Watershed-Wide Flood Risk Assessment

Atlas 14 Flood Risk and Resiliency: Phase 2

Prepared for
Nine Mile Creek Watershed District

July 2022

4300 MarketPointe Drive, Suite 200
Minneapolis, MN 55435
952.832.2600
www.barr.com

Contents

List of Tables

List of Figures

List of Appendices, Attachments, or Exhibits

Certification

I hereby certify that this report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Michael McKinney
PE #: 54943

July 12, 2022
Date

Abbreviations

AEP	Annual Exceedance Probability
BCA	Benefit-Cost Analysis
BCR	Benefit-Cost Ratio
DDF	Depth Damage Function
FEMA	Federal Emergency Management Agency
GIS	Geographical Information System
MNDNR	Minnesota Department of Natural Resources
MNDOT	Minnesota Department of Transportation
NMCWD	Nine Mile Creek Watershed District
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
QAQC	Quality Assurance & Quality Control
ROI	Return on Investment
ROW	Right of Way
TAC	Technical Advisory Committee
TP-40	Technical Paper 40
USDA	United States Department of Agriculture
WOMP	Watershed Outlet Monitoring Program

1 Project Introduction and Background

The Nine Mile Creek Watershed District (NMCWD) has a long history in flood planning and floodplain management going back to the 1960s. The NMCWD's Water Management Plan identifies several policies and actions related to reducing risk to public safety and permanent structures from flooding, including working with cities to address increased flood potential from Atlas 14 rainfall frequency estimates and understanding and addressing the potential for increased flood risk due to predicted changes in climate.

In 2020, the Nine Mile Creek Watershed District hired Barr Engineering Co. (Barr) to conduct a watershed-wide review of flood risk to better understand and characterize flood potential under existing conditions and with consideration for our changing climate. The overall project was split into several phases. Under the first phase of the project (Phase 1), Barr updated the NMCWD's watershed-wide hydrologic and hydraulic model in XPSWMM to incorporate recent model updates completed by several member cities (Edina, Bloomington, Richfield, and Minnetonka) and refine other areas of the model (Eden Prairie and Hopkins) (Barr, 2021).

With the completion of Phase 1 in early 2021, NMCWD approved the scope of work for Phase 2 of the Atlas 14 Flood Risk and Resiliency study: *Watershed-wide Flood Risk Assessment*. Aligning with NMCWD Water Management Plan policies related to risk reduction and addressing increased flood risk due to predicted changes in climate, the major goals of Phase 2 were to (a) perform a watershed-wide flood risk assessment to help NMCWD, its communities, and other partners gain a better understanding of flood risks throughout the watershed under current precipitation estimates and future climate change projections, (b) characterize the risk of flooding from systems failures, such as culvert failure, along the creek system, and (c) to develop a framework for evaluating flood mitigation projects. To accomplish the goals of Phase 2, the following major work tasks were completed to further refine the model, evaluate climate change projections, and quantify flood risk throughout the watershed:

- Task 1. Simulate rainfall events (100-year snowmelt and Atlas 14 events, and mid-21st century rainfall estimates) and identify flood-prone structures and roadways (Section 2)
- Task 2. Update model calibration (Section 3)
- Task 3. Stakeholder review of model results and flood inundation mapping (Section 4)
- Task 4. Quantify potential flood damage costs (Section 5)
- Task 5. Risk analysis for potential pipe failures or clogging at creek crossings (Section 6)
- Task 6. Development of a framework for evaluating potential flood mitigation and/or resilience projects along the Nine Mile Creek corridor or in upland areas (Section 7)

This report summarizes the methodology and results for each of the tasks and identifies conclusions and next steps moving into Phase 3 of the project.

2 Model Updates & Climate Change Evaluation

The NMCWD watershed-wide XPSWMM model described in the Phase 1 technical memorandum (Barr, 2021) was developed to model NOAA Atlas 14 precipitation frequency estimates (Perica et al., 2013) up to the 100-year, 24-hour event. Atlas 14 precipitation frequency estimates serve as an update to the U.S. Weather Bureau's Technical Paper 40 (TP-40) published in 1961 (NWS, 1961) and were developed using a longer, more-current rainfall record. Atlas 14 rainfall depth estimates for the 100-year recurrence interval are significantly higher than TP-40 estimates in the Twin Cities areas (e.g., the Atlas 14 100-year, 24-hour cumulative rainfall depth is nearly 25% greater than the TP-40 estimate for the same duration and recurrence interval). While greater than TP-40, Atlas 14 estimates are not reflective of future climate change, as precipitation frequency estimates are entirely based on the existing rainfall record.

To align with NMCWD's goal of understanding and addressing the potential for increased flood risk due to predicted changes in climate, Phase 2 included evaluating flood potential for a rainfall event that reflects future climate change projections, in addition to Atlas 14 precipitation frequency estimates. The following subsections outline rainfall events evaluated, related model updates and quality assurance / quality control (QAQC) measures, and identification of potentially impacted roadways and structures.

2.1 Precipitation Events Evaluated

Precipitation events evaluated to represent existing conditions (Atlas 14) and a future, mid-21st century estimate are outlined in Table 2-1. Currently, the available information regarding locally-downscaled future precipitation estimates is limited. The Michael Simpson and Latham Stack study on long-term extreme weather trends in the Twin Cities area (Simpson et al., 2014) indicates mid-century 100-year and 10-year, 24-hour rainfall estimates of 10.2 and 6.6 inches, respectively, under moderately optimistic greenhouse gas emission scenarios. These estimates were used to inform the selection of a precipitation event to represent mid-21st century precipitation frequency estimates. As outlined in Table 2-1, Atlas 14 precipitation frequency estimates with cumulative depths similar to depths predicted in the Simpson and Stack study were used to approximate mid-21st century precipitation predictions. This approach, developed in consultation with NMCWD staff, Board of Managers (Board), and the technical advisory committee (TAC), was taken so that all modeled precipitation events could be related directly to Atlas 14 annual exceedance probabilities (AEP). Using this approach, the Atlas 14 500-year, 24-hour event was modeled to represent a mid-21st century 100-year, 24-hour precipitation event and the Atlas 14 50-year, 24-hour event was used to represent a mid-21st century 10-year, 14-hour precipitation event.

In addition to the 24-hour rainfall events modeled, a 100-year, 10-day snowmelt runoff event was modeled to evaluate the effects of significant snowmelt, or combination of snowmelt and springtime rain events. Hydrologic conditions in the model were manipulated to reflect frozen soil conditions. Comparing high water levels from the 100-year, 24-hour rainfall event to the 100-year, 10-day snowmelt event, the snowmelt event is often "critical" (i.e., the event the produces the highest maximum water surface elevation for a given return interval) in landlocked basins and basins with limited outflow capacity (e.g., basins with low-capacity outlets).

