Montana Bureau of Mines and Geology

Open-File Report 567

Developing a Viable Water Supply for the Town of Broadview, South-Central Montana

by
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Montana Bureau of Mines and Geology

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A RENEWABLE RESOURCES GRANT PROJECT
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THE TOWN OF BROADVIEW

Cover Photo: Water production (about 120 gpm) during test drilling in the Gooseneck Creek area.

Table of Contents

Figures

Tables

Appendices

EXECUTIVE SUMMARY

This project was designed to develop a new water supply for the town of Broadview. Broadview currently taps ground water from relatively deep wells completed in the Eagle Sandstone. The current supply is inadequate in quality and quantity. Additional water for fire suppression and irrigation of lawns and trees depends on the Broadview Pond; unfortunately, it has been dry for the past several years. Broadview has a history of water problems and shortages that are frequently worsened by drought. In the 1930s, Broadview had a shallow water supply that failed, resulting in a strong population decline. A fire in 1934 burned most of the town because of inadequate water for fire suppression. Water prospects were so pessimistic at that time that circa 1939 the town actually sold the water tower to Lewistown for $340. Broadview has shown significant potential to expand its role as a bedroom community to Billings, but this potential has been hindered by the inadequate water supply. Residents are having difficulty maintaining healthy trees, lawns, and gardens, in addition to the hazard of insufficient water for fire suppression.

Sites were identified for developing ground-water resources based on interpretations of recently published geologic data, historic hydrologic data, and hydrologic measurements collected during the project. This information was used to define geologically favorable sites for developing viable water supplies. The most promising area was located about 7–8 miles west of town near Gooseneck Creek. This project constructed five test wells to assess four locations in the Gooseneck Creek area for municipal water-supply development. Three of these wells produced adequate quantities of good quality water. The assessment included detailed measurements of ground-water quality and long-term aquifer testing to identify optimum pumping rates and impacts to nearby water resources. Finally, ground-water flow, recharge areas, and discharge areas were mapped to help the town of Broadview understand the long-term viability of these water supplies.

INTRODUCTION

The town of Broadview is located in northwestern Yellowstone County near the drainage divide between Painted Robe Creek and Comanche Basin (fig. 1). Comanche Basin is an internally drained region that formed as the result of faulting along the west–northwest-trending Lake Basin Fault Zone. Painted Robe Creek is a tributary to the Musselshell River. Faulting and subsequent differential erosion has resulted in a pronounced topographic basin consisting of sandstone-rimmed uplands draining towards the interior of the depression, which is developed on shale. Most of the area is privately owned with the exception of state land (fig. 2). The surficial geology of the Broadview area is shown in figure 3. The age of rocks at the land surface progresses from older Cretaceous rocks in the western part of the study area to Tertiary rocks in the east. Remnants of several high-level terraces and pediment surfaces are located in the northwestern part of the study area. The Comanche Basin, Hailstone Basin, and stream valleys contain Quaternary lake sediments, alluvium and colluvium. The Bull Mountain Basin is a major structural feature expressed by the decreasing age of sediments from west to east. Near the town of Broadview, rocks dipping steeply towards the east and northeast are the result of down warping into the deeper parts of the structural basin. The project documented the feasibility of developing ground-water supplies capable of providing water to Broadview. Water-quality samples were collected and analyzed to determine if potable water could be produced. In addition, aquifer tests were conducted to verify adequate water quantity and to document potential impacts of water development. The results of this project will provide the first steps for Broadview to develop a water supply that will furnish the needs of the community.

BACKGROUND

Water is a critical issue in the survival of the town of Broadview, located in northwestern Yellowstone County. This project is the result of efforts spearheaded by residents, the mayor, and the town council. Marginal water supplies for Broadview have limited development potential and led to the abandonment of small businesses and residences. Water shortages caused major problems during the drought of the "Dirty Thirties." A large fire in 1934 swept through Broadview and burned much of the town to the ground. Historical reports relate the selling of Broadview's water tower to Lewistown in 1939 for $340 because the limited water supply was unable to fill the tower. More recent water problems include a house fire in the spring of 2002 in which the fire department was hampered because of the inadequate water supply. Because of the limited water supply, the fire department was forced to let the house burn in order to save neighboring houses. Home insurance rates are currently rated as class 10 and have doubled for many residents because of inadequate fire suppression capabilities supplied by the municipal water supply. Lawns and trees are either dead or dying, reducing property values in the community.

The Broadview water system is currently supplied by two wells completed in the Eagle Sandstone. The "good" well (15969) is located on the west side of town and is completed at a depth of about 1,000 ft. This is the primary well for the municipal water supply and is pumped at a rate of 24 gallons per minute. A nearby well (15974) was drilled to a depth of 1,100 ft and has been abandoned. The "new" well (163110) was drilled in 1995 and is located about 1,200 ft north of the "good" well. This well is about 1,100 ft deep and yields about 10 gallons per minute to the system. The water quality of the Eagle aquifer near Broadview is dominated by high concentrations of sodium and sulfate ions, as shown in the water-quality analyses from wells 15969 and 15974 (table 1). The high sodium concentration results in extremely high sodium adsorption ratios (SAR), ranging from 60 to 100. This water is unsatisfactory for most uses and is unusable for watering trees, lawns, and gardens. In the past, irrigation water and fire-suppression water were pumped from the Broadview pond located north of town (fig. 1). Broadview has two water systems: a domestic system currently supplied by the wells and an irrigation system supplied by the Broadview pond when available. The Broadview water supply has very poor quality. The existing high sodium and sulfate concentrations can cause significant health problems. Parts of Broadview have low pressures in water lines that could potentially allow back-pressure and subsequent contamination from other sources.

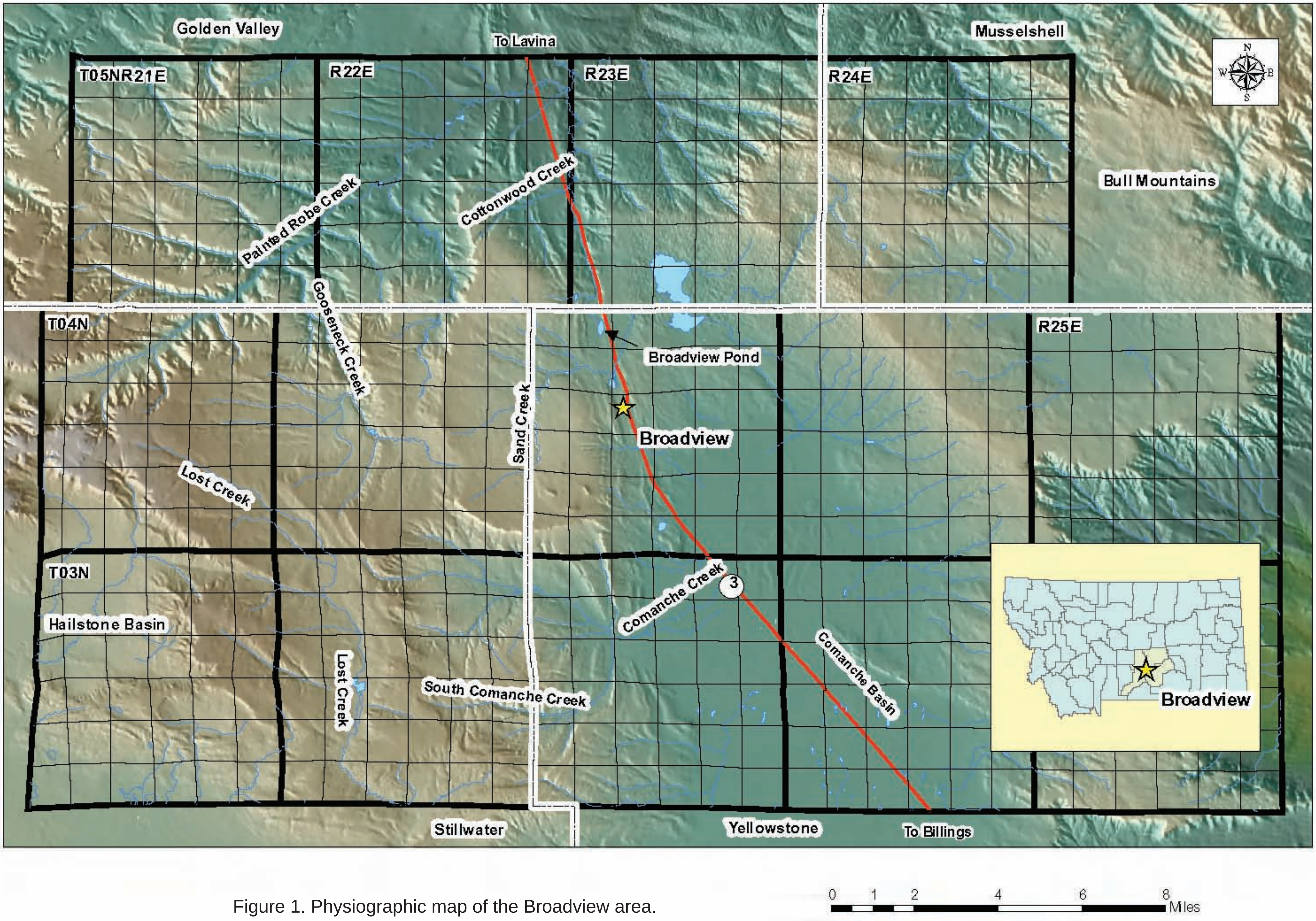


Figure 1. Physiographic map of the Broadview area.

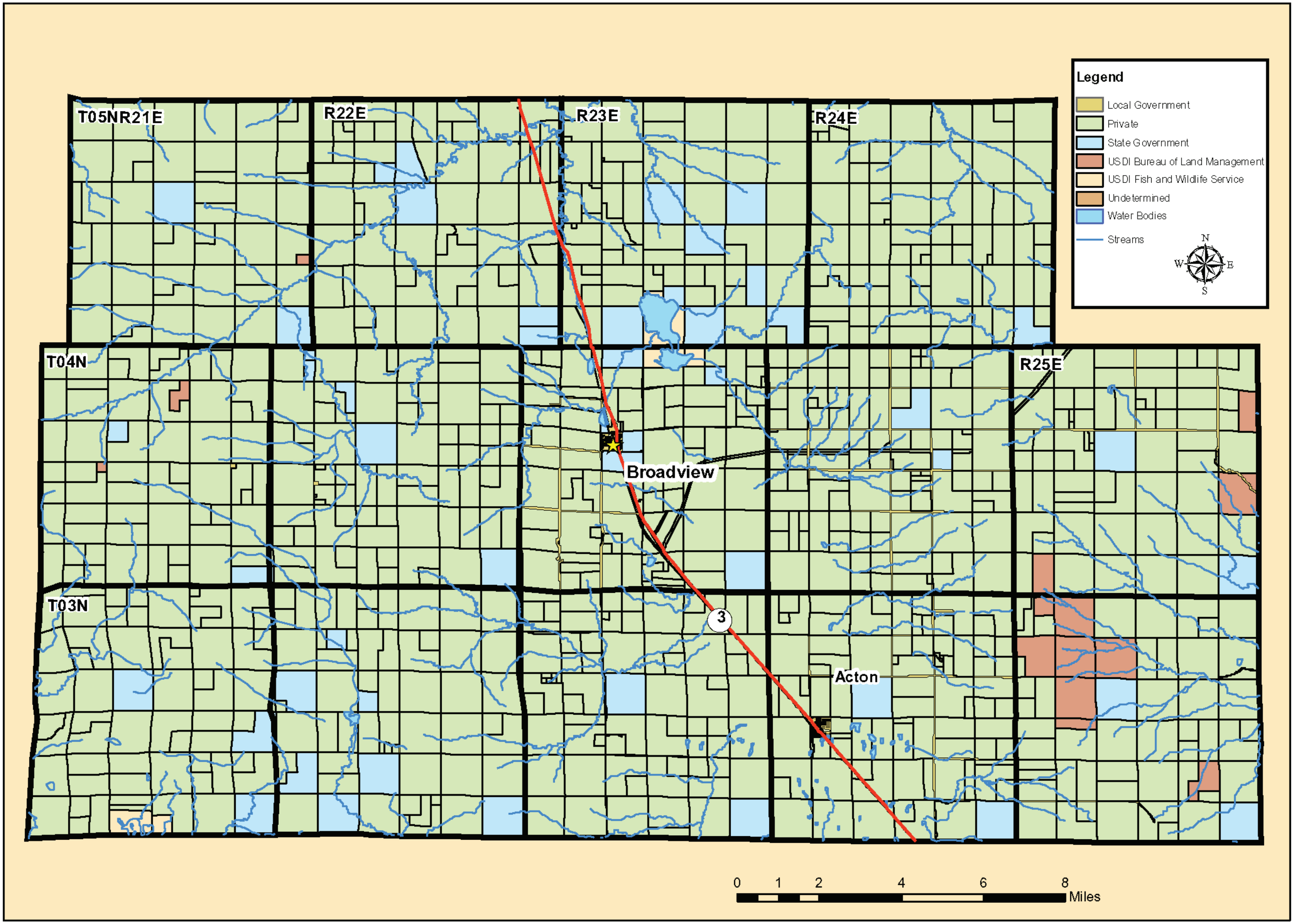


Figure 2. Land ownership in the Broadview area, from proposal.

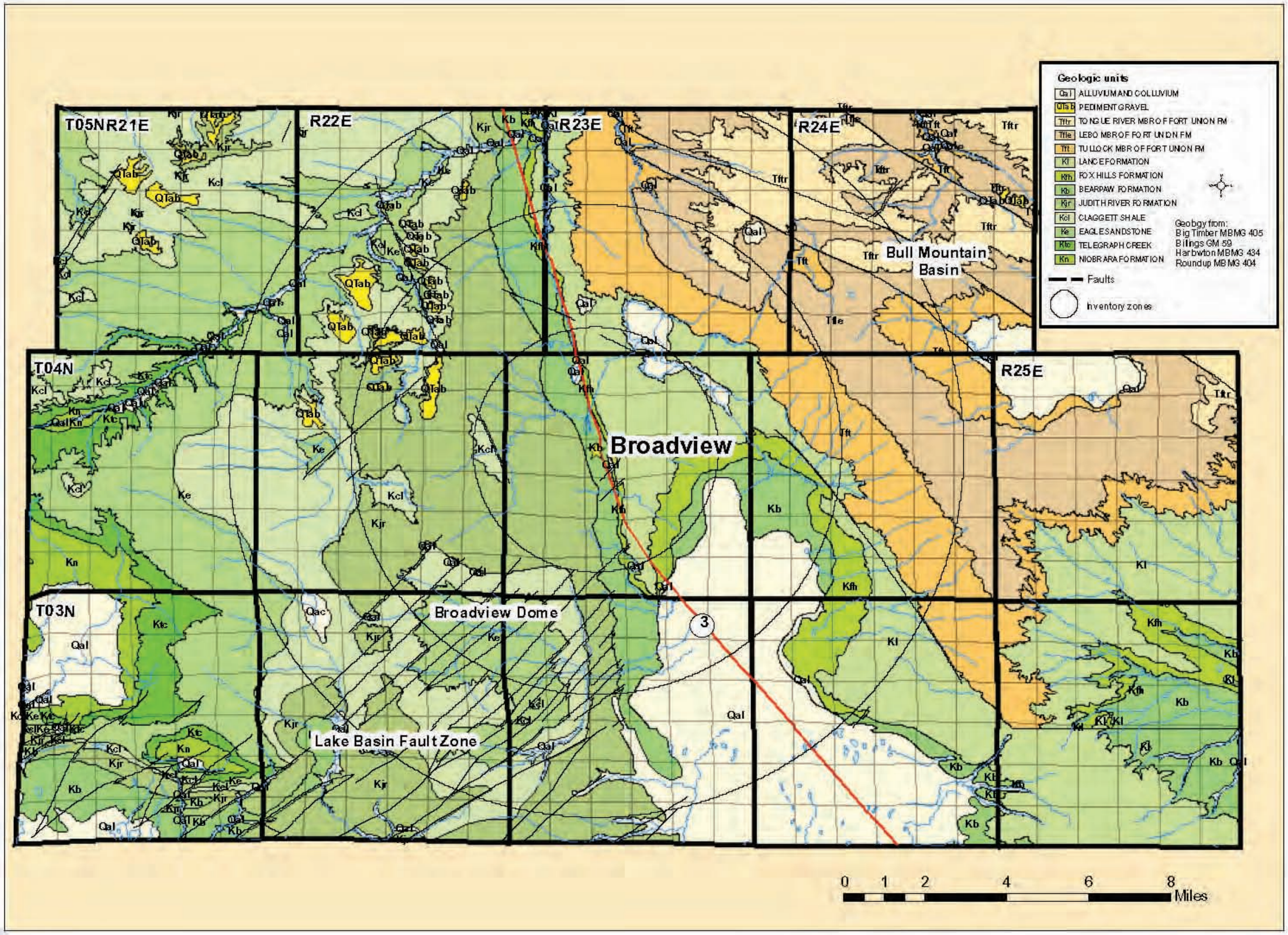


Figure 3. Geologic map of the Broadview area identifying potential aquifers for well development. Adapted from Lopez, 2000a,b; Wilde and Porter, 2000, 2001.

Table 1. Water quality from selected wells in the Broadview area.
TD'= well depth in feet
*Ion concentration in milligrams/Liter
**Lab specific conductivity(SC) in microsiemens/cm
***Sodium Adsorption Ratio (SAR) in standard units

T	R	SEC	TRACT	GWICID	TD'	SC**	CA*	CL*	HC03*	K*	MG*	NA*	S04*	AQUIFER	SAR***
03N	22E	6	ABAB	176921	70	957	84	14	350	2.8	46	42	177	EAGLE	0.9
03N	22E	17	AABD	14924	205	1300	132	16	347	3.4	70	61	385	EAGLE	1.1
03N	22E	32	DAAC	192189	80	6600	89	179			146	1556	3579	JUDITH RIVER	23.6
03N	22E	34	CCCA	176922	140	3620	9	62	655	1.9	4	949	1322	JUDITH RIVER	66.3
03N	23E	4	CBBC	1191	693	3921	5	56	602	1.7	1	1004	1562	EAGLE	104.4
03N	23E	6	CCDC	14941	164	2910	4	91	836	1.8	3	624	661	EAGLE	56.2
03N	23E	17	AAAD	1192	16		165	9	389		52	98 K	482	ALLUVIUM	1.7
03N	23E	18	BDDB	895451	5383			260	3120			1300 K		RED RIVER	
03N	23E	28	B	1193	8		85	16	490		22	156 K	232	JUDITH RIVER	3.9
03N	24E	12	A	1194	160		8	12	389		1	237 K	117	TULLOCK	21.7
03N	24E	14	CAAB	143992	207	2090	141	175	464	4.4	120	216	553	LANCE	3.2
03N	24E	20	B	1195	23		62	315	298		56	408 K	526	111ALVM	9.1
03N	24E	26	B	1196	12		542	257	468		1129		10000	111ALVM	
04N	22E	5	BCAA	184172	120	1694	179	10	352	3.8	94	102	793	EAGLE	1.5
04N	22E	14	ACCB	1315	450	2173	6	36	1031	1.9	6	556	229	JUDITH RIVER	38.4
04N	22E	15	CDCC	15944		2050	2	59	515	0.9	1	492	577	JUDITH RIVER	68.6
04N	22E	31	BCCC	192041	115	678	47	17	224	1.8	24	28	66	EAGLE	0.8
04N	23E	1	DDDA	15960	166	1850	14	26	612	2.1	21	316	234	TULLOCK	12.4
04N	23E	12	D	1316	97		51	103	476		43	755 K	1332	LANCE	18.8
04N	23E	14	ABBA	15965	410	4290	255	243	423	8.2	282	706	2308	LANCE	7.3
04N	23E	16	BCCC	15969	992	2410	5	42	453	1.1	3	677	819	EAGLE	59.2
04N	23E	16	BCCC	15974	1100	2770	2	45	450	0.7	0	632	923	EAGLE	114.9
04N	23E	20	B	1317			73	19	566		60	94 K	119		2.0
04N	24E	2	CCCC	1318	500	3770	21	51	350	2.9	8	862	1558	LANCE	40.3
05N	24E	25	BA	1385	7182		298	193	37		<.01	1352	3218	330MDSN	21.6

METHODS

This project collected and evaluated additional data needed to locate potable water supplies in the Broadview area. The specific goals were to document and test potential ground-water resources that would demonstrate adequate quantity and quality for a community water supply. Recent geologic mapping (Lopez, 2000a,b; Wilde and Porter, 2000, 2001) and regional hydrogeologic investigations (Olson and Reiten, 2002, 2003) were used to help evaluate potential locations of adequate water supplies. Figure 3 is a surficial geologic map of the Broadview area compiled from the recent mapping. Cretaceous and younger sedimentary rocks are the most likely sources of water supplies in the Broadview area. Well yield and water quality are probably directly related to primary porosity and permeability of the sandstone units and secondary porosity related to fracturing in the sandstone, with better yields and water quality associated with increased fracturing. Faults and fractures are often reflected at the land surface by linear features observable on maps and aerial photographs. These features were mapped and used as tools to define specific test well locations.

Figure 4 is a hydrostratigraphic diagram depicting the water-bearing potential of these units. The Eagle Sandstone appears to be a primary target because of good quality and moderate yields in the western part of the study area (see wells 176921 and 190421 in table 1 and fig. 11). Other target aquifers (fig. 3) that have shown potential to provide adequate supplies in other areas include the Judith River Formation, Fox Hills Sandstone, Hell Creek Formation, Lance Formation, and the Tongue River Member and Tullock Member of the Fort Union

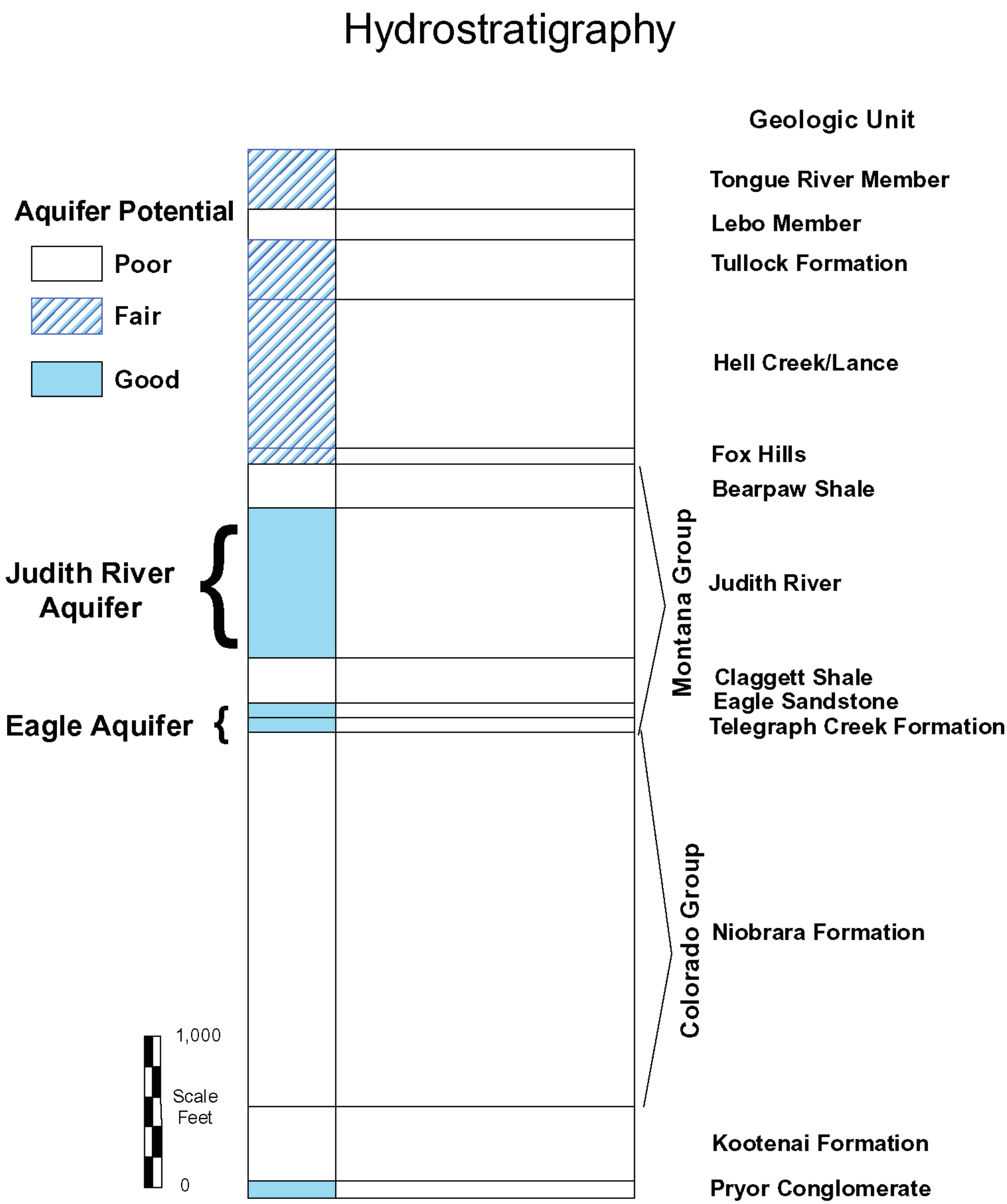


Figure 4. Hydrostratigraphy of potential aquifers in the Broadview area.

Formation (Olson and Reiten, 2002, 2003). The Judith River Formation has recently been developed by several wells yielding 50–100 gallons per minute (gpm) about 2.5 miles east of Molt. The Fox Hills and Hell Creek Formations form very productive aquifers that can yield over 100 gpm in eastern Montana and are commonly tapped as municipal supplies for small communities. The Lance Formation and Fort Union Formation also can be very productive in eastern Montana, with typical yields of 5–10 gpm, but wells in these formations can occasionally exceed 30 gpm. Prior to this project, information was insufficient to evaluate the water-supply potential of any of these aquifers in the immediate Broadview area.

Saline seeps have significantly degraded the quality of soil and water resources near Broadview (Custer, 1979; Lewis and others, 1979; Miller and others, 1981; Duaime and others, 1991). The Lake Basin, Hailstone Basin, and Comanche Basin are areas of natural high salinity and are prone to the development of saline seeps. Water in springs and the shallow ground water of the Comanche Basin rank as some of the poorest quality water in Montana. Because of the increased salinization of many shallow springs and wells, other aquifers upgradient of saline seeps or at greater depths must be developed to provide drinking water. Deep wells have been tried in Broadview and have proven to be inadequate in both quality and quantity to supply the needs of the community. Careful evaluation of relatively shallow sources appears to be the best option to meet the community's current needs. Reliable sources of water are an essential need that must be filled before the community can maintain the existing population base and allow for growth potential as a bedroom community for Billings.

Available Water-Well Data

Water-well records from 698 sites, stored in the Montana Bureau of Mines and Geology Ground-Water Information Center (GWIC), were reviewed and compiled as part of this investigation. These data are listed by location (township, range, section, and tract) in GWIC (http://mbmggwic.mtech.edu/). These records include site locations, lithologic logs, well construction reports, geologic sources, site visit and inventory data, water-quality data, water-use data, well yields, and other well information. In most cases the well data have not been verified. As a result, confidence in the data increases at wells that have been physically visited and inventoried. Data from these wells were used to design well inventory strategies and to develop many of the maps presented later in this report.

Local Knowledge of Water Resources

Historical background, anecdotal information, and experience of local area residents can often provide insight into the availability of water resources of an area. The Broadview town council provided input regarding their knowledge of water resources in the area. In addition, they provided names of other residents with knowledge of local geology and water resources. Input from local well drillers proved to be another valuable resource. Discussions with MBMG geologists and hydrogeologists that have been involved with regional mapping projects were good sources of background information on the character and distribution of geologic units as well as the water-bearing potential of many of these units.

Target Areas

During the early phases of the project it was evident that while other aquifers should be evaluated to attempt to locate ground-water supplies close to Broadview, the Eagle Sandstone did have a significant potential to be developed. As a result two target areas were identified, and inventory and other field work was focused on these areas where the Eagle aquifer was close to the land surface.

Broadview Dome. The first target area was the Broadview Dome area, which is located in parts of T. 3 N., R. 22 E. and T. 3 N., R. 23 E. (fig. 5). Several high-yield wells owned by Thelmar Mosdahl were reported. Unfortunately, the available data indicate relatively poor quality water in this area. In spite of the poor water quality, efforts were focused on the Broadview Dome area to verify reportedly high well yields and to verify the extent of poor water quality.

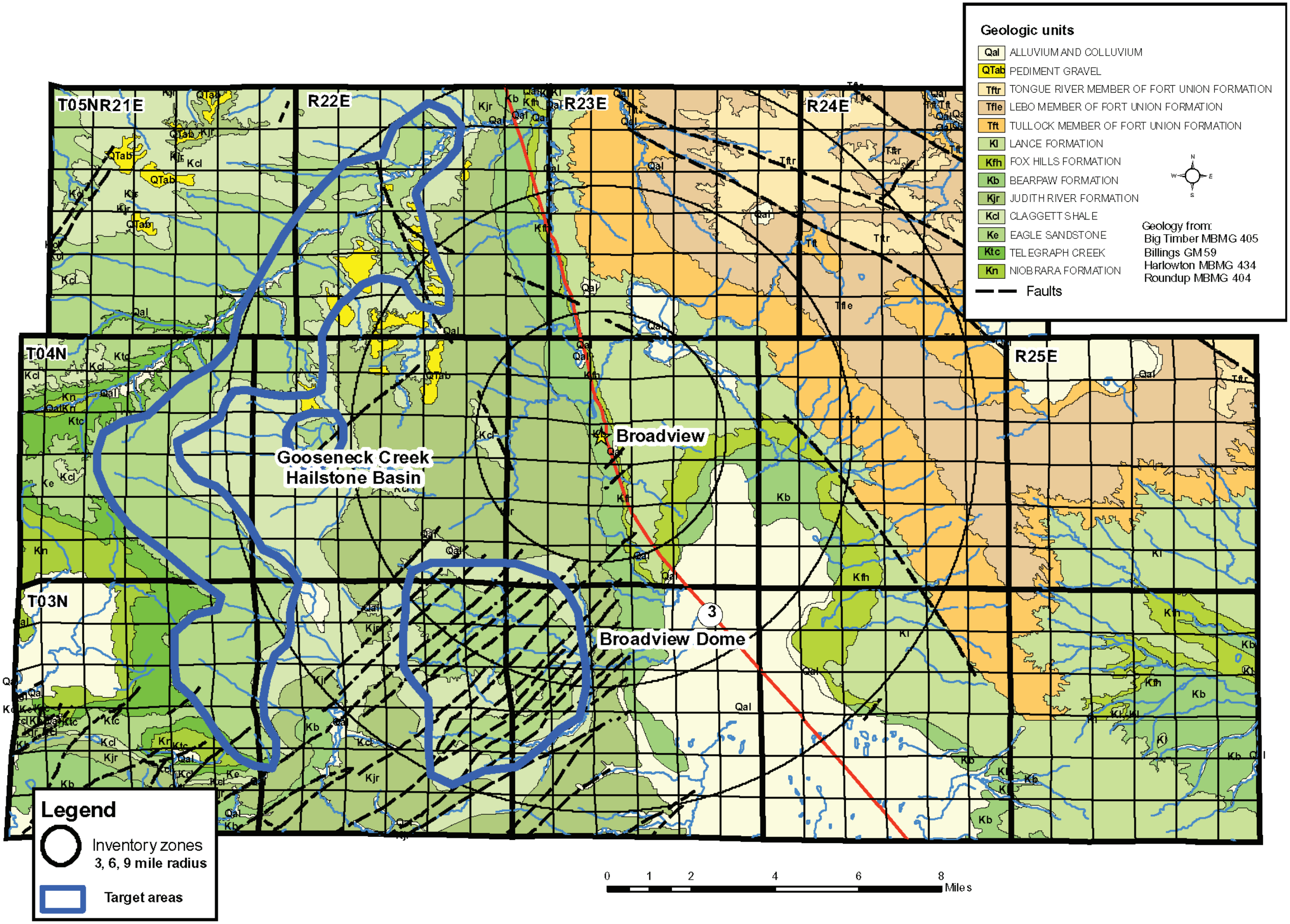


Figure 5. Two target areas were defined (Gooseneck Creek–Hailstone Basin and Broadview Dome) based on geologic maps showing Eagle Sandstone at the land surface.

Gooseneck Creek–Hailstone Basin area. The second area was located about 6–12 miles west of Broadview between the east edge of Hailstone Basin and Gooseneck Creek, where the Eagle Sandstone covers the land surface. Previous work in the Lake Basin area (Reiten, 2005) indicates that this area has good potential for constructing moderately high-yield wells with fairly good water quality. Efforts focused on the 6- to 9-mile zone in the area west of Broadview (fig. 5). Previous work has documented several wells yielding 20–100 gpm and producing excellent quality water for municipal purposes. As a result of the documented water quality and well yields, it was determined that additional hydrogeologic investigations should focus on this area.

RESULTS

Currently Broadview has two municipal wells with a total yield capacity of about 36 gpm. These wells produce relatively highly mineralized water with specific conductivities (SC) ranging from 2400 to nearly 2800 μS/cm and SAR values ranging from 59 to 115 (table 1). The water is corrosive, requiring frequent replacement of production lines and plumbing fixtures. In addition, because of the high SAR values, the water is unsuitable for watering lawns, trees, and gardens. A reasonable water supply to meet anticipated demands would consist of two primary wells, each capable of producing 30 gpm of potable water, plus a backup well with similar yield potential. Ideally the water would have SC less than 1000 μS/cm, low sodium concentrations, and SAR values less than 3. The goal of this project was to identify, locate, and test sites where aquifers producing adequate quantities of good quality water could potentially be developed. The best potential sources of good quality ground water are likely located near recharge areas where mineral content of water is relatively low. An added benefit is that such wells producing water from relatively short flow paths are generally shallow. Anticipated well depths are likely to be less than 100–200 ft.

