Baseflow Restoration in Minnehaha Creek Watershed with Stormwater Infiltration

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MINNEHAHA CREEK WATERSHED DISTRICT

Department of BIOPRODUCTS AND BIOSYSTEMS ENGINEERING
UNIVERSITY OF MINNESOTA

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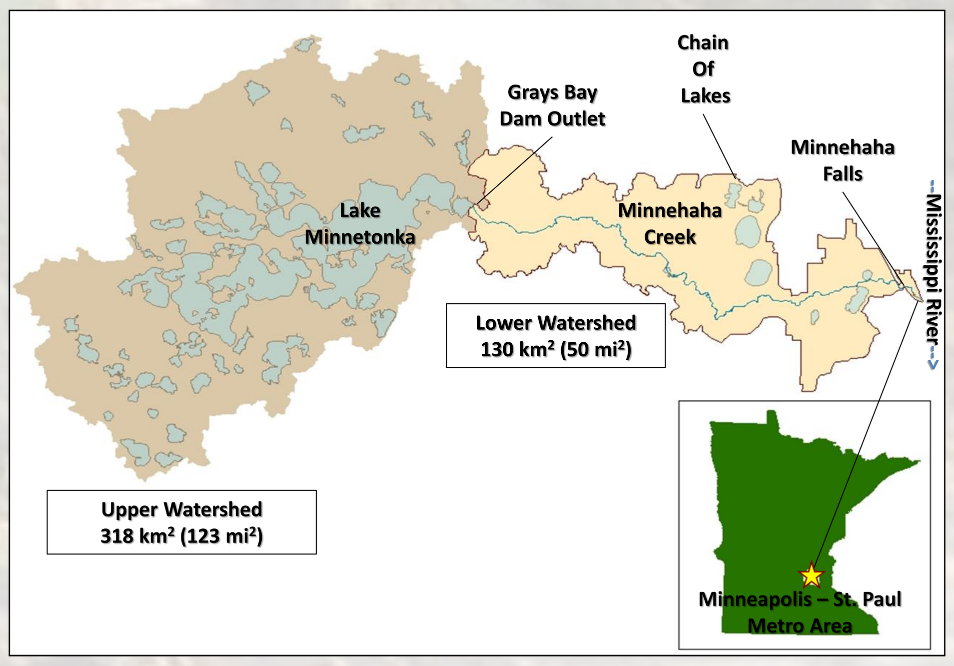
Abstract

Minnehaha Creek is among the most valued surface water features in the Minneapolis, MN metro area. Flow in Minnehaha Creek is heavily dependent on discharge from the stream's origin, Lake Minnetonka, the outlet of which is closed during drought periods to maintain water elevations in the lake resulting in low- (or no-) flow conditions in the creek. Stormwater runoff entering directly to the creek from the creek's largely urbanized watershed exacerbates extremes in flow conditions. As a result, there is great interest in enhancing the cultural and ecosystem services provided by Minnehaha Creek through improvements in streamflow regime by reducing flashiness and sustaining increased low-flows. Determining the potential for achieving improvements in flow requires first that the current sources of water contributing to low-flows in the creek be identified and quantified. Work on this source identification has involved a number of different approaches, including analyses of the streamflow record using a hydrologic system model framework, examination of the underlying geology of the region, estimation of groundwater-surface water exchange rates within the channel and riparian corridor using temperature probe, seepage meter, and piezometer measurements, and analyses of the stable isotopes of oxygen and hydrogen in samples of stream water, groundwater, and rainfall.

Analysis of baseflow recessions using the method of Brutsaert and Nieber (1977) indicates that only a small portion of the catchment, likely just the riparian zone, contributes to baseflows. This result appears to be supported by the observation that the limestone/shale bedrock layer underlying the surficial aquifer has a non-zero permeability, and in a significant portion of the watershed the layer has been eroded away leaving the surficial aquifer 'bottomless' and highly susceptible to vertical (down) water loss. In addition, the analysis of the stable isotopes indicates that much of the low flow volume originates from surface storages including wetlands and small lakes within the watershed, rather than a groundwater source. From the stable isotope analysis it is estimated that only 5 % of the water recharging into the surficial aquifer seeps into the creek. The groundwater-surface water exchange measurements along the main channel throughout the watershed show a trend that groundwater enters into the creek in the upper reaches, while the flux exchange is from the creek to groundwater in the lower reaches. To address the issue of low groundwater contribution to low-flows in the creek it is proposed to divert stormwater to key locations within the riparian zone along the creek, and to infiltrate that water and store it for slow release to the creek during non-rain periods.

