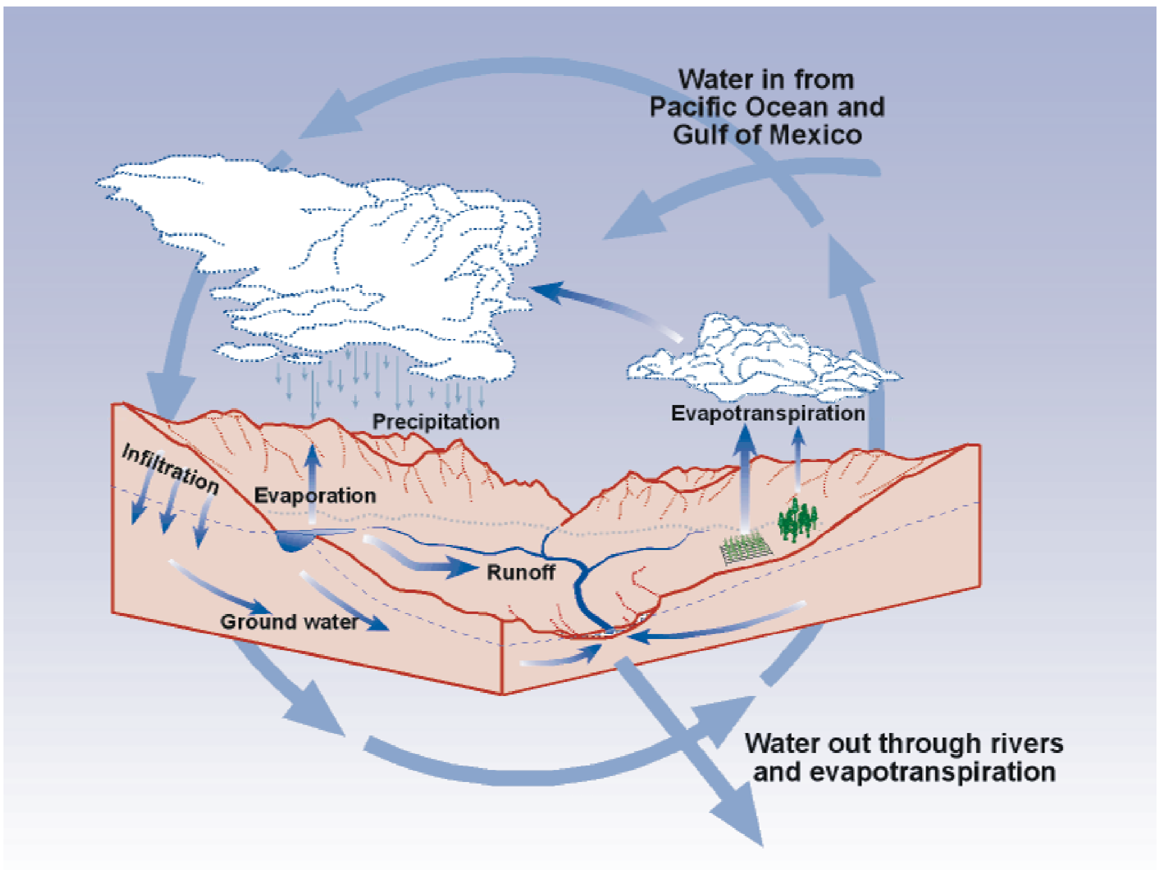
HYDROGEOLOGY OF THE NORTH HILLS, HELENA, MONTANA

MONTANA BUREAU OF MINES AND GEOLOGY

Open-File Report 544



Prepared in cooperation with the

LEWIS AND CLARK COUNTY
WATER QUALITY PROTECTION DISTRICT

HYDROGEOLOGY OF THE NORTH HILLS, HELENA, MONTANA

by James P. Madison

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Butte, Montana
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INTRODUCTION

The North Hills of the Helena Valley is located in north-central Montana and about 8 miles north of Helena, Montana (figure 1). The study area is 52 square miles and is comprised of mostly flat, gentle southerly sloping pediment surfaces and alluvial plain surrounded on the west, north, and east by slightly rugged mountainous terrain.

The North Hills is the fastest growing area in Lewis and Clark County, and one of the fastest growing areas in the state. From 1990 to 2000, the Helena Valley Northwest Census Designated Places (CDP), which includes that portion of the North Hills bounded by Lincoln Road on the south and Interstate 15 on the east (about a 27-square mile area), showed that the population increased from 1,215 to 2,082, an increase of 71 percent (Department of Commerce, 2006). Since 2000, the population has undoubtedly increased as many more new homes have been built and are continuing to be built. Some of the new homes are being built on 5 to 20 acre tracts, but many are being constructed on less than 1 acre lots such as the development in 11N4W24, 11N3W6, and the recently started development in 11N3W17 (see appendix 1 for a description of the location system). Because city services do not extend to the North Hills, the residents depend on water pumped from private or public wells for their domestic water source. In addition, the residents dispose of their waste water through septic systems.

Beginning in the late 1990's, and continuing to the present day, more than 30 wells in the North Hills area have gone dry or the water in the well has dropped to a level that can't be pumped (Kathy Moore, Lewis and Clark County Water Quality Protection District Manager, per. commun., 2004). Meanwhile, long-term well hydrographs in some areas of the North Hills have shown steadily decreasing water-level trends (figure 2). What caused the decreasing trends in water levels? Was the decrease due to the increase demand placed on the aquifer from the increase in population, or was the decrease due to climatic factors that led to less recharge?

In July 2001, some citizens in the North Hills became concerned about the decline in water levels in wells and petitioned the Montana Department of Natural Resources and Conservation (DNRC) to create a Controlled Groundwater Area. The citizens filing the petition recognized the need to collect hydrogeologic information so that informed decisions could be made concerning future development in the North Hills.

In 2002, the DNRC established a temporary Controlled Groundwater Area. The purpose of the temporary Controlled Groundwater Area was to closely track new wells being installed in the area, install flow meters so that usage could be measured, collect water samples from these new wells for nitrate analysis, and monitor water levels in these wells. In essence, the DNRC, through the temporary Controlled Groundwater Area, started a systematic data-collection effort as the first step to assess the declining water-level trends.

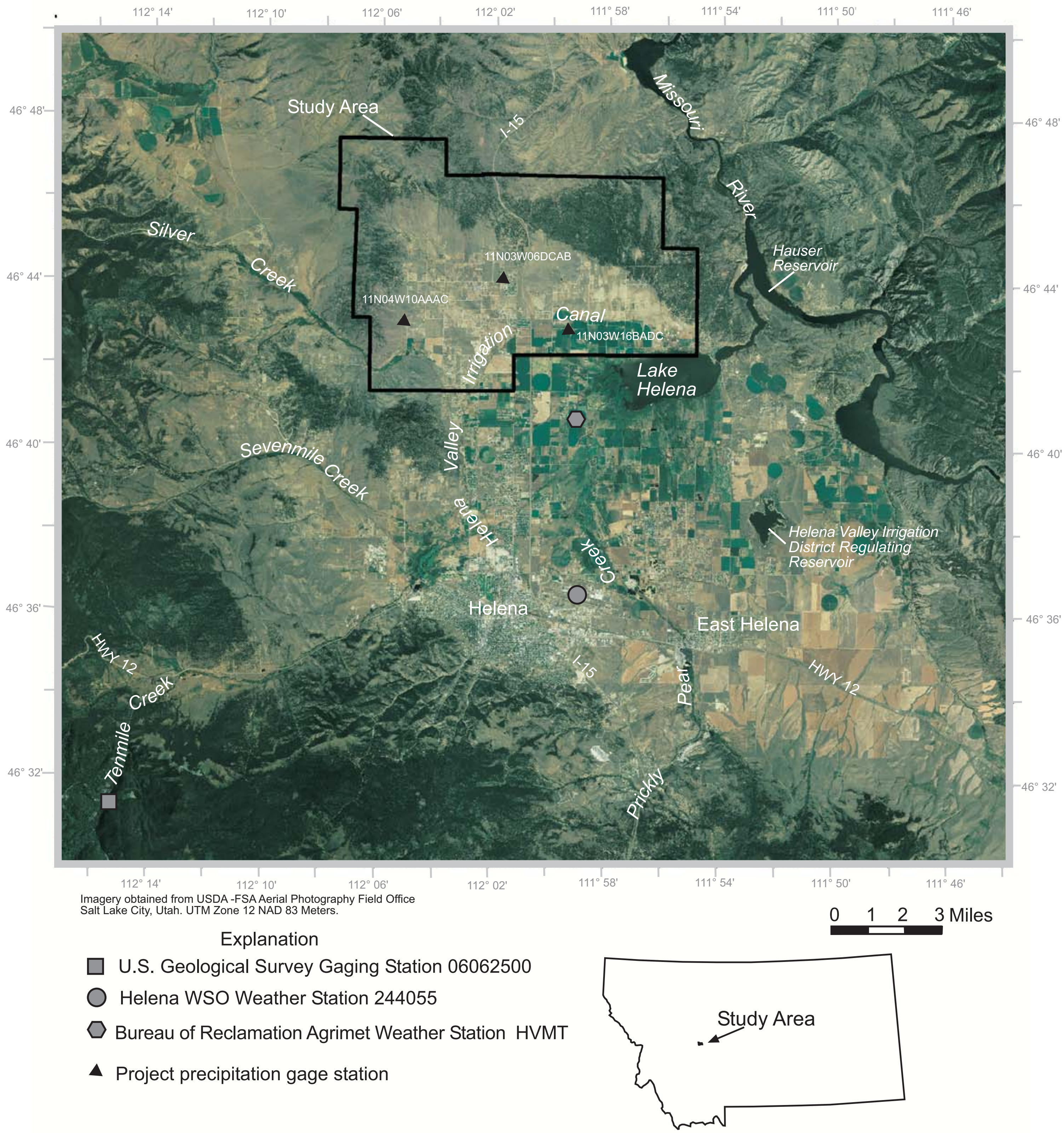
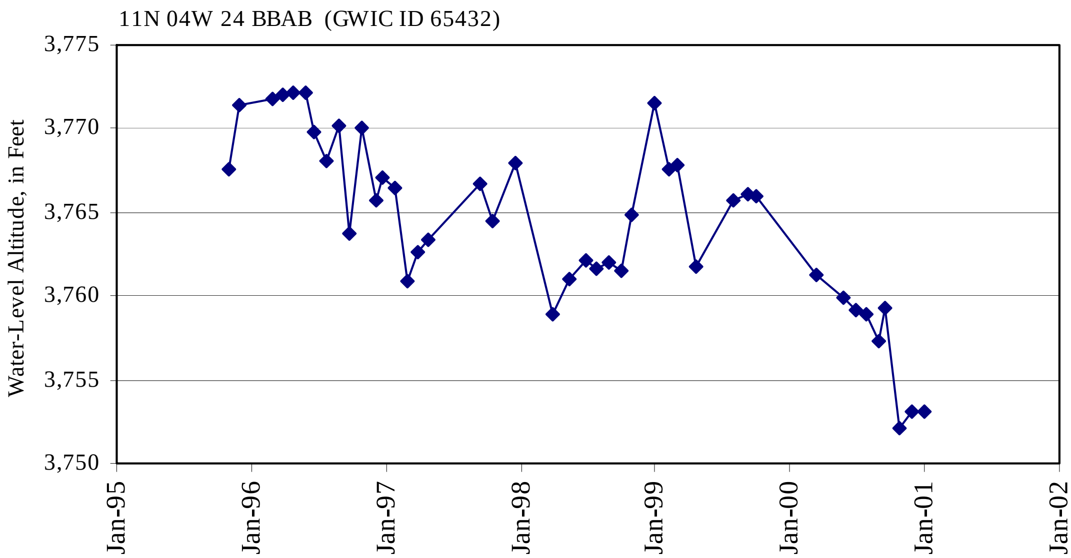


Figure 1--The North Hills study area encompasses an area of about 52 square miles in the north end of the Helena Valley, about 8 miles north of Helena, Montana. Silver Creek is located along the southwest part of the study area. More than 15,000 acres of land are irrigated in the Helena Valley, mostly for the production of hay. Of the total acreage irrigated, about 1,100 acres are located in the study area. Water is delivered to this acreage via a 6-mile section of the Helena Valley Irrigation Canal.



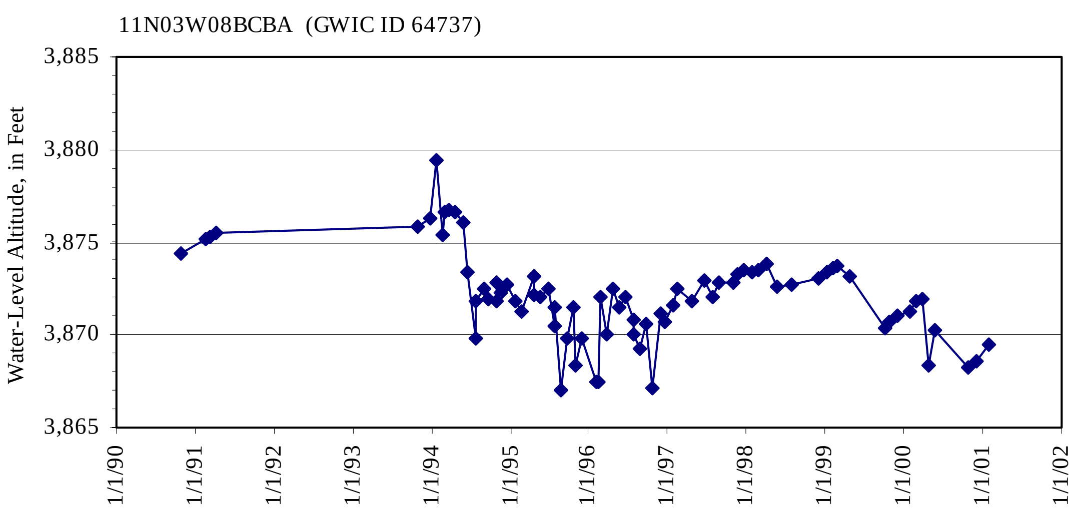


Figure 2–In 2000 and 2001 water levels in wells were dropping, and in some cases the water level dropped to the point where water could not be extracted from the well (a dry well). Citizens of the North Hills became concerned that because of all of the development and population growth that occurred between 1990 and 2000 that the aquifer was being over drafted. The two hydrographs above are used to show examples of water levels in 1999 and 2000.

Purpose and Scope

In 2004, through a cooperative effort with the Lewis and Clark County Water Quality Protection District, the Montana Bureau of Mines and Geology (MBMG), in collaboration with the DNRC, started a data collection and interpretation effort to assess why water levels have dropped and wells have gone dry. The goal of this project was to assess the change in water levels in wells. This goal was achieved through the following specific objectives:

1. Establish a monitoring well network and monitor water levels in wells;

2. Define the potentiometric surface and the direction of ground-water flow;

3. Determine the geologic framework and aquifer geometry, and how this relates to transmitting water to wells;

4. Determine the sources of ground-water recharge/discharge and quantify these sources;

5. Assess how water levels in wells respond to recharge and discharge sources; and

6. Assess the distribution of nitrate in the ground-water system.

Water level was measured in 193 wells (appendix 2). Most of these wells were domestic-supply wells, but included some dedicated monitoring wells and unused domestic wells. Fourteen of these wells have been monitored since 2001 of which 10 have water-level record that go back to at least 1995. Eleven wells were equipped with continuous water-level recorders consisting of either transducers or Stevens Type-F chart recorders. All wells were surveyed for latitude, longitude, and altitude using survey-grade GPS. The well completion reports and water-level records for these monitoring wells are stored in the MBMG's Ground Water Information Center (GWIC) database accessible at http://mbmggwic.mtech.edu/. Water-level altitudes in wells measured between September 2005 and March 2006 were used to construct a potentiometric map.