Discussion of Water Resources with Drillers and Local Residents

Several local well drillers were contacted as part of drilling contract negotiations. Their general consensus was that only a few aquifers could reliably produce 30 gpm in the area. In addition, identifying areas where these aquifers had adequate quality and quantity was generally unpredictable. The Eagle Sandstone was acknowledged as the best potential aquifer for developing a municipal supply. Other aquifers commonly were too mineralized or of limited yield potential.

Broadview residents and town council members provided insight into the water development potential in the area. Several of the wells they specifically identified as potential supplies were identified and evaluated. In all cases the water quality and yield potential were inadequate. A visit with Dennis Beeman, a long-time Broadview resident who has been involved with oil and gas and other geologic investigations in the Broadview area, was recommended.

Mr. Beeman was visited on November 27, 2007. He has lived in the town of Broadview for many years and has been involved in past searches for water supplies. He has logs of the Conover 1 oil-well test located about 1 mile west of Broadview. The top of the Eagle is interpreted at 510 ft. A geologist interpreted the logs and identified two zones of high porosity in the Eagle Sandstone at depths of 635 to 645 ft (32% porosity) and 665 to 690 ft (27% porosity). E-logs used to interpret porosities were the Specific Potential, Resistivity, and Conductivity logs. If permeability was high these could be potential production zones for water development fairly close to Broadview. Mr. Beeman referred to a regional zone of high porosity and a likely potential production zone about 120 ft below the top of the Eagle Sandstone. Water quality was likely to be similar to the current town water supply. It might be slightly fresher based on shorter flow paths and shallower depth. The production at this well was not successfully tested because it was believed the zones of high porosity were plugged off by cement prior to testing. The cost of testing this location was outside the scope of this project and unlikely to produce a significantly improved water source over the current municipal water supply.

Site Visits and Data Compilation

The town council was interested in finding an adequate water supply as close to Broadview as possible. As a result three zones were set up to concentrate our initial inventory. Zone 1 identified wells to inventory within a 3-mile radius of town. Zone 2 identified wells to inventory between 3 to 6 miles from town. Zone 3 identified wells to inventory within 6 to 9 miles from town (fig. 3). The site visits verified well locations, well depth, well yield, static water level, pumping water level, and field water-quality parameters (Specific Conductance, pH, Water Temperature, Dissolved Oxygen, Oxidation Reduction Potential, Nitrates, and Nitrites). Geologic conditions were evaluated in areas with potential to construct wells with adequate yields and good quality water.

Data from 287 wells that were visited as part of this project or were previously inventoried were compiled and evaluated. The well inventory started in Zone 1 and proceeded to the more distant Zones 2 and 3. East of Broadview, the well inventory focused on the water-resource potential in the uppermost Cretaceous and Paleocene sedimentary rocks (Fox Hills Formation, Hell Creek Formation, Lance Formation, and Tullock and Tongue River Members of the Fort Union Formation). Figure 6 is a geologic map showing field SC, well depth, aquifer, and yield of all field-checked wells in the Broadview area with the exception of wells completed in the Eagle aquifer. Recalling that the general requirements needed for an adequate water supply are well yields of 10–50 gpm and SC less than 1000 μS/cm, perusal of this map allows one to quickly identify locations with water-development potential. Although a few wells had adequate yield potential and others had adequate water quality, no aquifers within a 9-mile radius on the east side of Broadview appeared to have sufficient yield potential and adequate water quality for further testing (fig. 6). Similar results were indicated by reported water-quality analyses from this area. These are summarized on a geologic map showing Stiff diagrams of water quality from selected wells (fig. 7). The Stiff diagrams represent the concentration of major anions and cations reported in millequivalents/liter from water analyses. The diagrams are all scaled the same; the larger the Stiff diagram, the more mineralized the water. Most of the samples indicated high sodium concentrations and high mineral concentrations, which are unsuitable for a municipal water supply.

None of the Cretaceous and Paleocene geologic units listed above are found in the inventory zones located west of Broadview. As a result of the geology, the inventories west of Broadview concentrated on the Judith River Formation and the Eagle Sandstone. Very little development potential was documented in wells inventoried in the Judith River Formation (fig. 6). Similarly, the Eagle Sandstone within Zones 1 and 2 appears to have only limited potential for development. Based on this assessment, there appears to be little chance of developing a municipal water supply close to town with significantly better water quality and better well-yield potential than the existing wells.

The additional data collected from the site visits and well inventory are summarized in figure 8, a geologic map of the study area showing measured field water-quality parameters and either measured or reported well yields in the Eagle aquifer.

Although some water-supply development potential appears to be associated with the Broadview Dome, better potential appears to be located in the eastern part of the Gooseneck Creek–Hailstone Basin area. An area spanning several sections along the township boundary between T. 4 N., R. 21 E. to T. 4 N., R. 22 E. and T. 3 N., R. 21 E. to T. 3 N. 22 E. appears to have development potential. Field measurements from several of the wells in this area are reported as having SC values less than 1000 μS/cm and yields ranging from 10 to 70 gpm. This relatively good water quality is confirmed in Stiff diagrams constructed from samples of several Eagle aquifer wells located near the southwestern corner of T. 4 N., R. 22 E. An area with water quality and yield potentials similar to well 176921 could easily be developed into a suitable water supply for the town of Broadview. This well is located in T. 3 N., R. 22 E., sec. 6 ABAB. The reported yield is 60 gpm of calcium-bicarbonate type water with total dissolved solids (TDS) of 555 mg/L and SAR less than 1.0.

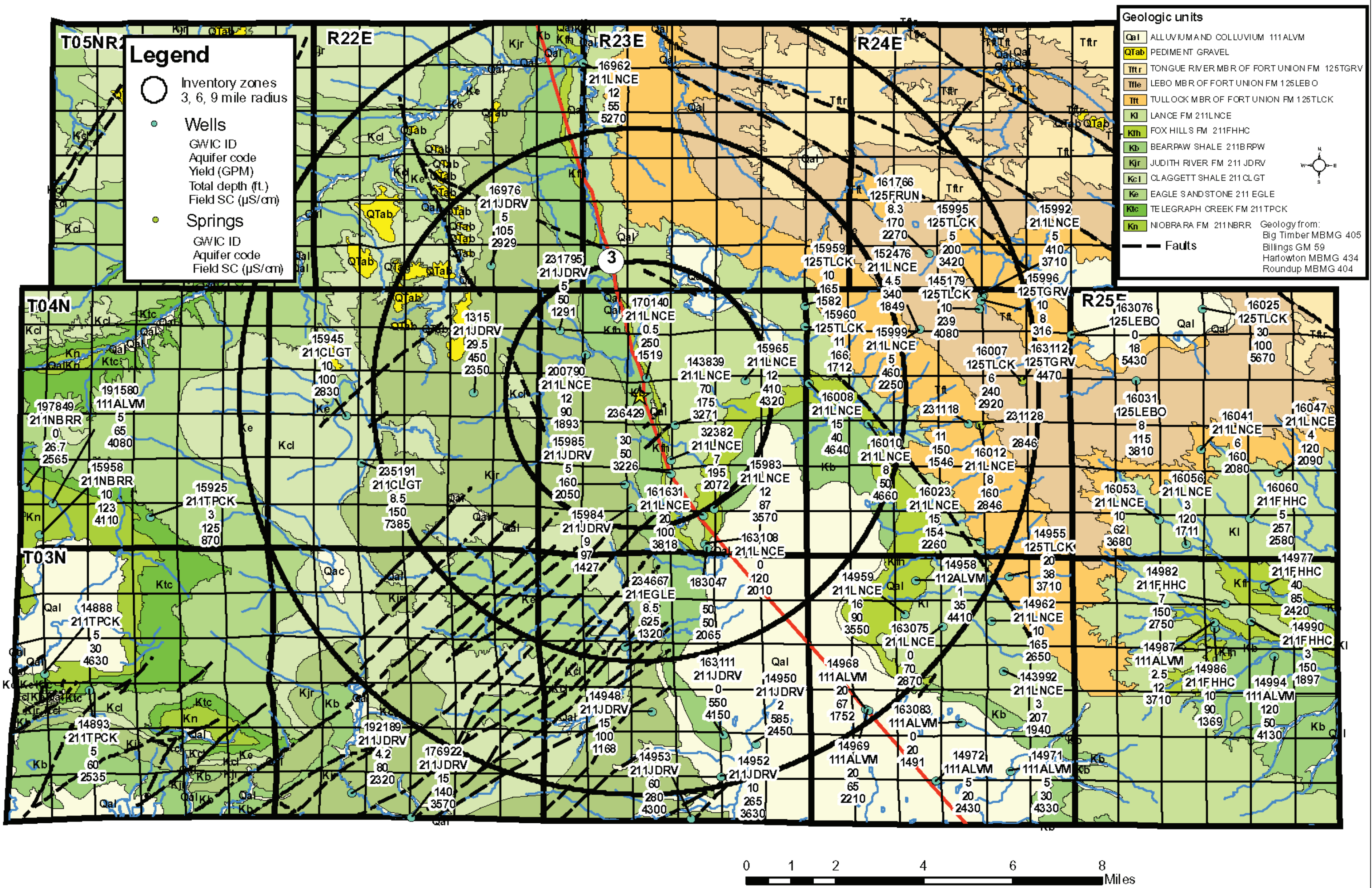


Figure 6 . Ground-water resource summary of the Broadview area based on site visits of selected wells and springs (all geologic sources except the Eagle Sandstone.)

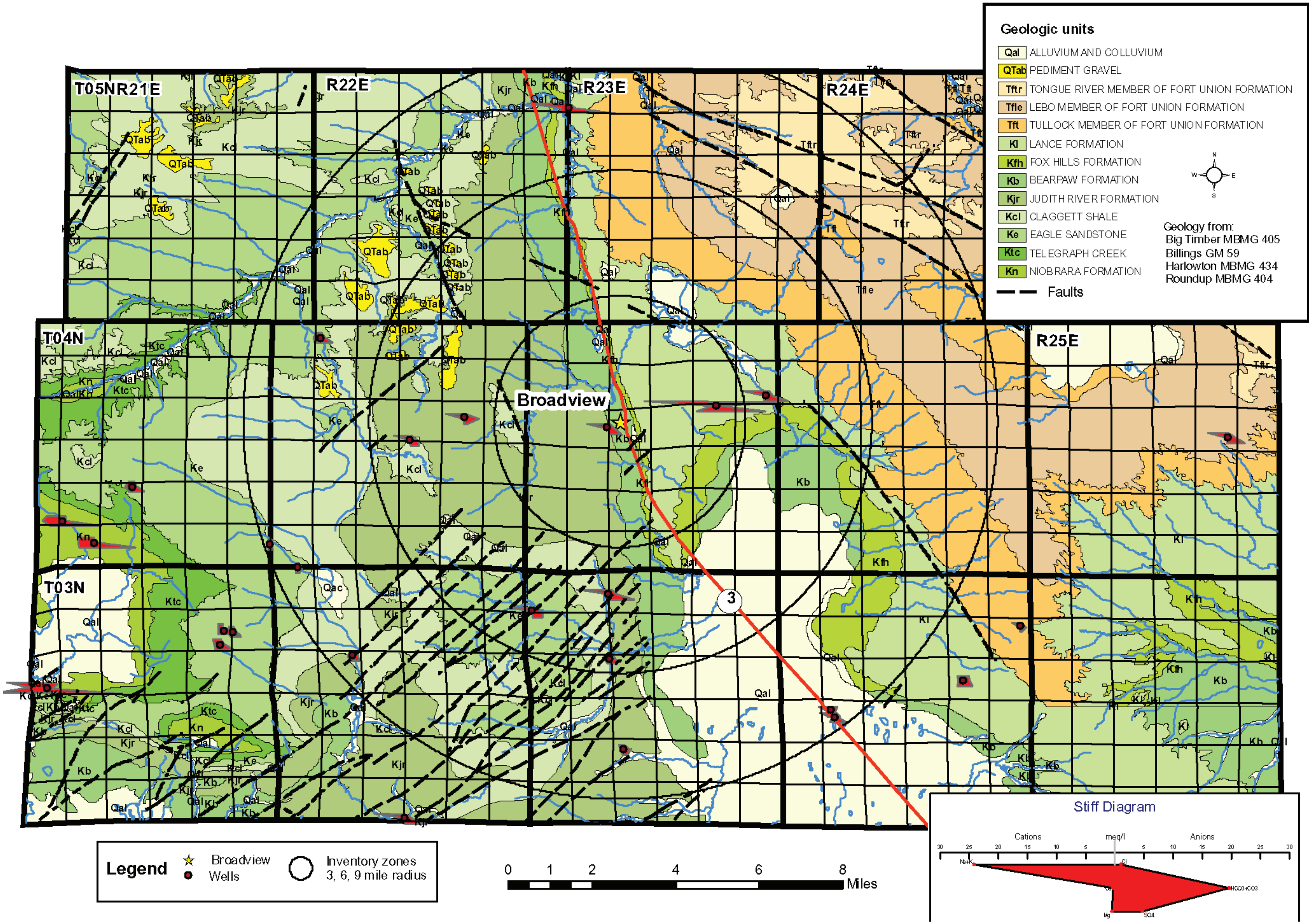


Figure 7. Geologic map showing water quality (Stiff diagrams) in the Broadview area.

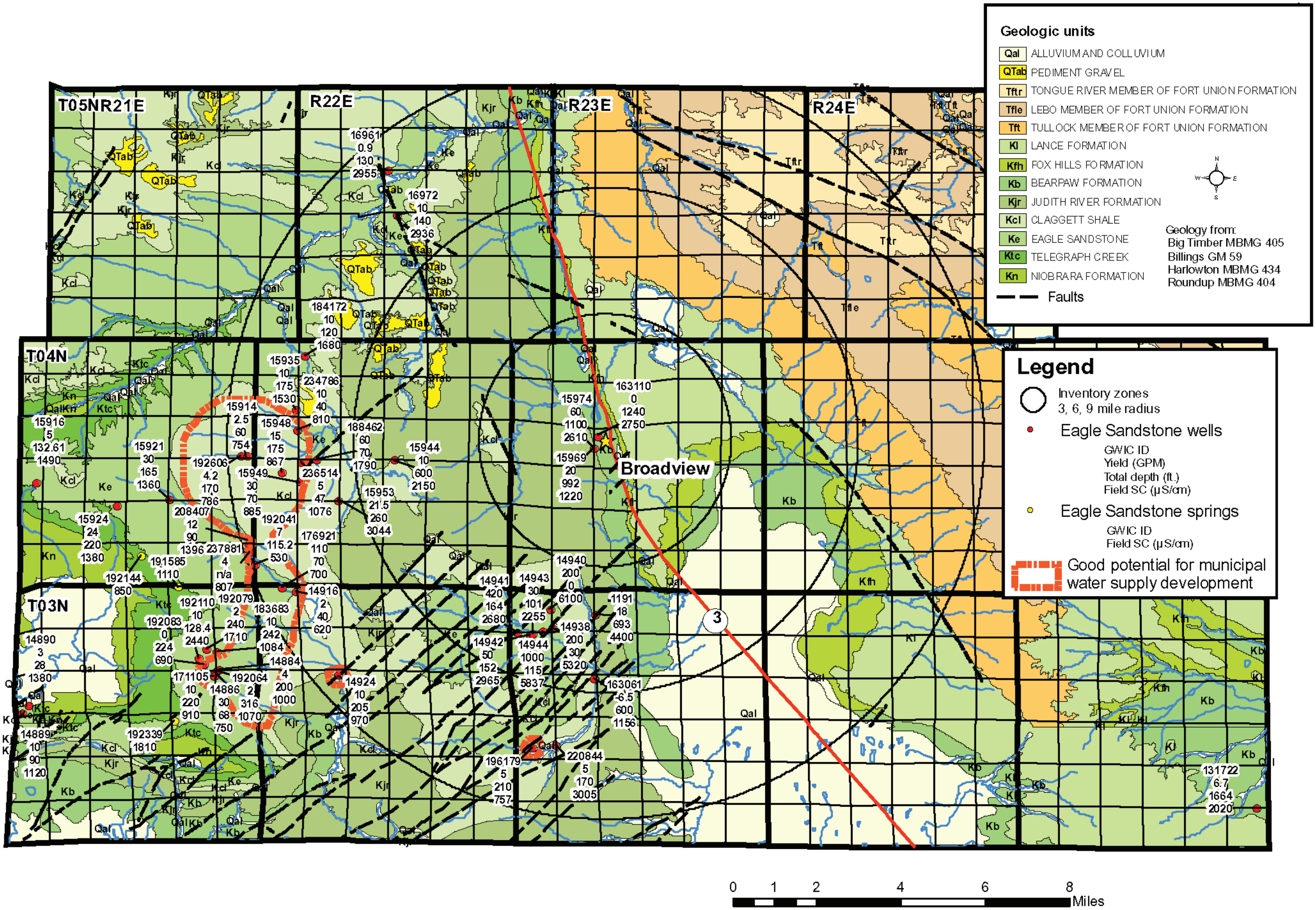


Figure 8. Ground-water resource summary of the Broadview area based on site visits at selected Eagle Sandstone wells and springs.

Target Areas

Broadview Dome Preliminary Assessment

The Broadview Dome is a structural uplift associated with the Lake Basin Fault Zone (fig. 9). The Eagle Sandstone lies at the surface over most of the Dome. These rocks are disrupted by a series of closely spaced *en echelon* faults. Lithologic descriptions from a water well constructed in T. 3 N., R. 23 E., sec. 6 DDC reported drilling through a rubble zone of faulted and fractured rocks. This well (14944) is reported to yield about 1000 gpm. Several other high-yield wells are reported from this area.

A flowing well test was conducted at a well located at T. 4 N., R 22 E., sec. 6 CCDC (14941) in northwestern Yellowstone County. The well is completed in the Eagle Sandstone and is located within the Broadview Dome. Faulting and folding in this area are attributed to the Lake Basin Fault Zone and have resulted in localized areas of very high-yield wells. A test was conducted to verify the flows reported from a previous test as part of a change in a water right. Yields of over 700 gpm had been reported from this well based on the previous test using the same flow meter and a similar set-up. The test site was visited in the afternoon of April 12, 2007. The valve was opened at about 11:00 AM and the reported flow was about 390 gpm. At about 2:00 PM the well was flowing with the valve in the full open position. The flow-measuring section was set up at a flat area at an elevation of about 75 ft below the flowing well. The pipeline was level both upstream and downstream, and no turbulence appeared to be affecting the flow meter. A few minor leaks were identified below the well head and above the flow meter. Flow losses were estimated at 20–30 gpm. The flow meter reading was at about 390 gpm when the site was visited. Considering the estimated flow loss at the leaks, the well appears to be producing about 410 to 420 gpm. This is significantly less than the reported flow rate of over 700 gpm. The valve at the wellhead was shut off at about 2:40 PM, ending the test after producing about 90,000 to 92,000 gallons of water. Comparing flows at the end of the test to the beginning, little if any flow reduction was observed over the 220-minute test. It is likely that this well could maintain flows sufficient to supply the town of Broadview.

Although the sustained flow from this well is more than adequate to supply the municipal needs for the town of Broadview, this well produces poor quality water (SC ranging from 2600 to 2700 μS/cm) and is an unlikely source for a municipal water supply without significant treatment to remove salts. Moderately high yields have also been reported at two nearby wells (14942 and 14943). These wells (14941, 14942, and 14943) have similar water quality, with SC ranging from about 2200 to 3000. This range of SC is similar to what is reported from Broadview's current water supply. A very high-yield well (14944) is reported to yield about 1000 gpm, but produces very salty water with an SC of about 5800 μS/cm. This is significantly poorer quality than Broadview's current water supply. The south and west part of the Broadview Dome were investigated to determine if a viable municipal water supply is possible in this area. Although high yields and adequate water quality may be present in the Eagle aquifer in this part of the Dome, the faulting appears to have divided the aquifer into distinct compartments containing similar head and water quality. Currently, we do not have enough information to predict if a viable municipal well could be constructed in this area. The predominance of poor quality water makes the Broadview dome area a poor choice for further exploration.

Gooseneck Creek Area Preliminary Assessment

It was initially thought that the Gooseneck Creek area would have only minor potential because of the limited extent of Eagle Sandstone at the land surface. The geologic map (fig. 3) shows a small outlier of the Eagle Sandstone covering most of section 17 in T. 4 N., R. 22 E. Surrounding this outlier, the Claggett Shale is the surficial geologic unit. Water-quality data collected from wells in this area indicated that fresher water existed than would be expected based on the reported geology. Wells underlying areas mapped as Claggett Shale had very good water quality. Recent hydrogeologic mapping in south-central Montana has shown that in most areas with Claggett Shale at the land surface, the underlying Eagle aquifer contains highly mineralized water (Olson and Reiten, 2003). The relatively fresh ground water underlying areas mapped as Claggett in the Gooseneck Creek area contradicted this expectation. Based initially on the water-quality data, it appears

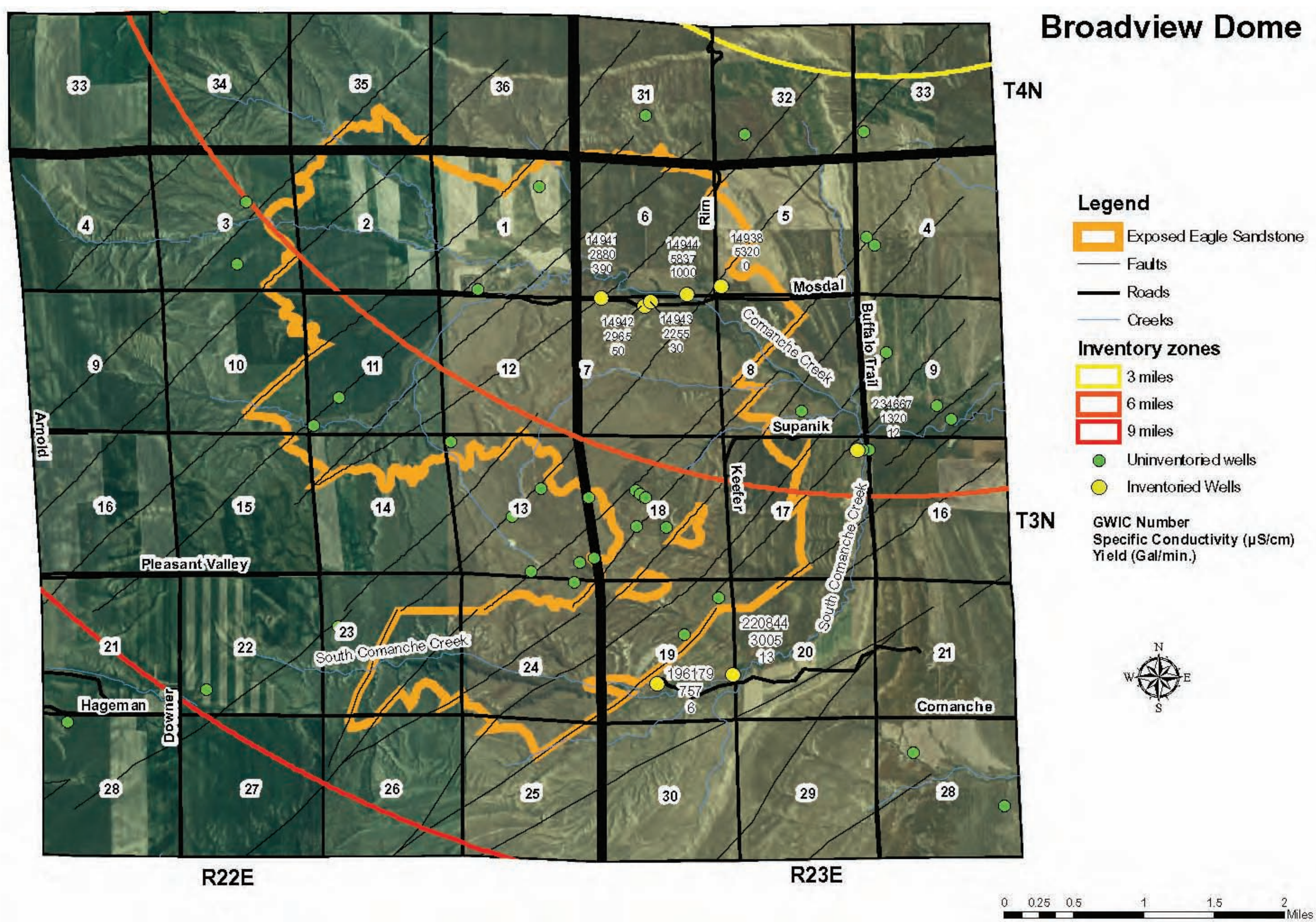


Figure 9. Aerial photo of the Broadview dome showing selected hydrogeologic features.

that much of the area originally mapped as Claggett Shale may be Eagle Sandstone. If true, this new geologic information could change several square miles of the Gooseneck Creek area from being unlikely to likely locations to explore for good quality ground-water resources. As a result, additional geologic investigations, water-quality analyses, test drilling, and test pumping were focused in this area.

Geology. As a result of the contradiction of good quality water underlying areas mapped as Claggett Shale, a more detailed investigation of the surficial geology was initiated in the Gooseneck Creek area. A geologic windshield survey indicated surficial deposits of sandstone, eolian sand, and sandstone hoodoos in areas mapped as Claggett Shale. This area was re-mapped by David Lopez (fig. 10) and corrections were sent to the MBMG State Map Program for editing (Lopez, personal communication). In addition to changes in the mapping of the surficial geologic units, adjustments were also made to mapped locations of faults. It was suspected that faults and fault zones could potentially result in increased porosity and permeability in sandstone layers. As observed in the Broadview Dome area, this increased porosity and permeability could increase ground-water flow and potential productivity of water wells. A primary consideration was to locate test well sites in areas of faulting and fracturing that could increase well-yield potential.

Water Development Potential. Several additional wells were sampled to verify water quality in the Gooseneck Creek area. The results of the water-quality analyses are shown in table 2. The water quality samples from all of the wells met or were very close to meeting the SC goal of 1000 µS/cm or less, and many wells showed relatively high yield potential (fig. 11). Stiff diagrams constructed from water-quality data are shown in figure 12. These diagrams show that the water in this area is dominated by cations of calcium and magnesium and anions of bicarbonate and sulfate. This type of water indicates relatively short flow paths and residence time and is typical of parts of an aquifer located close to the recharge area. Inventoried and reported well yields ranged from 10 to 60 gpm in this area. These encouraging results imply that it is possible to construct wells capable of supplying the needs of Broadview in this area.

An unused water well was located in T. 4 N., R. 22 E., sec, 20 CBBB (15949), about 100 ft south of the Assumption Church Cemetery (fig. 11). This is referred to as the Cemetery well. No lithologic log or well completion report was found for this well. It was reported by the owner to have been drilled in the 1950s. Since very little information was available for this well, a downhole camera was used to view and videotape the well. Results of the video determined that the well was completed as an open hole with 6-in steel casing set from about 3 ft above ground to 9 ft. The bottom of the well is at a total depth of 68 ft below ground level. The borehole appeared to be completed entirely in fairly competent sandstone. No wash outs or obvious weak zones in the borehole wall were visible. Based on the downhole video recording, it appeared to be a good well to test pump for a water sample and to help estimate water-production potential at this location.

Test pumping at the Cemetery well was essentially a short-term aquifer test. Aquifer tests are commonly conducted to estimate aquifer properties that can then be used to project impacts of water development. Short-term aquifer tests can also be merely quick tests to develop an approximate range of pumping rates and development potential of an aquifer. The transmissivity and storage coefficients are aquifer properties commonly estimated from aquifer tests. Transmissivity (T) is the volume of water flowing through a cross-sectional area of an aquifer that is 1 ft times the aquifer thickness (b), under a hydraulic gradient of 1 ft/ 1 ft in a given amount of time (usually a day). The storage coefficient of an aquifer is the volume of water released from an aquifer per 1 ft surface area per 1 ft change in head. This does not refer to water flowing through an aquifer, but to the aquifer's ability to store water. The size of the storage coefficient is dependent on whether the aquifer is unconfined or confined. In regard to a confined aquifer, water derived from storage is relative to: (1) the expansion of water as the aquifer is depressurized (pumped) and (2) compression of the aquifer. In a confined aquifer setting, the load on top of an aquifer is supported by the solid rock skeleton and the hydraulic pressure exerted by water (the hydraulic pressure acts as a support mechanism). Because of these variables, the storage coefficient of most confined aquifers ranges from 10^{-5} to 10^{-3} (0.00001 to 0.001). Conversely, in

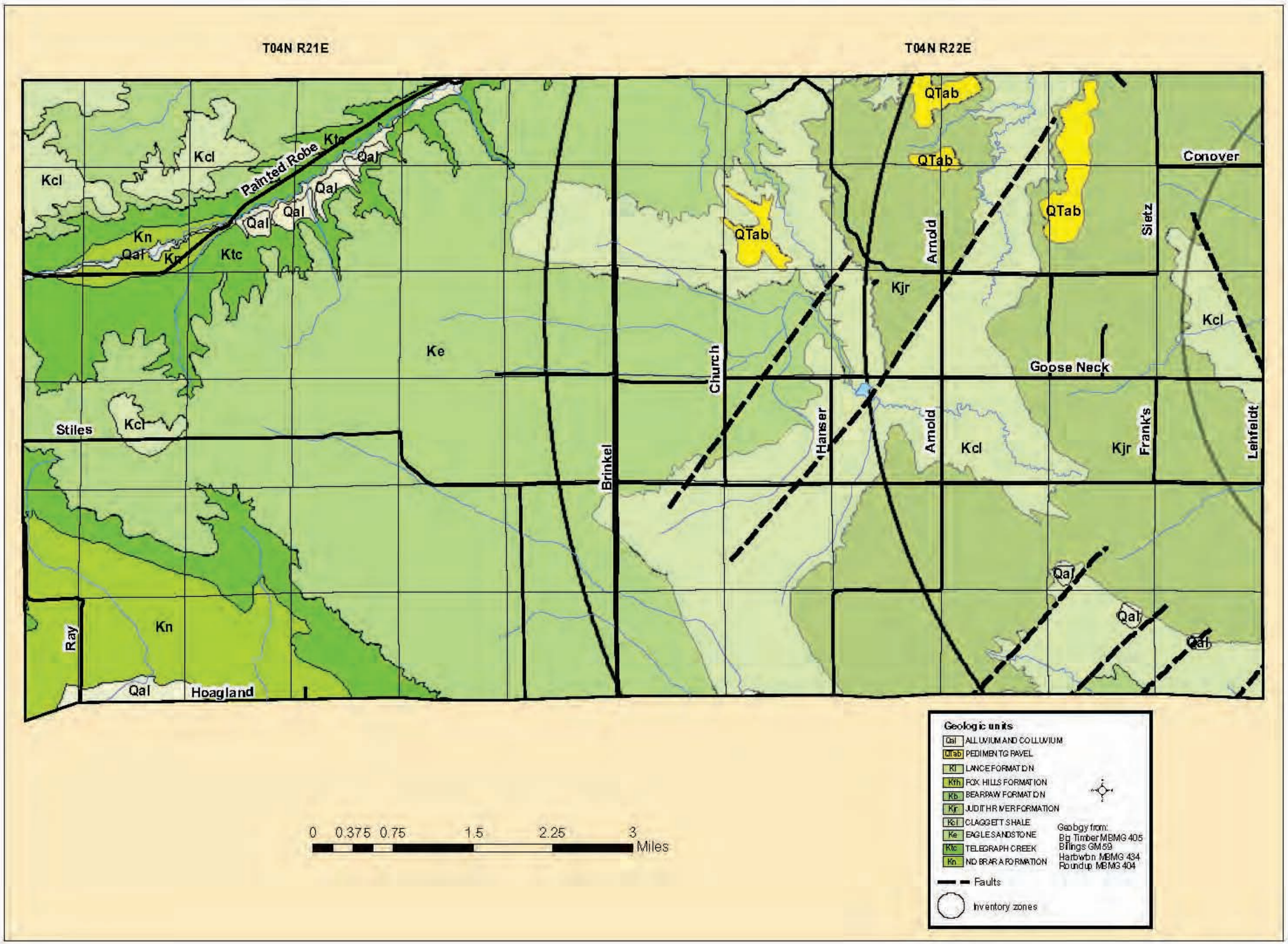


Figure 10. Revised geologic map of the Gooseneck Creek area (revised geology from Lopez, personal communication, 2007).

Table 2. Water-quality data from Eagle aquifer water samples in the Gooseneck Creek area.

