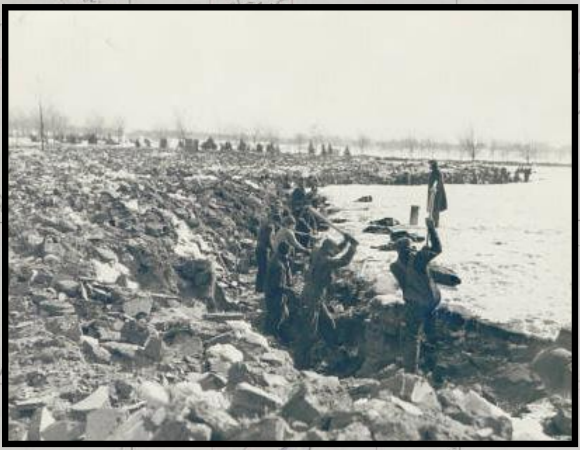
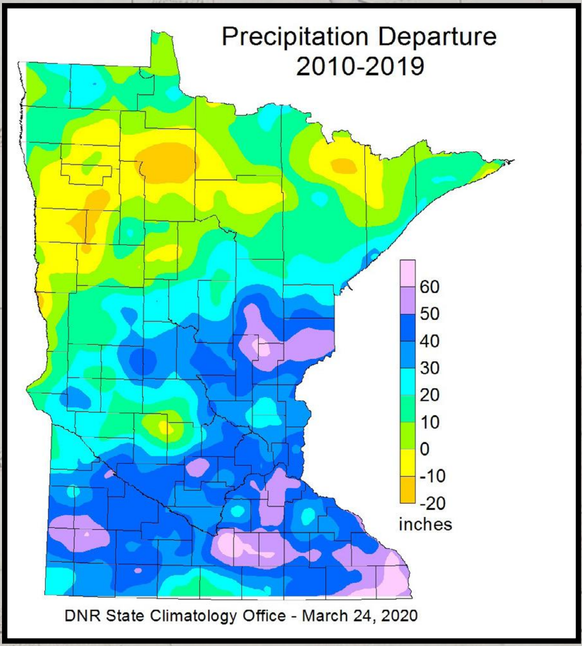
LAKE NOKOMIS AREA GROUNDWATER & SURFACE WATER EVALUATION





PARTNERS:

April 2022

Minneapolis City of Lakes

Minneapolis Park & Recreation Board

MINNEHAHA CREEK WATERSHED DISTRICT

Hennepin

DNR

USGS science for a changing world

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ACRONYMS

BWC – Blue Water Commission

DNR – Minnesota Department of Natural Resources

FEMA – Federal Emergency Management Agency

FIRMS – Flood Insurance Rate Maps

MAC – Metropolitan Airports Commission

MCWD - Minnehaha Creek Watershed District

MnDOT – Minnesota Department of Transportation

MPCA – Minnesota Pollution Control Agency

MPRB – Minneapolis Park and Recreation Board

MSL – Mean Sea Level

NWI – National Wetland Inventory

OHW – Ordinary high-water level

U of M – University of Minnesota

USGS – United States Geological Survey

WPA - Works Progress Administration

INTRODUCTION

The Minnesota Department of Natural Resources' (DNR) State Climatology Office observed that the Twin Cities recorded the wettest seven years on record from 2013-2019. In 2014, shortly after this wet period began, property owners southwest of Lake Nokomis in Minneapolis, Minnesota, began to report water concerns to the City of Minneapolis. The concerns included reports on wet basements, wet backyards, extended periods of saturated soils in previously dry areas, sinkholes, and impacts to private sewer laterals (the line that runs from a house to the street). Between 2014-2018, the City of Minneapolis received water concern reports from 21 property owners in three separate "Areas of Concern". **Figure 1** shows the location and given names for the three areas of Concern, along with the number and type of reported concerns within each:

- **Nokomis Parkway:** 3 homes reported wet basements to the City of Minneapolis
- **West Nokomis**: 13 homes reported wet basements to the City of Minneapolis
- **Solomon Park**: 5 homes reported wet backyards to the City of Minneapolis

In response to these property owner concerns, the City of Minneapolis assembled a multi-agency team ("Team") because surface water and groundwater management fall under several jurisdictions. Staff from the U.S. Geological Survey, Minnesota Department of Natural Resources, Hennepin County, Minnehaha Creek Watershed District, Minneapolis Park and Recreation Board, and the City of Minneapolis, came together to evaluate and understand what could be contributing to the water concerns and to help identify mitigation measures for homeowners and community leaders. The Team also coordinated with staff from the University of Minnesota, Metropolitan Council, Minnesota Department of Transportation (MnDOT), the Metropolitan Airports Commission (MAC), and the City of Richfield to share and interpret data. This report presents the approach, findings, and recommendations resulting from this four-year agency collaboration.

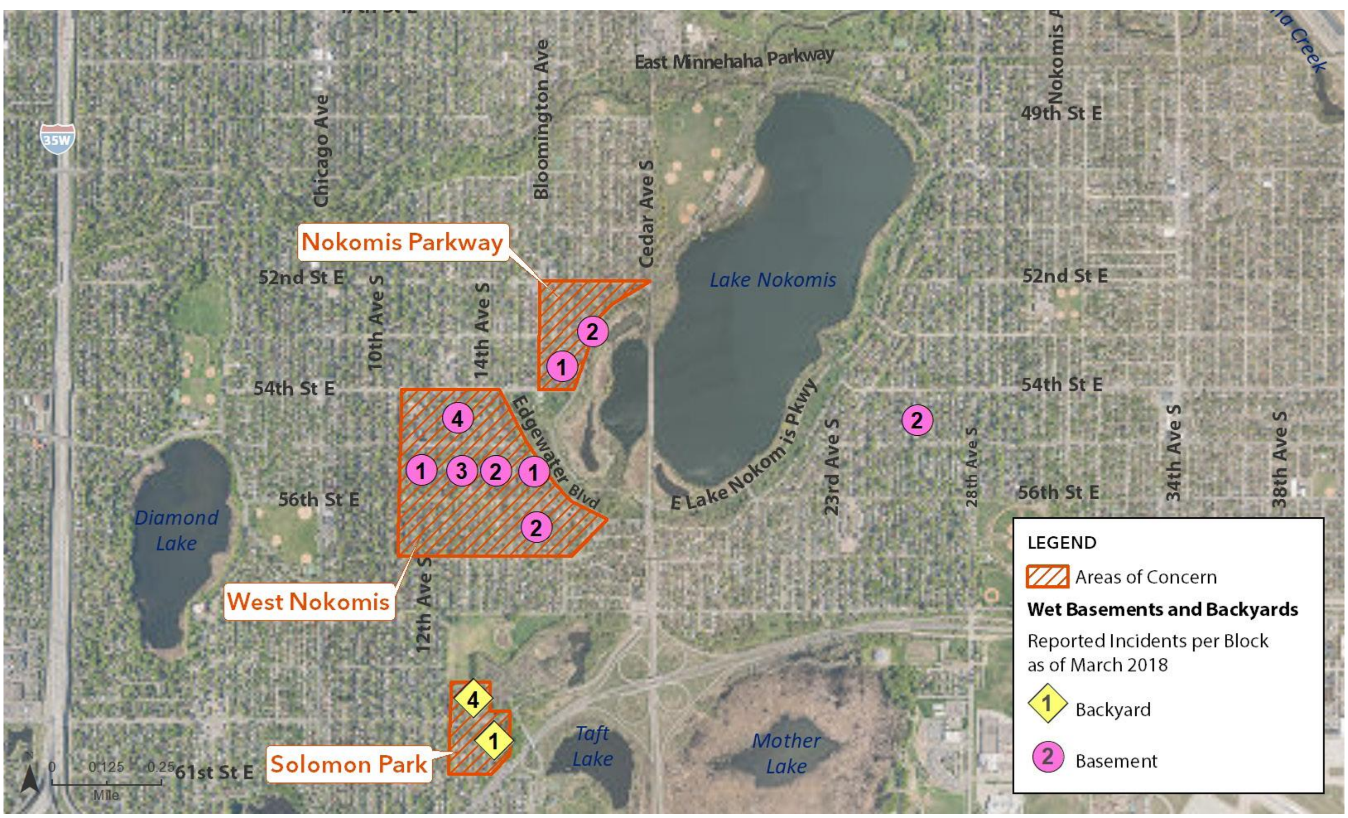


Figure 1: Mapped Water Concerns. *City of Minneapolis data showing reported wet basements and backyards concerns as of March 2018. (Credit: MCWD; Data Source: City of Minneapolis)*

EVALUATION APPROACH

The Team cataloged over 30 proposed hypotheses, put forth since 2014, as to what might be contributing to the water issues. The Team distilled the hypotheses down to seven factors and evaluated each to determine if they were contributing to the reported water concerns. The seven factors evaluated by the Team were:

- Geology & Hydrology: Historic and recent geological and hydrological data
- Residential Development: 1910s-1950s land use changes
- Precipitation Records & Climate Change: Historic and recent precipitation data
- Groundwater Recharge & Levels: Historic and recent groundwater data
- Lake Nokomis Water Levels: Historic and recent lake level data
- Minnehaha Creek Water Levels: Historic and recent creek level data
- Redevelopment & Stormwater Management: 2010s land use changes and associated stormwater control measures

EVALUATION FINDINGS

After evaluating existing data, gathering new data, and reviewing past studies, the Team found the following:

1. **11,000+ years ago,** glaciers created the landscape, geology, and hydrology around Lake Nokomis. From a geologic standpoint, the landscape around Lake Nokomis was naturally formed to hold and absorb water. The Minnesota Geological Survey (MGS) has found that most lakes in Minneapolis originated as ponded water in former ice blocks, and many of these lakes decreased in size as the climate warmed. Where lakes decreased in size, MGS has found organic material such as peat, at the surface and on top of lake sediment. MGS' surficial geology map in **Figure 2** identifies numerous peat deposits around Lake Nokomis. Peat is a wetland soil that contains partially decomposed plant material which allows it to absorb and retain large quantities of water, like a sponge. Because peat can hold water so effectively, it can be a barrier to allowing water to drain to deeper layers of the soil and can perch water above it.

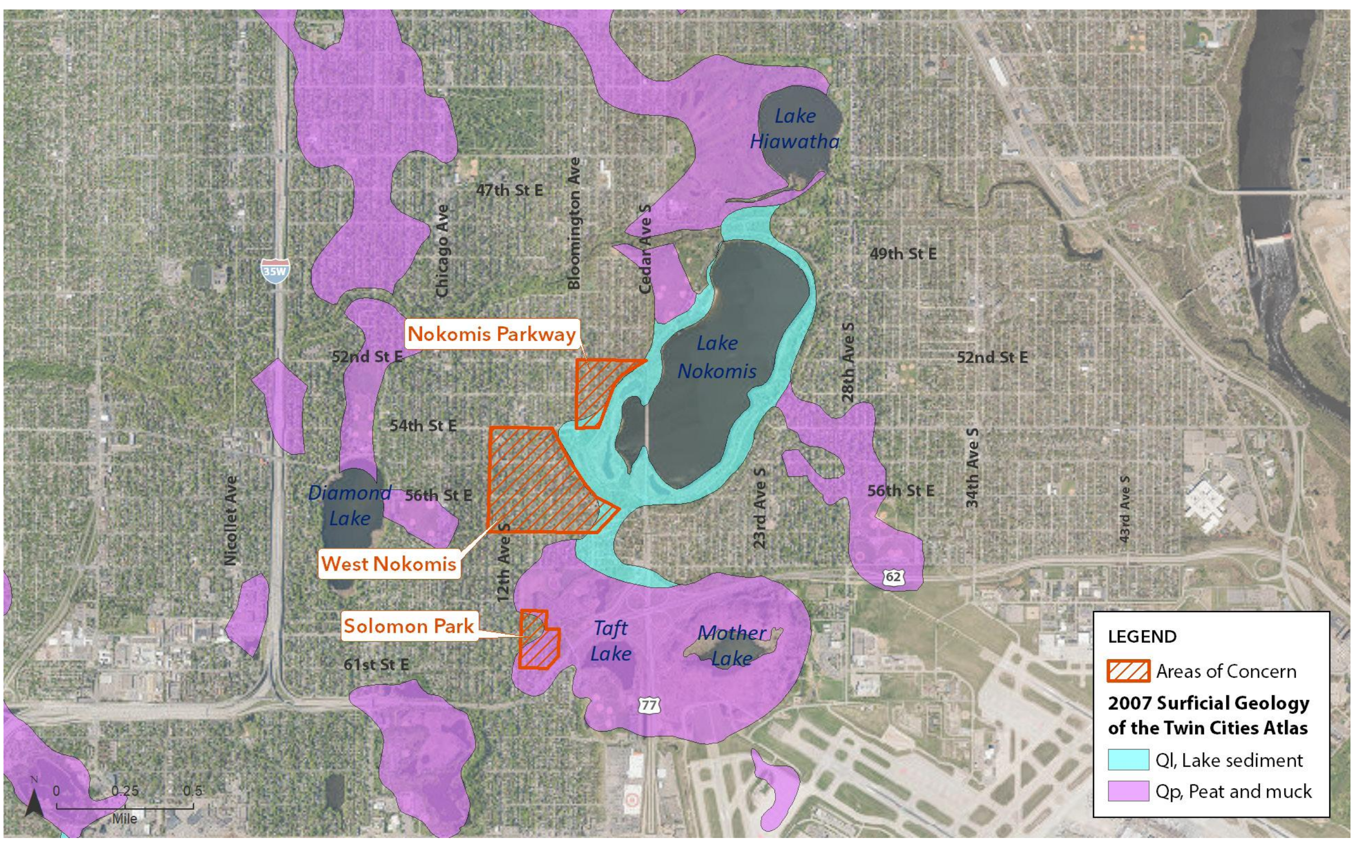


Figure 2: Surficial Geology Atlas. *Excerpt from the 2007 "Surficial Geology of the Twin Cities Metropolitan Region,Minnesota" which shows the peat and lake sediment layers. (Credit: MCWD; Data Source: Meyer, 2007)*

2. **Nearly 170 years ago, the first government land survey documented over 1,500-acres of lakes and wetlands adjacent to and neighboring present-day Lake Nokomis.** In 1853, prior to Minnesota statehood and expanded White settlement, the U.S. Surveyor General's Office surveyed the landscape around Lake Amelia (present-day Lake Nokomis). A digitized version of the 1853 land survey is shown in **Figure 3**. In 1853, Lake Amelia (present-day Lake Nokomis) was approximately 240-acres with a 13-acre wetland on the southwest side of the lake, Mother Lake was approximately 260-acres with an 88-acre wetland on the west side of the lake, and a 1,600-foot stream channel flowed out of the Mother Lake wetland into Lake Amelia.

3. **Over 110 years ago, Lake Nokomis and its natural wetlands and peat bogs, were excavated to convert the lake from a shallow water wetland into an open water lake.** During this time wetlands were considered unsanitary and useless, and they were viewed as an obstacle to development. MPRB transformed the Lake Nokomis area and undertook the "most ambitious lake-shaping plan in the history of Minneapolis Parks" (MPRB, 2021). Over the course of four years, this massive excavation project removed 2.5 million cubic yards of wetland, peat, and lake soil (comparable to ~250,000 dump truck loads) from Lake Nokomis and placed it as fill over adjacent low-lying wetlands and peat bogs. This excavation project reshaped the lake, reduced the water area by 100-acres, and deepened the lake. Theodore Wirth (Superintendent of Minneapolis parks from 1906–1935), noted that "the transformation of formerly unsanitary and unsightly sections" led to the residential development and park creation that anchors the area we know today (The Minneapolis Star, 1934).

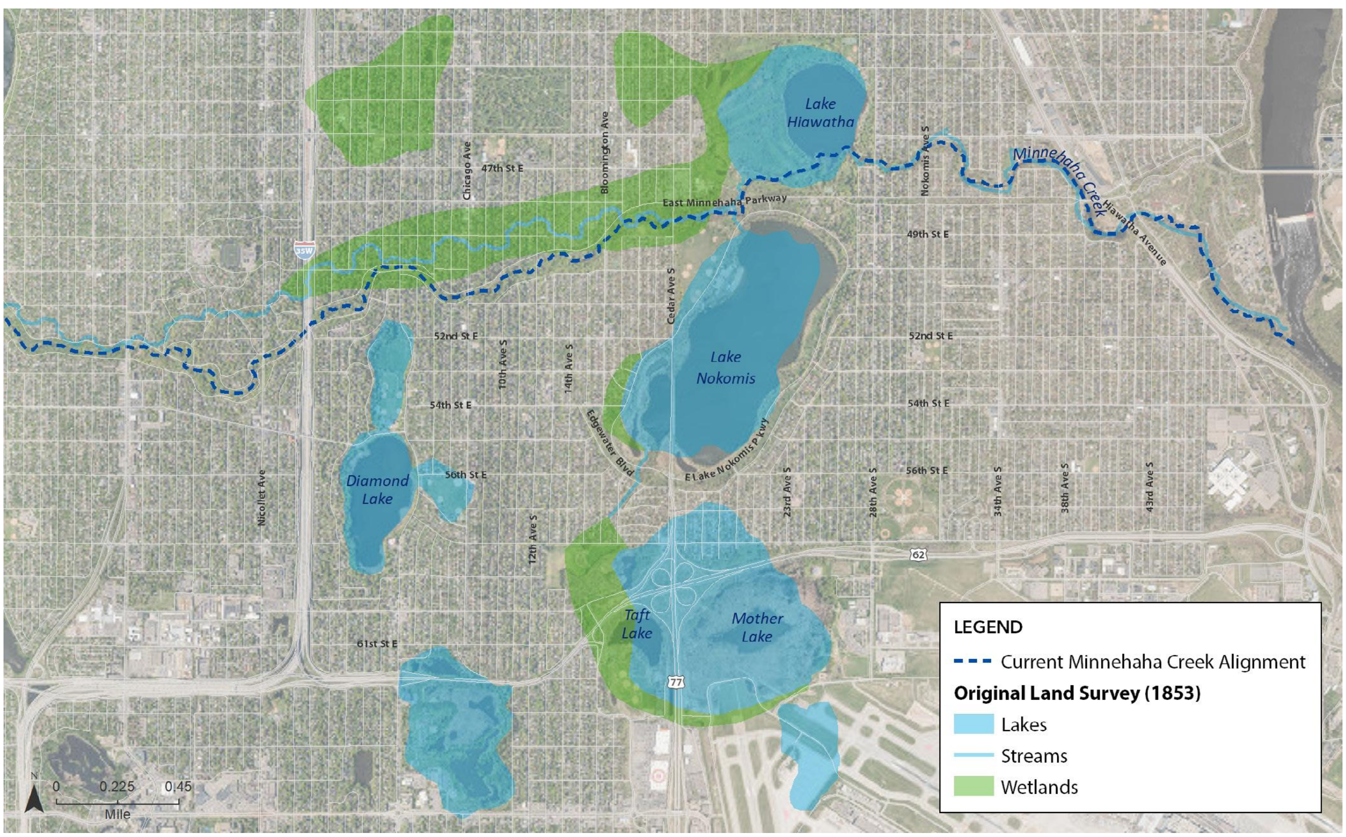


Figure 3. Digitized 1853 Original Land Survey Map. *1853 survey of lake, wetland, and stream boundaries overlaid on the present-day landscape around Lake Nokomis. (Credit: MCWD; Data Source: GLO Historic Plat Maps)*

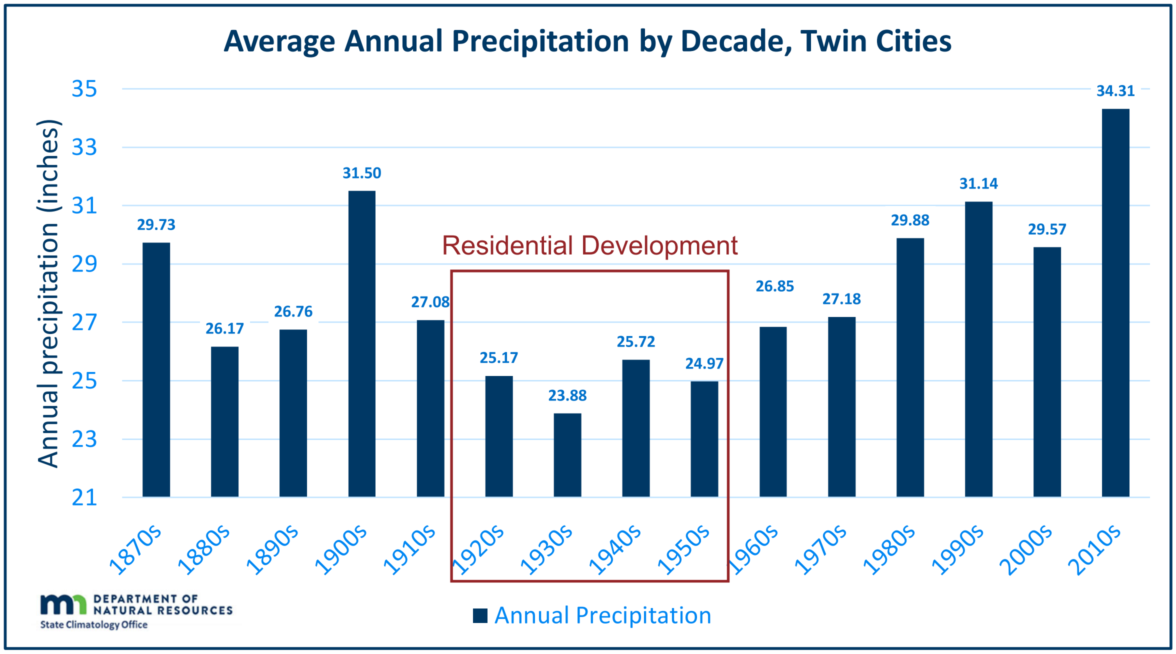


***Figure 4: Average Annual Precipitation.** The Twin Cities average annual precipitation was the lowest during the 1920s-1950s. Precipitation totals have been increasing since the 1950s. (Credit: DNR State Climatology Office)*

4. **100 years ago, residential development began around Lake Nokomis and coincided with the driest period on record for the Twin Cities.** Lake Nokomis' transformation, and the subsequent residential development that followed from the 1920s-1950s, coincided with the drought that began in the 1920s and lasted into the 1950s (**Figure 4**). During these 40 years when homes were being built in historically wet areas, the average annual precipitation was approximately 25-inches and resulted in a long-term precipitation deficit. This drought caused Lake Nokomis to fall to its lowest recorded level of 809.67-feet in 1932, which is 5.7-feet below the current ordinary high-water level of 815.40-feet. As a result, these dry conditions created perceptions that water was relatively easy to manage even over former wetland areas. This resulted in homes being built over filled wetlands, peat soil, and the former footprint of Lake Nokomis.

5. **80 years ago, during the development of the Lake Nokomis area, underlying wetland and peat soils caused problems for underground infrastructure, roads, and parkland, including during the Dust Bowl drought.** City of Minneapolis records from the 1930s note that sewer lines needed to be repaired shortly after installation with pilings and encased in concrete due to poor soil conditions. 1941 records show when 58th Street was extended towards 15th Avenue, peat bogs up to 16-feet in depth were encountered and excavated. Additionally, MPRB records note that 20-years after the dredging of Lake Nokomis, the peat soils settled and required extensive restoration work that was carried out by the Works Progress Administration (WPA). Between 1936-1939, WPA workers dug peat up to 15-feet deep and regraded over 52 acres of peat ground around the lake after it had cracked. 1939 reports note that WPA workers also excavated 33,875 cubic yards of peat (equivalent to over 3,300 dump truck loads) from under walks, curbs, and pavements that had settled.

6. **Peat soils continue to be discovered and mapped.** The surficial geology atlas from MGS shows that areas of peat exist in the Lake Nokomis area. Even outside of those mapped MGS areas, peat has been found at the surface and up to 50-feet deep. MPRB's WPA records note that peat soils were removed from Lake Nokomis and used to fill depressions by Minnehaha Creek, and that peat soils from Mother Lake were used to fill depression on the south side of Lake Nokomis. Additionally, soil drilling records from the past two decades note the presence of peat in around Lake Nokomis. Given the movement of peat in and around Lake Nokomis, and the discovery of peat soils outside of mapped areas, it is likely that peat soils exist in small pockets

throughout the area that were too small to be documented on MGS' geology atlas.

7. **During 2010-2019, the Twin Cities experienced the wettest decade on record.** The DNR Climatology Office notes that over the past decade, the average annual precipitation was 34.31-inches. This means the Twin Cities received nearly 100-inches (8.33-feet) more precipitation in the 2010s than they did during each individual decade (1920s, 1930s, 1940s and 1950s) when the homes around Lake Nokomis were built. The 2010s also included the wettest seven years on record from 2013-2019, resulting in an accumulated precipitation surplus of 32-inches during those seven years. Precipitation was also found to be increasing outside of the growing season, which increases groundwater recharge and could increase the amount of precipitation directed to the regional shallow water table and the peat soils in the area.

8. **Surplus precipitation is trapped by buried peat soils.** Because of peat's ability to absorb and retain large quantities of water, peat soils continued to cause water issues in 2020-2021, even during drought conditions. Peat soils that are buried under fill can restrict the downward movement of precipitation into the ground. This has likely caused the peat soils to trap the surplus precipitation from 2013-2019, and form perched groundwater systems that are causing the reported water concerns. Because peat soils act like a giant sponge, once they are wet, they can hold onto water for extended periods of time. This likely explains why property owners around Lake Nokomis continued to experience water issues during drought conditions in 2020 and 2021, even though groundwater levels and surface water levels trended lower.

9. **Lake Nokomis and Minnehaha Creek are not driving groundwater levels.** Groundwater well data confirmed that the amount of precipitation soaking into the ground is driving groundwater levels in the Lake Nokomis area, not the water levels in Lake Nokomis or Minnehaha Creek. Groundwater wells across the Twin Cities show that groundwater levels are responding in the same way despite being in different geographies, demonstrating that precipitation is driving groundwater levels and not local watershed features.

10. **The physical elevation of most basements with water issues revealed that they are elevated at least 5-feet, and up to 19-feet, higher than the regional shallow water table or surface water.** This demonstrates that the regional shallow water table, Lake Nokomis, and Minnehaha Creek are not contributing to the water issues for most reported basements; and that perched groundwater near those basements could be contributing to the water issues.

11. **Land use change and redevelopment over the past decade, and associated stormwater management activities do not contribute to the reported water concerns.** Minor redevelopment has occurred in the Lake Nokomis watershed over the past several decades. The total amount of water infiltrated by stormwater management practices is modeled to be approximately 1% of the total regional groundwater recharge.

EVALUATION CONCLUSIONS

The water issues were found to be a result of underlying geology, historic land use decisions, and increased precipitation caused by climate change. Given that peat soils have historically caused issues in the Lake Nokomis area, the Team's understanding is that underlying peat soils have recently absorbed and trapped the record high precipitation surplus and have caused most of the reported water concerns.

Figure 5 shows the areas with reported water concerns and a conceptual cross-section of the Areas of Concern. Figure 5 also graphically represents what is and is not contributing to the water concerns for each of three Areas of Concern: Nokomis Parkway, West Nokomis, and Solomon Park. Property owners in each Area of Concern experienced water issues for slightly different reasons:

- **Nokomis Parkway Area of Concern:**
    - **Issues Experienced:** Wet basements
    - **Conclusion:** Homes were built over former wetlands, within the former Lake Nokomis basin, and below the current normal water level of Lake Nokomis. Record-breaking precipitation and groundwater recharge are likely exacerbating existing water issues due to area's geologic history.
- **West Nokomis Area of Concern:**
    - **Issues Experienced:** Wet basements

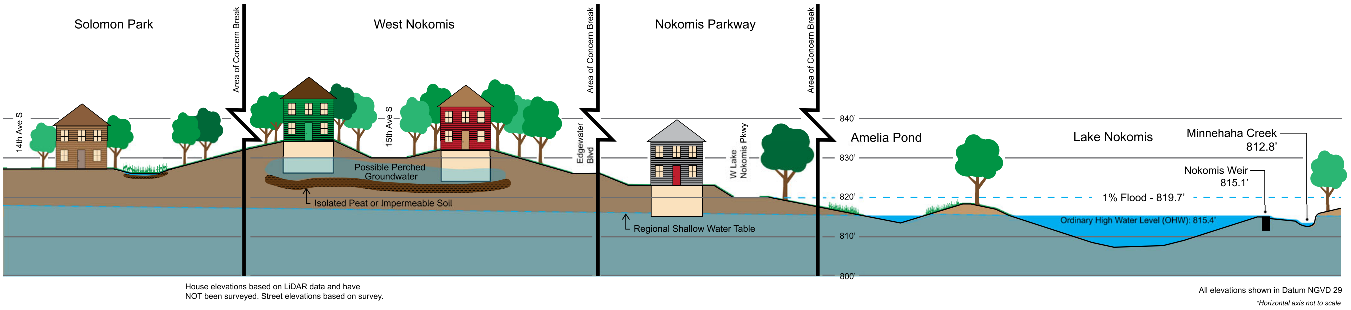


Figure 5: Conceptual Cross Section. *Cross section showing the elevation of water features relative to the elevation of homes experiencing water issues in the Areas of Concern. (Credit: Stantec)*

- **Conclusion:** Homes were built adjacent to historically filled wetlands, in areas where peat was deposited, in areas of naturally occurring peat soils, and, in some instances, over the former stream channel between Mother Lake and Lake Nokomis. Lake Nokomis, Minnehaha Creek, and the regional shallow water table are not contributing to the water issues as they are 5-feet to 19-feet lower than the affected basements. This indicates that issues are resulting from record-breaking precipitation being trapped by peat soils, which caused localized perched groundwater systems.

» **Solomon Park Area of Concern:**

- **Issues Experienced:** Wet backyards
- **Conclusion:** Homes were built on or adjacent to former or existing mapped wetland with peat soils. Peat soils have prevented record-breaking precipitation from soaking into the ground and resulted in standing water.

MOVING FORWARD: LAKE NOKOMIS AREA NEXT STEPS & RECOMMENDATION

The Lake Nokomis area water issues have been found to be localized and driven by geologic history, past land-use decisions, and climate change in the form of record rainfall. As a result, it is recommended that property owners experiencing water issues consider implementing mitigation measures on site, to protect their property and infrastructure from water impacts. Next steps for local governments and the Team for the Lake Nokomis area will include leveraging state funding to map local geology and perched groundwater, continuing to collect and monitor surface and groundwater data from the area, while also identifying and sharing resources to support property owners in implementing individual mitigation measures.

Beyond the Lake Nokomis area, the partners on the Team have drawn on the lessons learned from the Lake Nokomis case study and are actively working on climate change action planning. **Appendix A** summarizes the climate action work the partners are supporting and implementing across Minnesota's communities and landscapes.

RECOMMENDATION

» Property owners experiencing water issues consider implementing mitigation measures on site, to protect their property and infrastructure from water impacts.

NEXT STEPS

Quantify:

» **University of Minnesota (U of M), USGS, MGS:** Leverage allocated state funds to quantify and more precisely delineate the local geological and hydrogeological features in the Lake Nokomis area. Conduct soil borings to specifically map peat and wetland soils that are causing perched groundwater conditions and affiliated issues and assess the potential impact to properties around Lake Nokomis. Develop guidelines to predict areas across the region which may experience similar issues.

» **City of Minneapolis**: Provide project support to the U of M, USGS, and MGS effort to map the extent of peat and wetland soils (geologic features) in the Lake Nokomis Areas of Concern.

Assist:

» **City of Minneapolis**: Leverage data and guidelines from the U of M to continue identifying areas potentially impacted by climate driven shifts in surface and groundwater patterns across the city. Continue to evaluate and respond to emerging water issues, including those at Lake Nokomis, using established prioritization frameworks.

- **City of Minneapolis:** Continue evaluating existing laws, policy frameworks, and resources that are available to assist all affected property owners within the city with water mitigation measures; identify potential gaps and continue advocating for appropriate legislative support for local climate adaptation.
- **City of Minneapolis:** Continue identifying and sharing resources on the city's website to support actions property owners might consider implementing to mitigate localized water related impacts.

Monitor:

- **Hennepin County:** Continue to collect, monitor, and analyze groundwater data from the wells on the southwest side of Lake Nokomis and near Solomon Park.
- **Minneapolis Park and Recreation Board:** Continue to collect, monitor, and analyze Lake Nokomis water levels; and operate the Lake Nokomis outlet structure according to the Lake Nokomis Outlet Operating Plan.
- **Minnehaha Creek Watershed District:** Continue to implement and expand the watershed wide real-time sensor network (RESNET) to collect, monitor, and analyze water level information across the watershed, including at Lake Nokomis.

MOVING FORWARD: REGIONAL AND STATE-WIDE COORDINATION FOR CLIMATE ACTION

The wet weather between 2013-2019 resulted in new state-wide precipitation records and the highest recorded water levels in many of Minnesota's lakes, streams, and groundwater wells. Climate change is expected to continue shifting precipitation patterns and hydrology in ways that will impact natural systems and the built environment.

Local but Widespread Impacts of Climate Change Underscores the Need for Coordinated Action

The Lake Nokomis Area Groundwater and Surface Water Evaluation offers a case study on how climate change is already impacting people and communities at a local scale. It also reinforces the need for a coordinated partnership approach across various levels of government, to efficiently collect and evaluate data at multiple scales and to convene partners at appropriate levels to develop effective climate adaptation strategies.

Mobilizing a team of federal, state, county, watershed, and city partners to address local and specific impacts of climate change is not a repeatably sustainable approach to successfully planning or responding to the level of climate adaptation needed at a regional and state scale. The partnership surrounding the Lake Nokomis area issues has revealed many insights which the Multi-Agency Team are carrying forward to advance in synchrony on the issue of climate action across all of Minnesota. **Appendix A** summarizes the climate action work these partners are supporting and implementing across Minnesota's communities and landscape.

1.0 LAKE NOKOMIS AREA EVALUATION

1.1 WATER CONCERNS IN LAKE NOKOMIS NEIGHBORHOODS

During 2014-2018, 21 property owners southwest of Lake Nokomis in Minneapolis, Minnesota reported wet basements, wet backyards, impacts to private sewer laterals, sinkholes, and extended periods of saturated soils in previously dry areas. During this five-year period, the City of Minneapolis received reports about deteriorating private sewer laterals (the lines that run from a house to the street) and groundwater impacts to basements and foundations. Additionally, the Minneapolis Park and Recreation Board (MPRB) observed impacts to Lake Nokomis beaches and shorelines due to high water levels on the lake.

1.2 MULTI-AGENCY TEAM & STUDY PARTNERS

In response to property owner concerns and because groundwater and surface water management in Minneapolis falls under multiple jurisdictions, the City of Minneapolis assembled a Team in November 2017 to evaluate and diagnose the reported concerns. The Team included staff from U.S. Geological Survey, Minnesota Department of Natural Resources, Hennepin County, Minnehaha Creek Watershed District, Minneapolis Park and Recreation Board, and the City of Minneapolis. The Team also coordinated with staff from the University of Minnesota, Metropolitan Council, Minnesota Department of Transportation (MnDOT), the Metropolitan Airports Commission (MAC), and the City of Richfield to share and interpret data and attend meetings to provide insight and recommendations.

Each agency on the Team dedicated technical experts to study and answer the following questions:

- What is causing the high-water issues in these Minneapolis neighborhoods?
- What can be done to help mitigate the water issues?

Since late 2017, the Team has collectively spent thousands of hours to investigate the water concerns and invested resources to gather new data. Throughout the investigation, the Team communicated findings to members of the public and policy makers through seven technically focused multi-agency meetings, 12 multi-agency leadership meetings, five public meetings, a public open house, and a City of Minneapolis dedicated webpage and email address (nokomisgroundwater@minneapolismn.gov).

As part of the study, the Team recommended preparation of this paper to document the evaluation, findings, and conclusions into one comprehensive document. The Team asked MCWD to lead the drafting of the paper, who contracted with Stantec (formerly Wenck) to assist with the drafting.

1.3 TEAM'S STUDY APPROACH & STUDY AREA

The Team's first step involved defining the study area for the evaluation. The Team used data from the City of Minneapolis to identify where basement and backyard water concerns had been reported to the city. The Team identified three separate "Areas of Concern" where water concerns had been reported to the city. This paper will refer to the three Areas of Concern as Nokomis Parkway, West Nokomis, and Solomon Park. **Figure 6** shows the location of the three Areas of Concern and the type of reported concerns within each:

- Nokomis Parkway: 3 homes reported wet basements to the City of Minneapolis
- West Nokomis: 13 homes reported wet basements to the City of Minneapolis
- Solomon Park: 5 homes reported wet backyards to the City of Minneapolis

The data in **Figure 6** show the locations of the reported basement and backyard water concerns as of March 2018.

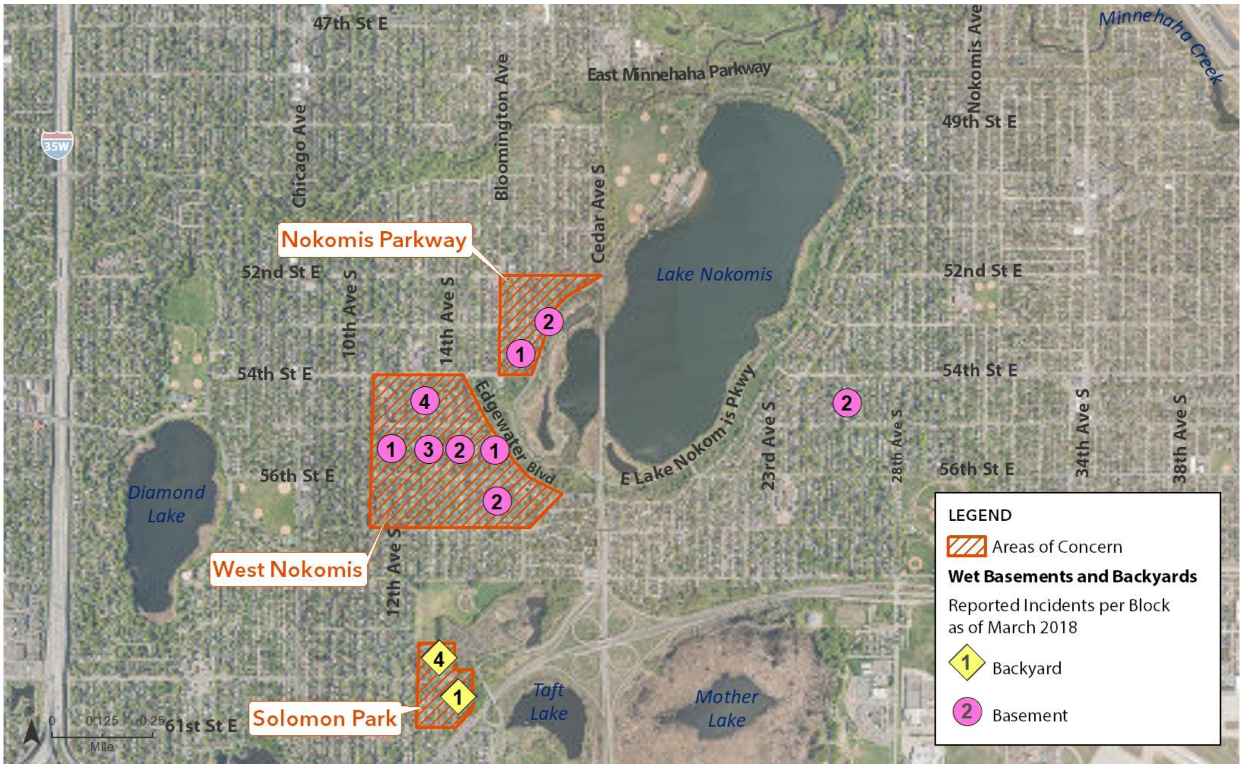


Figure 6: Reported Water Concerns. *City of Minneapolis data showing reported wet basement and backyard concerns as of March 2018. (Credit: MCWD; Data Source: City of Minneapolis)*

The Team's second step involved assembling all the working hypotheses that residents, policy makers, and agency staff thought might be contributing to the water issues, which ultimately resulted in more than 30 hypotheses. The Team reviewed these hypotheses and identified seven factors by which these hypotheses could be grouped. The seven potential factors that were evaluated are:

» Geology & Hydrology: Historic and recent geological and hydrological data

» Residential Development: 1910s-1950s land use changes

» Precipitation Records & Climate Change: Historic and recent precipitation data

» Groundwater Recharge & Levels: Historic and recent groundwater data

» Lake Nokomis Water Levels: Historic and recent lake level data

» Minnehaha Creek Water Levels: Historic and recent creek level data

» Redevelopment & Stormwater Management: 2010s land use changes and associated stormwater control measures

To determine how these factors might be contributing to the water issues, the Team collected new data, analyzed past data, and reviewed existing studies including but not limited to:

» Reviewing surficial geology atlases underlying the Areas of Concern

» Reviewing original land surveys of the Areas of Concern

» Reviewing the history of residential development of the Areas of Concern

» Reviewing MPRB historical park improvement reports

» Compiling and analyzing precipitation data

» Reviewing groundwater recharge rate models

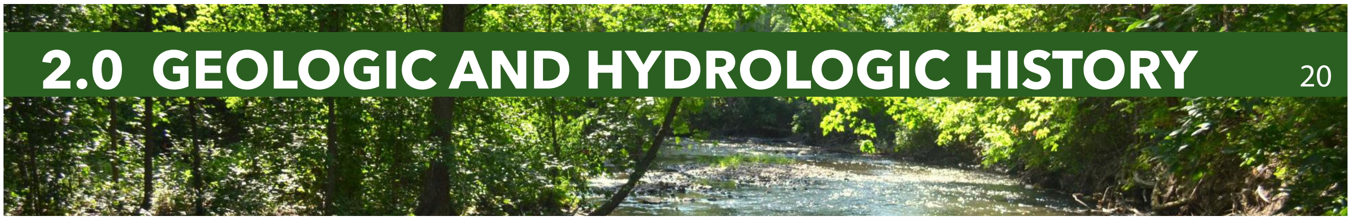
» Installing six new groundwater monitoring wells and reviewing groundwater elevation data from the new and nearby existing monitoring wells

» Reviewing surface water elevation data for Lake Nokomis, nearby lakes, and Minnehaha Creek

» Reviewing stormwater infrastructure data within the Areas of Concern

- Reviewing land use change over the past decade
- Reviewing over 70 past studies and data resources related to surface water and groundwater in the Areas of Concern

Through this data review, the Team evaluated possible connections of these factors to the Areas of Concern and drew working conclusions. Chapters 2-8 of this paper review each of these seven factors and their associated studies and data. Each of these chapters end with a section titled, "Areas of Concern Findings" which outlines if the factor was found to be contributing towards the reported water concerns.



2.0 GEOLOGIC AND HYDROLOGIC HISTORY

The geologic features that lie beneath the Areas of Concern provide key information on how the landscape was formed, why water occurs where it does (above and below ground), and how water works within the the landscape today. This chapter will examine the geology, including the presence of peat soils, the pre-settlement hydrologic landscape, present day wetlands, and the present day floodplain.

2.1 GEOLOGIC HISTORY

Over 11,000 years ago, ice inched southward across Minnesota as glaciers provided the raw materials for much of Minnesota's present-day landscape. As those glaciers retreated and melted, they laid the course for how water drains across the land today. These past geological deposits determined where surface water and groundwater now occur and how that water flows. Steenberg et al. (2018) notes that:

> In addition to rivers, Hennepin County is marked by a large number of lakes. Each lake represents a former ice block or cluster of ice blocks left behind by the Grantsburg sublobe and/or the Superior lobe. Underlying bedrock topography also controls the orientation of lakes, such as the chain of lakes in Minneapolis that overlies a large valley in the bedrock surface. Many of these lakes decreased in surface area throughout the Holocene Epoch, the normal results of a warmer post-glacial climate. In areas where lake levels have decreased, organic material (unit Qp) can be found at the land surface on top of and interbedded with lake sediment (unit Ql). . .Further alteration of the landscape post-glacially resulted from industrialization and establishment of human society. (Plate 3)

2.1.1 Surficial Geology

Surficial geology maps show the type of unconsolidated materials which are beneath the topsoil layers of the land surface. In 2007, the Minnesota Geologic Survey (MGS) published a geologic atlas titled, "Surficial Geology of the Twin Cities Metropolitan Region, Minnesota". **Figure 7** shows an excerpt from the 2007 Twin Cities surficial geology atlas for the Lake Nokomis area. In 2018, MGS published a revised surficial geology atlas specifically for Hennepin County. **Figure 8** shows an excerpt from the 2018 Hennepin County surficial geology atlas for the Lake Nokomis area. Additional details from the 2007 and 2018 MGS surficial geology atlases can be found in **Appendix B**.

Both the 2007 and 2018 MGS surficial geology atlases for the Areas of Concern note the presence of lacustrine deposits, fine grained inorganic silts, clays with organic materials including peat and muck, areas where artificial fill (non-native soil and material) was placed over peat and muck, and areas where Lake Nokomis was drained, excavated, and filled with other materials.

This means that the three Areas of Concern were built on, next to, or in-between historic wetlands with peat soils and lake-basin soils that were drained, excavated, and filled with other material for development. Despite being buried with fill, these peat, muck and former lake basin features are still present under the landscape today.

2.2 PEAT SOILS

The MGS geologic atlases notes the presence of peat soils within and near the Areas of Concern. This is an important finding because peat can only form in areas that are saturated with water, which reduces oxygen and thus plant decomposition, resulting in accumulating organic plant matter. This means that areas mapped with peat or near peat were historically low lying and wet.

2.2.1 Formation and Accumulation

It is important to understand the distinction between how peat forms and the process in which it accumulates. The DNR (2021) notes:

> Peat formation requires low-oxygen conditions that prevent normal decomposition of plant debris. This occurs in areas of poor drainage where precipitation exceeds evaporation. The water table lies at or near the surface in these areas, saturating dead plant material. As a result, organic materials accumulate year-after-year, forming the partially decomposed mass known as peat.

