Groundwater Flow Model Inversion to Assess Water Availability in the Fox Hills-Hell Creek Aquifer

Photo Courtesy of Doug Davidson

By
Kimberly Fischer

ND Water Resource Investigation No. 54
North Dakota State Water Commission

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Introduction

In much of western North Dakota, the Fox Hills lower Hell Creek (FH-HC) aquifer is the only source capable of producing large quantities of fresh groundwater. Historically it has provided water for municipal, domestic, stock and industrial users in western North Dakota. Since the 1990s, construction of the Southwest Pipeline has provided a new source of water for many municipalities. However, the FH-HC aquifer remains an important water source for domestic, stock and industrial users. In valleys along the Yellowstone, Little Missouri, and Knife rivers the potentiometric surface of the FH-HC aquifer is above the land surface, creating flowing head wells. Flowing head wells are an important resource because they can be installed in remote pastures without the need for electricity to power a pump. Most of the flowing wells installed in the Fox Hills aquifer have a small diameter casing not compatible with installation of a submersible pump. Therefore, when the aquifer pressure head at a Fox Hills well location declines below the land surface, the rancher will need to replace that well. The FH-HC aquifer pressure head is currently declining at an average rate of approximately one foot per year in western North Dakota. At this rate of decline the majority of the flowing wells will stop flowing in the next 100 years (Honeyman, 2007).

Western North Dakota is experiencing an increase in water demand for use by the oil industry. Water is used to dilute the salt-saturated brine entrained with produced oil to prevent accumulations of salt on the well's tubing and other works in oil wells completed in the Ratcliffe and Interlake Formations. Beginning on a large scale in 2007, water is also needed to develop oil wells in the Bakken and Three Forks Formations by hydraulic fracturing. Following well installation, gelled water and sand or other proppant is pumped at high pressure into the well bore creating fractures in the surrounding formation to provide a path for oil to flow to the well. As previously mentioned, in many areas the FH-HC aquifer is the only source capable of producing large quantities of fresh water. However, allowing additional appropriation from the FH-HC aquifer will locally increase the rate of decline of the pressure head and shorten the time until the head falls below the land surface and naturally flowing wells cease to flow. If hydraulic fracturing techniques can be adapted to other oil-bearing shales, such as the Tyler Formation, the demand for fracking water could extend into southwestern North Dakota, which is an area with limited fresh water alternatives to the FH-HC aquifer.

Purpose and Scope

The purpose of this project was to gain a better understanding of the hydrogeology of the FH-HC aquifer that will provide a foundation for the development of a long-term management policy. To provide a better understanding of the hydrogeology and flow system of the aquifer, a groundwater flow model was developed. This model will facilitate the evaluation of pending water permit applications.

The objectives of the modeling study were: 1) Develop a hydrostratigraphic framework including both an assessment of the FH-HC aquifer and overlying aquitards. 2) Develop a groundwater flow model. The model will be used to A) Determine the differences between regional and site specific hydraulic properties caused by the complexity of the depositional environment through the use of both forward and inverse methods (parameter estimation) to estimate aquifer and aquitard hydraulic properties and to then compare the results to those properties expected based on lithologies. B) Develop the water budget and flow system of the aquifer for both pre-development and present conditions. C) Predict the equilibrium pressure head resulting from the current level of discharge and use.

The concern for the FH-HC aquifer is that wells are largely deriving water from storage in the aquifer and that water levels will continue to decline indefinitely into the future. For long-term mining of the aquifer not to occur, water must be derived from the overlying aquitards. Following Mary Hill's principle of parsimony (Hill and Tiedeman, 2007) the model should start as simple as possible with complexity added as needed. Therefore, the starting point for the model of the FH-HC aquifer is a one-layer model that does not account for transient leakage through the overlying aquitard. The ability to calibrate this model with reasonable parameters would validate this conceptualization as occupying the solution space. It would show that there is a significant possibility that water levels will continue to decline and additional development would only exacerbate the problem.

Physiographic Setting

The FH-HC aquifer extends from near the foothills of the Rocky Mountains, easterly across the Williston (Montana and North Dakota), Powder River (southern Montana and Wyoming) and Denver (Colorado) basins. The 35,000 square mile study area for this model overlies the Williston basin and extends south from the Canadian border past the North Dakota-South Dakota border and east from the Cedar Creek anticline to the Missouri River, roughly 160 miles by 230 miles (Figure 1). North and east of the Missouri River the FH-HC aquifer is not as important a water supply source, except near where it outcrops or subcrops. Other sources of water are more readily available and the Fox Hills' water quality is characterized by higher dissolved solids concentrations, due to the relatively large distance from the recharge areas.

Except along narrow outcrop areas, the FH-HC aquifer is a confined aquifer. Pressure heads in the study area range from 2,900 feet above mean sea level in the southwest corner of North Dakota, along the Cedar Creek anticline, to approximately 1,500 feet above mean sea level in the northeast portion of the basin (Figure 2). The general movement of water is from the southwest, where the aquifer is being recharged, to the north and east, forming a fan towards the Yellowstone and Missouri Rivers. The overall direction of flow is locally influenced by discharge to the major river valleys (Yellowstone, Missouri, and Souris, particularly where the Fox Hills is close to the surface) (Figures 2 and 3).

Climate

Western North Dakota is semi-arid. Daily temperatures, based on the 1931-1960 time period, average 73° F in the summer and 17° F in the winter. The mean annual precipitation ranges from less than 15 inches near the boundary with Montana to 15-17 inches along the south-flowing portion of the Missouri River in North Dakota. The FH-HC aquifer's recharge area in southwestern North Dakota and farther west and south averages less than 15 inches of precipitation per year. Most of the precipitation occurs between April and September. Any precipitation occurring in the winter months is almost always snow (Jensen, n.d.). Due to the semi-arid climate, most of the precipitation does not reach the FH-HC aquifer.

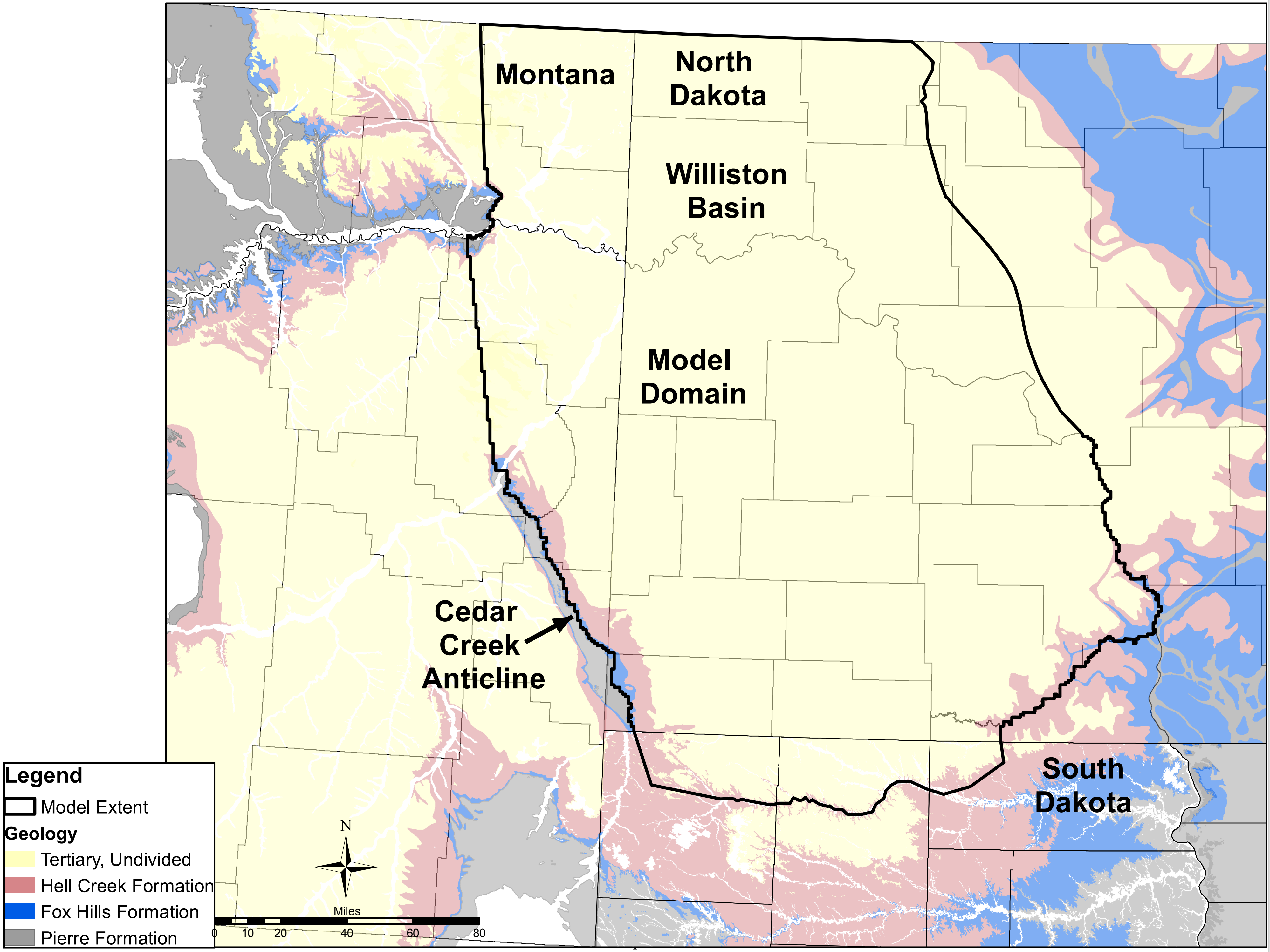

Figure 1. Aerial extent of Fox Hills Formation in the Williston Basin and location of model domain.

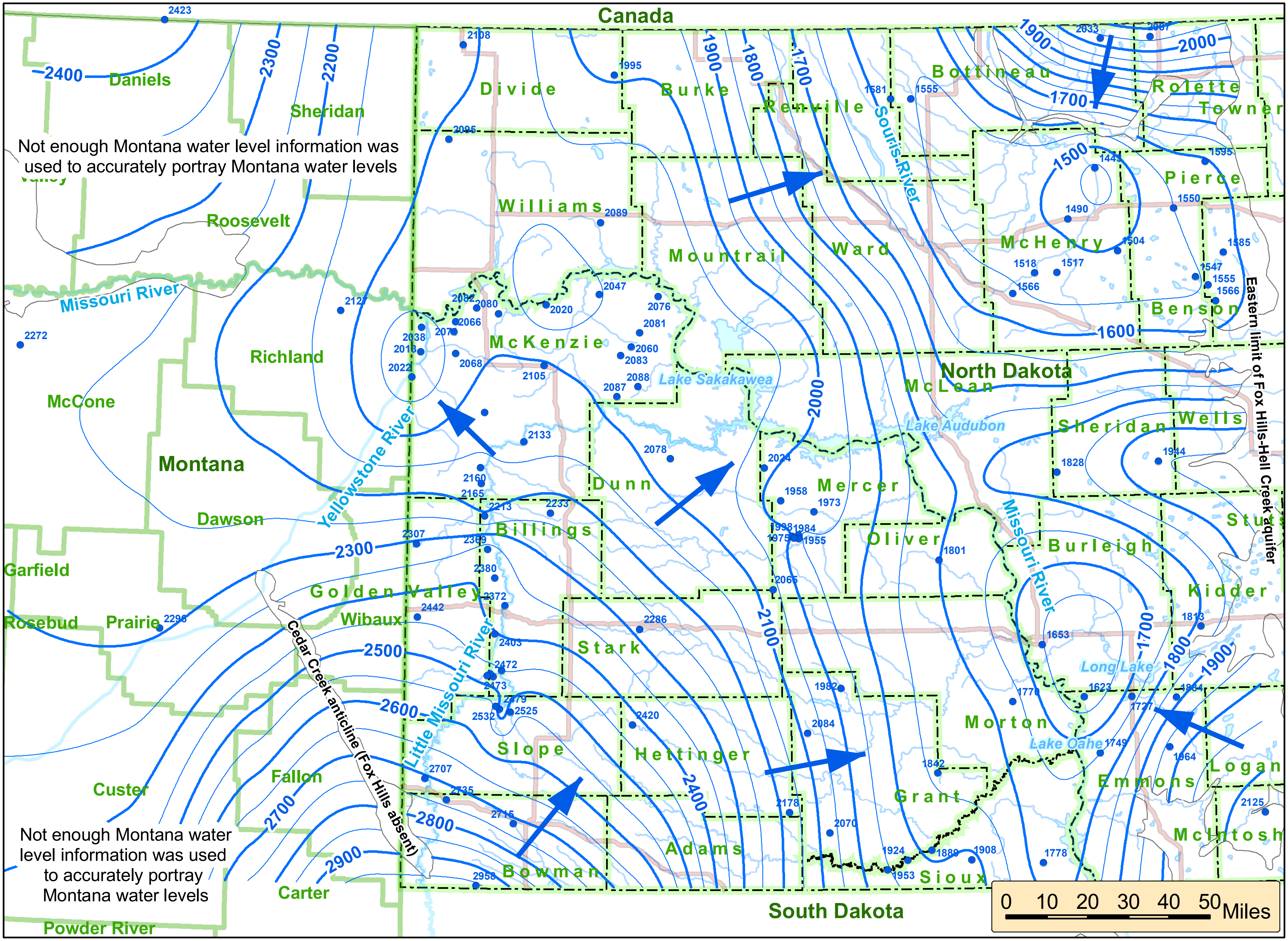

Figure 2. Potentiometric surface of the Fox Hills-Hell Creek aquifer in feet above sea level (as projected to Jan 1, 2009) Wanek, 2009.

Geology

The FH-HC aquifer occurs in the Williston Basin that underlies western North Dakota, extending into northwestern South Dakota eastern Montana, and southern Saskatchewan. The Fox Hills and Hell Creek Formations are mostly buried in North Dakota. Outcrops in or near the study area occur in the southwest along the Cedar Creek anticline, in the northwest along the Poplar Dome (Montana) and in the southeast along the Missouri and Cannonball rivers. East of the Missouri River in North Dakota the Fox Hills and Hell Creek Formations subcrop under glacial sediments rather than outcrop. The depth to the aquifer ranges from land surface, to approximately 2,000 feet below land surface in the central and south-central parts of the Williston basin (Figure 3).

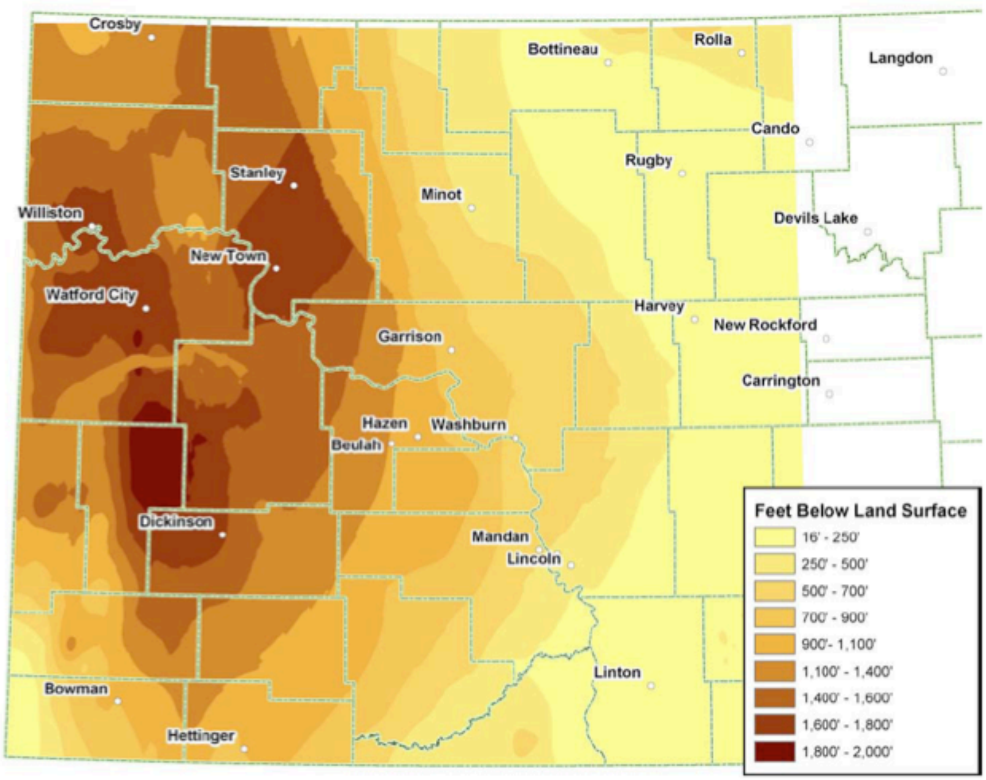

Figure 3. Approximate Depth to the FH-HC aquifer (Honeyman, 2007).

The Fox Hills Formation was formed as a shoreline to near shore feature when sediment eroded from the rising Rocky Mountains was deposited in marine to brackish water as the last Cretaceous seaway retreated easterly, evolving from an offshore to tidal depositional environment. The Fox Hills Formation has been divided into four members, from bottom to top the Trail City, Timber Lake, Bullhead, and Colgate members. The deepest, Trail City Member of the Fox Hills Formation, has a gradational contact with the underlying Pierre Formation. Which is conceptually thought of as a marine clay/shale deposited beyond the influence of shoreline clastic depositional events. The Trail City Member generally consists of silty to sandy shale and represents deeper offshore suspension fallout. The overlying Timber Lake Member consists of sandstone that was deposited episodically by storm wave action. The overlying Bullhead Member and overlying Colgate Member were both deposited continually by current dominated shoreline or tidal processes. The Bullhead Member is characterized by alternating beds of sandstone, siltstone and shale, while the Colgate Member is mainly sandstone that forms the most laterally continuous part of the FH-HC Aquifer (Daly, 1984).

The Hell Creek Formation is a clastic wedge associated with the retreat of the Cretaceous seaway. It is made up of poorly consolidated sandstone, siltstone, claystone, and carbonaceous and bentonitic beds. It consists of predominately nonmarine sediments intermixed with marine and brackish facies. Deposition occurred in fluvial channel systems and floodplains as laterally migrating channel belts and floodplains deposited sediment from the uplifting Rocky Mountains (Murphy et al, 2002). The Hell Creek portion of the FH-HC aquifer occurs in the lower third of the formation in locations where sandstone beds allow water to flow freely between the two formations. Thicker sections of sand in the lower Hell Creek Formation may be associated with deltaic deposits along the transition from primarily marine Fox Hills sedimentation to primarily nonmarine Hell Creek sedimentation.

The upper Hell Creek Formation and overlying Fort Union Group create an aquitard above the FH-HC aquifer. The boundary between the Hell Creek Formation and Fort Union Group marks the boundary between Cretaceous and Tertiary periods. While the Cretaceous-Tertiary boundary marks an identifiable point in geologic time, deposition in the Williston Basin was similar across the boundary as finer sand, silt and clay was deposited over a broad landscape by flooding streams.

Water Quality

The FH-HC aquifer is characterized by sodium bicarbonate type water, particularly as the distance increases from recharge sources. Nearly all the calcium and magnesium cations in Fox Hills waters have been replaced by sodium from interbedded clayey sediments within the FH-HC aquifer and overlying sediments. Sodium comprises 98 to 99 percent of the total cations. The high concentration of sodium contributes to a total dissolved solid level generally exceeding 1,000 milligrams per liter (mg/l). The Environmental Protection Agency (EPA) classifies total dissolved solids as a secondary contaminant for which the recommended limit is 500 mg/l. The secondary drinking water standards are a set of non-enforceable guidelines on constituents that may cause cosmetic or aesthetic effects.

Except for areas close to sources of recharge, concentrations of fluoride in FH-HC water are near the primary drinking water standard of 4 mg/l. Primary drinking water standards are legally enforceable standards that apply to public water systems. This has caused many communities that relied on FH-HC water to switch to Southwest Pipeline water for their municipal water supply. For a more detailed analysis of FH-HC water quality refer to Wanek, 2009 and Thorstenson et al, 1979.

Wells Completed in the FH-HC Aquifer

Wanek compiled an inventory of wells completed in the FH-HC aquifer in his 2009 recommended decision for the City of Alexander, water permit application number 5990 (Appendix D). The original inventory gathered well information from available sources for 16 counties in western North Dakota. For this project, the inventory of Fox Hills wells was extended south and east to the South Dakota border and Missouri River, including Fox Hills wells located in another five counties, Adams, Bowman, Grant, Sioux and Morton Counties. Figure 4 shows the location of the inventoried wells with the yellow outline depicting the spatial extent of the inventoried counties. While some Fox Hills wells east of the yellow boundary line in figure 4 are included in the inventory, not all of the Fox Hills wells in those eastern counties were inventoried.

Beginning in 1972, the North Dakota Board of Water Well Contractors has required water well contractors to file with the board well drillers' reports of completed wells and test holes. Wanek reviewed well driller reports for Fox Hill wells in 16 counties. An additional 5 counties were reviewed for this study. Well depth, land surface elevation and expected elevation of FH-HC aquifer were compared to information in well drillers' reports to determine if wells were completed in the aquifer. County groundwater studies, State Water Commission database, registered wells, U.S. Forest Service listing of wells, and wells identified in communication with area ranchers were also reviewed as part of the inventory. Indicated well locations are approximated based on the information in the well driller reports and have not been field checked for accuracy.

Information for wells completed in Montana was compiled in the original survey using the Montana Bureau of Mines and Geology and the University of Montana's Ground-Water Information Center (GWIC) website. The website provides private well information for wells completed in Montana. For more information on Montana wells included in the Fox Hills well survey refer to Wanek 2009.
Fox Hills wells were inventoried in an area (Figure 4) approximately coinciding with the model domain area (Figure 1). The inventory does not include the many relatively shallow Fox Hills wells in North Dakota east of the Missouri River where the Fox Hills or lower Hell Creek formations subcrop under glacial drift. Similarly, the inventory of Fox Hills wells does not include wells in Prairie or Fallon Counties in southeastern Montana where the Fox Hills Formation outcrops along the Cedar Creek anticline.

Well locations in figure 4 were color-coded based on the classification of well type. Flowing wells are shown in red, pumped wells are in blue, Hell Creek wells included in the inventory are squares and monitoring well sites are delineated by a green triangle. Unused non-flowing head wells are 'standby'. The number of wells in each category is listed in table 1a and 1b.

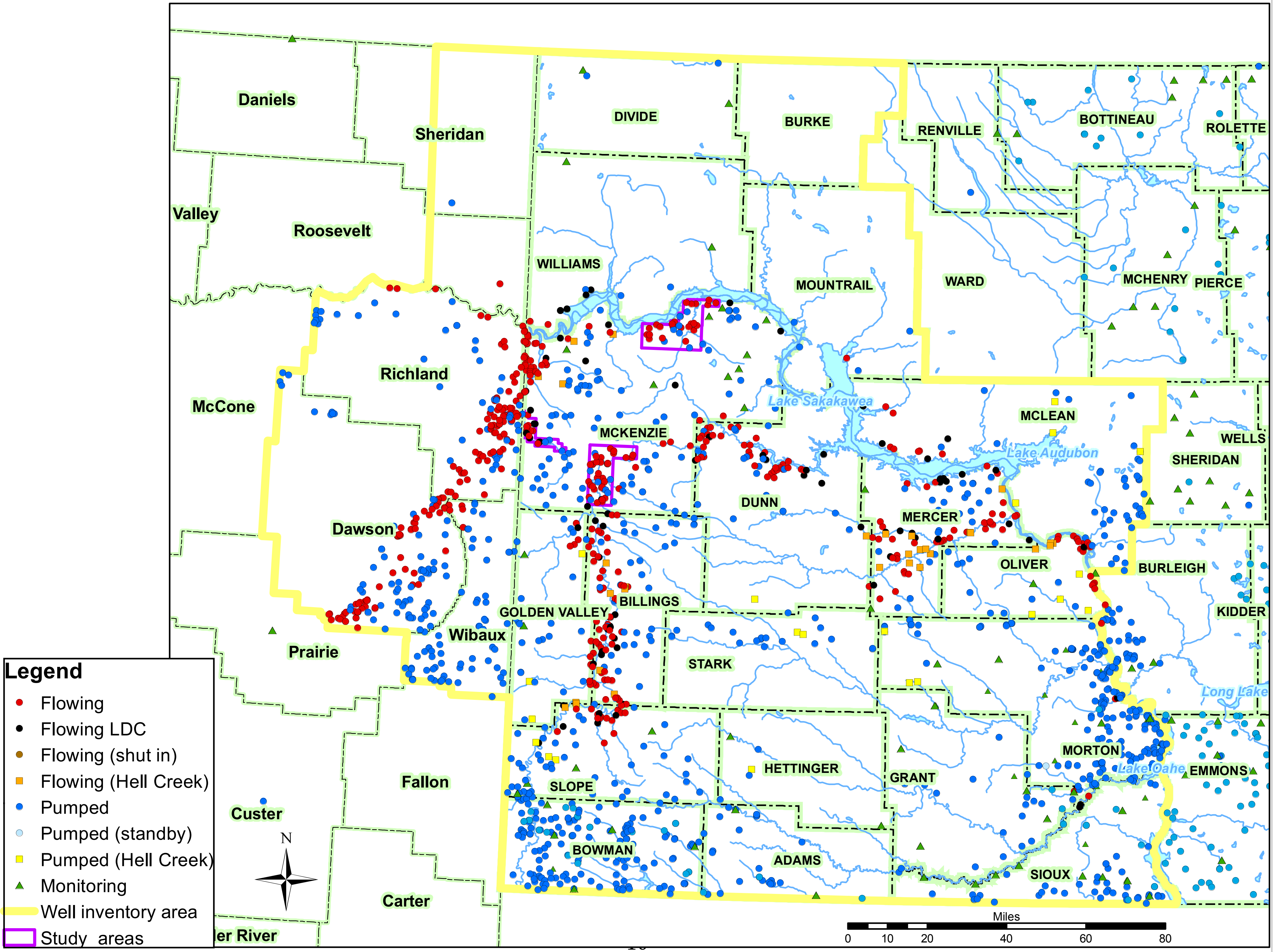

Figure 4: Location of Fox Hills-Hell Creek wells.

LDC = Large diameter casing (capable of being pumped)

Table 1a. Fox Hills Wells by type, primarily from 21 North Dakota counties and three Montana counties.

Well Type	North Dakota	Montana	Total
Flowing	283	148	431
Flowing LDC	89	1	90
Flowing Shut-in	15	4	19
Pumped	972	181	1,153
Pumped Standby	54	3	57
Flowing Hell Creek	31	0	31
Pumped Hell Creek	24	0	24
Monitoring	133	3	136
Total	1,601	340	1,941

LDC stands for large diameter casing, capable of accommodating a submersible pump (not specified for the Montana wells). Twenty-two of the 133 North Dakota monitoring wells have been plugged. The 56 wells listed as Hell Creek may be part of the FH-HC aquifer, but more likely have some hydraulic separation from the underlying aquifer (Wanek, 2009).

Table 1b. Fox Hills wells (as listed above in Table 1a) in use:

Well Type	North Dakota	Montana	Total
Flowing	283	148	431
Flowing LDC	89	1	90
Pumped	972	181	1,153
Total	1,344	330	1,674

LDC or large diameter casing in the tables and figures refers to wells with at least a 4-inch diameter casing, a diameter practical for installing a submersible pump. As is evident in tables' 1a and 1b most of the flowing head wells have smaller diameter casing, too small to install a submersible pump. A more detailed breakdown of the type of wells is included in table 2. The number of inventoried wells in each county is listed in table 3.

Table 2. Use of the listed Fox Hills Wells.

Well Type	ND Wells	MT Wells	Total
Flowing Domestic/Stock	47	2	49
Flowing Domestic/Stock LDC	13	-	13
Flowing Domestic	38	74	112
Flowing Domestic LDC	20	-	20
Flowing Stock	196	60	256
Flowing Stock LDC	42	-	42
Flowing Municipal LDC	8	1	9
Flowing Rural Water LDC	3	-	3
Flowing Industrial	2	6	8
Flowing Industrial LDC	3	-	3
Flowing Shut-in	12	4	16
Flowing Shut-in LDC	3	-	3
Flowing Unknown	-	6	6
Flowing Hell Creek	31	-	31
Pumped Hell Creek	24	-	24
Pumped Domestic/Stock	93	-	93
Pumped Domestic	385	69	454
Pumped Stock (+1 'wildlife' well)	415	85	500
Pumped Municipal	36	3	39
Pumped Rural Water	1	-	1
Pumped Industrial	40	16	56
Pumped Standby	54	3	57
Pumped Unknown	-	7	7
Pumped Irrigation	2	1	3
Monitoring	111	3	114
Monitoring-Plugged	22	-	22
Total	1,601	340	1,941

* The Fox Hills irrigation wells, one in Montana and two in North Dakota, are near areas where the Fox Hills Formation outcrops and are for use at golf courses and/or an athletic fields not requiring a high pumping rate.

Table 3. 1,941 identified Fox Hills (and select Hell Creek) wells by county.

County	Wells	County	Wells
Adams*	24	Morton*	202
Benson	12	Mountrail*	5
Billings*	113	Oliver*	38
Bottineau	21	Pierce	14
Bowman*	163	Renville	2
Burke*	0	Rolette	4
Burleigh	43	Sheridan	12
Divide*	4	Sioux*	59
Dunn*	68	Slope*	80
Emmons	77	Stark*	22
Golden Valley*	48	Williams*	13
Grant*	28	Custer, MT	1
Hettinger*	7	Daniels, MT	1
Kidder	30	Dawson, MT*	171
Logan	91	McCone, MT	1
McHenry	14	Prairie, MT	1
McIntosh	11	Richland, MT*	90
McKenzie*	236	E. Roosevelt, MT	1
McLean*	62	E. Sheridan, MT	1
Mercer*	98	Wibaux, MT*	73

* Counties in which well drillers reports (or Montana's GWIC website) were reviewed for Fox Hills wells.

The original survey of Fox Hills wells using well driller's reports, county groundwater studies, the State Water Commission's well and water permit databases, registered wells, and information supplied by the US Forest Service or by ranchers, showed that most wells were installed during the 1960s through 1980s. Seventy percent of flowing wells were installed at this time. Very few wells were reported before the 1960s. Flowing head wells were commonly installed using 2 inches or less diameter casing and the annular space was typically not filled with cement over its entire length. Corrosion of the well casing through time could result in flow along the outside of the casing to the surface or into overlying formations. The FH-HC aquifer pressure head is commonly greater than the head in the immediately overlying formations. As water flows along the outside of the casing or through holes in the casing, water can escape through permeable strata; however, most zones are less transmissive than the FH-HC aquifer and will be pressured up near the leaking Fox Hills well until a quasi-equilibrium is reached. Shallow zones that are connected to the surface may lose even more water because once the leaking water surfaces there is no resistance to leakage. Leakage is evident at some wells visited by water seeping up around the well and by water level measurements that show an uncharacteristic deviation from previous measurements. If seventy-five percent of the identified flowing wells leak at 0.1 gpm approximately 63 acre-feet per year of water is lost.

Fieldwork was conducted during the summer of 2008 in three flowing head well locations in McKenzie County (outlined in purple in figure 4). The purpose of the fieldwork was to determine how many Fox Hills wells were in use, as compared to the number of known wells, primarily from well driller's reports, and to determine an average flow rate for flowing wells. Roughly summarizing the results of the fieldwork, there were 50 percent more Fox Hills wells than previously identified in the well drillers reports. These wells were probably installed before well driller's reports were required. About two thirds of the flowing wells visited were flowing continuously, mostly valved down to a low flow rate. The remaining third were being regulated by use of a float valve in a tank or by some other method. Discharge from measured flowing head wells averaged 1.9 gallons per minute (gpm). For more information regarding the 2008 fieldwork refer to Wanek 2009, included in Appendix D.

Based on the average measured flow rates, the quantity of FH-HC water passing through flowing wells can be estimated as (521 wells) (1.9 gpm) (2/3 discharging wells) (1.6 ac-ft/yr per 1gpm) = 1,100 acre-feet per year. If unrecorded wells were added to this estimate, using a multiplier of 1.5, 1,600 acre-feet per year would be discharging to free flowing wells. The remaining third of flowing wells that are being contained is using much less water than free-flowing wells. Assuming each regulated well is using 400 gallons per day, the quantity of water discharged can be estimated as (521 wells) (400 gpd) (1 day/1440 minutes) (1/3 contained wells) (1.6 ac-ft/yr per 1gpm) = 77 acre-feet per year. The uncertainty associated with the quantity of water lost by flowing wells is part of the reason for developing a groundwater model.

Flow Model Development

The groundwater flow model of the FH-HC aquifer is a mathematical representation of the physical system using MODFLOW-2005 (Harbaugh et al., 2005). Simplifying assumptions are made about the physical properties of the system in order to simulate the complex system.

MODFLOW-2005 is a computer program that solves the three-dimensional groundwater flow equation to simulate groundwater flow through a porous medium using a block center finite difference method (Harbaugh et al., 2005). Three-dimensional groundwater flow is described by the following equation:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W = S_s\frac{\partial h}{\partial t}$$

where K_{xx}, K_{yy}, and K_{zz} are values of hydraulic conductivity along the x, y and z axis;
h is the potentiometric head (L);
W is sources and or sinks of water (t^{-1});
S_s is the specific storage of the porous material (L^{-1}); and
t is time (t).

In the finite difference method the physical system is divided into cells with a node at the center of each cell at which head is calculated. Harbaugh and others (2005) provide an in-depth discussion of this method. Observations are equated to equivalent items simulated by MODFLOW using the observation process (Hill et al., 2000).

Flow Model

The active model area is approximately 35,000 square miles (Figure 1). The area is divided into 345 rows by 303 columns, oriented north south, with cells 3,650ft by 3,650ft. The grid was generated in the State Plane coordinate system (NAD83, units ft, Zone is ND South). The grid origin is located in the NW corner of the model area at easting 849,530.25ft and northing 1,247,491.55ft. Vertically, the aquifer is represented as one confined layer. Hydrostratigraphic information was compiled in North Dakota using available lithologic logs from the North Dakota State Water Commission and geophysical logs from the North Dakota Industrial Commission's Oil and Gas division. The aquifer in Montana was delineated based on information from Montana's Ground Water Information Center. The bottom of the aquifer was defined as the transition to the top of the Pierre Formation, primarily from the increase in gamma ray detections and decrease in electrical resistivity indicating a higher clay or shale content. The top of the aquifer, corresponding to the lower portion of the Hell Creek, is harder to delineate due to the variability of the nonmarine depositional environment. An inclusive approach was utilized to try and encompass the entire aquifer thickness. Figure 5 delineates the modeled aquifer thickness. Delineating additional layers, by separating the lower Hell Creek aquifer, could potentially produce a more detailed model than the one layer model.

The model was discretized into a steady-state stress period followed by transient yearly stress periods. The yearly transient stress periods were further divided into 15 time steps. The steady-state stress period, representing conditions in 1942, was to allow the simulated water levels to come into equilibrium with the boundary conditions. Hydrologic stresses and groundwater flow rates are assumed to have been constant or steady-state prior to 1942. The calibrated transient model runs from January 1, 1943 through December 31, 2009. The model was run in prediction mode to December 31, 2039 to determine future water levels at the current level of use.

Hydraulic Conductivity

The distribution of hydraulic properties in the FH-HC aquifer is variable due to the layered nature of the depositional environment (as discussed in the geology section). The FH-HC aquifer is non-homogeneous because it is comprised of layers characterized by different values of hydraulic conductivity. For example the FH-HC aquifer the Colgate member of the Fox Hills Formation has a higher hydraulic conductivity than other portions of the aquifer, and as such will act as the major conduit of groundwater flow. Values for hydraulic properties were collected from all available literature sources for use as initial values in the model. Initial estimates for hydraulic conductivity were determined from single well pumping and recovery tests, laboratory measurements on sidewall core samples and from interpretation of geophysical logs in the North Dakota County Studies. Estimates ranged from 0.1 to 2.1 feet per day and averaged 2.0 feet per day. Table 4 lists the average hydraulic conductivity for each source.

Table 4: Summary of hydraulic conductivity values.

Average Hydraulic Conductivity	Source	Test Type
2 ft/d	Thorstenson, 1979	Drill stem tests and core samples
1.65 ft/d	Croft, 1978	Aquifer tests, drill stem tests and core samples
1.6 ft/d	Anna, 1981	Drawdown tests
2 ft/d	Croft, 1985	Resistivity curves of logs in the county study
2.1 ft/d	Croft, 1973	Flow recovery tests
0.66 ft/d	Ackerman, 1980	Core samples
1.9 ft/d	Randich, 1979	Core samples

Hydraulic conductivity was parameterized using a depth dependent approach. With depth, effective stress increases causing the aquifer material to compress and the hydraulic conductivity to decrease. The elevation of the aquifer varies from land surface to a depth greater than 2,000 feet below land surface. A multiplier array was used to achieve spatial variation. The hydraulic conductivity for a given cell was calculated from a formula from the Hydrogeologic Unit Flow Package 2 (Anderman et al, 2003);

$$K_{depth} = K_{surface} 10^{-\lambda d}$$

Where
K_{depth} is the hydraulic conductivity at depth d (L/T)
$K_{surface}$ is the hydraulic conductivity projected to a reference surface (L/T)
λ is the depth dependent coefficient (L^{-1}) and
d is the depth below the reference surface (L)

Figures 6 and 8 show the effects of variance of the multiplier with depth below land surface.

A multiplier for hydraulic conductivity was modified during parameter estimation. The hydraulic conductivity calculated during calibration is a combination of fine and coarse materials that make up the aquifer. It is lower than measured values, 0.71 feet per day at land surface. This is because, the modeled hydraulic conductivity is regional and the measured values are point values. The regional hydraulic conductivity reflects the interconnectedness of the sand bodies and the point values of hydraulic conductivity reflect the hydraulic conductivity of the sand bodies at that point. At a depth of 2,000 feet below land surface, slightly more than 1/3 or 0.44 feet per day would reduce the hydraulic conductivity. Figure 6 shows the spatial distribution of hydraulic conductivity, figure 5 shows the modeled aquifer thickness and figure 7 shows the spatial distribution of the transmissivity.

The modeled transmissivity (equal to the aquifer thickness multiplied by the hydraulic conductivity) in figure 7, is likely high due to the inclusion of the Hell Creek Formation in the modeled aquifer thickness. The Hell Creek aquifer likely includes a higher percentage of siltstone and claystone then it would if just the Fox Hills Formation was modeled. This could be a point of revision in further model studies.

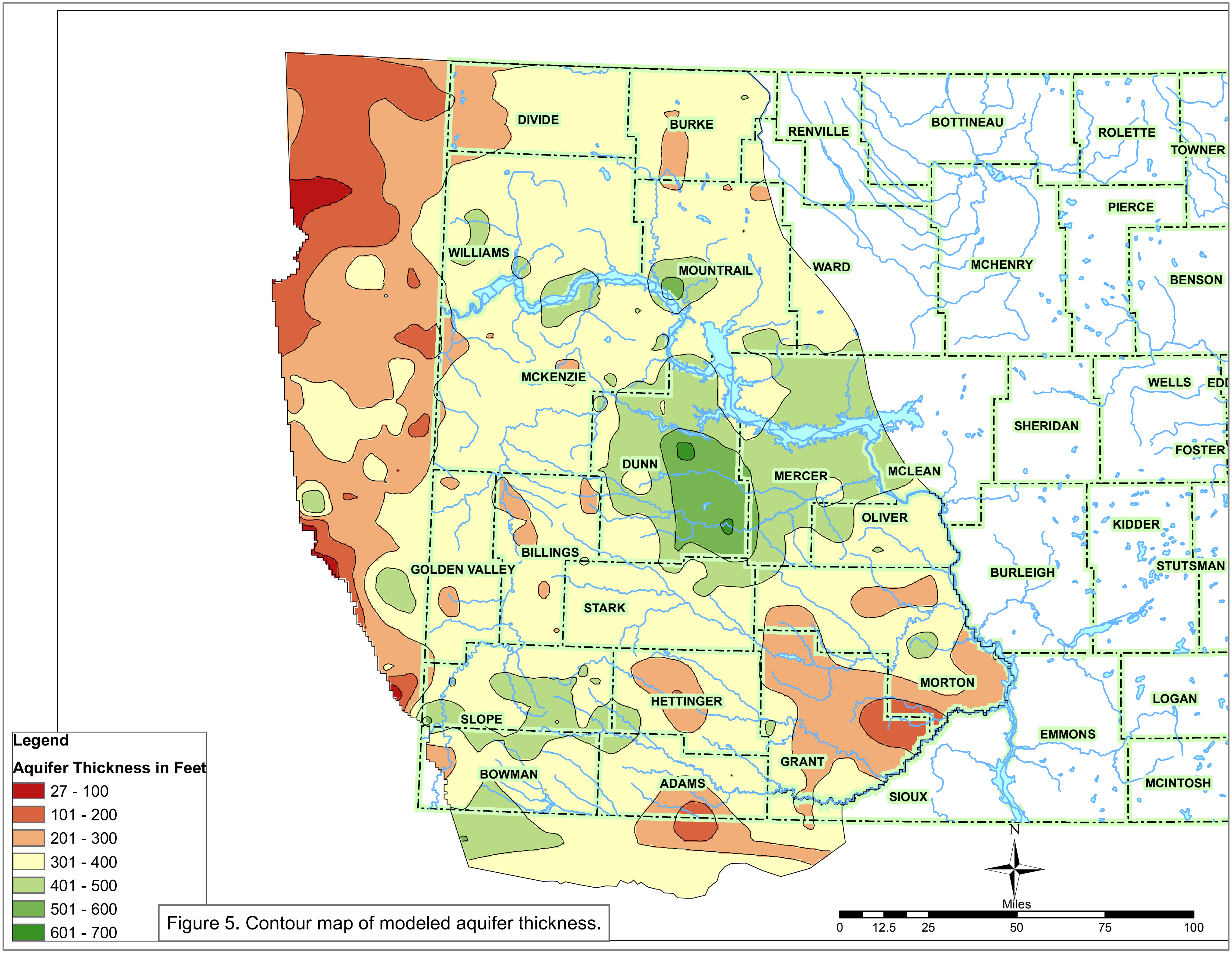

Figure 5. Contour map of modeled aquifer thickness.

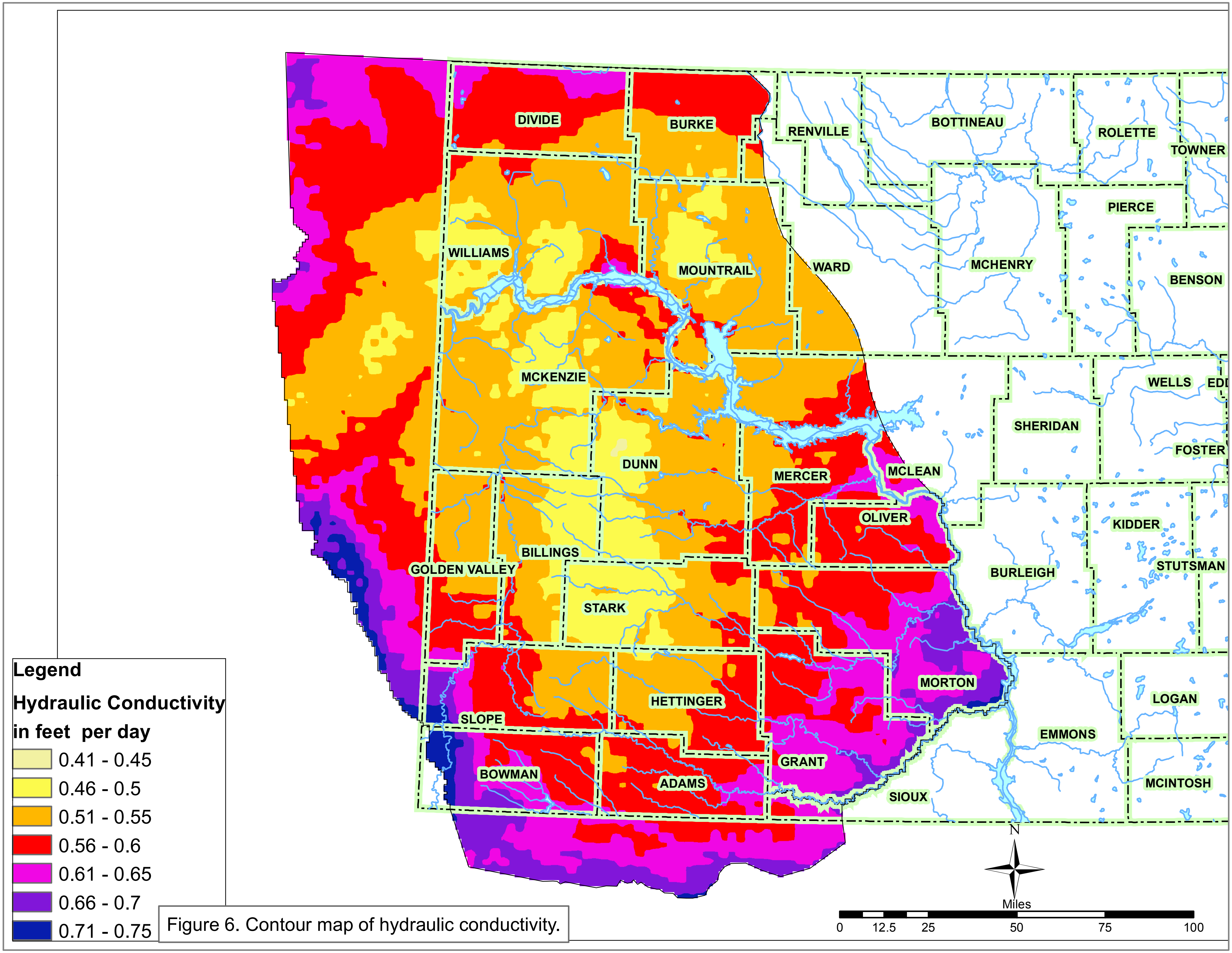

Figure 6. Contour map of hydraulic conductivity.