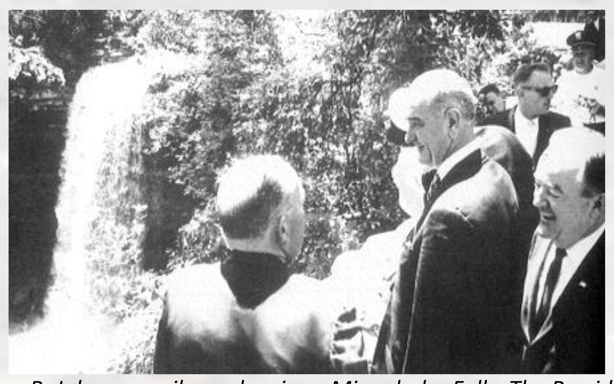
Project Location



Flowing nearly 22 miles from its origin at the Grays Bay Dam Outlet of Lake Minnetonka to the Mississippi River, Minnehaha Creek ranks among the Twin Cities' most valued natural resources. The focus of this project was on the lower portion of the Minnehaha Creek watershed (highlighted) that contains the entire length of the creek.

The Problem…

The storied Minnehaha Falls are perhaps the creek's most popular feature and attract over a half a million visitors each year. Frequent drought periods – which have left the creek and its falls dry in 9 of the last 14 years – impair both the ecological and cultural value of the creek.



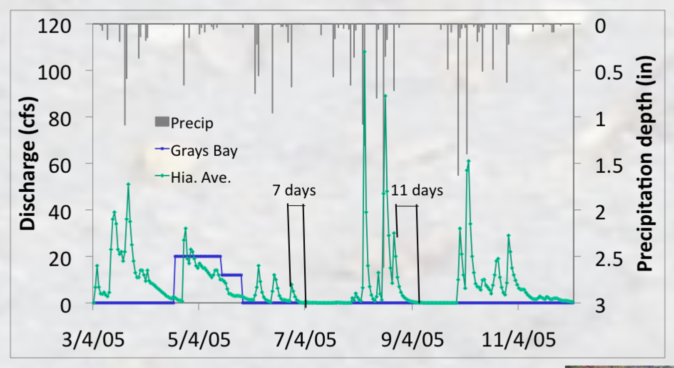
President Lyndon B. Johnson smiles as he views Minnehaha Falls. The Presidents June 1964 visit coincided with a drought during which flow in the creek had ceased. To provide the president with a view of the falls, the City released 6 million gallons of water from Minneapolis fire hydrants (Halleberg 1995).

Given interest in both improving flow conditions in the creek and managing stormwater runoff, we have posed the following question:

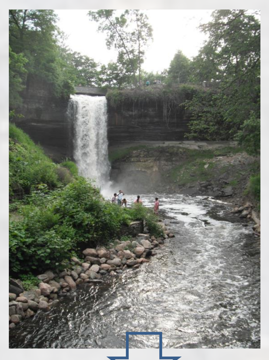
"Can stormwater runoff be infiltrated and stored in the shallow aquifer to contribute to baseflow in Minnehaha Creek?"

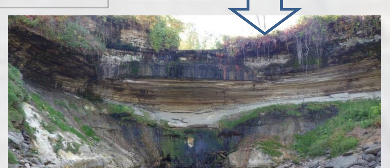
To answer this question, we must first understand the following:

- ***What is the existing contribution of groundwater relative to other sources of flow in Minnehaha Creek across a spectrum of flow conditions?***
- ***What is the existing status of groundwater-surface water interactions in Minnehaha Creek? How do groundwater contributions vary spatially along the creek? Can we identify specific locations suitable for artificial recharge (and subsequent stream discharge) through focused stormwater infiltration?***
- ***What are the underlying factors that drive observed groundwater-surface water interactions in the Minnehaha Creek system (e.g., geology, altered hydrology and groundwater residence time, etc.)?***



Outflow from Lake Minnetonka at Grays Bay and 20 miles downstream at a USGS gauging station below Hiawatha Ave. during 2005. Apart from Lake Minnetonka only providing discharge to moderate flows, the time from the hydrograph peak to zero flow can be as short as 7 days. Extremes in flow conditions are exacerbated by stormwater drainage throughout the creek's urbanized watershed.