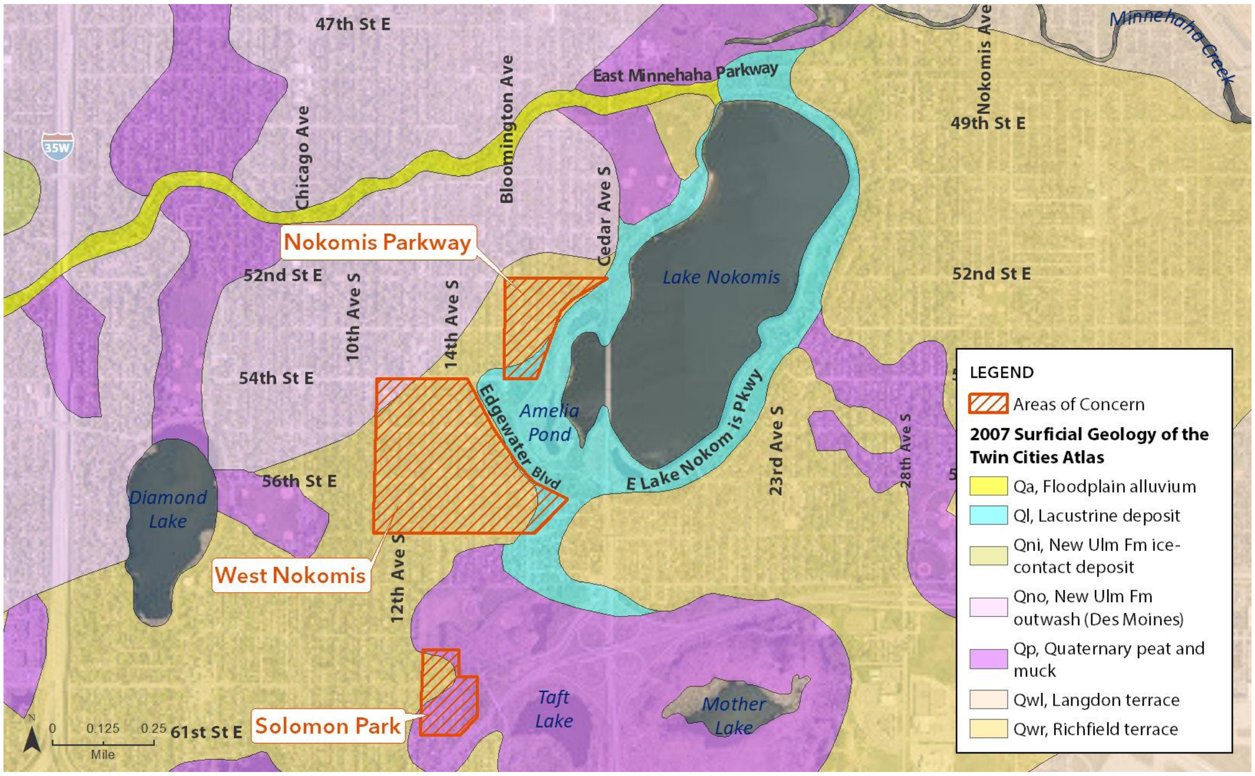


Figure 7: 2007 Surficial Geology Atlas. *Excerpt from the 2007 Surficial Geology Atlas of the Twin Cities for the Lake Nokomis area. (Credit: MCWD; Data Source: Meyer, 2007)*

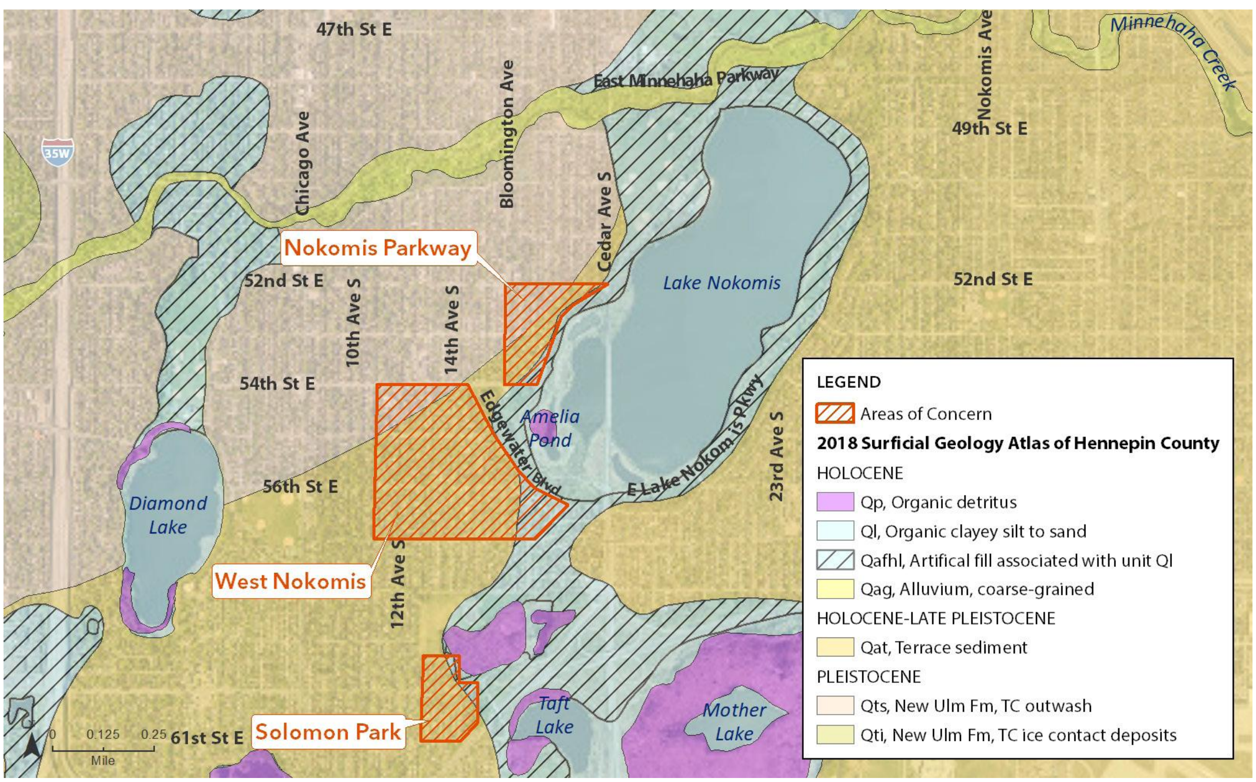


Figure 8: 2018 Surficial Geology Atlas. *Excerpt from the 2018 Surficial Geology Atlas of Hennepin County for the Lake Nokomis area. (Credit: MCWD; Data Source: Steenberg et al., 2018)*

It is likely that the peat within and near the Areas of Concern began to form thousands of years ago and was influenced by the topography and warming climatic conditions. In 1919, the MGS, in cooperation with the USGS and the United States Bureau of Mines, published "The Peat Deposits of Minnesota." In this MGS publication, Soper (1919) notes:

> The topography of the land surface has been the most important factor in controlling the distribution of peat in Minnesota, while the climatic conditions have controlled the quantity which has formed. No matter how favorable the climate may be, peat cannot accumulate unless the topography is such that lakes, ponds, swamps, or other moist depressions prevail. (p. 38)

Andriesse (1988) found that peat accumulation over time can result in primary, secondary, and tertiary peats:

> Peat accumulating in the initial depression is called primary peat . . . The development of primary peats reduces the surface retention of the reservoir. . .Secondary peats are those that develop beyond the confines of the basin or depression.Tertiary peats are those that develop above the physical limits of groundwater, the peat itself acting as a reservoir holding a volume of water by capillary forces up above the level of the main regional groundwater-table. This reservoir forms a perched water-table fed only by precipitation.

Understanding how peat forms and accumulates highlights the fact that the Areas of Concern were historically wet, with wetlands and lakes, and the placement of artificial fill over top the peat soils has not changed this fact.

2.2.2 Water Retention

Because peat soils contain partially decomposed plant material, they have the capacity to absorb and retain large quantities of water (Severson, 1980). Because peat can hold water so effectively, it can create an impermeable layer and restrict the downward movement of precipitation into deeper layers in the soil.

Peat soils can act like a giant sponge. Once they are wet they can hold onto water for extended periods of time, which can create water issues for basements and infrastructure.

In recent years, the Areas of Concern received record precipitation discussed in Chapter 4. Once peat soils absorbed and retained this precipitation, they likely prevented it from draining further. This can cause water to accumulate, or perch, above peat and form perched groundwater systems. **Figure 9** shows a perched groundwater system. The USGS (1989) defines perched groundwater as "groundwater separated from an underlying body of groundwater by an unsaturated zone". The USGS (1989) also notes that "perched groundwater is held up by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure."

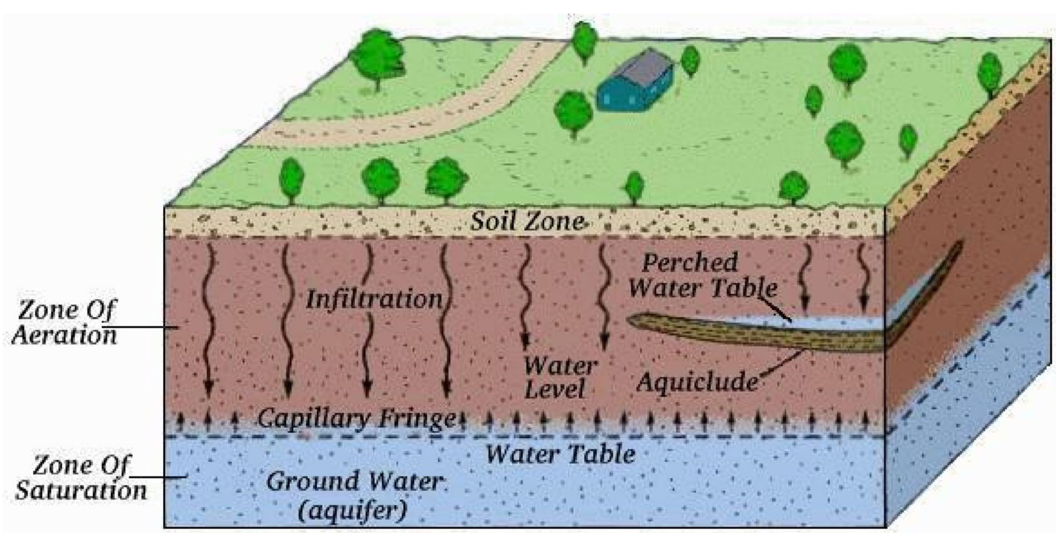


Figure 9: Perched groundwater. *Perched groundwater or water tables are separate from the underlying groundwater system. (Government of Nepal, 2021)*

2.2.3 Low Bearing Strength

Hanson (1966) found that "peat and muck, differ radically from the mineral soils in that their low volume weight and higher water-holding capacity result in low bearing strength". Rezanezhad (2016) found that peat has a unique combination of physical properties "including low bulk density, high total porosity, and the ability to swell and shrink upon wetting and drying." Hobbs (1986) as cited in Rezanezhad (2016) found that "peat [is] a highly compressible material." Therefore, Waddington et al. (2010), as cited in Rezanezhad (2016), noted:

> Peatland surfaces may therefore exhibit daily to seasonal vertical movement due to swelling and shrinking. The vertical movement of the ground surface is accompanied by changes in water storage, but also in hydraulics, biogeochemistry and thermal properties.

Peat's low bearing strength is important to keep in mind, especially as depressions and sinkhole-like damage have been reported along the streets in the Areas of Concern and in the park space around Lake Nokomis. In October 2017, MPRB issued a communication noting that above average rainfall over the past two years (2016 and 2017) resulted in saturated soils and ground subsidence or settling in some areas around the Nokomis-Hiawatha Regional Park. In this MPRB communication, the MPRB (2017) noted that:

> The soft, very porous, peat-like material ground that compromises much of the area slowly compresses over time, and patches of compressed soil may "settle" slightly lower than the surrounding ground. These are not caused by broken or weakened stormwater pipes and are not sinkholes.

These compressed and settled areas around the Lake Nokomis Park space are outside the known peat areas mapped by MGS in **Figure 7** and **Figure 8**. This means peat may be present in other areas around Lake Nokomis and within the Areas of Concern. Section 3.2.2 supports this understanding, as it documents known peat areas within Lake Nokomis Park that are not mapped on **Figure 7** and **Figure 8**. Additionally, Section 3.2.2 discusses the steps that have been taken over time to mitigate peat compressing and settling within the Lake Nokomis Park, further documenting the history and significance of peat and the water issues that have been experienced since the area was developed.

2.3 PRE-SETTLEMENT HYDROLOGIC LANDSCAPE

The first public land survey for the state of Minnesota began in 1848, and was performed by the U.S. Surveyor General's Office, in anticipation of new settlers moving to Minnesota. The original public land survey provides an understanding of the physical geography prior to Minnesota statehood and expanded White settlement. The area around Lake Amelia (present day Lake Nokomis) was surveyed in the summer of 1853 and is shown in **Figure 10** on the following page.

In 1853, lakes and wetlands occupied approximately 1,500 acres. Today this same area has approximately 650 acres of lakes and wetlands.

This 1853 land survey shows that the area around Lake Nokomis was abundant with water features including six lakes and numerous wetlands. The six lakes included Rice Lake (present day Lake Hiawatha), Lake Amelia (present day Lake Nokomis), Mother Lake, Duck Lake (present day is a runway at the Minneapolis-St. Paul Airport), Mud Lake (present day Legion Lake), and Diamond Lake. Together, the footprint of these lakes in 1853 covered nearly 920 acres. In addition to the 920 acres of lakes, the 1853 survey also mapped a series of wetlands which totaled approximately 510 acres, including an approximately 300-acre wetland complex west of Rice Lake along Minnehaha Creek; an approximately 13-acre wetland on the southwest side of Lake Amelia; an approximately 88-acre wetland west of Mother Lake; and an approximately 110-acre wetland north of Diamond Lake and Minnehaha Creek. Lastly, the 1853 map shows a stream which flowed north out of the Mother Lake wetland into Lake Amelia. In total, the lakes and wetlands present in the 1853 survey occupied approximately 1,500 acres. In comparison, the total lakes and wetland present today occupy approximately 650-acres. From a geologic and hydrologic standpoint, the landscape around Lake Nokomis naturally formed to hold, absorb, and drain water from the landscape. This is evidenced by the numerous lakes and wetlands present prior to expanded White settlement. This water rich landscape supports the finding that the Areas of Concern were historically wet which led to the formation of peat soils.

In 2017 the U of M scanned Minnesota's original public land surveys and digitized the boundaries of the lakes, streams, wetlands, and other water resource elements. **Figure 11** shows the footprint of lakes, streams, and wetlands present in 1853 prior to settlement against the present-day landscape for the Lake Nokomis area. The blue shaded areas show the extent of lakes in 1853, the green shaded areas show the extent of wetlands that were present in 1853, the blue line shows the 1853 Brown's Creek alignment (present day Minnehaha Creek) prior to its alteration in the early 1900s, and the blue line southwest of Lake Nokomis shows a stream that flowed out of the Mother Lake wetland into Lake Amelia (present day Lake Nokomis) in 1853.

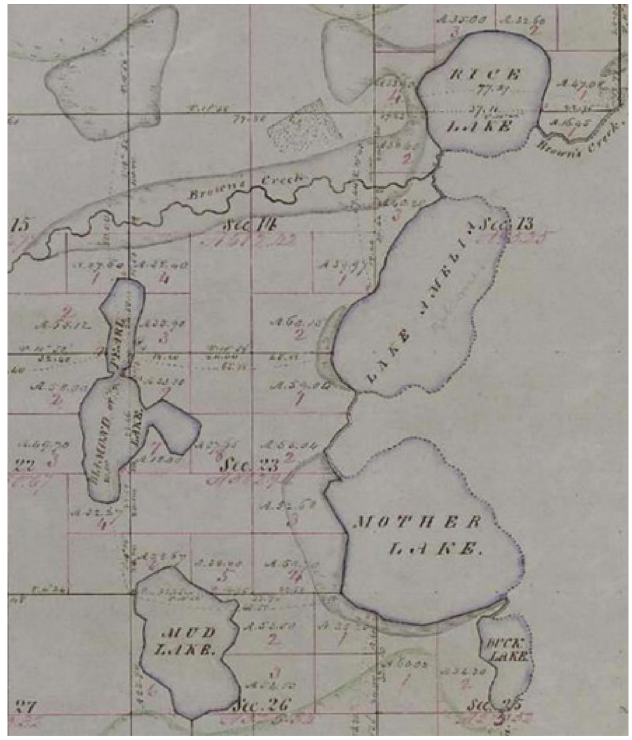


Figure 10: 1853 Public Lands Survey Plat Map. *In 1853 the landscape around Lake Amelia (present day Lake Nokomis) was surveyed and platted. The landscape in 1853 was water rich with many lakes and wetlands. (Credit: GLO Historic Plat Maps)*

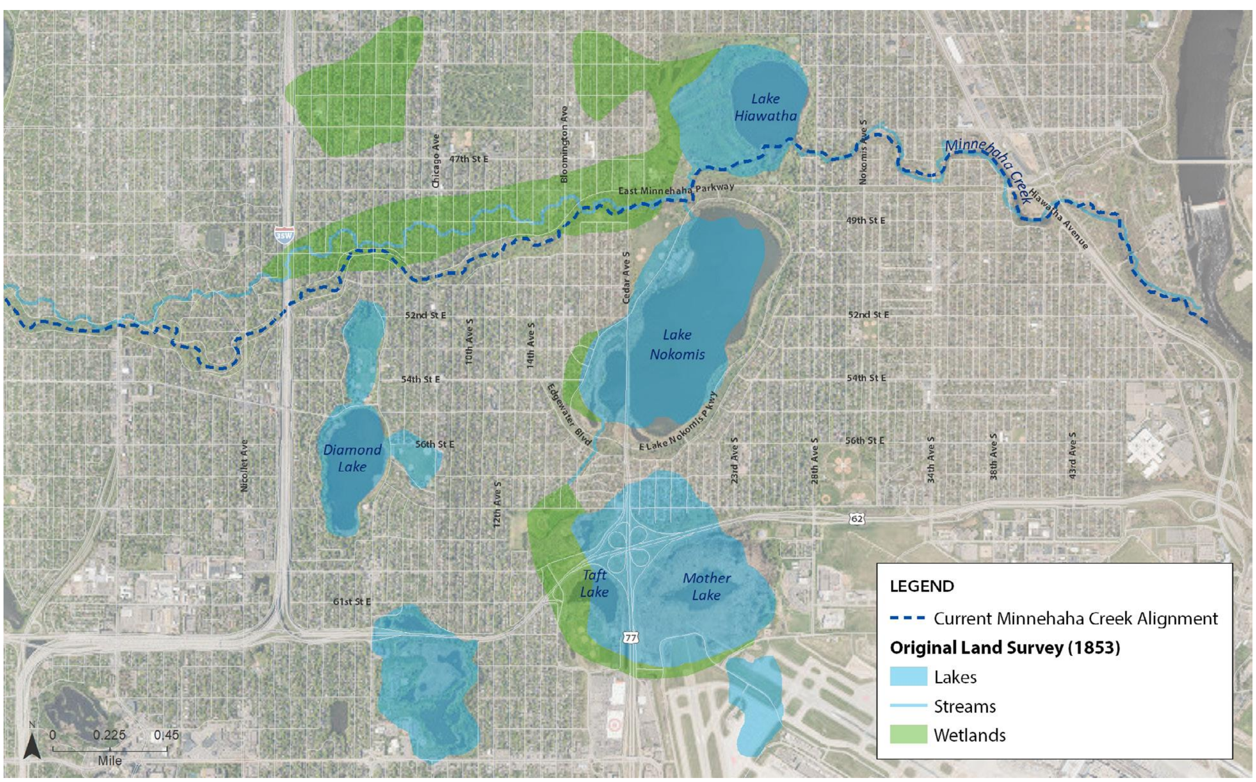


Figure 11: Digitized 1853 Original Land Survey Map. 1853 survey of lake, wetland, and stream boundaries overlaid on the present-day landscape around Lake Nokomis. (Credit: MCWD; Data Source: GLO Historic Plat Maps)

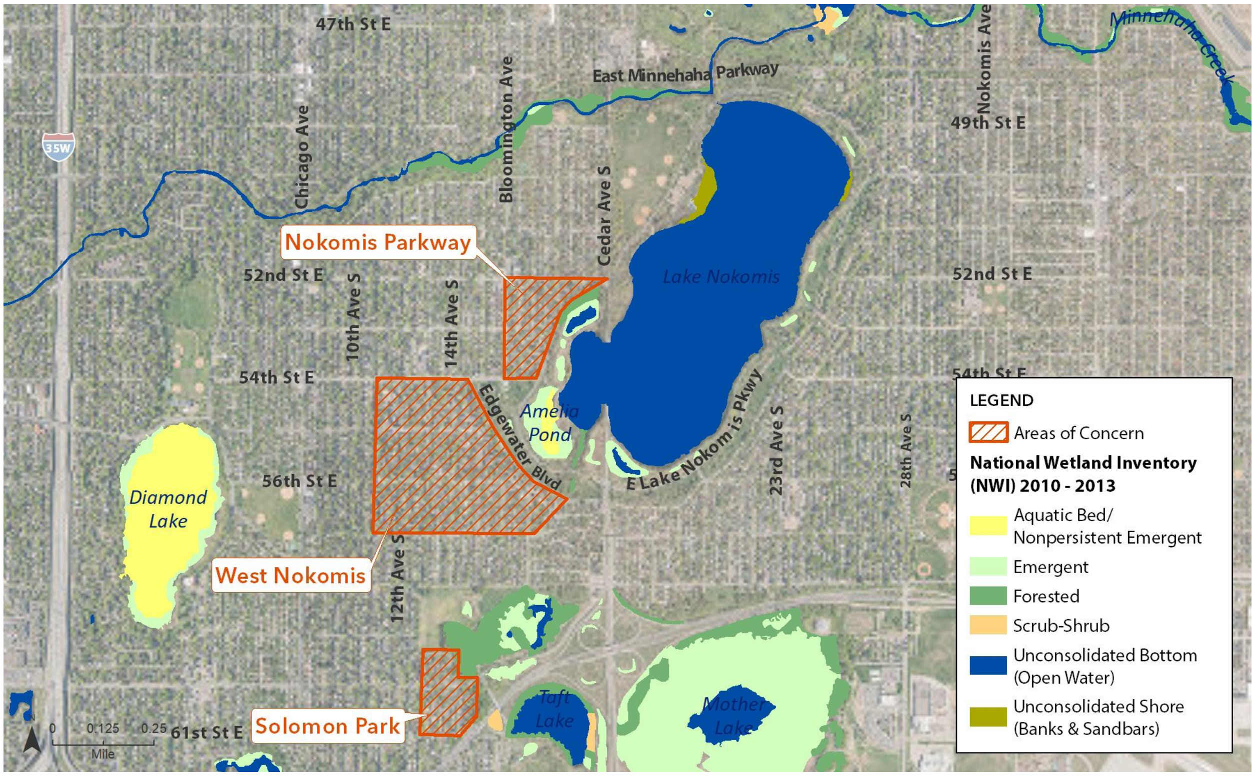


Figure 12: Existing Wetlands. National Wetland Inventory maps the current wetlands around the Areas of Concern. (Credit: MCWD; Data Source: National Wetland Inventory)

2.4 PRESENT DAY WETLANDS

The U.S. Fish and Wildlife Service oversees the National Wetlands Inventory (NWI) which provides a nationwide inventory on wetlands. The NWI for the Lake Nokomis area is shown in **Figure 12** and is overlaid with the Areas of Concern boundaries. Comparing **Figure 12** to **Figure 11**, the loss of wetlands and lakes since 1853 is very apparent. Currently, the Solomon Park Area of Concern contains properties that fall within a forested wetland type and the Nokomis Parkway Area of Concern contains properties adjacent to a forested wetland.

2.5 PRESENT DAY FLOODPLAIN

The Federal Emergency Management Agency (FEMA) oversees the National Flood Insurance Program. Under that program and with local assistance, FEMA prepares Flood Insurance Rate Maps (FIRMs) to inform the public on their risk of flooding. The FIRMs are based on hydrologic modeling, weather data, and observations.

As a result of new information gathered by FEMA, portions of Solomon Park and the adjacent properties were added to the FEMA 100-year floodplain in November 2016. Solomon Park is located within FEMA floodplain Zone AE and has the same 100-yr flood elevation as Lake Nokomis and Mother Lake at 819.7 feet. The current FEMA map for the Lake Nokomis area is shown below in **Figure 13** and is overlaid with the Areas of Concern boundaries. The Solomon Park Area of Concern contains properties that fall within the FEMA 100-year floodplain and the Nokomis Parkway contains properties that fall within the FEMA 500-year floodplain.

FEMA floodplain areas are usually low-lying areas adjacent to waterbodies and have poorly drained soils. High water levels in floodplain areas can be expected, which means any infrastructure within a floodplain is prone to flood damage during times of extreme precipitation.

The DNR is currently working with FEMA to revise the FEMA 100-year floodplain maps with modern precipitation data, known as Atlas 14. The DNR and FEMA will be reviewing these map updates with various stakeholders and communities throughout 2022 and beyond.

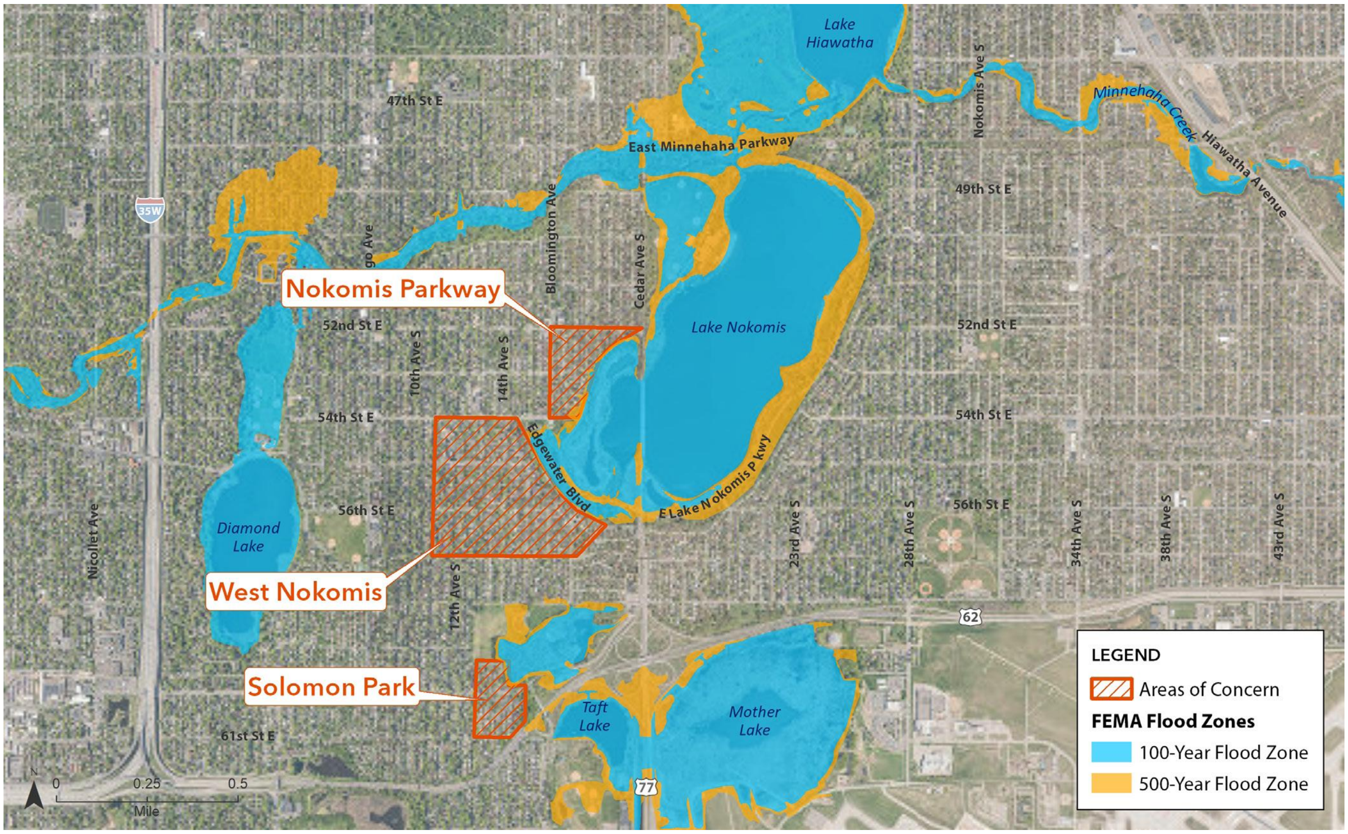


Figure 13: FEMA Flood Zones. *FEMA flood insurance rate map (FIRM) for the Areas of Concern. (Credit: MCWD)*

2.6 AREAS OF CONCERN GEOLOGY AND HYDROLOGIC HISTORY FINDINGS

The 2018 MGS surficial geology atlas notes the presence of peat soils within and adjacent to the Areas of Concern. Peat soils were formed because of the Area of Concern's low-lying topography and poor drainage, which ultimately led to the formation of lakes, wetlands, and peat bogs.

2.6.1 Nokomis Parkway

The surficial geology maps in **Figures 14** and **Figure 15** show that some of these homes were built over and adjacent to drained, excavated, and filled lake sediment.

The homes along Lake Nokomis Parkway are adjacent to an existing wetland (**Figure 16**) and the 100-year FEMA floodplain for Lake Nokomis (**Figure 17**).

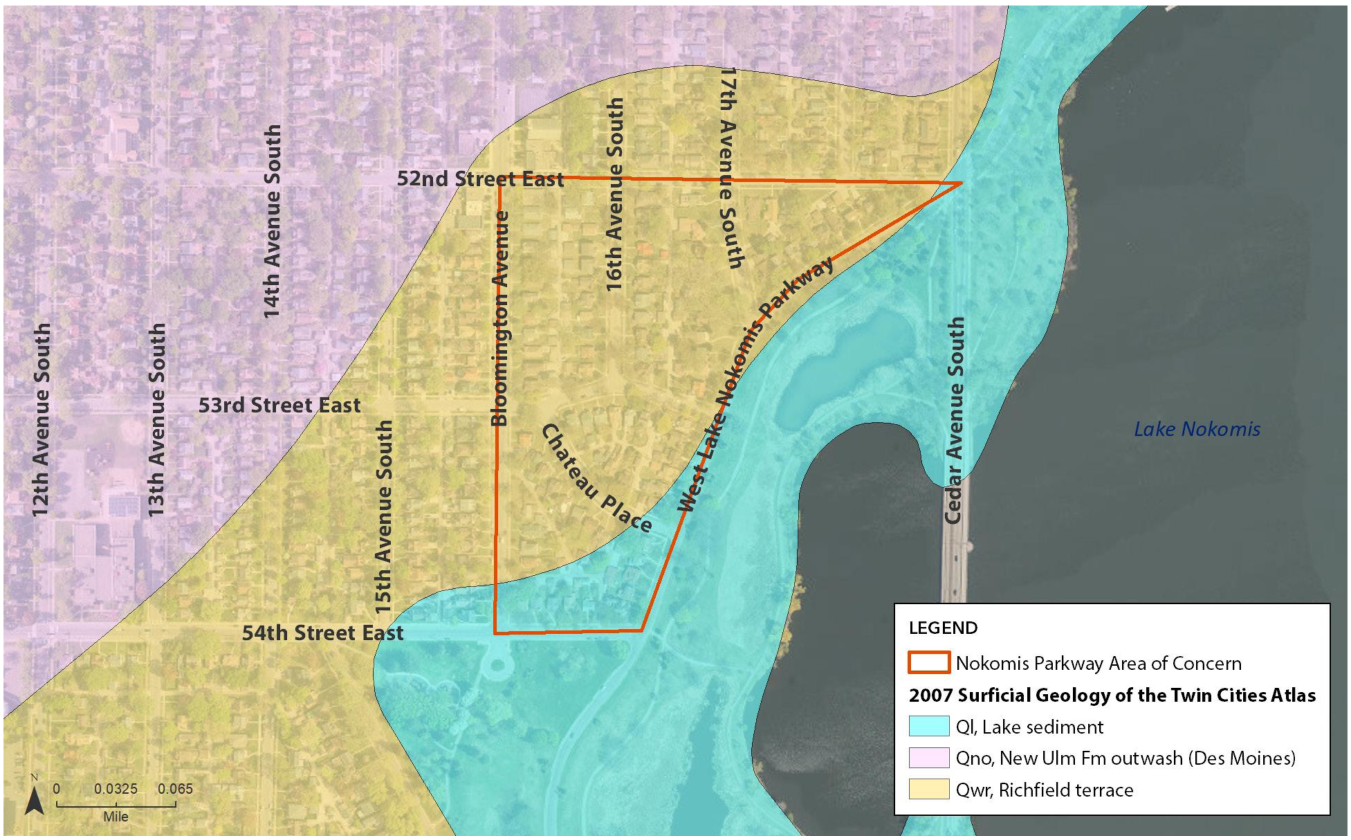


Figure 14: 2007 Surficial Geology Atlas for the Nokomis Parkway Area of Concern. *Excerpt from the 2007 Surficial Geology Atlas of Hennepin County for the Nokomis Parkway Area of Concern shows homes were built over areas of lake sediment. (Credit: MCWD; Data Source: Meyer, 2007)*

Figure 15: 2018 Surficial Geology for the Nokomis Parkway Area of Concern. *Excerpt from the 2018 Surficial Geology Atlas of Hennepin County for the Nokomis Parkway Area of Concern shows homes were built over areas of Lake Nokomis that were drained and filled. (Credit: MCWD; Data Source: Steenberg et al., 2018)*

Figure 16: Existing Wetlands Adjacent to Nokomis Parkway Area of Concern. *Mapped wetlands adjacent to the Nokomis Parkway Area of Concern. (Credit: MCWD; Data Source: National Wetland Inventory)*

Figure 17: FEMA Flood Zone for the Nokomis Parkway Area of Concern. *FEMA flood insurance rate map (FIRM) for the Nokomis Parkway Area of Concern. (Credit: MCWD)*

2.6.2 West Nokomis

The surficial geology maps in **Figure 18** and **Figure 19** show that some of these homes were built over and adjacent to drained, excavated, and filled lake sediment, and some of them are near mapped peat areas. The homes along Edgewater Boulevard are near mapped wetlands (**Figure 20**) and adjacent to the 100-year FEMA floodplain for Lake Nokomis (**Figure 21**).

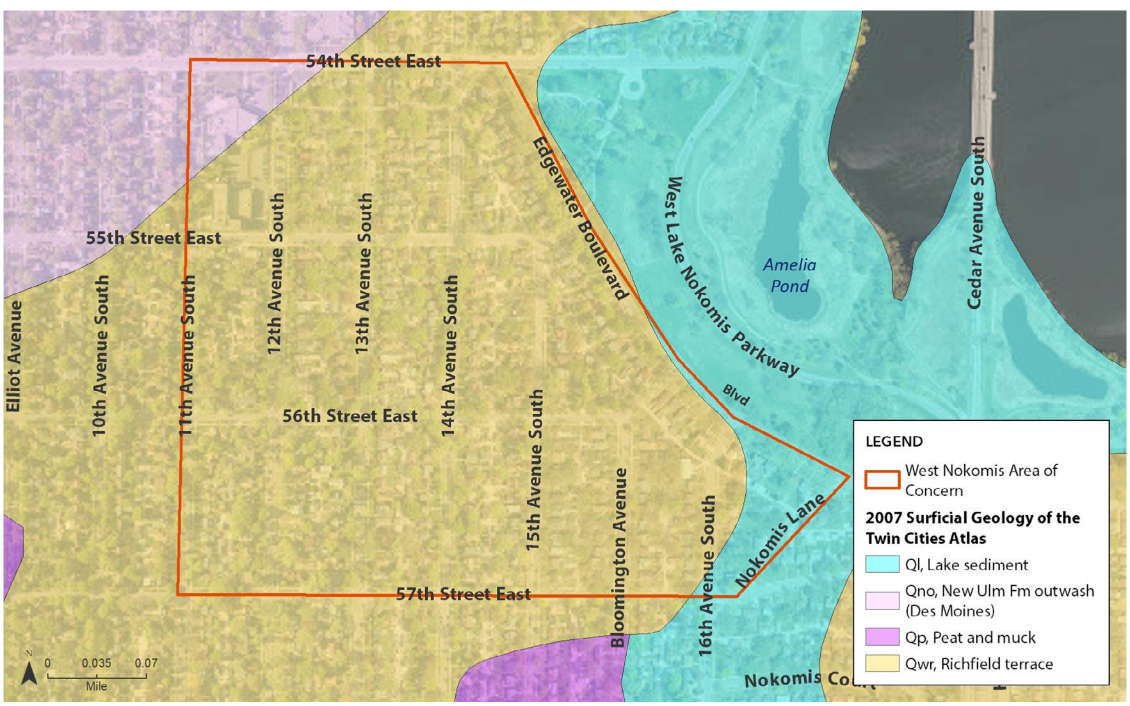


Figure 18: 2007 Surficial Geology Atlas for the West Nokomis Area of Concern. *Excerpt from the 2007 Surficial Geology Atlas of Hennepin County for the West Nokomis Area of Concern shows homes were built over areas of lake sediment and near mapped peat areas. (Credit: MCWD; Data Source: Meyer, 2007)*

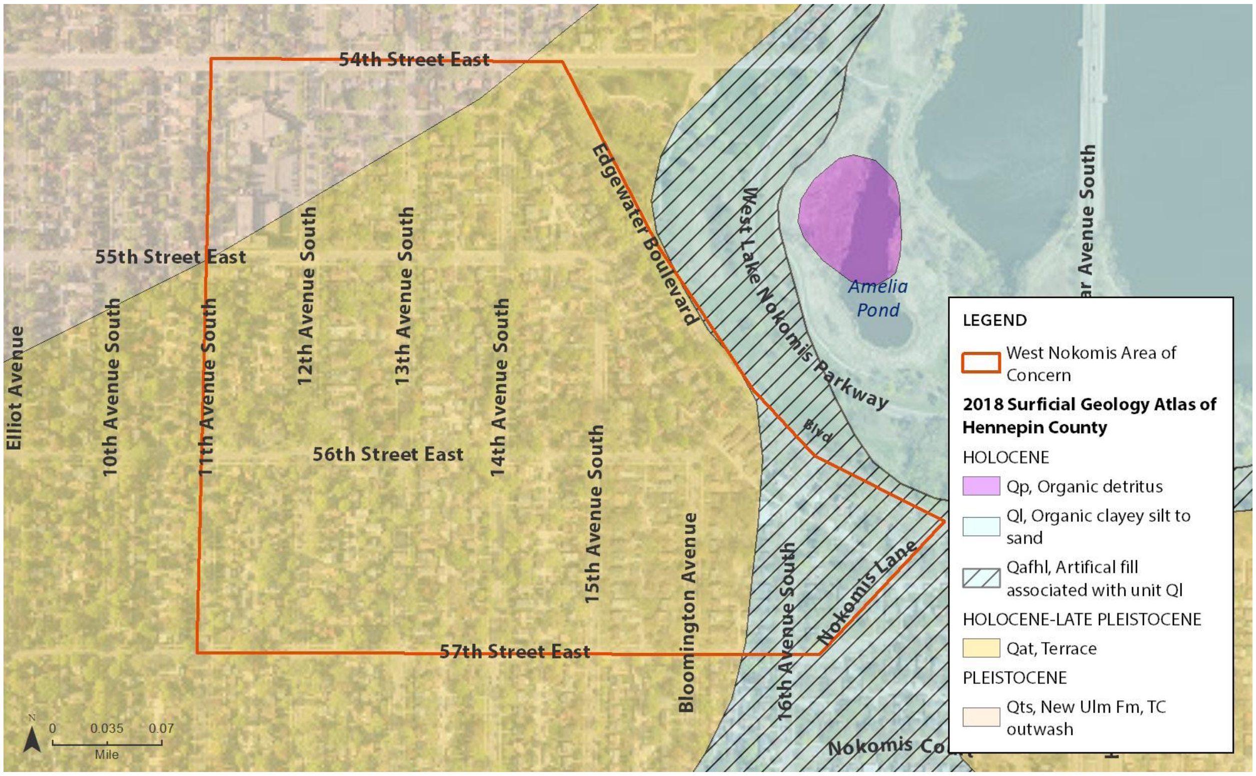


Figure 19: Surficial Geology Atlas for the West Nokomis Area of Concern. *Excerpt from the 2018 Surficial Geology Atlas of Hennepin County for the West Nokomis Area of Concern shows homes were built over and adjacent to drained, excavated, and filled lake sediment, and some of them are near mapped peat areas. (Credit: MCWD; Data Source: Steenberg et al., 2018)*

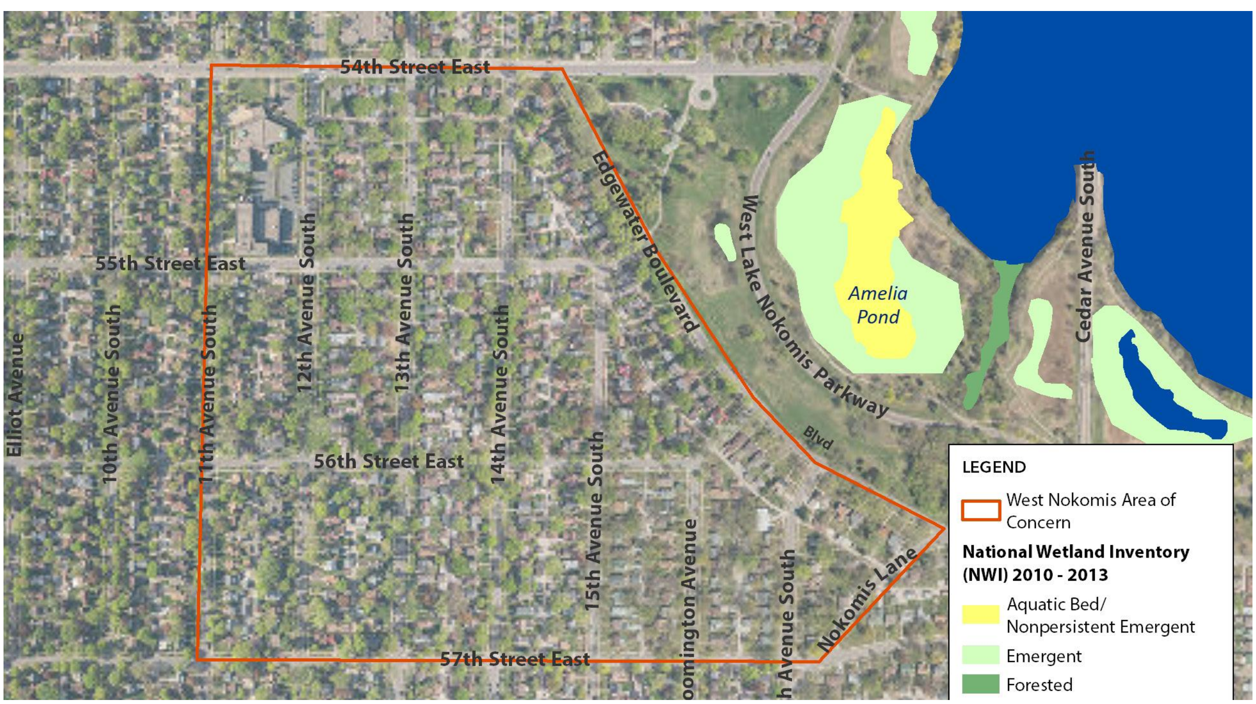


Figure 20: Existing Wetlands Adjacent to West Nokomis Area of Concern. *Mapped wetlands adjacent to the West Nokomis Area of Concern. (Credit: MCWD; Data Source: National Wetland Inventory)*

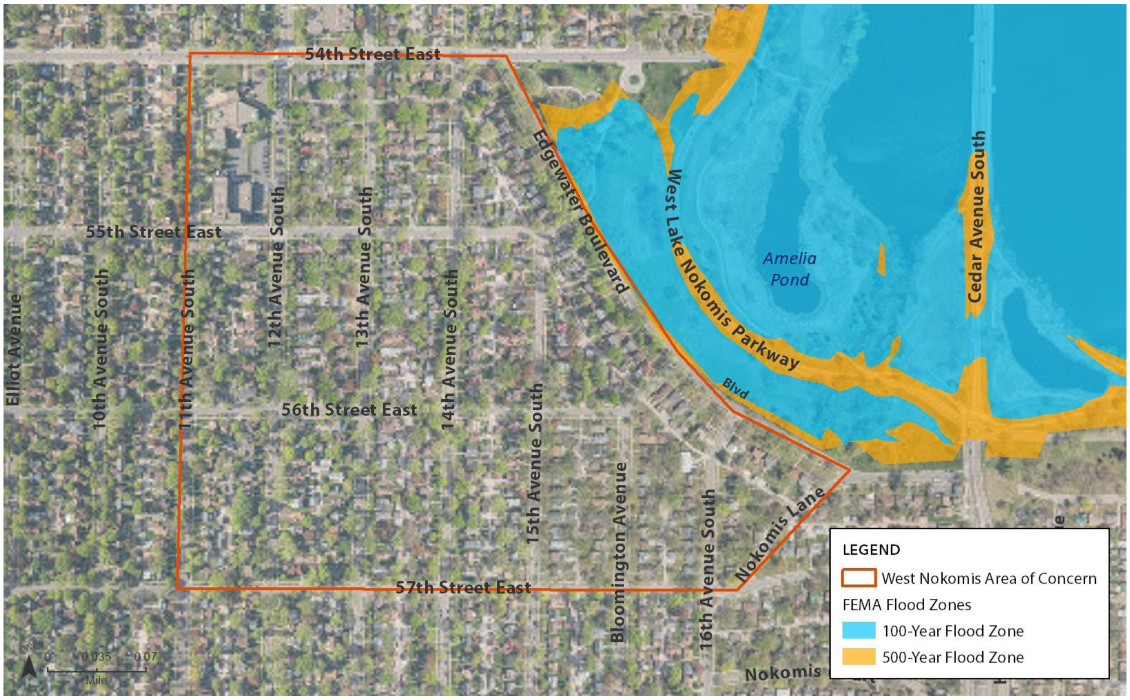


Figure 21: FEMA Flood Zone for the West Nokomis Area of Concern. *FEMA flood insurance rate map (FIRM) for the West Nokomis Area of Concern. (Credit: MCWD)*

2.6.3 Solomon Park

The surficial geology maps shown in **Figure 22** and **Figure 23** identify that some of these homes were built over and adjacent to drained, excavated, and filled lake sediment, and some of the homes were built over and adjacent to mapped peat areas. Some properties along 14th Avenue have backyards within an existing wetland system (**Figure 24**) and the 100-year FEMA floodplain for Lake Nokomis (**Figure 25**).

