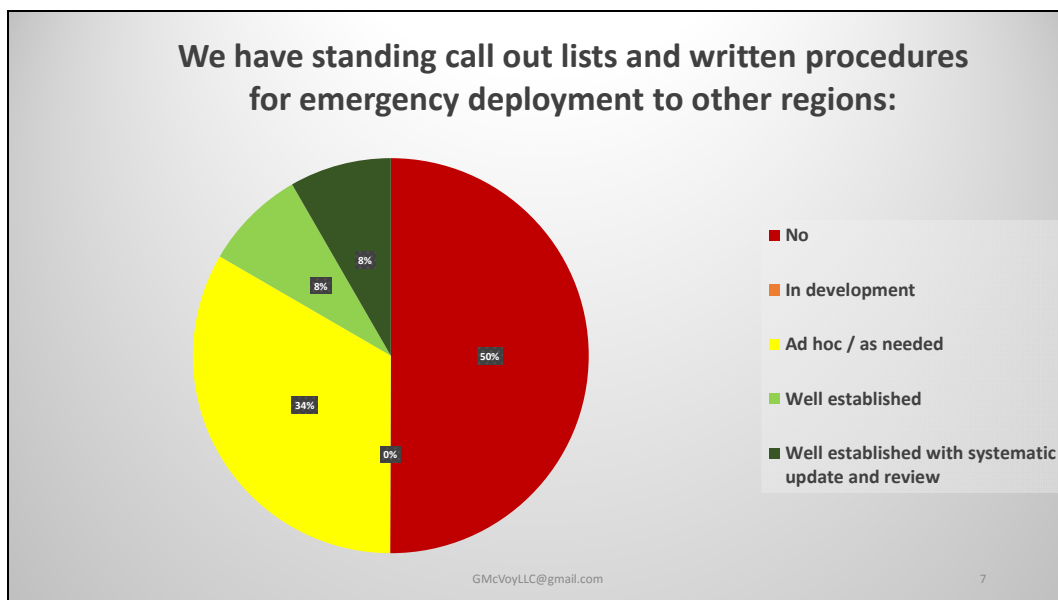
not just a digital copy, is important. The online version gets updated, but not always the hard copy.

2nd Floor is going to make a new Call-Out list and monthly updates will occur. Executive office wants to be involved in these activities. They had six people assisting from Governor's office last time (more than the two in the past).

Assessment / Observations / Possible Next Steps

This activity seems well in hand – although some follow up with a few districts which indicated lower levels of readiness may be warranted. Especially good to see the front office engaged – a true indication of support.

STANDING CALL OUT LISTS AND WRITTEN PROCEDURES FOR EMERGENCY DEPLOYMENT TO OTHER DISTRICTS:



District survey commentary:

- We would use the same "lists" as what we use within our region. Procedures and details for deployment would vary depending upon the circumstance.
- This response would be based on requests from ODOT Central Office, possibly via OEMA or requests from other Districts for assistance after a large event. The District Emergency Coordinator would assist in coordinating any requests for resources.
- "I would not call this "ad hoc" but more "as needed" and based off of the State plan for response."
- "District 08 counties are able to muster crews and available resources quickly to prepare for any requested deployment, and have done so successfully in the past."
- "As requested"

May 27, 2015 Statewide discussion notes:

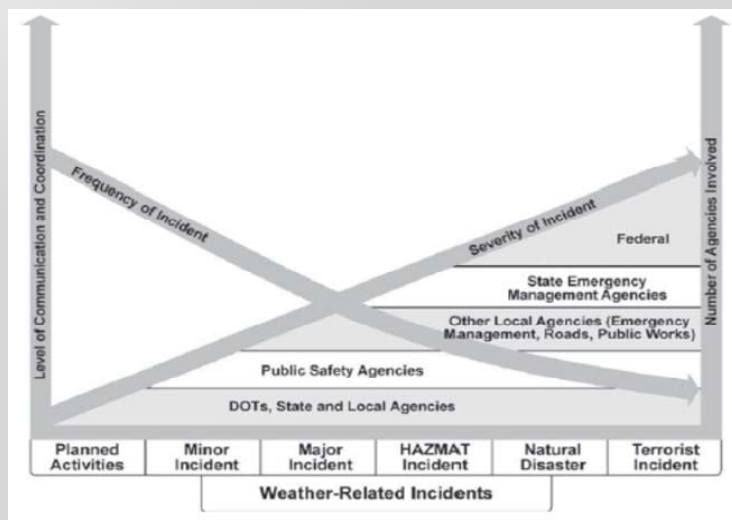
- NY State example—districts took good care of themselves, but less so across borders. Working across borders requires a lot of administration in advance (cash, methods to reach home, someone to show them around, etc.). The more we did this, the better we got. Zone defense.
- Some districts don't get hit often, but District 6 gets it a lot.
- Issues with the requesting State being able to offer staff accommodations; Union contract provisions.

Assessment / Observations / Possible Next Steps

Activity seems well in-hand; some follow up with those districts indicating some reservations regarding readiness may be warranted.

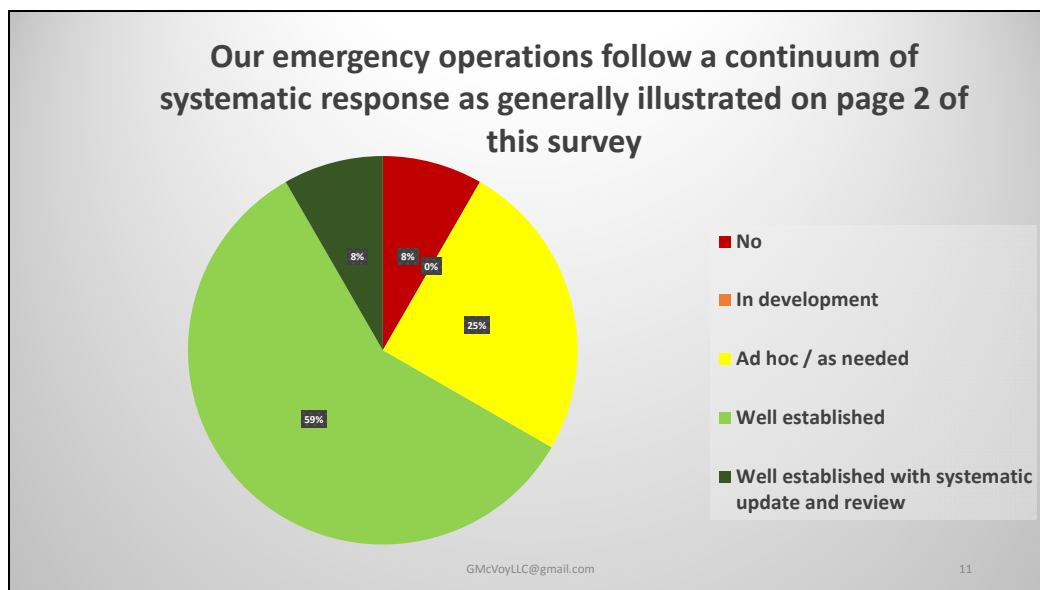
EMERGENCY OPERATIONS FOLLOW THE NCHRP REPORT 325 CONTINUUM OF RESPONSE:

ETO Continuity of Response (survey page 2):



Adapted from: NCHRP REPORT 525: Volume 6, Guide for Emergency Transportation Operations
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_525v6.pdf

GMcVoyLLC@gmail.com



DISTRICT SURVEY COMMENTARY:

- “I feel what is illustrated on page 2 accurately reflects what we follow.”
- “Our response does follow the chart referenced above. The updates and reviews of this response at the State level will come from the ODOT Emergency Coordinator. Our District Emergency Coordinator has been part of past reviews.”

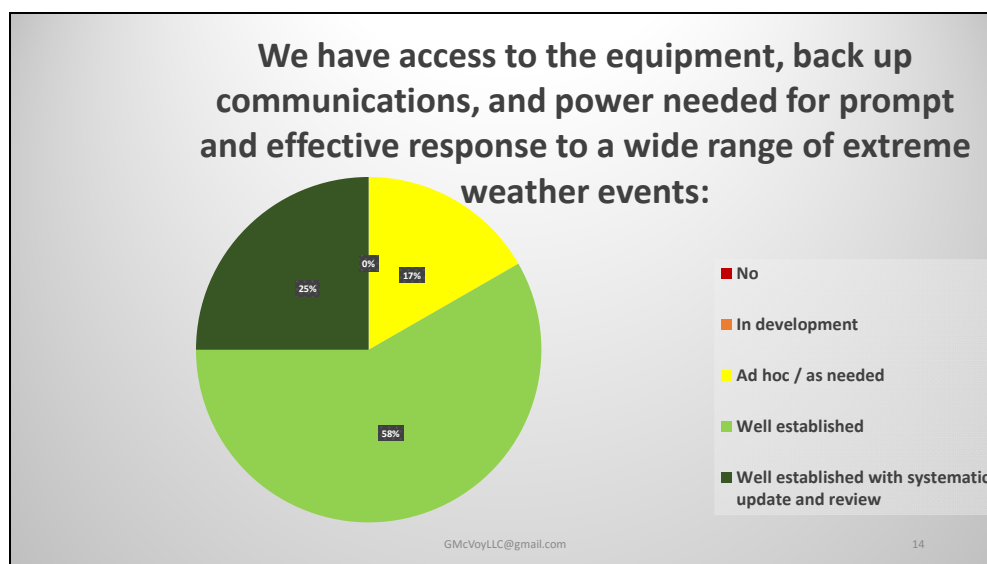
May 27, 2015 Statewide discussion notes:

- Pretty good at response between districts; some districts haven’t had a lot of incidents/emergencies.
- Emergencies don’t happen enough to stay sharp all the time. Constant practice/refinement (Union contract example).
- Water transport activities as an example of improvement with practice and the value of being proactive with partners such as the Health Dept.

Assessment / Observations / Possible Next Steps

Activity seems very well in hand – some follow up with those districts suggesting reservations may be warranted.

ACCESS TO THE EQUIPMENT, BACK UP COMMUNICATIONS, AND POWER:



District survey commentary:

- "Back-up communications and power at ODOT Facilities are in place. Each county garage has equipment available for use in an emergency. Any equipment not available could be rented during an emergency or obtained from neighboring Districts. This plan is in place."
- "Backup generators have been installed at all county garage locations as well as the District Office Complex."
- "Believe we are prepared, but sure there are some gaps in coverage."

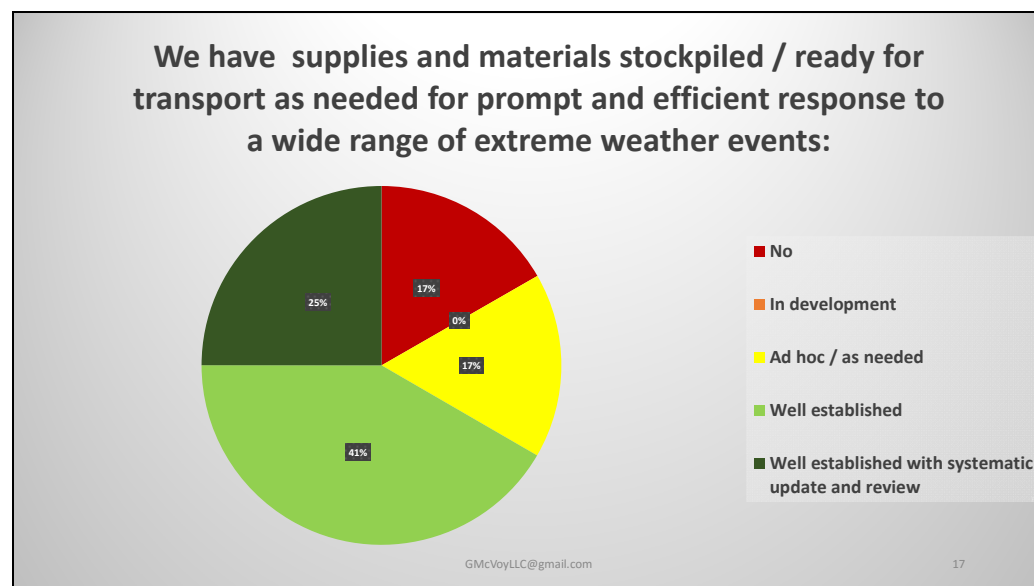
May 27, 2015 Statewide discussion notes:

Remarkably good access to the tools needed for contingencies including equipment.