The geologic framework and aquifer geometry were determined by interpreting some of the more than 2,000 well completions reports on file in GWIC. Field investigations to observe rock outcrops and to describe drill cuttings during well installations added to our knowledge of the area. Previously published geologic mapping was an important source for determining the geologic framework and aquifer geometry.

The sources of ground-water recharge and discharge were easily determined through observation and familiarity with the area. Average ground-water discharge from wells was estimated using average measured usage for about 140 residences. Recharge from irrigation, including leakage from the Helena Valley Irrigation canal and laterals was quantified using published leakage rates for the canal, laterals, and irrigated fields. Leakage to the ground-water flow system from Silver

Creek was estimated using indirect methods for quantifying stream flow. Underflow through the system was calculated using Darcy's law and transmissivity from a long-term aquifer test, measured gradients and aquifer widths.

Well hydrographs were used to determine where and how the water levels in North Hills' aquifers respond to the various sources of recharge and discharge. The long-term stream flow record for Tenmile Creek was used as a surrogate for assessing temporal leakage to the ground-water flow system from Silver Creek.

PREVIOUS INVESTIGATIONS

The geology of the northern part of the Boulder Batholith and of the Helena mining district was described by Knopf (1913, 1963). Mineral deposits of the Helena mining area were reported on by Pardee and Schrader (1933). The faulting and seismicity of the Helena area were described by Freidline and others (1976), Reynolds (1979), Schmidt (1977, 1986), Stickney (1978, 1987), and Stickney and Bartholomew (1987). Lorenz and Swenson (1951) were the first to report on the water resources of the Helena Valley. Wilke and Coffin (1973) described the ground-water quality of the valley. Wilke and Johnson (1978) investigated the depth to water table and area inundated by the June 1975 flood. Moreland and Leonard (1980) evaluated the shallow part of the aquifer system beneath the valley. Briar and Madison (1992) developed a ground-water budget and numerical ground-water flow model for the valley-fill aquifer system. Thamke (2000) assessed the hydrology of the bedrock aquifer surrounding the Helena valley-fill aquifer; her study provided data on water-level trends in wells and ground-water quality.

ACKNOWLEDGMENTS

The author wishes to thank several people for their assistance in conducting this investigation. Kathy Moore, Lewis and Clark County Water Quality Protection District Manager, for her time and assistance in collecting water levels from wells and her knowledge of the North Hills. Russell Levens, Department of Natural Resources and Conservation (DNRC), assisted in collecting water levels in wells and surveying all of the wells. Kathy Arndt from the DNRC Helena regional office also should be acknowledged for her efforts measuring water levels in wells and compiling water quality and flow reports from well owners. H&L Drilling and Treasure State Drilling allowed observations during the drilling of several wells; Treasure State was also kind enough to pull a couple of pumps to recover snagged well probes. Finally, the many land owners should be acknowledged for allowing access to their wells for monitoring purposes.

GEOGRAPHY

The North Hills is an area in the north part of the Helena Valley. The Helena Valley is an intermontane basin in the north-central part of the Northern Rocky Mountains physiographic province. The Continental Divide, which separates the Columbia River drainage from the Missouri River drainage is about 10 miles to the west of the North Hills. The Missouri River is about 1.5 miles to the east of the study area.

PHYSIOGRAPHY

Pediment surfaces and alluvial plains form a gentle, southerly sloping surface that comprise most of the North Hills. It is the gentle nature of the topography and the south-facing exposure that make this an attractive area to live. The pediment surfaces and alluvial plains are surrounded on the west, north, and east by slightly rugged mountainous terrain. The lowest altitude of the study area is Lake Helena, at 3,650 feet near the southeast corner of the study area. The highest altitude is about 5,150 feet in the northwest part of the study area.

CLIMATE

The North Hills has a semiarid climate similar to areas in Montana east of the Continental Divide. Average annual precipitation at the Helena Weather Service Office (WSO) weather station, about 8 miles to the south of the study area, is 11.90 inches based on 112 years of record; at the Helena Valley, Montana (HVMT) Agrimet station, located about 1.7 miles to the south, the average annual precipitation is 9.2 inches based on 10 years of record. Nine out of ten years, the Agrimet Station total precipitation was less than that at the Helena WSO weather station; total precipitation in 2005 for 3 project rain gaging stations operated in the study area (figure 1) were less than the Helena WSO weather station by about 25 percent (figure 3). Based on the Agrimet HVMT station and the project rain gaging stations, total annual precipitation in the North Hills is probably less than that recorded at the Helena WSO weather station and it may be as much as 25 percent less, but accurate determination can only be made with more data from the North Hills precipitation gages. Based on 114 years of record, the coldest month is January with an average temperature of 20.5°F, and based on 113 years of record, the warmest month is July, with an average temperature of 68.1°F.

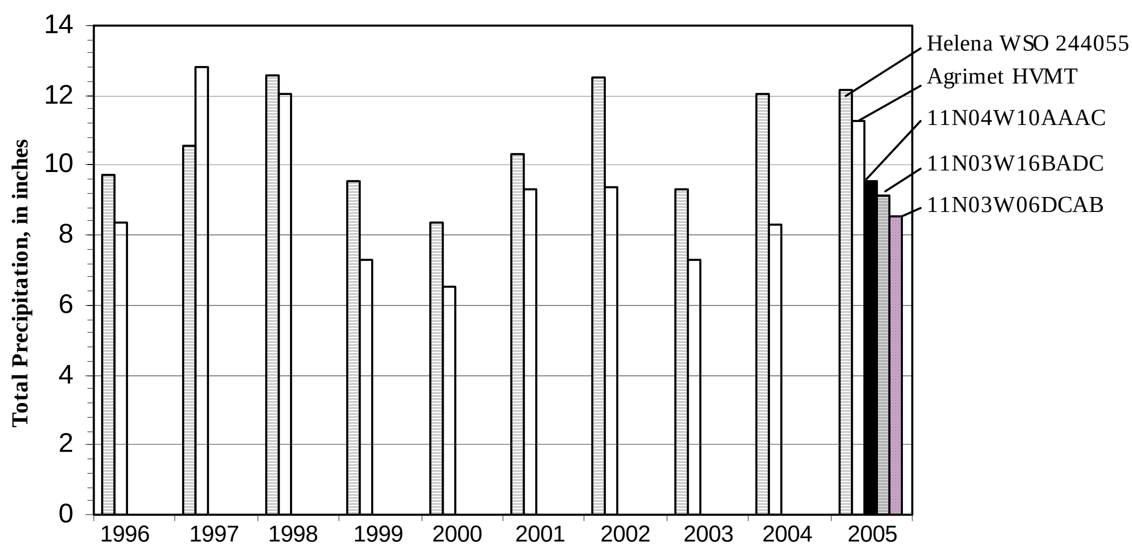


Figure 3–Annual precipitation at the Helena WSO Station, the Bureau of Reclamation Station HVMT, and at three project stations in the North Hills.

STREAM FLOW

Silver Creek enters the southwest corner of the study area, and usually flows for about 2 miles before its water completely infiltrates into the ground. During high flow, the water probably flows farther down stream before soaking into the ground. Within the study area, water is diverted from Silver Creek for irrigation of about 40 acres. Unfortunately, a “ditch rider” is not assigned to Silver Creek, so diversion records do not exist.

A gaging station does not exist on Silver Creek; long-term mean monthly flow was estimated using techniques of Parrett and others (1989) developed for ungaged basins in the upper Missouri River basin (table 1). Although stream flow in Silver Creek is relatively small, it is an important source of ground-water recharge for the southwest part of the study area.

Table 1--Calculated monthly mean and annual mean streamflow for Silver Creek

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
				Streamflow, in cubic feet per second								
0.73	0.74	1.05	2.92	8.47	9.17	4.03	1.96	1.46	1.33	1.03	0.89	2.82
				Streamflow, in acre feet								
45	41	66	175	525	550	250	121	88	83	64	55	2,060

The calculated flow in Silver Creek gives a rough estimate of the average flow in Silver Creek, but does not provide a way to estimate the annual mean for the past few years. The long-term streamflow record for Tenmile Creek may be used as an indication of how the streamflow in Silver Creek fluctuates if it is assumed that the streamflow in Tenmile Creek is proportional to the streamflow in Silver Creek and that the two respond to changes in climate similarly.

Annual mean streamflow in Tenmile Creek at USGS gage 06062500 recorded since 1970 is presented in figure 4. In 2000, the annual mean streamflow in Tenmile Creek was 1.74 cubic feet per second (cfs), or 10 percent of the mean annual flow of 16.8 cfs. If streamflow in Silver Creek is proportional to streamflow in Tenmile Creek, in 2000 Silver Creek streamflow would have been 10 percent of the annual mean streamflow. An irrigator that uses Silver Creek water reported that in 2000 he produced 10 percent of the normal amount of hay produced from his land because not enough water was available from Silver Creek (William Gehring, per. commun., 2006).

Also plotted on the graph is the 24-month Standard Precipitation Index (SPI) for the Helena WSO weather station calculated quarterly since 1970. To quote Hayes (2006), *”The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero. (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. ”*

The SPI is useful for determining how streamflow responds to long-term precipitation anomalies.

For Tenmile Creek, the 24-month SPI correlates quite well with annual mean streamflow (figure 5). This indicates that annual mean streamflow responds to 24 month precipitation anomalies. The 12-, 18-, 30-, 36-, and 48-months SPI correlated more poorly with annual mean streamflow than the 24 month SPI and are not presented.

HYDROGEOLOGY

Ground-water flow in the North Hills is strongly controlled by the orientation and water-bearing properties of the geologic material through which they flow. The depth and yield of wells can best be understood from the context of the material in which they are completed.

GENERAL GEOLOGY

Detailed descriptions of the geology of the Helena area have been made by Knopf (1913), Pardee (1925), Lorenz and Swenson (1951), Knopf (1963), Schmidt (1977, 1986), Stickney (1978, 1987), Reynolds (1979), Stickney and Bartholomew (1987), Briar and Madison (1992), and Thamke (2000). The reader is referred to these sources for detailed discussions about the geology of the Helena area.

The North Hills consists of pediment surfaces and alluvial plains that form a gentle southerly sloping surface surrounded on the west, north, and east by folded and faulted pre-Tertiary bedrock (figure 6). The pre-Tertiary bedrock consists mostly of lower middle Proterozoic Belt Supergroup rocks.

The Belt Supergroup rocks include the Greyson, Spokane, Helena, and Empire formations. The Greyson Formation consists of siltite and argillite with quartzite in the uppermost part of the formation. The Spokane consist of argillite and siltite with limestone and dolostone in the uppermost and lower parts. The Empire Formation consists of thinly and evenly laminated light and dark-green dolomitic argillite or argillite and siltite. The Helena Formation is predominantly dolomite, dolomitic siltite, and dolomitic argillite. These units are generally very fractured at the outcrop; locally the fracturing is so intense that the bedding attitude cannot be discerned. In the southwest corner of the study area the lower middle Proterozoic rocks have been intruded by late Proterozoic gabbro sills and dikes and by upper Cretaceous quartz monzonite.

In the northeast part of the study area, Paleozoic rocks are exposed northeast of the Eldorado Thrust Fault. The Paleozoic Rocks include the Madison Limestone; the Big Snowy Group which consist of mudstone, siltstone, and limestone; and the Phosphoria, Quadrant, and Amsden formations which consist of sandstone, limestone, siltstone, and dolostone beds.

Poorly to moderately consolidated Tertiary (undivided) sediments crop out at several locations in the southeast part of the study area (figure 6). In other parts of the study area, the Tertiary valley fill is concealed by a few feet to several hundred feet of Quaternary alluvium. In the area of the

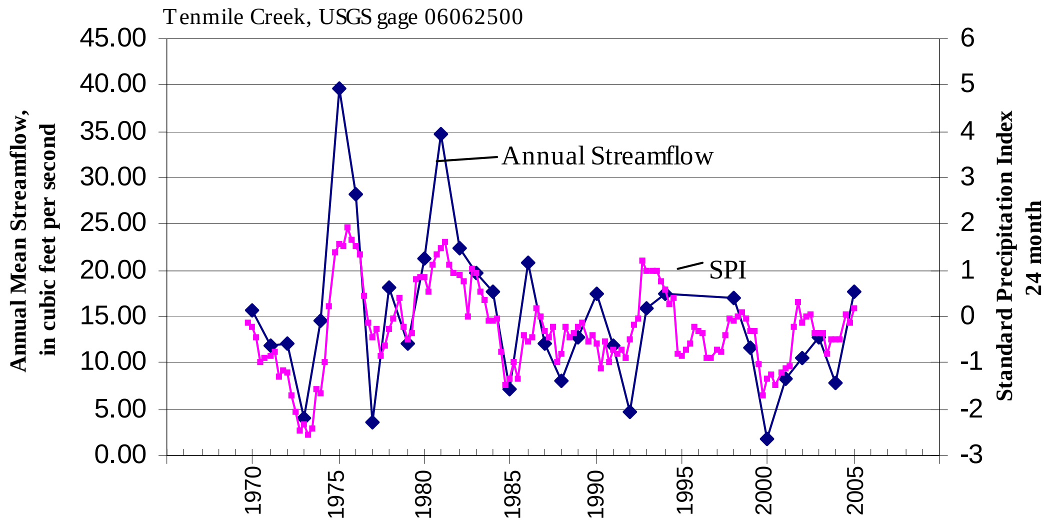


Figure 4–Annual mean streamflow for Tenmile Creek since 1970 and the 24 month Standard Precipitation Index for the Helena WSO weather station calculated quarterly. Tenmile Creek responds to 24 month precipitation anomalies which reflects the ground water component on streamflow. Annual mean streamflow in Silver Creek probably responds to the SPI in a similar fashion. Annual mean streamflow for 1995-1997 not reported.

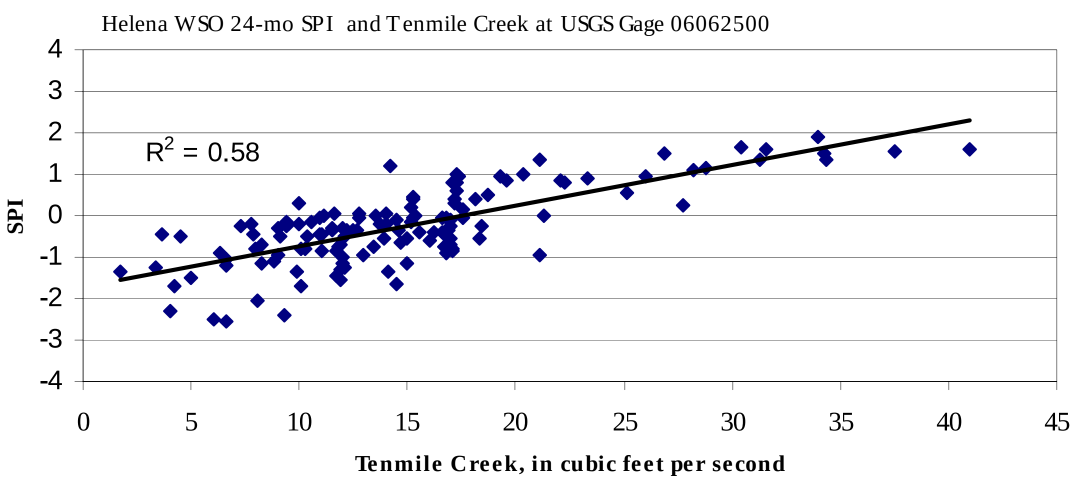


Figure 5–The 24-month Standard Precipitation Index correlates the best with annual mean flow in Tenmile Creek compared with the 12, 18, 30, and 36 month SPI. Linear interpolation between annual mean streamflow was used to generate data points for the correlation.

bedrock outliers in the west part of the study area the Quaternary alluvium is thin and Tertiary strata are absent. Near Lake Helena, the Tertiary sediments may be up to 6,000 feet thick based on gravity analyses (Davis and others, 1963). The Tertiary valley fill consists mostly of interbedded silt and clay with lenses of sand and gravel ranging from a few inches to a few feet.