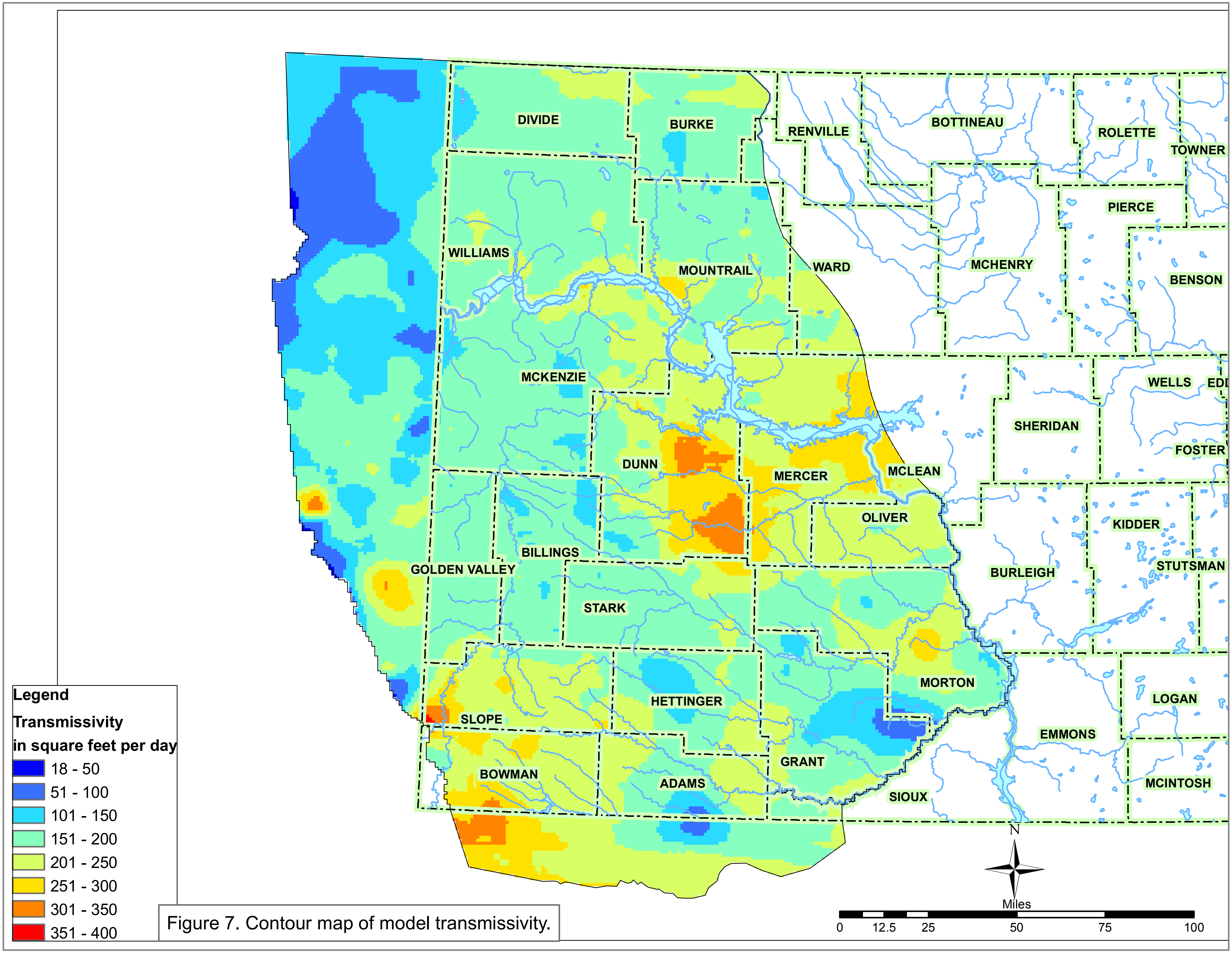

Figure 7. Contour map of model transmissivity.

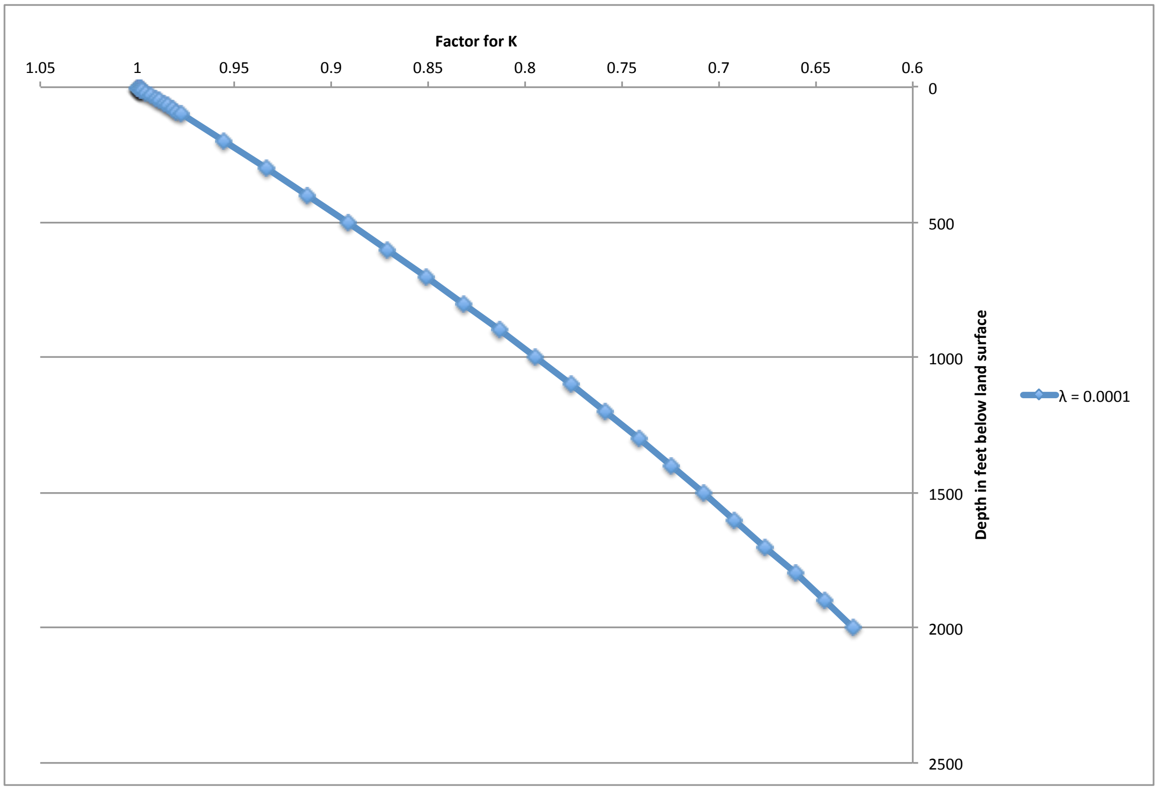

Figure 8. Decline with depth of hydraulic conductivity or specific storage relative to the depth below land surface.

Specific Storage

Storativity of the aquifer is not often determined because most of the testing is done on a single pumped well. The depth of the aquifer makes it impractical to install monitoring wells around a pumped well. The estimated storativity of the aquifer (0.0003) was divided by the aquifer thickness to determine the specific storage. As with hydraulic conductivity, specific storage is not constant with depth but rather decreases with depth in response to increased loading. As the effective stress increases, the volume in the pore spaces of the soil decreases as the soil compresses, and therefore the volume of water released per unit mass of soil per unit drawdown in head (specific storage) decreases. During parameter estimation a multiplier for specific storage was calculated and multiplied by the same depth dependence array as the hydraulic conductivity. The depth decay function is exponential, causing the specific storage to initially decrease more rapidly with depth. At greater depths the specific storage would be a constant value. The multiplier was originally 1, now 3.315. This changes the estimated storativity of the aquifer from 0.0003 to 0.001 at land surface. At a depth of 2,000 feet below land surface, the storativity would be approximately 0.0006. The specific storage values (storativity/aquifer thickness) range from a maximum of 3.17×10^{-4} (ft^{-1}), to a minimum of 3.52×10^{-7} (ft^{-1}), and averages 1.55 x 10^{-6} (ft^{-1}). Literature values (Anderson et al, 1992) of specific storage for dense sand range from 6.1 x 10^{-5} – 3.96 x 10^{-5}(ft^{-1}), and for fissured or jointed rock range from 2.1 x 10^{-5} – 1.0 x 10^{-6}(ft^{-1}).

Boundary Conditions

Details of the boundary conditions and how they are represented in the MODFLOW model are shown in figures 9, 10 and 11. Groundwater recharge that occurs as ungaged runoff along the Cedar Creek anticline is represented in the MODFLOW model as four recharge zones (Figure 9). Each zone has a multiplier that was estimated during inverse calibration. The zones were demarcated based on visually identifying possible recharge sources through areal photography and head distribution of observed water levels. A possible model improvement could be to include temporal variations in recharge along the Cedar Creek anticline. Figure 9 shows the location and magnitude of recharge in inches per year.

General head boundaries (GHB) are used to represent lateral flow into and out of the system, because they allow flow across the boundary to vary based on the head differential between the model and the specified head. The head differential is multiplied by the conductance to calculate the groundwater flux into or out of the cell (Harbaugh et al., 2005).

$$Q = C(h - h_{ref})$$

where C is the boundary conductance (L^2T^{-1}),
h is the hydraulic head in the model cell (L), and
h_{ref} is the hydraulic head on the outside of the model boundary (L)

Head elevations for, h_{ref}, were determined using available water levels from well data and the potentiometric surface map from figure 2, (Wanek, 2009). The head assigned to the GHB in Montana, from in-between the Cedar Creek anticline and the Poplar Dome, is 2,100 feet (Figure 10). The heads representing outflows along the Missouri River range from 1750 to 1650 feet and along Cannonball Creek the hydraulic head is represented as 1,720 feet.

The conductance calculated for each cell, is a product of the hydraulic conductivity multiplied by the length of the cell and the saturated thickness divided by the distance between the specified head and the cell node.

$$C = KA/L$$

where
K is the hydraulic conductivity of the material in the direction of flow (LT^{-1})
A is the cross-sectional area perpendicular to the flow (L^2), and
L is the length of the prism parallel to the flow path (L)

The cross sectional area is the product of the cell width, 3,650 ft, by the average aquifer thickness for each cell shown in figure 5. Conductance values range from 1.4 ft^2/d where the model thickness is the smallest to 131 ft^2/d where the model thickness is the largest. The specified head remained constant throughout the model simulation. No flow model boundaries occur when the general head boundary is absent.

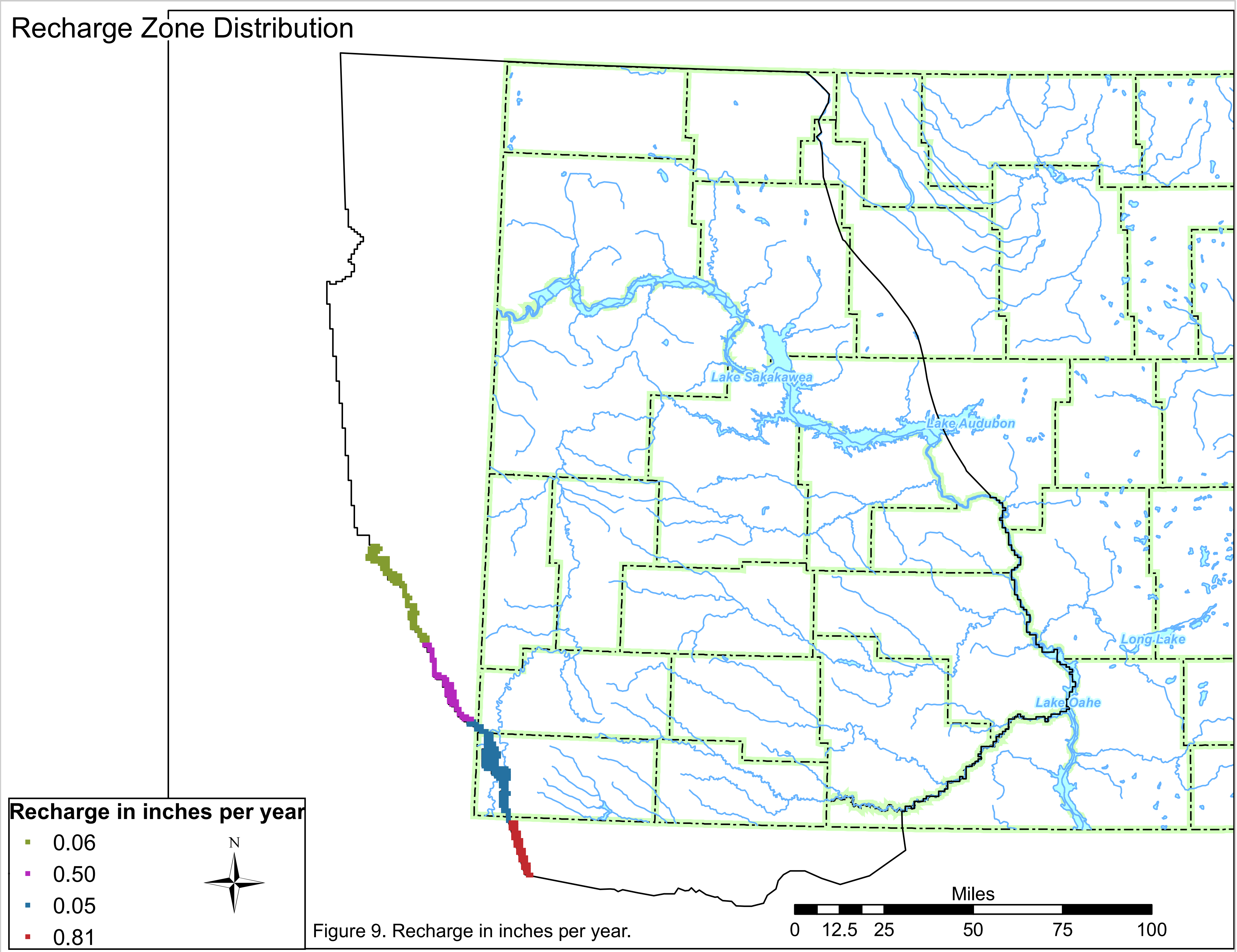

Figure 9. Recharge in inches per year.

Pumping Well, Flowing Well, Stream and General Head Boundary Distribution, 2009

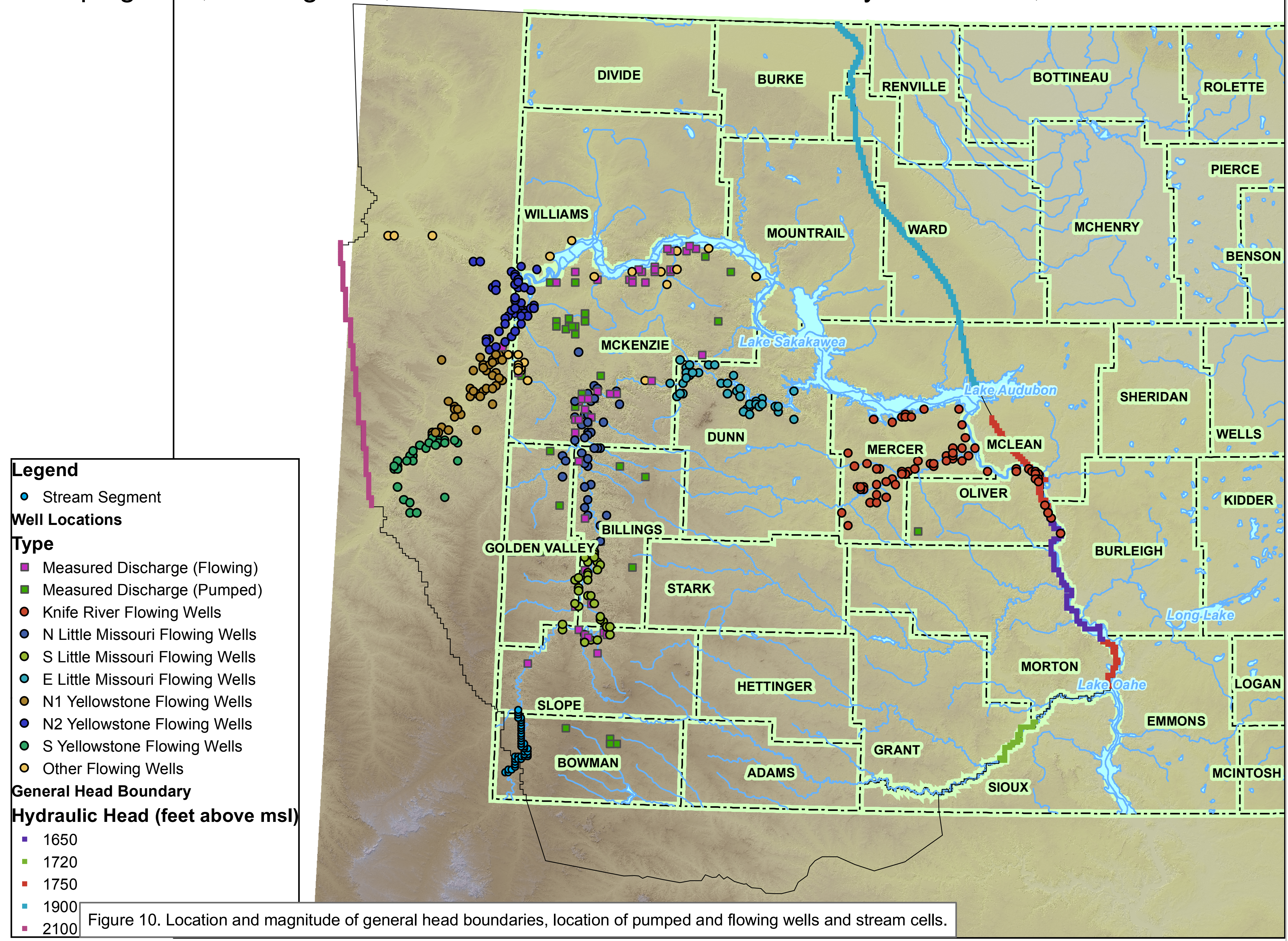

Figure 10. Location and magnitude of general head boundaries, location of pumped and flowing wells and stream cells.

Pumping Well and Flowing Well Discharge Rate, 2009

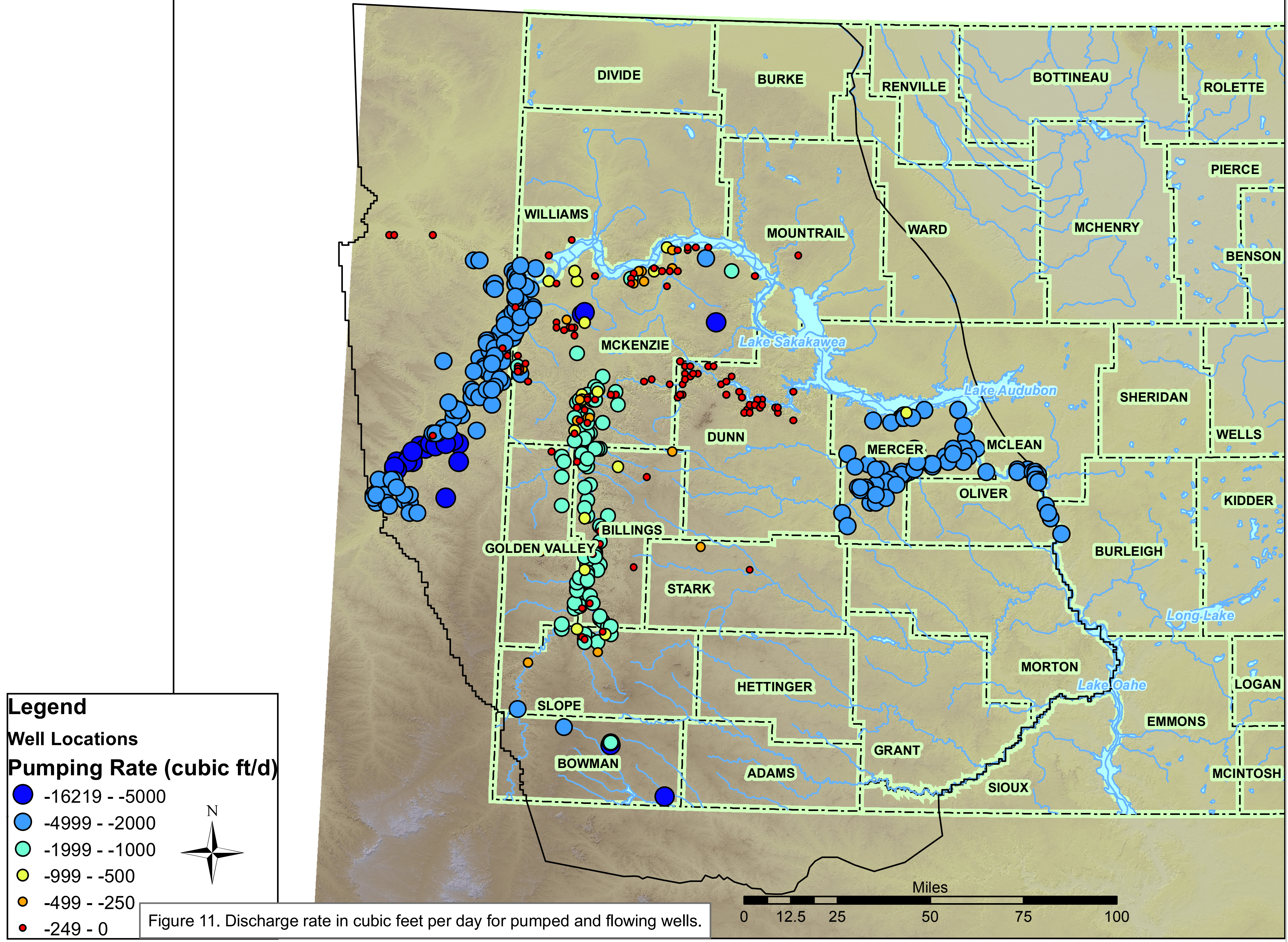

Figure 11. Discharge rate in cubic feet per day for pumped and flowing wells.

Pumped and flowing wells are the primary source of discharge in the interior portion of the basin. Reported water use, from North Dakota, is available for permitted pumping from 1972 to present. Purple squares (Figure 10) represent the location of wells where measured flows from flowing wells are available and green squares represent the location of reported use from pumped wells. Flowing wells in the Little Missouri and Knife River valleys have periodically been measured. The average discharge was used as an initial input for known flowing wells without a measured value of discharge. However, the exact volume of water discharged to flowing wells and an exact number of flowing wells are not precisely known. During parameter estimation a multiplier for the average discharge was calculated based on location. The flowing wells were split into eight zones (Figure 10); Knife River, south Little Missouri, north Little Missouri, east Little Missouri, south Yellowstone, middle Yellowstone, north Yellowstone and outliers. An additional zone for discharge to pumping wells in Glendive Montana was also used in the model. Figure 11 shows the location and magnitude of pumping from permitted water use and estimates of discharge due to flowing wells. Because discharge from all flowing wells is not known, there is no direct measurement of the accuracy of this estimation.

The revised multi-node well (MNW2) package (Konikow et al., 2009) was used to represent discharge from pumping and flowing wells. MNW2 was selected due to its ability to decrease the volume of water discharged from flowing wells as the elevation of the potentiometric surface nears the user specified land surface. Flowing wells, in the model, were set to a fixed measured discharge rate when available and an estimated discharge rate if no measured value was available. Once the potentiometric surface drops below the specified elevation the well stops discharging water. Conversely if the potentiometric surface rises above the land surface again the well begins discharging water. The rate of discharge from flowing wells likely does not change very often. A valve is adjusted to discharge the amount needed to fill a stock tank. Through time, when the discharge decreases due to a drop in pressure, the valve is adjusted to maintain a level of flow. A linear relationship for discharge was assumed between measurements for wells measured in the decadal survey. The pumping or flow rate in relation to the water-level elevation in the well, and the water level information for the cell from the time the well starts pumping through 2039 is provided in Appendix B.

Wells were added and deleted as records indicated throughout the model simulation. Some wells installed before the 1970s have incomplete records, mainly involving the well installation date. The distribution of wells with known drilling dates was used as a comparison distribution for wells with no installation date. Measured pumpage averages about 25% of the water use estimated for the model (Figure 12). This has become more prominent since 1992, due to North Dakota communities switching from Fox Hills wells to Southwest Pipeline water for their municipal source. The estimated discharge is about twice as much in the Yellowstone Valley versus the Little Missouri Valley. This could be due to more wells being installed in the wider Yellowstone Valley and the model not being as well constrained in Montana, causing higher than expected flow rates estimated from Montana wells.

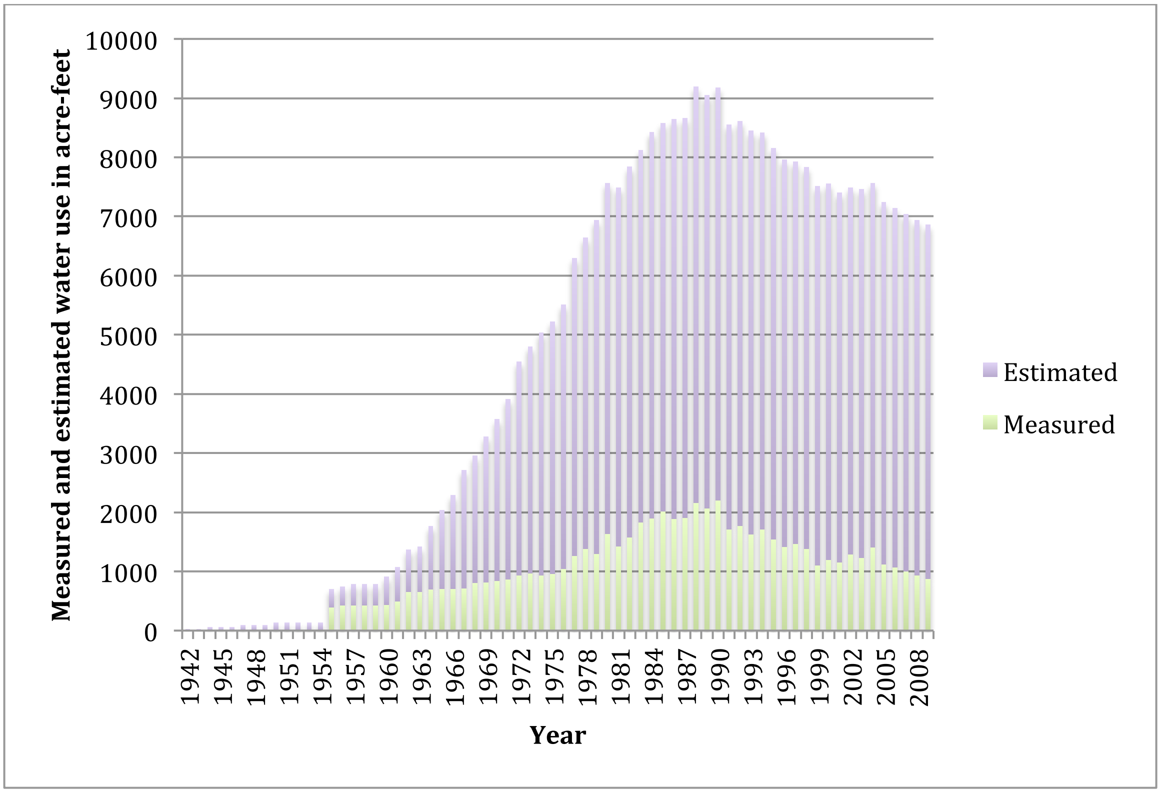

Figure 12. Annual water use from the Fox Hills-Hell Creek aquifer.

Stream flow measurements from the Camp Crook, South Dakota USGS gage were used to determine groundwater interaction with the Little Missouri River in the southwest portion of the state where the FH-HC aquifer is close to the surface (Figure 10). The flow observations are available since June of 1956; flow observations were repeated from 1957 to 1970 and for 1942 through 1955. The observations vary by year and are presented graphically in figure 13. Measurements range from approximately 460 acre-feet in 2002 to 42,700 acre-feet in 1978. The Little Missouri River is simulated to the USGS gage in Marmarth North Dakota using the MODFLOW streamflow routing package (SFR1) (Prudic, 2004).

Stream leakage is calculated based on the head difference between the stream and aquifer and a conductance term. Leakage is added or subtracted from the volume of stream flow in each reach. Recharge stops when the stream is dry. The stream segment specified in the model is broken up into reaches. Every model cell the Little Missouri River flows through between the model boundary and the gage in Marmarth, ND is a reach. The flow for the first reach is specified and calculated for subsequent reaches as the inflow minus the leakage in the previous reach. The conductance of the streambed is calculated as a product of the hydraulic conductivity of the streambed by the width of the stream by the length of the reach divided by the thickness of the streambed. Conductance is calculated for each reach from the hydraulic conductivity, stream length and streambed thickness.

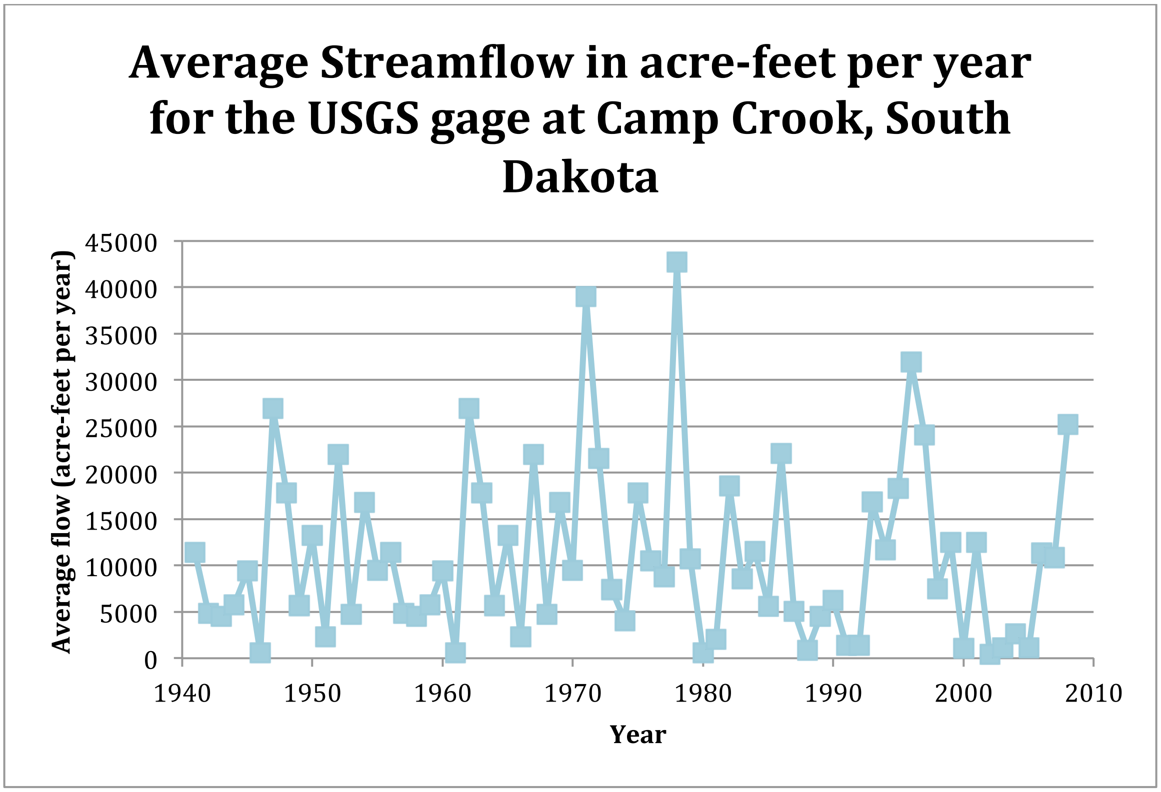

Figure 13. Average stream flow in the Little Missouri River in acre-feet per year for the USGS gage at Camp Crook, South Dakota.

The first stress period in the model representing 1942 is a steady-state stress period. Boundary conditions used in the transient model are the same as those used for the steady-state stress period for GHBs and recharge. Discharge to flowing and pumped wells and stream flow parameters were based on available data. For a summary of model inputs and outputs and the related MODFLOW package refer to table 5.

Table 5: Summary of model boundary conditions represented by MODFLOW.

Summary of model inputs and outputs		MODFLOW Package
Inflows	Infiltration along Cedar Creek anticline	Recharge
	Percolation from overlying aquifer	Recharge
	Stream flow	Streamflow Routing
	Lateral flow into the basin	General Head Boundary
Outflows	Groundwater Pumping	Multi-node Well 2
	Flowing Wells	Multi-node Well 2
	Flow to Streams	Streamflow Routing
	Lateral flow out of the basin	General Head Boundary

Parameter Estimation

The model was calibrated using UCODE_2005 (Poeter, 2005) which uses a modified Gauss-Newton nonlinear regression procedure that minimizes the sum-of-squared-weighted-residuals to estimate optimal parameter values. The Gauss-Newton equation (Hill and Tiedemann, 2007):

$$d_r = (X_r^T \omega X_r)^{-1} X_r^T \omega (y - y'(b_r))$$

where: r indicates the number of the parameter estimation iteration;
d_r is a displacement vector indicating the change in parameter values;
X_r is the sensitivity matrix calculated for the parameter values in b_r;
b_r is the vector of parameter values;
ω is the weight matrix; and
X_r^T is X transpose.

UCODE calculates the sensitivities needed for the regression by perturbation. Hill and Tiedeman (2007) provide an in depth description of parameter estimation with UCODE_2005.

Calibration Quality

Model quality is evaluated by the reasonableness of the estimated parameter values, similarity of simulated heads and flows to those observed in the field, and lack of bias in the residuals. A residual is the difference between a measured value observed in the field and the equivalent value simulated by the model.

$$\text{residual} = (\gamma_{\text{measured}} - \gamma_{\text{simulated}})$$

A weighted residual compensates for measurement error. Here, the weight is calculated as the inverse of the measurement variance.

weight = (1/variance)

Nonlinear regression is used to minimize the sum-of-squared-weighted-residuals (SOSWR) in which simulated values from MODFLOW (Harbaugh, 2000) are subtracted from the observed values and this difference is squared and weighted. Sensitivities of the simulated values to the estimated parameters are determined by perturbation. The residuals and sensitivities are used in the modified Gauss-Newton method to determine the combined linear change of parameter values to minimize the SOSWR. Because the relationship between parameters and observations is nonlinear this process is repeated until the change of parameter values is less than a user specified fraction of the parameter values. This is called convergence of the parameter estimation process. After the regression, parameter values are evaluated to determine if they are hydrologically reasonable.

Observations of water levels were compiled to assess groundwater flow direction and to establish potentiometric surface elevation to compare the simulated results. The North Dakota State Water Commission and USGS collected the water level information from observation wells. Most wells have many observations taken at different times. In some cases water level observations from driller logs have been used in the model. There is more uncertainty associated with these observations due mainly to location and elevation. The observations from these logs were evaluated individually to determine if the reported observation was reasonable. Ideally, observations from driller logs would be field verified and checked before use in the model. Water level information in the Montana portion of the basin was obtained from Montana's Ground Water Information Center. Altogether there are 3,319 observations.

The calculated error variance is a measure of the data accuracy. Significant deviations from 1.0 indicate that the model fit is inconsistent with observation weighting. Currently all hydraulic head observations are weighted the same. The weights represent a 90% confidence that heads are within 45 feet. The weight includes errors in water-level measurements and elevation, some of the problems with elevation stem from approximated location information. Location can be particularly problematic in areas along the Little Missouri and Knife River valleys that are characterized by high relief. Observation wells established by the USGS or the North Dakota State Water Commission have been field checked and may have had the elevation surveyed. These wells should have a larger weight than observations from driller's logs. Weights that better represent measurement error are a possible model improvement.

The distribution of residuals is evaluated graphically because any bias noted in the graphs may suggest errors in the conceptual model. A graph of the measured versus simulated values should exhibit a straight line with a slope of 1.0 passing through the origin. Models with less bias will have a graph that is most similar to this ideal. Deviations from this line should be randomly and independently distributed. If the line deviates from the 1:1 correlation, an alternative conceptual model may provide a better fit. Figure 14 shows the unweighted simulated values versus the unweighted observations.

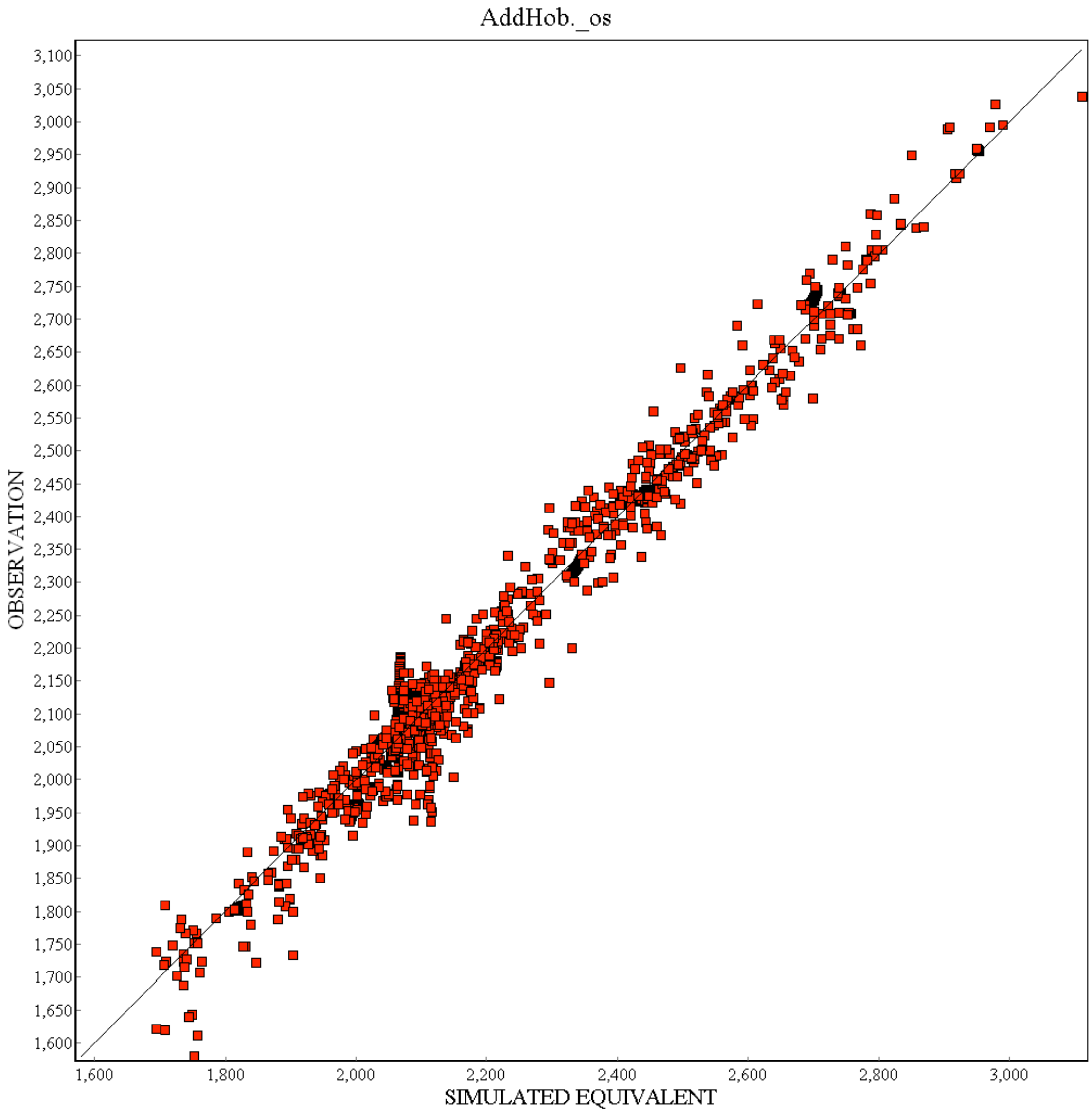

Figure 14. Unweighted observed versus unweighted simulated values. A perfect model with perfect data would have y = x.

A graph of weighted measured versus weighted simulated values demonstrates the same concept but corrects for uncertainty associated with measurements. A graph showing weighted observed versus weighted simulated values for the model is shown in figure 15.

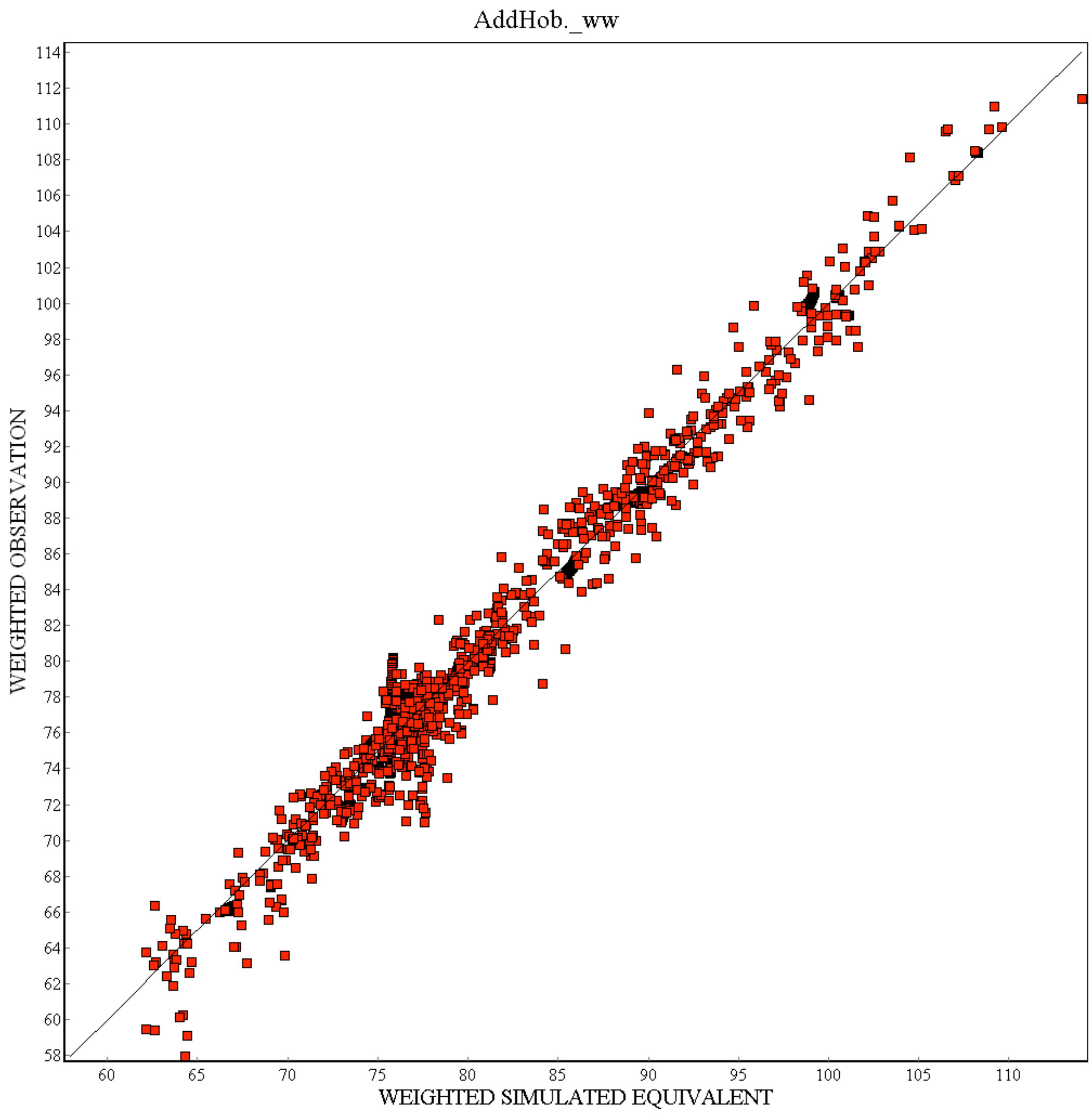

Figure 15. Weighted observed versus weighted simulated values. A perfect model with perfect data would have y = x.

A graph of weighted residuals versus simulated values and a graph of weighted residuals versus time may reflect spatial or temporal bias. These graphs should form a uniform horizontal band centered on zero with approximately the same number of positive and negative residuals. Trends in the data can indicate that the conceptual model may be flawed. For example, if more of the residuals are positive it suggests that the simulated heads are too low. Alternative model constructs could include estimation of a parameter that could increase the amount of water entering the basin. Conversely if the residuals are more negative it indicates the simulated values are too high and alternative models need to be constructed to create a more representative model. A graph showing weighted observed residuals versus weighted simulated values for the model is represented in figure 16. The vertical linear feature clearly visible in this figure represents water levels from one well, hydrograph 7878 in Appendix A. The water levels in this well have been influenced by the geology of the Nesson anticline. Gas is trapped in the crest of the anticline in the relatively permeable FH-HC aquifer. When the pressure build up caused by the gas is relieved, water levels will decline as shown in the hydrographs.