Assessment / Observations / Possible Next Steps

Activity seems very well in-hand; some follow up may be warranted to insure the system stays sharp.

SUPPLIES AND MATERIALS:



District survey commentary:

- “Most of what we would use is not "stockpiled" in the sense that it is only for use during emergencies, but are tools, equipment, and material that we use on a routine basis.”
- "District 08 has limited supplies and materials which could be used for emergency response but does have the capability to acquire supplies within our scope of responsibility."
- “As a DOT, stockpiling of materials is not our routine operation. We do of course stockpile materials to aid in the clearing of roadways from snow and ice. We also have equipment to aid in the cleaning of the roadway in the event of extreme weather in the spring (tornado).”

May 27, 2015 Statewide discussion notes:

Traffic incident management—vehicles ready to go; not as applicable to regional applications.

Is there a wish list of “ought to haves” i.e. “stockpiles”? Can’t stockpile everything, some private sources. The main thing is to be able to get it.

Temporary bridges—too many liabilities; if we have to use one, we will detour traffic; in Ohio, National Guard can be called on in emergencies. When a bridge is out, the OC ...

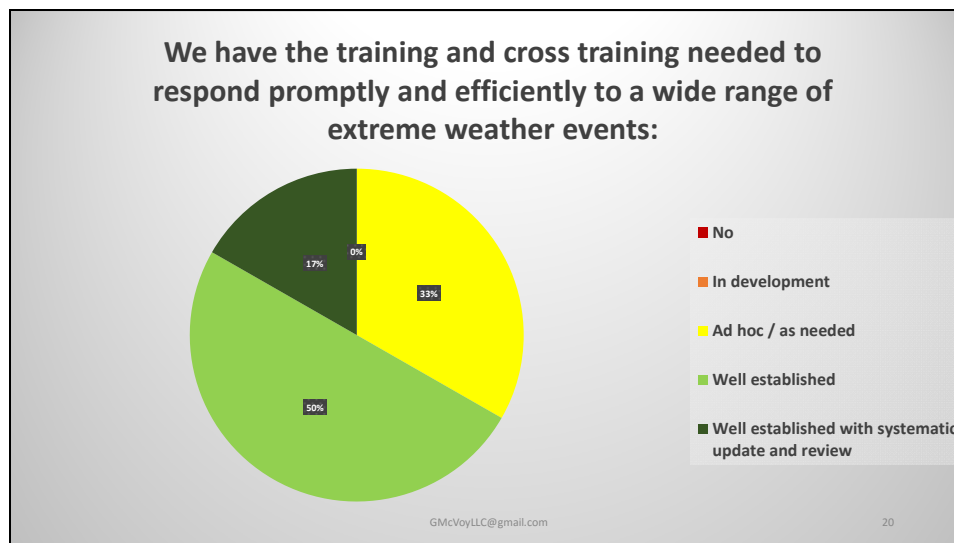
ODOT has detour routes for every major highway.

Assessment / Observations / Possible Next Steps:

Procurement effectiveness seems to offset the need for stockpiling materials. Similarly, the detour planning work already completed and effectiveness of the National Guard in responding to bridge wash outs, etc. is seen to mitigate this need.

Follow up starting with those districts suggesting reservations may be warranted. Follow up with the Guard to be sure they are still ready to deal with incidents involving bridges may be prudent. Use of formal “after action reports” to insure continuous improvement and learning across the organization may be particularly useful here.

TRAINING AND CROSS TRAINING:



District survey commentary:

- “The District 08 counties and Emergency Coordinator participate in the local agencies emergency exercises. We do receive a fair number of invitations annually. Most are tabletop but go a long way to promote readiness. These structured exercises include after action reviews and the opportunities for comment.”
- “Lost a lot of experience with agency retirements. Not sure if new employees have enough tenure to be effective.”

May 27, 2015 Statewide discussion notes:

Within the last 2 years, there hasn’t been as much training. New hires go from District to District for some training.

There have been a lot of emergencies in past 2 years, so there has been OJT.

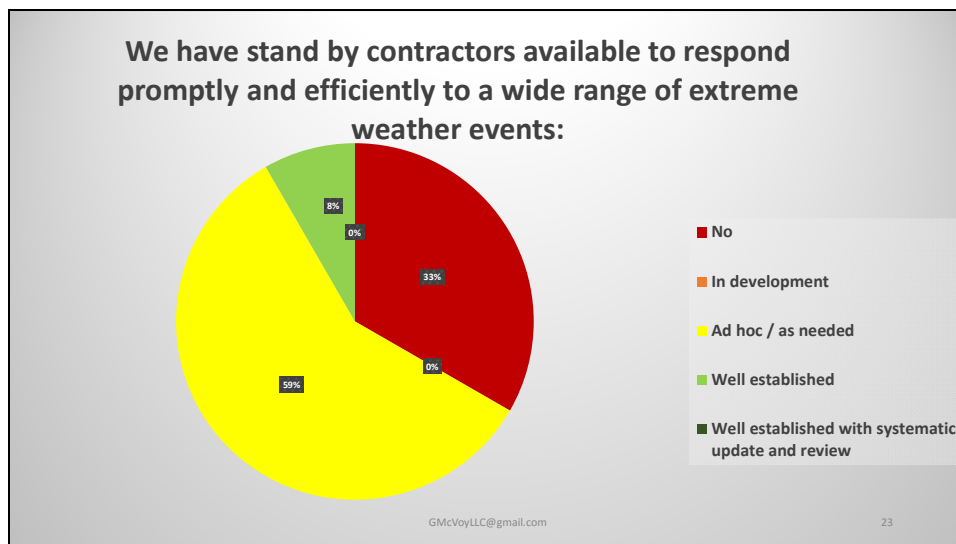
Training with the locals (4X per year) in one district.

A range of certifications/training, so, for the most part, there are appropriately trained staff.

Assessment / Observations / Possible Next Steps

Activity seems to generally be in-hand; some follow up may be warranted to insure the system is and continues to function effectively.

STAND-BY CONTRACTORS:



District survey commentary:

- Contracts are in place for use, trucking, etc.
- “We have had trucking contracts or Purchase Orders established for hauling salt in the event we need to move quantities within our District or ODOT.”
- “The 101G Contract is available for use to obtain contractor help. We also have a good working relationship with the local contractors. They are always willing to respond quickly if District 08 requests assistance during an emergency. The contractors are not “stand by” but will respond quickly if asked. They have done so in the past with good results.”
- “Some heavy equipment contracts are available. Contractors have been canvassed at the beginning of winter to determine their availability and/or willingness to assist the DOT in the event of blizzard type conditions.”
- “As recently as last year used outside vendors to assist.”

May 27, 2015 Statewide discussion notes:

Had contracts, but for 20 years never used it. Stopped doing it, then needed a contractor. They were able to call up someone and get immediate response. They had the contact and knew who to call.

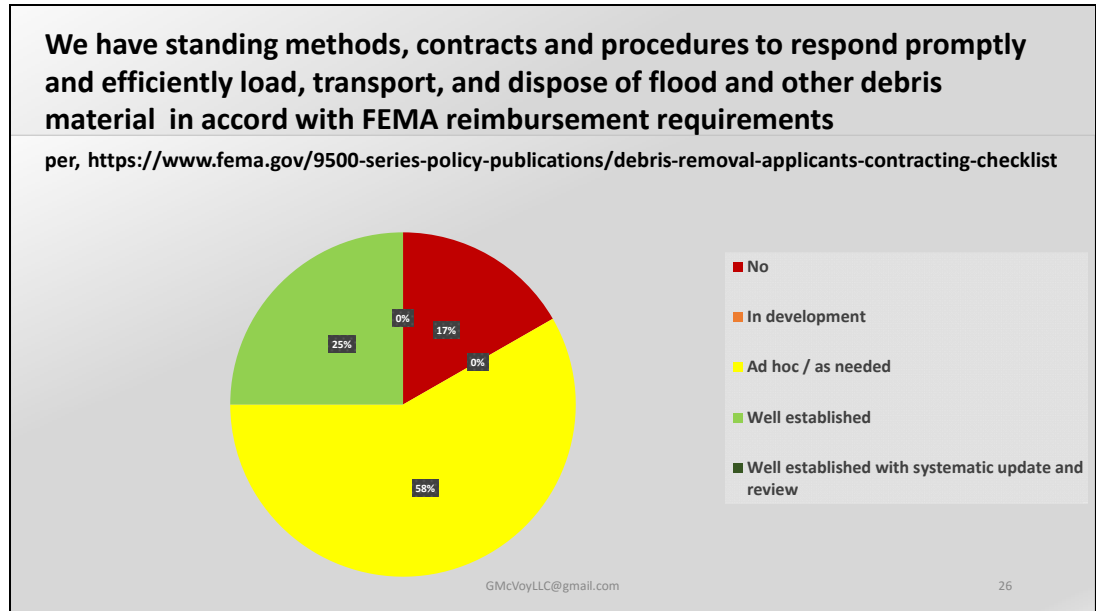
Utilize contractors as needed. Don't necessarily need formal agreements.

Assessment / Observations / Possible Next Steps

Procurement effectiveness seems to offset the need for standby contracting, albeit with some reservations regarding FHWA ER funding reimbursement which may require competitive bidding.

Follow up starting with those districts suggesting reservations may be warranted. Follow up with the FHWA and FEMA may be prudent to insure their reimbursement requirements can be met without standby contractors.

DEBRIS DISPOSAL METHODS, CONTRACTS AND PROCEDURES PER FEMA:



District survey commentary:

- “ODOT support group under direction of State Emergency Management Agency (EMA)”
- “In the past we have employed different methods of dealing with flood and other debris material. It has depended on the specific situation and quantity.”
- “Based on the response to the Clermont County tornado a few years ago in which ODOT and contracting resources were obtained and used through OEMA, I would have to say we do have procedures in place and ready.”
- “Not quite sure.”

May 27, 2015 Statewide discussion notes:

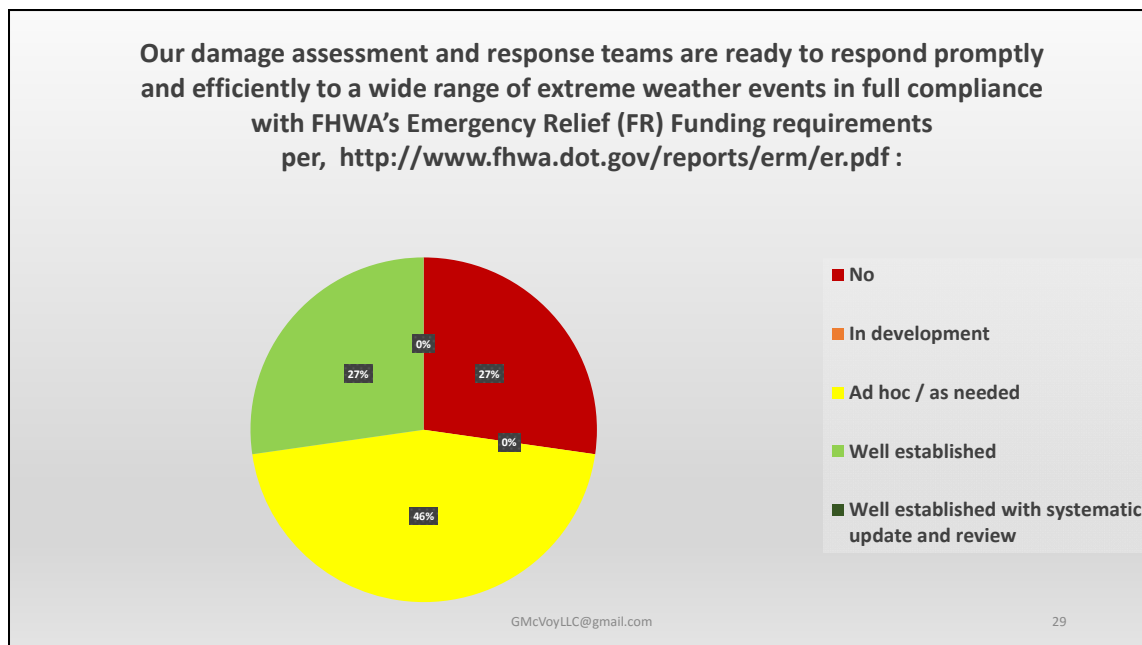
HMAAs don’t have the lead. Counties have the lead in arranging disposal.

