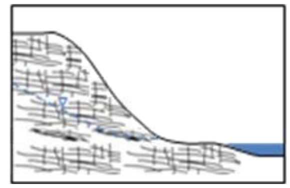
Karst Spring:
Generalized Monitoring Strategy



General Hydrologic Characteristics of Karst Springs

Karst spring means a location of concentrated groundwater discharge from conduits in bedrock (predominantly solution enhanced conduits or zones in carbonate rocks). Karst springs typically are observed along carbonate rock faces in the vicinity of major groundwater discharge zones, such as the Mississippi River. Karst springs are found issuing from the Prairie du Chien Group and the Platteville Formation in the metro area. These springs tend to form along bedding plane fractures above lower permeability carbonate rocks. The potentiometric surface in the carbonate rock slopes toward the major river, intersecting the ground surface along cliffs and bluffs (thus providing a hydraulic means for artesian conditions necessary to spring formation). Vertical joints, fractures, and bedding planes that have been enlarged through dissolution of the carbonate rock form a network of preferential flow paths in the rock above the lower permeability carbonates, concentrating flow over a large area into a narrow conduit zone.

Karst springs are numerous along the bluffs of the Mississippi River, south of Washington Avenue to Fort Snelling. These springs form in the Platteville Formations, at the top of the Hidden Falls Member (a more massive dolomite, compared to the overlying Carimona and Magnolia Members). The Hidden Falls Members serves to impede downward flow as the potentiometric surface slopes toward the river. The result is a number of springs issuing forth from outcrop faces of Platteville Formation, cascading down the face of the Hidden Falls member, and discharging as spring-fed brooks into the Mississippi River. Springs in the Prairie du Chien Group also form. An example are springs along the St. Croix River in Denmark Township, Washington County.

At a large scale (e.g., acres to square miles), regional groundwater flow trends (direction, potentiometric surface, etc.) can be used to predict where hydrologic conditions would be conducive to karst spring formation. But because karst spring formation is also predicated on the nature of solution cavity connectivity, the actual location of a spring cannot be accurately predicted. The approximate spring shed of a karst spring can be estimated from potentiometric maps and groundwater modeling simulations but karst networks, superimposed on the potentiometric surfaces, result in some uncertainty in the “spring shed” of a given spring. In some cases, flow paths and connectivity can be delineated using dye tracing methods.
Karst springs are places where groundwater’s inevitable flow toward the major rivers have been intercepted by localized geologic conditions that bring the water to the ground surface “prematurely”. But in almost all cases, the water that issues from the springs flows quickly along surface channels to the river. The water is taking a slightly different pathway to its ultimate destination. However, karst springs often have special significance because they can be places of beauty, biodiversity, and cultural importance.

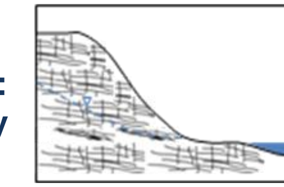
Generalized Monitoring Plan

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:

- Spring 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 karst springs will require coordination with DNR, nearby water appropriators, WMO's (if applicable), 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
Spring Flow • Headwater site	Change in spring flow is a key indicator of effects on spring.	Hourly or less	1 stream gauging site	$5,000 - $15,000	Availability of suitable cross-sections; access; stage vs. Doppler measurements	$1,000-$4,000	Need for cross-section maintenance; site maintenance; Manual measurement verification of flow rate
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 spring 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 • Midway between pumped well(s) and spring	Change in aquifer water level is a key indicator of potential effect on spring flow.	15 minutes or less	A piezometer, pressure transducer, and data logger at each site	$ 12,000 - $ 40,000	Depth of piezometers; need for well screens (assumes 2-inch diameter piezometers)	$50	Well maintenance fee to MDH
Other Parameters	These data provide indicators of the overall health of the spring	Hourly or less		$ 1,500- $3,000	Assumes dedicated pressure transducers and data loggers. Remote telemetry estimated to cost additional $3,000 per piezometer.	$1,000	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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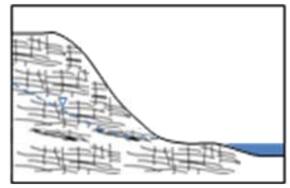
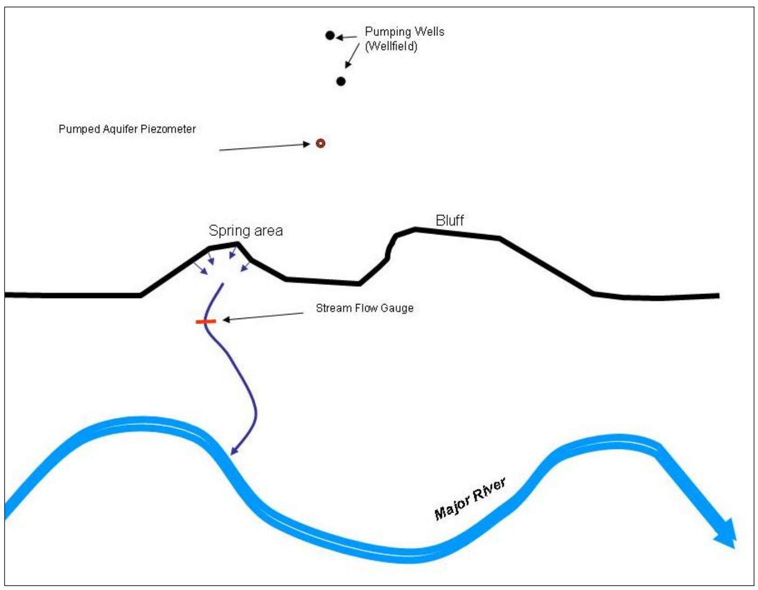


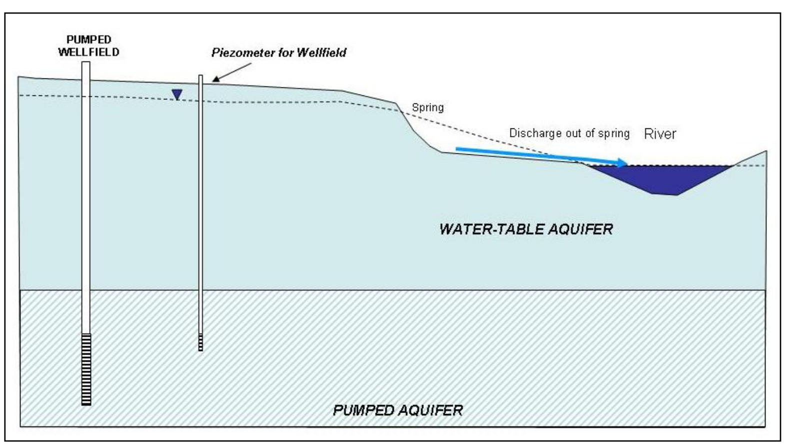
To facilitate the discussion of monitoring programs, a generalized hydrologic setting for a karst spring is presented. The karst spring is assumed to:

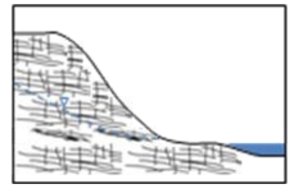
(1) have location downgradient of the spring area where flow coalesces into a stream that can be monitored for flow ;

(2) have high-capacity groundwater pumping in the region near the spring; and

(3) pumping is from an aquifer deeper than the surficial water-table aquifer.







A generalized monitoring system and program consists of the following:

Spring-Flow Monitoring
Purpose
Gauging at appropriate locations will generate data on: (headwater spring contribution to spring-fed creek baseflow (and temporal variability).

Location(s)
Continuous stream flows measurements should be made at one gauging location: below the headwaters spring area where spring flows coalesce to a single stream at a monitorable location.

Measurement Frequency
Continuous measurement is important because correlations need to be developed between stream flow, meteorological influences, and pumping. At a minimum, measurements should be made hourly.

