Advancing Flood Resilience of Transportation Systems

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MN County Engineers Association Summer Conference

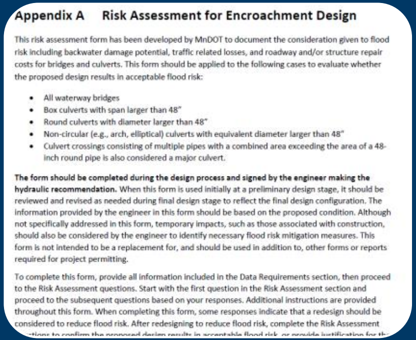
June 11, 2026

DEPARTMENT OF TRANSPORTATION

mndot.gov

Background

- Transportation infrastructure & flood impacts
- Observed and projected rainfall trends



Appendix A   Risk Assessment for Encroachment Design

This risk assessment form has been developed by MnDOT to document the consideration given to flood risk including backwater damage potential, traffic related losses, and roadway and/or structure repair costs for bridges and culverts. This form should be applied to the following cases to evaluate whether the proposed design results in acceptable flood risk:

- All waterway bridges
- Box culverts with span larger than 48"
- Round culverts with diameter larger than 48"
- Non-circular (e.g., arch, elliptical) culverts with equivalent diameter larger than 48"
- Culvert crossings consisting of multiple pipes with a combined area exceeding the area of a 48-inch round pipe is also considered a major culvert.

The form should be completed during the design process and signed by the engineer making the hydraulic recommendation. When this form is used initially at a preliminary design stage, it should be reviewed and revised as needed during final design stage to reflect the final design configuration. The information provided by the engineer in this form should be based on the proposed condition. Although not specifically addressed in this form, temporary impacts, such as those associated with construction, should also be considered by the engineer to identify necessary flood risk mitigation measures. This form is not intended to be a replacement for, and should be used in addition to, other forms or reports required for project permitting.

To complete this form, provide all information included in the Data Requirements section, then proceed to the Risk Assessment questions. Start with the first question in the Risk Assessment section and proceed to the subsequent questions based on your responses. Additional instructions are provided throughout this form. When completing this form, some responses indicate that a redesign should be considered to reduce flood risk. After redesigning to reduce flood risk, complete the Risk Assessment

Flood resilience guidance

- ‘Check storm’ concept and application
- Hydraulic Risk Assessment overview

Supporting Resources

- MnDOT resources
- Additional resources (Atlas 15 & others) coming soon

Background: Roads & Floods

MnDOT’s Drainage Infrastructure

~11,000+ miles of roadway

~2,660 Bridges over Waterways

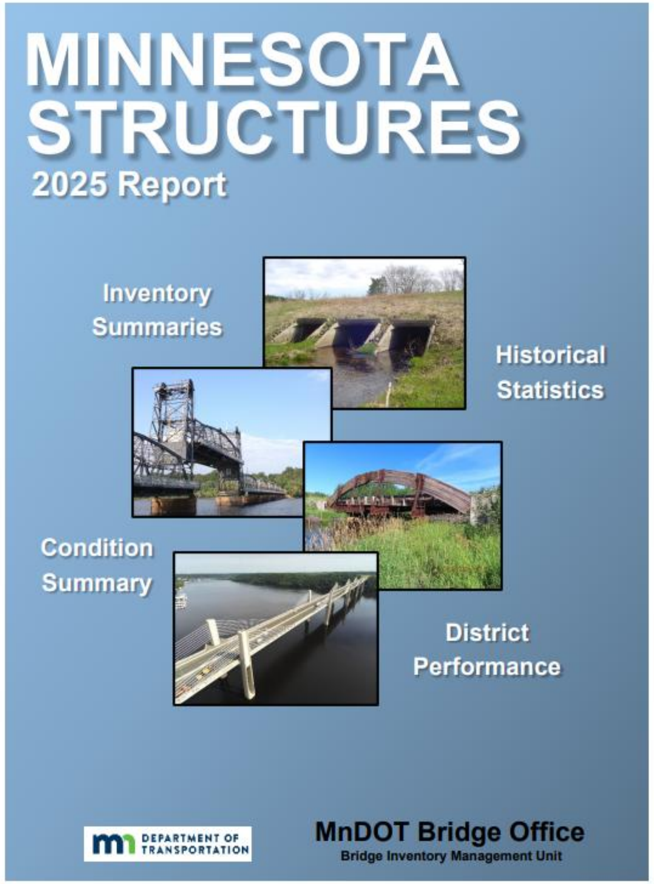
>70,000 Culverts

~80,000 Stormsewer Pipes

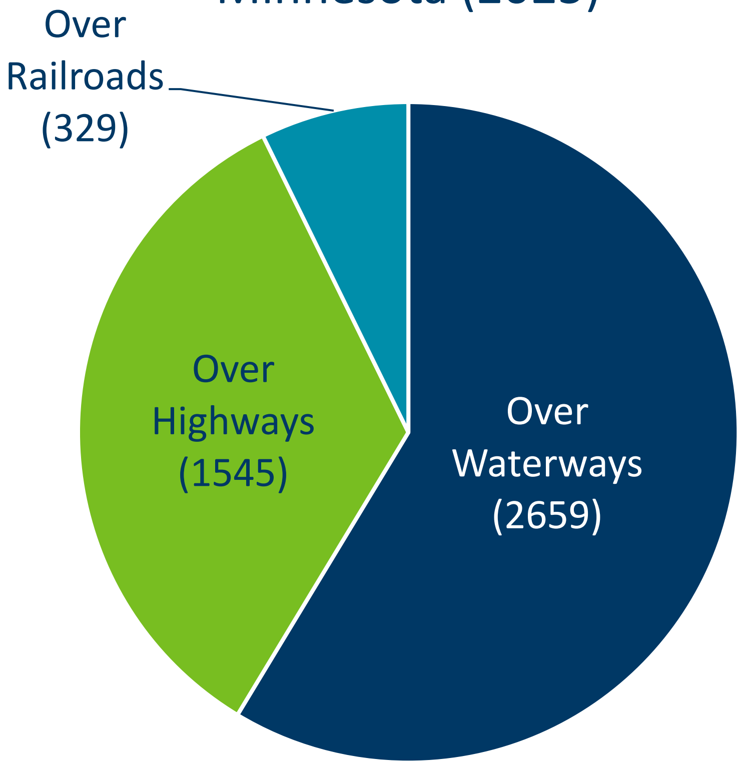
~1,700 Stormwater Facilities

… & many other assets served!

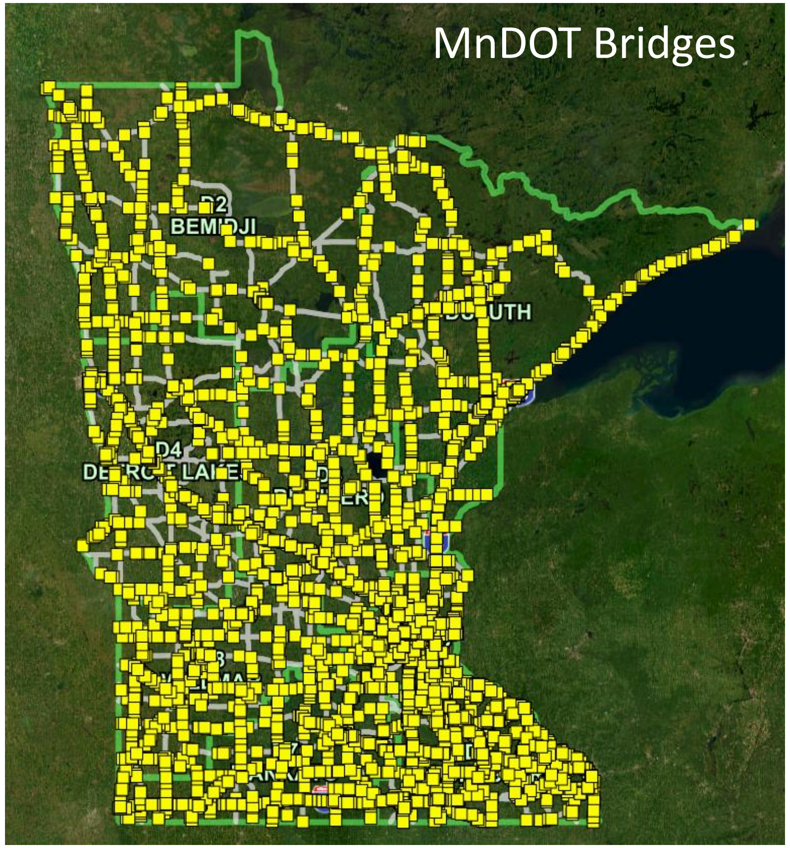
Trunk Highway Bridges (≥10’)



