GEI Consultants

Consulting Engineers and Scientists

Hartley Pond and Dam Feasibility Study - Draft

Duluth, Minnesota

Submitted to:
Minnesota Department of Natural Resources
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St. Paul, MN 55155

Submitted by:
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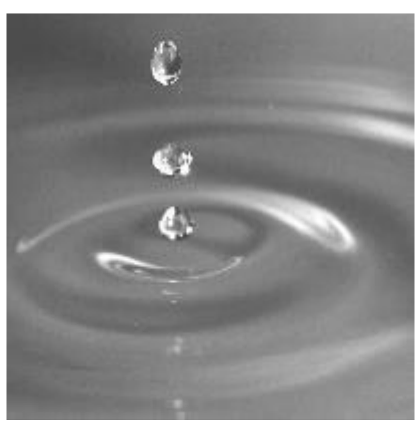

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Table of Contents

Table of Tables

Table of Figures

Appendices

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Executive Summary

This feasibility study completed by GEI Consultants, Inc. (GEI) was commissioned by the State of Minnesota Department of Natural Resources (MNDNR) to evaluate specific future conditions intended to eliminate the negative impacts of warm water outflow from Hartley Pond and the migration and sediment barrier of Hartley Dam on the coldwater brook trout resources of Tischer Creek in Duluth, Minnesota. An earlier investigation found that the impoundment warms up the creek during the growing season to temperatures not suitable for trout both in the impoundment and downstream from the dam. The dam is also a barrier to fish passage and stream sediment transport. In the latest master plan for the Hartley Nature Center, a feasibility study was recommended to evaluate alternatives for the restoration of Tischer Creek and elimination of negative impacts to coldwater resources from the dam and impoundment.

To compare potential future conditions, an alternatives analysis was prepared that includes detailed hydrologic and hydraulic modeling, a multi-criteria decision analysis (MCDA) along with feedback from a committed group of stakeholders that include Duluth staff, Hartley Nature Center staff, University of Minnesota at Duluth (UMD) faculty, MNDNR, and the South St. Louis County Soil and Water Conservation District.

The modeling effort was informed by real-time precipitation and impoundment stage data collected by UMD during this project. While a full calibration of the existing conditions model was outside the project scope, data from a large, late September 2023 rain event was used to improve the model's estimates of flow and depth over the dam for that event.

This preliminary calibration of the existing conditions model was used to represent the base, no action alternative, against which all other alternatives were compared. This comparison is particularly important because the dam has the capacity to provide flood mitigation storage that had been identified by pervious hydraulic studies. The City of Duluth requested that the flood mitigation capacity of the existing structure should not be compromised. This is critical because downstream of the dam there are several dozen properties that are at risk of flooding during large precipitation events.

Alternatives evaluated include: 1) no action; 2) stream route around (leaving the dam in place and continuing to use it for peak flow mitigation); 3) dam removal; and 4) open-bottom culvert through the dam embankment. If the ultimate goal is to develop the most sustainable alternative that meets the project criteria, our recommendation is to completely demolish the dam and acquire property that would be potentially flooded during high flow events once the dam is removed (Alternative 3). Because acquiring these flood prone properties would take time and money to accomplish, the next best alternative that meets the project criteria is a properly sized, open-bottom culvert constructed at the former bed elevation of Tischer Creek and running through the earthen dam embankment (Alternative 4).

1. Introduction

1.1 Purpose

The purpose of the Feasibility Study (FS) is to identify the most effective and efficient alternative for eliminating negative impacts to brook trout and other coldwater resources of Tischer Creek that are caused by the dam, including warm water discharges, longitudinal disconnect, and habitat degradation. The Hartley Pond and Dam FS goals are to:

1. Relax constraints on the ecological and geomorphic functions of Tischer Creek caused by the Hartley Dam.
2. Preserve and/or increase the historical, ecological, recreational, educational, and aesthetic value of Tischer Creek and the Hartley Nature Center.

The FS goals and objectives are based partially on the Instream Flow Council's five components of watershed health:

Biology: Improve and protect coldwater inputs to support coldwater fish and invertebrates. Improve brook trout habitat. Unique opportunity to increase high-quality native riparian vegetation and plant communities.

Hydrology: Restore a more natural hydrologic regime of Tischer Creek and associated floodplain.

Geomorphology: Restore ecological function and habitat diversity by prioritizing restoration to a stable and resilient form, with an emphasis on reconnecting streams to floodplains.

Water Quality: Decrease water temperature throughout the watershed, reduce impacts of designated and non-designated impairments to water quality.

Connectivity: Temporal: Enhance resilience of native ecosystems through continuous physical, chemical, and biological interactions over time.

Longitudinal: Restore stream and floodplain longitudinal connectivity and continuity for aquatic and sediment transport.

Lateral: Reconnect incised channels to floodplains for better sediment and nutrient processing.

Additional goals and objectives listed in the MNDNR Request for Proposal include maintaining existing recreational ecosystem services within the park (e.g., fishing, biking), restoring natural ecosystem functions and aesthetics, maintaining/enhancing outdoor educational opportunities offered by the park, and avoiding an increase of flood risk within the watershed and flood damage downstream of Hartley Pond. These goals and objectives were considered a starting point for developing the FS.

This report presents the evaluation of potential long-term alternative trajectories for Hartley Dam, Hartley Pond, and Tischer Creek developed by GEI Consultants, Inc. (GEI). The dam is owned and maintained by the City of Duluth (City). This study aims to prepare conceptual-level designs and economic analyses of alternatives for Hartley Dam to aid the City in future planning and decision-making. Additionally, to assist in the alternative's evaluation, preliminary conceptual designs and associated cost estimates were developed to compare and evaluate estimated construction and lifecycle costs.

1.2 Project Location

Hartley Pond is located in the north-central portion of the City of Duluth, St. Louis County, Minnesota (**Figure 1**). As one of the City's premier natural areas, 620 acres have been recognized as the "Hartley Natural Area" (HNA) under the Duluth Natural Areas Program (DNAP). Hartley Pond and Dam are included within this HNA.

Hartley Dam is primarily an earthen embankment with a concrete spillway located on Hartley Pond. The dam consists of an earthen embankment, a concrete spillway structure along with an earthen emergency spillway north of the spillway on the downstream left back.

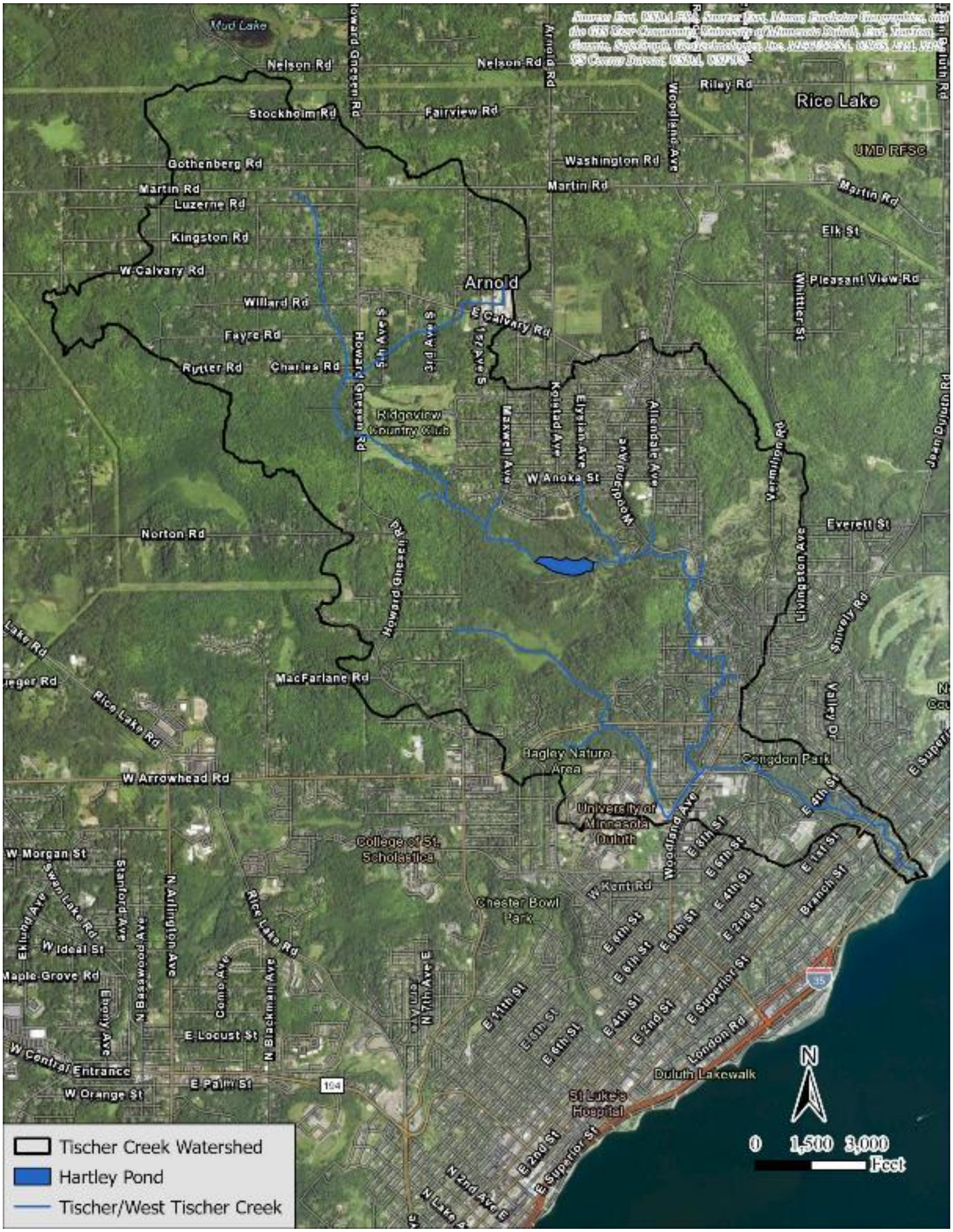


Figure 1. Project location map of Hartley Pond and its location within the Tischer Creek watershed.

1.3 Related Planning Documents

The following plans and studies related to Hartley Pond and Dam were compiled and reviewed for this project:

- Hartley Duluth Natural Areas Program Management Plan (City of Duluth, 2019)
- Hartley Park Mini-Master Plan (City of Duluth, 2014)
- Essential Spaces: Duluth Parks, Recreation, Open Space and Trails Plan (City of Duluth, 2022)
- Restoration Strategy – Duluth Urban Area Watershed Restoration and Protection Strategy Document (MPCA, 2017)
- Hartley Dam Emergency Action Plan (Barr, 2014)

1.4 Related Statutes

Minnesota Statutes, Section 103G.515, authorize the MNDNR to inspect dams and issue orders directing dam owners to make necessary repairs. The same section directs the MNDNR to adopt rules governing dam safety. The specific rules governing Minnesota's Dam Safety Program are parts 6115.0300 through 6115.0520 defining which dams are subject to state jurisdiction and establishing three dam hazard classes.

The MNDNR defines "Public Waters" as all waterbasins and watercourses that meet the criteria set forth in Minnesota Statutes, Section 103G.005 that are identified on Public Water Inventory maps authorized by Minnesota Statutes, Section 103G.201. Hartley Pond and Tischer Creek are identified Public Waters.

1.5 Scope of Work

The scope of work for this feasibility study includes four tasks as described below.

Task 1: Populate Steering Committee and Finalize List of Alternatives for Evaluation.

- The Steering Committee was identified by the Minnesota Department of Natural Resources (MNDNR), City staff, and Hartley Nature Center (HNC).

Steering Committee Member	Affiliation
John Lindgren	MNDNR
Jeramy Pinkerton	MNDNR
Karl Koller	MNDNR
Brianna Speldrich	MNDNR
Kate Kubiak	City of Duluth
Tom Johnson	City of Duluth
Jim Shoberg	City of Duluth
Tim Beaster	South St. Louis Soil and Water Conservation District
Matt Willey	Hartley Nature Center

Judy Gibbs	Hartley Nature Center Stewardship Committee
John Swenson	University of Minnesota Duluth

- One field trip with MNDNR, City of Duluth, and Hartley Nature Center staff was completed to discuss possible alternatives.
- Alternatives to be evaluated by the FS were finalized.

Task 2: Gather Data, Fill data gaps, and Define Project Area and Process.

- Available data was collected, reviewed, and utilized for the preparation and completion of the Feasibility Study.
- The Project area and process for hydrologic and hydraulic modeling was defined.

Task 3: Implement Public Information Process.

- Three public information meetings were held at the HNC.
- The City of Duluth public information process will include meetings with the Natural Resources Commission, Parks and Recreation Commission Hartley Stewardship Committee, Public, and City Council.

Task 4: Alternatives Analysis and Feasibility Report.

- Alternatives were modeled and analyzed for feasibility.
- Three Steering Committee meetings were held at Duluth City Hall.
- Draft Report submitted to the MNDNR and Steering Committee for review.
- Final Report submitted to the MNDNR and Steering Committee for review.
- Final report delivered to the MNDNR with accompanying package of all data collected or generated during the process.

1.6 Elevation Datum

Elevations in this report are in feet (ft) and referenced with respect to the North American Vertical Datum of 1988 (NAVD88) datum.

1.7 Limitation of Liability

Our professional services for preparing this report were performed in accordance with generally accepted engineering practices; no other warranty, express or implied, is made.

2. Site Background

2.1 Tischer Creek

The Tischer Creek watershed is located in east Duluth and is approximately 7.6 square miles in area down to the mouth at Lake Superior. The watershed area contributing to Hartley Pond and the dam is just over 3.5 square miles. The watershed contains both the main stem of Tischer Creek and the West Branch of Tischer Creek. Together their total creek length is approximately 11.2 miles (SWCD, 2016). Tischer Creek is listed as impaired for E. coli (*Escherichia coli*) by the Minnesota Pollution Control Agency (MPCA). Additionally, Tischer Creek is a State-designated trout stream that supports a naturally reproducing brook trout population.

Tischer Creek, located in the City of Duluth and Rice Lake, is an urban trout stream that flows through one of the most heavily used parks in the City of Duluth. It provides thousands of students with a natural resource for investigating watershed science and coldwater stream ecology. Neighborhoods around the creek are provided with a relatively unique resource, compared to other large urban areas. The creek provides an urban fishery and a scenic setting as it flows through the City of Rice Lake, Hartley Park, and the City of Duluth where it enters a bedrock canyon before discharging into Lake Superior. A vertical profile of Tischer Creek is provided in **Figure 2**.

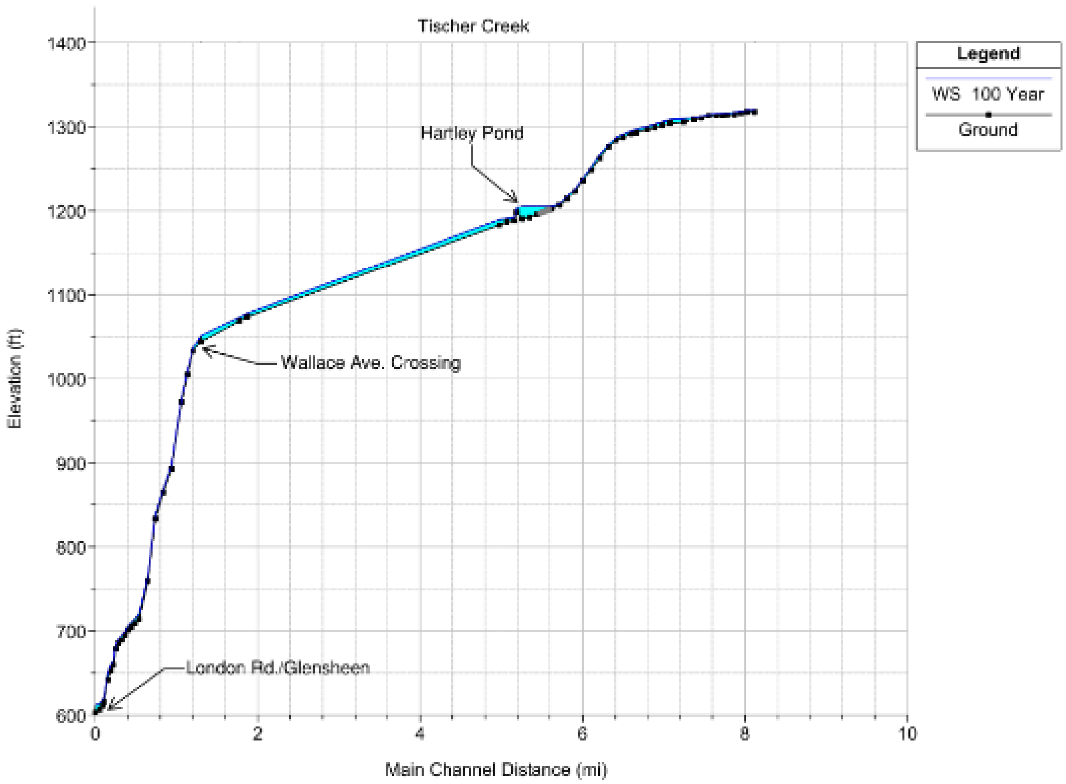
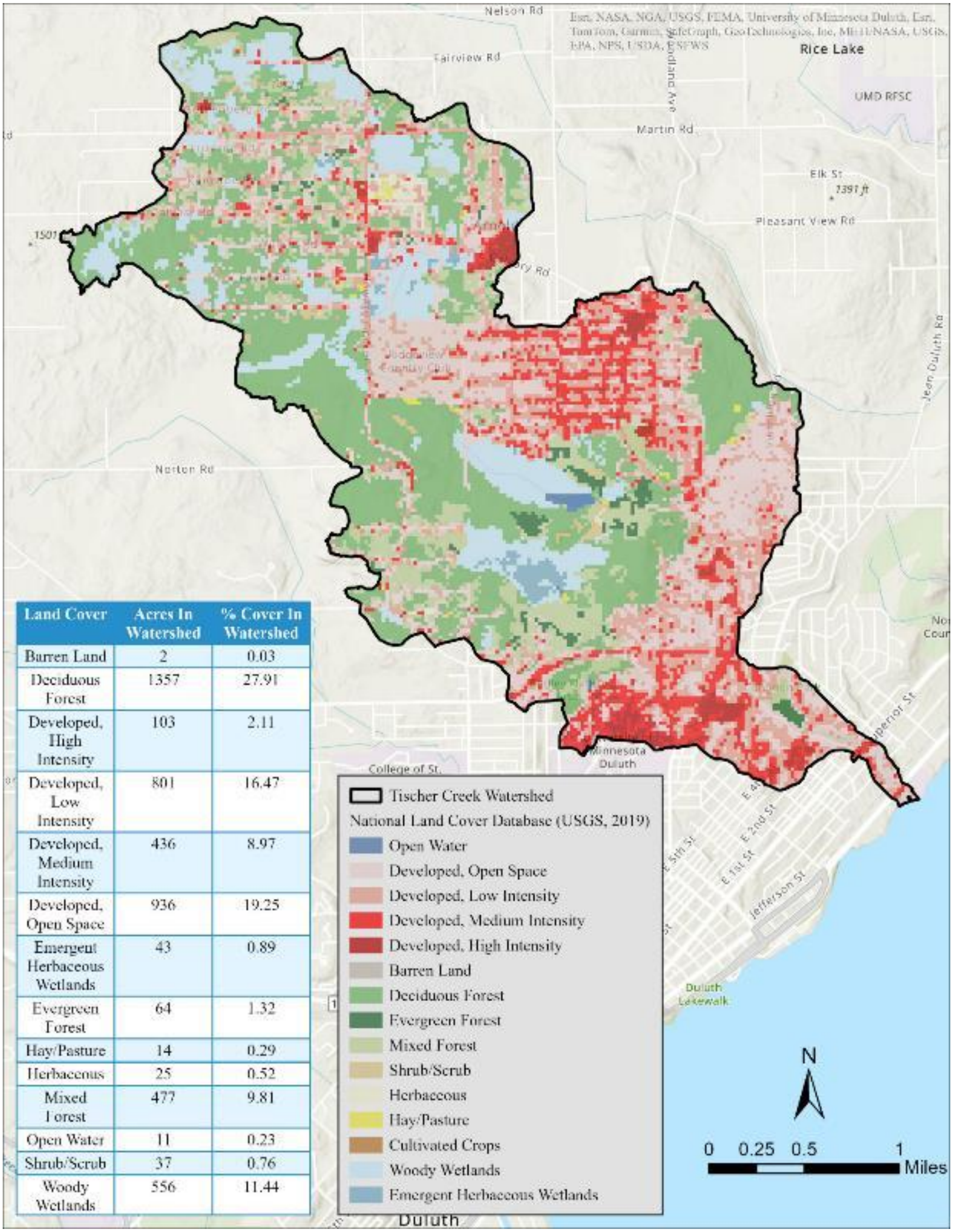


Figure 2. Tischer Creek vertical profile (FEMA, 2022).

Tischer Creek is impacted by stressors common to suburban and urban watersheds. In its headwaters, the stream has fair amounts of impervious surface and runoff that is not treated (**Figure 3**). It is also ditched for a considerable distance and flows through a highly manicured golf course. The headwaters also contain wetland areas and artesian wells that are indicative of the shallow water table that feeds the creek.