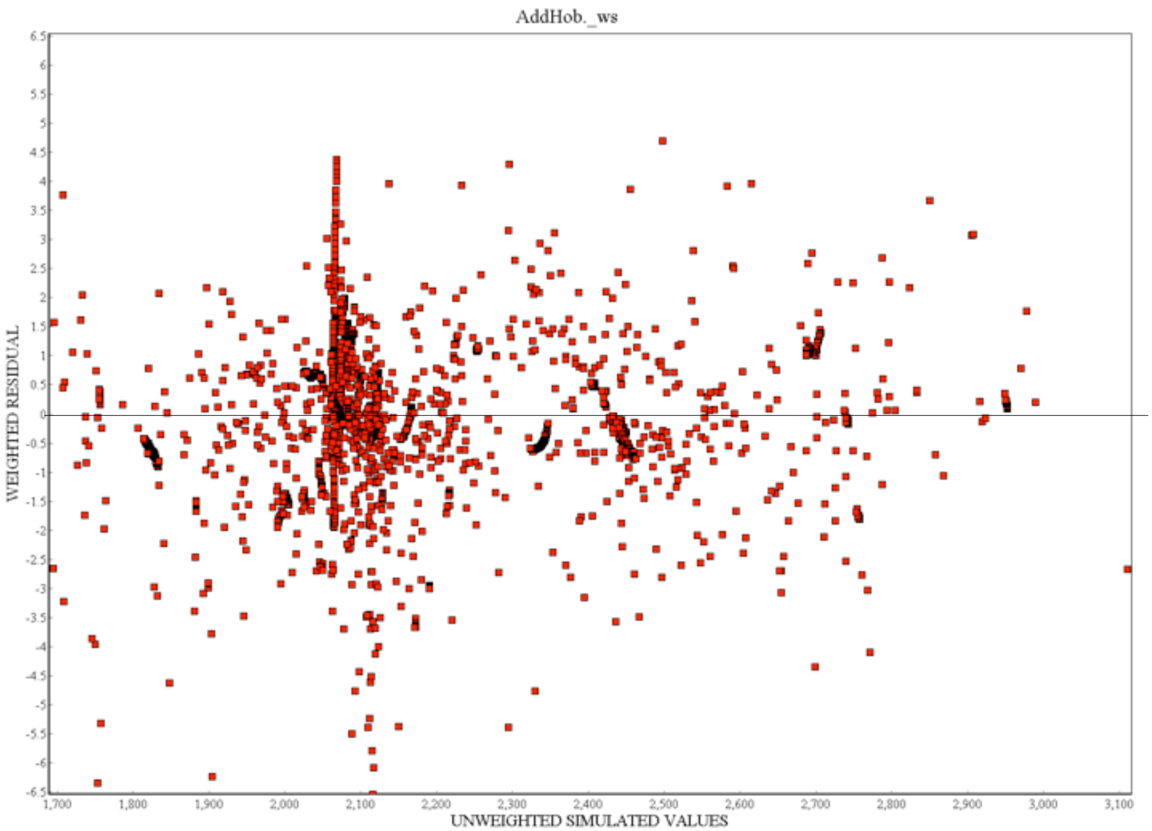

Figure 16. Weighted residuals versus simulated equivalents.

A graph showing residuals through time for the model is represented in figure 17. The lowest residuals in 1972 are caused by water level observations in pumping wells, surveyed as part of the county ground water studies. Most of the water level observations in Montana were taken as part of a study of the FH-HC aquifer undertaken from 1993 to 1995. The increased positive residuals in 1995 are from observations in Montana.

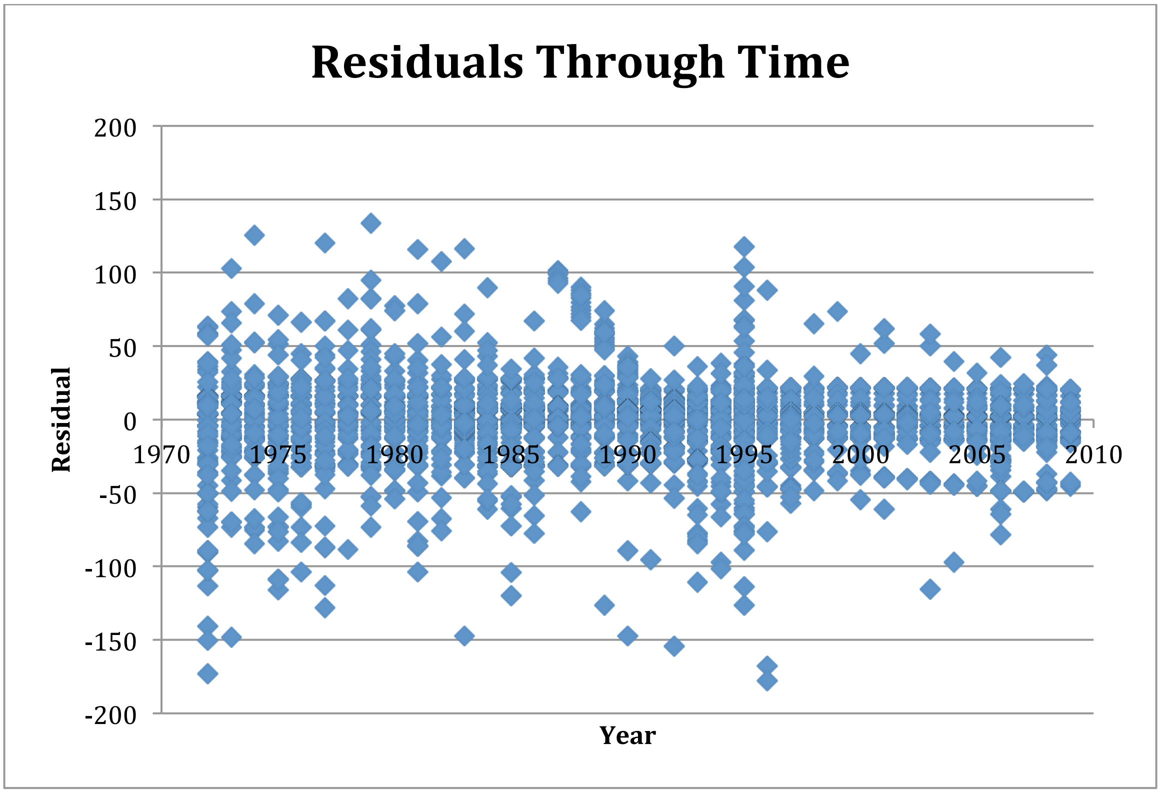

Figure 17. Residuals through time.

Assumptions underlying nonlinear regression require a normal distribution of measurement errors. True error will never be known so the distribution of residuals is evaluated as a surrogate. The residuals should plot as a straight line on normal probability paper if the residuals are normally distributed. The graph (Figure 18) suggests that there may be room for improvement in the conceptual model.

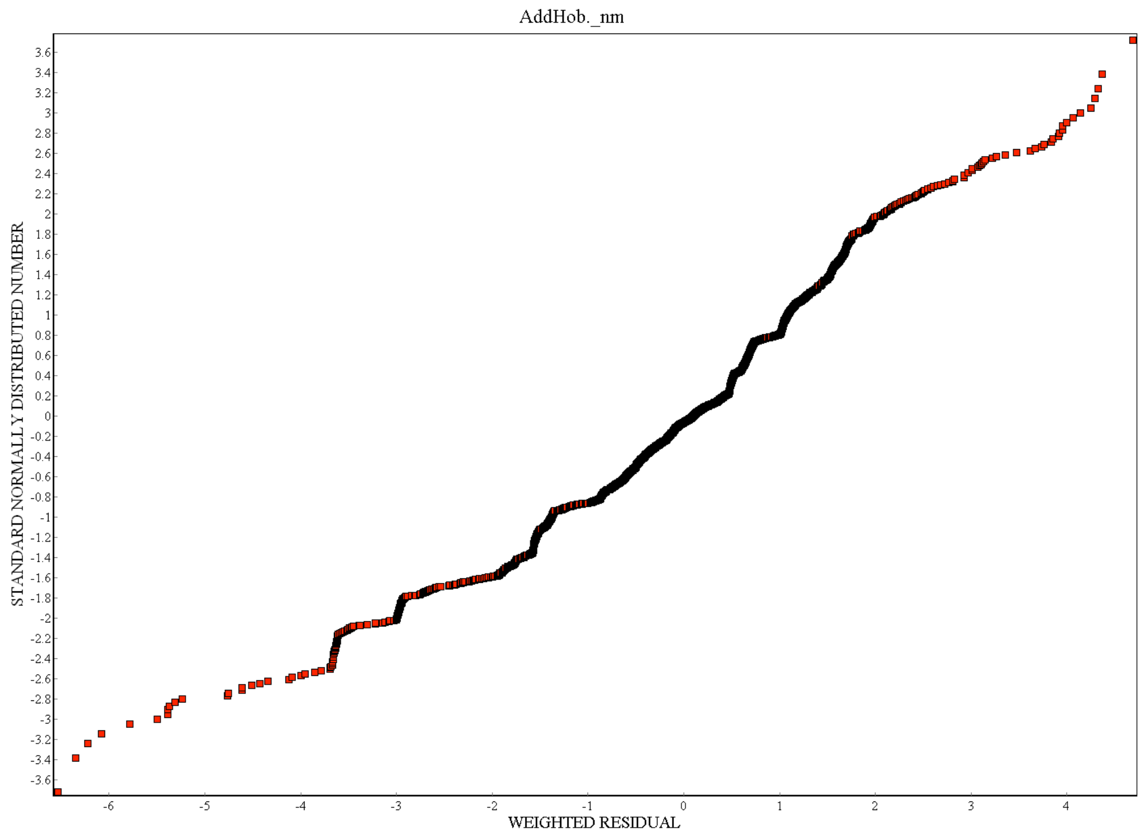

Figure 18. Normal Probability graph showing the trend of weighted residuals.

For a quick analysis the residuals of observations in Montana, residuals from drillers logs observations and residuals from wells influenced by gas in the formation (7877 and 7878 in Appendix A) were removed. The resulting graph (Figure 19) shows a straighter line, the remaining tail is mainly a result of outliers.

The spatial distribution of residuals for all times are mapped to examine whether there is a random pattern of positive and negative, small and large, residuals throughout space. A preponderance of residuals of the same sign in some areas can be used to develop better conceptual models. Figure 20 depicts the spatial distribution of residuals throughout the model time domain. The model shows a fairly random distribution of residuals with few large negative or positive residuals. More residuals are concentrated in the major river valleys as this is where the concentration of observations is located. Some large residuals occur along river valleys where the relief is great; uncertainty associated with land surface elevation is likely a major constraint.

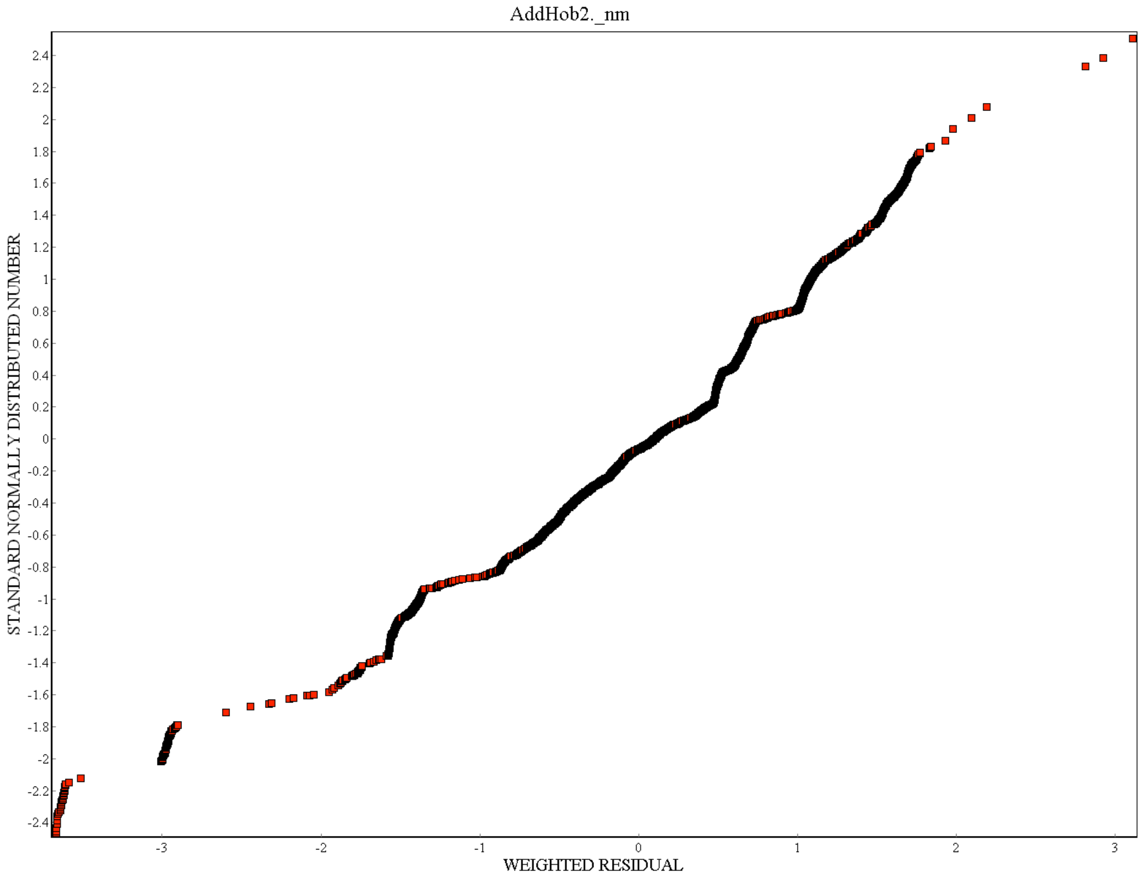

Figure 19. Normal Probability graph showing the trend of weighted residuals (residuals from driller log observations and residuals for wells influenced by formation gas removed).

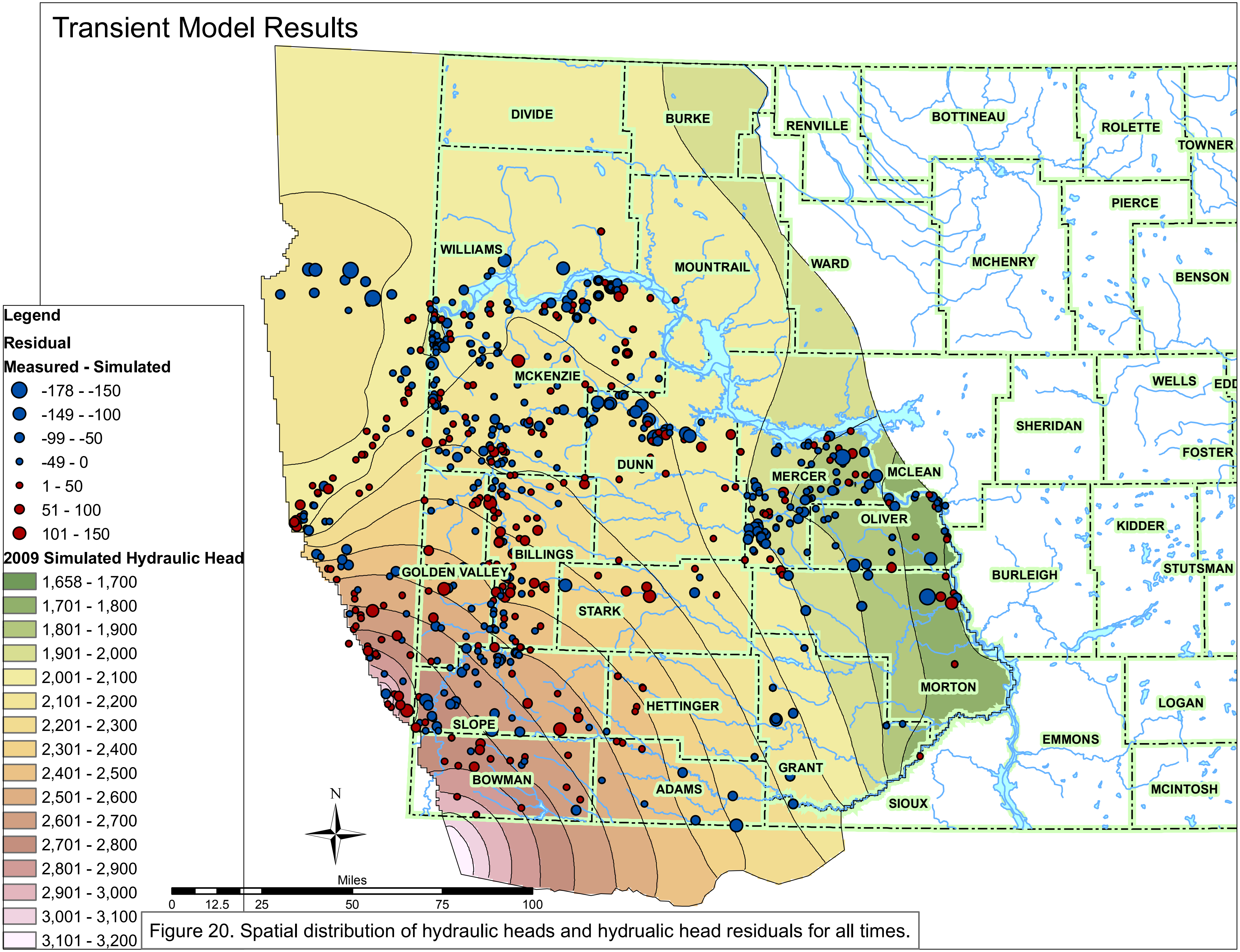

Figure 20. Spatial distribution of hydraulic heads and hydrualic head residuals for all times.

The hydrographs in Appendix A can also be evaluated to determine how well the simulated water levels match the observed water level trends. For the most part the model does a good job of matching the observed trends in water levels. There is some evidence of the previously mentioned uncertainty in the land surface elevation, as the simulated water levels match the trend but not the elevation of the observed water levels, for examples of this trend refer to hydrographs; 131-102-07DDD1, 135-097-04DCA, 139-096-07AA, 140-102-06DCC, 140-102-10DCA. Also hydrographs near the cities of Golva and Dodge (hydrographs 140-105-30CCC6, 144-091-10CBC) show an increase in water levels as each of the respective cities switched to the Southwest Pipeline, Dodge in 1996 and Golva in 2006. In the northeast section of the model domain the model does a poor job of matching the steep decline seen in the observed water levels (hydrographs 151-095-04DBD2, 151-095-30ACA, 153-094-23CCC1), this could be due to the proximity of the general head boundary. Other notable information from the hydrographs is an 11 foot rise in the water level in the southeast portion of the model domain (hydrograph 136-081-07DDC1), this could be occurring due to the aquifer being close to the surface and consequentially closer to potential recharge. A comparison of the precipitation trends with the water levels shows a correlation between wet periods and aquifer rebound and dry periods and aquifer decline.

Results

As of July 2012, there are four water permit applications for the FH-HC aquifer awaiting review within the model area. Understanding the results for the calibrated transient model will provide insight to key aquifer components. The calibrated transient model is also used as basis for prediction at the current level of use in the latter portion of this report. Additionally, the model will be used to determine the drawdown that would occur from the additional level of pumping that would occur if the water permit applications were approved.

Recharge along the Cedar Creek anticline was estimated during calibration. There is a clear correlation between the location of small streams flowing off the Cedar Creek anticline and recharge to the aquifer as is evident by the recharge multipliers along the Cedar Creek anticline. Most of the recharge along the anticline occurs just east of Baker, Montana from intermittent tributaries to the Little Missouri River. Figure 9 summarizes the recharge values in inches per year.

The volume of water discharged from flowing wells was also a significant unknown at the start of this modeling project. Well inventories have shown that there are approximately 54% more flowing wells than were previously known about (Wanek, 2009). Model calibration has shown that most of the discharge from flowing wells occurs in the southern portions of the Yellowstone and Little Missouri River basins. Pumping rates along the Yellowstone River could be inflated due to elevated heads in the initial condition and the greater uncertainty associated with the Montana portion of the model. However based on conversations with the Montana Bureau of

Drawdown

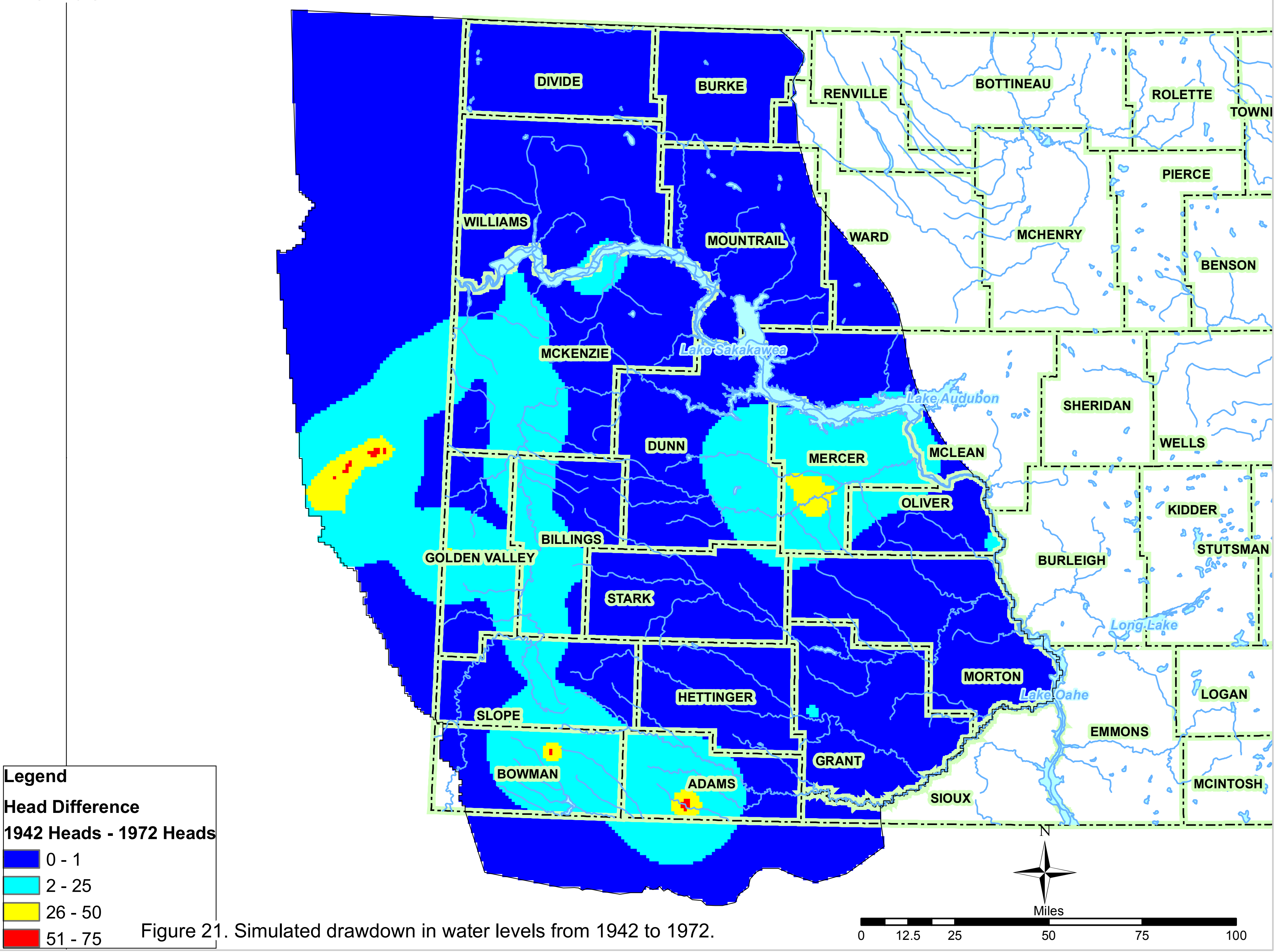

Figure 21. Simulated drawdown in water levels from 1942 to 1972.

Drawdown

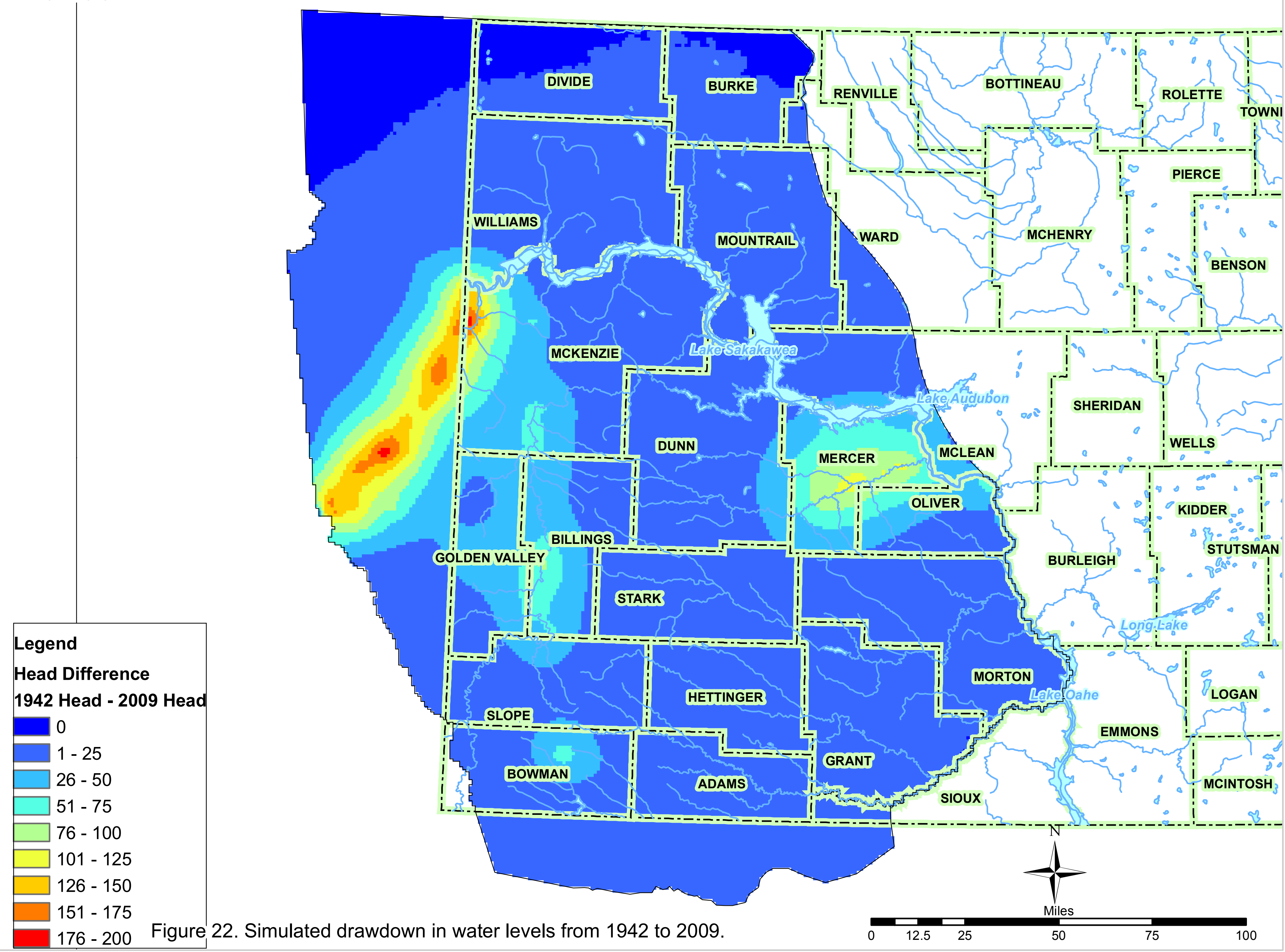

Figure 22. Simulated drawdown in water levels from 1942 to 2009.

Mines and Geology, the drawdown occurring in Montana is greater, approximately 2-5 feet per year, than the average drawdown occurring in North Dakota, approximately 1 foot per year justifying the greater pumping rates and drawdown (Figures 21 and 22) seen along the Yellowstone River in Montana. For a summary of optimized parameter values refer to table 6.

Table 6: Summary of optimized parameter values.

Parameter	Optimized Value
Hydraulic Conductivity	0.71
Specific Storage multiplier	3.32
Recharge Cedar Creek Anticline North (in/yr)	0.06
Recharge Cedar Creek Anticline N Middle (in/yr)	0.50
Recharge Cedar Creek Anticline S Middle (in/yr)	0.05
Recharge Cedar Creek Anticline South (in/yr)	0.81
Flowing Wells N Yellowstone Multiplier	6.96
Flowing Wells M Yellowstone Multiplier	8.14
Flowing Wells S Yellowstone Multiplier	18.8
Glendive Wells Multiplier	10.7
Flowing Wells Knife River Multiplier	11.5
Flowing Wells N Little Missouri Multiplier	3.97
Flowing Wells S Little Missouri Multiplier	5.15
Flowing Wells W Little Missouri Multiplier	0.00
Flowing Wells Outliers Multiplier	0.00
Sum of Squared Weighted Residuals	5760.2
Upper Calculated Error Variance Limit	1.73
Calculated Error Variance	1.65
Lower Calculated Error Variance Limit	1.58

To assess sources of recharge and discharge, a zone budget analysis was conducted for 11 defined zones (Figure 23) using ZONEBUDGET (Harbaugh, 1990, 2008). Quantities of flow for the steady-state model in 1942 and the transient model in 1972 and 2009 in acre-feet per year are summarized in tables 7a, 7b and 7c. Zones were divided based on sources of discharge and recharge. To simplify results zones 2, 7 and 9 were combined to represent flowing and pumped wells along the Little Missouri River. Similarly zones 3, 5 and 6 represent discharge from pumped and flowing wells along the Yellowstone River. Separation of these zones occurred based on flowing well zones. For a full accounting of the results of the zone budget analysis, including the flow between zones, refer to Appendix C. The largest components of recharge occur in zone 4 as a result of recharge occurring in South Dakota, represented as recharge occurring along the Cedar Creek anticline. This source of recharge, accounts for 74% of the total annual inflow in 2009. The two main sources of discharge occur along the Yellowstone River in zones 3, 5 and 6, and along the Knife River Valley in Zone 10, 29% and 20% of the total discharge respectively.

Table 7a: Summary of zone budget analysis for 1942 (flow between zones not shown).

In	Zone 1 acre-ft/yr	Zone 2 + 7 + 9 acre-ft/yr	Zone 3 + 5 + 6 acre-ft/yr	Zone 4 acre-ft/yr	Zone 8 acre-ft/yr	Zone 10 acre-ft/yr	Zone 11 acre-ft/yr
General Heads	0	0	0	0	0	0	57
Recharge	100	89	188	2163	0	0	0
Stream	0	0	0	9	0	0	0
Out							
General Heads	459	0	0	0	265	399	1008
Stream	0	0	0	422	0	0	0
Multi-node Wells	0	0	21	0	0	0	0

Table 7b: Summary of zone budget analysis for 1972.

In	Zone 1 acre-ft/yr	Zone 2 + 7 + 9 acre-ft/yr	Zone 3 + 5 + 6 acre-ft/yr	Zone 4 acre-ft/yr	Zone 8 acre-ft/yr	Zone 10 acre-ft/yr	Zone 11 acre-ft/yr
General Heads	0	0	0	0	0	0	57
Recharge	100	89	188	2163	0	0	0
Stream	0	0	0	9	0	0	0
Out							
General Heads	362	0	0	0	265	396	990
Stream	0	0	0	420	0	0	0
Multi-node Wells	164	752	1330	491	69	1064	37
Change in Storage (In-Out)	115	755	1277	428	82	1035	74

Table 7c: Summary of zone budget analysis for 2009.

In	Zone 1 acre-ft/yr	Zone 2 + 7 + 9 acre-ft/yr	Zone 3 + 5 + 6 acre-ft/yr	Zone 4 acre-ft/yr	Zone 8 acre-ft/yr	Zone 10 acre-ft/yr	Zone 11 acre-ft/yr
General Heads	147	0	0	0	0	151	79
Recharge	100	89	188	2163	0	0	0
Stream	0	0	0	11	0	0	0
Out							
General Heads	97	0	0	0	265	180	925
Stream	0	0	0	369	0	0	0
Multi-node Wells	460	1094	2774	345	320	1733	119
Change in Storage (In-Out)	126	1326	2171	278	677	1097	110

Table 8: Summary of the total budget for 1942,1972, and 2009 in acre-feet.

In	1942	1972	2009
General Heads	57	57	377
Recharge	2,540	2,540	2,540
Stream	9	9	11
Out			
General Heads	2,131	2,013	1,467
Stream	422	420	369
Multi-node Wells	21	3,909	6,845
Change in Storage (In-Out)		3,766	5,785

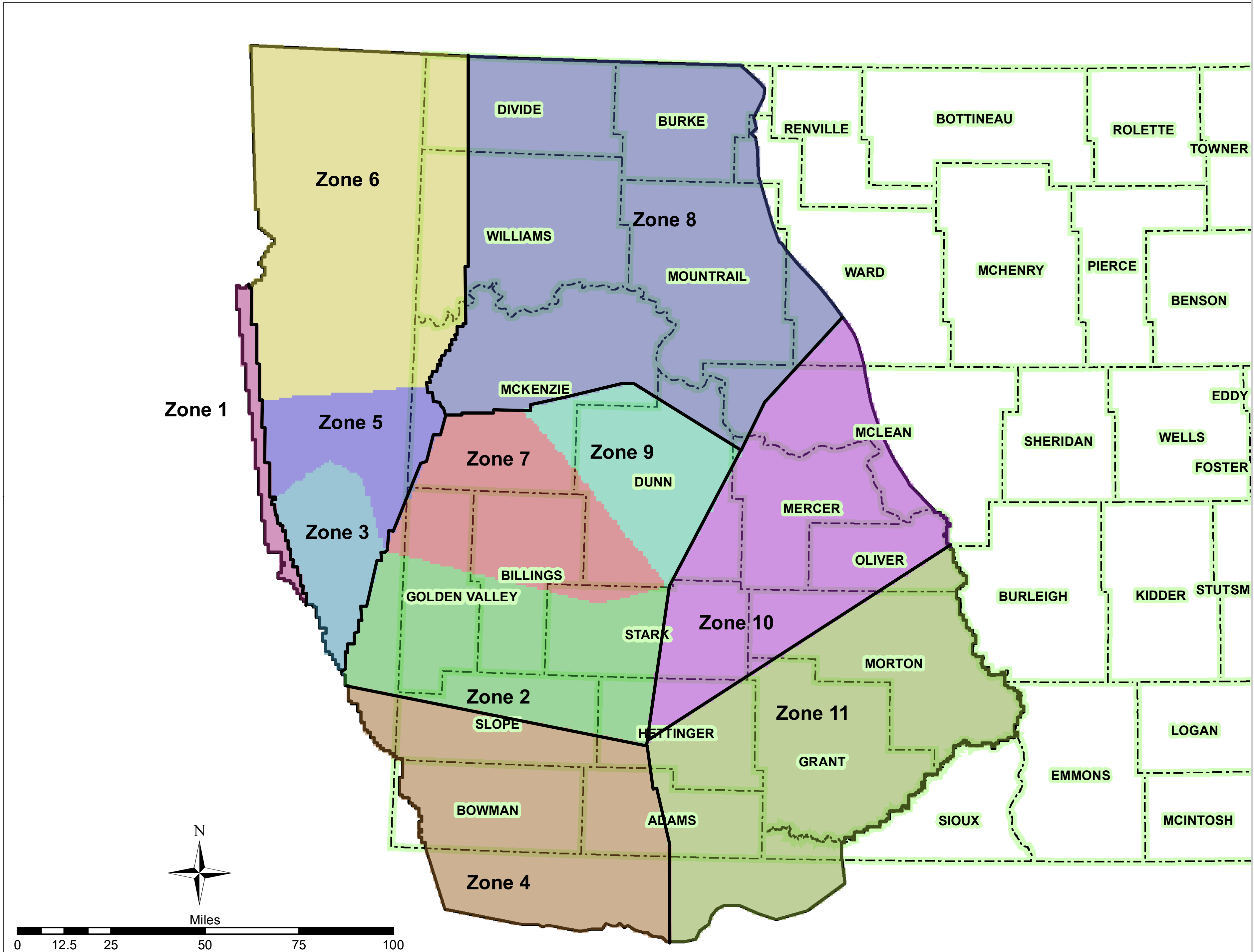

Figure 23. Zones used in the FH-HC aquifer model for zone budget analysis.

The simulated heads for 1942, 1972 and 2009 are contoured in figure 24. The simulated drawdown in water levels from 1942 to 1972 is contoured in figure 21 and the simulated drawdown from 1942 to 2009 is contoured in figure 22. In response to flowing wells and pumping in the aquifer, drawdown is occurring in the major river valleys along the Yellowstone, Little Missouri and Knife rivers. Most of the drawdown has occurred in the last 30 years.

The general head boundaries were specified at a distance of 5 miles. These general head boundaries are effectively constant head boundaries for the model because of the relatively small specified distance. This places the flowing head wells along the Knife River close to a constant head boundary. By 2009, the boundary is supplying 370 acre-feet to the flowing wells in zone 10. This is approximately 20% of the well discharge for zone 10, but it does indicate that the model would under predict future drawdown in the area. If the model predicts excessive future drawdowns from further development in this area, then this is an additional justification for not granting the permit application. The same issue is occurring with the GHB in Montana between the Cedar Creek anticline and the Poplar Dome, in zone 1, where 362 acre-feet per year is being derived from the boundary.

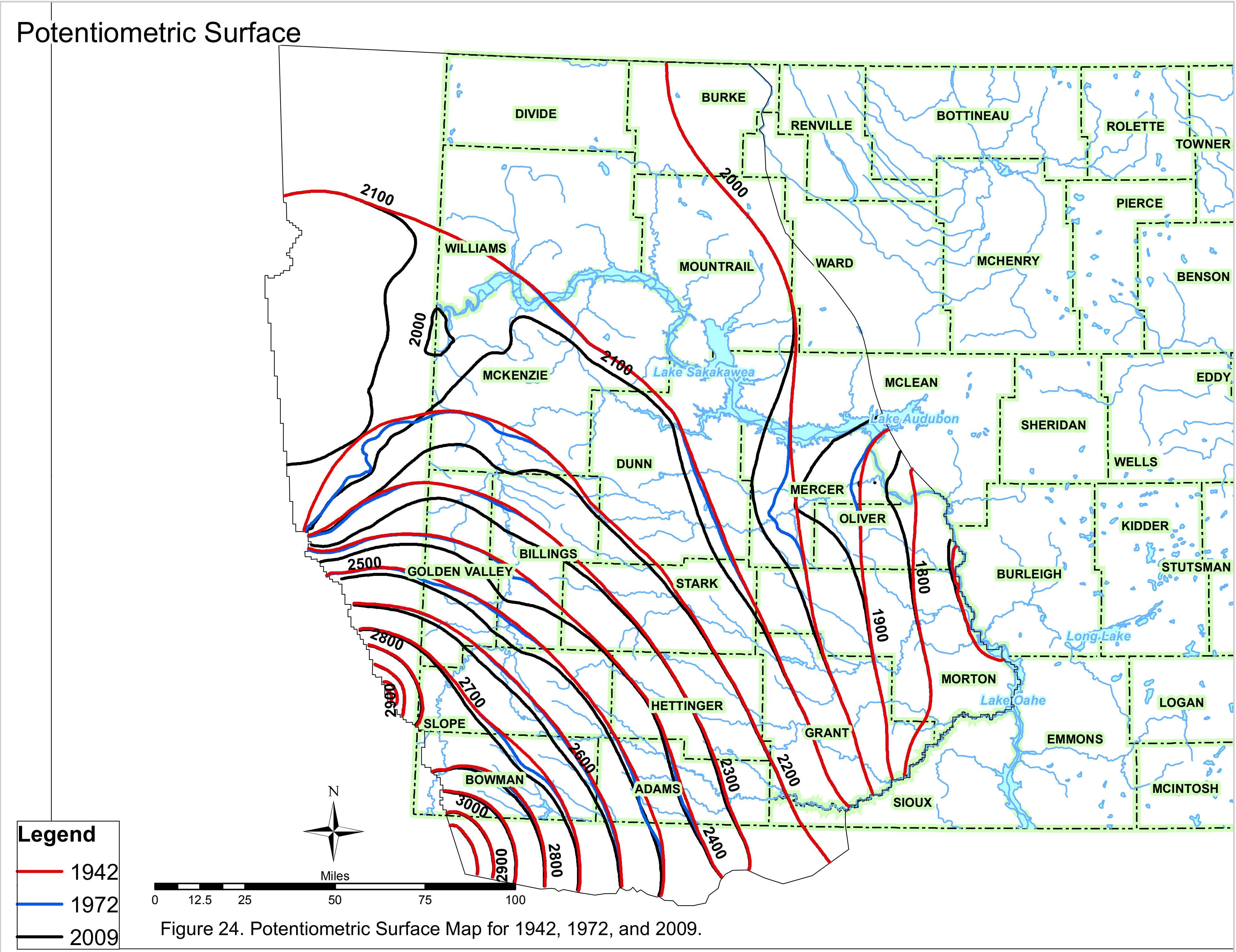

Figure 24. Potentiometric Surface Map for 1942, 1972, and 2009.

Interaction between the FH-HC aquifer and overlying aquifers was a significant unknown at the start of this study. The clayey member of the upper Hell Creek Formation forms an aquitard above the FH-HC aquifer. Sedimentary units dominated by clays are commonly the least permeable parts of the groundwater flow system. However, the depositional environment of the Hell Creek Formation primarily occurred in flood plains and fluvial channel systems, leading to spatial variability in the geology of the formation. One of the goals of this modeling study was to determine how leakage through this layer affects the regional groundwater flow system. To this end, two recharge parameters simulating leakage were specified for the model based on the head differential with the overlying aquifers. One of the parameters was positive, indicating recharge from leakage, in areas where the head in the overlying aquifers was higher than the head in the FH-HC aquifer. The other zone was negative for areas where the FH-HC head is higher than the head in overlying aquifers and the FH-HC aquifer could be losing water from leakage through the aquitard. During parameter estimation it was determined that leakage from overlying sediments is a very small component of the groundwater budget, negligible in comparison to the other components of the budget. An acceptable calibration was achieved assuming no leakage occurs to the FH-HC aquifer. This model shows that most of the water discharged by the wells from the FH-HC is derived from storage as of 2009 (tables 7c and 8). Though it may be possible to develop a FH-HC aquifer with significant transient leakage (leakage is head dependent with water derived from storage in the aquitard), it would not invalidate this model as part of the solution domain. Demonstrating that wells could derive a larger and larger percent of their water from the overlying aquitards, which would eliminate future mining, is not enough. Any future model must show that significant leakage must be occurring to invalidate this model. Given the uncertainties of the hydrostratigraphy, well yield and elevations etc, this seems unlikely to be done. Therefore given that further water level declines is the primary management concern for the FH-HC aquifer, this model should be the basis for management of the aquifer.

Summary of Model Calibration

A regional model of groundwater flow in the FH-HC aquifer was developed to provide a better understanding of the aquifer and a foundation for management policy. Groundwater flow in the confined aquifer system primarily is from the southwest to the northeast. The main components of recharge occur from lateral flow into the system, recharge along the Cedar Creek anticline and stream flow from the Little Missouri River where the aquifer is close to the surface. Discharge primarily occurs from underflow to areas east of the Missouri River and from discharge to pumped and flowing wells. Lateral boundary conditions were represented as no flow or general head boundaries. The model was calibrated using available hydraulic head observations from 1972 through 2009. Multipliers were estimated for hydraulic conductivity, specific storage, recharge, discharge to flowing wells, streambed conductance and some general head boundary conductivities using UCODE_2005.

In general the model accurately simulates water levels and water level fluctuations. As such this model can be used as a water management tool with an understanding of its limitations and areas that could use improvement. The simplicity of the one layer model likely creates some biases in the model results. For example, ignoring storage in the overlying aquitard, if significant, will result in the model over predicting drawdown. This would become a larger issue as the time of prediction increases. Another limitation is caused by the scarcity of available data. Future work could include adding detail in the southeast as more water level information becomes available. There are still parts of the model that could use improvement, particularly in the southeast part of the model domain in Grant and Morton Counties.

Prediction

The calibrated transient model was run in prediction mode to predict the equilibrium pressure head resulting from the current level of discharge and use. A thirty-year period from 2010 to 2040 is considered. Water level elevations at 74 locations are predicted as delineated in figure 25. Locations chosen for prediction are wells that have been monitored as part of the flowing well studies conducted at decadal intervals, monitoring wells for the NDSWC or the USGS, and the locations of pending permit applications for the FH-HC aquifer that lie within the model domain.