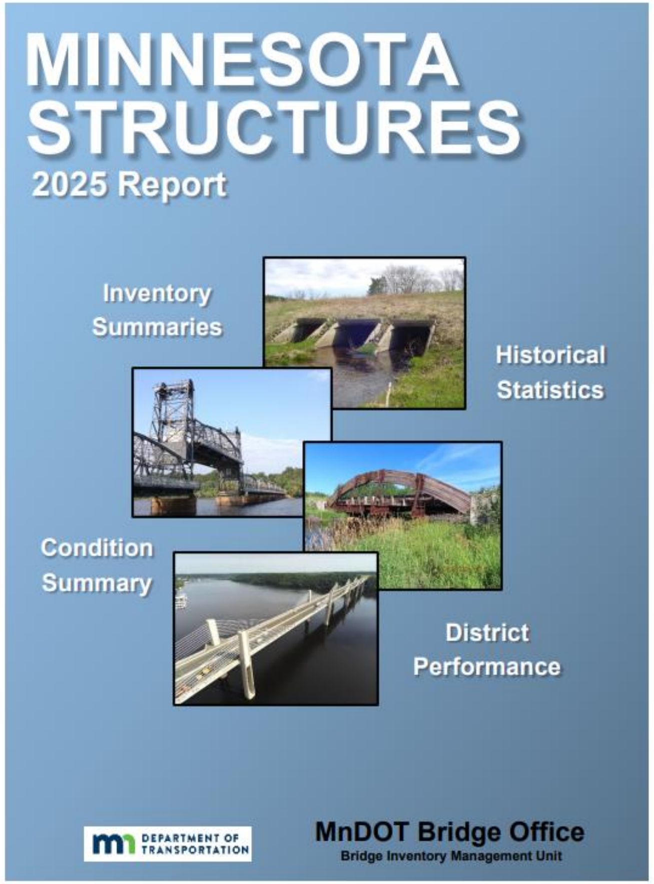
4,453 Trunk Highway Bridges in Minnesota (2025)



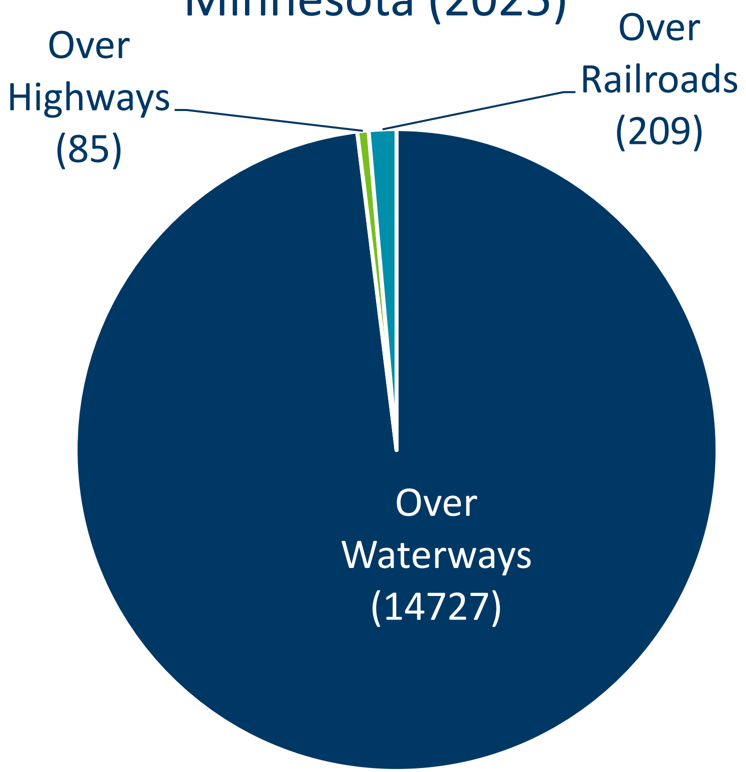
Structures may be counted multiple times due to combination under record codes.



Local Bridges (≥10')



15,261 Local Highway Bridges in Minnesota (2025)



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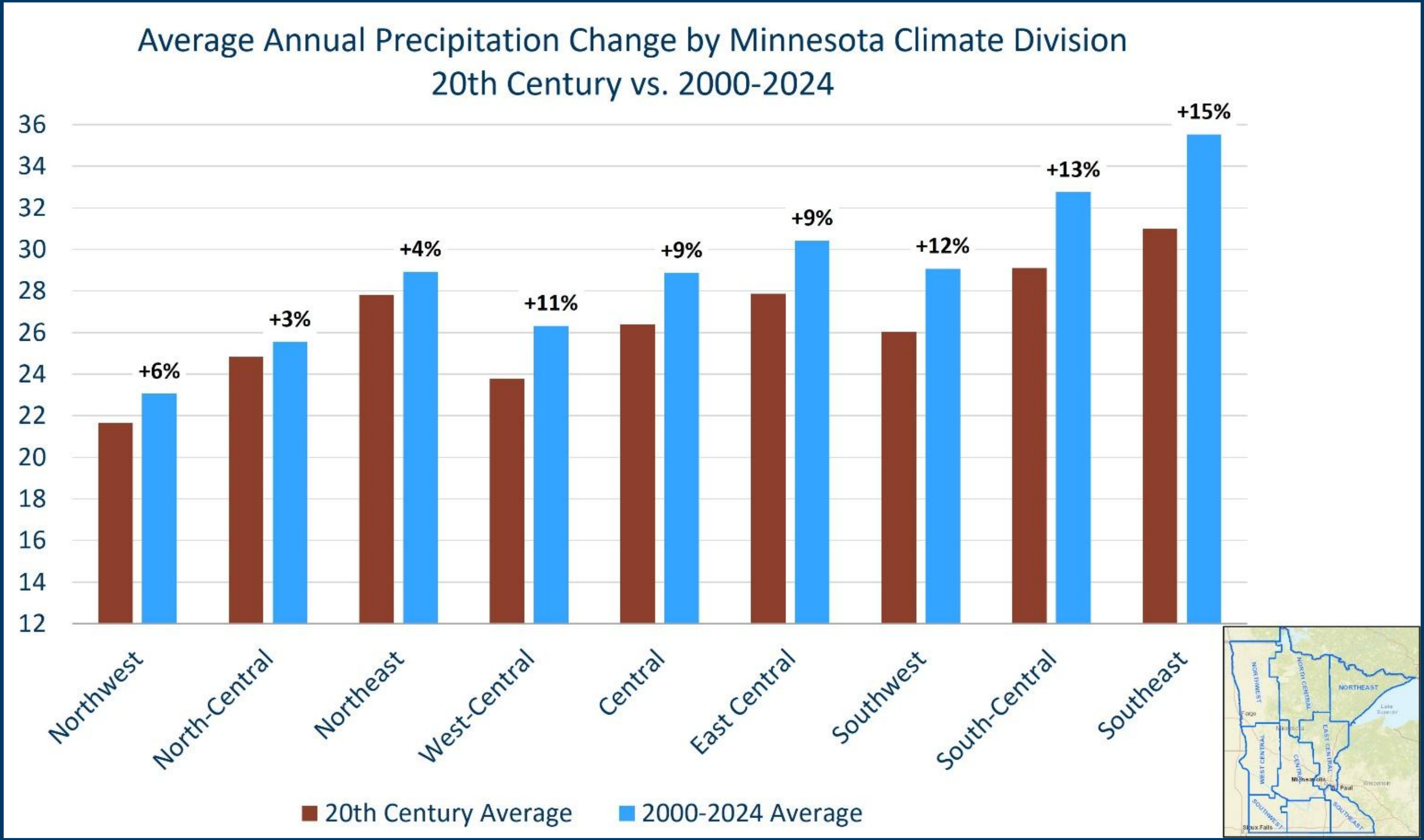
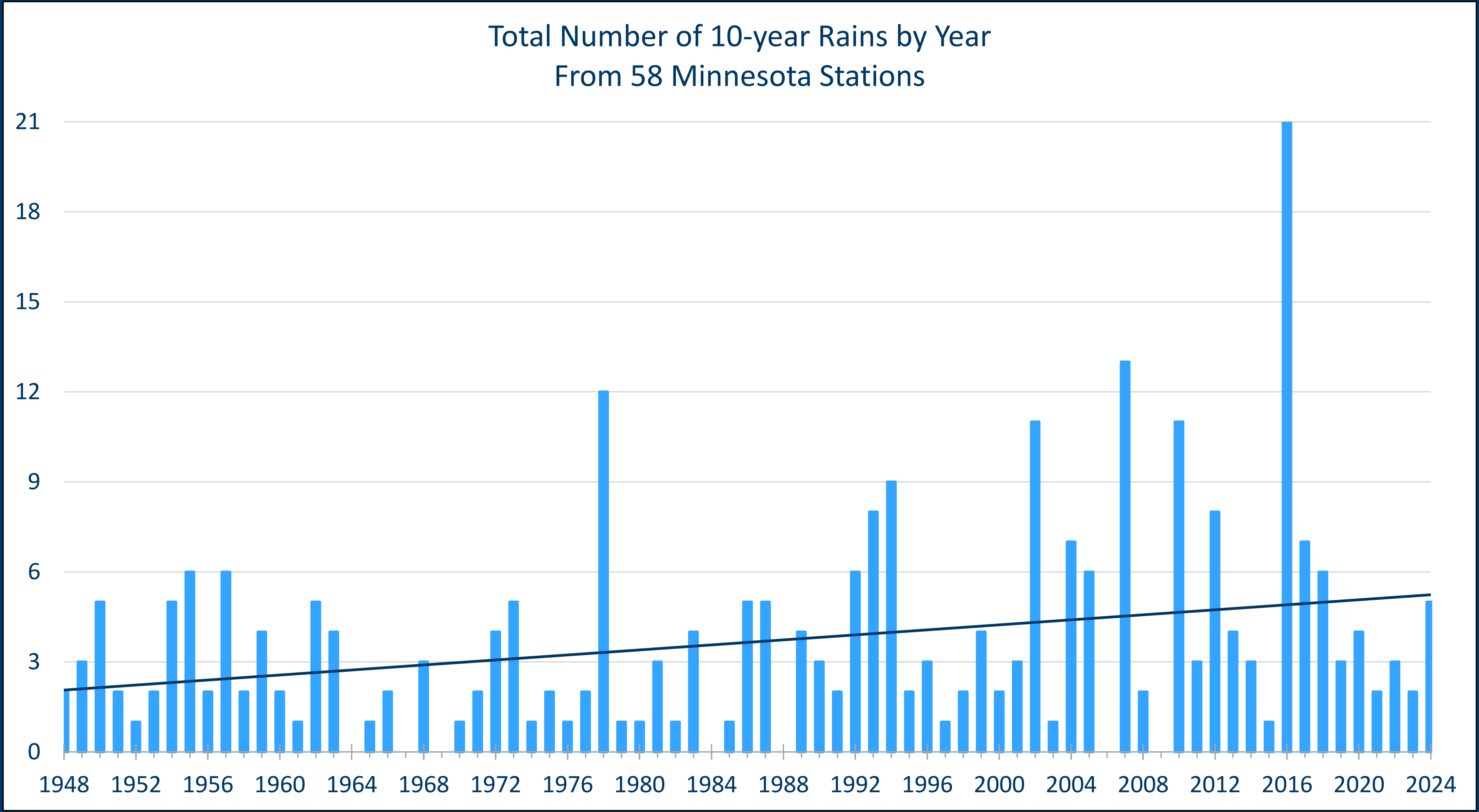