Below the golf course, it flows into Hartley Park and into Hartley Pond where the creek is impounded by Hartley Dam. This dam, while providing a pond resource for the community, creates a complete barrier to migration of fish and other aquatic organisms. The pond also slowly accumulates sediment and increases water temperatures to levels lethal to brook trout, which negatively impacts downstream conditions for a considerable distance. The stream then flows through urbanized Duluth with private and public parks scattered along the floodplain valley. This area contains the University of Minnesota – Duluth, many private residences and the Mount Royal Shopping Center. After flowing through the urbanized section, the creek begins its descent through the bedrock canyon, which is mostly protected by the City's Congdon Park. This scenic area of waterfalls and the intact riparian forest is a natural gem for the City of Duluth.



Land Cover	Acres In Watershed	% Cover In Watershed
Barren Land	2	0.03
Deciduous Forest	1357	27.91
Developed, High Intensity	103	2.11
Developed, Low Intensity	801	16.47
Developed, Medium Intensity	436	8.97
Developed, Open Space	936	19.25
Emergent Herbaceous Wetlands	43	0.89
Evergreen Forest	64	1.32
Hay/Pasture	14	0.29
Herbaceous	25	0.52
Mixed Forest	477	9.81
Open Water	11	0.23
Shrub/Scrub	37	0.76
Woody Wetlands	556	11.44

Figure 3. Land cover within the Tischer Creek watershed (USGS, 2019).

2.2 Climate

2.2.1 Historic and Current Climate

The climate of Duluth, Minnesota is humid continental, experiencing cold, snowy winters and cool to moderately warm summers (USGS, 2006, Eichenlaub, 1979). The proximity of Duluth to Lake Superior results in cooler summers and warmer winter temperatures, and large variations from average regional weather. The average annual precipitation is approximately 31.2 inches, and the average annual snowfall is 86 inches.

According to observed trends from the MNDNR Minnesota Climate Explorer, temperature, precipitation, and Palmer Drought Severity Index for the Lake Superior-South Watershed has increased relative of the reporting period, over the last 50 years, and past century (MNDNR, 2023). The average annual temperature for the entire reporting period (1895 to 2023) was 37.71 degrees Fahrenheit (F) and the average temperature for the 21st century was 39.23 degrees F. The trend for the past 50 years is an increase of 0.38 degrees F per decade (**Figure 4**).

The average precipitation for the entire reporting period averaged 28.20 inches, and the average for the past 21st century was 28.85 inches. The trend for the past 50 years is an increase of 0.46 inches per decade. The average Palmer Drought Severity Index (PSDI) for July was 0.41, and the average for the 21st century was 1.40. The trend for the past 50 years is an increase of 0.35 inches per decade.

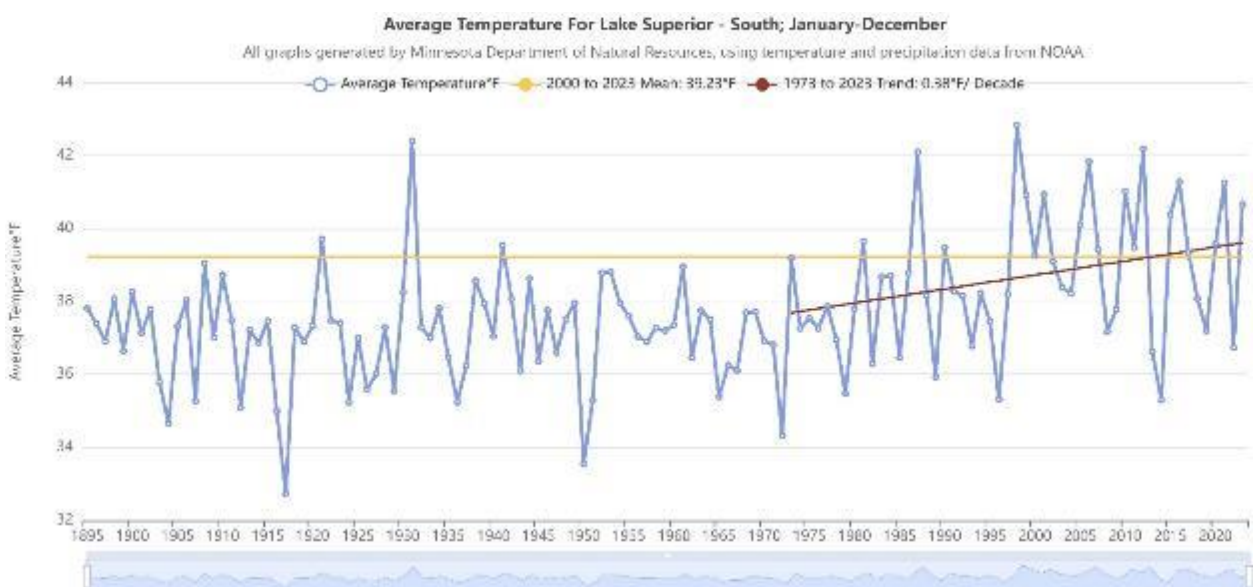


Figure 4. Average annual temperature (1895-2023), mean annual temperature (2000-2023), and trend of average annual temperature (1973-2023) (MNDNR, 2023).

Similarly, recorded daily precipitation totals were downloaded for the Duluth International Airport weather gauge to identify trends in the annual maximum daily precipitation (National Oceanic and Atmospheric Administration (NOAA), 2023a). The Duluth International Airport precipitation record is continuous from 1948 through 2023, and the average maximum daily precipitation event for the entire reporting period was 2.26 inches. The average for the past 30 years (1994-2023) was 2.20 inches. The trend over the entire record is quite variable, with a slight decreasing trend, predominantly due to the low annual maximum daily precipitation recorded from 2014-2022 (**Figure 5**). However, the two largest precipitation events on record occurred in 2012 (June 19, 4.14 inches) and 2010 (May 23, 3.93 inches). In addition to the highest single-day precipitation event, the 5-day period from June 16 through June 20, 2012, had the highest 5-day precipitation total of 8.24 inches of rain, with 7.25 inches of the total occurring between June 19 and June 20, resulting in catastrophic flooding throughout Duluth.

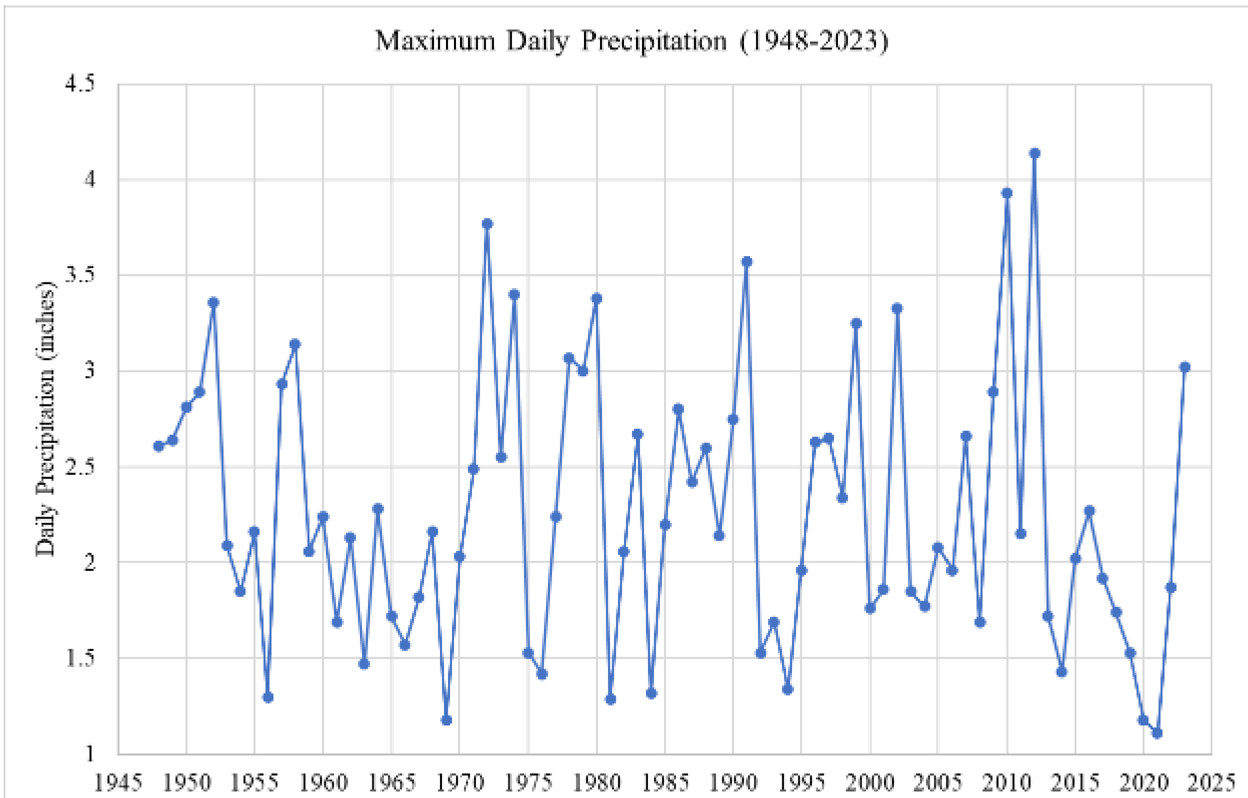


Figure 5. Maximum daily precipitation by year (NOAA, 2023a).

2.2.2 Climate Change Projections

The MNDNR Climate Explorer was used to project trends in temperature and precipitation within the Lake Superior-South Watershed. The Climate Explorer utilizes eight different climate projection models to estimate annual temperature and precipitation ranges for the future. Generally, the modeled mean temperature for Lake Superior-South Watershed from the Modeled Present era into the Mid-Century (2040-2059) increases by approximately 3.55 degrees F and the modeled annual precipitation remains relatively the same.

Additionally, the U.S. Environmental Protection Agency's (EPA) Climate Resilience Evaluation and Awareness Tool (CREAT) provides projections for changes in storm intensity. EPA CREAT models the 100-yr storm intensity as defined by two climate scenarios – one where future conditions are not as stormy and precipitation occurs more equally through multiple storm events ("not as stormy"), and another where future conditions are stormy and more precipitation during single events is more likely ("stormy"). This analysis projects an 11.2% increase in the 100-yr storm intensity by 2035 and 21.8% increase by 2060 under the stormy scenario (EPA, 2023). The National Oceanic and Atmospheric Administration (NOAA) Atlas 14 Point Precipitation Frequency Estimates tool approximates that a total of 6.41 inches (in.) of rain is the 100-yr storm event precipitation total for the Tischer Creek watershed in 2023 (NOAA, 2023b). Under the EPA CREAT projections for the "stormy" scenario, the 100-yr storm precipitation totals would increase to 7.13 in. of precipitation by 2035 and 7.81 in. of precipitation by 2060.

2.3 Geology

The geology in Duluth is characterized by the presence of bedrock at or near the land surface, consisting of Proterozoic volcanic and igneous rocks, intrusions, and sedimentary rocks (Miller et al., 2002). Stream networks and density are influenced by bedrock type and faulting (USGS, 2006). Duluth's landscape is dominated by a steep rocky bluff formed by a combination of the Duluth Complex and various other intrusive rocks, which parallels the St. Louis River Estuary and Lake Superior shoreline.

The geologic setting of Tischer Creek Watershed is influenced by the region's glacial history and underlying bedrock geology. Much of the land in and around Duluth is shaped by glacial deposits. During the last ice age, the Laurentide Ice Sheet covered this area. As the glacier advanced and retreated, it deposited a variety of sediments, including till, glacial outwash, and glacial lake sediments. Tischer Creek's flow patterns, sediment transport and types of soils in the watershed are affected by both the bedrock and the glacial deposits. The bedrock consists of the ancient volcanic Duluth Complex, a large geological formation in the region, that is known for its bedrock combination of basalt and gabbro. The bedrock formation has a significant role in the topography and slope of the channel.

The upper portions of the watershed consist of mostly glacial deposits, which is important because till and outwash sediments have unique hydrological properties (**Figure 6**). The glacial deposits can act as aquifers, storing and transmitting groundwater, provide baseflow for streams, and provide filtration to help prevent groundwater contamination. The presence of the tills is also a source of sediment in the watershed. During heavy rainfall or snowmelt periods, these sediments can mobilize in higher flows and increase lateral channel instability and turbidity within the streams. Knowledge and distribution of these glacial deposits are essential for identifying areas suitable for development and preservation and surface and groundwater interactions to reduce water quality pollution. Understanding the presence of these deposits is also essential for conserving wetland and stream habitat and biodiversity.

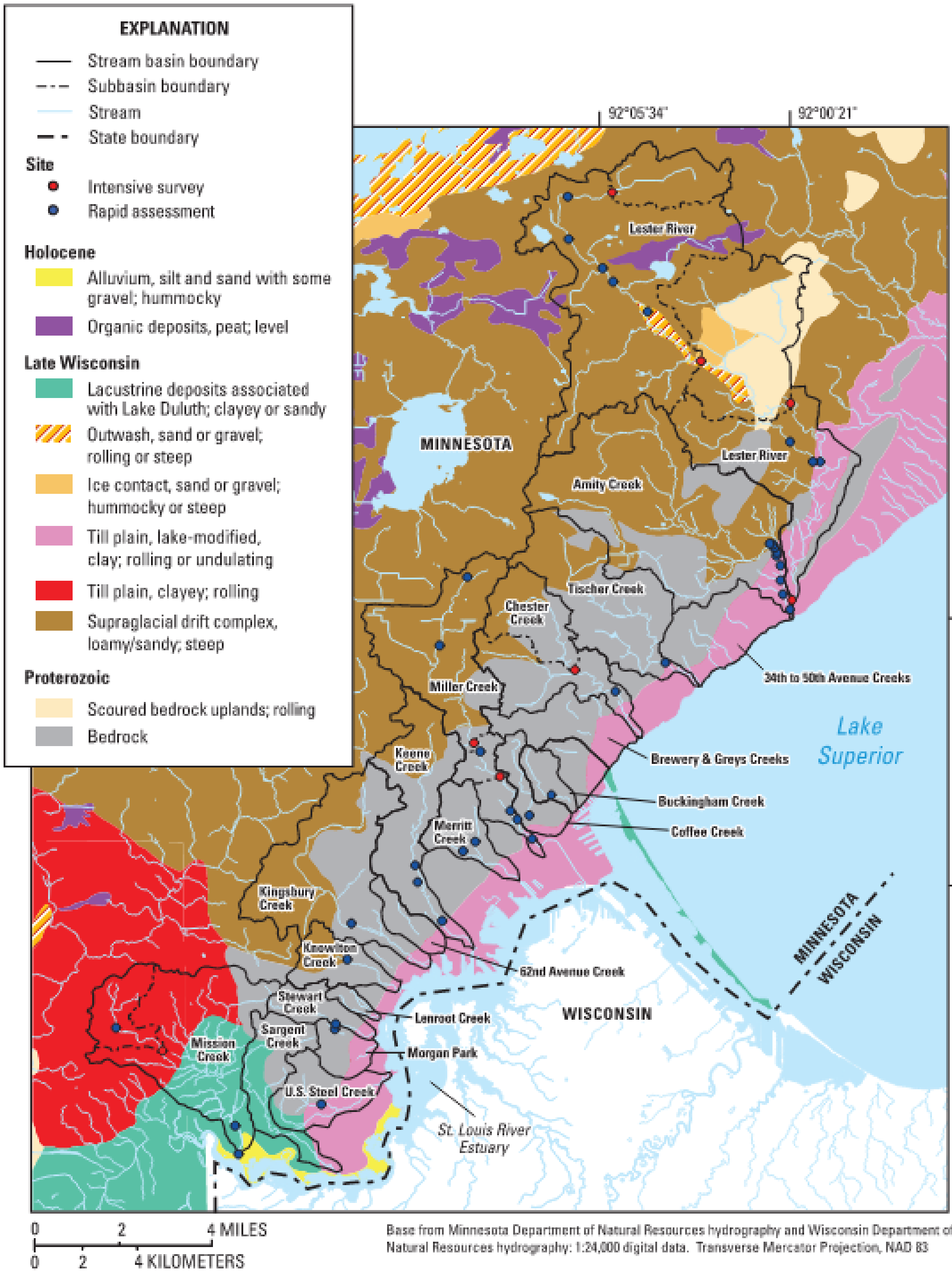


Figure 6. Surficial geology and geomorphology of the Duluth, Minnesota area (from University of Minnesota – Duluth Geology Department and others, 1997).

2.4 Hartley Park

Located in Duluth's Woodland neighborhood, Hartley Park is a 660-acre city park filled with woods, trails, wildlife, ponds, and views (Hartley Nature Center, 2023). Hartley Park has approximately 12 miles of multi-use trails and is one of the most popular parks within the City of Duluth. The park is managed by the City of Duluth Parks and Recreation department in partnership with HNC. HNC provides outdoor education, clubs and events, recreational programs, rentals, among many other services to the park and the community.

The park is named after Guilford Hartley, who owned the land on which the park currently exists in the late 1800s and early 1900s. Guilford Hartley purchased the land from 1890-1911 and cleared the land for commercial produce and dairy. Along with clearing the land, Hartley Road and the Hartley Pond were constructed in 1913. Hartley Pond was constructed by a man-made dam on Tischer Creek. The Hartley estate failed to pay taxes in 1931 and the agricultural fields were abandoned. In 1941, the Hartley land was cleared of buildings and earned park status from the City of Duluth. Hartley Nature Center officially became a non-profit environmental education corporation in 1987.

2.5 Hartley Pond Dam

Although Hartley Pond has existed since 1913 with the construction of the original dam on Tischer Creek, the dam has been re-constructed several times, including in 1963, 1975, and 1985 for maintenance and improvements and following failure events (City of Duluth, 1974, U.S. Army Corps of Engineers, 1980, City of Duluth, 1987). The original pond was constructed to create a duck and goose sanctuary on the Hartley property. The dam was constructed with local borrow with a concrete spillway structure and two-foot-wide spillway crests with stop logs. Aerial photography from 1948 shows the extent of Hartley Pond, which appears to be smaller in size than its current footprint (**Figure 7**).

In 1963, the pond was drained, the accumulated silt was dredged, and the height of the dam and spillway were raised to improve trout habitat (City of Duluth, 1974). Unfortunately, the work completed in 1963 did not replace the sluiceway for flood relief. Severe flooding in August and September of 1972 resulted in 30 to 40 ft of the earthen dam being completely washed out to the north abutment of the spillway structure and scoured a portion of the downstream dam on the south side of the spillway (**Figure 8**). The dam reconstruction process began in 1974 due to mounting pressure from the Woodland Community Club and downstream property owners. Due to spiraling costs, the dam design changed, elevation was lowered, and the fish ladder was removed. In the reconstruction permit application, the total cost for the final repairs was quoted at $175,000. The dam was reconstructed in 1975.

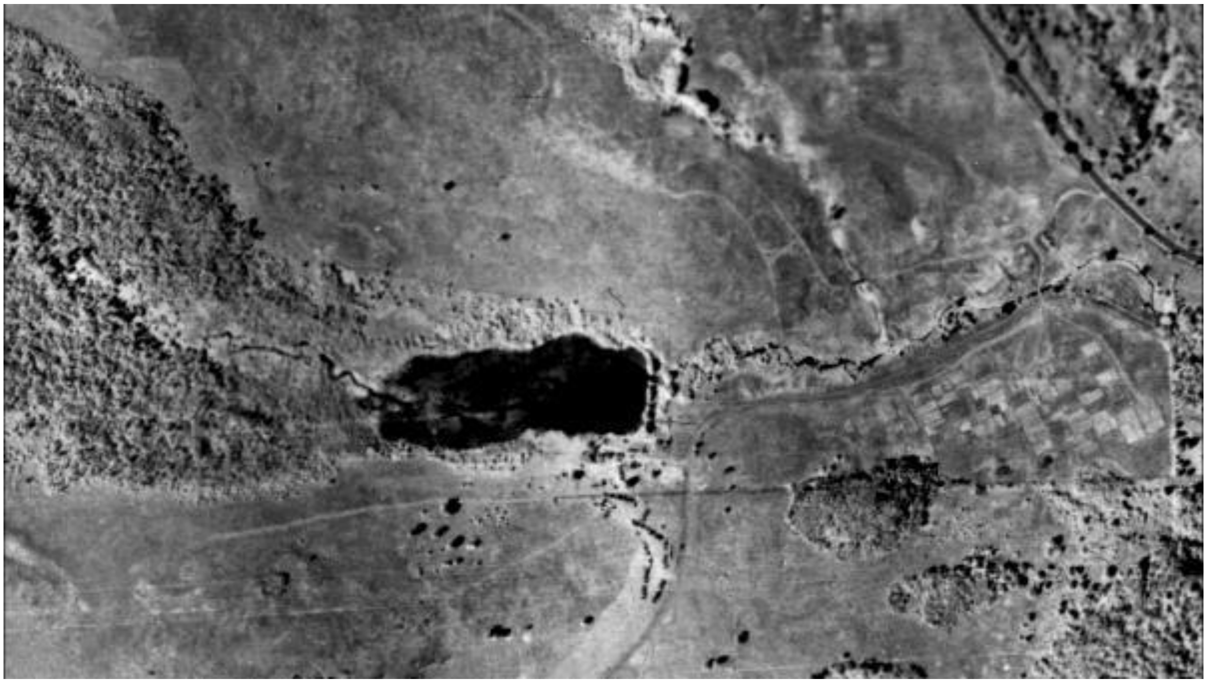


Figure 7. Aerial photography from 1948 showing the extent of Hartley Pond (UMN, 2015).