EMA-every county is required to have a debris program; Governor’s declaration enacted a debris program. EMA works together with ODOT to identify debris pile locations.

Assessment / Observations / Possible Next Steps

As long as counties can do their jobs, this should not be an issue. This, of course, highlights the need for systematic coordination with county officials.

DAMAGE ASSESSMENT TEAMS PER FHWA EMERGENCY RELIEF (ER):



District survey commentary:

- “Direction provided by CO (Counties)”
- “In past events our damage assessment team has consisted of our Roadway Services Engineer, an Area Engineer in Construction, and possibly the county TA. If it is a Federal Event an FHWA representative has visited the sites with the team.”
- “At the District level, we do not have any formal teams for damage assessment but can provide a wide range of engineering expertise if requested. We do not have formal response teams but our county forces are ready to respond quickly during

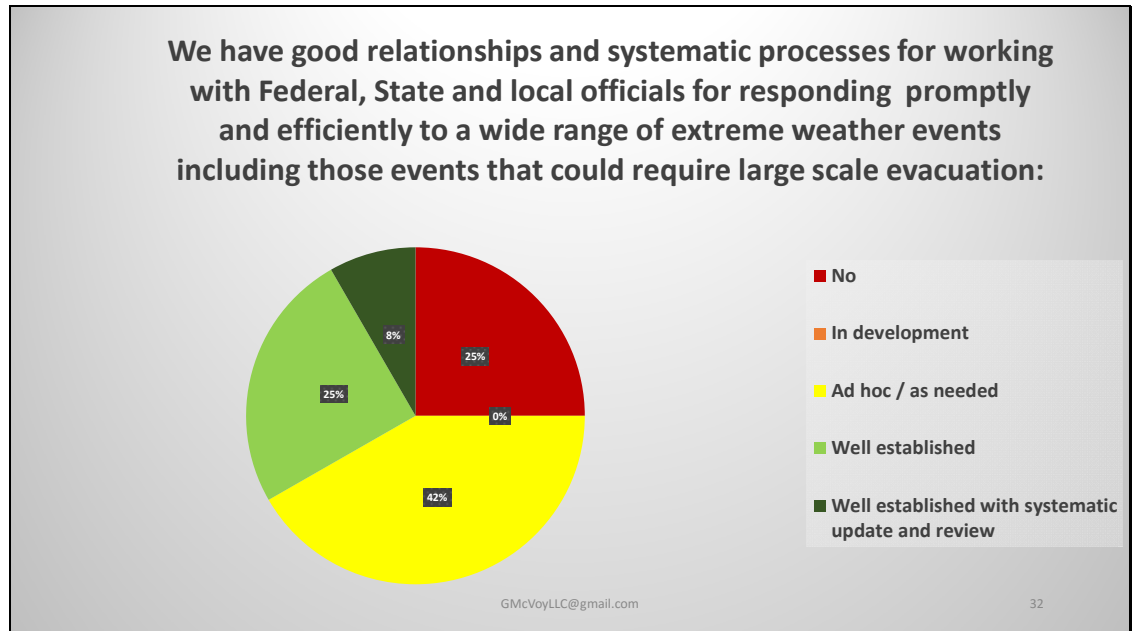
May 27, 2015 Statewide discussion notes:

- Bridge in Cincinnati example, if it's a bridge they'll do a damage assessment (Carl Merckle).
- “Well-oiled machine with exceptional staff.” (Cleveland example).
- “Don't have anyone FEMA trained”. They have access to bridge experts, etc.

Assessment / Observations / Possible Next Steps

While consensus of the group seemed to suggest good coverage on this issue, follow-up, starting with those districts suggesting reservations, could be warranted. Follow up with the State and County Emergency Operations as part of regular preparedness work may be prudent just to insure that methods and procedures are in place to cover a variety of contingencies. Use of formal “after action reports” to insure continuous improvement and learning across the organization may also be helpful in this instance.

RELATIONSHIPS WITH FEDERAL, STATE AND LOCAL OFFICIALS:



District survey commentary:

- “Direction provided by CO (County?)”
- “We have a good relationship with all those that might be involved. We have had success in coordinating with them in the past.”
- “District 08 has forged good communications and working relationships with various agencies over the years. We do meet from time to time via planned exercises to discuss various scenarios and ODOT’s availability to assist within the realm of our capability.”

May 27, 2015 Statewide discussion notes:

- Knowing the people and having trust can make a difference.
- Local Emergency Response Coordinators are key. Each district has a local emergency response expert. Designated contacts should meet on a regular basis.
- It is helpful if the Executives know each other, DOT to Emergency Management, etc. to insure smooth and prompt direction when policy issues grey.

Assessment / Observations / Possible Next Steps

Follow-up, starting with those districts suggesting reservations, may be warranted. Follow up with the State and County Emergency Operations as part of regular preparedness work may be prudent.

WHAT ABOUT EMERGENCY TRANSPORTATION OPERATIONS (ETO) KEEPS YOU UP AT NIGHT?

- “Nothing. We are prepared and respond appropriately as called upon.”

- “Safety of the employees performing the work.”
- “Widespread communications disruptions.”
- “Nothing....our team is well trained and ready to respond.”
- “Having enough employees with experience to lead and manage an event. We have lost a lot of experience in the last 5 -6 years.”
- “None of it keeps me up at night. In the 24 years I've been with the Department I've been involved with a variety of events including large scale flooding, tornadoes, etc. Although a lot of what you do in reacting to them can be similar, each event is unique. You learn what works, what doesn't work, and adjust accordingly.”
- “Our preparedness and response is in pretty good shape in this District. I have a great deal of confidence in our County Managers and their crews. I am always concerned with their safety when they are out during Snow and Ice operations, floods and tornado debris clean-up, etc. We have had them all in this District but, overall, I sleep pretty well.”
- “The ability to add personnel quickly in the event a major incident occurred where employees could not report to work.”
- “Regional ice storm that knocks out power.”

May 27, 2015 Statewide discussion notes:

Running out of salt has been a concern.

Assessment / Observations / Possible Next Steps

See general conclusions.

ODOT EMERGENCY TRANSPORTATION OPERATIONS - COMMENTS AND RECOMMENDATIONS

Judging from survey results, and discussions; ODOT seems relatively well equipped and prepared to respond to the threats posed by extreme weather as they might affect the ODOT system.

This is not to say that:

- extreme weather threats are not significant,
- this or any system is capable of eliminating these threats,
- there is no room for further improvement,
- every aspect of the organization in each location is equally prepared to respond to an extreme event, or
- continued diligence and preparation is not required.

Accordingly, we recommended the following:

- Follow-up with districts which expressed a potential for improvement in each of the topic areas surveyed, in order to understand what can and should be done in light of this information.
- Implementation of formal “after action” reviews as an essential component of the continuous improvement philosophy under the Incident Command Structure (ICS) / Continuity of Operations / Continuity Program Management Cycle (<https://www.fema.gov/continuity-operations>)
- Preparation for the inevitable threats posed by extreme weather should continue in keeping with the responsibilities entrusted to ODOT.

CLIMATE RESILIENCE - SPECIAL TOPICS

In addition to the VAST analysis, where specific facilities were identified as vulnerable based on a composite weighting model, the project identified three special topic areas as worthy of more detailed investigation. These topic areas are:

- vulnerability of pavements,
- air quality, and
- future heavy goods movement facilitated by the opening of the Northwest Passage.

With regard to pavement vulnerability the project team discussed this issue with ODOT pavement engineers and conducted recent or ongoing research by the Transportation Research Board²⁹ and others that provides a contrasting perspective. With regard to future air quality concerns and the potential of the Northwest Passage, these issues are unique and, to date, have not received significant attention of researchers with respect to their potential impacts in Ohio.

PAVEMENT PERFORMANCE

Past research suggests pavement performance is potentially vulnerable to increasing average temperatures^{30,31,32}. The prevailing opinion of more recent research³³ and of staff within ODOT's Office of Pavement Design indicates that that rising average temperatures of 2-5.5°F should not cause significant pavement degradation³⁴. Asphalt pavements are not sensitive to this magnitude of temperature change over a 50-year period. ODOT asphalt pavement specifications can be adjusted to adapt to any long-term increases in temperature because ODOT resurfaces every 10 -14 years.

Climate change effects in Ohio identified in Task 1 include the cycling of drought followed by heavy precipitation and the potential for soil stressing, especially for clay soils found in many parts of Ohio. Drying and wet cycles can cause significant shrinking and swelling of soils, which, in turn, can stress road and bridge foundations and pavements. This is of particular concern for secondary highways constructed on shallower foundation soils.

Given the conflicting conclusions on the topic of pavement vulnerability identified in previous research, RSG identified pavement performance as a special topic for the Comprehensive Infrastructure Vulnerability Assessment. For this special topic, RSG

²⁹ Potential Impacts of Climate Change on U.S. Transportation. Special Report 290. Transportation Research Board. 2008.

³⁰ TRB Special Report 290. Potential Impacts of Climate Change on U.S. Transportation. 2008.

³¹ Climate Change Implications for Flexible Pavement Design and Performance in Southern Canada. ASCE Journal of Transportation Engineering. October 2009.

³² The Effects of Climate Change on Highway Pavements and How to Minimize Them. UK Department of Transport. October 2008.

³³ Method for Evaluating the Implications of Climate Change for Design and Performance of Flexible Pavements. Transportation Research Board, No. 2305. 2012

³⁴ Working Paper 2 of the ODOT Infrastructure Vulnerability Assessment (March 5, 2014) projected potential temperature changes for Ohio, based on the IPCC Emissions Scenario A2, of 3.0-5.5°F by mid-century and 5.5-7.5°F by end of century.

reviewed additional recent research literature and consulted with four pavement specialists. A summary of this new research is provided below.

DISCUSSION OF LITERATURE SOURCES REVIEWED

RSG identified a number of literature sources related to climate change impacts on pavements. Pertinent information from a select list of these sources is described in this section.

*Implications of Climate Change on Pavement Performance and Design*³⁵

This report was written for the Delaware University Transportation Center in September, 2011. It is one of a number of sources we identified describing pavement modeling work, where researchers are integrating global climate change models with pavement degradation models to estimate the impacts of various climate change effects on pavements. For example, these models are used to estimate the effect of temperature changes on frequency and intensity of pavement cracking and rutting.

Figure 30 below is a collection of figures from the report and is used to underscore the importance of considering changes in changes in the mean and variance of climate change impacts. For example, an increase in mean temperature simply means there will be more warm days than cold days. However, an increase in the variance of temperature means there will be more extreme cold and extreme warm days. There are different impacts, and therefore different adaptation strategies, for changes in average versus changes in variance.

FIGURE 30: STATISTICAL CONSIDERATIONS FOR CLIMATE CHANGE

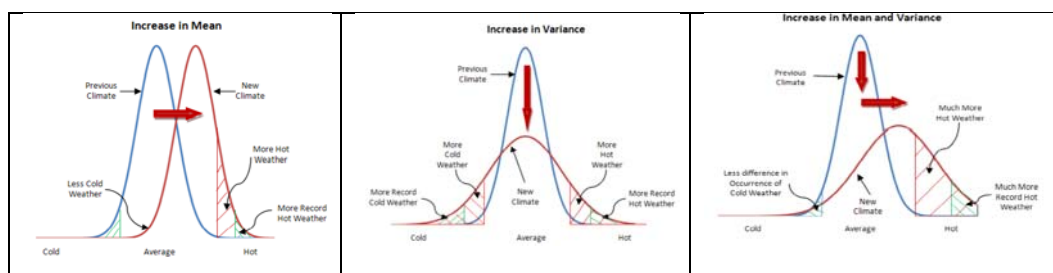


Table 21 from the report is shown to illustrate how the researchers modeled temperature and precipitation changes by season for three future years. As shown, the mean and variance change by season and year, making development of adaptation strategies potentially more complex.

