Ground water recharge and discharge
(including ground water-surface water interactions)

Ground water-surface water interaction is a term that has entered our vocabulary. Since water moves from areas of high to low potential, lakes and rivers represent points of ground water recharge or discharge. Recharge and discharge of ground water more accurately describe the processes we label as interaction. Water often goes through chemical, physical, and biological changes. These changes are typically greatest at points of recharge and discharge; i.e. places that we label as zones of interaction. In the following discussion, I use the terms recharge, discharge, and ground water-surface water interaction interchangeably.

There are several individuals at the Agency and elsewhere (e.g. United States Geological Survey) who are much more qualified than I to discuss ground water-surface water interactions. If you have a ground water-surface water problem that is keeping you up at night, let me know and I'll put you in contact with one of the experts. Some useful web sites are shown below.

http://toxics.usgs.gov/pubs/wri99-4018/Volume1/sectionC/1402_Glynn/ (using isotopes to measure recharge)
http://water.usgs.gov/pubs/pp/pp1423-c/ (site example of recharge and discharge measurements using a variety of techniques)
http://water.usgs.gov/pubs/circ/circ1139/ (ground water-surface water interactions)
http://sofia.usgs.gov/geer/posters/wtr_interactions/ (ground water-surface water interactions)
http://toxics.usgs.gov/pubs/wri99-4018/Volume3/SectionE/3602_Schlottman/ (site example of ground water-surface water interactions)

GWMAP WORK

GWMAP had two studies in which we required information about ground water recharge and discharge. The St. Cloud study focused on characterizing recharge. The Verdi study focused on ground water-surface water interactions.

St. Cloud Study

In 1996, GWMAP began a study to determine effects of land use on ground water quality. We installed a 44-well monitoring network near St. Cloud. We added two surface water sampling points to this network. An unconfined sand aquifer underlies the study area (http://www.pca.state.mn.us/water/groundwater/gwmap/gw-stcloudlu.html).

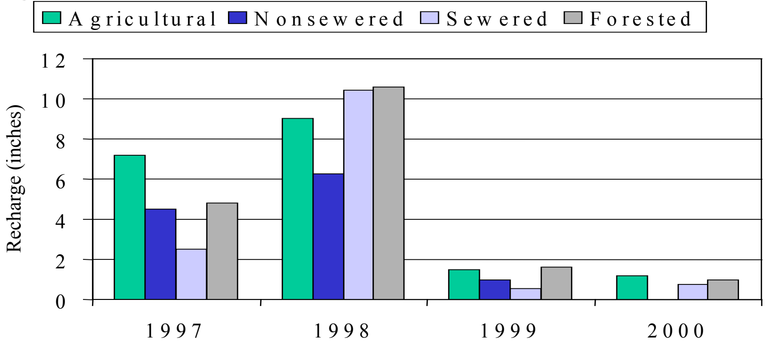
An important objective of the study was to identify seasonal patterns in ground and surface water quality. We first required an understanding of how recharge occurred. We used three methods to help us understand recharge.

- Water levels in monitoring wells were measured monthly using an electronic tape.
- Continuous water level recorders were installed in four monitoring wells. Water levels were recorded at one-hour intervals.
- Tritium samples were collected from wells.

Water Level Measurements

To calculate annual recharge, we subtracted minimum water level from maximum water level for a particular year, then adjusted for porosity. The method misses recharge that occurs after the maximum measurement, may miss small recharge events, and is likely to miss the exact time when the maximum water level occurs. We observed relatively small differences in recharge between different land uses during the study period (Figure 1).

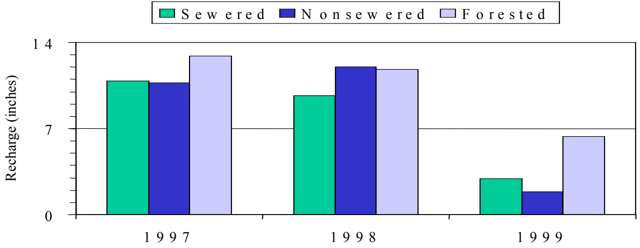
Figure 1



Continuous Recorders

To calculate recharge, we computed daily fluctuations in water levels. Positive changes represent recharge, while negative changes represent water level decline. By summing the recharge events and correcting for porosity, we calculated annual recharge. Figure 2 shows different results than Figure 1. First, recharge calculated with the continuous recorders is greater than the values calculated with an electronic tape. Second, the difference between forested land use and urban areas was much greater in 1999, when recharge was lowest.