Observation of well drilling resulted in a better understanding of the subsurface geology. At location11N03W10BBBB (GWIC ID 223525), a well drilled there penetrated about 500 feet of Tertiary material before encountering bedrock. The cuttings from that hole consisted mostly of silt and clay with minor sand; because the hole was sloughing, steel casing was driven, and the 20 to 40 feet of open hole ahead of the casing yielded less than 1 gallon/minute (gpm). At location 11N03W06BDCC (GWIC ID 222567) about 280 feet of Tertiary valley fill was drilled through before drilling into bedrock. Cutting from this interval also consisted of silt and clay with very little sand. South of these wells, the Tertiary section probably gets thicker.

Quaternary alluvium covers most of the study area where bedrock is not exposed. The alluvium is thinnest near the bedrock outcrops and thickens to the south. At site 11N03W17CBDB (GWIC ID 204558), 300 feet of alluvium was encountered. Tertiary sediments were not encountered, so this is a minimum thickness for the Quaternary. The Quaternary alluvium consists of sandy pebble-to-cobble gravel with sand lenses and minor silt lenses. The sand and gravel clasts reflect the mostly red siltites and argillites from which they were weathered. Drillers commonly describe this material as “shale gravel”.

The Helena Valley fault trends northwest through the northern part of the study area. There is no evidence that there has been any recent movement along this fault. The inferred Scratch Gravel Hills Fault (Stickney, 1987) was recently trenched. The results of the trenching show that a suspected fault scarp at the surface was not a fault (Mike Stickney, geologist, MBMG, per. commun., 2006).

AQUIFER GEOMETRY AND HYDRAULIC CHARACTERISTICS

Based on the geologic map of the North Hills study area (figure 6 and Stickney, 1987), well completion reports, and field observations of well installations, three aquifers were delineated within the North Hills (plate 1). These three consist of the pre-Tertiary bedrock aquifer, Tertiary aquifer, and the Quaternary aquifer. Although separated into three aquifers for consideration in this discussion, nothing prevents ground-water flow from one aquifer to the other, and therefore a ground-water flow continuum exists across rock units within the ground-water flow system.

Water is derived from the pre-Tertiary bedrock aquifer through the secondary porosity developed by the joints and fractures in the bedrock. Wells drilled into the bedrock depend on encountering enough saturated fractures that will yield an adequate volume of water for domestic use. In some cases, adequately fractured rock is not encountered; the well is drilled deeper and deeper hoping that eventually a good fracture will be encountered. As a result, some wells drilled into the bedrock aquifer are several hundred feet deep; and in some cases there are two deep wells near each other because yields in the first one were too low to be of use. Within the North Hills study

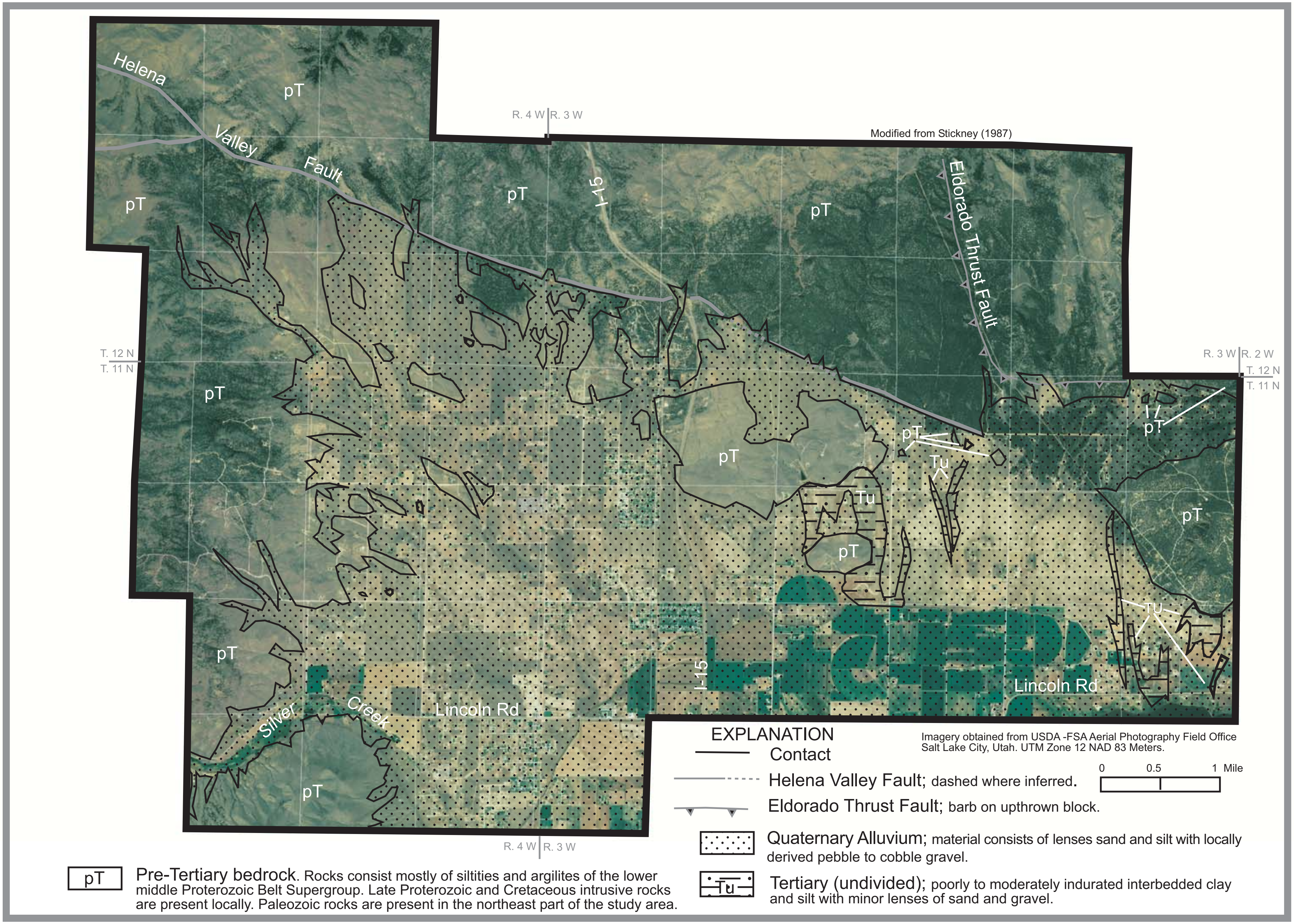


Figure 6--Generalized geologic map of the North Hills, Helena, Montana. Most houses are built on valley fill which consists of the Quaternary alluvium and Tertiary sediment . Near Lake Helena, the valley fill may be up to 6,000 feet thick.

area, wells completed in the bedrock have been reported up to 1,000 feet deep, but the average bedrock well is about 200 feet deep. Well yields up to 100 gpm have been reported, with an average yield of about 20 gpm.

The Tertiary aquifer was delineated using the geologic map, well cuttings, and well completion reports. The depth to which casing was hammered into the ground by well drillers served as the best guide for delineating the northern extent of the Tertiary aquifer. Prior to this study, it was thought that much of the area delineated as Tertiary aquifer in plate 1 was only underlain by bedrock aquifer (Briar and Madison, 1992; Thamke, 2000). Too many wells in this area have casing driven more than 200 feet below land surface for the material in this area to be bedrock; drillers typically do not hammer steel casing into bedrock because a bedrock hole will stay open and does not require steel casing to prevent it was sloughing. There also are many wells that produce adequate water from less than 200 feet in this area, so the material meets the definition of an aquifer. In the Tertiary aquifer, drillers generally target a sand or gravel lens of sufficient thickness and aerial extent that will yield 5 gpm or greater. There is no way to predict at what depth a lens of this sort will be encountered. In the absence of a sand or gravel lens, the Tertiary silt and clay will yield less than 1 gpm to about 20 to 40 feet of open bore hole during drilling. It is possible that in the absence of a sand or gravel lens that 100 to 200 feet of the Tertiary could be screened and a sand pack installed to increase the yield of a well to an adequate rate of about 5 gpm.

Along the north edge of the Tertiary aquifer, wells are sometimes drilled through the Tertiary and into the pre-Tertiary bedrock aquifer. At site 11N03W06DCAB (GWIC ID 213255), the well penetrated about 150 feet of Tertiary valley fill and was completed in bedrock to a total depth of 210 feet below land surface.

Well depths in the Tertiary aquifer have been reported up to 800 feet, but the average is about 190 feet. The maximum well yield reported for the Tertiary aquifer is 500 gpm, with an average of 20 gpm.

At site 11N03W07DCA (GWIC ID 193704), a well completed in the Tertiary aquifer was pumped in 2002 for 24 hours at a rate of 65 gpm. The reported transmissivity determined for this aquifer test was about 760 $feet^2$/day determined using the pumping-well drawdown/recovery data and about 1,100 $feet^2$/day using drawdown/recovery data from a nearby observation well. In 2004, the same well was pumped again at a rate of 98 gpm for 72 hours; The reported transmissivity, determined using the drawdown/recovery data for the pumping well and two observations wells, was 1,650 $feet^2$/day.

The Quaternary aquifer was delineated using the geologic map (Stickney, 1987), observation of well cuttings, and well completion reports. The Quaternary aquifer is distinguished from the Tertiary aquifer most readily by yields and well depths. Yields are greater and depths are shallower for wells completed in the Quaternary aquifer. Drillers often describe the cuttings from wells in this area as “shale gravel”, which reflects the locally derived red and green siltite and argillite clasts. Well yields are high because of the permeable nature of the gravel composing the aquifer. Average well depth is shallower than the Tertiary aquifer because the highly permeable nature of the aquifer does not require penetration deep into the aquifer to yield an adequate flow of water for domestic needs.

The Quaternary aquifer directly overlies the Tertiary aquifer in most areas of the study area. The depth of the contact below land surface is unknown because wells have not been drilled deep enough to define this contact. In the southwest part of the study area, the Tertiary aquifer may be absent and the Quaternary aquifer may overlie the pre-Tertiary bedrock aquifer.

Well depths have been reported up to 600 feet, but the average is 120 feet. Yields have been measured up to about 900 gpm, with a reported average yield of 35 gpm.

At site 11N03W17CADA (GWIC ID 199989), a 244 feet deep well completed in the Quaternary aquifer was pumped at 894 gpm for 72 hours. Remarkably the water level in the well was only drawn down about 15 feet after 72 hours of pumping. The reported transmissivity determined for this aquifer test was about 18,800 feet^2/day determined using the pumping-well drawdown/recovery data and about 15,100 feet^2/day using drawdown/recovery data from a nearby observation well.

POTENTIOMETRIC SURFACE AND DIRECTION OF GROUND-WATER FLOW

Water levels were measured periodically between 2003 and 2006 in most of the 193 well monitoring network (appendix 2). Some of the wells were only measured once, while some were equipped with continuous water-level monitoring that measured the water level thousands of times. Some of the wells have water-level records that date back before 2003. The water level information is stored in the MBMG's Ground Water Information Center (GWIC) database accessible at http://mbmggwic.mtech.edu/. The measuring point for all monitoring wells was surveyed for latitude, longitude and altitude using survey-grade GPS.

The potentiometric surface in the Quaternary, Tertiary, and pre-Tertiary bedrock aquifer was determined using water levels measured during September 2005 through March 2006 (plate 2). Seven wells were not used in contouring the potentiometric surface, but are plotted on the plate. Water-level altitude in these seven wells are influenced by vertical hydraulic gradients when compared to nearby wells of different depths. Horizontal ground-water flow is perpendicular to the potentiometric contours and down gradient. Ground-water flow in the North Hills aquifers is generally from the north to the south.

The shape and slope of the potentiometric surface corresponds to the topography and material through which the ground water flows. The potentiometric contours are generally parallel to the valley-fill/bedrock contact. The contours tend to wrap around the bedrock that protrudes out into the valley in 11N03W04 and 11N03W05. The hydraulic gradient in the bedrock and Tertiary aquifers is similar and ranges between 0.018 to 0.036, but does not appear to be any steeper or flatter in any one aquifer. The similarity in gradients suggest that the two aquifers may share similar hydraulic characteristic. Hydraulic gradients in the Quaternary aquifer are less steep compared to the gradient in the two other aquifers and range between 0.0025 to 0.008. These flatter gradients reflect the higher transmissivity in the Quaternary aquifer compared to the pre-

Tertiary bedrock and Tertiary aquifers.

GROUND-WATER RECHARGE AND DISCHARGE

One of the questions that prompted this study was whether or not the quantity of water discharged from wells exceeded recharge in the North Hills and caused water levels to decline. To answer this question, a ground-water budget was constructed for the North Hills study area. What the budget attempts to accomplish is to describe and quantify the sources of recharge to and discharge from the North Hills aquifers.

Ground-water recharge to and discharge from the North Hills aquifers is described by the following equation:

(SC_in) + (IC_in) +(IFP_in) + (AR_in) = (DR_out) + (UF_out) + (WL_out)

where:

SC_in = Recharge from infiltration of Silver Creek streamflow,
IC_in = Recharge from the Helena Valley Irrigation Canal and laterals,
IFP_in = Recharge from infiltration of excess irrigation water and precipitation applied to irrigated fields,
AR_in = Infiltration of aerial recharge,
DR_out = Discharge to drains,
UF_out = Discharge through underflow through the southern boundary of the study area, and
WL_out = Discharge through withdrawal from wells.

Recharge to the North Hills aquifers is through infiltration of Silver Creek streamflow, irrigation water, and precipitation. Recharge from Silver Creek was estimated using the calculated streamflow presented in table 1. Assuming all of Silver Creek infiltrates into the ground and that about 60 acre-feet per year is diverted from the stream for irrigation, mean annual recharge from this source is about 2,000 acre-feet.

Leakage from Helena Valley Irrigation Canal and laterals were estimated using leakages rates defined by Briar and Madison (1992). Their measurements show that the main canal loses about 0.63 cubic feet per second per mile and that the smaller laterals lose at 1/3 of this rate. In the study area there are about 6.2 miles of main canal and 5.3 miles of laterals. Assuming that the canal and laterals have water in them for 150 days per year, about 1,220 acre feet of water infiltrates into the ground-water flow system from this source.

About 1,190 acres of land are irrigated within the North Hills study area from water diverted from the Helena Valley Irrigation Canal. Briar and Madison (1992) estimated the amount of excess irrigation water applied to the irrigated area within the Helena Valley which includes the area irrigated in the North Hills. Their analysis accounted for the total volume of water applied plus any precipitation falling on the irrigated area and the water consumed by evapotranspiration. Their analysis shows that on average, about 1.5 acre feet of water per acre of irrigated land is not consumed in the root zone and recharges the ground water system. Annual average recharge in irrigated areas of the North Hills is about 1,825 acre feet.