Boundary conditions during prediction mode were consistent with boundary conditions used during the calibrated model. The general head boundary representing flow into and out of the system remained constant, using the same parameter values used in the calibrated model. Recharge due to precipitation and percolation from overlying aquifers also remained constant using the multipliers estimated during parameter estimation. Stream flow measurements from the gage at Camp Crook, South Dakota were repeated reusing measurements from the past thirty years. The measured discharge to pumped wells in 2009 was repeated for the prediction simulation with one exception. An industrial permit that was previously not using water commenced selling water to the oil industry in 2010. The pumping rate for that well was increased to account for the additional known water use. The estimated rate of discharge and the number of flowing wells entered into the model remained the same as in 2009. The MNW2 package is head dependent, in that it decreases the discharge rate as the potentiometric surface elevation nears the land surface and ceases discharge when the potentiometric surface is at the land surface. When the potentiometric surface is not near the land surface, the rate of discharge for flowing wells remains constant based on discharge information where available and estimated rates of discharge when discharge data is not available. The hydrographs in Appendix B delineate the water levels for the flowing well prediction locations. The hydrographs include the decline rate of the flowing wells and the pumping rate for the transient model for the entire modeled time period.

Figure 26 is the cumulative discharge for measured and flowing wells from 1972 through 2039. The discharge from flowing wells in prediction mode decreases from approximately 5,970 acre-feet in 2010 to 5,180 acre-feet at the end of 2039. The change is due to the decrease in discharge as flowing wells stop flowing.

Prediction Locations

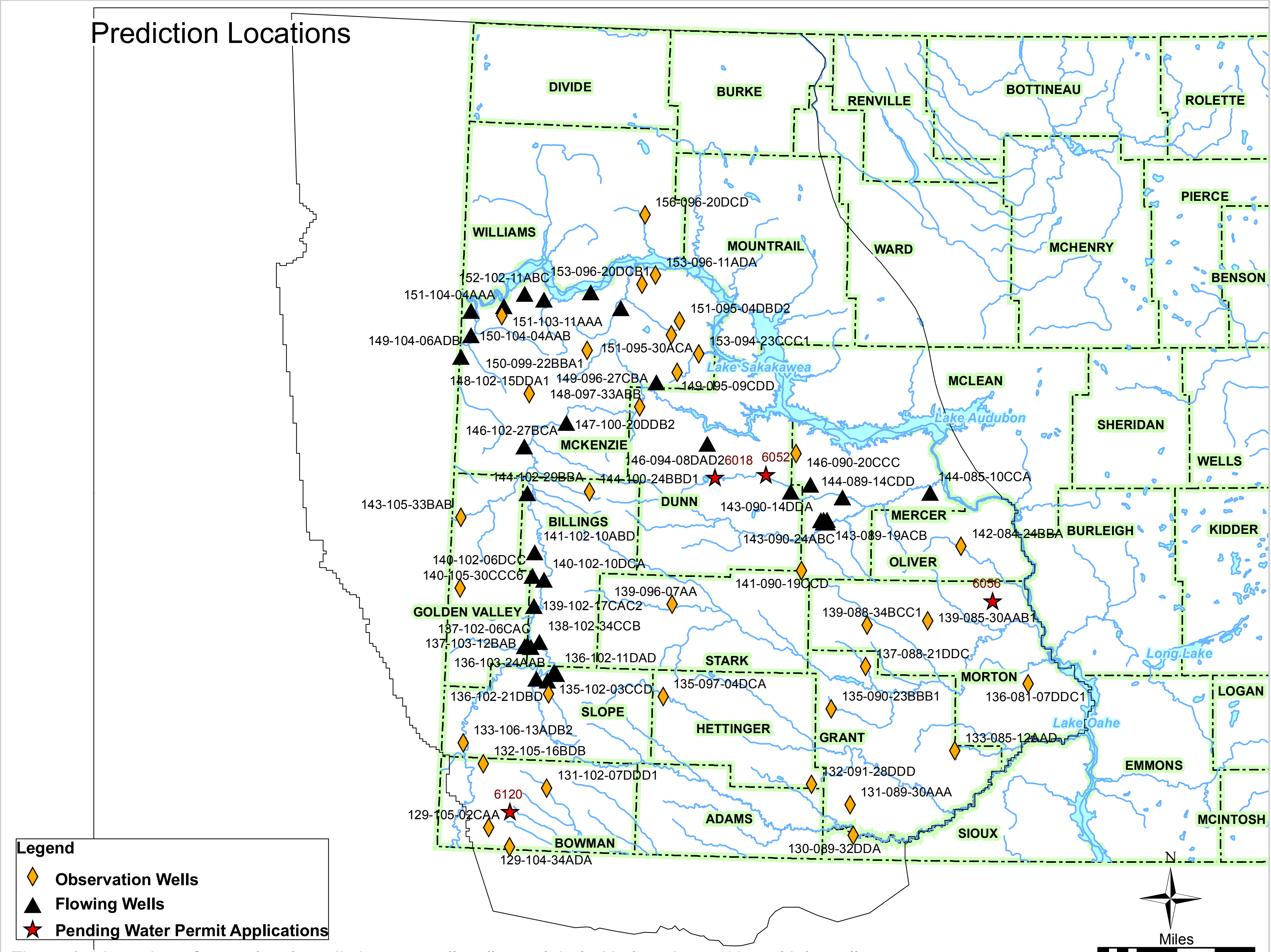

Figure 25: Location of water level predictions, not all wells are labeled in locations with multiple wells.

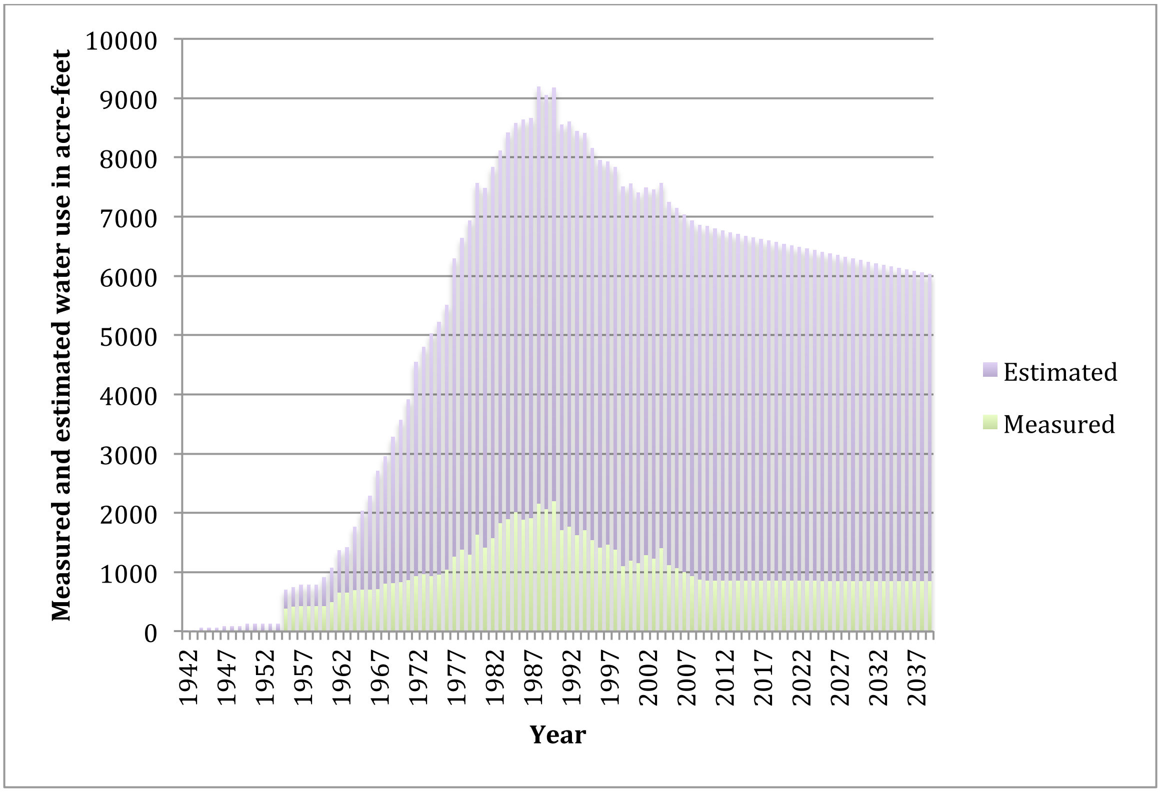

Figure 26. Annual water use from the Fox Hills-Hell Creek aquifer, measured water use after 2009 is the 2009 rate.

The predicted heads for the end of 2039 with the current level of water use, and the 2009 simulated water levels are contoured in figure 27.

The simulated drawdown in water levels from 2009 to 2039 is contoured in figure 28. There is a depression centered in Mckenzie County where water levels are projected to decrease between 50 and 55 feet in the next 30 years. For this part of the basin, far from the recharge area, the aquifer water levels continually decline due to the large discharge rates from pumped and flowing wells. In areas of flowing heads along the Little Missouri River the decline of the aquifer slows as the discharge to flowing wells decreases due to the potentiometric surface nearing the land surface. This phenomenon may also be occurring in the Knife River Valley. However the proximity to the general head boundary creates a constant source of recharge to the aquifer. This recharge may be inflating water levels in the Knife River Valley (see the hydrographs in Appendix A).

Upper and lower 95% confidence intervals for the prediction locations average approximately 7 feet and are presented in figures 29a and 29b. The confidence intervals on the predictions include the uncertainty associated with the parameter values using parameters for prediction in UCODE (Poeter et al, 2008).

Potentiometric Surface

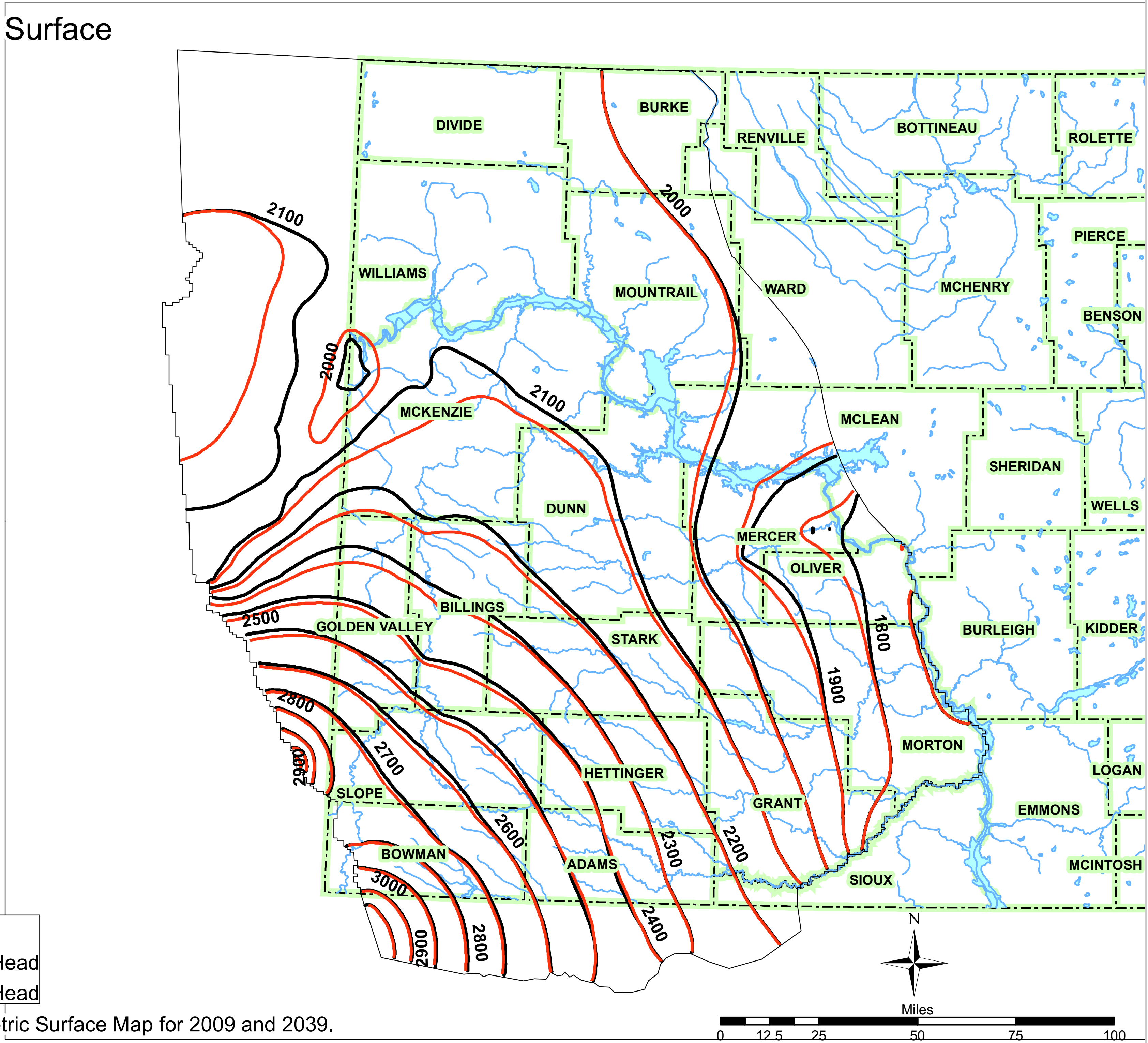

Figure 27. Potentiometric Surface Map for 2009 and 2039.

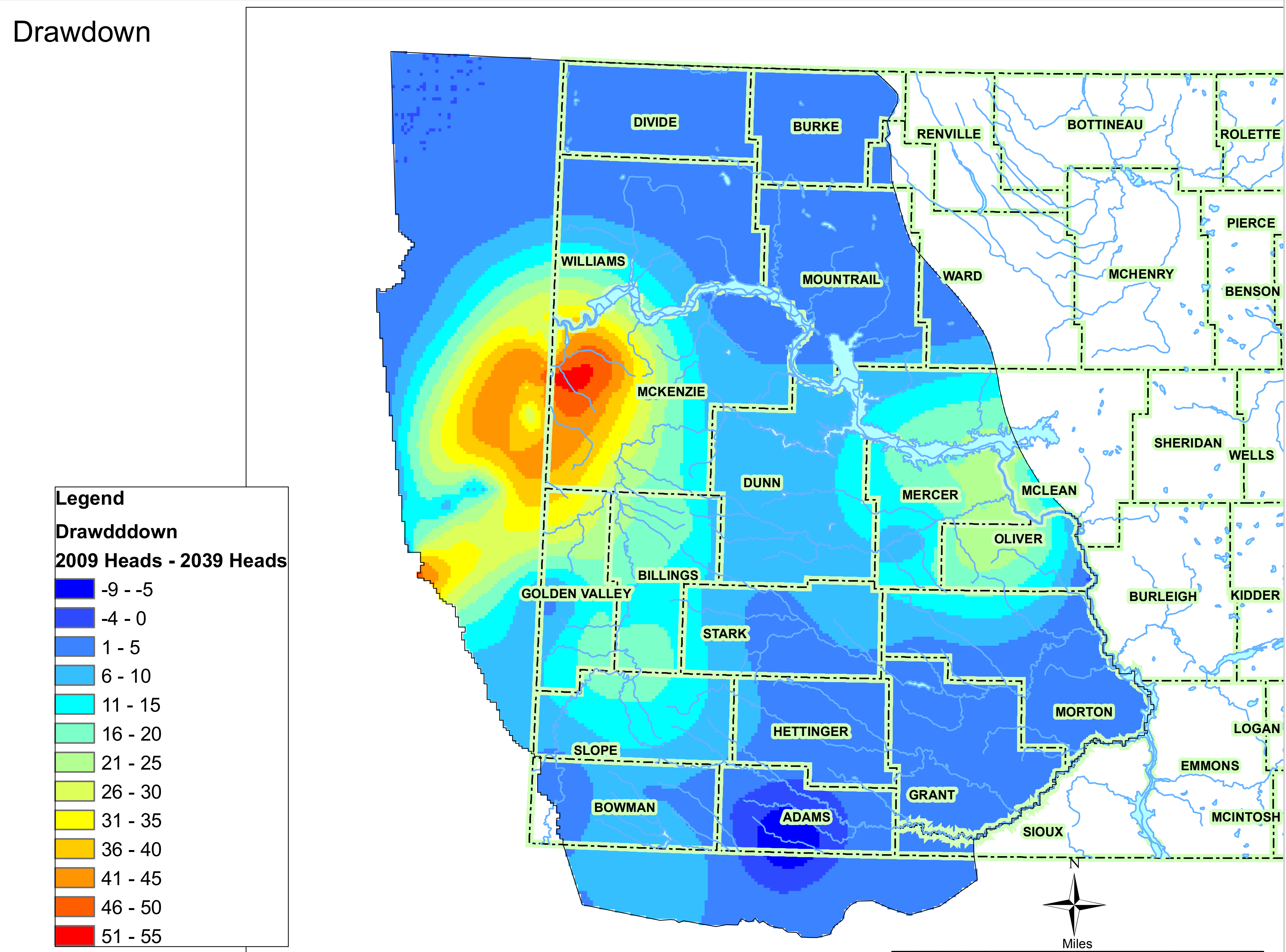

Figure 28. Simulated drawdown in water levels from 2009 to 2039.

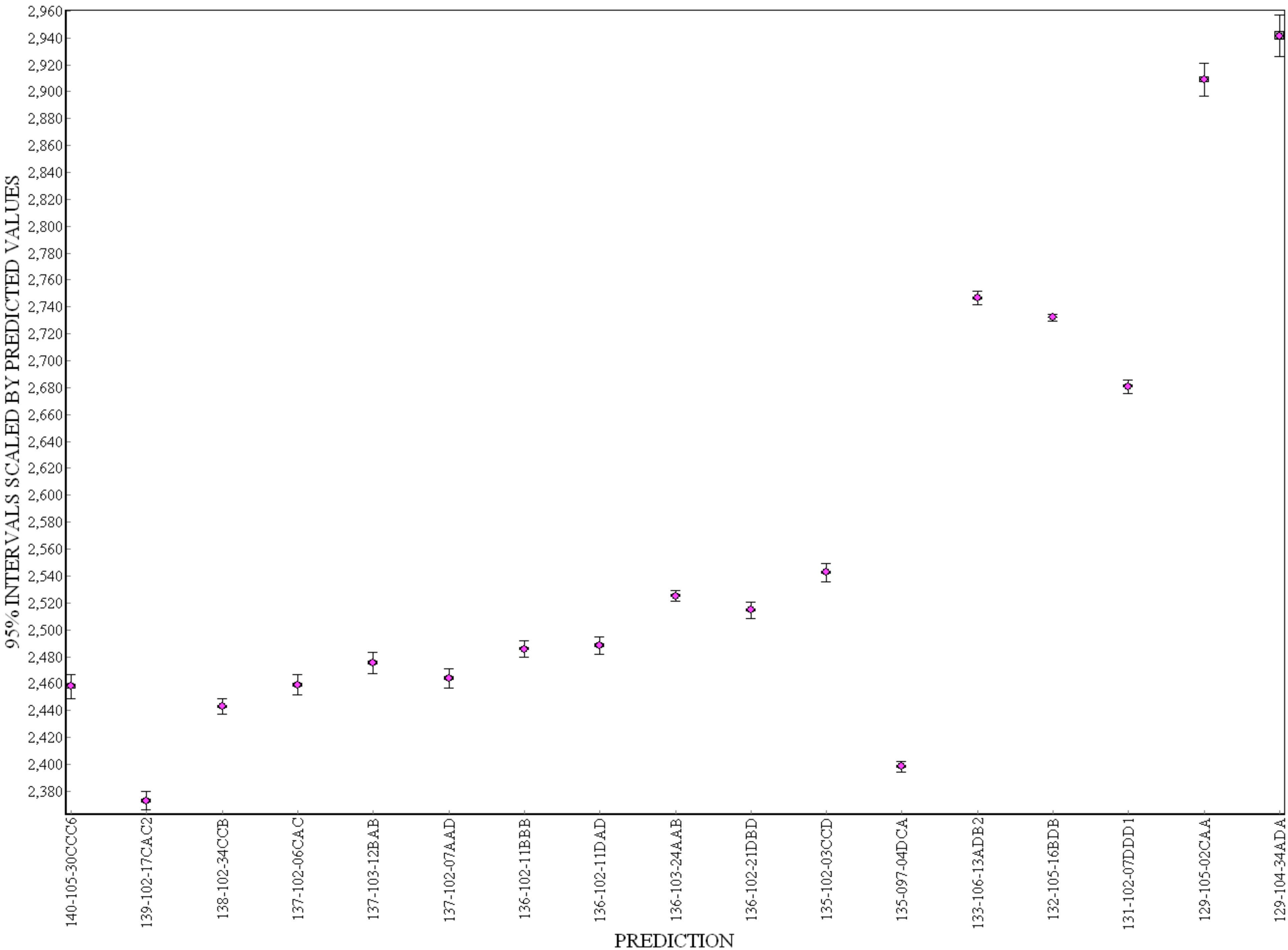

Figure 29a. Black lines are 95% confidence intervals and gray bars are one standard deviation for each prediction.

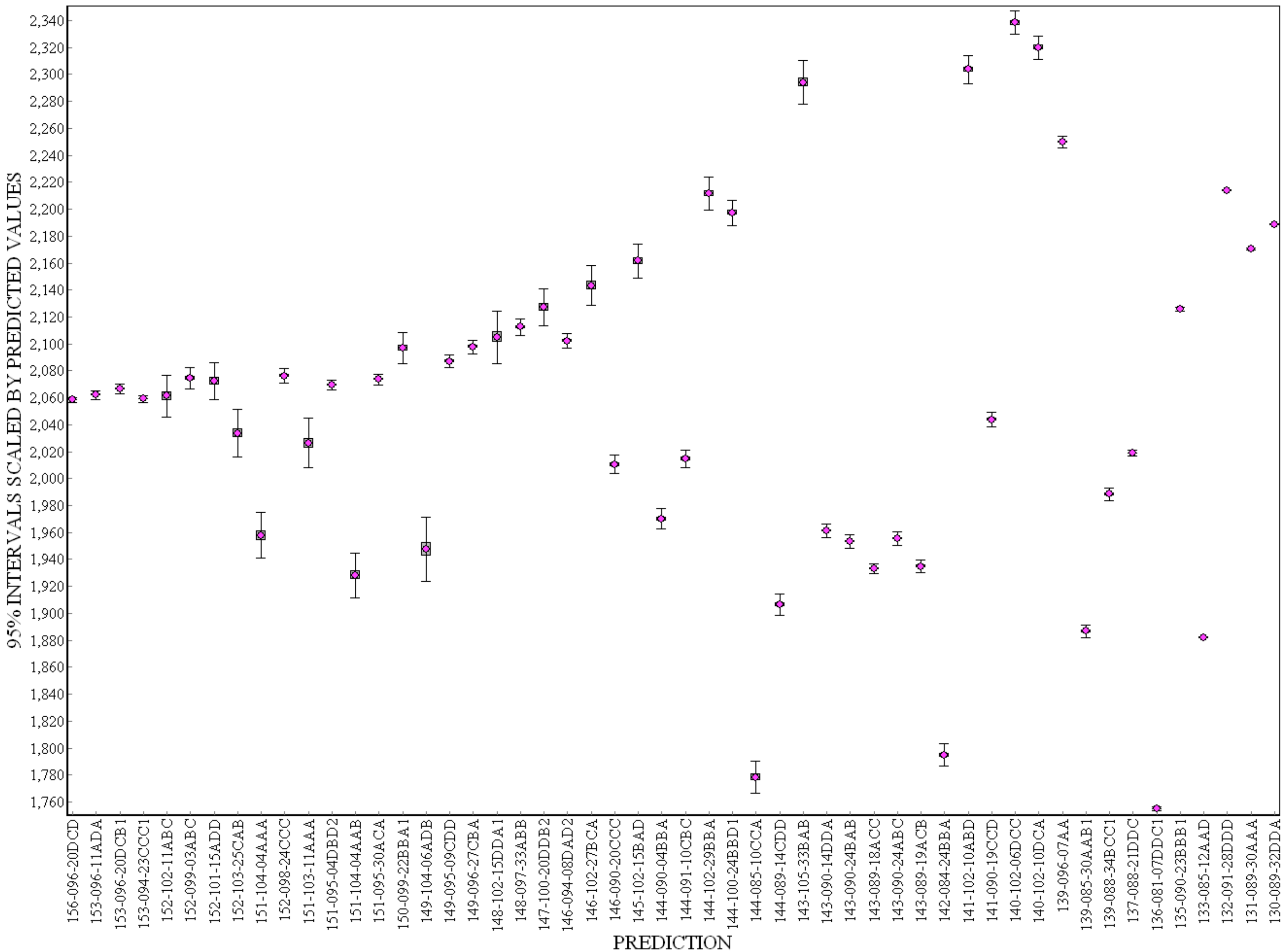

Figure 29b. Black lines are 95% confidence intervals and gray bars are one standard deviation for each prediction.

Prediction Results

As with the forward model, a zone budget analysis was conducted for the prediction model using the zones previously defined. Quantities of flow for 2039 in acre-feet per year are summarized in table 9. For a full accounting of the results of the zone budget analysis refer to Appendix C. The table indicates that the change in storage in zones 2+7+9 and zone 8 exceeds the discharge to the wells continuing the trend seen in table 7c. This is a result of the impact of the Montana wells causing drawdown of the aquifer in western North Dakota. Additionally, zones 2+7+9 and 10 show a significant decline in yield to flowing wells, developing from the aquifer dropping below the land surface. Wells in zone 10 are still deriving almost half of their water from the storage in the zone. Between 2009 and 2039 the wells have increased the annual flow from the general head boundary by 110 acre-feet. The actual water that could be derived from sources to the east is likely a small fraction of this. This would result in the drawdown being greater than predicted. With the prediction showing both declines in yield to wells and that the wells in zones 2+7+9 and 10 are still deriving much of their water from storage it can be concluded that any additional appropriation in these areas would only exacerbate the continuing decline in heads and flow rates at the existing wells. Table 10 provides a summary of the total budget from the zone analysis.

Table 9: Summary of zone budget analysis for 2039.

In	Zone 1 acre-ft/yr	Zone 2 + 7 + 9 acre-ft/yr	Zone 3 + 5 + 6 acre-ft/yr	Zone 4 acre-ft/yr	Zone 8 acre-ft/yr	Zone 10 acre-ft/yr	Zone 11 acre-ft/yr
General Heads	223	0	0	0	0	197	83
Recharge	100	89	188	2163	0	0	0
Stream	0	0	0	3	0	0	0
Out							
General Heads	32	0	0	0	264	116	916
Stream	0	0	0	325	0	0	0
Multi-node Wells	460	993	2247	345	301	1558	117
Change in Storage (In-Out)	68	1301	1461	296	693	689	151

Table 10: Summary of the total budget for 1942,1972, and 2009 in acre-feet.

In	1942	1972	2009	2039
General Heads	57	57	377	502
Recharge	2,539	2,539	2,539	2,539
Stream	9	9	11	3
Out				
General Heads	2,131	2,013	1,466	1,328
Stream	422	420	369	325
Multi-node Wells	21	3,907	6,845	6,021
Change in Storage (In-Out)		3,765	5,784	4,660

The purpose of this project was to gain a better understanding of the hydrogeology of the FH-HC aquifer to provide a foundation for the development of a long-term management policy. The prediction model indicates that future pumping will continue to derive water from storage and that water levels will continue to decline. The model has demonstrated a likelihood that the water appropriated from the aquifer is derived mostly from aquifer storage causing groundwater mining to occur at the current level of use. Therefore, if the goal is to protect existing flowing wells, this report is a sufficient basis to deny permits to appropriate water from the FH-HC aquifer. The only exceptions would be near the recharge area in southwestern North Dakota where there may be some potential to capture rejected recharge and where the aquifer discharges to the Missouri River in south central North Dakota.

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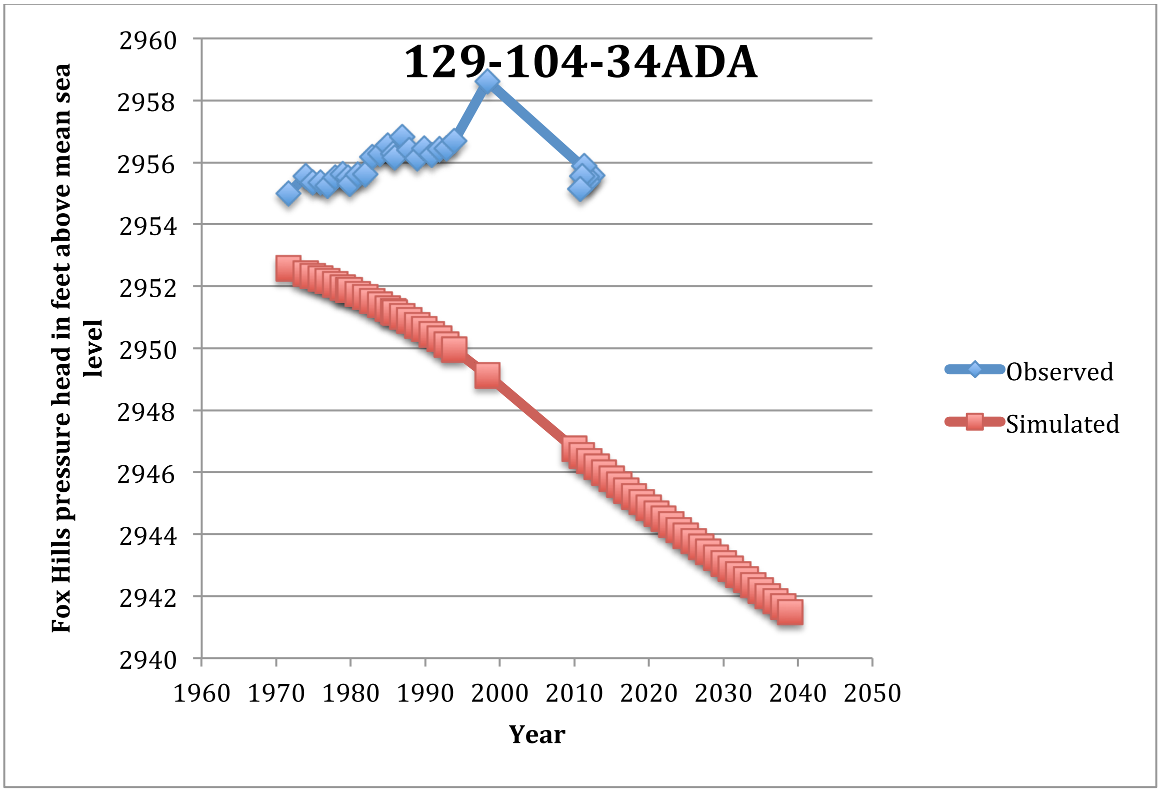
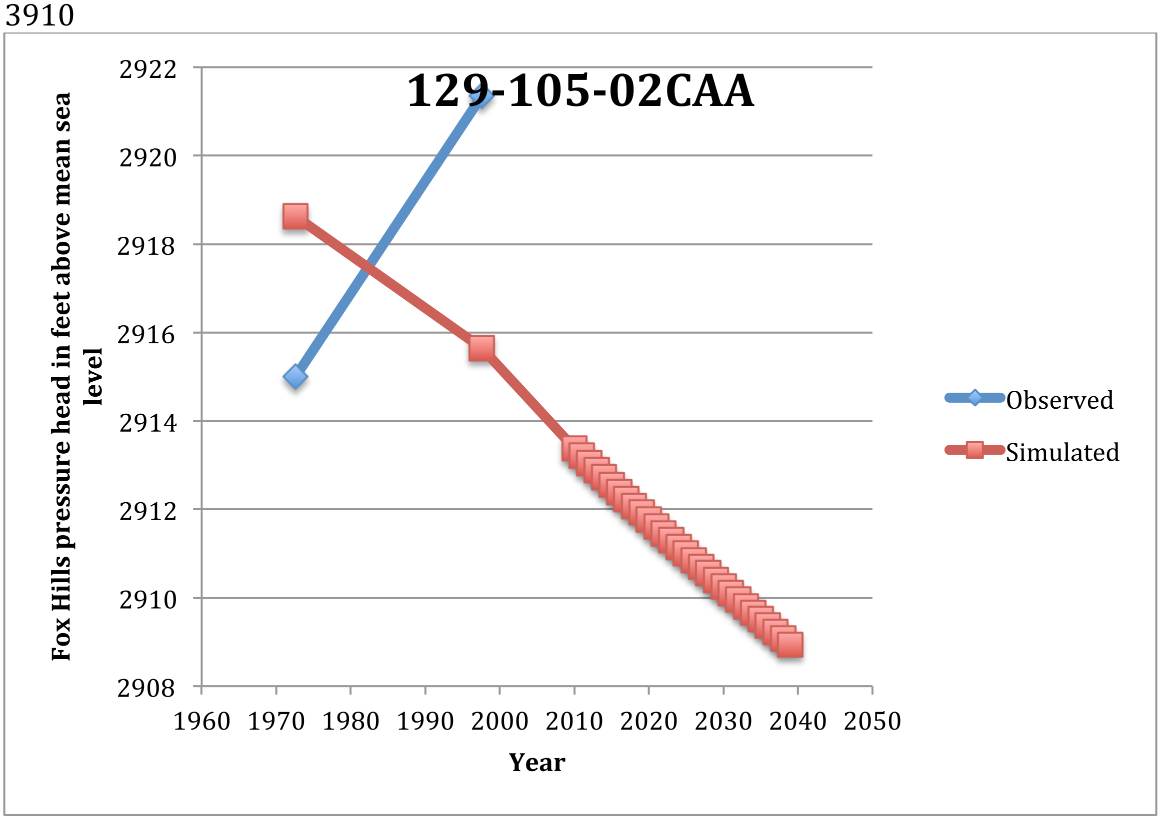
APPENDIX A

HYDROGRAPHS OF MEASURED VERSUS SIMULATED PRESSURE HEADS IN FOX HILLS-HELL CREEK AQUIFER WELLS

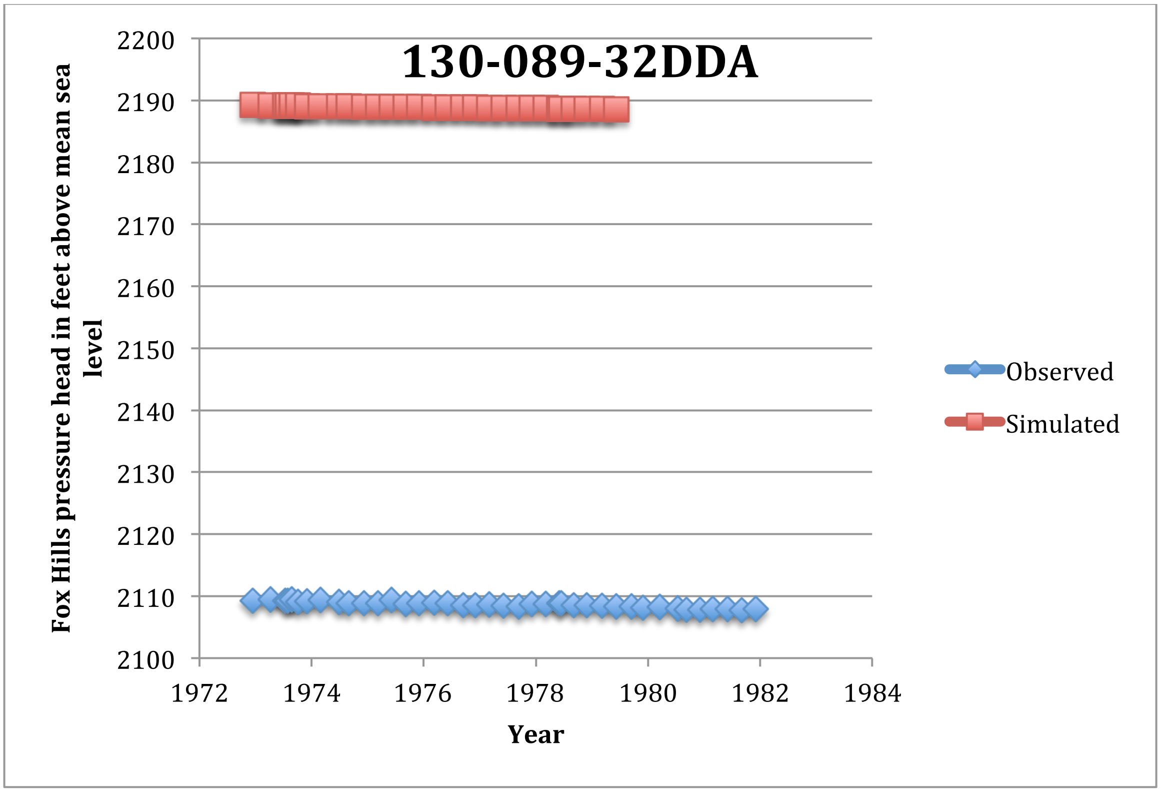
3908


129-104-34ADA
Fox Hills pressure head in feet above mean sea level
2960
2958
2956
2954
2952
2950
2948
2946
2944
2942
2940
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

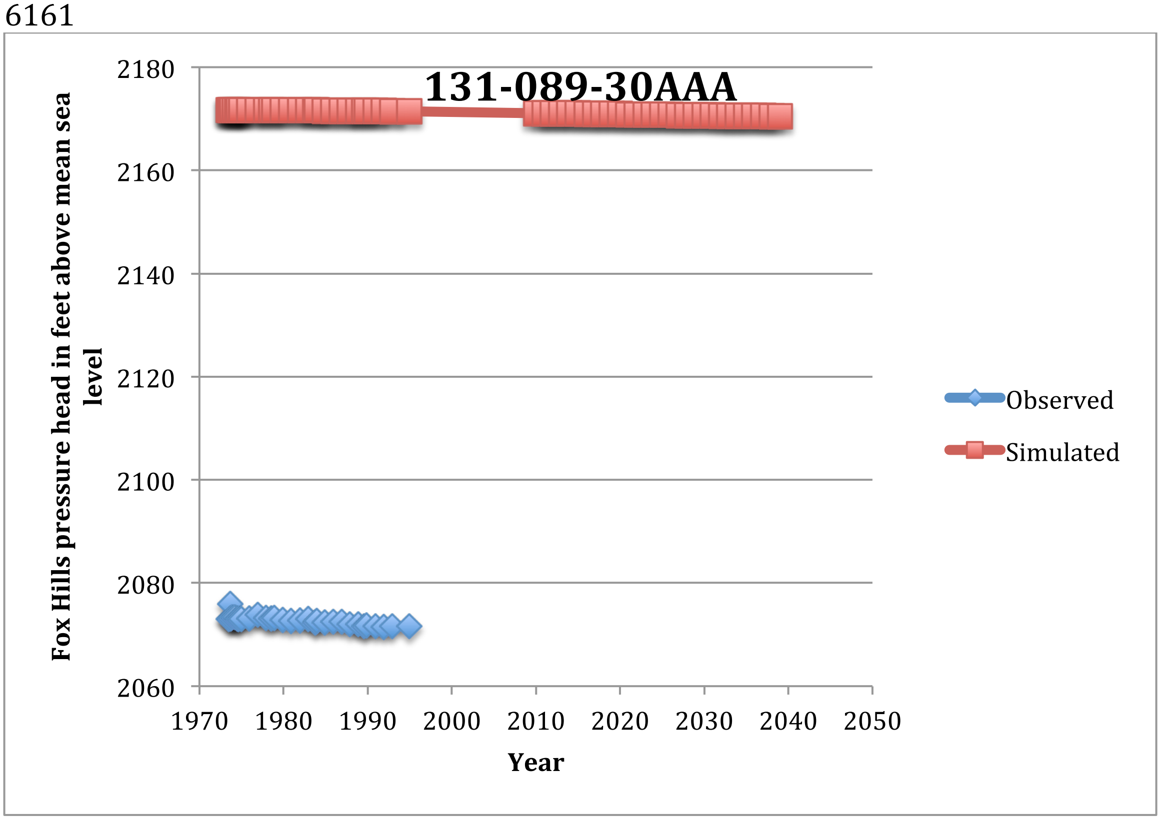
3910


129-105-02CAA
Fox Hills pressure head in feet above mean sea level
2922
2920
2918
2916
2914
2912
2910
2908
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

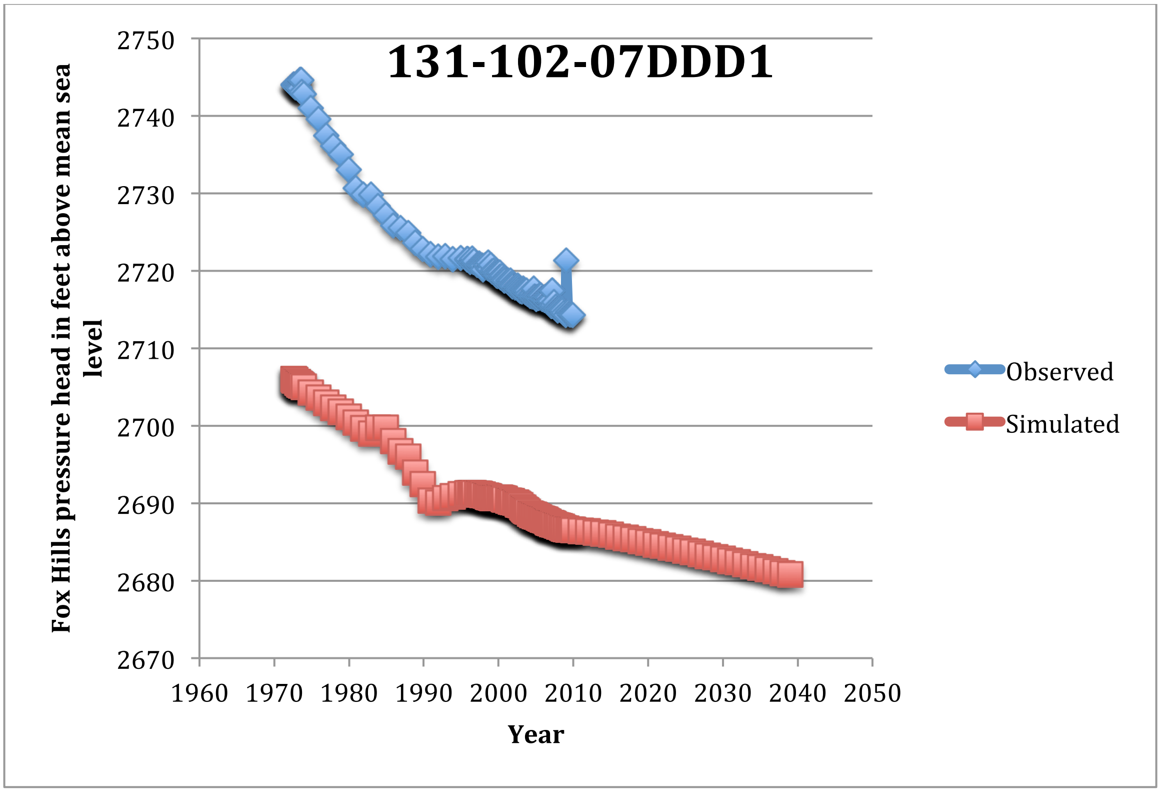
6146


130-089-32DDA
Fox Hills pressure head in feet above mean sea level
2200
2190
2180
2170
2160
2150
2140
2130
2120
2110
2100
1972
1974
1976
1978
1980
1982
1984
Year
Observed
Simulated

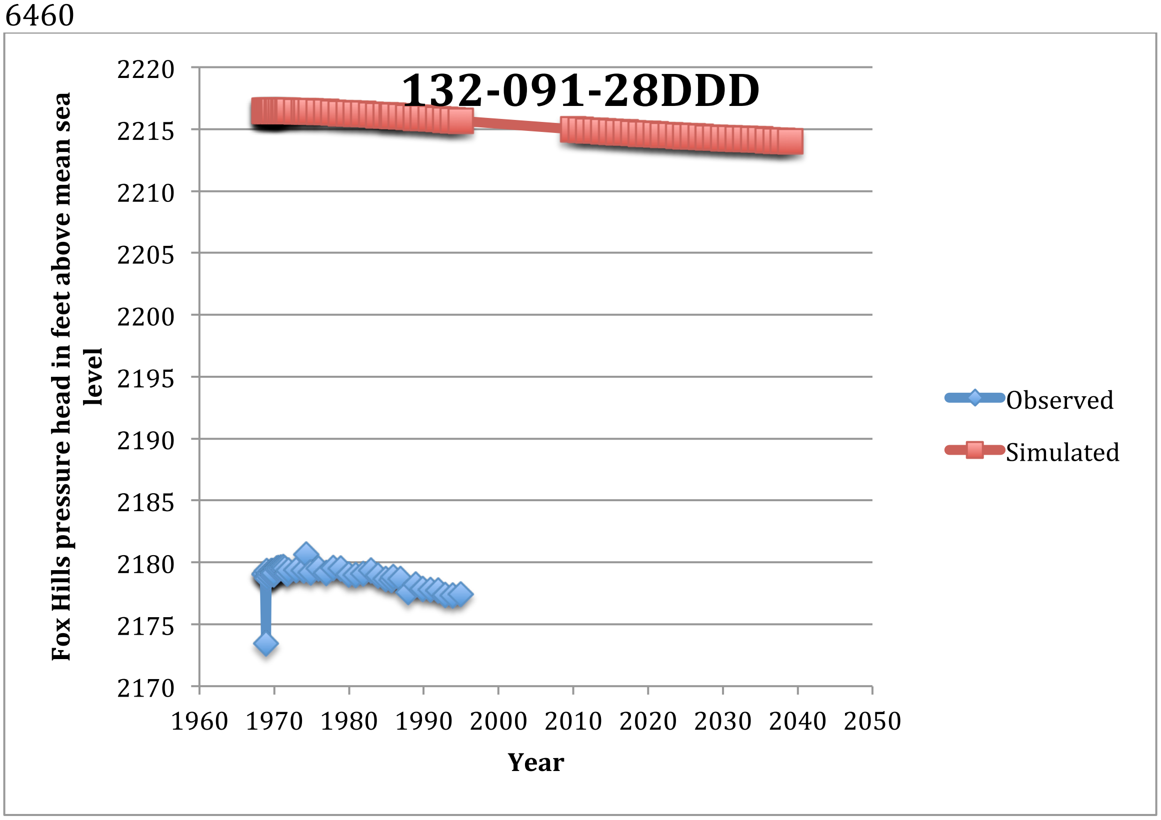
6161


131-089-30AAA
Fox Hills pressure head in feet above mean sea level
2180
2160
2140
2120
2100
2080
2060
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