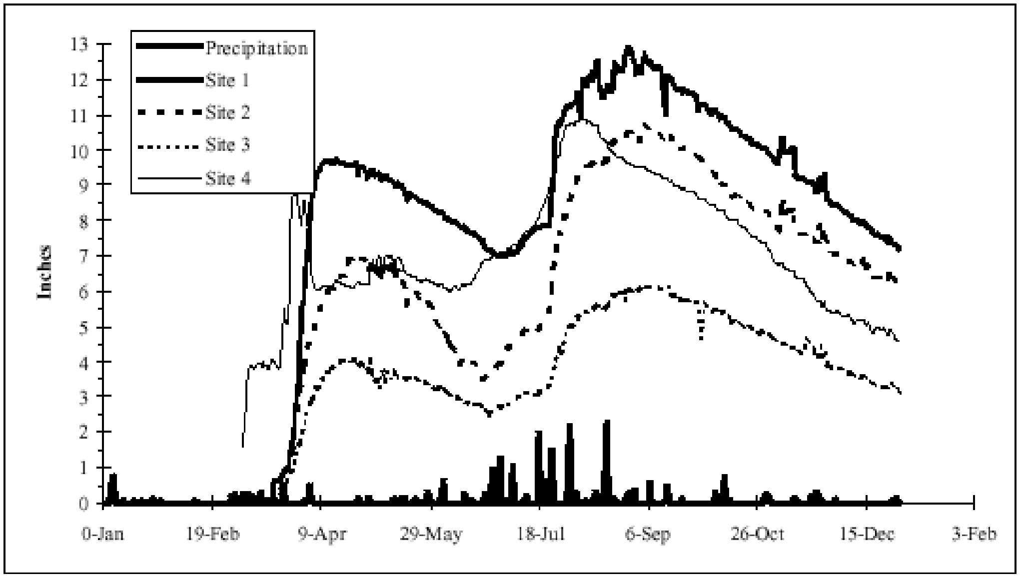
Figure 2



The continuous recorders provided additional information about recharge that would not have been collected using electronic tapes. Some of our conclusions are summarized below.

1. By overlaying plots of recharge and precipitation, we observed the greatest period of recharge in spring after the soil thaws (Figure 3). Snow that melts prior to recharge infiltrates and is stored in the soil, or runs off once the soil is saturated. It also appeared that complete soil thaw was not required to initiate recharge. Holes in the soil ice will act as conduits for infiltration. The rate of soil thaw and the thickness of soil ice are important factors affecting the quantity of recharge.

Figure 3



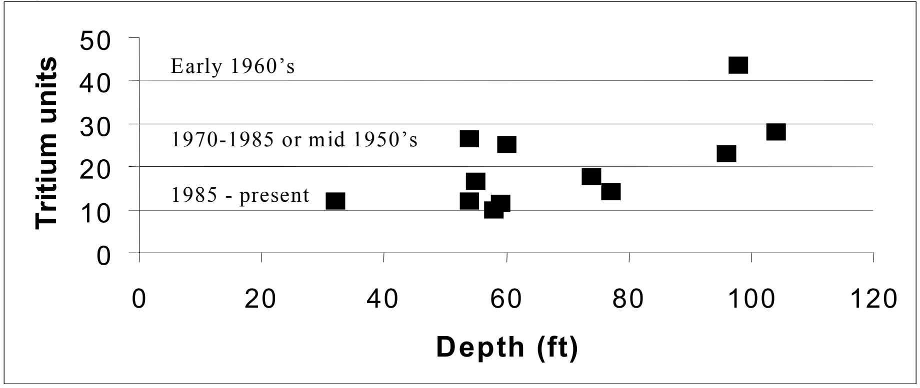
2. In spring, recharge occurs over a period of ten days or less, unless significant precipitation occurs during this time. The ground water hydrograph is similar to a stream hydrograph, except that response times are longer.
3. By mid-summer, the soil is relatively dry and evapotranspiration is high. It thus takes considerable precipitation to wet the soil before recharge can occur. Figure 3 shows that recharge in July of 1997 occurred only after a week of heavy rain. Heavy rains in the fall did not lead to additional recharge, since most of the precipitation went into soil storage. In 1998 and 1999, we observed no summer recharge.
4. Annual recharge was correlated ($R^2 = 0.927$) with the amount of precipitation (as snow) between December and March, but was not correlated with precipitation during any other month or season. In fact, the correlation with winter precipitation was about twice as strong as the correlation between recharge and annual precipitation ($R^2 = 0.471$).
5. The difference in recharge between different land uses was greatest in dry years.

