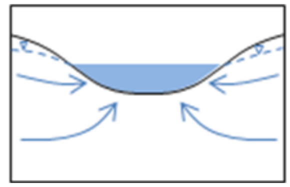
Discharge Lake/Wetland:
Generalized Monitoring Strategy



General Hydrologic Characteristics of Discharge Lakes & Wetlands

Discharge lakes and wetlands are in direct hydraulic connection with the water-table aquifer and receive inflows from groundwater because the lake stage is generally lower than the surrounding water-table elevation. Discharge lakes and wetlands lose water via surface-water outlets such that the rate of groundwater inflow is balanced by outflows from the groundwater system (including evapotranspiration). As such, a discharge lake acts as a groundwater sink by removing water from the groundwater system.

The elevation of the surface-water outlet(s) from the lake control the lake stage and indirectly, the rate of groundwater inflow into the lake or wetland. All other conditions being equal, if the outlet is raised, the groundwater inflows are reduced. If the lake or wetland outlet is raised such that there no longer is flow out of the lake or wetland, the lake/wetland may become a flow-through lake/wetland or possibly a recharge lake/wetland. Conversely, if the outlet is lowered, more groundwater inflows into the lake/wetland and out of the groundwater flow system.

If climatological conditions change to the point where evapotranspiration and reduced precipitation result in the lakes stage dropping below the outlet, groundwater inflows are likely insufficient to keep up with the reduction in runoff and precipitation. The lake/wetland may continue to be a discharge lake/wetland but the discharge source could be through evapotranspiration rather than surface-water outflows.

Groundwater pumping in the vicinity of a discharge lake or wetland can change the overall water balance of the lake/wetland. Groundwater pumping may cause a lowering of the water table, thereby reducing the hydraulic gradient into the lake/wetland and decreasing groundwater inflow into the lake/wetland. If the water table is lowered below the lake-stage elevation, groundwater inflows could cease altogether. Therefore, in order to understand the effects of pumping on discharge lakes and wetlands, it is important that the lake's water balance be understood so that the groundwater component to the water balance can quantified relative to other sources..

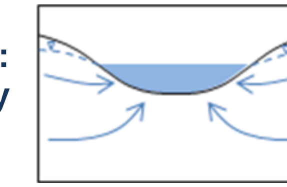
Generalized Monitoring Plan

Although every setting is unique – monitoring plans must take into account local conditions, existing monitoring programs, and coordination among overlapping governmental units – all monitoring should incorporate the following elements:

- Lake-stage monitoring
- Stream flow monitoring
- Groundwater withdrawal rate monitoring
- Potentiometric level monitoring
- Monitoring of other parameters, as a local need is identified

Coordination and Reporting

Monitoring related to discharge lakes/wetlands will require coordination with DNR, nearby water appropriators, WMO's (if applicable), lake associations, and Metropolitan Council (if applicable). Data should be compiled annually in a report to coordinating agencies. All monitoring data should be compiled in electronic form. Alternatives to annual reporting could be a dedicated web site where data can be downloaded.



Typical Monitoring Costs

The following are approximate costs for a generalized monitoring program, as described above. It is important to recognize that local settings may differ from the generalized assumptions. For example, drilling costs for piezometers will vary, depending on the depth to the pumped aquifer (or if there is more than one pumped aquifer) and the need for well screens (instead of open hole intervals). There may be some cost savings realized if existing monitoring installations are already present (e.g., there is an established gauging station or a piezometer). These cost estimates should only be used as a starting point for estimating the actual cost of a particular monitoring program.