³⁵ The Implications of Climate Change on Pavement Performance and Design. University of Delaware University Transportation Center (UD-UTC). September, 2011.

TABLE 21: CHANGES IN MEAN AND VARIANCE FOR TEMPERATURE AND PRECIPITATION

Year	Climate Indicator	Criteria	Spring	Summer	Fall	Winter
2030	Temperature	Mean change (C)	0.72	0.74	0.75	0.66
		Standard deviation (%)	2.1	14.21	2.31	-7.94
	Precipitation	Mean change (%)	3.54	-0.19	-0.09	2.05
		Standard deviation (%)	4.11	-0.36	2.58	-0.76
2050	Temperature	Mean change (C)	0.3	1.31	1.34	1.18
		Standard deviation (%)	3.73	25.26	4.11	-14.11
	Precipitation	Mean change (%)	6.3	-0.34	-0.16	3.65
		Standard deviation (%)	4.11	-0.65	4.59	-1.36
2100	Temperature	Mean change (C)	2.25	2.29	2.34	2.06
		Standard deviation (%)	6.53	44.17	7.19	-24.67
	Precipitation	Mean change (%)	11.01	-0.59	-0.28	6.38
		Standard deviation (%)	12.77	-1.13	8.03	-2.37

RSG discussed the issue of greater climate variability in Ohio with State Climatologist Jeff Rogers and he provided this response:

“I am not aware of any studies that have estimated the increase in variance that we might expect in Ohio. The whole idea is fairly theoretical, there is no guarantee that the scenario of greater variance in future temperatures will ever really occur. The more likely scenario, probably also illustrated in the U Delaware report, is that the climate averages will simply shift to the right toward higher temperatures. That too, will of course also cause problems with rutting of roadways, so the problem is likely to occur more frequently as the climate warms.”

Climate Change Implications for Flexible Pavement Design and Performance in Southern Canada³⁶

This paper describes modeling work performed to estimate climate change effects on pavement in southern Canada for sites that are proximate to northern Ohio and therefore are relevant to the ODOT study. The modeling work described in this paper does suggest the potential for pavement impacts. However, the paper also suggests modeled impacts are similar to impacts currently occurring and that there are sufficient adaptive measures to deal with future anticipated impacts. A number of quotes from this paper are supplied below further illustrate the author’s thoughts.

“Pavement performance simulations conducted using the mechanistic-empirical pavement design guide and data from the Canadian long term pavement performance program for six of these sites also suggest that rutting issues will be exacerbated by climate change and that maintenance, rehabilitation, or reconstruction will be required earlier in the design life” (p 773).

“None of the potential impacts suggested through this study fall beyond the range of conditions presently experienced in North America—analogous pavement structures and environmental and traffic situations are represented in the LTPP database. PG ratings and other material properties can be altered and structural designs can be improved for new asphalt pavements. Maintenance schedules can be advanced or deferred and systems can be put in place to monitor and predict

³⁶ Climate Change Implications for Flexible Pavement Design and Performance in Southern Canada. Journal of Transportation Engineering. October, 2009.

freezing and thawing effects on pavement strength and restrict traffic accordingly” (p 780).

Table 22 is included below to illustrate the modeling work performed by the authors using the MEPDG model (Mechanistic Empirical Pavement Design Guide). The table shows the percent change in cracking and deformation of pavements for a number of Canadian sites.

TABLE 22: MEPDG MODELING RESULTS

Analysis site	IRI (% change)	Cracking (% change)			Deformation (% change)	
		Longitudinal	Alligator	Transverse	AC	Total ^a
British Columbia (baseline)	1.55 m/km	6.8 m/km	0.7%	19.1 m/km	2.1 mm	10.7 mm
CGCMA2x	-0.7	-1.9	7.5	-96.9	16.9	3.8
HadCM3B21	1.9	0.0	10.5	87.1	19.3	4.8
Alberta (baseline)	2.34 m/km	551.1 m/km	28.9%	399.6 m/km	5.5 mm	19.0 mm
CGCMA2x	1.3	9.3	11.4	0.0	22.7	-0.5
HadCM3B21	1.7	5.8	7.3	0.0	31.8	4.7
Manitoba (baseline)	2.54 m/km	450.8 m/km	48.2%	399.6 m/km	2.9 mm	14.5 mm
CGCMA2x	2.0	2.9	6.0	0.0	35.9	-0.9
HadCM3B21	2.4	2.9	5.8	0.0	34.1	2.3
Ontario (baseline)	1.92 m/km	33.3 m/km	4.6%	399.6 m/km	4.2 mm	12.1 mm
CGCMA2x	1.0	1.7	10.5	0.0	27.0	9.0
HadCM3B21	1.6	5.7	13.1	0.0	28.9	10.3
Quebec (baseline)	2.12 m/km	1647.7 m/km	0.5%	399.6 m/km	5.3 mm	21.8 mm
CGCMA2x	-0.9	0.0	4.4	0.0	13.9	-3.2
HadCM3B21	-0.5	-0.7	2.2	0.0	16.8	-0.8
Newfoundland (baseline)	1.79 m/km	5.3 m/km	0.1%	399.6 m/km	1.2 mm	9.1 mm
CGCMA2x	-1.1	5.4	14.3	0.0	21.9	-1.1
HadCM3B21	-0.6	4.3	14.3	0.0	21.9	0.6

^aIncludes all layers (asphalt, base, subbase, and subgrade).

The findings of this study are generally consistent with an earlier study conducted for southern Canada highways³⁷. The study did not find significant climate change impacts, but did point out that secondary and tertiary roads with high traffic volumes would have more impacts.

Climate Change Impact on the Pavement Maintenance and Rehabilitation Costs Associated with the Australian National Highway Network³⁸

While specific to Australia, this paper contains a number of findings relevant to Ohio.

First, the paper discusses how changes in traffic activity from climate changes can significantly affect pavements. For example, low-lying areas prone to sea level rise could experience emigration to inland areas thereby increasing traffic levels and pavement impacts to inland roads. Similarly, Ohio may experience the same problem if lake level decline on Lake Erie shifts freight traffic to Ohio roads.

³⁷ The Road Well-Traveled: Implications of Climate Change for Pavement Infrastructure in Southern Canada. Environment Canada and University of Waterloo. March, 2007.

³⁸ Climate Change Impact on the Pavement Maintenance and Rehabilitation Costs associated with the Australian National Highway Network. Risk Research Group, Geospatial and Earth Monitoring Division, Geoscience Australia.

Second, the paper discusses the “Thornthwaite Moisture Index” as metric for understanding pavement impacts. This may be a useful metric for ODOT to use within adaptation planning. As stated on page 492 of the paper:

“Climate in both models is represented by the “Thornthwaite moisture index” (Thornthwaite, 1948), which is a function of precipitation, temperature and potential evapotranspiration. The latter depends on a range of factors including temperature and length of daylight hours. Roads in areas with higher value for the Thornthwaite index will deteriorate faster than those with a lower value for the same traffic loading. A warmer and wetter climate leads to a higher rate of pavement deterioration, both as function of time and as a function of the pavement load (unit: equivalent standard axles; ESALs).

EXPERT OUTREACH

T2ASCO

RSG spoke with TJ Young of T2ASCO who has over 25 years of experience in asphalt plant operations. He has worked in nearly every state in the country and has written and taught extensively, including for the National Asphalt Pavement Association (NAPA). We reached out to Mr. Young to see what the asphalt production sector is doing in light of climate change. Mr. Young is aware of many initiatives to reduce greenhouse gas emissions from asphalt production, but is not aware of any commercial production of asphalt mixes being produced on a large scale to adapt to climate change effects on pavements.

National Asphalt Paving Association (NAPA)

The National Asphalt Paving Association is the trade association for asphalt pavement material producers and paving contractors on the national level. RSG contacted Kent Hansen, the Director of Engineering at NAPA. Mr. Hansen reported that while NAPA is involved in greenhouse gas emissions reductions projects, it is not currently involved in any pavement adaptation studies. Key points from the conversation:

- There are many ways the pavement industry can adjust to climate change.
 - Change the binder specification.
 - Increase the amount of recycled pavement in mixes to reduce any potential costs associated with a better performance mix.
 - Do not allow maintenance activities, like resealing, to lapse to prevent future problems associated with water infiltration.
 - Make sure proper funding is available for pavement maintenance. With this in effect, we can better limit problems.
 - Implement “perpetual pavements”. These pavements are thicker so problems occur closer to the surface, which is easier to replace.
 - Use materials which are not susceptible to frost.
- Traffic volumes are critical to pavement wear and deterioration. Therefore, it is important to consider both the combined effects of climate change and traffic volume. In the case of Ohio, it is important to consider if there will be any

significant increases in traffic volume or heavy vehicles (to accommodate freight movement) as a result a redistribution of traffic due to climate change effects or due to land use changes.

- Potentially more important to focus on the design of bridges than pavements given their longer lifespan.

Texas Transportation institute

RSG spoke with Tom Scullian who is a pavement innovator at the Texas Transportation Institute (TTI). Mr. Scullian is involved in “balanced mix design”, where mixes are developed to handle a range of environmental conditions which cause both cracking and rutting. This type of design may be advantageous in some environments for adapting to climate change. Balanced design asphalt provides the stiffness to avoid rutting in high temperatures, but also the flexibility to avoid cracking in low temperatures.

Here is a synopsis of Mr. Scullian’s comments:

- Traditional mixes and design procedures are not working well.
- Unprecedented pavement failures occurred in Texas in the summer of 2011. In this, there were approximately 15 days without rain and where the ambient temperature reached 110°F. This led to significant rutting and longitudinal cracking. Jointed concrete pavements built in the 1930’s also failed.
- More performance tests need to be conducted for designing mixes and roads. In Texas, there is a test facility where “balanced mix design” is tested for both rutting and cracking.
- Pavements should be designed for weather extremes (increases in variance) such as what was observed in 2011. Basing design on averages hides potential impacts where design failures occur.
- Subgrade drying is a big problem associated with clays.
- Asphalt companies can produce a binder to accommodate a wider surface temperature regime.
- Using RAP produces a stiffer pavement which can fail sooner than pavements relying solely on virgin aggregate.

University of New Hampshire

RSG identified the work of Dr. Jo Sias Daniel at the University of New Hampshire (UNH), who has used the Mechanistic-Empirical Pavement Design Guide (MEPDG) model was used to estimate pavement deterioration from climate change effects. The MEPDG model was run for several sites in the Northeast to evaluate changes from temperature increase only. Model result indicated minimal impacts would occur.

Here is a synopsis of Prof. Daniel’s thoughts:

- Temperature impacts on pavement surface can be addressed within the resurfacing maintenance cycle. Lower layers can be addressed on a longer-term cycle.
- Interstate pavements are less vulnerable to climate change as their design is robust.

- Frost susceptible soils should be identified to help avoid pavement buckling.
- Secondary roads deserve attention as they are less robust than interstates.
- Pavement modeling field is relatively young (approximately 5 years old). There are challenges downscaling climate data to local conditions.

KEY FINDINGS AND FUTURE ANALYSIS

- Adaptation planning should consider (1) changes in the mean, (2) changes in the variance, and (3) changes in both the mean and variance for various climate change parameters to fully understand the range of climate change impacts.
- Adaptation planning should consider increases in traffic volume resulting from changes in travel behavior resulting from climate change.
- Pavement modeling generally suggests pavement impacts will be minimal and that there are many ways to adapt pavements to climate change effects, if necessary.
- Secondary roads built on vulnerable clays soils prone to significant shrinking and swelling are prone to drought-inundation cycling which has been identified as one of the climate change effects for Ohio. Identification of these roads which also carry higher traffic volumes or access critical facilities (i.e. regional medical centers) will point to critical vulnerable infrastructure. This will be a future analysis of the project.