Table 2-1 Precipitation events evaluated

Model Condition	Return Interval	Duration	Cumulative Depth (in)[1]	Precipitation Distribution	Source
Existing Conditions	1-year	24-hour	2.49	MSE3	Atlas 14
	2-year	24-hour	2.86	MSE3	Atlas 14
	5-year	24-hour	3.57	MSE3	Atlas 14
	10-year	24-hour	4.27	MSE3	Atlas 14
	50-year	24-hour	6.38	MSE3	Atlas 14
	100-year	24-hour	7.47	MSE3	Atlas 14
	100-year snowmelt	10-day	7.2	NEH[2]	TR60[3]
Mid-21st Century	10-year[4] (50-year AT14)	24-hour	6.38	MSE3	Atlas 14[4]
	100-year[4] (500-year AT14)	24-hour	10.5	MSE3	Atlas 14[4]

1 Atlas 14 precipitation depths from NMCWD centroid. NOAA Atlas 14 Volume 8 Version 2. Latitude: 44.8718°; Longitude: -93.3762°

2 NEH: National Engineering Handbook (USDA, 1997).

3 TR60: USDA Technical Release No. 60 (USDA, 1985).

4 AT14: Atlas 14. The 24-hour Atlas 14 events closest to the mid-century moderate estimates (Simpson et al., 2014) were used to approximate the mid-century events: mid-century moderate 100-year and 10-year estimate = 10.2- and 6.6-inches, respectively. The Atlas 14 events selected to approximate the mid-century events are the 500-year (10.5 inches) and 50-year (6.38 inches), respectively.

2.2 Model Updates and Results

The Phase 1 NMCWD XPSWMM model was used to simulate all precipitation events described in Section 2.1. During large precipitation events, runoff can fill storage areas, overtop embankments and roads, and access new overflow pathways. For this reason, modeling of the largest precipitation events (i.e., the Atlas 14 500-year frequency precipitation and 100-year frequency snowmelt events) required model modifications to capture excess runoff, raise overflow elevations, and convey excess runoff. Additional storage areas and overland runoff conveyances were defined using the Minnesota Department of Natural Resources (MNDNR) 2011 LiDAR elevation dataset and other best-available surface elevation datasets.

After capturing excess volume model-wide, QAQC was performed to verify hydrologic and hydraulic input parameters and evaluate model hydrologic and hydraulic stability. Additionally, flood inundation mapping was reviewed watershed-wide to evaluate overflow modeling and verify appropriate overland flow conveyances were incorporated into the model.

A Mapbook showing flood inundation results and potential roadway impacts is included in Appendix A. Results presented were developed from the final, calibrated model (see Section3). Note that the 100-year flood inundation extents reflect the "critical" flood elevation (the higher maximum water surface elevation from the 100-year, 24-hour rainfall and 100-year, 10-day snowmelt events).

As part of the modeling analysis, potential structure and roadway impacts were identified using a Geographical Information System (GIS). The potential structure and roadway impacts are based solely on 2011 LiDAR elevation data and best-available structure and roadway location data. Model and mapping data sources reflect best-available data as outlined in the Phase 1 technical memorandum (Barr, 2021). Potential flood inundation impacts do not reflect surveyed structure low-entry elevations or road surface elevations. For these reasons, model results represent "potential" impacts of Atlas 14 and mid-century precipitation event modeling. Given the uncertainty in data accuracy, the Mapbook showing flood inundation results does not include identification of potential impacts to structures.

3 Model Calibration

Model calibration is the process of adjusting modeling hydrologic and hydraulic parameters to improve prediction of a monitored event (e.g., monitored stream flow during a monitored rainfall event). Performing model calibration improves the accuracy of model results and helps increase confidence that model parameters and results are representative of hydrologic and hydraulic conditions within the watershed.

As part of Phase 2 of the watershed-wide flood risk assessment, NMCWD requested that Barr recalibrate the NMCWD XPSWMM model. Prior to 2021, the NMCWD XPSWMM model had not been calibrated since 2005 during original model development. Similar to the 2005 calibration effort, the NMCWD model was calibrated to flow monitoring data collected at four Watershed Monitoring Outlet Program (WOMP) stations along Nine Mile Creek. Using the WOMP data collected by NMCWD and the Metropolitan Council (Met Council), Barr calibrated the XPSWMM model to three separate rainfall events from both 2019 and 2020. The model calibration process and results are summarized in a technical memorandum prepared by Barr and included as Appendix B of this report.

4 Stakeholder Review of Model Results

Stakeholder review was completed to solicit feedback and input from local and regional agencies with institutional knowledge of flooding within jurisdictions throughout the watershed. Draft flood inundation and potential impact results where shared with NMCWD staff, Board, and the TAC (i.e., "stakeholders") at meetings held in August of 2021. TAC members were asked to review key areas of flooding. Specifically, stakeholders were asked to review key areas of inundation within their respective jurisdictions to evaluate whether the flood inundation extents appear correct (i.e., does flooding shown match institutional knowledge of flood prone areas) and if the mapping is missing areas of known flooding.

Table 4-1 provides a summary of review comments provided by TAC members and outlines how comments were incorporated into the final NMCWD Phase 2 XPSWMM model.

Table 4-1 Summary of stakeholder review comments received

Organization	Response Provided?	Summary of Comment Review and Inclusion	Incorporated?
Bloomington	Yes	Provided comments asking for additional resolution in portions of the watershed near Bush Lake, review of divides along TH 169 and I-494 interchanges, inclusion of several new development projects, and review of missing inundation areas.	Yes: Barr added higher degree of resolution in areas tributary to Bush Lake, incorporated select developments, and reviewed highway areas.
Eden Prairie	Yes	Provided questions regarding areas of no known flooding and highlighted areas of recent projects and redevelopment (e.g., construction of a berm to protect home, construction of culvert upgrade project).	Yes: Barr incorporated the culvert upgrade project near BL-28D and evaluated all other provided comments. Model updates were made for select comments based on availability of data.
Edina	Yes	Responded that review is complete: no comments.	NA (no comments).
Hennepin Co.	Yes	Provided comments asking Barr to review flooding along several bridges and to confirm mapped flood inundation extents in specific locations.	Yes: Barr removed bridge overpasses from mapped inundation areas along county and MnDOT ROWs and incorporated other review comments.
Hopkins	Yes	Responded that review is complete: no comments.	NA (no comments).
Minnetonka	Yes	Responded that review is complete: no comments.	NA (no comments).
Richfield	Yes	Provided comments asking for resolution matching existing Richfield PCSWMM model inundation.	Yes: Barr updated modeling to reflect a higher subwatershed resolution in portions of Richfield.
MnDOT	No	NA (no comments provided)	NA (no comments).

5 Quantifying Potential Flood Damage Cost

Characterizing and quantifying potential flood damage costs are critical to understanding flood risk and evaluating the benefit of proposed flood mitigation projects. While several tools exist to evaluate potential flood damage cost at the scale of individual structures (e.g., the Federal Emergency Management Agency's (FEMA's) Benefit Cost Analysis (BCA) tool), there are fewer examples of tools or methodologies developed to evaluate flood damage at the scale of large watersheds (e.g., the scale of the NMCWD).

Working in consultation with NMCWD staff, Board, and TAC, Barr developed a methodology to evaluate flood damage cost using (a) geospatial structural data and surface elevation data, (b) flood inundation mapping results, and (c) FEMA-based depth damage function (DDF) curves to estimate annualized structural flooding damage costs for all potentially flood impacted structures in the watershed. The following subsections provide an overview of the methodology used to estimate potential flood damage costs, outline key assumptions and limitations of the analysis, and provide a summary of watershed-wide estimated direct flood damage costs.