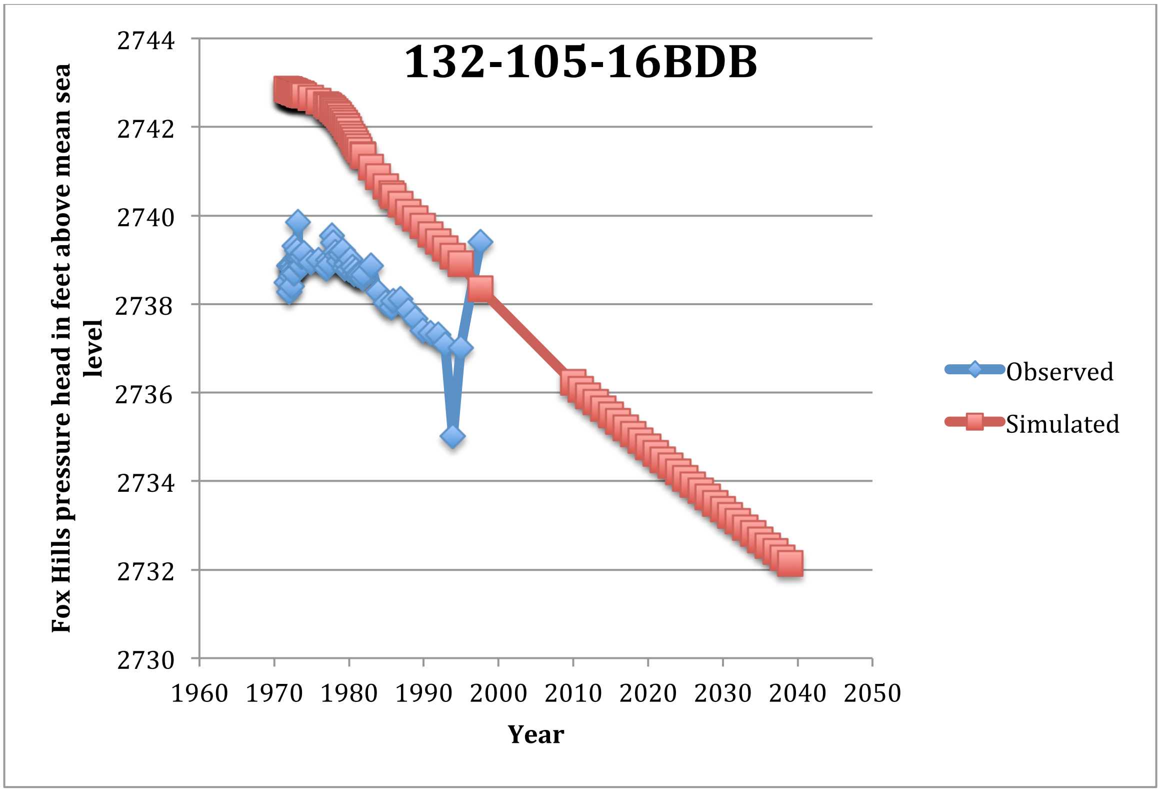
3966


131-102-07DDD1
Fox Hills pressure head in feet above mean sea level
2750
2740
2730
2720
2710
2700
2690
2680
2670
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated

6460


132-091-28DDD
Fox Hills pressure head in feet above mean sea level
2220
2215
2210
2205
2200
2195
2190
2185
2180
2175
2170
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated

4020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Fox Hills pressure head in feet above mean sea level
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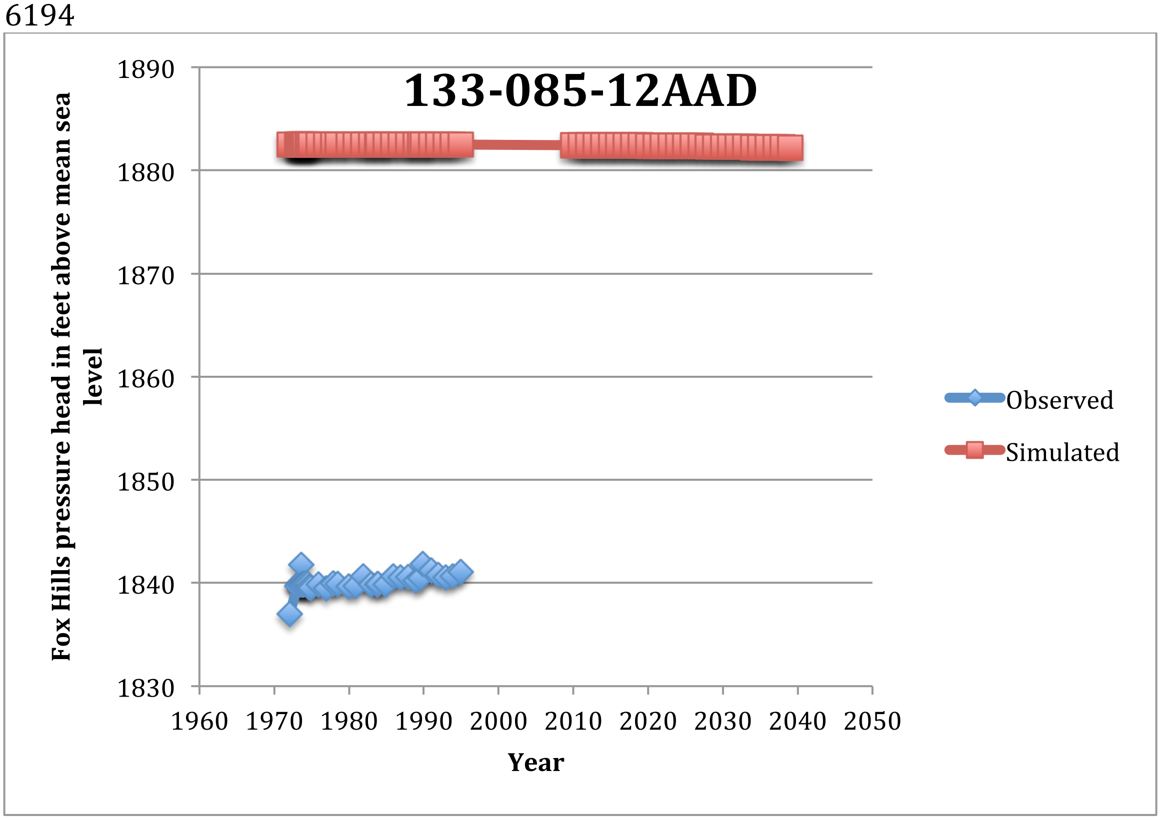
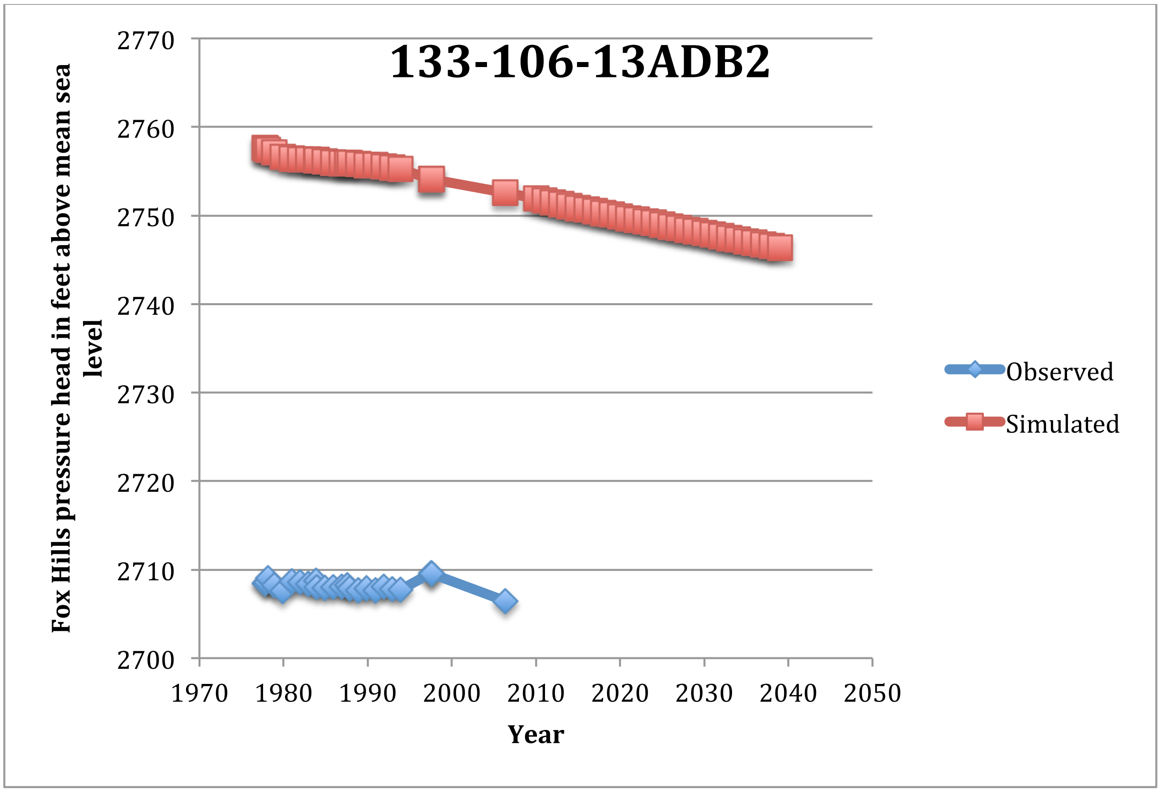
2742
2740
2738
2736
2734
2732
2730
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated

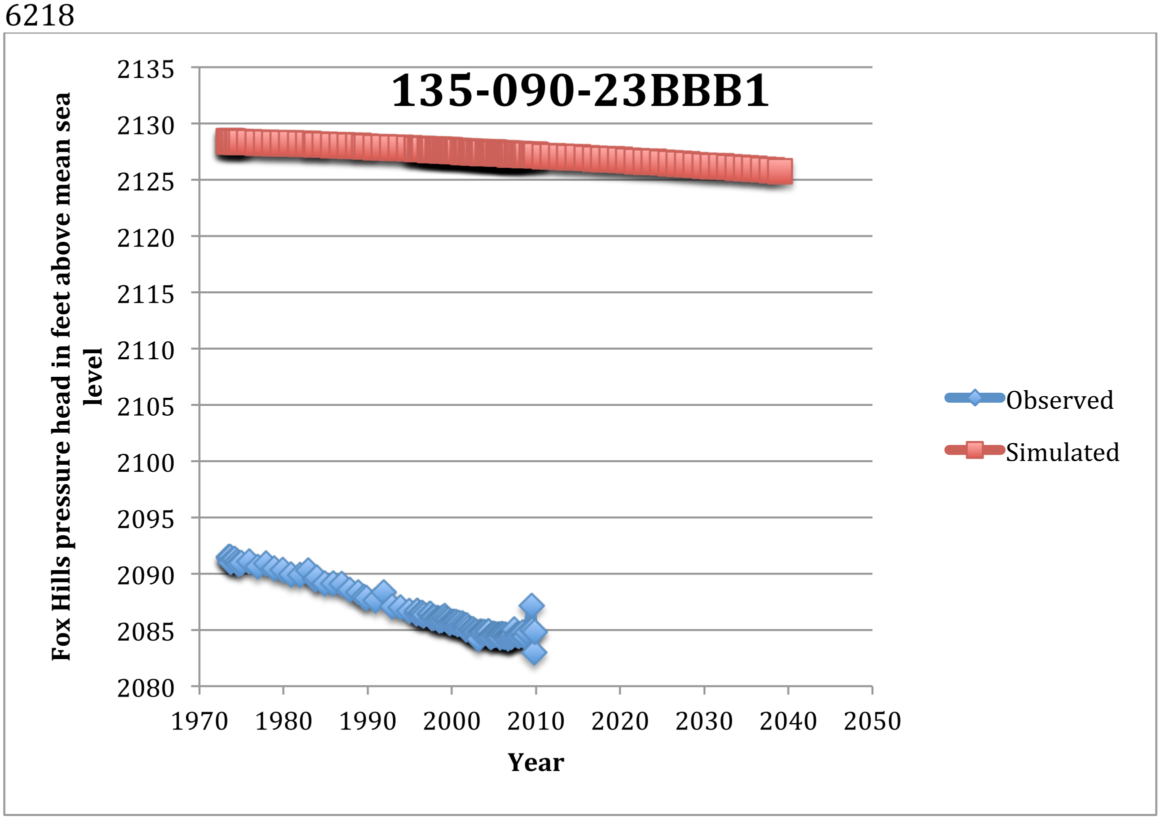
6194


133-085-12AAD
Fox Hills pressure head in feet above mean sea level
1890
1880
1870
1860
1850
1840
1830
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated

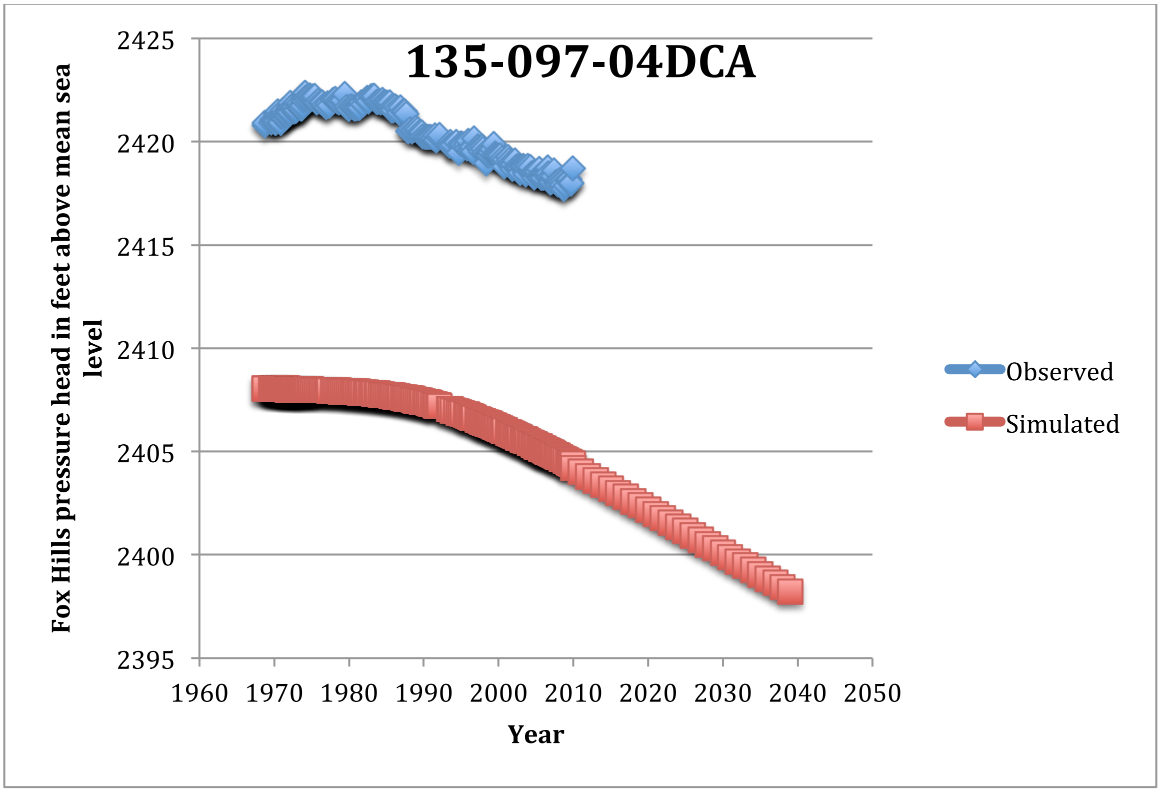
10488


133-106-13ADB2
Fox Hills pressure head in feet above mean sea level
2770
2760
2750
2740
2730
2720
2710
2700
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

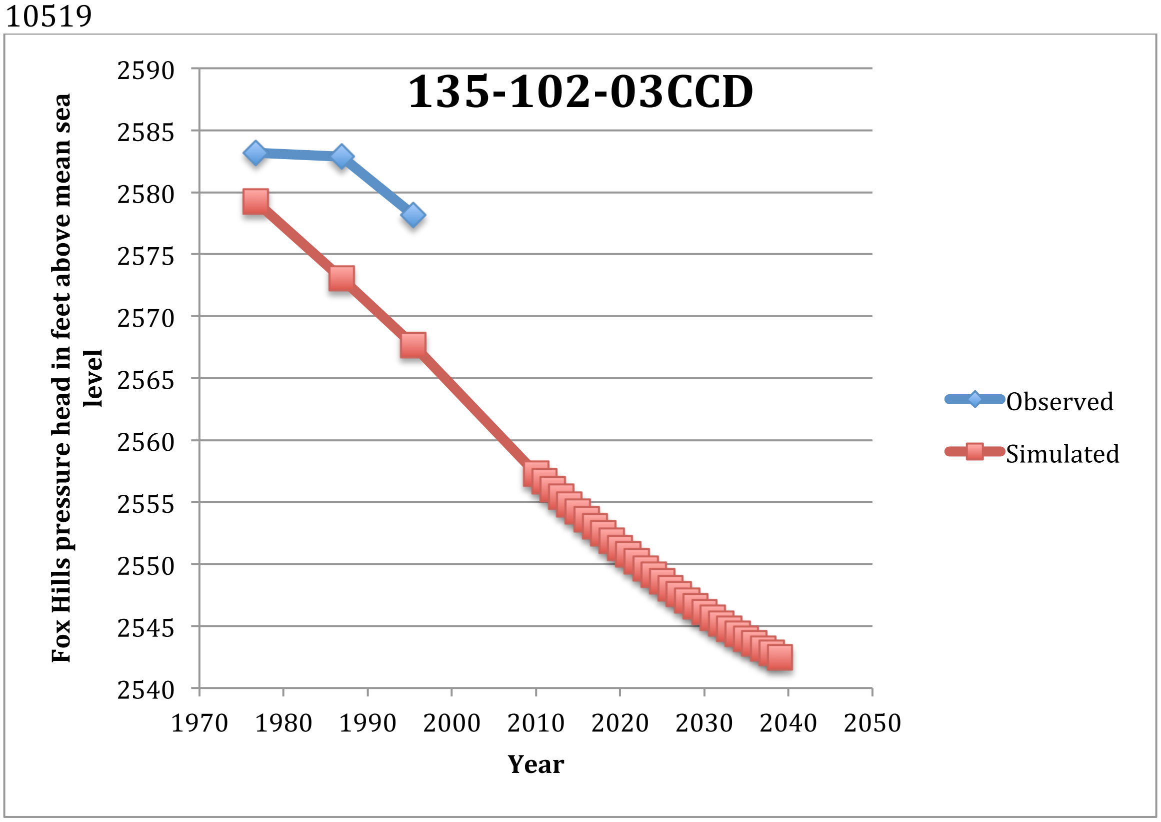
6218


135-090-23BBB1
Fox Hills pressure head in feet above mean sea level
2135
2130
2125
2120
2115
2110
2105
2100
2095
2090
2085
2080
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

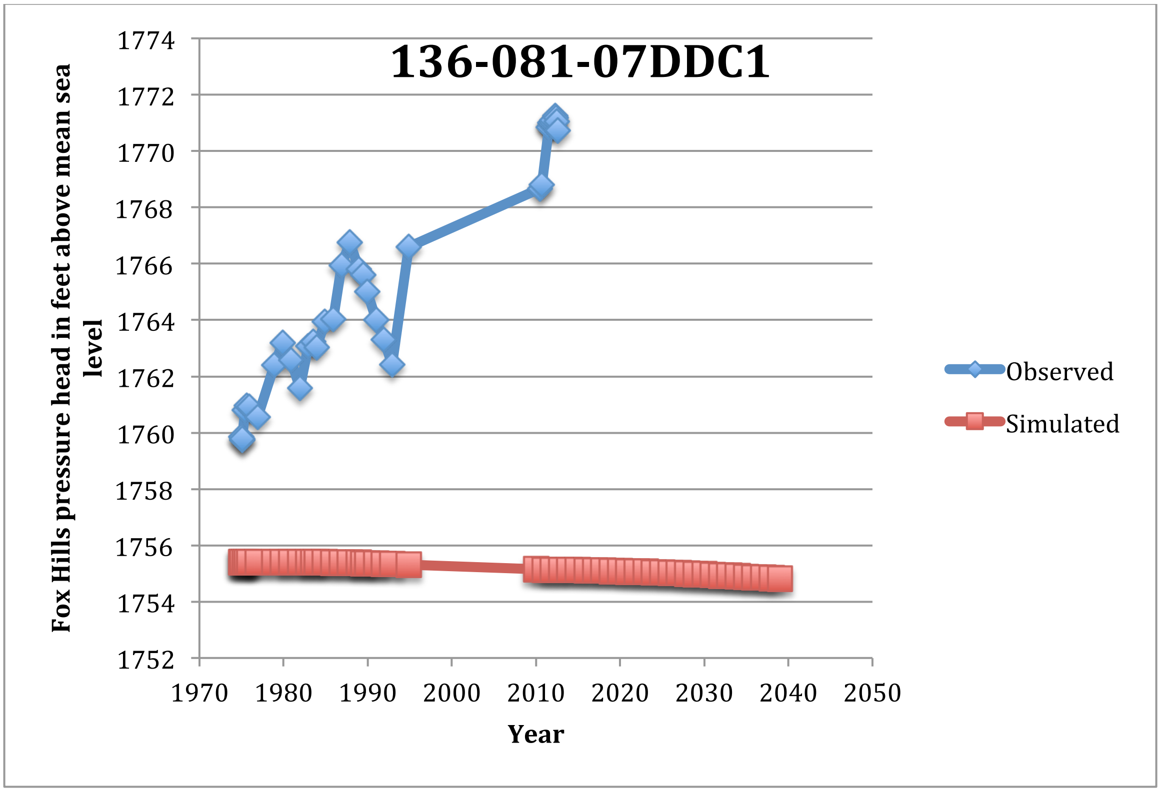
6538


135-097-04DCA
Fox Hills pressure head in feet above mean sea level
2425
2420
2415
2410
2405
2400
2395
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated

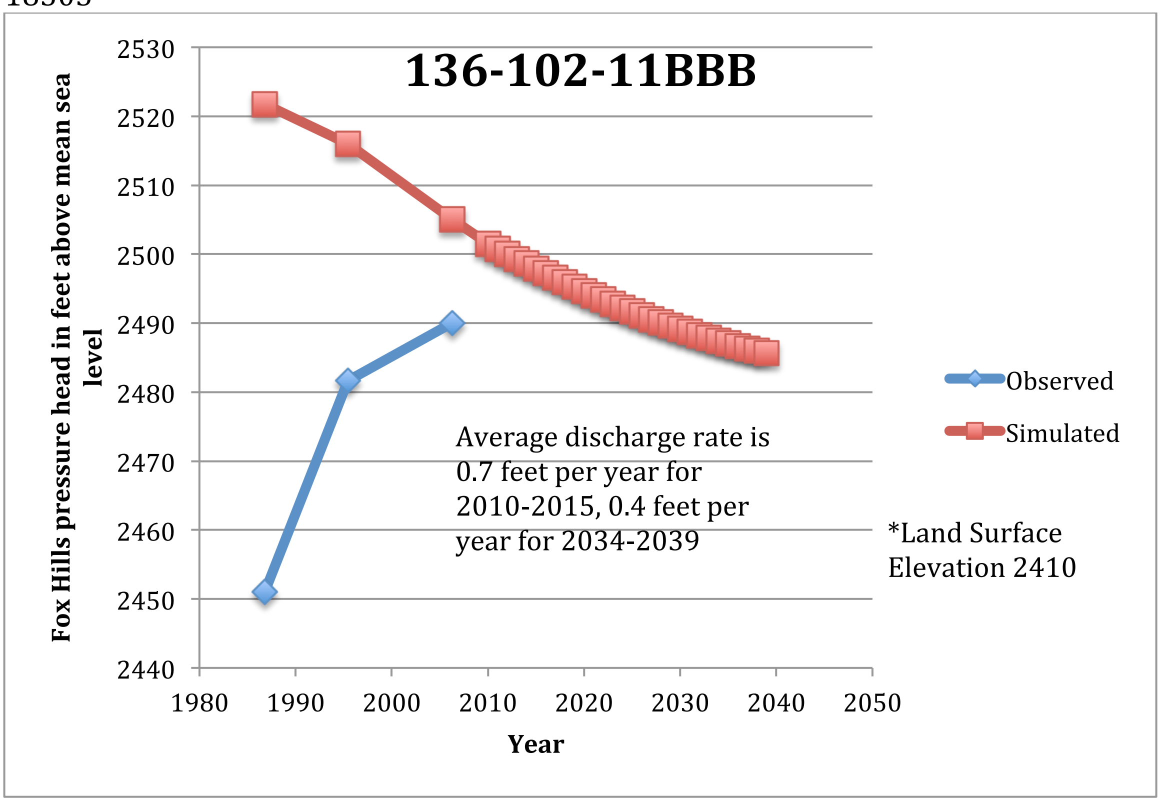
10519


135-102-03CCD
Fox Hills pressure head in feet above mean sea level
2590
2585
2580
2575
2570
2565
2560
2555
2550
2545
2540
1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated

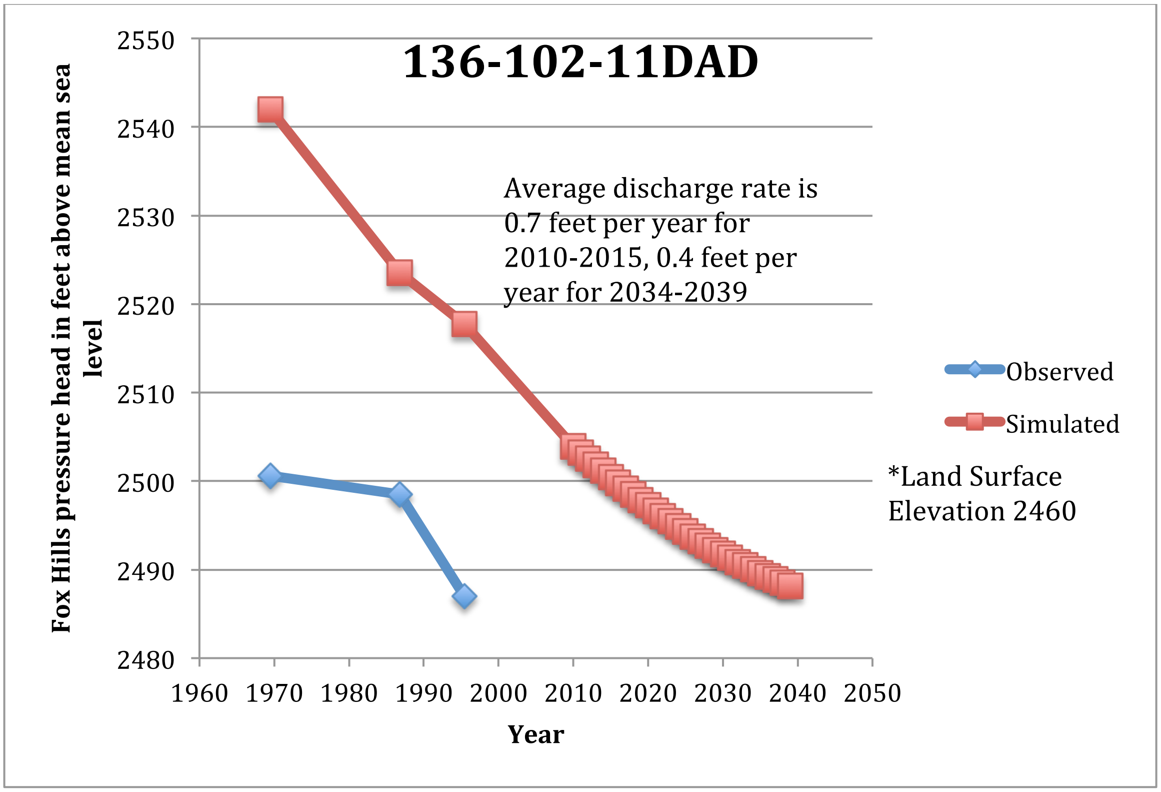
8719


136-081-07DDC1
Fox Hills pressure head in feet above mean sea level
1774
1772
1770
1768
1766
1764
1762
1760
1758
1756
1754
1752
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

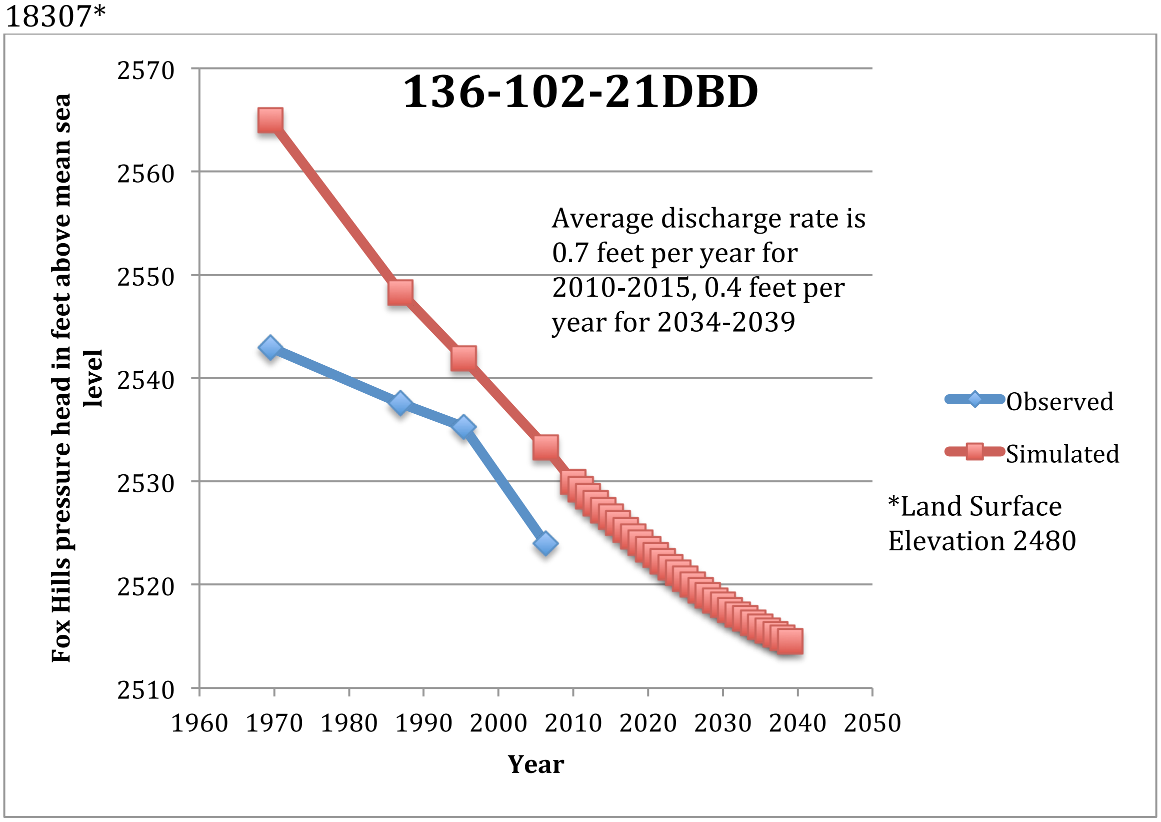
18305*


136-102-11BBB
Fox Hills pressure head in feet above mean sea level
2530
2520
2510
2500
2490
2480
2470
2460
2450
2440
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
Average discharge rate is 0.7 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
*Land Surface Elevation 2410

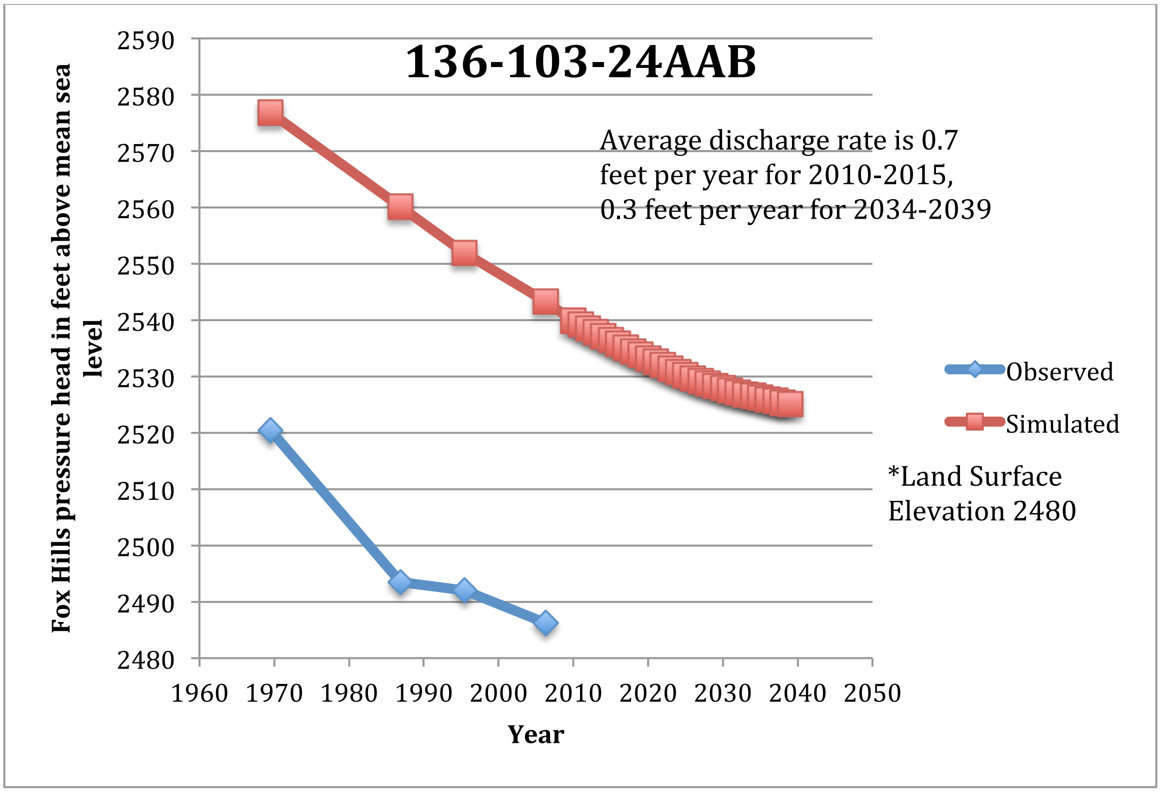
18306*


136-102-11DAD
Fox Hills pressure head in feet above mean sea level
2550
2540
2530
2520
2510
2500
2490
2480
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 0.7 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 2460

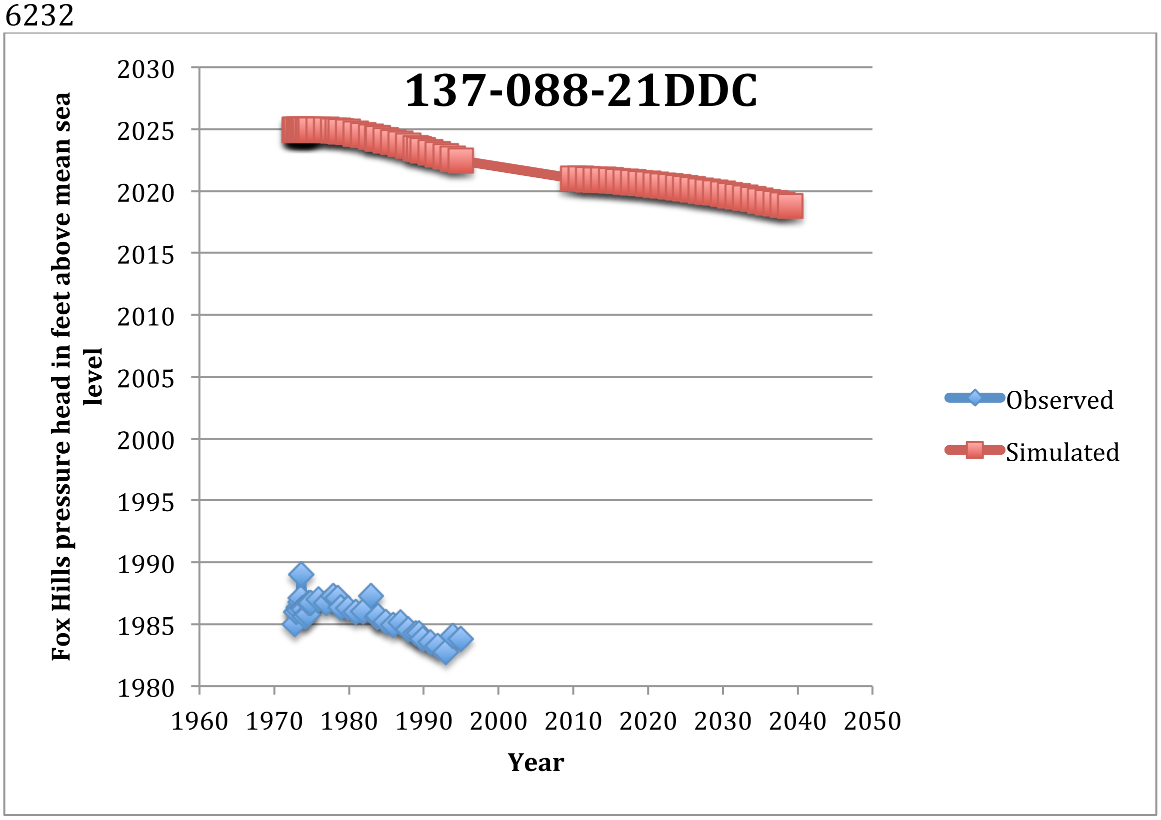
18307*


136-102-21DBD
Fox Hills pressure head in feet above mean sea level
2570
2560
2550
2540
2530
2520
2510
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 0.7 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 2480

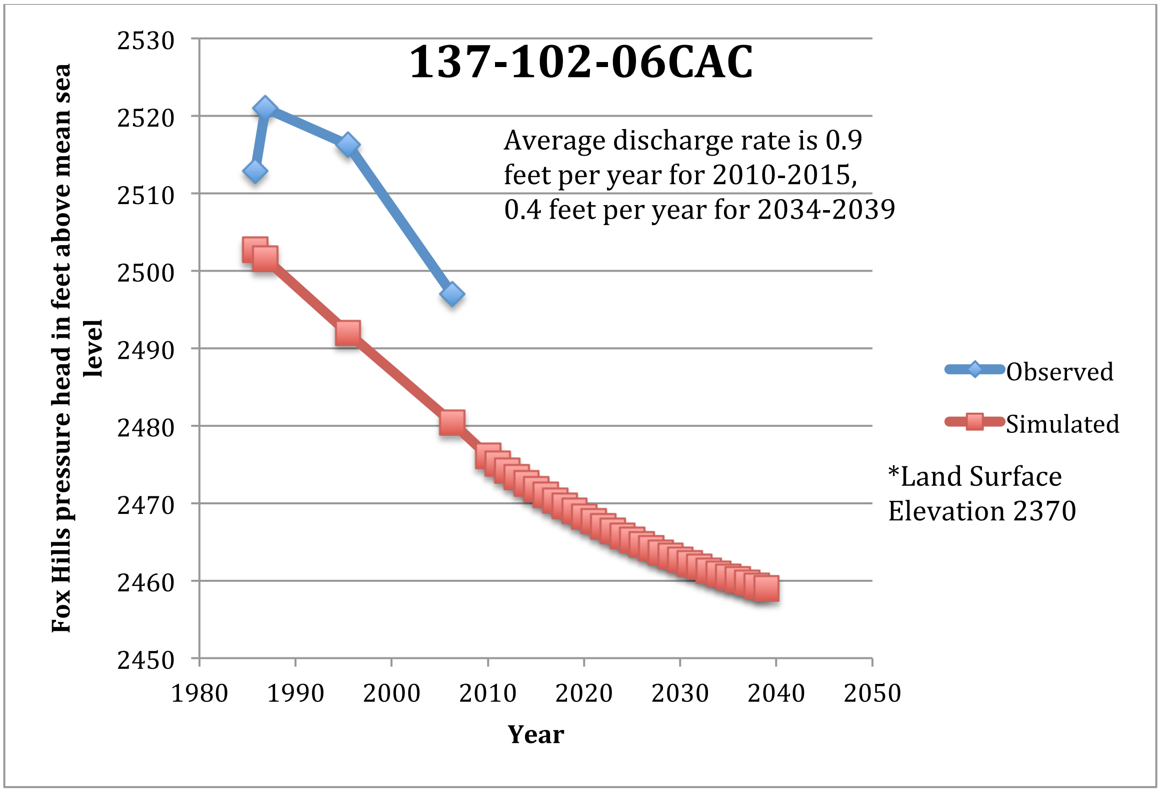
18304*


136-103-24AAB
Average discharge rate is 0.7
feet per year for 2010-2015,
0.3 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2590
2580
2570
2560
2550
2540
2530
2520
2510
2500
2490
2480
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
*Land Surface
Elevation 2480

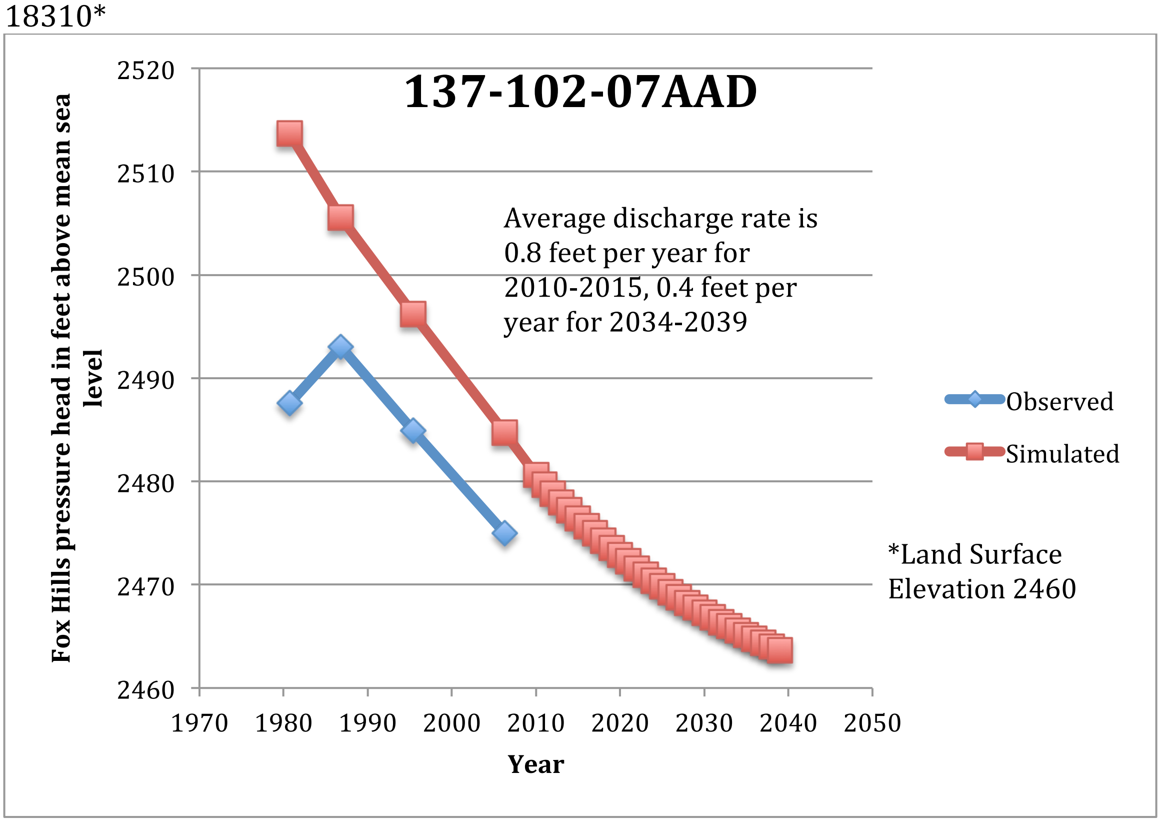
6232


137-088-21DDC
Fox Hills pressure head in feet above mean sea level
2030
2025
2020
2015
2010
2005
2000
1995
1990
1985
1980
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