	Justification	Frequency	Equipment	Capitol Cost[1]	Variables	Annual Cost[1]	Variables
Stream Flow - Lake outlet	Change in outlet stream flow is a key indicator of potential effect on discharge lakes/wetlands	2 X per year (July and October)	1 stream gauging site	$1,500 - $3,000	Availability of suitable cross-sections; access; desire for manual or automated measurements	$1,500-$2,500	Need for cross-section maintenance; site maintenance;
Groundwater Withdrawal - All pumped wells	Accurate and precise data are crucial to understand the relationship between pumping, changes in water level (i.e. drawdown), and stream flows.	5 minutes or less	SCADA-controlled data loggers in all pumped wells	$ 0 to $40,000 (assumes existing SCADA)	Electronic tabulation of flow rates for each well at 5-minute intervals may require modifications to existing system	$0 - $2,000	Cost dependent on SCADA system and requirements for manual formatting of tabulated data
Potentiometric Levels - Near lake, in direct line with pumped wells	Change in aquifer water level is a key indicator of potential effect on lake stage and outlet flow.	15 minutes or less	A piezometer, pressure transducer, and data logger at each site	$ 15,000 to $30,000	Depth of piezometers; need for well screens (assumes 2-inch diameter piezometers)	$1,500	Well maintenance fee to MDH,
Lake Stage	Pumping may affect lake stage. Lake stage is crucial to habitat and recreational use	Hourly or less	A piezometer, pressure transducer, and data logger in a stilling well	$100 to $3,000	Assumes dedicated pressure transducers and data loggers. Remote telemetry estimated to cost additional $3,000 per piezometer.	$100- $1,000	Assumes that downloading of data would occur along with piezometer transducer downloading)
Other Parameters	These data provide indicators of the overall health of the stream and its capability to support habitat	Hourly or less		$ 3,000 to $4,500	Assumes dedicated pressure transducers and data loggers. Remote telemetry estimated to cost additional $3,000 per piezometer.	$2,000	Assumes quarterly downloading of data by well-owner staff. Add $150 per piezometer for annual data from telemetry (if used)

[1]The above costs do not include costs for conducting aquifer testing (which may be a Water Appropriation Permit requirement for a new pumping well). Annual costs include an estimate of staff costs to the well owner for data handling and maintenance.

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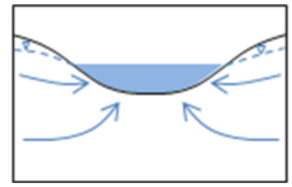
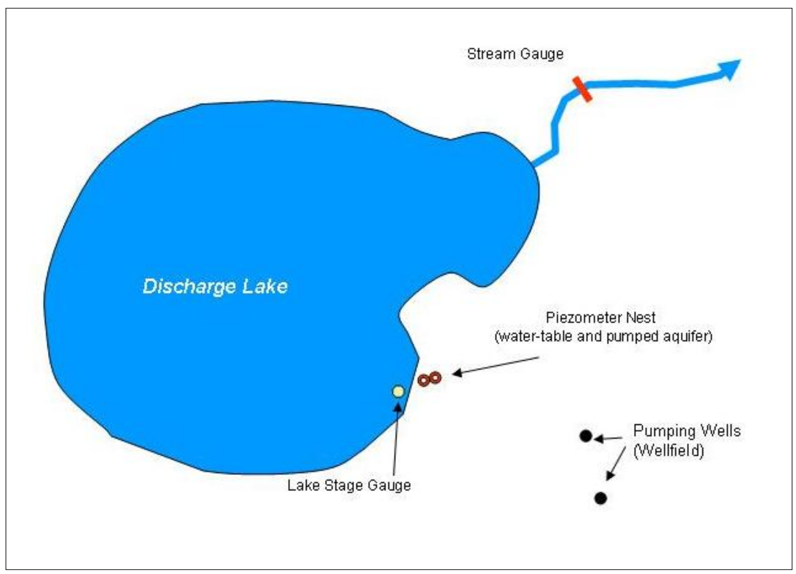
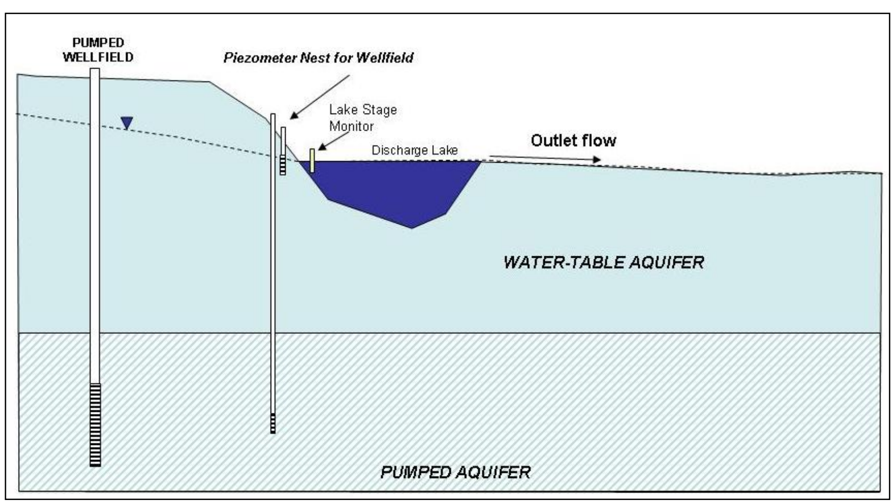