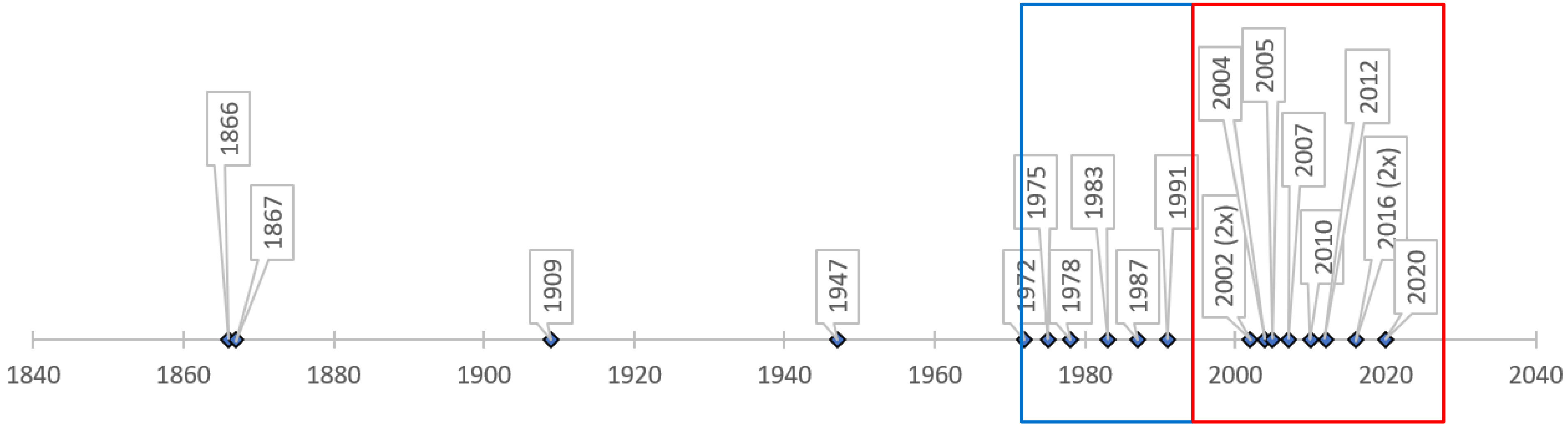
Average annual precipitation change by climate division for 20th century versus 2000-2024. Graph by Minnesota DNR State Climatology Office. Data from NOAA/NCEI, retrieved using DNR Climate Trends tool (https://arcgis.dnr.state.mn.us/ewr/climatetrends/)



Number of “10-year rains”—those that meet or exceed totals associated with 0.10 (10%) annual probability at any of 58 stations with consistent record in Minnesota from 1948 through 2024. Graph by Minnesota DNR State Climatology Office, with data from NOAA/Applied Climate Information System, using thresholds published from station list (option 1b) at https://hdsc.nws.noaa.gov/pfds/pfds_map_cont.html?bkmrk=mn.

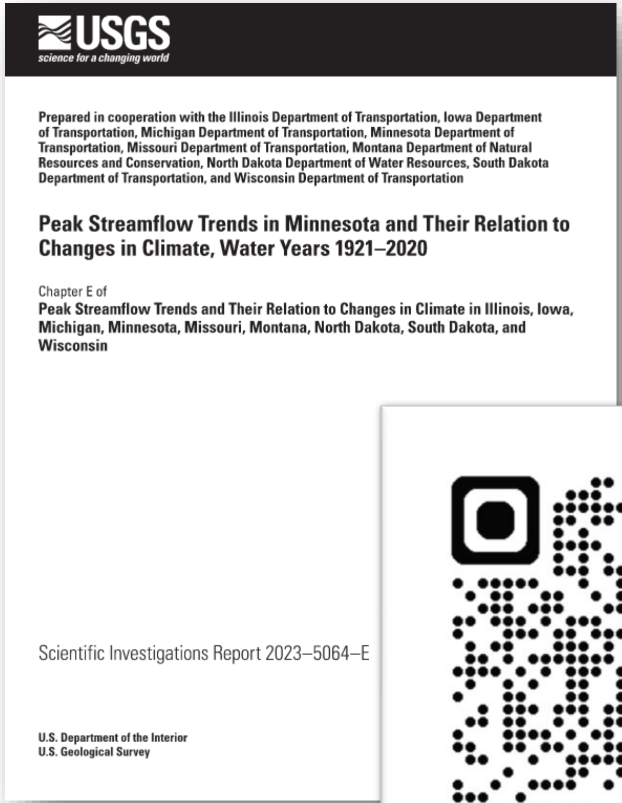
Mega-rain Events in Minnesota

- Mega-rain event = 6” of rain covering >1000 sq. mi. in 24 hours or less, with at least 8”+ of rain at some location
- 16 Mega-rains from 1973 to 2021
  - 5/16 (31%) occurred in the first 26 years (1973-1999)
  - 11/16 (69%) occurred in the most recent 22 years (2000-2021)



USGS Report on Nonstationarity in Peak Streamflow

*“From the onset of the U.S. Geological Survey streamgaging program through much of the 20th century, **the stationarity assumption was widely accepted within the flood-frequency community.** However, in recent decades, better understanding of climatic persistence (extended periods of wet or dry conditions) and concerns about potential climate change and land-use change have caused the stationarity assumption to be reexamined.”*


USGS
science for a changing world

Prepared in cooperation with the Illinois Department of Transportation, Iowa Department of Transportation, Michigan Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Montana Department of Natural Resources and Conservation, North Dakota Department of Water Resources, South Dakota Department of Transportation, and Wisconsin Department of Transportation