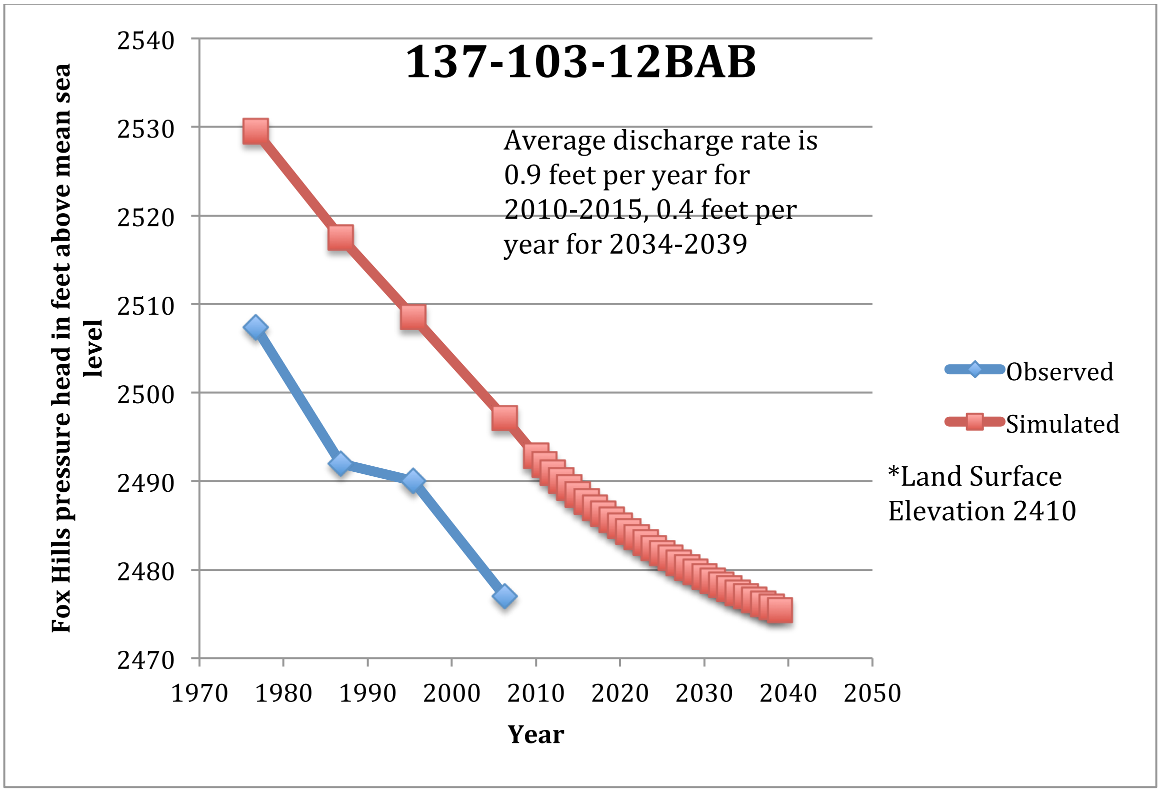
18309*


137-102-06CAC
Average discharge rate is 0.9 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2530
2520
2510
2500
2490
2480
2470
2460
2450
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
*Land Surface Elevation 2370

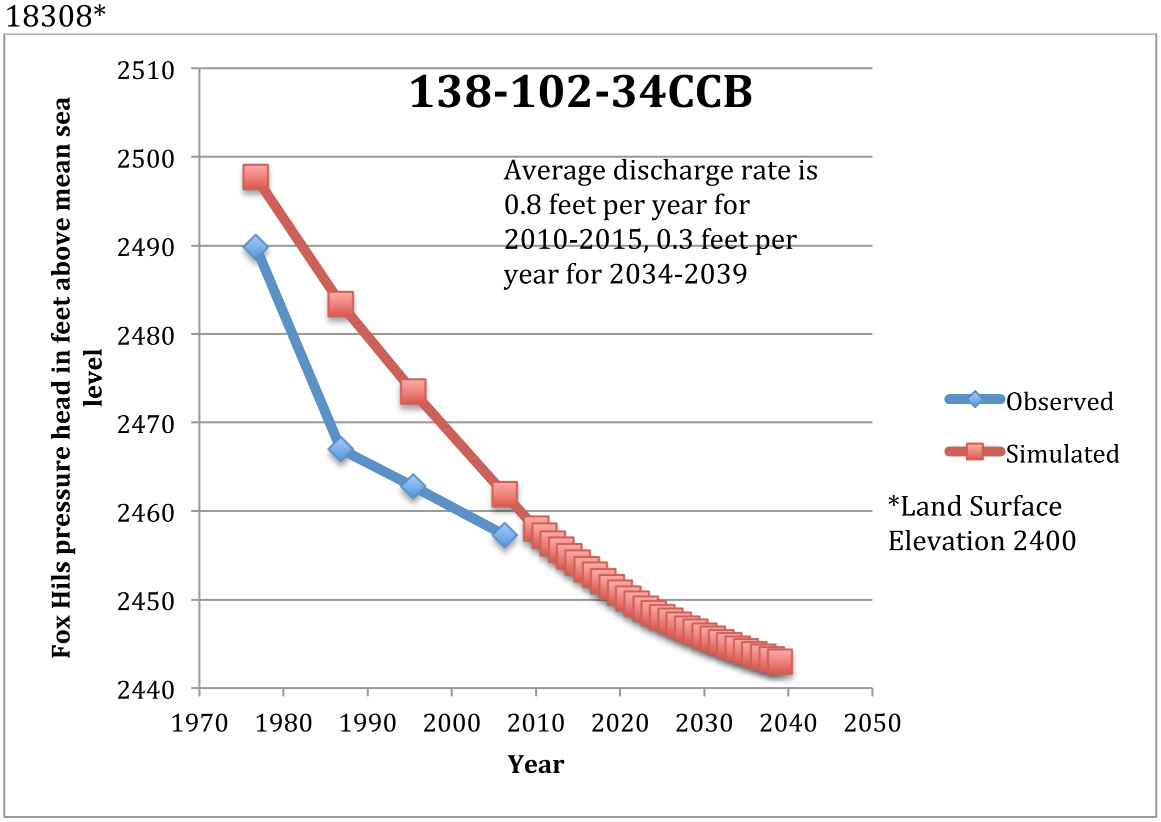
18310*


137-102-07AAD
Average discharge rate is 0.8 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2520
2510
2500
2490
2480
2470
2460
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
*Land Surface Elevation 2460

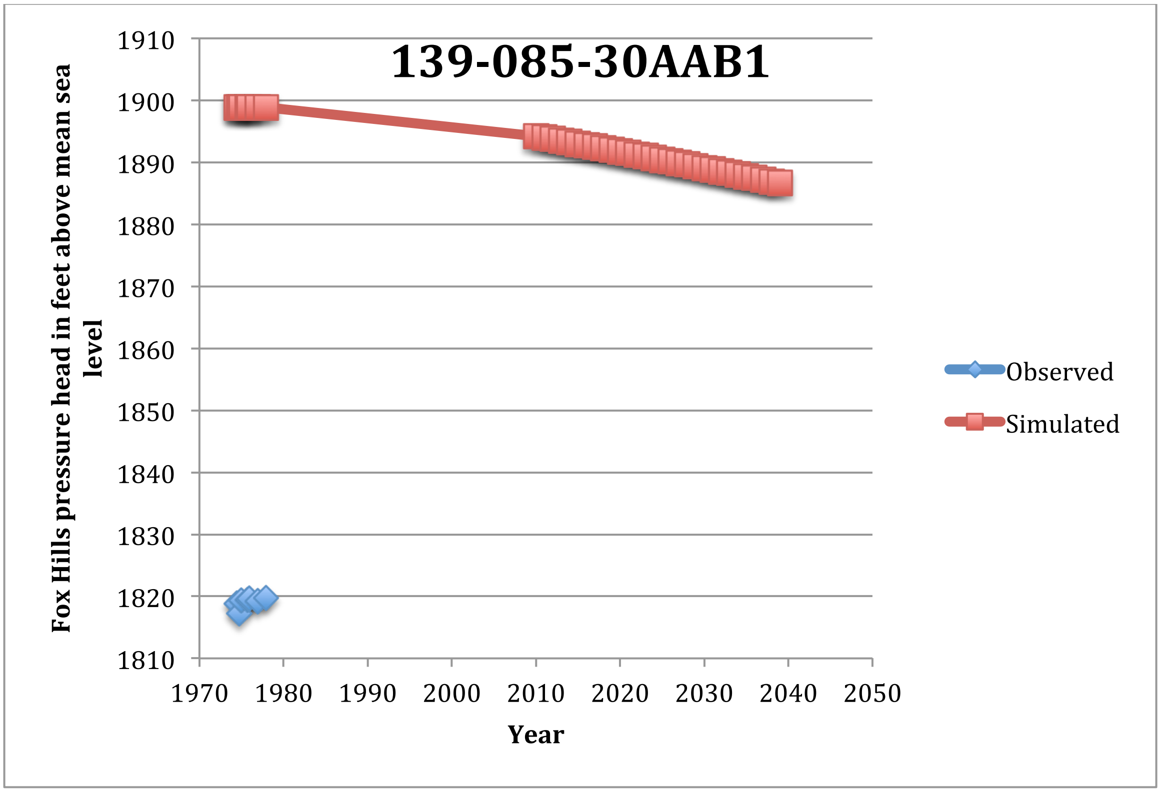
18311*


137-103-12BAB
Average discharge rate is 0.9 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2540
2530
2520
2510
2500
2490
2480
2470
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
*Land Surface Elevation 2410

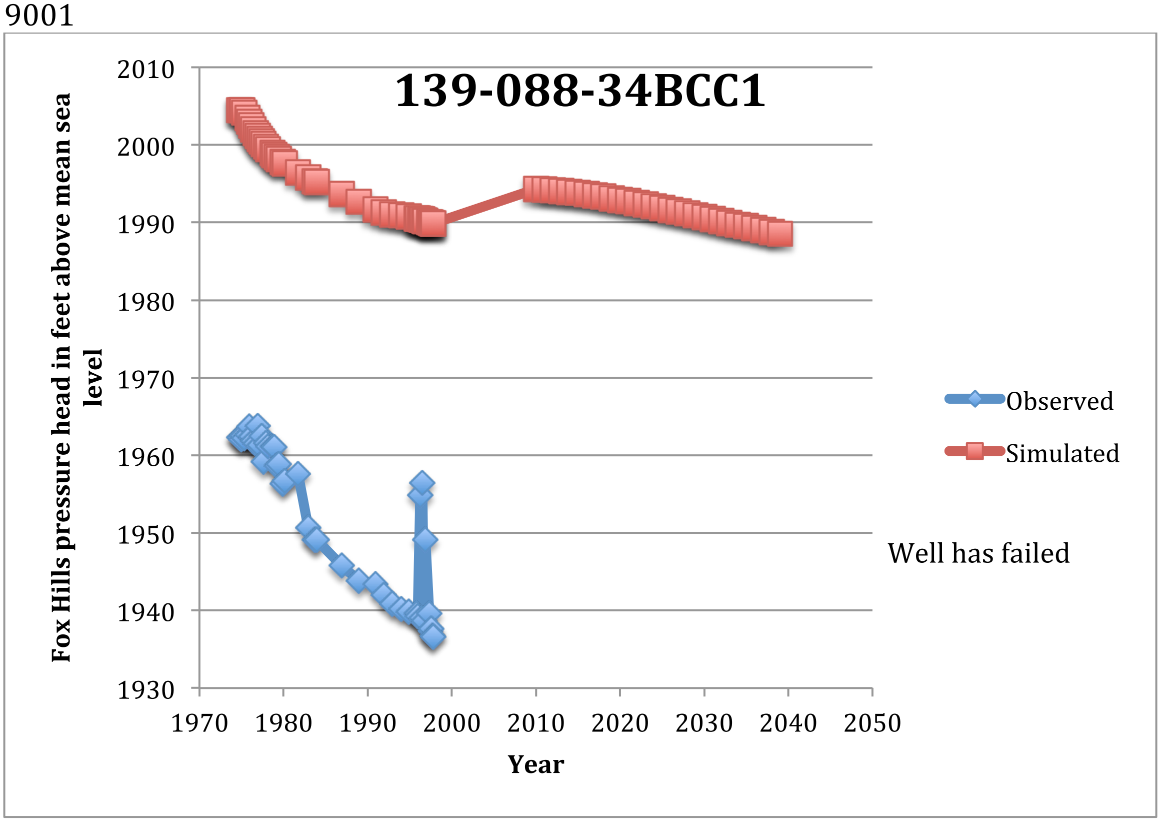
18308*


138-102-34CCB
Average discharge rate is 0.8 feet per year for 2010-2015, 0.3 feet per year for 2034-2039
Fox Hils pressure head in feet above mean sea level
2510
2500
2490
2480
2470
2460
2450
2440
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
*Land Surface Elevation 2400

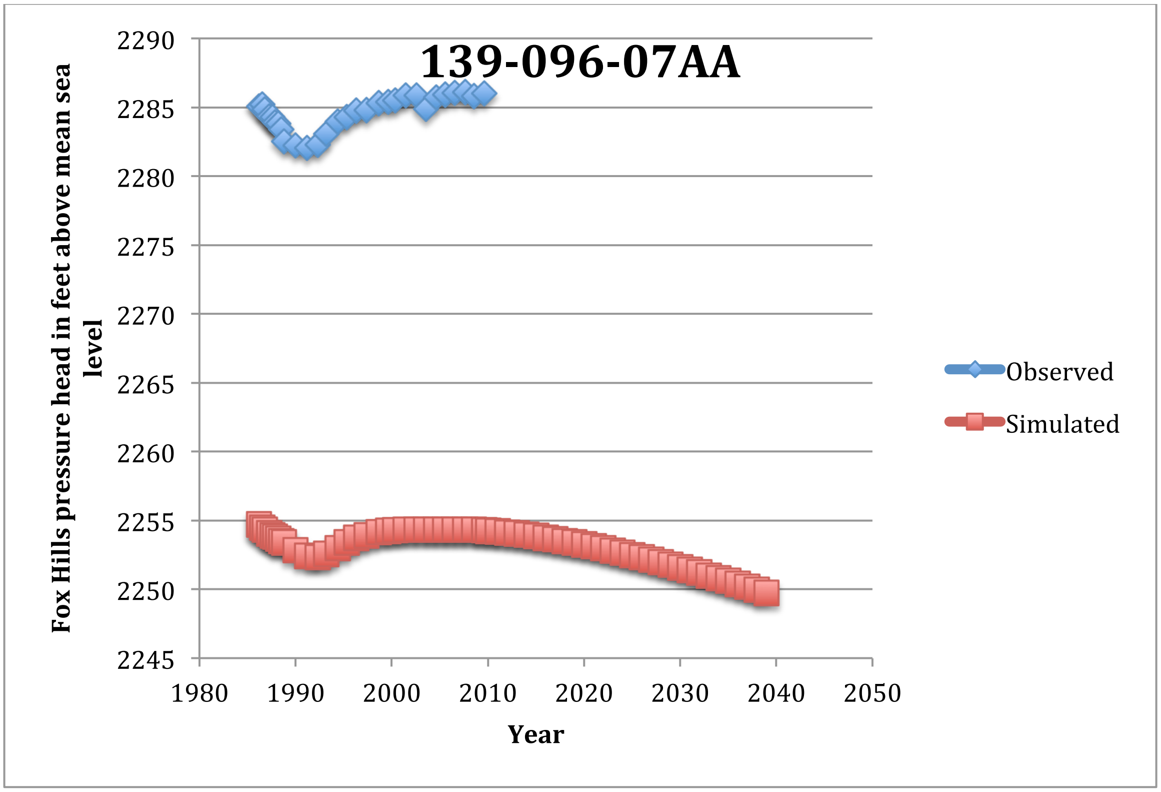
8947


139-085-30AAB1
Fox Hills pressure head in feet above mean sea level
1910
1900
1890
1880
1870
1860
1850
1840
1830
1820
1810
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

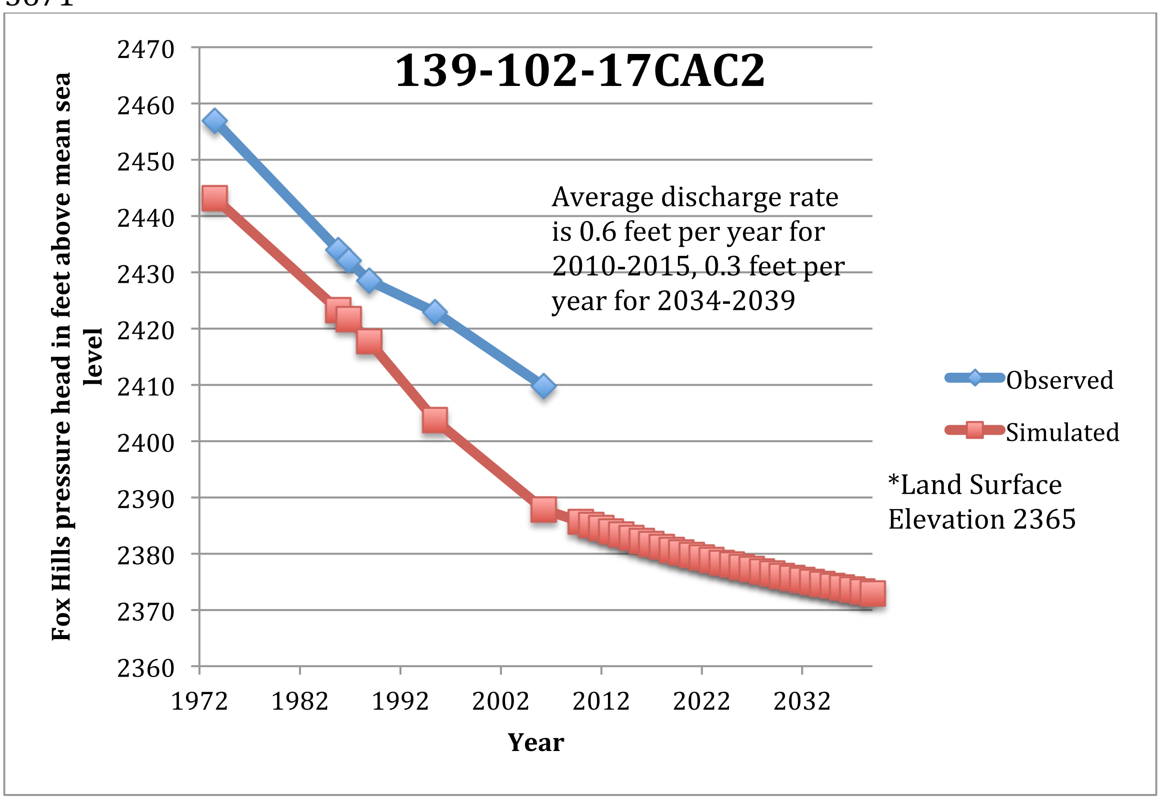
9001


139-088-34BCC1
Fox Hills pressure head in feet above mean sea level
2010
2000
1990
1980
1970
1960
1950
1940
1930
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
Well has failed

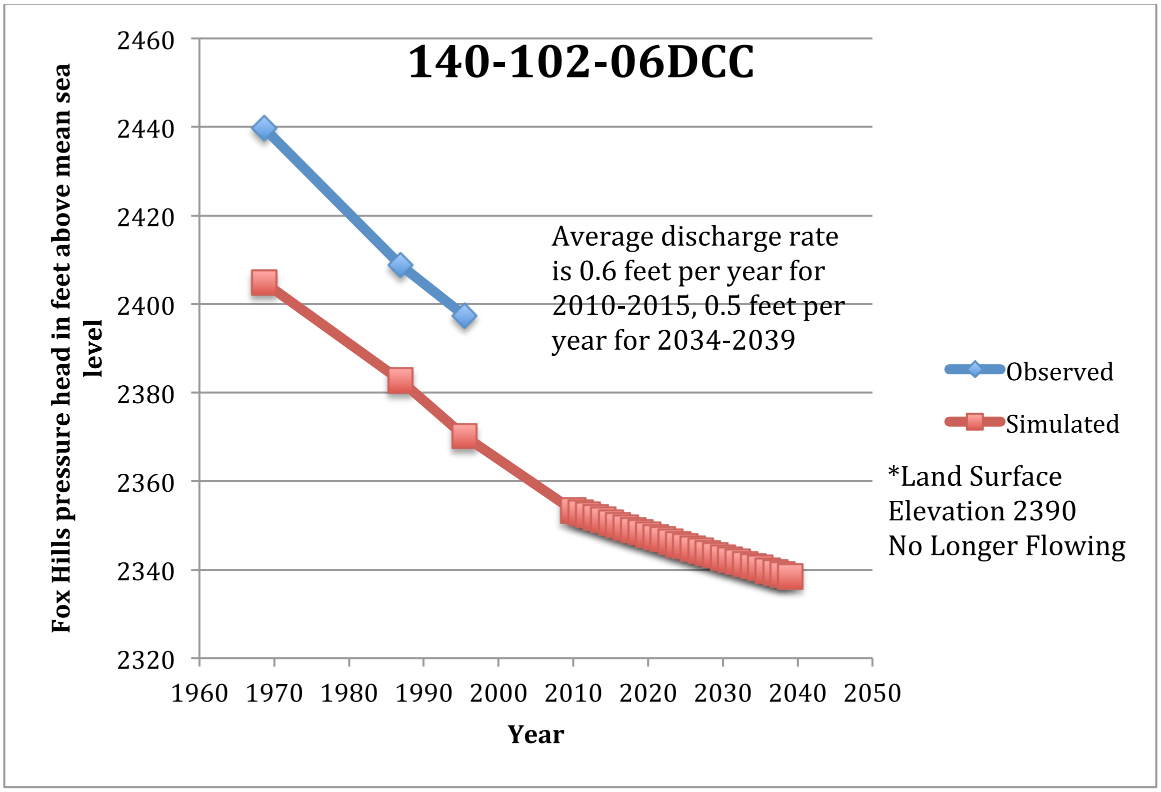
10611


139-096-07AA
Fox Hills pressure head in feet above mean sea level
2290
2285
2280
2275
2270
2265
2260
2255
2250
2245
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

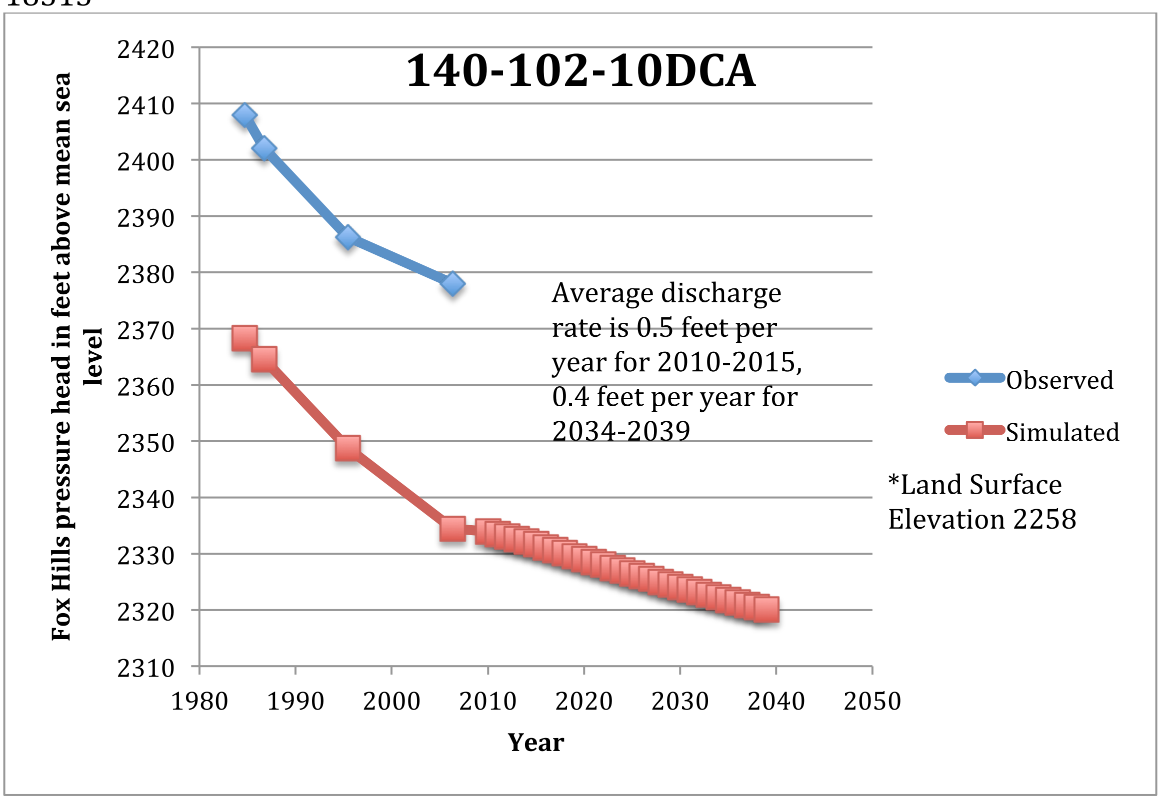
3671*


139-102-17CAC2
Fox Hills pressure head in feet above mean sea level
2470
2460
2450
2440
2430
2420
2410
2400
2390
2380
2370
2360
1972
1982
1992
2002
2012
2022
2032
Year
Average discharge rate is 0.6 feet per year for 2010-2015, 0.3 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 2365

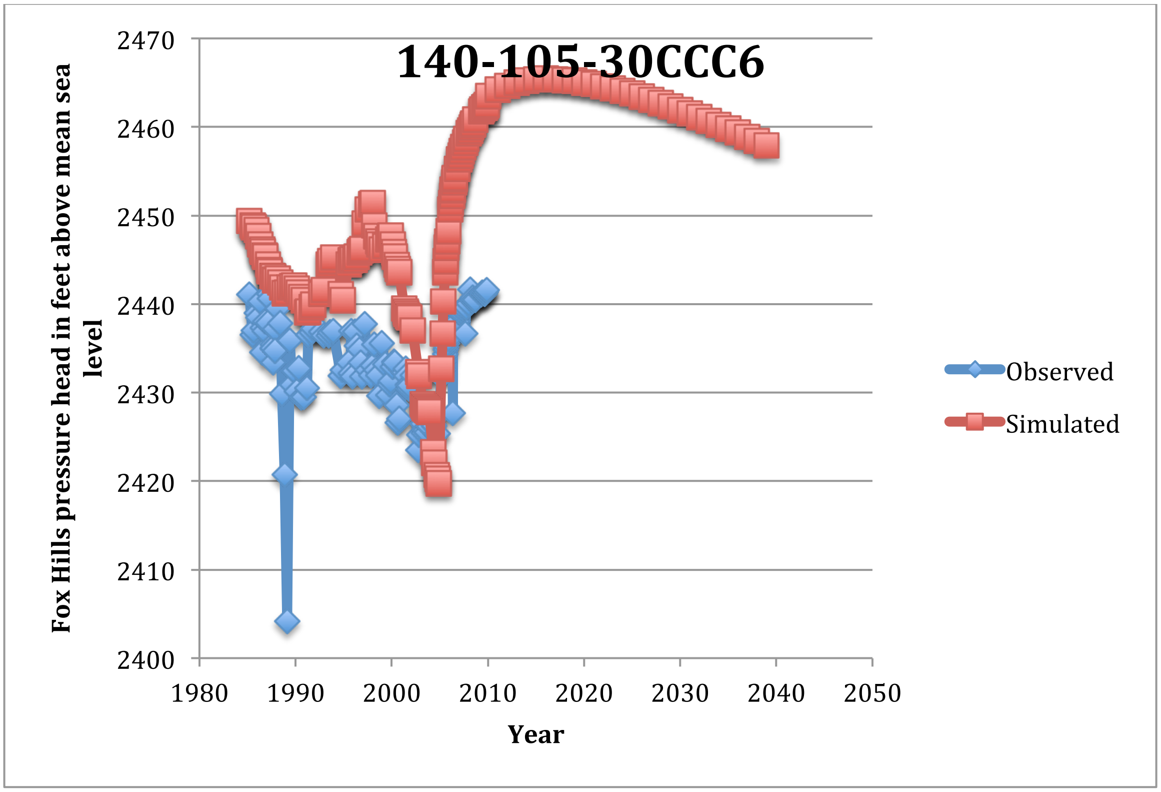
3677*


140-102-06DCC
Fox Hills pressure head in feet above mean sea level
2460
2440
2420
2400
2380
2360
2340
2320
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Average discharge rate is 0.6 feet per year for 2010-2015, 0.5 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 2390
No Longer Flowing

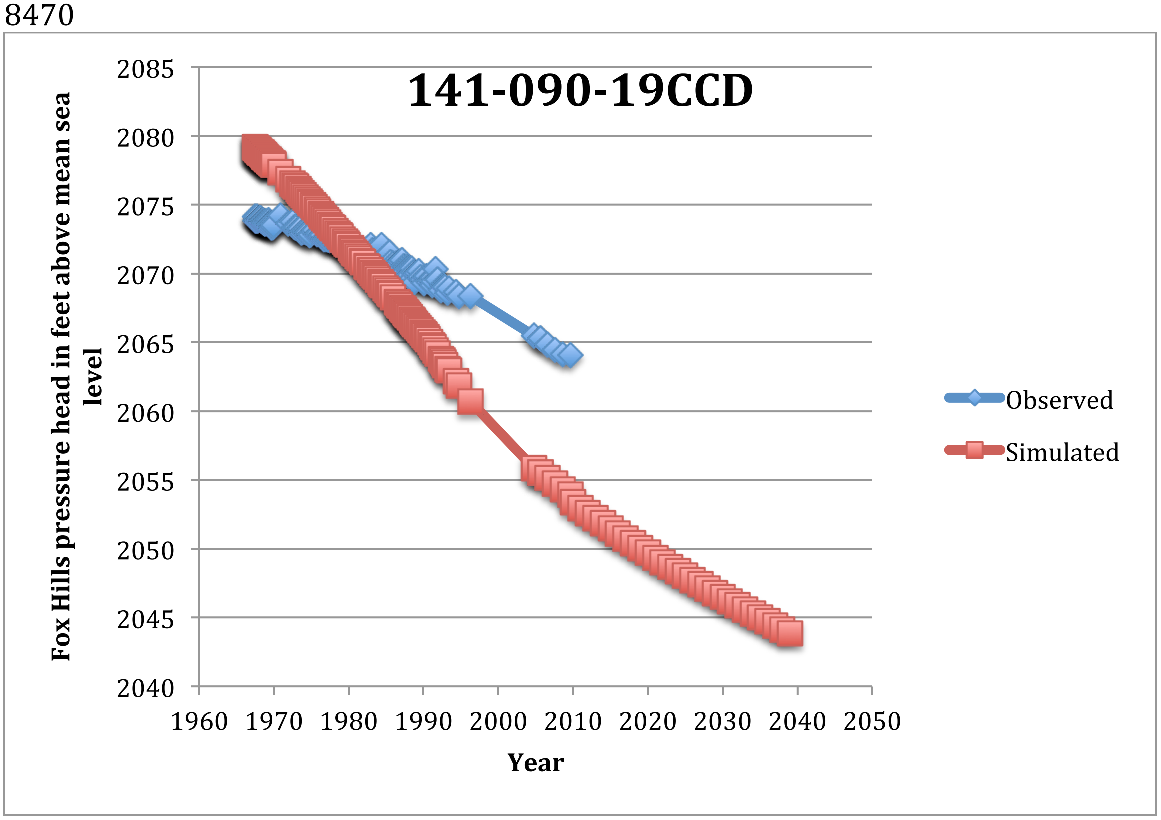
18313*


140-102-10DCA
Fox Hills pressure head in feet above mean sea level
2420
2410
2400
2390
2380
2370
2360
2350
2340
2330
2320
2310
1980 1990 2000 2010 2020 2030 2040 2050
Year
Average discharge rate is 0.5 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 2258

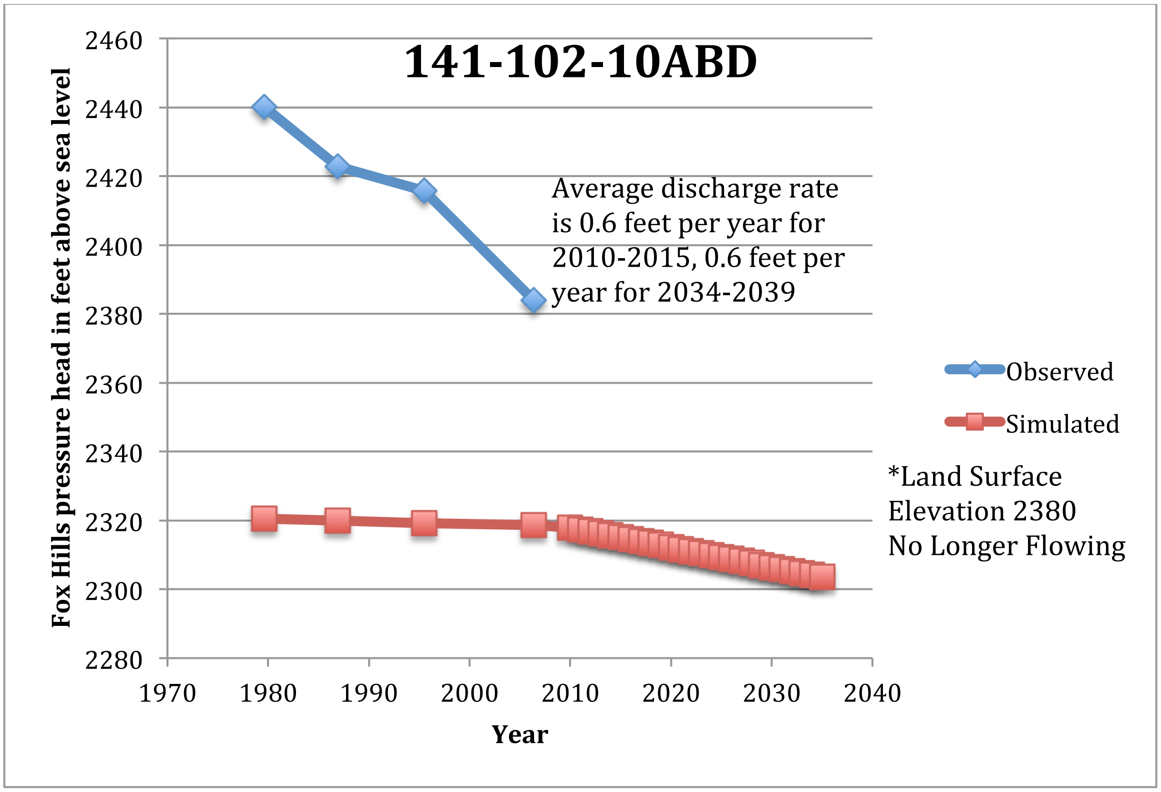
5940


140-105-30CCC6
Fox Hills pressure head in feet above mean sea level
2470
2460
2450
2440
2430
2420
2410
2400
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

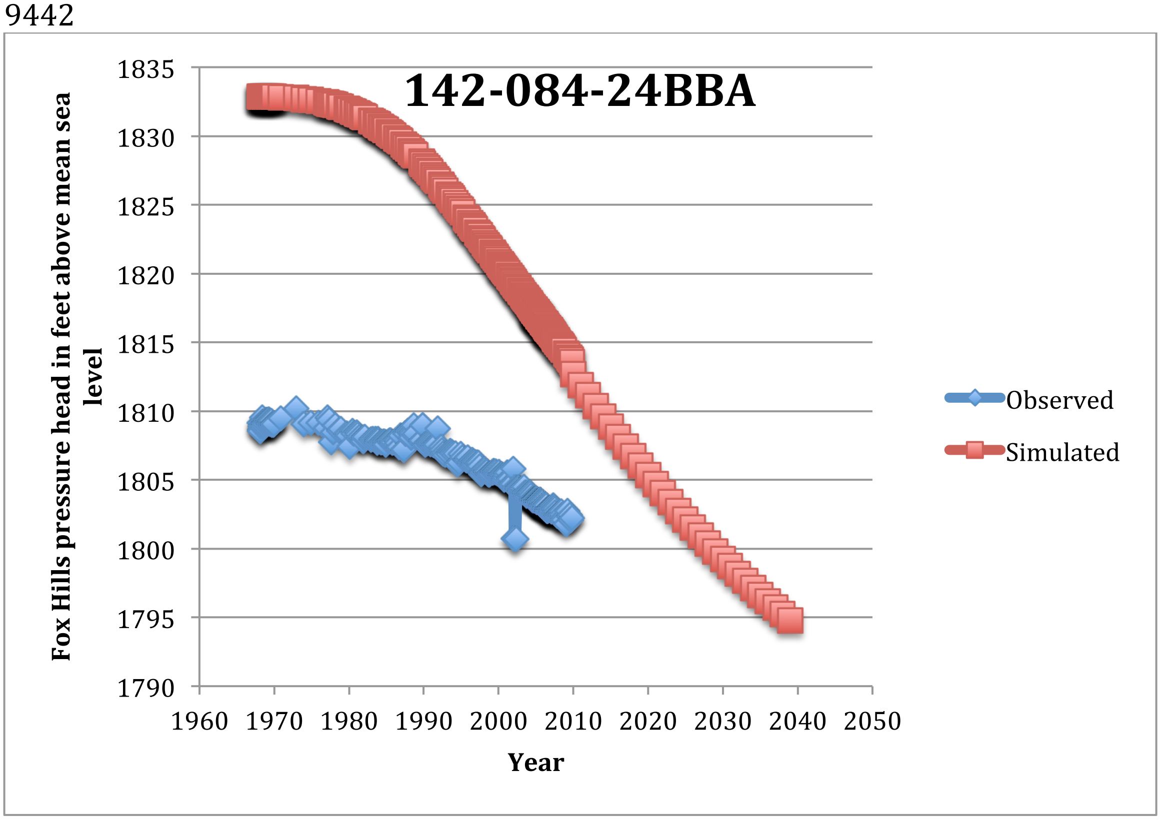
8470


141-090-19CCD
Fox Hills pressure head in feet above mean sea level
2085
2080
2075
2070
2065
2060
2055
2050
2045
2040
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

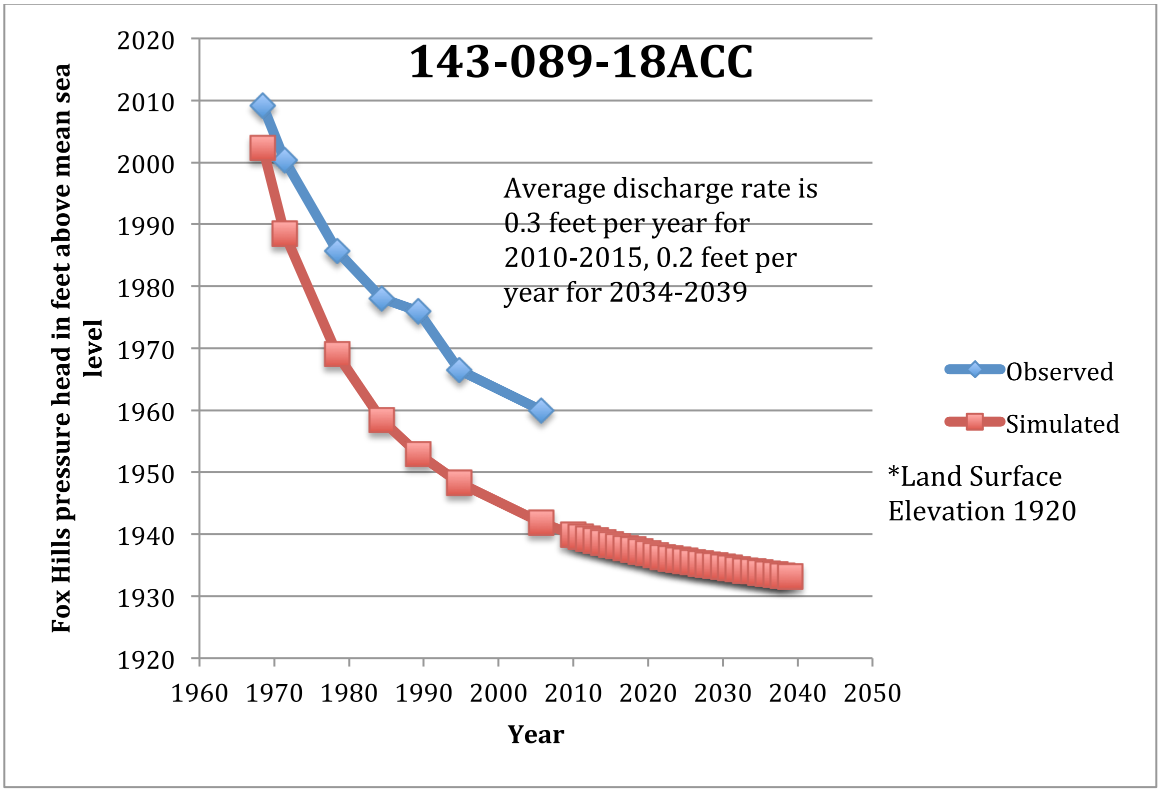
18381*


141-102-10ABD
Fox Hills pressure head in feet above sea level
2460
2440
2420
2400
2380
2360
2340
2320
2300
2280
1970
1980
1990
2000
2010
2020
2030
2040
Year
Average discharge rate is 0.6 feet per year for 2010-2015, 0.6 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 2380
No Longer Flowing

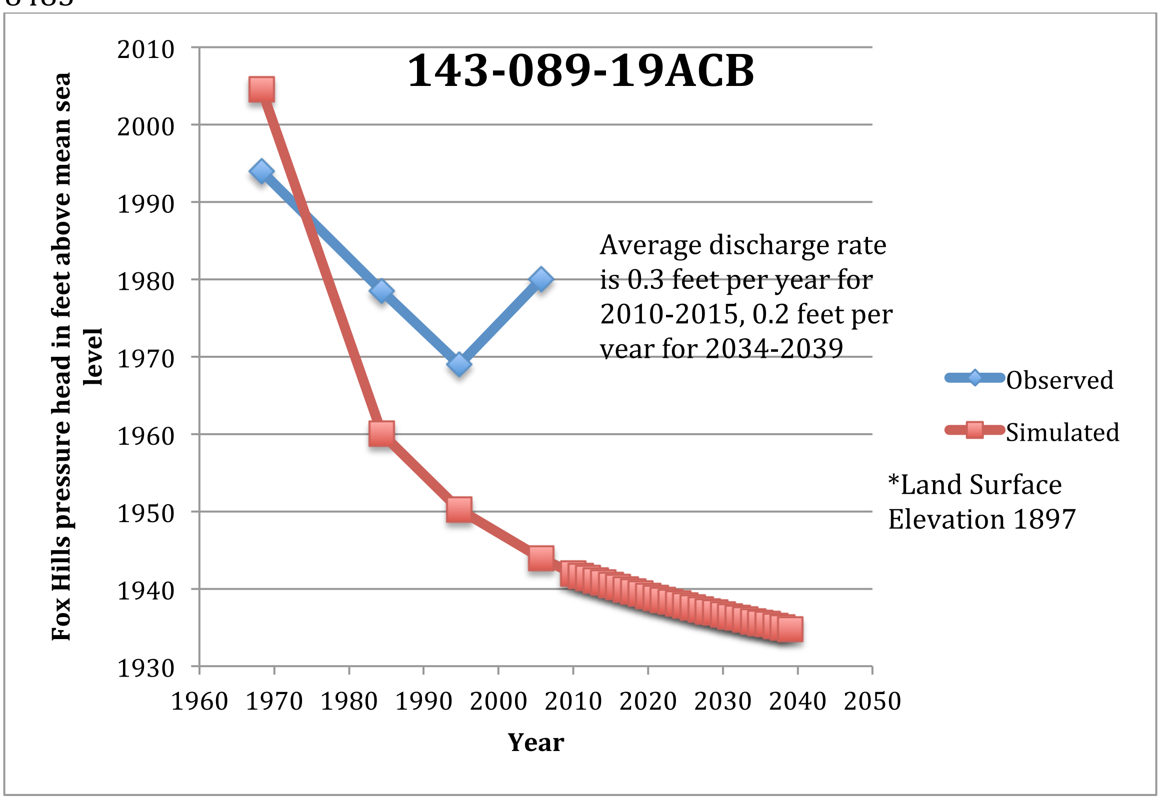
9442


142-084-24BBA
Fox Hills pressure head in feet above mean sea level
1835
1830
1825
1820
1815
1810
1805
1800
1795
1790
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