Minnehaha Falls went dry most recently in the fall of 2012.

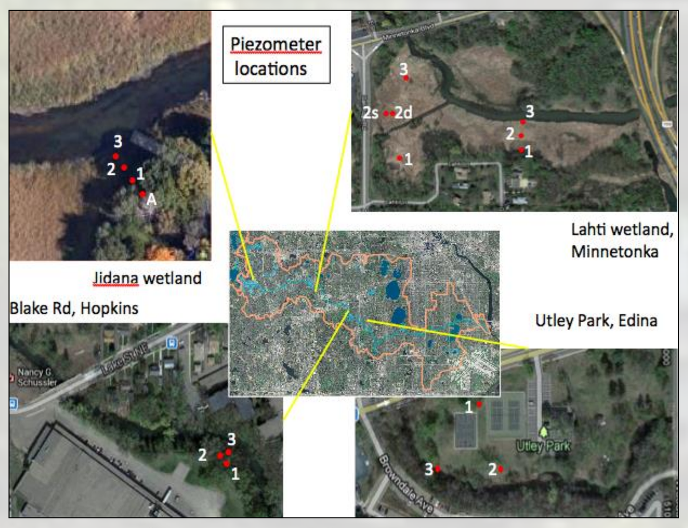
Field Investigations

To locate potential areas for use of stormwater to augment baseflow, site-specific measurements of groundwater flux were completed throughout the Minnehaha Creek Watershed.

Piezometer Measurements

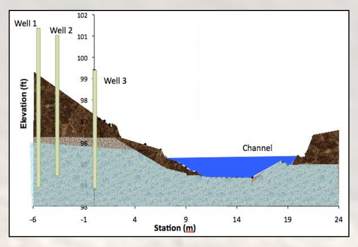
Piezometers were installed within the creek's riparian corridor to measure potential groundwater fluxes from the surrounding area into the creek.

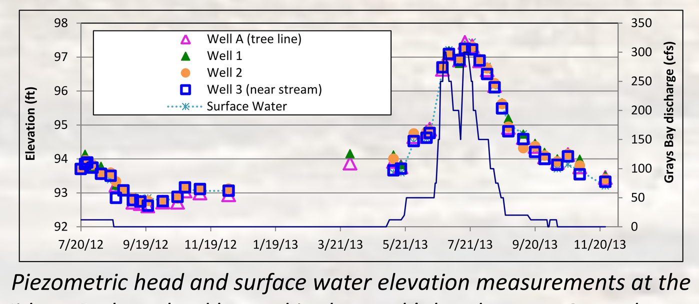
Undergraduate student Laina Breidenbach collecting water level data from one of several installed piezometers throughout the Minnehaha Creek Watershed. Water levels were also measured in the creek to determine a stage difference or hydraulic gradient between the creek and surrounding riparian corridor.



Location of piezometer installations along Minnehaha Creek. Filled circles denote approximate location of piezometers. Piezometers were placed at varying proximities to the creek at each location to better determine the spatial distribution of groundwater fluxes.

Cross-section of piezometers installed along the creek at Blake Road. A 1 to 2 ft. silt layer (dark brown shading) overlies a thick layer of compacted loamy sand till. This site is being reviewed for possible stormwater infiltration by MCWD.