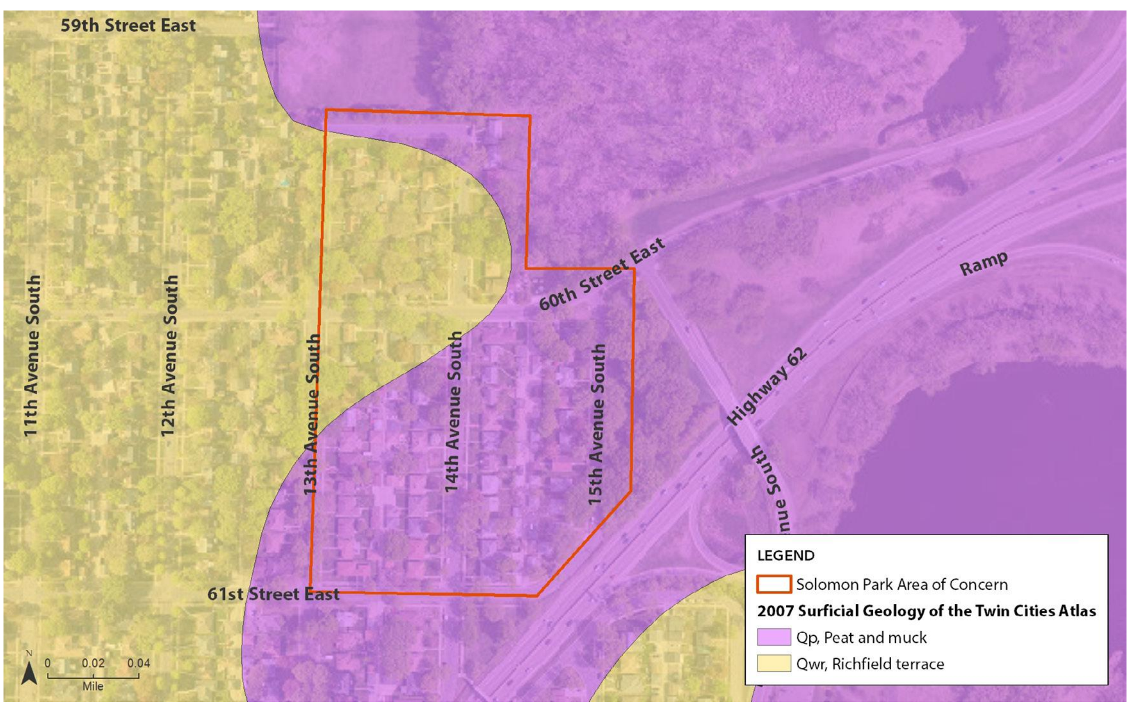


Figure 22: 2007 Surficial Geology Atlas for the Solomon Park Area of Concern. *Excerpt from the 2007 Surficial Geology Atlas of Hennepin County for the Solomon Park Area of Concern shows homes were built over mapped peat areas. (Credit: MCWD; Data Source: Meyer, 2007)*

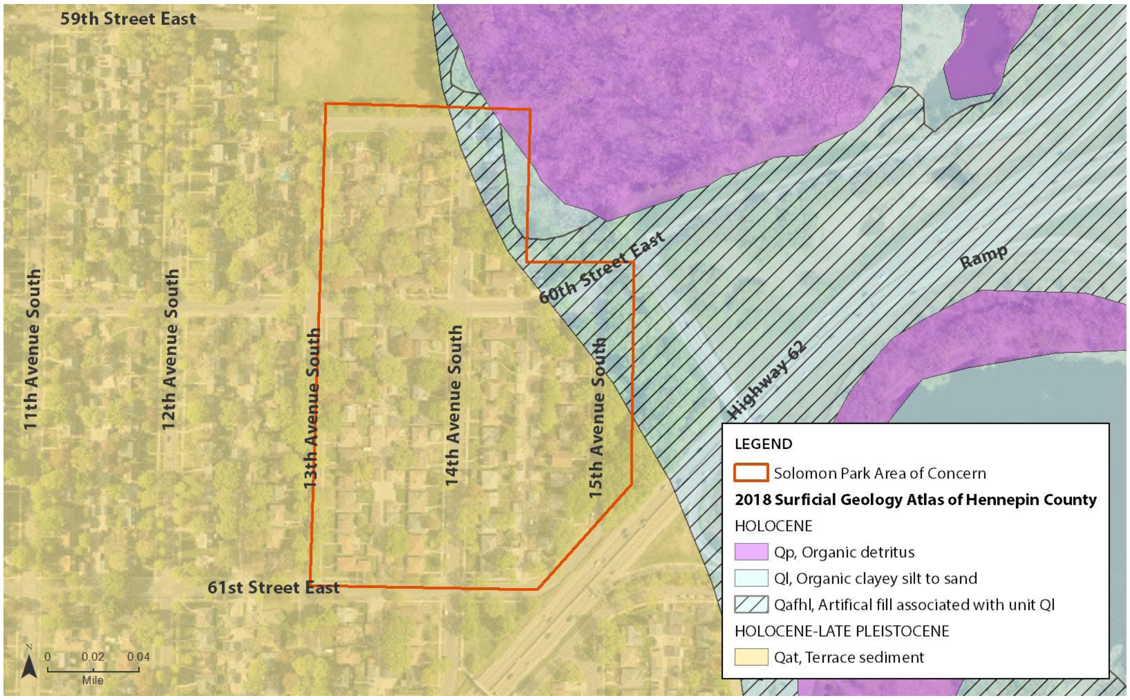


Figure 23: Surficial Geology Atlas for the Solomon Park Area of Concern. *Excerpt from the 2018 Surficial Geology Atlas of Hennepin County for the Solomon Park Area of Concern shows that some homes were built over and adjacent to drained, excavated, and filled lake sediment, and some of the homes were built on and adjacent to mapped peat areas. (Credit: MCWD; Data Source: Steenberg et al., 2018)*

Figure 24: Existing Wetlands and Solomon Park Area of Concern. *Mapped wetlands within and adjacent to the Solomon Park Area of Concern. (Credit: MCWD; Data Source: National Wetland Inventory)*

Figure 25. FEMA Flood Zone for the Solomon Park Area of Concern. *FEMA flood insurance rate map (FIRM) for the Solomon Park Area of Concern which shows some properties are located with the 100-year floodplain. (Credit: MCWD)*

Chapter 2 outlined how the hydrologic landscape was formed, the extent of lakes and wetlands that were present during the first government land survey, and the present-day footprint of wetlands and floodplains.

This chapter will examine how the hydrologic landscape was altered for residential development and parks, review historic infrastructure issues, and review historic water issues that have affected the area since it was developed.

3.1 1910s ALTERATIONS TO HYDROLOGICAL LANDSCAPE

Three years after the public land survey was completed for the Lake Nokomis area, in 1856, Minneapolis was incorporated as a city. Three decades later in 1883, the Board of Park Commissioners (present day MPRB) was established. In 1906 Theodore Wirth was appointed MPRB's Superintendent of Parks, and a year later under Wirth's leadership, the MPRB purchased the land around Lake Amelia. In 1910 the lake's name was changed from Lake Amelia to Lake Nokomis, and that same year Wirth presented his plan for alterations to the lake. MPRB (2021) notes these plans as being "the most ambitious lake-shaping plan in the history of Minneapolis parks."

The reduction of Lake Nokomis from over 300 acres of water to 200 acres was identified at the time as "the most ambitious lake-shaping plan in the history of Minneapolis parks".

The 1853 original public land survey shown in **Figure 11** indicates that the landscape around Lake Nokomis had naturally occurring wetlands. In the early 1900s, public perception of wetlands was that they were weedy, useless, and unsanitary spaces. An October 18, 1914, Minneapolis Sunday Tribune article noted, "For years Lake Nokomis has been little more than a weedy slough. Of course there was plenty of water in it, but the wild rice and cattails grew so rank that it was all but impossible to row a boat after midsummer" (Minneapolis Sunday Tribune, 1914b). The picture shown in **Figure 26** was taken in 1915 and appears to show wild rice growing abundantly throughout Lake Nokomis. In Minnesota, wild rice can grow in water up to three-feet deep.

Figure 26: South Section of Lake Nokomis Park in 1915. *The south section of Lake Nokomis in 1915, with what appears to be wild rice growing within the lake. (Credit: MPRB, 2021b)*

Wirth's 1910 plans proposed a radical alteration of the "unsanitary and unsightly" landscape around Lake Nokomis (Minneapolis Star, 1934). These plans would reshape the lake and reduce the water area of the lake from 300 acres to 200 acres and deepen the lake to an average depth of fifteen feet from its natural depth of five to twelve feet (MPRB, 2021a). A January 18, 1914, Minneapolis Sunday Tribune article noted that Lake Nokomis was to, "be made into a real park lake. . . work will be started as early in spring as the company can get machinery installed – dredging to change a weedy slough into a beautiful place" (Minneapolis Sunday Tribune, 1914a).

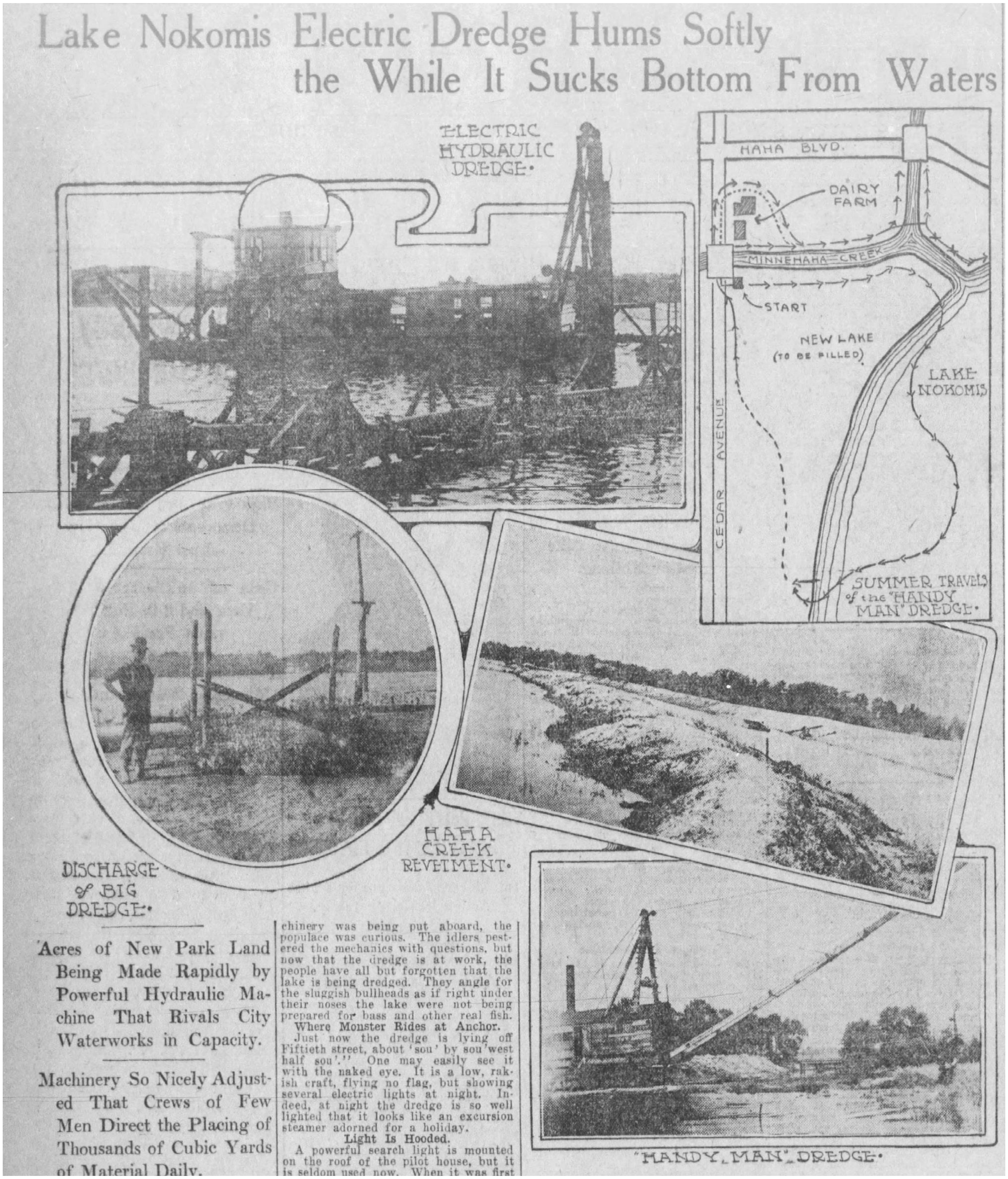
In the spring of 1914, Wirth's ambitious vision for Lake Nokomis came to life. In his 1945 book, "Minneapolis Park System, 1883-1944", Wirth chronicles his history with the Minneapolis Park System including specific detail to the period of early park expansion, planning, and development which took place while he was the primary planner. Within the Lake Nokomis chapter of his book, Wirth (1945) notes:

> Although Lake Nokomis (408 acres in area) was purchased in 1907 (for the small sum of $65,000), the improvement work did not begin until the spring of 1914. The area acquired consisted of about 300 acres of shallow water known as Lake Amelia, about 70 acres of mostly low, swampy farmland at the northwest corner, and about 38 acres of higher dry land at its northeast corner, as well as a small strip along the south boundary. The improvement plan contemplated reducing the water area from 300 to 200 acres (the minimum depth of the lake to be not less than eight feet and the low lands to be filled to well above the lake level), and increasing the total land from 108 acres to 208 acres. Estimated dredging operations amounted to between 2,000,000 and 2,500,000 cubic yards. . . The dragline dredge began the dyke work on May 12, 1914, at the northwest corner of the park and the hydraulic dredge began operations September 5 of the same year. These dredging operations were completed in December, 1918, and totaled 2,460,978 cubic yards, the cost of which was $262,473.12. . . Since the lake was dredged, the former muddy condition of the water has entirely disappeared and it is now as clear as any of our spring-fed lakes. . .Work on the Lake Nokomis improvements was under way over a period of eleven years (1914-1924). The total cost of the park when completed, including acquisition, was $806,566, assessed against a large benefited district—but the increase of real estate values in the district more than justified that expenditure. The transformation of that 400-acre tract—formerly shallow water surrounded by a peat bog and swampland, which had prevented earlier development of that large southeast section of residential properties—into a clear-water lake and an attractive, useful park and recreation area had its desired effect on the growth of the city in that direction. (p. 96-99)

Approximately 2.5 million cubic yards of lake sediment (equivalent to approximately 250,000 dump truck loads) was dredged from Lake Nokomis and used to fill low-lying wetlands and peat bogs around the lake.

Historic images and newspaper clippings from the dredging of Lake Nokomis are shown in Figures 27-30.

On September 27, 1914, the Star Tribune featured an article titled, "Lake Nokomis Electric Dredge Hums Softly the While it Sucks Bottom from Waters". Pictures from this Minneapolis Sunday Tribune article are shown in **Figure 27** and **Figure 28**).



Lake Nokomis Electric Dredge Hums Softly the While It Sucks Bottom From Waters

'Acres of New Park Land Being Made Rapidly by Powerful Hydraulic Machine That Rivals City Waterworks in Capacity.

Machinery So Nicely Adjusted That Crews of Few Men Direct the Placing of Thousands of Cubic Yards of Material Daily.

chinery was being put aboard, the populace was curious. The idlers pestered the mechanics with questions, but now that the dredge is at work, the people have all but forgotten that the lake is being dredged. They angle for the sluggish bullheads as if right under their noses the lake were not being prepared for bass and other real fish.

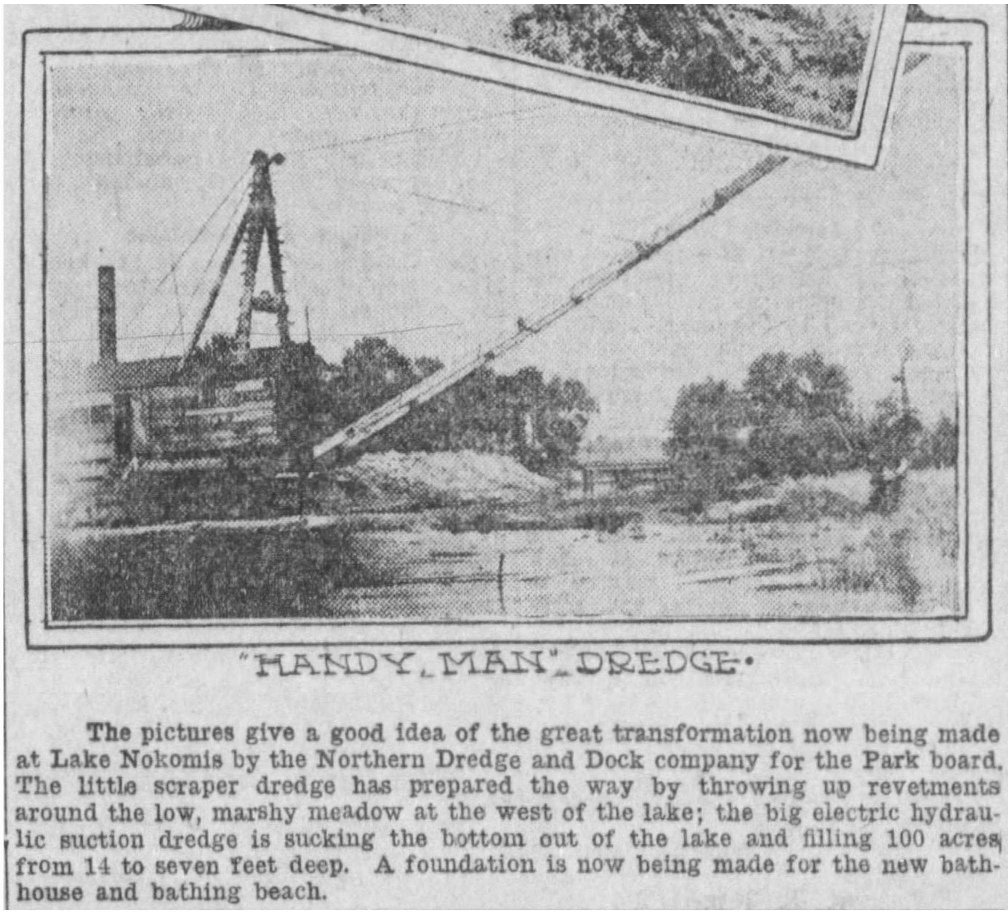
Where Monster Rides at Anchor.

Just now the dredge is lying off Fiftieth street, about 'sou' by sou'west half sou'.'' One may easily see it with the naked eye. It is a low, rakish craft, flying no flag, but showing several electric lights at night. Indeed, at night the dredge is so well lighted that it looks like an excursion steamer adorned for a holiday.

Light Is Hooded.

A powerful search light is mounted on the roof of the pilot house, but it is seldom used now. When it was first

***Figure 27: September 27, 1914, Minneapolis Sunday Tribune Article**. Lake Nokomis Electric Dredge Hums Softly the While it Sucks Bottom From Waters. (Credit: Minneapolis Sunday Tribune, 1914)*



"HANDY MAN" DREDGE.

The pictures give a good idea of the great transformation now being made at Lake Nokomis by the Northern Dredge and Dock company for the Park board. The little scraper dredge has prepared the way by throwing up revetments around the low, marshy meadow at the west of the lake; the big electric hydraulic suction dredge is sucking the bottom out of the lake and filling 100 acres from 14 to seven feet deep. A foundation is now being made for the new bathhouse and bathing beach.

Figure 28: Picture excerpt from September 27, 1914, Minneapolis Sunday Tribune Article. *"Handy Man" Dredge. (Credit: Minneapolis Sunday Tribune, 1914)*

The text that accompanied the picture in **Figure 28** above, noted:

> The pictures give a good idea of the great transformation now being made at Lake Nokomis by the Northern Dredge and Dock company for the Park board. The little scraper dredge has prepared the way by throwing up revetments around the low, marshy meadow at the west of the lake; the big electric hydraulic suction dredge is sucking the bottom out of the lake and filling 100 acres from 14 to seven feet deep. A foundation is now being made for the new bathhouse and bathing beach. (Minneapolis Sunday Tribune, 1914)

This September 27, 1914, Minneapolis Sunday Tribune (1914) article also noted:

> Already the cow pasture at the foot of the bank has been flooded. Before the big dredge finishes on that side of the lake it will have deposited nearly one million cubic yards of mud and sand on that old pasture, raising the level about seven feet. . . The contract calls for the average depth of 16 feet, and when the lake is depended to that extent –well, Nokomis will be "some lake." There will be no ugly weeds, cat-tails, wild rice or anything to disfigure the surface. Then friend "Taxpayer" will begin to rejoice in the pretty sheet of water his money has helped to buy and improve.

Material excavated from Lake Nokomis was used to fill surrounding swampland, lowland, and to buildup roadways. A May 17, 1914, Minneapolis Sunday Tribune article noted, "The specifications call for the filling of Cedar avenue from one to three or four feet just south of the bridge over Minnehaha Creek, and for the filling of the low land between Cedar avenue and the new shoreline of the lake, some of it five feet" (Minneapolis Sunday Tribune, 1914c). A couple years after the dredging started, Wirth (1945) noted:

> In 1916 when dredging operations started at Lake Nokomis, the section of the parkway between Cedar Avenue and Twenty-third Avenue South was brought to subgrade with material procured from the lake, and the roadway itself shifted about 50 feet south to run through the center of the strip." (p. 131)

It took four years to dredge Lake Nokomis deeper and fill the surrounding wetlands and lowland areas. Pictures of the Lake Nokomis dredging are shown below in **Figure 29** and **Figure 30**.

The transformation of the Lake Nokomis area had the desired effect for residential development in South Minneapolis. On January 22, 1934, The Minneapolis Star quoted Wirth saying:

> "The entire area comprising Nokomis and Hiawatha Parks," Mr. Wirth said, "two decades ago was useless land which impeded growth of the city in that large south section. Once the the delayed growth of the city in that direction was stimulated; property values increased, and residences building more than kept step with the improvements. No one can reasonably deny that the principal stimulant for this extensive, rapid growth is due in the largest degree to the transformation of formerly unsanitary and unsightly sections into areas of healthy conditions, attractive landscape features, and opportunities for useful recreational activities". The tremendous increase in land values during the 15 years which had elapsed between the two acquisitions, amounting to 1,000 per cent," he said, "was in the main due to the improvement of Lake Nokomis" (The Minneapolis Star, 1934).

To make the Lake Nokomis area more desirable for residential development, the MPRB dredging project physically changed where water sits on the surface of the landscape and filled land to create 100 acres of new upland parkland. This landscape alteration stimulated residential development of the area.

Figure 29: Dredge at Lake Nokomis. *Dragline dredge removing wetland and lake soils in 1914. (Credit: Wirth, 1945)*

Figure 30: Filling Swamps. Dredge fills were placed over a swamp northwest of Lake Nokomis in 1915. (Credit: MPRB, 2021)

3.2 1920s – 1950 DEVELOPMENT

This section will discuss the landscape alterations that were made outside of Lake Nokomis. Knowing how private development occurred on and adjacent to former wetlands and peat bogs is an important component to understand the water issues in the Areas of Concern.

After the town of Minneapolis was incorporated in 1856, it saw rapid population growth in the beginning of the 20th century. In 1900 Minneapolis' population was 202,718 people. By 1950 Minneapolis' population grew to its highest number to date with 521,178 people.

In 1995, Leah Chizek, on behalf of the Hale, Page, Diamond Lake (HPDL) Community Association, produced a report on the history of the neighborhood. In this report, Chizek (1995) notes the following about the post-Lake Nokomis dredging landscape:

> At this point, little residential development has been undertaken in the HPDL area. The first platted zone, Edenhurst, was not finished until 1917. The Minneapolis Park Board demonstrated incredible insight by developing Lake Nokomis so early, seeing as to how the local development boom was in full swing by the 1920s. Had Lake Nokomis not been dredged and created when it was, lake side property might not have developed until a significant time later.

The homes in the Lake Nokomis Areas of Concern were generally built over the four decades spanning from the 1920s-1950s, with the Nokomis Parkway homes built during the 1920s-1940s, the West Nokomis homes built during the 1930s-1940s, and the Solomon Park homes built during the 1940s-1950s. **Figure 31** shows an aerial photograph taken on November 5, 1929 which shows Lake Nokomis in the top right and also reveals that most of the Nokomis Parkway Area of Concern homes were already built and that only a few homes in the West Nokomis Area of Concerns had been built.

Figure 32 overlays the Areas of Concern boundaries on the 1853 Original Land Survey map, which shows that the Areas of Concern homes were built over, next to, or in-between former wetland systems, within the former Lake Nokomis footprint, and over the former channel from the Mother Lake wetland to Lake Nokomis. The former boundary of Lake Nokomis and wetlands shown in **Figure 33** correspond with the current surficial geology map boundaries for lake and wetland soils discussed in Section 2.1.1.

Figure 12 from Section 2.4 is shared again as **Figure 33** to show how the wetland and lake footprints were altered from from the 1853 original land survey to present day.

__Figure 31: Aerial Photo.__ November 5, 1929 aerial photo of Lake Nokomis and Hale Neighborhood areas. (Credit: Hennepin County Library, 2021)

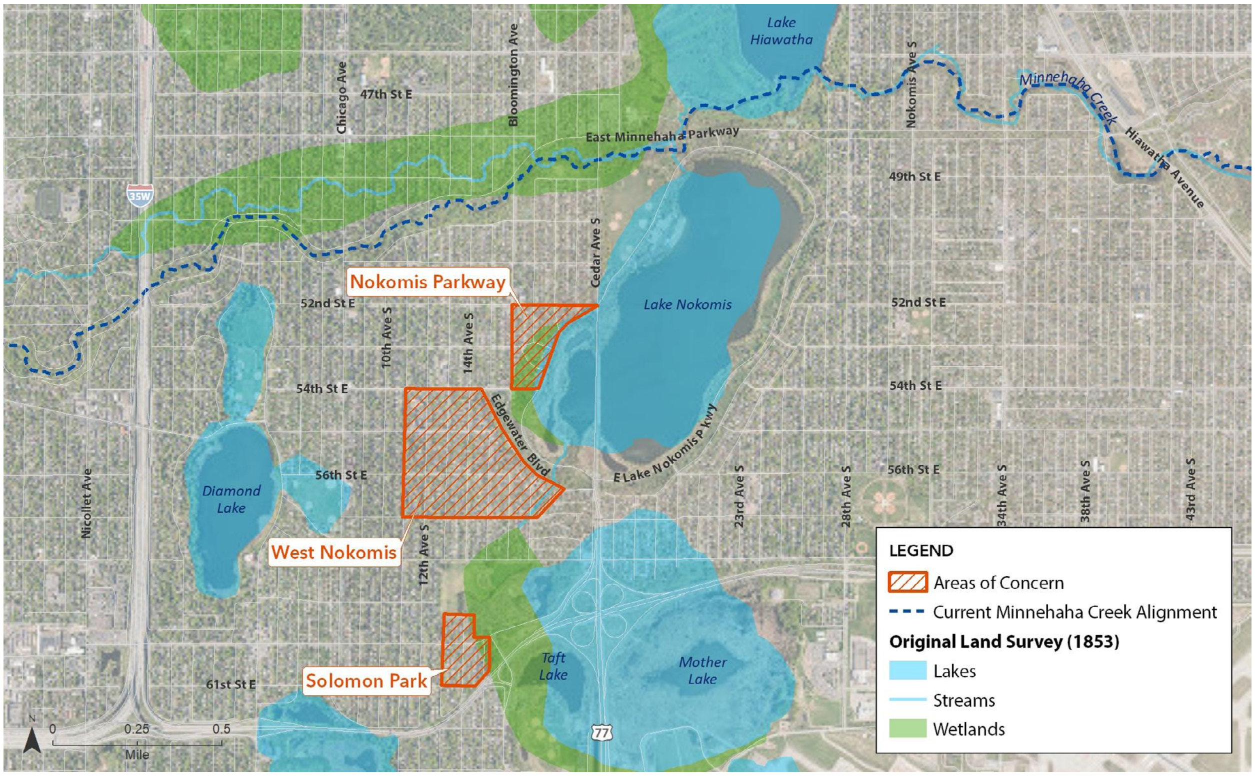


Figure 32. Digitized 1853 Original Land Survey Map. *Area of Concern boundaries overlaid on the 1853 land survey around Lake Nokomis. (Credit: MCWD; Data Source: GLO Historic Plat Maps)*

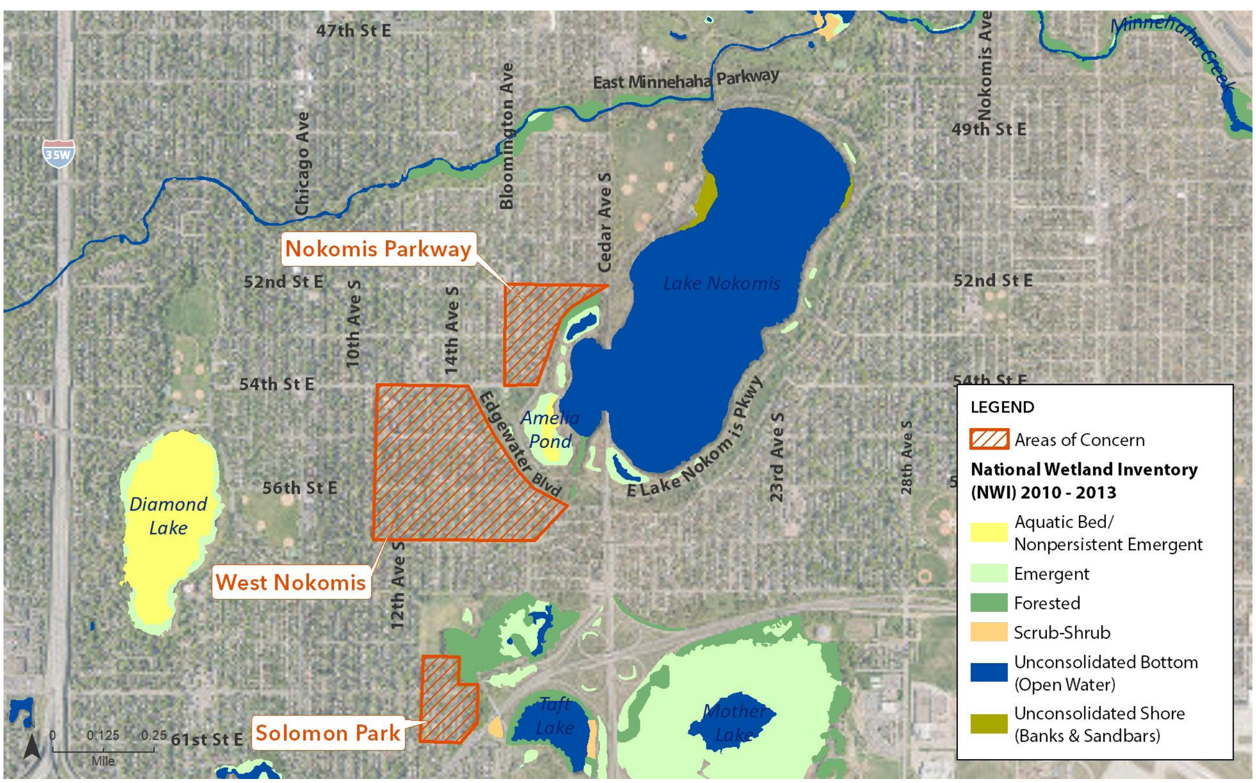


Figure 33. Existing Wetlands. *National Wetland Inventory maps the current wetlands around the Areas of Concern. (Credit: MCWD; Data Source: National Wetland Inventory)*

Chizek's (1995) report notes the following about the development of the HPDL area:

> By 1940, Hale-Page filled in considerably as bungalows filled in the street grid. . . Some land remained, however, most of which lay in low, swampy regions. Such areas were unattractive to both potential residents and developers; construction on marshy land prior to World War II was uneconomical, especially for the larger, custom-crafted homes which builders favored.
>
> Once postwar construction began, two distinct types of development occurred, one earlier than the other. At first, smaller and inexpensive homes were built on low, flat land, much of which used to be marshes. These homes were on the same low-lying fields that were too swampy for their economical development in earlier days. Furthermore, builders were not as concerned with gradual, custom development as they were through the thirties.

It is important to note that the housing development in the Areas of Concern coincided with the beginning of the driest period on record for the Twin Cities. Chapter 4 discusses that the Dust Bowl drought began in the 1920s, and abnormally dry weather persisted into the 1950s. As these 40 years of dry were perceived as the new "normal", more and more homes were built over former wetlands as Minneapolis reached its peak population in 1950.

3.2.1 Infrastructure Issues

As the residential areas developed around Lake Nokomis between the 1920s-1950s, the City of Minneapolis extended sanitary sewer and roads into the Lake Nokomis area. **Figure 34** maps the approximate years the City of Minneapolis' sanitary sewer lines were constructed in the Lake Nokomis area. Generally in the Areas of Concern, the Nokomis Parkway sanitary sewer lines were built during 1911-1930, the West Nokomis sanitary sewer lines were built during 1931-1950, and the Solomon Park sanitary sewer lines were built during 1931-1970.

City of Minneapolis construction records for the sanitary sewer line along 15th Avenue, in-between 55th and 56th Street, (shown in **Figure 35**) indicate that this sewer was installed in 1936 and a portion of this sewer line was installed on pilings due to poor soil conditions in the area. This sewer line underwent a series of repairs from 1937 to 1939, which included the installation of additional pilings and encasing sections of the pipe in concrete. Other streets in this area have similar sanitary sewer repair histories related to the poor soil conditions underlying and supporting the sewer infrastructure.

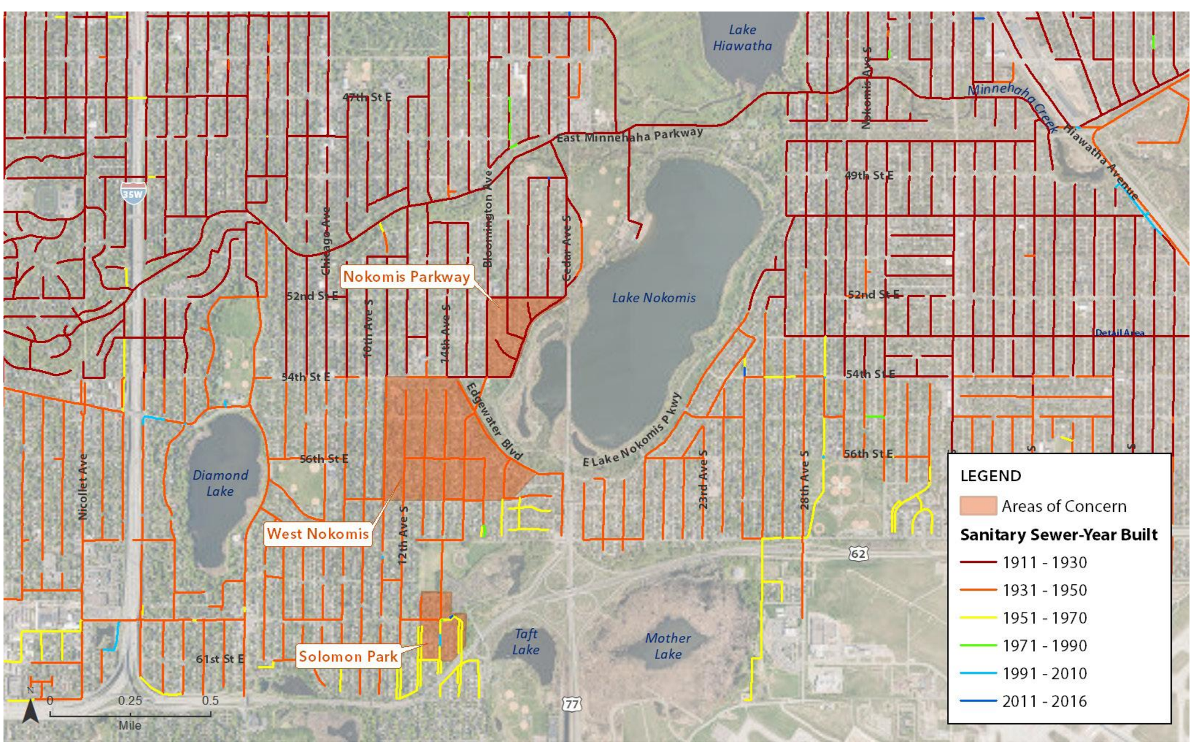


Figure 34: Sanitary Sewers. *City of Minneapolis sanitary sewer lines were constructed between 1911-1970 in the Areas of Concern. (Credit: MCWD; Data Source: City of Minneapolis)*

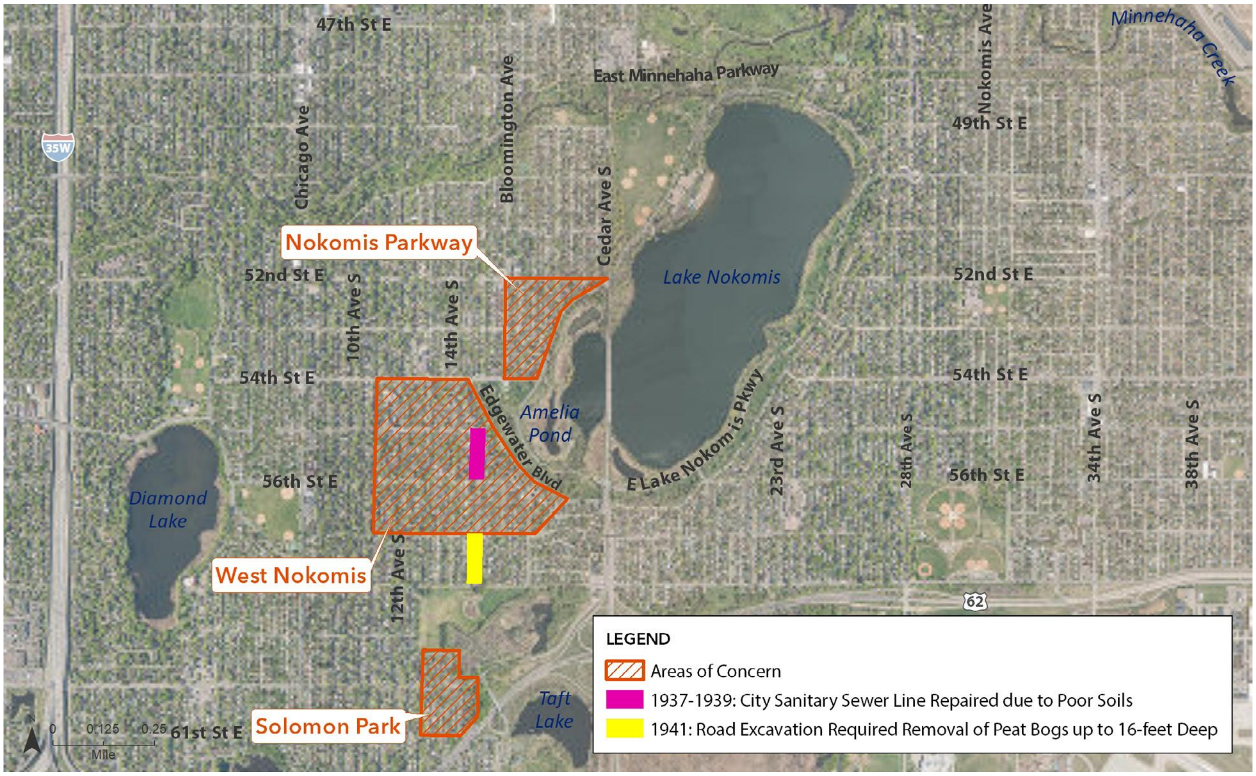


Figure 35: Historic Infrastructure Issues: *City of Minneapolis sanitary sewer line records note the sanitary line along 15th Avenue, in between 55th and 56th Street, required extensive repair after its installation in 1936 due to poor soils. Further south, road excavation work for 58th Street near 15th Avenue, required removal of peat bogs. (Credit: MCWD; Source: City of Minneapolis and Minneapolis Star Journal, 1941)*


WPA Crew to Fill in Peat Bog Death Trap

EXCAVATION WHERE RICHARD DROWNED
At Fifty-eighth street and Fifteenth avenue S.

Figure 36: WPA Crew to Fill in Peat Bog Death Trap. *Picture of a peat bog excavation at 58th Street and 15th Avenue was featured in the Minneapolis Star Journal May 13, 1941. (Credit: Minneapolis Star Journal, 1941)*

Figure 37: Street Excavation. *Pumping out water from a street excavation on 15th Avenue South near 58th Street on May 13, 1941. (Credit: Hennepin County Library, 2021a)*

The picture in **Figure 37** was taken on May 13, 1941, and it shows water being pumped out of a street excavation for 58th Street near 15th Avenue (mapped in **Figure 34**). The water was being pumped out after a child drowned in it the day before.

Figure 36 is from the May 13, 1941, Minneapolis Star Journal (1941) article on the drowning. The Minneapolis Star Journal (1941) article referenced work by the Works Progress Administration (WPA):

> WPA officials today said the hazard will be removed at the spot where a 5-year-old boy was drowned last night, as quickly as the ground becomes hard enough to move equipment in to fill a peat excavation in which 10 to 12 feet of water had accumulated. . . The excavation is at Fifty-eighth street and Fifteenth avenue S., at a point where peat was removed in a street extension project. . . WPA officials said it had been necessary to make several similar fills in extending Fifty-eighth street, in some instances digging peat out of old bogs to the depth of 16 feet.

This May 13, 1941, Minneapolis Star Journal article identified three important data points. The first is that the peat excavation had accumulated 10 to 12 feet of water, the second is that peat bogs had to be excavated up to 16-feet deep, and third is the note that the extension of 58th Street required several similar peat bog excavations. These data points reinforce Section 2.2.2 which noted peat's ability to retain water and its potential to form perched groundwater systems.

As Section 2.1 and 2.2 noted, peat soils are still present in and around the Area of Concern today, including outside of mapped areas by MGS, and have been documented to historically cause settling issues for infrastructure, even during the peak of the Dust Bowl drought.

In addition to historic public infrastructure issues, beginning in 2014, residents in the Areas of Concern expressed growing concern about deteriorating private sewer laterals (the lines that run from a house to the street) and subsequent costly repairs. **Figure 38** shows the approximate years of the City of Minneapolis sanitary sewer construction in the Lake Nokomis area and the extent of private sanitary sewer lateral repairs between 2012 and 2016. In reviewing this map, it's important to recognize that the average incidence of repairs within the Areas of Concern and the greater south Minneapolis area are relatively similar.

The Team did not explicitly study whether the number of lateral repairs has increased or if they have become more prevalent in parts of Minneapolis. The Team did identify that the infrastructure has likely reached the end of its serviceable life since some pipes are now over 100 years old. The Team also noted that periods of increased rainfall over peat soils can lead to perched groundwater systems that may contribute seepage or infiltration into cracks within the sanitary laterals. This inflow can carry small soil and sand particles. If enough of these particles migrate into or erode the pipe, a sinkhole or void can form due to the loss of the soil/ fill materials.

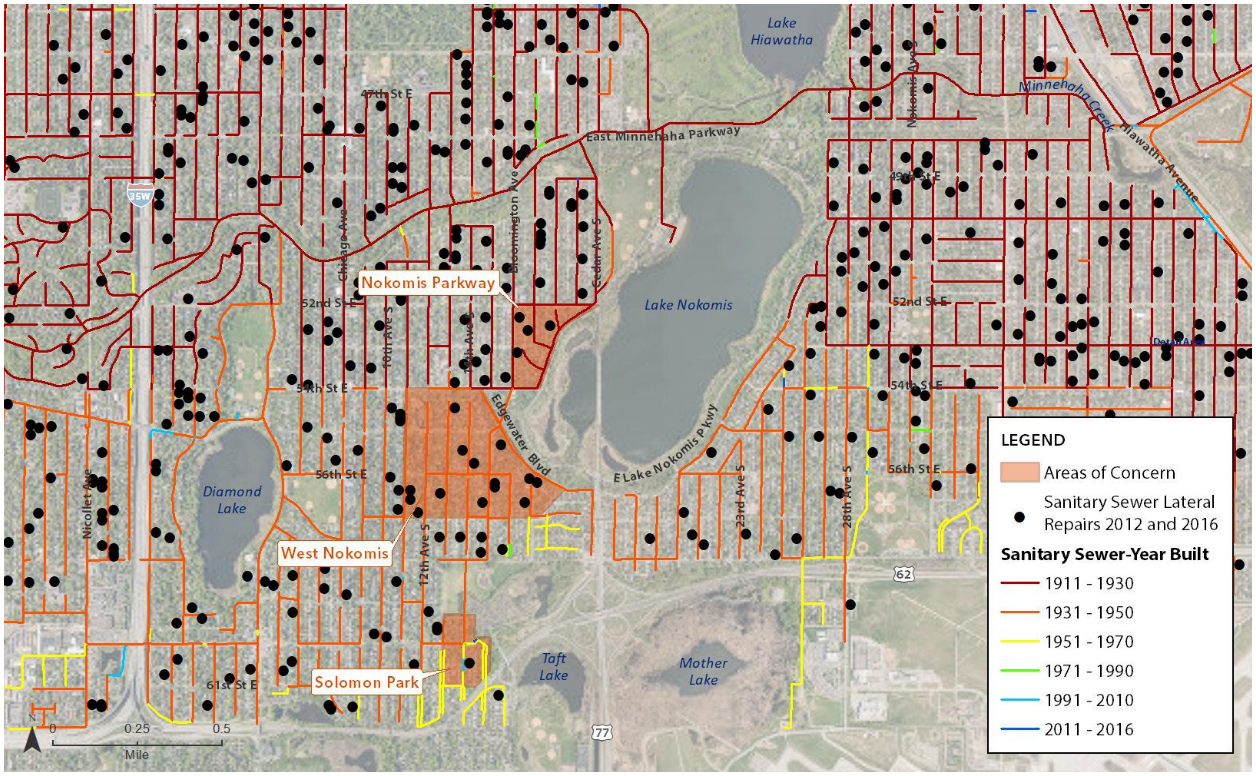


Figure 38. Private Sewer Lateral Repairs. *Reported sanitary sewer later repairs between 2012-2016. (Credit: MCWD; Data Source: City of Minneapolis)*

3.2.2 Parkland Issues

The 1914-1918 alterations to the hydrologic landscape around Lake Nokomis, including dredging and filling of wetland and peat soils, also caused issues for park improvements around Lake Nokomis. Wirth (1945) noted:

> Dredge fills on swampland, as is well known, take many years to settle to a final or permanent elevation – and in fact in our experience with them leads me to doubt that they ever do come to a complete standstill. At any rate, it appeared advisable to allow a reasonable period of time for settlement before undertaking the improvement on the newly-made land. As was foreseen and fully anticipated, much settlement took place over practically the entire area of dredge-filled former lowland, making necessary extensive restoration work. These operations were satisfactorily performed at intervals from 1934 through 1939, with the help of several Federal aid agencies—the Civil Works Administration, Emergency Relief Administration, Works Progress Administration, and the Works Projects Administration. (p. 97-99)

The WPA completed many rehabilitation and improvement projects within the park space around Lake Nokomis due to cracking and settling of peat soils. The 1936-1939 WPA improvements were documented with annual reports published by the Minneapolis Board of Park Commissioners:

» The 1936 WPA report notes that the land between Edgewater Boulevard and Lake Nokomis Parkway has previously been filled by dredging material, including peat soils, and that “the hot, dry summers over the past five years had caused a network of cracks to develop” in the peat over that area and over other large areas around Lake Nokomis. WPA workers turned this 40-acre area over to a depth of four feet to prevent reoccurring cracking of the peat then regraded and seeded it. (Minneapolis Board of Park Commissioners, 1936)

» The 1937 WPA report notes that 12 acres of peat ground west of the bathhouse were turned over to a depth of four feet, then regraded and seeded. Depressions along the south side of the lake were filled with peat hauled from Mother Lake. The picture in **Figure 39** shows WPA workers turning over peat to eliminate cracks. (Minneapolis Board of Park Commissioners, 1937)

Figure 39: Overturning Peat. *Peat soils at Lake Nokomis being turned over by WPA crews to eliminate cracks (Source: Minneapolis Board of Park Commissioners, 1937)*

» The 1938 WPA report notes that peat was excavated beneath curbs, sidewalks, and roadways that had settled in the south section of the park. The picture in **Figure 40** shows WPA workers excavating peat that was more than 15 feet deep. The report notes that the excavated peat was used to fill low land at 11th Avenue south of Minnehaha Creek and as surfacing material for newly graded sections in the vicinity. (Minneapolis Board of Park Commissioners, 1938)

Figure 40: Peat Excavation. *WPA crews excavating peat that was more than 15 feet in depth (Source: Minneapolis Board of Park Commissioners, 1938)*

» The 1939 WPA report (Minneapolis Board of Park Commissioners, 1939) notes that 25,275 cubic yards of peat was excavated from under walks, which is equivalent to approximately 2,520 dump truck loads (assuming 10 cubic yard dump truck). Another 8,600 cubic yards of peat was excavated at the north end of the park, which is equivalent to 860 dump truck loads. This Minneapolis Board of Park Commissioners (1939) report states:

> At the time of the construction of the park about twenty years ago, the areas on the east, south and west shores were built up with the material from the lake dredging operations. In later years, these areas had settled to a considerable extent necessitating frequent repairing of lawn, shores, curbs and pavement.
>
> In 1937 and 1938, many of the peat areas were turned over, plowed, regraded, and resurfaced by W.P.A. crews. In 1939, this work continued and pavement and walks throughout the parks were rehabilitated. . .
>
> Underlying peat caused the settling of the pavement at various points about the lake. The extent of this settlement varied from a few inches, in most places, to eleven inches in one location. (p. 12)

The picture in **Figure 41** shows curbing in 1939 that broke due to sinking of underlying peat.