A large area of the North Hills study area does not receive any recharge from irrigation sources or Silver Creek leakage. The only ground-water recharge that this area receives is from infiltration of rain and snow melt (plate 3). Directly measuring this component would be difficult. To estimate aerial recharge to the aquifer, it was assumed that ground-water flow past the 3,850 foot contour on the potentiometric map was derived only from rain and snow melt that had infiltrated through the unsaturated zone to recharge the ground-water system. A gradient of 0.026, a flow width of about 38,500 feet, and a transmissivity of 1,100 feet^2/day were used with Darcy's Law to estimate the flow past the 3,850 foot contour. Based on this calculation, average annual flow past the 3,850 foot contour is about 9,200 acre feet. This ground-water flux through the 3,850 contour is in good agreement with the flux out of the North Hills area calculated by Briar and Madison (1992).

Ground water discharges from the North Hills' aquifers to drains, wells, and as underflow through the south boundary of the study area. Agricultural drains along the south boundary of the study area collect shallow ground water and channel it to Lake Helena. Measurements by DNRC indicate that the average annual discharge is about 725 acre-feet.

Ground water flows out of the study area along the southern boundary. There is no way to directly measure this discharge, so Darcy's Law was used to calculate the discharge. Using a gradient of 0.0033, a flow width of 26,250 feet and a transmissivity of 18,000 feet^2 /day resulted in an estimated of the average annual underflow out of the area of about 12,970 acre feet.

Withdrawal of ground water by wells was estimated using metered usage from two subdivisions that totaled about 140 residences. Average usage for each residence was calculated to be 464 gallons/day. Based on usage during the winter, 162 gallons/day/residence is returned to the ground water system via septic systems. The remainder or 302 gallons/day/residence is consumed through irrigation. There are about 1,623 residences in the North Hills based on a count from recent aerial photographs. Annual consumption of ground water withdrawn from wells is estimated to be about 550 acre feet.

The estimated components of yearly recharge to and discharge from the North Hills Aquifer are summarized in the ground water budget presented in table 2. One purpose of the water budget was to determine how much water was being consumed by wells and what percentage of the budget this represents. Net yearly consumption from withdrawal of ground water by wells in the North Hills study area is about 550 acre feet and accounts for about 4% of the total budget.

Table 2---Average annual ground water budget for the North Hills area.								
	Recharge						Discharge	
	Acre-Feet						Acre-Feet	
AR_in	SC_in	IC_in	IFP_in	Total		UF_out	WL_out	DR_out
9,200	2,000	1,220	1,825	14,245		12,970	550	725
		% of total					% of total	
65	14	9	13	100		91	4	5

CHANGES IN WATER LEVELS

Water levels in wells respond to changes in sources of recharge and discharge. Typically, water levels in wells are lowest in spring, rise during spring runoff and the irrigation season, and fall throughout autumn and winter. The water levels rise during spring runoff and the irrigation season because during this period recharge exceeds discharge and water is put into storage. In the fall and winter discharge exceeds recharge, and water is removed from storage. So if from year to year more water recharges than discharges from an aquifer, hydraulic head in the aquifer will increase. The converse is true when discharge exceeds recharge.

Why did the water level in well 11N04W24BBAB (GWIC ID 65432) decline nearly 15 feet in 2000 and 2001? Figure 4 shows the annual mean discharge for Tenmile Creek. In 2000, the flow was 10 percent of normal. Assuming that Silver Creek streamflow was 10 percent of normal, recharge to the Quaternary aquifer in this part of the North Hills was probably only 10 percent of normal as well. Since the summer of 2001, water level in well 11N04W24BBAB has recovered to almost record high levels (figure 7).

Since 2003, when water levels in 11N04W24BBAB (GWIC ID 65432) recovered to normal levels, about 55 wells have been drilled in 11N04W24 (figure 8). In the future, if recharge from Silver Creek diminishes to near the rate that it was in 2000, water level in many of these wells could drop to a level that would negatively impact their performance. What happened with streamflow in 2000 was probably not an isolated incident. Between 1970 and 2000, the 24-month SPI has been near or below -1 on three different occasions, indicating that streamflow in Silver Creek may have been much below average on these occasions as well (figure 4).

Within the North Hills study area, some wells upgradient of the Helena Valley Irrigation Canal, and all wells downgradient show a seasonal response to ground-water recharge from leakage from the irrigation canal, laterals, and excess water applied to irrigated land (figure 9 and plate 3). In some areas, owing to a flat hydraulic gradient developed in the highly permeable Quaternary aquifer, the irrigation recharge affects water levels in wells more than a mile upgradient from the Helena Valley Irrigation Canal.

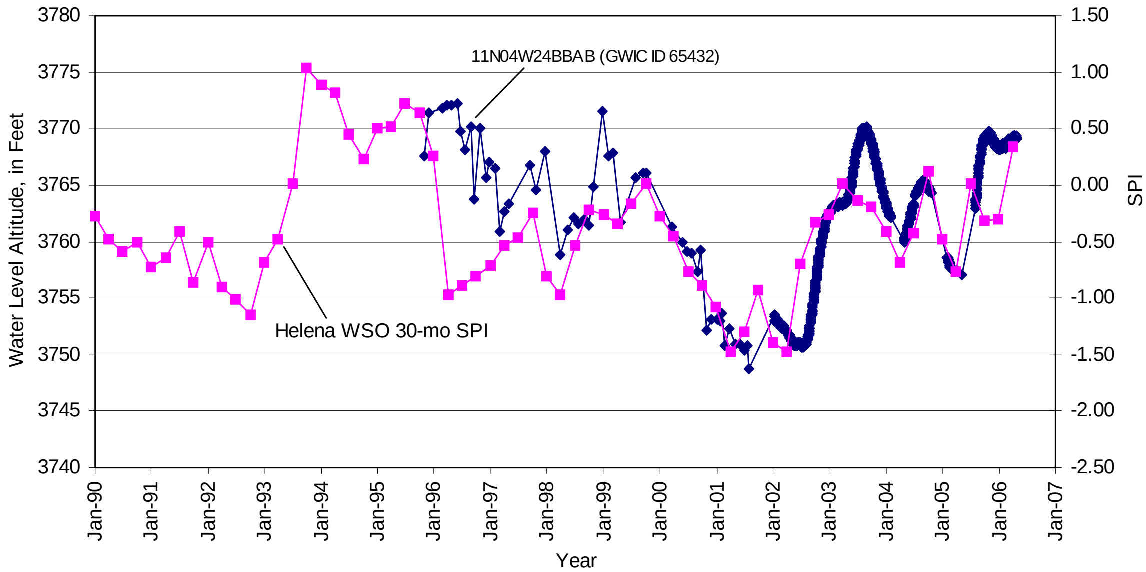


Figure 7–In 2000, streamflow in Silver Creek was probably 10 percent of normal (based on flow in Tenmile Creek) and ground-water recharge to the southwest part of the North Hills ground-water system was less than normal. As a result, the water level in well 11N04W24BBAB (GWIC ID 65432) continued to drop throughout 2000 and into 2001. The water level in the well seems to correspond to 30-month anomalies in climate.

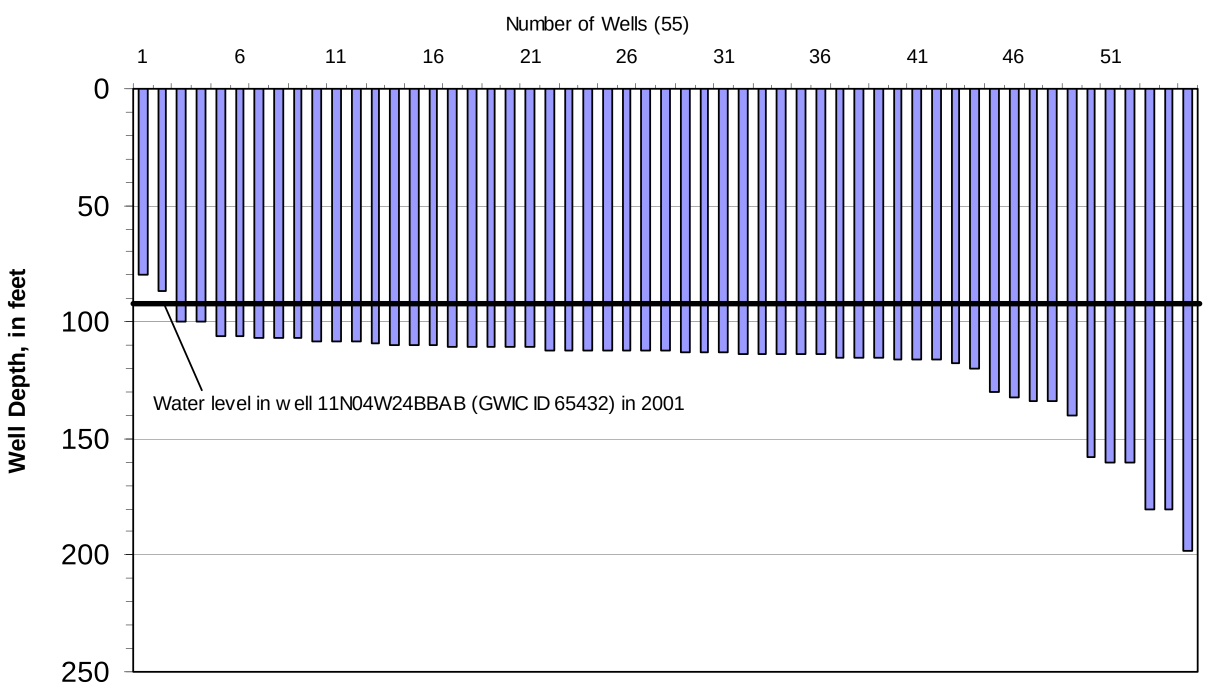


Figure 8– Since 2003, when water level in well 11N04W24BBAB (GWIC ID 65432) recovered, 55 wells have been drilled in 11N04W24. If depth to water is similar to 11N04W24BBAB (GWIC ID 65432) and water level responds similarly, many wells in the future could be impacted if Silver Creek streamflow responds to a dry climate like it did in 2000.

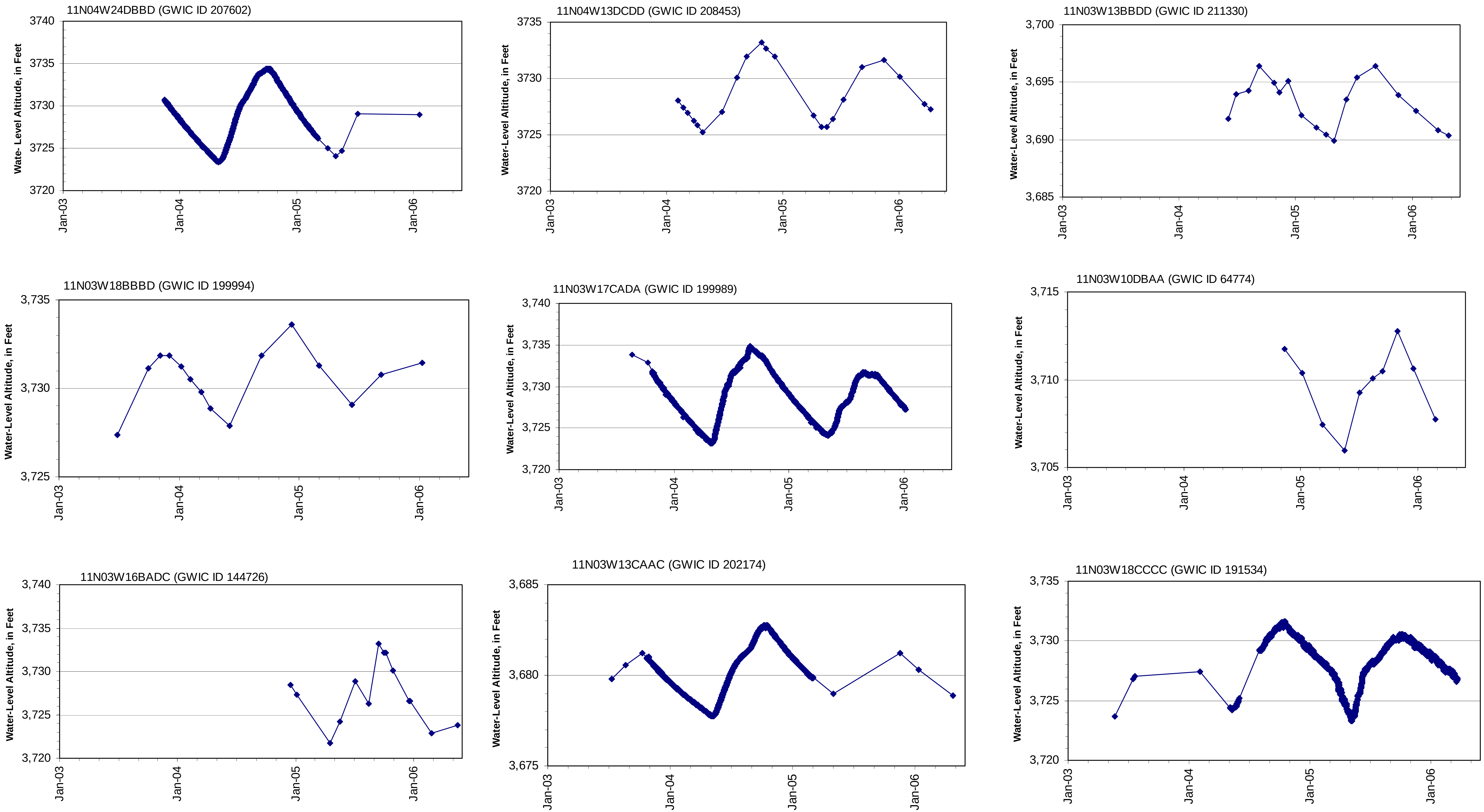


Figure 9– Hydrographs of North Hills wells influenced by recharge from leakage of water from the Helena Valley Irrigation Canal and laterals; and excess irrigation and precipitation on irrigated fields. In some areas, the influence is observed in wells more than a mile upgradient from the irrigation canal.

The ground-water flow system in most of the North Hills study area does not receive any recharge from losing streams or irrigation features (plate 3). The only recharge this area receives is from rain and snow melt. In May and June of 2005, the North Hills received close to 7 inches of rain. Although there was not any apparent immediate response in many hydrographs, a few showed relatively rapid response such as 11N04W02DBBB (GWIC ID 196245) which showed about a 4-feet rise in water level over about 6 months, and 11N04W11CCDB (GWIC ID 198749) which showed about a 7-feet rise over about a 2-month period.

An unusual response that many wells show, to varying magnitudes, is water levels that fall through the spring and summer and rise in the fall and winter (figure 10). It would be easy to explain this response as caused by a nearby pumping well or wells, but well 11N03W10BBAC (GWIC ID 205626) is an unused well in a relatively undeveloped area of the North Hills where there are no irrigation or community supply wells nearby that could cause the decline recorded by this hydrograph. It is not readily apparent what causes these fluctuations, but it could be due to the transient response of infiltrating rain and snow melt reaching the ground-water system. The hydrograph for well 11N03W06DCAD (GWIC ID 64702) shows a similar response but it is located in one of the most developed areas of the North Hills, and some of the decline may be caused by pumping in the summer, but it is not clear to what extent.