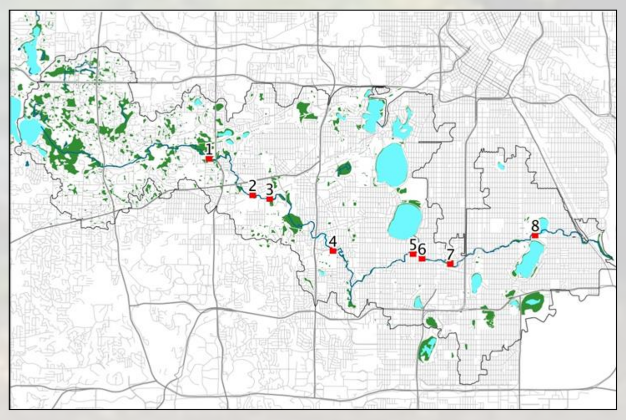


Piezometric head and surface water elevation measurements at the Jidana Park wetland located in the creek's headwaters. Groundwater head is highly correlated with Grays Bay discharge at this site.

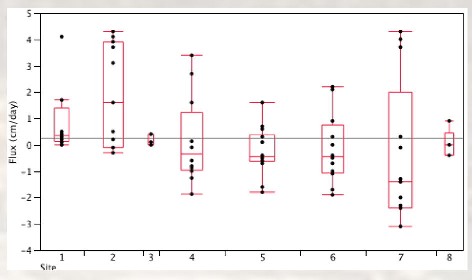
Seepage Meter Measurements

Seepage meters were placed within the channel bed to measure groundwater fluxes into or out of the creek.

(a) Close-up of hose-fittings used to attach the seepage meter to a plastic bag in which the change in a volume of water over a set period of time is measured. The valve is closed when the bag is removed or attached to avoid losing water. (b) Seepage meter deployed in streambed. (c) Trisha Moore measuring the volume of water in seepage meter bags 24 hours after deployment.



Locations of seepage meter measurements on Minnehaha Creek. Many of the locations were previously chosen, potential future locations for stormwater management as outlined by the Minneapolis Park & Recreation Board (MPRB).



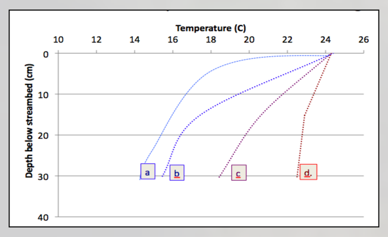
Location	Flux (cm/d)	Direction
1. Lahti Lane	0.5	upward
2. Blake	1.9	upward
3. Reach 20	0.2	upward
4. Utley Park	0.1	upward
5. James	0.3	downward
6. Humboldt	0.2	downward
7. Pleasant	0.1	downward
8. Hiawatha	0	neutral

Box plot and table of seepage meter measurements at 8 locations along Minnehaha Creek. Sites are presented in order from upstream to downstream. The gray horizontal line denotes the average flux across all sites (0.2 cm/day upward); average flux rates by site are listed in the table. Flux values less than 0 signify seepage of surface water into the streambed.

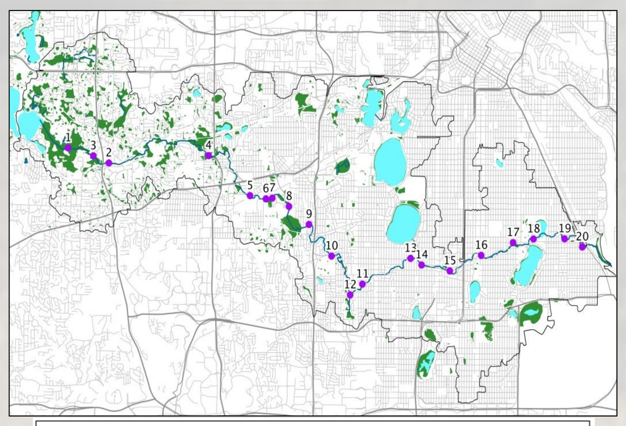
Temperature Probe Measurements

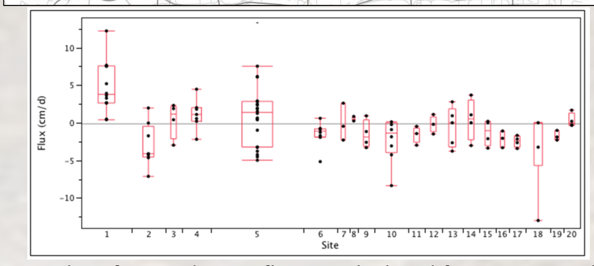
A temperature probe was inserted into the channel bed to measure temperature profiles within sediments and thereby quantify groundwater fluxes into or out of the creek.