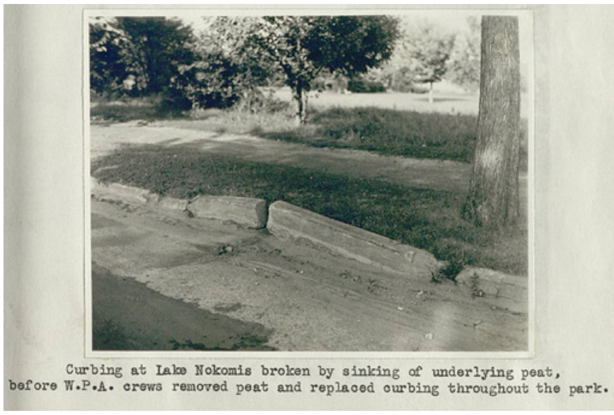


Figure 41 Broken Curbing. *Curbing at Lake Nokomis was broken by the sinking of underlying peat and required WPA crews to remove the peat and replace the curbing. (Source: Minneapolis Board of Park Commissioners, 1939)*

Section 2.1 and 2.2 discussed the presence of peat in the Areas of Concern and peat's characteristics. **Figure 42** maps the 2007 MGS surficial geology, the documented WPA peat excavated and filled areas, known infrastructure issues in Section 3.2.1, and Minnesota Department of Health soil boring data that notes the presence of peat. Given the extensive historical excavating and filling of peat, most of which has not been mapped in the MGS geology atlases, and continuing issues with peat in and around the Areas of Concern, the presence of peat under the Areas of Concern is quite likely.

Given historical and ongoing peat issues, the presence of peat under the Areas of Concern is quite likely.

Further investigation into the surficial geology and presence of peat soils under the Areas of Concern will be performed by the U of M – more details on this investigation are discussed in Chapter 11.

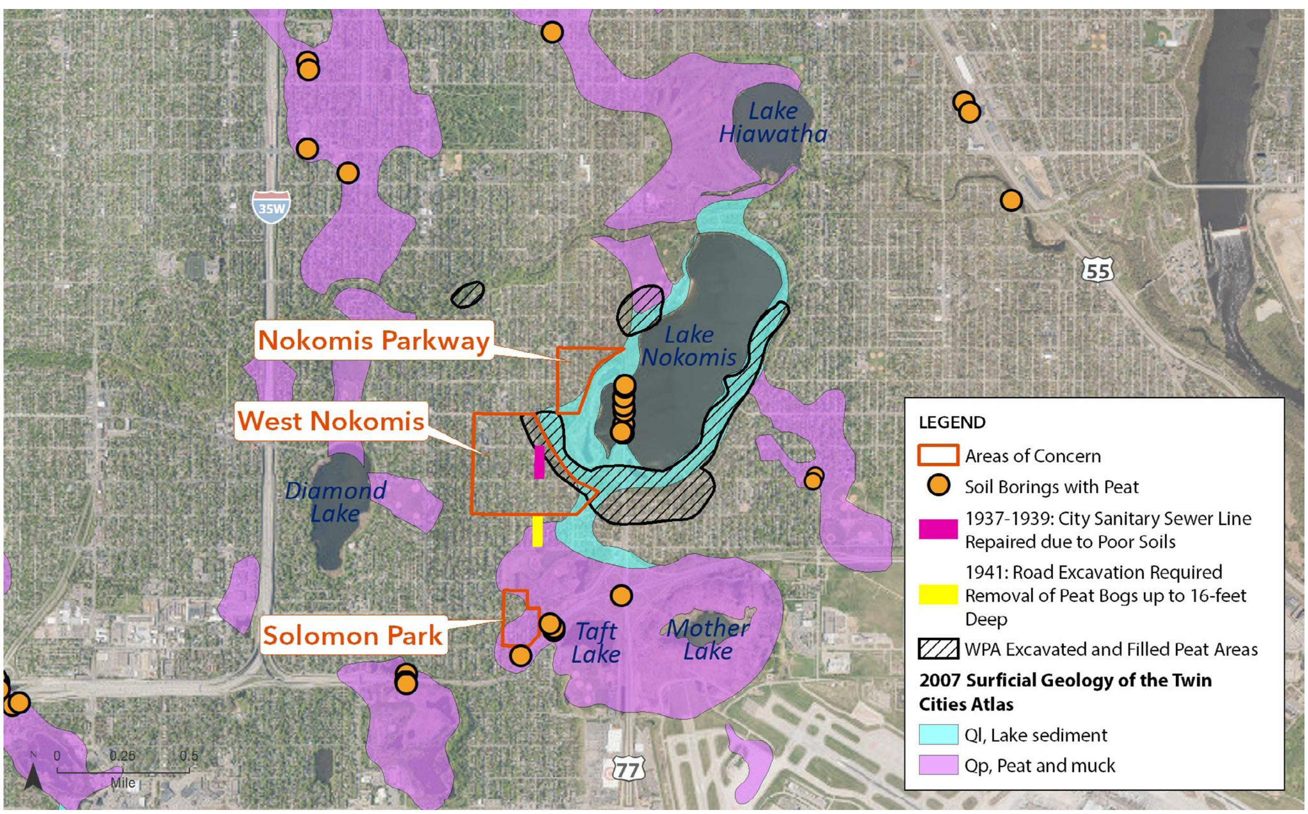


Figure 42: Mapped Peat. *Known peat areas from the 2007 Surficial Geology, documented WPA peat excavated and filled areas, and soil boring data from the Department of Health. (Credit: MCWD; Data Source: Minnesota Department of Health; Meyer, 2007; Minneapolis Board of Park Commissioners, 1936-1939)*

3.3 AREAS OF CONCERN 1910s-1950s DEVELOPMENT FINDINGS

Due to the peat soils and poor drainage, the area surrounding Lake Nokomis was undevelopable prior to the dredging of Lake Nokomis. Land alterations inside and outside of Lake Nokomis made the landscape marginally developable, by placing artificial fill over the wetlands and peat soils. Even though these land alterations took place during the Dust Bowl drought, the peat soils have historically caused problems for infrastructure and parkland around Lake Nokomis, and Theodore Wirth himself acknowledged the issue (Wirth 1945).

A century after residential development within the Areas of Concerns, property owners continue to encounter infrastructure and water problems that have historically affected the area. The underlying geology, presence of peat soils, and former mapped wetland areas all support the fact that the landscape around Lake Nokomis has been wet for thousands of years. As precipitation patterns increase, the landscape within the Areas of Concern will naturally take in more and more water because of its topography, underlying geology, and history of poor drainage.

3.3.1 Nokomis Parkway

The homes in this Area of Concern were built during the 1920s-1940s, with sanitary sewer lines built during 1911-1930. Some of the homes and sanitary sewer lines were built over former wetlands and the former Lake Nokomis basin (**Figure 43**).

Figure 43: 1853 Land Survey for the Nokomis Parkway Area of Concern. *The Nokomis Parkway Area of Concern boundary is overlaid on the 1853 land survey, which shows homes were built over a former wetland and the former basin of Lake Nokomis. (Credit: MCWD; Data Source: GLO Historic Plat Maps)*

3.3.2 West Nokomis

The homes in this Area of Concern are estimated to have been built during the 1930s-1940s, with sanitary sewer lines installed during 1931-1950. Some of the homes and sanitary sewer lines were built over the former channel that drained from the Mother Lake wetland into Lake Nokomis. The remaining homes were built in-between and adjacent to a former wetland system (**Figure 44**).

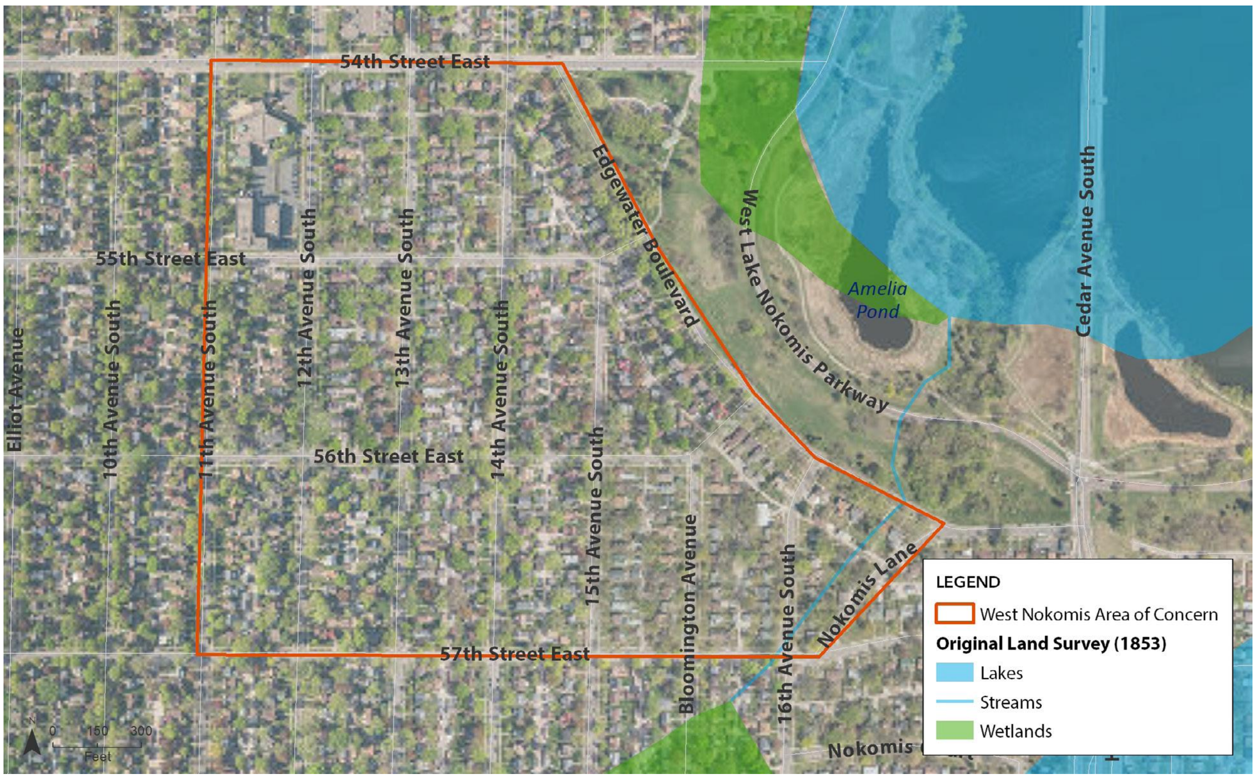


*Figure 44: **1853 Land Survey for the West Nokomis Area of Concern.** The West Nokomis Area of Concern boundary is overlaid on the 1853 land survey, which shows homes were built over the former channel that drained the Mother Lake wetland into Lake Nokomis and adjacent to former wetland systems. (Credit: MCWD; Data Source: GLO Historic Plat Maps)*

3.3.3 Solomon Park

The homes in this Area of Concern are estimated to have been built during the 1940s-1950s, with sanitary sewer lines installed during 1931-1970. **Figure 45** shows that some of the homes were built over the former wetland that was adjacent to Mother Lake and the remaining homes were built adjacent to a former wetland system.

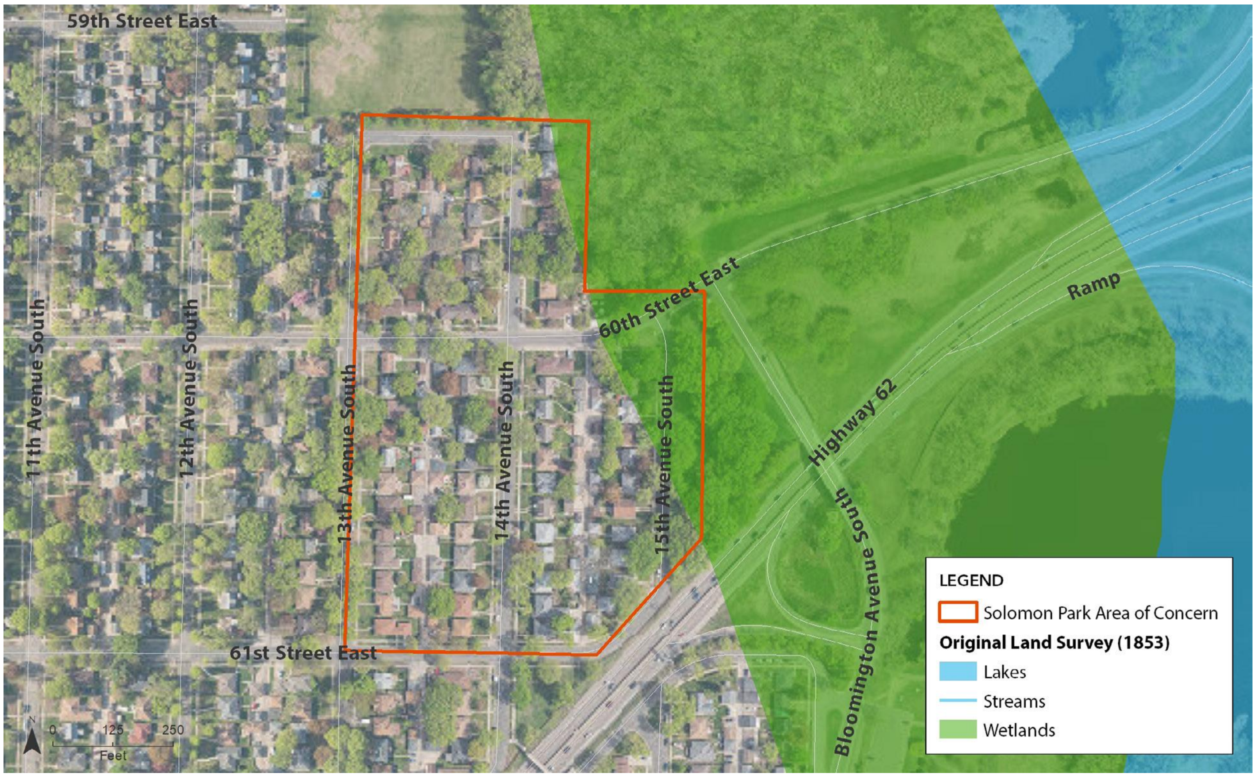


Figure 45: 1853 Land Survey for the Solomon Park Area of Concern. *The Solomon Park Area of Concern boundary is overlaid on the 1853 land survey, which shows homes were built over the former wetland that was adjacent to Mother Lake and the remaining homes were built adjacent to a former wetland system. (Credit: MCWD; Data Source: GLO Historic Plat Maps)*

4.0 PRECIPITATION RECORDS

Chapters 2 and 3 reviewed the surficial geology, pre-settlement hydrologic landscape, alterations to the hydrologic landscape, history of residential and park development, and historical infrastructure and parkland issues associated with the underlying geology in the Areas of Concern.

This chapter will examine Minnesota's precipitation data and compare how it has changed over the last century from when the Areas of Concern were developed to present day. Understanding how precipitation has changed over time is critical to understanding what is contributing to the water issues.

4.1 LOCAL PRECIPITATION RECORDS

The Twin Cities is fortunate to have a long-term data set for precipitation which dates to 1871. The DNR State Climatology Office gathers, archives, manages, and disseminates historical climate data to address questions involving the impact of climate on Minnesota and its citizens. Staff from the DNR's State Climatology Office reviewed past and current climate data for the Lake Nokomis area for this evaluation.

4.1.1 1920s-1950s Record Low Precipitation

Section 3.2 showed that residential development within each of the Areas of Concern generally occurred during the 1920s-1950s. During these 40 years of residential development, the average annual precipitation was approximately 25 inches and resulted in a record precipitation deficit and subsequent Dust Bowl drought. In 1936, the Dust Bowl drought peaked in the Twin Cities with record high temperatures and only 18.47 inches of annual precipitation, which is currently the sixth driest year on record for the Twin Cities.

Residential development within the Areas of Concern occurred during the driest 40 years on record for the Twin Cities.

In his book, Wirth (1945) notes impacts of rainfall on the parks water features:

> There have always been cycles of normal, subnormal, and abnormal rainfall, on which depend the water levels of our lakes and the flow of our streams. The last period of subnormal precipitation was an unusually long one, for during the twenty-five years from 1915 through 1940, only eight years had normal or abnormal precipitation, the other seventeen having been subnormal, with a total deficiency of 62.04 inches – in consequence of which our spring-fed lakes have been low at times and Minnehaha Creek practically dry during most of that period. Since Minnehaha Falls is so widely known and beloved through Longfellow's poem, "The Song of Hiawatha," it has always been a favorite spot for visitors from near and far, and during this dry period there were many who experienced keen disappointment on observing the sparse trickle of water go over the falls, instead of the expected thundering flow that at times in the past had plunged down the 55-foot leap. (p 81-82)

Figure 46 shows the average annual precipitation by decade in the Twin Cities and indicates a general increasing trend in annual precipitation in the Twin Cities. The acceleration of this wet trend started after the Dust Bowl drought and after the residential development within the Areas of Concern occurred. This means the residential development within the Areas of Concern coincided with the driest period on record for the Twin Cities.

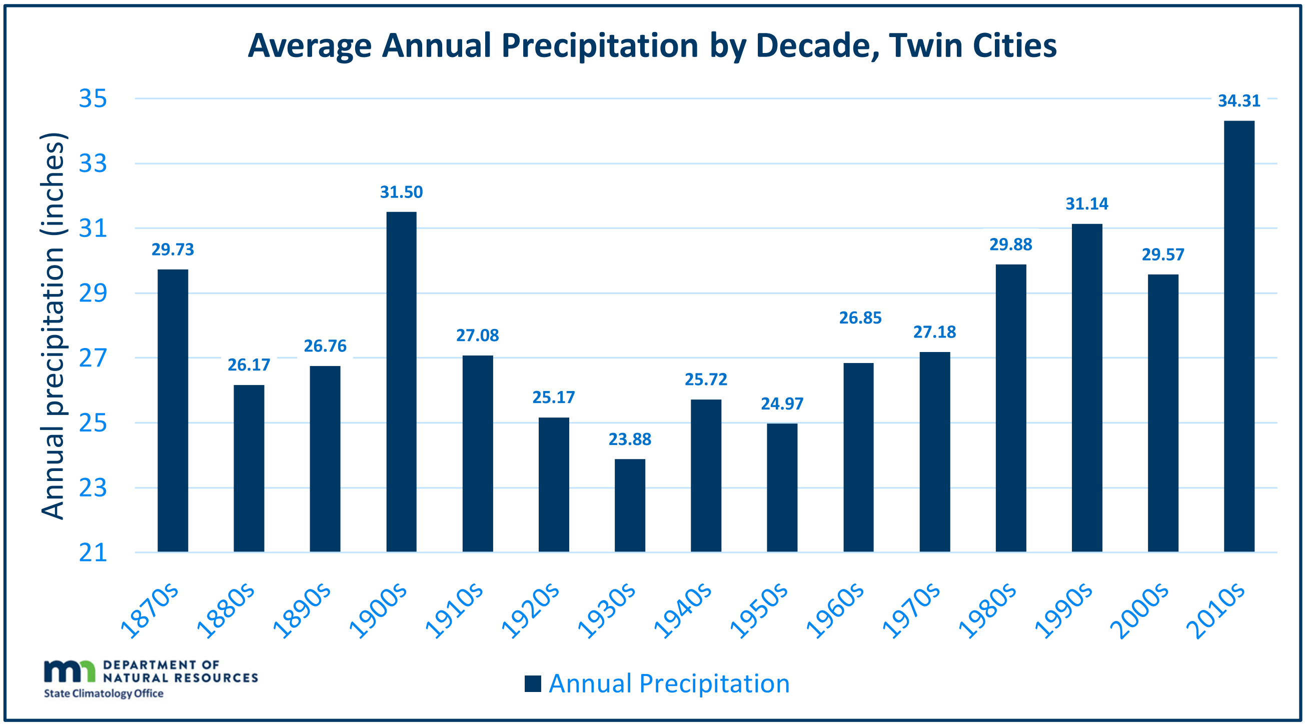


Figure 46: Average Annual Precipitation. *The Twin Cities average annual precipitation was the lowest during the 1920s-1950s. Precipitation totals have been increasing since the 1950s. (Credit: DNR State Climatology Office)*

4.1.2 2010s Record High Precipitation

The trend towards wetter conditions has been most pronounced across southern Minnesota, including the Twin Cities. During the last decade (2010-2019), the average annual precipitation in the Twin Cities was a record high 34.31 inches, which positions this period as the wettest decade on record since record-keeping began in 1871. This means the Areas of Concern received nearly 100 inches more precipitation in the 2010s than they did during each individual decade (1920s, 1930s, 1940s and 1950s) when homes within the Areas of Concern were built.

Between 2013 through 2019, the Twin Cities experienced the wettest seven years on record which accumulated a precipitation surplus of over 32 inches — equivalent to an extra years' worth of rain.

Eight of the 10 years in the 2010s (2010, 2013-2019) were wetter than recent climatological averages, resulting in the wettest five-year period (2015-2019), wettest six-year period (2014-2019), and the wettest seven-year period (2013-2019) on record. No seven-year period on record is even close to as wet as 2013 through 2019, where the annual precipitation average at the Minneapolis airport was nearly 37 inches—more than six inches above average. The record wet seven years from 2013-2019 resulted in an accumulated precipitation surplus of over 32 inches (based on the new 1991-2020 climatic normal for Minneapolis), which is equivalent to an additional year's worth of precipitation fall during this time. **Figure 47** shows the cumulative precipitation surplus from normal and how it built from January 2013 to December 2019.

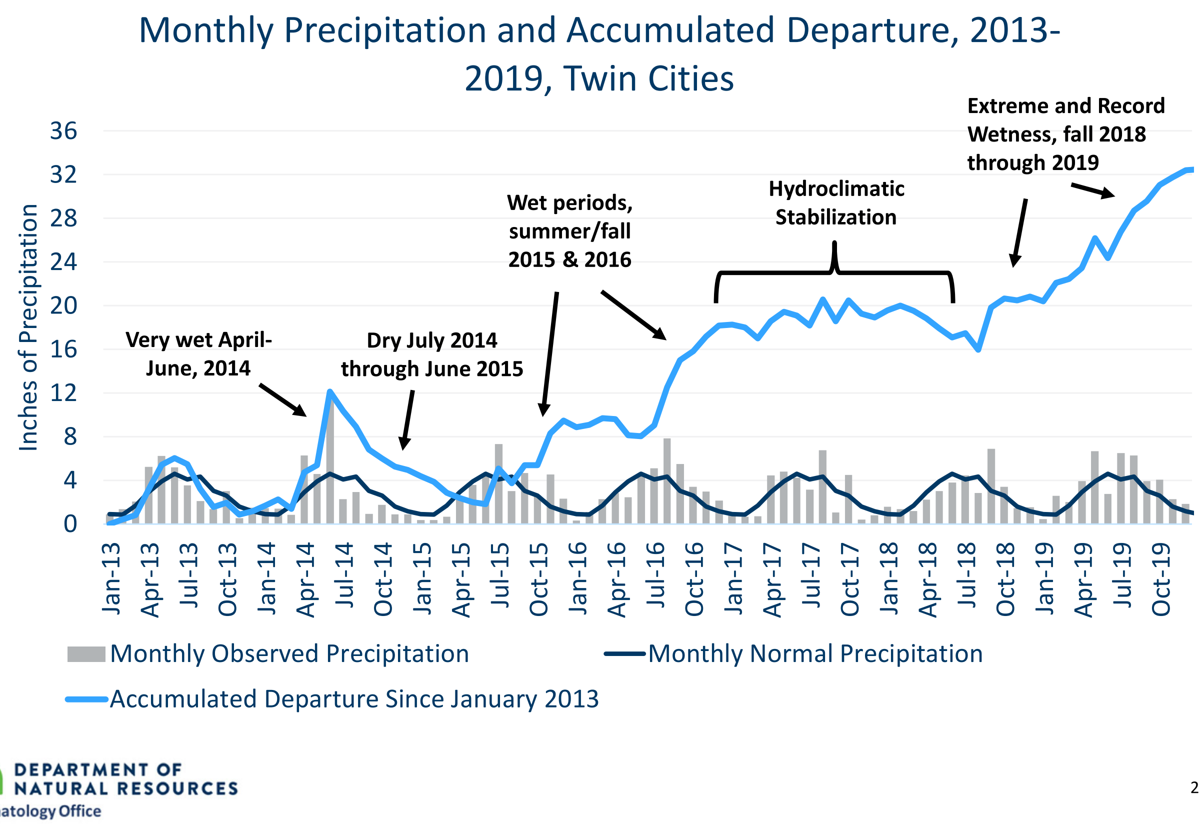


Figure 47: January 2013-December 2019 Precipitation Departure. *Graph showing state-average precipitation, departures from 1991-2020 "normal", and cumulative surplus beginning January 2013 and running through December 2019. (Credit: DNR State Climatology Office)*

Section 1.1 notes that the recent water issues in the Areas of Concern started in 2014. In 2014 the Twin Cities experienced the wettest first half of the year on record (January 1–June 30) with a total of 25.83 inches, which was nearly double the average for that timeframe. April 2014 recorded 6.27 inches of precipitation, which is the second wettest April on record. June 2014 recorded 11.36 inches, which currently ranks as the second wettest June on record for the Twin Cities. The heaviest June 2014 rainfall event occurred on June 19, when 4.13 inches of rain fell, which currently ranks at the sixth wettest calendar day on record in the Twin Cities. For reference, the highest calendar day rainfall total is 9.15 inches which occurred on July 23, 1987, and is often referenced as the "Twin Cities Super Storm". This record precipitation in 2014 caused flooding across Minnesota and resulted in a FEMA Federal Disaster Declaration for 35 counties across Minnesota, including Hennepin County. Additionally, this record precipitation in 2014 resulted in new record high water levels for 17 lakes and record flows for eight streams across MCWD.

4.13-inches of rain fell on June 19, 2014, which currently ranks as the sixth wettest day on record for the Twin Cities.

In 2016 the wet trend continued and the Twin Cities received 40.32 inches of precipitation, breaking the existing 105-year-old annual precipitation record of 40.15 inches. In 2019, a mere three years later, the Twin Cities broke the annual precipitation record again, with 43.17 inches which currently ranks as the wettest year on record.

The precipitation total in 2019 was not shaped by one or two extreme rainfall events, as is often the case with record years. Instead, an unusually high number of days with moderate to heavy precipitation occurred. In 2019, the Twin Cities experienced 12 separate calendar days with at least an inch of precipitation, tying for the most over the last 150 years.

In addition to 2016 and 2019 being the two wettest calendar years on record, they also currently rank as the top wettest water years. The USGS defines a water year, also known as the hydrological year, as the 12-month period between October 1st of one year and September 30th of the next year. A water year differs from a calendar year because it recognizes that part of the precipitation that falls in late autumn and winter accumulates as snow and does not drain until the following spring or summer. This 12-month water year provides the highest correlation between precipitation, water levels, and changes in water storage. **Figure 48** shows that the 2018-2019 water year currently ranks as the wettest on record and that the 2015-2016 water year tied for the second wettest on record.

RANK	SEASON	TOTAL PRECIPITATION
1	2018-2019	41.39
2	2015-2016	41.24
-	1996-1997	41.24
4	1982-1983	40.99
5	1891-1892	40.79
6	1880-1881	40.53
7	1985-1986	40.50
8	2001-2002	38.71
9	1964-1965	38.67
10	1983-1984	37.99

Figure 48: Twin Cities Water Year Rankings. *The 2018-2019 water year currently ranks as the wettest on record and the 2015-2016 water year currently ranks as the second wettest on record (Credit: National Weather Service)*

4.1.3 2020-2021 Drought Conditions

After the Twin Cities experienced the wettest year on record in 2019, the Twin Cities began to trend dryer in 2020. In mid-2020, dry conditions began to build and during the summer of 2021 drought designations began to occur across the Twin Cities. The DNR State Climatology Office's Climate Journal (DNR, 2021a) notes the following about the drought of 2021:

> A major drought overtook Minnesota during 2021, as persistent moisture deficits combined with above-normal temperatures across the state. In some parts of the state, the drought was as serious as anything experienced in over 40 years, though for most of the state it was the worst drought in 10-30 years. Although the period of greatest intensification and expansion began during the summer of 2021, dry conditions had been building in many areas since early and mid-2020.
>
> 2019 had been a record precipitation year for Minnesota, capping off the state's wettest decade on record. The wet conditions, however, largely ended during the 2019-20 winter, and by February, the state began the first of at least three multiple-month dry spells.
>
> Despite the significant precipitation deficits, the prior very wet period had buffered Minnesota against major moisture shortages.
>
> Dry conditions resumed on a statewide basis during September of 2020, when many areas received less than half of normal precipitation, and the state averaged just 1.46 inches, versus a normal value of 3.12 inches. Thus began a six-month run of statewide precipitation deficits, during which the state missed about 35% of its normal precipitation.
>
> Drought conditions expanded aggressively across Minnesota during June, thanks to an extraordinary early-summer heatwave, along with a continuation of very dry weather. It was Minnesota's third warmest and seventh driest June on record.
>
> In July, the extremely dry weather continued, with the month finishing second driest on record on a statewide basis.

Throughout most of 2021, Hennepin County was determined to be in moderate drought. In July 2021, the Twin Cities recorded 0.87-inches of rain, which increased Hennepin County's drought designation to severe in August 2021. **Figure 49** shows the cumulative precipitation departure from normal and how it has built from January 2020 to December 2021.

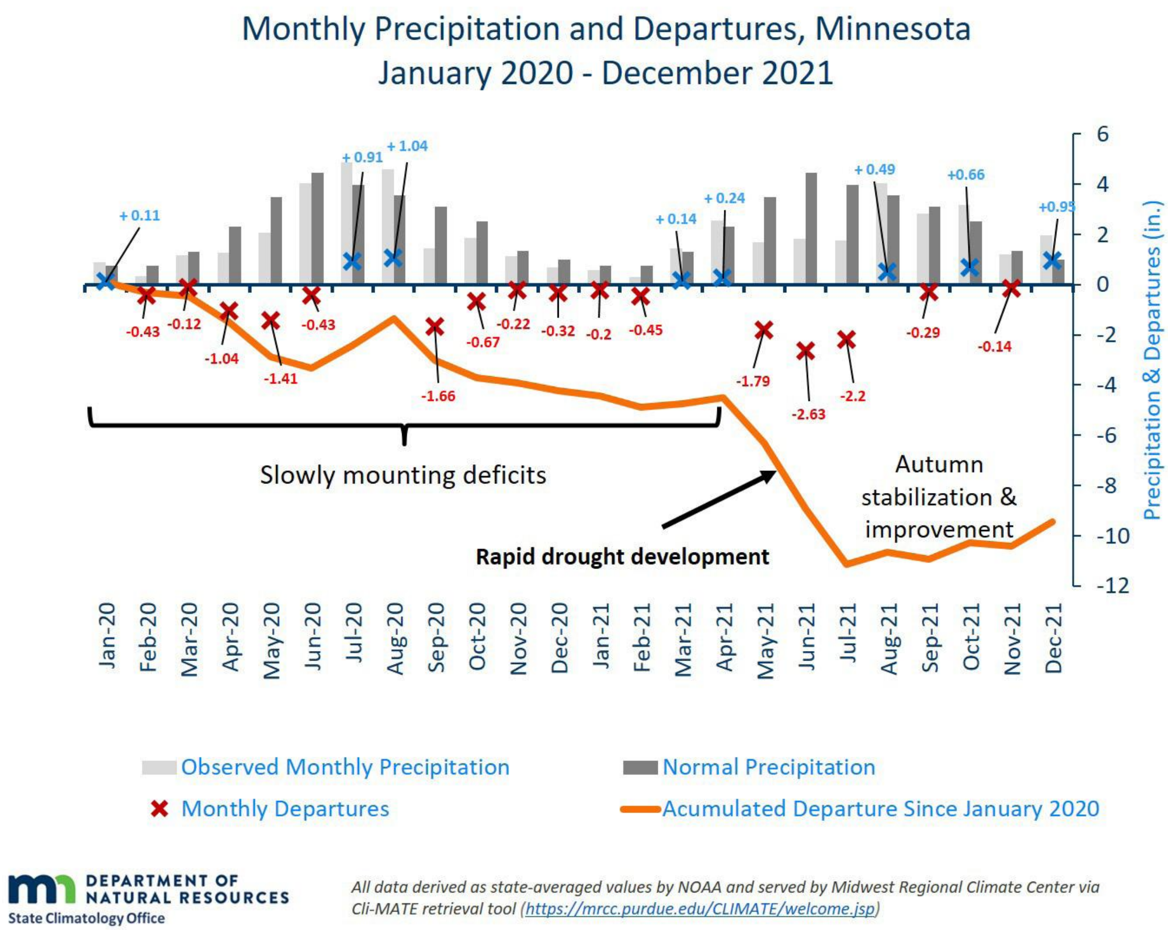


Figure 49: January 2020-December 2021 Precipitation Departure. *Graph showing state-average precipitation, departures from 1991-2020 "normal", and cumulative deficits beginning January 2020 and running through December 2021. (Credit: DNR State Climatology Office)*

According to the U.S. Drought Monitor, Hennepin County ended 2021 in a "moderate drought" designation, which means the area was experiencing lower than normal lake and river levels. Generally, water levels across the Twin Cities were lower in 2020 and 2021 due to the drought conditions, however, water issues in the Areas of Concern continued to be reported by property owners. Section 2.2.2 noted that peat soils can act like a sponge and that once they are wet, they can hold onto water for extended periods of time. This likely explains why property owners in the Areas of Concern continued to experience water issues during drought conditions in 2020 and 2021, when groundwater levels and surface water levels were lower.

4.2 PRECIPITATION CHARACTERISTICS

Beyond the increase in precipitation amounts since the 1930s, there have also been changes to other precipitation characteristics in the Twin Cities that have contributed to an increase in stormwater runoff, groundwater recharge (infiltration), or both.

4.2.1 Increased Frequency and Intensity

The frequency and intensity of precipitation events have also been increasing in the Twin Cities. **Figure 50** shows that annual precipitation totals and number of days with an inch of precipitation or more, were at all-time highs in the 2010s. **Figure 51** indicates the same is true when considering both the amount and the proportion of annual precipitation coming from "heavy" events.

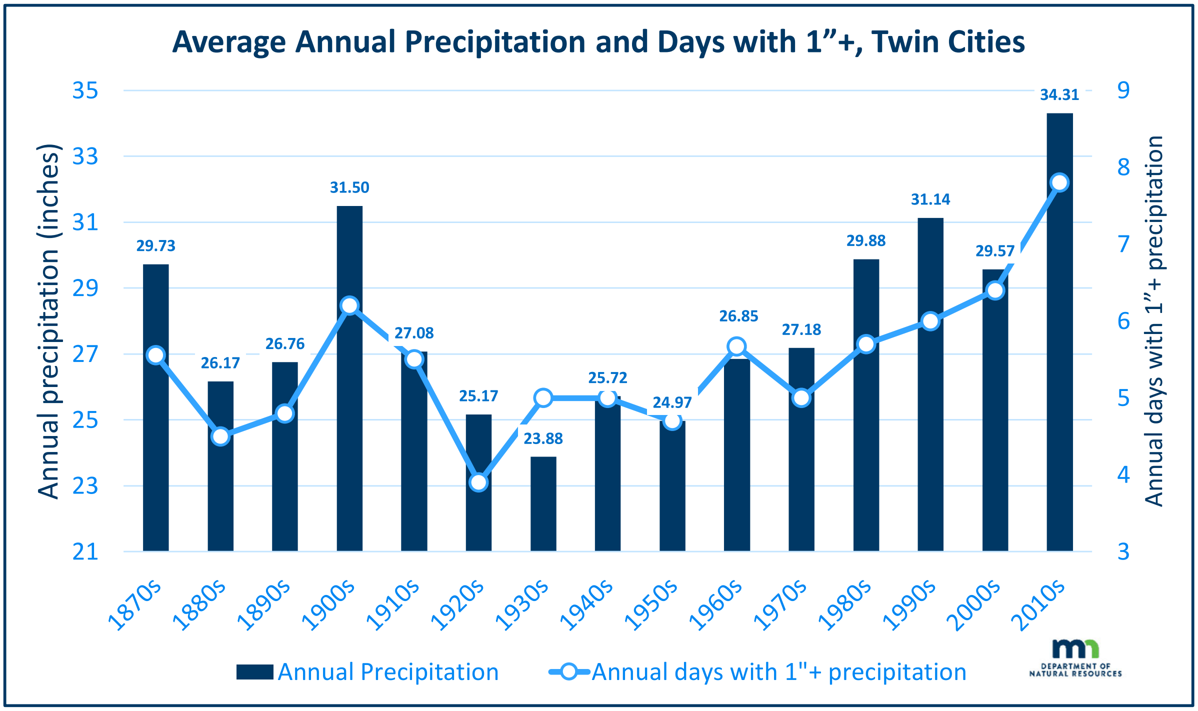


Figure 50: Average Annual Precipitation and Days with 1-inch or More of Rain. *Twin Cities average annual precipitation and counts of days with heavy precipitation, defined as one inch or more falling in a calendar day. (Credit: DNR State Climatology Office)*

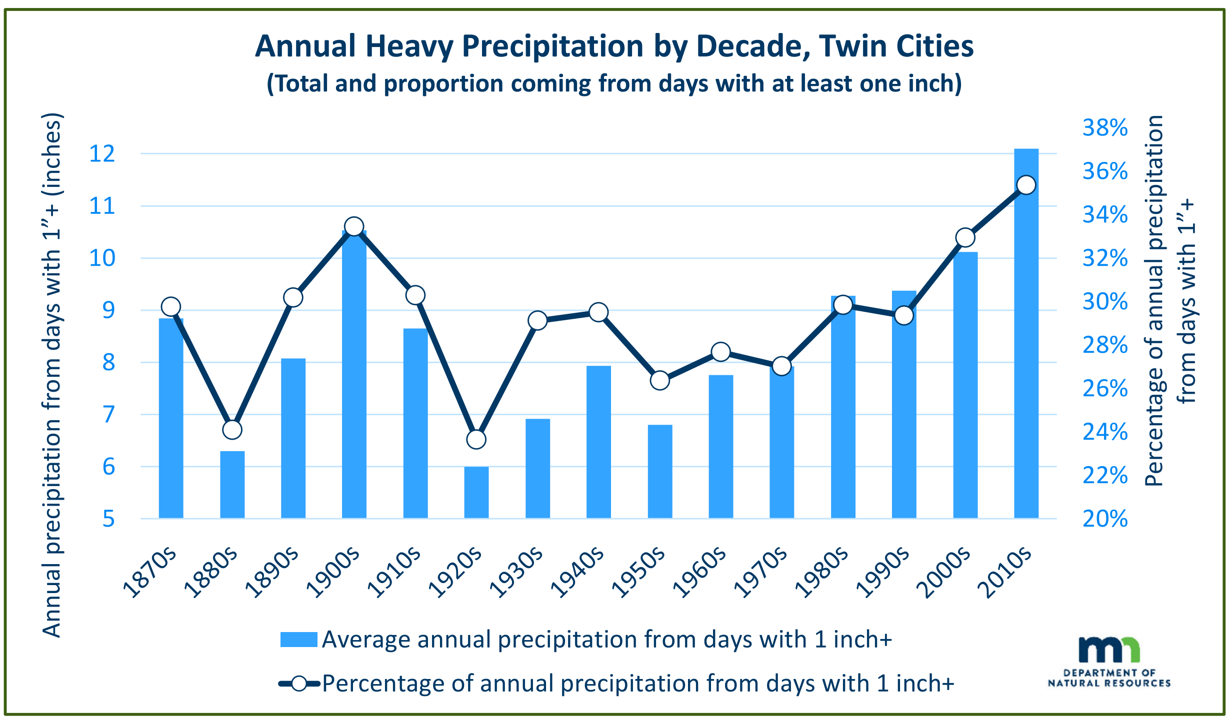


Figure 51: Annual Heavy Precipitation by Decade. *Expressed by decade, the Twin Cities annual sum and proportion of heavy precipitation, defined as total precipitation coming from days with one inch or more, and the percentage of annual precipitation coming from those days. (Credit: DNR State Climatology Office)*

The DNR State Climatology Office has examined the statewide weather station data and has observed the following increases in precipitation events from 1916 to 2019 across Minnesota:

» 20-40% increase in 1-inch+ daily precipitation totals
» 30-50% increase in 2-inch+ daily precipitation totals
» 60-90% increase in 3-inch+ daily precipitation totals

4.2.2 Expanded Precipitation Timing

Precipitation data also shows that rainfall events are taking place earlier and later in the year than the historical average. Thus, in addition to increases in the frequency and intensity of heavy rainfall, the length of the rainfall season is also increasing.

During the 2010s, the Twin Cities recorded an increase of precipitation in the months of March/ April and October/November. April 2013 was the sixth wettest April on record, April 2014 was the second wettest April on record and November 2015 was the sixth wettest November on record. Additionally, during 2013-2019, the Twin Cities set 16 new daily high precipitation totals for the months of March, April, October, and November.

This increase in precipitation in early spring and late fall has contributed to increased groundwater recharge rates (this is expanded upon in Section 5.1.1). This is because groundwater recharge potential is greatest in the spring and fall since soils are usually thawed but vegetation is dormant (not growing) and therefore is unable to take up water, resulting in more water soaking into the ground.

4.3 IMPACT OF INCREASED PRECIPITATION ON THE WATER CYCLE

Record high precipitation and changes to precipitation frequency, intensity, and timing have altered the water cycle in the Lake Nokomis area and greater Twin Cities area. As was documented in Section 3.1.2, in 2016 and 2019 the Twin Cities' annual precipitation totals increased more than 10 inches above normal from approximately 30 inches to over 40 inches per year. This significant increase in precipitation ignited a chain reaction that led to increased groundwater recharge and caused groundwater levels to rise (discussed next in Chapter 5), caused an increase in Lake Nokomis levels, (discussed in Chapter 6) and an increase in Minnehaha Creek levels (discussed Chapter 7).

The increase in total precipitation also caused soils to be saturated for longer lengths of time, which has led to reported wet backyards. Section 2.2.2 discussed the water retention characteristics of peat soils, and peat soils are known to be within the Solomon Park Areas of Concern where backyard water concerns were reported.

4.4 AREAS OF CONCERN PRECIPITATION FINDINGS

For the precipitation factor, the three Areas of Concern (Nokomis Parkway, West Nokomis, and Solomon Park) will be considered together because of the probability that precipitation does not vary substantially between the three areas.

The four decades between the 1920s-1950s were the driest on record for the Twin Cities and coincided with residential development within the Areas of Concern. The average annual precipitation during these 40 years was approximately 25 inches a year, which is the lowest on record. It is likely that these 40 years of low precipitation became the perceived "normal" and influenced perceptions that water was relatively easy to manage during residential development even in former wetland and lake areas.

During the wettest seven years on record, 2013-2019, the average annual precipitation increased to 36.24 inches. This means that nearly a century after development began in the Areas of Concern, the average annual precipitation increased over 11 inches a year between 2013-2019, when compared to the precipitation averages during the1920s-1950s.

After record setting precipitation occurred in the spring of 2014, residents in the Areas of Concern began to identify water concerns such as wet basements, standing water in backyards, private sewer lateral damage, and saturated parkland. These concerns continued through the duration of the wet weather into 2019.

Beyond the increased amounts of precipitation, there has also been an increase in the proportion of that precipitation coming from "heavy" rain events and a calendar year expansion of when rainfall is occurring. Rainfall has been increasing during the spring months of March and April and during the fall months of October and November, when groundwater recharge potential is greatest.

In 2020, the wet weather pattern stopped, and below normal precipitation led to a precipitation deficit throughout 2020 and into 2021. This dry weather persisted into December 2021 and resulted in a moderate drought designation for Hennepin County. However, the transition below normal precipitation in 2020 and 2021, did not stop water concerns from being reported in the Areas of Concern.

Record high precipitation in the 2010s increased groundwater recharge leading to increased surface runoff. An analysis of the water cycle impacts to groundwater and surface waters will be discussed in Chapters 5 through 7. Specifically, these future chapters will expand upon the influence of the 2013-2019 record precipitation and the corresponding impacts on groundwater recharge and water levels, respectively.

5.0 GROUNDWATER RECHARGE AND LEVELS

Chapter 4 documented that in 150 years of Minnesota weather records, the Areas of Concern have never experienced a wetter period than 2013-2019. This record wet weather resulted in a surplus of 32 inches of precipitation. This chapter examines how the precipitation surplus affected groundwater recharge and groundwater levels in and around the Areas of Concern.

5.1 GROUNDWATER RECHARGE

Both groundwater and surface water originate as precipitation. While their names are useful to describe where water exists relative to the landscape, they are connected as one resource within the water cycle. Precipitation either infiltrates into the soil and becomes groundwater or occurs as surface runoff, then discharges to lakes and streams, and eventually evaporates to begin the water cycle again (**Figure 52**).

Groundwater recharge is a major process of the water cycle where water moves downward (infiltrates) from the land surface through the soil to the water table. After precipitation hits the ground, it becomes either groundwater recharge or runoff depending on the surface soil conditions (blue arrows in the upper right image in **Figure 53**). Groundwater recharge is the primary method through which water moves into an aquifer, causing the capillary fringe and water table to increase (black arrows in **Figure 53**) and fluctuate over time. The USGS (2021) notes that capillary action is "the movement of water within the spaces of a porous material due to the forces of adhesion, cohesion, and surface tension".