State highway segments composed of rigid concrete pavements should be identified separately from those composed of flexible asphalt pavements. Concrete pavements have been observed to buckle under extreme heat regimens. This will be a future analysis of the project.

AIR QUALITY

RSG identified air quality as a special topic for the ODOT Infrastructure Resiliency study due to the high probability of increasing summertime temperatures in Ohio, the current existence of ground-level ozone concerns, and the anticipated strengthening of air quality standards.

Anticipated climate change effects in Ohio include average temperature increases of 3.0-5.5 degrees Fahrenheit over the next 50 years³⁹. Periods of prolonged heat waves and short-term periods of extreme heat are also anticipated to occur more frequently in Ohio over the course of the next century. Current research suggests air quality is potentially vulnerable to increasing average temperatures⁴⁰.

A new regime of higher temperatures could increase the duration and intensity of air pollution events, which, in turn, could affect human health and welfare. This white paper focuses on the effect of climate change on the following air pollutants: fine particulate matter (PM_{2.5}), nitrogen dioxide (NO₂), non-methane volatile organic compounds (NMVOCs), and ozone (O₃). It also addresses how increasing concentrations of these

³⁹ Working Paper 2 of the ODOT Infrastructure Vulnerability Assessment (March 5, 2014) projected potential temperature changes for Ohio, based on the IPCC Emissions Scenario A2, of 3.0-5.5°F by mid-century and 5.5-7.5°F by end of century.

⁴⁰ Forster, et al, 2007. Changes in Atmospheric Constituents and in Radiative Forcing. IPCC

pollutants could in turn affect ODOT operations, including the implementation of Ohio DOT infrastructure projects.

POTENTIAL AIR QUALITY IMPACTS

Recent studies have demonstrated that higher daily ambient air temperatures are more favorable to the formation of ground-level ozone⁴¹ in the presence of sunlight and increased ratios of NMVOC to NO_x concentrations⁴². A recent synthesis of multiple climate and emissions models for the years 2000-2050 suggests that temperature increases have the potential to increase ozone concentrations by 1-10 parts per billion (ppb) and PM-2.5 concentrations by 0.1 µg/m³ in polluted areas^{43,44}. One possible scenario is an increased number of both PM-2.5 and ozone concentration events due to spikes in emissions of PM-2.5 and ozone pre-cursors (NO_x and NMVOCs) in response to increased fuel burned during acceleration and for vehicle and building cooling.

POTENTIAL REGULATORY COMPLIANCE ISSUES

Higher ambient air temperatures and ambient air pollutant concentrations could increase the likelihood of exceedances of the federal National Ambient Air Quality Standards (NAAQS).

The likelihood of NAAQS exceedances could be greater if the EPA's proposed strengthening of the ozone ambient air quality standard is finalized.⁴⁵ In December 2014, the U.S. Environmental Protection Agency proposed to tighten the 8-hour NAAQS for ozone from the 2008 level of 75 ppb to a level within a range of 65-70ppb⁴⁶. The Cincinnati, Columbus, and Cleveland metropolitan areas are in non-attainment with the current ozone standard.

A non-attainment area is one or more counties which exceed the NAAQS for a given air pollutant.

The potential increase in ozone concentrations and the strengthening of the ozone standard affect the feasibility of future infrastructure projects proposed by the Ohio Department of Transportation (ODOT) for two reasons. First, a greater degree of non-attainment could trigger stricter SIP requirements.^{47,48} Second, this could trigger more ODOT staff resources

⁴¹ Lacour, et al. 2006. Relationship between ozone and temperature during the 2003 heat wave in France: consequences for health data analysis. BMC Public Health 2006, 6:261

⁴² Allen, J. February 2004. Tango in the Atmosphere: Ozone and Climate Change. http://www.giss.nasa.gov/research/features/200402_tango/. Viewed July 10, 2015.

⁴³ Weaver, et al. A preliminary synthesis of modeled climate change impacts on us regional ozone concentrations, B. Am. Meteorol. Soc., 90, 1843-1863, 2009.

⁴⁴ Tai, A.P.K, Mickley, L.J., & Jacob, D.J., 2012. Impact of 2000–2050 climate change on fine particulate matter (PM_{2.5}) air quality inferred from a multi-model analysis of meteorological modes. Atmos. Chem. Phys., 12, 11329–11337, 2012.

⁴⁵ Ambient Ozone Monitoring Regulations: Revisions to Network Design Requirements. Federal Register / Vol. 74, No. 135 / Thursday, July 16, 2009 / Proposed Rules.

⁴⁶ Proposed Revisions to National Ambient Air Quality Standards for Ozone. US EPA. December 2014.

⁴⁷ State Implementation Plan (SIP) – Infrastructure. Ohio Environmental Protection Agency. <http://www.epa.state.oh.us/dapc/SIP/infrastructure.aspx>. Viewed on July 9, 2015.

devoted to demonstrating compliance for proposed transportation projects along with ambient air quality studies for individual transportation projects.

OHIO AMBIENT AIR QUALITY

Non-Attainment Areas

Figure 31 shows attainment and non-attainment areas for ozone. Figure 32 shows the attainment and non-attainment areas for PM_{2.5} for the 24-hour (2006) and annual (1997) standards.

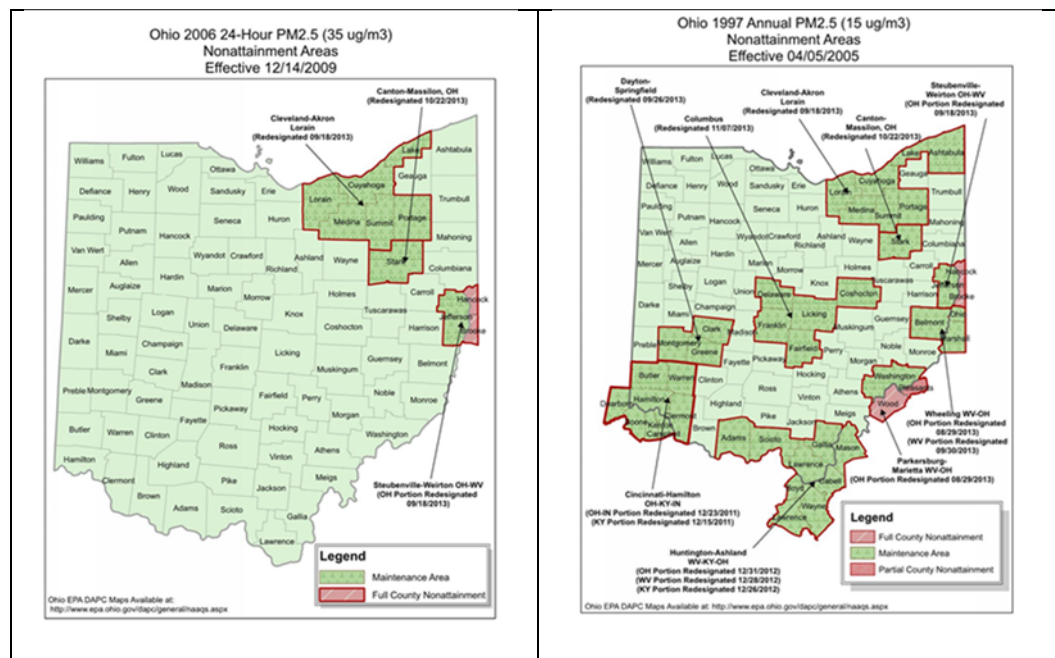
For ozone, the three metro areas of Cincinnati, OH-KY-IN, Columbus, OH, and Cleveland-Akron-Lorain, OH that have been classified as being in non-attainment with the EPA ozone air quality standard (75 parts per billion over an eight-hour period).

FIGURE 31: MAP OF OZONE ATTAINMENT AND NON-ATTAINMENT AREAS IN OHIO



Parts of Ohio are in non-attainment for PM 2.5 for the 24-hour and the annual standards.

FIGURE 32: MAP OF PM 2.5 ATTAINMENT AND NON-ATTAINMENT AREAS IN OHIO (24-HOUR AND ANNUAL STANDARDS)



EPA AMBIENT AIR MONITORING DATA

RSG evaluated ambient air quality data for Cincinnati, Columbus, and Cleveland as they are areas where pollutant concentrations are high relative to other areas in Ohio⁴⁹. Specifically, we evaluated air quality data for the past complete 10-year period to understand pollutant concentration trends. The results are provided in the following sections.

Ozone and Ozone Precursor Trends

Ambient ozone concentrations exceeded the ozone NAAQS standard for approximately the first half of the 10-year period of 2004-2014 (Figure 33). Ozone concentrations dip below the standard twice in the second half of the 10-year period, suggesting ozone conditions are improving. A continuation of this trend would potentially demonstrate attainment with the current ozone standard, and possibly the proposed (and more stringent) standard. The recent trend in ambient ozone concentrations can be attributed largely to declines in ambient concentrations of ozone precursors such as non-methane volatile organic compounds (NMVOCs) and nitrogen dioxide (NO₂). These are explained below.

⁴⁹ EPA Air Data. <http://www.epa.gov/airdata/>. Viewed 6/5/2015.

FIGURE 33: CONCENTRATIONS OF OZONE IN OHIO METRO AREAS

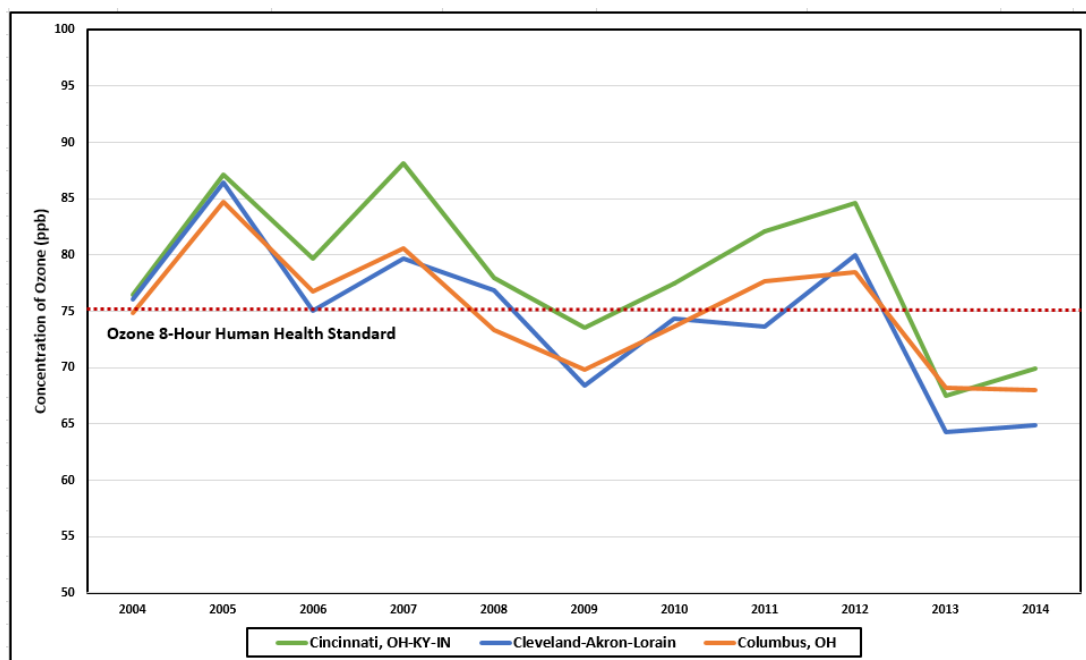


Figure 34 shows the median (50th percentile) concentration of NMVOC that are part of the EPA Photochemical Assessment Monitoring Stations (PAMS) monitoring program⁵⁰. These data reflect all anthropogenic NMVOCs (up to 72% of all volatile organic emissions are biogenic)⁵¹. As shown, NMVOC concentrations have declined significantly over the 10-year period. However, there is a noteworthy 18% increase in Cincinnati's concentration at the end of the period.

⁵⁰ EPA PAMS - Technology Transfer Network Ambient Monitoring Technology Information Center <http://www.epa.gov/ttnamti/pamsmain.html>. Viewed on July 10, 2015.