MAJOR IONS (mg/L)

Site_ID	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Silica	Bicarbonate	Chloride	Sulfate	Nitrate	Fluoride	Ortho-phosphate
15948	86.6	42.8	27.7	2.79	<0.005	<0.001	10.8	286.7	5.97	162	7.31 P	0.747	<0.10
236514	110	54.1	36.7	3.54	0.742	0.275	14.2	322.9	6.95	302	<0.25 P	0.675	<0.25
234786	84.6	41.9	28.4	2.55	<0.005	<0.001	11.4	317.5	5.19	140	7.00 P	0.687	<0.05
15949	89	44.1	37.6	2.97	0.287	0.266	16.3	371.8	6.52	181	<0.5 P	0.612	<0.10

TRACE METALS (µg/L)

	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Bromide	Cadmium	Chromium	Cobalt	Copper	Lead
15948	<2.0	<0.1	0.305	39	<0.1	75.6	<100	<0.1	<0.1	0.103	3.87	<0.2
236514	<2.0	<0.1	0.596	9.86	<0.1	143	<50	<0.1	<0.1	0.319	<0.2	<0.2
234786	<2.0	<0.1	0.347	37.8	<0.1	75.5	<50	<0.1	<0.1	<0.1	5.93	<0.2
15949	<2.0	<0.1	0.632	17.5	<0.1	190	<100	<0.1	<0.5	0.121	<0.2	<0.2

	Lithium	Nickel	Molybdenum	Silver	Selenium	Strontium	Titanium	Thallium	Uranium	Vanadium	Zinc	Zirconium
15948	24	<1.0	1.81	<0.5	3.69	717	1.69	<0.1	4.23	<0.1	28.9	<0.1
236514	57.7	<1.0	<1.0	<0.5	<0.5	2,555	1.4	<0.1	0.388	<0.1	47.7	<0.1
234786	25.8	<1.0	1.28	<0.5	2.97	755	1.19	<0.1	3.96	<0.1	11.9	<0.1
15949	49.1	<0.1	<1.0	<1.0	1.71	2,286	<1.0	<0.1	<0.05	<0.1	3.13	<0.1

OTHER PARAMETERS

	Total Dissolved Solids (mg/L):	Sum of Diss. Constituents (mg/L):	Field Conductivity (µmhos):	Lab Conductivity (µmhos):	Field pH:	Lab pH:	Water Temp (°C):	Hardness as CaCO3:	Akalinity as CaCO3 (mg/L):	Ryznar Stability Index:
15948	482	627	8.67	827	7.49	6.87	16.5	392	235.39	7.411
236514	689	853	1076	1033	7.13	7.1	11.6	497	264.92	6.971
234786	471	633	849	839	7.47	6.84	16.9	384	260.81	7.373
15949	562	751	896	856	7.39	7.35	10.11	404	305.1	6.782

	Sample #	Sample date	Sodium Adsorption Ratio	Phosphate, TD (mg/L as P):	Langlier Saturation Index:	Field Dissolved O2 (mg/L):	Field Redox (mV):
15948	2008Q0098	8/20/2007	0.615	<0.05	-0.271	38.9	0.94
236514	2008Q0099	8/21/2007	0.722	0.113	0.065	0.37	-176.3
234786	2008Q0097	8/20/2007	0.622	<0.05	-0.266	4.5	55.2
15949	2008Q0161	9/7/2007	0.823	<0.03	0.284	4.08	-53

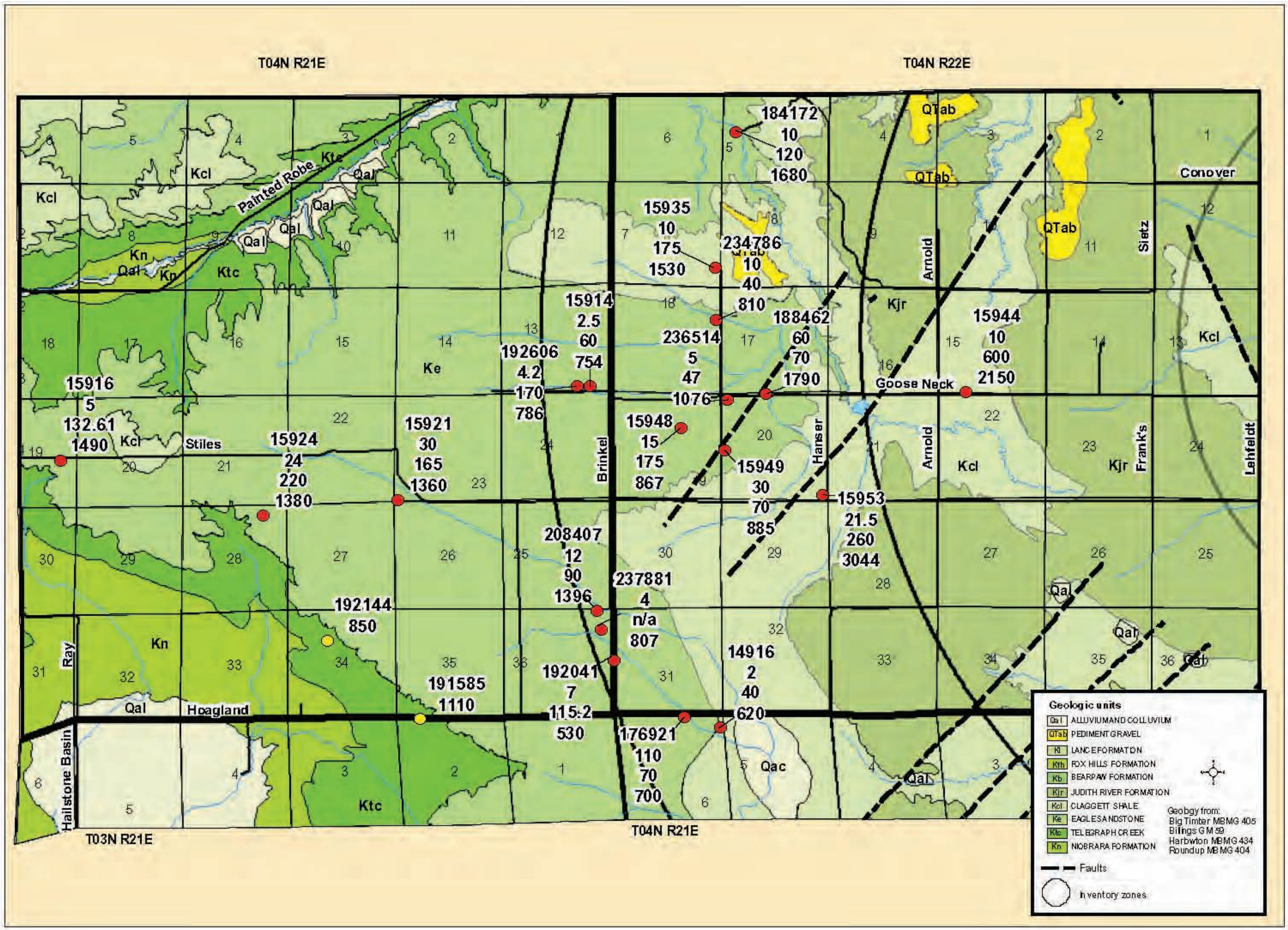


Figure 11. Ground-water resource summary of the Gooseneck Creek area based on site visits at selected Eagle sandstone wells and springs.

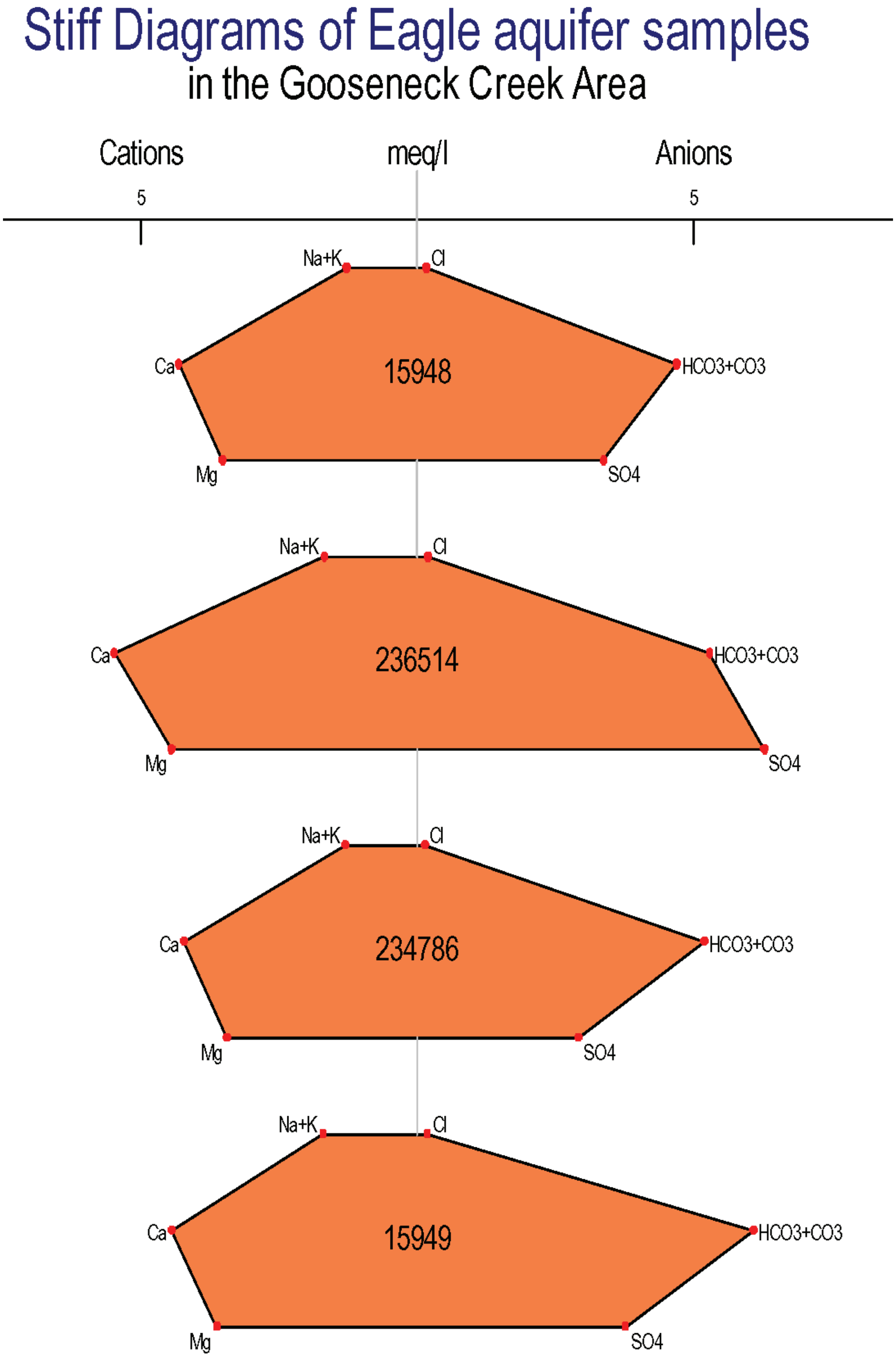
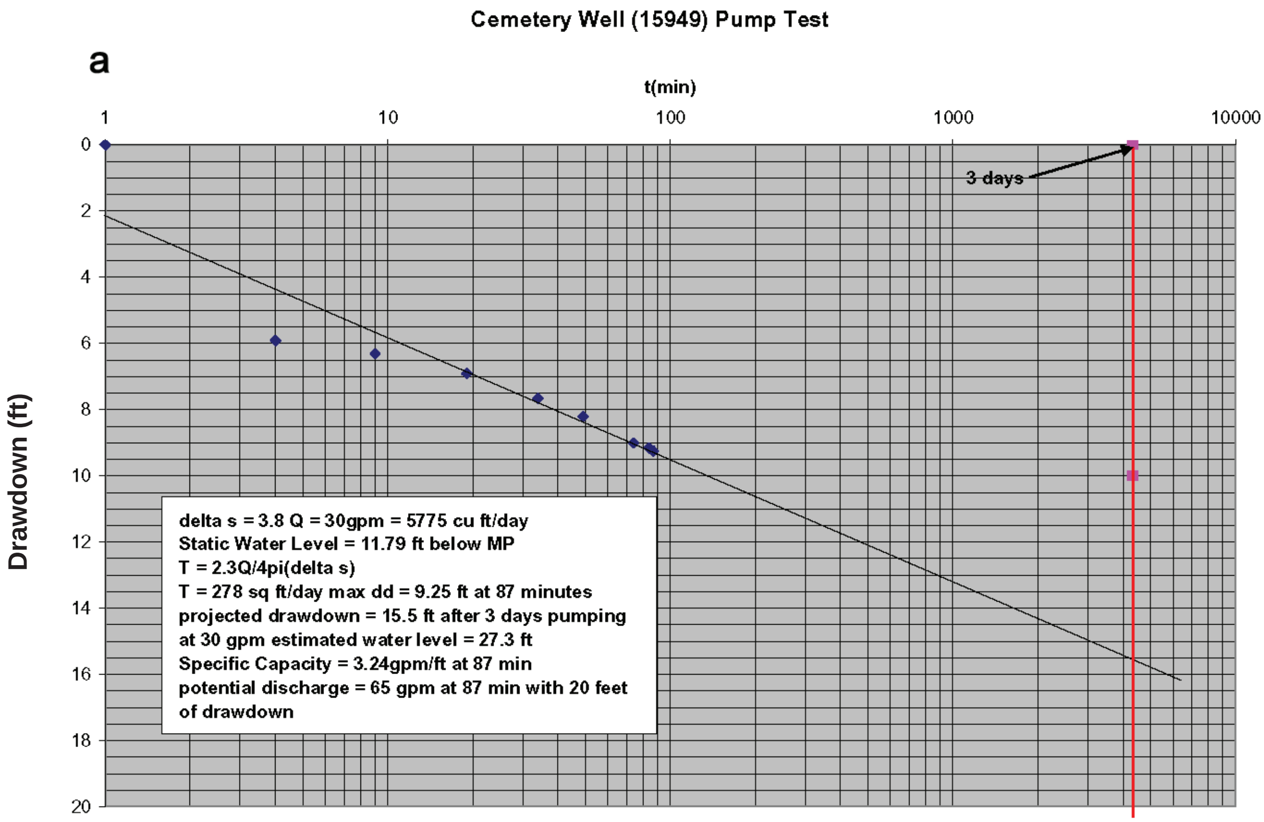


Figure 12. Stiff diagrams of Eagle aquifer samples in the Gooseneck Creek area.

an unconfined aquifer setting, the predominant source of water is from gravity drainage and the expansion of water and compaction of the rock skeleton are negligible. Thus, the storage coefficient is approximate to the value of the specific yield and ranges from 0.1 to about 0.3. The Cemetery well (14049) was test pumped on September 6, 2007 (fig. 13). The pump was set at a depth of 40 ft below ground surface. Prior to the test the static water level was measured at 11.79 ft below the top of the 6-in steel surface casing (9.79 ft below ground). The well was pumped at an average rate of 30 gpm for 87 min. Total drawdown at the end of the test was 9.25 ft. The transmissivity calculated from the drawdown portion of this test was 278 ft^2/day using the Cooper–Jacob method. Projected drawdown assuming the same rate of water-level decline over 3 days was 15.5 ft. This is equivalent to a pumping water level of 27.3 ft. A projected potential yield of 65 gpm at 87 min of pumping and 20 ft of drawdown was estimated based on the specific capacity calculated for this test of 3.24 gpm/ft. A water sample was collected and analyzed from the Cemetery well near the end of the pump test. The results shown in table 2 and figure 12 indicate very good quality water. Water-level recovery was monitored for 55 min after the pump was shut off. Over this period of time the water level had recovered 80% of the total drawdown. The transmissivity calculated from the recovery portion of the test was 364 ft^2/day.

Aquifer properties calculated using drawdown data from pumped wells are often not representative of actual aquifer conditions. In addition, it is typically not possible to calculate the storage coefficient using drawdown data from a pumped well. The average transmissivity of the drawdown and recovery portions of the



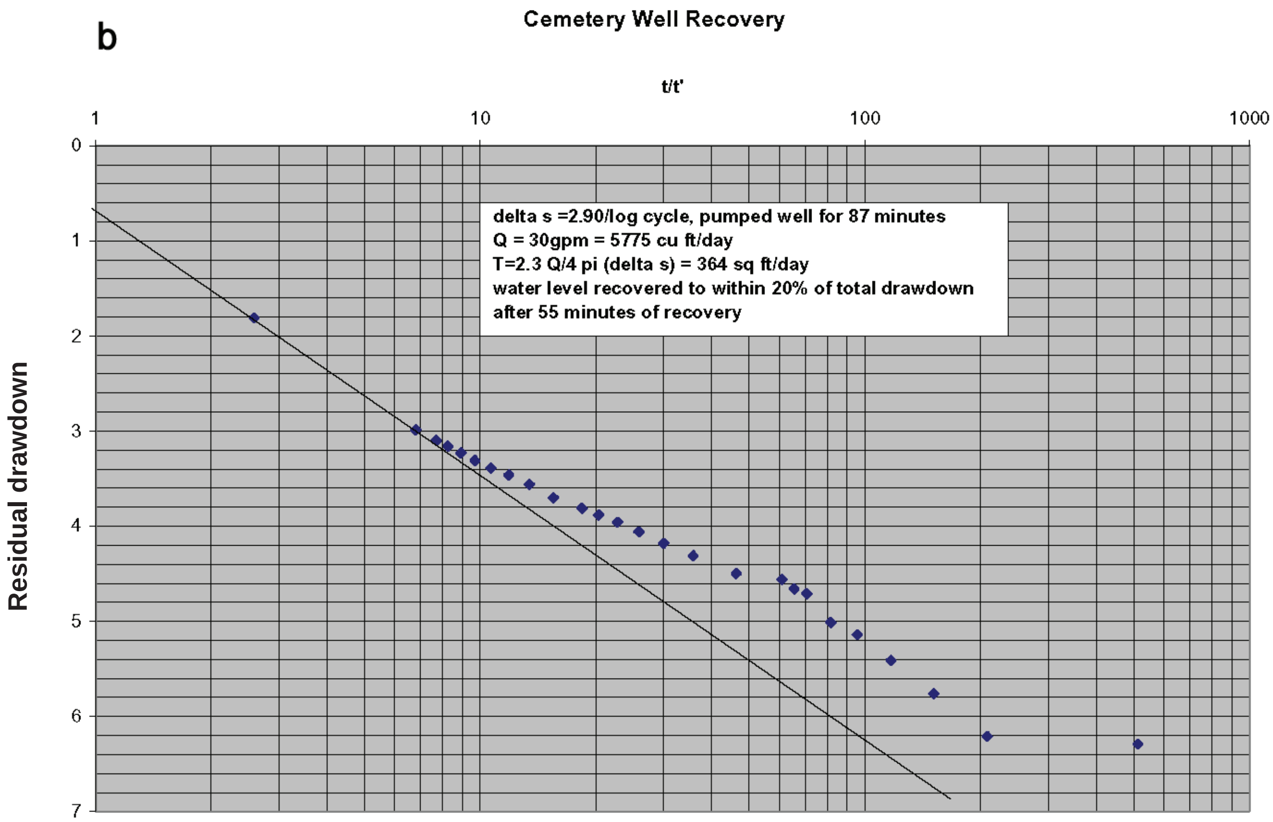


Figure 13. (a) Time-drawdown plot of drawdown from the Cemetery well aquifer test; (b) time-drawdown plot of recovery from the Cemetery well aquifer test.

test was 321 ft^2/day. This value may be close to the actual conditions, but the test was too short to be confident that this is the actual transmissivity. As expected, a storage coefficient could not be calculated from this test. It was originally expected that the Eagle Sandstone may be under unconfined conditions except where interbedded shale and clay layers form confining layers. Since no well log was available, the confined or unconfined nature of the aquifer was indeterminable. The test indicated that there is significant potential for developing a municipal water supply out of the Eagle aquifer in this area.

Other Areas

Within the past 5 years several wells with yields and quality similar to what is needed to supply Broadview were constructed in the Judith River Formation, about 2.5 miles east of Molt. These wells are located about 20 miles south of Broadview near the intersection of Molt Road and Buffalo Trail. The yield and quality of these wells verify that the Judith River Formation can be a viable resource in this general area. Unfortunately none of the Judith River Formation wells inventoried in the Broadview area had either the quality or yield potential desired for a new supply. As a result, the Judith River aquifer was not targeted as a likely source for additional exploration in the Broadview area.

On the western edge of the Gooseneck Creek area in the vicinity of T. 3 N., R. 22 E., sec. 6, several wells producing 10 to 70 gpm of good quality water have been tested as part of previous MBMG projects. There is a good potential to locate adequate municipal water supplies in this area. Since developing this area would require an additional 3-4 miles of pipeline to reach Broadview, detailed investigations were restricted to areas closer to town.

Gooseneck Creek Area Detailed Hydrogeologic Assessment

The Gooseneck Creek area stood out as a good place to explore for the town of Broadview's water supply. It is located several miles closer to Broadview than other potential sites. Most of the wells are relatively shallow (less than 200 ft deep). Several identified wells produce volumes of water similar to what is needed by the town. The results of pumping at the Cemetery well indicated significant development potential. Water quality is generally very good in this area. The current land uses do not appear to be significant threats to water quality in the aquifer. Nearly all of the land is either pasture or CRP. A major land owner had been contacted and was willing to allow access to his property for further investigations. As a result of these positive attributes, a detailed hydrogeologic assessment designed to explore for a suitable water supply for Broadview was conducted in this area.

Test Drilling

Four sites named BVIEW1 through BVIEW4 were selected to drill test wells. These sites are mapped in figure 14. Lithologic logs and construction reports of all wells drilled are in appendix A. Land access and surficial geology were primary selection criteria. In addition, surficial structural features were used as indicators of subsurface fracturing and potential increased well production. Faults mapped on the geologic map and surface lineaments identified on satellite images and aerial photographs are depicted in figure 14. Lineaments may represent faults or fracture zones that are visible as subtle alignments. Exploration drilling was initiated by drilling a test hole at the programmed site using the air rotary drilling method.

Six-inch steel surface casing was set in each of the test holes. Water-bearing zones are typically easily identified using this drilling method by observing the volume of water produced as drilling progresses. If significant volumes of water were encountered, the drilling would stop, allowing the well to recharge. The production rate could then be estimated by starting up the air compressors on the rigs and measuring the flow of water. Test holes with significant water production potential were constructed as wells using either 4- or 4.5-in ID PVC casing and 20-slot PVC well screen. Filter packs were not used around any of the well screens in an attempt to reduce well losses. Test holes with limited production potential were completed as open-hole wells.

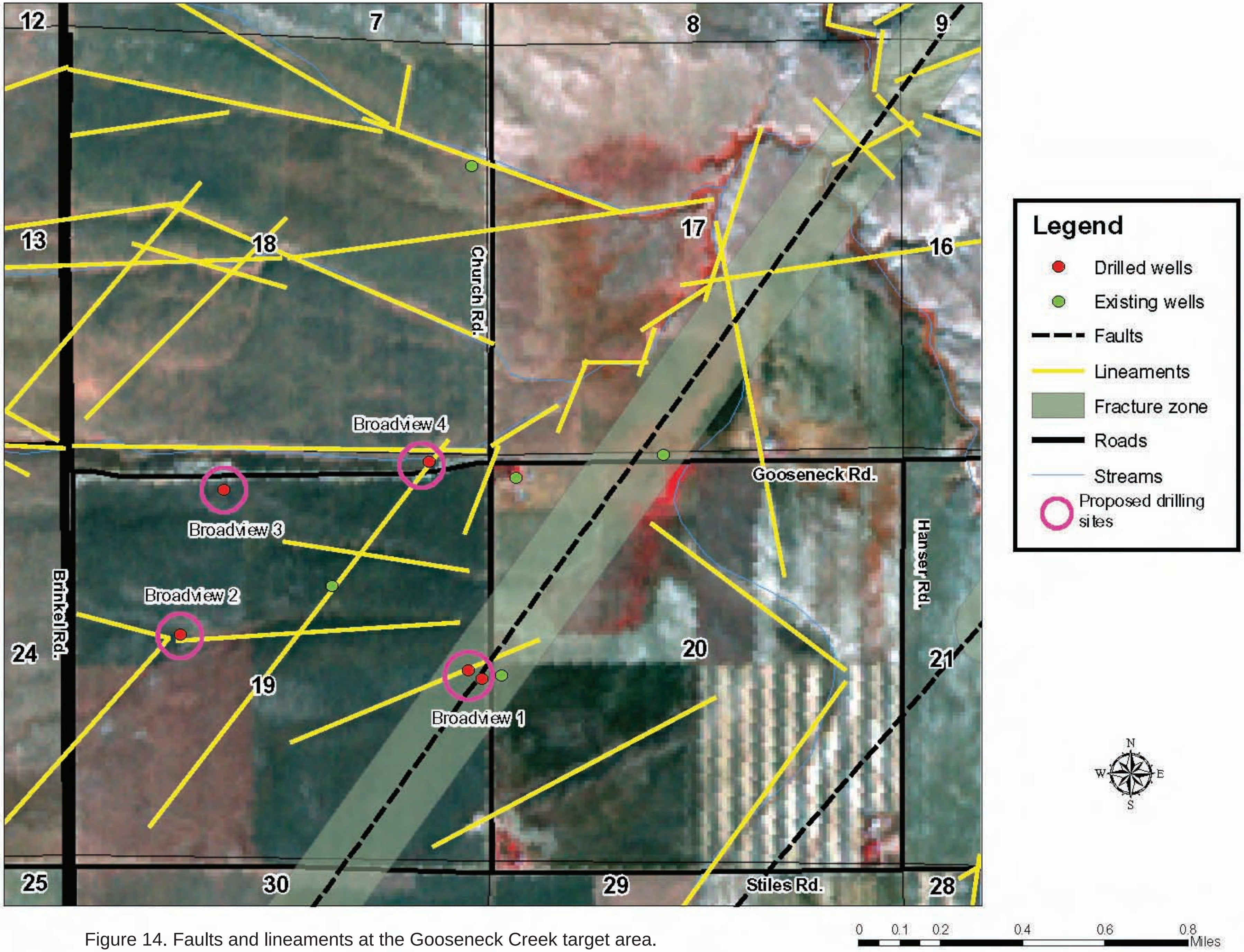


Figure 14. Faults and lineaments at the Gooseneck Creek target area.

Site BVIEW1 (T. 4 N., R. 22 E., sec. 19 BAAA) was selected because it is located close to the axis of a fault that trends NE–SW at a bearing of N 35° E. In addition, test pumping at the Cemetery well indicated good well yield potential and water quality that may be enhanced because of the fault. Two wells, BVIEW1 (240406) and BVIEW1A (240525), were constructed at this site. Drilling at well BVIEW1 did not encounter significant volumes of water until the bit reached a depth of 62 ft. Immediately underlying a 2-ft-thick very hard calcareous sandstone caprock, large volumes of water were produced. The aquifer was made up of gray, fine to medium salt and pepper sandstone. The sandstone was made up of well-sorted and rounded white quartz and black lithic sand grains. Distinctive green glauconitic minerals were a small but noticeable part of the sandstone. The base of this very permeable sandstone was at about 75 ft. The productive part of this aquifer was 13 ft thick. The aquifer overlies very fine-grained dirty sandstone interbedded with very thin laminations of carbonaceous shale that forms a basal aquitard. The total depth of this test hole was 80 ft. The test hole produced more than 120 gpm when the compressors were turned on. The produced water was tested and field water-quality parameters measured included: SC = 910 μS/cm, Temperature = 9.5°C, pH = 7.7, Dissolved Oxygen = 11.41 mg/L, Nitrates = 0, Nitrites = 0. The BVIEW1 well (240406) was constructed with 30 ft of 4.5-in 20-slot PVC screen set from 50 to 80 ft and 4.5-in casing set from 10 to 50 ft. The static-water level was 23.75 ft below land surface shortly after it was constructed on 11/15/2007.

Well BVIEW1A (240525) is located 213 ft NW of well BVIEW1. This well location was sited perpendicular to the trend of the fault. This well encountered similar stratigraphy as BVIEW1. Only a few minor water-production zones were encountered in the top 64 ft. A 1-ft-thick very hard calcareous caprock was penetrated from 63 to 64 ft. Underlying this caprock productive aquifer materials were encountered extending 11 ft to the base of the aquifer at 75 ft. The aquifer overlies very fine-grained dirty sandstone interbedded with very thin laminations of carbonaceous shale that forms a basal aquitard. The total depth of this test hole was 80 ft. The test hole produced more than 60 gpm when the compressors were turned on. The produced water was tested and field water-quality parameters measured included: SC = 932 μS/cm, Temperature = 9.7° C, pH = 7.7, Dissolved Oxygen = 11.55 mg/L, Oxidation Reduction Potential = -30.4, Nitrates = 0, Nitrites = 0. The BVIEW1A well (240525) was constructed with 30 ft of 4.0-in 20-slot PVC screen set from 50 to 80 ft and 4.0-in casing set from 10 to 50 ft. The static-water level was 19.4 ft below land surface shortly after it was constructed on 11/16/2007.

Site BVIEW2 (T. 4 N., R. 22 E., sec. 19 BCDA) was selected because it was aligned with intersecting lineaments (fig. 14). Drilling at this site had the potential to document if lineaments mapped from aerial photographs and satellite images could help determine fracture zones that may correlate to higher production in water wells. This test hole was drilled as a stratigraphic test to help determine the total thickness of the Eagle Sandstone in this area. Well BVIEW2 (240526) is located 3922 ft NW of well BVIEW1. Only a few minor water production zones were encountered while drilling this well. Most of the water appeared to be coming from a thin zone located at a depth of 15 to16 ft. In general the lithologies encountered at this location were finer grained and contained more carbonaceous shale than those at the first two test holes. Water production first tested with the air line set at a depth of 120. The test hole produced about 3.5 gpm. The produced water was tested and field water-quality parameters measured included: SC = 737 μS/cm, Temperature = 11.5°C, pH = 7.99, Dissolved Oxygen = 11.24 mg/L, Oxidation Reduction Potential = 96.3, Nitrates = 2 mg/L, Nitrites = 0. A distinctive lithologic break was noticed at 177 ft where the cuttings changed from predominantly sandstone to predominantly shale. The top of the Telegraph Creek Formation was interpreted to be located at this lithologic break. The total depth of this test hole was 200 ft. The test hole was used as an open-hole-completed well for the duration of testing at the site. The static-water level was 22.4 ft below land surface shortly after it was constructed on 12/3/2007. Cascading water from production zones above the static water level appeared to be the major source of water to this well. The well was plugged and abandoned following testing. The lineaments did not appear to be a good predictor of water-yield potential at this site.

Site BVIEW3 (T. 4 N., R. 22 E., sec. 19 BABD) was selected based on recommendations from the hydrogeologist working for Broadview's contract engineers. No lineaments or faults were noted near this site. This test hole was drilled to check the water-production potential at this location. This site is located 4120 ft northwest of the production well BVIEW1. Interbedded zones of relatively clean very fine to fine sand and dirty very fine sand with carbonaceous shale laminations were the predominant lithologies encountered. Only minor water-bearing zones were noted, with total production less than 0.5 gpm. The total depth of this test hole was 100 ft. The test hole was used as an open-hole-completed well (240527) for the duration of testing at the site. The static-water level was 52.54 ft below land surface shortly after it was constructed on 12/3/2007.

Site BVIEW4 (T. 4 N., R. 22 E., sec. 19 AAAB) was selected because it was aligned with intersecting lineaments (fig. 14). As at BVIEW2, drilling at this site had the potential to document if lineaments identified on aerial photographs and satellite images could help determine fracture zones that may correlate to higher production in water wells. This site is located 2868 ft north of the production well BVIEW1. This well encountered similar stratigraphy as BVIEW1. Only a few minor water-production zones were encountered in the top 38 ft. At this location 7 ft of productive aquifer materials was encountered at a depth of 38 ft. No hard calcareous sandstone caprock was encountered at this site. The base of the aquifer was at 45 ft. The aquifer overlies very fine-grained dirty sandstone interbedded with very thin laminations of carbonaceous shale that forms a basal aquitard. The total depth of this test hole was 50 ft.The test hole produced about 30 gpm when the compressors were turned on. The produced water was tested and field water-quality parameters measured included: SC = 820 µS/cm, Temperature = 9.9°C, pH = 7.85, Dissolved Oxygen = 17.1 mg/L, Oxidation Reduction Potential = 68.1, Nitrates = 0, Nitrites = 0. The BVIEW4 well (240528) was constructed with 30 ft of 4.0-in 20-slot PVC screen set from 20 to 50 ft and 4.0-in casing set from 5 to 20 ft. The static-water level was 11.66 ft below land surface shortly after it was constructed on 12/05/2007.

Maximum well yields are directly related to the thickness of fine- to medium-grained, clean, rounded, well-sorted sandstone making up the productive part of the aquifer. The maximum well yields indicate the volume of water when the aquifer is stressed to its upper limit. This commonly occurs when the well is being drilled and compressed air from the drill rig unloads the water up the borehole. This often is more than the well could sustain if continuously pumped. Nonetheless it is a good method to discriminate relative production potential. The thickest section of aquifer was 13 ft, found at well BVIEW1, and this well produced over 120 gpm when blown with air. At BVIEW1A the aquifer was 11 ft thick and the well produced 60 gpm. At BVIEW2 the aquifer was estimated to be 1 ft thick and the well produced 3.5 gpm. At BVIEW4 the aquifer was 7 ft thick and the well produced 30 gpm. Figure 15 is a plot based on our limited knowledge comparing aquifer thickness and maximum well yield in the Gooseneck Creek area. It shows an exponential relationship with an R^2 value of 0.98. This relationship may be helpful in estimating the yield potential in other locations using wells with limited lithologic data.

The relationship of mapped faults to increased productivity is clearly evident in the Broadview Dome area. It is unclear if the productivity identified in the Gooseneck Creek area is related entirely to the productive clean sandstone identified in test holes at BVIEW1, BVIEW1A, and BVIEW4 or if it is enhanced by fracturing of the sandstone associated with the mapped fault. The features mapped as lineaments do not appear to be associated with fracture zones that have enhanced porosity and permeability in the Eagle aquifer.