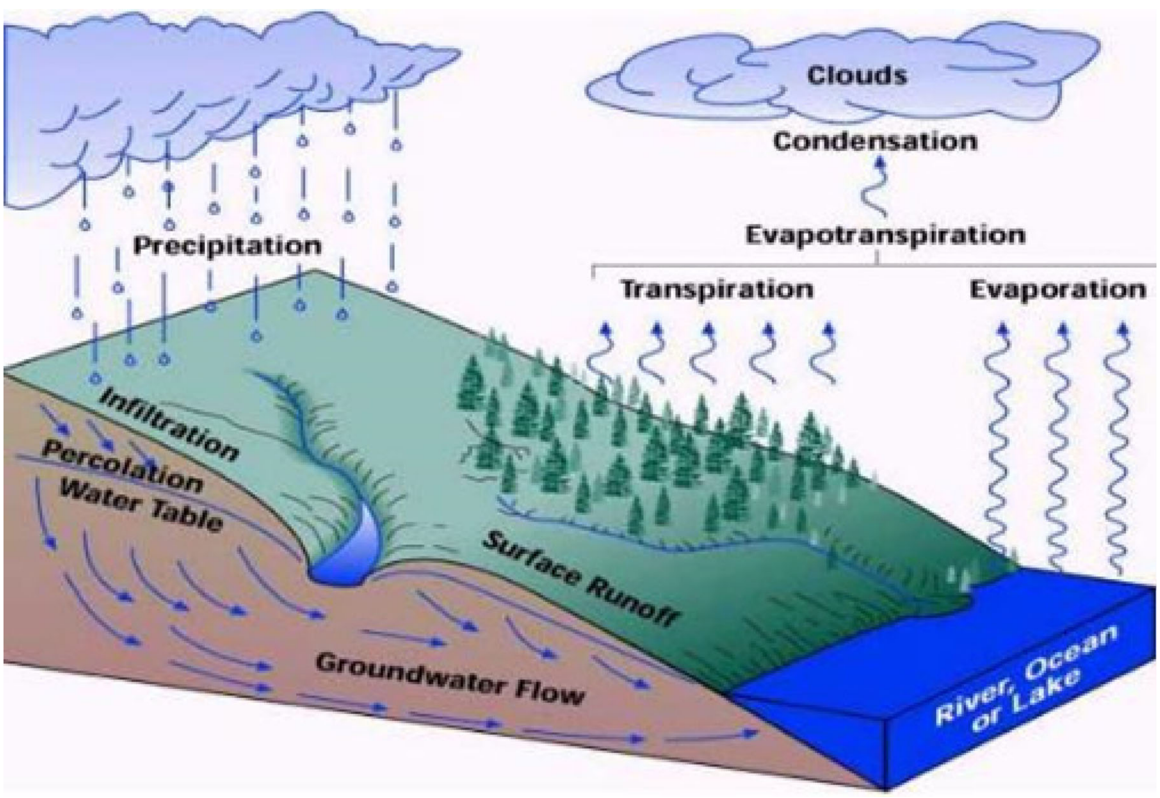


Figure 52*: The Water Cycle.* *Precipitation that infiltrates into the ground ultimately becomes groundwater that discharges to lakes and streams, and eventually evaporates to complete the water cycle. (Credit: Spokane Aquifer Joint Board, 2021).*

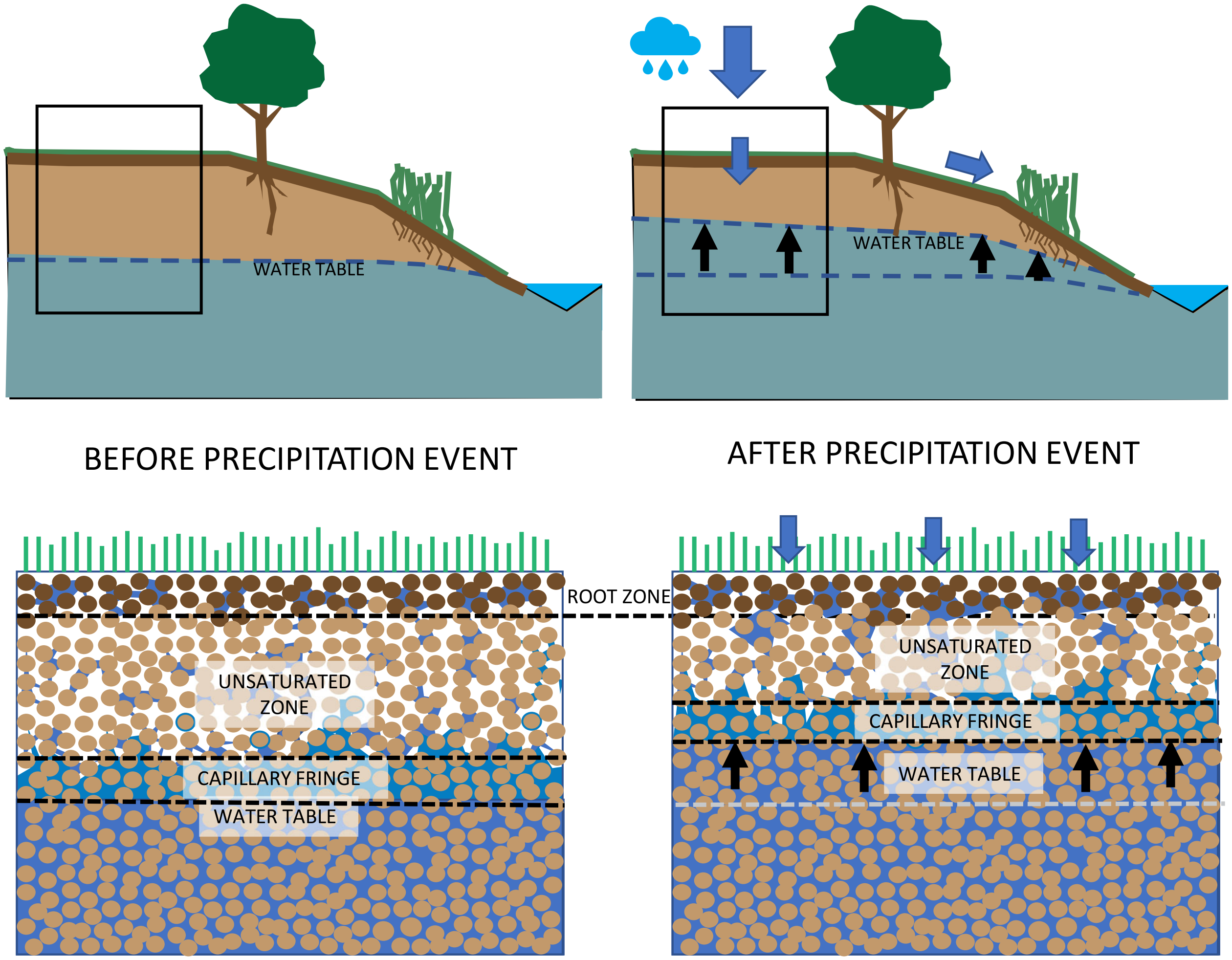


Figure 53: Groundwater Recharge. *Precipitation infiltrates into the ground (groundwater recharge), causing the capillary fringe and water table to increase. (Credit: Barr Engineering)*

The top of the unconfined aquifer is known as the water table. Above the water table is the unsaturated zone which contains rocks and soil that let water seep down. Below the water table is the saturated zone, which is where water has filled the spaces or pores between rock particles or fractures within the rocks. This is where groundwater is found and referred to as an aquifer. Groundwater in an unconfined aquifer can discharge to streams, lakes, wetlands, and ponds if the water table is high enough (this is expanded upon in Section 6.1).

5.1.1 Twin Cities Groundwater Recharge

The Metropolitan Council has extensively studied the Twin Cities regional groundwater and in doing so, created a detailed groundwater computer model currently known as Metro Model 3 (Metropolitan Council, 2014). Metro Model 3 modeling results suggest that annual groundwater recharge rates to the water table in the Lake Nokomis watershed have been increasing since approximately 2012. In 2013, modeling results suggested that groundwater recharge rates increased 30-45% over the previous average from 1988-2011, for the Lake Nokomis area and for most of the Twin Cities area. In 2014, due to record high spring precipitation, modeling results suggested that groundwater recharge rates continued to be well above historical averages across the Twin Cities, and modeling for the areas upgradient (to the west) of the Lake Nokomis watershed suggested that groundwater recharge rates increased over 75% from the historical averages.

Using Metro Model 3 data, **Figures 54, 55, and 56,** shows annual average groundwater recharge rates that were modeled for the Lake Nokomis watershed and surrounding area. The 1988-2011 image (**Figure 54**) shows the modeled annual groundwater recharge rate was 10-12 inches per year. The 2012-2016 images (**Figure 55**) shows that the modeled annual groundwater recharge rate increased to 14-16 inches per year, which is 2-4 inches more per year than the average during the 1988-2011 period. The 2017-2019 image (**Figure 56**) shows the modeled groundwater recharge rate increased again to 16.1-18 inches in the areas west of Lake Nokomis, which is 4-6 inches more per year than the average during the 1988-2011 period.

Groundwater modeling estimates that groundwater recharge rates increased 2-6 inches per year between 2012-2019, when compared to the previous 25 year average.

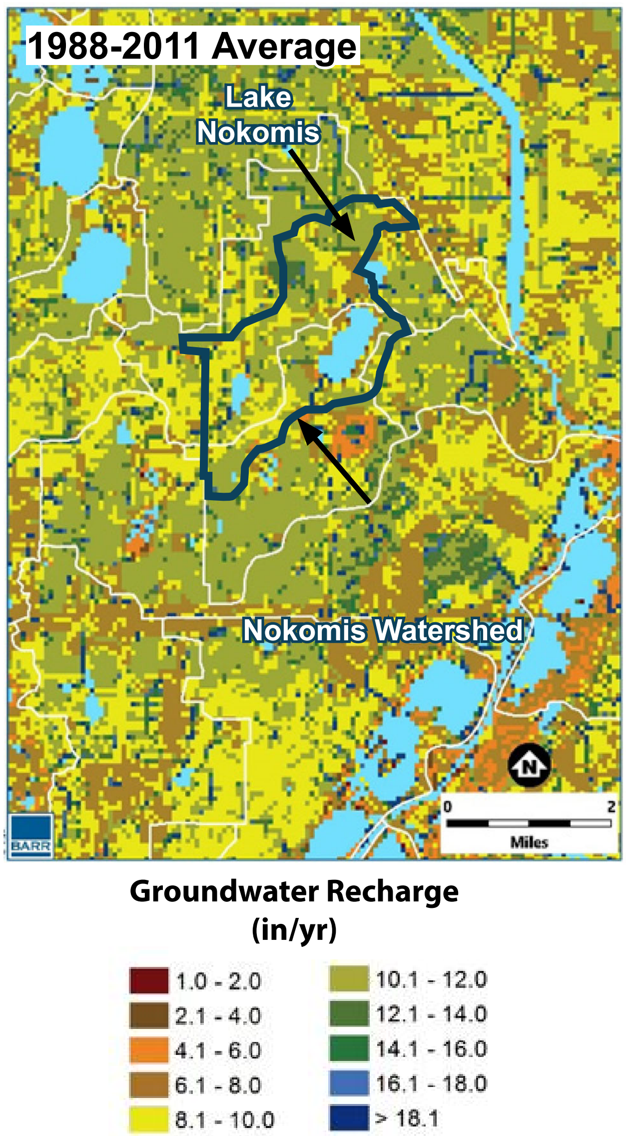


Figure 54: Groundwater Recharge 1988-2011. *Average annual recharge rates to the water table from 1988-2011. (Credit: Barr Engineering)*

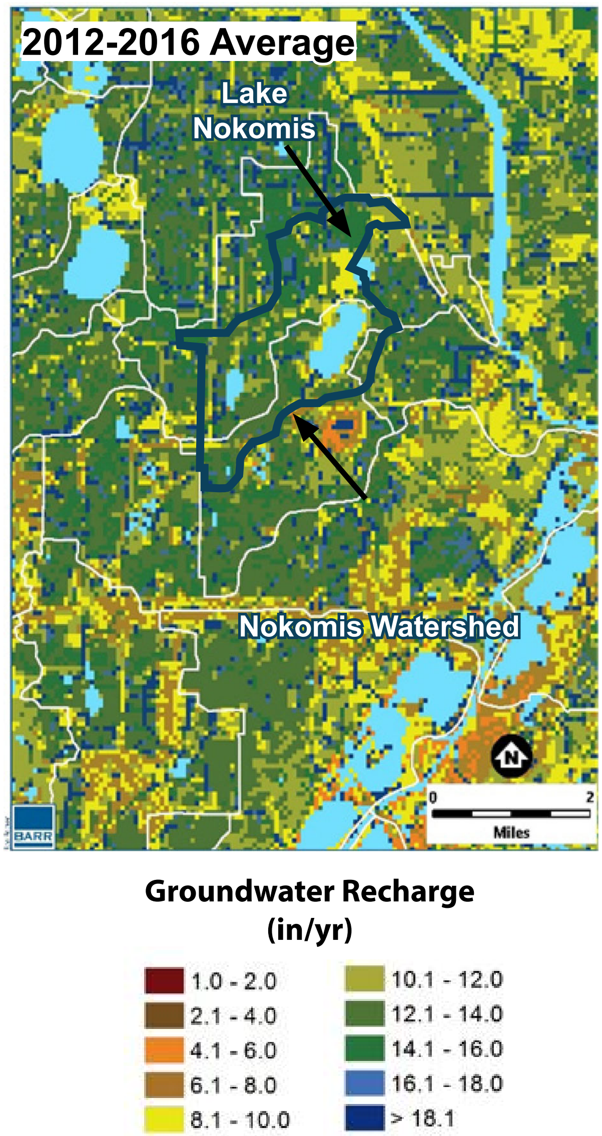


Figure 55: Groundwater Recharge 2012-2016. *Average annual recharge rates to the water table from 2012-2016. (Credit: Barr Engineering)*

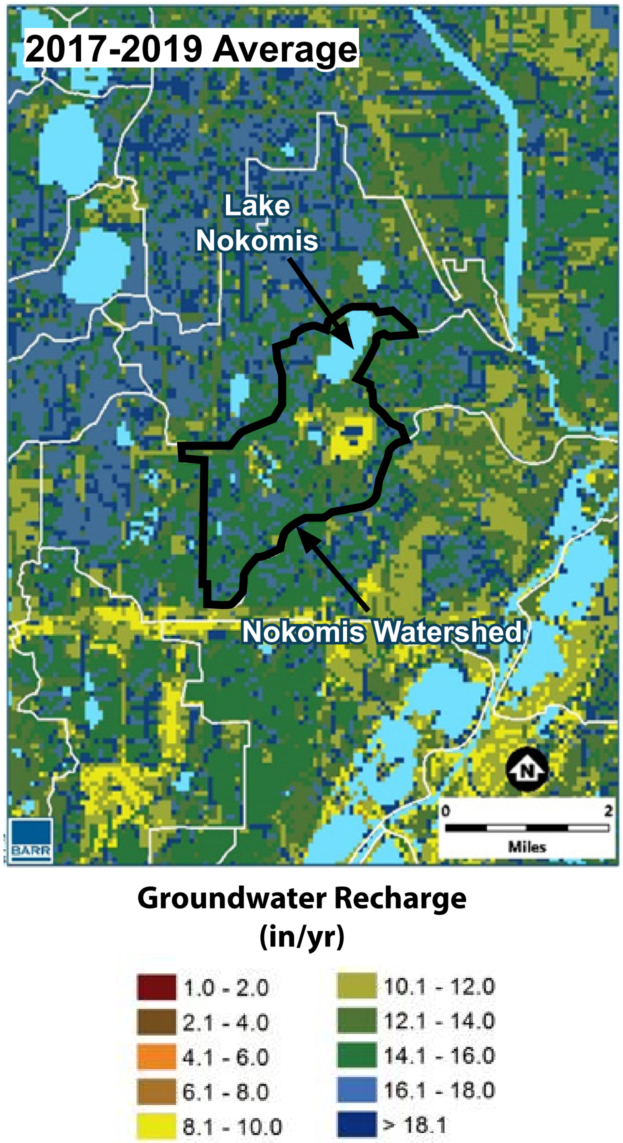


Figure 56: Groundwater Recharge 2017-2019. *Average annual recharge rates to the water table from 2017-2019. (Credit: Barr Engineering)*

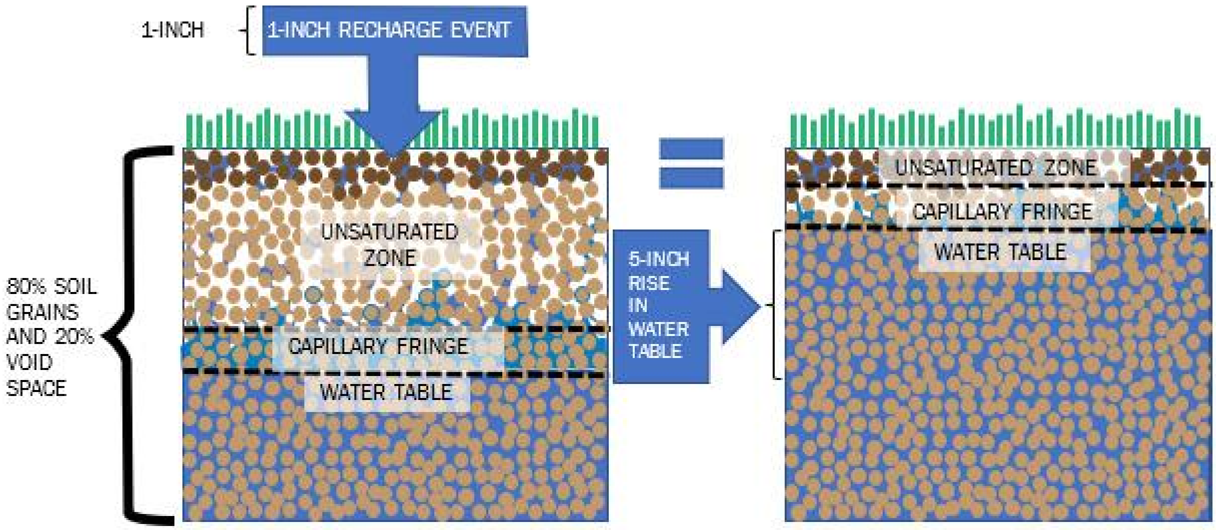


Figure 57: Water Table Rise. *Each inch of groundwater recharge can cause a five-inch rise in the water table elevation. (Credit: Barr Engineering)*

5.1.2 Areas of Concern Groundwater Recharge

Section 5.1.1 above explained that during 2012-2016 annual groundwater recharge rates for the Lake Nokomis area increased 2-4 inches per year when compared to historical averages. Assuming 20-40% void space (open spaces) in soil, each inch of groundwater recharge can cause the water table to rise about 5 inches (**Figure 57**). This recent increase of 2-4 inches per year in the recharge rate could raise the water table approximately 10 to 20 inches. This is significant for the Areas of Concern because of the underlying peat soils and the existing regional shallow water table in the area. Section 2.2.1 noted that buried peat can facilitate the formation of localized perched groundwater systems which are above the regional shallow water table.

The next two figures show the five-year running average of the estimated annual groundwater recharge in the Nokomis watershed as millions of gallons per year and as depth added to the water table. The recharge values were generated from the Soil Water Balance (SWB) calculation that is part of Metro Model 3, which incorporates daily meteorological, soil and land use data. **Figure 58** shows that the record wet precipitation during 2013-2019 added an estimated 1-1.2 billion gallons of annual recharge to the water table in the Lake Nokomis watershed, which is equivalent to filling over 1,500 Olympic-sized swimming pools or stacking over 15 feet of water on top of Lake Nokomis.

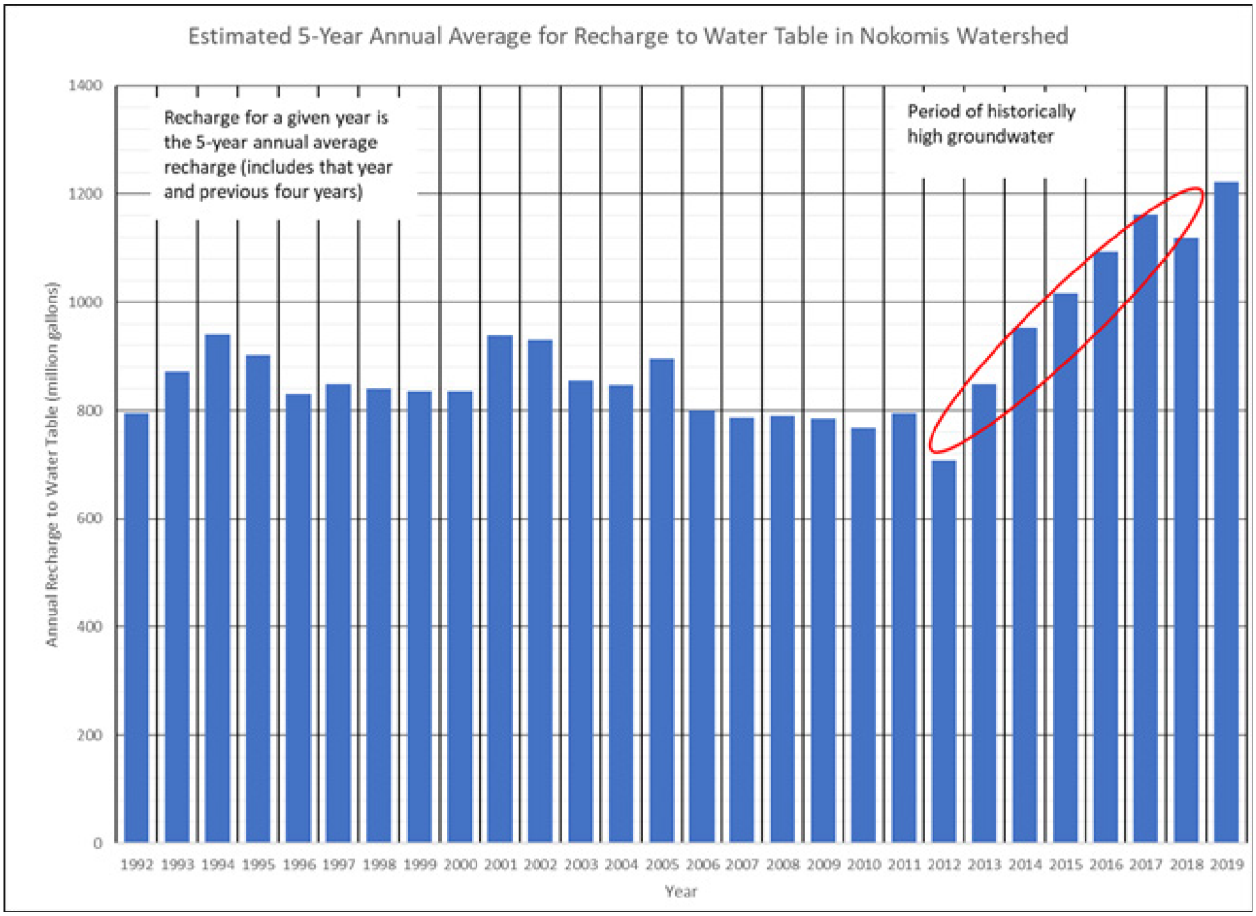


Figure 58: Estimated Annual Water Table Recharge. *The estimated 5-year annual average recharge to water table in Nokomis watershed shows a period of historically high groundwater recharge between 2013-2019. (Credit: Barr Engineering)*

Figure 59 shows that the record precipitation during 2013-2019, was estimated to increase the annual average water table elevation over 20 inches in the Lake Nokomis watershed.

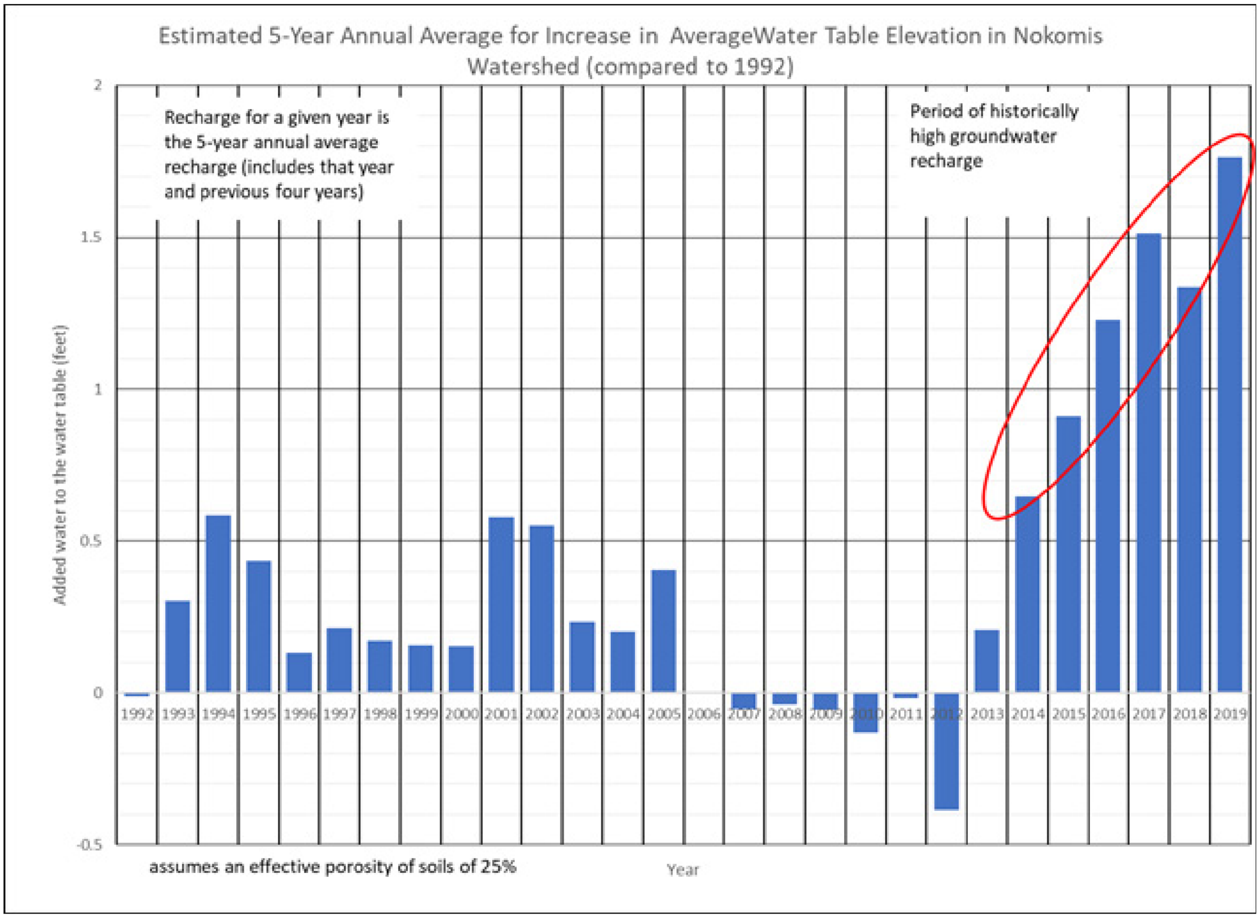


Figure 59. Estimated Annual Water Table Increase. *The estimated 5-year annual average increase to water table in the Nokomis watershed shows a period of historically high groundwater being added to the water table between 2014-2019. (Credit: Barr Engineering)*

Figure 60 visualizes the increased precipitation effects on the water table by showing the changes in the water cycle based on an average year of precipitation (30-inches) and a year with 40-inches of precipitation.

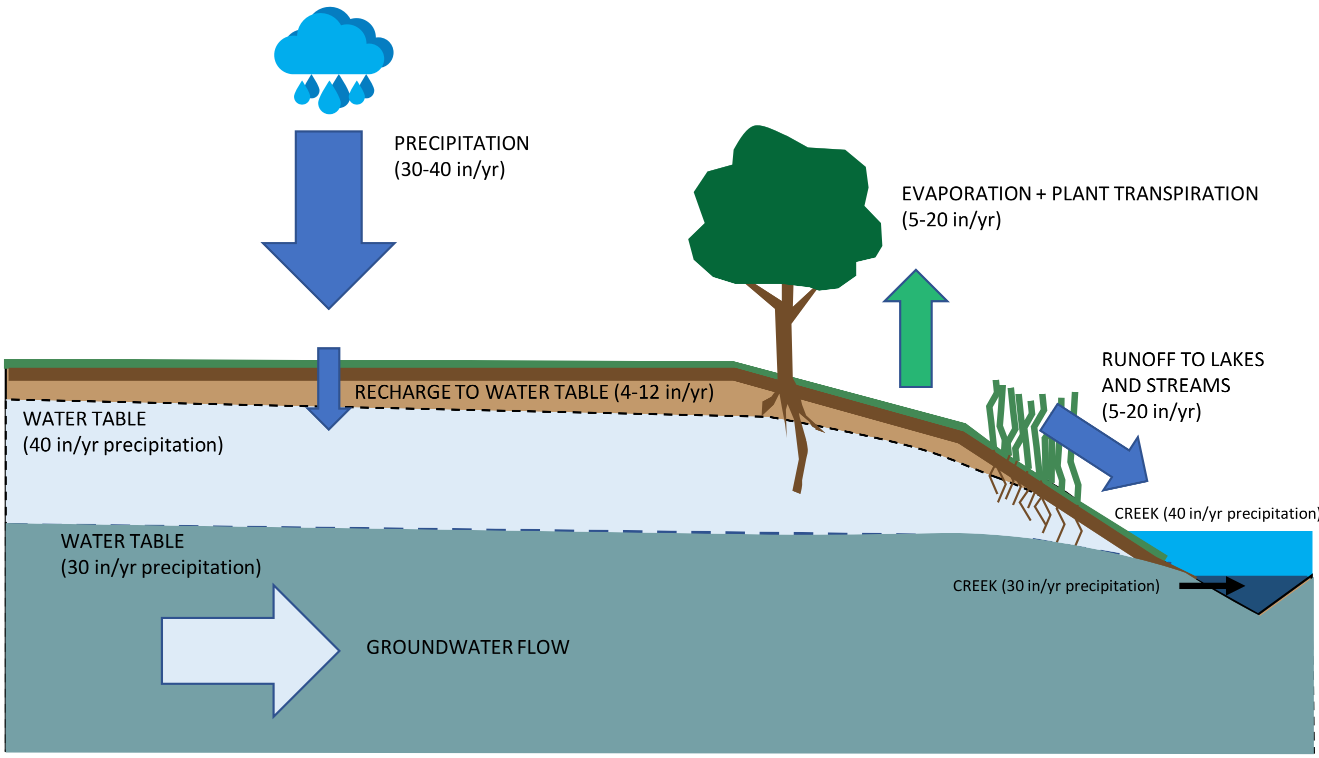


Figure 60: Water Cycle for the Lake Nokomis Area. *Simplified water cycle for the Lake Nokomis area which quantifies the changes in the water cycle based on an average year of precipitation (30-inches) and increased precipitation year (40-inches). (Credit: Barr Engineering).*

5.2 GROUNDWATER LEVEL DATA

With an understanding of increased groundwater recharge rates and the local surficial geology in the Areas of Concern, the Team sought to validate that understanding with local groundwater level data. However, there was only one well near the Areas of Concern that could provide groundwater data. Therefore, the Team initiated the installation of six additional wells (**Figure 61**) to better understand surface and groundwater interactions in the area.

Shallow wells were constructed in 2017 in Nokomis Park (ID 828304) and Solomon Park (ID 828305) to monitor the level of the local water table. Four additional wells (IDs 828341, 828342, 836654, and 836655) were installed in 2018 and 2019 to monitor water levels in the deeper Prairie du Chien and Jordan bedrock aquifers. An older well at Hope Lutheran Church (ID 200586) extends into the Prairie du Chien aquifer and measurements from this well have been recorded since 1979. Well data is available online using the DNR's Cooperative Groundwater Monitoring web page: https://www.dnr.state.mn.us/waters/cgm/index.html.

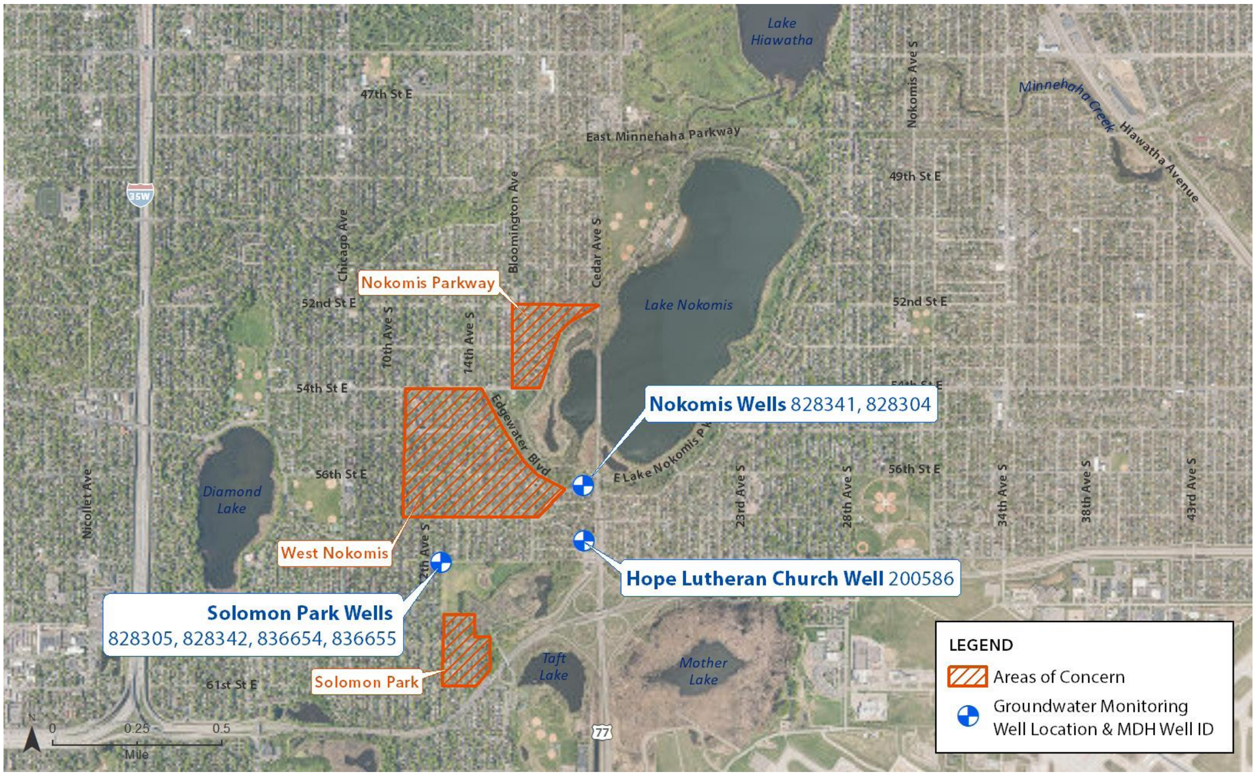


Figure 61. Groundwater Wells. *Seven groundwater monitoring wells exist near the near the Areas of Concern. (Credit: MCWD)*

5.2.1 Areas of Concern Shallow Groundwater Elevations and Flow Direction

Figure 62 shows the water elevation data for the shallow wells at Solomon Park and Nokomis Park, the surface water elevation for Lake Nokomis, and the precipitation totals for each day at the Minneapolis-St. Paul airport between November 2017 and August 2021. Since their installation in November 2017, the water table well at Solomon Park has ranged from 816.89-feet to 818.81-feet (23-inch range), the water table well at Nokomis has ranged from 814.82-feet to 818.10-feet (39-inch range), and Lake Nokomis has ranged from 814.03-feet to 817.01-feet (35-inch range).

Figure 62 also includes trend lines for the water years between 2017-2018, 2018-2019, 2019-2020, and 2020-2021 (note that the 2017 data starts on November 17, 2017, and the 2021 data ends on August 7, 2021).

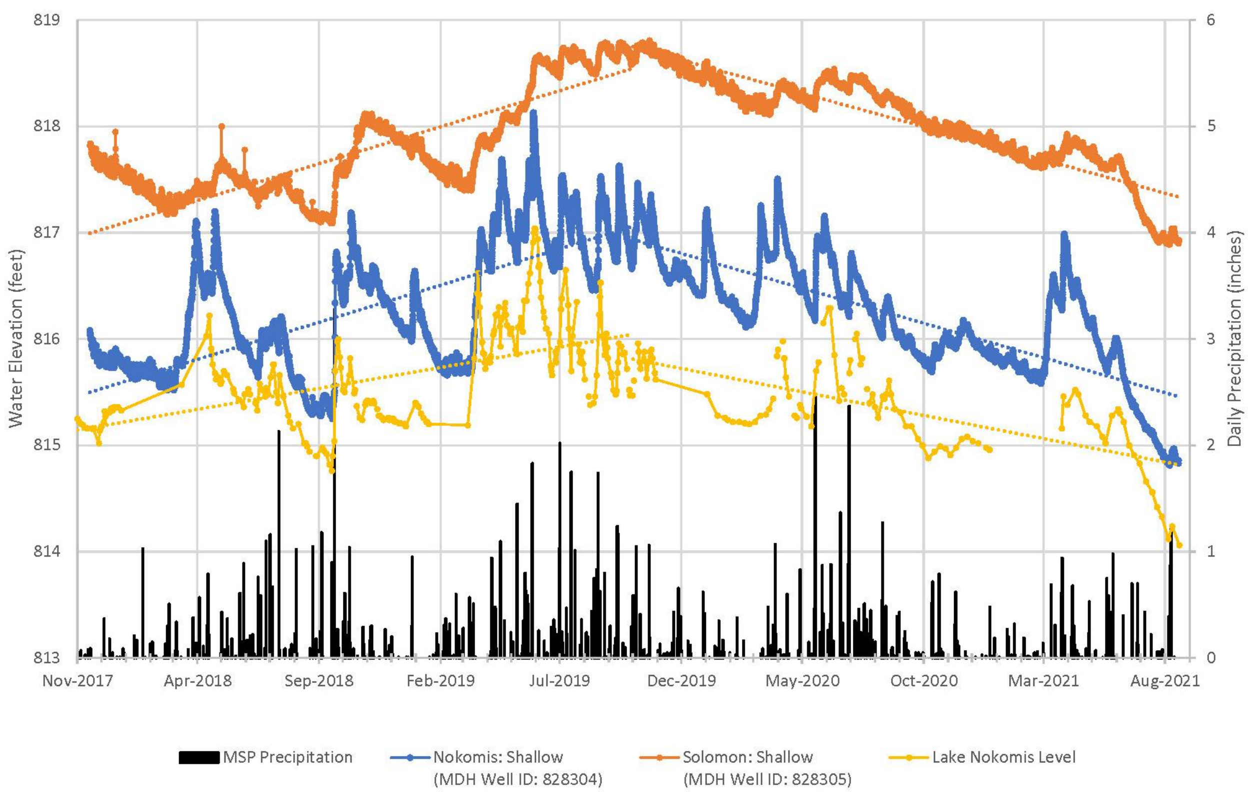


Figure 62. Elevations for Shallow Wells and Lake Nokomis. *Shallow Nokomis and Solomon wells, Lake Nokomis water elevations and precipitation. Dotted lines represent water year trend lines. (Credit: Stantec)*

The primary conclusions drawn from **Figure 62** include:

» There is a direct correlation between precipitation and water levels in the wells and Lake Nokomis.

- On September 20, 2018, the MSP airport recorded a 3.28-inch rain event, which caused a 6-inch spike in the Solomon shallow well, an 18-inch spike in the Nokomis shallow well, and nearly a 12-inch spike in the Lake Nokomis water levels (zoomed in graph shown in **Figure 63**).

» The dotted lines in **Figure 62** show:

- An increasing trend for the shallow wells and Lake Nokomis for the 2017-2018 and 2018-2019 water years, which is a result of record high rainfall and subsequent groundwater recharge that occurred during this timeframe.
- Conversely, the 2019-2020 and 2020-2021 water years show a decreasing trend for the shallow well and lake levels, which is a result of 2020 and 2021 having below normal precipitation totals and drought conditions.

» This immediate response to precipitation demonstrates the magnitude of groundwater recharge on the shallow water wells. Conversely, the winters of 2017, 2018, and 2019 show declining water levels because of low recharge during freezing temperatures. **Figure 64** shows the 2018-2019 winter groundwater level decline.

» Water elevations decrease from the Solomon well, to the Nokomis well, and to Lake Nokomis. This indicates a horizontal hydraulic gradient toward Lake Nokomis such that groundwater within the water table aquifer flows from west to east, towards the Mississippi River (**Figure 65**).

» The water elevation in the shallow wells mimics the water elevation in Lake Nokomis. This indicates that Lake Nokomis is connected to and is an expression of the shallow water table, which also supports the historical wetland makeup of the area.

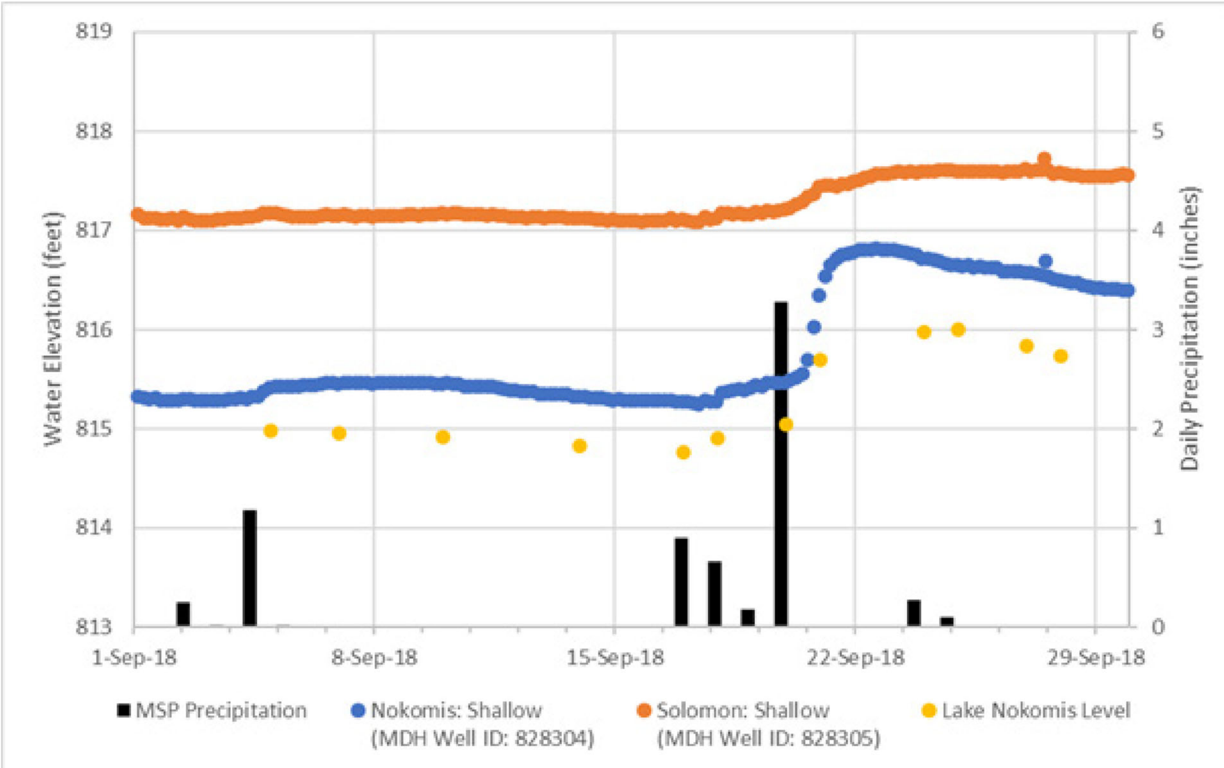


Figure 63: 3.28-inch Rain Event Impacts. *Both the Solomon and Nokomis shallow wells and Lake Nokomis water elevations spiked shortly after a 3.28-inch rain event on September 2, 2018. (Credit: Stantec*

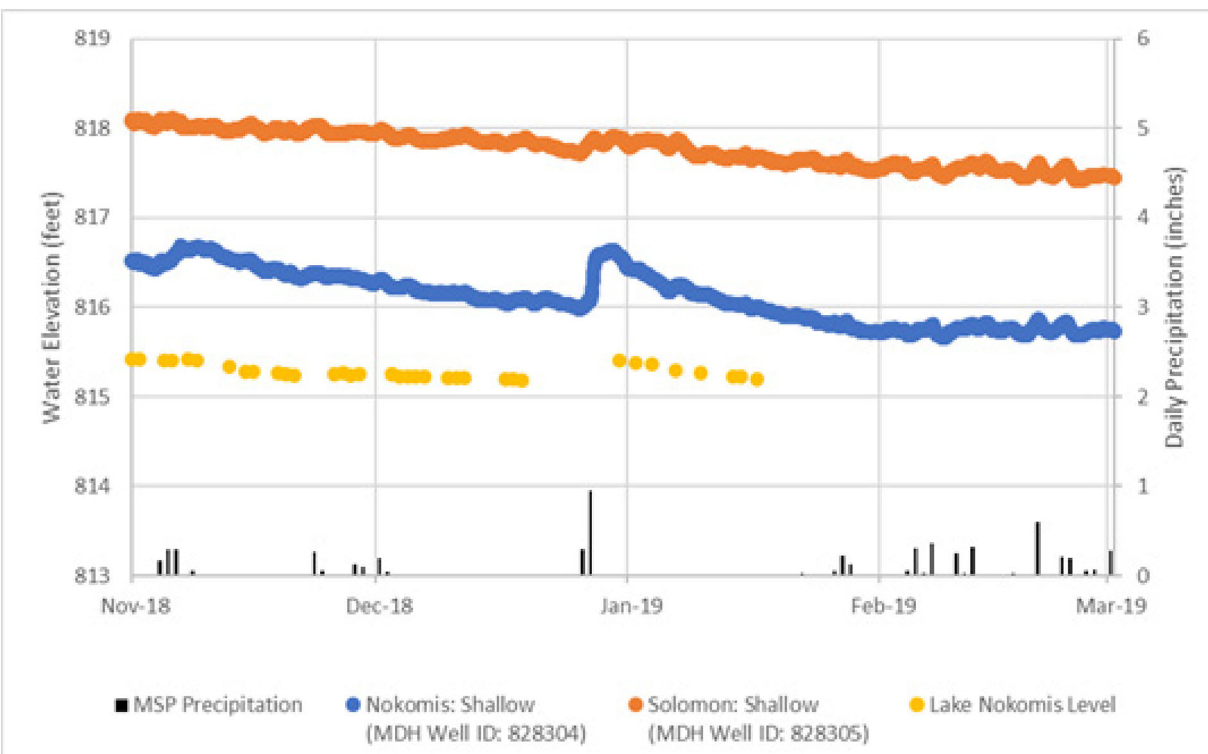


Figure 64. Winter Water Level Decline. *Both the Solomon and Nokomis shallow wells and Lake Nokomis water elevations decline during the 2018-2019 winter. (Credit: Stantec)*

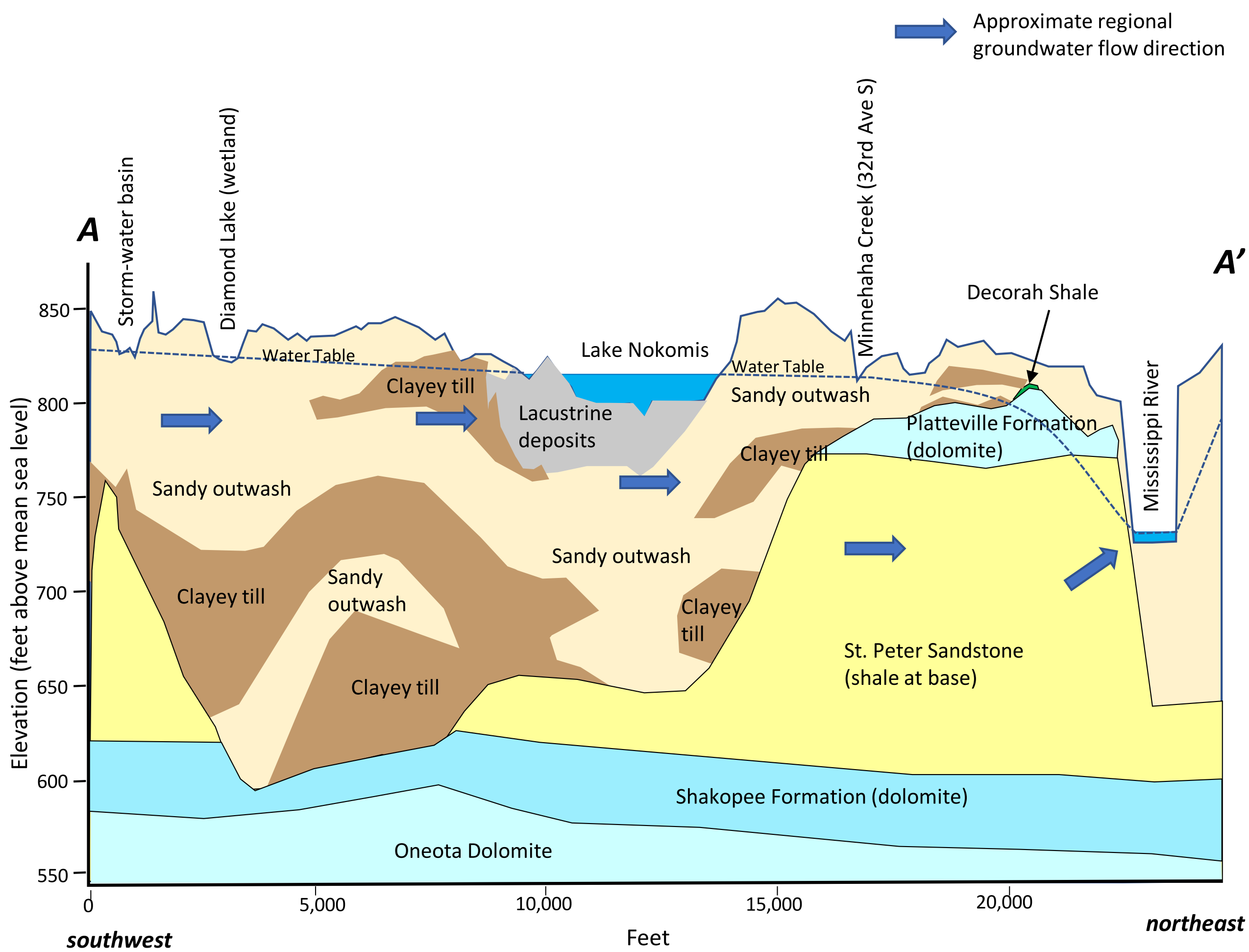


__Figure 65: Groundwater Gradient.__ The regional groundwater flows from west to east, towards the Mississippi River. (Credit: Steenberg, 2018)

5.2.2 Twin Cities Groundwater Elevations

The Team compared the Solomon Park and Nokomis Park shallow well elevations with other shallow wells across the Twin Cities to determine if there were any similarities or irregularities in the observed water table trends. Data from shallow wells across the Twin Cities also showed increasing water table elevations during the record high rainfall during 2013-2019.