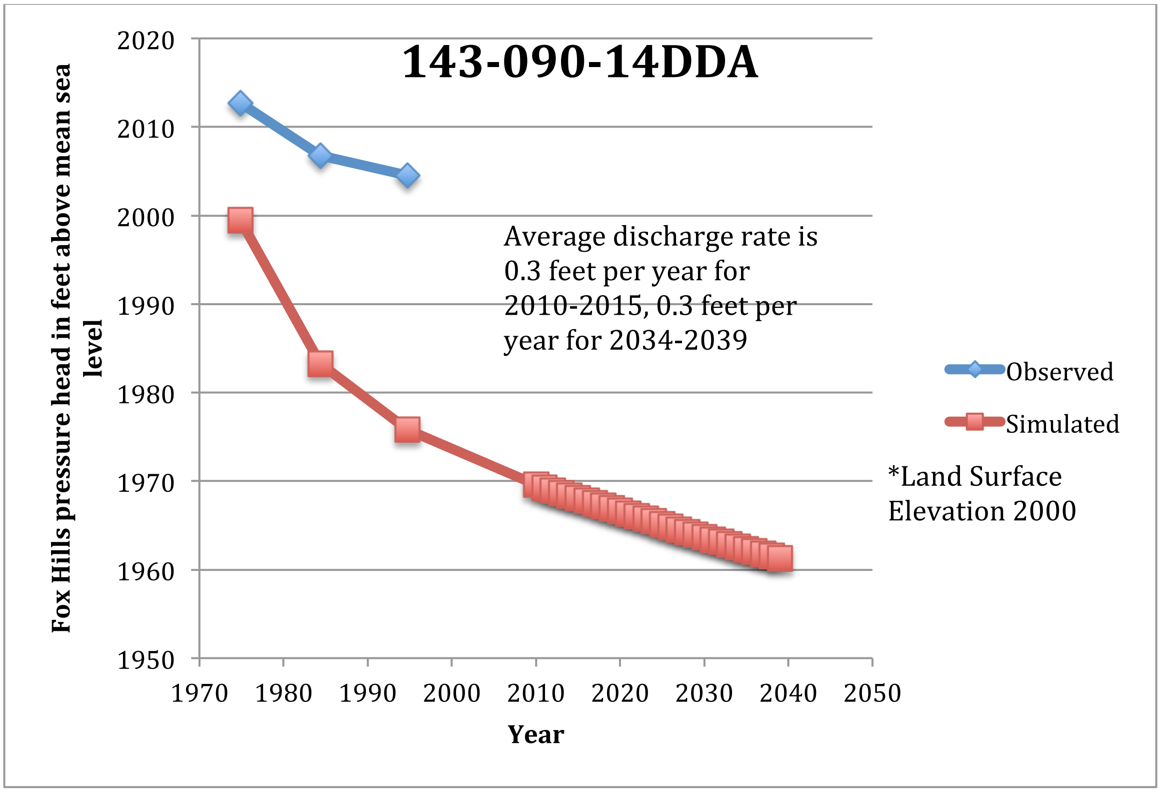
17570*


143-089-18ACC
Fox Hills pressure head in feet above mean sea level
2020
2010
2000
1990
1980
1970
1960
1950
1940
1930
1920
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Average discharge rate is 0.3 feet per year for 2010-2015, 0.2 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 1920

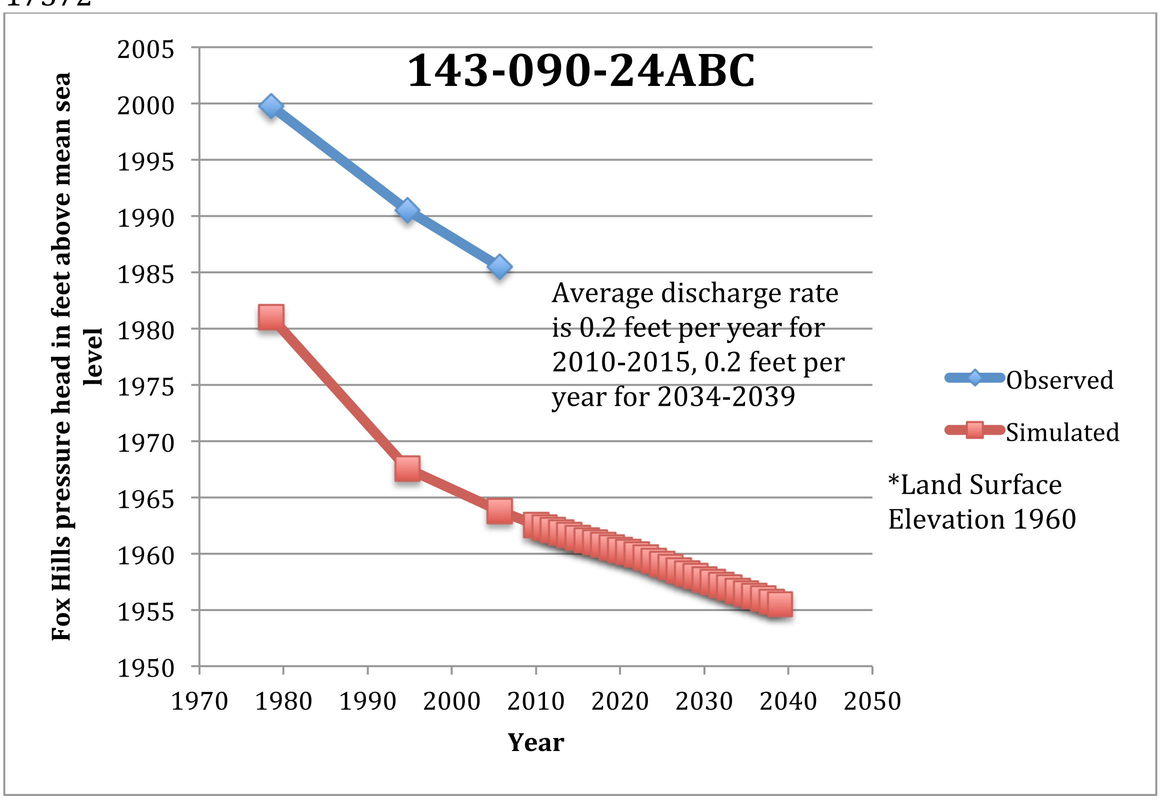
8485*


143-089-19ACB
Fox Hills pressure head in feet above mean sea level
2010
2000
1990
1980
1970
1960
1950
1940
1930
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Average discharge rate is 0.3 feet per year for 2010-2015, 0.2 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 1897

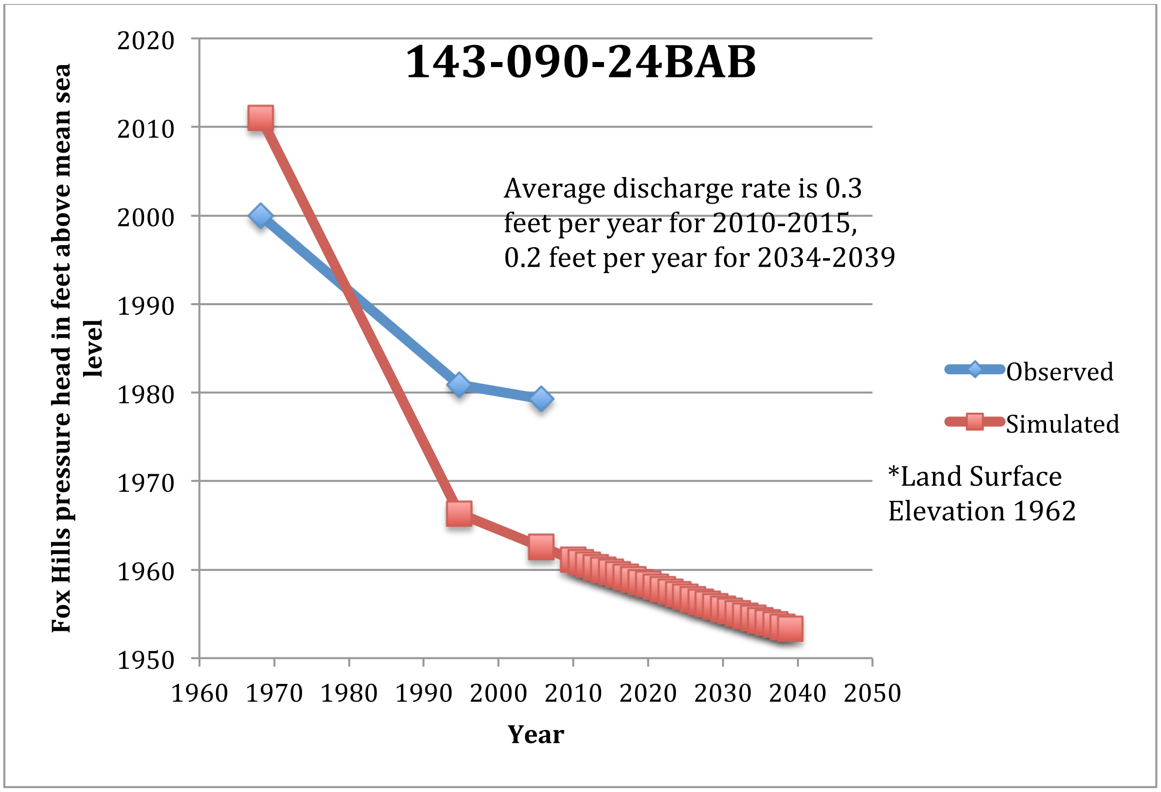
17571*


143-090-14DDA
Average discharge rate is 0.3 feet per year for 2010-2015, 0.3 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
Year
2020
2010
2000
1990
1980
1970
1960
1950
1970
1980
1990
2000
2010
2020
2030
2040
2050
Observed
Simulated
*Land Surface Elevation 2000

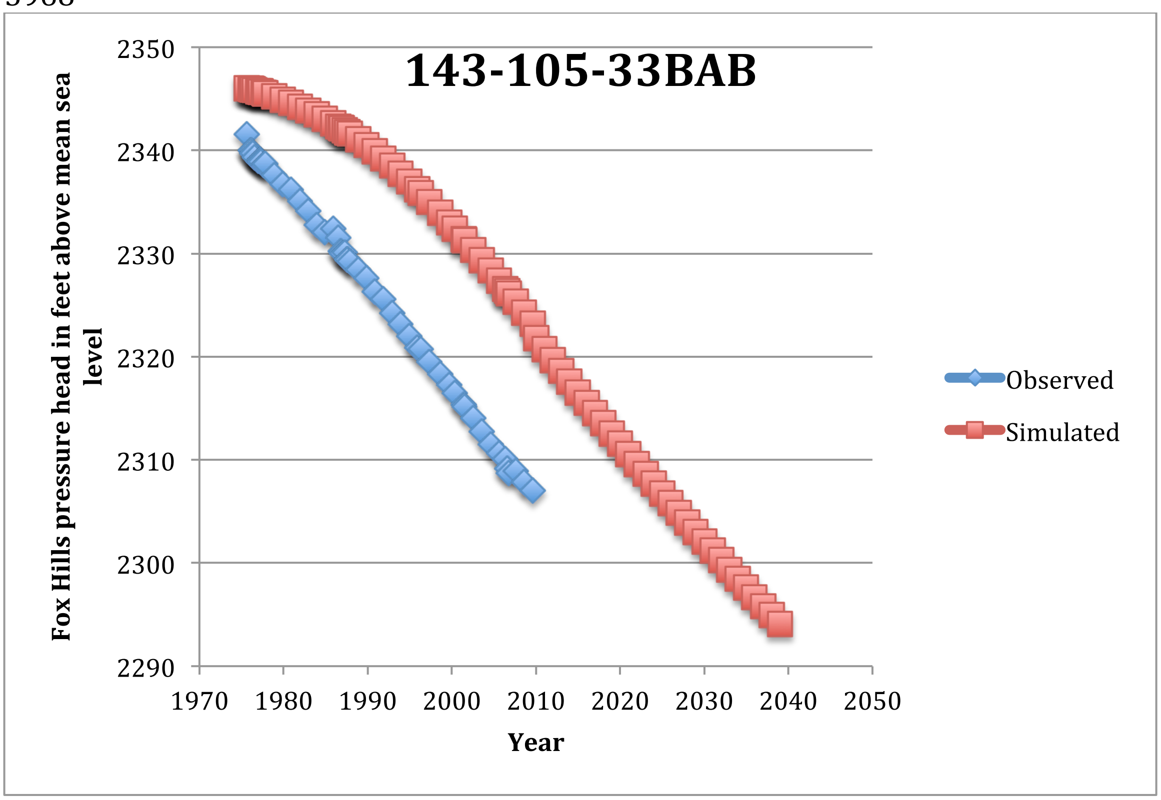
17572*


143-090-24ABC
Average discharge rate is 0.2 feet per year for 2010-2015, 0.2 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
Year
2005
2000
1995
1990
1985
1980
1975
1970
1965
1960
1955
1950
1970
1980
1990
2000
2010
2020
2030
2040
2050
Observed
Simulated
*Land Surface Elevation 1960

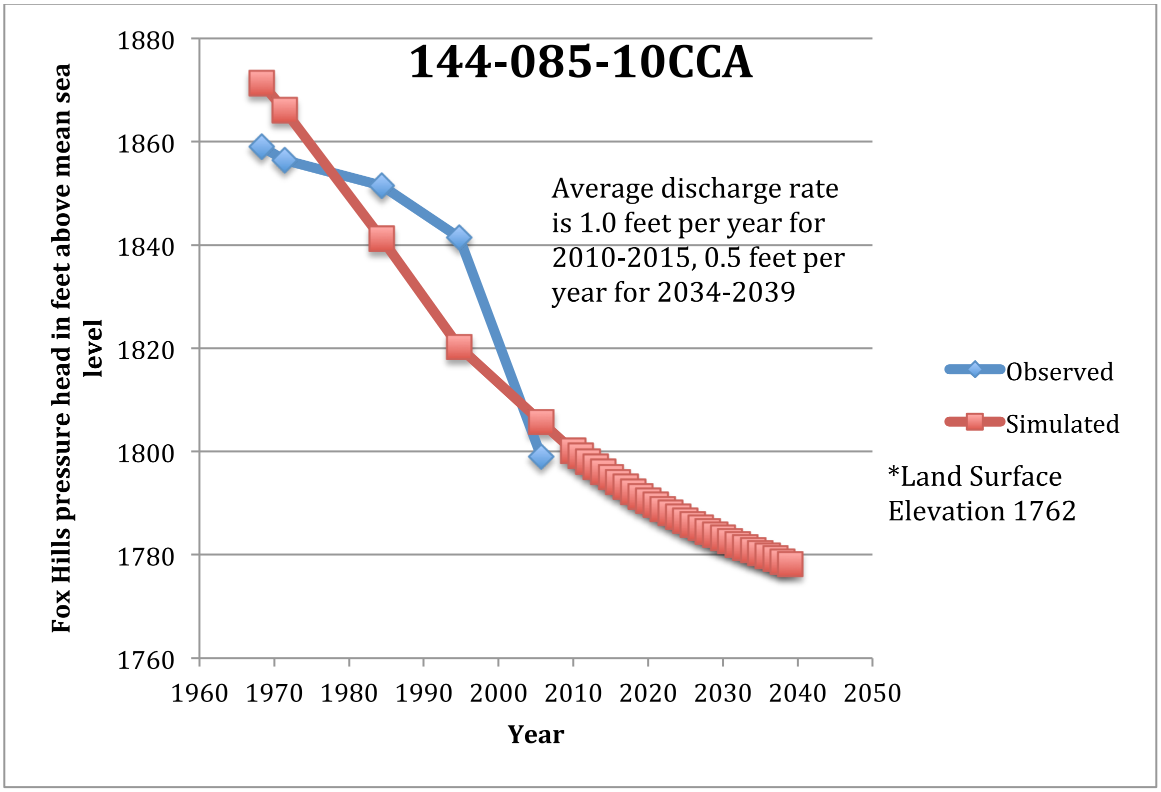
8486*


143-090-24BAB
Average discharge rate is 0.3
feet per year for 2010-2015,
0.2 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2020
2010
2000
1990
1980
1970
1960
1950
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated
*Land Surface
Elevation 1962

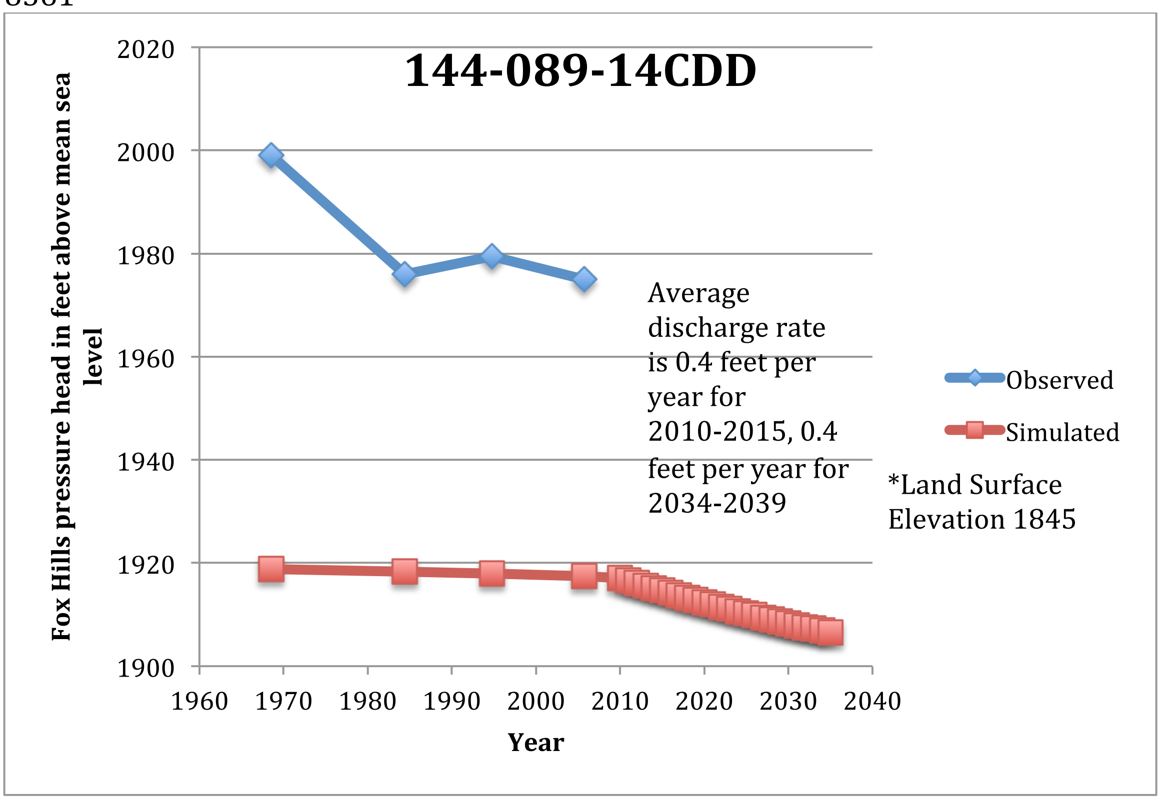
5968


143-105-33BAB
Fox Hills pressure head in feet above mean sea level
2350
2340
2330
2320
2310
2300
2290
1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated

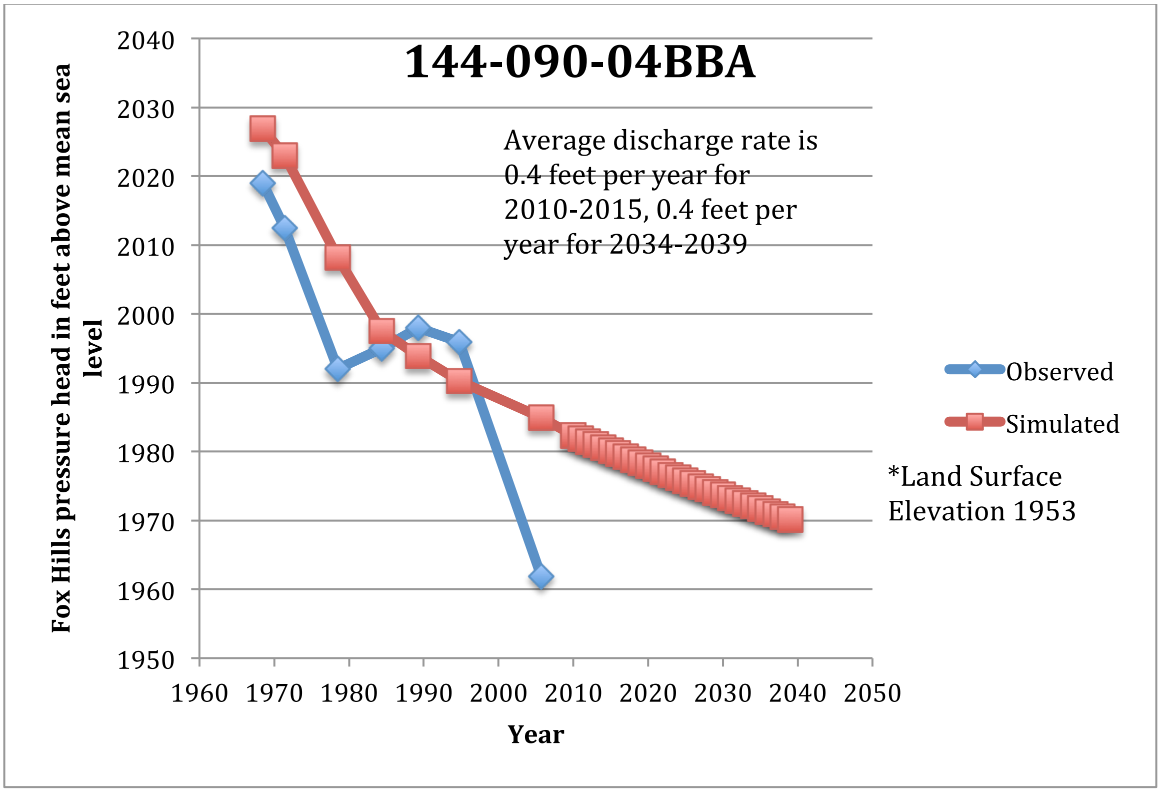
8514*


144-085-10CCA
Fox Hills pressure head in feet above mean sea level
1880
1860
1840
1820
1800
1780
1760
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 1.0 feet per year for 2010-2015, 0.5 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 1762

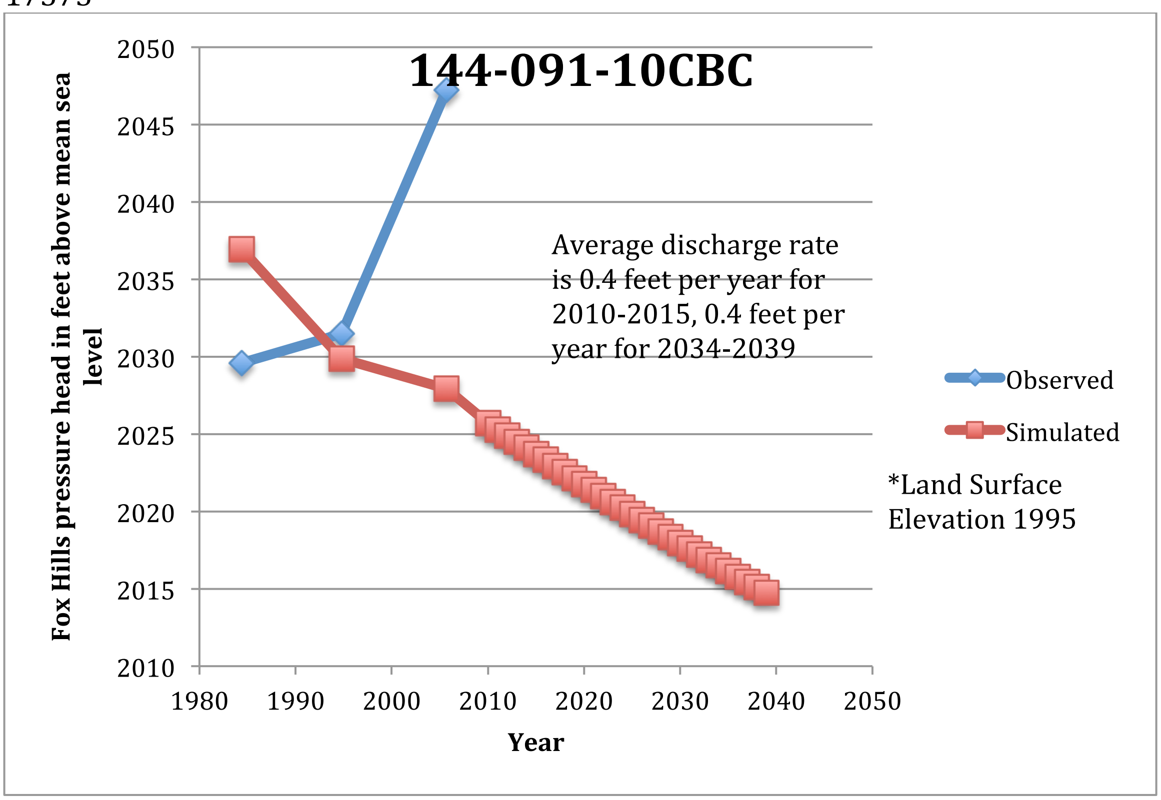
8561*


144-089-14CDD
Fox Hills pressure head in feet above mean sea level
2020
2000
1980
1960
1940
1920
1900
1960
1970
1980
1990
2000
2010
2020
2030
2040
Year
Average discharge rate is 0.4 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 1845

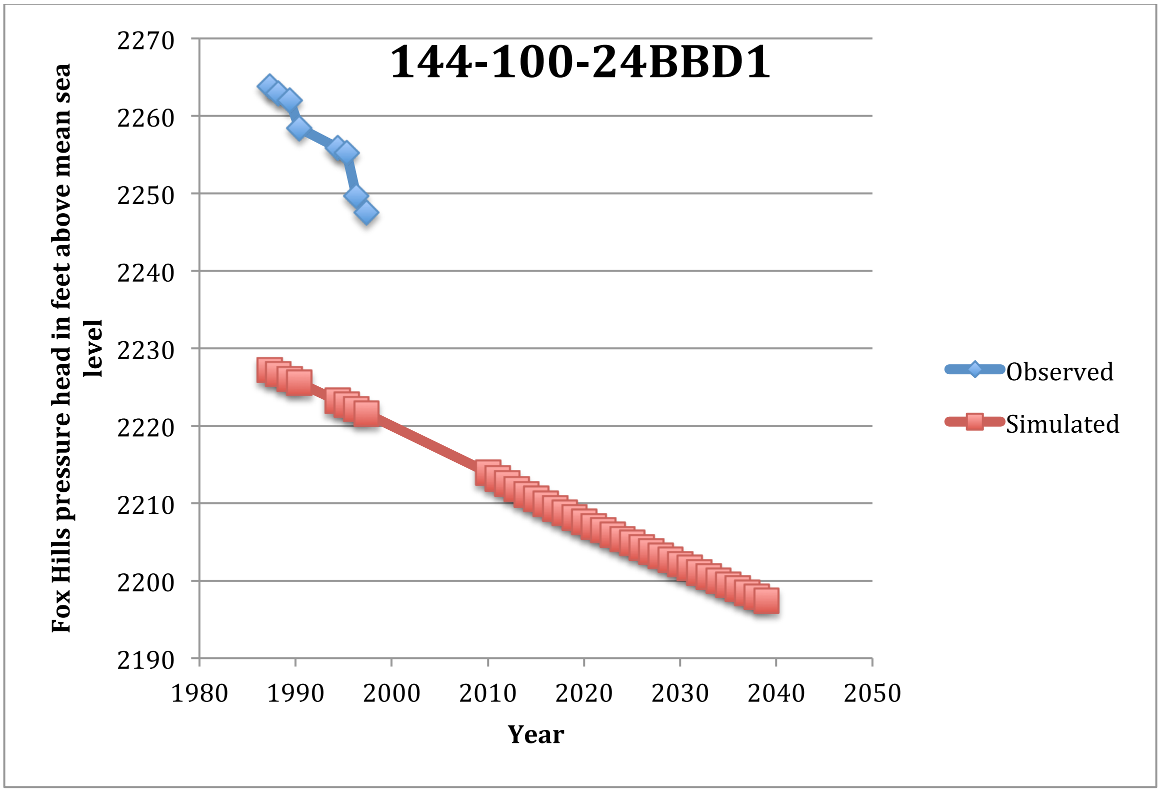
10821*


144-090-04BBA
Average discharge rate is 0.4 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2040
2030
2020
2010
2000
1990
1980
1970
1960
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
*Land Surface Elevation 1953

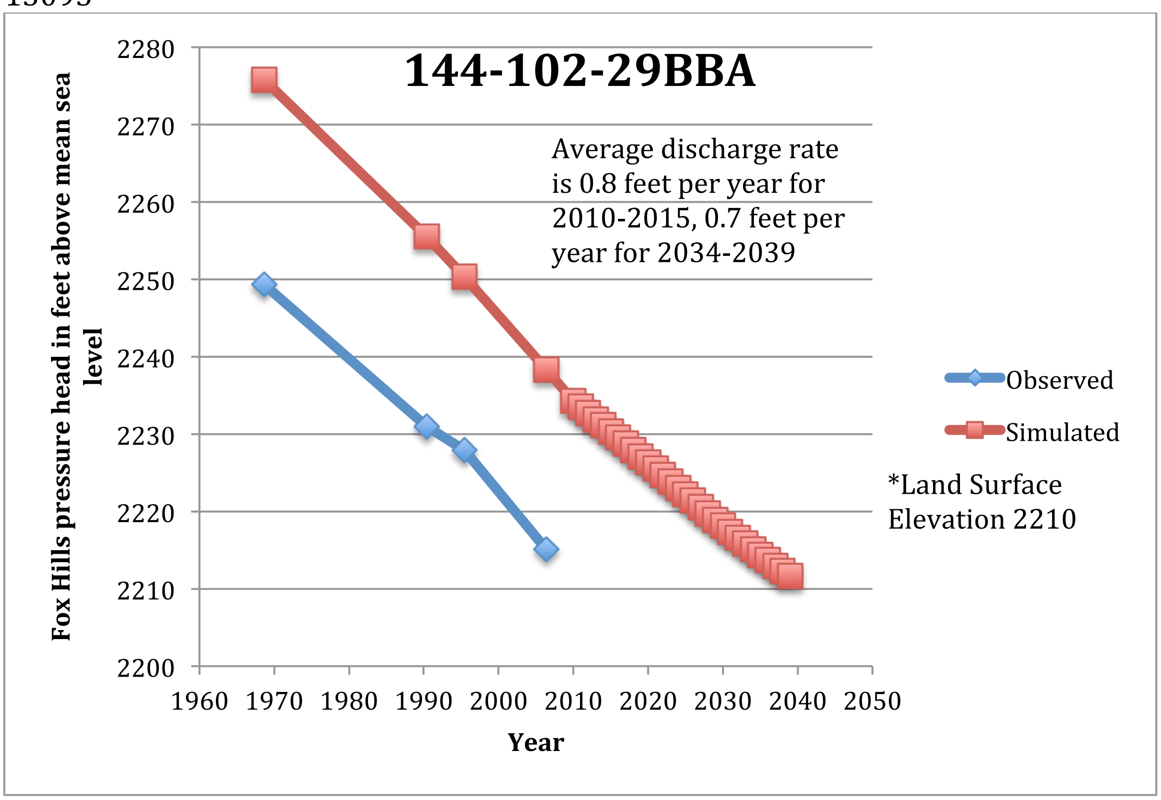
17573*


144-091-10CBC
Average discharge rate is 0.4 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2050
2045
2040
2035
2030
2025
2020
2015
2010
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
*Land Surface Elevation 1995

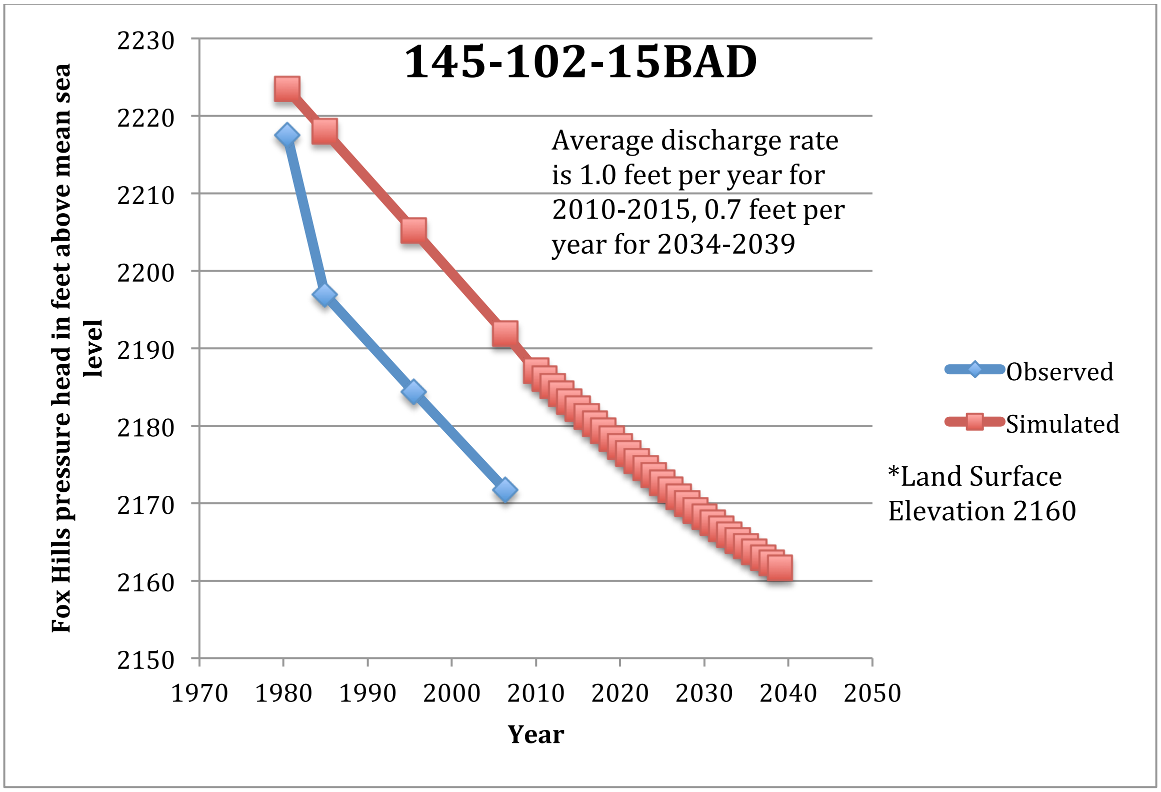
3712


144-100-24BBD1
Fox Hills pressure head in feet above mean sea level
2270
2260
2250
2240
2230
2220
2210
2200
2190
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

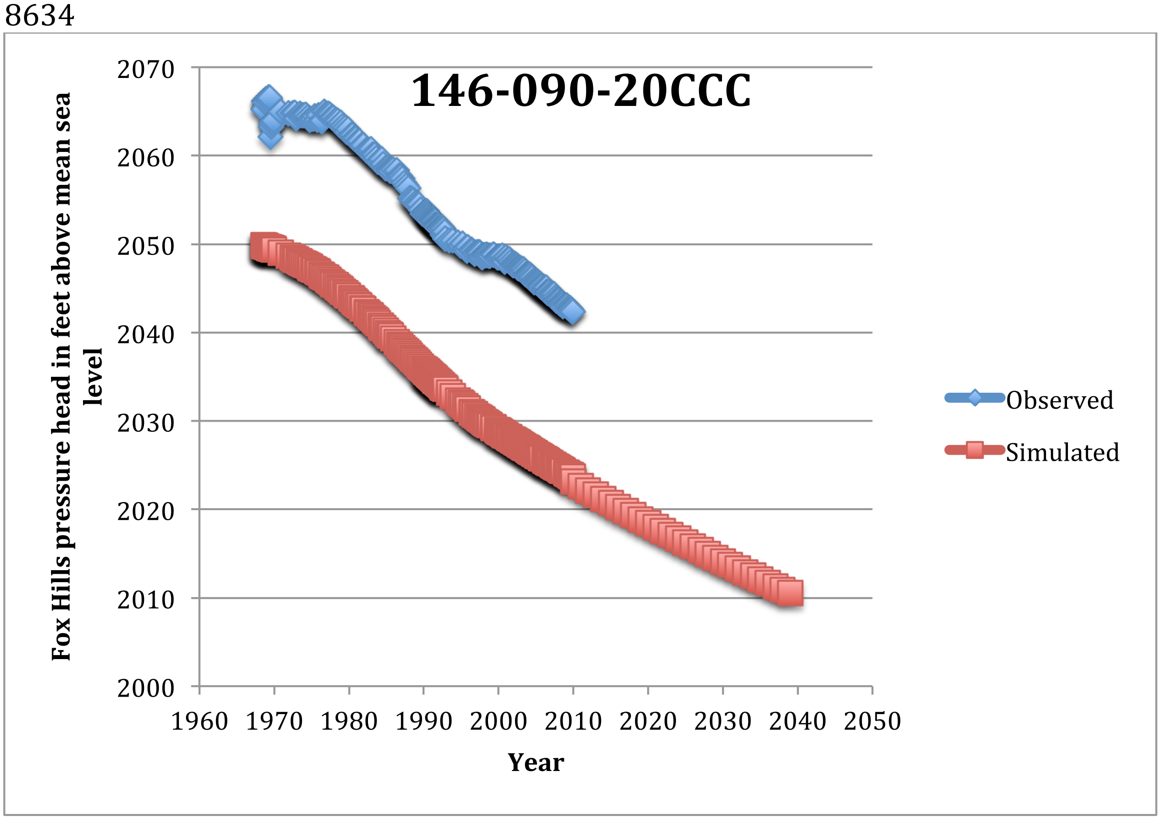
13095*


144-102-29BBA
Average discharge rate is 0.8 feet per year for 2010-2015, 0.7 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2280
2270
2260
2250
2240
2230
2220
2210
2200
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
*Land Surface Elevation 2210

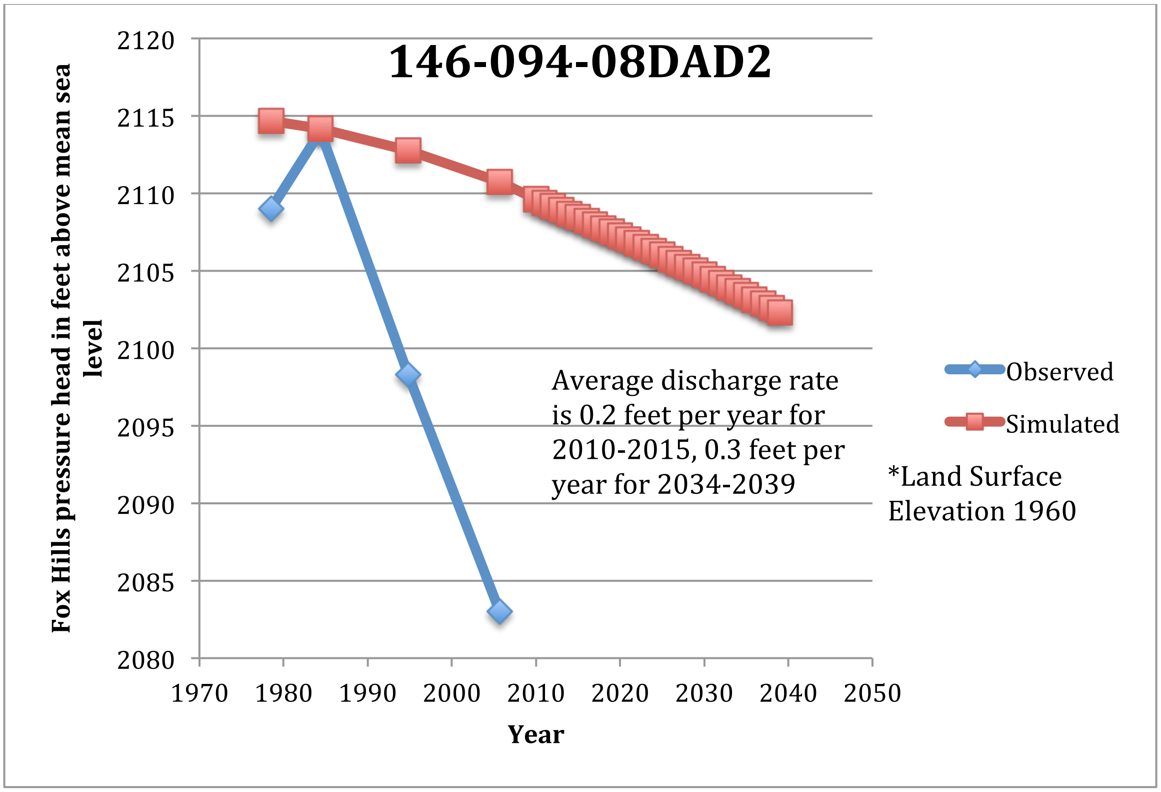
7570*


145-102-15BAD
Average discharge rate is 1.0 feet per year for 2010-2015, 0.7 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2230
2220
2210
2200
2190
2180
2170
2160
2150
1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated
*Land Surface Elevation 2160

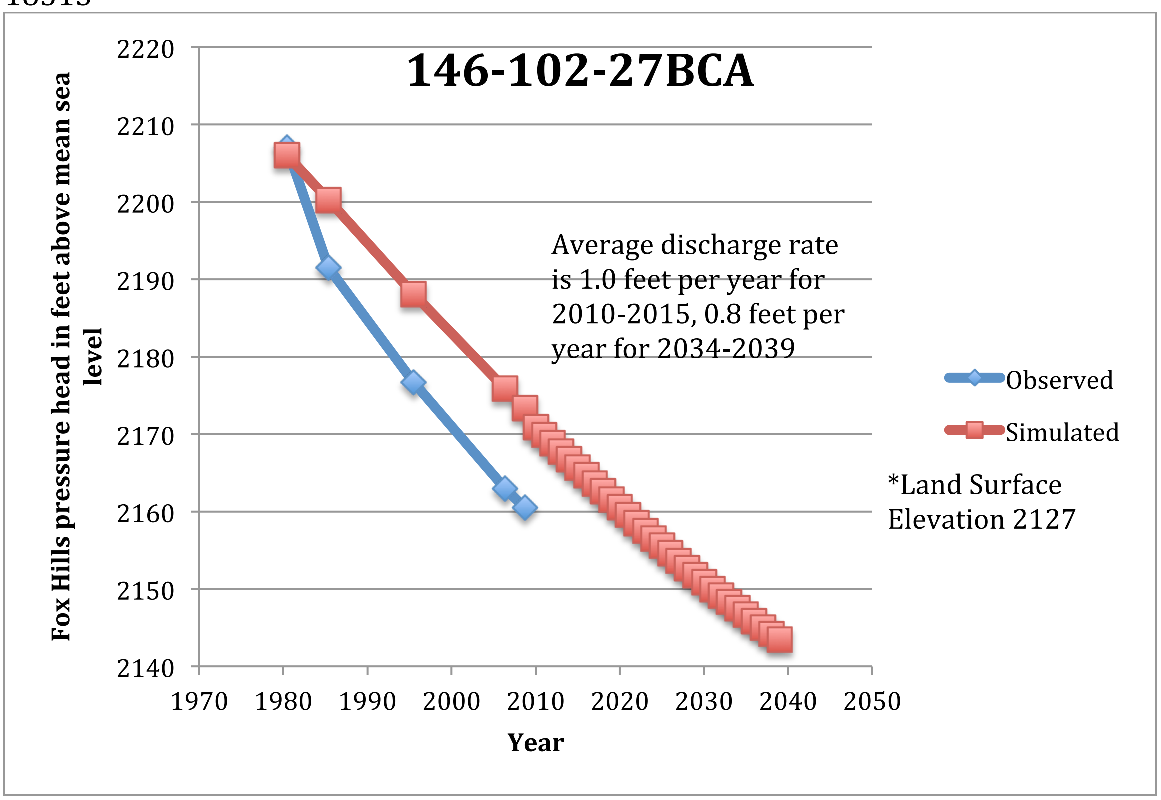
8634


146-090-20CCC
Fox Hills pressure head in feet above mean sea level
2070
2060
2050
2040
2030
2020
2010
2000
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated

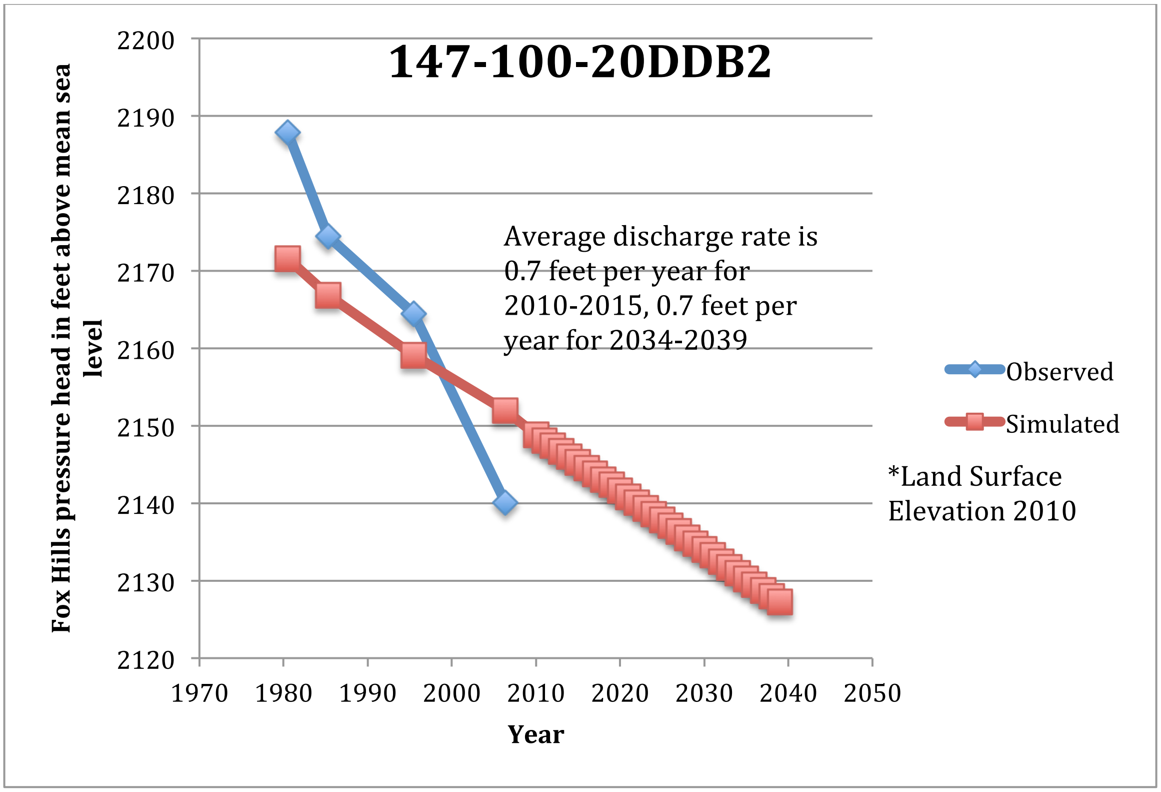
5164*


146-094-08DAD2
Fox Hills pressure head in feet above mean sea level
2120
2115
2110
2105
2100
2095
2090
2085
2080
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 0.2 feet per year for 2010-2015, 0.3 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 1960

