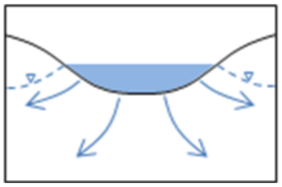
Losing Stream:
Generalized Monitoring Strategy



General Hydrologic Characteristics of Losing Streams

Most stream reaches in the metro area are gaining reaches (i.e. the stream flow increases in the downstream direction due to inflow of groundwater), especially along downstream reaches. In most cases, the losing portion of a stream is near it's headwaters as overland flows in the upper reaches of the watershed combine to form ephemeral tributaries, wetlands, or ponds. Further downstream, there is sufficient storage in the watershed to maintain continuous flow. Down-cutting of the stream bed by intermittent, high-energy flows results in the intersection of the stream bed with the water table. At this location, the stream changes from a losing stream (leaking water down to the water table) to a gaining stream (receiving flow from the water-table aquifer). Flow in the stream increases in a downstream direction due to groundwater inflows but also due to the contribution of additional overland flow and tributary flow.

Some streams in the metro area have losing reaches over portions of their downstream segment. Streams with large meanders may lose water to the water-table aquifer along the upstream portion of the meander but gain that flow back on the downstream portion – these are not really losing reaches because most streams will exchange flow between the alluvial aquifer over short distances but the overall water balance is unaffected. But there are some settings were a gaining stream will transition into a losing stream due to underlying geologic conditions.

Losing streams may be affected by nearby pumping. For a stream reach to be losing, the stream stage must be higher than the adjacent aquifer's potentiometric head (i.e. hydraulic gradients must be from the stream to the aquifer). If the water table is several feet below the bottom of the stream bed, leakage rates from the stream to the water table become independent of the potentiometric head of the aquifer and the stream is essentially perched. In this case, increased groundwater pumping will have little or no effect on stream flow. However, if the water-table elevation is above the elevation of the stream bed to slightly below the elevation of the stream bed, leakage rates from the stream reach to the water-table aquifer are "head dependent", meaning that pumping could reduce the water-table elevation and thereby increase the overall rate of leakage from the stream..

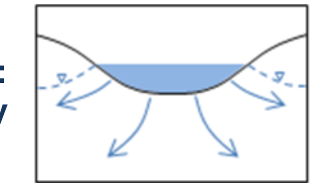
Generalized Monitoring Plan

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:

- 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 losing streams 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
Stream Flow - Upstream site - Downstream site	Change in stream flow can affect habitat, navigation, and recreational use.	Twice Per Year (July and October)	2 stream gauging sites	$3,000 to $5,000	Availability of suitable cross-sections; access; stage vs. Doppler measurements	$3,000-$5,000	Need for cross-section maintenance; site maintenance; Manual measurement 2X per year. If tributaries are present, additional gauging may be necessary.
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 stream, in direct line with pumped wells	Change in aquifer water level is a key indicator of potential effect on stream 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,
Other Parameters	These data provide indicators of the overall health of the stream and its capability to support trout 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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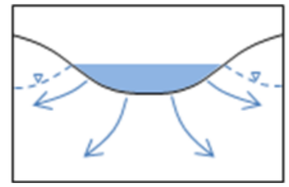
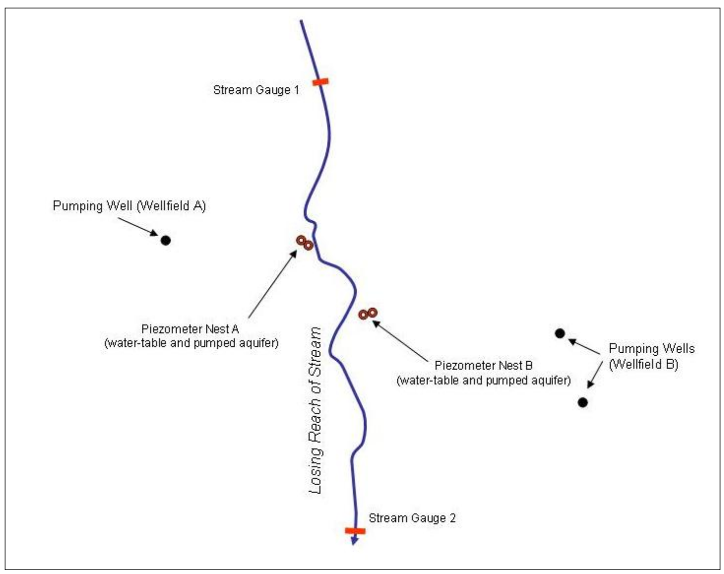
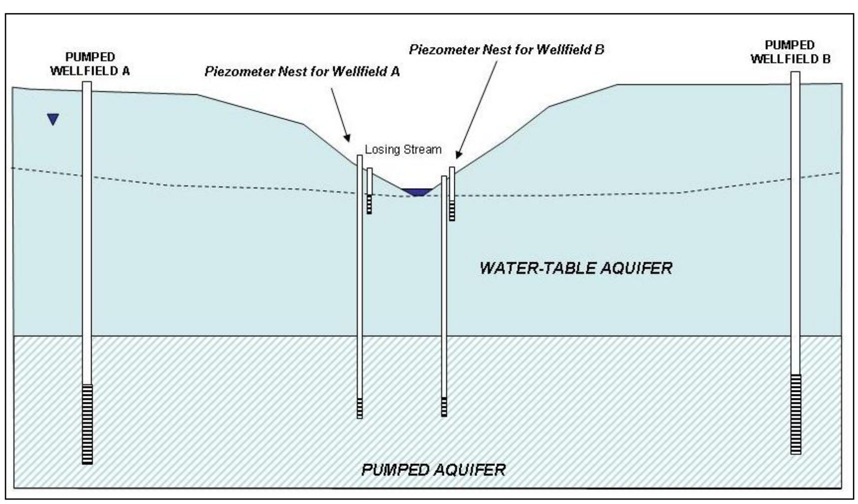