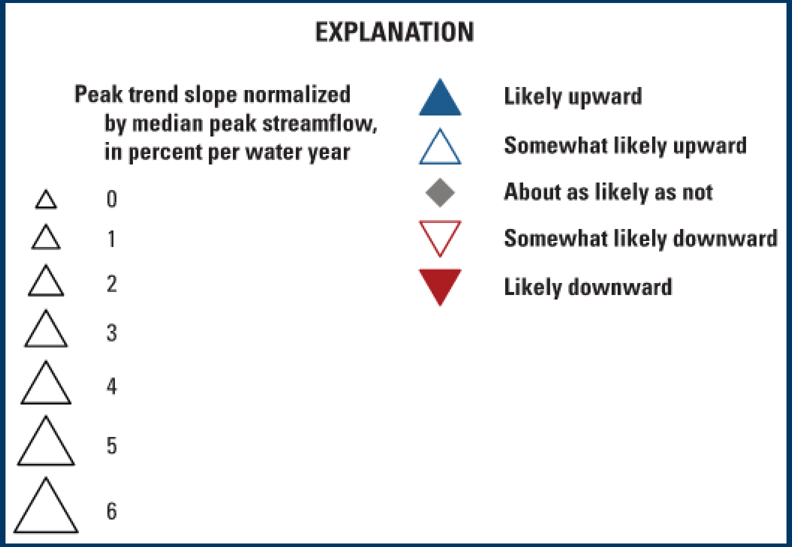
Peak Streamflow Trends in Minnesota and Their Relation to Changes in Climate, Water Years 1921–2020

Chapter E of
Peak Streamflow Trends and Their Relation to Changes in Climate in Illinois, Iowa, Michigan, Minnesota, Missouri, Montana, North Dakota, South Dakota, and Wisconsin

Scientific Investigations Report 2023–5064–E

U.S. Department of the Interior
U.S. Geological Survey

Ryberg, K.R., comp., 2024, Peak streamflow trends and their relation to changes in climate in Illinois, Iowa, Michigan, Minnesota, Missouri, Montana, North Dakota, South Dakota, and Wisconsin: U.S. Geological Survey Scientific Investigations Report 2023–5064, [variously paged], https://doi.org/10.3133/sir20235064.



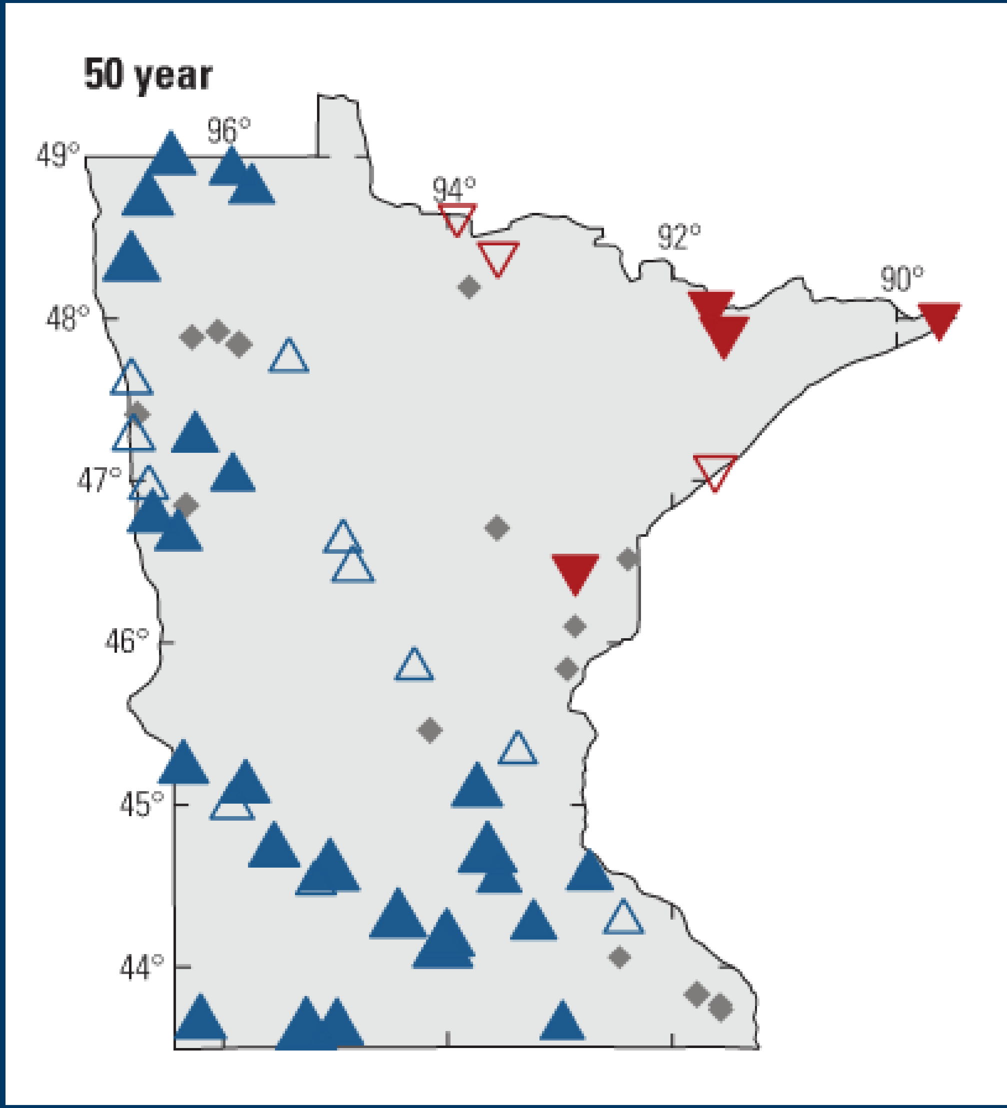


Figure 11. Maps showing likelihood and normalized magnitude of monotonic trends in median annual peak streamflow for streamgages in the 100-, 75-, 50-, and 30-year analysis periods in Minnesota.

Ryberg, K.R., comp., 2024, Peak streamflow trends and their relation to changes in climate in Illinois, Iowa, Michigan, Minnesota, Missouri, Montana, North Dakota, South Dakota, and Wisconsin: U.S. Geological Survey Scientific Investigations Report 2023–5064, [variously paged], https://doi.org/10.3133/sir20235064.