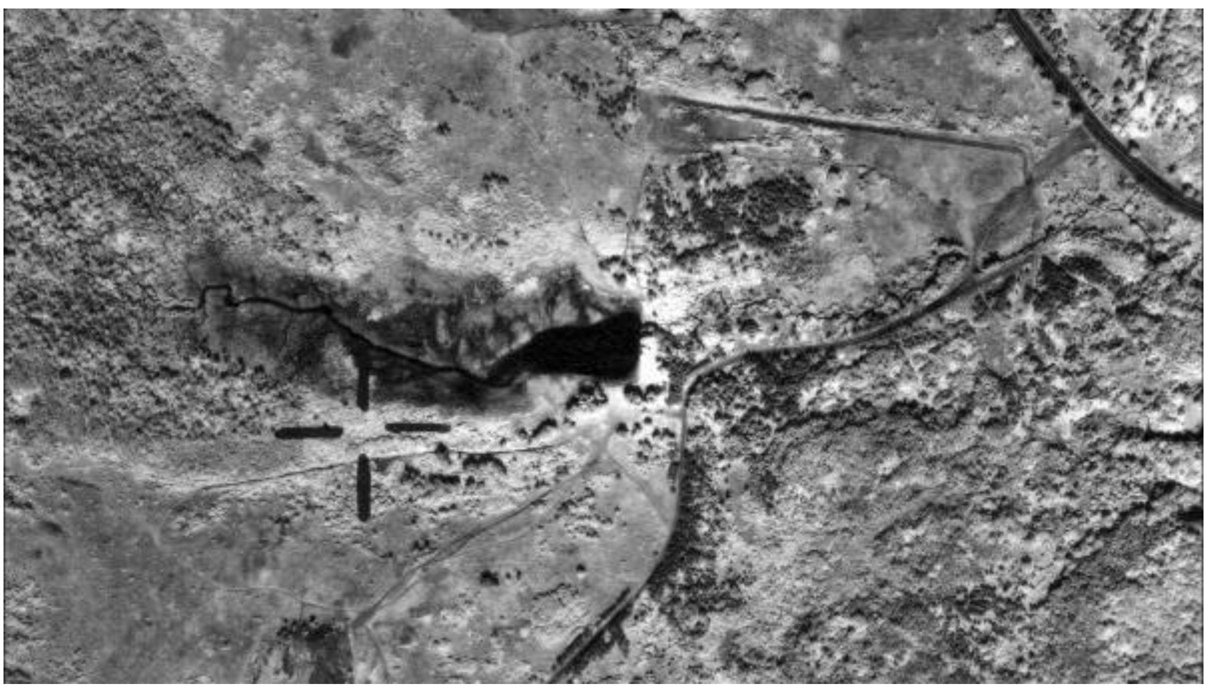


Figure 8. Aerial photography from 1972 showing the extent of Hartley Pond after the dam failure (UMN, 2015).

A series of geotechnical borings were completed in September of 1974 as a part of the construction scoping for repairing the dam. The boring locations and associated depth to bedrock are displayed in **Figure 9**. The bedrock depth in the area around the dam varies from 9.5 ft to 28 ft deep.

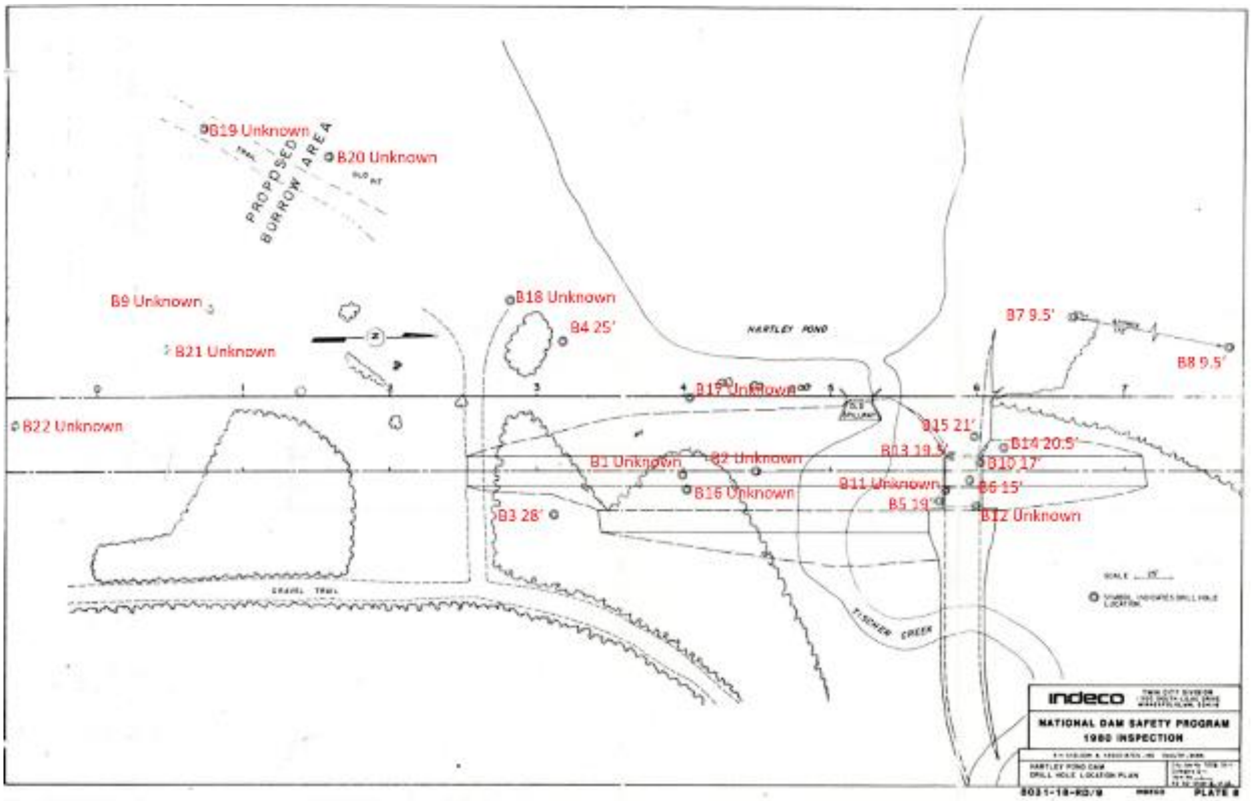


Figure 9. Geotechnical boring locations and bedrock depths from September 1974 survey (City of Duluth, 1974)

Several areas of cracking were noted in the 1980 dam safety inspection, which led to repair work in 1985. To complete the repair work, the water in Hartley Pond was nearly fully drained and the cracks were injected with epoxy (**Figure 10**). Additionally, the north and south walls were improved with thicker concrete walls. The work completed in 1985 resulted in the structure that exists today.

#2 9/18/85 WATER IN HARTLEY POND NEARLY DRAINED

#11 10/16/85 FACE OF SOUTH WALL AFTER INJECTION

Figure 10. Photos showing the draining of Hartley Pond (top) and the epoxy repairs (bottom) completed in 1985.

Currently, Hartley Pond has a surface area of approximately 11 acres and is located entirely within the City of Duluth. Emergent vegetation is visible throughout much of the western half of the basin, providing visual evidence of shallowing of the pond, with anticipated rapid succession to a wetland that would be dominated by emergent plants, such as cattails. Linear alignment of thick, floating-leaf aquatic vegetation is especially prominent along the historic stream channel of Tischer Creek in the western portion of the basin. In the event of conversion to an emergent wetland, the open-water portion of Hartley Pond would be reduced to the relatively small area near the dam, indicated in **Figure 11** (approximately 3 to 4 acres).

Figure 11. Aerial photography from 2022 showing the spatial extent of Hartley Pond (NAIP, 2022).

2.6 Biology

In 2021, the Minnesota Department of Natural Resources (MNDNR) measured instantaneous stream temperatures throughout the Tischer Creek Watershed. This study identified hot and cold spots within the watershed. Hot spots were identified within channelized, wetland, and impounded reaches. Cold spots were attributed to cold tributaries or springs that have direct groundwater input or heavily shaded areas. The 2021 data shows that there is relatively cool water flowing into Hartley Pond and warm water flowing from the impoundment downstream until Tischer intersects with a coldwater tributary downstream and temperatures reduce.

The MNDNR also conducted a trout survey and found that there are generally good populations of trout in the lower stream reaches with few or no trout directly below the Hartley Pond outlet. Upstream of Hartley Pond, the trout population is mostly absent with a small remnant population upstream of the Pond.

3. Existing Conditions

3.1 Field Work

Field work related to the project was conducted by Beaver River Consulting, GEI, and the University of Minnesota – Duluth (UMD). Beaver River Consulting collected survey-grade elevation data of the Hartley Dam components, earthen embankment, and the inlet of the secondary spillway to inform modeling efforts. Similarly, GEI captured photos of water stage height over Hartley dam during high flow events in 2023, to inform modeling efforts.

Scientists at UMD are in the process of completing a hydrologic investigation of Hartley Pond, focused on quantifying a water balance of Hartley Pond's inputs and outputs. This research utilizes a combination of field data, spatial data, and the application of equations to estimate parameters. The field data collected included the deployment of stream and lake gauges, piezometers, and a weather station. The project team coordinated with UMD staff to utilize relevant hydrological data to inform modeling efforts.

In addition, sediment thickness was measured using poling techniques at sampling point locations and along two transects at the west end of the pond to supplement sediment depth measurements previously completed by the MNDNR.

3.2 UMD Hartley Pond Water Budget

The UMD Hartley Pond water budget project is on-going and being supervised by Dr. John Swenson, an associate professor in the Earth and Environmental Sciences Department at UMD. Graduate student Madi Obertz is leading the data collection and currently continuing to work on the water balance calculations. The work includes gathering real-time, continuous rain, temperature, groundwater, and impoundment water levels (stage). The instruments were already installed when a fairly large fall rain event occurred toward the end of September 2023. The ground was already saturated when the event occurred. The event dropped more than 5 inches of rain over a 72-hour period.

The most important data set after precipitation is stage in Hartley Pond and UMD installed a continuous recording water level transducer that measures pond water level depth (stage) as a function of pressure. While the gage has yet to be tied into a surveyed elevation, the relative depth over the spillway (**Figure 12**) provides enough data to estimate both water surface elevation and flow over the dam.

Figure 12. Stage over Hartley Dam Spillway (note stage marking over the spillway- circled in red).

3.3 Floodplain Status

In the early years of Duluth's development, there were no floodplain zoning regulations limiting development in flood prone areas. In 1972, the City of Duluth adopted zoning regulations which included flood protection measures; however, the regulations were limited to a portion of the Lake Superior waterfront and did not effectively limit floodplain development throughout Duluth.

In 1974, the City of Duluth completed a hydrological study of the flood reduction capacity of the Hartley Dam as a part of the application process for the reconstruction of the Hartley Dam following the extensive damage to the earthen dam in the 1972 (City of Duluth, 1974). The completion of the hydrological study assisted with estimating floodplains associated with the 100-year flood event for Hartley Pond and approximating the flood reduction provided by the Hartley Pond and Dam system. Additionally, the United States Army Corps of Engineers (USACE) conducted a Duluth Area Stormwater Study, Hydrologic Analysis of Stream in 1974 which was integral in development of effective Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) for the City of Duluth (USACE, 1974). The hydrological study estimated that during a 100-yr. flood event, the culvert located at the Hartley field road immediately downstream of Hartley Dam would experience a peak flow of 630 cubic feet per second (CFS) without the dam and would receive a peak flow of 389 CFS with the dam, indicating that the Hartley Dam provided approximately 241 CFS of flood reduction.

The effective FEMA FIS for the City of Duluth was published in 1979 (FEMA, 1979) and became effective in 1980. The effective FIS utilized a steady-state model created in HEC-2, meaning that the flow rates remain constant over time and the model does not account for the dynamic storage properties of the Hartley Pond and Dam system. The upstream reach of Tischer Creek from the northern city limit to Hartley Road (including Hartley Pond), and the reach downstream from Vermillion Road to the confluence with Lake Superior were modeled using approximate methods which were obtained from the Duluth Area Stormwater Study (USACE, 1974). The upstream limit of detailed study for Tischer Creek within the effective FIS is located at Hartley Road, and the downstream limit is located at Vermillion Road.

The limits of detailed study in the effective FIS cover the area where flooding of man-made structures is prevalent within the Tischer Creek watershed during a 100-year flood event, which is shown on the respective Flood Insurance Rate Map (FIRM) as flood zone A. This area is prone to flooding of structures due to a variety of reasons, including the proximity of structures to Tischer Creek, undersized culverts at road crossings, and the confluence of Tischer Creek and West Tischer Creek.

In 2003, USACE completed a floodplain study of Tischer Creek to investigate flooding in the upstream reaches of Tischer Creek, reaching from 1st Avenue at the upstream limit to the culvert at Hartley Road as the downstream limit (USACE, 2003). The modeling approach studied the flood reduction potential of the Hartley Pond and Dam system, acknowledging its capacity for flood attenuation in a 100-year 24-hour storm scenario. Although the dynamic storage of the Hartley Pond and Dam system had been investigated in the hydrological study of the flood reduction capacity of the Hartley Dam (City of Duluth, 1974), the estimated flows associated with a 100-year 24-hour storm scenario in the 2003 USACE investigation are much more closely aligned with the flows identified in the effective and the preliminary FIS (FEMA, 1979 and 2022). The study estimated a peak flow of 1,290 CFS just upstream of Hartley Pond and a peak flow of 970 CFS at the Hartley Dam outlet, suggesting a peak flow reduction of 320 CFS.

FEMA is in the process of updating the FIS for St. Louis County, Minnesota, and released a preliminary FIS in October 2022 which is available to the public. The preliminary FIS model is a steady state model, created using a combination of ArcGIS, regression equations, HEC-GeoRAS, HEC-HMS, and HEC-RAS. Like the effective FIS model, the preliminary FIS model does not account for the dynamic storage properties of the Hartley Pond and Dam system. The upstream reach of Tischer Creek from the 1st Avenue to 450 ft. upstream of Hartley Road (including Hartley Pond), and the reach downstream from Vermillion Road to the confluence with Lake Superior were modeled using approximate methods. These analyses were carried out in 2016 using regression equations for the hydrologic component, and HEC-RAS 4.1 for the hydraulic component. The detailed study area spans from approximately 450 ft upstream of Hartley Road to approximately 90 ft downstream of Vermillion Road, which was investigated in 2021 using HEC-HMS 4.2.1 for the hydrologic component and HEC-RAS 5.0.5 for the hydraulic component (**Appendix A**). The floodplain boundaries were delineated using multiple topographic elevation data sources, all of which have less than ½ ft resolution. The current effective FIS model estimates a peak flow of 900 CFS where Tischer Creek intersects Lewis Street, approximately 7,130 ft downstream of Hartley Pond (FEMA, 1979). The preliminary updated FIS model estimates a peak flow of 1,267 CFS approximately 150 ft downstream of Fairmount Street, which is approximately 3,480 ft downstream of Hartley Pond (FEMA, 2022).

3.4 Hydrologic and Hydraulic Modeling

This study evaluates the hydrology and hydraulics of the watershed and creek upstream of the dam and downstream relative to existing conditions for proposed alternatives. We examined how precipitation is turned to streamflow; travels to the impoundment, and how fast the water rises up and goes over the dam.

Fortunately for this project, the University of Minnesota at Duluth (UMD) has been contemporaneously measuring the components of the hydrologic cycle of Hartley Pond. Their data has helped us establish what we believe is a stronger relationship between rain and streamflow than our first iteration of the watershed and creek model.

The models used for this project include:

1) U.S. Environmental Protection Agency (USEPA)'s (Storm Water Management Model) SWMM of the watershed, creek, and dam.
2) The hydraulic input from the upstream, approximate FIS HEC-RAS model. https://www.MNDNR.state.mn.us/waters/watermgmt_section/floodplain/fema_app.html
3) The hydraulic and hydrologic input from the detailed downstream FIS HEC-RAS model.

The USEPA SWMM freeware model was the main model used for this evaluation because it simulates hydrology and hydraulics together; is relatively easy to set up and adjust and is also one of the most frequently used and highly regarded urban runoff models on the market. We used the peak flow coming over the dam as the upstream boundary condition for the downstream HEC-RAS model. The downstream model started approximately 450 ft upstream of Hartley Rd. and ran to approximately 90 ft downstream of Vermillion Rd, an approximate stream length of 13,000 ft.

We added a very shallow groundwater layer to the watersheds of the Hartley Pond SWMM model and established a better correlation between model and stage data. It is important for us to distinguish here that this as a preliminary process. Design will be best served by calibrating to a longer and more complete rainfall, pond stage and creek flow data set. The current monitoring should continue into design and be used to improve model calibration and build more confidence in the model's future condition projections.

3.4.1 Existing Conditions Modeling

The model starts in the uppermost reaches of Tischer Creek and includes the associated watershed and the creek to approximately 785 ft downstream of the Hartley dam (**Figure 13**). The stream channel dimensions, and slope were approximated from aerials and topographic data. This includes approximately 3.2 miles of Tischer Creek and three unnamed tributaries. The confluence of Tischer Creek and West Tischer Creek is located approximately 1.9 miles downstream of the model boundary, and Tischer Creek enters Lake Superior approximately 3.2 miles downstream of the model boundary. The hydrology of the existing conditions was evaluated by modeling the area of investigation with the SWMM version 5.2 software (U.S. EPA, 2022). The focus of the SWMM model is to investigate the dynamic storage of the Hartley Pond and Dam system to understand the storage capacity and estimate the flow reduction in a 100-year, 24-hour precipitation event. The model was primarily constructed using information from FEMA models and reports, readily available spatial data, survey data, rain gauge and pond stage data, and SWMM model calculated flows were compared to FEMA flows (Existing Conditions SWMM model inputs and outputs can be found in **Appendix B**).

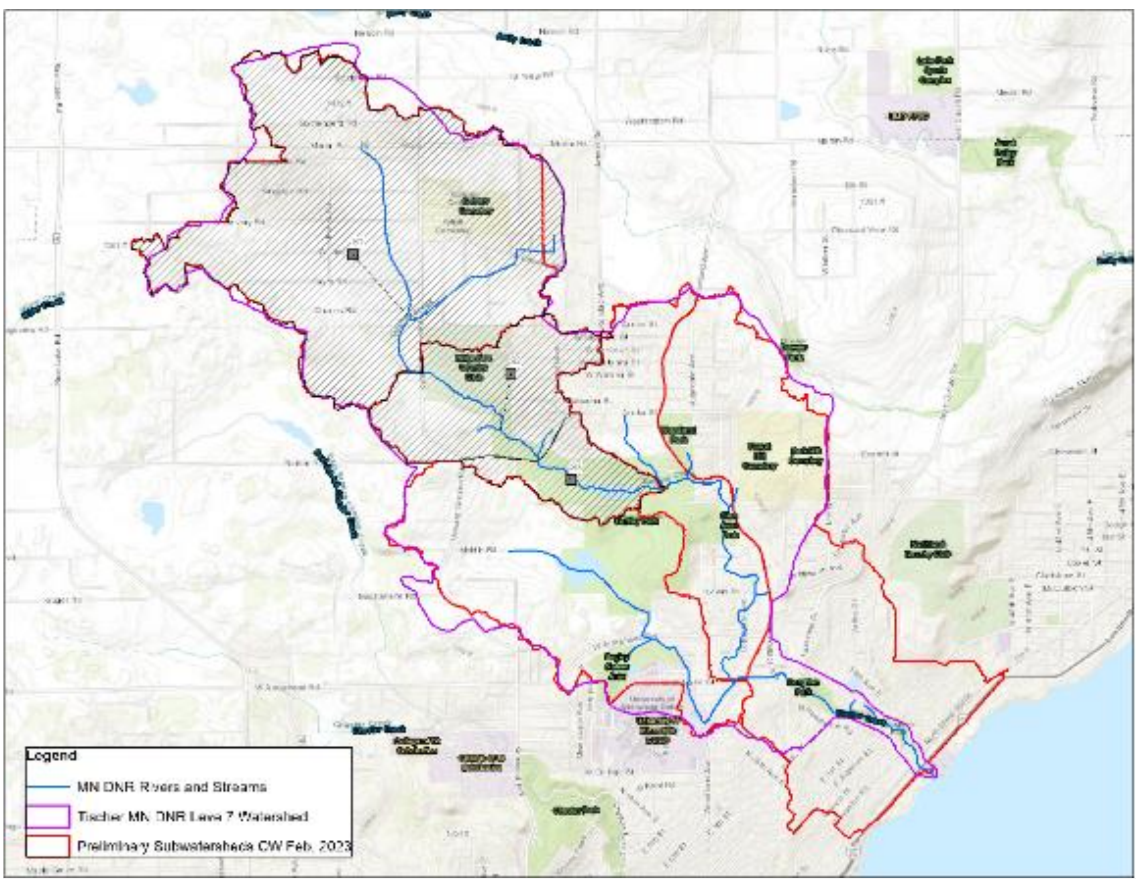


Figure 13. Tischer Creek watershed with Hartley Pond contributing sub-areas shown in cross-hatching.