5.1 Modes of Structural Flood Damage

Flooding and prolonged inundation can cause property damage to structures through a variety of modes of flood damage. The list below outlines three common modes of structural flood damage caused by flooding and routine inundation. The list below is not comprehensive of all potential modes of structural flood damage:

- **Direct flood impacts**: flood damage caused by inundation which overtops the structure foundation block and/or enters the structure through a low-entry point (e.g., window well, walkout basement entrance, etc.).
- **Indirect flood impacts**: flood damage caused by inundation and soil saturation against foundations (e.g., water infiltration through foundation cracks and joints, damage from hydrostatic pressure on foundations, etc.).
- **Sanitary sewer impacts**: flood damage caused by sanitary sewer backups (e.g., basement flooding in one structure causing sanitary sewer backups in neighboring structures).

Flood damage costs estimated for this study consider only "direct flood impacts" to structures, as estimating other modes of impact (e.g., indirect and sanitary flood risk impacts) was not reasonably feasible at the watershed scale given the project budget and limited availability of detailed information (e.g., basement elevations, sanitary sewer connection information, etc.). Watershed-wide flood damage costs summarized in this report also do not consider flood damage to non-structures, such as roads, critical infrastructure, and utilities. For these reasons, flood damage cost estimates provided in this report should be limited to use for comparative analysis of flood inundation impacts and for high-level evaluation of flood mitigation alternatives (see discussion in Section 5.3).

5.2 Direct, Annualized Flood Damage Cost Methodology

Barr developed a methodology to estimate an annualized, direct flood damage cost for all potentially impacted structures within the Nine Mile Creek watershed. The methodology utilizes (a) geospatial structure data and surface elevation data, (b) flood inundation mapping results, and (c) FEMA-based DDF curves. DDF curve methodology, including the curves themselves and standard flood damage cost assumptions, was developed from review of the FEMA BCA tool (FEMA, 2020) and a methodology for estimating structural flood depth was developed based on a method developed by Barr for the Edina Flood Risk Reduction Strategy (Edina, 2020). The following steps outline the methodology used to develop an annualized flood damage cost for each potentially impacted structure. Key assumptions are highlighted within each step:

1. Generate flood elevations for all modeled Atlas 14 return intervals (1-, 2-, 5-, 10-, 50-, 100-, and 500-year, 24-hour rainfall events: see Table 2-1).
2. Assign flood elevations to each potentially impacted structure (see example in Figure 5-1). When a structure was impacted from multiple inundation areas, the inundation area resulting in the greatest flood damage cost was utilized.
3. Assign flood depths (i.e., depth relative to low entry elevation) to each potentially impacted structure (see example in Figure 5-1).
    - **Key assumption**: low entry elevations were approximated based on the minimum apparent elevation along the structure outline as determined from 2011 MNDNR County LiDAR. Assumptions could be improved by obtaining surveyed low entry elevations for impacted structures.
4. Calculate the combined flood damage cost to structure and personal property associated with each flood depth for each return interval (Figure 5-2).
    - **Key assumption**: a modified version of the FEMA 1 story (no basement) DDF curve (FEMA, 2020) (Figure 5-2) was utilized to generate flood damage costs as a function of flood depth for all structures. Modification: no flood damages were applied to flood depth values less than 0 feet. The FEMA 1 story (no basement) curve was selected as the curve is similar to curves for a variety of non-residential structure types (e.g., light industrial, office, apartment, etc.).
    - **Key assumption**: several default assumptions from the FEMA Benefit-Cost Analysis Toolkit: Version 6.0 were utilized to estimate flood damage costs, including building replacement value ($100/square foot) and personal property contents value (50% of building replacement value).
    - **Key assumption**: for residential structures, the entire structure footprint was used to calculate structure replacement value. For non-residential and other large structures (>6,000 square foot footprint area), only the structure area overlapped by inundation was used to estimate the structure replacement value. This was done to avoid overestimating flood damage costs for large, non-residential structures where only a portion of the structure is likely to be impacted by inundation.
5. Calculate the annualized flood damage cost. Annualized flood damage was calculated by integrating combined damage over the annual exceedance probability (AEP) (Figure 5-2).

Annualized flood damage cost estimates are useful for comparative analysis of flood damage for flood prone areas throughout the watershed. Additionally, annualized flood damage cost estimates can be used to evaluate the benefit cost ratio (BCR) of proposed flood mitigation alternatives (see further discussion in Section 5.3).

- **Key assumption**: To avoid weighting the calculation of annualized flood damage cost by the lower return interval events, flood damage costs from the 1- and 2-year event were not utilized in the calculation of annualized flood damage.

The following section (Section 5.3) provides a summary of watershed-wide annualized flood damage cost estimates and provides a detailed discussion of results of the analysis and related recommendations.