Two long-term hydrographs in North Hills have shown declining water level trends since about 2000. These hydrographs are in the area where the ground-water flow system receives recharge only from rain and snow melt. The water level in well 11N03W11BBBA (GWIC ID 148259) has declined about 5 feet since 2000 (figure 11). This well is in a relatively undeveloped area of the North Hills, and the decline is probably related more to climate than over development of the ground-water resource by withdrawal from wells. Water level in well 11N03W08BCBA (GWIC ID 64737) has declined about 8 feet since 2000 (figure 12). It is located near one of the most developed areas in the North Hills, and some of the decline may be related to the withdrawal of ground water, but probably is mostly related to the dry conditions that the North Hills has experienced since 2000. The 2006 peak in the hydrograph is at a similar level to the 2005 peak, and this corresponds with the trend of the 30-month SPI for about the last few quarters.

NITRATE IN GROUND WATER

Between 2000 and July, 2006, water samples were collected from 127 wells for determination of nitrate concentration; for some samples, chloride concentration also was determined. The samples were collected by either the Lewis and Clark County Water Quality Protection District, the MBMG, or private well owners.

Nitrate in ground water may be derived from human and animal waste, organic nitrogen from soil, fertilizer, atmospheric deposition, or a combination of these sources. Large concentrations of chloride (>40 mg/L) in water samples may indicate a human source for nitrate because humans consume and dispose of NaCl (Thamke, 2000). In the North Hills, Thamke (2000) used land use, chloride concentrations, and nitrogen isotopes to infer that the source of nitrate in one well was organic nitrogen from soil or a combination of sources, and in another well, human or animal waste.

The U.S. Environmental Protection Agency (EPA) primary drinking water standard for nitrate established for public drinking-water supplies is 10 mg/L (U.S. EPA, 2002). Of the 127 wells sampled in the North Hills, the nitrate concentration in two wells exceeded the drinking water standard (figure 13). Well 11N04W24ADCA (GWIC ID 65369) had a nitrate concentration of 10.2 mg/L and a chloride concentration of 54.0 mg/L; based on the high chloride concentration in this well and the land use in the area, the nitrate may be derived from the disposal of human waste via the septic system at this site or a nearby site. At well 11N04W10BDBB (GWIC ID 214684) the nitrate concentration was 17.6 mg/L, and the chloride concentration was 20.0 mg/L; the source of the nitrate at this site may be organic nitrogen from soil or animal waste. Nitrate concentration at 11 sites was between 5 to less than 10 mg/L; at least three of these sites also had large (>40 mg/L) chloride concentrations suggesting nitrate derived from human waste; and at 4 sites, the chloride concentration was small (<40 mg/L) suggesting a source for the nitrate from animal waste, organic nitrogen from soil, fertilizer, or a combination of sources. At the remaining 114 sites, the nitrate concentration was less than 5 mg/L.

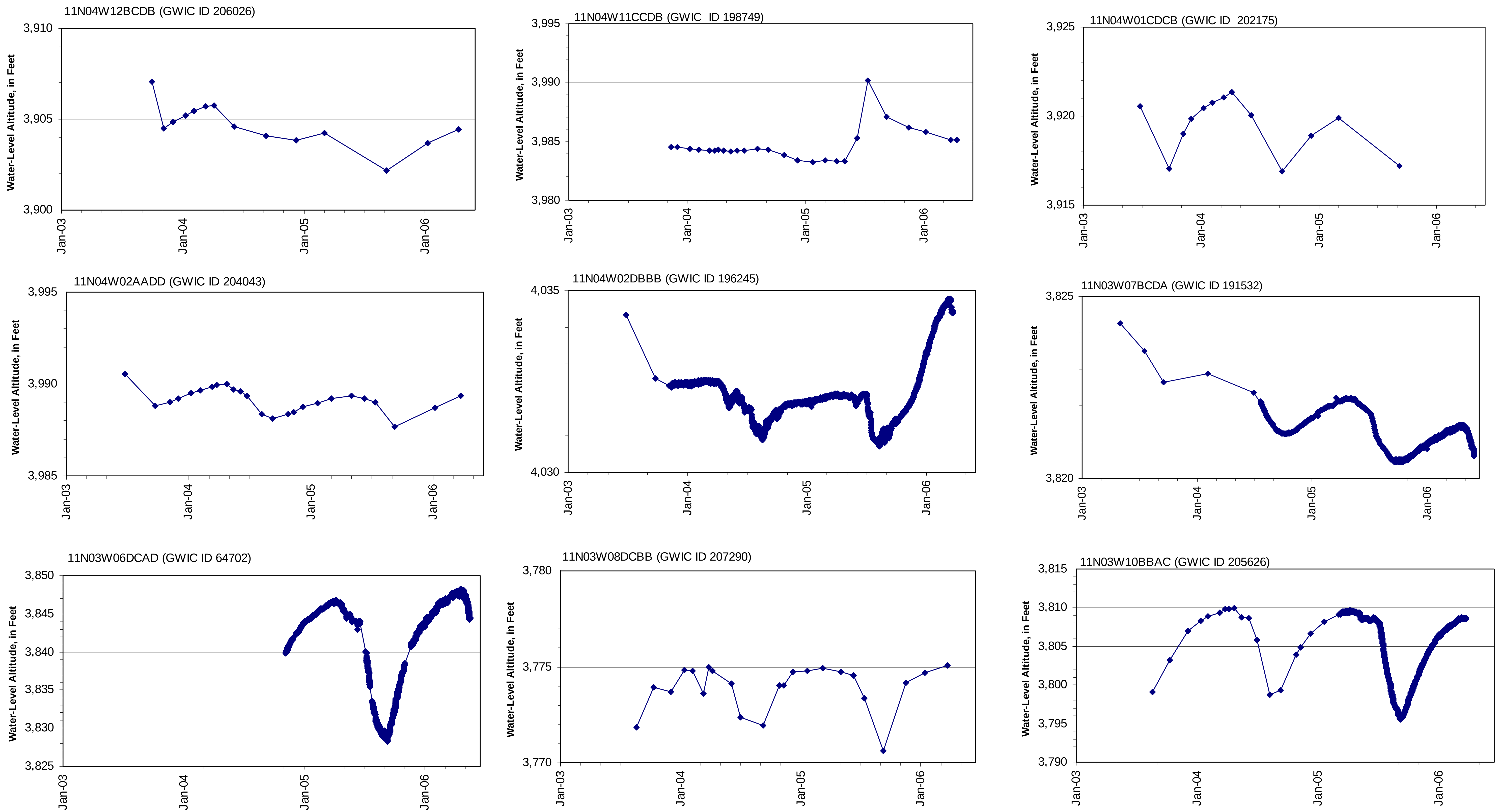


Figure 10–Well hydrographs for wells in the North Hills that are completed in the part of the ground-water system that is not influenced by the effects of irrigation. Recharge is by infiltration of rain and snowmelt. Some wells in the area responded within a few months to the almost 7 inches of rain that the North Hills received in May and June of 2005 as shown by 11N04W11CCDB and 11N04W02DBBB. Other wells respond oppositely to the wells effected by irrigation recharge. Their water levels fall throughout the spring and summer, and rise in the fall and winter. It would seem that these hydrographs reflect drawdown caused by a pumping well, but well 11N03W10BBAC is in a fairly undeveloped part of the North Hills, and there are no irrigation or community supply wells nearby.

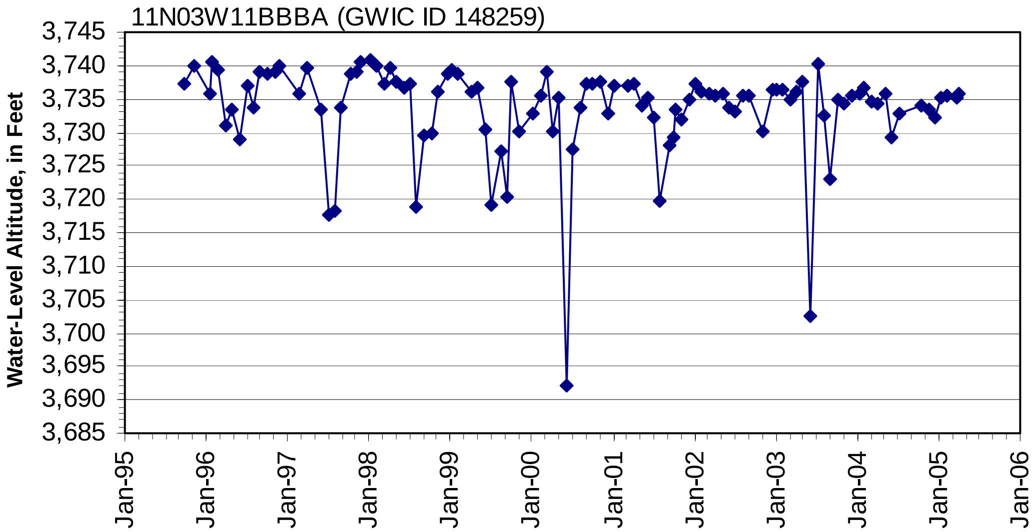


Figure 11–Water level in well 11N03W11BBBA (GWIC ID 148259) has declined about 5 feet since 2000. The well is located in a relatively undeveloped area of the North Hills. The decline probably reflects long-term climate trends.

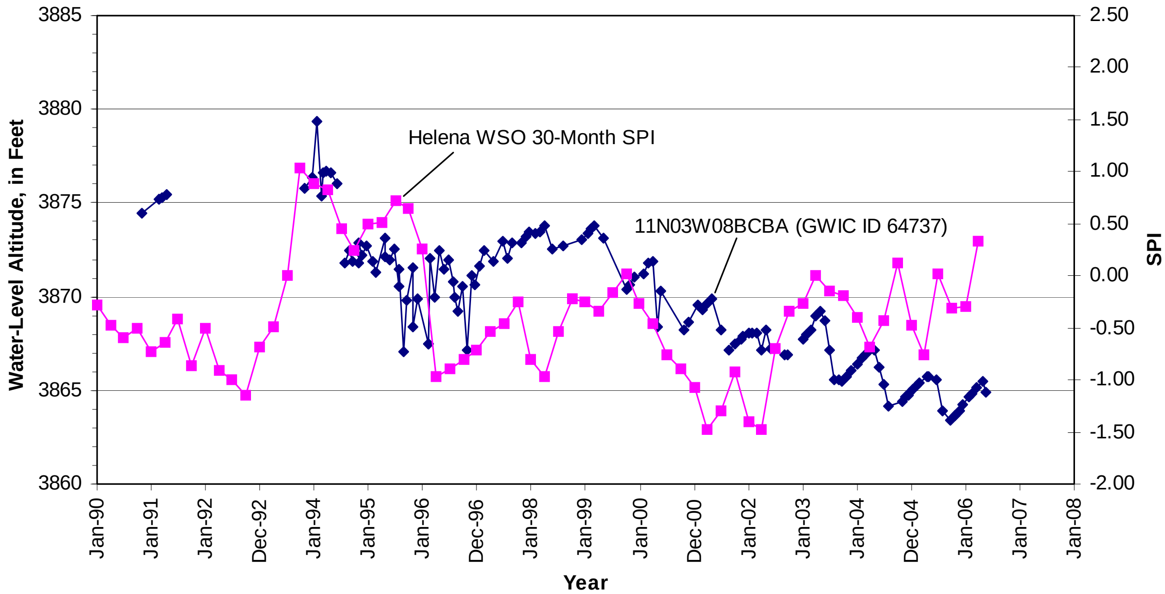


Figure 12– Water level in well 11N03W08BCBA (GWIC ID 64737) has declined about 8 feet since 2000. The 30-month SPI correlates with the hydrograph fairly well. The last two peaks of the well hydrograph are close to the same level. It may take several years of above normal precipitation (SPI near 1) for the water level in the ground-water flow system to rise to pre-2000 levels.

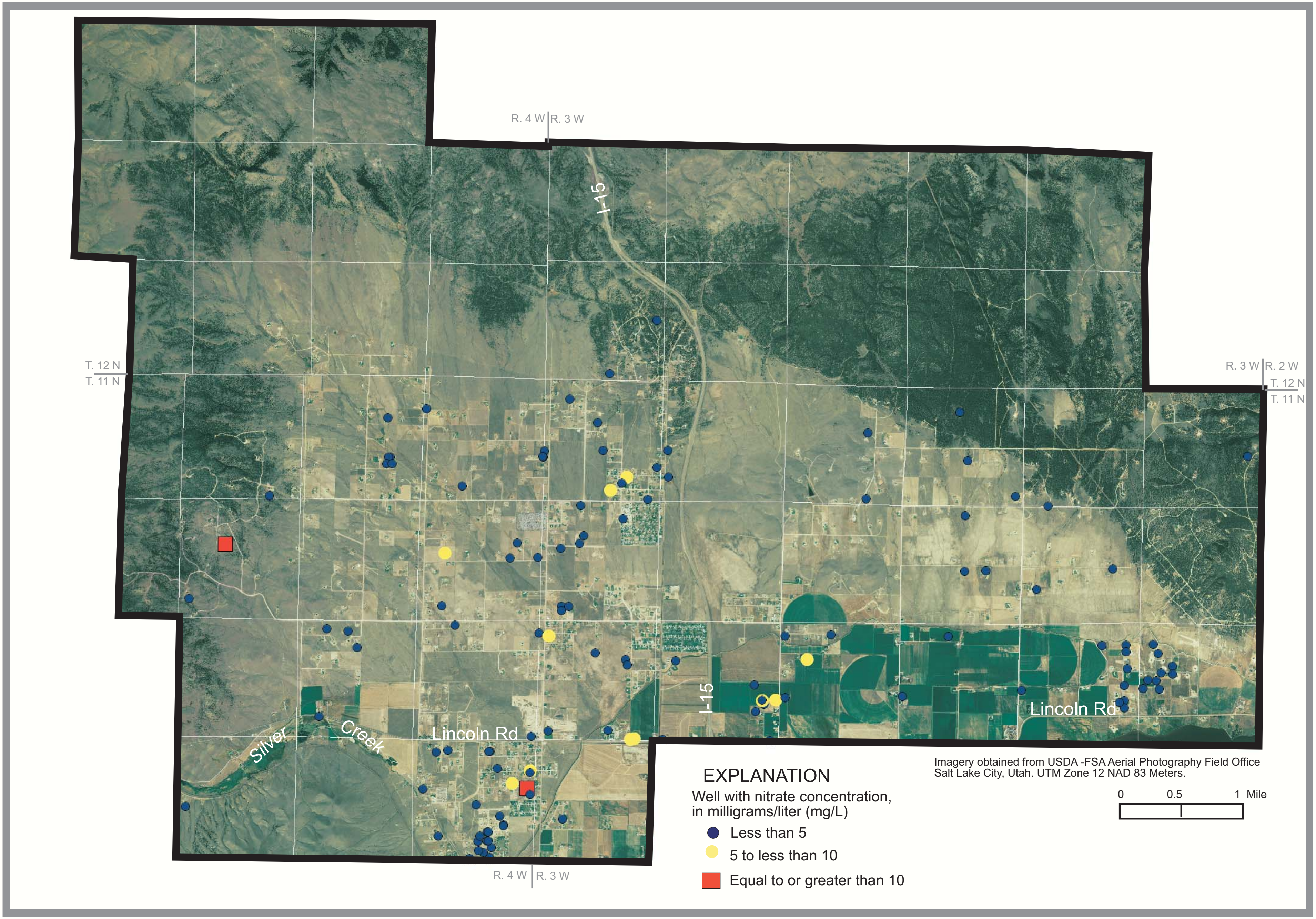


Figure 13--Nitrate concentrations in water samples from 114 wells were less than 5 mg/L; 5 mg/L to less than 10 mg/L in 11 wells; and 10 mg/L or greater in 2 wells. Samples were collected in 2000 through July, 2006.