(Left) Six inch graduations on temperature probe used to determine relative depth within channel sediments. (Right) Insertion of temperature probe into channel bottom sediments. The overall depth of measurements varied between locations and depended on the type of bed material present.



Profiles of (a) high and (b) medium groundwater flux to the creek, (c) no subsurface flux, and (d) surface water flux to surficial aquifer (loss).





Box plot of groundwater flux as calculated from measured streambed temperature profiles at 20 sites along the length of Minnehaha Creek. Numbered labels in the box plot correspond to numbered locations of temperature probe sites in the map. Positive flux values represent upward groundwater movement; negative flux values denote downward groundwater flux.

Desktop Analyses

An understanding of the contributions of various flow sources, particularly groundwater, in Minnehaha Creek is foundational to assessing the potential to augment those flows through stormwater infiltration. As such, several types of analysis were used to characterize flows and determine overall watershed conditions.

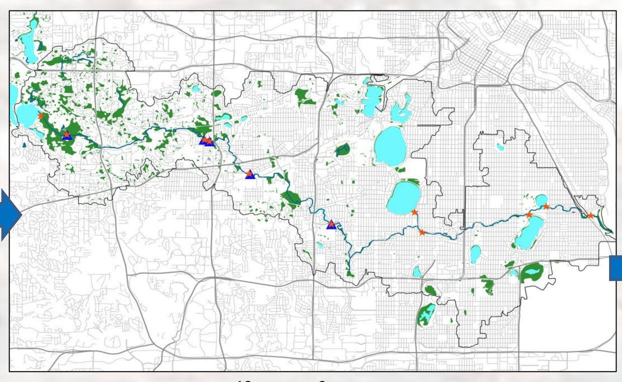
Flow Balance & Isotopic Analysis

In order to identify flow sources contributing to Minnehaha Creek, a flow balance was completed using flow data (2006-2012) from Grays Bay and Hiawatha Ave. gauge locations. Flow components were then further broken down using isotopes within collected water samples to determine the total groundwater input.

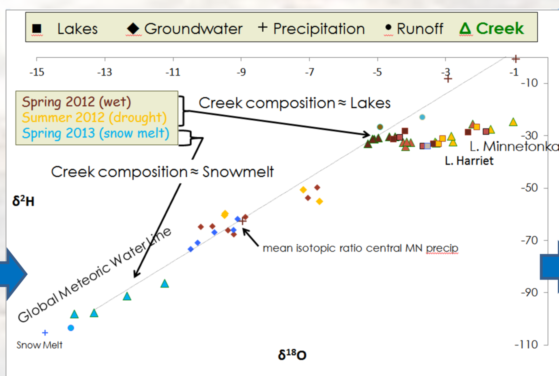
Flow Source	Annual Volume (acre-ft)	Annual Contribution (%)	Runoff Depth (inches)
Grays Bay	20,202	69%	3.09*
Storm flow	5,510	18%	2.06
Baseflow	3,903	13%	1.46
Total flow, Minnehaha Creek	**29,844**	**100%**	---

*Grays Bay depth calculated over upper Minnehaha Creek watershed area (123 mi²); storm and baseflow calculated over lower Minnehaha Creek watershed area (47 mi²).

Average annual flow contributions of Lake Minnetonka vid Grays Bay, stormwater runoff, and other baseflows to average annual stream flow in Minnehaha Creek for the period of 2006 to 2012.



Sample locations for ^{18}O and ^{2}H isotope analysis. Surface water samples are marked with a star symbol and groundwater samples were collected from locations marked with triangles. Samples were collected across a range of seasonal flow conditions.