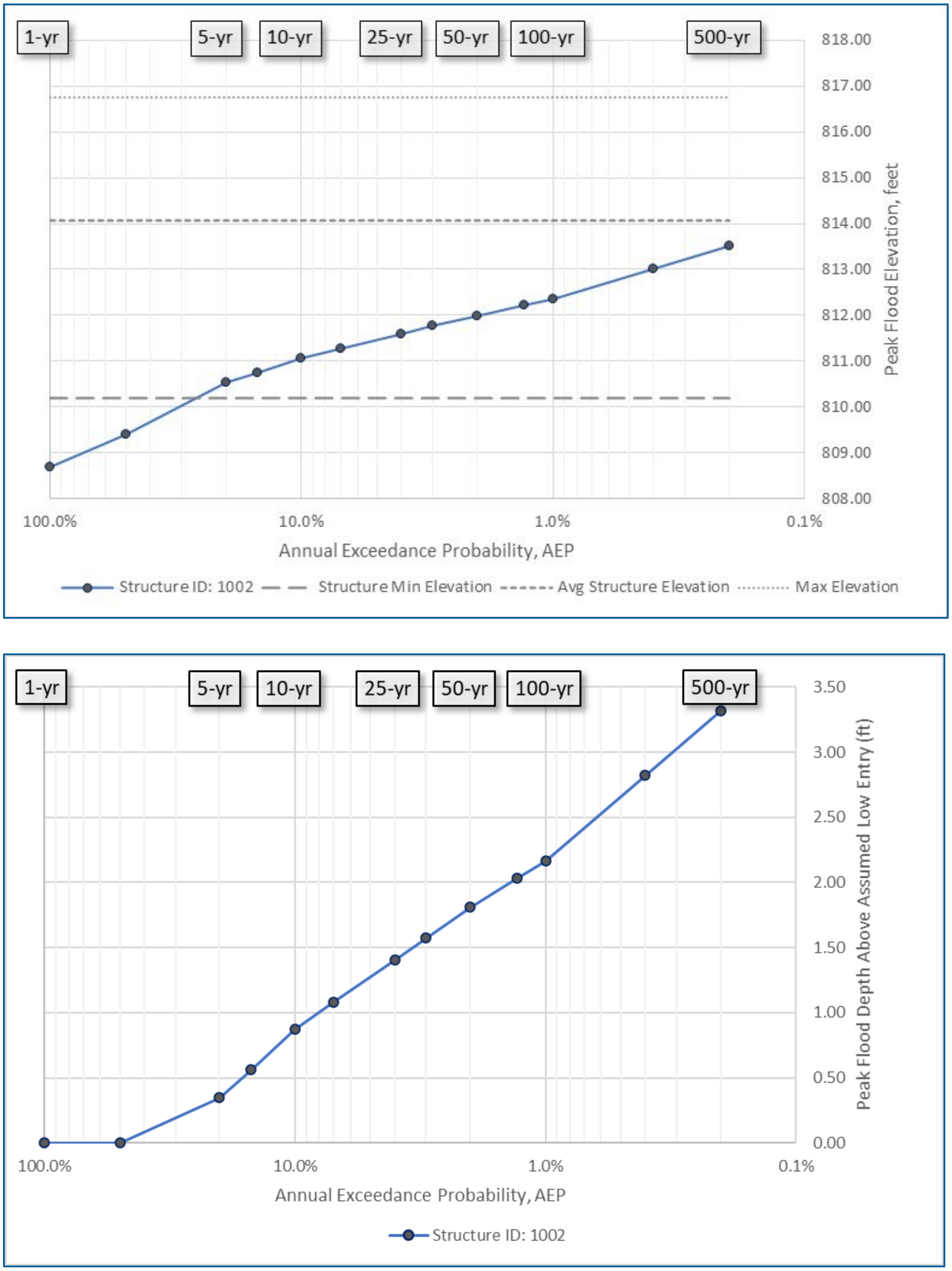
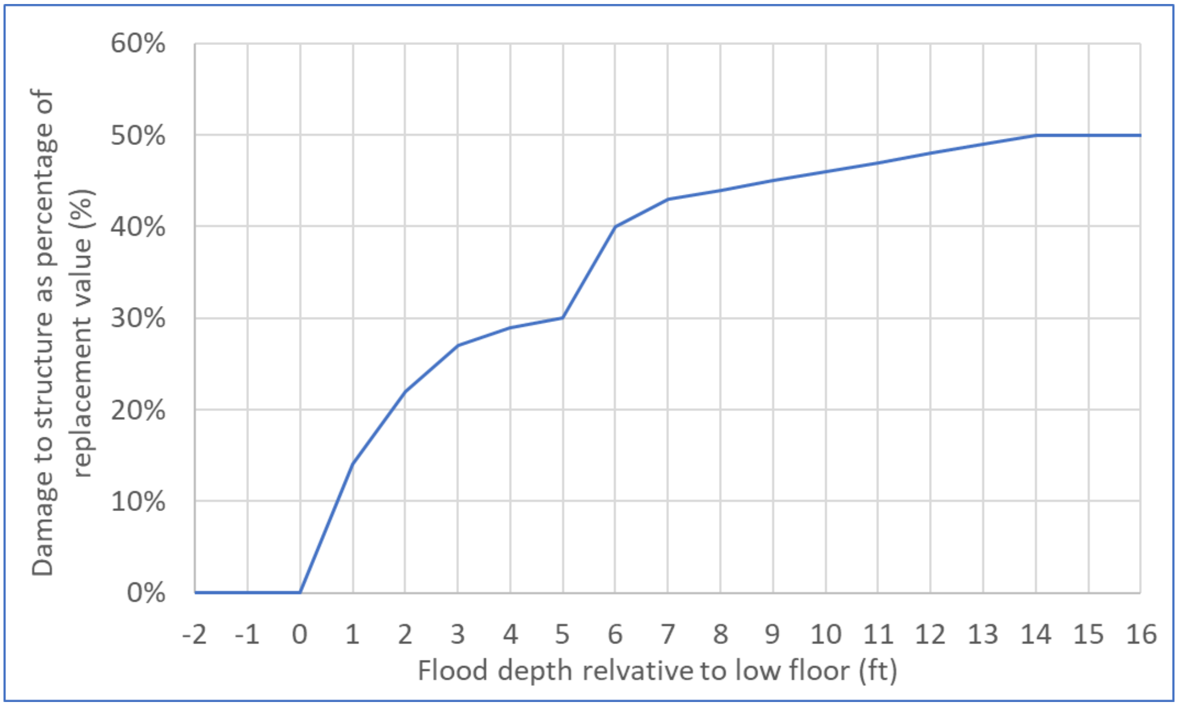


Figure 5-1 **Example of flood elevation (top) and flood depth (bottom) as a function of flooding annual exceedance probability.**



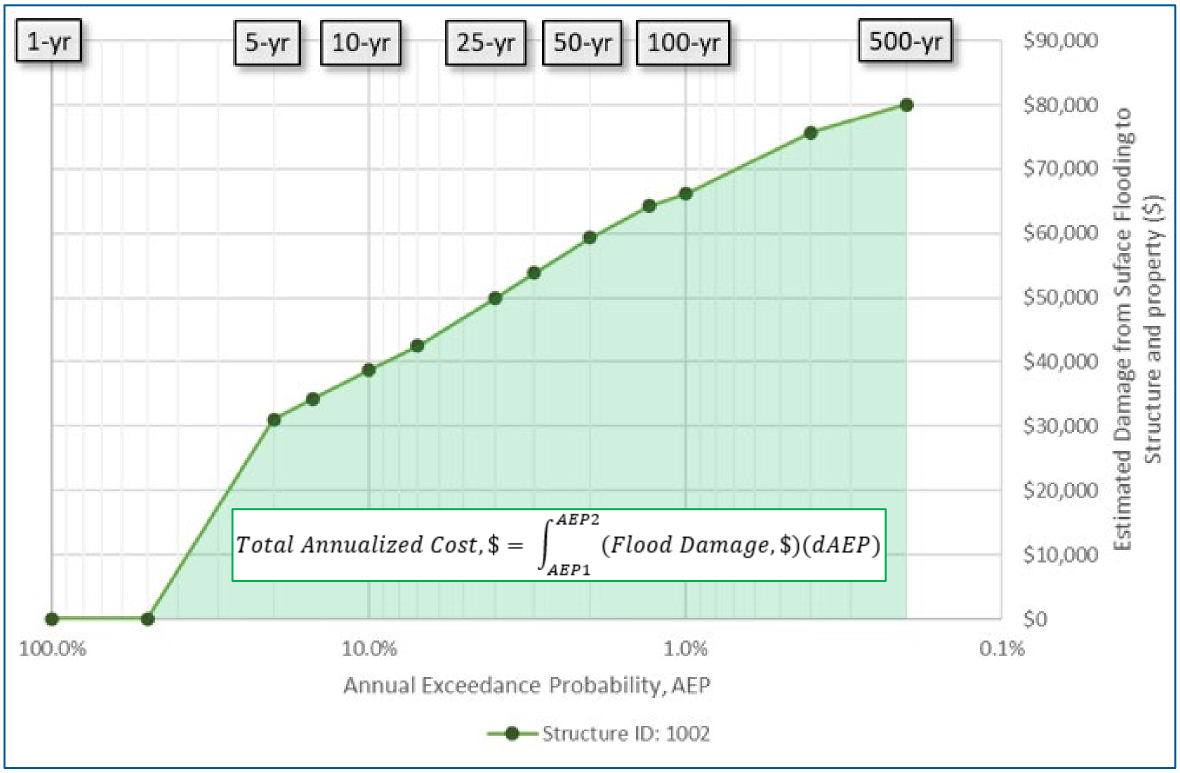


Figure 5-2 **Modified FEMA 1 Story (no basement) depth damage function (DDF) curve (top) and resulting estimated flood damage curve (bottom) as a function of flooding annual exceedance probability.**

5.3 Direct Flood Damage Cost Results and Recommendations

As summarized in Section 5.2, annualized flood damage costs were estimated for all potentially impacted structures within the Nine Mile Creek watershed. Annualized flood damage cost estimates can be used for flood mitigation planning and prioritization, comparative analysis of flood prone areas, and evaluation of proposed flood mitigation projects. The following subsections provide a summary of watershed-wide annualized flood damage cost estimates, a summary of how annualized flood damage costs can be used to evaluate proposed flood mitigation alternatives, and recommendations and considerations for utilizing annualized flood damage cost estimates for planning purposes.