The nearest shallow groundwater well, with the longest continuous data set (November 2010 – present), is located approximately 11 miles southwest of Lake Nokomis on the north side of Staring Lake in Eden Prairie and is shown in **Figure 66.**

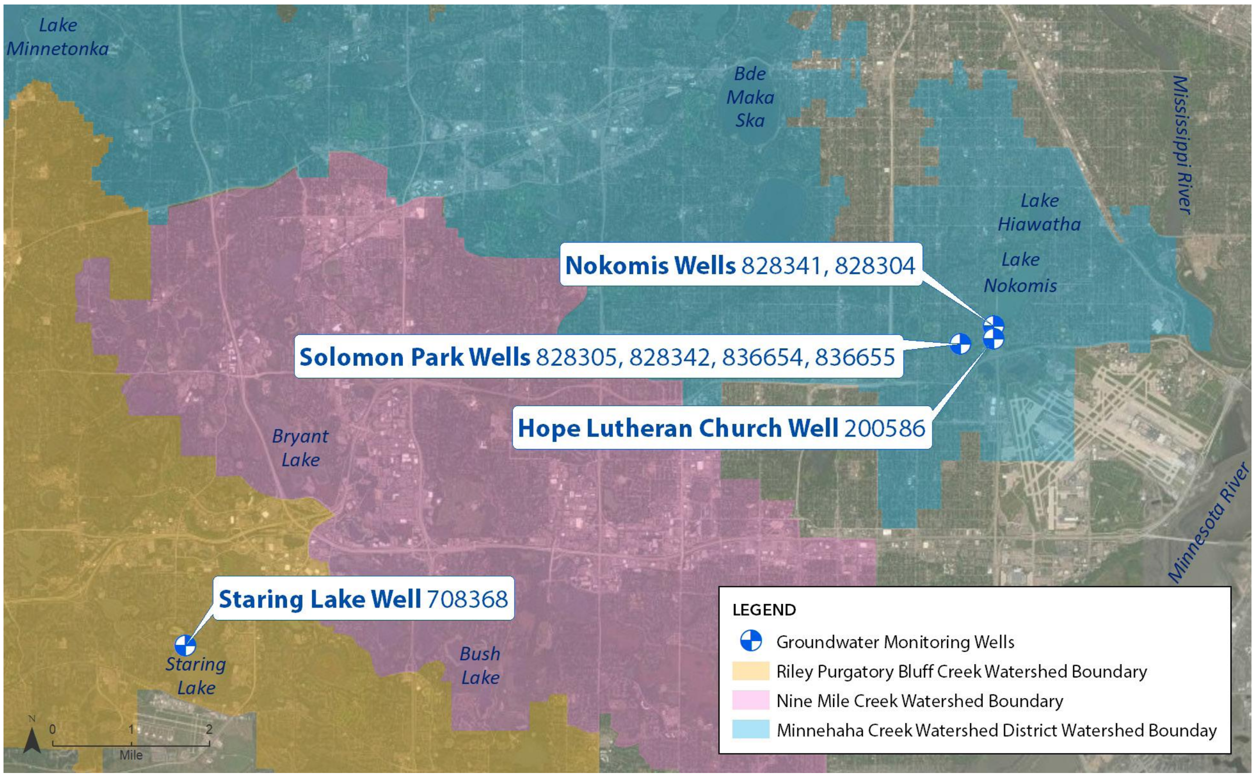


Figure 66. Shallow Groundwater Well Locations. *The wells near Lake Nokomis are in MCWD and the Staring Lake well is in the Riley Purgatory Bluff Creek Watershed. (Credit: MCWD)*

Figure 67 shows the shallow groundwater elevations from the water table wells at Staring Lake. Comparing the groundwater elevation data in these two water table wells reveals:

- The water table levels at the Nokomis and Staring Lake wells are statistically correlated because groundwater recharge is driven by precipitation at a regional scale. Therefore, the water table levels both react relatively quickly from precipitation inputs (recharge) or lack thereof (winter or dry periods) even though they are not in the same watershed.
- Between 2010 and 2019, the Staring Lake well data showed an increasing trend in water elevation of approximately 0.75-feet.
- The 2019-2020 and 2020-2021 (note that the 2021 data ends on August 7, 2021) water years for the Staring Lake well also show a decreasing trend which is a result of 2020 and 2021 having below normal precipitation totals and drought conditions.

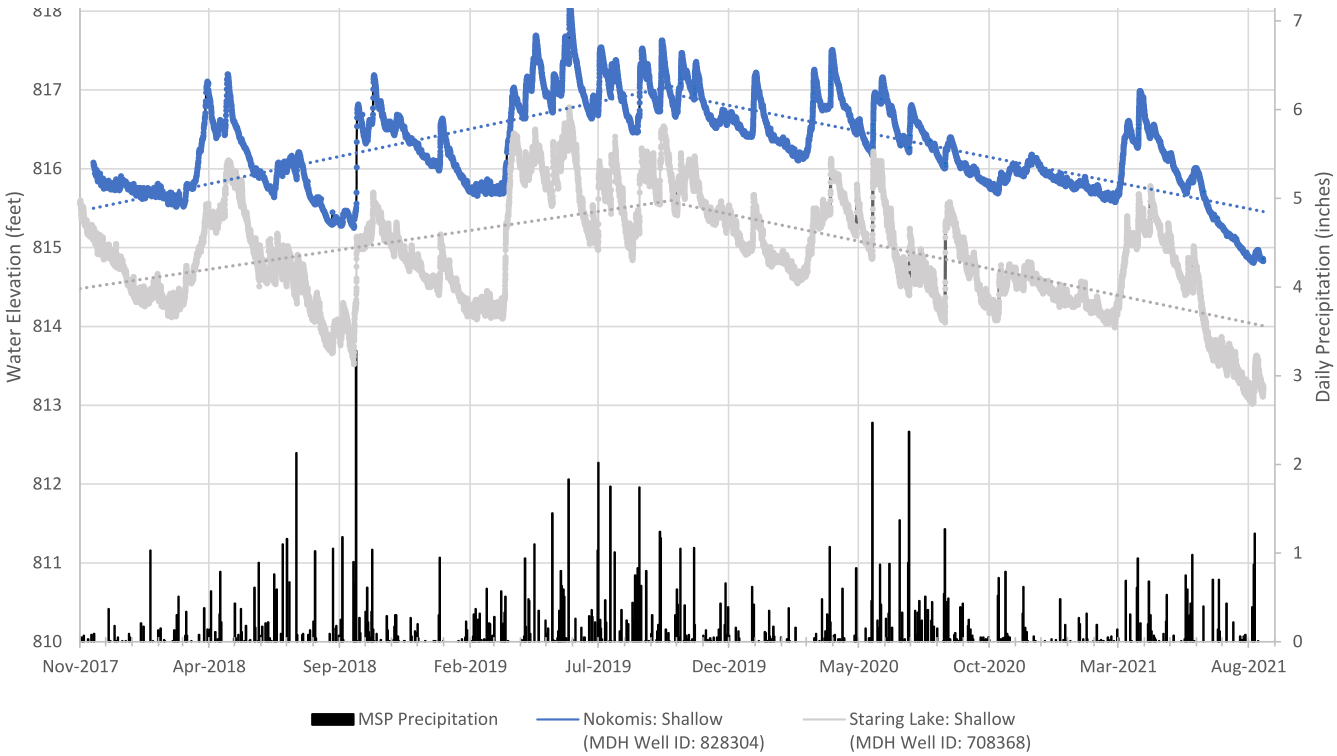


Figure 67: Lake Nokomis and Staring Lake Wells. *Comparison of Solomon and Nokomis shallow well data to a long-term shallow well at Staring Lake in Eden Prairie shows that the Nokomis and Staring wells are statistically correlated because groundwater recharge is driven by precipitation at a regional scale. Dotted lines represent water year trend lines. (Credit: Stantec)*

Groundwater well data demonstrates that groundwater recharge is driven by precipitation. Therefore, precipitation is driving the groundwater levels in the Areas of Concern, not the water levels in Lake Nokomis or Minnehaha Creek.

The Nokomis and Solomon Park water table wells are in the MCWD and the Staring Lake water table well is in the Riley Purgatory Bluff Creek Watershed District (RPBCWD), which are two different hydrologic surface watersheds. Surface water and groundwater in MCWD eventually drain to the Mississippi River and in RPBCWD the Minnesota River. This means the recharge and discharge of water into the Nokomis and Solomon Park water table wells are completely independent from the Staring Lake water table well. However, data from the Nokomis and Staring water table wells show that they are statically correlated because groundwater recharge is being driven by precipitation at a regional scale and therefore groundwater levels respond the same way, despite being in different surface watersheds.

This demonstrates that precipitation and associated groundwater recharge are driving groundwater levels in the Areas of Concern, and they are not driven by local watershed features (e.g., Minnehaha Creek, Lake Nokomis) or management systems (e.g., Lake Nokomis weir).

The data set for the Staring Lake well in **Figure 67** was truncated in November 2017 to match up with the Nokomis data records, which began in November 2017. The continuous data set for the Staring Lake water table well goes back to March 2011 (**Figure 68**) and indicates the full data set for the Staring Lake water table well goes back to November 2010 and indicates the lowest recorded water level was 813.24 feet on October 4, 2012, and the highest recorded water level was 817.98 feet on June 22, 2014. This record high elevation occurred three days after a 4.13-inch rain event on June 19, 2014, which Section 4.1.2 identified as the sixth wettest calendar day on record.

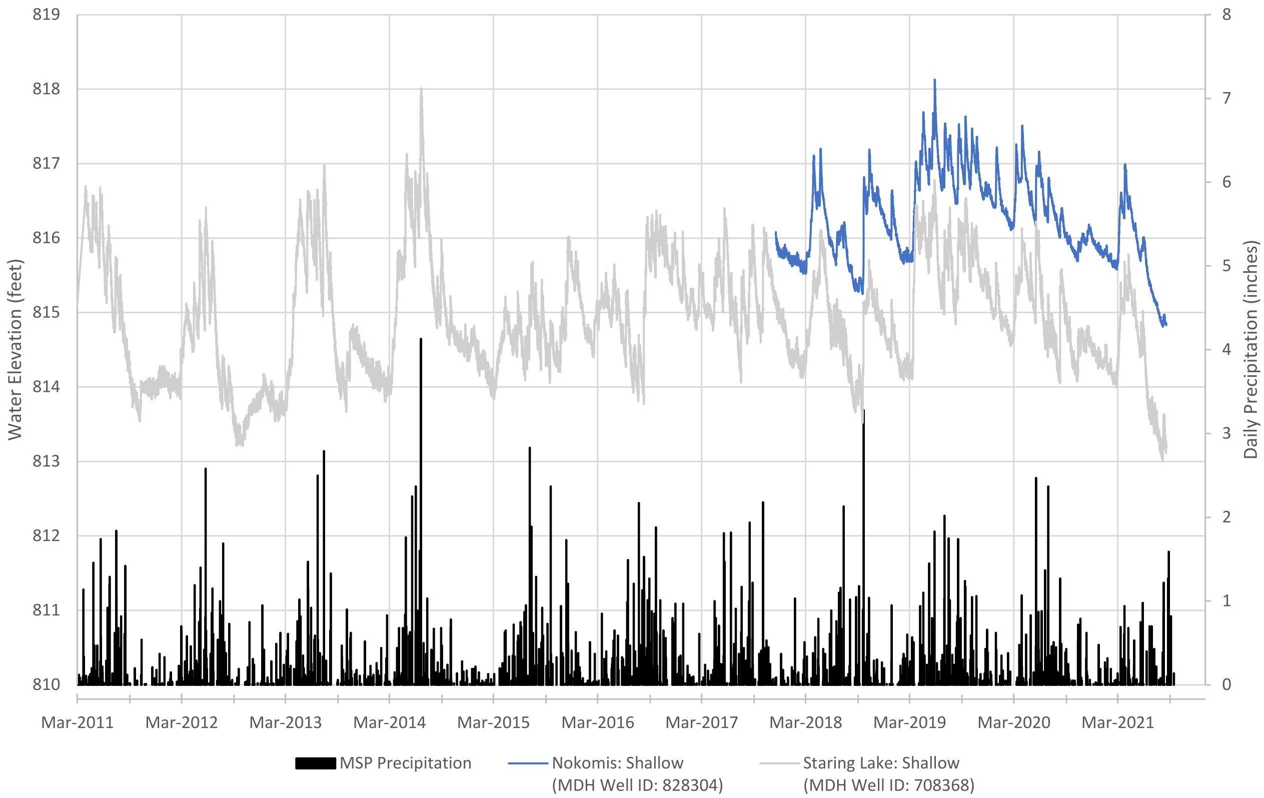


Figure 68: *Shallow Wells data starting at Staring Lake in 2011 and Lake Nokomis in 2017. (Credit: Stantec)*

Due to the water levels in these wells being statistically correlated, the Staring Lake shallow well data can be used to estimate what the Nokomis shallow well level may have been in June 2014 (**Figure 69**), which is when water levels peaked across the Twin Cities and water concerns began in the Areas of Concern. Using the Staring Lake shallow well data, the Nokomis shallow groundwater is estimated to have peaked around 819.30 feet in late June 2014. This is approximately two-feet higher than the highest recorded elevation since the well was installed in November 2017.

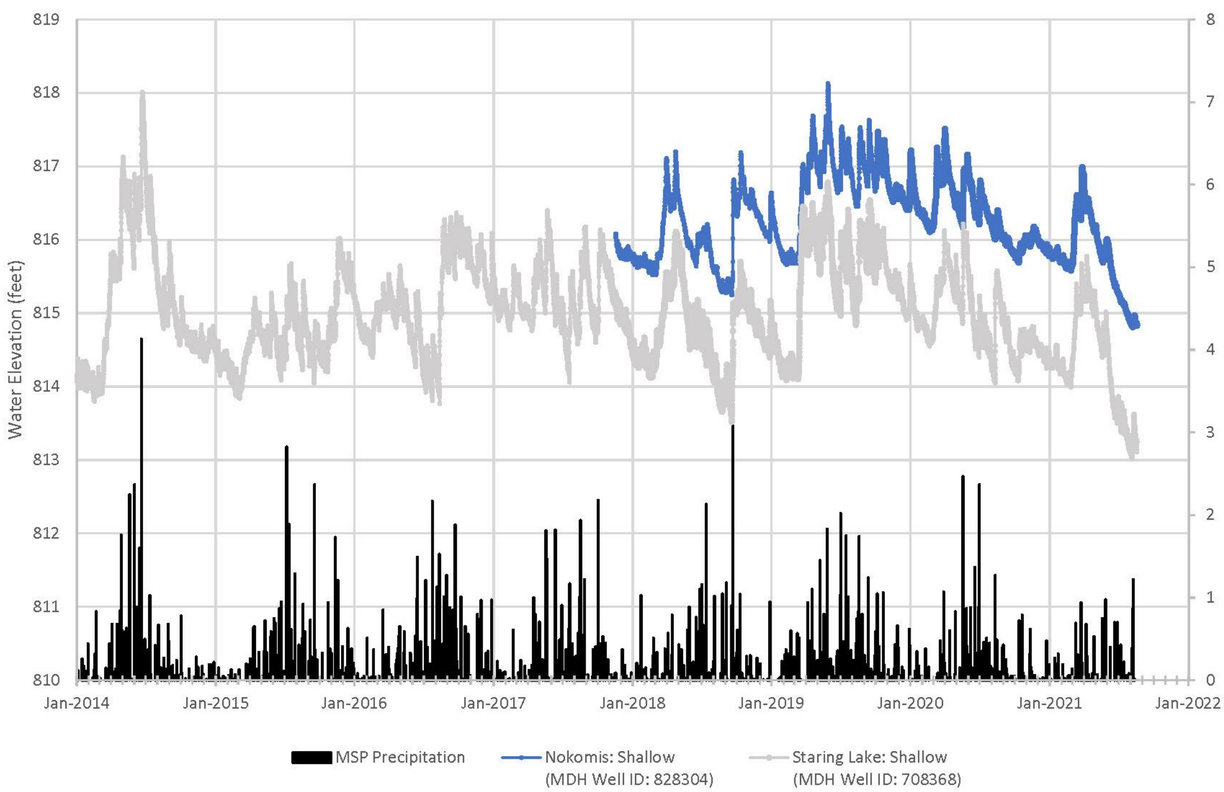


Figure 69. Shallow Wells at Staring Lake and Lake Nokomis. *Water elevations for the shallow wells at Staring Lake from January 2014 to August 2021, and Nokomis from November 2017 to August 2021. (Credit: Stantec)*

5.2.3 Nested Well Data Shows Vertical Groundwater Gradient

In addition to the water table wells, Section 5.2 noted that the Team also installed deeper wells adjacent to the shallow wells at Solomon and Nokomis Parks. Grouping well that are installed to monitor various well depths creates "nested wells" which can determine how groundwater moves vertically:

- If water elevations in the deep wells are lower than those in the shallow wells, then groundwater is moving downward through a confining layer and into a confined aquifer.
- If water elevations in the deep wells are higher than those in the shallow wells, then groundwater is moving upward through a confining layer and out of a confined aquifer.
- If water elevations in the deep wells are the same as the shallow wells, then an unconfined aquifer exists and there is no confining layer and confined aquifer.

Water elevations for the nested wells (shallow aquifer wells and deeper observation wells) at Solomon Park and Nokomis are shown in **Figure 70** and **Figure 71**, respectively.

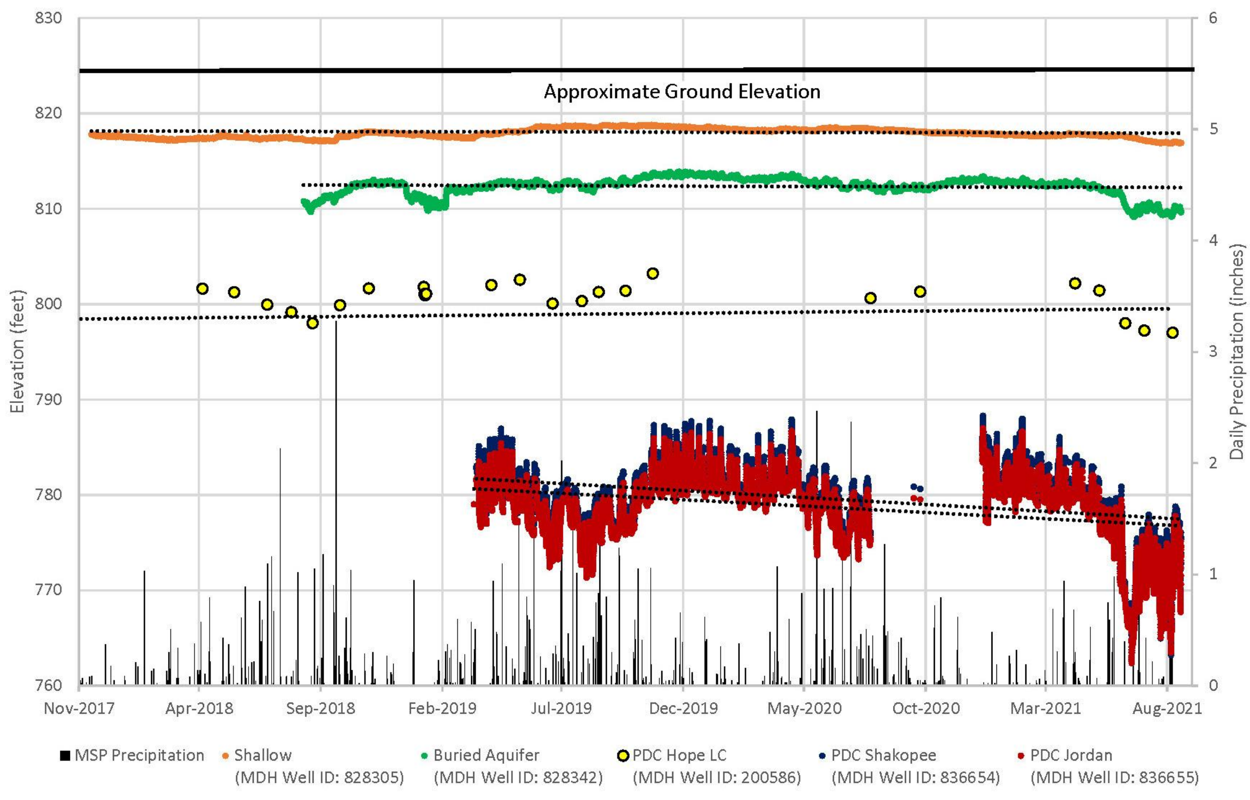


Figure 70. Solomon Park Wells. *Water elevations for the nested wells in Solomon Park. Dotted lines represent water year trend lines. (Credit: Stantec)*

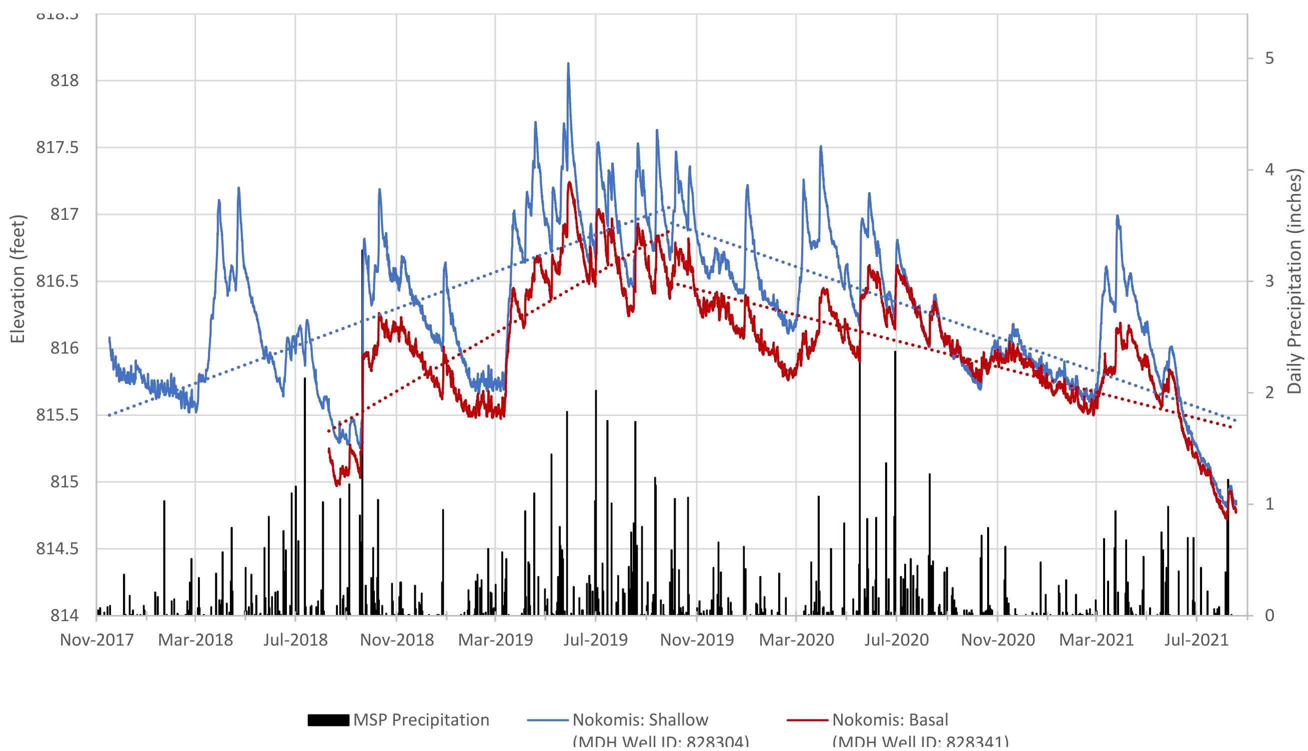


Figure 71. Nokomis Park Wells. *Water elevations for the nested wells in Nokomis Park. Dotted lines represent water year trend lines. (Credit: Stantec)*

Figure 70 and **Figure 71** show that there are distinct differences in the water elevations between the shallow and deep wells. This is especially evident with the Solomon Park well nest, where the five wells (including Hope Lutheran Church) extend into five different geologic units and indicate five different aquifers. The difference in water elevations indicates that the deeper aquifers are separated from the water table and that groundwater has the potential to move vertically downward from the water table aquifer to the deeper aquifers. This supports the Team's understanding that significant separation exists between the shallow water table (unconfined aquifer) and deep bedrock (confined) aquifer systems.

This nested well conclusion is also supported by the 2014, Baseflow Restoration in Minnehaha Creek Watershed with Stormwater Infiltration, study conducted by MCWD and U of M. Figure 7 in that study (inserted here as **Figure 72**) indicates significant separation of the water table and deeper bedrock aquifers over a large area. From roughly Lake Minnetonka in the west ("Jidana Wetland Site") to just west of Minnehaha Falls, the water table and bedrock (piezometric surface) aquifers are separated. The two aquifers converge only in the bluff areas at Minnehaha Falls and then rapidly decline to the Mississippi River.

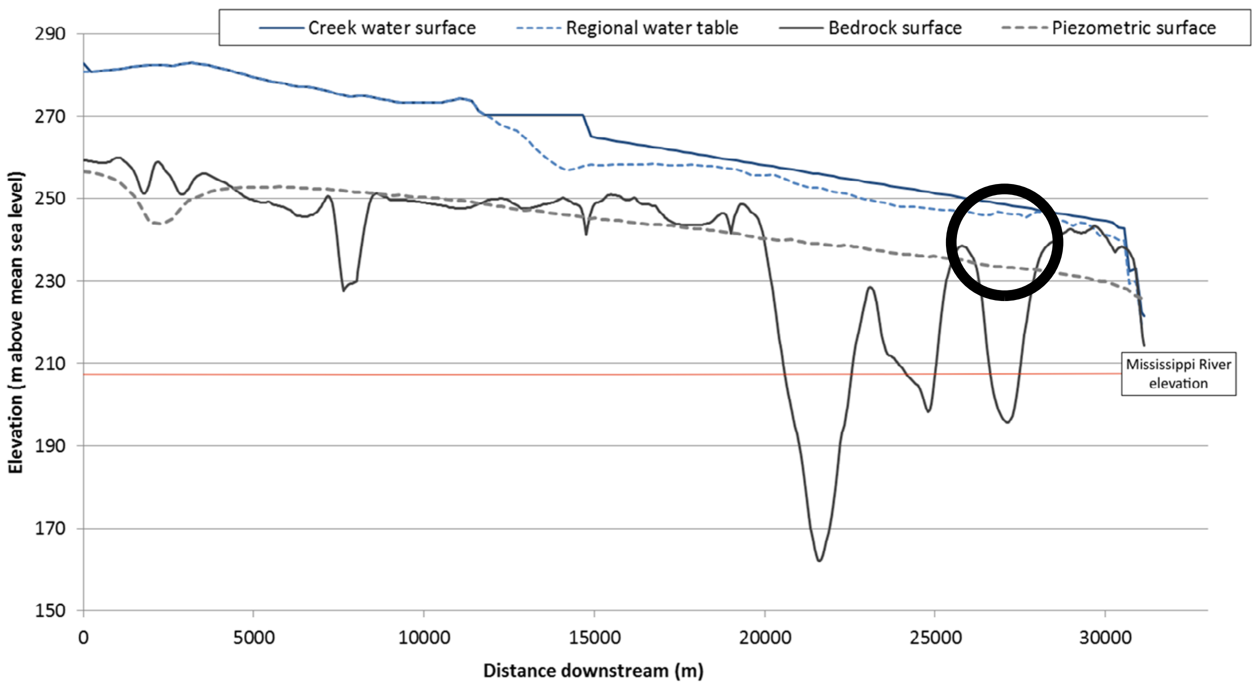


Figure 72. Minnehaha Creek Aquifer Systems. *Long profile depicting surficial and bedrock aquifer systems along the length of Minnehaha Creek. The black circle represents the approximate location of the Lake Nokomis Areas of Concern. (Credit: Moore et al. 2020)*

5.3 GROUNDWATER ELEVATIONS & AREAS OF CONCERN ELEVATIONS

Figure 73 and **Figure 74** were created to show the Areas of Concern spatially and vertically, to better visualize their position and elevation to each other, the water table, Lake Nokomis, and Minnehaha Creek. **Figure 73** includes a transparent, purple ellipse that runs from Minnehaha Creek in the north, to Solomon Park in the south. The area within the ellipse is shown to represent a conceptual slice or cross-section of the Areas of Concern landscape.

The middle and left sections of **Figure 74** show the approximate locations and elevations of the Areas of Concern. The road elevations near the Nokomis Parkway and West Nokomis Areas of Concern were surveyed during the fall of 2019. The Solomon Park Area of Concern elevations were estimated based on light detection and ranging elevation data (LiDAR) and City of Minneapolis sanitary pipe invert elevations. Basement elevations were estimated by subtracting eight feet from LiDAR surface elevations. See Appendix C for a larger image of **Figure 74**.

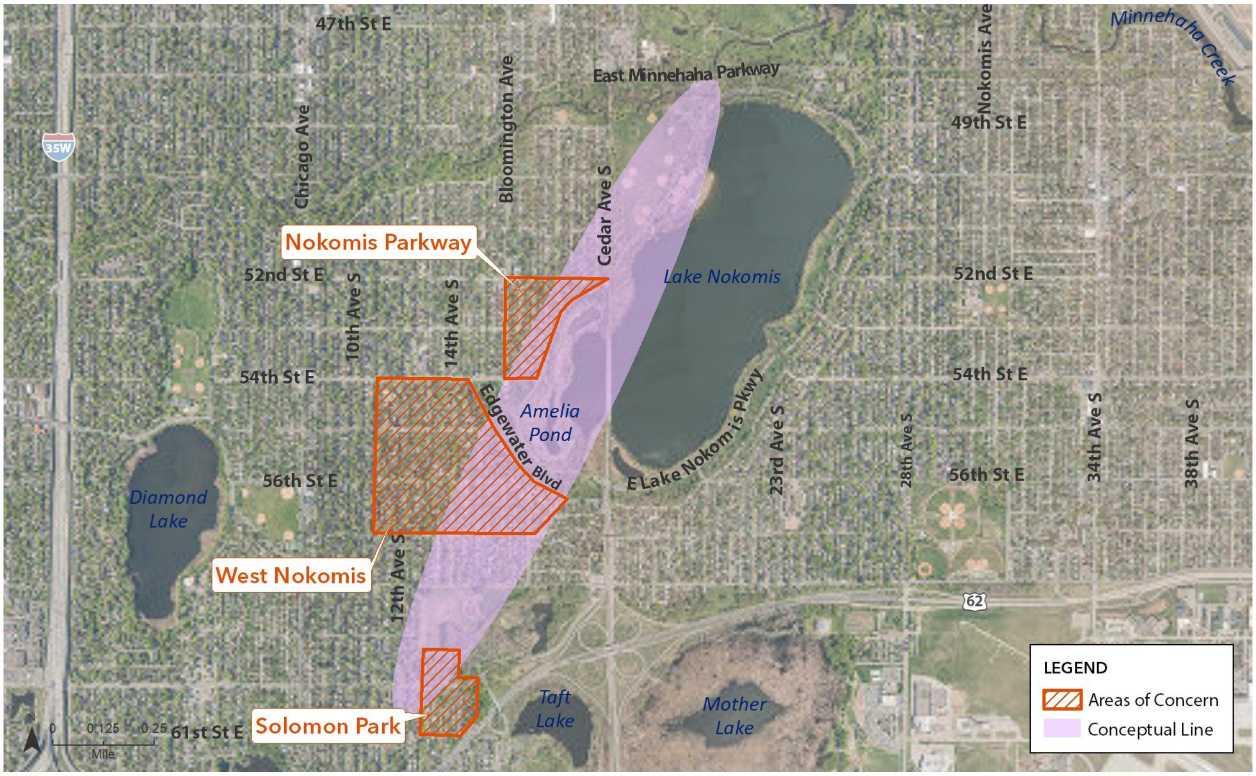


Figure 73: Areas of Concern Cross Section Area. *The area within the purple ellipse is shown as a conceptual slice in Figure 74. (Credit: MCWD)*

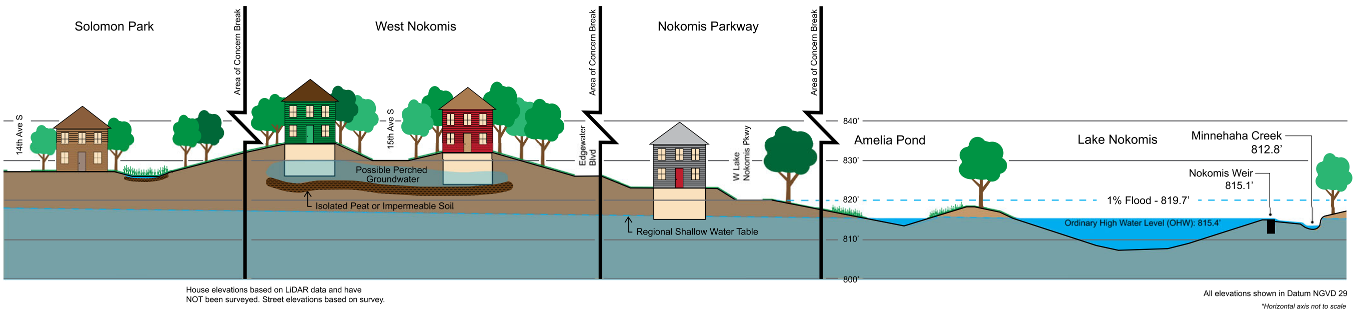


Figure 74 Conceptual Cross Section. *Cross section showing the elevation of water features and the Areas of Concern. From left to right: the shallow water table is shown with a gradient from Solomon Park towards Lake Nokomis based on groundwater well data; the Solomon Park Area of Concern properties, with reported backyard water concerns, vary in elevation between 823 to 830-feet; the West Nokomis Area of Concern homes with reported basement water concerns are estimated to have basement elevations between 823 to 832-feet; the Nokomis Parkway Area of Concern homes with reported basement water concerns are estimated to have basement elevations below the OHW (815.4-feet) of Lake Nokomis; the 1% FEMA flood elevation at 819.7-feet; Lake Nokomis at its ordinary high water level (OHW) at 815.4 feet per the DNR designation; Nokomis weir at 815.1-feet, which has been the runout elevation since 1931; Minnehaha Creek water level at 812.8-feet, which is the average elevation of the creek based on modeling. (Credit: Stantec)*
See ***Appendix C*** *for larger image of Figure 74.*

5.4 AREAS OF CONCERN GROUNDWATER FINDINGS

Groundwater recharge data and groundwater level data indicates that:

- Modeled groundwater recharge rates suggested an increase of 2-6 inches a year between 2012-2019, this was estimated to increase the water table nearly 2-feet.
- There is a direct correlation between precipitation and water level responses in the shallow water table wells and Lake Nokomis. This immediate response to precipitation demonstrates the magnitude of groundwater recharge on the shallow wells.
- Shallow groundwater elevations trended up during the wet periods of 2017-2019 and trended down during the dry periods of 2020-2021.
- A horizontal gradient exists in the water table from Solomon Park to Lake Nokomis.
- Lake Nokomis is connected to and an expression of the shallow water table.
- Other shallow groundwater wells across the Twin Cities trended upward between 2013-2019.
- The Staring Lake shallow groundwater well is statistically similar to the Nokomis shallow water table well. This demonstrates that precipitation and associated groundwater recharge are driving groundwater levels across the Twin Cities, including in the Areas of Concern, and that groundwater levels are not driven by Lake Nokomis or Minnehaha Creek.
- The shallow water table aquifer discharges to deep bedrock aquifers, and bedrock aquifers therefore do not influence the shallow water table aquifer.

5.4.1 Nokomis Parkway

As shown in **Figure 74**, the Team estimates that the three reported homes identified in Section 1.3 appear to have basements that were built below the OHW level of Lake Nokomis (815.4-feet) and the runout elevation (815.1-feet) of the Lake Nokomis weir which was constructed in 1931. Section 3.2 also notes that some of these homes were constructed within the former Lake Nokomis basin. This means that these homes are likely impacted by normal water levels in Lake Nokomis and that record precipitation and record groundwater recharge could exacerbate high water conditions for this Area of Concern.

5.4.2 West Nokomis

The Team estimates that the 13 reported homes identified in Section 1.3 appear to have basement elevations that vary from 823 to 832 feet (**Figure 74**). Since the water table elevations at the Nokomis well have ranged from 815 to 818 feet, which are 5-14 feet lower than the basement elevations, the local surficial groundwater is not driving the basement water concerns for this Area of Concern.

Even though these homes are not impacted by the shallow water table aquifer, the likely presence of peat soil means they may be impacted by one or more perched groundwater systems as discussed in Section 2.2.2. Therefore, the water issues in this Area of Concern are likely due to localized issues that are a result of the record precipitation infiltrating into the ground between 2013-2019.

Perched water tables are common throughout the Twin Cities, and they form when infiltrating precipitation becomes trapped above low permeability layers, such as peat, preventing water from infiltrating deeper to the regional water table. Perched water tables may be present either seasonally or throughout the year, depending on the permeability and lateral extent of the layers.

The reported water concerns in the West Nokomis and Solomon Park Areas of Concern are driven by neighborhood geology conditions and not regional groundwater.

5.4.3 Solomon Park

The Team estimates that the five reported wet backyards identified in Section 1.3 vary in elevation from 826 to 828 feet (**Figure 74**). Since the water table elevations at the Solomon Park well have ranged from 817 to almost 819 feet, which are 7-11 feet lower than the basement elevations, the local surficial groundwater is not driving the water concerns for the backyards in this Area of Concern. Rather, these backyard water concerns are due to localized peat soils that have absorbed record precipitation between 2013-2019.

6.0 LAKE NOKOMIS WATER LEVELS

Chapters 4 and 5 documented how record precipitation during 2013-2019 led to increases in groundwater recharge rates and groundwater levels during that time. Additionally, Chapter 5 concluded that Lake Nokomis is connected to and an expression of the shallow water table.

Since 2014, it has been suggested that the operation of the current stop-log outlet (also referred to as a weir) from Lake Nokomis to Minnehaha Creek, has increased lake levels which are then believed to have impacted the Areas of Concern. This chapter will examine the lake level history of Lake Nokomis and nearby lakes, the history of the Lake Nokomis outlet, and the operation of the current stop-log outlet structure to determine if it has had any effect on the Areas of Concern.

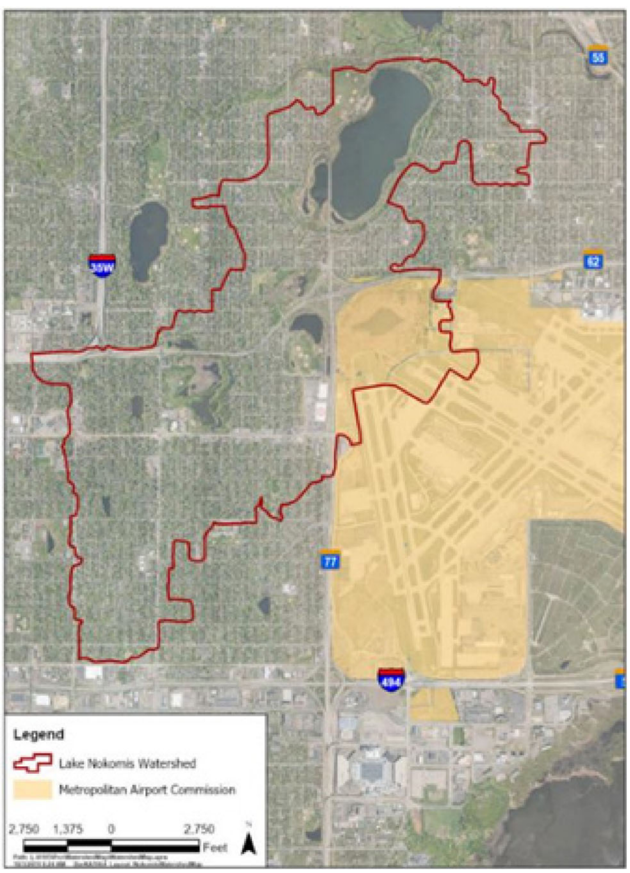


Figure 75: Lake Nokomis Watershed. *The watershed boundary for Lake Nokomis is outlined in red. (Credit: Stantec)*

6.1 LAKE NOKOMIS WATERSHED

The Lake Nokomis watershed is a fully developed urban watershed. The Lake Nokomis watershed drainage boundary, shown in **Figure 75**, is approximately 2,903 acres (4.5 square miles) and is encompassed by the:

- » City of Minneapolis (47%, 1,367 acres)
- » City of Richfield (46.5%, 1,352 acres)
- » Minneapolis-St. Paul (MSP) Metropolitan International Airport (9.5%, ~300 acres)

The portion of the MSP Airport land draining to Lake Nokomis has been questioned in recent years. The ~300 acres of the MSP Airport that drain to Lake Nokomis is approximately 8% of the entire MSP Airport. The remaining 92% (3,100 acres) of the MSP Airport drains southeast to the Minnesota River and is part of the Lower Minnesota River Watershed District. There have been no major recent changes to the MSP Airport drainage, and there are currently no published plans for the airport to change drainage routes in the future.

6.2 LAKE NOKOMIS WATER LEVEL RECORD

Figure 76 shows the recorded Lake Nokomis water levels starting in 1906 shown with the OHW (815.4-feet), weir outlet (runout) elevation (815.1-feet), and top of weir structure elevation (818.0-feet). Due to incomplete records, the Lake Nokomis water levels are not reported between approximately 1985 and 1997. Over the past 70 years (from 1950 to 2020), Lake Nokomis water levels consistently exceeded the OHW elevation except between 2004 and 2010. This is likely because annual precipitation was below average between 2003 and 2010, resulting in a nearly 20-inch precipitation deficit during those eight years. As Section 4.1.2 noted, above normal precipitation in the 2010s resulted in increasing water levels in Lake Nokomis due to a surplus of precipitation.

The Dust Bowl drought, noted in Section 4.1.1, caused Lake Nokomis to fall to its lowest recorded level of 809.67-feet on November 1, 1932, which is over 5.7 feet below the OHW of 815.4 feet. In contrast, the June 2014 record high precipitation and resulting flooding, caused Lake Nokomis to rise to its highest recorded level of 818.03-feet on June 23, 2014, which is over 2.6 feet above the OHW of 815.4 feet. This record high elevation occurred four days after a 4.13-inch rain event.

During the Dust Bowl drought, Lake Nokomis fell to its lowest recorded level, 809.67-feet, on November 1, 1932, which is 5.7-feet below the current OHW of 815.4-feet.

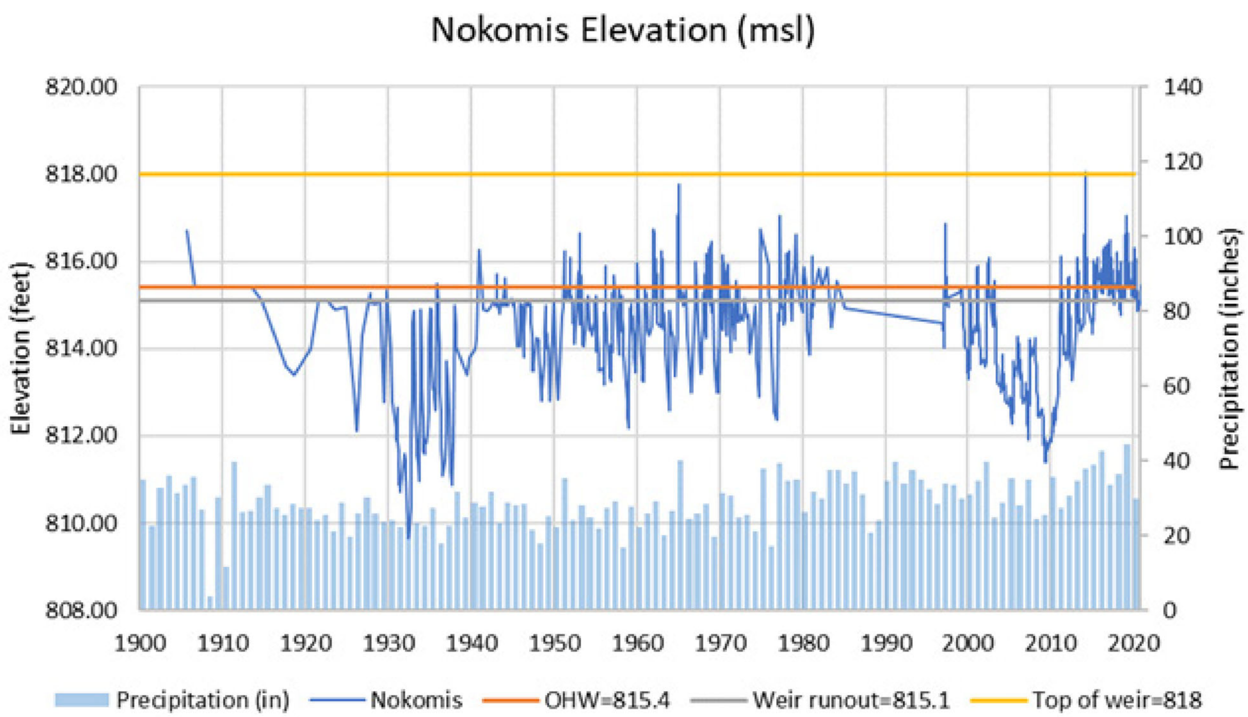


Figure 76: Lake Nokomis Water Levels. *Recorded water levels for Lake Nokomis shown in mean sea level (msl), and annual precipitation totals shown in inches per year. No lake level data is on record from 1985-1997. (Credit: Stantec; Data Source: MPRB)*

6.3 LAKE NOKOMIS OUTLET

In 1931, the MPRB constructed an outlet structure or dam at the Lake Nokomis outlet where the lake and Minnehaha Creek intersect. The elevation of the 1931 outlet structure was set at 815.10 feet, which is also known as the Lake Nokomis runout elevation. The picture in **Figure 77** shows the Lake Nokomis outlet in 1939 with Minnehaha Creek flowing into Lake Nokomis. Downstream of this Lake Nokomis outlet the MPRB installed another dam within Minnehaha Creek in 1937. **Figure 78** shows a picture of this dam being constructed and notes that boards may be installed in this dam to backup water into Lake Nokomis.