⁵¹ EPA Panel B. Relative amounts of VOC emissions from anthropogenic and biogenic sources, 2002

FIGURE 34: CONCENTRATIONS OF VOLATILE ORGANICS IN OHIO METRO AREAS

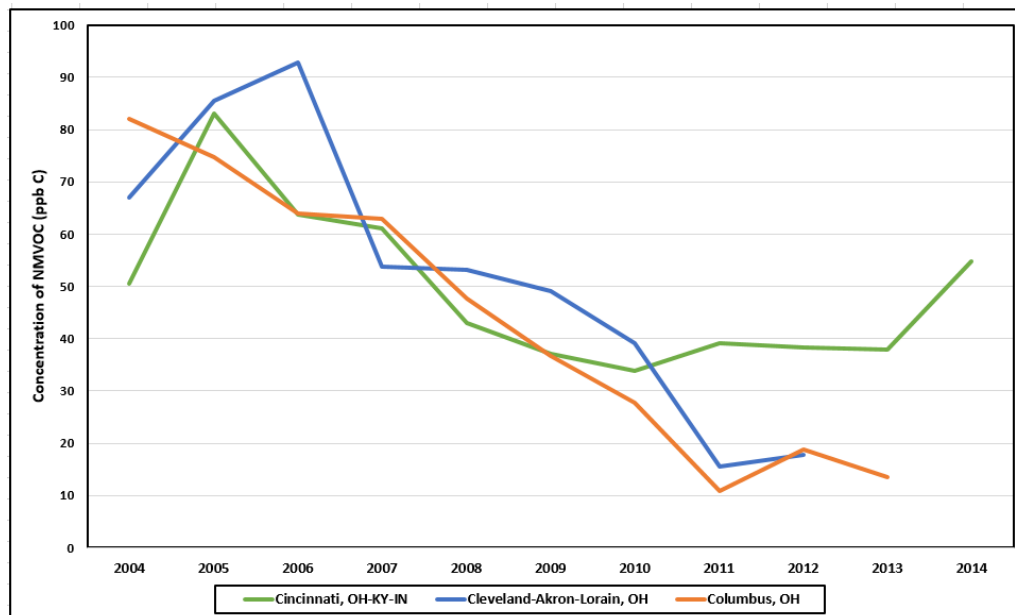
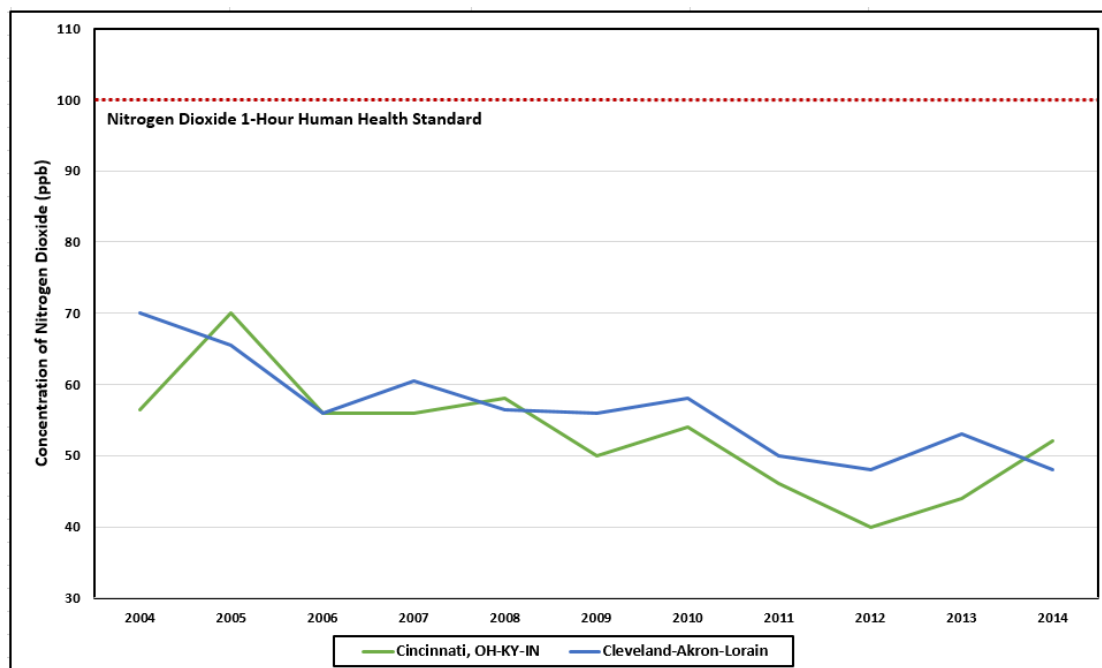


Figure 35 shows 98th percentile 1-hour NO_2 concentrations (the 98th percentile is the value which is only exceeded 2% of the hours of the year). As shown, NO_2 concentrations are well below the standard and decline steadily over the 10-year period.

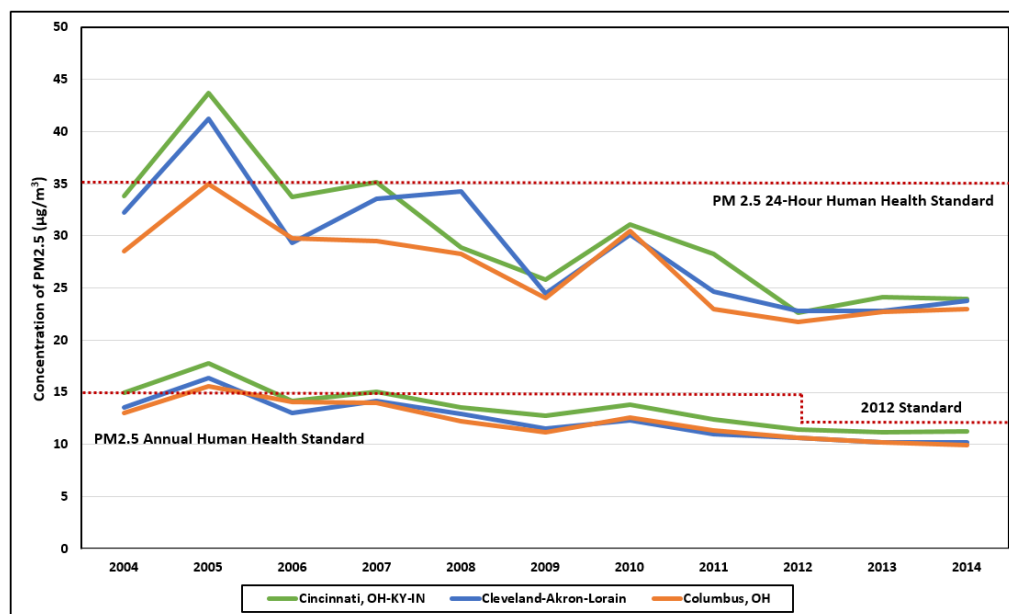
FIGURE 35: CONCENTRATION OF NITROGEN DIOXIDE IN OHIO METRO AREAS



Ohio Metro Area PM-2.5 Concentrations

Figure 36 below shows trends for PM-2.5 concentrations. As shown, the 98th percentile 24-hr concentrations and annual mean concentrations of PM-2.5 decline steadily over the period. The 24-hour and annual standards were regularly met after 2007 (note EPA strengthened the annual standard from 15 $\mu\text{g}/\text{m}^3$ to 12 $\mu\text{g}/\text{m}^3$ in 2012).

FIGURE 36: CONCENTRAIONS OF PM-2.5 IN OHIO METRO AREAS



MOBILE SOURCE EMISSIONS OUTLOOK

On-road mobile sources comprise up to 50% of total emissions responsible for the formation of ground-level ozone^{52,53}. Both the U.S. EPA and the Ohio EPA have long targeted mobile source emissions from vehicles through pollution control measures such as requiring increased fuel efficiency and changes to fuel composition (e.g., unleaded gasoline, ultra-low sulfur diesel, ethanol, etc.).

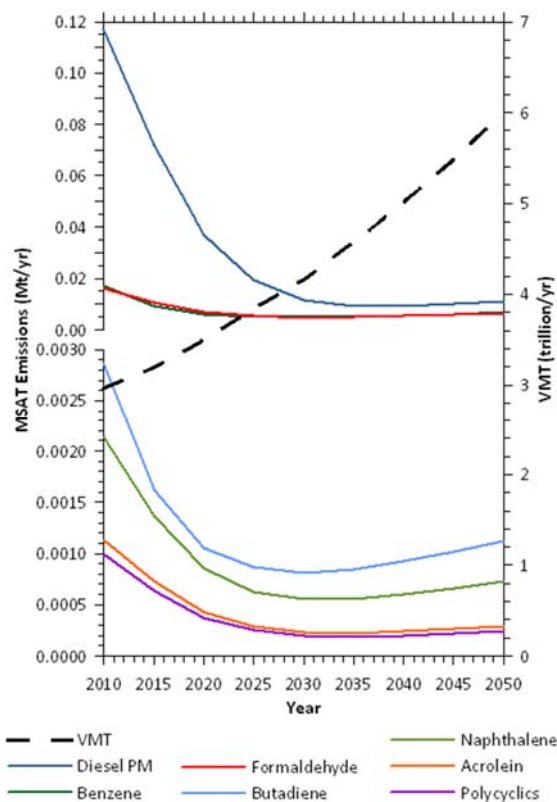
The FHWA published MSAT (mobile source air toxics) emissions projections for 2010-2050 from the EPA MOVES 2010b model⁵⁴. The results shown in Figure 37 below projects that future mobile source emissions will be significantly lower than current emissions despite an increase in vehicle miles travelled (VMT) from 3 trillion miles per year in 2010 to over 6 trillion miles per year by 2050.

⁵² Cars, Trucks, Buses, and "Nonroad" Equipment The Plain English Guide to the Clean Air Act. http://www.epa.gov/airquality/peg_caa/carstrucks.html. Viewed on July 10, 2015.

⁵³ Ohio State Implementation Plan – Emissions Inventory, 2010. http://www.epa.state.oh.us/dapc/SIP/E_Inventory.aspx. Viewed on July 10, 2015.

⁵⁴ FHWA, 2012. Interim Guidance Update on Mobile Source Air Toxic Analysis in NEPA. http://www.fhwa.dot.gov/environment/air_quality/air_toxics/policy_and_guidance/aqintguidmem.cfm

FIGURE 37: NATIONAL MSAT EMISSIONS TRENDS 2010 – 2050 FOR VEHICLES OPERATING ON ROADWAYS USING EPA'S MOVES2010B MODEL



KEY FINDINGS

- 2004-2014 EPA ambient air monitoring data for Ohio's metro areas demonstrate a decline in decadal ambient ozone concentrations. 2013 and 2014 concentrations fell below the 2008 NAAQS and demonstrate the potential for compliance with the upper limit of the proposed revised ozone standard.
- 2004-2014 EPA ambient air monitoring data for NO_x and NMVOC from Ohio's metro areas demonstrate a decadal decline in these ozone pre-cursor concentrations and compliance with the 1-hour NAAQS for NO_x.
- 2004-2014 EPA ambient air monitoring data for PM-2.5 in Ohio's metro areas demonstrate an ongoing decline in ambient PM-2.5 concentrations and compliance with the 2006 24-hour NAAQS. Trends also indicate ongoing compliance with the annual PM-2.5 NAAQS since 2011.
- Concentrations for both 24-hour and annual standards have remained steady since 2011 and do not appear to be at risk for non-compliance when accounting for climate model predictions of ambient PM-2.5 concentrations projected into the year 2050 (increase of 0.1 µg/m³).
- Ozone concentrations appear to be declining, and may need to continue this trend to offset a 1 – 10 ppb ozone concentration increase predicted by global climate models.

- Air quality modeling using the MOVES 2010b model suggests the trend in declining air pollutant concentrations could continue through 2050 if mobile source emissions continue to decline.
- Ongoing decreases in pollutant emissions and concentrations could help buffer the effects of climate change induced temperature changes and minimize the potential for regulatory burdens when developing future transportation projects.