5.3.1 Summary of Total and Annualized Flood Damage Cost Estimates

The following tables and figures provide a summary of watershed-wide annualized flood damage cost estimates calculated based on potential direct flood inundation impacts.

Table 5-1 provides a summary of the number of potentially impacted structures and total direct flood damage costs calculated for each modeled Atlas 14 return interval. In addition to total direct flood damage cost estimates, Table 5-1 also provides the total annualized cost (see Section 5.2) estimated for all potentially impacted structures within the Nine Mile Creek watershed.

Table 5-1 Total watershed-wide direct flood damage cost estimates per Atlas 14 return event and annualized flood damage cost estimate

Recurrence Interval	Number of Structures Potentially Impacted (#)	Total Direct Flood Damage ($)
1-year	70	$3,665,771
2-year	135	$7,291,001
5-year	348	$20,397,570
10-year	560	$37,187,108
50-year	1,270	$107,198,098
100-year	1,706	$157,543,414
500-year	2,727	$322,850,008
	Total Annualized Cost ($/year)	**$10,863,340**

Table 5-2 and Table 5-3 summarize watershed-wide total annualized flood damage cost based on municipality and type of structure (i.e., residential vs non-residential), respectively. Table 5-3 highlights that calculated annualized flood damage costs are divided nearly equally between residential and non-residential structures. Although there are far fewer non-residential structures impacted than residential, the larger footprints of non-residential structures and prevalence of non-residential structures in some large flood prone areas causes the total annualized cost calculated for non-residential structures to be similar in magnitude to the cost calculated for residential structures.

Table 5-2 Annualized flood damage cost estimates by municipality

Municipality	Number of Structures Potentially Impacted (#)	Total Annualized Flood Damage[1] ($)
Bloomington	1,093	$5,920,755
Eden Prairie	42	$174,091
Edina	916	$3,255,551
Hopkins	349	$844,471
Minnetonka	245	$583,546
Richfield	82	$84,926
Total	**2,727**	**$10,863,340**

Table 5-3 Annualized flood damage cost estimates by structure type

Structure Type	Number of Structures Potentially Impacted (#)	Total Direct Flood Damage ($)
Residential	2,311	$5,231,840
Non-Residential	416	$5,631,500
Total	**2,727**	**$10,863,340**

Figure 5-3 shows an example of a GIS map showing annualized flood damage cost estimates for a residential area in the Nine Mile Creek watershed, with damage costs summarized for individual structures and cumulatively by subwatershed. This type of GIS mapping can be used to identify flood prone areas throughout the watershed with high estimated annualized flood damage costs. Analysis of annualized flood damage costs at the watershed scale may be used to inform future prioritization of flood mitigation project areas (see discussion in Section 7).

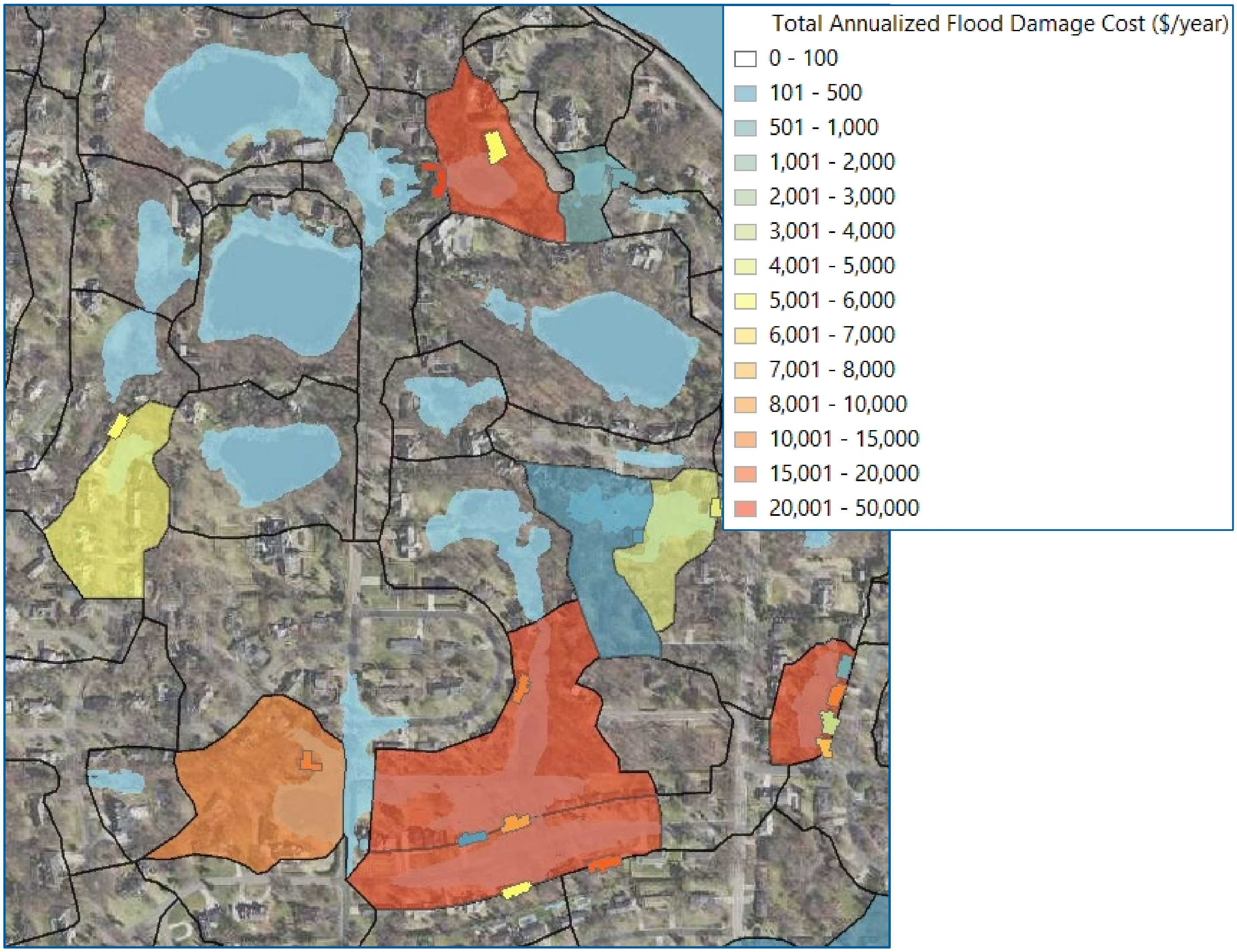


Figure 5-3 Example mapping of annualized flood damage cost estimates applied to structures and subwatersheds (100-year max water surface elevation shown in blue)

5.3.2 Utilizing Annualized Flood Damage Costs to Evaluate Benefit Cost Ratio of Flood Mitigation Alternatives

Flood damage cost estimates can be a powerful tool for evaluating the cost-benefit of proposed flood mitigation projects. The following steps outline how estimates of flood damage cost can be used to calculate a benefit-cost ratio (BCR) for a proposed flood mitigation alternative:

1. Calculate the annualized flood cost of existing flood damage (using the methodology outlined in Section 5.2)

2. Develop a flood mitigation alternative which reduces the number of structures impacted and/or the frequency of flooding impacts.
3. Develop a planning-level cost estimate for the flood mitigation alternative and annualize the cost. The Edina Flood Risk Reduction Study annualized costs based on an assumed 60-year infrastructure lifecycle using straight line basis for depreciation (Edina, 2020).
4. Calculate the annualized flood damage cost under the proposed flood mitigation alternative. The difference between the cost calculated in step 1 and step 4 is the annualized benefit ($/year) of the flood mitigation alternative.
5. Compare the annualized cost (step 4) to the annualized benefit (step 5) to calculate the annualized BCR for the alternative.