MN 19 at Henderson

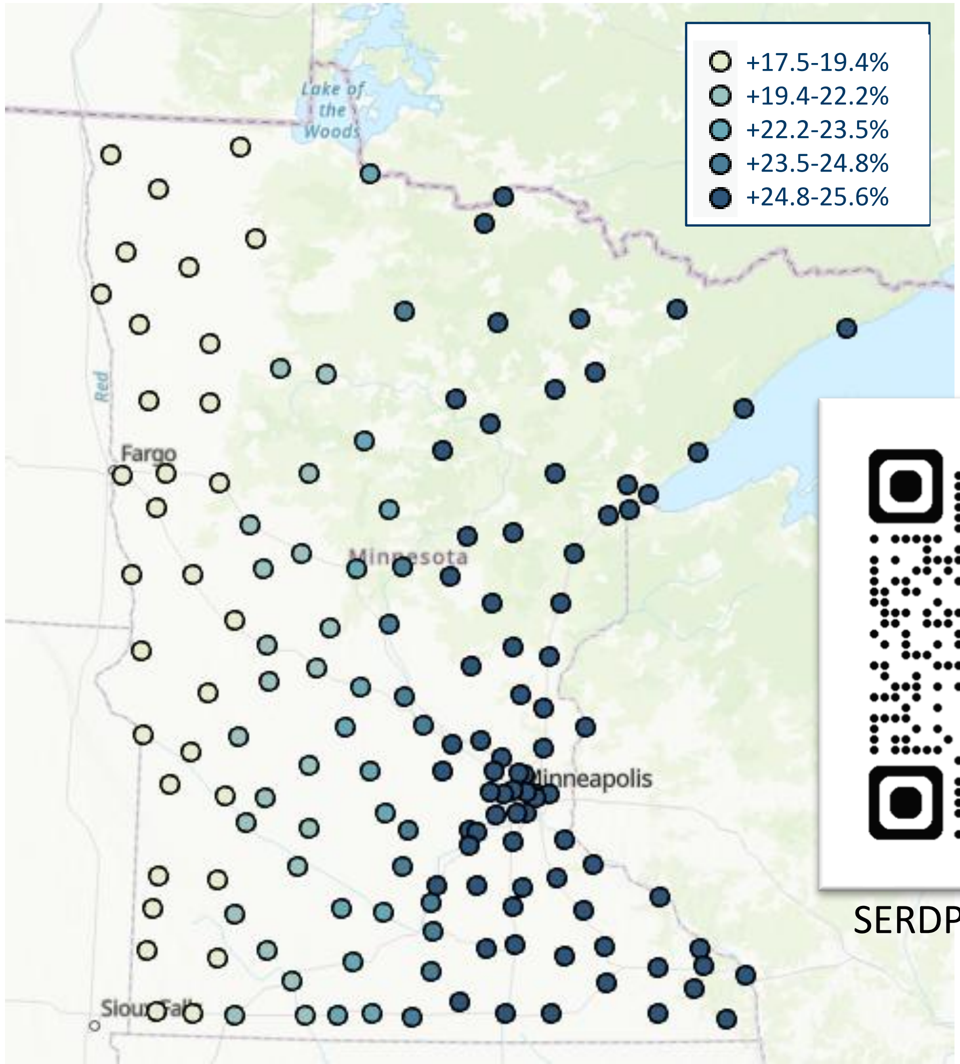

Hwy 76
NWS La Crosse
Money Creek,
southern Winona County
August 19, 2007


Brad Horn
HWY 74 in White
Water State Park, MN
August 20, 2007


MN 30 near Minnesota Lake

Future Precipitation Estimates

- Percent change in 10-year, 24-hour precipitation estimates
- Future year: 2085
- Emissions scenario: RCP 8.5
- Data source: Strategic Environmental Research and Development Program (SERDP/Department of Defense)



SERDP Precipitation Tool

DEPARTMENT OF TRANSPORTATION

MnDOT Flood Resilience Design Guidance

MnDOT’s Commitment to Resilience

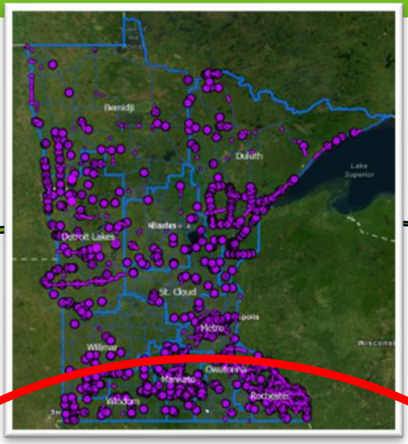
- Statewide plans with flooding identified as significant hazard, expected to increase with climate change:
  - State Hazard Mitigation Plan (2024)
  - Climate Action Framework (2022)
  - State Water Plan (2020)
  - MnDOT Statewide Multimodal Transportation Plan (2022)
  - MnDOT Resilience Improvement Plan (2024)
- Resilience: The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions.

What is “risk”?

Risk = Probability X Consequence

Probability of extreme rains & high stream flows is increasing, but risk doesn’t have to increase too; risk can be managed by minimizing the potential consequence.

TPDP: Resilience in the engineering process



Planning
- Flood event database
- Resilience Improvement Plan

Scoping
- Flood risk data
- TAMS HydInfra

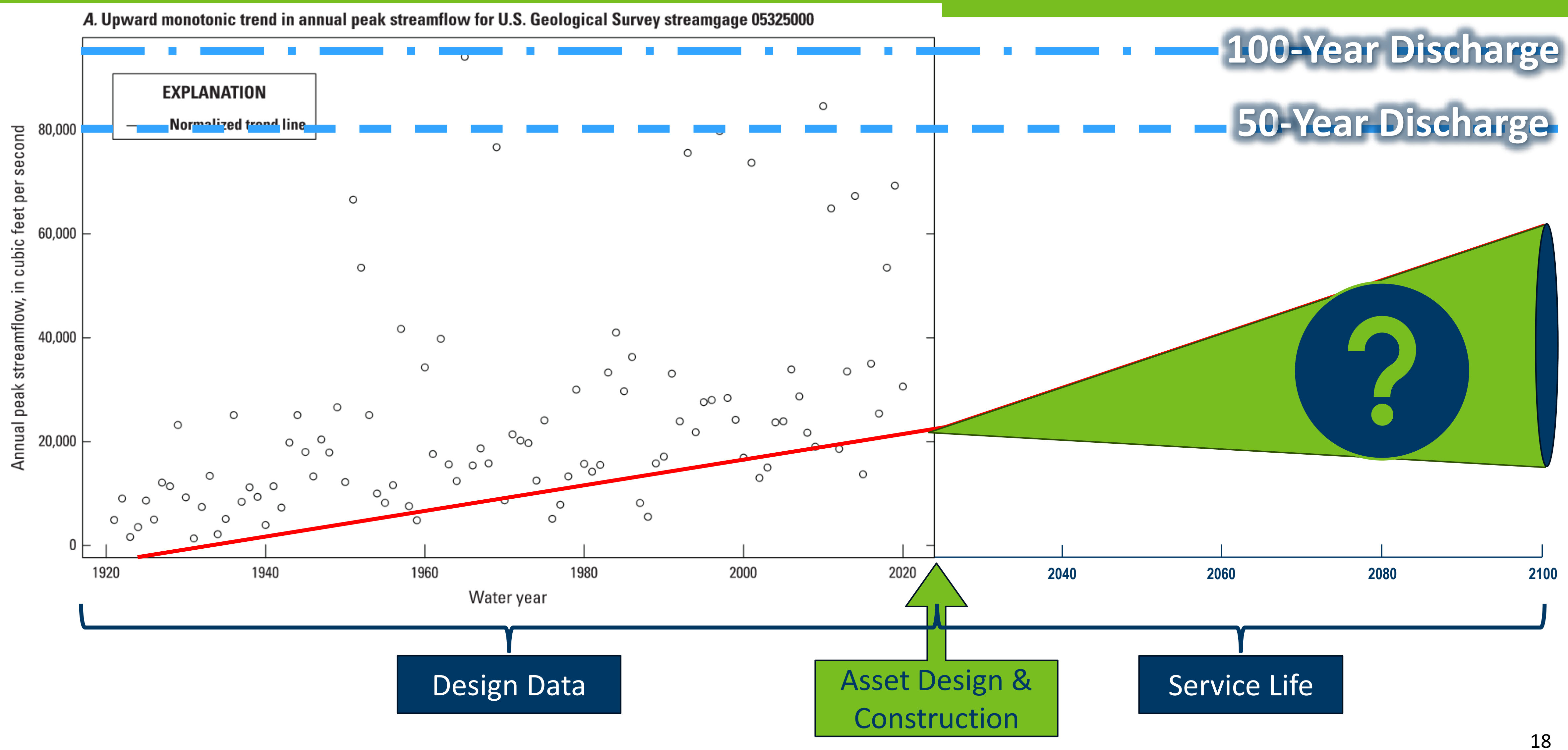
Prelim. Design
- Risk assessments
- Check storm

Final Design
- Design standards
- Adaptive capacity

Construction
- Flood forecasting
- Soil health

O & M
- Flood monitoring
- Data collection

Design Data vs. Service Life Timeframes



MnDOT’s Flood Resilience Design Guidance

- Flood-related background information
- MnDOT’s commitment to resilience
- Resilience throughout the transportation project development process
- Flood resilience design guidance
- Design resources

Scenario Planning: Check Storm

- Evaluate hydraulic performance for a range of conditions
- Check storm added to Chapter 3 of MnDOT's Drainage Manual
  - 100-year event if Q_{design} < 100-yr
  - If Q_{design} = 100-yr, increase by 15%
  - Larger historical event, future precipitation estimates, storm transposition, other methods may be applied
  - Placeholder until future precipitation estimates are adopted

MnDOT's Drainage Manual

Design Process: What's Changing?

Data Collection

Gather information about site (asset data, watershed data, rainfall data, history of flooding).

→

Design Criteria

Determine minimum design criteria.

→

Existing Condition Modeling

Develop hydrology and hydraulic model(s) of system to evaluate existing hydraulic performance, calibrate to past flood event(s).

↓

Proposed Condition Modeling

Modify H/H model to represent the proposed conditions.

→

New: Run the "check storm" event to identify potential flood impacts, then incorporate flood risk mitigation measures if needed.

→

Finalize Recommendations

Prepare final design recommendations to include in construction plans and specifications.

Check Storm Decision-Making

What do the check storm results show?	What should I do about it?
Inlets not meeting spread criteria	No need to add more inlets

"When performing a hydraulic analysis with a check storm, the analysis is not expected to meet all the design criteria, rather the check storm analysis is used to identify whether flood risk mitigation measures should be considered."

What about large culverts & bridges?