3.4.2 Existing Conditions Hydraulic Model

The area of investigation is included in the current effective FEMA model (FEMA, 1979). The original effective model was created in HEC-2 in 1977. FEMA is in the process of updating the Flood Insurance Study (FIS) and associated FIRM panels for the entire length of Tischer Creek, and the preliminary data has been made available to the public and the preliminary model was available from FEMA (FEMA, 2022). The FEMA models do not account for the dynamic storage of the Hartley Pond and dam system, which has implications for reducing downstream flow. Information from both the effective FIS and the preliminary FIS update were referenced to inform and calibrate the SWMM model. The following sections provide additional information on model creation.

3.4.3 Existing Conditions SWMM Model

Precipitation

The NOAA Atlas 14 Point Precipitation Frequency Estimates tool was used to estimate the total precipitation for a 100-year, 24-hour event as 6.41 inches for the area just upstream of Hartley Pond (NOAA, 2023). The 6.41 inches of precipitation was distributed to the model using a NRCS Type II distribution at 15-minute intervals over the 24-hour period.

Subcatchments

The subcatchment boundaries shown in **Figure 13** were estimated from two sources – existing watershed boundaries from the MNDNR level 7 hydrography dataset (MNDNR, 2023), and delineation of the watershed and sub-watersheds using the watershed tool in ESRI ArcMap 10.8 software (ESRI, 2023), using the USGS half-meter LiDAR dataset as the terrain source (USGS, 2022). In most locations, the subcatchment boundary uses the boundary from the delineation using the LiDAR data, however the boundary from the MNDNR level 7 hydrography dataset was used in the northeast area to better capture the upper reach of Tischer Creek. Basic subcatchment properties such as area, slope, etc., were calculated using spatial tools in ArcMap 10.8, including the subcatchment area, overland flow width, and average slope. After initial tests of the SWMM, the lower subcatchment was refined into two subcatchments to provide finer resolution in the area surrounding Hartley Pond.

Soil and Infiltration Parameters

Soils data was downloaded for the subcatchments from the NRCS Web Soil Survey (NRCS, 2023). The SWMM was constructed using the Green-Ampt approach, which requires inputs for average capillary suction, saturated hydraulic conductivity, and initial moisture deficit for each subcatchment. These values were estimated for each of the three subcatchments by calculating an area weighted average of the values provided in the Estimation of Green-Ampt Infiltration Parameters table by soil texture class as recommended by the SWMM manual (https://www.epa.gov/sites/default/files/2019-02/documents/epaswmm5_1_manual_master_8-2-15.pdf), as well as saturated hydraulic conductivity rates provided in the NRCS soil report. In general, the more conservative saturated hydraulic conductivity rate was selected. The value for the initial soil moisture deficit was chosen from the Moist Soil Climates column.

The NRCS polygons which were predominantly comprised of bedrock in the upper ~18 inches of the soil profile were removed from the area weighted average calculation described above and were included in the estimation of the percentage of impervious surface. In addition to the bedrock, the precent of impervious surface area coverage was estimated using the National Land Cover Database (USGS, 2019). The estimation was calculated with the following assumptions – Developed, Low Intensity (20% impervious), Developed, Medium Intensity (25% impervious), Developed, High Intensity (30% impervious), Emergent Herbaceous Wetland (100% impervious), Open Water (100% impervious). The Emergent Herbaceous Wetland and Open Water classes were included in the impervious surface percentage as these were assumed to be areas of full saturation.

Channel Model

The area of investigation includes approximately 3.2 miles of the upper section of Tischer Creek. To construct the channel and floodplain geometry in the SWMM model, cross section profiles were cut from the half-meter LiDAR (USGS, 2022) using the HEC-RAS 6.3.1 software (USACE, 2022). The cross-section station and elevation values were then copied into SWMM to construct the cross sections.

Manning's *n* is the model coefficient that represents the relative roughness or resistance to flow for the streambed, banks, and floodplain. The larger the Manning's *n* coefficient, the higher the drag forces from the bed and banks, slowing water velocities and raising water surface elevations. Manning's *n* values for the creek channel and overbanks were set to match the HEC-RAS model inputs from the preliminary FIS. A Manning's *n* coefficient of 0.15 was used to represent the forested floodplain areas, and a value of 0.11 was used to represent the overbank areas (Chow, 1959). A value of 0.06 was used to represent the Tischer Creek channel.

Hartley Pond Storage and Full Embankment Storage

In the SWMM model, Hartley Pond is represented by a storage unit node, which receives flow from Tischer Creek upstream, and drains downstream to Tischer Creek through a weir as the primary spillway. The storage unit was constructed using Hartley Pond bathymetry (**Figure 14**) data to accurately represent the area of storage for each 1-ft increment of depth, reaching a total depth of 8.6 ft at 1191 ft elev. at the bottom of the pond. Additionally, the storage of the full embankment height was estimated by using surveyed elevation data from the top of the embankment to measure the height difference from the bottom of the weir spillway to the top of the embankment, and the area of that elevation was approximated using ESRI ArcGIS Pro. The weir spillway was surveyed at 1199.6 ft elev., with the top of the embankment at 1207 ft elev.

The additional embankment storage allows for the model to account for a backwater effect in the scenario where inflow to Hartley Pond is exceeding outflow. Hartley Pond's water level was set to an initial depth of 8.6 ft so that water entering the pond would immediately begin spilling over the weir during the model simulation.

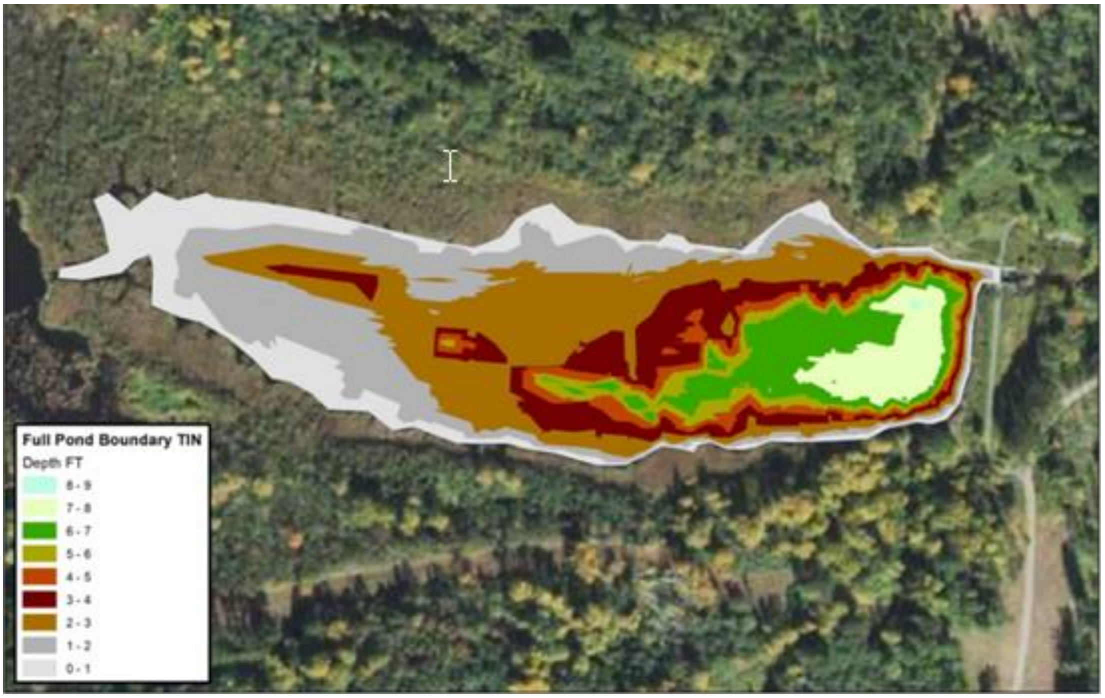


Figure 14. Hartley Pond bathymetry (MNDNR).

Hartley Dam and Overflow Spillway

The SWMM model includes two spillways out of Hartley Pond, the weir as the primary spillway and the overflow channel as the secondary spillway. The spillway elevations were determined by using GPS-surveyed data and measuring dimensions in the field. The weir is modeled as a transverse weir, with a horizontal crest length of 20 ft and a vertical weir opening height of 7.4 ft. The overflow (emergency spillway channel) invert elevation is set at 1203.0 ft. This is the elevation at which the water will spill into the overflow spillway which is 3.4 ft above the height of the primary spillway. The inlet of the secondary spillway is offset approximately 1 ft higher than the designed secondary spillway channel due to the presence of a walking trail along the edge of Hartley Pond.

Boundary Conditions

The model's upstream boundary is defined by the precipitation gauge in the uppermost subcatchment, which is routed to the confluence between Tischer Creek and the first unnamed tributary. The total precipitation for the 100-year, 24-hour event inputs 6.41 inches into each subcatchment over the 24-hour precipitation event. The downstream boundary is located approximately 785 ft downstream of Hartley Dam, and is set up as an outfall, defined by the invert elevation of the stream channel at this location (1186.7 ft).

3.4.4 Preliminary Calibration

A large two-day precipitation event occurred on September 23 and 24, 2023. UMD recorded the precipitation event with the weather station located on the south side of Hartley Pond and the lake gauge located on the north shoreline of Hartley Pond near the dam. UMD provided the data to the Hartley Dam Feasibility Study team to allow for data comparison to the existing conditions model. The September storm event resulted in 5.43 inches of precipitation over approximately 48 hrs. The event is roughly classified as a 25-year recurrence interval and resulted in an increase of 3.4 ft in water level within Hartley Pond.

The weather station and lake gage data were used as input data to create a SWMM model run to evaluate the model's accuracy against a large precipitation event. The data comparison indicated that the model was underestimating the flooding effect from the event, resulting from the model not accounting for shallow groundwater flow into the stream during the event. To account for this effect, the groundwater flow parameters were enabled and adjusted for all three subcatchments in the SWMM model to allow for portions of infiltrated water to be considered shallow groundwater flow and entered the stream flow. By enabling and adjusting the groundwater settings, the existing conditions model results more closely match the change in water level recorded in Hartley Pond (**Figure 15**).

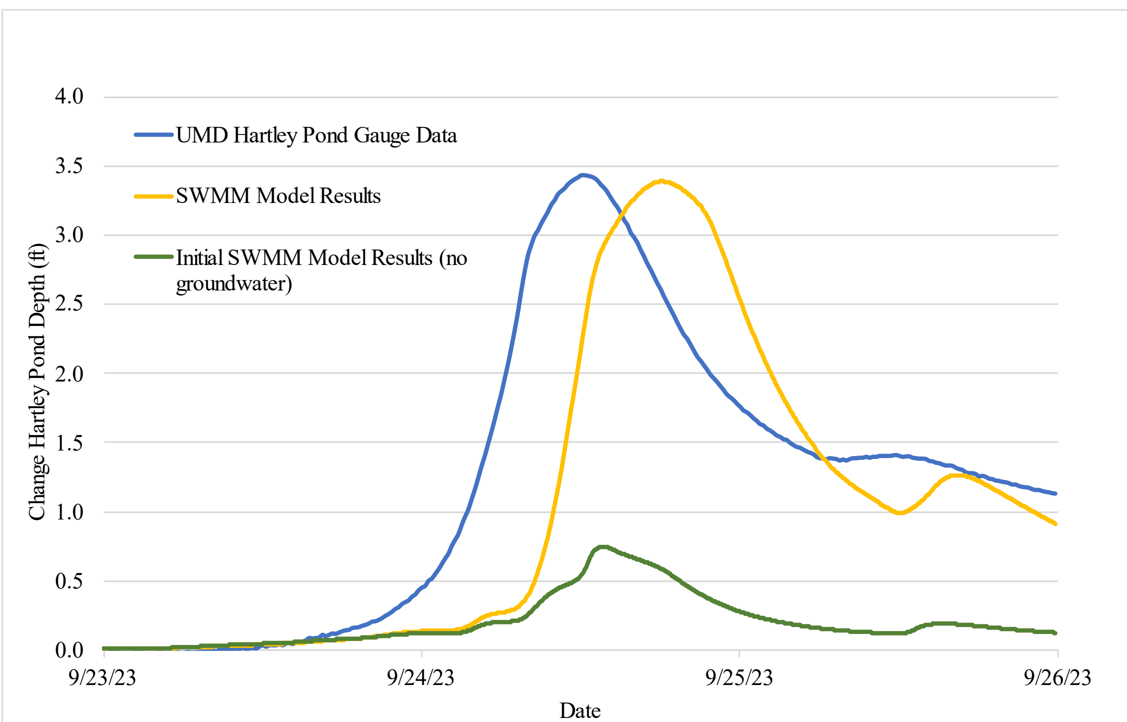


Figure 15. Hydrograph comparing the change in water level of Hartley Pond associated with the September 2023 precipitation event between the UMD Hartley Pond gage data and the SWMM existing conditions models.

The model input parameters, including watershed slopes, widths, and stream slopes and widths, were not adjusted to account for travel time. Thus, the model is calculating slower travel times than what was recorded at the Hartley Pond gauge. The primary focus of the model is to accurately represent the flooding peak flows and volumes that are entering Hartley Pond to understand how the Hartley Pond and Dam system behaves during flood events.

The data collected by UMD and the results from the SWMM model indicate that most of the precipitation from the storm event made its way to Hartley Pond via shallow groundwater flow and surface runoff. Although the region experienced drought throughout much of July and the entirety of August, multiple precipitation events had occurred in the weeks prior to 9/23, with one event resulting in 2.7 inches of rain on 9/5 (**Figure 16**). These precedent conditions would have resulted in a high groundwater table and reduced capacity for deep infiltration. Additionally, cooler temperatures preceding 9/23, as well as during the 9/23 and 9/24 event, may have reduced water uptake from vegetation in the watershed.

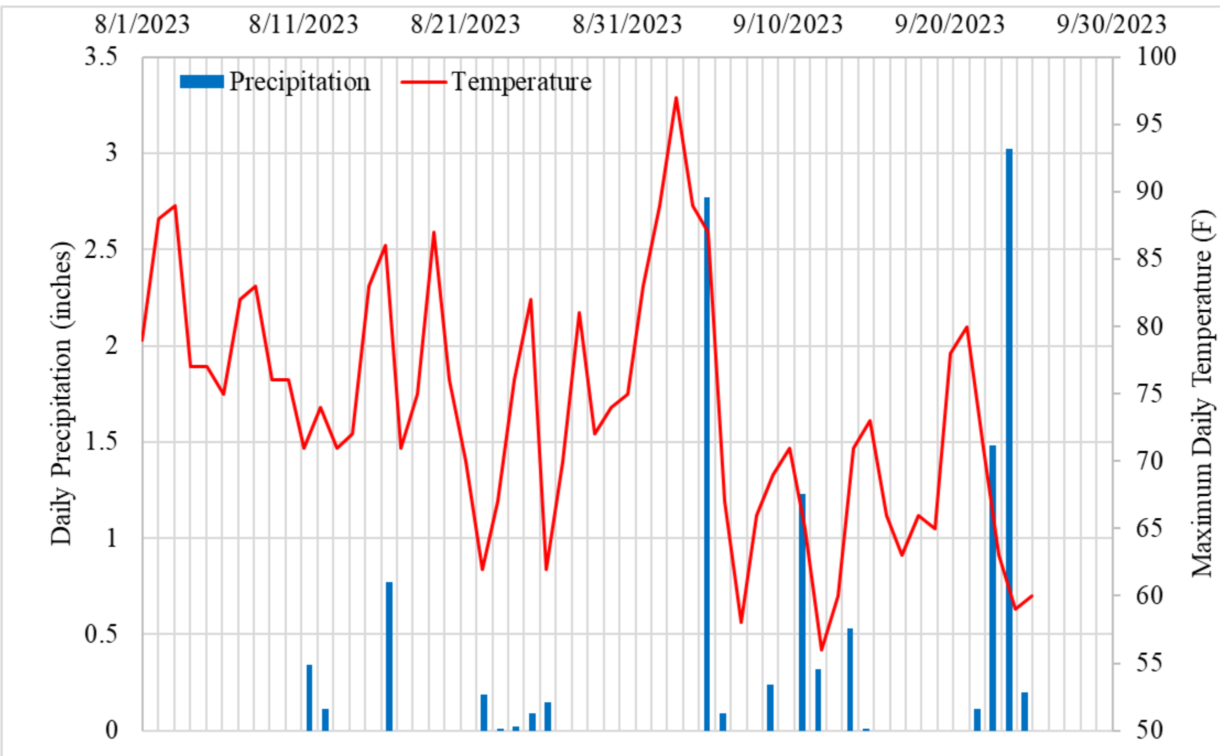


Figure 16. Air temperature and precipitation preceding the precipitation on 9/23 and 9/24. The data is from the weather station at the Duluth International Airport (NOAA, 2023a).

The changes to the SWMM model resulting from the UMD data comparison were used for the evaluation of the resulting flows from a 100-yr, 24-hr precipitation event.

3.4.5 Existing Conditions Model Summary

The Tischer Creek dynamic storage SWMM model estimates that a 100-yr, 24-hr precipitation event (6.41 inches of precipitation), a peak flow of 1,223 CFS enters Hartley Pond, with a 680 CFS peak flow downstream of Hartley Pond (**Table 1, Figure 17**). These results suggest that the Hartley Pond and surrounding embankment system has a capacity to provide 543 CFS reduction in flow resulting from a 100-yr, 24-hr precipitation event. The primary and secondary spillways were both active during the event simulation, with the primary spillway accounting for most of the flow (approximately 641 CFS).

Table 1. Existing Conditions Model Results Summary of the 100-yr, 24-hr Precipitation Event Simulation.

	Existing Conditions SWMM Model (100-yr, 24-hr Precipitation Event)
Total Precipitation (inches)	6.41
Peak Flow into Hartley Pond (CFS)	1,223
Peak Flow Downstream of Hartley Pond (CFS)	680
Peak Flow over Hartley Dam (CFS)	641
Peak Water Depth over Hartley Dam (feet)	4.5
Peak Flow through Secondary Spillway (CFS)	39
Peak Flow Reduction Capacity (CFS)	543

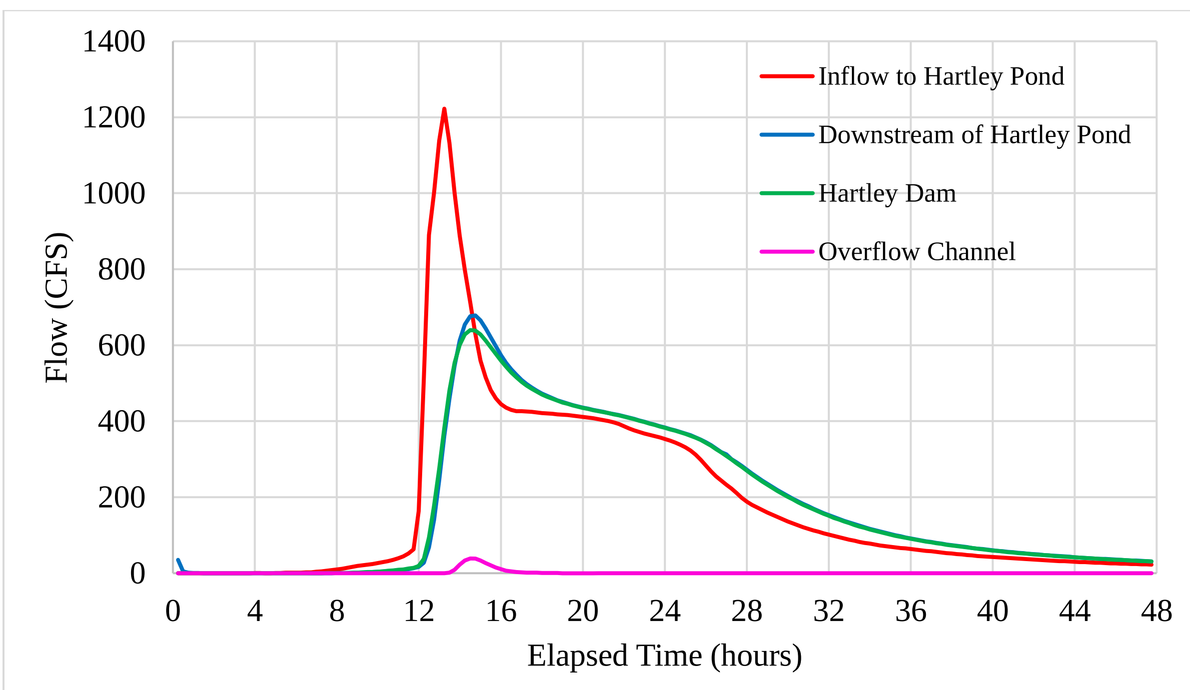


Figure 17. Modeled inflow and outflow of Hartley Pond, and flow over Hartley Dam and through the overflow channel for 100-yr, 24-hr precipitation event.

It is important to note that the pond's capacity for peak flow mitigation may be dependent on the intensity and duration of the precipitation event. The 100-yr, 24-hr precipitation event represents a flashy precipitation and stream flow event, where there is an intense and short-duration period of rain, resulting in a short duration of high flow within the stream channel. It may be that for certain snowmelt or rain on top of snow melt events that the peak flow is maintained to the point that the dam passes all the water flowing through the system.

4. Alternatives Evaluation

The project focuses on evaluating alternatives for the restoration and management of Hartley Pond, aiming to balance three critical, yet conflicting objectives: cooling the heat-gaining aspect that Hartley Pond has on the creek, restoring fish passage and longitudinal connectivity, and maintaining flood attenuation benefits of the impoundment storage. The alternatives evaluation took into consideration, stakeholder feedback, the SWMM model, and the use of a Multi-Criteria Decision Analysis (MCDA). We also estimated implementation costs for each alternative.