Comparing the BCR value for different flood mitigation alternatives is one way to evaluate the relative cost effectiveness of flood mitigation alternatives. As discussed in Section 5.3.3, while benefit-cost ratio is a useful tool for comparing alternatives, there are many other factors which should be considered when evaluating and comparing various flood mitigation alternatives.

5.3.3 Recommendations and Considerations

Total and annualized flood damage cost estimates presented in this study are useful for comparative analysis of flood prone areas, identification and prioritization of flood mitigation areas, and initial evaluation of flood mitigation alternatives. As outlined throughout Section 5.2, estimating flood damage costs at the scale of the entire watershed required several simplifying assumptions. Refinement of flood damage cost estimates should be considered when evaluating flood mitigation opportunities in a specific flood prone area.

The following list provides additional considerations which may be incorporated to refine cost-benefit calculations when evaluating flood mitigation opportunities in a specific flood area:

- **Modes of impact**: total and annualized flood damage costs only consider direct flood impacts (i.e., flood damage caused by inundation from surface water which overtops the structure foundation block and/or enters the structure through a low-entry point). Other modes of flood impact (e.g., indirect impacts, sanitary sewer impacts, etc.) should also be considered for a more comprehensive assessment of potential flood damage costs. See further discussion in Section 5.1.
- **Low entry elevations**: low entry elevations for all structures in this analysis were approximated based on LiDAR elevation data (Section 5.2). Survey of low entry elevations should be considered to better characterize potential flood impacts.
- **Non-structural and other impacts**: flood damage considerations discussed in Section 5 focus of flood damage costs to structures and property within structures. There are many other types of impacts which may need to be considered for a specific flood area (e.g., road inundation limiting emergency access, impacts to critical infrastructure, utility impacts, etc.).
- **Impacts of climate change**: the annualized flood damage cost analysis is based on return intervals as established by Atlas 14. As discussed in Section 2, Atlas 14 is based on the historic record and does not account for impacts of climate change. Shifts in the frequency and/or

intensity of extreme rainfall events (e.g., if an event which currently has a 500-year recurrence interval in the future occurs with a 100-year recurrence interval) can have a significant impact on calculated annualized flood damage costs.

- **Methods of evaluating flood mitigation alternatives**: Benefit-Cost Ratio (BCR) is a FEMA recommended strategy for evaluating the cost-effectiveness of flood mitigation projects. While this is an accepted strategy, the methodology can result in approval of projects that do not provide the desired level of protection to structures (e.g., is an alternative with a favorable BCA ratio but only provides a 25-year level of protection to structures a good project?). For this reason, it is important to establish goals for flood mitigation projects as well as consider alternative methods of evaluating cost-effectiveness (e.g., return on investment performance measures).

6 Pipe Failure Flood Risk Analysis at Creek Crossings

The NMCWD's hydrologic and hydraulic model and corresponding flood management elevations assume that the existing infrastructure is in good working condition with unrestricted flow during a simulated rainfall event. However, flood risk may increase significantly if a pipe were to become clogged with debris or fail entirely (e.g., joint separation resulting in pipe collapse). Barr performed a high-level review of impacts of pipe failure at 68 major crossings along Nine Mile Creek. Coordinating with NMCWD staff, Board, and TAC, eight of the crossings were selected for a further, more detailed modeling review to evaluate the impacts of complete and partial failure under a variety of hydrologic conditions.

The following subsections provide a summary of the high-level (Section 6.1) and detailed (Section 6.2) analysis of impacts from pipe failure at creek crossings.

6.1 High-level review of flood risk from pipe failure at Nine Mile Creek crossings

Barr performed a high-level GIS review of flood risk from pipe failure at 68 crossings (e.g., roadways, railroads) identified along Nine Mile Creek and its tributaries to identify the potential extent of flooding upstream of each crossing prior to water overtopping the roadway or railroad or flowing in another direction. No modeling was performed as part of the high-level GIS analysis. To evaluate the maximum possible extent of flood inundation caused by a complete pipe failure or clogging at each crossing, a geospatial analysis was performed at each crossing location to identify (a) the approximate total drainage area to each crossing and (b) the lowest overflow elevation from each crossing drainage area.

Using GIS mapping techniques, an inundation area was generated up to the overflow elevation from each crossing reviewed. This inundation area represents the maximum water surface elevation that could occur upstream of a creek crossing failure before overtopping and flowing over the roadway or railroad, or flowing in another direction. The crossing failure inundation area for each crossing is shown in the Mapbook included as Appendix C of this report. In some cases, pipe failure or clogging does not lead to significant upstream flooding due to the overflow elevation being at a shallow depth in comparison with the pipe crossing invert elevation (e.g., Appendix C, Mapbook Page 2). In other cases, the overflow elevation is high enough that the potential depth and inundation area upstream of the crossing is significant, resulting in potential flooding of structures and/or additional roadways. At some crossings, the overflow elevation is much higher than the pipe crossing invert elevation, resulting in a large overflow depth and inundation area upstream of the crossing that may not occur even under extreme combinations of elevated baseflow and precipitation (e.g., Appendix C, Mapbook Page 68). Results from the high-level review of failure at NMCWD crossing were reviewed with the NMCWD Board, staff, and TAC.

6.2 Detailed modeling review of flood risk from pipe failure at select Nine Mile Creek crossings

Eight (8) creek crossings were selected for a more detailed analysis of flood risk from pipe failure using the NMCWD calibrated XPSWMM model. Crossings were selected which have the potential to cause significant upstream flooding impacts to structures and/or roads (e.g., crossings with high "consequence" of failure). Additionally, pipe size, material and institutional knowledge of pipe condition were also considered when selecting crossings for more detailed analysis (e.g., crossings with a higher "likelihood" of clogging or failure). Ultimately, the following crossings were selected for more detailed analysis:

- HopCrk1: box culvert crossing at Chicago & SW RR crossing (Hopkins)
- EdCrk14: dual arch pipe crossing at 70th street crossing (Edina)
- MtkaCrk2: culvert crossing at C&N W RR crossing (Minnetonka)
- MtkaCrk4: culvert crossing at Milwaukee RR crossing (Minnetonka)
- EpCrk15: culvert crossing Bryant Lake Dr crossing (Eden Prairie)
- BRCrk7: box culvert crossing at Valley View Rd crossing (Edina)
- WBlmCrk5: box crossing at East Bush Lake Rd crossing (Bloomington)
- BlmCrk13: modified basket handle crossing at M.N. & S.R.R. crossing (Bloomington)

A modeling analysis was performed at each crossing to evaluate flooding and potential flood inundation impacts upstream of the crossing associated with the following four scenarios:

1. Baseflow only, pipe at crossing 50% plugged
2. Baseflow only, pipe at crossing 100% plugged
3. Baseflow + Atlas 14 100-year, 24-hr event, pipe at crossing 50% plugged
4. Baseflow + Atlas 14 100-year, 24-hr event, pipe at crossing 100% plugged

The "baseflow only" scenarios evaluate the potential upstream flood inundation after 10 days of baseflow conditions under the given crossing failure scenario (e.g., 50% or 100% plugged). These model scenarios were performed to provide NMCWD and municipal staff an estimate of inundation potential resulting from pipe failure or clogging during a period of no rainfall. Scenarios where the Atlas 14 100-year, 24-hour event was modeled show the maximum flooding extent caused by a large rainfall event occurring during a clogged or failed pipe condition.