- The check storm does not apply to designs based on flow frequency estimates.
- **Hydraulic data form** & **scour confirmation letter** already require designers to evaluate larger floods than design flood:
  - Design flood (50-yr or other based on ADT)
  - Greatest flood (500-yr or overtopping)
  - Basic flood (100-yr)

	Hydraulic Data		
	Mean velocity through structure		ft/s
	Main channel velocity		ft/s
*	Greatest flood (500-year frequency or overtopping –flow listed as multiple of 100 yr event flow)		ft^3/s
[1]	Road sag point elevation		ft
	Design stage (natural condition)		ft
*	Headwater elevation of the proposed structure		ft
	Stage increase of the proposed condition		ft
	Stage increase of the inplace condition		ft
	Minimum overflow area above sag point elevation (FOR overtopping)		ft^2
	Mean overflow velocity		ft/s
	Mean velocity through structure		ft/s
	Main channel velocity		ft/s
	Estimated preliminary pier scour depth		ft
	Estimated preliminary contraction scour depth		ft
[3]	Estimated preliminary total scour at pier elevation		ft
*	Basic flood (100-year frequency)		ft^3/s
	Design stage (natural condition)		ft
*	Headwater elevation of the proposed structure		ft
	Stage increase of the proposed condition		ft
	Stage increase of the inplace condition		ft
	Mean velocity through structure		ft/s
	Main channel velocity		ft/s
	Estimated preliminary pier scour depth		ft
	Estimated preliminary contraction scour depth		ft
[3]	Estimated preliminary total scour at pier elevation		ft
	Approximate flowline elevation		ft
	Skew		°
	Riprap size		

* Items to be shown on grading plan

[1] Location of sag w/ respect to bridge

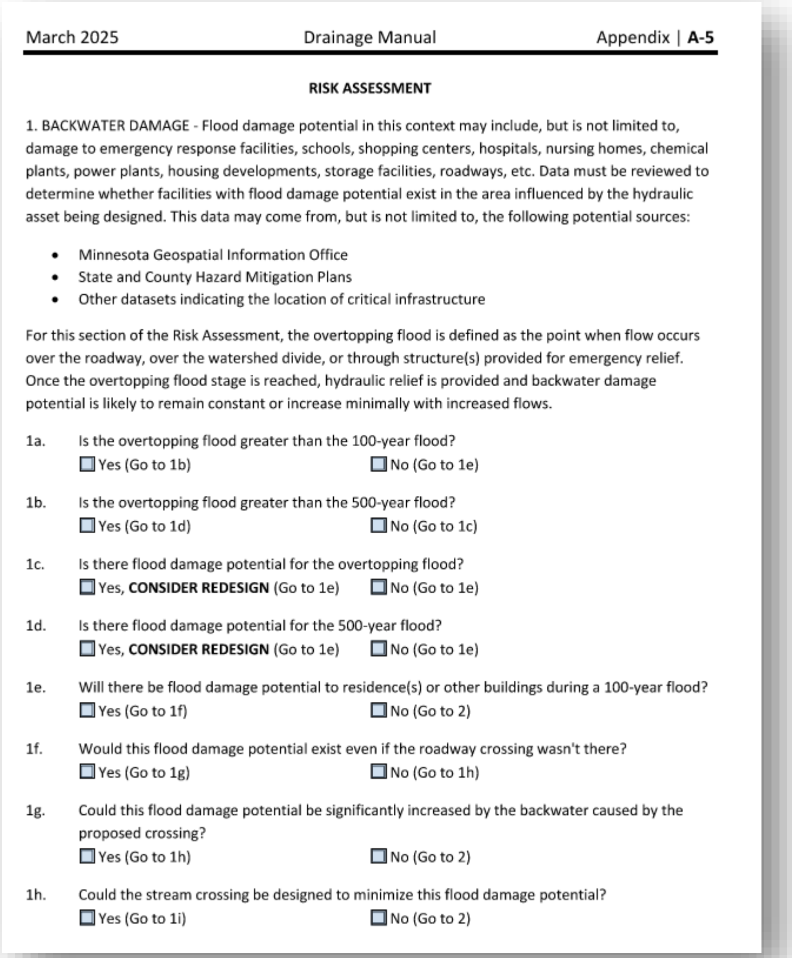
[2] Basis of low member elevation (e.g., matches existing, 3' vertical clearance above 50 yr event, 1' vert clearance above 100 yr event, meets clearance requirements and is equal to or higher than max observed highwater elev. etc.)

[3] Preliminary scour calculations do not include abutment scour. Abutment scour will be included in final scour computations.

What about large culverts & bridges?

- The check storm does not apply to designs based on flow frequency estimates.

- **Risk Assessment** already requires designers to evaluate larger floods than design flood
  - All CL culverts >48” and waterway bridges
  - Q_{design} & $Q_{overtopping}$ & Q_{100} & Q_{500}
  - Backwater damage, traffic-related losses, roadway and/or structure repair costs



March 2025 Drainage Manual Appendix | **A-5**

RISK ASSESSMENT

1. BACKWATER DAMAGE - Flood damage potential in this context may include, but is not limited to, damage to emergency response facilities, schools, shopping centers, hospitals, nursing homes, chemical plants, power plants, housing developments, storage facilities, roadways, etc. Data must be reviewed to determine whether facilities with flood damage potential exist in the area influenced by the hydraulic asset being designed. This data may come from, but is not limited to, the following potential sources:

- Minnesota Geospatial Information Office
- State and County Hazard Mitigation Plans
- Other datasets indicating the location of critical infrastructure

For this section of the Risk Assessment, the overtopping flood is defined as the point when flow occurs over the roadway, over the watershed divide, or through structure(s) provided for emergency relief. Once the overtopping flood stage is reached, hydraulic relief is provided and backwater damage potential is likely to remain constant or increase minimally with increased flows.

1a. Is the overtopping flood greater than the 100-year flood?
☐ Yes (Go to 1b) ☐ No (Go to 1e)

1b. Is the overtopping flood greater than the 500-year flood?
☐ Yes (Go to 1d) ☐ No (Go to 1c)

1c. Is there flood damage potential for the overtopping flood?
☐ Yes, **CONSIDER REDESIGN** (Go to 1e) ☐ No (Go to 1e)

1d. Is there flood damage potential for the 500-year flood?
☐ Yes, **CONSIDER REDESIGN** (Go to 1e) ☐ No (Go to 1e)

1e. Will there be flood damage potential to residence(s) or other buildings during a 100-year flood?
☐ Yes (Go to 1f) ☐ No (Go to 2)

1f. Would this flood damage potential exist even if the roadway crossing wasn't there?
☐ Yes (Go to 1g) ☐ No (Go to 1h)

1g. Could this flood damage potential be significantly increased by the backwater caused by the proposed crossing?
☐ Yes (Go to 1h) ☐ No (Go to 2)

1h. Could the stream crossing be designed to minimize this flood damage potential?
☐ Yes (Go to 1i) ☐ No (Go to 2)

…more about the **updated** Risk Assessment form

- Intended to be used as a decision-making aid, completed initially ***during*** design process, then revised to reflect final design.
- No more references to Least Total Economic Cost (LTEC) design process
- New question that considers increasing risk of extreme storms/floods:

4. Has the project been designed with flood risk mitigation measures to reduce potential damage associated with increasing risk of extreme storms/floods that exceed design event frequency (e.g., provide armoring to protect structure and/or roadway, provide additional flow capacity, incorporate features that can be modified for future adaptation)?