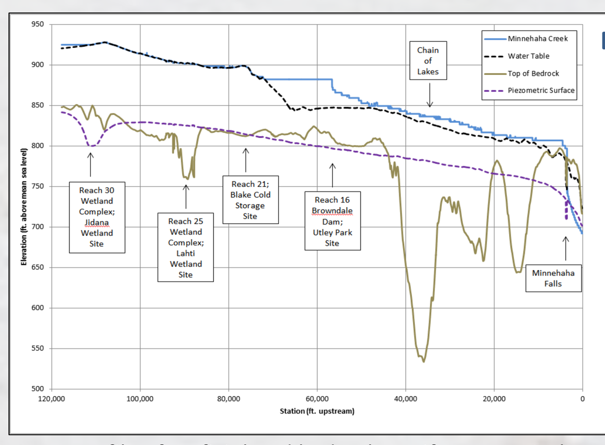
Plot of oxygen-18 ($\delta^{18}O$) and hydrogen-2 ($\delta^{2}H$) isotope ratios relative to the established standard of mean ocean water. Increasing δ values indicate an increasing concentration of heavier isotopes. As indicated by the relative position of the points, the creek's isotopic signature aligns more closely to that of its surface water sources (e.g., Lakes Minnetonka and Harriet) than to its adjacent riparian groundwaters, particularly during the transition from high to low flow conditions.

	% Total Flow in Minnehaha Creek			% Baseflow in Minnehaha Creek	
Sample event	**Runoff**	**Lakes**	**GW**	**Lakes**	**GW**
Spring 2012 (wet)	60	34	**6**	81	19
Spring 2012 (recession period)	--	90	**10**	84	16
Summer 2012 (drought)	--	>95	**<5**	95	5
Spring 2013 (snowmelt)	70	30	**<1**	**	**

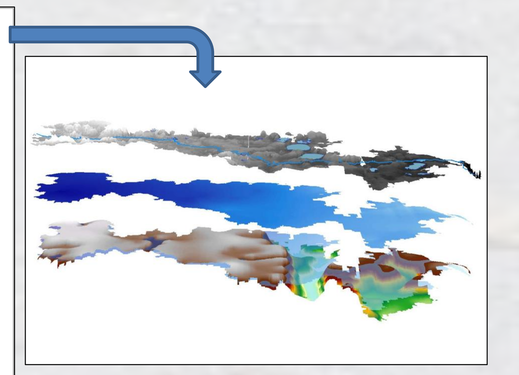
Results of end-member analysis using ^{18}O and/or ^{2}H isotopic compositions of Minnehaha Creek and its source waters; with percent contributions of flow sources relative to total flow (as measured at Hiawatha Avenue) and to baseflow (as determined by applying the baseflow filter of Nathan and MacMahon (1990) to the total stream flow record).

Underlying Geology

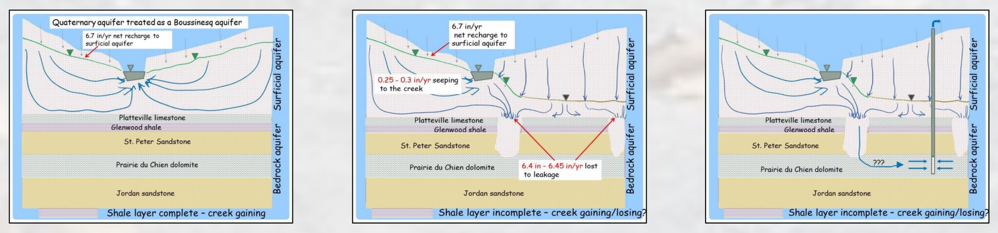
Compilation and characterization of geologic data for the watershed was critical in providing support for the presence of 'gaining' and 'losing' reaches along the creek.



Long profile of surficial and bedrock aquifer systems along Minnehaha Creek. Created using 1 M LiDAR Surface (MnGeo 2011) and subsurface layers from Tipping, 2011.



Long profile converted to a 3-D image of watershed. From top to bottom: 1 M LiDAR surface (MnGeo 2011), water table (surficial aquifer), top of bedrock aquifer, and piezometric surface (Tipping 2011).



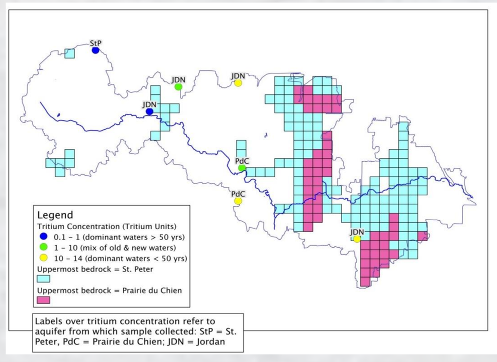
Conceptual illustration of losing and gaining reaches of the creek as influenced by underlying geology. The underlying Platteville-Decorah Shale formation inhibits downward flow , if present.