Flood inundation results for each of the four scenarios for the eight selected crossings are included as Appendix D of this report. Results included in Appendix D have been shared with the NMCWD staff, Board, and TAC.

7 Framework for Evaluating Flood Risk Reduction Projects

Throughout the course of Phase 2 of the Atlas 14 Flood Risk and Resiliency study, Barr engaged NMCWD staff, Board, and TAC members in a number of discussions related to defining a framework for evaluating flood risk reduction projects along the Nine Mile Creek corridor and in areas upland of the creek. Evaluation of flood mitigation projects in a built environment often involves the challenge of balancing various "trade-offs" (e.g., potential wetland and habitat impacts, more frequent high flows, loss of park space, loss of developable space, risk-transference, etc.). In an effort to minimize potential barriers to implementation of flood risk reduction projects, NMCWD has begun development of a framework to guide consideration of benefits and trade-offs of flood risk reduction projects. The following list provides a summary of framework-related discussions conducted at NMCWD Board and TAC meetings throughout the project, followed by a high-level summary of related tasks and next steps which will be conducted during Phase 3 of the Atlas 14 Flood Risk and Resiliency study.

- **TAC meeting #1 (April 27, 2021):** discussed publishing of flood inundation results, consideration of trade-offs (what is "on" and "off" the table), and TAC/Board coordination.
- **August regular board meeting (August 18, 2021):** discussed Board's role in leading / partnering on flood mitigation efforts. Presented draft Phase 3 concepts, including identification and evaluation of potential flood risk reduction projects along the creek corridor.
- **Board workshop (August 31, 2021):** Provided additional detail related to Phase 3 concepts, including examples of flood risk reduction projects and related management decisions.
- **TAC meeting #2 (August 31, 2021):** discussed engineered flood mitigation alternatives and related barriers to implementation, including NMCWD and FEMA rules related to rate control.
- **October regular board meeting (October 26, 2021):** discussed barriers to implementing flood risk reduction strategies and introduced concept of flood elevation "credits" associated with in-channel flood mitigation projects.
- **November regular board meeting (November 17, 2021):** presented summary of flood management efforts being undertaken by other metro watershed districts and watershed management organizations to address Atlas 14 flooding issues.
- **December regular board meeting (December 15, 2021):** presented a detailed scope of work for Phase 3 of the Atlas 14 Flood Risk and Resiliency project, including additional tasks for developing a framework for evaluating flood risk reduction projects.
- **TAC meeting #3 (December 17, 2021):** discussed data sharing / presentation of Phase 2 results and the scope of work for Phase 3, including the additional tasks for developing a framework for evaluating flood risk reduction projects.

8 Conclusions, Recommendations, and Next Steps

8.1 Conclusions and Recommendations

The NMCWD has a long history in flood planning and floodplain management going back to the 1960s. in the early-2000s, the NMCWD developed a watershed-wide hydrologic and hydraulic model that served as a water management tool for the NMCWD, cities, and other state and local agencies. Results of this model were also provided to the MNDNR and FEMA in the mid- to late-2000s in support of the Hennepin County FEMA map updates. The NMCWD updated its watershed-wide model in 2013-2015 to incorporate the Atlas 14 precipitation frequency estimates; revised flood management elevations along Nine Mile Creek and its tributaries were adopted by NMCWD in 2015. The NMCWD's 2017 Water Management Plan identifies several policies and actions related to reducing risk to public safety and permanent structures from flooding, including working with cities to address increased flood potential from Atlas 14 rainfall frequency estimates and understanding and addressing the potential for increased flood risk due to predicted changes in climate.

In early 2020, the NMCWD initiated the Atlas 14 Flood Risk and Resilience project, a watershed-wide review of flood risk, vulnerability, and identification of mitigation strategies to better understand the future of flooding and watershed management under existing conditions and with consideration of our climate change. The overall project was split into several phases. Under the first phase of the project (Phase 1), Barr updated the NMCWD's watershed-wide hydrologic and hydraulic model in XPSWMM to incorporate recent model updates completed by several member cities (Edina, Bloomington, Richfield, and Minnetonka) and refine other areas of the model (Eden Prairie and Hopkins) (Barr, 2021). In 2021, NMCWD conducted Phase 2 of the study, *Watershed-wide Flood Risk Assessment*, results of which are summarized in this report.

Throughout the course of Phase 2, Barr, NMCWD staff, Board, and the TAC worked in close coordination to (a) perform a watershed-wide flood risk assessment to help NMCWD, its communities, and other partners gain a better understanding of flood risks throughout the watershed under current precipitation estimates and future climate change projections, (b) characterize the risk of flooding from potential culvert clogging or failure along the creek system, and (c) begin development of a framework for evaluating flood mitigation projects. Conclusions and recommendations related to each of these key objectives of Phase 2 are summarized below.

8.1.1 Watershed-wide Flood Risk Assessment

The watershed-wide modeling analysis included simulation of rainfall events representing Atlas 14 precipitation frequency estimates for recurrence intervals ranging from 1-year to 500-year and a 100-year, 10-day snowmelt event (Table 2-1). The 500-year recurrence interval was included in the analysis as an approximate surrogate for mid-21st century projections reflecting impacts of climate change on extreme rainfall events (see Section 2.1). Flood inundation areas throughout the Nine Mile Creek watershed were mapped (Appendix A). Potential structure and roadway impacts were also identified based on 2011 LiDAR elevation data and best-available structure and roadway location data.

Results of the modeling analysis indicate numerous flood prone areas throughout the Nine Mile Creek watershed, with approximately 1700 potentially impacted structures in the 100-year critical event (the 100-year, 24-hour rainfall or 100-year, 10-day snowmelt event, whichever results in a higher maximum water surface elevation). Flood damage cost estimates conducted for potentially impacted structures within the Nine Mile Creek watershed (Section 5) indicate a total direct flood damage cost of approximately $157.6 million for the critical 100-year event and a total annualized cost of $10.9 million.

While some of the flood prone areas are along Nine Mile Creek and its tributaries or adjacent to lakes, many areas are more localized, including pluvial flood areas (flooding that occurs independent of an overflowing waterbody) and flood areas adjacent to other waterbodies.

Recommendations:

1. Given the numerous flood prone areas throughout the watershed, additional efforts to further characterize and prioritize the flooding issues and explore NMCWD’s role in mitigation planning are needed. These efforts will be undertaken in Phase 3 of the Atlas 14 Flood Risk and Resiliency project (see Section 8.2).
2. Given the numerous flood prone areas throughout the watershed, opportunities for regional flood risk mitigation projects within the creek corridor should be identified to reduce flood elevations along the creek corridor and/or create additional stream capacity to accommodate and support flood mitigation in upland areas tributary to the creek. This effort will be undertaken in Phase 3 of the Atlas 14 Flood Risk and Resiliency project (see Section 8.2).
3. A communications strategy should be developed by NMCWD, in conjunction with the TAC, to determine methods of publishing and sharing flood risk model results, including the format of results and potential corresponding messaging and educational materials to help the public understand the information. The communications strategy should include consideration of social vulnerability factors and how to target communications to help more vulnerable populations.
4. NMCWD should consider development of a protocol and schedule for routine model updates and model recalibration. This protocol could consist of case-by-case evaluation of development and redevelopment projects within the watershed or could be based on a specified time interval (e.g., model updates to occur on a three-year basis).