Tritium

Tritium has typically been used to identify ground water that is pre- or post-1953 in age (pre-nuclear testing). Some researchers have developed analytical methods for estimating recharge using tritium (Kanivetsky; http://az.water.usgs.gov/swgwrp/Pages/NavajoSandstone_desc.html). We used tritium to help us understand the vertical pattern of recharge in the aquifer. There is reliable data showing the concentrations of tritium in precipitation from mid-North America since nuclear testing began. The peak in tritium concentration occurred in the early 1960's. The half-life of tritium is slightly more than 12 years. Consequently, we know that if tritium concentrations increase with depth, we are going backwards in time toward the 1960's. Figure 4 shows this increasing pattern of tritium in ground water with depth in

St. Cloud. We assume the sand aquifer is relatively homogenous and therefore conclude that lower portions of the aquifer are being recharged within a period of 35 years or less.

Figure 4



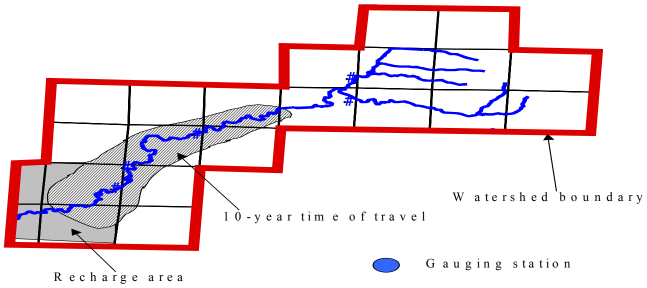
Additional tools

A surface water gauging station exists on the Sauk River near the western edge of St. Cloud. We performed slug tests in 23 shallow monitoring wells. We can therefore estimate ground water discharge to the Sauk River and calculate the contribution of ground water to river discharge. We can then use chemistry data to evaluate water quality impacts from groundwater discharge. We did not perform these calculations because there were few important differences between ground water and surface water chemistry. Ammonia was an exception. The median concentration of ammonia in ground water was 40 ug/L, which is equal to the Class 2A surface water standard. The median concentration of ammonia in the Sauk River was 110 ug/L. Ground water potentially plays an important role in diluting ammonia concentrations in the Sauk River.

Verdi Study (http://www.pca.state.mn.us/water/groundwater/gwmap/gw-verdi.pdf)

The Verdi Aquifer in Southwest Minnesota is a surficial sand aquifer that is highly vulnerable to contamination. Nitrate concentrations in water supply wells completed in the aquifer range from about 2 to more than 10 mg/L (the HRL for nitrate is 10 mg/L). Spring Creek is a small, intermittent stream that runs approximately down the center of the underlying aquifer. Although the area within a 10 year time of travel is relatively small, the Minnesota Department of Health included the entire Spring Creek watershed in the Verdi wellhead protection area (see Figure 5). The entire watershed was included because Spring Creek was considered a losing stream and could recharge the underlying aquifer. Land use in the watershed therefore has the potential to impact water quality in the aquifer.