Stakeholder engagement played a pivotal role in shaping the project's direction, ensuring that the proposed solutions align with both ecological and community interests. Financial support from city, state, and federal government hinges on meeting the project criteria, with coldwater stream restoration being a priority for funding agencies like the State of Minnesota, USEPA, NOAA, and others. Engaging stakeholders ensured that the proposed solutions would meet ecological and community interests, highlighting the project's commitment to collaborative decision making and the importance of meeting all project criteria to gain support.

The alternatives modeling was performed using the preliminarily calibrated SWMM model described in Section 3.4. Model input and output files are included in **Appendix C** and digital copies of the models will be sent to the City of Duluth as a separate deliverable. This model represents baseline existing conditions and provides the peak flow reduction target for the 100-year precipitation event that alternatives must achieve. The project employed the SWMM and the UMD pond water balance data to assess how well various alternatives could achieve the project's hydraulic objectives. The modeling was essential for understanding the impact of the proposed changes on basin hydraulics without altering watershed hydrology. The modeling process also included the use of natural channel design principles and advanced LiDAR data to approximate channel shape for model cross-sections, providing a detailed analysis of feasibility in terms of construction, cost, hydrology, and hydraulics.

Off-line Pond

Because the dam removal and open-bottom culvert alternatives drain the impoundment, each of them includes construction of an off-line pond in the stream floodplain in order to retain a pond feature in Hartley Park. This pond option would potentially satisfy some stakeholders who would like to continue to see a pond in Hartley Park. However, we did not create a separate H/H model for the pond sub-alternatives because we assumed the pond would not add substantial storage to these alternatives since the pond would likely already be filled with groundwater or surface water before potential flooding events occur. The open-bottom culvert alternative also includes a sub-alternative without a pond. The sub-alternative without a pond was included to evaluate an alternative scenario where constructing an off-line pond is not completed due to community sentiment, cost, shallow bedrock, or some other reason.

The assumption that the pond would be sustained through groundwater inputs is partly what prompted the UMD Hartley Pond water balance study. An interpretation of the UMD data is that dry weather conditions may negatively impact pond water levels. State resource professionals on the Steering Committee were not as concerned that a pond excavated into the groundwater table would have water level dramatically impacted by weather conditions, based on anecdotal observations of other isolated ponds around Duluth and throughout Minnesota. Understanding that a ponds water level would be influenced by precipitation and groundwater, the UMD data should be referred to during future decision-making processes, along with an analysis of other small, isolated ponds in Minnesota.

Tischer Creek and Hartley Pond are identified as “Public Waters” on the Minnesota Public Waters Inventory maps authorized by Minnesota Statutes, Section 103G.201. Elimination of a public waters requires the completion of a mandatory Environmental Impact Statement (EIS) and trout stream realignment or more than 1-acre of excavation in a public water requires a mandatory Environmental Assessment Worksheet (EAW). Alternative 1 would result in no change to public waters. Alternatives 2, 3, and 4 would result in a modification and/or excavation of the Hartley Pond public water and realignment of the Tischer Creek (trout stream) public water. The modification of the public waters may not require an EIS for removal of the public water of the state (pond), if changes to the pond are considered partial drainage/changing the dimensions of the pond, rather than elimination. While an EIS may not be required, an EAW will be required because of the trout stream realignment, Hartley Pond modification, or the potential off-line pond excavation.

Multi-Criteria Decision Analysis

The MCDA process was a key component in evaluating the alternatives against both qualitative and quantitative criteria. This approach helped to reduce ambiguity in the decision-making process by objectively ranking the strengths and weaknesses of each alternative. The MCDA criteria were grouped into three categories: ecological restoration, channel/floodplain connectivity, and direct human benefits (**Table 2**). These categories encompassed a range of considerations including habitat access for aquatic species, restoration of natural hydrologic regimes, and human use benefits like flood control, fishing, and education. The MCDA facilitated an informed evaluation of each alternative’s potential performance, emphasizing the project’s goal of finding a balanced solution that addresses the complex needs of the ecosystem and the community.

Table 2. Criteria used to rank alternatives for the MCDA

Ecological Restoration	Restore to natural conditions
	Restore natural stream hydrology (no in-line impoundment)
	Enhance temperature and sediment transport
Channel/Floodplain Connectivity	Restore longitudinal and lateral connectivity (including fish passage)
	Restore a stable floodplain and habitat diversity
Direct Human Benefits	Do not increase risk of flood damage downstream
	Enhance brook trout fishing
	Maintain recreational services
	Maintain or enhance educational opportunities

Finally, estimated costs were approximated. For alternatives that drawdown the pond, there will be sediment to manage. Currently our estimates of total sediment to manage are crude and sediment management can often be a driving factor in overall dam removal management costs. Our quantity estimates are speculative at this point, which means the cost estimates are high level for planning purposes only.

It is important to note that for the purposes of the feasibility study, the level of investigation of design and modeling of each alternative has been carried out to evaluate whether each alternative could be considered realistic regarding construction, cost, water flow, water storage, aquatic habitat and fish passage, and other environmental and social factors.

4.1 Alternative 1 – No Action

This alternative maintains the current status quo, with the dam structure remaining in place without any modifications or interventions. This alternative serves as a baseline against which the impacts of the other alternatives are compared. The existing dam structure will continue to function as is.

4.1.1 Alternative 1 – No Action Modeling

Alternative 1 is the no-action alternative that leaves the current Hartley Pond and Dam system in place. Detailed information regarding the existing conditions modeling is provided in Section 3.4. The Tischer Creek dynamic storage SWMM model estimates a peak flow of 1,223 CFS entering Hartley Pond, and a 680 CFS peak flow leaving Hartley Pond. These results suggest that the Hartley Pond and surrounding earthen embankment system has a capacity to provide approximately 543-CFS reduction in flow during a 100-yr, 24-hr flood event. The primary and secondary spillways were both active during the event simulation, with the primary spillway accounting for most of the flow (approximately 641 CFS).

Along with evaluation of existing conditions, a variety of climate change scenarios were applied to the model to see how much more likely embankment overtopping would be. Overtopping for an earthen embankment is essentially considered a primary failure mode by dam designers. Dam break modeling usually assumes a massive rain event overtops the embankment and the embankment fails as it gets progressively overtopped. Dam breach modeling for the Hartley Dam was conducted by Barr Engineering for Duluth in 2014 (Barr, 2014).

To understand the resiliency of the Hartley Pond Dam and earthen embankment, three additional precipitation event scenarios were analyzed using the existing conditions model to evaluate the current system in the context of larger 100-yr, 24-hr precipitation event resulting in higher flows entering the system. The climate change scenarios investigated consist of the EPA CREAT "stormy" 2035 projection, EPA CREAT "stormy" 2060 projection, and the 0.3 Probable Maximum Precipitation (PMP) scenario.

EPA CREAT "Stormy" 2035 Scenario

Under the EPA CREAT projections for the stormy scenario, the 100-yr, 24-hr storm precipitation totals would increase to 7.13 in. of precipitation by 2035. The 7.13 inches of precipitation was distributed to the existing conditions model using a NRCS Type II distribution at 15-minute intervals over the 24-hour period. The existing conditions model estimates a peak inflow to the pond of 1,507 CFS into the pond, with a peak downstream outflow of 881 CFS. Both the primary and secondary spillways were active during the model run. In this scenario, Hartley Pond is projected to reach a maximum depth of 13.7 ft during the flood event.

EPA CREAT "Stormy" 2060 Scenario

Under the EPA CREAT projections for the stormy scenario, the 100-yr storm precipitation totals would increase to 7.81 in. of precipitation by 2060. The 7.81 in. of precipitation was distributed to the existing conditions model using a NRCS Type II distribution at 15-minute intervals over the 24-hour period. The existing conditions model estimates a peak inflow to the pond of 1,793 CFS into the pond, with a peak downstream outflow of 1,092 CFS. Both the primary and secondary spillways were active during the model run. In this scenario, Hartley Pond is projected to reach a maximum depth of 14.1 ft during the flood event.

Probable Maximum Precipitation Scenario

For dam break modeling of Hartley Pond Dam, the state would likely require the use of a Probable Maximum Precipitation (PMP) event. In this case the storm size evaluated would be the 0.3*PMP. The rainfall estimate for the 0.3 PMP event was attained from NOAA's "Hydrometeorological Report No. 51-Probable Maximum Precipitation Estimates, United States, East of the 105th Meridian" (1978), and is estimated as 9.5 inches of precipitation. The 9.5 inches of precipitation was distributed to the existing conditions model using a NRCS Type II distribution at 15-minute intervals over the 24-hour period. The existing conditions model estimates a peak inflow to the pond of 2,524 CFS into the pond, with a peak downstream outflow of 1,604 CFS. Both the primary and secondary spillways were active during the model run. In this scenario, Hartley Pond is projected to reach a maximum depth of 15.1 ft during the flood event.

In the context of a changing regional climate which is projected to experience both increased annual precipitation and more intense storms, it is important to evaluate how the existing conditions may handle these larger events. Hartley Pond is estimated to have a maximum capacity of 16 ft of water depth prior to over-topping the earthen berm, at which point the risk of catastrophic failure substantially increases. The results from these three climate scenarios suggest that increased annual precipitation and more intense storms would result in higher stress on the dam, with a higher probability of dam failure due to overtopping.

4.1.2 Alternative 1 – No Action MCDA

This alternative is the status quo. This means leaving the dam and pond in place; on the one hand the flood control benefit of the dam remains in place if the dam remains in place. On the other hand, the inevitable long-term succession of an in-line pond in a suburbanizing landscape is to become wetland. This will happen both as the watershed leaches solids to the creek and as the creek picks up its own bed, erodes its own banks, and ends up in the pond. Also, as the pond shallows and heats up in the summer, plant and algae growth accelerate, leading to ever increasing sources of organic detritus at the bottom of the pond. Hartley Pond is experiencing anthropogenic-enhanced pond to wetland succession.

This alternative has benefits from a flood control perspective; however, Hartley Dam is classified as a Class I - High Hazard Dam by Minnesota Rule 6115.0340: Defined as, failure of dam would probably result in "loss of life or serious hazard, damage to health, main highways, high-value industrial or commercial properties, major public utilities, or serious direct or indirect, economic loss to the public. " This dam can impound ~15-ft of water in a flood and is composed of a concrete spillway and an earthen embankment. The likely failure mode of this kind of dam is through the loss of integrity of the embankment. Earthen embankments can lose their integrity slowly as root and animal activity bore away inside and water seeps through in unexpected ways. This is referred to as a piping failure. Embankments can also give way all at once and fail catastrophically. The assumed failure mode for dam break analysis with embankment overtopping is for the embankment wall to give way nearly instantaneously. The Hartley Pond Emergency Action Plan (EAP) addresses both kinds of potential embankment failures (Barr, 2014).

With the replacement of the spillway in the late 80’s, and assuming a 50-year lifespan, the dam may have another 15 to 20 years of life remaining. While the embankment is not showing any obvious signs of failure, as the years wear on, inspection and planned maintenance will need to become more frequent. The EAP recommends two formal inspections a year and an inspection after all potential emergency events.

Assumptions:

- Ongoing inspection and maintenance will be required to ensure that the dam, including the embankment is currently and continues to be structurally sound. The dam will have to be rebuilt when it reaches the end of its serviceable life.
- The pond is in an active state of anthropogenic succession to a wetland and without intervention (e.g., dredging) it will result in an emergent wetland and reduced open water area.
- The dam will continue to meet its current purpose of flood flow reduction.
- No permitting or regulatory processes associated with dam modification or removal.
- No immediate new costs; only ongoing maintenance and future replacement.

Strengths:

- No immediate capital costs.
- Does not disrupt current stakeholder interests or land uses.
- Reduces the 100-year storm peak flows.

Weaknesses:

- Maintains a Class I - High Hazard Dam.
- Is a fish passage barrier.
- Degrades water quality, affecting temperature and dissolved oxygen levels.
- Traps sediment, causing stream instability both upstream and downstream.
- Alters natural flow pattern and connectivity.
- Ongoing maintenance costs (emergency spillway clean-out and embankment maintenance).
- Potential for higher future costs due to repairs or emergency actions.
- Dam safety concerns increase with age.
- Loss of potential benefits from restoration, such as improved ecosystem function and connectivity.
- Vulnerability to climate change impacts.

Unknowns/Considerations:

- Long term maintenance.

Table 3. MCDA Scores for Alternative 1: No Action

Feasibility Criteria	Criteria Score[1]	Comment
Restore natural stream hydrology	1	Impoundment negatively alters natural stream hydrology
Restore a stable floodplain and habitat diversity	1	Not possible with impoundment
Enhance temperature and sediment transport	1	Not possible with impoundment
Restore longitudinal and lateral connectivity	1	Not possible with impoundment

Maintain recreational services	4	Requires ongoing maintenance of the pond
Enhance brook trout fishing	1	Not possible with impoundment
Restore to natural conditions	1	Impoundment is not the natural condition
Maintain or enhance educational opportunities	3	Requires ongoing maintenance of the pond
Do not increase risk of flood damage downstream	5	There will be no change in risk of flood damage downstream but leaves a high hazard dam in-place
Total Criteria Score	**18**	

Notes: [1]Criteria scoring scale of 1 to 5. 1 = lowest potential for meeting criteria and 5 = highest potential for meeting criteria.

4.1.3 Alternative 1 – No Action Estimated Implementation Cost

Costs associated with Alternative 1 are difficult to quantify and are dependent on factors such as long-term maintenance, major repairs, and/or replacement of embankment or spillway; maintenance/dredging of Hartley Pond; and costs associated with catastrophic failure of the dam. At a minimum, Operations and Maintenance (O&M) costs would be required to maintain the status quo. O&M = cost of all work ever done on the dam since original construction; in current dollars divided by the number of years over the period of work.

4.2 Alternative 2 – Stream Route Around

Alternative 2 proposes to re-direct the stream to a new, naturalized channel running along the north side of the pond and through the existing emergency spillway while maintaining the existing dam structure. Flows at or below bankfull will be directed to this new channel. An earthen berm will be constructed linearly between the new channel and the north side of the pond. This will, serve as a physical barrier between the newly created stream channel and the pond, preventing direct hydraulic interaction and controlling uncontrolled overbank flows and potential erosion. Upstream of the reconfigured channel, a control structure will be installed at the juncture of Tischer Creek and the new channel. This feature will be engineered to initiate a deliberate overflow into the pond behind the existing dam when the creek is at or above bankfull stage, thereby utilizing the dam’s capacity for flood storage during peak flow events.

The control structure is envisioned to be either a riprap or concrete weir with the overflow set at bankfull elevation. The structure would be designed to allow bankfull flows to be split two ways: into the pond and down the newly constructed channel. The new channel will be designed to work with the natural topography and be a low gradient Rosgen E type channel for most of its length. The channel through the emergency spillway will transition to a step pool channel with large rock structures installed to manage energy but still pass fish. The current dam structure will remain but be reconfigured with a riser pipe outlet, designed to regulate outflows during a storm event. In this alternative the existing pond will be set at a slightly lower elevation. During higher flows, the existing spillway will be utilized. See **Figure 18** below and the larger format drawing in **Appendix D** for a plan view and profile schematic of this alternative.

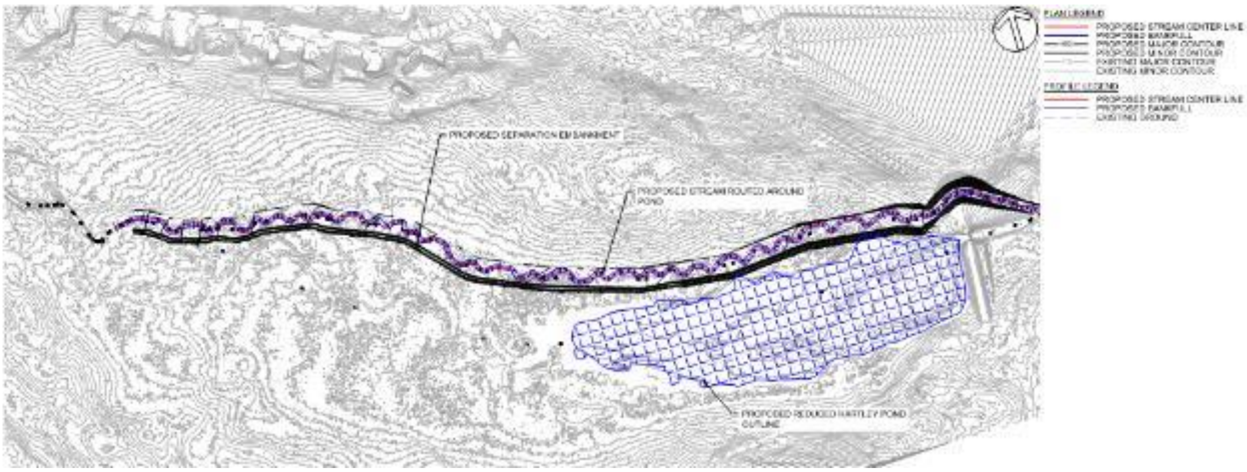


Figure 18. Plan view schematic of the stream route around alternative.

4.2.1 Alternative 2 - Stream Route Around Modeling

Alternative 2 investigates the feasibility of routing Tischer Creek to the north of Hartley Pond while utilizing the existing Hartley Pond basin as an offline storage system to retain water during higher flows (**Figure 19**). Routing the channel to the north of the existing pond was chosen due to spatial limitations south of Hartley Pond, and routing to the north allows for additional benefit of utilizing the existing secondary overflow channel out of Hartley Pond to tie back into the main Tischer Creek Channel at the downstream end of the routed channel.

Figure 19. Modeled Tischer Creek channel re-route (purple) in relation to current stream channel (blue).

To evaluate Alternative 2, a dynamic model was constructed using SWMM software to investigate the flow and storage dynamics. Design drawings depicting the stream route and channel design are provided in **Appendix D**. The alternative uses the Hartley Pond basin as an offline storage system, which allows for water to drain out of the basin using a combination of a standpipe and the existing dam to re-enter Tischer Creek downstream of the Hartley Pond dam and embankment.

The proposed re-routed channel is approximately 2,650 ft in length. The model was constructed utilizing information from the existing conditions SWMM model to assign cross section geometry, elevations, slopes, and dynamic storage properties. In addition, the model was constructed iteratively in tandem with CAD design drawings of the re-routed channel to inform channel cross section profiles, slopes, and stream lengths. The re-routed stream channel was designed to be approximately 3 ft of bankfull depth and 16 ft of bankfull width, with a 3 to 4.5 ft berm constructed on the right overbank to contain flow.

For Alternative 2, the re-routed channel is the primary flow route of the model. Flow that exceeds bankfull flows in **Figure 19** is routed over the weir and down the floodplain to the Hartley Pond storage node. The weir is modeled as a transverse weir with an inlet offset of 1 ¾ ft, 3:1 side slope, six ft of height, and a width of 50 ft. The parameters of the weir were designed to roughly mimic the flood attenuation capacity of the existing conditions in a 100-yr, 24-hr precipitation scenario. The floodplain between the weir and the Hartley Pond storage node is estimated to be approximately 1,700 ft in length, and the cross-section profile was cut from the half-meter LiDAR (USGS, 2021) using the HEC-RAS 6.3.1 software (USACE, 2022). The Hartley Pond storage node parameters were modeled identically to that described in Section 3.4.

Alternative 2 includes three potential outlets for the Hartley Pond basin, a standpipe as the primary spillway and the existing dam as the secondary spillway. Properties for the secondary spillway are identical to those described in section 3.4. The standpipe outlet system was modeled using two model elements – a transverse weir as the vertical inlet pipe, and a circular conduit to represent the drainpipe which connects to the existing Tischer Creek channel at the same location where the re-routed channel ties back into the existing Tischer Creek channel. The standpipe inlet was modeled at approximately 6.4 ft in diameter with an inlet offset of 8 ft, which drains to a 200 ft drainpipe that is 5 ft in diameter with a 2% slope.

The Alternative 2 SWMM model estimates that the peak flow of 1,223 CFS entering the system is split to approximately 708 CFS being sent to the re-routed Tischer Creek channel, and approximately 513 CFS being routed over the overflow spillway to the floodplain and into the Hartley basin storage system (**Figure 20**). At the downstream end of the model where the re-routed channel and the Hartley Pond storage system primary and secondary outlets connect, the model estimates a peak flow of 807 CFS suggesting an approximately 416 CFS reduction of flow. The standpipe conveys the majority of the flow, with an estimated peak flow of 155 CFS, while the existing dam conveys a peak flow of 84 CFS. It is important to note that if this alternative were selected, steps would need to be taken to optimize the design to match the existing conditions peak flow reduction.