8.1.2 Risk analysis for potential pipe clogging or failure at creek crossings

The NMCWD’s hydrologic and hydraulic model and corresponding flood management elevations assume that the existing infrastructure is in good working condition with unrestricted flow during a simulated rainfall event. However, flood risk may increase significantly if a pipe were to become clogged with debris or fail entirely. To assess this risk, a high-level review of flood risk associated with potential pipe failure was conducted for 68 major creek crossings throughout the watershed (Appendix C). Maps were generated for each creek crossing showing the overflow location, size and type of culvert, and potential extent of flooding upstream of each crossing prior to water overtopping the crossing (typically a roadway or railroad) or flowing in another direction.

Eight creek crossings were selected for more detailed analysis based on the potential for significant upstream flooding impacts to structures and/or roads (e.g., crossings with high "consequence" of failure) or higher likelihood for clogging or failure due to factors such as pipe size, material, or institutional knowledge of pipe condition. A modeling analysis was performed for each of the eight crossings to evaluate the flood impacts of complete or partial failure under baseflow conditions and during a 100-year, 24-hour rainfall event. Maps were generated for each crossing showing the extent of inundation and potentially impacted structures after 10 days (Appendix D).

Recommendations:

1. The crossing failure analysis results should be shared with partnering organizations (municipalities, Hennepin County, MnDOT, rail authority, etc.). Results may be used to inform infrastructure inspection, including prioritization of crossings with higher consequence of failure.

8.1.3 Framework for Evaluating Flood Mitigation Projects

Addressing flooding issues throughout the Nine Mile Creek watershed will require careful consideration and balance of benefits and trade-offs, especially considering the fully developed nature of the watershed. Constraints including potential environmental impacts (e.g., wetlands, water quality, tree loss) and/or potential transfer of flood risk will need to be considered when evaluating potential flood risk reduction projects. Addressing flooding issues will also likely involve partnerships with other public and private entities. Throughout the course of Phase 2 of the Atlas 14 Flood Risk and Resiliency study, Barr engaged NMCWD staff, Board, and TAC members in numerous discussions related to defining a framework for evaluating flood risk reduction projects in the Nine Mile Creek watershed.

Recommendations:

1. Continue development of a framework and/or guidelines for NMCWD and its partners to evaluate flood mitigation projects. This effort will be undertaken in Phase 3 of the Atlas 14 Flood Risk and Resiliency project (see Section 8.2).

8.2 Next Steps

8.2.1 Phase 3

Building off the work completed in Phase 2, NMCWD will be completing Phase 3 of the Atlas 14 Flood Risk and Resiliency Project in 2022-2023. The primary objectives of Phase 3 are to (a) identify and evaluate cost-effective flood risk reduction projects within the creek corridor, (b) further watershed-wide characterization and planning for flooding issues within the watershed, (c) develop an approach for partnerships in future flood risk reduction projects, and (d) explore opportunities to improve flood risk resiliency and remove barriers to implementation of flood risk reduction projects. Additionally, Phase 3 will include development of a strategy to communicate flood risk information to the community, including emergency managers, watershed residents, and other property owners within the watershed.

A high-level summary of major work tasks from the Phase 3 scope is included below:

- **Task 1: Flood resiliency analysis along the Nine Mile Creek corridor**. Identify and evaluate regional opportunities to mitigate flooding by optimizing use of major storage areas and the floodplain. This task includes identifying opportunities, related modeling, cost estimating, and benefit-cost analysis.
- **Task 2: Characterize Flooding Issues and Develop Framework for Flood Risk Reduction Projects**. Tasks and next steps related to addressing flooding issues throughout the Nine Mile Creek watershed in conjunction with municipalities and other potential project partners, including:
    - Social vulnerability flood risk characterization;
    - Characterizing watershed-wide flooding and further defining the NMCWD's role in future flood mitigation planning;
    - Prioritizing NMCWD-led flood risk areas for future feasibility studies (if applicable);
    - Developing guidelines for project partnerships with municipalities and other public entities; and
    - Developing a framework for consideration of project benefits and trade-offs.
- **Task 3: Communicate flood risk**. Coordinate with NMCWD staff, Board, and TAC to develop a communication and public education strategy related to reporting and sharing of modeling results

8.2.2 Future Considerations

Phase 3 of the NMCWD's Atlas 14 Flood Risk and Resiliency project includes identifying opportunities within or adjacent to the creek system to increase or better utilize available flood storage to help address local and regional flooding issues (Task 1). Pending results of the analysis, the NMCWD may wish to pursue implementation of one or more projects, which would include conducting a feasibility study as a next step.

Recognizing the numerous flood prone areas throughout the watershed and that flood storage projects originating from the Phase 3 analysis (Task 1) may not sufficiently address the flooding issues, we anticipate that additional long-range flood mitigation planning efforts may be warranted, including evaluating options to increase conveyance capacity throughout the Nine Mile Creek system.

References

Barr Engineering Co. (Barr). 2021. 2020 Atlas 14 Model Update Documentation Memorandum. Prepared for Nine Mile Creek Watershed District. January 20, 2021. 23271819.00.

City of Edina (Edina). 2020. City of Edina Flood Risk Reduction Strategy. Appendix C. April 7, 2020.

Federal Emergency Management Agency (FEMA). 2020. Benefit-Cost Analysis Toolkit: Version 6.0. Release Notes: July 2020. https://www.fema.gov/grants/guidance-tools/benefit-cost-analysis.

National Weather Service (NWS). 1961. Technical Paper 40: Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. U.S. Department of Commerce, Washington D.C.

S. Perica, D. Martin, S. Pavlovic, I. Roy, M. St. Laurent, C. Trypaluk, D. Unruh, M. Yekta and G. Bonnin. 2013. NOAA Atlas 14 Volume 8 Version 2, Precipitation-Frequency Atlas of the United States, Midwestern States. NOAA, National Weather Service, Silver Spring, MD, 2013.

Stack LJ, Simpson MH, Gruber J, Moore TL, Yetka L, Eberhard L, Gulliver J, Smith J, Mamayek T, Anderson M and Rhoades J. 2014. Long-term climate information and forecasts supporting stakeholder-driven adaptation decisions for urban water resources: stormwater drainage system vulnerability, capacity, and cost, under population growth and climate change. Final project report: Sectoral Applications Research Program FY2011," Climate Program Office, National Oceanic and Atmospheric Administration, 2014.

United States Department of Agriculture (USDA). 1997. National Engineering Handbook. Chapter 4: Storm Rainfall Depth and Distribution.

United States Department of Agriculture (USDA). 1985. Technical Release No. 60 (TR60): Earth Dams and Reservoirs. Soil Conservation Service Engineering Division.

Appendix A

Mapbook of NMCWD Flood Inundation & Potential Impacts

Appendix B

NMCWD Phase 2: XPSWMM Model Calibration

Appendix C

Mapbook: High-level Review of Failure at NMCWD Crossings

Appendix D

Mapbook: Detailed Modeling Review of Failure at Select NMCWD Crossings