To facilitate the discussion of monitoring programs, a generalized hydrologic setting for a discharge lake is presented.

The discharge lake is assumed to:

(1) have an outlet that carries flow from the basin;
(2) groundwater inflows that are larger than groundwater outflows;
(3) have high-capacity groundwater pumping in the region near the lake; and
(4) pumping is from an aquifer deeper than the surficial water-table aquifer..





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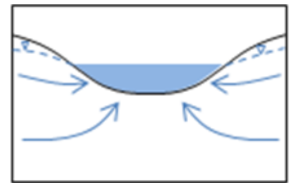

A generalized monitoring system and program consists of the following:

Stream-Flow Monitoring

Purpose

It is important to quantify the rate of stream flow into and out of the lake in order to understand the water balance of the lake. Changes in lake stage may be correlated with reduce stream flows, rather than a drop in the water table. Stream flow measurements can be automated or manual gauging can take place across reliable cross sections on a periodic basis.

Location(s)

Accuracy is important in stream-flow measurements. Stable stream cross sections should be identified or established. Where a reliable rating curve (i.e. relationship between stage height and stream flow) can be developed, stage height can be monitored using manual staff-gauge readings. Periodic manual stream gauging should be conducted to verify the reliability of the rating curve. Other options include the use of automated devices to directly measure average stream flow.

Measurement Frequency

While continuous measurements are preferable, periodic measurements during precipitation periods is typically sufficient, such as in July and October.

Equipment/Method

Both accuracy and precision are important in stream-flow measurements. Stable stream cross sections should be identified or established. Where a reliable rating curve (i.e. relationship between stage height and stream flow) can be developed, stage height can be monitored using bubblers or pressure transducers in stilling wells. Periodic manual stream gauging should be conducted to verify the reliability of the rating curve. Other options include the use of automated Doppler measurement devices to directly measure average stream flow.

Groundwater Withdrawal Rates

Purpose

Accurate and precise pumping rate measurements for individual wells are crucial to understanding the relationship between pumping, changes in potentiometric levels in the aquifer (i.e. drawdown), and stream flows-lake-wetlands stage. Before a causal link can be established, correlations need to be developed between pumping and responses in the aquifer and lake. These correlations cannot be relied upon unless the data are accurate, precise, and frequent. These types of data are important not only in establishing a potential causal effect but also to refute the existence of a hypothesized effect.

Location(s)
Each high-capacity pumped well

Measurement Frequency
Groundwater withdrawal rates must be accurately measured and recorded on a continuous basis for each high-capacity pumped well. At a minimum, measurements should be made every 5 minutes or less.

Equipment/Method(s)
SCADA systems should be capable of measuring and tabulating flow measurements on an interval of approximately 1 minute or less. Electronic tabulation (such as spreadsheets) should be developed and maintained for each well that provides a continuous record of pumping rate at the above interval. Each flow measurement should correspond with an accurate date and time.

Potentiometric Levels
Purpose
In general, high-capacity pumping will affect surface water bodies only if the pumping also affects potentiometric levels in the aquifer that is being pumped and the water-table aquifer. In other words, in order to affect stage elevation and/or flows into/out of surface-water bodies, pumping must induce drawdown. But, it is important to understand that the absence of observed drawdown effects near gaining surface-water features is not, by itself, an indicator that pumping is not affecting the gaining feature. It is possible that pumping even far away from a gaining feature can capture groundwater that would otherwise flow into the gaining feature without ever inducing measurable drawdown in the groundwater system at the gaining feature.