POTENTIAL IMPACTS OF THE NORTHWEST PASSAGE

Mark Locker of ODOT's Maritime and Freight Program has indicated the potentially significant changes that could occur in Ohio from an opening of the Northwest Passage. The Northwest Passage is a maritime shipping route through Canada's Arctic. While currently far from being an established route, it could become a major maritime shipping route in 20 to 30 years if the Arctic polar ice cap continues retreating.

The Northwest Passage is relevant to ODOT in that it could significantly increase maritime freight traffic to the St. Lawrence Seaway and ultimately the state's Lake Erie ports and related infrastructure. The shrinking of this ice cap could increase the area of open, navigable polar waters creating the "Northwest Passage" – a water passage which would allow ships from China & Russia to navigate through the islands of the Canadian Archipelago to the St. Lawrence Seaway and, ultimately, to the Great Lakes in lieu of west coast ports. The Northwest Passage has been sought for the last 2-3 centuries with virtually all efforts being stopped by sea ice.

While potentially many years from being viable, this route is potentially faster (due to the shorter distance) and far less expensive (due to reduced need to transload freight) than current freight routes. In addition, the majority of the US population lives east of the Mississippi; therefore, this route will have more potential to serve a larger population.

Navigation through the Northwest passage has become possible in the last few years during summer. Some companies are shipping goods through the passage in very recent summers, though there continues to be significant challenges with navigation through the area due to large floating blocks of ice. Nevertheless these factors suggest freight shipping to and from Ohio Lake Erie water ports could significantly increase at some future date. Freight shipping via Ohio railways and roads would increase in response.

Figure 38 shows the route taken by the "Nordic Orion" in September, 2013, a ship which carried 73,500 tons of coal from Vancouver to Finland through the Northwest Passage.¹ This is thought to be the first voyage through the Northwest Passage.

FIGURE 38: THE NORDIC ORION'S ROUTE, SEPTEMBER 2013

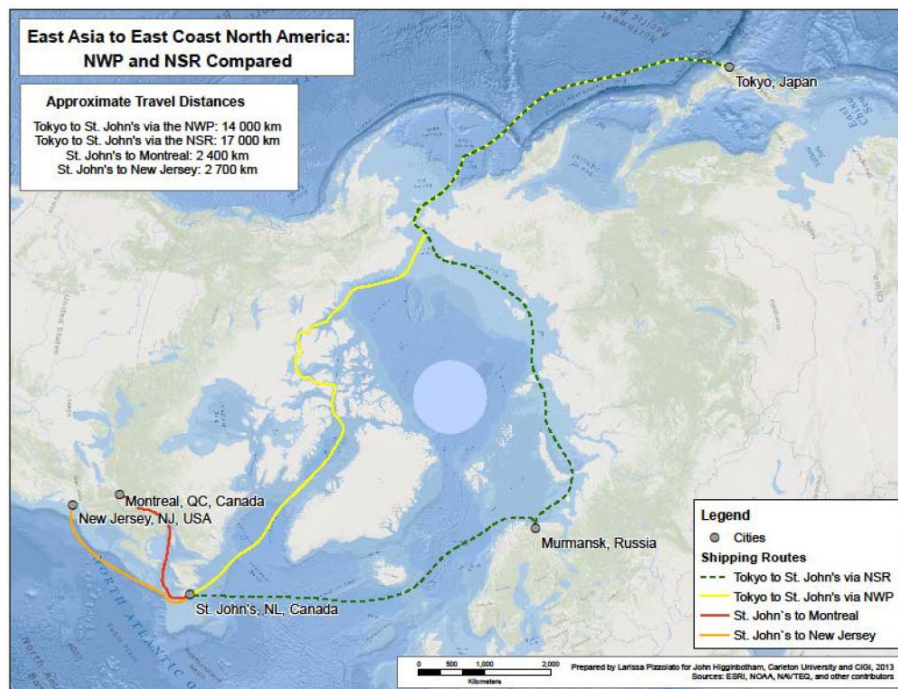


Source: http://yle.fi/uutiset/luoteisvaylan_avannut_nordic_orion_saapuu_porin_satamaan/6874171

Figure 39 shows both the Northwest Passage and Russia's Northern Sea Route (NSR). The NSR, depicted with the green dotted line is already being used for shipping. In 2010, "non-Russian commercial shippers started using Russia's Northern Sea Route with the transit of the "M/V Nordic Barents", a modern heavy ice class bulk carrier, from Norway to China".⁵⁵ Also depicted is a red line showing how ships can access the St. Lawrence Seaway (and ultimately the Great Lakes) from the Northwest Passage.

⁵⁵ "The Age of the Arctic: The Rush as Just Begun". Pacific Maritime Online. Michael Moore, June, 2014. Available at: <http://www.cigionline.org/articles/age-of-arctic-rush-has-just-begun>

FIGURE 39: THE NORTHWEST PASSAGE AND RUSSIA'S NORTHERN SEA ROUTE (NSR) ⁵⁶



RSG identified a number of literature sources related to climate change impacts on pavements. Pertinent information from a select list of these sources is described below.

Age of the Arctic: The Rush has Just Begun⁵⁷

This is an article written by Michael Moore in “Pacific Maritime Online”. It provides a sense for how marine activity is increasing in the Arctic. Moore cites two main reasons for increases in Arctic activity:

1. Increased availability of resources such as fisheries, oil & gas, and minerals,
2. Potential shipping routes from Asia and the Pacific Coast to Europe.

The article also quotes John Higginbotham (colleague of Marc-Andre Roy at CPCS), who states:

“We have to look ahead 30, 40, and 50 years. A whole new maritime economy could appear in the North American Arctic – fishing, oil, minerals, and tourism. With vision and planning, the region will come to look more like Norway.”

However, the author cautions that there are constraints in the Northwest Passage, such as shallow waters, lack of charts, lack of infrastructure, and the presence of more sea ice than in other shipping routes.

⁵⁶ North American Arctic Corridors and Gateways. Presented by John Higginbotham at NAFTA-NEXT, Chicago, IL, April, 2014.

⁵⁷ “The Age of the Arctic: The Rush as Just Begun”. Pacific Maritime Online. Michael Moore, June, 2014. Available at: <http://www.cigionline.org/articles/age-of-arctic-rush-has-just-begun>

***Is Nicaraguan Canal a Boon for Trade or a Boondoggle?*⁵⁸**

This is an article in National Geographic about a new shipping canal under consideration in Nicaragua. As the title suggests, it expresses skepticism about the success of this potential project. Part of the skepticism is based on the knowledge that more shipping could occur through the Arctic thereby eliminating the need for the canal.

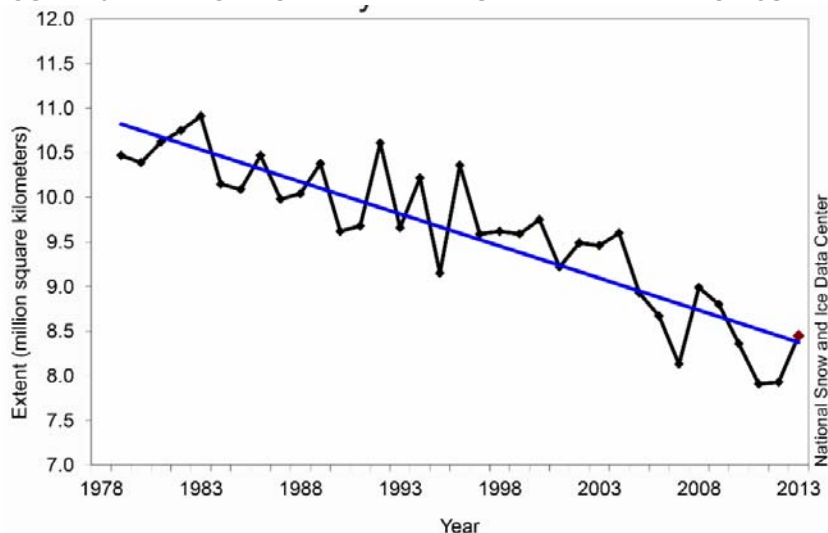
“The Panama Canal, they say, which has gigantic new locks scheduled to be operational next year, is more than capable of meeting future demand. They also cite projections for global warming that suggest ships could traverse an ice-free Arctic by the middle of the century, further reducing demand for passage through Central America.”

***North American Arctic Corridors and Gateways*⁵⁹**

This was a presentation given by John Higginbotham at NAFTANEXT, Chicago, IL, April, 2014. The following graphics are included to help emphasize the Arctic changes.

Figure 40 illustrates the reduction in Arctic sea ice. As shown, average sea ice extent has decreased from approximately 10.5 to 8.5 million square kilometers from 1979 to 2013.

FIGURE 40: AVERAGE MONTHLY ARCTIC SEA ICE EXTENT FROM JULY 1979 - 2013



⁵⁸ Is Nicaraguan Canal a Boon for Trade or a Boondoggle? National Geographic. Available at: <http://news.nationalgeographic.com/news/2014/03/140329-nicaragua-canal-hknd-panama-wang-jin-world/>

⁵⁹ North American Arctic Corridors and Gateways. Presented by John Higginbotham at NAFTANEXT, Chicago, IL, April, 2014.

Figure 41 shows a new icebreaker vessel, which will be able to operate in the NSR year round. This vessel is anticipated to start operating in approximately three years.

FIGURE 41: RUSSIAN LK-60 ICEBREAKER



**Will
make it
possible
to use the
Northern
Sea
Route all
year
around**

Dimensions:

- 173 meters long
- 34 meters wide
- price tag of €1.1 billion
- overall power of 60 MW
- variable draught from 8.5 m to 10.8 m

**Ready for operations in
2017**

NCHFP Report 17: Multimodal Freight Transportation within the Great Lakes-Saint Lawrence Basin⁶⁰

This report focuses on opportunities and constraints in the Great Lakes-Saint Lawrence Basin (GLSB). This is an important document in that it addresses the constraints, which would potentially limit Arctic shipping's impact on Ohio Lake Erie ports. Two constraints were identified:

1. Temporary closure of the locks and dams in the St. Lawrence Seaway due to ice and maintenance.
2. Bottlenecks at intermodal centers and roads at St. Lawrence Seaway and Great Lakes ports.

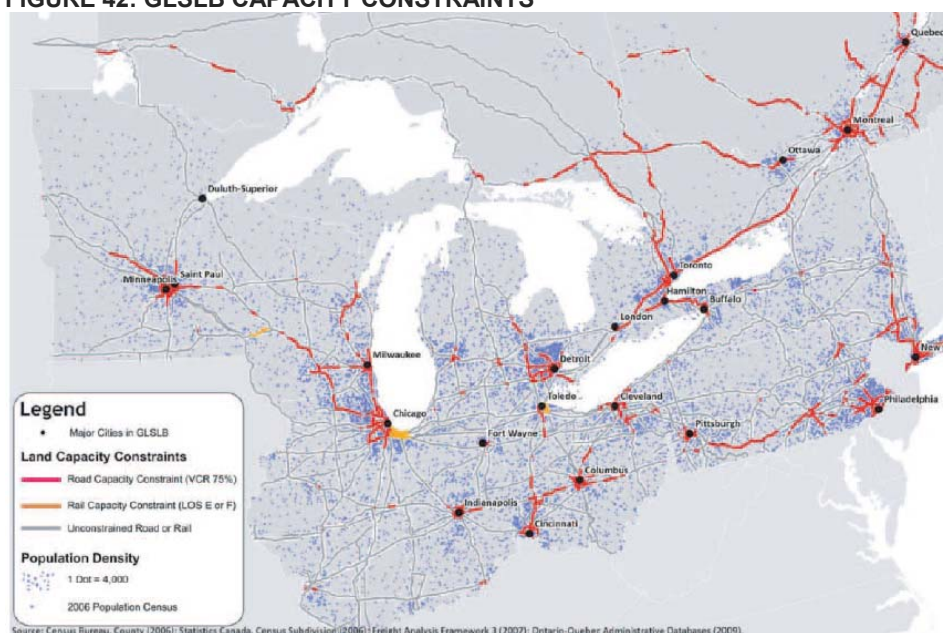
The following section will describe a third constraint – the size of the locks and dams.