Aquifer Response Tests

Preliminary Step-Drawdown Test at BVIEW1. The BVIEW1 site appeared to be the best location for a long-term aquifer test in the Gooseneck Creek area based on lithology of the aquifer in this area and the volume of water produced during drilling. Prior to conducting a long-term test a step-drawdown test was conducted. Interpretations from the step-drawdown test can provide preliminary estimates of the aquifer properties and estimates of the well efficiency. More importantly, this test was designed to evaluate the highest pumping rate that can be maintained for a longer time period. A pump was set in the production well (BVIEW1) at 50 ft below ground. Water levels were measured using an electronic sounder at the production well (BVIEW1-240406). Data loggers were installed in an observation well 213 west of the production well (BVIEW1A-240525) and an observation well 254 ft east of the production well (Cemetery well-14949). The step-drawdown test was started at the first step with a pumping rate of 46 gpm. After 15 min at this step the valve was opened setting the pumping rate of step 2 to 60 gpm. Step 2 was maintained at 60 gpm for 16 min. Step 3 was

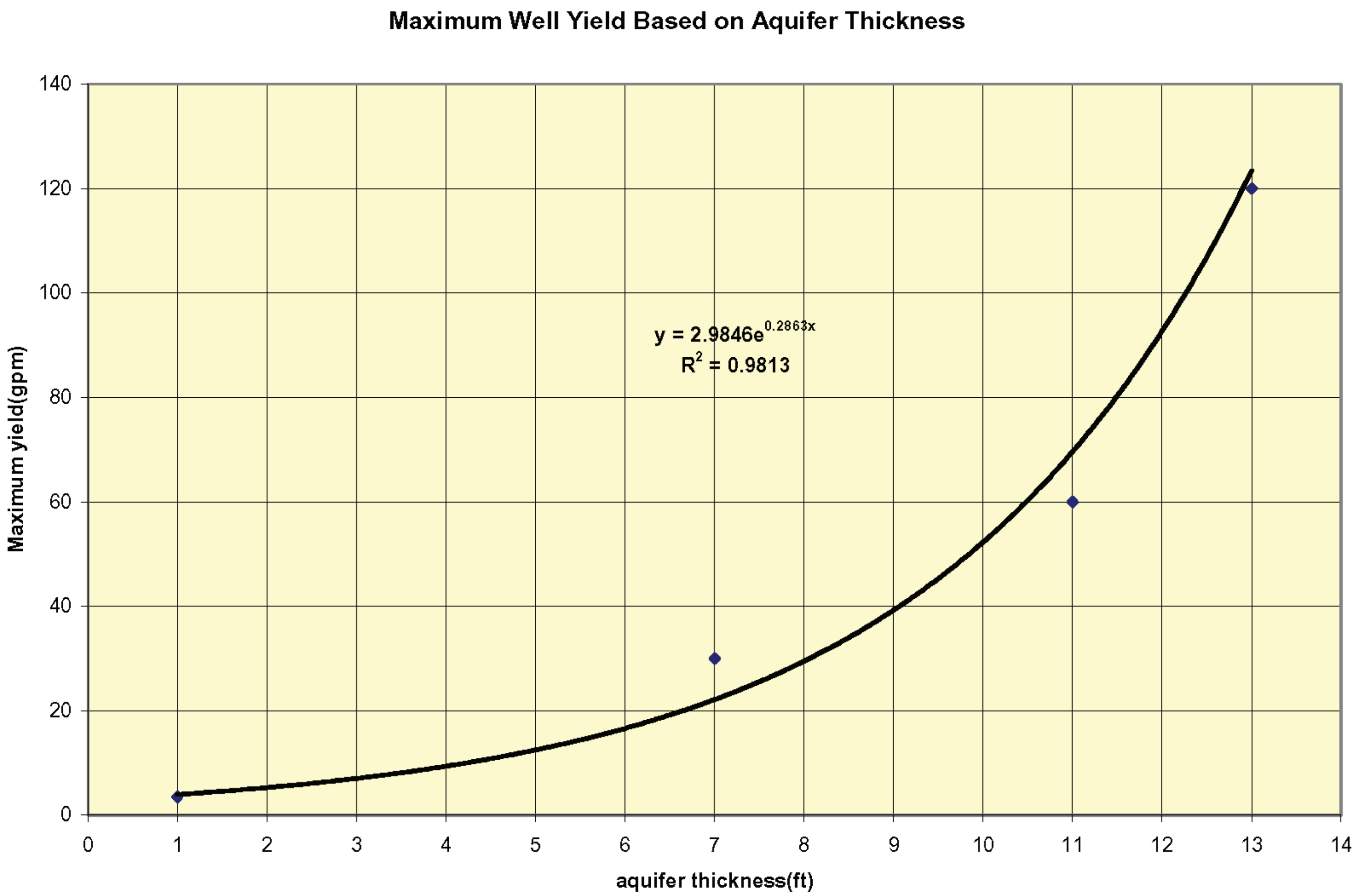


Figure 15. Comparison of maximum well yield to aquifer thickness in the Gooseneck Creek area.

maintained at 70 gpm for 17 min. Step 4 was maintained at 80 gpm for 17 min. The well was pumped at the final rate of 90 gpm for 31 min. The water-level response of the BVIEW1 step-drawdown test is clearly evident in the production well and the Cemetery well 254 ft east of the production well. Each pumping step is depicted by a unique sloped line in figures 16a and 16b. In contrast, at BVIEW1A, which is located 213 ft from the production well, the pumping steps are not expressed as unique slopes (fig. 16c) but a more generalized line with a steadily increasing slope. At the end of the test the maximum drawdown at the production well was 13.8 ft at BVIEW1 (production well), 11.17 ft at the Cemetery well, and 8.33 ft at BVIEW1A. Under homogeneous-isotropic conditions drawdown caused by the cone-of depression around a production well decreases with increasing distance. In this test the observation well closer to the production well (BVIEW1A) had less drawdown than the more distant observation well (Cemetery well).

This response indicates that anisotropic conditions are likely to be related to the position of each well with regard to the fault. In addition, the smoother response to the pumping steps at BVIEW1A may also be a result of the anisotropic conditions in the aquifer associated with the fault zone.

The step-drawdown test provided some general indications of hydrologic conditions impacted by the fault at this site. More importantly it provided a method to estimate the pumping rate that could be maintained for the duration of the test. It was anticipated for the long-term test that 25 to 30 ft of head would be available before the pumping-water level would reach the pump intakes. The projected drawdown at the production well (fig. 16a) implied that a pumping rate of 46 gpm should be well above the pump intakes after 3 days of pumping. In contrast, the higher pumping rates projected water levels either close to or well below the estimated depth of the pump intakes.

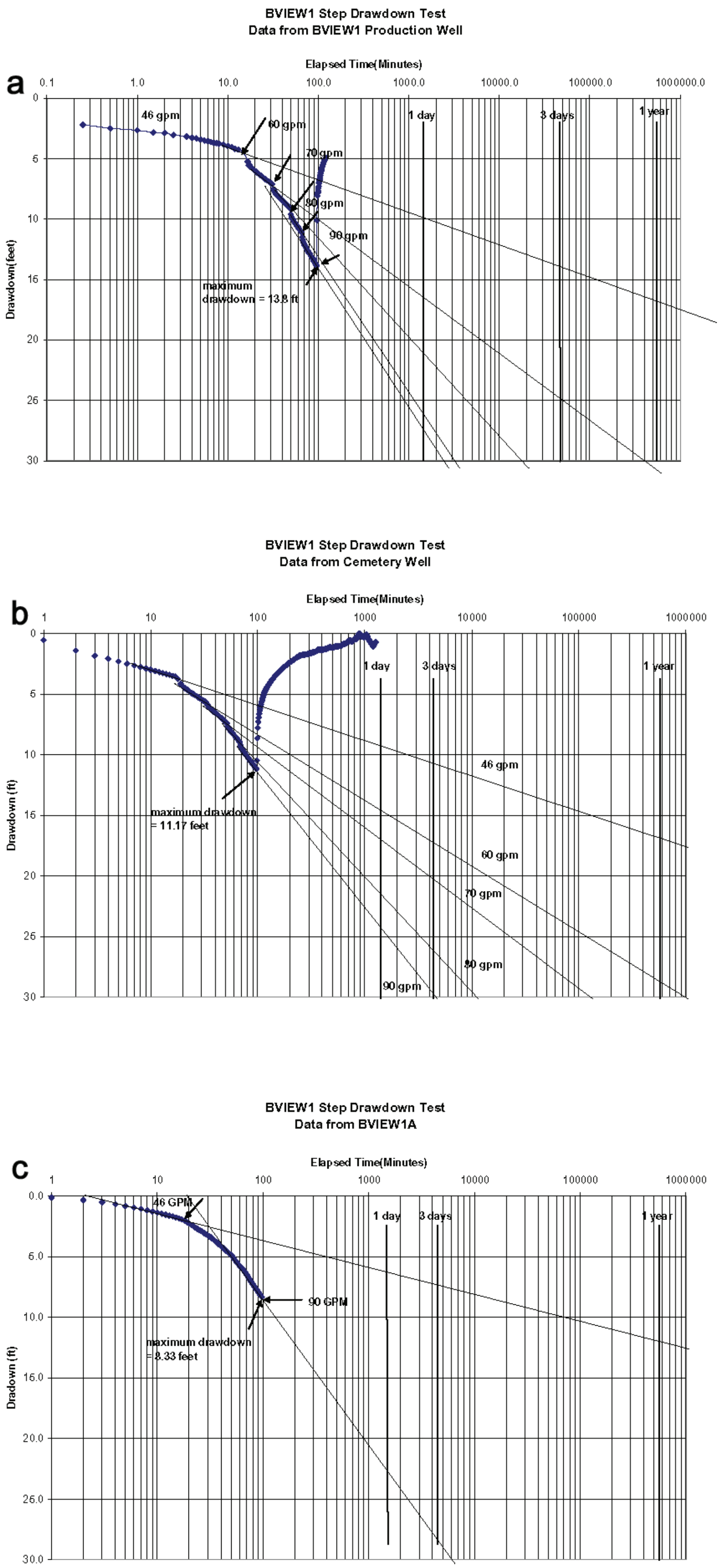


Figure 16. BVIEW1 step-drawdown test results and projections for (a) BVIEW1, (b) Cemetery well, and (c) BVIEW1A.

BVIEW1 Aquifer Response Test. The BVEW1 aquifer test was started on December 10, 2007. The test pump was set at 50 ft below ground in the production well. A data logger was set up immediately above the pump intakes. Data loggers were installed in three of the observation wells and periodic hand measurements were collected in the other six wells. Data loggers were programmed to collect readings every minute during the test and periodic measurements were collected with an electronic well sounder for calibration. Based on the results of the step-drawdown test, the long-term aquifer response test was planned to run for 3 days at a constant pumping rate within the range of 45 to 50 gpm. The pumping rate was measured using an in-line totalizing flow meter. Water-level measurements were taken in six outlying wells to determine the extent of the cone-of-depression around the production well. A map of all wells measured during the test is shown in figure 17. Figure 18 is a map view showing details of the immediate test area. Data loggers were installed in two nearby observation wells: the Cemetery well, located 254 ft east of the production well, and BVIEW1A, located 213 ft northwest of the production well. A data logger was installed in a stock well (Jones well-188462) located about 3700 ft northeast of the production well to determine if impacts of pumping at BVIEW1 would affect water levels at this existing well.

The pump was shut down temporarily because of difficulties with the generator after about 1 day of pumping. The pump was off for about 75 min and the water levels recovered rapidly at the production well and nearby observation wells until the pump was restarted. The rate of change of drawdown steadily approached the original rate and the short time the pump was off did not significantly impact the test. The initial pumping rate was about 48 gpm. The rate declined slightly during the test to about 45 gpm at the end of the test. The total volume of water pumped was measured at 189,950 gallons (0.58 acre ft). The test was run for 4280 min. Considering the pump was off for

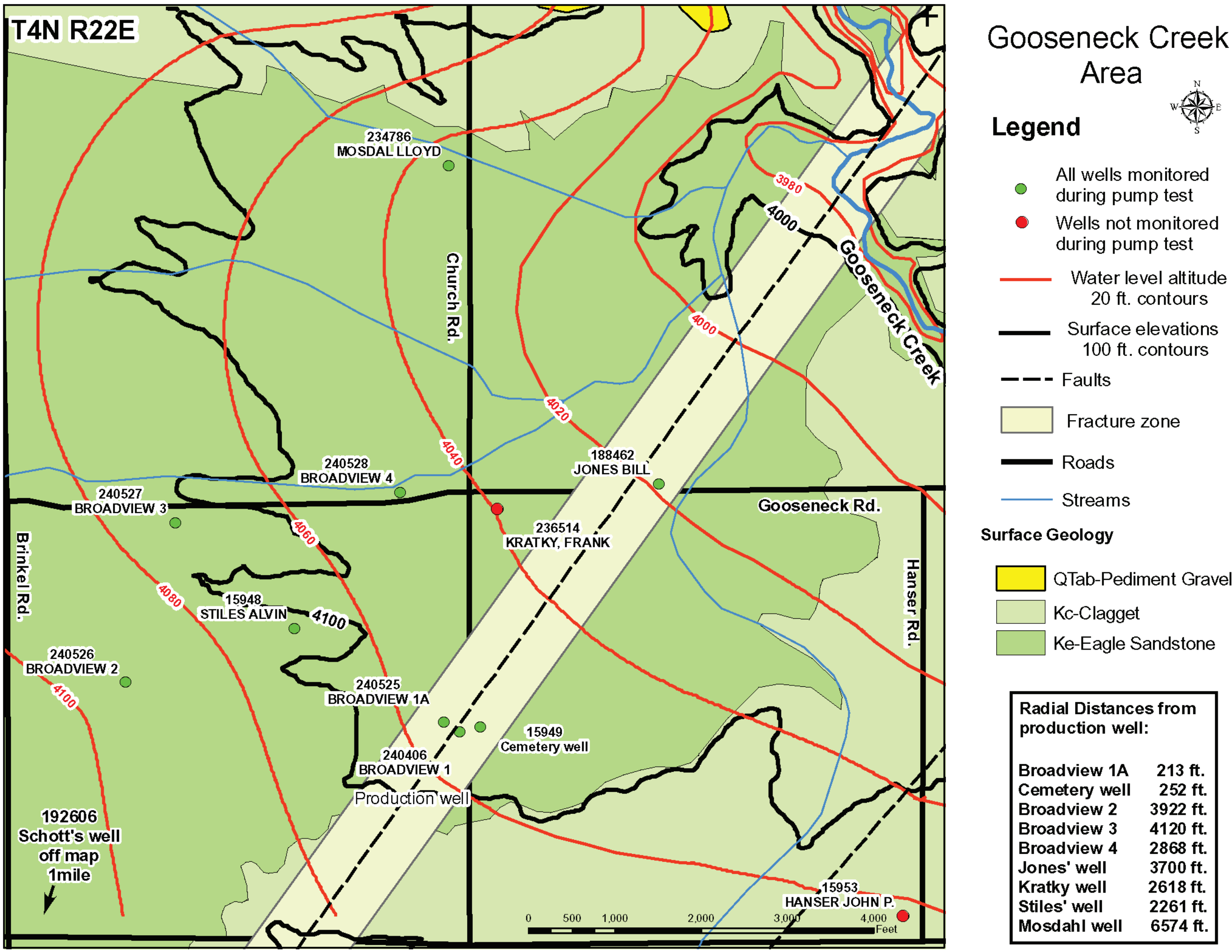


Figure 17. Location of all wells monitored during the BVIEW1 aquifer test.

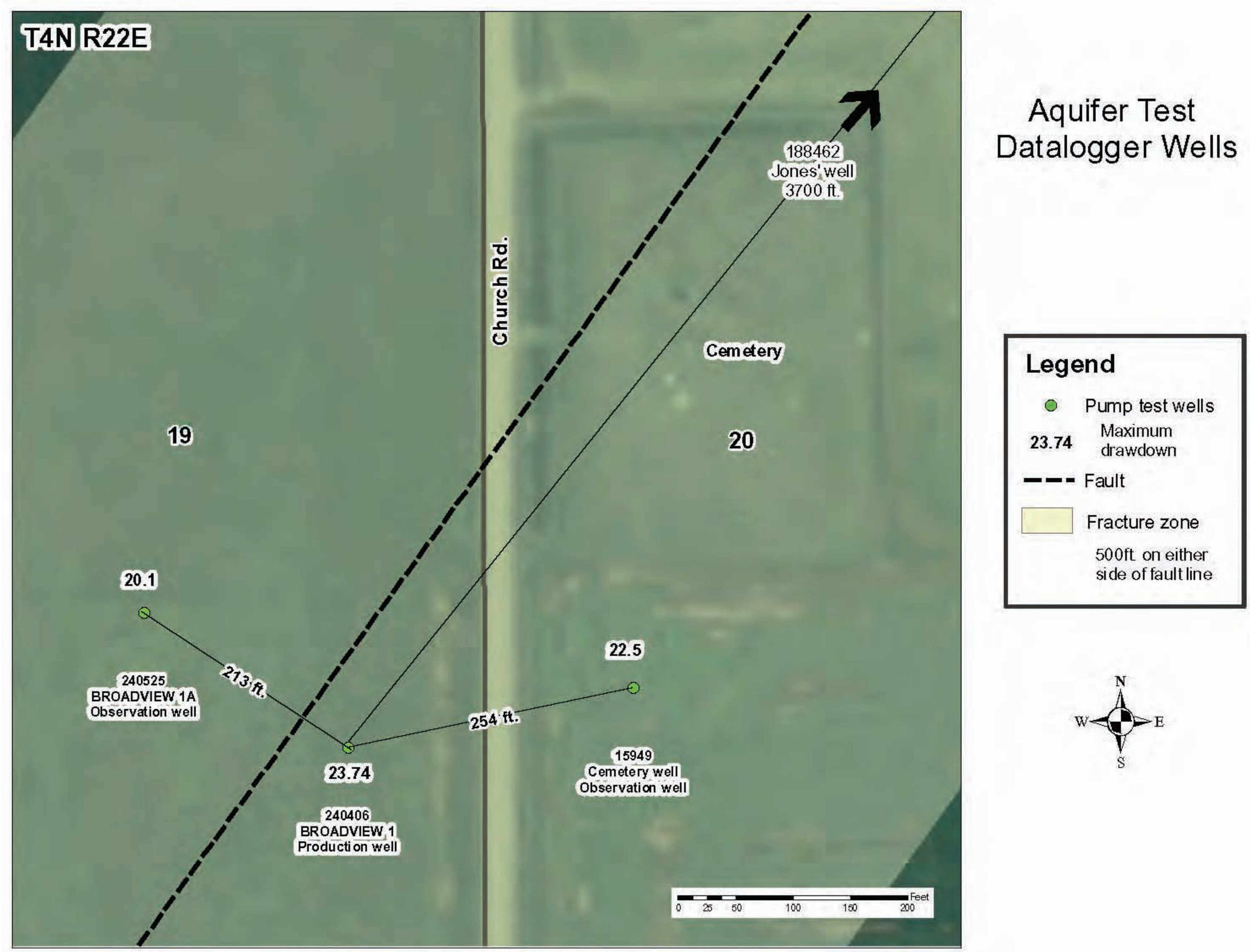


Figure 18. Locations of nearby wells monitored during the BVIEW1 aquifer test.

about 75 min, water was pumped for 4205 min. The average rate for the entire test was 45.2 gpm based on our observations and the totalizing meter.

Hydrographs showing the water-level response of all wells measured during the test are shown in figure 19. Individual hydrographs for each well are located in appendix B. Water levels in the production well and nearby observation wells responded immediately to pumping. The maximum drawdown observed was 23.74 ft at the production well (BVIEW1-240406), 20.1 ft at BVIEW1A (240525), and 22.5 ft at the Cemetery well (15949). Similar to drawdown patterns during the previous step-drawdown test, the magnitude of drawdown at the observation well closer to the production well (BVIEW1A, r = 213 ft) was less than at the more distant observation well (Cemetery well, r = 254 ft). This indicates anisotropic conditions in the aquifer, probably related to the nearby fault. None of the other observation wells appeared to respond to pumping at BVIEW1 during this test. These observation and domestic/stock wells were monitored periodically during the test and many appear to be responding to other background water-level fluctuations, discharges from the domestic/stock well being measured, or discharges from other wells. A water-level decline of about 3 ft was observed at BVIEW3 and may be a response to this test. If this was caused by the pumping at BVIEW1, greater responses would have been expected at the Stiles well (15948) and BVIEW2 well (240526), which are located closer to and generally between the production well and BVIEW3. The timing of water-level responses at BVIEW3 appears to be directly related to pumping at BVIEW1 during the aquifer test. This is puzzling because of the lack of water-level response at observation wells located closer to the production well. While these responses are not clearly understood, it is unlikely that they indicate potential significant water-level declines resulting from development of BVIEW1. The responses could be evaluated as part of additional aquifer testing. The most obvious fluctuations are at the Jones stock well (188462). As expected, the data logger recorded water-level declines at this well whenever this stock well started pumping. Instantaneous but relatively minor water-level fluctuations at the Cemetery well appear to be directly related to pumping at the Jones stock well, which

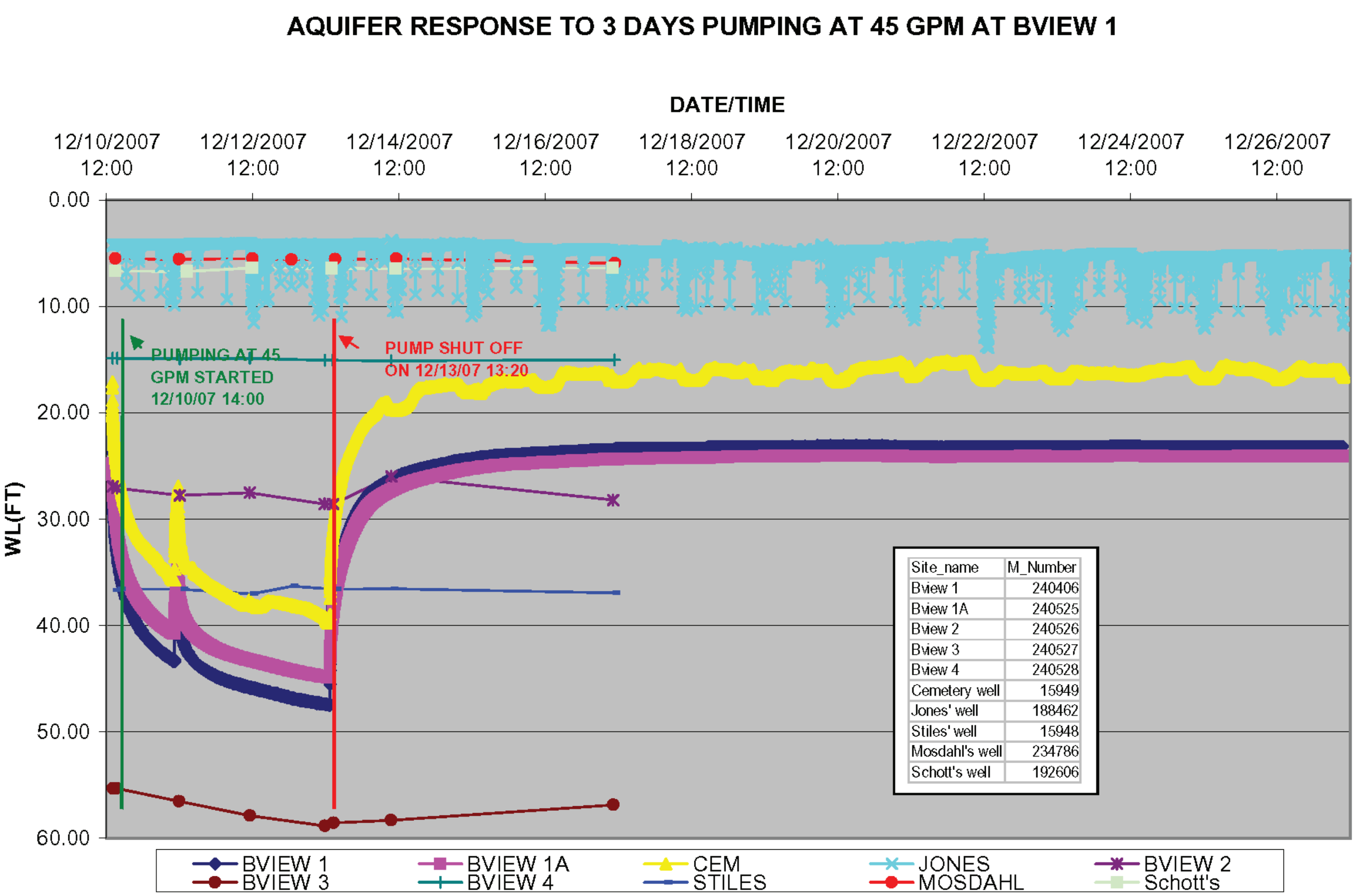


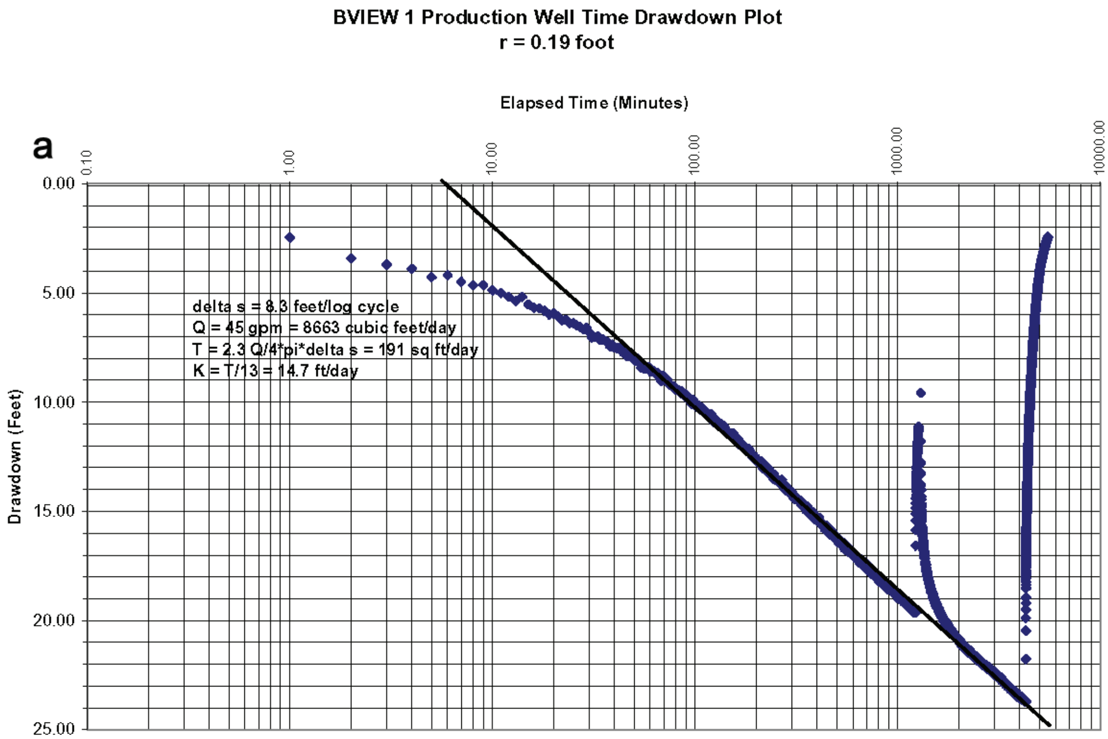
Figure 19. Aquifer response to 3 days pumping at 45 gpm at BVIEW1.

is located about 3600 ft to the northeast. Considering the magnitude and timing of water-level responses at the Cemetery well during the BVIEW1 pump test, it would seem likely that some response from this test would be observed at the Jones stock well. No such responses were observed. The water-level response of the Cemetery well to pumping at the Jones stock well and lack of water-level response at the Jones well to pumping at the BVIEW1 production well during the aquifer-response test are probably related to anisotropic conditions in the aquifer associated with the fault. Based on the lack of significant water-level responses at existing stock and domestic wells, long-term pumping at BVIEW1 will not significantly impact these water supplies.

Time-drawdown plots of data from the production well (BVIEW1) and observation wells BVIEW1A and the Cemetery well were plotted to estimate aquifer transmissivity and the storage coefficient (figs. 20–25). Figures 20–22 are semilog time-drawdown plots from the pumping phase and semilog residual drawdown plots from the recovery phase of the test. These plots were evaluated using the Cooper-Jacob method for the pumping phase and the Theis method for the recovery phase. Figures 23–25 are log-log time-drawdown plots constructed for the pumping phase of the test. These plots were evaluated using the Theis method for the pumping phase of the test. Aquifer properties calculated from the BVIEW1 test range from transmissivities of 138 ft^2/day to 214 ft^2/day and storage coefficients of 0.000045 to 0.00011. Aquifer parameters calculated from this test are listed in table 3. The average transmissivity for this site was estimated at 200 ft^2/day. Differences in the storage coefficient appeared to relate to the anisotropic aquifer conditions associated with the fault. The average storage coefficient calculated from observations at BVIEW1A located across the fault from the production well is 0.000092. The average storage coefficient calculated from observations at the Cemetery well, located on the same side of the fault as the production well, is 0.000047. These storage coefficients indicate storage across the fault towards the northwest is twice the storage along and away from the fault to the northeast.

Figure 26 is a cross-sectional view of hydrogeologic conditions at the pump test site. It shows the relatively thin productive part of the Eagle Sandstone sandwiched between overlying and underlying aquitards. The starting static-water level and final pumping level are shown in relationship to the aquifer. This diagram shows the aquifer is under confined conditions. The low storage coefficients calculated from the aquifer test confirm the confined nature of the Eagle aquifer at this location. The overlying confining beds protect the aquifer from impacts of nearby surface spills or discharges.

Distance-drawdown plots were constructed based on the transmissivities and storage coefficients calculated from time-drawdown data from BVIEW1A and the Cemetery well (fig. 27) using Theis equation methods developed by Lohman (1979). The plots can be used to determine expected interference at specific distances from the production well. Plots on figure 27 are the semilog curves showing the drawdown produced at various distances from well BVIEW1, discharging at 45 gpm for 3 days from a confined aquifer: T = 200 ft^2/day and S = 0.000092 (values calculated using BVIEW1A time-drawdown data) and T = 200 ft^2/day and S = 0.000047 (values calculated using the Cemetery well time-drawdown data). The actual maximum drawdowns at the end of the 3-day BVIEW1 aquifer response test for BVIEW1 (production well: r = 0.19 ft, dd =23.74 ft), BVIEW1A (observation well: r = 213 ft, dd = 20.1 ft), and the Cemetery well (observation well: r = 254 ft, dd = 22.5 ft) are shown on the distance drawdown plot. The observed readings at BVIEW1A and the Cemetery well plot on the curve are predicted by the aquifer parameters for each observation well. The drawdown measured at the production well (BVIEW1) is much less than would be expected. Typically, turbulent flow in pumping wells produces well losses, and well efficiencies calculated by distance-drawdown plots are rarely better than 80%. Well efficiencies calculated using distance-drawdown projections at BVIEW1 range from 300% to 315%. The cause of this anomaly is not clear, but it is probably related to increases in aquifer storage associated with the faulted and fractured rocks near the production well. Because of the increased aquifer storage around the fault, drawdown at the production well is less than would be predicted in a homogenous/isotropic aquifer. Outside the fault zone drawdown trends would follow those predicted by the Theis equation. The transmissivity calculated at the production well is nearly identical to those values calculated in the production well. The similarity of the calculated transmissivities and the doubling of the storage coefficient across the fault vs. away from the fault indicate the aquifer storage in the fault zone is greater than outside of the fault zone. This could account for the lack of water-level response as the result of pumping in more distant wells monitored during the test.



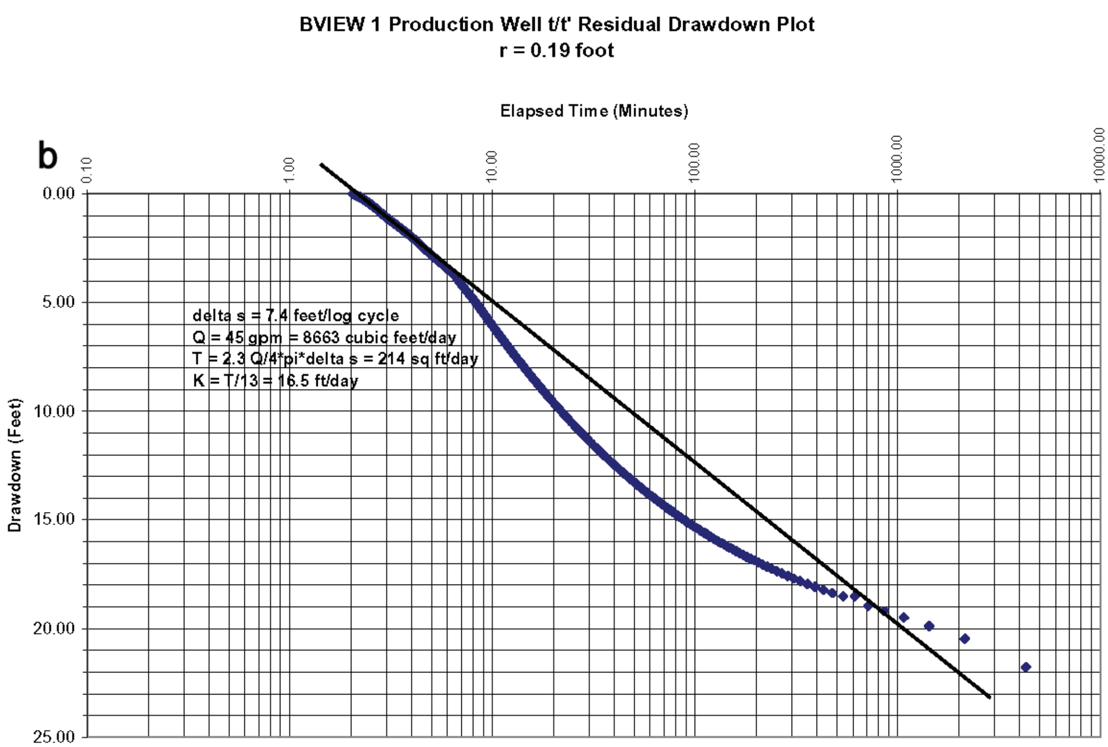


Figure 20. Semi-log plot of (a) time-drawdown and (b) recovery at BVIEW 1 responding to 3 days of pumping at BVIEW1.