SUMMARY AND CONCLUSIONS

The North Hills of the Helena Valley is located in north-central Montana and about 8 miles north of Helena, Montana. The study area is 52 square miles and contains more than 1,600 residences.

The North Hills is the fastest growing area in Lewis and Clark County, and one of the fastest growing areas in the state. From 1990 to 2000, the population of a portion of the North Hills went from 1,215 to 2,082, an increase of 867 people (71 percent).

Beginning in the late 1990's, and continuing to the present day, more than 30 wells in the North Hills area have gone dry or the water in the well has dropped to a level that cannot be pumped. This prompted a group of concerned citizens to petition the Montana Department of Natural Resources and Conservation to create a temporary Controlled Groundwater Area; the Controlled Groundwater Area was established in 2002, and data collection began in 2003 as the first step in assessing why water levels were falling.

Average annual precipitation at the Helena WSO weather station, about 8 miles to the south of the study area, is 11.90 inches. Precipitation data from a weather station located about 2 miles south of the North Hills and three project stations, indicate that average annual precipitation falling on the North Hills may be up to 25 percent less than the average annual precipitation at the Helena WSO weather station.

Silver Creek is the only perennial stream in the North Hills and flows through the southwest corner of the study area. Silver Creek emerges from a bedrock canyon, and most times loses all of its stream flow by infiltration into the valley-fill sediments. Calculated average annual streamflow for Silver Creek is 2.82 cfs or 2,060 acre feet/year.

The North Hills area is comprised of mostly flat, gentle southerly sloping pediment surfaces and alluvial plain surrounded on the west, north and east by slightly rugged mountainous terrain composed mostly of lower middle Proterozoic rocks of the Belt Supergroup. Poorly to moderately consolidated Tertiary sediments outcrop in the southeast part off the North Hills and consist of interbedded clay and silt with lenses of sand and gravel. The Tertiary sediments underlie and are concealed in most places by pediment surfaces and alluvial plain. Quaternary alluvium covers most of the study area where bedrock is not exposed. The alluvium is thinnest near the bedrock outcrops and thickens to the south, where it may be up to 600 feet thick.

Based on the geologic map of the North Hills study area, well-completion reports, and field observations of well installations, three aquifers were delineated within the North Hills. These three consist of the pre-Tertiary bedrock aquifer, Tertiary aquifer, and the Quaternary aquifer. Although separated into three aquifers, nothing prevents ground-water flow from one aquifer to the other, and therefore a ground-water flow continuum exists across rock units within the ground-water flow system. Well depths in the pre-Tertiary bedrock aquifer have been reported up to 1,000 feet, but the average bedrock well is about 200 feet deep. Wells yields have been reported up to 100 gallons per minute, with an average yield of about 20 gallons per minute. Well depths in the Tertiary aquifer have been reported up to 800 feet, but the average is about

190 feet; the maximum well yield reported for the Tertiary aquifer is 500 gallons per minute, with an average of 20 gallons per minute. In the Quaternary aquifer, well depths have been reported up to 600 feet, but the average is 120 feet; yields have been measured up to about 900 gallons per minute, with a reported average yield of 35 gallons per minute.

The potentiometric surface in the Quaternary, Tertiary, and pre-Tertiary bedrock aquifers was determined using water levels measured during September 2005 through March 2006. Ground-water flow in the North Hills' aquifers is generally from the north to the south, and all three aquifers appear to function as single hydrostratigraphic unit.

Recharge to the North Hills aquifers is through infiltration of Silver Creek streamflow, irrigation water, and precipitation. Ground water discharges from the North Hills' aquifers to drains, wells, and as underflow through the south boundary of the study area. Discharge of water through wells for mostly watering grass in the summer is 550 acre feet, which is about 4 percent of the total amount discharged from the aquifer. A large part of the North Hills ground-water system is recharged only from rain and snow melt.

In 2000, the streamflow in Silver Creek was about 10% of normal. The aquifer in the southwest part of the study area received less recharge because of this, and water level in wells fell during the summer of 2001. Since then streamflow has increased and the water levels in the wells have returned to normal.

In other parts of the North Hills where the ground-water system is recharged only by rain and snow melt, water levels in some wells have declined. Although the decline in some wells is near the most developed part of the North Hills, the decline has also been measured in wells where development is minimal. The decline, therefore, is probably related more to climatic anomalies and to a lesser extent over drafting by well withdrawals.

Of the 127 wells sampled in the North Hills, the nitrate concentration in two wells exceeded the U.S. EPA drinking water standard. Nitrate concentration at 11 sites was between 5 to less than 10 mg/L. At the remaining 114 sites, the nitrate concentration was less than 5 mg/L. The source for nitrate appears to be human and animal waste, organic nitrogen from soil, fertilizer, atmospheric deposition, or a combination of these sources.

RECOMMENDATIONS

The following recommendations for consideration are as follows:

1. New wells should be drilled at least 20 feet and preferably 50 feet deeper than surrounding wells to allow for fluctuations in the potentiometric surface due to fluctuations caused by drought and future development as illustrated in figure 8.

2. Lewis and Clark County or some other stakeholder group should consider leasing or buying Silver Creek water rights to ensure streamflow and ground-water recharge to the southwest part

of the North Hills ground-water system.

3. Develop high capacity community-supply wells in the Quaternary aquifer for use in areas underlain by Tertiary or pre-Tertiary bedrock aquifers.

4. Developers could contract with the U.S. Bureau of Reclamation to use water from the Helena Valley Irrigation Canal for lawn watering at current and future high-density development(s) .

5. A stream gaging station should be established on Silver Creek near the southwest part of the North Hills study area to monitor streamflow. The streamflow data could be used to a assess recharge to the ground-water system and to alert citizens of potential declining water levels during anomalously (30 month) dry periods.

6. A subset of wells monitored for this study should continue to be monitored. Important locations to consider for long-term monitoring include the ground-water system under 11N04W24B which is effected by Silver Creek leakage. Other important areas include 11N03W06 and 11N03W07 where there has been a significant development and declining water levels.

7. Develop a numerical ground-water flow model to test and refine the aquifer geometry, aquifer properties, and ground-water budget.

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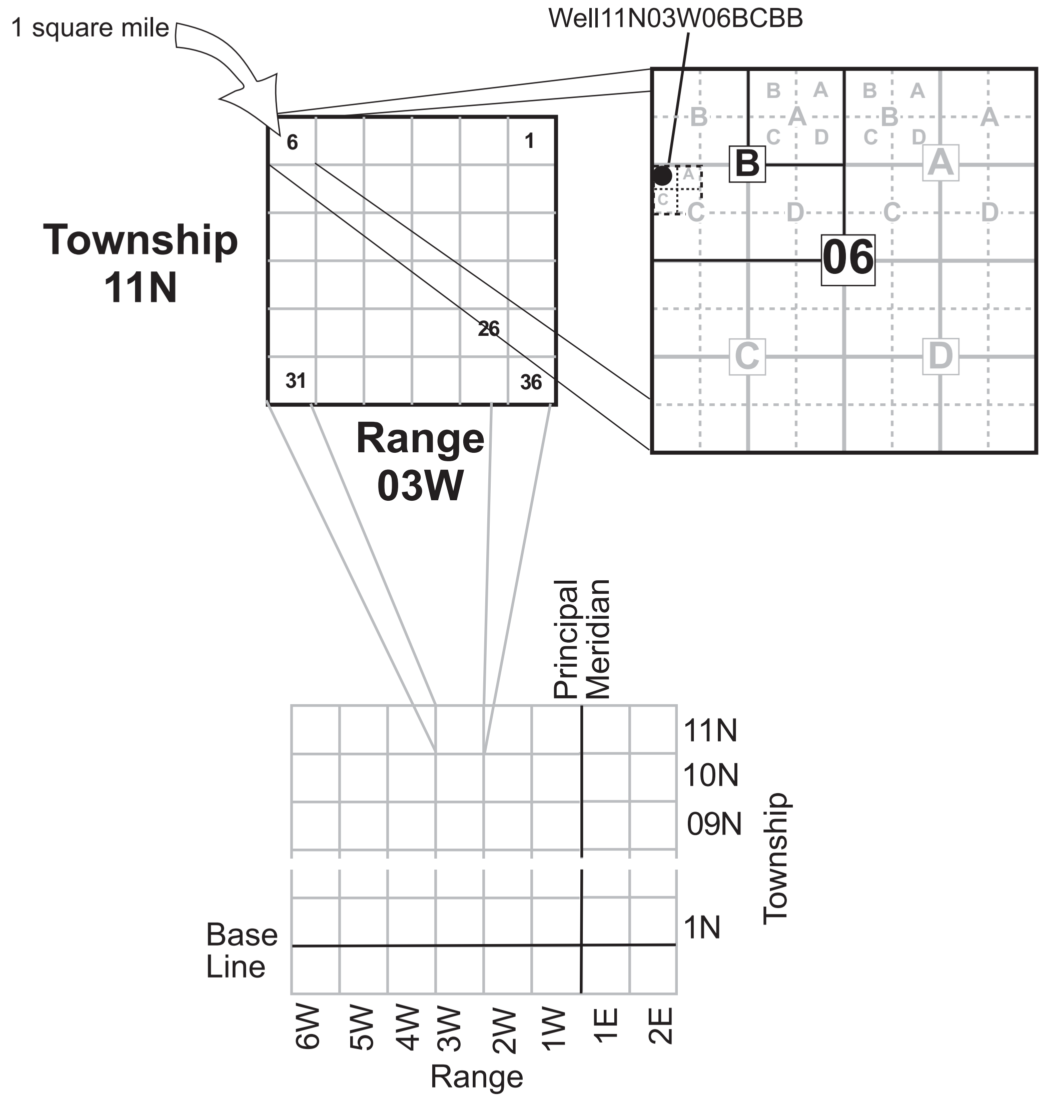
APPENDIX 1

LOCATION SYSTEM



The locations of wells and other sites are designated by location numbers, which are based on the rectangular system for the subdivision of public lands. Each number consists of as many as 14 characters and is assigned according to the location of the site within a given township, range, and section. The first three characters specify the township and its position north (N) of the Montana Base Line. The next three characters specify the range and its position west (W) of the Principal Meridian. The next two characters indicate the section. The next three or four characters indicate the position of the site within the section. The first letter denotes the quarter section (160-acre tract); the second, the quarter-quarter section (40-acre tract); the third, the quarter-quarter-quarter section (10-acre tract); and the fourth, the quarter-quarter-quarter-quarter section (2½-acre tract). The subdivisions of the sections are numbered A,B,C, and D in a counterclockwise direction beginning in the northeast quadrant. The last two characters form a sequence number that is assigned on the basis of order of inventory within that tract. For example the location number 11N03W06BCBB01 refers to the first well (01) inventoried in the NW¼ NW¼ SW¼ NW¼ sec. 06, T. 11 N., R. 3 W.

Appendix 1--Location numbering system.

APPENDIX 2

MONITORING WELLS

Appendix 2--North Hills monitoring wells.

GWIC ID	Location	Latitude	Longitude	Land Surface Altitude, in Feet	Total Depth of Well, In Feet Below Land Surface	Last Measurement Date	Last Static Water Level, in Feet Below Land Surface	Static Water Level Readings
147303	11N03W01DAAB	46.7401	-111.9170	4,121	255	5/16/06	148.65	12
145955	11N03W02CDCD	46.7338	-111.9523	3,914	254	2/27/06	212.99	40
143641	11N03W03DBBC	46.7392	-111.9667	3,980	178	5/16/06	69.45	11
128054	11N03W03DDDB	46.7349	-111.9582	3,945	390	5/16/06	169.6	12
198421	11N03W04ACDD	46.7420	-111.9838	4,024	48	3/24/06	34.57	15
218715	11N03W04DCAC	46.7385	-111.9835	3,940	--	5/16/06	36.15	11
213253	11N03W04DCDB	46.7358	-111.9854	3,941	324	9/8/05	47.48	6
207289	11N03W05CBBC	46.7395	-112.0200	3,997	170	4/12/06	86.45	8
64640	11N03W05CCBC	46.7367	-112.0198	3,965	70	5/17/06	67.09	143
64649	11N03W05CCBC	46.7363	-112.0191	3,965	110	5/17/06	68.12	12
211387	11N03W06AACD	46.7453	-112.0245	4,075	260	5/16/06	76.35	16
206390	11N03W06BBDB	46.7452	-112.0365	4,061	139	4/12/06	62.31	26
206392	11N03W06BBDB	46.7461	-112.0375	4,074	150	1/9/06	76.14	9
213254	11N03W06BCAB	46.7447	-112.0387	4,052	121	1/9/06	55.32	4
206393	11N03W06BCBA	46.7440	-112.0390	4,042	177	1/9/06	44.85	12
216062	11N03W06BCBB	46.7439	-112.0402	4,049	118	6/8/05	48.01	2
216045	11N03W06BDAD	46.7430	-112.0324	4,030	260	9/8/05	44.49	4
64686	11N03W06DAAA	46.7404	-112.0209	3,990	95	5/17/06	107.68	21
143645	11N03W06DBBB	46.7399	-112.0315	4,000	174	5/17/06	103.01	24
206412	11N03W06DBDD	46.7375	-112.0263	3,969	209	4/5/04	98.18	5
213255	11N03W06DCAB	46.7359	-112.0281	3,952	210	12/21/05	105.65	11
206394	11N03W06DCAB	46.7367	-112.0272	3,966	200	5/17/06	115.8	41
64702	11N03W06DCAD	46.7352	-112.0274	3,950	130	5/16/06	105.59	16,270
214234	11N03W06DCDB	46.7352	-112.0289	3,941	200	1/11/05	99.01	4
64712	11N03W06DCDC	46.7333	-112.0288	3,924	130	6/10/05	102.55	8
187850	11N03W06DDCD	46.7340	-112.0234	3,931	100	5/17/06	76.84	34
180458	11N03W07BBAA	46.7331	-112.0354	3,922	125	4/11/06	92.53	26
208433	11N03W07BCBD	46.7278	-112.0388	3,888	150	3/23/06	66.82	26
191532	11N03W07BCDA	46.7285	-112.0355	3,884	100	6/12/06	63.31	13,494
211645	11N03W07CCCA	46.7202	-112.0386	3,849	240	2/28/05	81.31	4
211328	11N03W07CCCA	46.7208	-112.0386	3,854	134	1/9/06	75.89	7
214644	11N03W07CCCD	46.7192	-112.0382	3,844	--	9/8/04	86.52	2
219654	11N03W07CCDA	46.7207	-112.0381	3,856	134	1/9/06	76.04	2
206648	11N03W07CCDB	46.7199	-112.0371	3,847	320	1/9/06	120.6	26
212123	11N03W07CDCB	46.7208	-112.0372	3,851	281	9/7/05	156.81	5
202171	11N03W07DCAC	46.7210	-112.0277	3,830	100	1/5/06	19.09	1,808
64737	11N03W08BCBA	46.7294	-112.0169	3,925	208	5/17/06	60.07	161
213904	11N03W08DCAB	46.7219	-112.0061	3,818	340	1/13/06	35.62	5
207290	11N03W08DCBB	46.7214	-112.0098	3,813	535	3/24/06	38.09	23
216091	11N03W08DDAC	46.7216	-112.0014	3,816	120	1/13/06	38.72	2
176011	11N03W09CABB	46.7237	-111.9942	3,832	240	5/16/06	45.73	12
176012	11N03W09CABB	46.7243	-111.9942	3,841	140	5/16/06	41.6	12
219837	11N03W09CCAC	46.7217	-111.9966	3,818	128	3/24/06	46.55	4
219841	11N03W09CDBD	46.7217	-111.9922	3,820	156	3/24/06	50.82	4
176010	11N03W09DADA	46.7250	-111.9790	3,837	259	5/16/06	106	11

Appendix 2--North Hills monitoring wells (Continued).