Equipment/Method
Both accuracy and precision are important in stream-flow measurements. Stable stream cross sections should be identified or established. Automated measurement devices should be used. 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, weirs, and/or flumes 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 spring flows. Before a causal link can be established, correlations need to be developed between pumping and responses in the aquifer and spring. 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 springs 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 spring flow, pumping must induce some drawdown. But, it is important to understand that the absence of observed drawdown effects near spring features is not, by itself, an indicator that pumping is not affecting the spring. It is possible that pumping even far away from a spring can capture groundwater that would otherwise flow into the spring without ever inducing measurable drawdown in the groundwater system at the spring.

Location(s)
It is recommended that a piezometer be installed approximately midway between each pumping center (i.e. well field) and the spring and completed in the pumped aquifer. If there are multiple springs from the same aquifer unit discharging in the same area, only one piezometer is needed.

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.

Other Parameters

Purpose

Temperature, dissolved oxygen, and specific conductance data provide indicators of the overall water quality of the spring.

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

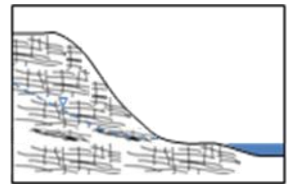
Aquifer testing may be done on existing or new pumped wells.

Measurement Frequency

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

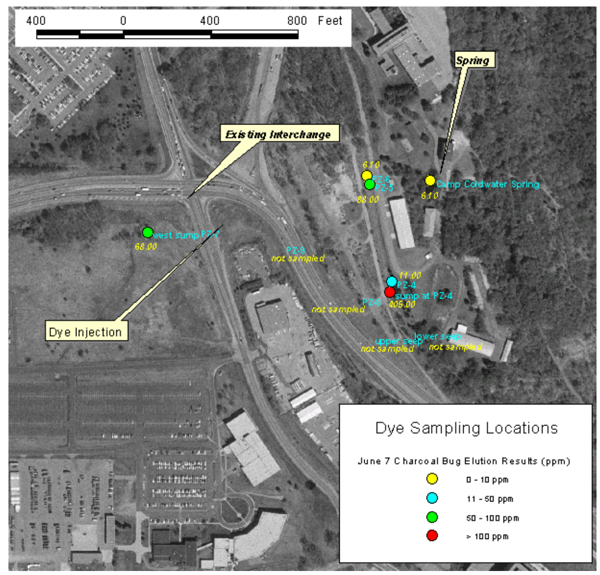
Equipment/Method(s)

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



Monitoring Case Study/Example: Camp Coldwater Spring, Minneapolis

Camp Coldwater Spring is located above the Mississippi River, northeast of the Minneapolis-St. Paul Airport on property where the former U.S. Bureau of Mines research facility was sited. The spring is near historic Fort Snelling and has historical and cultural significance to Native Americans. During reconstruction of the Highway 62- Highway 55 interchange, concerns were raised regarding the effects of dewatering on the spring. Spring flow monitoring was implemented and dye trace studies were performed. Conduit flow paths between the dewatering area and the spring were definitively established through dye tracing.



Groundwater discharges from the Platteville Formation at the upper contact of the massive (i.e. poorly bedded) Hidden Falls Member. The flows are directed into a man-made pond area of about ½ acre. The pond discharges through a culvert beneath a dirt road into a steep drainage leading to the Mississippi River. At the discharge end of this culvert, a continuous flow monitoring system has been established using a flume/weir system attached to the end of the culvert.

System to Monitor Effects of Pumping on Valley Creek

A monitoring system and program is already in place for Camp Coldwater Spring. This program includes the following:

Stream-Flow and Spring-Flow Monitoring

Spring flows from the culvert discharge of the spring pond are monitored using a weir/flume system with continuous stage recorders. In the past, temperature has also been monitored. A record of several yeas has been established.

Potentiometric Levels

During construction of the Highway 62-55 interchange, piezometers were installed upgradient of the spring for purposes of monitoring the effects of construction dewatering on the spring. These piezometers have subsequently been removed.