Figure 5

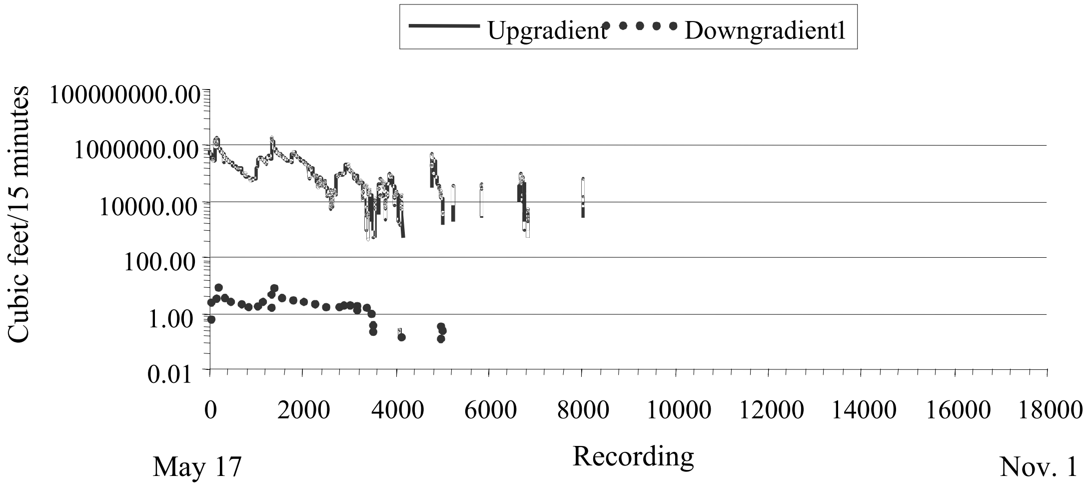


In 2000, we established five surface water gauging stations on Spring Creek. We sampled chemistry at these five locations and sampled chemistry from 12 monitoring wells completed in the aquifer. We also sampled for concentrations of stable isotopes in both Spring Creek and in the aquifer (^{18}O and ^{2}H). In fall of 2000 we installed continuous water level recorders in three wells. We then repeated our sampling procedure in 2001. Unfortunately, we have not (and may never) review the data from the continuous recorders. The following discussion includes only results from 2000.

Flow Measurements

Discharge measurements during 2000 indicate about 8 million cubic feet (60 million gallons) of water seeped through Spring Creek and presumably into underlying aquifers (see Figure 6). This is equivalent to about one inch of recharge across the three square mile recharge area shown in Figure 5. Seepage from Spring Creek primarily occurred during May and June.