Additional Analyses

Reach	1892-Width (ft)	1912-Width (ft)	2012-Width (ft)
1	37	-	35
2	29	43	34
3	38	49	80
4	43	-	39
6	34	-	34
7	33	31	34
8	34	29	33
9	33	31	33
10	38	32	32
11	15	26	36
12	29	-	33
Total (average)	**31**	**31**	**38**

A channel width analysis was conducted for the length of Minnehaha Creek for use in reach-scale groundwater flux calculations and to determine the magnitude of any potential historical channel widening. Although sinuosity has been decreased significantly, channel width measurements from 1892 and 1912 survey maps (Reaches 1-12) and 1 M LiDAR data (MnGeo 2011) did not indicate significant channel widening.

Tritium data compiled by Tipping (2011), was plotted and used as an indicator of groundwater age across the lower Minnehaha Creek Watershed. Groundwater age tends to decrease with distance downstream along Minnehaha Creek indicating more rapid recharge and, likely, reduced residence time in the surficial aquifer. Reduced residence time in the lower portion of the watershed correlates with measured 'losing' (surface to aquifer) reach-scale fluxes.



Many thanks to Yvette Christianson, Tiffany Forner, James Wisker, and Michael Hayman of MCWD, Udai Singh of MWMO, Perry Jones of the USGS, and University of Minnesota students: Laina Breidenbach, Tom Detrich, Michael Kramer, Ugonna Ojiaki, Jess DeGennero, & Lauren Sampedro. We also thank MCWD and MWMO for the opportunity and funding required to conduct research within the Minnehaha Creek Watershed.

Overall Conclusions

- Surface waters (e.g., lakes, wetlands) are the predominant source of flow in Minnehaha Creek, particularly during low flow periods. In late August 2012, less than 10% of flow in the creek (< 1 cfs) was attributed to groundwater based upon the isotopic composition of water in the creek.
- Watershed-wide groundwater fluxes are influenced by strong *downward* gradients. As reported by Tipping (2011), median travel time through the surficial aquifer to the underlying bedrock aquifer is on the order of one-half year. This means that water infiltrated far from the creek riparian zone is "lost" to deep bedrock recharge rather than discharging to the creek as baseflow.
- According to preliminary streamflow recession analysis (not shown here) by the method of Brutsaert and Nieber (1977) about 5% of the watershed is underlain by effective stream-feeding aquifers. This result corroborates with geologic data indicating rapid vertical travel throughout the surficial aquifer and indicates that very little groundwater is available during drought periods (as demonstrated by isotopic data).
- Groundwater fluxes are generally upward between the creek's headwater wetlands and Browndale Dam. Flux magnitudes ranged from 0.1 to 1.9 cm·d^{-1} as determined with seepage meters and temperature profile measurements. Between Browndale Dam and Hiawatha Ave., groundwater fluxes were generally in the downward direction, and ranged from 0 to 0.4 cm·d^{-1}.
- Considering evidence from seepage measurements, groundwater fluxes inferred through streambed temperature profiles, piezometric head measurements, and characterization of subsurface conditions, groundwater discharge could be augmented through focused stormwater infiltration at sites upstream of Browndale Dam such as:
  - The Cold Storage site along Blake Rd. in Hopkins, MN
  - Utley Park in Edina, MN

  **These areas were chosen due to the presence of the Platteville-Glenwood shale formation and/or the presence of an underlying sandy-clay till to constrain or prevent seepage loss.*
- Potential for baseflow augmentation may be limited below the Chain of Lakes.