GWIC ID	Location	Latitude	Longitude	Land Surface Altitude, in Feet	Total Depth of Well, In Feet Below Land Surface	Last Measurement Date	Last Static Water Level, in Feet Below Land Surface	Static Water Level Readings
218593	11N03W09DADB	46.7248	-111.9797	3,827	--	5/16/06	91.5	11
216095	11N03W10ACDD	46.7271	-111.9633	3,857	420	9/9/05	114.53	1
205626	11N03W10BBAC	46.7326	-111.9745	3,918	420	3/24/06	109.28	1,539
64774	11N03W10DBAA	46.7258	-111.9633	3,842	420	2/27/06	134.3	10
214679	11N03W10DBBB	46.7256	-111.9672	3,833	158	9/8/05	67.27	4
148259	11N03W11BBBA	46.7330	-111.9544	3,900	350	5/17/06	166.61	131
202172	11N03W13BBCA	46.7170	-111.9333	3,753	108	1/13/06	59.88	24
213340	11N03W13BBDC	46.7159	-111.9325	3,748	140	4/25/06	58.55	7
211330	11N03W13BBDD	46.7170	-111.9326	3,761	142	4/25/06	70.59	18
199440	11N03W13BCCD	46.7126	-111.9342	3,709	117	4/25/06	21.16	14
207344	11N03W13BCDB	46.7135	-111.9319	3,732	120	4/25/06	45.38	10
202173	11N03W13BCDD	46.7126	-111.9327	3,716	119	4/25/06	29.1	15
216083	11N03W13BDAA	46.7144	-111.9262	3,748	159	4/25/06	74.4	2
207043	11N03W13BDBC	46.7144	-111.9299	3,744	121	4/25/06	57.65	12
215273	11N03W13BDCA	46.7133	-111.9278	3,721	140	4/25/06	48.43	5
209571	11N03W13BDCB	46.7134	-111.9298	3,734	140	4/25/06	48.89	8
202174	11N03W13CAAC	46.7115	-111.9267	3,710	83	4/25/06	30.8	2,002
218545	11N03W13CAAD	46.7106	-111.9256	3,699	80	1/13/06	18.4	2
222744	11N03W13CBAA	46.7116	-111.9322	3,708	80	4/25/06	23.63	3
206413	11N03W13CBBB	46.7116	-111.9352	3,717	74	4/25/06	28.76	12
213341	11N03W14AACD	46.7160	-111.9397	3,752	120	4/25/06	60.09	6
207737	11N03W14AADB	46.7169	-111.9383	3,762	120	4/25/06	68.62	20
207738	11N03W14AADC	46.7161	-111.9382	3,741	120	4/25/06	47.71	13
220184	11N03W14ABCC	46.7170	-111.9455	3,767	120	4/25/06	66.21	3
195216	11N03W14ABDB	46.7168	-111.9425	3,764	120	4/25/06	67.02	12
207735	11N03W14ADAB	46.7152	-111.9382	3,750	120	4/25/06	56.98	12
207736	11N03W14ADAC	46.7140	-111.9379	3,756	120	4/25/06	64.45	10
216081	11N03W14CAAA	46.7112	-111.9473	3,712	92	1/13/06	13.78	4
219651	11N03W14DAAB	46.7118	-111.9381	3,721	100	4/25/06	34.62	3
212664	11N03W14DAAC	46.7099	-111.9382	3,704	89	4/25/06	14.79	7
216089	11N03W14DAAD	46.7107	-111.9375	3,711	100	4/25/06	21.19	5
222745	11N03W14DACA	46.7099	-111.9392	3,705	120	4/25/06	12.83	3
214702	11N03W14DACC	46.7091	-111.9399	3,693	98	4/25/06	6.23	5
221138	11N03W14DADD	46.7089	-111.9368	3,690	97	4/25/06	5.05	3
199988	11N03W15BAAC	46.7177	-111.9698	3,761	60	4/6/04	44.56	8
195637	11N03W15CBCC	46.7106	-111.9775	3,698	16	5/17/06	6.1	51
144726	11N03W16BADC	46.7177	-111.9906	3,784	240	5/18/06	60.25	14
892125	11N03W16BBBB	46.7175	-111.9988	3,781	125	5/16/06	51.4	65
191556	11N03W16DAAD	46.7103	-111.9778	3,700	50	11/17/04	4.48	13
199989	11N03W17CADA	46.7085	-112.0110	3,748	244	1/5/06	21.1	3,232
204557	11N03W17CBDB	46.7096	-112.0171	3,762	240	1/4/06	33.31	9
204558	11N03W17CBDB	46.7094	-112.0174	3,761	300	1/4/06	33.02	9
204554	11N03W17CBDB	46.7097	-112.0174	3,763	240	1/4/06	33.88	24
204564	11N03W17CCBC	46.7062	-112.0201	3,757	200	4/12/06	32.9	11
204563	11N03W17CCBC	46.7065	-112.0201	3,758	200	3/23/06	32.93	26

Appendix 2--North Hills monitoring wells (Continued).

GWIC ID	Location	Latitude	Longitude	Land Surface Altitude, in Feet	Total Depth of Well, In Feet Below Land Surface	Last Measurement Date	Last Static Water Level, in Feet Below Land Surface	Static Water Level Readings
199992	11N03W18ACAA	46.7144	-112.0271	3,799	134	5/17/06	72.01	20
199993	11N03W18ACAD	46.7138	-112.0265	3,805	135	5/17/06	68.11	18
216643	11N03W18ADCA	46.7141	-112.0229	3,797	120	4/12/06	62.97	11
64879	11N03W18ADDC	46.7123	-112.0215	3,781	100	3/23/06	53.9	11
199994	11N03W18BACC	46.7161	-112.0366	3,829	220	1/9/06	97.87	15
216048	11N03W18BADD	46.7161	-112.0327	3,826	140	1/5/06	85.01	1,217
125628	11N03W18BBBC	46.7175	-112.0391	3,850	124	5/17/06	87.44	61
216645	11N03W18BBBC	46.7172	-112.0407	3,848	159	12/8/04	107.25	1
191534	11N03W18CCCC	46.7055	-112.0406	3,798	100	3/24/06	71.23	2,439
193769	11N03W19CBDA	46.6948	-112.0378	3,774	112	9/8/05	43.32	13
191537	11N03W20BBBB	46.7043	-112.0199	3,755	43	10/31/05	26.02	12
5846	11N03W21BBAA	46.7041	-111.9933	3,690	46.4	5/17/06	3.72	261
211339	11N04W01CCCA	46.7350	-112.0597	3,970	125	9/7/05	75.08	4
202175	11N04W01CDCB	46.7353	-112.0564	3,966	98	9/7/05	49	13
219998	11N04W01DADA	46.7391	-112.0418	3,988	350	1/9/06	146.94	4
217991	11N04W01DADA	46.7391	-112.0423	3,988	314	1/9/06	146.24	4
217956	11N04W01DADB	46.7391	-112.0436	3,990	330	1/9/06	146.08	2
204043	11N04W02AADD	46.7447	-112.0630	4,073	170	3/23/06	84.09	25
208573	11N04W02ACAD	46.7435	-112.0698	4,065	219	4/13/06	75.7	15
211906	11N04W02ADAA	46.7438	-112.0636	4,060	131	9/7/05	72.34	7
199997	11N04W02BADB	46.7458	-112.0755	4,109	280	4/12/06	53.87	27
214703	11N04W02CDDD	46.7346	-112.0754	4,060	304	1/6/06	141.64	4
209292	11N04W02DBAA	46.7387	-112.0696	4,041	197	1/6/06	60.55	10
196245	11N04W02DBBB	46.7398	-112.0726	4,057	80	3/24/06	22.74	3,466
213257	11N04W02DBDC	46.7379	-112.0699	4,038	169	1/6/06	80.88	5
216078	11N04W02DBDD	46.7379	-112.0691	4,038	156	1/6/06	76.16	4
209185	11N04W02DBDD	46.7387	-112.0693	4,039	100	1/6/06	58.73	8
213511	11N04W02DCCC	46.7339	-112.0734	4,039	480	6/9/05	131.07	2
221168	11N04W04DAAA	46.7405	-111.9785	4,015	114	9/9/05	43.83	1
706051	11N04W09ADAD	46.7288	-112.1068	4,345	250	5/25/06	34.11	66
215716	11N04W09DDBC	46.7207	-112.1115	4,353	450	1/6/06	146.66	3
221166	11N04W10BCBA	46.7290	-112.1046	4,400	264	1/6/06	80.36	3
214684	11N04W10BDBB	46.7281	-112.0983	4,304	220	4/13/06	71.7	12
202176	11N04W10CCCA	46.7211	-112.1047	4,226	560	4/13/06	52.3	14
138466	11N04W10CCCD	46.7190	-112.1042	4,183	250	3/23/06	30.76	41
211340	11N04W11CADC	46.7229	-112.0772	4,017	340	3/23/06	10.82	8
198749	11N04W11CCDB	46.7191	-112.0824	4,062	340	4/13/06	76.35	26
169705	11N04W12ADBC	46.7284	-112.0466	3,909	220	1/9/06	80.47	13
206026	11N04W12BCDB	46.7271	-112.0594	3,949	200	4/13/06	44.35	14
206837	11N04W12CCBD	46.7206	-112.0598	3,910	400	3/23/06	150.04	17
168597	11N04W12CDDC	46.7193	-112.0556	3,891	250	1/9/06	142.09	7
65271	11N04W12CDDD	46.7191	-112.0536	3,890	176	5/17/06	137.21	166
207600	11N04W13ADAC	46.7140	-112.0448	3,838	220	1/9/06	107.31	6
216653	11N04W13ADCD	46.7123	-112.0446	3,835	400	1/9/06	97.75	2
209187	11N04W13DCBB	46.7074	-112.0517	3,828	200	4/12/06	98.96	16

Appendix 2--North Hills monitoring wells (Continued).

GWIC ID	Location	Latitude	Longitude	Land Surface Altitude, in Feet	Total Depth of Well, In Feet Below Land Surface	Last Measurement Date	Last Static Water Level, in Feet Below Land Surface	Static Water Level Readings
208453	11N04W13DCDD	46.7049	-112.0475	3,814	200	4/12/06	86.81	22
208454	11N04W13DDDC	46.7048	-112.0436	3,804	180	3/1/05	76.85	6
202177	11N04W14BABD	46.7174	-112.0764	3,957	502	4/13/06	10.65	25
181560	11N04W14BADD	46.7154	-112.0747	3,928	220	3/23/06	42.16	12
209466	11N04W14BBAD	46.7176	-112.0801	3,996	550	8/6/04	68.4	2
187372	11N04W18ADDB	46.7124	-112.0432	3,830	137	5/17/06	97.15	17
202178	11N04W22CBCB	46.6957	-112.1049	4,056	218	1/18/06	55.99	8
189417	11N04W24ABDD	46.7005	-112.0489	3,815	155	5/17/06	89.08	20
65422	11N04W24ABDD	46.7008	-112.0489	3,815	95	5/17/06	89.4	16
211891	11N04W24ADCC	46.6978	-112.0460	3,801	112	9/8/05	69.05	6
211890	11N04W24ADCC	46.6977	-112.0472	3,805	112	9/8/05	72.48	6
195887	11N04W24ADDC	46.6977	-112.0437	3,795	100	9/8/05	63.01	12
65432	11N04W24BBAB	46.7030	-112.0584	3,845	120	6/12/06	74.95	6,619
200000	11N04W24BCCA	46.6982	-112.0627	3,849	300	9/8/05	44.32	11
218567	11N04W24CBAA	46.6963	-112.0589	3,839	160	9/9/05	41.66	1
199442	11N04W24CBCA	46.6941	-112.0619	3,847	280	9/8/05	39.79	5
197572	11N04W24CDDA	46.6908	-112.0527	3,800	115	1/18/06	69.61	10
217987	11N04W24DACB	46.6950	-112.0482	3,806	110	1/18/06	74.82	1
213264	11N04W24DACC	46.6939	-112.0484	3,801	111	1/18/06	73.39	5
213262	11N04W24DACC	46.6940	-112.0483	3,802	111	1/18/06	73.89	5
213261	11N04W24DACC	46.6940	-112.0482	3,801	111	1/18/06	73.53	5
213259	11N04W24DACC	46.6939	-112.0482	3,802	112	1/18/06	73.76	5
222890	11N04W24DBAA	46.6966	-112.0482	3,809	116	1/18/06	77.67	1
222891	11N04W24DBAA	46.6966	-112.0476	3,808	113	1/18/06	76.43	1
223346	11N04W24DBBB	46.6967	-112.0513	3,816	113	1/18/06	85.79	1
222672	11N04W24DBBC	46.6956	-112.0528	3,817	116	1/18/06	86.38	1
222674	11N04W24DBBC	46.6956	-112.0522	3,816	114	1/18/06	85.43	1
222673	11N04W24DBBD	46.6957	-112.0512	3,813	113	1/18/06	83.23	1
207602	11N04W24DBBD	46.6950	-112.0501	3,809	110	1/18/06	80.48	1,925
217071	11N04W24DBCA	46.6949	-112.0512	3,812	140	1/18/06	82.18	1
217072	11N04W24DBCB	46.6949	-112.0520	3,819	100	1/18/06	83.82	1
206641	11N04W24DBCC	46.6926	-112.0525	3,808	107	1/18/06	78.93	10
220000	11N04W24DBCC	46.6938	-112.0519	3,810	111	1/18/06	81.84	2
217073	11N04W24DBCC	46.6938	-112.0521	3,809	120	1/18/06	80.11	1
217099	11N04W24DBCC	46.6938	-112.0520	3,809	160	1/18/06	79.64	2
220001	11N04W24DBCC	46.6938	-112.0519	3,810	110	1/18/06	80.33	2
217982	11N04W24DBDB	46.6938	-112.0500	3,805	114	1/18/06	76.5	2
217989	11N04W24DBDB	46.6948	-112.0488	3,808	112	1/18/06	76.89	3
220003	11N04W24DBDB	46.6950	-112.0500	3,809	115	1/18/06	80.47	2
220002	11N04W24DBDC	46.6940	-112.0502	3,811	114	1/18/06	77.34	1
213258	11N04W24DBDC	46.6938	-112.0502	3,806	116	1/18/06	77.1	5
217983	11N04W24DCAA	46.6932	-112.0482	3,799	112	1/18/06	71.58	2
217984	11N04W24DCAB	46.6932	-112.0492	3,800	115	1/18/06	73.39	2
217988	11N04W24DCAB	46.6932	-112.0493	3,801	115	1/18/06	73.31	2
204585	11N04W24DCBB	46.6931	-112.0512	3,806	107	1/18/06	77.1	12