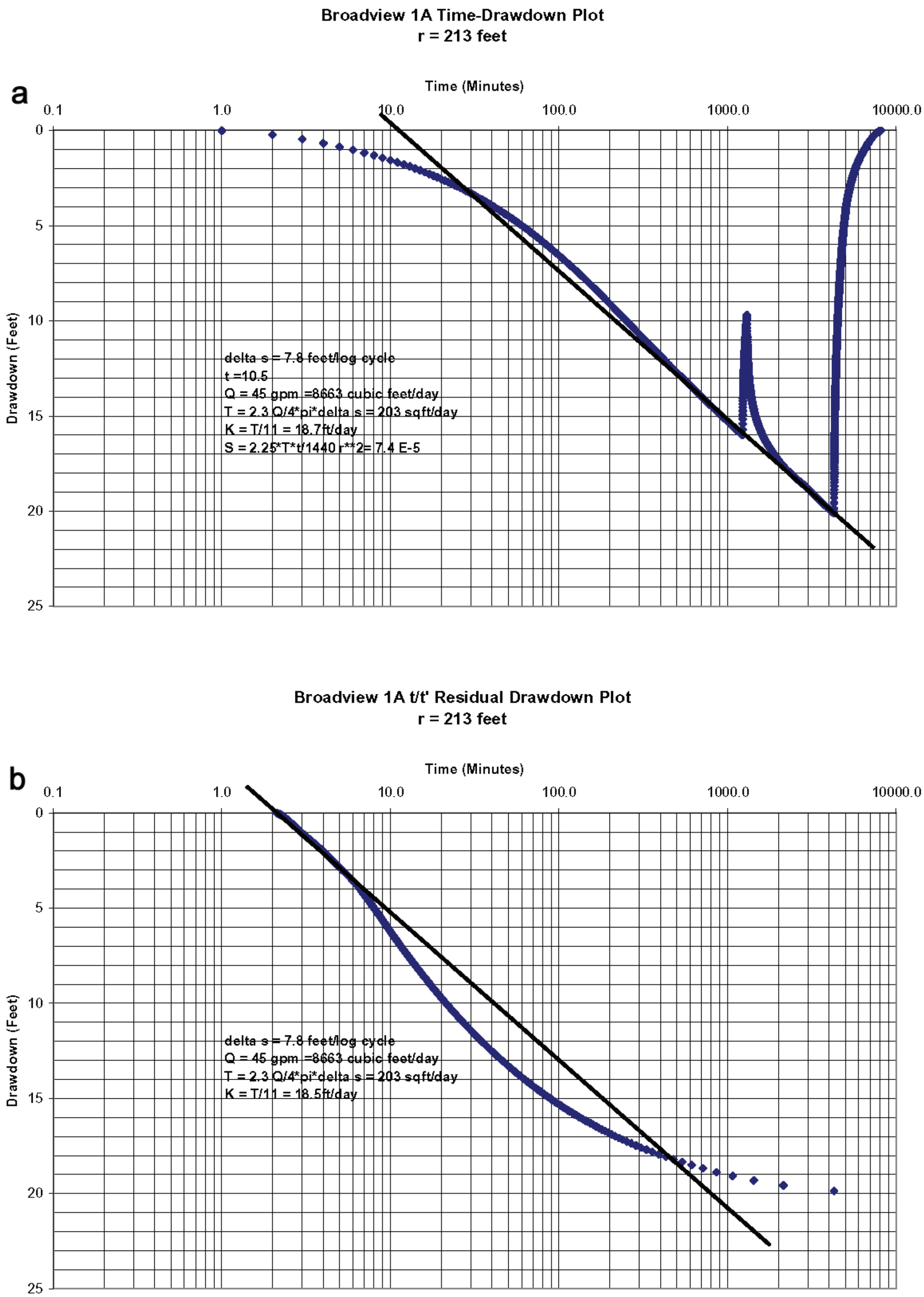
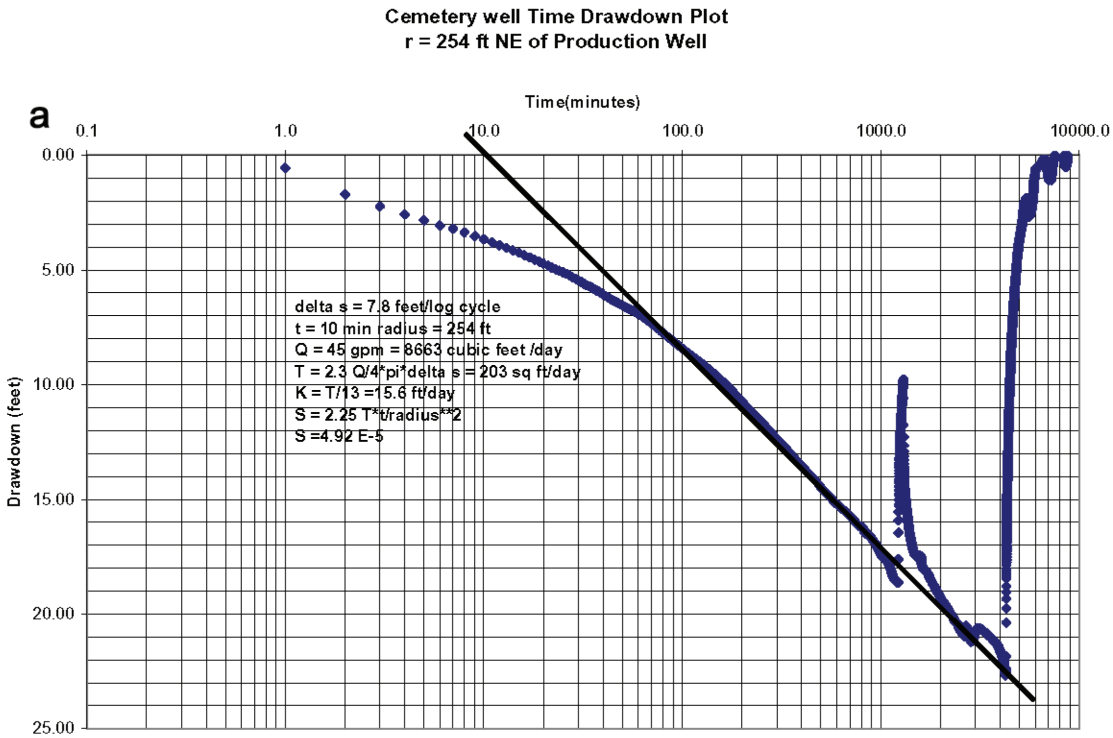


Figure 21. Semi-log plot of (a) time-drawdown and (b) recovery at BVIEW 1A responding to 3 days of pumping at BVIEW1.



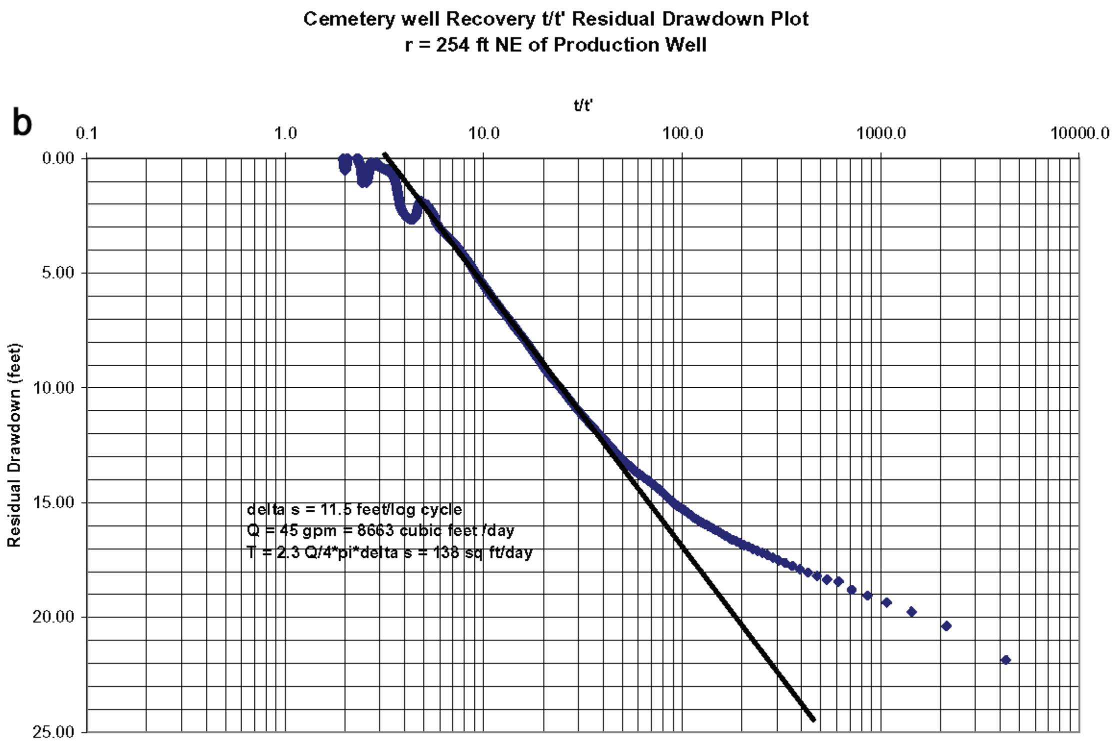


Figure 22. Semi-log plot of (a) time-drawdown and (b) recovery at the Cemetery well responding to 3 days of pumping at BVIEW1.

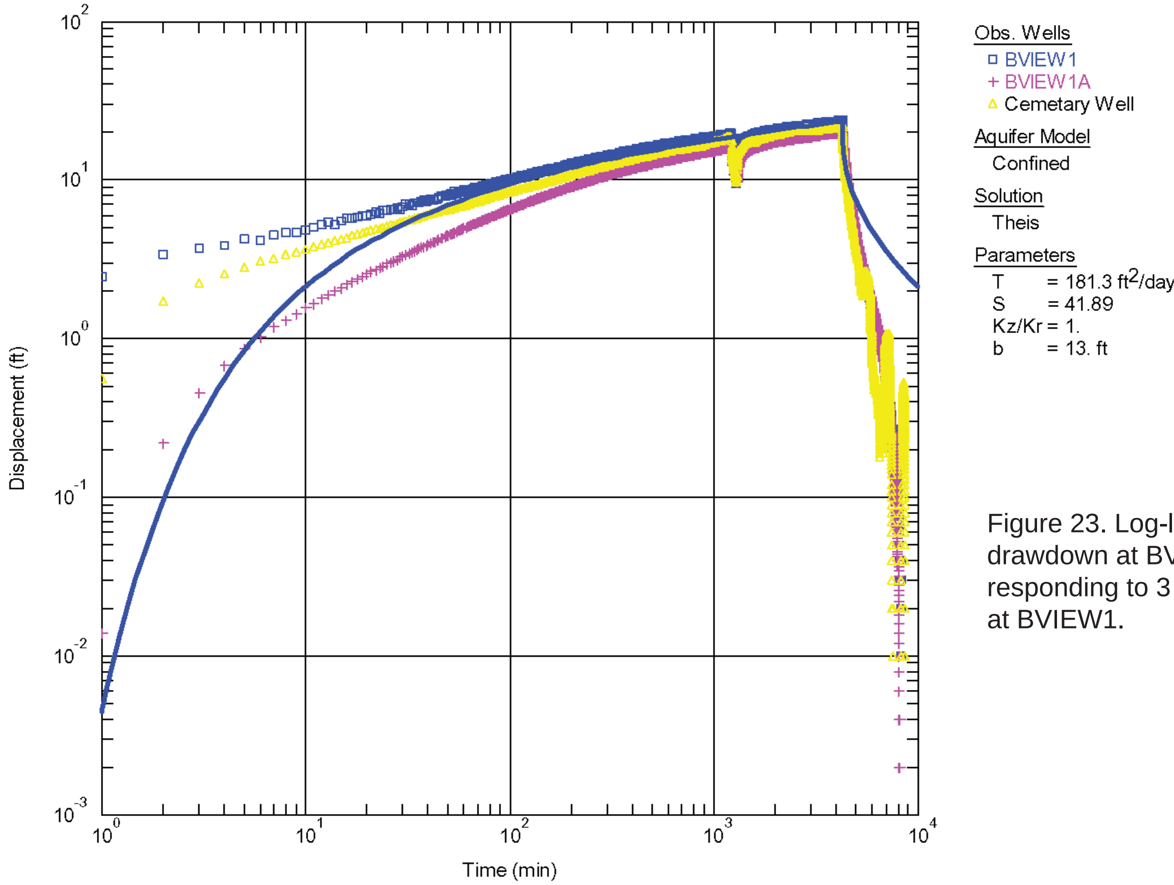


Figure 23. Log-log plot of time-drawdown at BVIEW1 well responding to 3 days of pumping at BVIEW1.

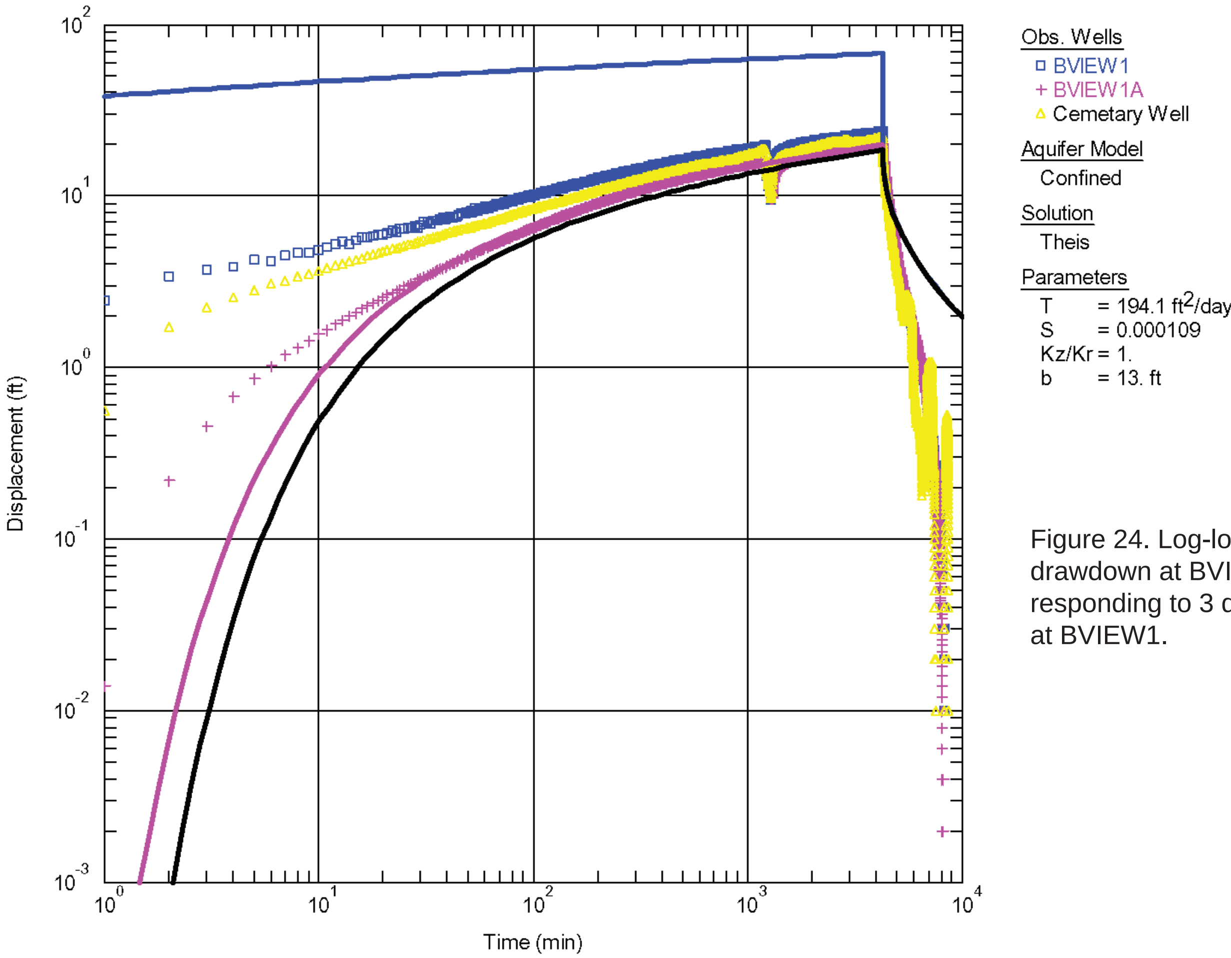


Figure 24. Log-log plot of time-drawdown at BVIEW1A well responding to 3 days of pumping at BVIEW1.

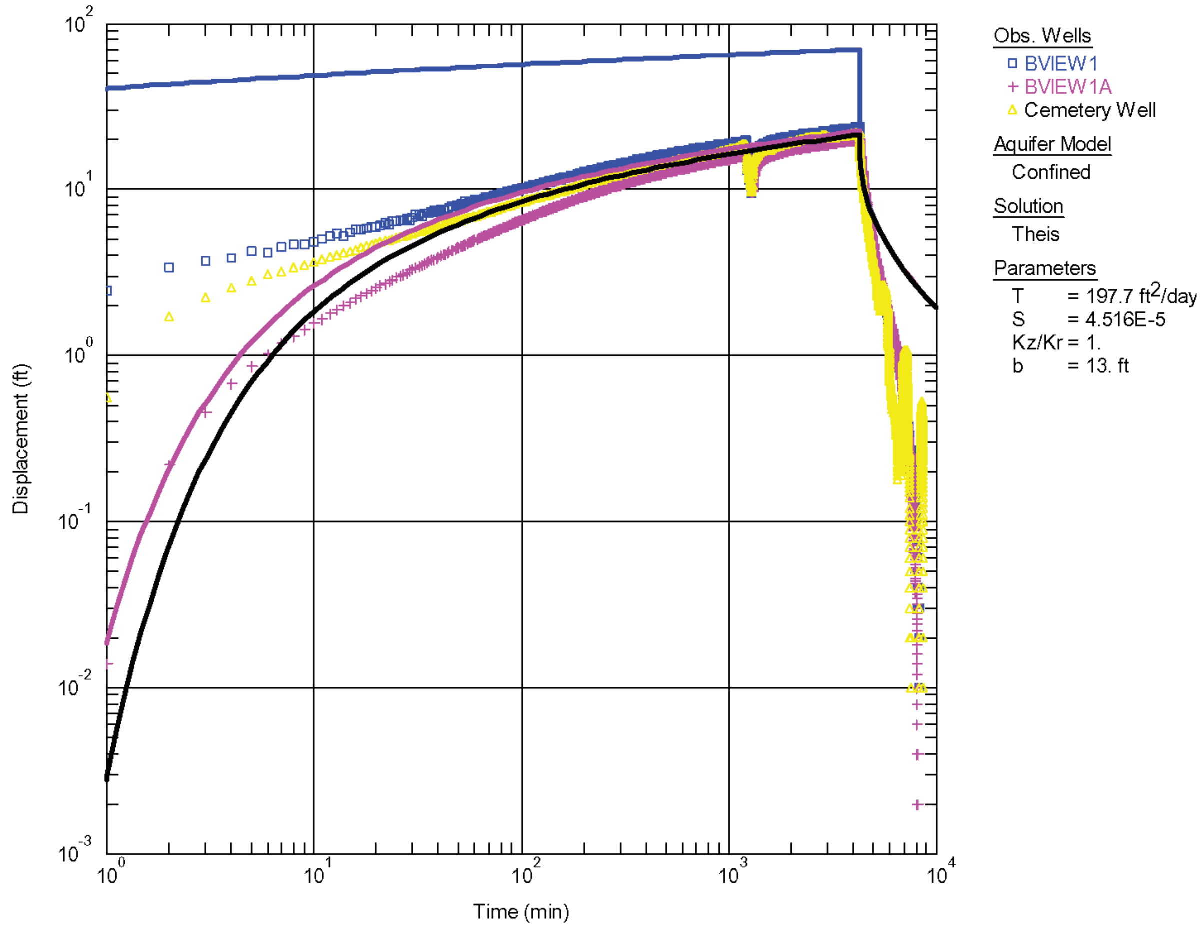


Figure 25. Log-log plot of time-drawdown at Cemetery well responding to 3 days of pumping at BVIEW1.

Table 3. Estimates of aquifer parameters from the BVIEW1 aquifer response test

Pumping Well	Aquifer Thickness	Observation Well	Radial distance feet from pumping well	Analysis Method	Transmissivity ft2/day	Hydraulic Conductivity ft/day	Storage Coefficient
BVIEW1	13	BVIEW1	0.19	Theis log-log (drawdown)	181	13.9	NA
BVIEW1	13	BVIEW1A	213	Theis log-log (drawdown)	194.1	14.9	0.00011
BVIEW1	13	Cemetery well	254	Theis log-log (drawdown)	197.7	15.2	0.000045
BVIEW1	13	BVIEW1	0.19	Cooper/Jacob semilog drawdown	191	14.7	NA
BVIEW1	13	BVIEW1	0.19	Theis semilog recovery	214	16.5	NA
BVIEW1	13	BVIEW1A	213	Cooper/Jacob semilog drawdown	203	15.6	0.000074
BVIEW1	13	BVIEW1A	213	Theis semilog recovery	203	15.6	NA
BVIEW1	13	Cemetery well	254	Cooper/Jacob semilog drawdown	203	15.6	0.0000492
BVIEW1	13	Cemetery well	254	Theis semilog recovery	138	10.6	NA

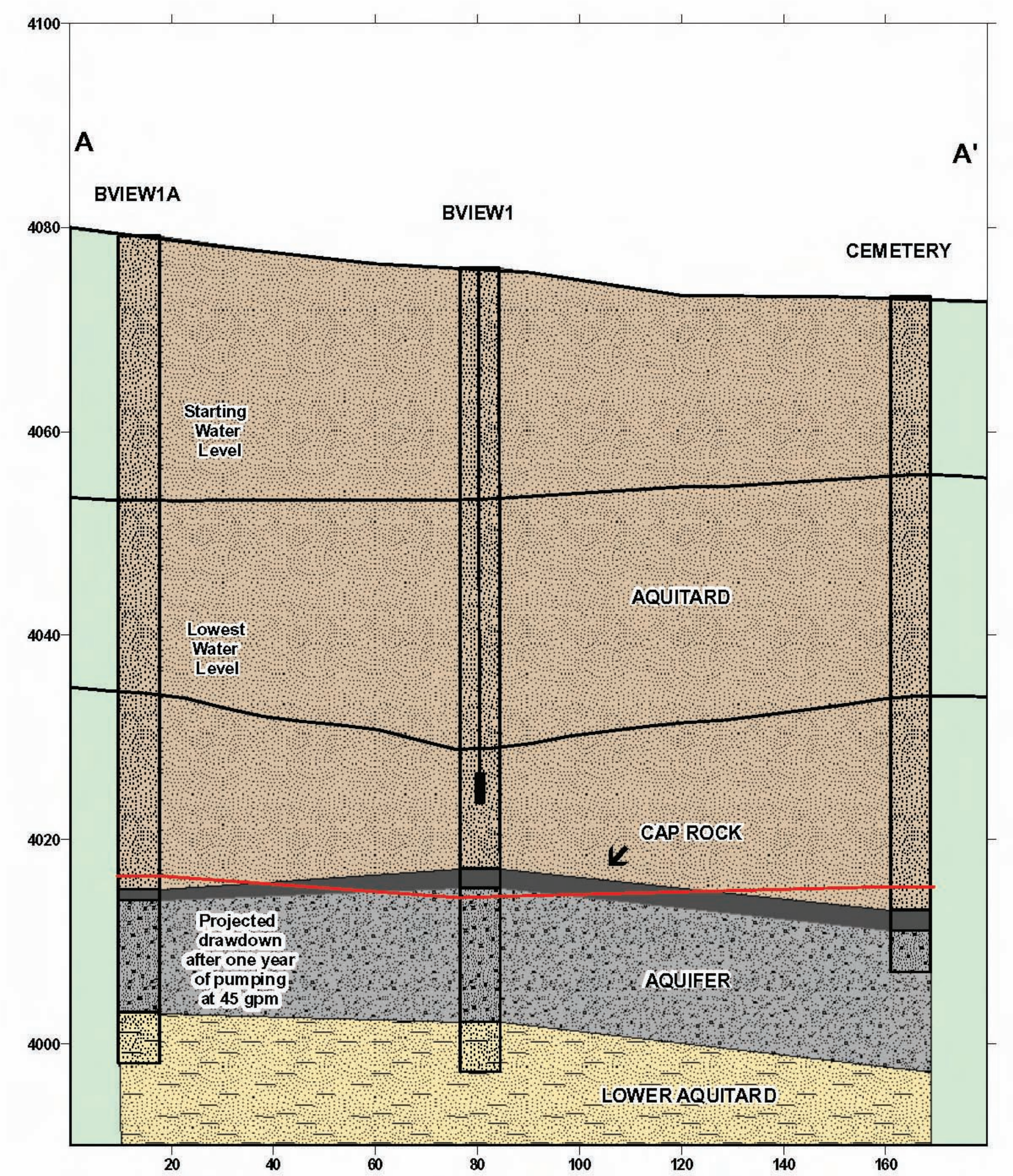


Figure 26. Cross-sectional view of drawdown and projected drawdown from the BVIEW1 aquifer response test.

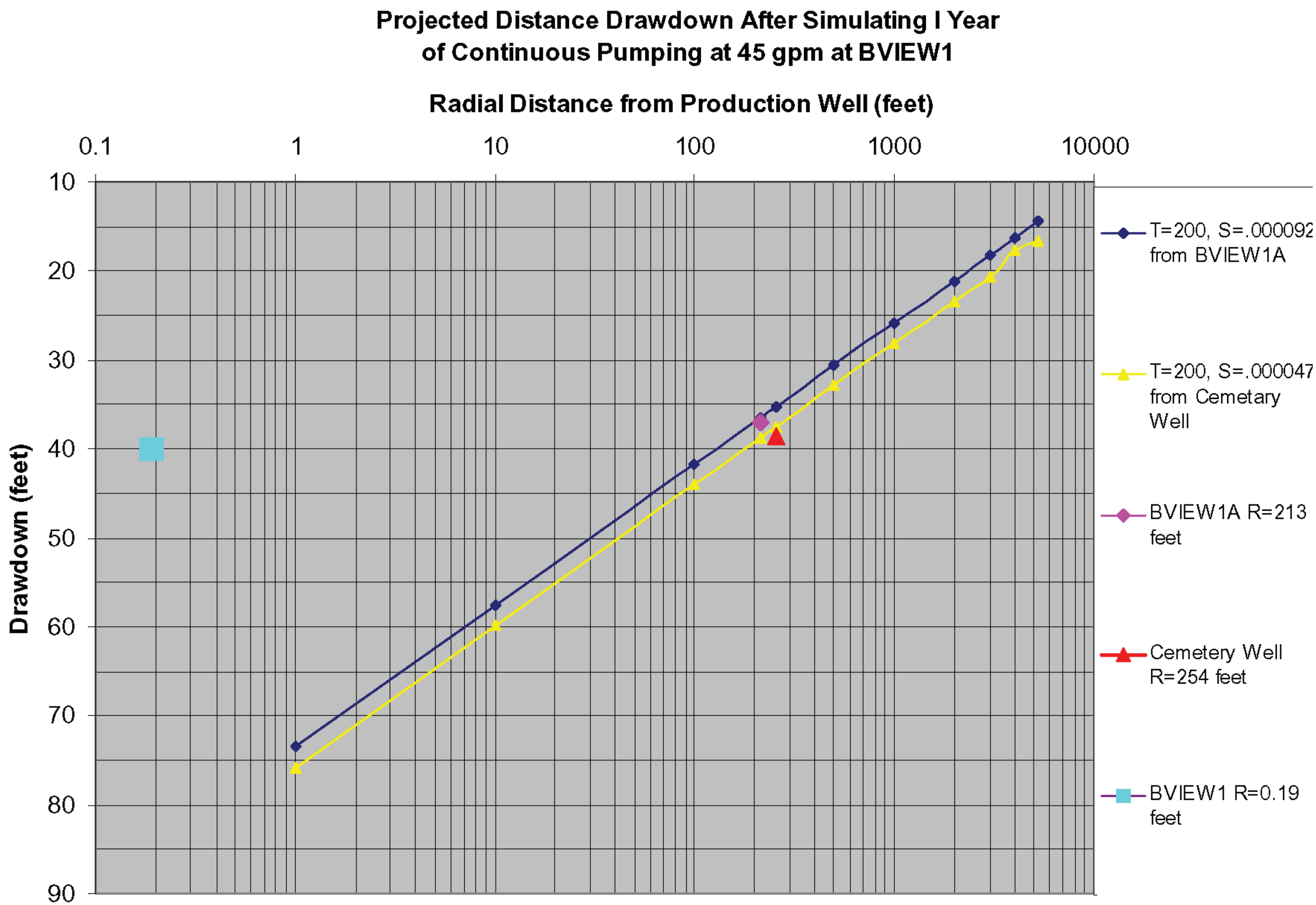


Figure 27. Semi-log plots of the drawdown produced at various distances from a well discharging at 45 gpm for 3 days from a confined aquifer for which T = 200 ft^2/day and S = 0.000092 and T = 200 ft^2/day and S = 0.000047.

A water-quality sample was collected shortly before the pump was shut off after nearly 3 days of pumping and is representative of what would be expected after prolonged use as a municipal supply. Data from this sample are summarized in table 4. The total dissolved solids (TDS) is 584 mg/L or about 1/3 the mineral concentration of Broadview's current supply. The water is dominated by ions of calcium and bicarbonate, indicating a position relatively close to the recharge area. The SAR is 0.77, which makes the water excellent for lawns, plants, and trees. Nitrates were not detected at this location, indicating little or no negative agricultural impacts. Iron (0.901 mg/L) and manganese (0.247 mg/L) are at moderate levels. The water is hard, with hardness as calcium carbonate at 440.9 mg/L. All trace elements tested are better than the water quality standards.

BVIEW4 Step-Drawdown Test. A short-term step-drawdown test was conducted at BVIEW4 (fig. 28). The water-production zone of the Eagle aquifer is from 38 to 45 ft below ground level. This unit is overlain and underlain by aquitards with little potential for water production. Based on water production during drilling and the fact that the static-water level is above the top of the productive zone, the aquifer is under confined conditions at this location. A step-drawdown test was conducted on December 6, 2007. The pumping rate was maintained at a constant rate for about 15 min for each step and allowed to continue at the maximum rate for about 1.5 hours (fig. 28a). Water-level recovery was monitored for 38 min and the water level recovered to within 5% of the total drawdown (fig. 28b). Water was pumped at 4.5 gpm for the first step. Total drawdown at the end of this step was 0.93 ft. Water was pumped at 13.5 gpm for the second step. The drawdown attributed to this pumping rate was 3.49 ft. Total drawdown at the end of this step was 4.42 ft. Water was pumped at 20 gpm for the third step. The drawdown attributed to this pumping rate was 3.88 ft. Total drawdown at the end of this step was 8.3 ft. Water was pumped at 27 gpm for the fourth step. The drawdown attributed to this pumping rate was 6.41 ft. Total drawdown at the end of this step was 14.71 ft. The time-drawdown projection at the last pumping rate was used to calculate the transmissivity (261 ft^2/day) and hydraulic conductivity (37 ft/day). The transmissivity calculated from the recovery part of the test was156 ft^2/day and hydraulic conductivity was 22 ft/day. The average transmissivity of the drawdown and recovery parts of the test was 208 ft^2/day and the average hydraulic conductivity was 30 ft/day. A storage coefficient could not be calculated for this test. Projections of drawdown from each of the steps are shown in figure 29. There was about 23 ft of available head from the static-water level to the top of the productive zone. Projecting the time drawdown out to 1 year of continuous pumping at a rate of 20 gpm would exceed the available head by 2–3 ft. In contrast, projecting the time drawdown out to 1 year of continuous pumping at 13.5 gpm would be nearly 12 ft less than the available head. Based on these projections, a well at or near this location could maintain a pumping rate of 13.5 gpm and probably as much as 15 gpm without exceeding the available head. These are preliminary values and a longer term test would be required to verify the maximum rate at this site.

Field water-quality parameters were measured during each pumping step. During the first step pumping at 4.5 gpm, the following field parameters were recorded: SC = 816 μS/cm, Temperature = 9.5°C, pH = 7.14, Dissolved Oxygen = 8.71 mg/L, ORP = 92.4, Nitrates = 2 mg/L, Nitrites = 0. During the second step pumping at 13.5 gpm, the following field parameters were recorded: SC = 817 μS/cm, Temperature = 9.4°C, pH = 7.06, Dissolved Oxygen = 8.05 mg/L, ORP = 72.5, Nitrates = 2 mg/L, Nitrites = 0. During the third step pumping at 20 gpm, the following field parameters were recorded: SC = 821 μS/cm, Temperature = 9.3°C, pH = 7.07, Dissolved Oxygen = 7.98 mg/L, ORP = 64.4, Nitrates = 2 mg/L, Nitrites = 0. During the fourth step pumping at 27 gpm, the following field parameters were recorded: SC = 820 μS/cm, Temperature = 9.5°C, pH = 7.09, Dissolved Oxygen = 7.86 mg/L, ORP = 61.1, Nitrates = 2 mg/L, Nitrites = 0.

Based on the field parameters, water in the Eagle aquifer at this location has excellent quality. The field parameters change very little at the different pumping rates. The ORP was positive, indicating water under oxidizing conditions. Low levels of nitrates were recorded at this site, but since the accuracy of test strips used to measure nitrate and nitrite concentrations can be suspect, the nitrate concentrations at this location should be verified by lab analysis. Future development at this location will need to consider the potential for nitrates.

Table 4. Water-quality analysis from BVIEW1 (240406) collected at end of aquifer-response test on 12/13/2007 after pumping for 4230 minutes at 45 gpm.