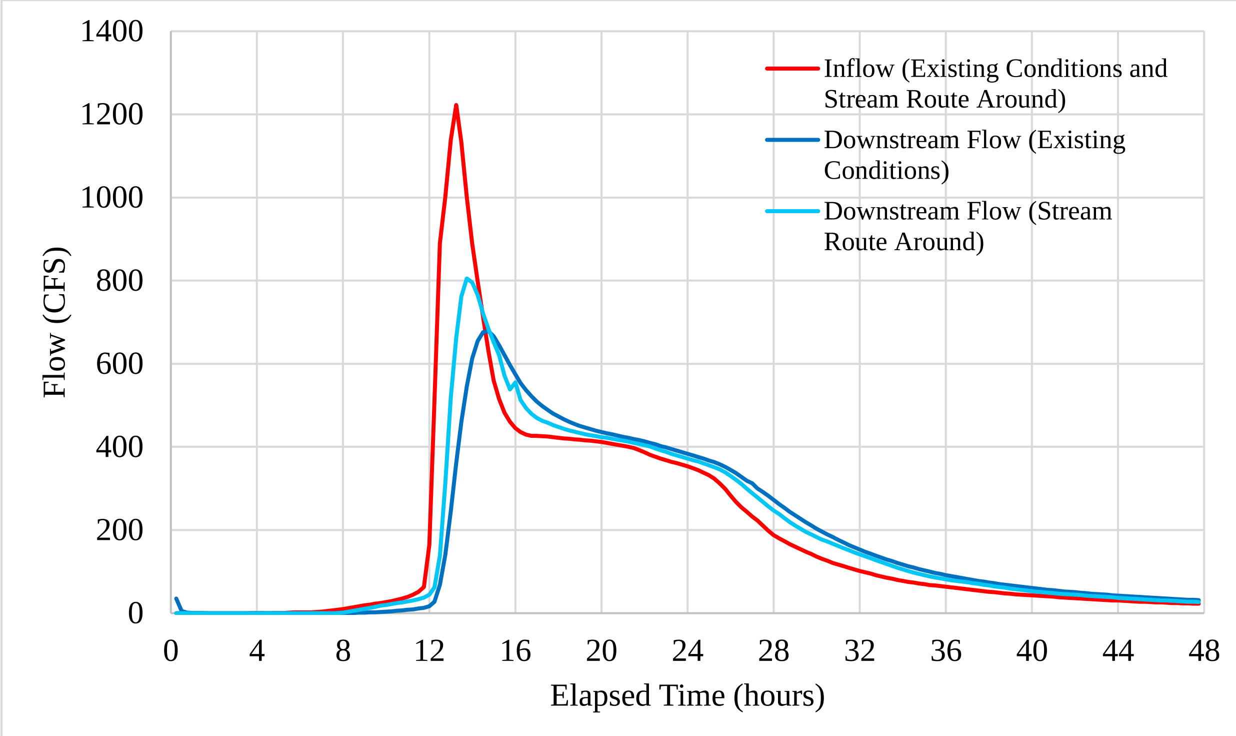


Figure 20. Comparison of modeled inflow and outflow of Hartley Pond for 100-yr, 24-hr precipitation event for the existing conditions model and the stream route around model.

Note: The delineated flood extents below Hartley Dam that are presented in the following sections were created using the USGS 2021 ½ meter resolution LiDAR, which is currently the highest resolution publicly available data. The preliminary FIS floodplain delineations use a variety of elevation data sources, all of which have less than ½ foot resolution. GEI reviewed these surfaces and determined that they are well aligned for this preliminary level of analysis, and the minimal differences will not affect the outcomes of the feasibility study. However, it is important to note that the preliminary FIS floodplain boundaries displayed below may show slight differences than the FIRM panels due to the difference in elevation source data. These floodplain figures are approximate and should only be relied upon in relative terms to each other and nothing more.

The downstream flood extents of Alternative 2 were estimated using the downstream HECRAS model. Approximated differences between the flood extents of Alternative 2 and the flood extents determined in the preliminary St. Louis County FIS are Provided in **Appendix E**.

4.2.2 Alternative 2 – Stream Route Around MCDA

The stream route-around provides an alternate route for the creek around the impoundment and dam. It keeps both the dam and peak flood control in place and can provide fish passage. However, this alternative is, based on preliminary cost estimates, the most expensive one (see Section 5 for more detail). This alternative has the creek running to the north of the impoundment cutting into the slope somewhat and then dropping quickly over the emergency spillway back down to the creek.

This alternative carries the creek up above its normal bed around the impoundment. In this elevated position, it may not pick up groundwater but rather may lose some water though the bottom of the channel to groundwater. In very low flow periods, this could potentially be an issue for maintaining flow downstream. This alternative also relies on an off-channel, transverse weir that directs all flow up to bankfull to the new channel and for flows greater than bankfull allows part of the higher flows to go through the old channel down to the pond.

The pond is also outfitted with a new controlled outlet. This outlet is a riser pipe that take a right angle through the embankment and discharges below the dam helping throttle outlet flows from the pond, since the new channel flows are only limited by channel dimensions and bed slope. The additional outlet helps throttle pond outflows enough that the total flow coming around, through or over the dam is approximately the same as existing conditions. The hydraulic modeling of this alternative suggested that the height of water in the pond should be dropped several ft so that peak flow control targets could be met. So that while the pond would remain, its footprint would be slightly smaller than it is now.

Because the weir upstream splits high flows down two channels, the total stream power that directly influences sediment transport is also split. Therefore, it is possible that this overall drop in power for any one channel results in some sediment deposition at these high flows.

Assumptions:

- Bankfull flows manageable with an upstream diversion structure.
- Existing dam and new berm will maintain structural integrity.
- Constructed berm and channel resistant to erosion in high-flow events.
- Sufficient depth to bedrock for channel construction.
- Groundwater input maintains baseflow for both the channel and pond.
- Existing pond will be excavated to improve and maintain water quality.

Strengths:

- Remove fish passage barrier.
- Restores longitudinal connectivity.
- Improves water quality.
- The low flow riser pipe offers water level management.
- Hartley Pond may remain a “public water” post-project.

Weaknesses:

- Maintains a Class I – High Hazard Dam.
- Design complexities due to dam and unforeseen environmental conditions along the new route.
- Risk of not meeting objectives if the new route and pond under-perform.
- Significant future monitoring and maintenance required.

- Potential sediment deposition maintenance upstream and in the pond area.
- Channel around the impoundment may sometimes be a "losing stream," with water potentially seeping into the bed and into groundwater.
- Long-term maintenance will be required on the existing dam embankment.

Unknowns/Considerations:

- Retains existing pond services.
- Berm and channel through the emergency spillway will require on-going maintenance.

Table 4. MCDA Scores for Alternative 2: Dam Route-Around

Alternative 2 – Stream Route Around MCDA		
Feasibility Criteria	**Criteria Score[1]**	**Comment**
Restore natural stream hydrology	3	A stream will be restored; however, it will not be within the natural valley and will have engineered geomorphology
Restore a stable floodplain and habitat diversity	3	A floodplain will be constructed for the stream channel, but not in original valley
Enhance temperature and sediment transport	4	During low flow conditions, water and sediment will be routed through the constructed channel
Restore longitudinal and lateral connectivity	4	The constructed channel will have longitudinal connectivity
Maintain recreational services	5	The restored stream and pond will maintain and enhance recreational services
Enhance brook trout fishing	4	The restored stream will improve temperatures and connectivity for brook trout populations
Restore to natural conditions	3	Not natural conditions, but improvement on the stream
Maintain or enhance educational opportunities	5	Educational opportunities relative to the stream and pond will be maintained and enhanced
Do not increase risk of flood damage downstream	5	Hydrology and hydraulic modeling has shown reduction in peak discharge
Total Criteria Score	**36**	

Notes: [1]Criteria scoring scale of 1 to 5. 1 = lowest potential for meeting criteria and 5 = highest potential for meeting criteria.

4.2.3 Alternative 2 – Stream Route Around Estimated Implementation Cost

Table 5. Alternative 2 – Stream Route Around Estimated Implementation Cost

Alternative 2 – Stream Route Around Estimated Implementation Cost					
No.	**Item**	**Quantity**	**Unit**	**Cost/unit**	**Cost**
1	Mobilization	1	LS	$196,644.13	$196,644
2	Access Trail, Installation/Decommission	1	LS	$10,000.00	$10,000
3	Cut Common Channel Excavation (P)	11000	CU YD	$6.00	$66,000
4	Fill Common Channel Excavation (P)	7500	CU YD	$6.00	$45,000
5	Structure Removal	1	LS	$75,000.00	$75,000
6	Inflow Diversion Structure	1	LS	$150,000.00	$150,000
7	Low Flow Standpipe	1	LS	$300,000.00	$300,000
8	Overflow Channel Stabilization	1	LS	$200,000.00	$200,000
9	Stream Diversion System	1	LS	$30,000.00	$30,000
10	Stream Restoration	3800	LIN FT	$225.00	$855,000
11	Dam Pool Excavation	66667	CU YD	$12.00	$800,000
12	Tree Planting	4471	EACH	$20.00	$89,421
13	Seeding	9	ACRE	$1,000.00	$8,942
14	Erosion Control Blanket	43280	SY	$3.00	$129,839
15	Sediment Control	1	LS	$50,000.00	$50,000
	Subtotal				**$3,005,846**
	Contingencies		**20%**		**$601,169**
	Estimated Cost				**$3,607,015**

4.3 Alternative 3 – Dam Removal

Alternative 3 proposes the removal of the existing dam, with the subsequent restoration of the stream channel within the valley's natural topography. This process involves channel restoration through the valley enhancing the existing remnant channel and restoring the channel where one does not currently exist with reference channel pattern and dimensions. The channel would most likely be a meandered Rosgen C type channel through the existing valley. Some removal of sediment and grading of a floodplain and new channel will be required. The inclusion of a pond feature in this alternative would function primarily as a landscape element rather than a flood control mechanism. We have specified that the pond is approximately 3 acres in size fed by groundwater with no direct connection to Tischer Creek on the upstream side. The pond outlet could be connected to the channel through a small flow-in flow-out channel to allow for overwintering of fish populations. The pond depth would be determined prior to construction based on geotechnical analysis and desired outcome of partners. Assuming the pond would be filled with groundwater, it would not contribute to reducing peak flows or flood storage capacity (no active storage). See **Figure 21** below and the larger format drawing in **Appendix D** for a plan view and profile schematic of this alternative.

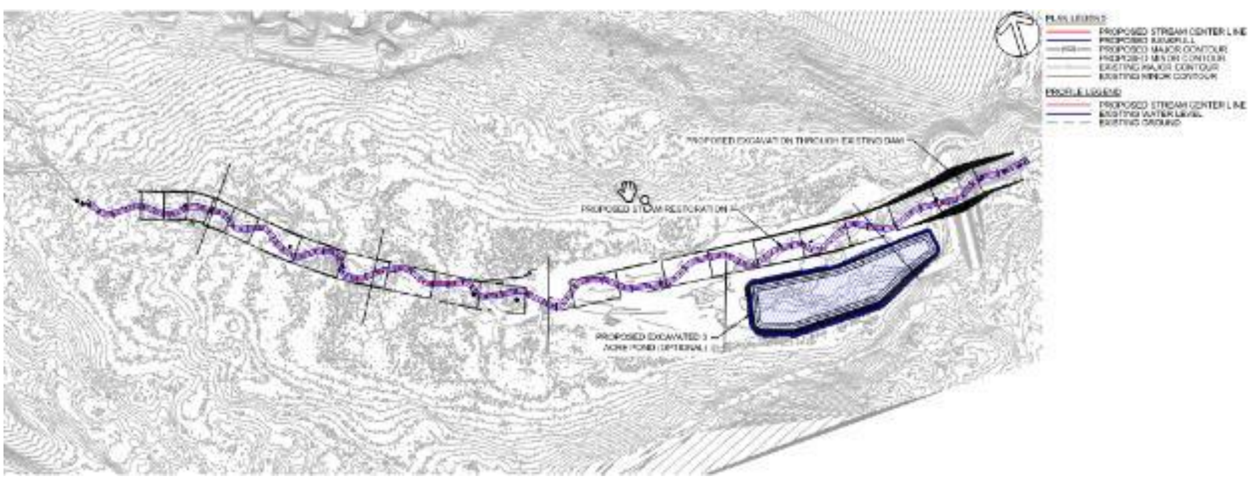


Figure 21. Plan view schematic of the dam removal alternative.

4.3.1 Alternative 3 – Dam Removal Model

Alternative 3 evaluates the feasibility of removing Hartley Dam and restoring the stream channel through the Hartley Pond basin. Alternative 3 models the system with the dam and embankment removed and the channel restored to resemble the floodplain profile immediately upstream of the current pond. Alternative 3 was constructed using SWMM software to investigate the flow dynamics.

Alternative 3 was modeled using two components - the restored stream channel through the Hartley Pond basin and the existing channel downstream of Hartley Pond. The restored stream channel is 1,740 ft in length and the cross-section profile was cut from the half-meter LiDAR (USGS, 2021) using the HEC-RAS 6.3.1 software (USACE, 2022). The Manning's n for the restored channel was set to 0.06 and was set to 0.11 for the floodplain. The existing downstream channel is the same channel described for Alternative 1.

Alternative 3 uses a peak flow of 1,223 CFS entering the system, with a downstream peak flow of 1,186 CFS (**Figure 22**). The 37 CFS flow reduction results from the slowing of flow from the roughness of the floodplain.

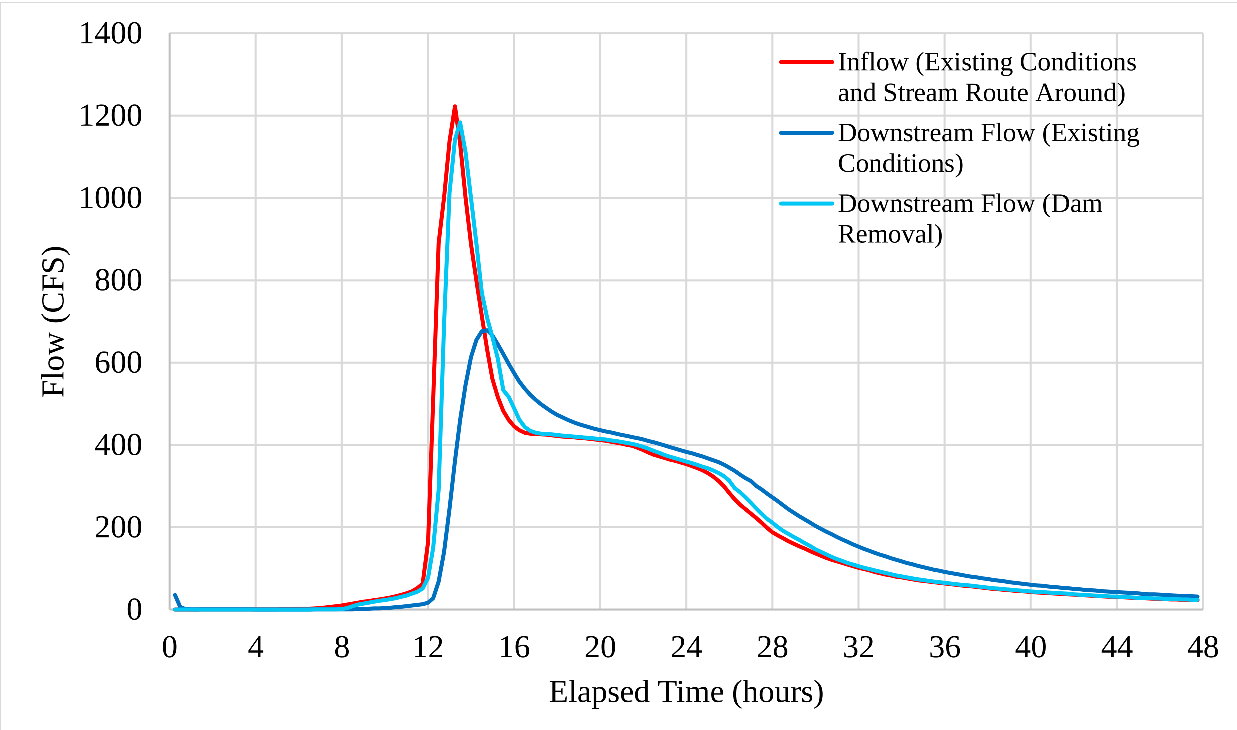


Figure 22. Comparison of modeled inflow and outflow of Hartley Pond for 100-yr, 24-hr precipitation event for the existing conditions model and the dam removal model.

The downstream flood extents of Alternative 3 were estimated using the downstream HECRAS model. Approximated differences between the flood extents of Alternative 3 and the flood extents determined in the preliminary St. Louis County FIS are Provided in **Appendix E**.

4.3.2 Alternative 3 – Dam Removal MCDA

If the dam removal alternative is to meet the restoration, connectivity, and human benefit goals, it would have to include property acquisition of the additional properties that would potentially flood without the dam in place for peak flood control. The property acquisition within the floodplain could take many years at a significant cost. Despite the time and cost considerations, this is the only alternative that completely removes the dam, eliminating any possibility of a catastrophic flood proceeding down the creek valley following an embankment failure.

From a constructability standpoint, this is a fairly straightforward alternative. Impoundment water level drop can be controlled through the existing spillway and embankment. This control can also be configured and managed so that legacy sediment is essentially dewatered in place behind the embankment. There would need to be some active grading and re-working of sediments to limit unwanted erosion as the channel down cuts through these sediments with pond drawdown. Fish and other fauna can be captured during drawdown and relocated elsewhere.

Dewatering the sediments in place also helps consolidate the sediment. With the limited legacy sediment investigation to date, it is very difficult to speculate how much total sediment has accumulated and to partition that sediment into its organic and inorganic fractions. This is important because organic sediments tend to have a very high-water content and will tend to lose mass as some carbon is oxidized after the sediment is exposed to the atmosphere. The inorganic sediment will consolidate as it dewaters both as a function of the dewatering but also because some of the organics oxidize and gravity will squeeze water out of pore space.

A potential program for the City acquisition of properties that would potentially flood after the dam is removed is described in more detail in Section 5.

Assumptions:

- Stream and valley ecosystem recovers post-restoration.
- Groundwater input maintains baseflow.
- Excavate pond to improve and maintain water quality.
- No changes to FEMA preliminary floodplain maps.

Strengths:

- Eliminates Class I – High Hazard Dam, reducing safety risks.
- Removes fish passage barrier.
- Restores longitudinal connectivity and biodiversity.
- Improves water quality.
- More effective sediment transport management.
- Greatest resilience to climate variability.
- Design and construction process may be less complicated and more cost-effective.
- May not require an EIS for removal of the public water of the state (pond), if changes to the pond are considered partial drainage/changing the dimensions of the pond, rather than elimination.

Weaknesses:

- Removing the dam does not provide peak flow attenuation.

Table 6. MCDA Scores for Alternative 3: Dam Removal

Alternative 3 – Dam Removal MCDA		
Feasibility Criteria	**Criteria Score[1]**	**Comment**
Restore natural stream hydrology	5	Restore the stream through the natural valley
Restore a stable floodplain and habitat diversity	5	Restores stream channel and floodplain in existing natural valley
Enhance temperature and sediment transport	5	Removing impoundment will enhance stream temperature and restore sediment transport
Restore longitudinal and lateral connectivity	5	Removing the dam will remove the fish passage barrier
Maintain recreational services	5	The restored stream and pond will maintain and enhance recreational services
Enhance brook trout fishing	5	Removing impoundment and restoring the stream channel will improve temperatures and connectivity for brook trout populations
Restore to natural conditions	5	The stream will be restored to the natural valley
Maintain or enhance educational opportunities	5	Educational opportunities relative to the stream and pond will be maintained and enhanced
Do not increase risk of flood damage downstream	1	Does not reduce peak flood flows
Total Criteria Score	**41**	

Notes: [1]Criteria scoring scale of 1 to 5. 1 = lowest potential for meeting criteria and 5 = highest potential for meeting criteria.

4.3.3 Alternative 3 – Dam Removal Estimated Implementation Costs

Table 7. Alternative 3 – Dam Removal Estimated Implementation Costs

Alternative 3 – Dam Removal Estimated Implementation Cost					
No.	**Item**	**Quantity**	**Unit**	**Cost/unit**	**Cost**
1	Mobilization	1	LS	$137,274.50	$137,275
2	Access Trail, Installation/Decommission	1	LS	$10,000.00	$10,000
3	Cut Common Channel Excavation (P)	13500	CU YD	$6.00	$81,000
4	Fill Common Channel Excavation (P)	7000	CU YD	$6.00	$42,000
5	Structure Removal	1	LS	$75,000.00	$75,000

6	Stream Diversion System	1	LS	$30,000.00	$30,000
7	Stream Restoration	3500	LIN FT	$225.00	$787,500
8	Pond Excavation	40000	CU YD	$12.00	$480,000
9	Tree Planting	11926	EACH	$20.00	$238,515
10	Seeding	24	ACRE	$1,000.00	$23,852
11	Erosion Control Blanket	47733	SY	$3.00	$143,198
12	Sediment Control	1	LS	$50,000.00	$50,000
	Subtotal				$2,098,339
	Contingencies		**20%**		$419,668
	Estimated Cost				**$2,518,007**

4.4 Alternative 4a and 4b – Open-bottom Culvert with and without a Pond

Alternative 4 proposes the installation of an open-bottom culvert through the dam embankment at the approximate elevation of the original channel through the impoundment. The culvert and streambed in the culvert would be designed to pass fish and bankfull flows without restriction but would restrict flows above bankfull. This alternative would leave the rest of the dam embankment, the spillway, and the emergency spillway in place. The channel will be restored within its natural valley, thus restoring the channel connectivity and floodplain ecology. During intense rainfall, the floodplain in the former impoundment can temporarily hold back flood flows. This controlled inundation is intended to be brief to minimize any long-term impact on the vegetation. Future design would need to balance mitigating downstream flooding with both fish passage and releasing water quickly enough to limit the ecological impacts of inundation. See **Figure 23** below and the larger format drawing in **Appendix D** for a plan view and profile schematic of this alternative.