☐ Yes (Go to 5; Describe below) ☐ No, **CONSIDER REDESIGN** (Go to 5)

Summary of how project has been designed with flood risk mitigation measures:

Supporting Resources

MnDOT State Aid Resources

Preliminary plans

Preliminary bridge plan review

- Preliminary bridge plan review process (PDF)
- Preliminary bridge plan review checklist (PDF)
- Minimum Bridge Width Summary Chart (PDF)

Hydraulics

- Hydraulic guidelines (PDF)
- Data tables
  - Bridge (Word)
  - Culvert (Word)
- Bridge scour evaluation procedure (PDF)
- Bridge scour plan of action templates
- 2012 local bridge hydraulics - class 101

MnDOT Bridge State Aid Resources Page

Updated MnDOT Drainage Manual

- Chapter 1 – Introduction *(DONE)*
- Chapter 2 – Pipe Materials *(DONE)*
- Chapter 3 – Hydrology *(DONE)*
- Chapter 4 – Channels and Ditches *(DONE)*
- Chapter 5 – Culverts *(DONE)*
- Chapter 6 – Energy Dissipators *(In Progress)*
- Chapter 7 – Storage Facilities *(In Progress)*
- Chapter 8 – Storm Drainage Systems *(DONE)*
- Chapter 9 – Bridges *(In Progress)*
- Appendix A – Risk Assessment for Encroachment Design *(DONE)*

MnDOT's Drainage Manual

Atlas 15 Overview

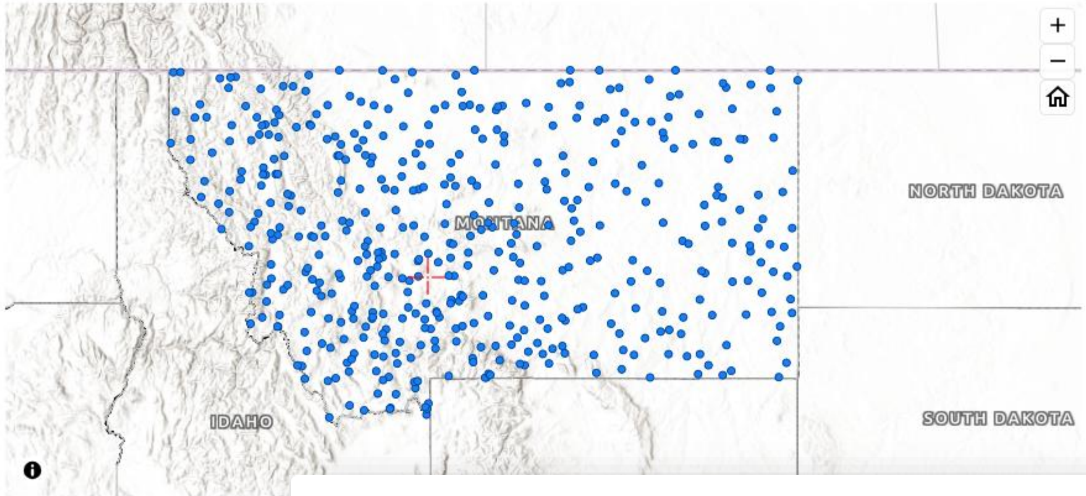
- **Volume 1:** Current/Updated Rainfall Estimates (as of 2023)
  - Anticipating preliminary estimates available in 2026 (?)
- **Volume 2:** Projected Rainfall Estimates
  - Scenario (SSP-245 & SSP-585) or Global Temperature Index (1.5° to 5° C)
  - 2030, 2040, 2050…2100
  - Anticipating this will be released late 2026 or early 2027 (?)

NOAA's Atlas 15 Info Page

Atlas 15 Volume 1

Volume 1
Current Estimates as of 2023

Show Stations



Search Location of Interest

Search Location...

Chart | Table | Supplementary Info

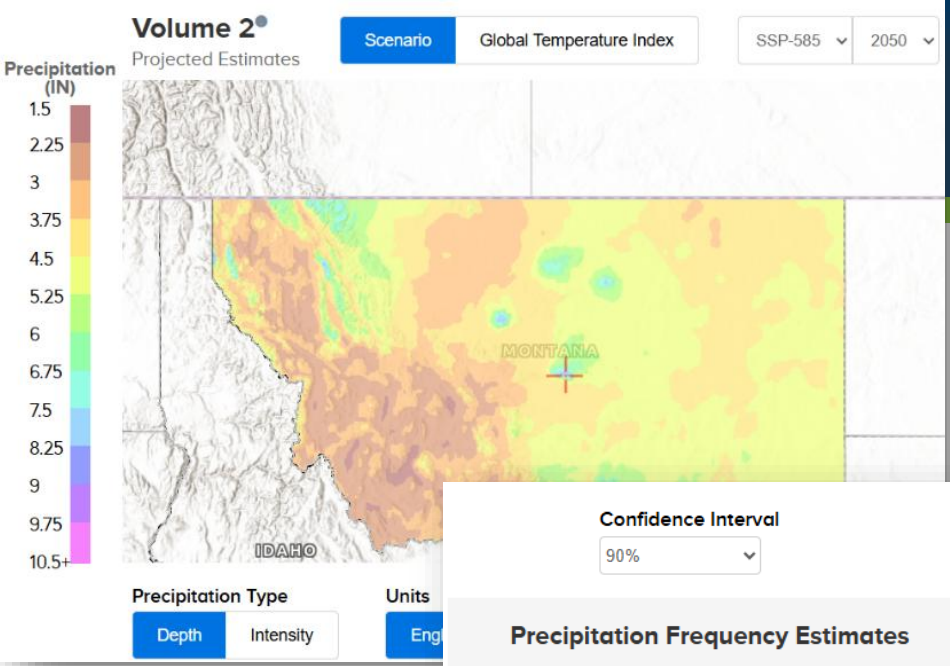
Compare

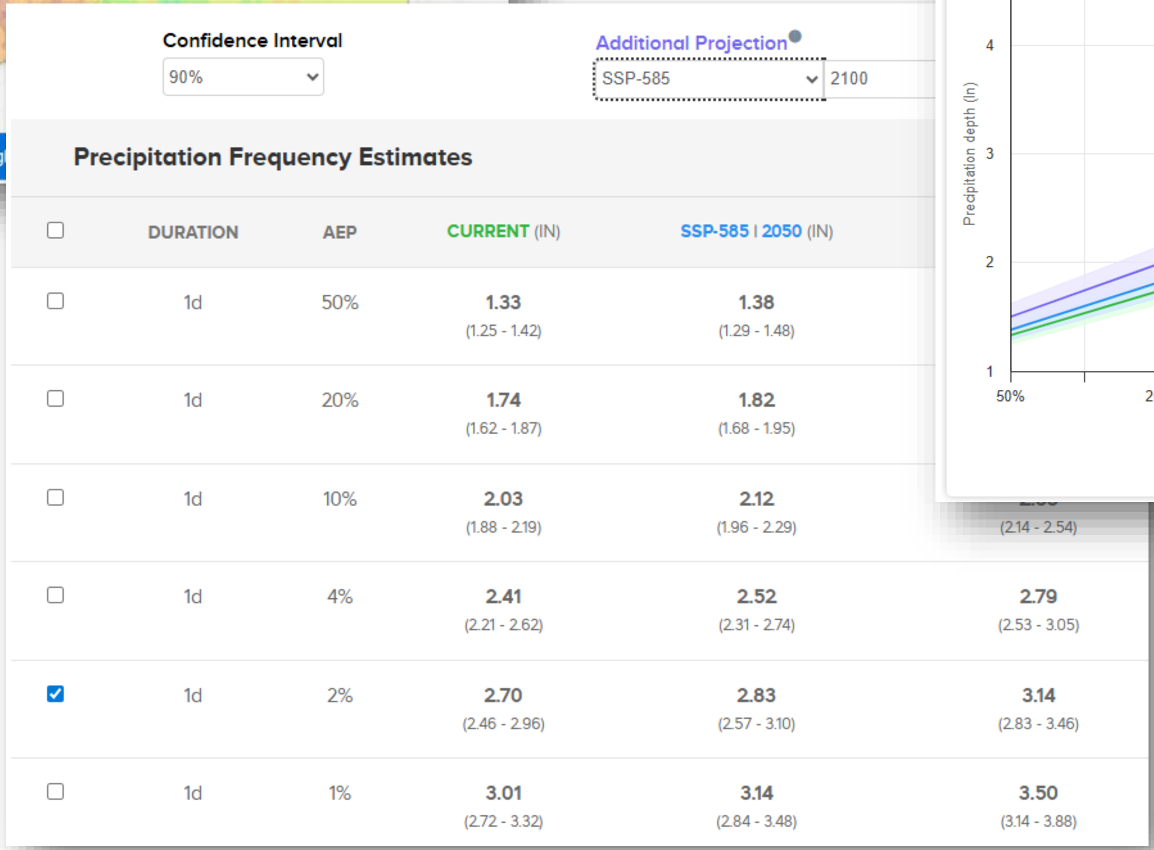
Current AMS-based Precipitation Frequency Estimates (IN) with 90% Confidence Intervals