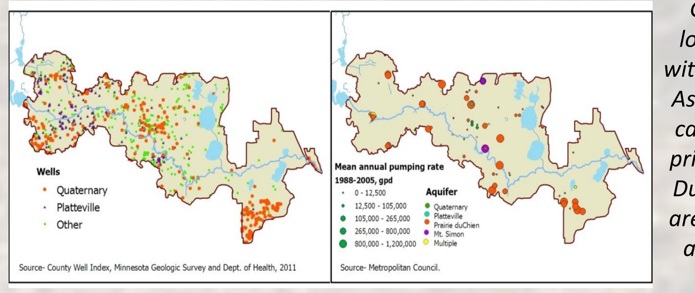
Potential factors driving observed groundwater-surface water interactions within Minnehaha Creek

- Geologic Controls: the Platteville Limestone and buried bedrock valleys.

-Minnehaha Creek is directly connected to the water table within the surficial aquifer in the upper portion of the watershed, but the water table diverges in the lower portion of the watershed indicating potential losses to the underlying aquifer. This finding correlates directly with expected losses within the unconsolidated sediments of the buried bedrock valley in the lower portion of the watershed.

-The Platteville Limestone is generally considered an 'aquitard', but in areas where the layer has eroded away, the surficial aquifer is considered 'bottomless' and surface waters have a direct connection to the deeper, Prairie Du Chien Aquifer (overall 'loss' of groundwater). This finding is supported by Tritium data, with 'younger' waters observed in areas with direct connection to the deeper aquifer system.

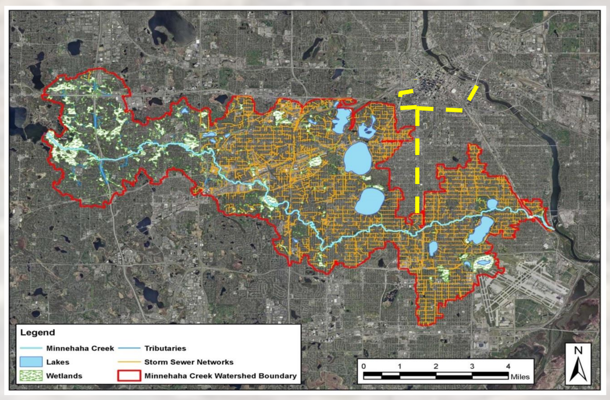
- Groundwater pumping present within the watershed may be exacerbating surface water losses to groundwater.



Groundwater pumping locations and magnitude within the lower watershed. As noted in the map, large capacity wells are located primarily within the Prairie Du Chien Aquifer. In some areas this aquifer can have a direct connection with Minnehaha Creek.

- Increases in impervious surfaces and subsurface drainages within the urbanized watershed reduce infiltration into the surficial aquifer and increase the 'flashiness' of storm events.

Potential sources and sinks of flow to Minnehaha Creek within an increasingly urbanized watershed. Interstate 35W stormwater drainage system indicated by yellow dashed lines. Aerial photograph from MnGeo 2012 and all other data provided by MCWD.



Future Steps

- Development of a Decision Support Tool to aid MCWD in use of previously collected data and new data for long-term management of baseflow.
- Investigate where groundwater is going
  - 'French drain' effect of sanitary sewer interceptors and I-35W storm sewer tunnel).
  - Determine effects of groundwater pumping within the watershed.

Pumping rate (gpd)	Number of wells	Yield (10^6 ft³/yr/well) Low	Yield (10^6 ft³/yr/well) High	Total Yield (10^6 ft³/yr) Low	Total Yield (10^6 ft³/yr) High
0-12,500	24	0	0.006	0	14.6
12,500-105,000	13	0.006	0.051	7.90	66.4
105,000-256,000	7	0.051	0.129	35.8	90.7
265,000-800,000	9	0.129	0.389	116	350
800,000-1,200,000	8	0.389	0.584	311	467
		TOTAL (million ft³/yr)		470.7	988.7
		TOTAL (inches/yr)		4.1	8.5

(Left) Observed leak in I-35W storm sewer tunnel during construction. (Right) Preliminary analysis results for groundwater pumping within the lower watershed.

- Further geotechnical exploration and piezometer installation at several sites of interest (e.g. MPRB proposed Best Management Practice (BMP) Sites).
- Addition of injected tracer studies and completion of pilot studies on several sites of interest to determine potential for artificial baseflow augmentation.
- Continue collection of water samples for isotope analysis and review existing analyses to confirm conclusions made.

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