Major Ion Results

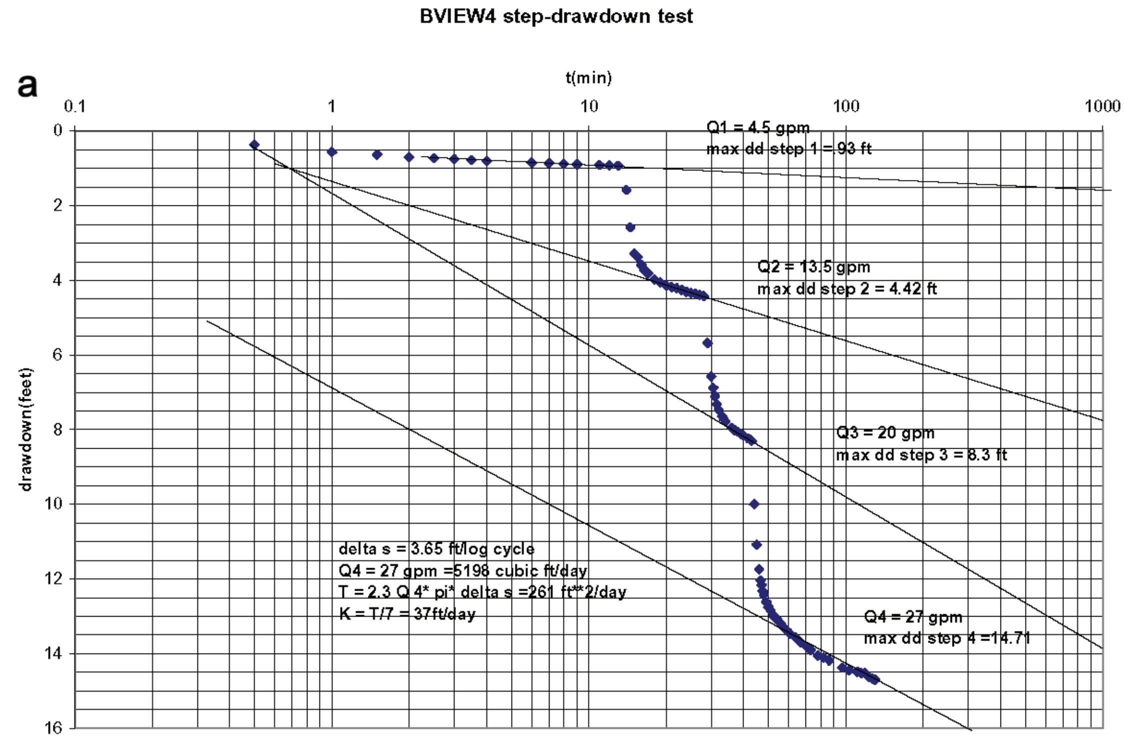
	mg/L	meq/L		mg/L	meq/L
Calcium (Ca)	95.800	4.780	Bicarbonate (HCO_3)	367.500	6.023
Magnesium (Mg)	49.000	4.032	Carbonate (CO_3)	0.000	0.000
Sodium (Na)	36.500	1.588	Chloride (Cl)	6.920	0.195
Potassium (K)	3.640	0.093	Sulfate (SO_4)	191.000	3.979
Iron (Fe)	0.901	0.048	Nitrate (as N)	<0.10 P	0.000
Manganese (Mn)	0.247	0.009	Fluoride (F)	0.345	0.018
Silica (SiO_2)	18.000		Orthophosphate (OPO_4)	<0.05	0.000
Total Cations		10.622	**Total Anions**		10.215

Trace Element Results (µg/L)

Aluminum (Al):	<1.0	Cesium (Cs):	<0.1	Molybdenum (Mo):	<1.0	Strontium (Sr):	2,505.000
Antimony (Sb):	<0.1	Chromium (Cr):	<0.1	Nickel (Ni):	0.548	Thallium (Tl):	<0.1
Arsenic (As):	<0.2	Cobalt (Co):	0.164	Niobium (Nb):	<0.1	Thorium (Th):	<0.05
Barium (Ba):	14.700	Copper (Cu):	<0.2	Neodymium (Nd):	<0.1	Tin (Sn):	0.200
Beryllium (Be):	<0.1	Gallium (Ga):	<0.1	Palladium (Pd):	5.190	Titanium (Ti):	2.240
Boron (B):	145.000	Lanthanum (La):	<0.1	Praseodymium (Pr):	<0.1	Tungsten (W):	<1.0
Bromide (Br):	<100	Lead (Pb):	<0.2	Rubidium (Rb):	2.390	Uranium (U):	<0.05
Cadmium (Cd):	<0.1	Lithium (Li):	62.300	Silver (Ag):	<1.0	Vanadium (V):	<0.1
Cerium (Ce):	<0.1	Mercury (Hg):	NR	Selenium (Se):	<0.5	Zinc (Zn):	3.470
						Zirconiuim (Zr):	0.304

Field Chemistry and Other Analytical Results

**Total Dissolved Solids (mg/L):	584.08	Field Hardness as $CaCO_3$ (mg/L):	NR	Ammonia (mg/L):	NR
**Sum of Diss. Constituents (mg/L):	770.80	Hardness as $CaCO_3$:	440.90	T.P. Hydrocarbons (µg/L):	NR
Field Conductivity (µmhos):	896	Field Alkalinity as $CaCO_3$ (mg/L):	NR	PCP (µg/L):	NR
Lab Conductivity (µmhos):	878	Akalinity as $CaCO_3$ (mg/L):	301.82	Phosphate, TD (mg/L as P):	<0.01
Field pH:	7.05	Ryznar Stability Index:	7.028	Field Nitrate (mg/L):	0
Lab pH:	7.05	Sodium Adsorption Ratio:	0.767	Field Dissolved O_2 (mg/L):	NR
Water Temp (°C):	9.7	Langlier Saturation Index:	0.011	Field Chloride (mg/L):	NR
Air Temp (°C):	0	Nitrite (mg/L as N):	0	Field Redox (mV):	-48.3



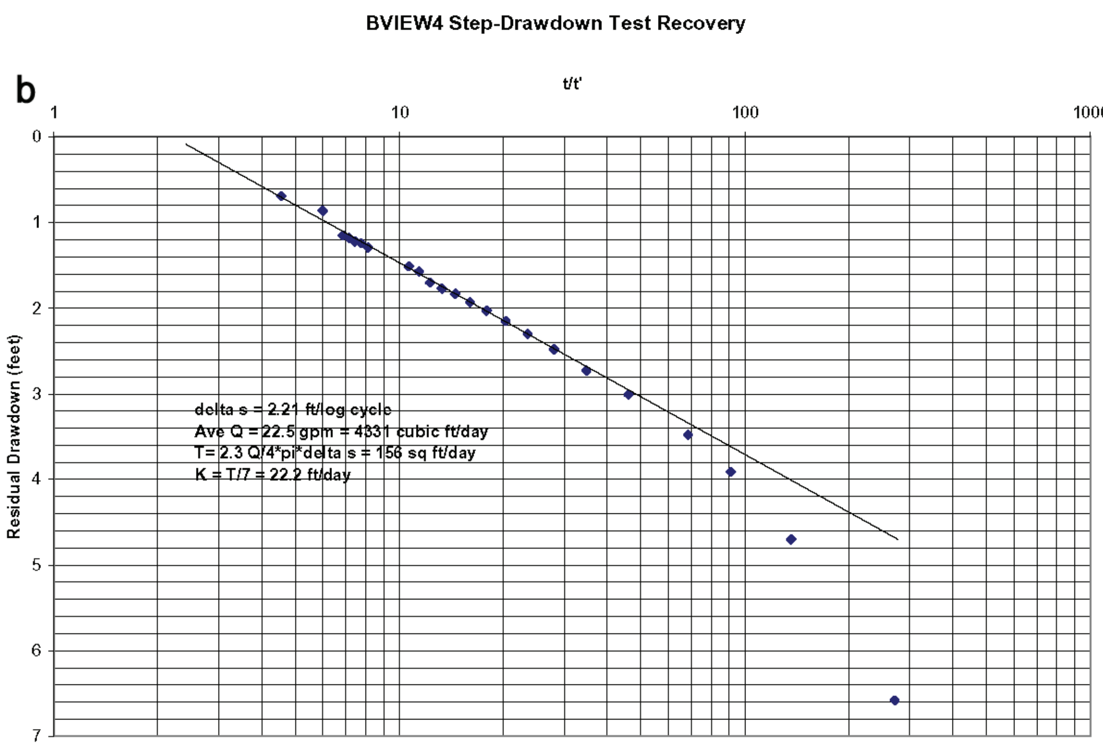


Figure 28. BVIEW4 step-drawdown test. (a) Time-drawdown-discharge plot; (b) t/t′- residual drawdown recovery plot.

WATER SUPPLY DEVELOPMENT POTENTIAL

The Gooseneck Creek area has good potential for developing a water supply for Broadview. The BVIEW1 site has adequate well yields and very good water quality. Test wells constructed as part of this project have identified the productive aquifer zones. Very little additional testing will be required to construct a production well at this location. The BVIEW4 site has good potential for developing a production well. This may require some additional test drilling and aquifer response testing to finalize a second location. Backup wells could be constructed at both of these sites. The summary of hydrogeologic conditions in the following section demonstrates the potential for ground-water development in this area.

Hydrogeology

The hydrogeology of the Gooseneck Creek area is favorable for developing a municipal water supply for the town of Broadview. The Eagle aquifer has good potential for additional development without impacting existing water resources. The water quality is excellent, easily meeting drinking water standards. Ground water is recharged by precipitation and snowmelt infiltrating the uplands, underlain primarily by Eagle Sandstone from about 2 miles west of Gooseneck Creek to the east rim of Hailstone Basin. Ground water is discharged to wells, springs, evapotranspiration, and ultimately Gooseneck Creek. This area covers about 12.5 sections (8100 acres). Based on work conducted for this project, the Gooseneck Creek area is the closest source of good water capable of meeting the municipal needs of the town.

Geology

A closer look at the geology of this area was undertaken to determine the extent of high porosity zones that appear to directly relate to aquifer productivity. Regional oil-well logs, water-well data, and test holes drilled for this project were evaluated in an attempt to map the thickness and extent of these productive zones. Two to three good porosity zones were identified in oil and gas geophysical logs from a north–south cross section located about 1 mile west of Broadview. The regional dip projects upward from these zones to the approximate levels of productivity found in the Gooseneck Creek area. There only appears to be one zone in the Gooseneck Creek area and this appears to thin towards the west. Locally, the productive sands in the Eagle aquifer are not present at BVIEW3 and are only 1 ft thick at BVIEW2. This zone appears to thicken towards the east, reaching the maximum observed thickness of 13 ft at BVIEW1. The thickness of this porosity zone is based on limited information but does imply that the best potential for water development in the Gooseneck Creek area is in parts of sections 17,18,19, and 20, T. 4 N., R. 22 E. The relationship of well yield to mapped faults is not clear. Increased fracturing can significantly increase well yields as noted in the Broadview dome area.

Aquifer Properties

The average transmissivity of the Eagle aquifer is estimated at 200 ft^2/day based on interpretations of the BVIEW1 aquifer test. The average hydraulic conductivity is 15.4 ft/day. The storage coefficient ranges from 0.000047 to 0.000092, indicating confined aquifer conditions. These estimates are reasonable for the Eagle aquifer and are within the range of aquifer parameters estimated from numerous aquifer tests from wells in Cretaceous aquifers in central Montana (table 5). The average transmissivity and hydraulic conductivity calculated from the BVIEW4 step test are 208 ft^2/day and 30 ft/day, respectively.

Mapped fault zones appear to be good places to explore for water resources because of the potential for increased aquifer storage. These areas could produce significant quantities of water with limited impacts to nearby wells.

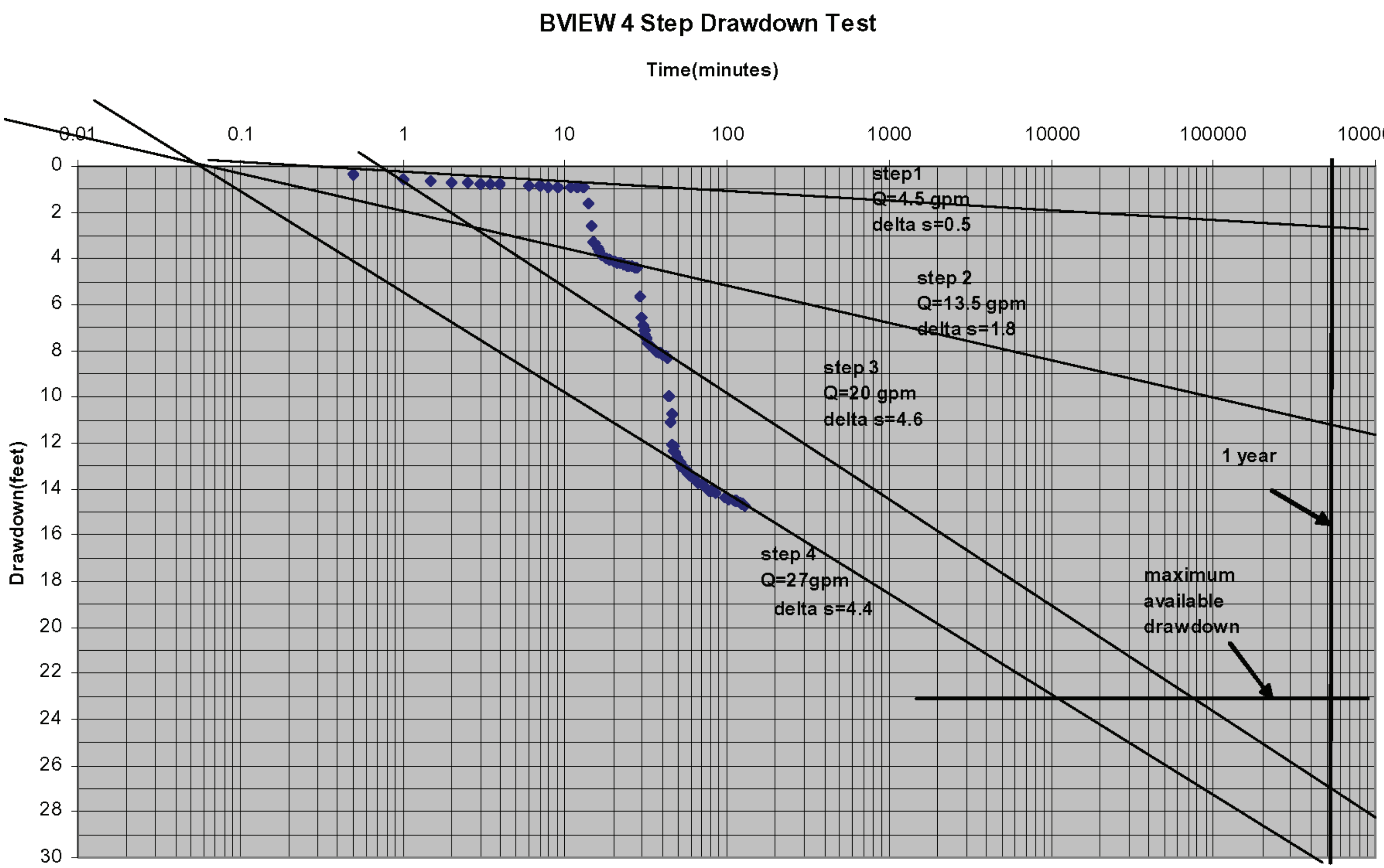


Figure 29. Projected drawdown at BVIEW4 resulting from pumping continuously for 1 year at BVIEW4.

Table 5 . Summary of Aquifer Tests in Selected Aquifers of Central Montana

Well #	Well Name	Location				Aquifer	Test Date	Test Type	Analysis Type	Tranmissivity FT^2/Day	Storage Coefficient	Reference
27192	Grass Range # 1 City of Grass Range	15N	23E	28	BBB	Multiple Third Cat Swift, Morrison	Jan-73	Air Lift	Specific Capacity Conversion	22.2	NA	O'Connell 1995
None	Winnett #2	14N	27E	6	DBD	Multiple Second Cat Third Cat	Oct-94	Pumping (Recovery)	Cooper-Jacobs	9.4	NA	O'Connell 1994
26623	Kochivaar	15N	12E	23	BA01	Kootenai	Not Reported	Flow Recovery	Cooper-Jacobs	23	NA	Zimmerman 1966
1929	Moccasin AG	15N	14E	16	DCDD01	Kootenai	Not Reported	Flow Recovery	Cooper-Jacobs	100	NA	Feltis 1977
2003	Caner	16N	11E	36	BA01	Kootenai	Not Reported	Flow Recovery	Cooper-Jacobs	249	NA	Zimmerman 1966
None	Unknown	16N	12E	35	AC01	Kootenai	Not Reported	Flow Recovery	Cooper-Jacobs	77	NA	Zimmerman 1966
28373	Phillips	16N	18E	8	CAA01	Kootenai	Oct-68	Pumping (Recovery)	Cooper-Jacobs	15	NA	Feltis 1973
None	Unknown	15N	18E	15	ADD	Swift	Oct-68	Contained Flow	Cooper-Jacobs	508	NA	Feltis 1973
None	Unknown	15N	18E	23	ADB	Swift	Oct-68	Pumping (Recovery)	Cooper-Jacobs	59	NA	Zimmerman 1966
29657	Antilla	17N	10E	33	BB01	Kootenai	Not Reported	Flow Recovery	Cooper-Jacobs	116		Zimmerman 1966
29687	Skelton Ranch	17N	10E	33	AA02	Kootenai	Not Reported	Flow Recovery	Cooper-Jacobs	184	NA	Zimmerman 1966
None	Winnett # 1 & 2	14N	27E	6	DBD	Multiple Second Cat Third Cat	Sep-98	Pumping	Theis	16	8.80E-06	MBMG file data
895628	Ohio	16N	27E	26	BBBB	First Cat	Jun-97	Constant Head	Cooper-Jacobs	211	NA	MBMG file data
28493	Burt #2	16N	27E	25	BDD	Third Cat	Jun-97	Constant Head	Cooper-Jacobs	29	NA	MBMG file data
127844	Marcott	20N	26E	9	CDAB	Eagle	Not Reported	Constant Head	Cooper-Jacobs	19.9	1.1E-04	Reiten 1993
34882	Elevator Ridge	21N	24E	26	CCBC	Eagle	Not Reported	Constant Head	Cooper-Jacobs	76	1.9E-05	Reiten 1993
132077	Haines Ridge	21N	24E	26	CACA	Eagle	Not Reported	Constant Head	Cooper-Jacobs	73	1.4E-04	Reiten 1993
27255	Solf 7 & 8	15N	28E	34	CDCD	Eagle	Sep-97	Constant Head	Cooper-Jacobs	570	4.0E-05	MBMG file data

Ground-Water Flow

Ground-water flow is generally from the west to the east across the Gooseneck Creek area. Figure 30 is a map of the potentiometric surface based on water levels measured on December 2008 for most wells and estimates of water-level measurements based on inventoried or reported water levels from a few of the outlying wells. Ground water flows from the ground-water divide located within ¼ mile of the Hailstone Basin rimrocks to the west and discharges to springs, wells, and ultimately Gooseneck Creek. A ground-water divide coincides with a watershed divide about 1 mile east of Gooseneck Creek. East of this divide ground water flows generally towards the east. The existing Broadview municipal wells are probably along this regional flow path. West of this divide ground water flows towards Gooseneck Creek. South of Gooseneck Creek ground-water flow is continuous from the west to the east flowing past the southern extent of the ground-water divide. Recharge to the aquifer is from infiltration of snowmelt and rainfall. The recharge area extends from the ground-water divide near the east rim of Hailstone Basin to approximately the ½ mile west of Church road in the Gooseneck Creek area (figs. 30 and 31).

Water Quality

The sample collected at BVIEW1 near the end of the aquifer test indicated excellent water quality from this source (table 4). The TDS is 584 mg/L or about one-third the mineral concentration of Broadview's current supply. The water is dominated by ions of calcium and bicarbonate, indicating a position relatively close to the recharge area. The SAR is 0.77, which makes the water excellent for lawns, plants, and trees. Nitrates were not detected at this location, indicating little or no negative agricultural impacts. Iron (0.901 mg/L) and manganese (0.247 mg/L) were at moderate levels. The water is hard, with hardness as calcium carbonate at 440.9 mg/L. All trace elements tested were better than the water quality standards.

Similar water quality was found in most nearby Eagle wells (table 2). The dissolved minerals in the Eagle aquifer increased slightly to the east. For example, the SC in the Jones stock well (188462) was 1790 µ/cm. There is a potential for more mineralized water at sites approaching the discharge area (Gooseneck Creek).

Table 6 compares the redox measurements (ORP) with several other constituents from water samples in the Gooseneck Creek area. There appear to be both positive and negative relationships between ORP and constituents of concern for a municipal water supply. Strongly negative ORP readings are associated with low nitrates and moderately high iron and manganese concentrations. Moderately high nitrate concentrations appear to be associated with water under highly oxidized conditions. While moderately high iron and manganese concentrations may require some treatment, these are aesthetic concerns and are generally easily and inexpensively treated at the observed concentrations. In contrast, nitrates are a public health concern; the levels observed are approaching the public health standard of 10 mg/L and are high enough to trigger additional sampling at a municipal water supply. The other constituents shown in table 6 are all well below levels of concern, but do indicate association of several constituents with ORP. The high ORP values in the Gooseneck Creek area are closer to the recharge areas where the water is more oxidized. Higher nitrate concentrations should be anticipated in these areas than farther down the flow path where strongly negative ORPs are more likely to be found in the water.

Water-Supply Development

The aquifer tests at BVIEW1 and BVIEW4 indicate a sustained rate of about 60 gpm could be developed from wells near these sites. Regulatory constraints will probably require new wells be drilled at or near these locations. Any new wells should be test pumped to verify these predictions. Testing should include water-level monitoring at selected existing wells to document responses to long-term test pumping. Considering the relatively shallow depth of wells, additional test drilling would be a relatively inexpensive method to define the extent of the aquifer and monitor response to pumping. Figures 32 through 34 are long-term projections of drawdown from the aquifer tests. Projected drawdown at the BVIEW1 production well predicts about 40 ft of

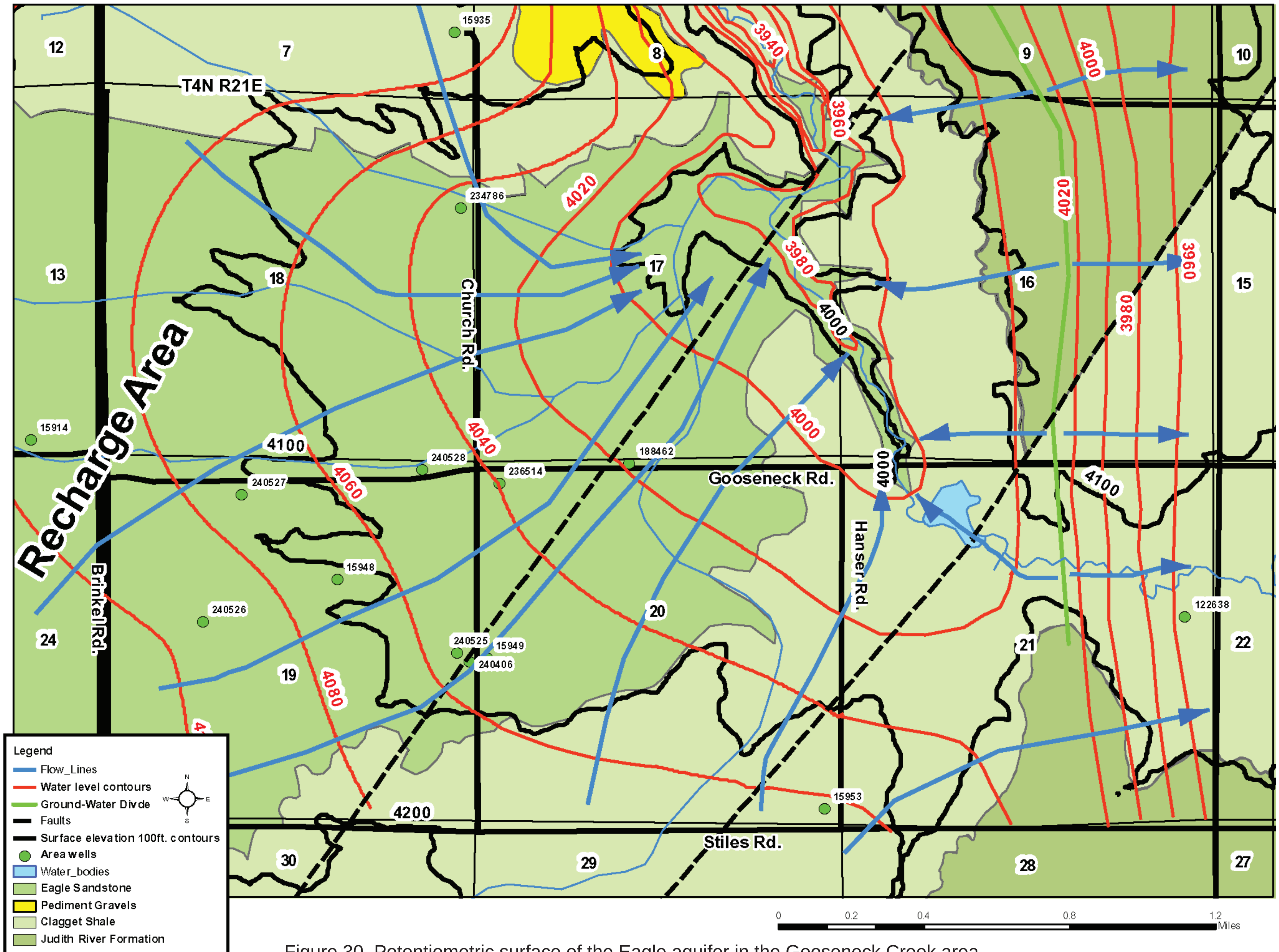


Figure 30. Potentiometric surface of the Eagle aquifer in the Gooseneck Creek area.

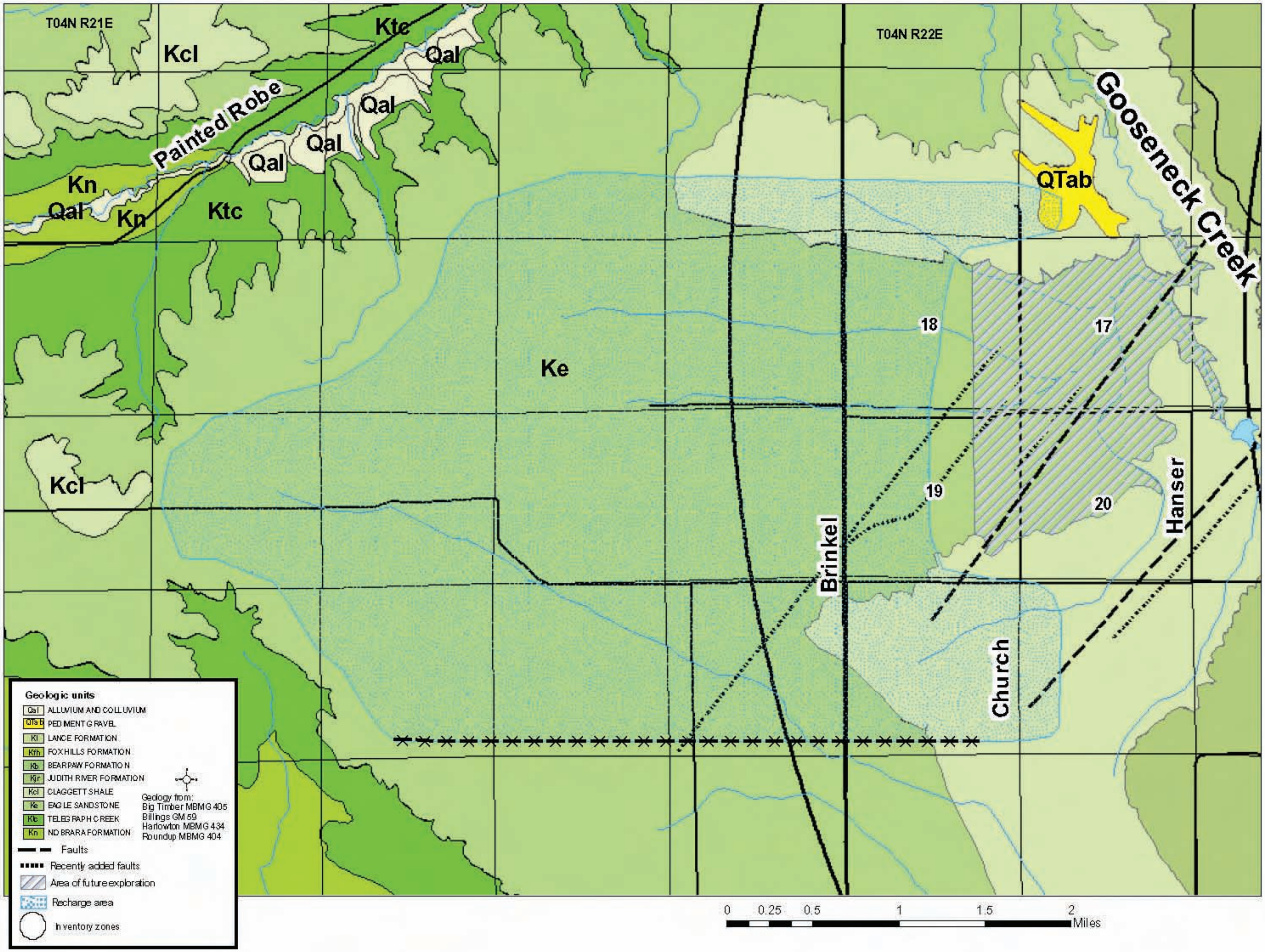


Figure 31. Exploration map identifying possible locations suitable for constructing wells for the town of Broadview.

Table 6. Field redox (ORP) measured in several samples from the Gooseneck Creek area show significant relationships (both positive and negative) between ORP and constituents of concern for municipal water systems.

Site_ID	Sample #	Sample date	Total Dissolved Solids (mg/L):	Lab pH:	Water Temp (°C):	Field Dissolved O2 (mg/L):	Field Redox (mV):	Iron	Manganese	Nitrate
15948	2008Q0098	8/20/2007	482	6.87	16.5	17.77	99.6	<0.005	<0.001	7.31 P
236514	2008Q0099	8/21/2007	689	7.1	11.6	0.37	-176.3	0.742	0.275	<0.25 P
234786	2008Q0097	8/20/2007	471	6.84	16.9	4.5	55.2	<0.005	<0.001	7.00 P
15949	2008Q0161	9/7/2007	562	7.35	10.11	4.08	-53	0.287	0.266	<0.5 P
240406	2008Q0331	12/13/2007	584.08	7.05	9.7	3.26	-48.3	0.901	0.247	<0.10 P

Site_ID	Sample #	Sample date	Arsenic	Barium	Boron	Copper	Lithium	Molybdenum	Selenium	Uranium
15948	2008Q0098	8/20/2007	0.305	39	75.6	3.87	24	1.81	3.69	4.23
236514	2008Q0099	8/21/2007	0.596	9.86	143	<0.2	57.7	<1.0	<0.5	0.388
234786	2008Q0097	8/20/2007	0.347	37.8	75.5	5.93	25.8	1.28	2.97	3.96
15949	2008Q0161	9/7/2007	0.632	17.5	190	<0.2	49.1	<1.0	1.71	<0.05
240406	2008Q0331	12/13/2007	<0.2	14.7	145	<0.2	62.3	<1.0	<0.5	<0.05

drawdown after 1 year of continuous pumping at 45 gpm (fig. 32) for a total of 23.6 million gallons (72.4 acre ft). This amount of drawdown will drop the water level to just below the confining layer. Reducing the pumping rate or the pumping duration will prevent the water level from dropping to this level. As the result of pumping BVIEW1 for 1 year at 45 gpm, the water levels in the Cemetery well and BVIEW1A are projected to be several feet above the top of the aquifer.

The hydrogeologic conditions in much of the eastern ¼ of Sections 18 and 19 and parts of Sections 17 and 20, T. 4 N., R. 22 E., indicate good potential for developing a municipal water supply (fig. 31). The cross-hatched area in figure 31 indicates good potential for developing additional wells in the Eagle aquifer. Eagle Sandstone is at the surface in this area and the hydrogeologic information collected and interpreted during this project strongly indicates productive aquifer materials underlie this area. The land over most of the recharge area is currently in CRP and it is unlikely that major land-use changes will occur in the future. Essentially this land is in native condition, and while it may be occasionally cut for hay production, little or no fertilizer or other agricultural chemicals have been applied. As a result, contamination from surface sources or agricultural practices is unlikely. The productive aquifer zones should be penetrated by wells less than 100 ft deep. Several additional faults were mapped as the result of new geologic mapping (Lopez, personal communication). Targeting exploration towards the faulted areas has a good potential for more productive wells because of the potential for increased aquifer storage. Significant changes in water quality are possible over this area. Based on the potentiometric map and regional gradients, ground water flows from recharge areas in the west towards Gooseneck Creek. In general, the dissolved-mineral concentration in the aquifer is likely to increase towards the east. It is unlikely that dissolved-mineral concentrations would reach problem levels over this entire area. The nitrate concentrations are likely to be higher in areas closer to the recharge areas that have high positive redox potential (>30). These areas appear to be restricted to the northwestern part of the cross-hatched area. Identifying areas of the aquifer with negative ORP measurements is likely to ensure low nitrate concentrations. Future development should include monitoring potential impacts to existing wells in the area. This could be accomplished by drilling wells to use as monitoring points during future aquifer-response tests and by incorporating existing wells. The faulted rocks in this area appear to significantly affect the spread of drawdown cones around producing wells. It appears that these impacts tend to increase aquifer storage and reduce well interference impacts. Historic water-level trends from stock wells located in T. 3 N., R. 22 E., sec. 6 ABAB (176921) and T. 4 N., R. 22 E., sec. 31BCCC (192041) are shown in figure 35. These wells both show a strong recovery from a multiyear drought during the early 2000s. In addition, well 176921 supplies a feedlot and several outlying stock tanks. It is reported to produce over 100 gpm and has not shown any significant drop in water-levels due to pumping.