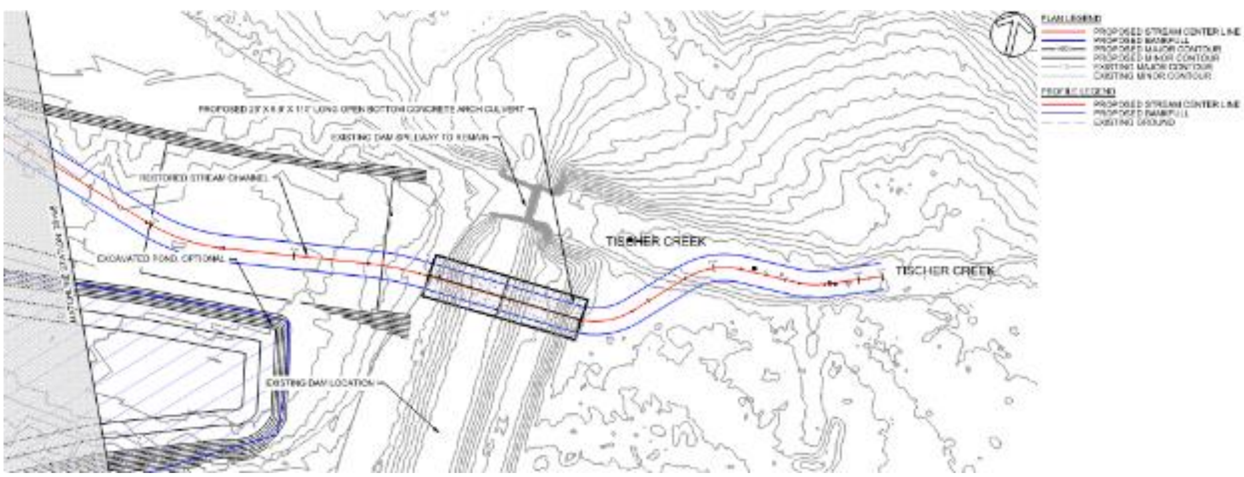


Figure 23. Plan view schematic of the open-bottom culvert, including constructed pond alternative.

For the sake of comparison, we have created two sub-alternatives for the open-bottom culvert option. The first sub-alternative (4a) includes the same pond option described in the dam removal alternative the second alternative (4b) does not include the pond.

4.4.1 Alternative 4 – Open-bottom Culvert Model

Alternative 4 proposes adding a culvert through the dam embankment. The culvert would be sized to allow for fish passage and bankfull flows to pass through but limit the flood flows. The flood flow reduction would come from the hydraulic constriction caused by the culvert and would not be an actively managed flow restriction device. The existing dam spillway would be left in place and would be utilized as a secondary spillway through which flow could be routed during large flow events. Alternative 4 was modeled using SWMM. It is important to note that the pond identified in Alternative 4a was not included in the modeling process, as it was assumed that the pond would be filled with groundwater and would not contribute to reducing peak flows or flood storage capacity (no active storage).

Alternative 4 was modeled by using the geometry from the existing conditions model, which is described in detail in Section 3.4. The model was updated to include the flood flow reduction culvert, which is routed through the dam embankment. The culvert is modeled as a 110-ft long, open-bottom design so that a natural channel system can be routed through the embankment. A cross section displaying the culvert design is provided in **Figure 24**. The Manning's n coefficient for the culvert was set to 0.055 to closely resemble the roughness of Tischer Creek's natural channel. Additionally, the downstream node was lowered from 1,191-ft elevation to 1,190.12-ft elevation to more closely match the flood reduction properties estimated in the 100-yr, 24-hr precipitation scenario for the existing conditions model.

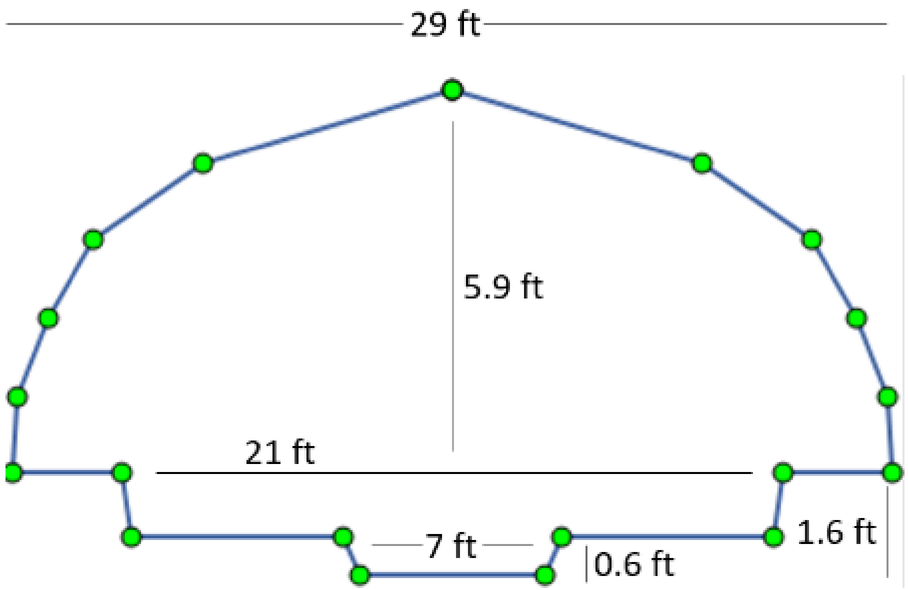


Figure 24. Culvert design and spacing for Alternative 4 SWMM model.

Alternative 4 uses a peak flow of 1,223 CFS entering the system, with a downstream peak flow of 647 CFS (**Figure 25**). The culvert accounts for the majority of the peak flow, with only 9 CFS of the flow being routed over the existing dam spillway. The estimated 576 CFS peak flow reduction is higher than the flow reduction estimated in the existing conditions model. It is important to note that if this alternative were selected, steps would need to be taken to optimize the design to match the existing conditions peak flow reduction.

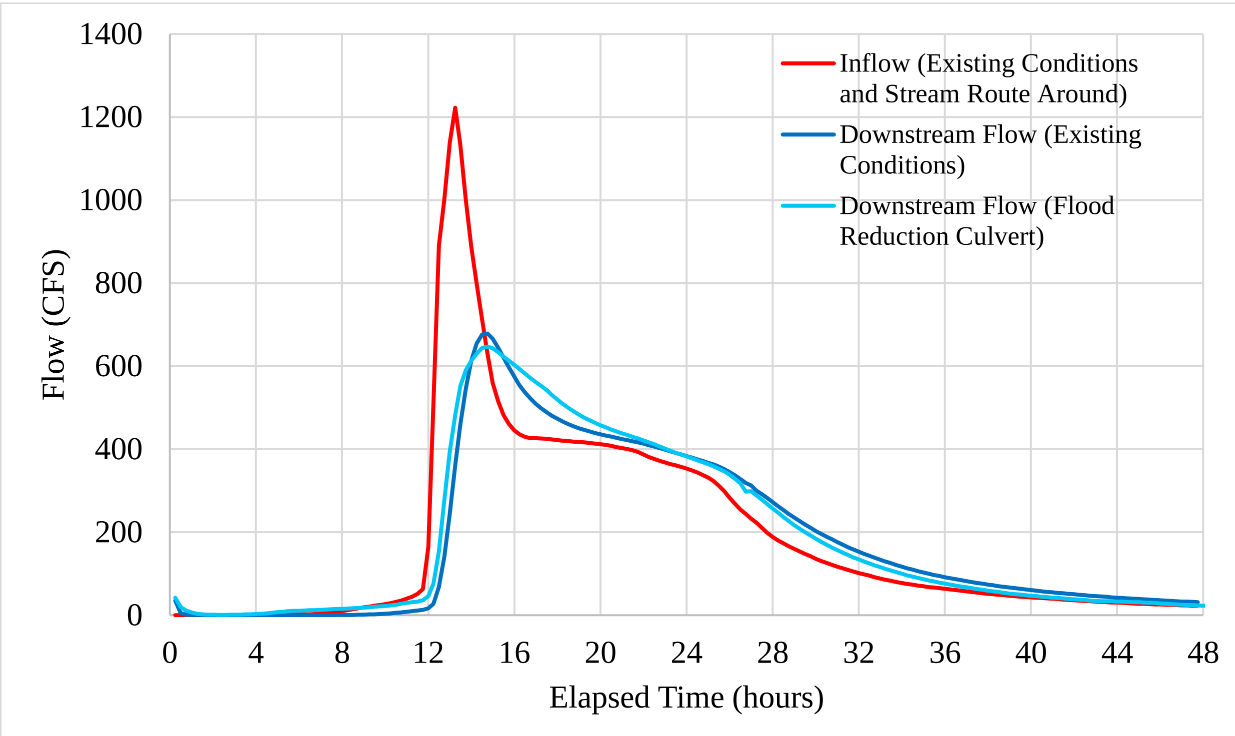


Figure 25. Comparison of modeled inflow and outflow of Hartley Pond for 100-yr, 24-hr precipitation event for the existing conditions model and the Flood Reduction Culvert model.

Additional SWMM modeling was conducted to evaluate Alternative 4's capacity for fish passage through the open-bottom culvert by investigating low-flow scenarios to understand stream velocities under more common conditions. The Alternative 4 SWMM model was run using 2-yr, 1-yr, and 6-month, 24-hr precipitation events, as well as a baseflow scenario in which no precipitation event occurs. Results of the calculated velocities through the open-bottom culvert are provided in **Table 8**.

Table 8. Modeled low-flow velocities through the open-bottom culvert proposed in Alternative 4.

Feasibility Criteria	Precipitation (inches)	Peak Velocity (ft/sec)
2-yr, 24-hr	2.68	5.41
1-yr, 24-hr	2.28	4.55
6-month, 24-hr	1.94	4.44
Baseflow (5 CFS)	N/A	1.38

By comparison, sustained swimming speeds of salmonids are and burst speeds between 8 feet per second (fps) and 20+ fps (**Figure 26**). Cruising speed for young brook trout (3” to 5”) ranges from 0 – 2 fps **(Figure 27)** (Kilgore, Bergendahl, and Hotchkiss. 2010).

The SWMM model reports only average velocities through the culvert. As the MDNR *Reconnecting Rivers: Natural Channel Design in Dam Removals and Fish Passage* manual notes, velocity distributions near large substrates are very complex resulting in small eddies that provide resting areas. Velocities in general decrease closer to the bottom. The distribution of velocity is far more important to fish passage than are mean column velocities.

This preliminary design work shows that for base flows up to potentially bankfull flow, this culvert is fish passable for trout. Final design can improve estimates of potential velocities, refine culvert sizing as long as it continues to sufficiently regulate flood flows, and provide a bed substrate with a mix of particle sizes and placement that permit fish to burst when needed and “hide/rest” in the hydraulic shadow of larger stone when needed. Substrate particle size and bed substrate placement will be designed to be stable during the design phase based on modeled velocities and shear stresses at the 100-year storm peak flows.

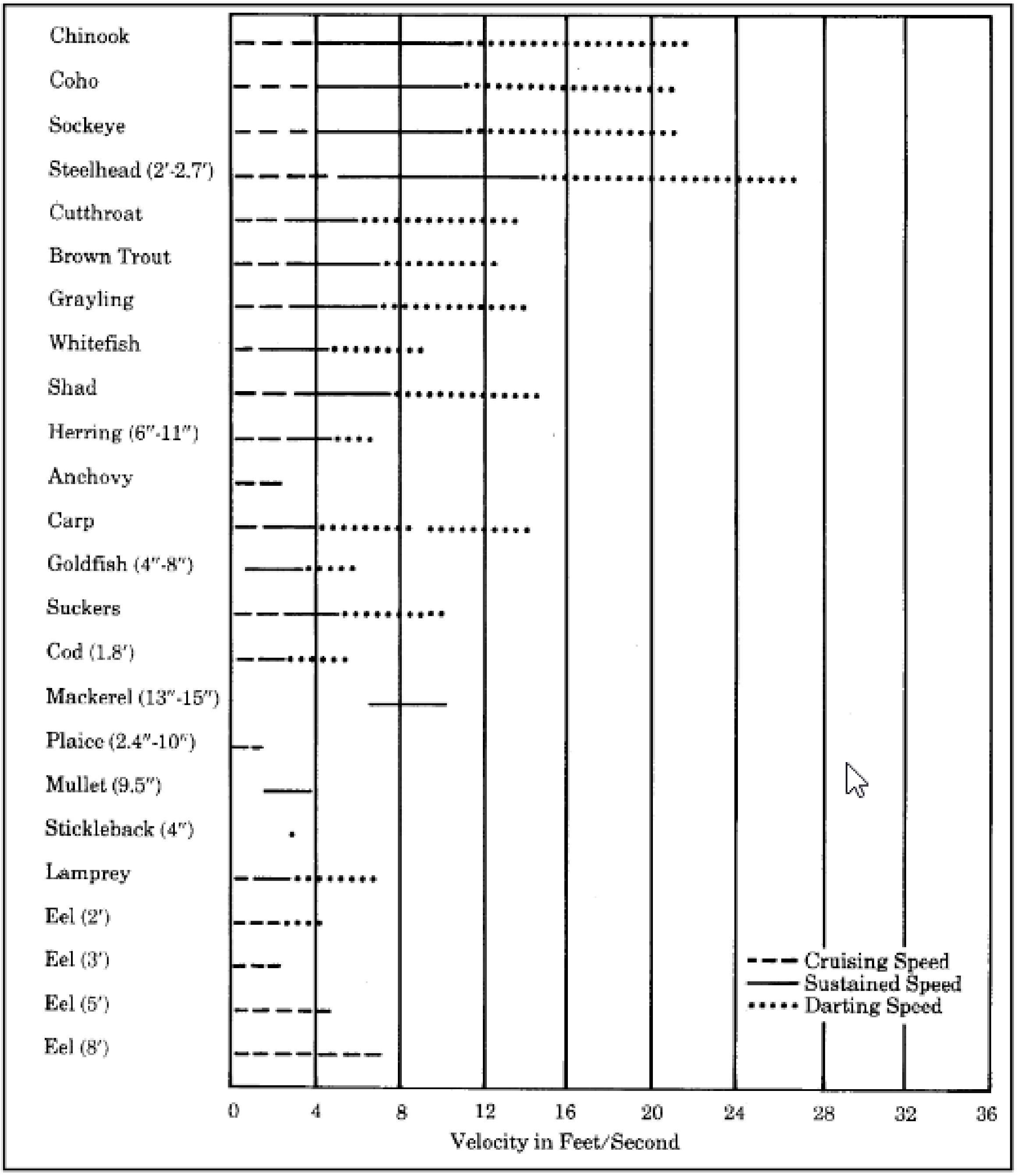


Figure 26. Relative Swimming Abilities of Adult Fish (Kilgore, Bergendahl, and Hotchkiss. 2010).

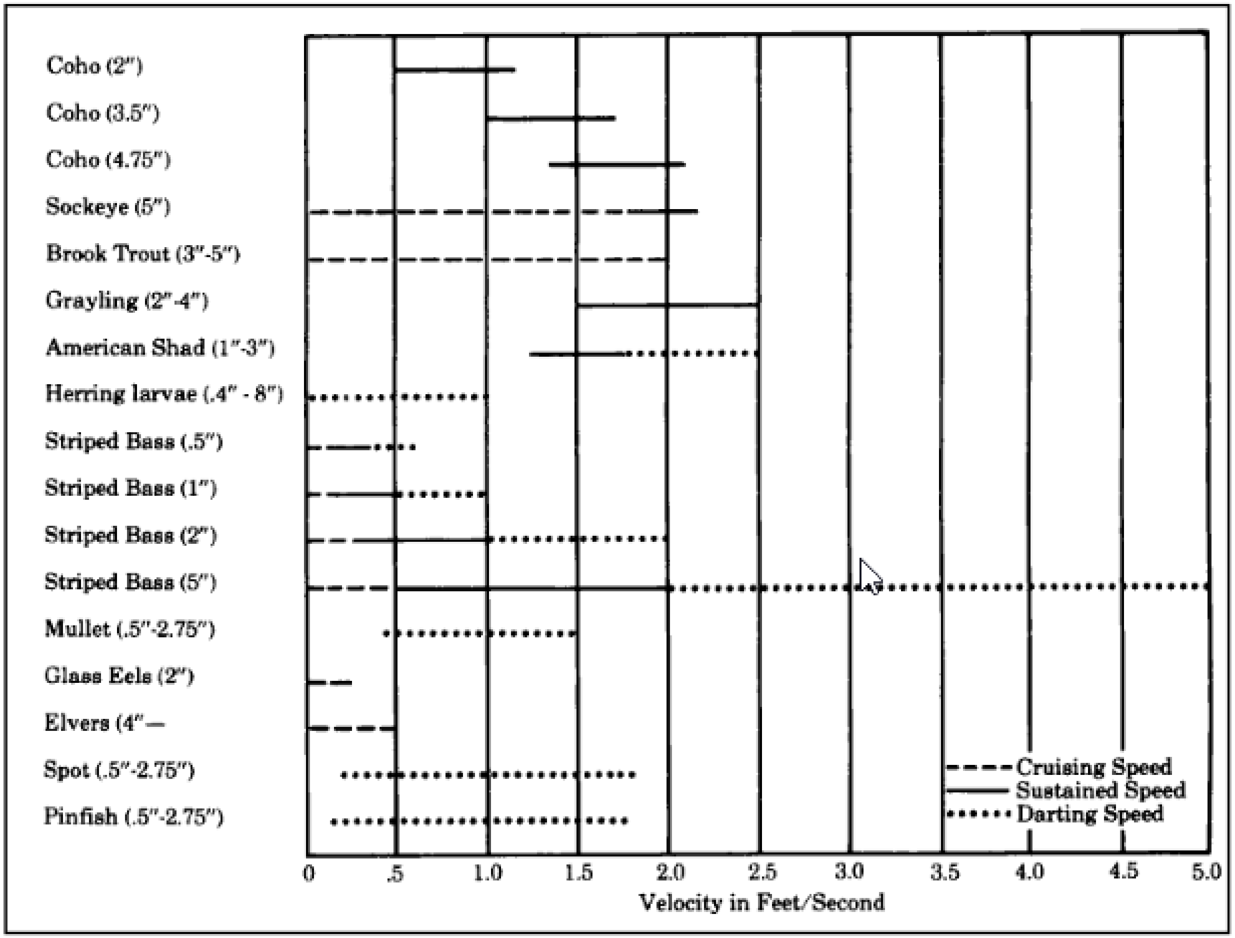


Figure 27. Relative Swimming Abilities of Young Fish (including brook trout) (Kilgore, Bergendahl, and Hotchkiss. 2010).

4.4.2 Alternative 4a and 4b – Open-bottom Culvert with Pond and without Pond MCDA

The open-bottom culvert alternative has two sub-alternatives, one that includes the construction of a pond on the newly exposed floodplain and the second without a pond. The pond sub-alternative proposes a smaller pond than the current Hartley Pond, in roughly the same location as the pond behind the dam today. We have specified that the pond is approximately 3 acres in size fed by groundwater with no direct connection to Tischer Creek on the upstream side. The pond outlet could be connected to the stream channel through a small flow-in flow-out channel to allow for overwintering of fish populations. The pond area and depth would be determined during design based on geotechnical analysis and desired outcomes of partners. It is assumed the pond has no flood mitigation benefits because most of the time it will be full of groundwater and will have no capacity for flood water. The pond is proposed to potentially retain a pond feature in Hartley Park for habitat and education purposes.

The open-bottom culvert presents a slightly greater construction challenge than the dam removal alternative because the culvert will be built through the existing dam embankment. Also, a true open bottom culvert requires either cast-in-place concrete footers or if the sub-soils are deemed too soft, footers supported on pilings. Sometimes open-bottom culverts are just over-sized culverts with their bottom buried and covered with a suitable substrate sized to pass fish, not wash away, and prevent sedimentation issues.

For this option, it is particularly important that a thorough geotechnical evaluation is performed both to potentially inform any pond construction, i.e., depth to groundwater and bedrock and soil composition as well as for open-bottom culvert construction.

In terms of managing legacy sediment, this alternative would potentially be sequenced much the same way as dam removal so the sediment can mostly be managed passively while the impoundment is dewatered, and the new culvert constructed.

Another advantage of this alternative is that the culvert becomes the prime outlet, and both the spillway and emergency spillway can remain in place. This means total head/energy/pressure on the dam embankment and the new culvert is limited because water has three different paths to leave the impoundment. Relieving the water head/energy/pressure from the dam embankment could help increase the lifespan of the dam embankment and make maintenance and inspection of the entire embankment and spillway much easier because it will be fully exposed most of the time.

Assumptions:

- Flow-limiting culvert design will effectively reduce flood flows.
- Design will withstand peak flow stresses.
- Excavate pond to improve and maintain water quality.

Strengths:

- Reduces continuous water head/energy pressure on the embankment.
- Removes fish passage barrier.
- Restores channel longitudinal connectivity.
- Improves water quality.
- Natural river design can help manage sediment transport more effectively, reducing downstream erosion and upstream aggradation.
- Passive flood control, reducing/maintaining downstream flood impacts.
- May not require an EIS for removal of the public water of the state (pond), if changes to the pond are considered partial drainage/changing the dimensions of the pond, rather than elimination.