To facilitate the discussion of monitoring programs, a generalized hydrologic setting for a losing stream is presented. The trout stream is assumed to:

(1) originate at its headwaters at some point upstream of the pumping centers;
(2) flow toward a larger river that is downstream of the pumping center;
(3) continue to gain flow (both groundwater and surface-water runoff);
(4) have high-capacity groundwater pumping in the region near the losing stream (in this example, pumping wells on either side of the stream); and
(5) pumping is from an aquifer deeper than the surficial water-table aquifer.





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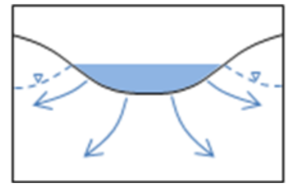

A generalized monitoring system and program consists of the following:

Verification of Connectivity with Groundwater
The first step in monitoring should be the installation of a piezometer within about 25 feet of the stream bank and directly in line with the proposed pumping center. The purpose of this piezometer is to establish that the water table elevation at the steam is above the stream's bottom elevation or within 10 feet of the bottom elevation. If the water table is deeper, no additional monitoring would likely be necessary because the stream reach is likely perched above the water table. However, a single measurement is not sufficient to make this observation conclusive – a year's worth of monitoring would be prudent.

Stream-Flow Monitoring
Purpose
Periodic stream flows measurements are made at two gauging locations: above and below the losing reach of interest. Gauging at these two locations will obtain data on: (1) upstream contribution to stream flow (and temporal variability); (2) stream losses to groundwater along the remainder of the stream reach; (3) contribution of surface-water inflows and duration of hydrograph influence. While continuous measurement of stream flow would be preferred (and in some cases, may be more cost effective), periodic measurements during low-flow periods will likely be sufficient for most settings.

Location(s)
Periodic stream flows measurements should be made at two gauging locations: upstream of the reach that may be affected by pumping and downstream of this reach.

Measurement Frequency
Stream gauging should be conducted at least twice per year during low-rainfall periods such as July and October. Additional measurements are desirable.

Equipment/Method
Both accuracy and precision are important in stream-flow measurements. Stable stream cross sections should be identified or established. Automated measurement devices can be used but manual stream gauging is acceptable. 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.

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. Before a causal link can be established, correlations need to be developed between pumping and responses in the aquifer and stream. 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 surfacewater bodies, pumping must induce drawdown. But, it is important to understand that the absence of observed drawdown effects near gaining surfacewater features is not, by itself, an indicator that pumping is not affecting the stream. It is possible that pumping even far away from a stream can increase streamflow losses to groundwater without ever inducing measurable drawdown in the groundwater system at the gaining feature.