Figure 42 shows land based capacity constraints for the GLSLB area. As shown, there are constraints along the route from Ohio ports to the Northwest Passage. These are evidenced by the red shading in Buffalo, Montreal, and Quebec. There are also constraints shown

⁶⁰ NCFRP Report 17: Multimodal Freight Within the Great Lakes-Saint Lawrence Basin. Transportation Research Board of the National Academies. Washington, DC. 2012.

around Cleveland and Ohio. These constraints could create bottlenecks for Northwest Passage related freight.

FIGURE 42: GLSLB CAPACITY CONSTRAINTS



Below are a few quotes from this source, which are included to better illustrate the issue of constraints.

“Seasonality: the 3-month closure of the St. Lawrence Seaway from late December to late March, due mainly to maintenance and ice, discourages shippers from using multimodal marine transportation as this implies reorganizing supply chains in winter months.”

“Capacity constraints and congestion are most significant around Chicago, the GLSLB’s most important transportation hub. Capacity constraints around Chicago and other major urban centers in the GLSLB, including Minneapolis, Detroit, Toronto, and Montreal, are resulting in increased transit time and cost with reduced reliability, particularly for general cargo, which critically depends on rail intermodal and truck transportation to/from major centers.”

“Second, capacity constraints in the GLSLB are likely to intensify significantly over the next 30 years if appropriate measures to address capacity are not addressed.

“Third, capacity constraints are currently most significant on the region’s roadways, but railways are likely to become increasingly capacity-constrained going forward.

“Fourth, if not addressed, capacity constraints will likely stretch further from urban centers, on both roadways and railways, creating new bottlenecks elsewhere in regional supply chains.”

Unlocking the Value of the Great Lakes-St. Lawrence River Maritime Transportation System⁶¹

This source was authored by Marc-Andre Roy and provides further discussion of the constraints facing the St. Lawrence Seaway. Mr. Roy describes how the current locks were designed to accommodate smaller ships and that they will have to be expanded in order to accommodate the size of modern vessels.

“The size of ships that can enter the GLSLR marine transport system is constrained by the physical dimension of the locks in the system.”

“When constructed in the 1950s, the Seaway dimensions could, at that time, accommodate much of the world’s shipping. Since that time vessels have become much larger, largely with the aim of generating greater economies of scale from shipping. As a result, it is estimated that fewer than 25% of the world cargo fleet can navigate the GLSLR system. Certainly, most large container vessels that serve US and Canadian coastal ports cannot enter into the GLSLR system”

“Little can be done to change the physical size constraints of the GLSLR lock system, short of major works projects to expand lock capacity, as is currently being done in Panama with the construction of a new, larger canal (at an estimated cost of \$5.25 billion)⁵⁹. The technical feasibility of such a GLSLR system capacity expansion is not known and it is unlikely that such a project could be justified on economic or commercial grounds.”

Mr. Roy also notes the locks are remaining open for longer time periods, reflecting sea ice conditions in the Arctic.

“The Montreal-Lake Ontario (MLO) locks and Welland Canal locks were open 283 days and 285 days in 2012, respectively. This is longer than most previous years, and the trend is increasingly longer seasons.⁴⁵ The 2013 season is expected to be a record 287 days.”

On the other hand, Mr. Roy notes:

“...it is highly unlikely that year-round operations will be possible within the lock system.”

One last observation of this document is of the Great Lakes water levels, a topic considered earlier in this study.

“Water levels in the GLSLR and their connecting channels are expected to continue to fluctuate and it is expected that the future will experience more extreme water levels – both high and low – relative to historical patterns”⁶²

⁶¹ Unlocking the Value of the Great Lakes-St. Lawrence River Maritime Transportation System. CPCS, Ref: 13361. Mark-Andre Roy. February 12, 2014.

⁶² Adaptive Management Plan for Addressing Extreme Water Levels, Prepared by the International Great Lakes-St. Lawrence River Adaptive Management Task Team (May 2013), http://ijc.org/boards/stlawrencerivertaskteam/files/2012/06/FinalReport_Adaptive-Management-Plan_201305301.pdf

KEY FINDINGS AND FUTURE ANALYSIS

- Preparations are underway for significant increases in transportation and resource development activity in the Arctic.
- Major changes in freight shipping could arise in 20 – 30 years if the Arctic ice continue its current rate of retreat.
- There are a number of significant infrastructure capacity constraints in the St. Lawrence Seaway and Great Lakes that could result in:
 - Significant congestion increases if Northwest Passage freight traffic became a reality, or
 - Preclusion altogether of larger vessels unable to navigate through the locks system.

While potentially many years from being viable, this route is potentially faster and less expensive (due to reduced freight transloading) than current freight routes. Some companies are shipping goods through the passage in recent summers, though there continues to be significant challenges with navigation through the area due to large floating blocks of ice. Nevertheless, these factors suggest freight shipping to and from Ohio Lake Erie water ports could significantly increase at some future date. Freight shipping via Ohio railways and roads would increase in response.

Key points from discussion with Mark Locker of ODOT:

- The shrinking polar ice cap makes the Northwest Passage a possibility for future maritime shipping.
- The Northwest Passage is a very attractive route for Russia, and East Asia.
- The Port of Toledo is already receiving iron ore from Russia.
- Approximately 70% of US population is east of the Mississippi. The Northwest Passage would mostly serve this population.
- The Northwest Passage is attractive to countries like China as they would not have to ship to California and truck freight from there to the East Coast.
- Mode changes add significant cost to shipping freight. The Northwest Passage has the potential to reduce the number of mode changes needed to bring freight from places such as China to America's East Coast.
- There is no fee for using the Northwest Passage. "...Fees for ships to go through the Panama Canal have tripled in the past five years to \$450,000 per passage for a vessel carrying 4,500 containers" which is about average.⁶³
- Canadians are concerned about border safety.

⁶³ <http://www.bloomberg.com/news/2013-03-11/maersk-line-to-dump-panama-canal-for-suez-as-ships-get-bigger.html>

RECOMMENDATIONS FOR ADVANCING THE RESILIENCY PLAN

1. Identify lead office within ODOT-Office of Planning.
2. Annual Tasks
 - (1) Issues, data collection and analysis that need to be monitored on an ongoing basis, as part of input to ODOT's transportation planning function:
 - a. What climate stressors will affect the proposed facility either directly or through effects on the surrounding ecology?
 - b. What are the impacts of these stressors on the affected environment for the facility (and to what extent is any proposed facility in an area vulnerable to climate change)?
 - c. What is the risk to the asset and to the affected environment given expected changing climatic conditions?
 - d. To what extent do these stressors influence the desired characteristics of the proposed facility (e.g., efforts to avoid, minimize, or mitigate potential risks)?
 - e. What are the recommended strategies for protecting the function and purpose of the proposed facility?
 - f. Ongoing weather data analytics to understand the geographic location and severity of the emergency declarations and the amount of funds provided for emergency relief.
 - g. Improve data collection for weather-related hazard events. Include "Prior flood hazard" as a data element within the department's GIS system. Assign responsibility for updating the data on a regular basis.
 - (2) Ongoing refinement of VAST model for the 3 asset types:
 - (a) Initial refinement of scales and weights in VAST model based on input from Districts.
 - (b) Annual inspection visit to the top ranked vulnerable assets in each asset class. Revise VAST model as necessary to conform to best data/knowledge from USGS and from field inspections.
 - (c) Update list of critical facilities, re run VAST to determine whether there is a different prioritization of assets. Critical facilities, in the current model, consist solely of regional medical centers. Traffic operations

centers, ODOT regional maintenance facilities, and emergency response system components (e.g. fire, EMS, and police) could be added to the vulnerability assessment model.

(d) Consider expanding the VAST model to other facilities:

(i) Point Assets:

1. Airports (104)
2. Water Ports (8 on Lake Erie, 3 on Ohio River)
3. Passenger Terminals
4. Freight Terminals
5. Transit Stops

(ii) Fixed Route Assets

1. Marine Highways (716 miles), M70 (parallel to Interstate 79) and M90 (parallel to Interstate 90)
2. Waterways
3. Railways
4. Bikeways (4,207 lane miles)
5. Pedestrian Facilities
6. Stormwater Management Systems

(iii) Other Asset Types

1. Evacuation Routes
2. Maintenance and Operations Facilities
3. Traffic Signals and Traffic Control Centers
4. Emergency Operating Systems
5. Back-up power
6. Communications
7. Fueling
8. Other Intelligent Transportation Systems
9. Telecommunication Corridors
10. Ecosystems that Complement or Mitigate Transportation Systems – wetlands, floodplains, roadside vegetation, areas of rock fall, and mitigation areas.

Interagency Coordination:

- (1) Coordinate with ODOT Emergency Transportation Operations:
 - (a) Follow-up with districts which expressed a potential for improvement in each of the topic areas surveyed, in order to understand what can and should be done in light of this information.
 - (b) Implementation of formal “after action” reviews as an essential component of the continuous improvement philosophy under the Incident Command Structure (ICS) / Continuity of Operations / Continuity Program Management Cycle
(<https://www.fema.gov/continuity-operations>)
 - (c) Preparation for the inevitable threats posed by extreme weather should continue in keeping with the responsibilities entrusted to ODOT.
- (2) Coordinate with ODOT Asset Management:
- (3) Develop advisory team of ODOT and extra-ODOT, including climate scientists from USGS/NWS.

APPENDIX A: ODOT STAFF CONSULTED IN DEVELOPMENT OF RESILIENCY PLAN

1. Matt Perlik, ODOT Office of Environment
2. Noel Alcala, ODOT Office of Environment
3. Chris Merklin, PE, ODOT Geotechnical Engineer
4. Aric Morse, PE, ODOT Pavement Engineer
5. Jeff Syar, PE, ODOT Hydraulics Engineer
6. Becky Humphries, PE, ODOT Hydraulics Engineer
7. David Ryley, PE, ODOT Hydraulics Engineer
8. Thomas Lyden, PE, ODOT Operations
9. Michael Brokaw, PE, ODOT Structures
10. Sean Meddles, PE, ODOT Structures
11. Waseem Khalifa, PE, PhD, ODOT District 11
12. Carl Merkle, ODOT Emergency Response Liaison
13. Greg Giaimo, ODOT Planning
14. Scott Phinney, ODOT Planning
15. Drew Hurst, ODOT Planning
16. Mark Locker, ODOT Freight Planning

APPENDIX B: EXPERTS CONSULTED IN DEVELOPMENT OF RESILIENCY PLAN

1. Jo Sias Daniel, PhD. University of New Hampshire Department of Civil Engineering
2. Jacob Hoover, Ohio Emergency Management Agency
3. Rob Hyman, FHWA Climate Resiliency Specialist
4. Brian Beucler, FHWA Climate Change Team
5. Drew Gronewold (10-2013)
6. David Rutter, Hydrologist, Mid-Ohio Regional Planning Commission (10-25-13)
7. Jeff Rogers, State Climatologist, Ohio State University (10-30-13)
8. Scott Jackson, Greg Koltun, Chad Osterheim, USGS, Columbus 10-30-13)
9. Dev Niyogi, Indiana State Climatologist
10. Tony Durm, ODOT (11-7-13)
11. Lauren Hay, USGS (11-8-13)
12. James Noel, NOAA, Wilmington, OH
13. Ray Davis, NOAA, Wilmington, OH
14. Thomas Scullion, Texas Transportation Institute

APPENDIX C: RESEARCH LITERATURE

17. Intergovernmental Panel on Climate Change, IPCC Working Group Fifth Assessment Report (7 June 2013 Draft).
18. IPCC Special Report on Emissions Scenarios, Summary for Policymakers, IPCC Working Group III
19. The National Climate Assessment from the National Climate Assessment and Development Advisory Committee (NCADAC), a 60-person Federal Advisory Committee. Draft January 11, 2013.
20. National Academy of Sciences TRB Special Report 290 “Potential Impacts of Climate Change on U.S. Transportation”. 2008
21. On-line resources from the Federal Highway Administration (FHWA) initiative to establish transportation climate change and extreme weather vulnerability assessments (e.g. see http://www.fhwa.dot.gov/environment/climate_change/adaptation/webinars/may_16_2013/session151613.pdf)
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