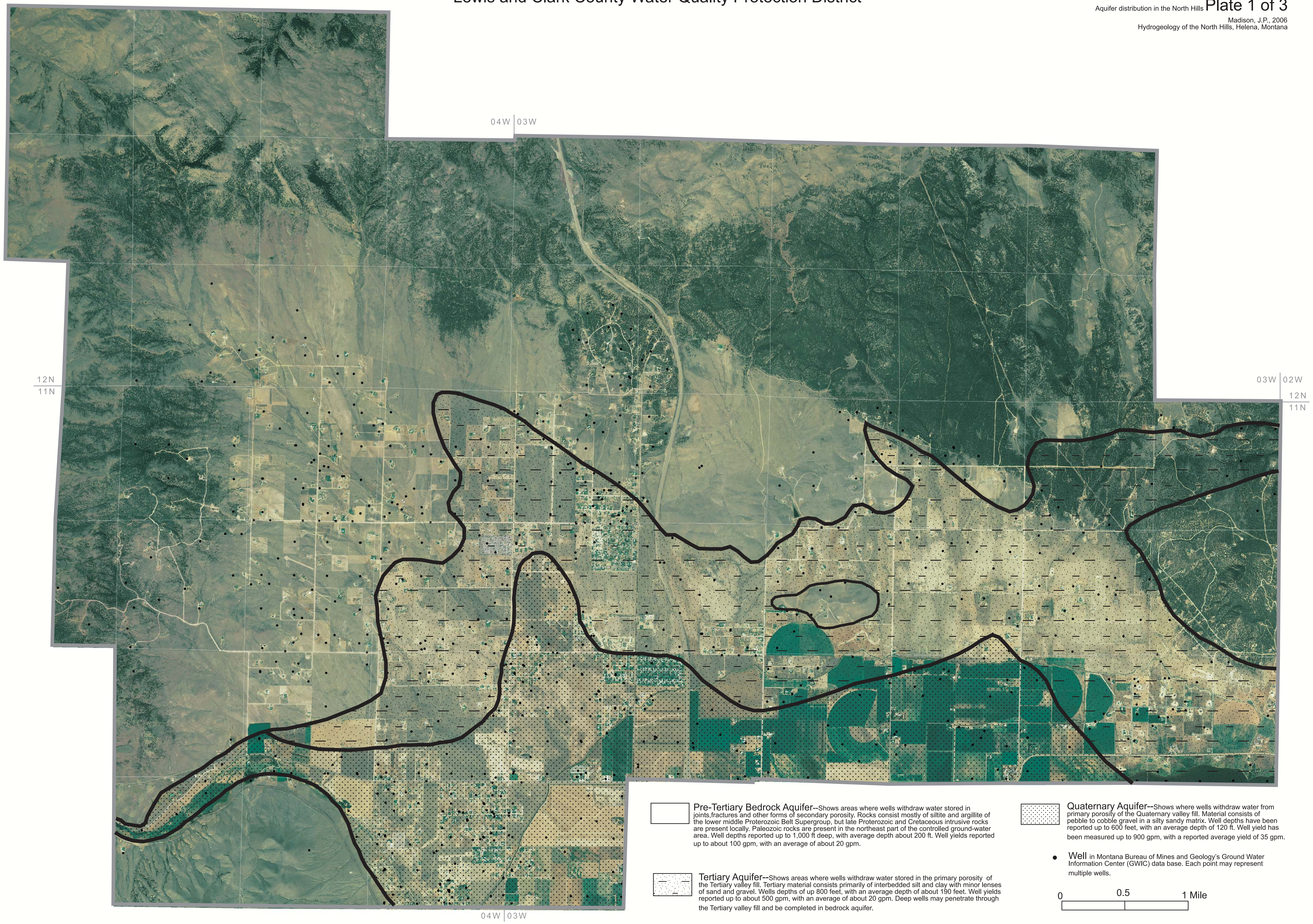
Appendix 2--North Hills monitoring wells (Continued).

GWIC ID	Location	Latitude	Longitude	Land Surface Altitude, in Feet	Total Depth of Well, In Feet Below Land Surface	Last Measurement Date	Last Static Water Level, in Feet Below Land Surface	Static Water Level Readings
204590	11N04W24DCBB	46.6931	-112.0510	3,805	118	1/18/06	69.77	13
204583	11N04W24DCBB	46.6920	-112.0512	3,803	108	1/18/06	74.72	10
206643	11N04W24DCBC	46.6927	-112.0525	3,808	107	1/18/06	78.74	10
204588	11N04W24DCBC	46.6919	-112.0528	3,807	158	1/18/06	76.91	11
204589	11N04W24DCBD	46.6920	-112.0510	3,803	106	1/18/06	74.35	11
204587	11N04W24DCBD	46.6918	-112.0510	3,802	111	1/18/06	73.54	10
206644	11N04W24DCBD	46.6919	-112.0511	3,803	106	1/18/06	74.24	10
202179	11N04W24DCCA	46.6912	-112.0505	3,799	100	1/18/06	71.33	11
194433	11N04W24DCCB	46.6906	-112.0518	3,798	136	1/18/06	68.83	9
194432	11N04W24DCCC	46.6900	-112.0507	3,794	120	1/18/06	65.39	8
212618	12N03W31ADDC	46.7558	-112.0222	4,257	350	4/12/06	0.6	8
208488	12N03W31DBBD	46.7542	-112.0295	4,230	327	4/12/06	85.48	28
66332	12N03W31DDAC	46.7502	-112.0222	4,133	53	5/16/06	16.67	50

Montana Bureau of Mines and Geology

Prepared in cooperation with the
Lewis and Clark County Water Quality Protection District

Open-File Report 544
Aquifer distribution in the North Hills Plate 1 of 3
Madison, J.P., 2006
Hydrogeology of the North Hills, Helena, Montana



Pre-Tertiary Bedrock Aquifer--Shows areas where wells withdraw water stored in joints,fractures and other forms of secondary porosity. Rocks consist mostly of siltite and argillite of the lower middle Proterozoic Belt Supergroup, but late Proterozoic and Cretaceous intrusive rocks are present locally. Paleozoic rocks are present in the northeast part of the controlled ground-water area. Well depths reported up to 1,000 ft deep, with average depth about 200 ft. Well yields reported up to about 100 gpm, with an average of about 20 gpm.

Tertiary Aquifer--Shows areas where wells withdraw water stored in the primary porosity of the Tertiary valley fill. Tertiary material consists primarily of interbedded silt and clay with minor lenses of sand and gravel. Wells depths of up 800 feet, with an average depth of about 190 feet. Well yields reported up to about 500 gpm, with an average of about 20 gpm. Deep wells may penetrate through the Tertiary valley fill and be completed in bedrock aquifer.

Quaternary Aquifer--Shows where wells withdraw water from primary porosity of the Quaternary valley fill. Material consists of pebble to cobble gravel in a silty sandy matrix. Well depths have been reported up to 600 feet, with an average depth of 120 ft. Well yield has been measured up to 900 gpm, with a reported average yield of 35 gpm.

Well in Montana Bureau of Mines and Geology's Ground Water Information Center (GWIC) data base. Each point may represent multiple wells.

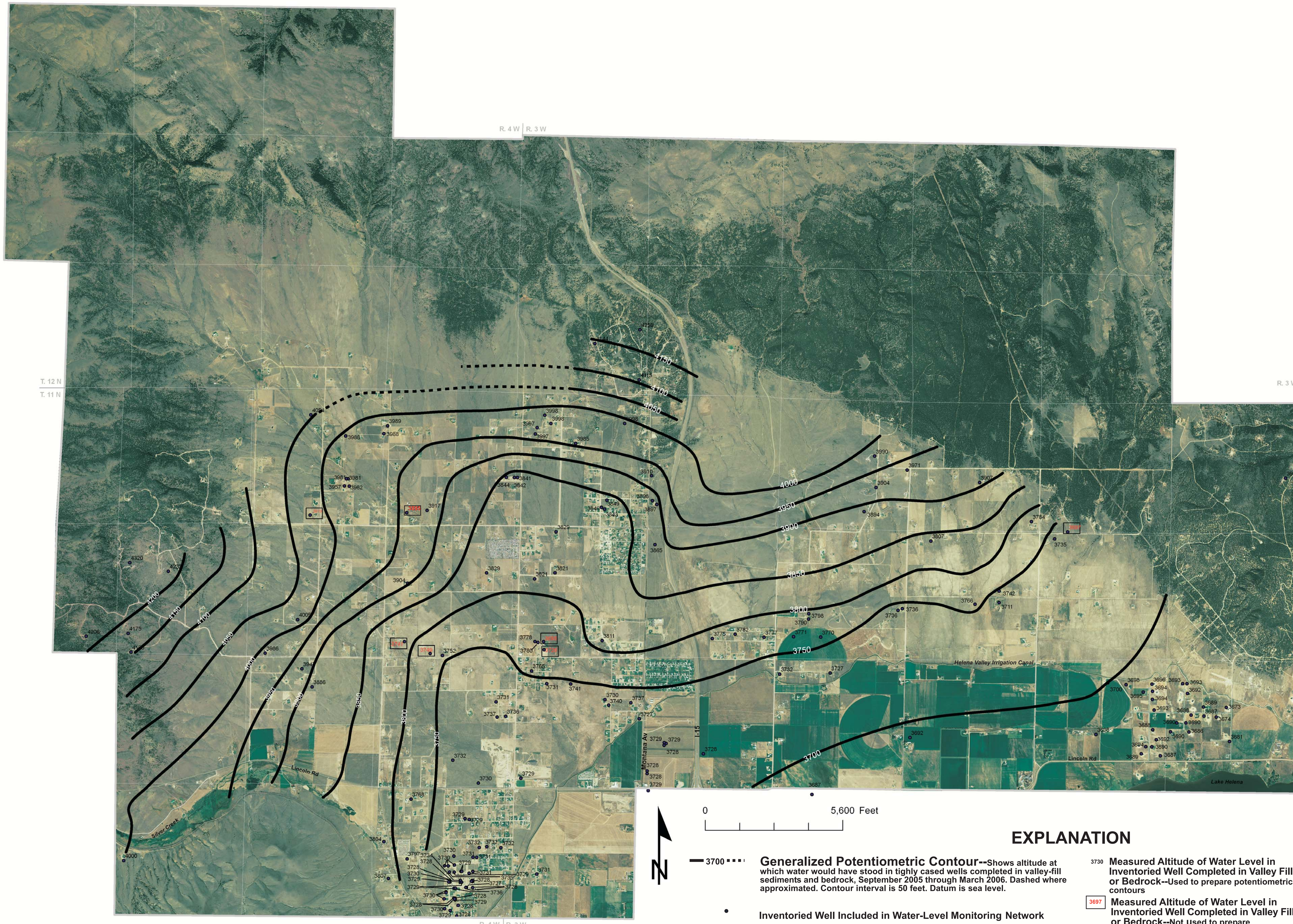
0 0.5 1 Mile

Map Showing Distribution of Aquifers, North Hills, Helena Valley, Montana

Montana Bureau of Mines and Geology

Prepared in cooperation with the
Lewis and Clark County Water Quality Protection District

Open-File Report 544
Potentiometric map of the North Hills **Plate 2 of 3**
Madison, J.P., 2006
Hydrogeology of the North Hills, Helena, Montana



EXPLANATION

3700 — Generalized Potentiometric Contour--Shows altitude at which water would have stood in tighly cased wells completed in valley-fill sediments and bedrock, September 2005 through March 2006. Dashed where approximated. Contour interval is 50 feet. Datum is sea level.

• Inventoried Well Included in Water-Level Monitoring Network

3730 Measured Altitude of Water Level in Inventoried Well Completed in Valley Fill or Bedrock--Used to prepare potentiometric contours

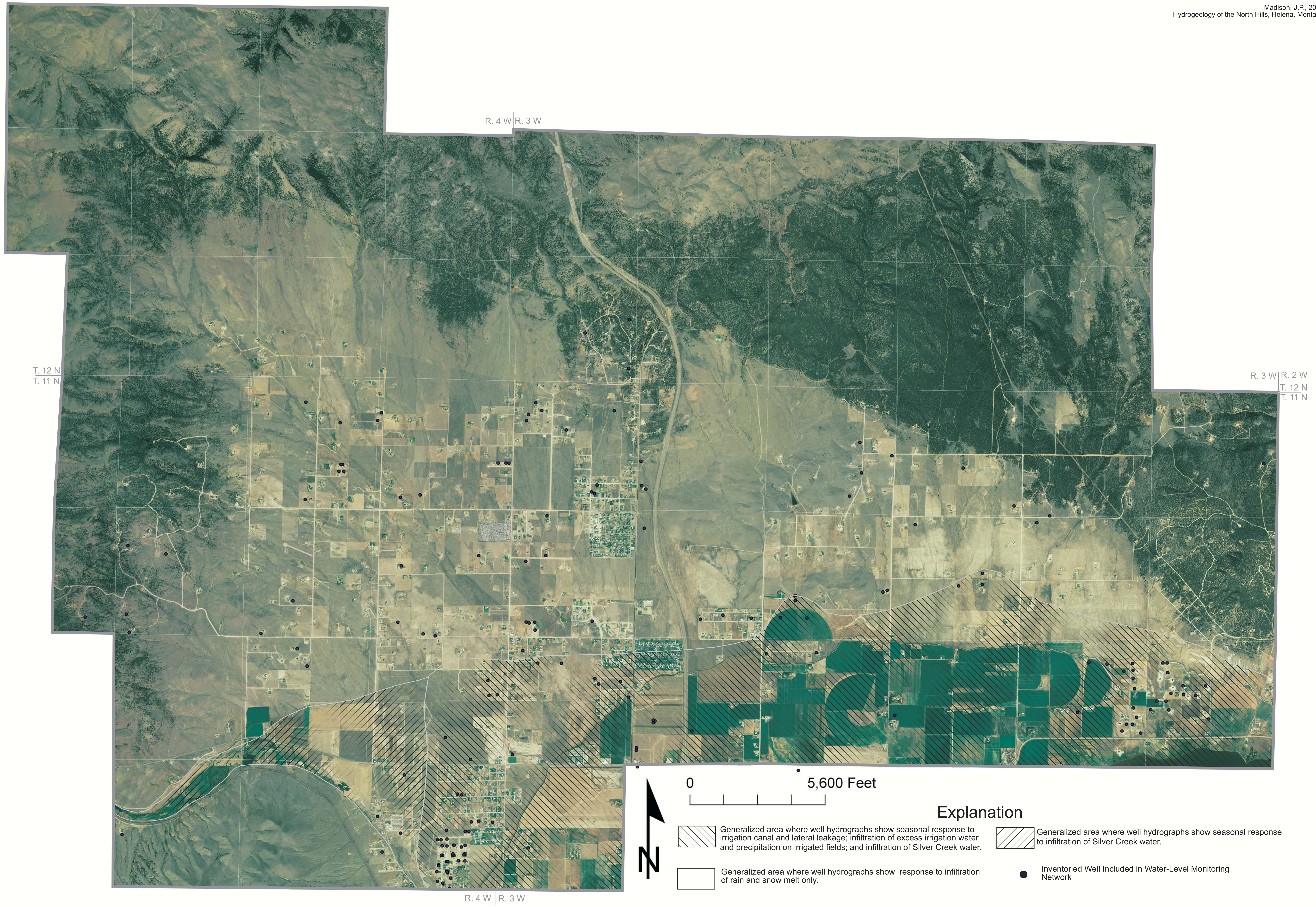
3697 Measured Altitude of Water Level in Inventoried Well Completed in Valley Fill or Bedrock--Not used to prepare potentiometric contours

Map Showing Altitude and Configuration of the Potentiometric Surface, North Hills, Helena Valley, Montana

Montana Bureau of Mines and Geology

Prepared in cooperation with the
Lewis and Clark County Water Quality Protection District

Open-File Report 544
Aquifer response to recharge Plate 3 of 3
Madison, J.P., 2006
Hydrogeology of the North Hills, Helena, Montana



Map Showing Types of Hydrograph Responses in Wells, North Hills, Helena Valley, Montana