Data from piezometers located between pumping centers and the lake will provide an indication of how extensive the pumping center's cone of depression is and how it changes over the course of a year. The purpose of the well nests adjacent to the trout stream is to correlate changes in the potentiometric surface of both the pumped aquifer and the water table aquifer with stream flows and lake stage. These data are useful in developing a causal relationship between pumping, potentiometric heads, and stream flow. They are also useful in determining if changes in stream flow and lake stage are in response to local pumping or to regional effects, such as regional pumping (many miles away) or climatic/meteorological conditions.

Location(s)
It is recommended that a nest piezometer be installed approximately next to the lake/wetland, in direct line with each pumping center (i.e. well field) and the lake/wetland and completed in the pumped aquifer. The piezometer nest should consist of one

piezometer screened at approximately the same interval as pumping wells in the area and one piezometer screened across or just below the water table.

Measurement Frequency
Such systems are capable of recording head measurements at intervals of 15 minutes or less – a frequency level that is recommended. At a minimum, measurements should be made every 15 minutes or less.

Equipment/Method(s)
Piezometers in bedrock units (i.e. pumped aquifers) should have screens or open-hole intervals that span at least one transmissive zone (e.g., significant horizontal fracture) but should not span the entire aquifer. A screen or open hole interval of less than 20 feet would be preferred. The screen or open hole should preferably be at approximately the same stratigraphic horizon as the mid-point of the open hole portion of the pumped well(s). Water-table piezometers should have screens no longer than 10 feet. In all cases, piezometers should be equipped with pressure transducers and automated data logging systems. They are typically much more cost effective and precise than manual measurements. A system for a single piezometer is usually less than $2,000 and requires download of data on a quarterly basis. Remote telemetry and/or interface with SCADA systems is also possible.

Lake Stage Monitoring

Purpose
To a great extent, concerns over the effects of pumping will relate to lake/wetland stage because lake/wetland stage is a parameter that many users of the lake or wetland will be most keenly aware. Many lakes have a record of lake stage levels, collected usually by volunteers. Most wetlands do not. Some of these records are good and some are of uncertain quality. Most are not collected frequently enough. For lakes and wetlands near high-capacity pumping areas, reliably establishing the natural fluctuation of lake stage is very important..

Location(s)
The location for lake stage monitoring should be at a readily accessible but protected location (to minimize disturbance, accidental damage, and vandalism).

Measurement Frequency
Ideally, hourly measurements would be ideal. Daily measurement should be a minimum frequency.

Equipment/Method(s)
Lake stage should be recorded using stilling wells (to protect from wave action and other interferences) and automated pressure transducers (or other automated stage recorders). Manual staff gauge measurements could augment automated measurements on a bi-weekly to monthly schedule. If there is the capability to manual measure on a regular basis (e.g., there are volunteers from a lake association), manual

measurements with a staff gauge could substitute for a stilling well with automated measurements.

Other Parameters

Purpose

Temperature, dissolved oxygen, and specific conductance data provide indicators of the overall health of the lake/wetland.

Aquifer test pumping of new wells can allow for quantification of aquifer parameters and regional drawdown effects.

Groundwater flow modeling is useful in evaluating the vast amount of data that will be collected over time.

Location(s)

Temperature, dissolved oxygen, and specific conductance data may be collected at stream gauging stations or lake stage monitoring locations.

Aquifer testing may be done on existing or new pumped wells.

Measurement Frequency

Temperature, dissolved oxygen, and specific conductance data may be collected using automated measuring equipment for relatively low cost.

Equipment/Method(s)

New wells should have some sort of aquifer (pumping) test performed to quantify aquifer parameters and regional drawdown effects.