Based on the available data compiled, collected, and interpreted as part of this project, the potential for

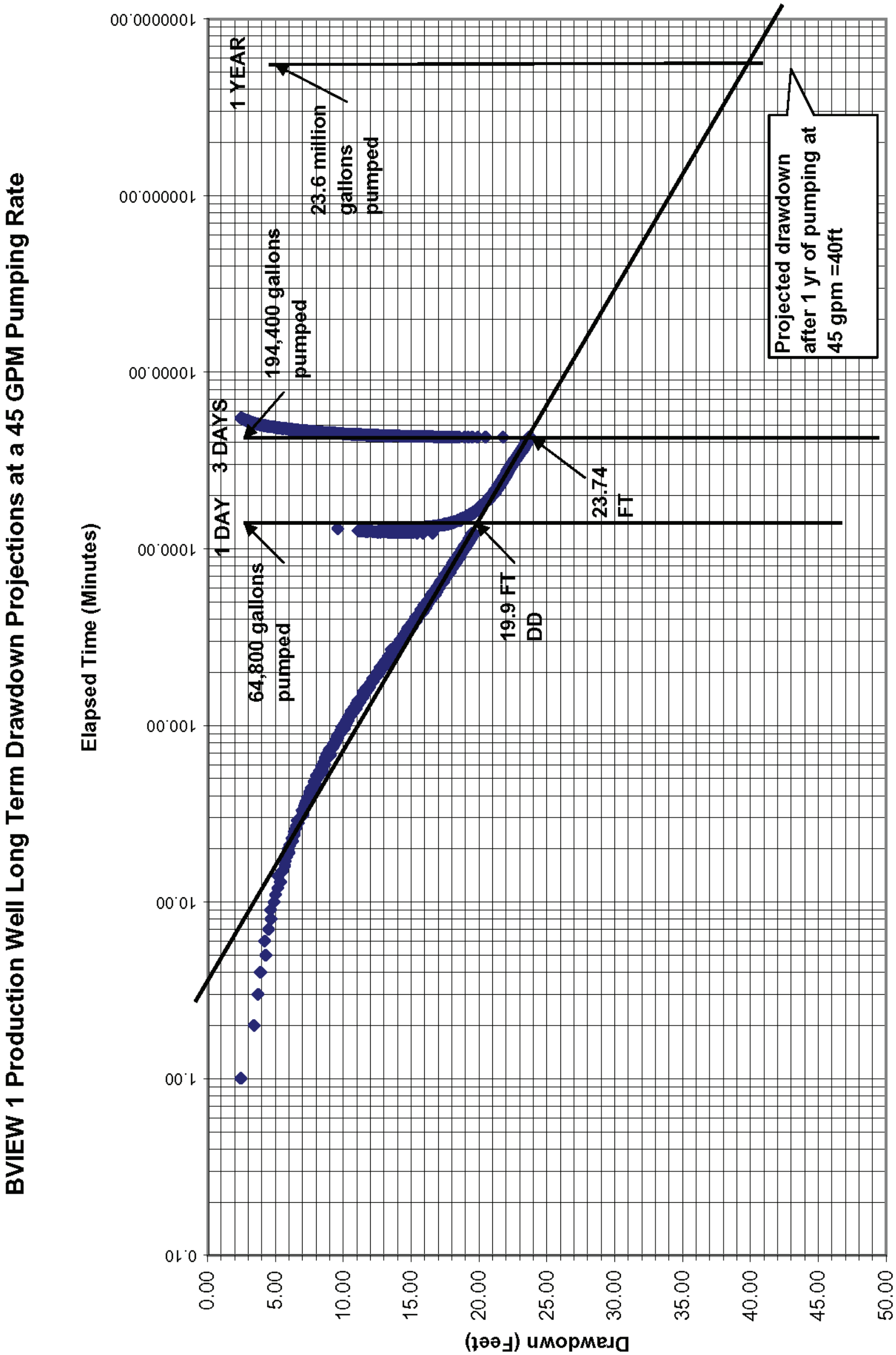


Figure 32. Projected drawdown at the BVIEW1 well resulting from pumping continuously for 1 year at BVIEW1.

developing a municipal water supply in the Gooseneck Creek area appears very good. There appears to be an adequate source of ground water that is fresher by a factor of three than the current Broadview water supply. Aquifer-response test results indicate impacts to existing water supplies are likely to be insignificant. There is very little potential for contaminants to directly impact new water supplies because of the confined nature of the aquifer and existing land uses. The best site identified is BVIEW1, with the potential to produce 40–45 gpm for extended periods of time. The BVIEW4 site has good potential for producing up to 15 gpm. Production wells located near these sites should produce similar quantities of water. Exploration should target the stratigraphic horizon shown to be very productive. The sandstone in this zone contains well-sorted fine- to medium-grained sand and produces large volumes of water easily detectable when drilled using the air-rotary method. Only the productive aquifer zones should be screened and aquifer-response tests should be conducted to determine potential productivity and interference to existing wells. Field testing of field parameters including redox and nitrates should be conducted at all new wells to reduce the risk of producing high nitrate water. Developing this water supply will require a 7- to 8-mile long pipeline to reach Broadview. However, the combination of high quality and adequate quantity makes a far better water supply than any other source identified closer to town.

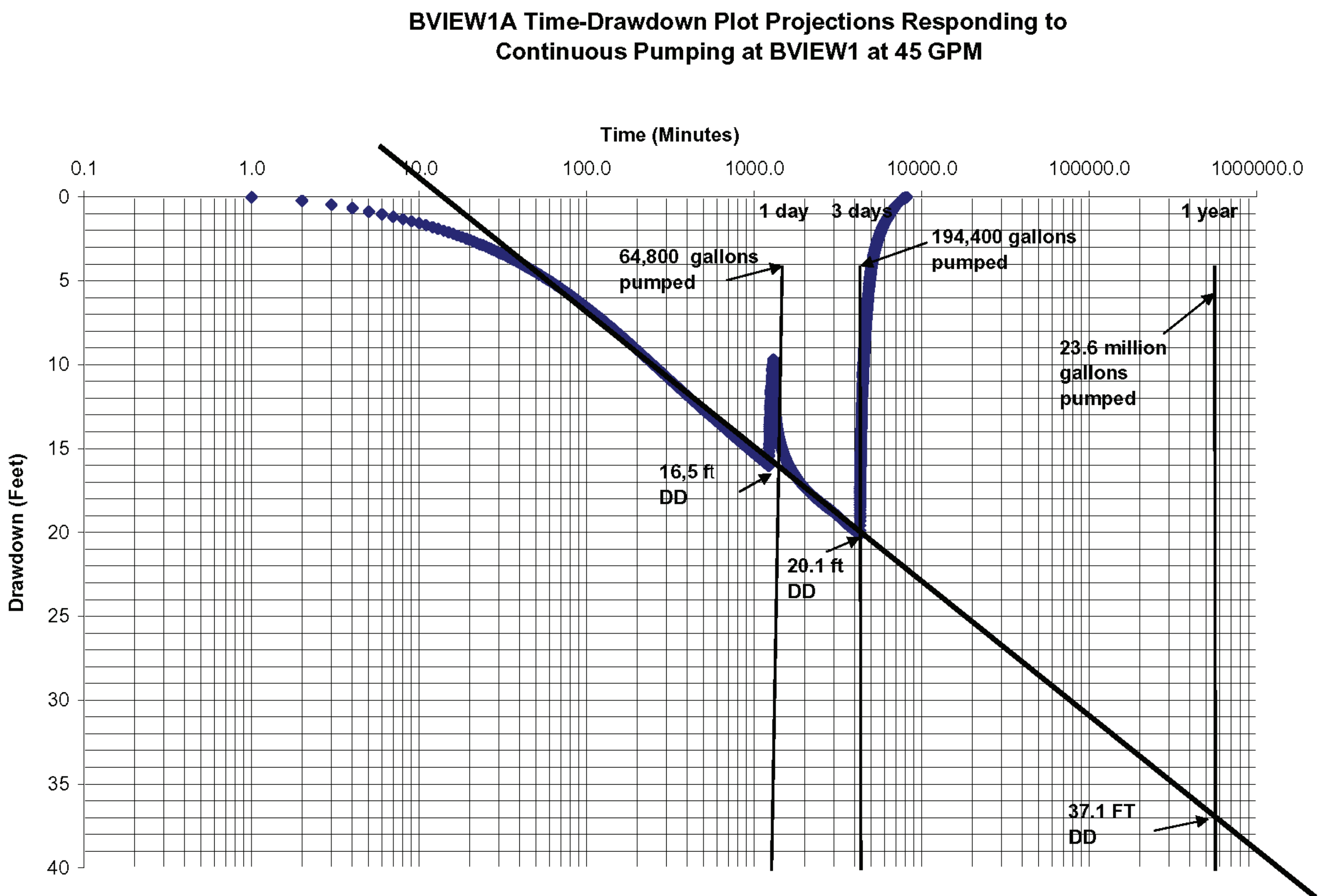


Figure 33. Projected drawdown at the BVIEW1A well resulting from pumping continuously for 1 year at BVIEW1.

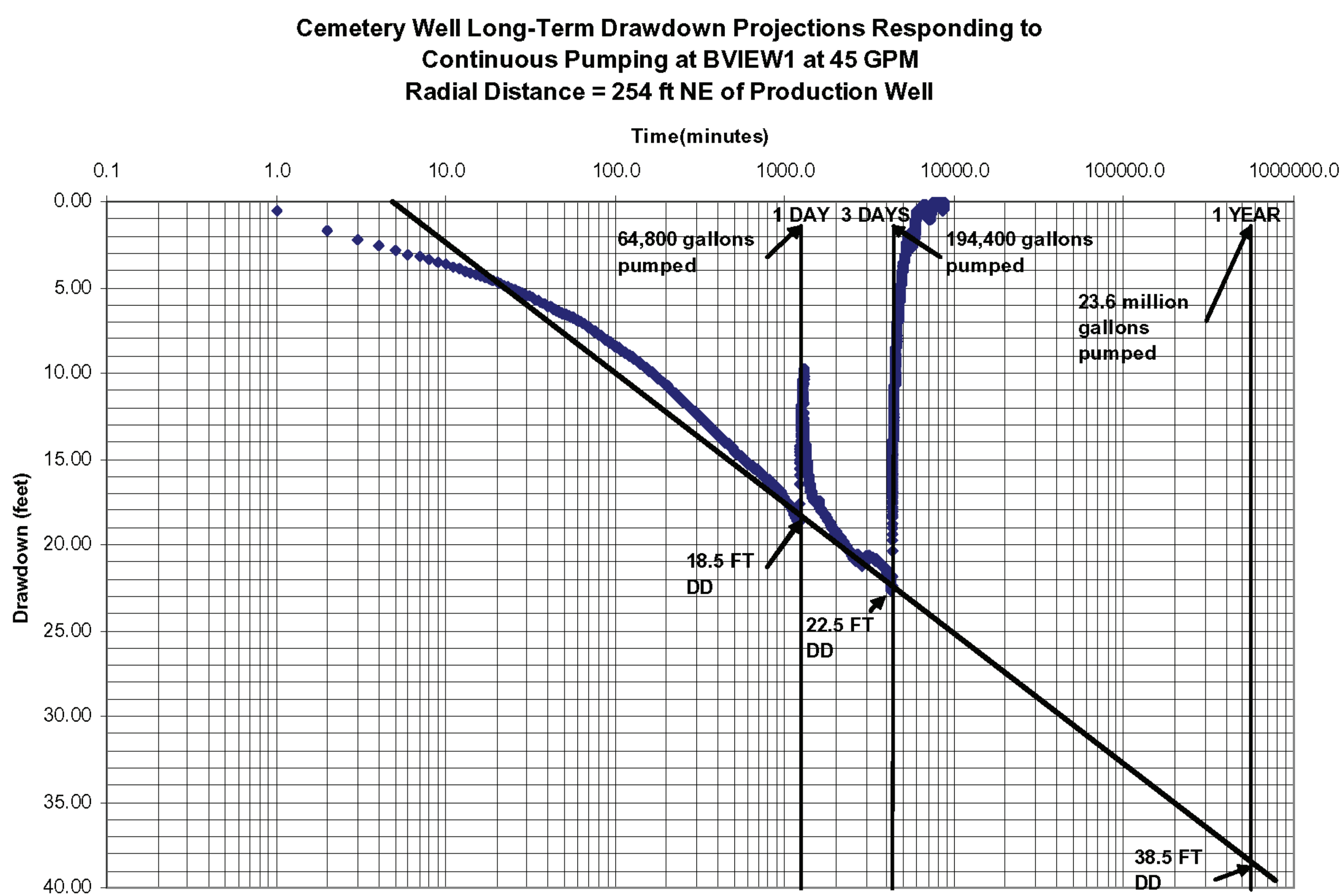
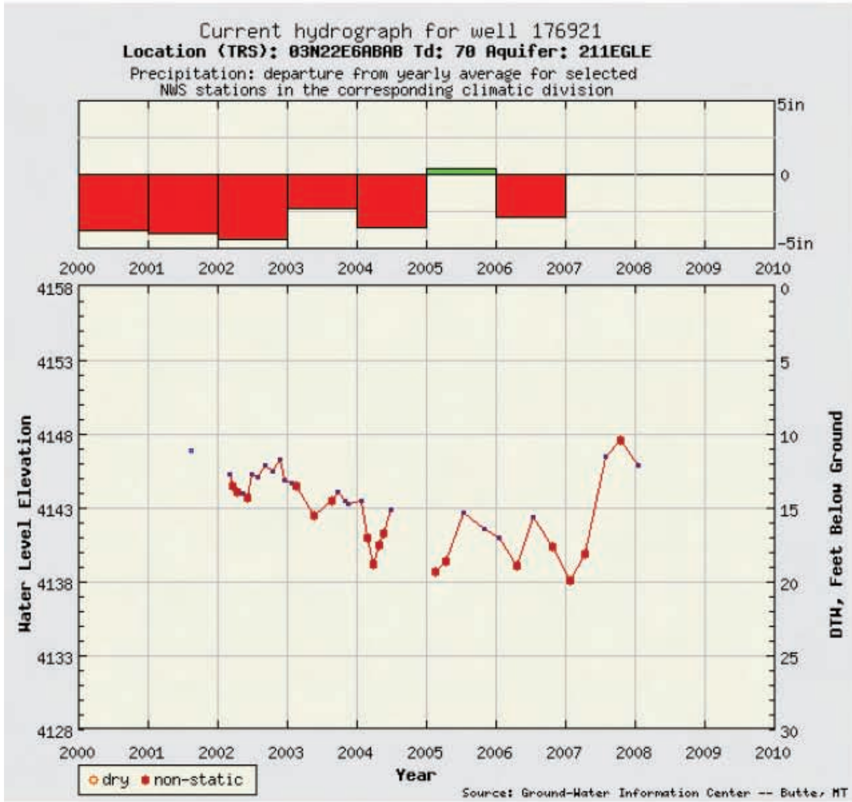


Figure 34. Projected drawdown at the Cemetery well resulting from pumping continuously for 1 year at BVIEW1.



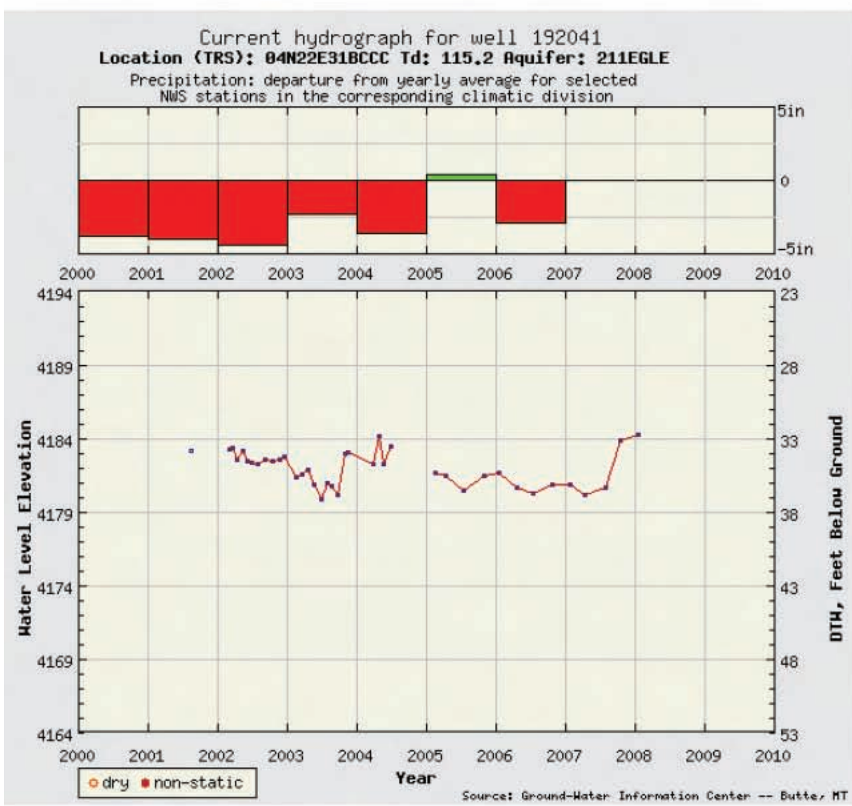


Figure 35. Historical water-level fluctuations at two Eagle aquifer wells located southwest of the Gooseneck Creek area.

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APPENDICES

Site Name: CITY OF BROADVIEW-BVIEW1
GWIC Id: 240406

Section 1: Well Owner

Owner Name
N/A

Section 2: Location

Township	Range	Section	Quarter Sections
04N	22E	19	NE¼ NE¼ NE¼ SE¼

County	Geocode
STILLWATER	

Latitude	Longitude	Geomethod	Datum
46.083336	109.03075	NAV-GPS	NAD83

Altitude	Method	Datum	Date
4076	MAP	NAD83	1/14/2008

Addition	Block	Lot

Section 3: Proposed Use of Water
TEST WELL (1)

Section 4: Type of Work
Drilling Method: AIR ROTARY

Section 5: Well Completion Date
Date well completed: Thursday, November 15, 2007

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	18	7.875
18	80	5.875

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	18	6	0.25			STEEL
12	50	4.5			SPLINE	PVC-SCHED 40

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
50	80	4.5		.020	SCREEN-CONTINUOUS-PVC

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	18	BENTONITE GROUT	Y

Section 7: Well Test Data

Total Depth: 80
Static Water Level: 23.75
Water Temperature: 13.6

Air Test *

120 gpm with drill stem set at 80 feet for 0.5 hours.
Time of recovery 0.5 hours.
Recovery water level 23.75 feet.
Pumping water level _ feet.

Pump Test *

Depth pump set for test 50 feet.
45 gpm pump rate with 23.74 feet of drawdown after 71.33 hours of pumping.
Time of recovery 72 hours.
Recovery water level 23.75 feet.
Pumping water level 47.49 feet.

* *During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log
Geologic Source

211EGLE - EAGLE SANDSTONE

From	To	Description
0	5	SAND, LIGHT YELLOWISH BROWN,VERY FINE TO FINE GRAINED, NONCALCAREOUS, LOOSE,SOFT, WEATHERED EAGLE SS
5	26	SANDSTONE, LIGHT YELLOWISH BROWN, VERY FINE TO FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING,COMPETANT, MODERATELY HARD, CEMENTED, NONCALCAREOUS
26	32	SANDSTONE, LIGHT GRAY, VERY FINE TO FINE GRAINED,

		HARD, COMPETANT,CEMENTED, CALACAREOUS
32	39	SANDSTONE, GRAY, VERY FINE TO FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING, COMPETANT, CEMENTED,CALCAREOUS, DAMP
39	40	SHALE, BLACK, HARD, CARBONIFEROUS, INJECTED WATER TO CLEAR CUTTINGS
40	60	SANDSTONE, GRAY, VERY FINE TO FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING, COMPETANT, CEMENTED, CALACAREOUS, MAKING A SMALL AMOUNT OF WATER AT 46 FT., OILY CUTTINGS AT 50 FT, MAKING 4 GPM WITH AIRLINE SET AT 60 FT. FIELD PARAMETERS: SC=1146,TEMP=13.6,DO=11.69MG/LPH=7.8,NITRATE=0,NITRITE=0
60	62	SANDSTONE,GRAY, VERY FINE TO FINE GRAINED, WELL CEMENTED, CALCAREOUS, VERY HARD, AQUITARD, CAPROCK
62	75	SANDSTONE,GRAY, LIGHT GRAY AND BLACK, FINE TO MEDIUM GRAINED, WELL SORTED, ROUNDED, 70% QUARTZ, 20% LITHICS, 5% COAL, MINOR GLAUCONITE,THIN COAL AT 66 FT., NONCALCAREOUS, CEMENTED, HIGH POROSITY, SALT AND PEPPER SS, MAKES ALOT OF WATER, PRODUCTION IS ESTIMATED AT 120 + GPM, FIELD PARAMETERS:SC=910, TEMP=9.5 C, DO=11.41MG/L, PH=7.70, NITRATES=0,NITRITES=0
75	80	SANDSTONE, GRAY, VERY FINE GRAINED, SUBANGULAR, POOR SORTING, RATTY, INTERBEDDED WITH BLACK SHALE, CARBONACEOUS,OILY, REDDISH TINT , LOWER AQUITARD

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:	AL HICKS
Company:	ADT/PRO PUMP
License No:	WWC-508
Date Completed:	11/15/2007

Site Name: CITY OF BROADVIEW-BVIEW1A
GWIC Id: 240525

Section 1: Well Owner

Owner Name		
STILES, ALBERT		
Mailing Address		
CHURCH ROAD		
City	**State**	**Zip Code**
BROADVIEW	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
04N	22E	19	NE¼ NE¼ NE¼ SE¼

County	Geocode
STILLWATER	

Latitude	Longitude	Geomethod	Datum
46.083694	109.031444	NAV-GPS	NAD83

Altitude	Method	Datum	Date
4079	MAP	NAD83	1/14/2008

Addition	Block	Lot

Section 3: Proposed Use of Water
TEST WELL (1)

Section 4: Type of Work
Drilling Method: AIR ROTARY

Section 5: Well Completion Date
Date well completed: Friday, November 16, 2007

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	18	7.875

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	18	6	0.25			STEEL

Completion (Perf/Screen)

From	To	Diameter	# of	Size of	Description

			Openings	Openings	
50	80	4		.020	SCREEN-CONTINUOUS-PVC

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	18	BENTONITE GROUT	Y

Section 7: Well Test Data

Total Depth: 80
Static Water Level: 19.4
Water Temperature: 9.7

Air Test *

1 gpm with drill stem set at 63 feet for 0.5 hours.
Time of recovery 0.5 hours.
Recovery water level 19.4 feet.
Pumping water level _ feet.

Air Test *

60 gpm with drill stem set at 80 feet for 0.5 hours.
Time of recovery 0.5 hours.
Recovery water level 19.4 feet.
Pumping water level _ feet.

* *During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

Section 9: Well Log
Geologic Source

211EGLE - EAGLE SANDSTONE

From	To	Description
0	9	SAND, LIGHT YELLOWISH BROWN,VERY FINE TO FINE GRAINED, NONCALCAREOUS, LOOSE,SOFT, WEATHERED EAGLE SS
9	12	SANDSTONE, LIGHT YELLOWISH BROWN, VERY FINE GRAINED, COMPETANT, MODERATELY HARD, CEMENTED, NONCALCAREOUS, SLIGHTLY WEATHERED EAGLE SS

12	25	SANDSTONE, LIGHT YELLOWISH BROWN TO LIGHT BROWNISH GRAY, VERY FINE TO FINE GRAINED,SUBANGULAR TO SUBROUNDED, POOR TO MODERATE SORTING, MODERATELY HARD, CEMENTED, NONCALCAREOUS
25	26	SANDSTONE, LIGHT GRAY, VERY FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING, VERY HARD, CEMENTED, CALCAREOUS, CAPROCK
26	27	SANDSTONE, YELLOWISH BROWN, FINE, MODERATELY HARD, COMPETENT, NONCALCAREOUS
27	28.5	SANDSTONE, LIGHT GRAY, VERY FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING, HARD, COMPETANT,CEMENTED, CALACAREOUS, CAPROCK
28.5	30	SANDSTONE, YELLOWISH BROWN, FINE, MODERATELY HARD, COMPETANT, NONCALCAREOUS
30	32	SANDSTONE, GRAY, VERY FINE TO FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING, COMPETANT, CEMENTED,CALCAREOUS, HARD
32	32.5	SHALE, VERY DARK GRAY, SILTY,CARBONACEOUS, OILY
32.5	38	SANDSTONE, GRAY, FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING, COMPETANT, MODERATELY HARD, NONCALCAREOUS
38	58	SANDSTONE, GRAY,,VERY FINE GRAINED, SILTY, SUBROUNDED, POOR SORTING,SHALEY, MODERATELY, HARD, OILY, RATTY, NONCALCAREOUS
58	63	SANDSTONE, GRAY, VERY FINE TO FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING, COMPETANT, CEMENTED,CALCAREOUS, WET, MAKING 1 GPM WITH AIRLINE SET AT 63 FT, FIELD PARAMETERS: TEMP=13C,SC=1118,PH=7.95, NITRATE=0,NITRITE=0
63	64	SANDSTONE,GRAY, VERY FINE TO FINE GRAINED, WELL CEMENTED, CALCAREOUS, VERY HARD, AQUITARD, CAPROCK
64	75	SANDSTONE, LIGHT GRAY, FINE TO MEDIUM GRAINED, WELL SORTED, WELL ROUNDED, 70$ QTZ, 20% LITHICS, 5% COAL, MINOR GLAUCONITEMAKING 70 GPM WITH AIRLINE SET AT 80 FT,FIELD PARAMETERS: TEMP=9.7C,SC=932,DO=11.55,ORP=-30.4
75	80	SANDSTONE, GRAY, VERY FINE GRAINED, SILTY, SUBANGULAR, POOR SORTING, RATTY, INTERBEDDED WITH BLACK SHALE, CARBONACEOUS,OILY, REDDISH TINT , BENTONITE LAYER AT 75 FT., LOWER AQUITARD

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:	AL HICKS
Company:	ADT/PRO PUMP
License No:	MWC-508
Date Completed:	11/16/2007

Site Name: CITY OF BROADVIEW-BVIEW2
GWIC Id: 240526

Section 1: Well Owner

Owner Name		
STILES, ALBERT		
Mailing Address		
CHURCH ROAD		
City	**State**	**Zip Code**
BROADVIEW	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
04N	22E	19	NE¼ SE¼ SW¼ NW¼

County	Geocode
STILLWATER	

Latitude	Longitude	Geomethod	Datum
46.085	109.046022	MAP	NAD83

Altitude	Method	Datum	Date
4125	DEM	NAD83	1/14/2008

Addition	Block	Lot

Section 3: Proposed Use of Water
TEST WELL (1)

Section 4: Type of Work
Drilling Method: AIR ROTARY

Section 5: Well Completion Date
Date well completed: Monday, December 03, 2007

Section 6: Well Construction Details
Borehole dimensions

From	To	Diameter
0	18	7.875
18	200	5.875

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
-2	18	6	0.25			STEEL

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
18	200	5.875			OPEN HOLE

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	18	BENTONITE GROUT	Y

Section 7: Well Test Data

Total Depth: 200
Static Water Level: 22.4
Water Temperature: 11.5

Air Test *

3 gpm with drill stem set at 120 feet for 0.5 hours.
Time of recovery 0.5 hours.
Recovery water level 22.4 feet.
Pumping water level _ feet.

Air Test *

4 gpm with drill stem set at 180 feet for 0.5 hours.
Time of recovery 0.5 hours.
Recovery water level 22.4 feet.
Pumping water level _ feet.

Air Test *

4.5 gpm with drill stem set at 200 feet for 0.5 hours.
Time of recovery 0.5 hours.
Recovery water level 22.4 feet.
Pumping water level _ feet.

* *During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

WELL WAS PLUGGED AND ABANDONED ON 12/17/07. CASING WAS FILLED W/ 3/8" CHIPS TO 3' BELOW GROUND, CUT CASING TO 3' BELOW GROUND AND BACKFILLED UPPER 3 FEET WITH NATIVE SOIL .

Table 2. Water-quality data from Eagle aquifer water samples in the Gooseneck Creek area.

MAJOR IONS (mg/L)

Site_ID	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Silica	Bicarbonate	Chloride	Sulfate	Nitrate	Fluoride	Ortho-phosphate
15948	86.6	42.8	27.7	2.79	<0.005	<0.001	10.8	286.7	5.97	162	7.31 P	0.747	<0.10
236514	110	54.1	36.7	3.54	0.742	0.275	14.2	322.9	6.95	302	<0.25 P	0.675	<0.25
234786	84.6	41.9	28.4	2.55	<0.005	<0.001	11.4	317.5	5.19	140	7.00 P	0.687	<0.05
15949	89	44.1	37.6	2.97	0.287	0.266	16.3	371.8	6.52	181	<0.5 P	0.612	<0.10

TRACE METALS (µg/L)

	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Bromide	Cadmium	Chromium	Cobalt	Copper	Lead
15948	<2.0	<0.1	0.305	39	<0.1	75.6	<100	<0.1	<0.1	0.103	3.87	<0.2
236514	<2.0	<0.1	0.596	9.86	<0.1	143	<50	<0.1	<0.1	0.319	<0.2	<0.2
234786	<2.0	<0.1	0.347	37.8	<0.1	75.5	<50	<0.1	<0.1	<0.1	5.93	<0.2
15949	<2.0	<0.1	0.632	17.5	<0.1	190	<100	<0.1	<0.5	0.121	<0.2	<0.2

	Lithium	Nickel	Molybdenum	Silver	Selenium	Strontium	Titanium	Thallium	Uranium	Vanadium	Zinc	Zirconium
15948	24	<1.0	1.81	<0.5	3.69	717	1.69	<0.1	4.23	<0.1	28.9	<0.1
236514	57.7	<1.0	<1.0	<0.5	<0.5	2,555	1.4	<0.1	0.388	<0.1	47.7	<0.1
234786	25.8	<1.0	1.28	<0.5	2.97	755	1.19	<0.1	3.96	<0.1	11.9	<0.1
15949	49.1	<0.1	<1.0	<1.0	1.71	2,286	<1.0	<0.1	<0.05	<0.1	3.13	<0.1

OTHER PARAMETERS

	Total Dissolved Solids (mg/L):	Sum of Diss. Constituents (mg/L):	Field Conductivity (µmhos):	Lab Conductivity (µmhos):	Field pH:	Lab pH:	Water Temp (°C):	Hardness as CaCO3:	Akalinity as CaCO3 (mg/L):	Ryznar Stability Index:
15948	482	627	8.67	827	7.49	6.87	16.5	392	235.39	7.411
236514	689	853	1076	1033	7.13	7.1	11.6	497	264.92	6.971
234786	471	633	849	839	7.47	6.84	16.9	384	260.81	7.373
15949	562	751	896	856	7.39	7.35	10.11	404	305.1	6.782

	Sample #	Sample date	Sodium Adsorption Ratio	Phosphate, TD (mg/L as P):	Langlier Saturation Index:	Field Dissolved O2 (mg/L):	Field Redox (mV):
15948	2008Q0098	8/20/2007	0.615	<0.05	-0.271	38.9	0.94
236514	2008Q0099	8/21/2007	0.722	0.113	0.065	0.37	-176.3
234786	2008Q0097	8/20/2007	0.622	<0.05	-0.266	4.5	55.2
15949	2008Q0161	9/7/2007	0.823	<0.03	0.284	4.08	-53

		WITH AIRLINE SET AT 120 FEET, FIELD PARAMETERS: TEMP-11.5C, SC=737,DO=11.24MG/L, PH=7.99, ORP=96.3,NITRATE=2MG/L, NITRITE=0
126	131	SANDSTONE,GRAY, VERY FINE TO FINE GRAINED,SUBANGULAR, POOR SORTING,COMPETANT, CLEANER THAN ABOVE, DRILLS SMOOTH

From	To	Description
131	147	SANDSTONE, GRAY, VERY FINE TO FINE,SUBANGULAR, POOR SORTING, SUBANGULAR, INTERBEDDED WITH BLACK, CARBONACEOUS SHALE AND CLAY, INTERSPERSED HARD (SANDSTONE) AND SOFT (SHALE/CLAY) LAYERS
147	175	SANDSTONE, LIGHT GRAY, FINE GRAINED, SUBROUNDED, CLEANER THAN ABOVE UNIT, PICKED UP A LITTLE MORE WATER WHEN AIRLIFTING AT 160 FT (YIELD = 4 GPM), HARD LAYERS AT 165 AND 168 FEET, FIELD PARAMETERSTEMP=11 C,SC=828,PH=8.0,ORP=28.1,DO=11.09MG/L,NITRATE=2,NITRITE=0
175	177	SANDSTONE, GRAY, VERY FINE, SUBANGULAR, POOR SORTING, INTERBEDDED WITH VERY DARK BROWNISH GRAY CLAY, HARD DRILLING
177	180	SHALE, BLACK, CARBONACEOUS, OILY, TELEGRAPH CREEK FORMATION
180	200	SHALE, BLACK, CARBONACEOUS, OILY, INTERBEDDED WITH SANDSTONE, GRAY, VERY FINE,WATER PRODUCTION WITH AIRLINE SET AT 200 FEET, YIELD=4.5 GPM, FIELD PARAMETERS:T=11.5 C,SC=1061, PH=8.10,DO=12.25MG/L,ORP=-5.5,NITRATE=2MG/L, NITRITE=0, WATER IS CASCADING FROM PRODUCTION ZONES NEAR THE BASE OF THE STEEL CASING TO THE WATER TABLE AT 22.4FT BELOW GROUND

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:	AL HICKS
Company:	ADT/PRO PUMP
License No:	WWC-508
Date Completed:	12/3/2007

Site Name: CITY OF BROADVIEW_BVIEW3
GWIC Id: 240527

Section 1: Well Owner

Owner Name		
STILES, BERT		
Mailing Address		
CHURCH ROAD		
City	**State**	**Zip Code**
BROADVIEW	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
04N	22E	19	SE¼ NW¼ NE¼ NW¼

County	Geocode
STILLWATER	

Latitude	Longitude	Geomethod	Datum
46.090083	109.043722	NAV-GPS	NAD83
Altitude	**Method**	**Datum**	**Date**
4127	DEM	NAD83	1/14/2008

Addition	Block	Lot

Section 3: Proposed Use of Water
TEST WELL (1)

Section 4: Type of Work
Drilling Method: AIRROTARY

Section 5: Well Completion Date
Date well completed: Monday, December 03, 2007

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	18	7.875
18	100	5.875

Casing

From	To	Diameter	Wall	Pressure	Joint	Type

0	18	6	0.25			STEEL

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
18	100	5.875			OPEN HOLE

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	18	BENTONITE GROUT	Y

Section 7: Well Test Data

Total Depth: 100
Static Water Level: 52.54
Water Temperature: 14.5

Air Test *

_ gpm with drill stem set at 100 feet for 0.5 hours.
Time of recovery 0.5 hours.
Recovery water level 52.54 feet.
Pumping water level _ feet.

* *During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

WELL IS COMPLETED IN THE EAGLE SANDSTONE AS AN OPEN HOLE COMPLETION. SURFACE CASING ONLY.