Data from piezometers located between pumping centers and the trout stream 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 from the headwaters springs. 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 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 river, in direct line with each pumping center (i.e. well field) and the stream 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.

Other Parameters
Purpose
Temperature, dissolved oxygen, and specific conductance data provide indicators of the overall health of the stream.

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.

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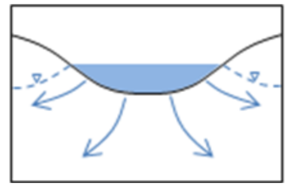
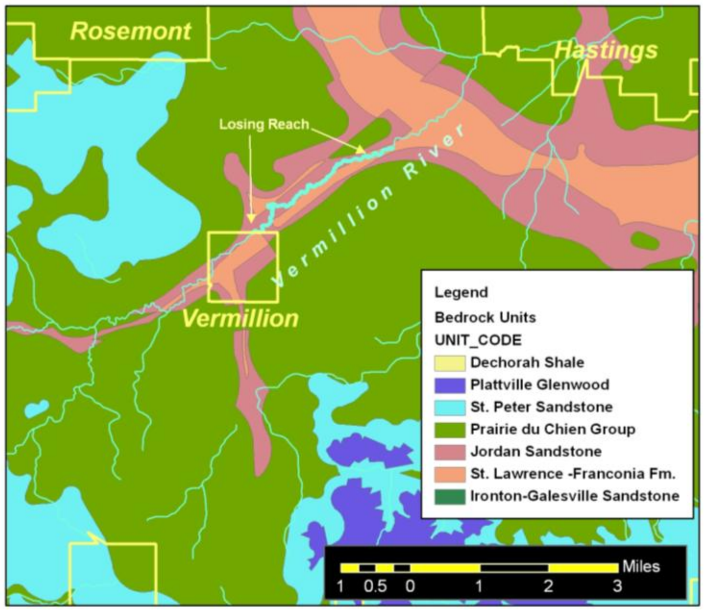


Monitoring Case Study/Example: Vermillion River

The Vermillion River has headwaters in Scott County and flows east across central Dakota County. Near its confluence with the Mississippi river, the Vermillion River turns south-southeast, roughly paralleling the Mississippi River before discharging into the Mississippi River just south of the Dakota County line in Goodhue County. In the headwaters area, the Vermillion River is likely a losing stream but over most of its length, it is gaining water via groundwater inflows. However, south of Hastings, the Vermillion River flows over an area of sandy outwash and a buried bedrock valley where the Prairie du Chien Group has been eroded away. Historical gauging information suggests that along this reach, the Vermillion River loses some flow to the surrounding aquifer system. As the Vermillion River passes over the falls at Hastings and turns southeast to parallel the Mississippi River, it once again becomes a gaining stream. .



System to Monitor Effects of Pumping on Vermillion River

Contouring of potentiometric heads in the area of the Vermillion River identified this reach as potentially losing. In 2008, The U.S. Geological Survey performed stream gauging along this reach and confirmed that the reach is losing.

<u>Potentiometric Levels</u>

Contouring of water levels from the County Well Index has been used, in part, to identify this reach as a losing reach. These data suggest that portions of the reach may be sufficiently above the top of the water table that the river is perched and disconnected from the regional groundwater flow system. One or more water-table piezometers in this area with continuous water-level recorders would confirm this and also serve as a system to obtain longer term records of fluctuation.

Stream-Flow Monitoring

Stream flows were monitored by stream-flow monitoring with hand-held meters at cross sections along the Vermillion River in 2008. If portions of the losing reach are connected with the groundwater system, more frequent monitoring may be warranted. However, continuous flow monitoring may not be necessary unless high-capacity pumping is located near the area where the stream is losing but connected.

Groundwater Withdrawal Rates

Collection of continuous records of pumping for high capacity wells should be adopted for wells near the Vermillion River.

Other Parameters

No additional data collection would be necessary at this time. If high-capacity wells are installed near the losing reaches, a well nest near the river and between the pumping center and the river should be installed.