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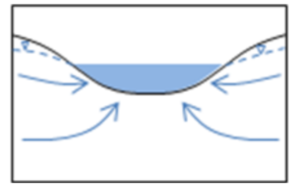


Monitoring Case Study/Example: George Watch Lake, Anoka County

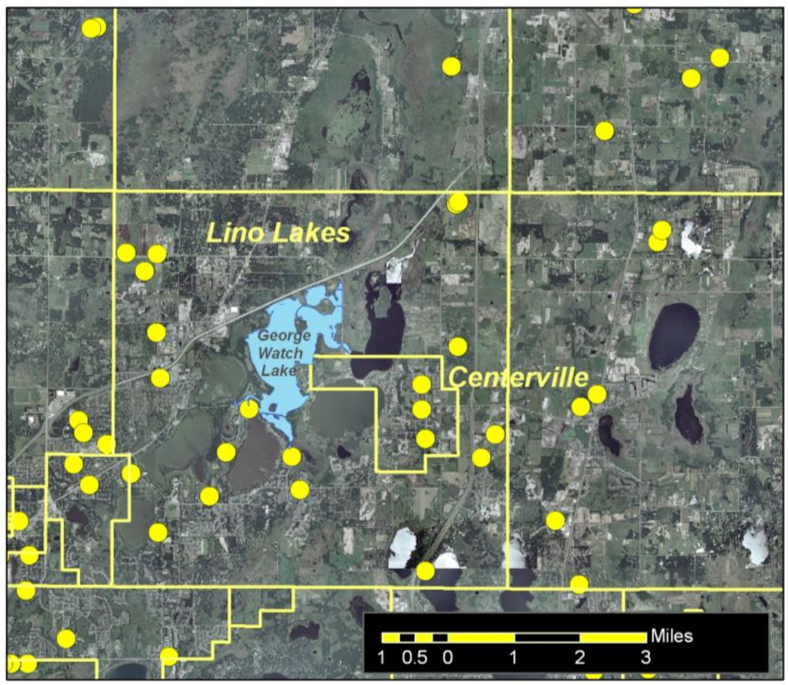
George Watch Lake in Anoka County was identified as a lake that may meet the criteria for a discharge lake – potentiometric heads in the water-table aquifer appear to be above the lake stage and the lake has an outlet.

System to Monitor Effects of Pumping on George Watch Lake

The current monitoring system, if any, is unknown. A monitoring program might include the following:

<u>Potentiometric Levels</u>

Contouring of water levels from the County Well Index has been used, in part, to identify George Watch Lake as a discharge lake These data suggest that lake stage is below the surrounding regional water table and is a surface-expression of the water table. This means that changes in the water-table elevation could result in changes in groundwater flow into the lake. In particular, a lowering of the water table over time could result in decreases in lake stage.



Wells with Water Appropriations Permits

It is important to understand the correlation between the elevation of the water table and pumping. In order to do this, installing another piezometer adjacent to the water-table piezometer (i.e. a piezometer nest) would serve to relate any water-table elevation changes to changes in the potentiometric elevation of the pumped aquifer.

<u>Stream-Flow Monitoring</u>

For discharge lakes, it is important to understand the overall water balance of the lake. Components of the lake water balance, such as evapotranspiration can be difficult to measure. Tributary stream outflows, however, can be measured by gauging stream inflows. Periodic stream gauging of flows will help better define the lake's water balance. Continuous recording devices probably are not necessary.

Lake Stage Monitoring

Continuous lake stage monitoring at a secure location should be initiated if not already underway. It is important to obtain an understanding of the natural fluctuation of the lake stage over time so that changes that are outside of normal fluctuation ranges can be identified. It is also important to obtain data that relate lake stage to water-table elevation.

Groundwater Withdrawal Rates

Surrounding communities obtain groundwater from the Franconia-Ironton-Galesville aquifer. It is absolutely critical that ALL high capacity wells in the area accurately and continuously measure the pumping rates of each well and maintain these records. Flow rates are necessary – not power use or on-off records. In the absence of good pumping records it will be nearly impossible to understand the effects of pumping on the lake.

Other Parameters

Lake quality parameters, such a temperature, turbidity, clarity, etc. are useful for many evaluations but are likely not necessary for the purposes described herein.