Section 9: Well Log

Geologic Source

211EGLE - EAGLE SANDSTONE

From	To	Description
0	6	SAND, LIGHT YELLOWISH BROWN,VERY FINE TO FINE GRAINED, NONCALCAREOUS, LOOSE,SOFT, WEATHERED EAGLE SS
6	28	SANDSTONE,YELLOWISH BROWN, VERY FINE TO FINE GRAINED, SUBROUNDED, MODERATE SORTINGSOFT, COMPETANT, NONCALCAREOUS,
28	31	SANDSTONE, LIGHT GRAY, VERY FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING, VERY HARD, CEMENTED, CALCAREOUS, CAPROCK

31	32	SANDSTONE, GRAY, VERY FINE TO FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING, COMPETANT, CEMENTED,CALCAREOUS
32	36	SANDSTONE, YELLOWISH BROWN, VERY FINE TO FINE GRAINED, SUBANGULAR, POOR SORTING, COMPETANT, NONCLACAREOUS,SOFT
36	37	SHALE, VERY DARK GRAY, SANDY,CARBONACEOUS, OILY
37	45	SANDSTONE,YELLOWISH BROWN, VERY FINE TO FINE GRAINED, SILTY, SOFT, COMPETANT, NONCALCAREOUS, CLEANER AT 39 FT
45	49	SANDSTONE, GRAY,,VERY FINE GRAINED, SILTY, SUBROUNDED, MODERATE SORTING, NONCALCAREOUS, DAMP
49	60	SANDSTONE,GRAY, VERYFINE TO FINE GRAINED,SUBROUNDED, MODERATE SORTING, FRACTURED, NONCALCAREOUS,, MORE WATER THAN ABOVE UNIT
60	61	SHALE, VERY DARK REDDISH BROWN TO BLACK, SILTY,CARBONACEOUS, OILY
61	62	SANDSTONE, GRAY, FINE TO MEDIUM GRAINED CLEAN, SUBROUNDED, MODRATE SORTING,COMPETANT,
62	63	SHALE, VERY DARK REDDISH BROWN TO BLACK, SILTY, CARBONACEOUS, OILY
63	65	SANDSTONE,GRAY,FINE GRAINED, SUBROUNDED, MODERATE SORTING, COMPETANT, CLEAN, WET
65	70	SHALE,VERY DARK GRAY TO BLACK, CARBONACEOUS, OILY
70	98	SANDSTONE,GRAY,VERY FINE TO FINE GRAINED, SUBANGULAR , POOR SORTING, SILTY, RATTY SAND, DAMP,CLAY BOOTING UP,STARTED INJECTING WATER AT 80 FT, OILY

From	To	Description
98	99	SANDSTONE, GRAY,VERY FINE TO FINE GRAINED, SUBANGULAR, POOR SORTING,HARD, WELL CEMENTED, WITH VERY THIN LAYERS OF CARBONACEOUS SHALE
99	100	SANDSTONE, GRAY, VERY FINE GRAINED, SILTY, SUBANGULAR, POOR SORTING, RATTY, INTERBEDDED WITH BLACK SHALE, CARBONACEOUS,OILY

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

Name:	AL HICKS
Company:	ADT/PRO PUMP
License No:	WWC-508
Date Completed:	12/3/2007

Site Name: CITY OF BROADVIEW-BVIEW4
GWIC Id: 240528

Section 1: Well Owner

Owner Name		
STILES, ALBERT		
Mailing Address		
CHURCH ROAD		
City	**State**	**Zip Code**
BROADVIEW	MT	

Section 2: Location

Township	Range	Section	Quarter Sections
04N	22E	19	NW¼ NE¼ NE¼ NE¼

County	Geocode
STILLWATER	

Latitude	Longitude	Geomethod	Datum
46.091017	109.033371	NAV-GPS	NAD83

Altitude	Method	Datum	Date
4063	DEM	NAD83	1/14/2008

Addition	Block	Lot

Section 3: Proposed Use of Water
TEST WELL (1)

Section 4: Type of Work
Drilling Method: AIR ROTARY

Section 5: Well Completion Date
Date well completed: Tuesday, December 04, 2007

Section 6: Well Construction Details

Borehole dimensions

From	To	Diameter
0	18	7.875
18	50	5.875

Casing

From	To	Diameter	Wall Thickness	Pressure Rating	Joint	Type
0	18	6	0.25			STEEL
5	20	4			SPLINE	PVC-SCHED 40

Completion (Perf/Screen)

From	To	Diameter	# of Openings	Size of Openings	Description
20	50	4		.020	SCREEN-CONTINUOUS-PVC

Annular Space (Seal/Grout/Packer)

From	To	Description	Cont. Fed?
0	18	BENTONITE GROUT	Y

Section 7: Well Test Data

Total Depth: 50
Static Water Level: 11.66
Water Temperature: 9.9

Air Test *

30 gpm with drill stem set at 50 feet for 0.5 hours.
Time of recovery 0.5 hours.
Recovery water level 11.66 feet.
Pumping water level _ feet.

* *During the well test the discharge rate shall be as uniform as possible. This rate may or may not be the sustainable yield of the well. Sustainable yield does not include the reservoir of the well casing.*

Section 8: Remarks

WELL IS COMPLETED AS A 4-INCH PVC CASED WELL IN THE EAGLE FORMATION.

Section 9: Well Log

Geologic Source

211EGLE - EAGLE SANDSTONE

From	To	Description
0	9	SAND, LIGHT BROWN,VERY FINE TO FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING,MIXTURE OF WINDBLOWN SAND, COLLUVIUM, AND WEATHERED EAGLE SANDSTONE

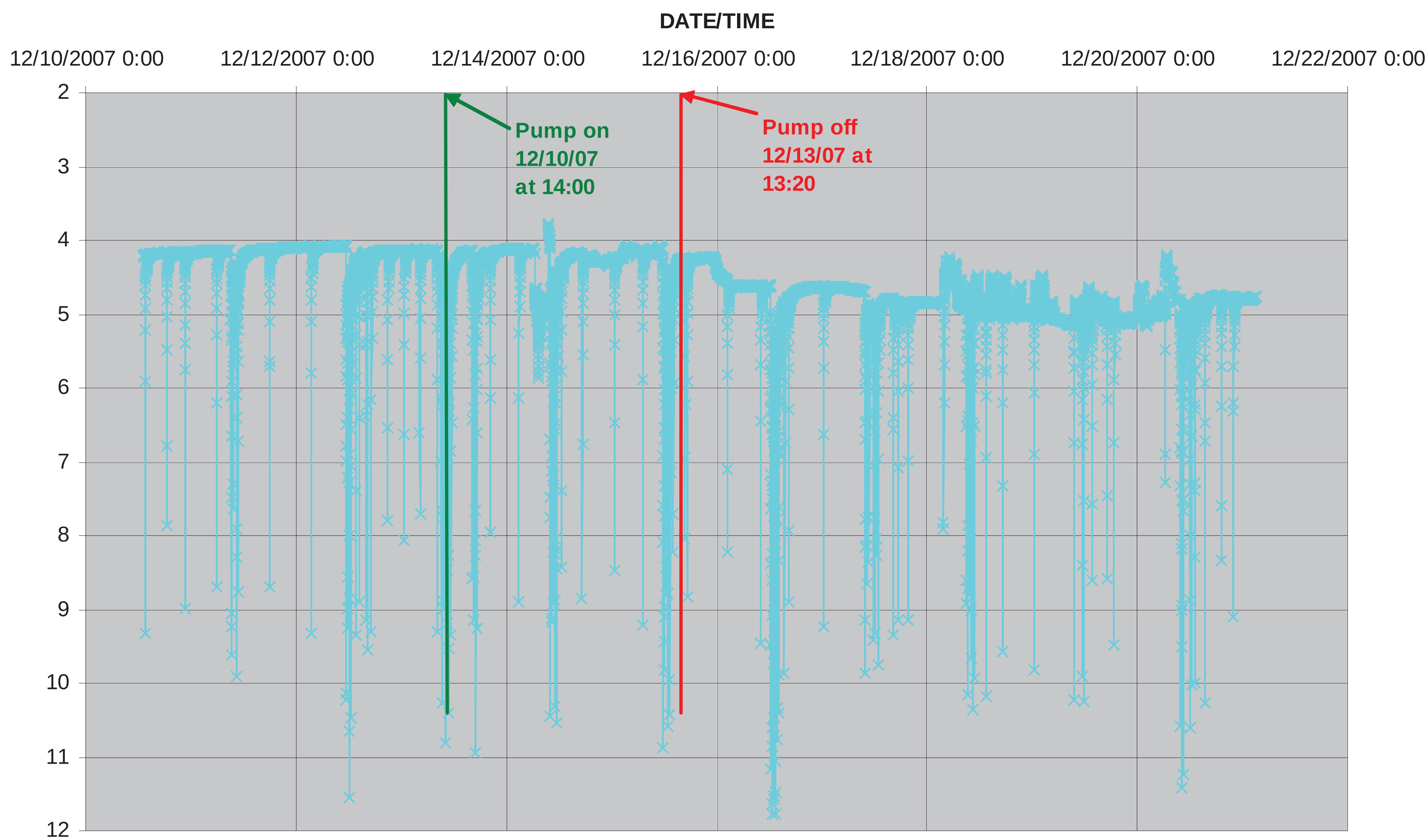
9	17	SANDSTONE, LIGHT YELLOWISH BROWN,VERY FINE GRAINED, SUBANGULAR, POOR TO MODERATE SORTING, COMPETANT, SOFT
17	38	SANDSTONE, GRAY, VERY FINE TO FINE GRAINED, SILTY, SUBANGULAR, POOR TO MODERATE SORTING, COMPETANT, CEMENTED,CALCAREOUS, DAMP
38	45	SANDSTONE,GRAY, FINE TO MEDIUM GRAINED,WELL SORTED, ROUNDED, 75% QUARTZ, 25% LITHICS, MINOR GLAUCINITE,SALT AND PEPPER SANDSTONEMOST OF THE WATER PRODUCED FROM THIS ZONE
45	47	SANDSTONE, GRAY, VERY FINE GRAINED, SUBANGULAR, POOR SORTING,THIN LAYERS OF CARBONACEOUS SHALE, OILY
47	50	SHALE, VERY DARK REDDISH BROWN TO BLACK, SILTY,CARBONACEOUS, OILY, SET AIRLINE AT 50 FT AND PRODUCED ABOUT 30 GPM, FIELD PARAMETERS: TEMP=9.9 C,SC=820,PH=7.85,DO=17.1 MG/L,ORP=68.1

Driller Certification

All work performed and reported in this well log is in compliance with the Montana well construction standards. This report is true to the best of my knowledge.

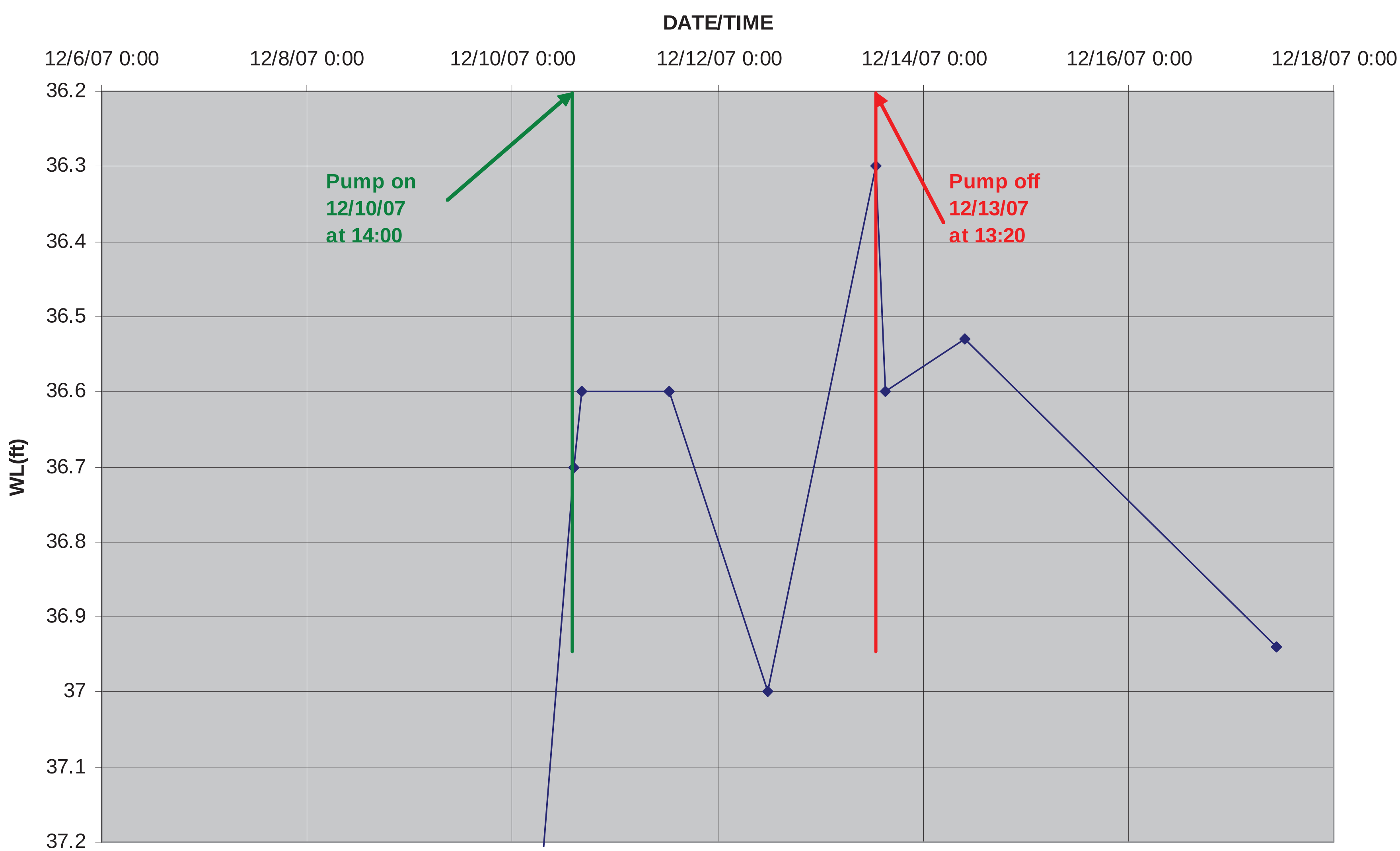
Name: AL HICKS
Company: ADT/PRO PUMP
License No: WWC-508
Date Completed: 12/4/2007

WATER-LEVEL FLUCTUATIONS AT THE JONES STOCK WELL (188462)



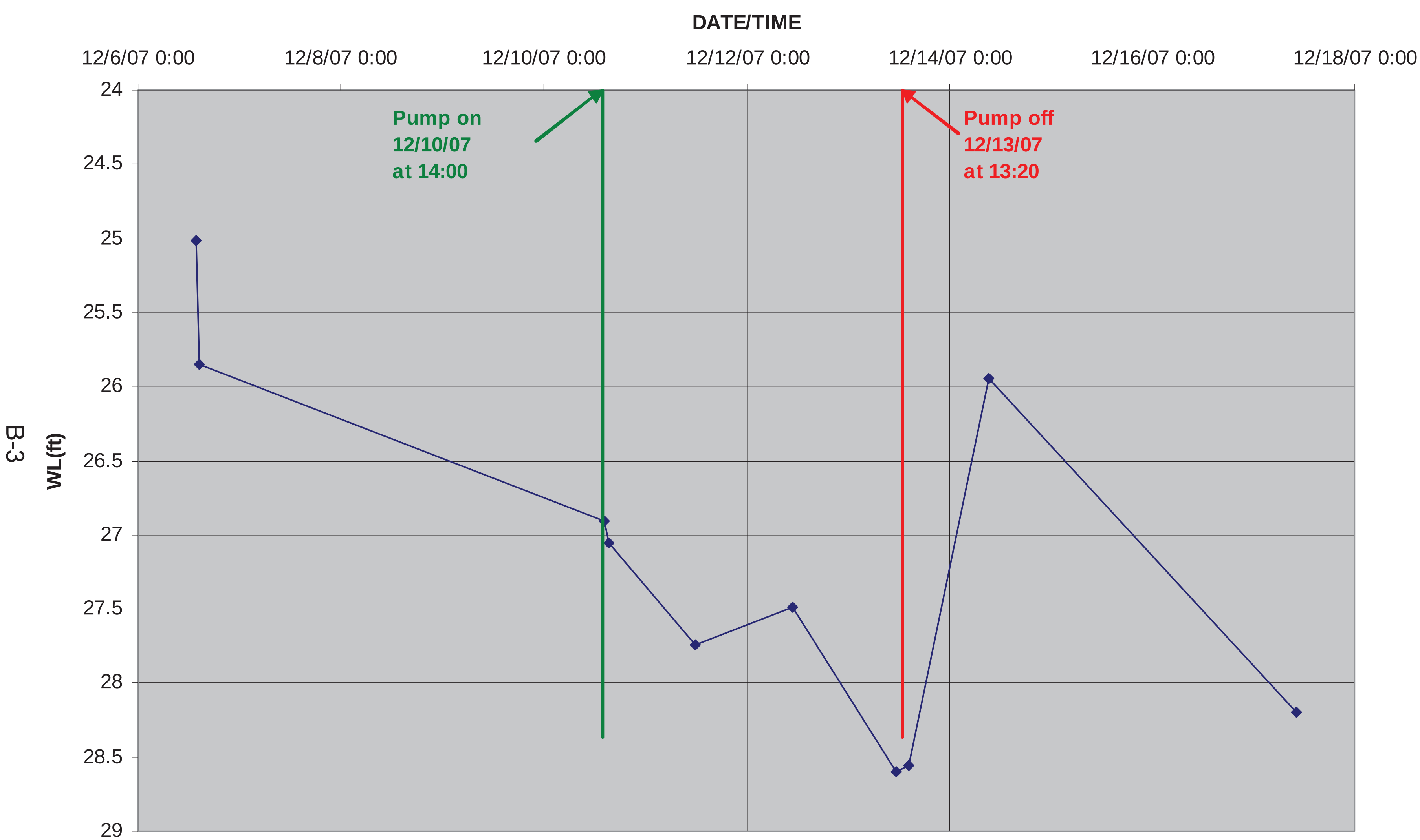
B-1

WATER-LEVEL FLUCTUATIONS AT THE STILES WELL (15948)

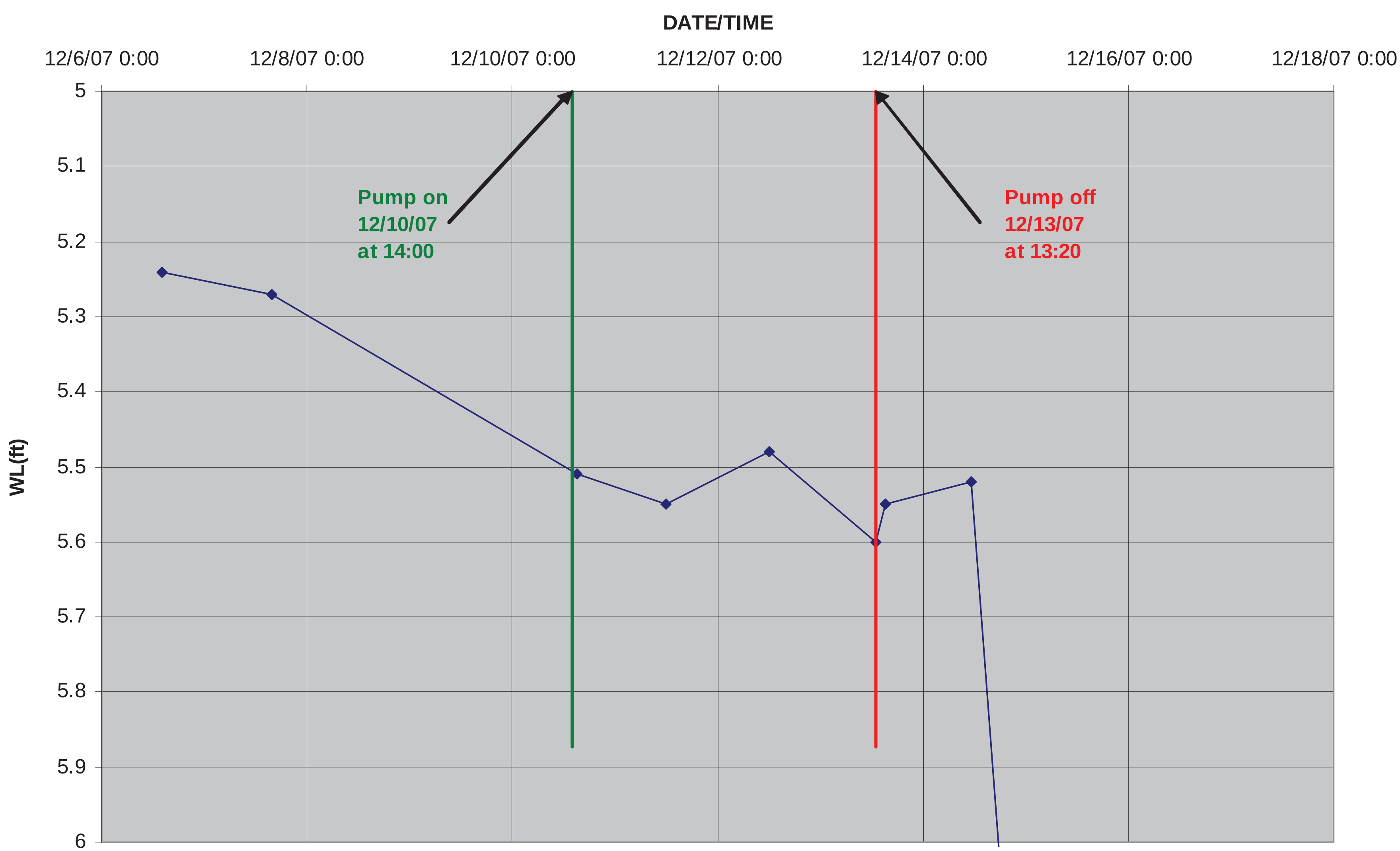


B-2

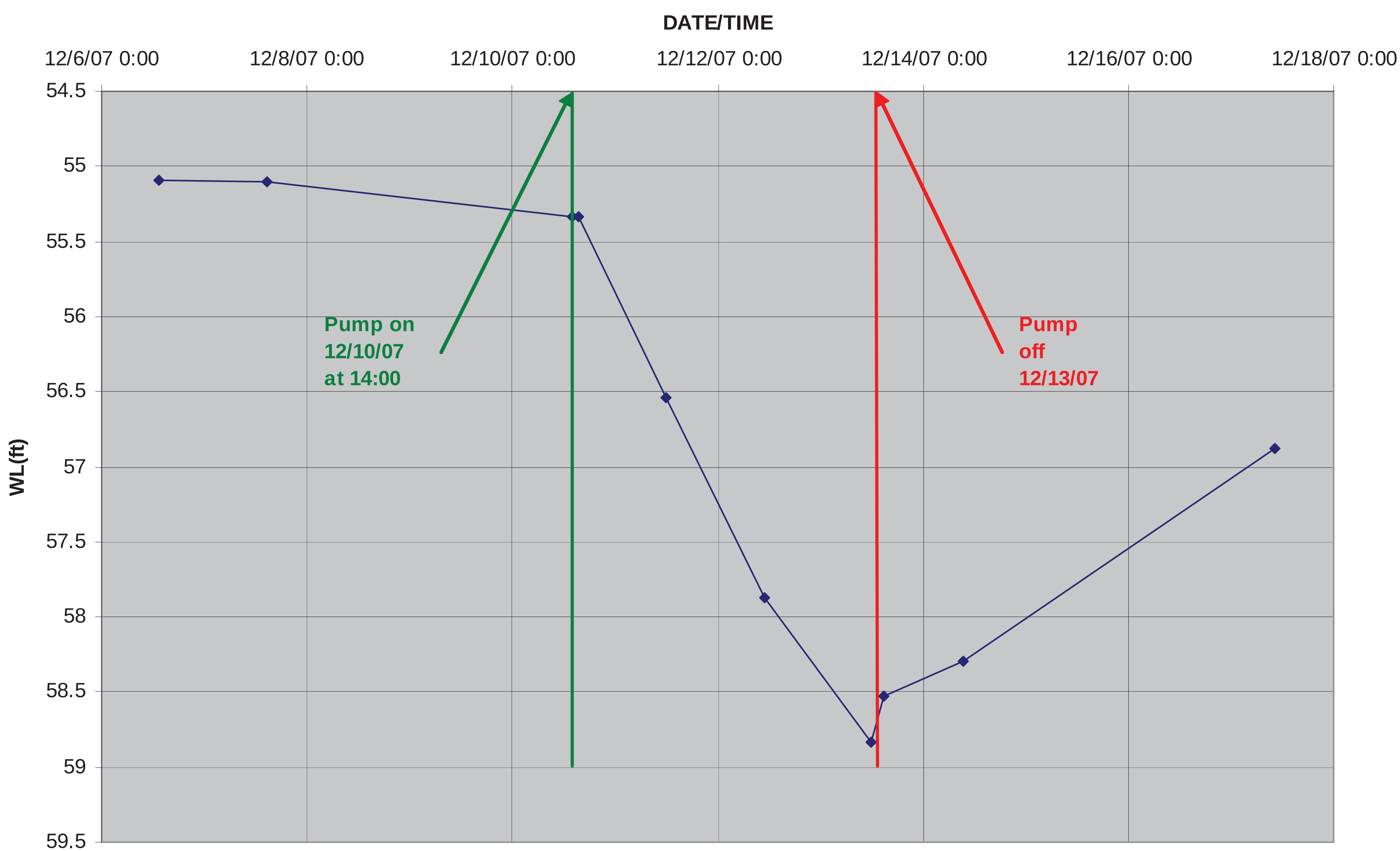
WATER-LEVEL FLUCTUATIONS AT BVIEW2 (240526)

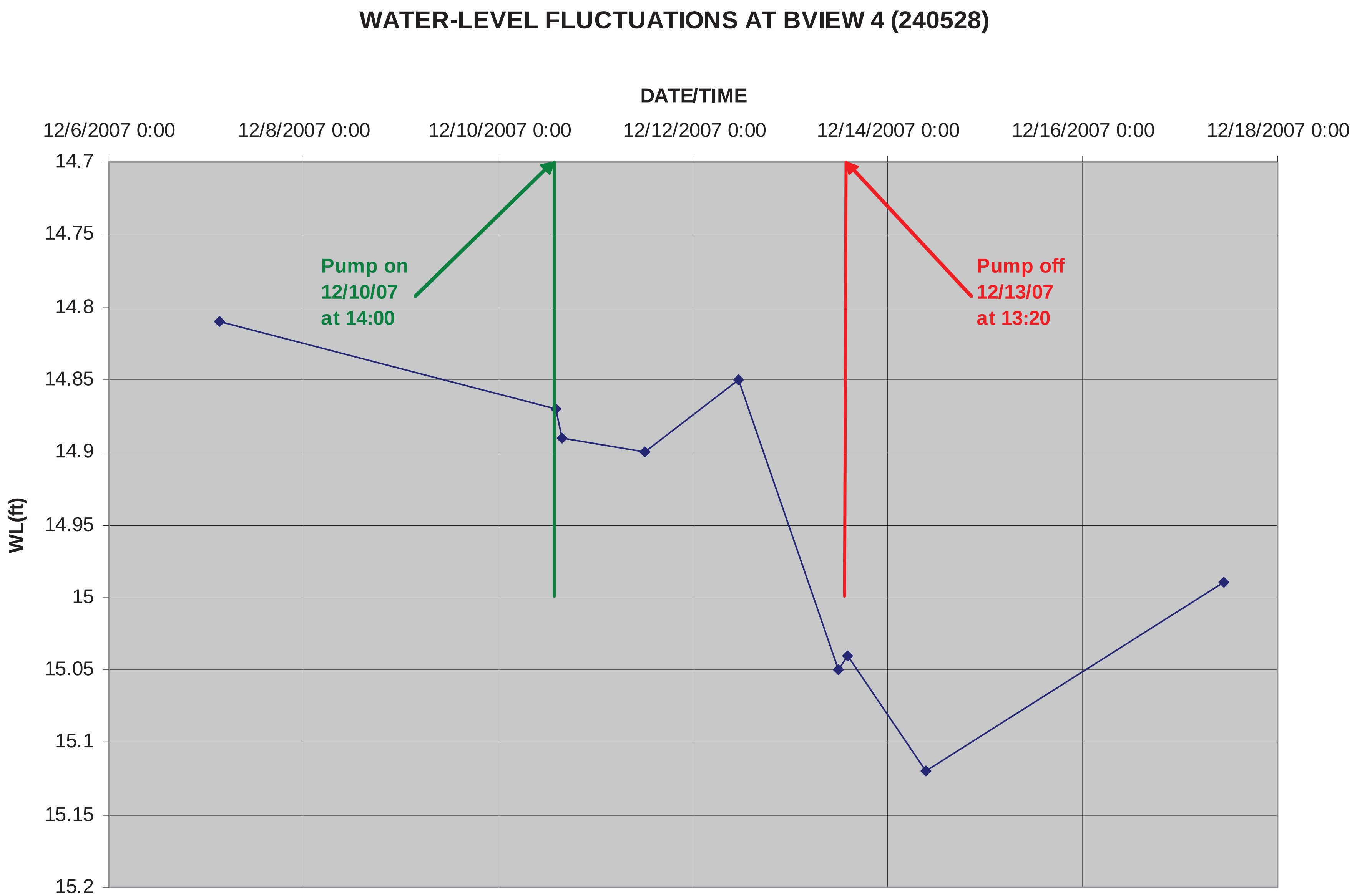


WATER-LEVEL FLUCTUATIONS AT THE MOSDAHL WELL (15948)



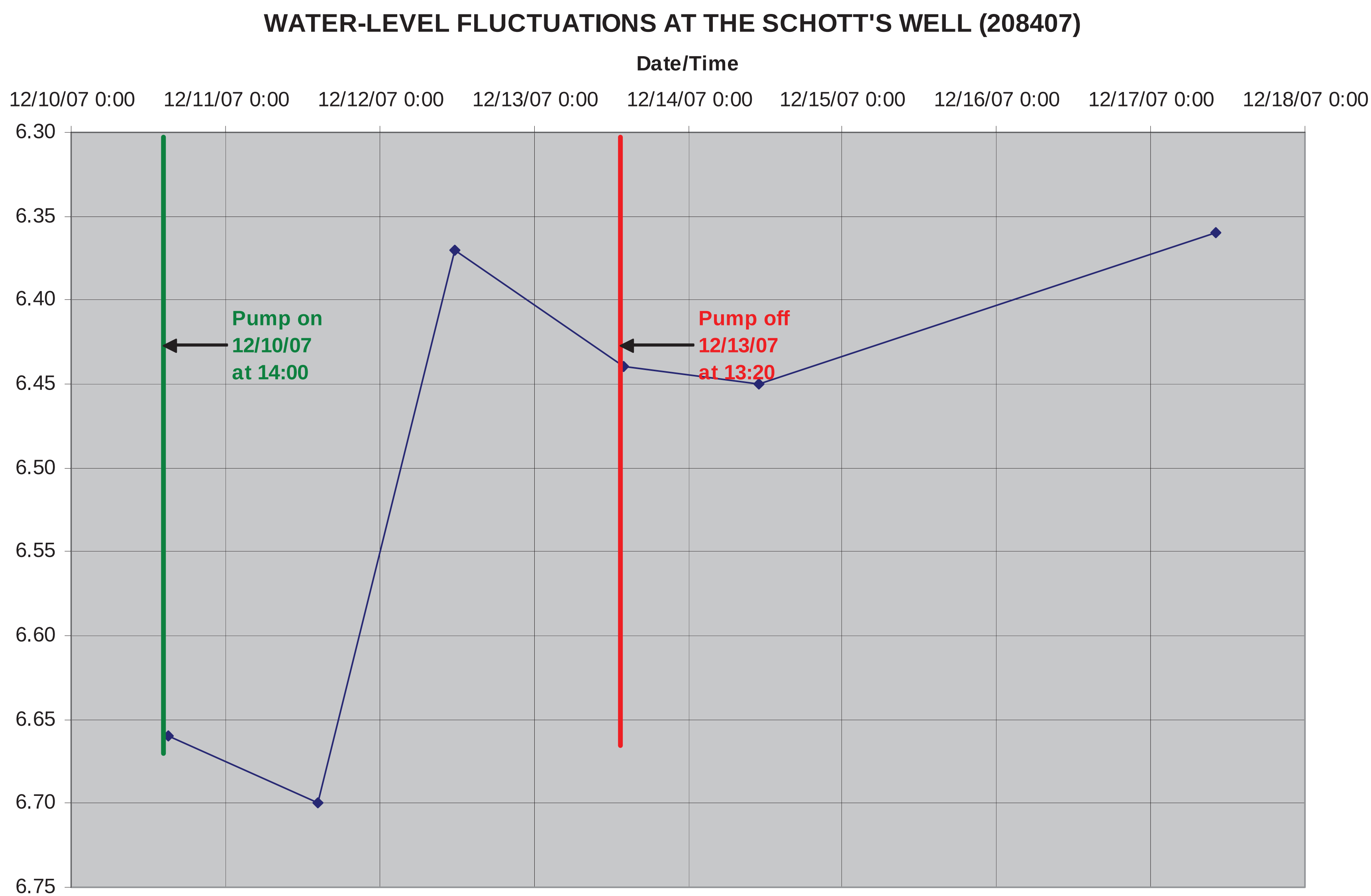
WATER-LEVEL FLUCTUATIONS AT BVIEW 3 (240527)





WATER-LEVEL FLUCTUATIONS AT BVIEW 4 (240528)
DATE/TIME
12/6/2007 0:00
12/8/2007 0:00
12/10/2007 0:00
12/12/2007 0:00
12/14/2007 0:00
12/16/2007 0:00
12/18/2007 0:00
WL(ft)
14.7
14.75
14.8
14.85
14.9
14.95
15
15.05
15.1
15.15
15.2
Pump on
12/10/07
at 14:00
Pump off
12/13/07
at 13:20

B-6


WATER-LEVEL FLUCTUATIONS AT THE SCHOTT'S WELL (208407)
Date/Time
12/10/07 0:00
12/11/07 0:00
12/12/07 0:00
12/13/07 0:00
12/14/07 0:00
12/15/07 0:00
12/16/07 0:00
12/17/07 0:00
12/18/07 0:00
WL(ft)
6.30
6.35
6.40
6.45
6.50
6.55
6.60
6.65
6.70
6.75
Pump on
12/10/07
at 14:00
Pump off
12/13/07
at 13:20

B-7