Figure 6



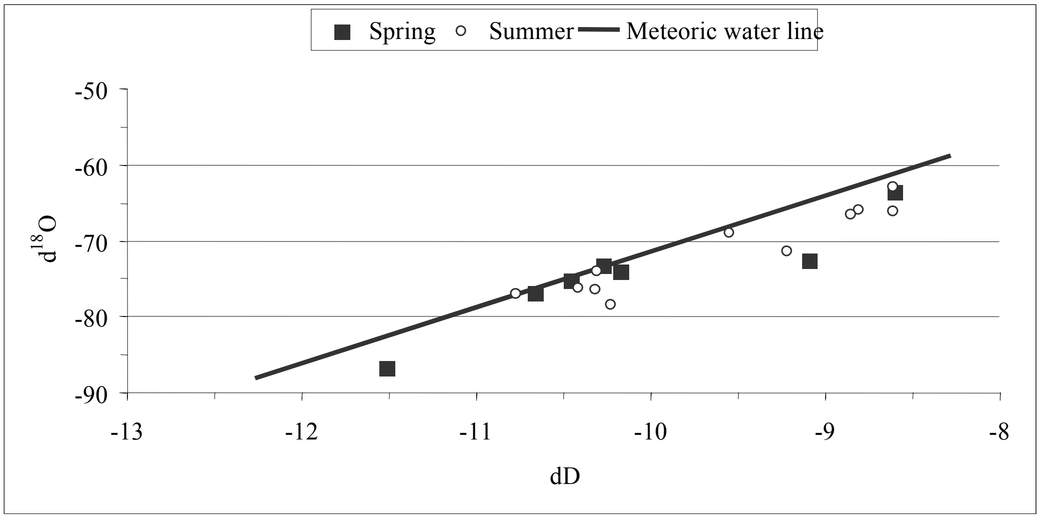
Chemistry

Seepage from Spring Creek appeared to contribute to aquifer recharge, as indicated by changes in chloride and organic carbon concentrations and distribution of herbicides in the aquifer. Eh differed between winter, spring, and summer sampling events. Eh was greatest in winter and decreased steadily through spring and into summer. The decrease during spring and summer may be related to input of dissolved organic carbon from Spring Creek. Concentrations of organic carbon in Spring Creek were 6.2 mg/l, compared to a median concentration of 1.2 mg/l in ground water. The carbon could stimulate microbial activity and drive the Eh down. Chloride concentrations were greatest for the May 31 sampling event and lowest for the July 24 event. These correlate with peak stream discharge (late May) and little or no stream discharge (July). Median chloride concentrations were 16 mg/L in surface water and 5 mg/L in deep public supply wells. Chloride concentrations in monitoring wells were 11 mg/L. The differences in chloride (a conservative tracer) concentration suggest recharge from Spring Creek. Without knowing chloride concentrations in soil water and recharge through soil infiltration (which we could estimate from our water level recorder information), we cannot conduct mass balance calculations to estimate the contribution of Spring Creek to ground water recharge. The herbicides acetochlor, metolochlor, atrazine, alachlor, and degradates of these four chemicals were detected in surface water samples. Herbicides were detected in two of ten monitoring wells. These two wells are north of Spring Creek and were sampled in May, at a time when measured stream seepage was greatest. Surface water is a potential source for these pesticides due to high pesticide concentrations in the up-gradient surface water samples and the likelihood of stream seepage to ground water.

Stable Isotopes

The distribution of stable isotopes of oxygen and hydrogen provide useful information for understanding aquifer recharge. Winter precipitation is depleted in ^{2}H and ^{18}O relative to summer precipitation. Furthermore, evaporation leads to enrichment of ^{2}H and ^{18}O in water, resulting in ^{2}H/^{18}O slopes of 3 to 6 compared to a slope of about 8 for precipitation water (Coplen, 1993). Figure 7 illustrates concentrations of stable isotopes of oxygen and hydrogen in surface water during spring and summer. Two conclusions are evident from Figure 7. First, cold and warm water signatures are evident for the spring and summer samples, with spring samples plotting to the left in Figure 7, while summer samples plot to the right. If Spring Creek contributes to recharge, cold water from snowmelt enters the aquifer in spring, while warm water from precipitation enters the aquifer in summer. Second, data for both sampling events plot along the meteoric (precipitation) water line. This means there is no evidence of fractionation (i.e. evaporation) in water reaching the aquifer. Assuming some seepage from Spring Creek reaches the aquifer, we conclude that recharge to the aquifer is relatively rapid, since water that resides in the creek does not have time to undergo evaporation.

Figure 7



We collected stable isotope samples in spring and summer in six wells. We compared the isotopic concentrations between the two sampling events for each well. Two wells showed strong, positive temperature relationships, while a third well showed a positive temperature relationship. This means that a cold water signature was observed in spring and a warm signature in summer, reflecting a strong positive response to snowmelt and infiltrating rainfall. The two wells with the strongest responses are located close to Spring Creek, while the third well is close to another creek north of Spring Creek. The furthest up-gradient well showed the strongest response, as would be expected if seepage from Spring Creek contributes to aquifer recharge. The strong positive response near the well field may reflect surface water from Spring Creek being pulled into the aquifer due to pumping in the public supply wells. Three wells showed a negative response, in which a cold water signature was observed in the summer and a warm signature in the spring. Each of these wells is located away from Spring Creek, and the negative response may reflect a delayed response as aquifer water moves laterally away from Spring Creek.

For more on the exciting world of isotopes, see
http://www.iaea.or.at/worldatom/inforesource/other/isotopes/one.html.