	Annual Exceedance Probability (%)					
Duration	50%	20%	10%	4%	2%	1%
60 minutes	0.453 (0.413 - 0.496)	0.659 (0.592 - 0.736)	0.829 (0.732 - 0.939)	1.09 (0.945 - 1.26)	1.33 (1.13 - 1.55)	1.59 (1.34 - 1.83)
120 minutes	0.585 (0.538 - 0.634)	0.796 (0.723 - 0.877)	0.957 (0.858 - 1.07)	1.19 (1.05 - 1.35)	1.41 (1.22 - 1.63)	1.66 (1.41 - 1.90)
3 hours	0.685 (0.633 - 0.738)	0.912 (0.832 - 0.997)	1.08 (0.975 - 1.19)	1.32 (1.17 - 1.48)	1.52 (1.33 - 1.74)	1.76 (1.52 - 2.00)
6 hours	0.883 (0.820 - 0.947)	1.15 (1.06 - 1.25)	1.34 (1.22 - 1.46)	1.58 (1.43 - 1.75)	1.78 (1.58 - 1.98)	1.98 (1.76 - 2.24)
12 hours	1.13 (1.06 - 1.21)	1.48 (1.37 - 1.59)	1.71 (1.58 - 1.85)	2.02 (1.85 - 2.21)	2.26 (2.04 - 2.48)	2.50 (2.25 - 2.79)
1 days	1.44 (1.35 - 1.54)	1.88 (1.75 - 2.02)	2.19 (2.03 - 2.37)	2.60 (2.38 - 2.83)	2.91 (2.65 - 3.19)	3.24 (2.93 - 3.57)
2 days	1.78 (1.66 - 1.90)	2.32 (2.15 - 2.50)	2.69 (2.47 - 2.92)	3.18 (2.90 - 3.48)	3.56 (3.22 - 3.92)	3.94 (3.54 - 4.37)

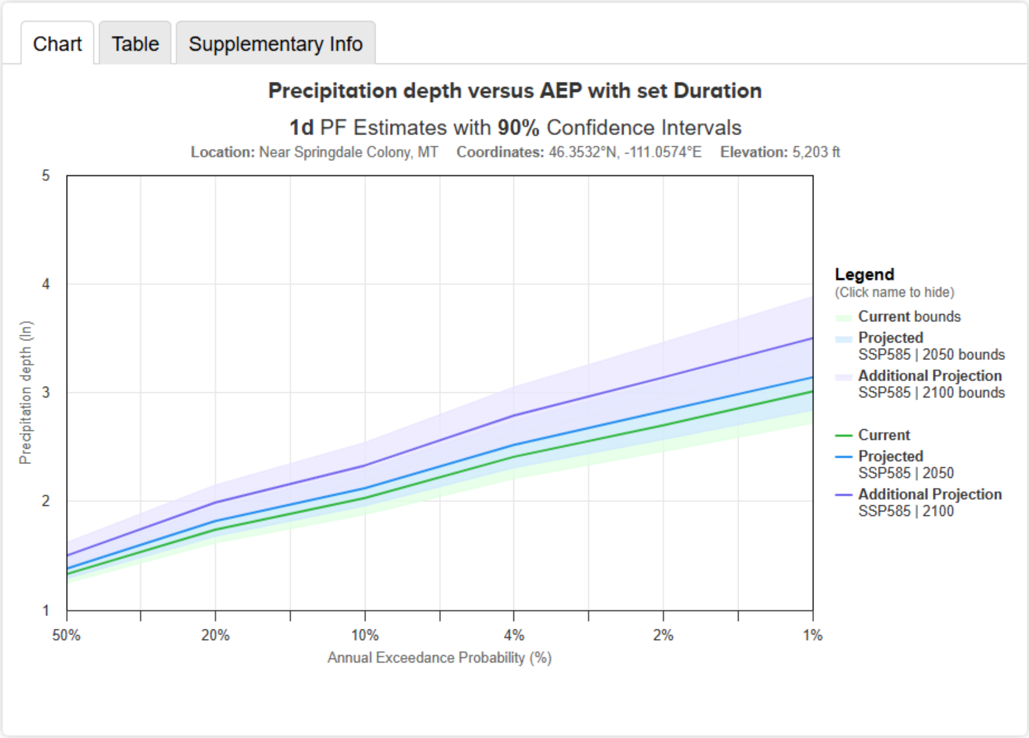
Atlas 15 Pilot over Montana

Atlas 15 Volume 2





	DURATION	AEP	CURRENT (IN)	SSP-585 | 2050 (IN)	
☐	1d	50%	1.33 (1.25 - 1.42)	1.38 (1.29 - 1.48)	
☐	1d	20%	1.74 (1.62 - 1.87)	1.82 (1.68 - 1.95)	
☐	1d	10%	2.03 (1.88 - 2.19)	2.12 (1.96 - 2.29)	(2.14 - 2.54)
☐	1d	4%	2.41 (2.21 - 2.62)	2.52 (2.31 - 2.74)	2.79 (2.53 - 3.05)
☑	1d	2%	2.70 (2.46 - 2.96)	2.83 (2.57 - 3.10)	3.14 (2.83 - 3.46)
☐	1d	1%	3.01 (2.72 - 3.32)	3.14 (2.84 - 3.48)	3.50 (3.14 - 3.88)



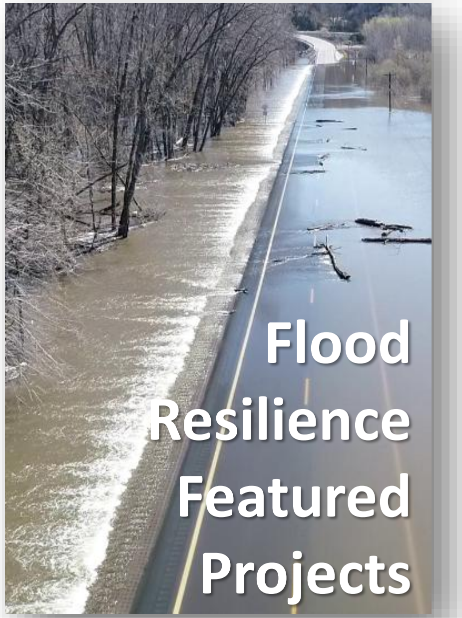
MnDOT's ***anticipated*** Atlas 15 Adoption

- Design event: Atlas 14 → Atlas 15 Volume 1
- Check storm: Current criteria → Atlas 15 Volume 2 (future timeframe & scenario TBD)
- New regionalized IDF curves?
- New rainfall distributions from NRCS to replace MSE distributions?

Design Resources (Coming Soon!)

Design Resource	Primary Application
MnDOT Drainage Manual	Provide a basis for uniform design practice for typical roadway and waterway drainage designs.
MnDOT Flood Event Database	Provide basic information about locations where flooding has been observed within MnDOT right of way.
MnDOT Flood Risk Assessment Tool	Provide a method for designers to evaluate flood risk and compare cost-effectiveness of flood resilience alternatives.
Check Storm Examples	Show how to apply the check storm to a variety of design cases.
Check Storm Assessment Worksheet	Document results of check storm analysis, including anticipated flood risks and resilience strategies that will be implemented with a project.
Flood Resilience Featured Projects	Provide examples of flood resilience projects that have been implemented by MnDOT.

MnDOT's Flood Resilience Website



Summary

- Commitment to providing a safe, functional, and resilient transportation system today and into the future
- Likelihood of extreme rains & high stream flows are increasing; risk doesn’t have to increase
  - Minimizing consequences of flooding by making infrastructure more resilient → minimizing risk of flooding
- Check storm can be applied to identify potential flood consequences, inform designer of need for flood risk mitigation measures
  - Adoption of Atlas 15 Volume I and II

MN Silver Jackets: MN Flood Center Strategic Plan

Participating Agencies

Federal

- Federal Emergency Management Agency (FEMA)
- National Oceanic and Atmospheric Administration (NOAA)
- Natural Resource Conservation Service (NRCS)
  Minnesota | Natural Resources Conservation Service
- U.S. Army Corps of Engineers (USACE)
- U.S. Geological Survey (USGS)

State

- Minnesota Board of Water and Soil Resources
- Minnesota Department of Commerce
- Minnesota Department of Labor and Industry
- Minnesota Department of Natural Resources (MN DNR)
- Minnesota Department of Transportation (MnDOT)
- Minnesota Homeland Security and Emergency Management (HSEM)

- Objectives:
  - ✓ Develop a common mission (purpose & need statement)
  - ✓ Conduct stakeholder engagement
  - ✓ Conduct research and outreach to established flood centers
  - ✓ Identify data and resources currently available within partner agencies
  - ✓ Identify additional data and resources needed to improve flood preparedness, monitoring, response, and recovery in MN
  - ✓ Develop strategic plan and identify potential funding sources
- Partners: USACE (lead), BWSR, DPS/HSEM, MDA, MnDNR, MnDOT, MNIT MnGeo, MPCA, MSU, NWS, UMN, USGS, NRCS, MDH, Met Council

Why the name "Silver Jackets"?

During disaster response, agencies are often identified by the color jacket or shirt they wear. For example, FEMA has typically worn blue jackets or shirts and USACE has worn red. The name 'Silver Jackets' was coined to represent many agencies working together to tackle flooding issues.

Thank you!

Rachel Pichelmann, PE, CFM

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