Figure 77: Lake Nokomis Outlet. *Photo Caption: The outlet dam at the north side of Lake Nokomis showing wing walls newly faced with limestone by W.P.A. crews. (Credit: Minneapolis Board of Park Commissioners, 1939)*

The original Lake Nokomis outlet structure remained in place for 70 years and was retrofitted in 2001 after a citizen committee, known as the Blue Water Commission (BWC), voiced water quality concerns for Lake Nokomis. A diagnostic study conducted by MCWD during 1997-98 found that the water quality from storm sewers discharging to Minnehaha Creek was more polluted than water in Lake Nokomis and an order of magnitude more polluted than water discharged to Minnehaha Creek from Lake Nokomis. When flashy peak flows from Minnehaha Creek flowed into Lake Nokomis, it was discharging phosphorus into the lake. A picture of such an event is shown in **Figure 78** and was taken on August 19, 1997, during a rain event which caused Minnehaha Creek to flow into Lake Nokomis.

Figure 78: ***Minnehaha Creek Flows into Lake Nokomis.*** *Picture showing Minnehaha Creek flowing over the Lake Nokomis outlet and into Lake Nokomis on August 19, 1997 (Credit: MCWD)*

With this information the BWC (1988) recommended modifying the Lake Nokomis outlet structure to divert or reduce the inflows from Minnehaha Creek that occur during high flow periods to block phosphorus from entering the lake. Retrofitting the Lake Nokomis outlet was anticipated to reduce 172 pounds of phosphorus per year and provide some control of rough fish migration into the lake.

In 2001, the City of Minneapolis, MPRB, and MCWD partnered on a series of projects focused on improving the water quality of Lake Nokomis. One of those projects was to retrofit the original 1931 Lake Nokomis outlet structure with an inflatable weir. The inflatable weir was intended to inflate automatically and prevent creek flow from entering the lake if an abrupt rise in the creek level was detected by sensors on both the lake side and the creek side of the weir. The inflated weir was also supposed to deflate after the abrupt rise in the creek level dissipated. The inflatable weir was found to not operate consistently, and therefore, the MCWD and MPRB decided to replace the inflatable portion with a removable stop-log outlet structure.

The inflatable weir remained until 2012 when the inflatable portion of the weir was replaced with a new structure which contained removable stoplogs. This present day stop-log outlet was built on top of the original 1931 outlet structure, thereby maintaining the runout elevation of 815.10 feet. The MPRB has operated the stop-log weir structure since its construction in 2012.

In recent years, concerns have been raised that the operation of the current stop-log outlet structure has caused an increase in Lake Nokomis water levels. Lake Nokomis water level data and Lake Nokomis stop-log outlet operation data do not show a clear relationship between the number of days the stop-log weir is open and the number of days with Lake Nokomis water levels below the OHW or runout elevations. **Figure 79** shows a steady increase in the number of days each year that the weir has been open due to the record precipitation.

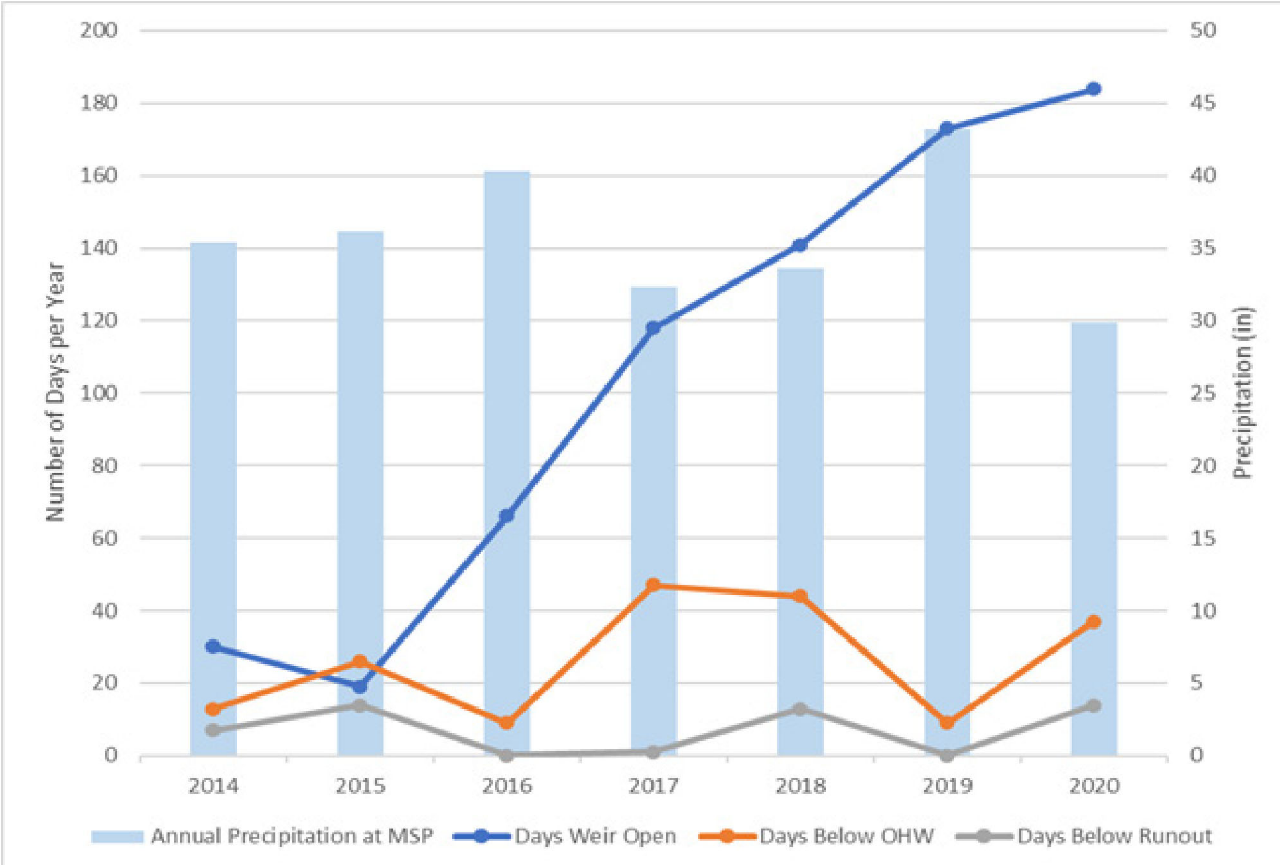


Figure 79: Nokomis Weir Operations. *Chart comparing the annual number of days the weir was open, days Lake Nokomis was below its OHW, days Lake Nokomis was below the runout elevation, and the total annual precipitation. (Credit: Stantec; Data Source: MPRB)*

In 2014 Minnehaha Creek levels remained high due to record spring flooding and the weir was only open for 30 days. However, during those 30 days the Lake Nokomis level dropped by nearly four feet and the lake ended 2014 below the runout elevation (815.10-feet). For comparison, in 2016 the stop-log weir was open 66 days (twice as much as in 2014), but the lake did not fall below the runout elevation. Again, in 2019 the stop-log weir was open 173 days (nearly six times as much as 2014), but the lake never fell below the runout elevation. There does not appear to be a correlation between the number of days the weir is open and how fast the water level in Lake Nokomis falls.

6.3.1 Powderhorn Lake Comparison

The Team compared Lake Nokomis water level fluctuations to a nearby lake to better understand the impact of the weir operation. Powderhorn Lake is about 1.7 miles away from Lake Nokomis and is a landlocked lake, which means it is not connected to Minnehaha Creek in any way via surface water. **Figure 80** shows that over the past decade water level fluctuation in Powderhorn Lake has been very similar to that in Lake Nokomis, including sustained high-water levels since 2015.

It is likely that the water level fluctuation is similar in both lakes because of similar precipitation and runoff. Further, water level fluctuations are similar in Nokomis and Powderhorn before and after the 2012 Lake Nokomis outlet modification indicating replacement of the inflatable weir did not materially change the lake outlet function and capacity.

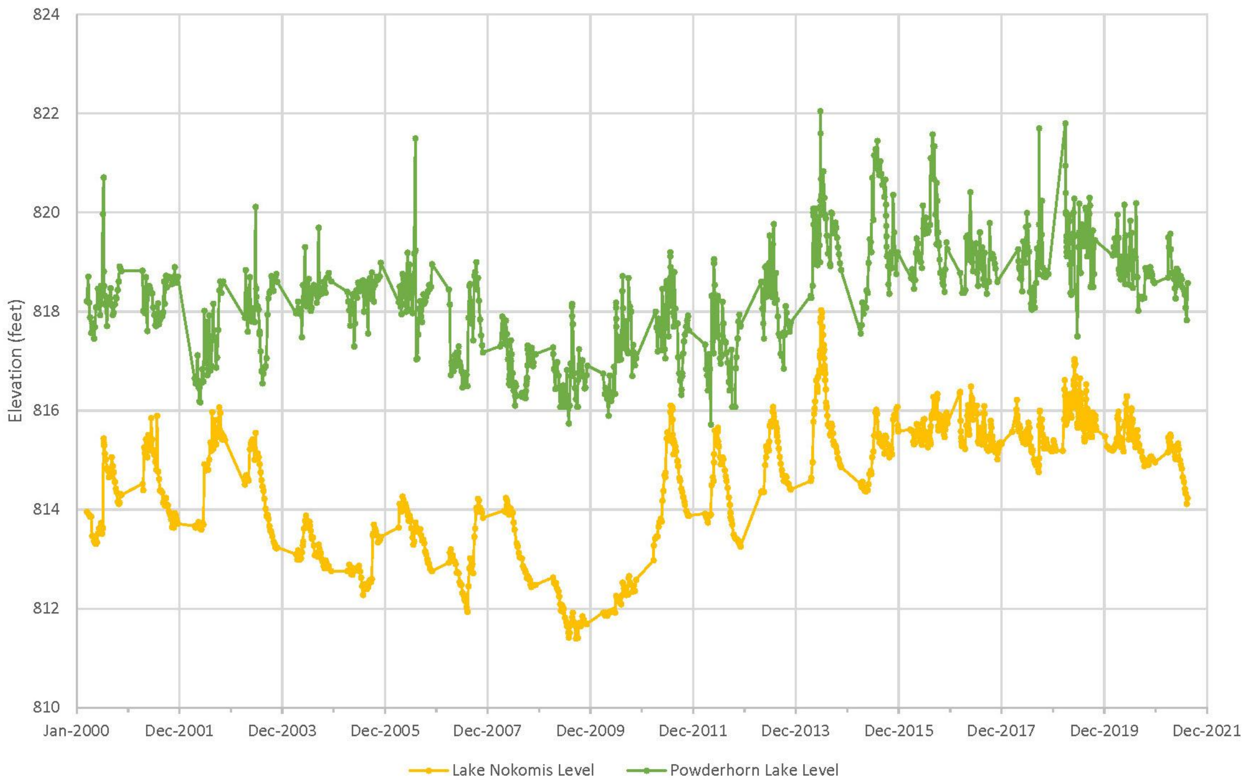


Figure 80. Lake Nokomis and Powderhorn Lake Levels. *Comparison of Lake Nokomis and Powderhorn Lake levels shows similar water level fluctuation. (Credit: Stantec; Data Source: MPRB)*

6.4 AREAS OF CONCERN LAKE NOKOMIS FINDINGS

Lake Nokomis' recorded water levels reflect recorded precipitation patterns. During the Dust Bowl drought in 1932, Lake Nokomis fell to its lowest recorded elevation of 809.67-feet. Conversely, 2014 was extremely wet during the first half of the year and resulted in Lake Nokomis rising to its highest recorded elevation of 818.03-feet. This recorded range of water levels shows that Lake Nokomis was 8.36-feet (~100-inches) higher in 2014 than it was in 1932. This 100-inch difference in water levels coincides with precipitation data in Section 4.1.2, which identified that the Areas of Concern received nearly 100 inches more precipitation in the 2010s than they did during the 1930s, when some of the Areas of Concern homes were built.

Lake Nokomis' runout elevation of 815.1-feet was established 90-years ago in 1931 with the construction of an outlet where Lake Nokomis intersects with Minnehaha Creek. This outlet was constructed when homes were being built in the Nokomis Parkway and West Nokomis Areas of Concern. Recent alterations to the outlet structure have maintained the 815.1-feet runout elevation. Data on lake levels and operation of the current stop-log outlet structure do not show a relationship between the number of days the stop-log outlet is open and lake level.

Section 5.2.1 notes that the elevation of Lake Nokomis is an expression of the shallow water table which explains its response to historical precipitation patterns, the lack of correlation between the number of days the current stop-log weir is open, and how fast the water level can fall.

The similarity in water level fluctuations between Powderhorn Lake and Lake Nokomis supports the finding that precipitation, associated groundwater recharge, and water table elevations are driving water levels in Lake Nokomis and not the operation of the current stop-log outlet structure.

6.4.1 Nokomis Parkway

The Nokomis Parkway conclusion for the Lake Nokomis water level factor is the same as the groundwater conclusion in Section 5.3.1, which is restated below:

> As shown in **Figure 74**, the Team estimates that the three reported homes identified in Section 1.3 appear to have basements that were built below the OHW level of Lake Nokomis (815.4-feet) and the runout elevation (815.1-feet) of the Lake Nokomis weir which was constructed in 1931. Section 3.2 also notes that some of these homes were constructed within the former Lake Nokomis basin. This means that these homes are likely impacted by normal water levels in Lake Nokomis and that record precipitation and record groundwater recharge could exacerbate high water conditions for this Area of Concern.

6.4.2 West Nokomis

Section 5.2.1 showed that Lake Nokomis is an expression of the shallow water table and that the shallow water table does not intersect the assumed basement elevations within the West Nokomis Area of Concern. This conclusion is reinforced by reviewing the Lake Nokomis water elevation data which shows that Lake Nokomis' elevations are not driving the water issues in the West Nokomis Area of Concern as these basements are estimated to have bottom elevations between 823-832-feet (**Figure 74**) which are 7.6-16.6 feet higher than the OHW of Lake Nokomis and 8-17 feet higher than the outlet of Lake Nokomis. This data demonstrates that Lake Nokomis, and its associated management through the operation of the stop-log outlet, cannot physically cause the water issues for this Area of Concern as surface water cannot flow uphill.

Lake Nokomis water levels cannot physically cause water issues for the West Nokomis and Solomon Park Areas of Concern because surface water cannot flow uphill.

6.4.3 Solomon Park

The elevations of the yards within this Area of Concern generally range from 826-828-feet (**Figure 74**). Lake Nokomis' elevations are not driving the yard water issues in the Solomon Park Area of Concern as these yards are 10.6-12.6 feet higher than the OHW of Lake Nokomis and 11-13 feet higher than the outlet of Lake Nokomis. This data demonstrates that Lake Nokomis and its associated management through the operation of the Lake Nokomis weir cannot physically cause the water issues for this Area of Concern as surface water cannot flow uphill.

7.0 MINNEHAHA CREEK WATER LEVELS

Record precipitation during 2013-2019, contributed to record water levels and flows in Minnehaha Creek during that time. Since Lake Nokomis discharges to Minnehaha Creek, some have hypothesized that high and sustained flows in Minnehaha Creek during 2013-2019, may have contributed to the reported water impacts within the Areas of Concern. This chapter reviews the 2014 Minnehaha Creek Baseflow study, the USGS hydrograph data for Minnehaha Creek, and elevation data for Minnehaha Creek, to determine if Minnehaha Creek is contributing to the reported water issues in the Areas of Concern.

7.1 MINNEHAHA CREEK CONNECTIVITY TO THE WATER TABLE

The Baseflow Restoration in Minnehaha Creek Watershed with Stormwater Infiltration study conducted by MCWD and U of M (Moore et al., 2020) investigated the connectivity of Minnehaha Creek to the water table between 2012-2013 (2012 was a below normal precipitation year). Moore et al. (2020) reported Minnehaha Creek in 2012 to be a "gaining" stream upstream of Browndale Dam in Edina and a "losing" reach downstream of the Browndale Dam. A losing reach indicates that the water table is at a lower elevation than water in the creek and that water in the creek may then infiltrate or discharge to the water table. Conversely, a gaining reach is when the water table exceeds the creek water elevation and discharges to the creek. **Figure 81** illustrates a gaining and losing stream reach.

Figure 82 (previously shown in Section 5.2.3) highlights the approximate location of the Areas of Concern in the black circle and the elevations of the water table and Minnehaha Creek. The elevation of the water table is noticeably lower than the elevation of Minnehaha Creek adjacent to the Areas of Concern (black circle). This graphic supports the notion that Minnehaha Creek is a losing reach throughout this stretch.

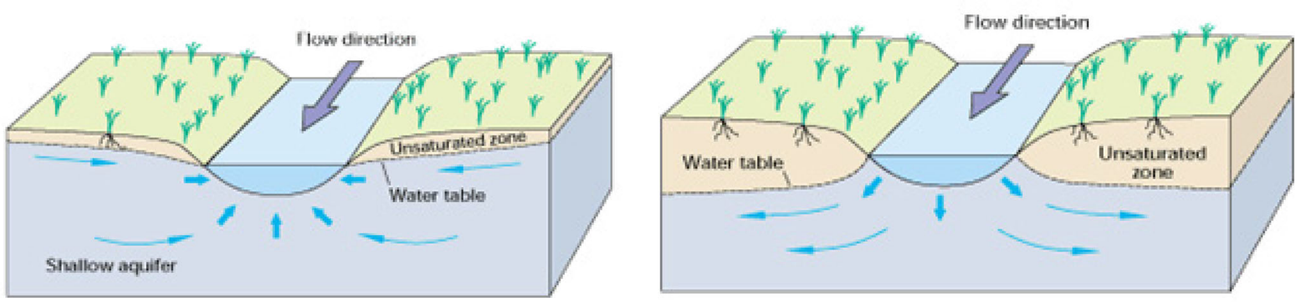


Figure 81: Gaining and Losing Streams. *Left: Water table level exceeds the creek level and discharges to the creek resulting in a gaining stream reach. Right: Water table level is lower than the creek which causes the creek to discharge to the water table, resulting in a losing stream reach. (Credit: USGS, 2021)*

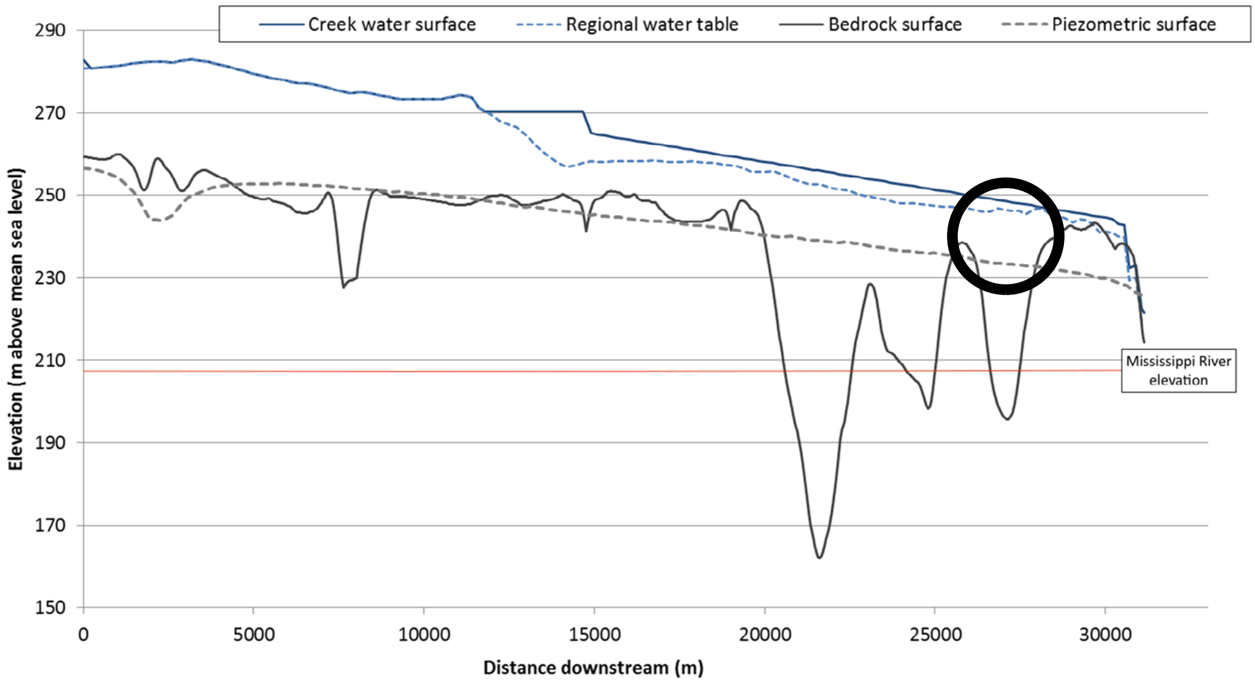


Figure 82. Minnehaha Creek Aquifer Systems. *Long profile depicting surficial and bedrock aquifer systems along the length of Minnehaha Creek. The black circle represents the approximate location of the Lake Nokomis Areas of Concern. (Credit: Moore et al., 2020)*

Moore et al. (2020) also noted that within 30 to 250-feet of Minnehaha Creek, shallow groundwater flow is diverted toward Minnehaha Creek. The Areas of Concern are located approximately 2,000 to 7,000 feet south of Minnehaha Creek, well outside the 30 to 250-foot-wide localized water table gradient. This means the localized influence of Minnehaha Creek is not contributing to the reported water issues in the Areas of Concern.

The localized influence of Minnehaha Creek on the water table is not contributing to the reported water concerns in the Areas of Concern.

7.2 MINNEHAHA CREEK HYDROGRAPH

In the 1960 USGS publication A Primer on Water, Leopold and Langbein (1960) note:

> Streamflow is what is left over after precipitation has supplied the demands of vegetation and the process of evaporation. Leftovers or differences tend to vary greatly with time. For example, suppose the rainfall in one year is 40 inches, evaporation and plant transpiration 20 inches. This leaves 20 inches to be carried off by the streams. Suppose in the next year rainfall is 30 inches, 25 percent less than in the year before. If evaporation and transpiration were the same, which is quite possible, streamflow would be only 10 inches, 50 percent less than in the year before. Thus a 25 percent change in

rainfall becomes a 50 percent change in runoff. This means that the flow of streams is highly variable and sensitive to changes in rainfall. (p. 35)

Section 4.1.2 noted that in 2016 and 2019, the Twin Cities annual precipitation totals increased more than 10-inches above normal from approximately 30-inches to over 40-inches per year. Applying Leopold and Langbein's (1960) statement above, this means that the 10-inch increase in precipitation totals during 2016 and 2019 (25% more than normal), resulted in a 50% increase in runoff across MCWD which ultimately increased flows into Minnehaha Creek. This 50% increase in runoff is visualized in **Figure 60 (Section 5.1.2)**, which shows a simplified water cycle for the Lake Nokomis area based on an average precipitation year (30-inches) and an increased precipitation year of 40-inches.

Leopold and Langbein (1960) note that generally a 25% change in rainfall results in a 50% change in runoff. Applying this to Minnehaha Creek implies that the 25% increase in rainfall during 2016 and 2019, resulted in a 50% increase in runoff to Minnehaha Creek.

Since 2006, the USGS in partnership with MCWD, has measured real-time continuous flow and elevations of Minnehaha Creek at Hiawatha Avenue (downstream of Lake Nokomis. This data shows that eight of the highest recorded creek flows have occurred since 2013 (**Figure 83**).

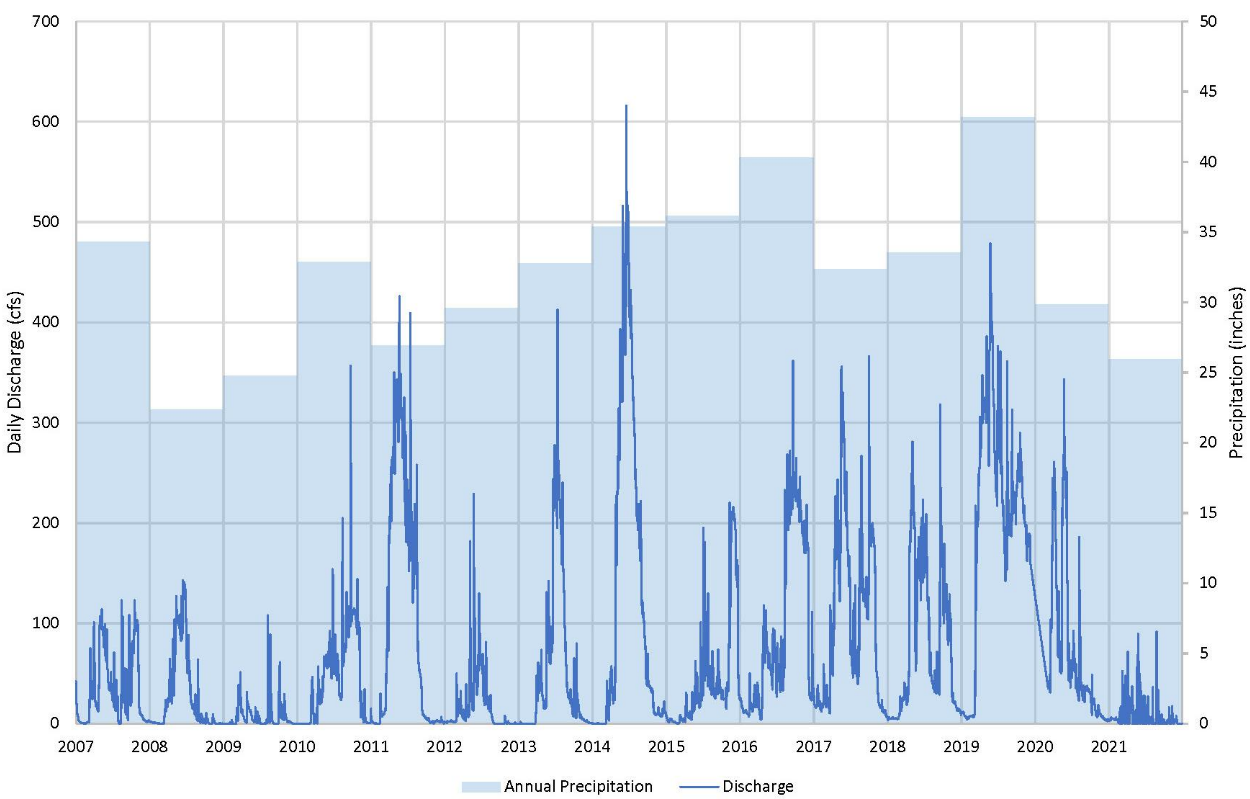


Figure 83. Minnehaha Creek Flow. *Real-time Minnehaha Creek flows measured by the USGS at Hiawatha Avenue. (Credit: Stantec; Data Source: USGS)*

Applying Leopold and Langbein's (1960) generalization on how a 25% change in precipitation results in a 50% change in runoff helps to explain the record high flows in Minnehaha Creek during 2013-2019, especially in 2014, 2016, and 2019:

- 2014: The first half of the year (January 1-June 30) recorded a 50% increase in precipitation, which generally implies that this year saw a 100% increase in runoff or twice as much as normal between January 1 to June 30.
- 2016 and 2019: Both these years recorded over 40-inches of precipitation, which is a 25% increase from normal. This generally implies that these years saw a 50% increase in runoff from normal.

In 2016, MCWD began measuring the elevation of Minnehaha Creek near Lake Nokomis. MCWD monitoring data from 2016-2020 shows that Minnehaha Creek remained below the Lake Nokomis runout outlet elevation (815.1-feet) for 94.7% of the time – only exceeding 815.1-feet for 97 days during this five-year period. This demonstrates that for over 94% of the time during this five-year period, Minnehaha Creek was lower than the Lake Nokomis outlet.

During 2016-2020, Minnehaha Creek was lower than the Lake Nokomis outlet for over 94% of the time.

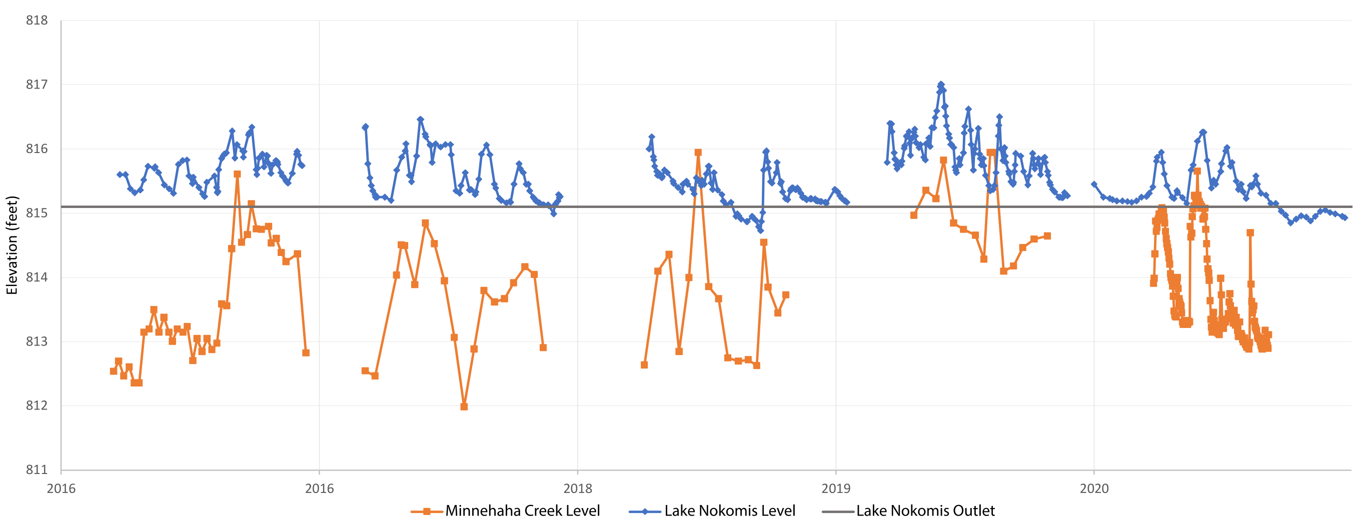


Figure 84. Minnehaha Creek and Lake Nokomis Water Levels. *Measured water levels for Minnehaha Creek between 2016-2020 show that the creek was below the Lake Nokomis oulet (815.1-feet) for over 94% of the time. (Credit: Stantec)*

7.3 AREAS OF CONCERN MINNEHAHA CREEK FINDINGS

The high flows on Minnehaha Creek between 2013-2019, are a direct result of increased precipitation, especially in 2014, which had the wettest first half of the year on record, and in 2016 and 2019, which are currently the second wettest and all-time wettest years on record respectively.

However, even during these record wet years, water levels in Minnehaha Creek remained below the Lake Nokomis runout elevation for 94.7% of the time during 2016-2020. Additionally, all three Areas of Concern are well outside the 30 to 250-foot width of the localized water table gradient of Minnehaha Creek.

7.3.1 Nokomis Parkway

Minnehaha Creek's water levels are not contributing to the reported water issues in the Nokomis Parkway Area of Concern. This is due to the fact that monitoring data from 2016-2020 revealed that Minnehaha Creek was lower than the Lake Nokomis runout elevation for over 94% of the time. This data demonstrates that Minnehaha Creek and its associated management through the operation of the Gray's Bay Dam are not contributing to the reported water issues in this Area of Concern.

7.3.2 West Nokomis

Minnehaha Creek's water levels are not contributing to the reported water issues in the West Nokomis Area of Concern because these basements are estimated to have bottom elevations between 823-832 feet (**Figure 85**), which are approximately 10-19 feet higher than the average elevation of Minnehaha Creek (812.8 feet). This data demonstrates that Minnehaha Creek and its associated management through the operation of the Gray's Bay Dam are not contributing to the reported water issues in this Area of Concern.

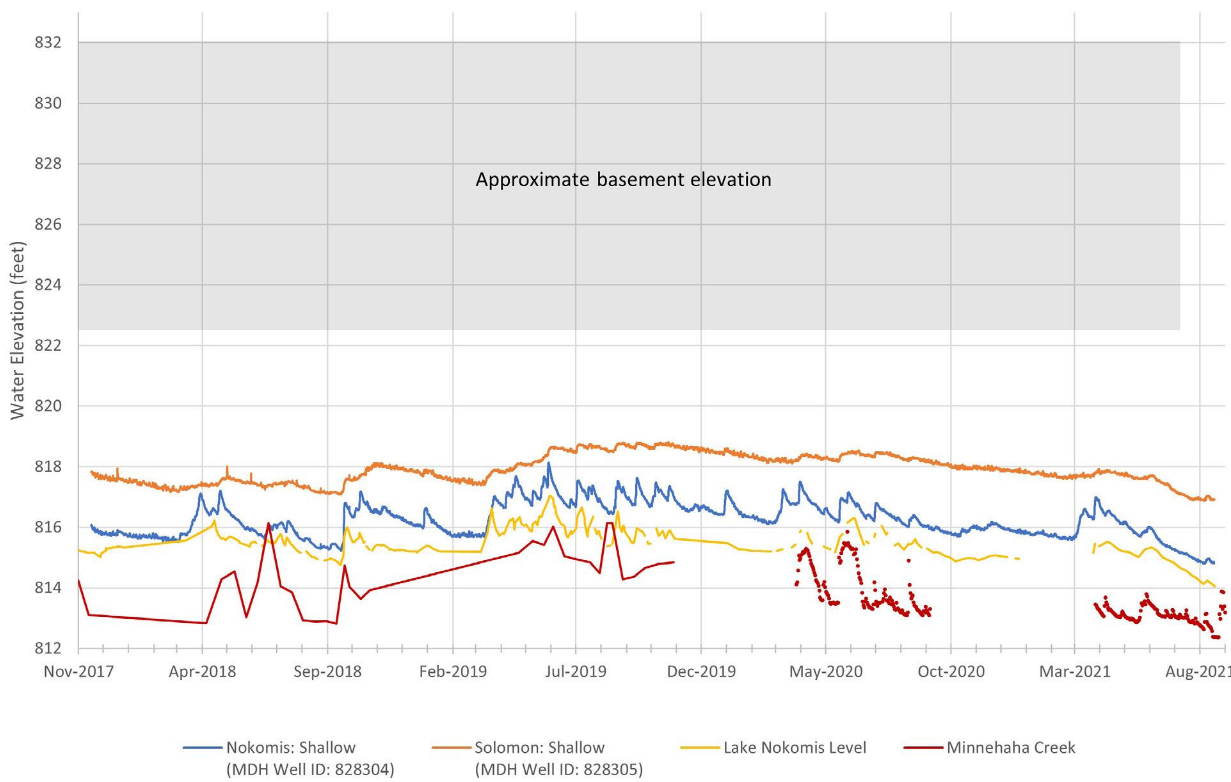


Figure 85. Minnehaha Creek Elevations and West Nokomis Area of Concern Basement Elevations.
In reviewing the elevations of the West Nokomis Area of Concern basement concerns, the basements are 10-19 feet higher than Minnehaha Creek.

7.3.3 Solomon Park

Minnehaha Creek's water levels are not contributing to the reported water issues in the backyards of the Solomon Park Area of Concern because these yards are estimated to have elevations between 826-828 feet (**Figure 86**), which are 13-15 feet higher than the average elevation of Minnehaha Creek (812.8 feet). This data demonstrates that Minnehaha Creek and its associated management through the operation of the Gray's Bay Dam are not contributing to the reported water issues in this Area of Concern.

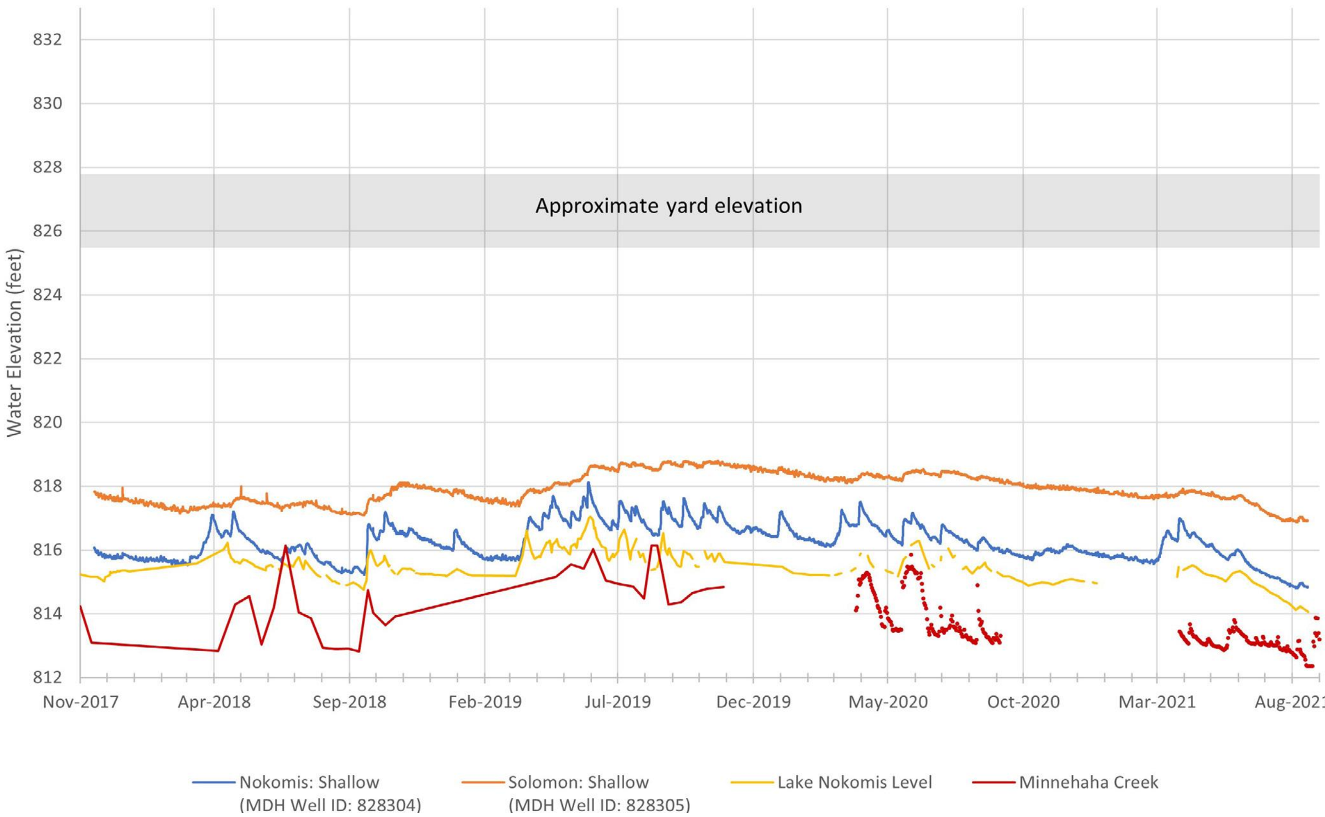
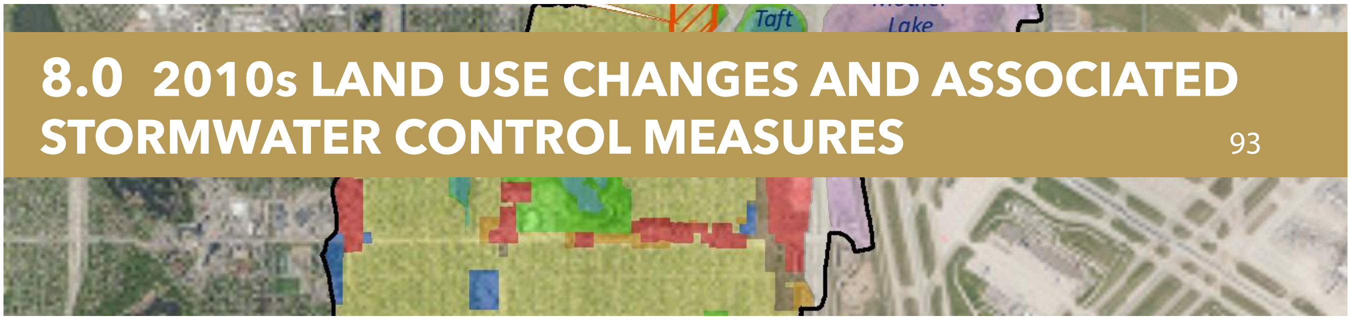


Figure 86. Minnehaha Creek Elevations and Solomon Park Area of Concern Backyard Elevations.
In reviewing the elevations of the Solomon Park Area of Concern backyard concerns, the backyards are 13-15 feet higher than Minnehaha Creek.



8.0 2010s LAND USE CHANGES AND ASSOCIATED STORMWATER CONTROL MEASURES

Chapter 3 discussed how land alterations and land-use decisions a century ago have contributed to the current water issues in the Areas of Concern. Since 2014, concerns have been raised that more recent alterations (over the past decade) to impervious surfaces may have increased runoff volumes and that infiltration by stormwater control measures (SCMs), such as stormwater ponds and infiltration projects, may have increased levels in Lake Nokomis and the water table. This chapter examines the Lake Nokomis watershed and its land use changes over the past decade, stormwater management, and estimated SCM infiltration volume.

8.1 LAKE NOKOMIS WATERSHED LAND USE

Section 6.1 noted that the drainage area of Lake Nokomis is approximately 2,903 acres. **Figure 87** shows that Lake Nokomis watershed is fully developed and consists of mostly single-family residential development, and there are scattered blocks of parks and recreational areas, in addition to highly concentrated pockets of highway, commercial and institutional land.

Land development in the Lake Nokomis watershed has been relatively minor over the past several decades. Because the Lake Nokomis watershed is fully developed, only minor changes in land use (redevelopment) are occurring. Any new impervious surfaces associated with redevelopment are subject to city, MCWD, and state regulations for the rate and volume of stormwater runoff. For areas that did undergo redevelopment, stormwater control measures (SCMs) were installed according to city, MCWD, and state regulatory standards. These standards require developers to mitigate the effects of increased runoff from new development.

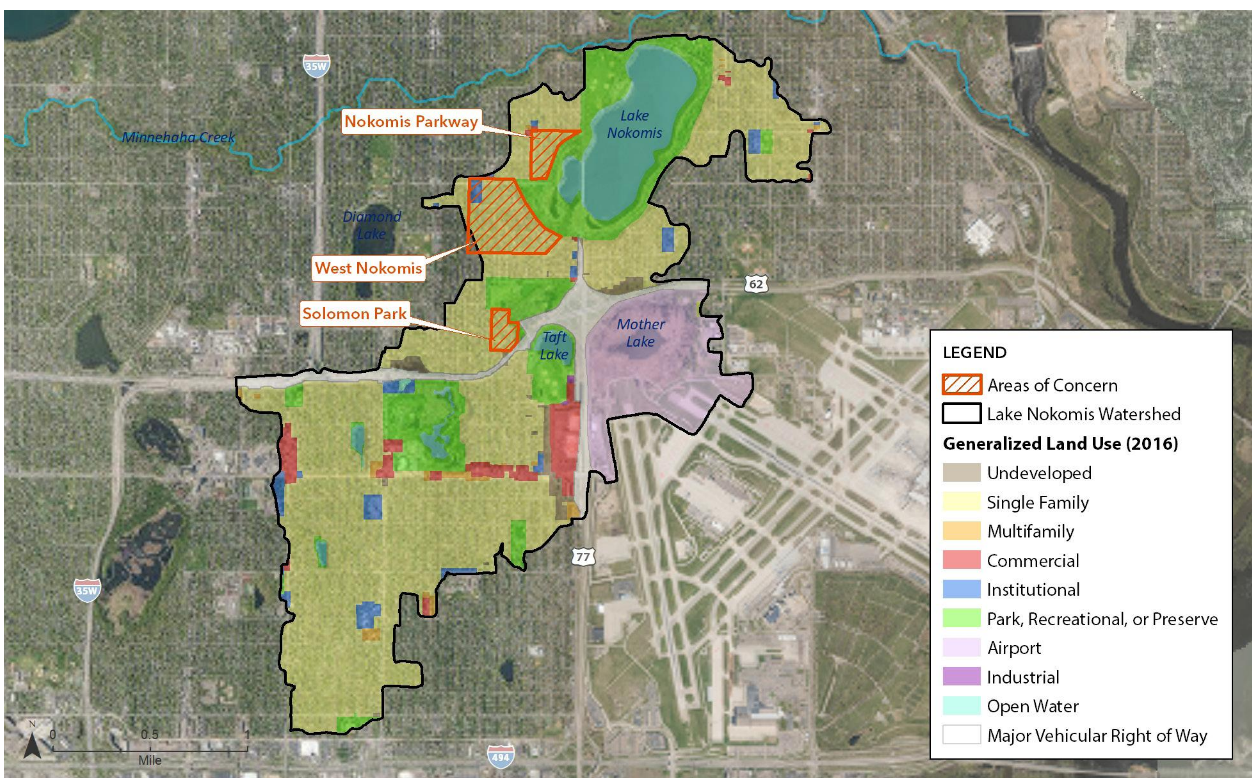


Figure 87. Land Use in Lake Nokomis Watershed. *The Lake Nokomis watershed is fully developed, and its highest land use is single family residential. (Credit: MCWD; Data Source: Metropolitan Council)*

8.2 STORMWATER CONTROL MEASURE

A stormwater control measure (SCM) is a dedicated treatment practice which is intentionally constructed to remove pollutants and slow the speed at which urban runoff flows off the landscape. SCMs may include practices like stormwater ponds, stormwater wetlands, rain gardens, bioretention basins, and infiltration trenches. Some of these practices (i.e., bioretention basin, infiltration trench) are specifically designed to capture and temporarily store stormwater before allowing it to infiltrate into the soil. As water moves through soil, chemical, biological and physical processes remove pollutants and delay peak stormwater flows.