Weaknesses:

- Maintains a Class I – High Hazard Dam.
- Long-term maintenance will be required on the existing dam embankment.
- Short-term ecological and geomorphological impacts (e.g., sediment deposition on upstream floodplain and aggradation in the channel).

- Potential need for downstream hard armoring.
- Impedes on floodplain connectivity.

Unknowns/Considerations:

- Substrate within culvert may not be maintained during peak flow events.

Table 9. MCDA Scores for Alternatives 4a and 4b: Open-Bottom Culvert with and without Pond (revised scores without pond are shown in parentheses)

Alternative 4 – Open-Bottom Culvert MCDA		
Feasibility Criteria	**Criteria Score[1]**	**Comment**
Restore natural stream hydrology	4	Restore the stream through the natural valley; however stream will flow through a culvert at dam structure
Restore a stable floodplain and habitat diversity	4	Restores channel and floodplain in existing natural valley; however, the structure will be constricting
Enhance temperature and sediment transport	4	Removing impoundment will reduce and maintain channel temperatures; however, the structure will be constricting during higher flows and may cause aggradation
Restore longitudinal and lateral connectivity	4	Removing the dam will remove the fish passage barrier; however, during high flows the structure may be a velocity barrier
Maintain recreational services	5 (4)	The restored stream and pond will maintain and enhance recreational services
Enhance brook trout fishing	5	Removing impoundment and restoring the stream channel will improve temperatures and connectivity for brook trout populations
Restore to natural conditions	4	The stream will be restored to the natural valley; however, the structure will be constricting
Maintain or enhance educational opportunities	5 (4)	Educational opportunities relative to the stream and pond will be maintained and enhanced
Do not increase risk of flood damage downstream	5	Culvert will be used to reduce peak flood flows
Total Criteria Score	**40 (38)**	

Notes: [1]Criteria scoring scale of 1 to 5. 1 = lowest potential for meeting criteria and 5 = highest potential for meeting criteria.

4.4.3 Alternative 4 – Open-Bottom Culvert Estimated Implementation Cost

Table 10. Alternative 4 – Open-Bottom Culvert Estimated Implementation Cost

Alternative 4 – Open-Bottom Culvert with Pond Estimated Implementation Cost					
No.	**Item**	**Quantity**	**Unit**	**Cost/unit**	**Cost**
1	Mobilization	1	LS	$185,305.39	$185,305
2	Culvert Excavation	1763	CU YD	$12.00	$21,156
3	Culvert + Wingwall Install	1	EACH	$750,000.00	$750,000
4	Cut Common Channel Excavation (P)	13500	CU YD	$6.00	$81,000
5	Fill Common Channel Excavation (P)	7000	CU YD	$6.00	$42,000
6	Stream Diversion System	1	LS	$30,000.00	$30,000
7	Stream Restoration	3500	LIN FT	$225.00	$787,500
8	Pond Excavation	40000	CU YD	$12.00	$480,000
9	Tree Planting	11926	EACH	$20.00	$238,515
10	Seeding	24	ACRE	$1,000.00	$23,852
11	Erosion Control Blanket	47733	SY	$3.00	$143,198
12	Sediment Control	1	LS	$50,000.00	$50,000
	Subtotal				$2,832,525
	Contingencies		**20%**		$566,505
	Estimated Cost				**$3,399,030**

4.5 Other Alternatives Considered

Rock Arch Rapids

In this alternative the existing pool above the dam would remain at the same elevation. A series of rock arches would be constructed to allow for fish passage through the dam. Because this structure would not reduce stream temperatures for brook trout this alternative was not analyzed further.

Double limiting Culvert

The Double Limiting Culvert Alternative analyzed the feasibility of removing the primary dam spillway, restoring the channel to its original profile, and constructing a series of two flow-limiting culverts through the existing dam embankment and an additional embankment to account for flood storage. The idea was to lower the height of the embankment that is out there now, so that if an embankment failed during high water, the ensuing flood wave would be le rand and some flood reduction in the impoundment would occur. Hartley Pond would no longer remain; however, water would be stored behind berms during high flows. This alternative was initially modeled using SWMM, however the alternative was not developed as a final alternative it was determined that a single flood reduction culvert placed in the location of the existing embankment (Alternative 4) provides a similar benefit in a more logical configuration. The double embankments still needed to be five to six ft high and would be a significant cost and impact to the floodplain.

Spillway Flood Gate

The Spillway Flood Gate Alternative proposed opening up the spillway down to approximately the former channel elevation and adding a “smart” gate system to the open spillway. This structure, normally open, would be strategically activated in anticipation of significant precipitation events and flows, backing up water behind the closed gate and mitigating flood flows. The channel will be restored within its natural valley, thus restoring the channel connectivity and floodplain ecology. During intense rainfall, the floodplain in the former impoundment can temporarily hold floodwaters. This controlled inundation is intended to be brief to minimize any long-term impact on the vegetation. Future design would need to balance mitigating downstream flooding with releasing water quickly enough to limit the ecological impacts of inundation.

This alternative was initially evaluated with SWMM and demonstrated from a hydraulic perspective that it could provide the required flood mitigation. However, this alternative is envisioned as completely automatic. The gate activators would be connected to a web-based application that would be connected both to weather forecast tools as well as continuous recording in-stream stage monitors in the creek and at the dam. The system would activate the gate based on an algorithm that accounts for impending, significant precipitation events and rising creek flows. It would also have a sophisticated alarm system that would alert personnel day or night of a potential event and permit manual over-ride of the gate activation.

This alternative is similar to the open-bottom culvert option, except it adds a new, active mechanical system that relies on a sophisticated network of monitoring and forecasting tools. The gate would have to be inspected, maintained, and operated on a regular basis. Also, the gate needs to seat at the channel bottom to shut properly. The bottom also needs to permit fish passage, meaning sediment and debris will be moving over that bottom, potentially complicating gate closure on a regular basis. This system requires significant annual attention and operating costs (e.g., annual fee for the web-based forecasting and activation package). By comparison, the open-bottom culvert (Alternative 4) is completely passive and still performs hydraulically similarly to the gate alternative. Therefore, we judged this alternative to be similar but inferior to the open-bottom culvert option and was not considered further.

Table 11. Combined MCDA Table

	Feasibility Criteria											
Alternative	**Restore Natural Stream Hydrology**	**Restore a stable floodplain and habitat diversity**	**Enhance temperature and sediment transport**	**Restore longitudinal and lateral connectivity**	**Maintain recreational services**	**Enhance brook trout fishing**	**Restore to natural conditions**	**Maintain or enhance educational opportunities**	**Do not increase risk of flood damage downstream**	**Permit Consideration**	**Projected Cost**	**Score**
1 – No Action	1	1	1	1	4	1	1	3	5	NA	Operation & Maintenance	18
2 – Stream Route Around	3	3	4	4	5	4	3	5	5	Possibility to permit / EAW considering partial drainage / changing dimensions of Hartley Pond	$3,607,015	36
3 – Dam Removal	5	5	5	5	5	5	5	5	1	Possibility to permit / EAW considering partial drainage / changing dimensions of Hartley Pond	$2,518,007	41
4a and 4b – Open-Bottom Culvert with and without Pond	4	3	4	4	5 (4)	5	4	5 (4)	5	Possibility to permit / EAW considering partial drainage / changing dimensions of Hartley Pond	$3,399,030	40 (38)

5. Conclusions and Recommendations

This feasibility study is intended to provide alternatives that will meet the project objectives including reduce the water temperature within the creek from Hartley Pond; provide fish passage to the upstream reaches of the creek, and still maintain the flood control properties of the existing dam and impoundment. These options have primarily been evaluated in terms of their hydrology, hydraulics, and flood reduction benefits. These analyses are for comparative purposes only and should not be considered preliminary design, per se.

Additional data collection should be performed during the design phase under the final design grant award to effectively develop a design that meets these three primary project criteria. The recommended data includes: 1) a legacy sediment investigation that includes total volume of settled sediment and sediment type (e.g., organic vs inorganic and sediment contamination); 2) additional hydrologic and hydraulic model calibration with a longer precipitation, groundwater, pond stage and creek flow data set; including high flow rating curves for the gages; 3) new geotechnical evaluation, including borings down to bedrock at the location of proposed changes, including at the new culvert and constructed pond locations. GEI also recommends a detailed floodplain study downstream that includes a structural and property analysis but this can be separate from any dam design work, if full dam removal is not the selected alternative. The floodplain study downstream that includes a structural and property analysis would be required for Alternative 3 – Dam Removal. The floodplain study would not be required for the design of Alternative 2 – Stream Route Around nor Alternative 4 – Open-Bottom Culvert because these alternatives do not significantly alter existing downstream flows. The current UMD and MPCA monitoring should also continue into design and be used to improve model calibration and build more confidence in the model's future condition projections.

We have narrowed the potential alternatives down to two that we think best meet all the project criteria and that scored the highest on the MCDA summarized in **Table 11**. Alternative 3 – Dam Removal (Score of 41 on the MCDA), including property acquisition of additional properties projected to flood, is the most climate resilient and sustainable alternative because it eliminates the dam but provides essentially the same level of flood protection if the additional structures are removed from the floodplain. Because the path forward for this alternative potentially includes an uncertain timeline for private property acquisition, we recommend Alternative 4 – Open-Bottom Culvert, as the second option that meets the project criteria (Score of 40 on the MCDA with a pond and 38 without a pond). More detail on these alternatives is provided below and Alternatives 1 – 4 are also summarized in **Appendix F**.

5.1 Alternative Selection

5.1.1 Most Climate-Resilient and Sustainable Alternative

We have identified Alternative 3 - Dam Removal as the most climate-resilient and sustainable alternative because it is the only alternative that completely removes the dam. The spillway and embankment are structures that have a finite lifetime. This lifetime is unknown because it is strongly dependent on the amount and timing of attention and work to keep them structurally sound. A critical issue with an earthen embankment is overtopping, a prime instigator of embankment failure. While the modeling work and the climate projections do not show overtopping, these are only projections. These projections are based on statistical approximations of the future. We cannot say what the most extreme event the dam will see within the forecast windows will be; therefore, there is always some risk that an event or series of events will occur that will cause dam failure. The only way to reduce that risk to zero is to remove the dam.

However, as the modeling demonstrates, the dam does provide peak flow control for potential flood events. Taking out the dam without doing anything else raises the risk that flooding during large events is more likely to occur downstream of the dam (Dam Removal Estimated Flood Extents – **Appendix E**).

5.1.2 Most Cost-Effective, Fish Passage, and Flood Attenuation Alternative

Alternative 4 - Open-bottom Culvert installed at or near the historic Tischer Creek channel bed, through the existing dam embankment is the next best alternative that meets all the project criteria after dam removal from a cost, construction feasibility, and permitting perspective. Alternative 4 also has a higher MCDA score than Alternative 1 and Alternative 2. This is the most realistic alternative that currently meets most of the project objectives. This alternative could be designed and constructed with an off-line pond, so that open water habitat continues in Hartley Park. The off-line pond may also eliminate the requirement for a mandatory EIS. We have provided a preliminary design of an open-bottom culvert to demonstrate how this alternative would function to control high flows and meet fish passage criteria to bankfull flows. This culvert has been simulated in the SWMM model to demonstrate potential performance. Note that while the existing conditions SWMM model was checked against and had inputs adjusted to better match UMD Hartley Pond stage data for a large multi-day rain event in September 2023, we do not consider this a calibrated model. A calibrated model would be driven by a continuous time series of measured precipitation and air temperature and would have continuous pond stage and creek flow data to compare model results against.

Another advantage of this alternative is that the culvert becomes the prime outlet, and both the spillway and emergency spillway can remain in place. This means total head/energy/pressure on the dam embankment and the new culvert is limited because water has three different paths to leave the impoundment. Relieving the water head/energy pressure from the dam embankment could increase the lifespan of the dam embankment and make maintenance and inspection of the embankment and spillway much easier because it will be fully exposed most of the time.

5.2 Recommendations to Support Long-Term Flood Risk Reduction

While the open-bottom culvert is currently the best, realistic alternative, we would still recommend that Duluth consider, development of a phased plan to manage property currently in the floodplain. Duluth is fortunate that Tischer Creek is relatively steep through the City and has cut a sufficiently deep valley with very little difference between the projected 100-year water surface elevation (WSE) and the 500-year WSE in the current FIS (**Figure 22**). However, there are locations in the City where culverts restrict high flow and back up water, increasing potential flooding impacts. The most egregious example is the culvert at Woodland Avenue, that shows a backwater effect approximately 1,200 linear ft upstream for events equal to or greater than the 50-year rain event.

A future flood mitigation plan should evaluate both culvert restrictions as well as flood prone properties and prioritize culvert replacements in conjunction with property acquisition within the floodplain. This is a strategy that would serve any Hartley Pond alternative in the long-term and would ultimately reduce the risks of property damage and other impacts into the future for any alternative.

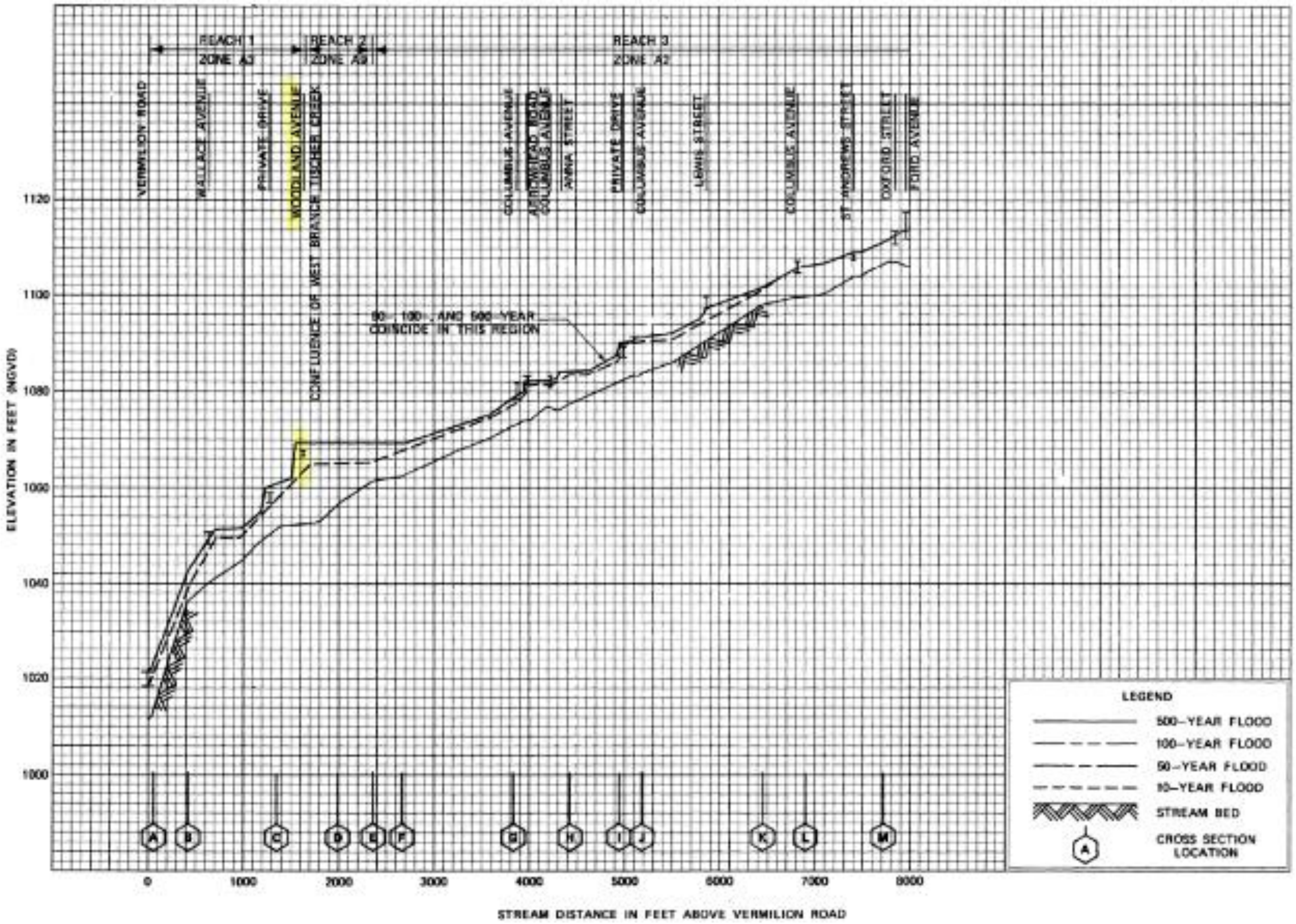


Figure 28. Current flood profile through the City of Duluth. Note that the 50-yr, 100-yr and 500-yr flood profiles essentially plot as one line. Also note long flat backwater caused by an undersized culvert under Woodland Avenue (FEMA FIS, 1979).

5.3 Recommendations to Support Design

The feasibility study provides scientific results and engineering concepts so that reasonable planning decisions can be made from this effort. Additional data will need to be collected during the design phase to reduce uncertainty associated with construction, project costs, and all other objectives. Because the flood control aspect is so critical to the community, the hydrology and hydraulic modeling effort should provide a high level of confidence that the proposed design will meet the flood control objectives. This will be accomplished during the design phase through the completion of the FEMA Conditional Letter of Map Revision (CLOMR)/ Letter of Map Revision (LOMR) process.

The foundation for a modeling effort that provides this level of comfort, starts with a well-calibrated model. A well-calibrated model, as noted above, includes a robust, continuous data set that covers as much as a year of precipitation, pond stage and creek data. It does not have to necessarily be years' worth of data, but should capture big rain events, multiple rain events some occurring during saturated soil conditions, as well as low flow events. Model performance can then be judged by how well it fits all the data and not just one event.

This calibration helps verify that both the conceptual model of the watershed and creek dynamics are reasonable, and the proposed project effect on the hydrology and hydraulics are generally well-understood and predictable. The design model would not generally change watershed hydrologic input, but rather just the hydraulic inputs. Therefore, calibration with a longer data set that includes precipitation, air temperature, pond stage and creek flow, either upstream or downstream or both, would be sufficient to develop a robust calibration and design tool.

Because hydrology and hydraulics are and were so important to the overall success of this project, a significant amount of time has been devoted to them in this phase of the work. This included the preliminary calibration of the model using existing datasets and spreadsheet model. One design aspect that requires additional data is the impoundment legacy sediment investigation. Some work has been done by MNDNR, but a larger characterization effort should be undertaken to include sediment volume, composition, and contaminants. This should include: 1) more extensive poling to locate top of sediment and depth to refusal (thickness of sediments); 2) grab samples at various depths should be collected and samples analyzed for percent organic material, sand, silt, clay, and larger particles as well as 3) analyzed for potential contaminant concentrations (**Table 12**).

Table 12. Base Line Sediment Parameter List for Dredged Sediments (MPCA, 2014).

Parameter	Analytical method*
Arsenic	SW-846 6010 or 6020
Cadmium	SW-846 6010 or 6020
Chromium III	SW-846 6010 or 6020
Chromium VI	SW-846 6010 or 6020
Copper	SW-846 6010 or 6020
Lead	SW-846 6010 or 6020
Mercury	SW-846 7471
Nickel	SW-846 6010 or 6020
Selenium	SW-846 6010 or 6020
Zinc	SW-846 6010 or 6020
Total Phosphorus	EPA 365.3/365.4
Nitrate + Nitrite	
Ammonia-Nitrogen	
Total Kjeldahl Nitrogen	
PCBs (Total)	SW-846 8082
Total Organic Carbon	SW-846 9060
Sieve and Hydrometer Analysis	ASTM D-422

*Use the most current version available for Minnesota Certification for all analytical methods.

Lastly, while some geotechnical work has been done on site, there is enough site variability that an additional geotechnical investigation should be performed during the design phase to identify underlying material type, allowable bearing pressure (for the culvert) and depth to groundwater and bedrock.

5.4 Final Recommendations

We recommend that the following steps are performed if Alternative 3 – Dam Removal or Alternative 4 – Open-Bottom Culvert are selected for advancing into a final design process and construction:

- Work with community stakeholders to select preferred alternative. This is currently being completed through the City of Duluth process.
- Funding and Design: Identify funding sources, including grants and partnerships, to support project implementation. Develop comprehensive design plans that meet objectives including reducing the water temperature within the creek from Hartley Pond, providing fish passage to the upstream reaches of the creek, and maintaining the flood control properties of the existing dam and impoundment. Complete final design to include the following additional data collection:
    - Legacy sediment investigation that includes total volume of settled sediment and sediment type (e.g., organic vs inorganic and sediment contamination).
    - Hydrologic and hydraulic model calibration with a longer precipitation, groundwater, pond stage and creek flow data set; further developed high flow rating curves for the gages.
    - Geotechnical evaluation, including borings down to bedrock at the location of proposed changes, such as the new culvert and constructed pond location.
- Permitting and Construction: Work with permitting agencies to obtain all permits required. Solicit bids from qualified contractors.
- Build project.
- Conduct detailed floodplain analysis downstream, including existing structures downstream of Hartley Dam and within floodplain of Tischer Creek, considering current and future climate scenarios. A future flood mitigation plan should evaluate both culvert restrictions as well as flood prone properties and prioritize culvert replacements in conjunction with property acquisition within the floodplain. This is a strategy that would serve any Hartley Pond alternative in the long-term and would ultimately reduce the risks of property damage and other impacts into the future for any alternative.

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