In reaction to high water concerns near Lake Nokomis, there have been concerns regarding large-scale infiltration SCMs installed in the Lake Nokomis watershed over the last 10 to 15 years. Some have suggested that these systems are sending too much water into the soil causing the water table to increase. The Team estimated the total amount of water infiltrated from these SCMs and determined that it is nominal compared to the groundwater recharge from the record precipitation.

Revisiting **Figure 58**, the total amount of groundwater recharge to the Lake Nokomis watershed has been approximately 1-1.2 billion gallons of water per year since 2014. For comparison, the total SCM infiltration volume in the Lake Nokomis watershed can be computed using the assumptions that:

- The watershed is 37% impervious;
- That infiltration SCMs manage runoff from 2% of the watershed; and
- That all annual rainfall is infiltrated (no bypass)

These assumptions result in the estimated calculation that annual SCM infiltration is approximately 10 million gallons, which is just 0.15-inches of recharge over the watershed and 1% of the total groundwater recharge in the Lake Nokomis watershed.

8.2.1 Lake Nokomis Stormwater Wetlands

To improve and protect Lake Nokomis from land use changes, MCWD, the cities of Minneapolis and Richfield, and others have implemented strategic SCMs to improve water quality in Lake Nokomis. One such example is the chain of three stormwater wetlands adjacent to Lake Nokomis that were constructed in 2001, as recommended by the Blue Water Commission. These stormwater wetlands were constructed as part of a series of projects that the City of Minneapolis, MPRB, and MCWD partnered on, including the 2001 inflatable Nokomis weir, to improve the water quality of Lake Nokomis.

Recently, concerns have been raised that these stormwater wetlands may be impacting the water table level in the Areas of Concern. These stormwater wetlands were constructed in the former low-lying wetland and peat bog areas that were filled during the Lake Nokomis dredging project noted in Section 3.1. Therefore, when these stormwater wetlands were constructed in 2001, they were constructed within an existing wetland area that measured over 5.8 acres. These stormwater wetlands use sedimentation (pollutants and sediment are removed via gravity settling), not infiltration, to capture and allow pollutants from runoff to settle before the water drains into Lake Nokomis. These stormwater wetlands have no effect on the volume of runoff entering Lake Nokomis or the water table, as they are simply intercepting the water to clean it before it drains to Lake Nokomis. MCWD measures sediment accumulation in the stormwater wetlands approximately every three years and removes accumulated sediment as needed, which last occurred in 2011 for Amelia Pond.

Finally, Chapter 5 identified that Lake Nokomis is an expression of the shallow water table and that the shallow water table does not impact the assumed basement elevations for most of the reported water concerns. Additionally, Chapter 6 noted that Lake Nokomis water elevations are not contributing to most of the reported water concerns. Therefore, since the shallow water table and Lake Nokomis water levels are not contributing to most of the reported water issues, then the water levels in these stormwater wetlands are also not capable of contributing to the water issues.

8.3 AREAS OF CONCERN FINDINGS

For this factor, the conclusion for the three Areas of Concern (Nokomis Parkway, West Nokomis, and Solomon Park) are combined.

Land use data and MCWD permit records over the past decade indicates there has been no significant land development or increases in runoff volume due to land use changes. Finally, stormwater control measures contribute only a nominal amount (1%) of water to the water table when compared to total groundwater recharge in the Lake Nokomis watershed. Therefore, land use changes in the Lake Nokomis watershed over the past decade and their associated infiltration SCMs are not contributing to the reported water issues.

After evaluating existing data, gathering new data, and reviewing existing studies, the Team found the following findings about the factors evaluated in Chapters 2-8.

1. **11,000+ years ago,** glaciers created the landscape, geology, and hydrology around Lake Nokomis. From a geologic standpoint, the landscape around Lake Nokomis was naturally formed to hold and absorb water. The MGS has found that most lakes in Minneapolis originated as ponded water in former ice blocks, and many of these lakes decreased in size as the climate warmed. Where lakes decreased in size, MGS has found organic material such as peat, at the surface and on top of lake sediment. MGS' surficial geology map in **Figure 2** identifies numerous peat deposits around Lake Nokomis. Peat is a wetland soil that contains partially decomposed plant material which allows it to absorb and retain large quantities of water, like a sponge. Because peat can hold water so effectively, it can be a barrier to allowing water to drain to deeper layers of the soil and can perch water above it.

2. **Nearly 170 years ago, the first government land survey documented over 1,500-acres of lakes and wetlands adjacent to and neighboring present-day Lake Nokomis.** In 1853, prior to Minnesota statehood and expanded White settlement, the U.S. Surveyor General's Office surveyed the landscape around Lake Amelia (present-day Lake Nokomis). A digitized version of the 1853 land survey is shown in **Figure 3**. In 1853, Lake Amelia (present-day Lake Nokomis) was approximately 240-acres with a 13-acre wetland on the southwest side of the lake, Mother Lake was approximately 260-acres with an 88-acre wetland on the west side of the lake, and a 1,600-foot stream channel flowed out of the Mother Lake wetland into Lake Amelia.

3. **Over 110 years ago, Lake Nokomis and its natural wetlands and peat bogs, were excavated to convert the lake from a shallow water wetland into an open water lake.** During this time wetlands were considered unsanitary and useless, and they were viewed as an obstacle to development. MPRB transformed the Lake Nokomis area and undertook the "most ambitious lake-shaping plan in the history of Minneapolis Parks" (MPRB, 2021). Over the course of four years, this massive excavation project removed 2.5 million cubic yards of wetland, peat, and lake soil (comparable to ~250,000 dump truck loads) from Lake Nokomis and placed it as fill over adjacent low-lying wetlands and peat bogs. This excavation project reshaped the lake, reduced the water area by 100-acres, and deepened the lake. Theodore Wirth (Superintendent of Minneapolis parks from 1906–1935), noted that "the transformation of formerly unsanitary and unsightly sections" led to the residential development and park creation that anchors the area we know today (The Minneapolis Star, 1934).

4. **100 years ago, residential development began around Lake Nokomis and coincided with the driest period on record for the Twin Cities.** Lake Nokomis' transformation, and the subsequent residential development that followed from the 1920s-1950s, coincided with the drought that began in the 1920s and lasted into the 1950s (**Figure 4**). During these 40 years when homes were being built in historically wet areas, the average annual precipitation was approximately 25-inches and resulted in a long-term precipitation deficit. This drought caused Lake Nokomis to fall to its lowest recorded level of 809.67-feet in 1932, which is 5.7-feet below the current ordinary high-water level of 815.40-feet. As a result, these dry conditions created perceptions that water was relatively easy to manage even over former wetland areas. This resulted in homes being built over filled wetlands, peat soil, and the former footprint of Lake Nokomis.

5. **80 years ago, during the development of the Lake Nokomis area, underlying wetland and peat soils caused problems for underground infrastructure, roads, and parkland, including during the Dust Bowl drought.** City of Minneapolis records from the 1930s note that sewer lines needed

to be repaired shortly after installation with pilings and encased in concrete due to poor soil conditions. 1941 records show when 58th Street was extended towards 15th Avenue, peat bogs up to 16-feet in depth were encountered and excavated. Additionally, MPRB records note that 20-years after the dredging of Lake Nokomis, the peat soils settled and required extensive restoration work that was carried out by the WPA. Between 1936-1939, WPA workers dug peat up to 15-feet deep and regraded over 52 acres of peat ground around the lake after it had cracked. 1939 reports note that WPA workers also excavated 33,875 cubic yards of peat (equivalent to over 3,300 dump truck loads) from under walks, curbs, and pavements that had settled.

6. **Peat soils continue to be discovered and mapped.** The surficial geology atlas from MGS shows that areas of peat exist in the Lake Nokomis area. Even outside of those mapped MGS areas, peat has been found at the surface and up to 50-feet deep. MPRB's WPA records note that peat soils were removed from Lake Nokomis and used to fill depressions by Minnehaha Creek, and that peat soils from Mother Lake were used to fill depression on the south side of Lake Nokomis. Additionally, soil drilling records from the past two decades note the presence of peat in around Lake Nokomis. Given the movement of peat in and around Lake Nokomis, and the discovery of peat soils outside of mapped areas, it is likely that peat soils exist in small pockets throughout the area that were too small to be documented on MGS' geology atlas.
7. **During 2010-2019, the Twin Cities experienced the wettest decade on record.** The DNR Climatology Office notes that over the past decade, the average annual precipitation was 34.31-inches. This means the Twin Cities received nearly 100-inches (8.33-feet) more precipitation in the 2010s than they did during each individual decade (1920s, 1930s, 1940s and 1950s) when the homes around Lake Nokomis were built. The 2010s also included the wettest seven years on record from 2013-2019, resulting in an accumulated precipitation surplus of 32-inches during those seven years. Precipitation was also found to be increasing outside of the growing season, which increases groundwater recharge and could increase the amount of precipitation directed to the regional shallow water table and the peat soils in the area.
8. **Surplus precipitation is trapped by buried peat soils.** Because of peat's ability to absorb and retain large quantities of water, peat soils continued to cause water issues in 2020-2021, even during drought conditions. Peat soils that are buried under fill can restrict the downward movement of precipitation into the ground. This has likely caused the peat soils to trap the surplus precipitation from 2013-2019, and form perched groundwater systems that are causing the reported water concerns. Because peat soils act like a giant sponge, once they are wet, they can hold onto water for extended periods of time. This likely explains why property owners around Lake Nokomis continued to experience water issues during drought conditions in 2020 and 2021, even though groundwater levels and surface water levels trended lower.
9. **Lake Nokomis and Minnehaha Creek are not driving groundwater levels.** Groundwater well data confirmed that the amount of precipitation soaking into the ground is driving groundwater levels in the Lake Nokomis area, not the water levels in Lake Nokomis or Minnehaha Creek. Groundwater wells across the Twin Cities show that groundwater levels are responding in the same way despite being in different geographies, demonstrating that precipitation is driving groundwater levels and not local watershed features.
10. **The physical elevation of most basements with water issues revealed that they are elevated at least 5-feet, and up to 19-feet, higher than the regional shallow water table or surface water.** This demonstrates that the regional shallow water table, Lake Nokomis, and Minnehaha Creek are not contributing to the water issues for most reported basements; and that perched groundwater near those basements could be contributing to the water issues.
11. **Land use change and redevelopment over the past decade, and associated stormwater management activities do not contribute to the reported water concerns.** Minor redevelopment has occurred in the Lake Nokomis watershed over the past several decades. The total amount of water infiltrated by stormwater management practices is modeled to be approximately 1%of the total regional groundwater recharge.

The Team's evaluation found that each of the three Lake Nokomis Areas of Concerns experienced water issues for slightly different reasons. This is due to the characteristics of each location, and how each is responding to record breaking precipitation based on the geologic history of the area, the subsequent development of the land, the movement of peat soils in the area, and the respective elevations of each area. These distinctions are discussed below.

10.1 NOKOMIS PARKWAY AREA OF CONCERN

- Between 2014-2018, three homes reported wet basements to the City of Minneapolis.
- The homes are estimated to have been constructed during the 1920s-1940s, with sanitary sewer lines built during 1911-1930. Some of the homes and sanitary sewer lines were constructed over former wetlands and the former Lake Nokomis basin.
- The three reported homes appear to have basements that were built below the OHW (815.4-feet) of Lake Nokomis and the runout elevation (815.1-feet) of the Lake Nokomis weir, which was constructed in 1931. This means these homes are likely impacted by normal water levels in the lake (**Figure 88**).
- Record precipitation and record groundwater recharge could be exacerbating conditions for these property owners, given that the water table was estimated to increase 20-inches during this period, and that Lake Nokomis is an expression of the groundwater.
- Minnehaha Creek is not contributing to the water issues, as the creek was lower than the Lake Nokomis outlet for 94.7% of the time between 2016-2020. Additionally, the Nokomis Parkway Area of Concern is located approximately 2,000 feet south of Minnehaha Creek, which is well outside Minnehaha Creek's 30 to 250-feet wide localized influence on the water table gradient.

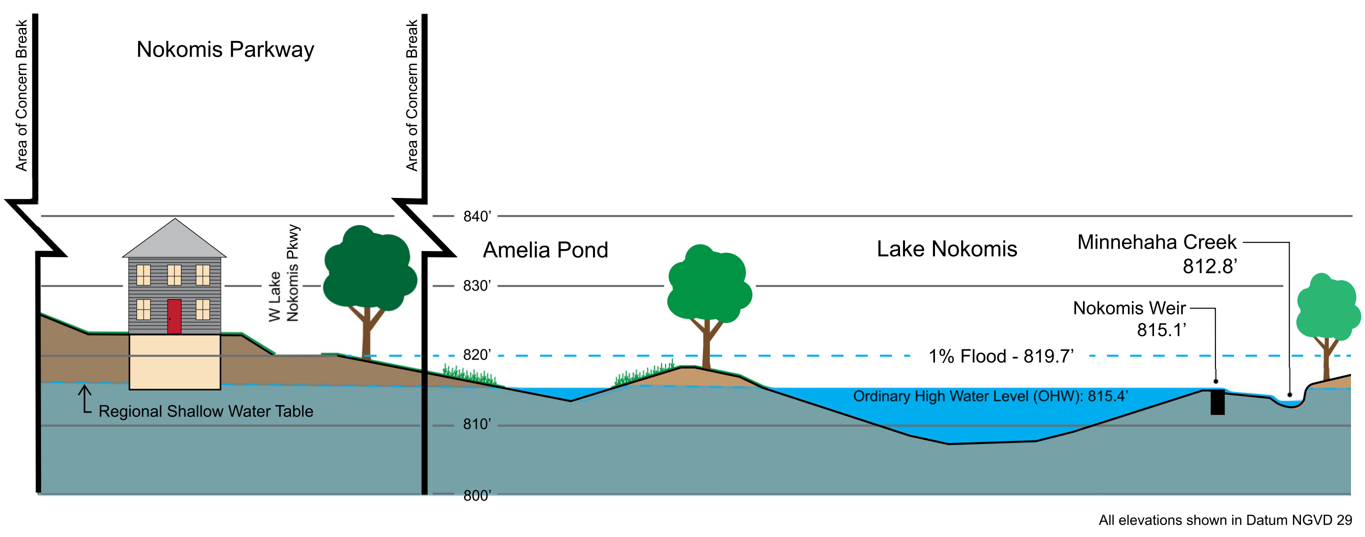


Figure 88: Conceptual Cross Section for Nokomis Parkway. *Cross section showing that some homes in the Nokomis Parkway Area of Concern were constructed below the OWH of Lake Nokomis. (Credit: Stantec)*

10.2 WEST NOKOMIS AREA OF CONCERN

» Between 2014-2018, 13 homes reported wet basements to the City of Minneapolis.

» The homes in this Area of Concern are estimated to have been constructed during the 1930s-1940s, with sanitary sewer lines installed during 1931-1950. Some of the homes and sanitary sewer lines were constructed over the former channel that drained from the Mother Lake wetland into Lake Nokomis. The remaining homes were constructed in-between and adjacent to a former wetland system.

» The 13 reported homes appear to have basement elevations that vary from 823 to 832-feet (**Figure 89**), which are:

- 5-14-feet higher than the regional shallow water table
- 7.6-16.6-feet higher than the OHW of Lake Nokomis
- 8-17-feet higher than the outlet of Lake Nokomis
- 10-19-feet higher than the average elevation of Minnehaha Creek (812.8-feet)

» Given that peat soils have historically caused issues in the area, the Team's understanding is that underlying peat soils have formed a confining layer and prevented increased precipitation from infiltrating down, resulting in locally perched groundwater systems that are contributing to these reported water concerns.

» Lake Nokomis and Minnehaha Creek are not contributing to the reported water issues because their water elevations are 7-19-feet lower than the basements with reported water issues.

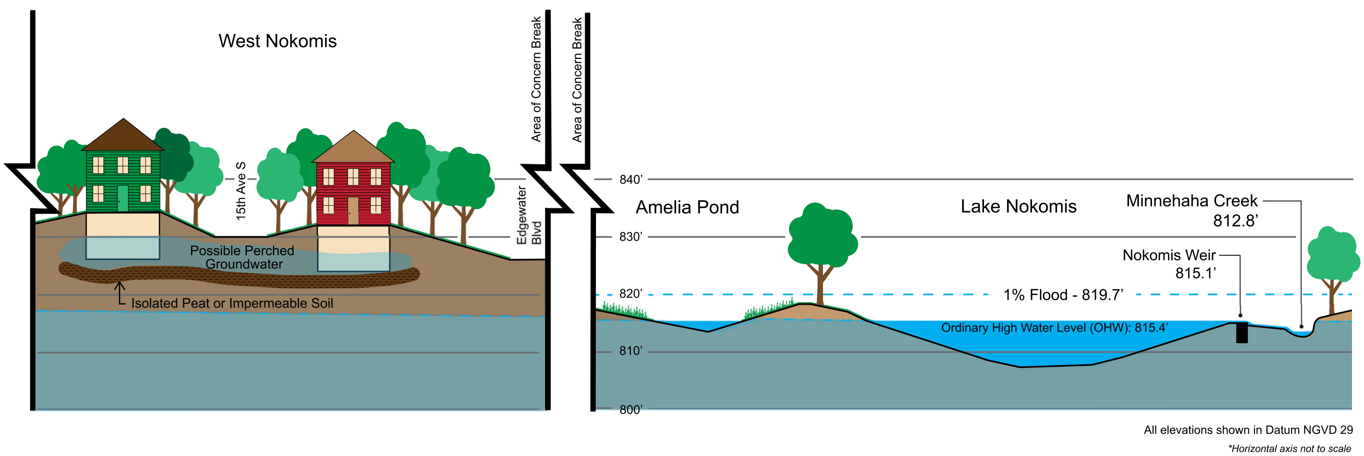


Figure 89: Conceptual Cross Section for West Nokomis. *Cross section showing that homes in the West Nokomis Area of Concern likely have basements that are located within perched groundwater (Credit: Stantec)*

10.3 SOLOMON PARK AREA OF CONCERN

- Between 2014-2018, five homes reported wet backyards to the City of Minneapolis.
- The homes in this Area of Concern are estimated to have been constructed during the 1940s-1950s, with sanitary sewer lines installed during 1931-1970. Some of the homes were built over the former wetland that was adjacent to Mother Lake and the remaining homes were built adjacent to an existing mapped wetland system.
- The surficial geology map shows some of the homes were built on and adjacent to mapped wetlands and peat areas.
- Some properties along 14th Avenue have backyards within the 100-year FEMA floodplain for Lake Nokomis.
- The five reported homes appear to have backyard elevations that vary from 826 to 828 feet (**Figure 90**), which are:
    - 7-11 feet higher than the regional shallow water table
    - 10.6-12.6 feet higher than the OHW of Lake Nokomis
    - 11-13 feet higher than the outlet of Lake Nokomis
    - 13-16 feet higher than the average elevation of Minnehaha Creek (812.8 feet)
- The reported backyard water concerns are due to localized peat soils that have absorbed record precipitation between 2013-2019.
- Lake Nokomis and Minnehaha Creek are not contributing to the reported water issues.

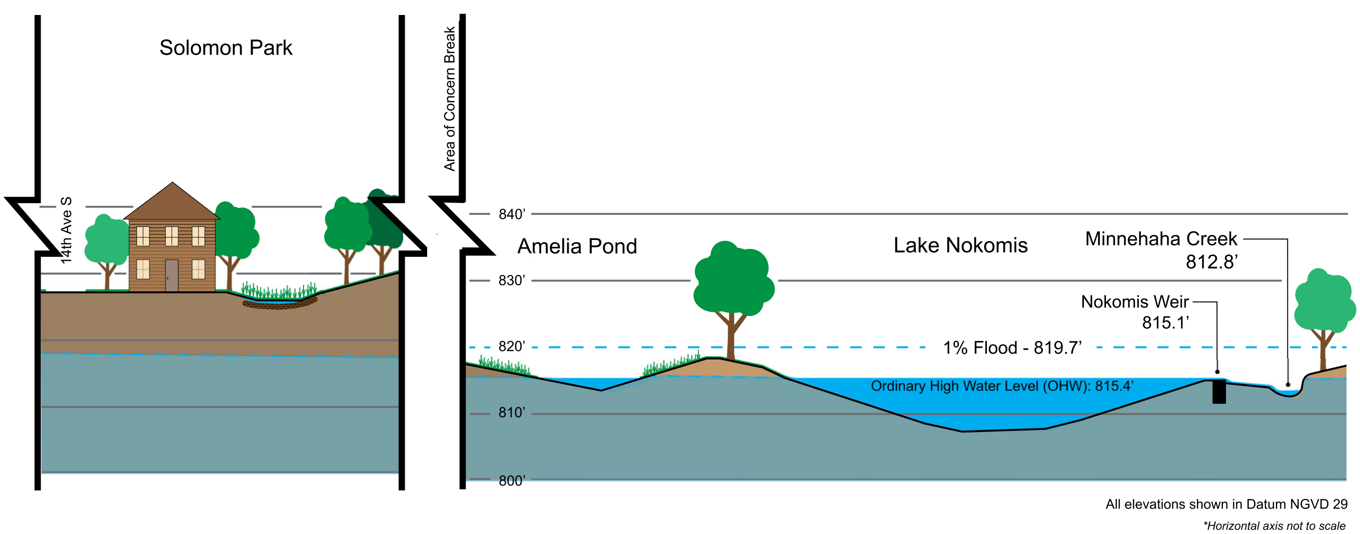


Figure 90: Conceptual Cross Section for Solomon. *Cross section showing that backyards in the Solomon Park Area of Concern are 7-16 feet above the regional shallow water table and surface water elevations. (Credit: Stantec)*

11.0 LAKE NOKOMIS AREA RECOMMENDATION & NEXT STEPS

The Lake Nokomis area water issues have been found to be localized and driven by geologic history, past land-use decisions, and climate change in the form of record rainfall. As a result, it is recommended that property owners experiencing water issues consider implementing mitigation measures on site, to protect their property and infrastructure from water impacts. Next steps for local governments and the Multi-Agency Team for the Lake Nokomis area will include leveraging state funding to map local geology and perched groundwater, continuing to collect and monitor surface and groundwater data from the area, while also identifying and sharing resources to support property owners in implementing individual mitigation measures.

Beyond the Lake Nokomis area, the partners on the Multi-Agency Team are already actively working on climate change action planning. **Appendix A** summarizes the climate action work the partners are supporting and implementing across Minnesota's communities and landscapes.

RECOMMENDATION

» Property owners experiencing water issues consider implementing mitigation measures on site, to protect their property and infrastructure from water impacts.

NEXT STEPS

Quantify:

» **U of M, USGS, MGS:** Leverage allocated state funds to quantify and more precisely delineate the local geological and hydrogeological features in the Lake Nokomis area. Conduct soil borings to specifically map peat and wetland soils that are causing perched groundwater conditions and affiliated issues and assess the potential impact to properties around Lake Nokomis. Develop guidelines to predict areas across the region which may experience similar issues.

» **City of Minneapolis**: Provide project support to the U of M, USGS, and MGS effort to map the extent of peat and wetland soils (geologic features) in the Lake Nokomis Areas of Concern.

Assist:

» **City of Minneapolis**: Leverage data and guidelines from the U of M to continue identifying areas potentially impacted by climate driven shifts in surface and groundwater patterns across the city. Continue to evaluate and respond to emerging water issues, including those at Lake Nokomis, using established prioritization frameworks.

» **City of Minneapolis:** Continue evaluating existing laws, policy frameworks, and resources that are available to assist all affected property owners within the city with water mitigation measures; identify potential gaps and continue advocating for appropriate legislative support for local climate adaptation.

» **City of Minneapolis:** Continue identifying and sharing resources on the city's website to support actions property owners might consider implementing to mitigate localized water related impacts.

Monitor:

» **Hennepin County:** Continue to collect, monitor, and analyze groundwater data from the wells on the southwest side of Lake Nokomis and near Solomon Park.

» **Minneapolis Park and Recreation Board:** Continue to collect, monitor, and analyze Lake Nokomis water levels; and operate the Lake Nokomis outlet structure according to the Lake Nokomis Outlet Operating Plan.

» **Minnehaha Creek Watershed District:** Continue to implement and expand the watershed wide real-time sensor network (RESNET) to collect, monitor, and analyze water level information across the watershed, including at Lake Nokomis.

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Cover Photos Descriptions:

Left Top Photo:

Works Progress Administration workers turning over peat around Lake Nokomis in 1937.
Credit: Minneapolis Board of Park Commissioners

Left Bottom Map:

2010-2019 precipitation departure for Minnesota.
Credit: DNR

Right Bottom Photo:

Groundwater well being installed near Lake Nokomis.
Credit: MCWD

Background Map:

1853 Original Land Survey Map.
Credit: GLO Historic Plat Map

13.0 GLOSSARY

Aquiclude: geologic material such as clays and shales that can store water but cannot transmit water effectively.

Aquifer: a geologic formation or structure that stores and/or transmits water, such as to wells and springs. Use of the term is usually restricted to those water-bearing formations capable of yielding water in sufficient quantity to constitute a usable supply for people's uses. (USGS)

Baseflow: the flow coming from groundwater inputs to a stream or river system (MPCA).

Capillary Fringe: the movement of water within the spaces of a porous material due to the forces of adhesion, cohesion, and surface tension. (USGS)

Confined aquifer: soil or rock below the land surface that is saturated with water. There are layers of impermeable material both above and below it, and it is under pressure so that when the aquifer is penetrated by a well, the water will rise above the top of the aquifer. (USGS)

Confining layer: an impermeable layer of geologic stratum such as an aquiclude overlaying a confined aquifer. The confining layer restricts movement of water in and out of a confined aquifer.

Geology: the science of earth's history and its life especially as recorded in rocks.

Groundwater: water that flows or seeps downward and saturates soil or rock, supplying springs and wells. (USGS)

Ordinary high water level: the boundary of water basins, watercourses, public waters, and public waters wetlands, and: (1) an elevation delineating the highest water level that has been maintained for a sufficient period of time to leave evidence upon the landscape, commonly the point where the natural vegetation changes from predominantly aquatic to predominantly terrestrial; (2) for watercourses, the ordinary high water level is the elevation of the top of the bank of the channel; and (3) for reservoirs and flowages, is the operating elevation of the normal summer pool. (DNR)

Perched groundwater: a small zone of groundwater held above the primary water table by an impermeable layer.

Recharge (groundwater): The process involved in the absorption and addition of water to the zone of saturation; also, the amount of water added. (USGS)

Saturated zone: A subsurface zone in which all the interstices or voids are filled with water under pressure greater than that of the atmosphere. (USGS)

Surface water: water that is on the Earth's surface, such as in a stream, river, lake, or reservoir. (USGS)

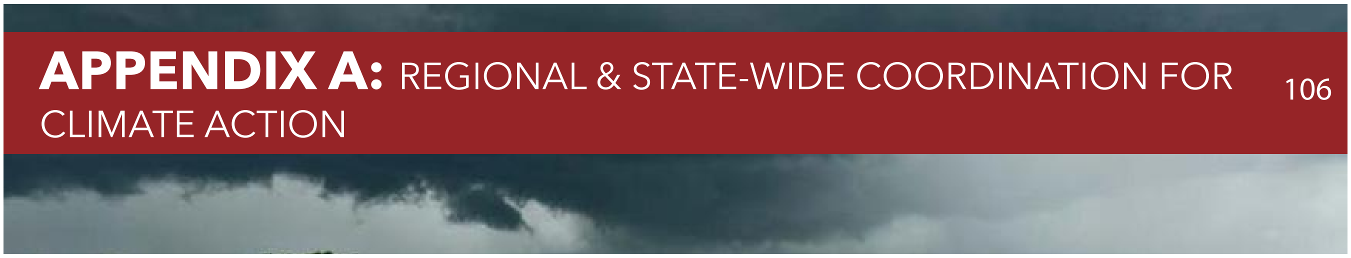
Team: the multi-agency staff experts who have studied and contributed data regarding Lake Nokomis Areas of Concern water issues.

Unsaturated zone: A subsurface zone above the water table in which the pore spaces may contain a combination of air and water. (USGS)

Water table: the upper surface of the saturated zone is called the water table.

Water year: A continuous 12-month period selected to present data relative to hydrologic or meteorological phenomena during which a complete annual hydrologic cycle normally occurs. The water year used by the U.S. Geological Survey runs from October 1 through September 30, and is designated by the year in which it ends. (USGS)

Unconfined aquifer: an aquifer whose upper water surface (water table) is at atmospheric pressure, and thus is able to rise and fall. (USGS)



APPENDIX A: REGIONAL & STATE-WIDE COORDINATION FOR CLIMATE ACTION

Climate Change Drives the Need for Action

The wet weather between 2013-2019 resulted in new state-wide precipitation records and the highest recorded water levels in many of Minnesota's lakes, streams, and groundwater wells. As climate change increases Minnesota's precipitation, it will continue to drive shifts in hydrology that will impact natural systems and the built environment.

The Lake Nokomis Area Groundwater & Surface Water Evaluation offers a local case study on how climate change is already impacting Minnesota's communities. As the effects of climate change are expected to increase in scope and magnitude in the coming decades, it will threaten both the natural and built environments and will include widespread local impacts across Minnesota's communities. Not all areas will experience the same type or magnitude of impacts.

New, Sustainable Governance is Needed

Mobilizing a multi-agency team of federal, state, county, watershed, and city resources to react to local water issues, such as this Lake Nokomis area evaluation, is not a sustainable approach to adapt to the widespread effects of climate change. With this awareness in mind, the Team has identified that new climate governance models are needed to:

» Understand and predict climate change impacts

» Convene and plan for climate change impacts

» Implement, measure, and adapt to climate change impacts

Understand and Predict Climate Change Impacts

The impacts of climate change in Minnesota have revealed state, regional, and local level data gaps that are impeding our ability to diagnose the causes of today's water issues as well as predict where impacts will occur in the future. Without more complete data sets and predictive capabilities, planning to address a known future vulnerability is very difficult and time intensive. We need to be able to proactively predict issues and impacts at a systems scale to infrastructure, natural systems, people, and the economy. With this need in mind, the multi-agency team will continue to coordinate and support each other in the development of cohesive plans to expand technical capabilities in data collection and analysis to understand and predict the impacts of climate change, establish goals, and evaluate potential adaptation solutions.

Weather and Climate Data

» Support Hennepin County's effort to increase the county's network of automated weather and environmental monitoring stations (Hennepin West Mesonet) in areas most vulnerable to flooding and heat.

» Support the DNR's effort to provide dynamically downscaled climate projection data to enable local decision-making.

» Support an appropriation from the Minnesota legislature to fund the University of Minnesota's study to generate climate model projections, in three square mile areas, for the entire state of Minnesota.

Surface Water Data

» Support MCWD, Hennepin County and USGS' effort to build out MCWD's network of 25 remote sensors, known as RESNET, which provides real-time data on water level, flow, and pollutant loading throughout MCWD.

Ground Water Data

» Support MCWD, Hennepin County, and DNR's effort to install additional groundwater wells throughout MCWD and Hennepin County.

Analytical Tools

- Support MCWD's development of a machine learning model that will forecast future water levels based on the vast quantity of newly available RESNET data, which will provide real time flood forecasting at the 25 RESNET locations throughout MCWD.
- Support MCWD's development of a two-dimensional watershed model which will integrate state topographic and municipal infrastructure data to create a high-resolution planning tool to pinpoint, quantitatively evaluate, and drive decisions on climate adaptation projects and policies at a watershed scale.
- Support Hennepin County's effort to develop a mapping tool to comprehensively identify the sites most at risk for flooding of all types (fluvial, pluvial, and groundwater) to guide effective mitigation and response actions.
- Coordinate with Metropolitan Council to discuss the need for a regional groundwater study to evaluate future recharge rates to the water table and model the effects of climate change on groundwater levels. Use this study/modeling to predict areas across the Twin Cities where water tables may rise, resulting in groundwater flooding and could cause conflicts with built infrastructure and underground utilities

Convene and Plan for Climate Change Impacts

In addition to needing fuller data sets and new analytical tools, planning for climate change impacts will require a coordinated agency response and new governance models because no single entity in Minnesota has all the authority and resources or owns all the infrastructure needed to adapt to climate change. Therefore, each agency must understand their role and contextualize it against the roles, responsibilities, and organizational capabilities of city, regional, state, and federal agencies. Adapting to climate change impacts will be most effective when agencies are able to align priorities, form partnerships and leverage scarce resources. With this need in mind, the multi-agency team will support efforts to convene and plan with agency partners.

Convene

- Support MCWD's effort to convene partners to share MCWD's data-driven system understanding of the watershed and build consensus around the issues, align goals, and guide the development of a coordinated watershed-wide climate adaptation implementation plan.
- Support the implementation of Hennepin County's Climate Action Plan, including the county's effort to convene partners to further develop action plans for climate adaptation strategies, pursue collaborations for greater impact, and raise a collective voice for climate policy.

Plan

- Support Hennepin County in the development of a groundwater plan that considers the impacts of climate change, including extreme weather events and wet/dry cycles, on groundwater resources, surface-level groundwater hazards, and drinking water availability.
- Support Hennepin County in the development of an Integrated Water Management Plan that will consider findings from the groundwater plan.

Implement, Measure, and Adapt to Climate Change Impacts

After each agency understands their role and capabilities within climate adaptation, as well as those of other agencies, they can begin to coordinate implementation actions with other agency partners. Implementation actions may include any of the following: funding, outreach, policy changes, projects, programs, regulation, etc. The multi-agency team's current recommended implementation actions are identified below.

Funding

- Support the Minnesota Environmental Quality Board's State Water Plan strategy to develop new and updated resiliency financing mechanisms.
- Support an appropriation from the Minnesota legislature for the Minnesota Pollution Control

Agency's proposal to provide [$21.1 million to establish the Local Government Stormwater Construction Grant program] for stormwater upgrades in communities.

- Support the development of a new Minnesota Public Facilities Authority funding program to support resilient infrastructure projects.

Policy

- Seek public assistance from the state and federal government for groundwater flooding impacts. Much like the public assistance that is granted to support areas affected by surface flooding, tornadoes, etc., public assistance is also needed for groundwater flooding impacts to protect and adapt private and public infrastructure.
- Support Hennepin County's strategy to reassess policies and practices to manage increased stormwater volumes.

Projects

- Support MPRB's effort to protect and restore diverse natural habitats that provide multiple benefits including resiliency to extreme weather events.
- Support the City of Minneapolis' efforts to incorporate stormwater infrastructure as part of City projects, which would manage the volume and rate of stormwater runoff.
- Support MCWD's effort to optimize the operation of the Gray's Bay Dam using the machine learning model.
- Support the City of Minneapolis' efforts to plan and invest in storm infrastructure improvements through the use of hydraulic and water quality models.
- Support MCWD's effort to implement high-impact capital projects watershed wide, which would manage the volume and rate of stormwater runoff.
- Support MPRB, MCWD, and the City of Minneapolis in the implementation of the water resource projects identified in the MPRB Minnehaha Parkway Regional Trail Master Plan, which would manage the volume and rate of stormwater runoff and create additional floodplain storage along Minnehaha Creek.
- Support Hennepin County's and the City of Minneapolis' efforts to promote and expand the use of green infrastructure as a tool to better manage increased stormwater resulting from the shift to a wetter climate.
- Support Hennepin County's effort to protect and restore streams, wetlands, floodplains, habitat, and uplands.
- Support the DNR's Climate Change Project in Shoreland and Floodplain areas that will translate and communicate science-based information on climate change into actionable best practices for developing resilient communities and informed citizens.

Regulation

- Support the City of Minneapolis in the implementation of their updated stormwater ordinance, which will reduce the volume and control the rate of stormwater runoff from redevelopment and reconstruction projects.
- Support Hennepin County's effort to develop stormwater design standards for mid-century precipitation projections.

In 2007 MGS surficial geology atlas, Meyer (2007) describes the map units that underlay the Lake Nokomis Areas of Concern as show in **Figure 91**.

- **Ql: Lacustrine deposits** – Sand, loamy sand, and loam, with local organic-rich layers; includes human-made beaches. In places overlies muck or peat. Covered by thick, artificial fill in developed areas. Width of exposure varies depending on the water level in the lake. Many deposits along the edges of lakes and bogs are too narrow to be shown.
- **Qp: Peat and muck** – Partially decomposed plant matter deposited in marshes. Includes fine-grained organic matter laid down in ponded water, and marl (calcareous clay) at depth in places. Also includes narrow deposits of alluvium along streams, narrow beach deposits, and small bodies of open water. In developed areas, many of these deposits have been buried under artificial fill (Meyer, 1985; Meyer and Hobbs, 1989; Lusardi, 1999); the organic sediment is commonly removed prior to filling in areas where major structures are built.
- **Qno: Outwash** – Sand, gravelly sand, and gravel. Deposited by meltwater issuing from the ice margin. . . Commonly bounded by scarps where laid down in channels.
- **Qwr: Richfield terrace** – . . . Most contacts with other map units are scarps . . .

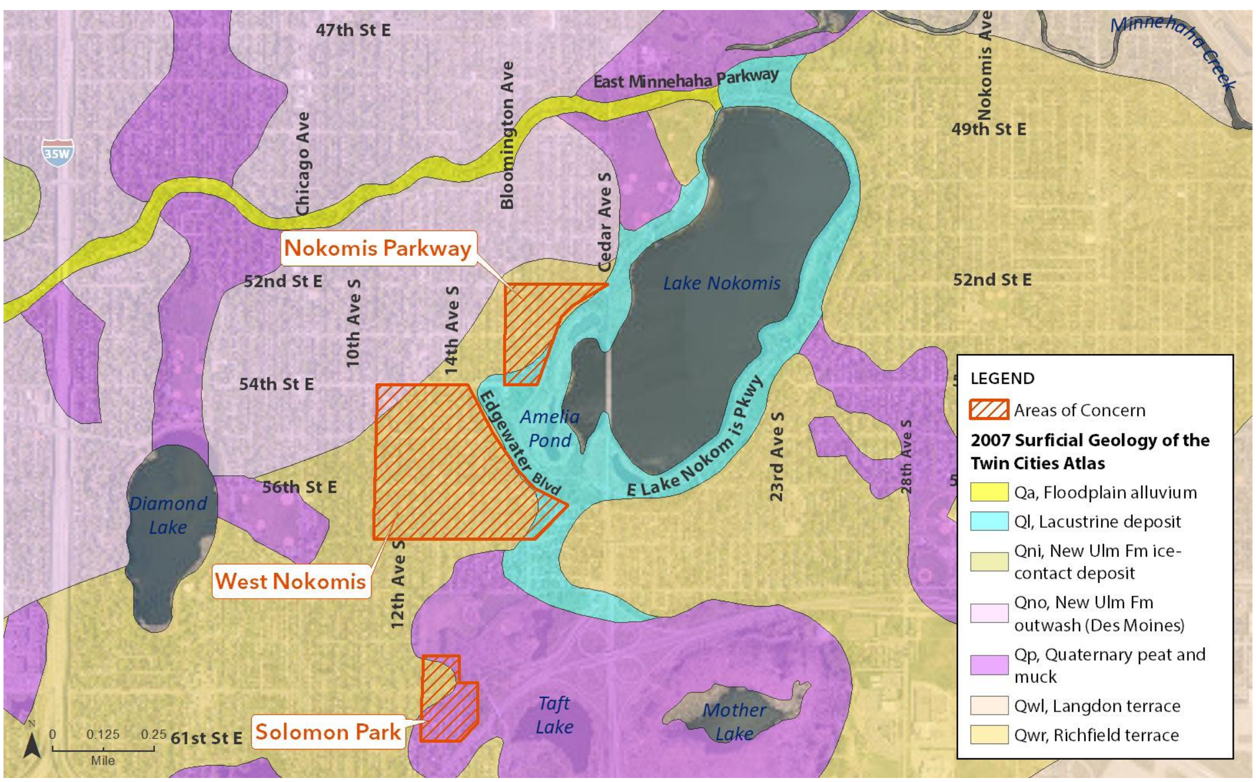


Figure 91: Surficial Geology Atlas: *Excerpt from the 2007 Surficial Geology Atlas of the Twin Cities for the Lake Nokomis area. (Credit: MCWD; Data Source: Meyer, 2007).*

Plate 3 of the 2018 Hennepin County surficial geology atlas, Steenberg et al. (2018) describes the map units that underlay the Areas of Concern as shown in **Figure 92**:

» **Ql: Organic clayey silt to sand** – Fine-grained organic matter (sapropel), may be both massive and laminated, fine-grained, sand, silt, and clay in current and former lake basins or other areas of non-flowing water. . . Most, if not all, of these lakes originated as water ponded in former ice-block locations. Where patterned (unit QAfhl), the lake was drained, excavated, and filled with other material. Unit is especially common in developed areas. Lacustrine deposits.

» **Qp: Organic detritus** – Partially decomposed, fine- to coarse-grained plants matter in post-glacial land surface depressions currently or formerly beneath the water table. Only sediment with organic content greater than 50% is mapped. It is commonly underlain by organic-rich, Holocene Epoch, lacustrine, fine-grained sand, silt, and clay. . . Peat.

» **Qat: Terrace sand and gravel** – Similar to unit Qag in composition but no longer part of the present day channel of the Crow, Mississippi, and Minnesota Rivers. Deposited by formerly fast-flowing, channelized glacial meltwater related to glacial River Warren and the ancestral Crow and Mississippi Rivers. Terrace sediment.

» **Qts: Fine-grained sand to sandy gravel** – Fine-grained sand to gravel of mixed provenance. . . The surface expression is channelized to the west but expands into a broad plain to the east. The plain is marked by numerous kettle depressions and pits representing former buried ice blocks that eventually melted; many of these pits are now lakes. . . Twin Cities member outwash.

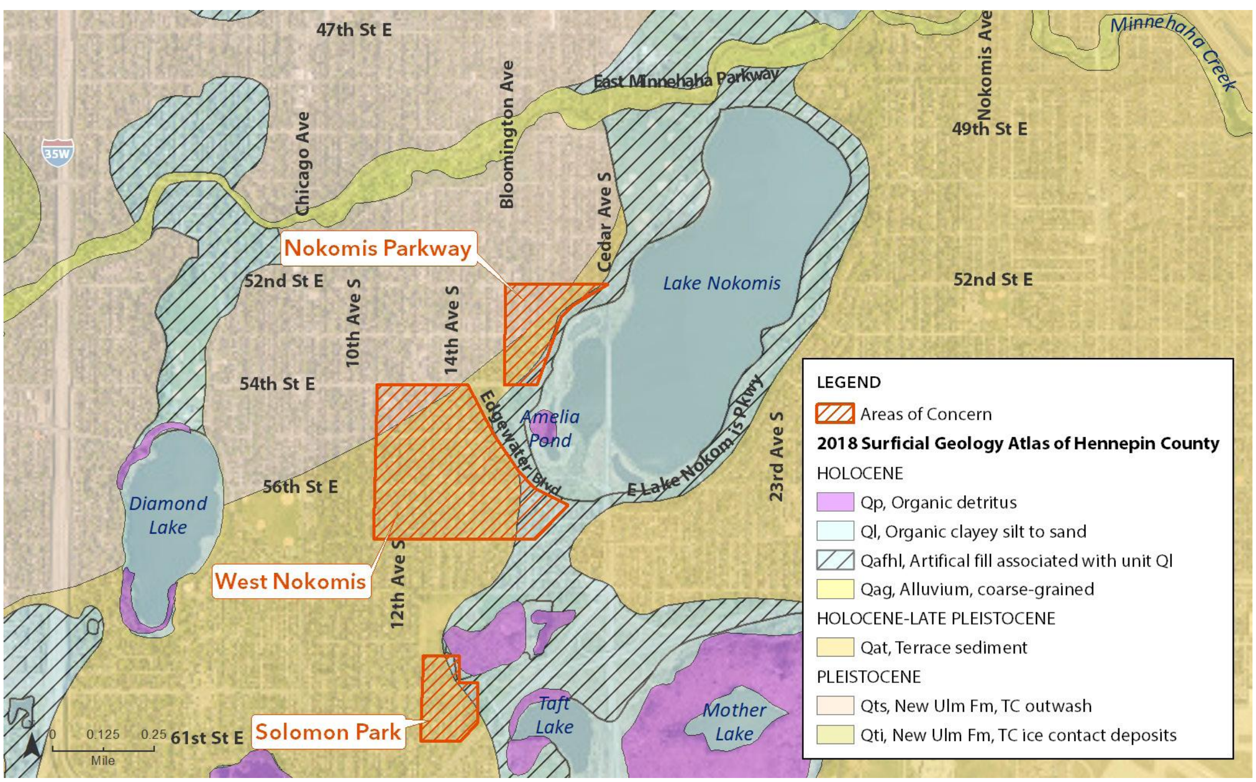
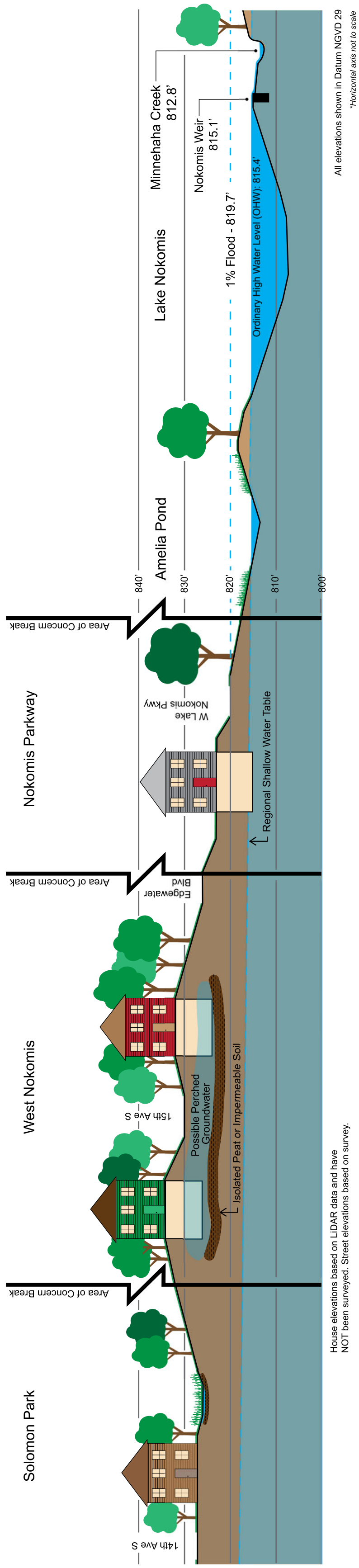


Figure 92: 2018 Surficial Geology. *Excerpt from the 2018 Surficial Geology Atlas of Hennepin County for the Lake Nokomis area. (Credit: MCWD; Data Source: Steenberg et al., 2018)*


Solomon Park
West Nokomis
Nokomis Parkway
Amelia Pond
Lake Nokomis
Minnehaha Creek
812.8'
Nokomis Weir
815.1'
1% Flood - 819.7'
Ordinary High Water Level (OHW): 815.4'
840'
830'
820'
810'
800'
14th Ave S
15th Ave S
Edgewater Blvd
W Lake Nokomis Pkwy
Area of Concern Break
Area of Concern Break
Area of Concern Break
Possible Perched Groundwater
Isolated Peat or Impermeable Soil
Regional Shallow Water Table
House elevations based on LIDAR data and have NOT been surveyed. Street elevations based on survey.
All elevations shown in Datum NGVD 29
*Horizontal axis not to scale