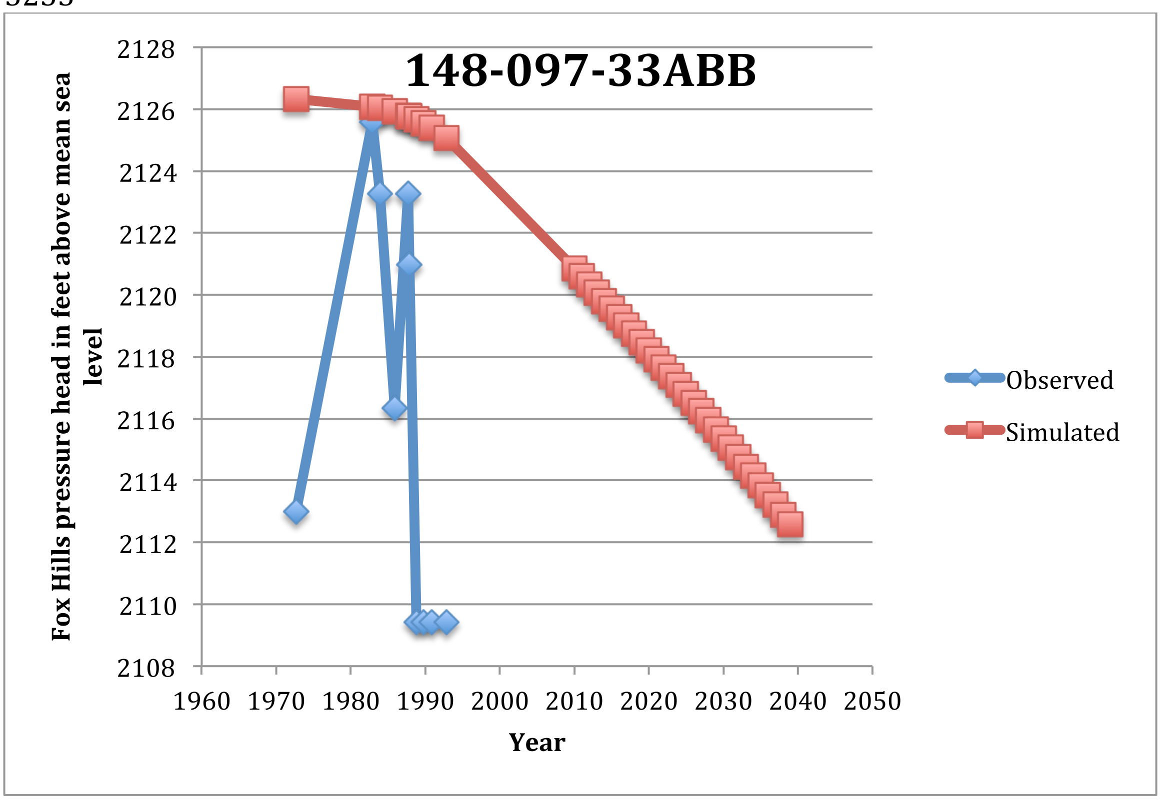
18315*


146-102-27BCA
Fox Hills pressure head in feet above mean sea level
2220
2210
2200
2190
2180
2170
2160
2150
2140
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 1.0 feet per year for 2010-2015, 0.8 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 2127

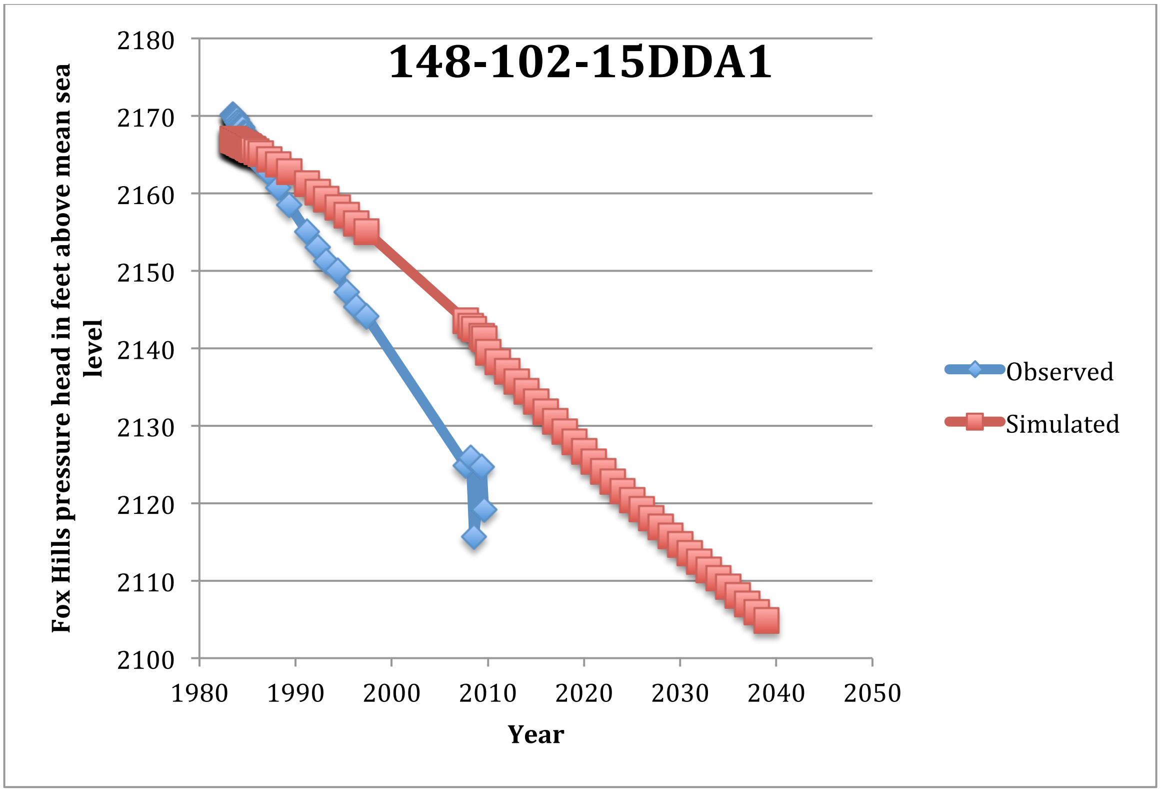
7598*


147-100-20DDB2
Fox Hills pressure head in feet above mean sea level
2200
2190
2180
2170
2160
2150
2140
2130
2120
1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Average discharge rate is 0.7 feet per year for 2010-2015, 0.7 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 2010

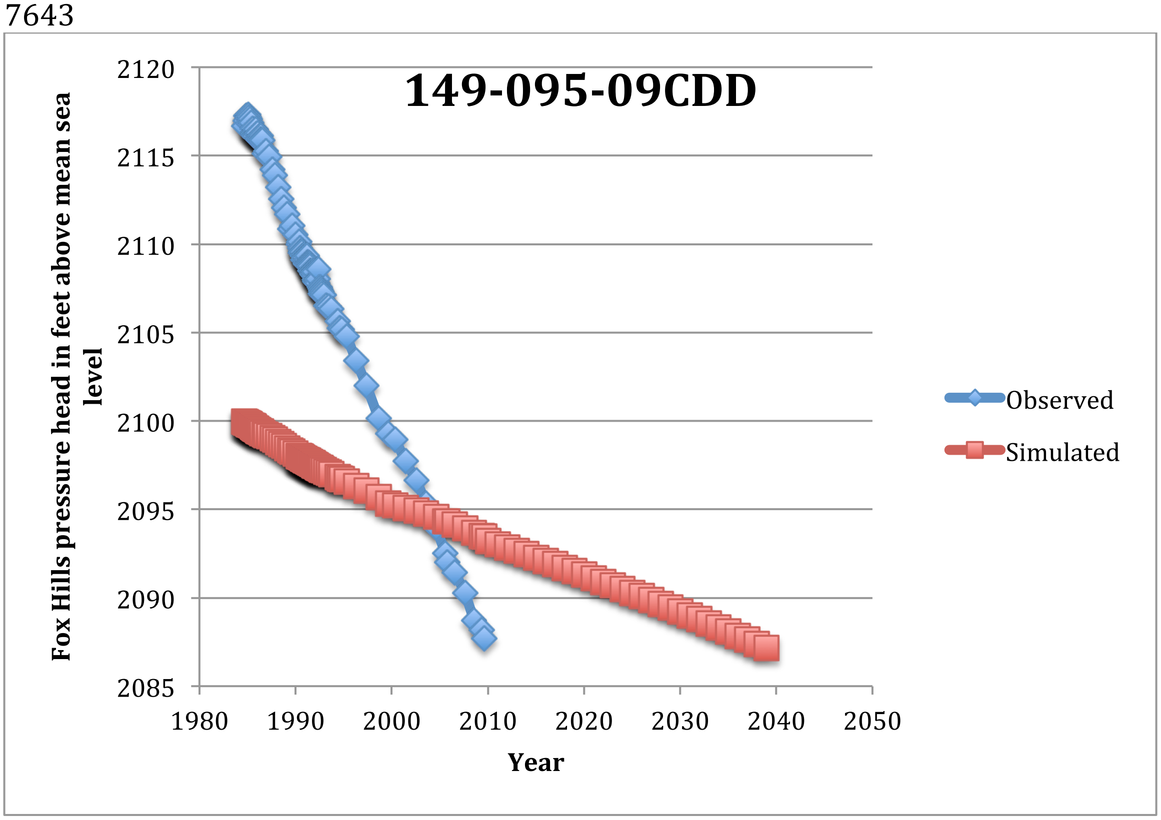
5253


148-097-33ABB
Fox Hills pressure head in feet above mean sea level
2128
2126
2124
2122
2120
2118
2116
2114
2112
2110
2108
1960 1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated

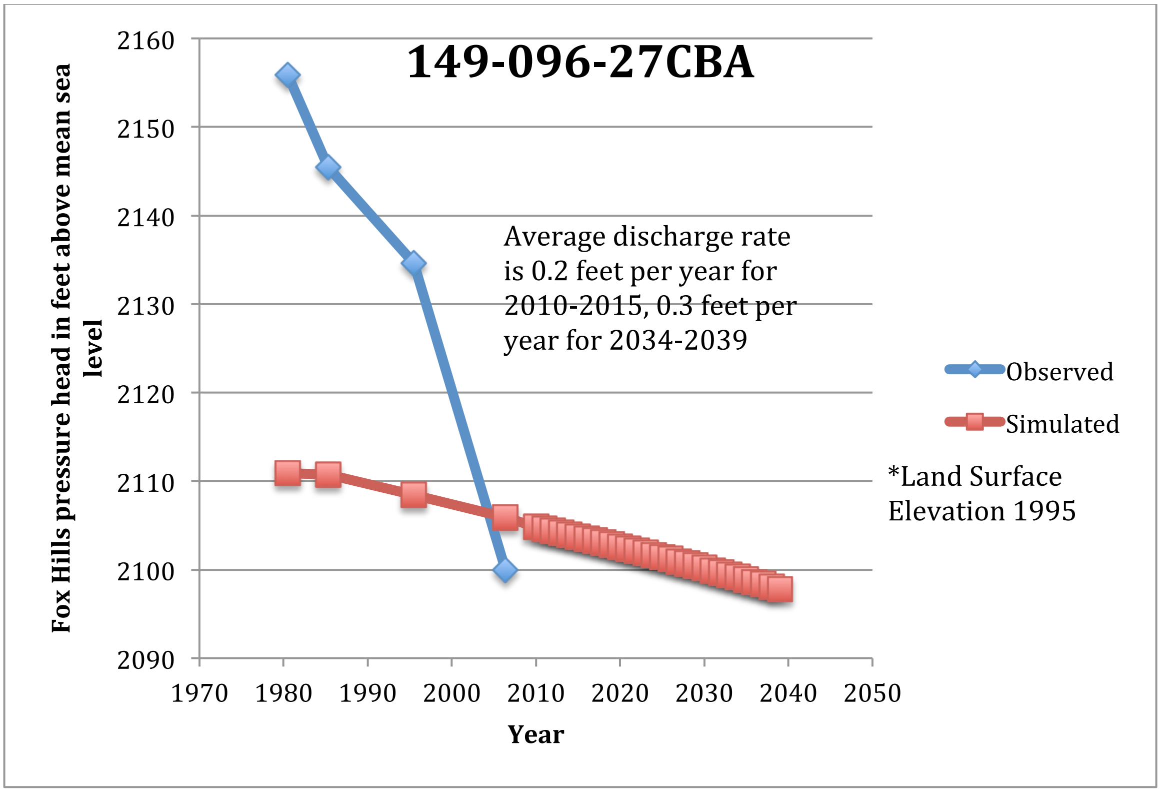
7623


148-102-15DDA1
Fox Hills pressure head in feet above mean sea level
2180
2170
2160
2150
2140
2130
2120
2110
2100
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

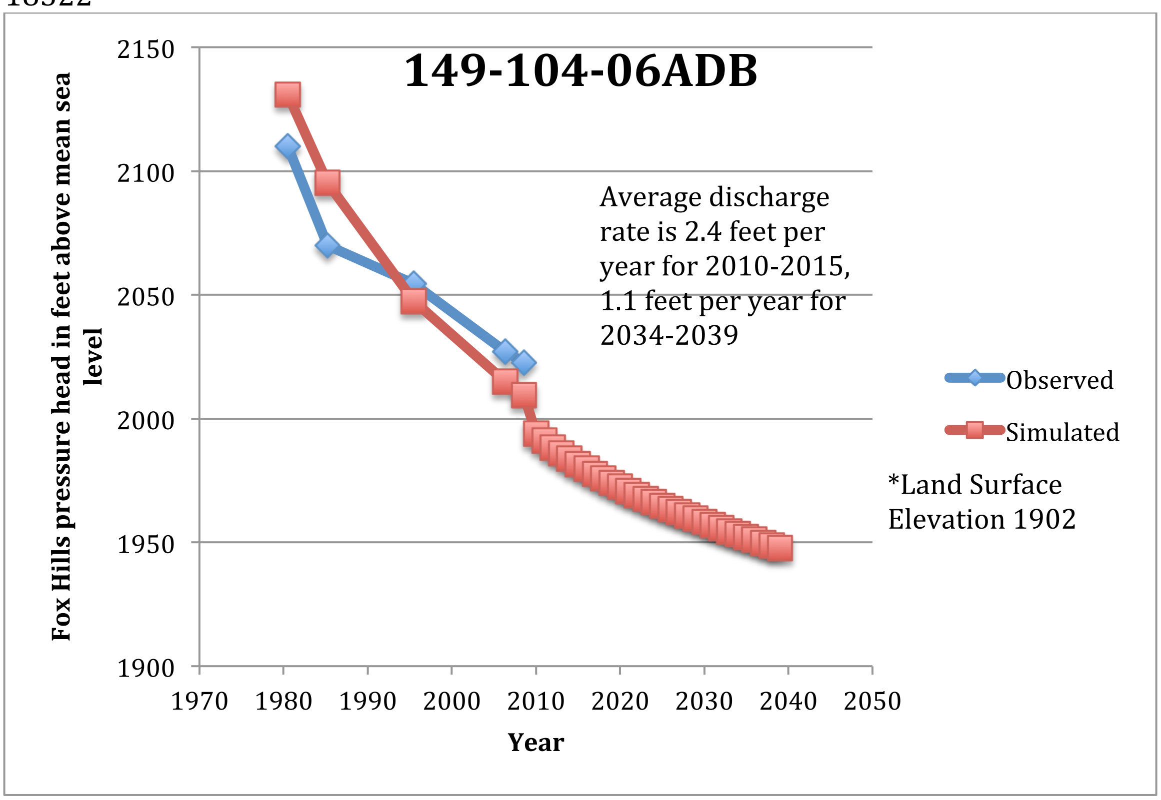
7643


149-095-09CDD
Fox Hills pressure head in feet above mean sea level
2120
2115
2110
2105
2100
2095
2090
2085
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

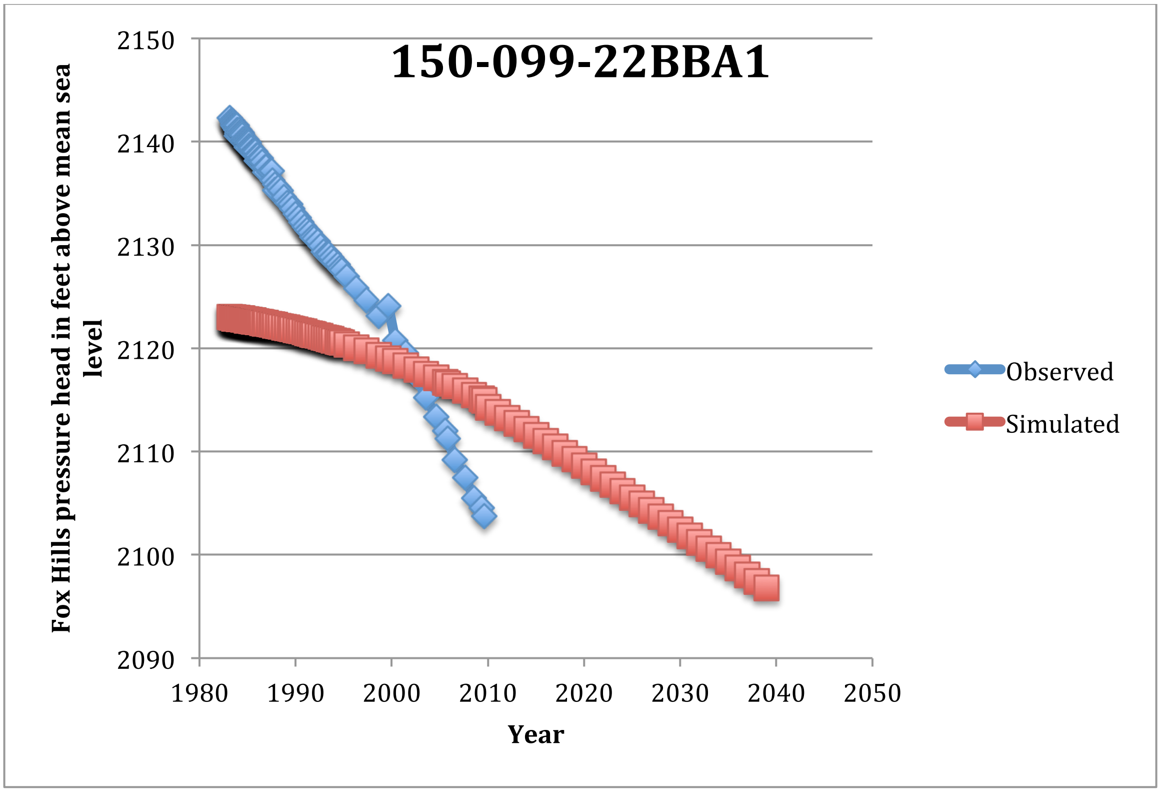
7644*


149-096-27CBA
Fox Hills pressure head in feet above mean sea level
2160
2150
2140
2130
2120
2110
2100
2090
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 0.2 feet per year for 2010-2015, 0.3 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 1995

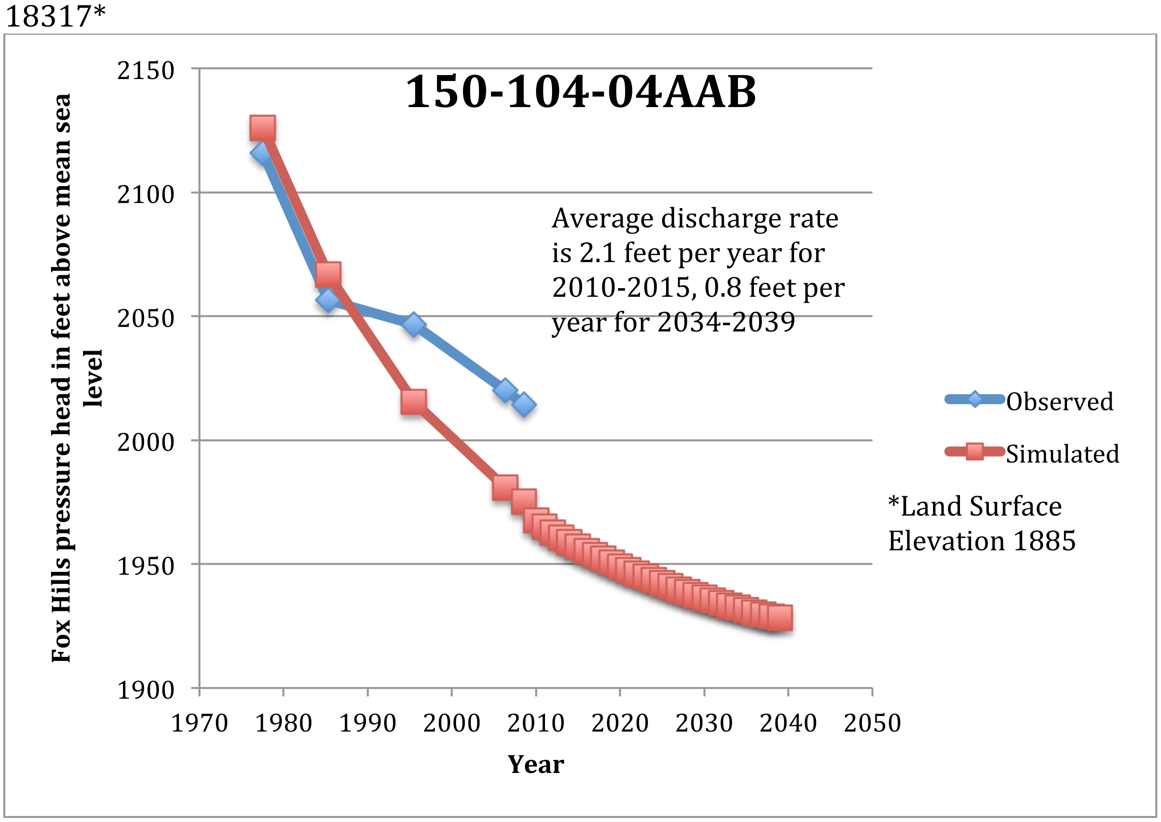
18322*


149-104-06ADB
Fox Hills pressure head in feet above mean sea level
2150
2100
2050
2000
1950
1900
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 2.4 feet per year for 2010-2015, 1.1 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 1902

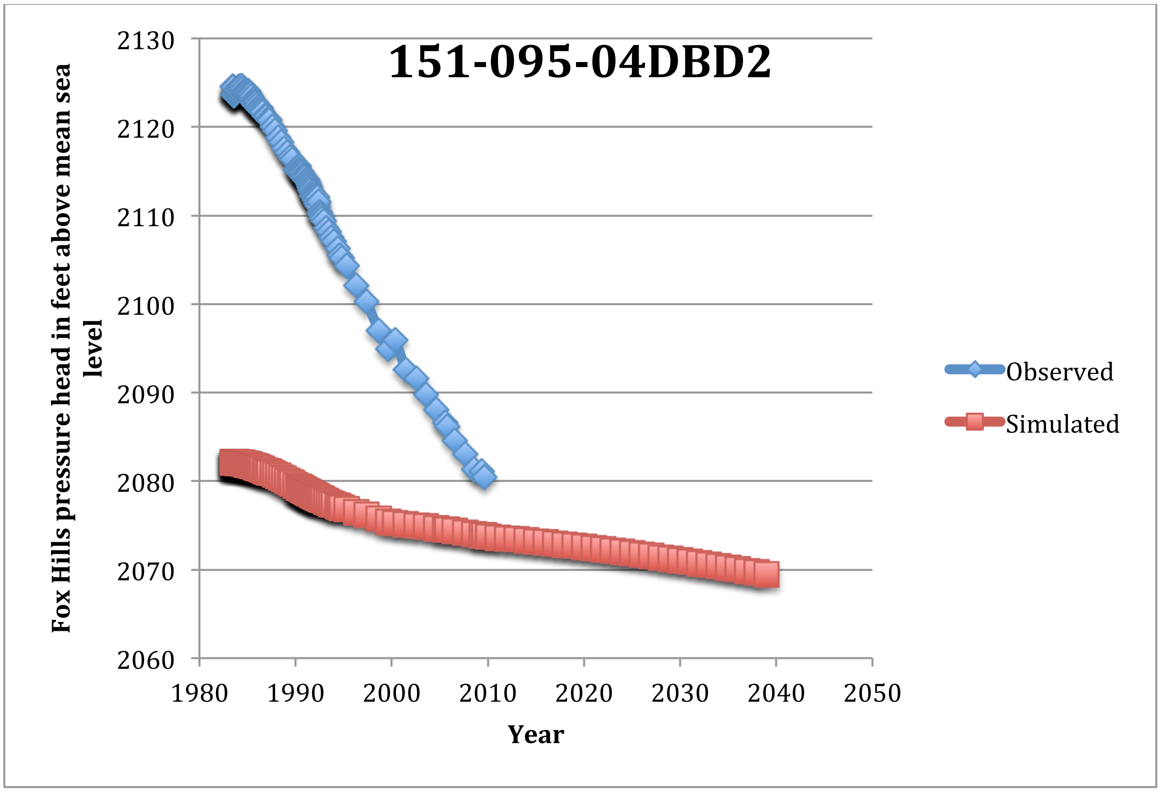
7699


150-099-22BBA1
Fox Hills pressure head in feet above mean sea level
2150
2140
2130
2120
2110
2100
2090
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

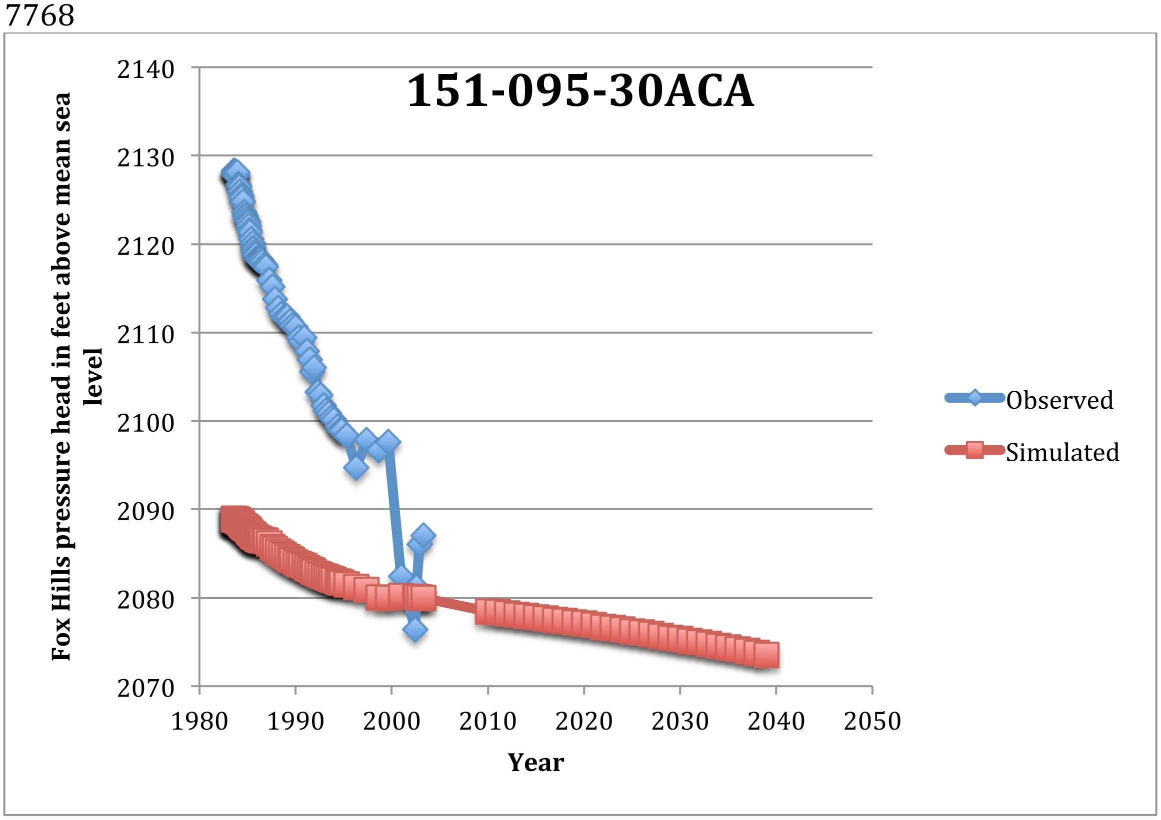
18317*


150-104-04AAB
Fox Hills pressure head in feet above mean sea level
2150
2100
2050
2000
1950
1900
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 2.1 feet per year for 2010-2015, 0.8 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 1885

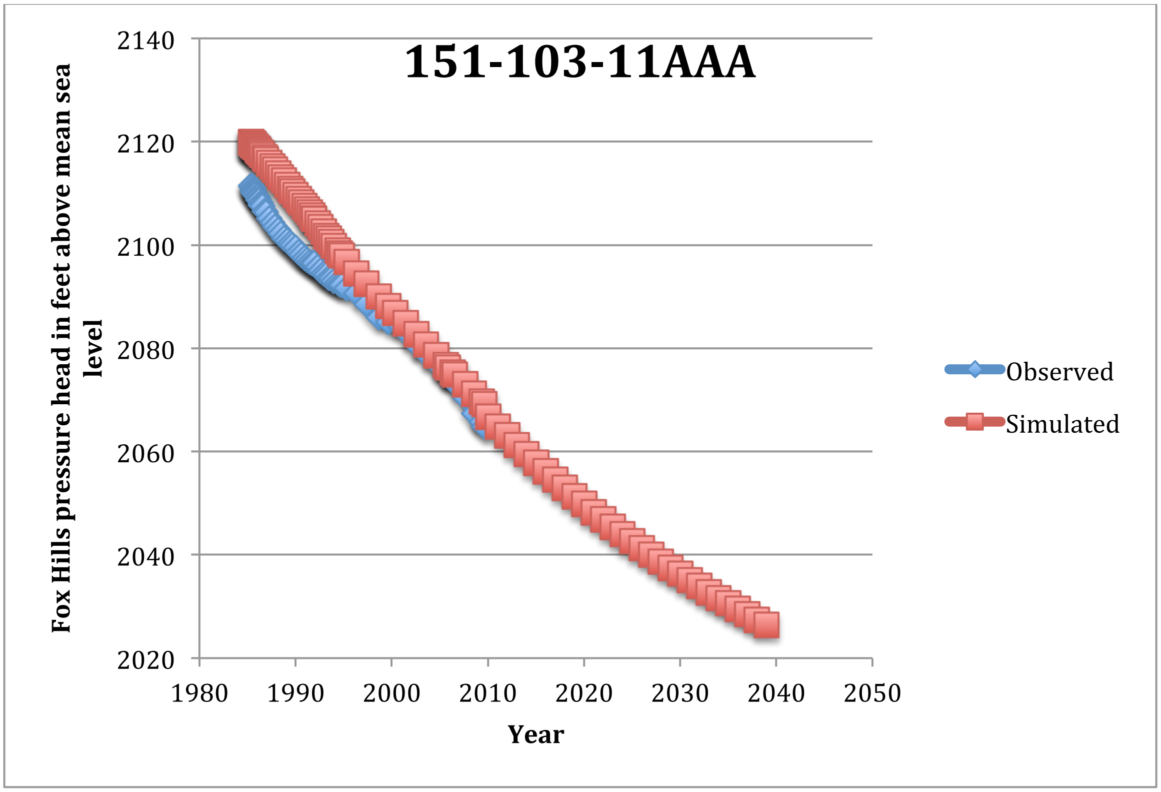
7766


151-095-04DBD2
Fox Hills pressure head in feet above mean sea level
2130
2120
2110
2100
2090
2080
2070
2060
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

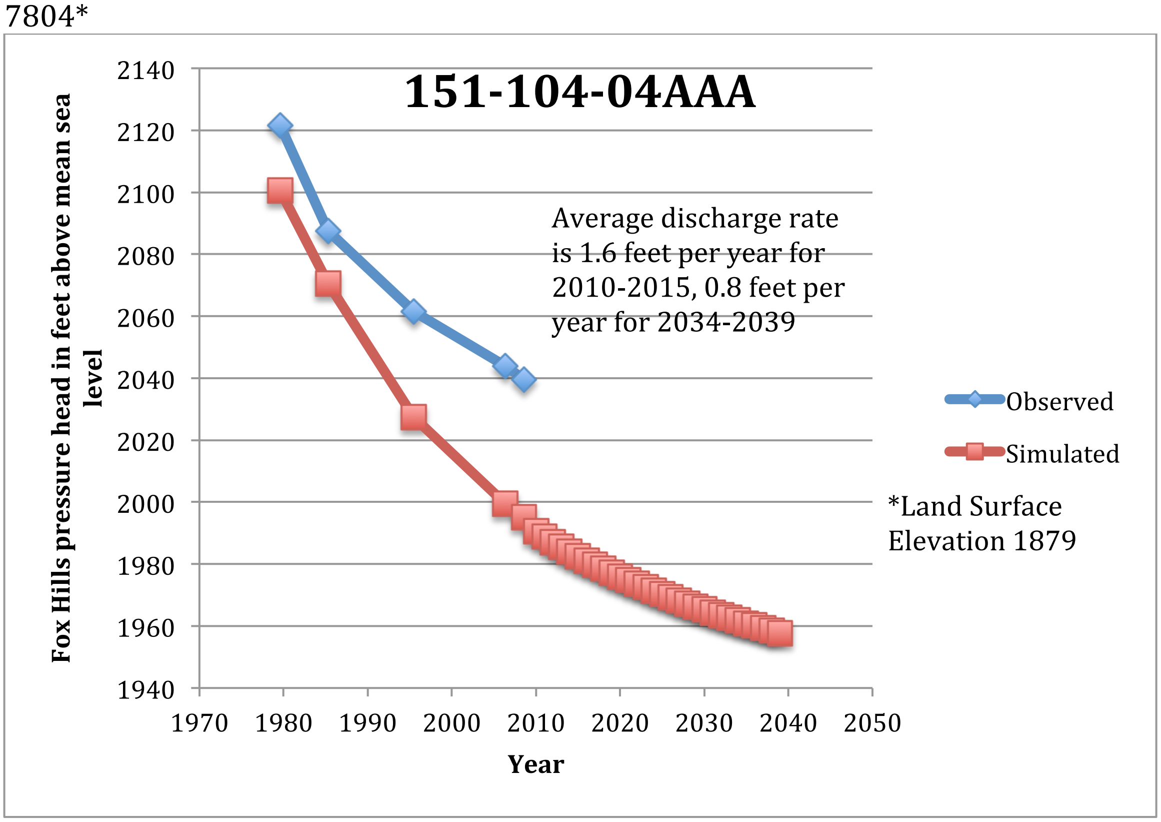
7768


151-095-30ACA
Fox Hills pressure head in feet above mean sea level
2140
2130
2120
2110
2100
2090
2080
2070
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

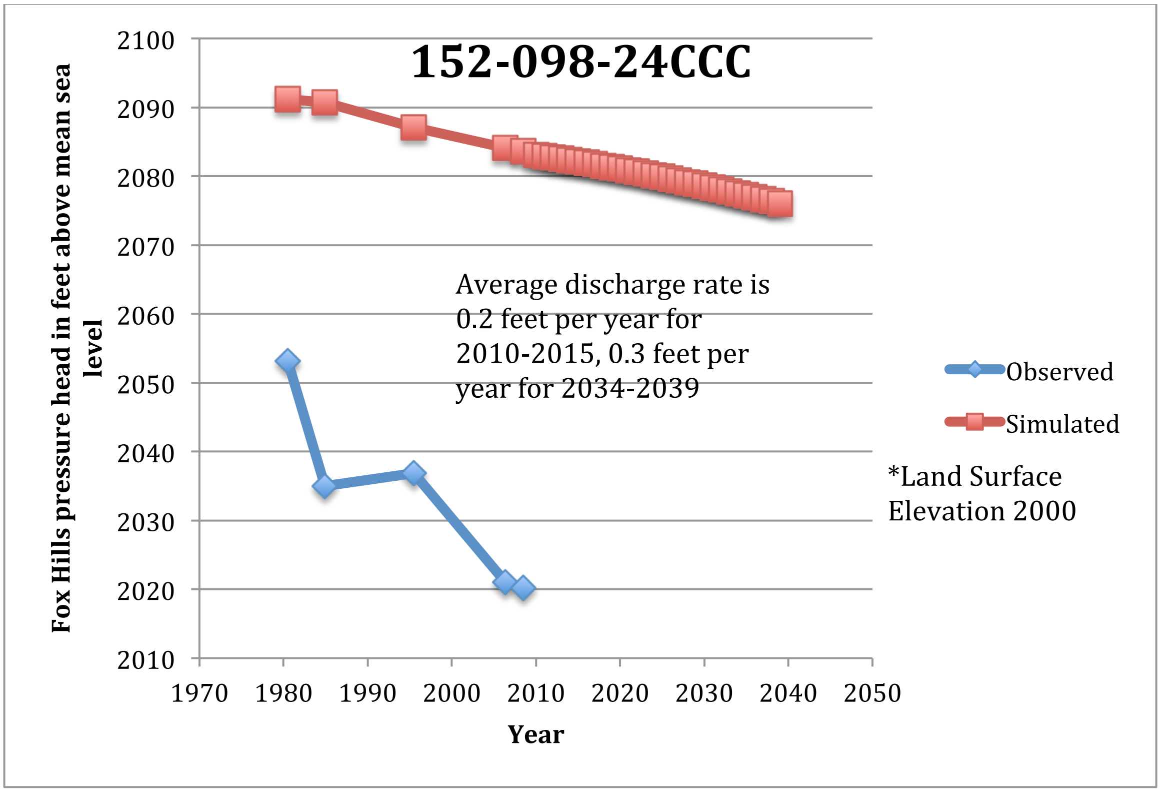
7796


151-103-11AAA
Fox Hills pressure head in feet above mean sea level
2140
2120
2100
2080
2060
2040
2020
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

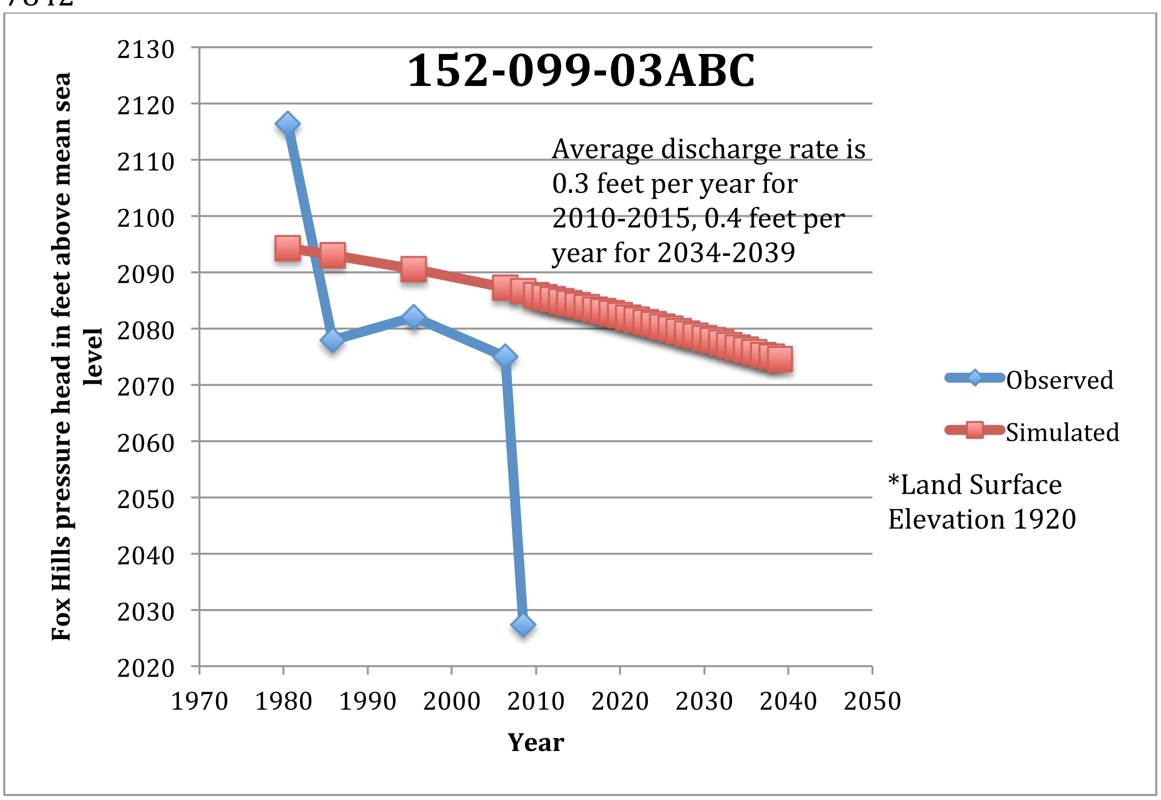
7804*


151-104-04AAA
Fox Hills pressure head in feet above mean sea level
2140
2120
2100
2080
2060
2040
2020
2000
1980
1960
1940
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 1.6 feet per year for 2010-2015, 0.8 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 1879

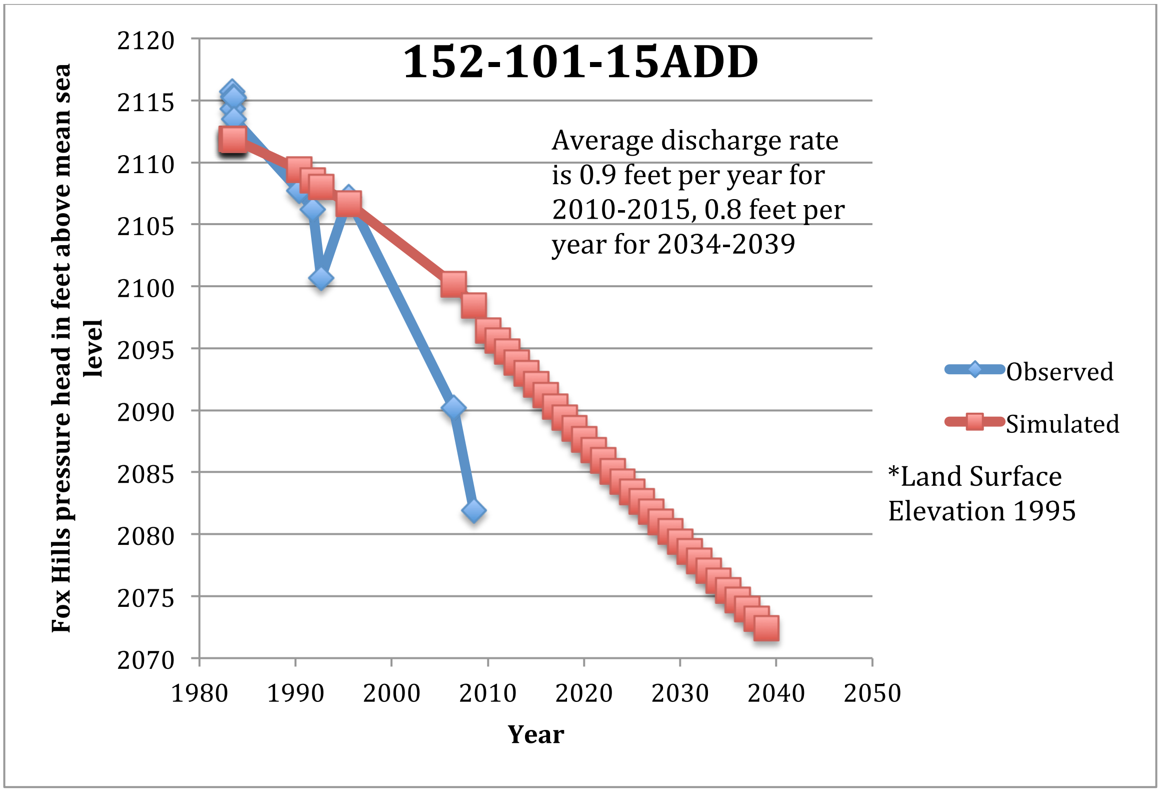
7838*


152-098-24CCC
Fox Hills pressure head in feet above mean sea level
2100
2090
2080
2070
2060
2050
2040
2030
2020
2010
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 0.2 feet per year for 2010-2015, 0.3 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 2000

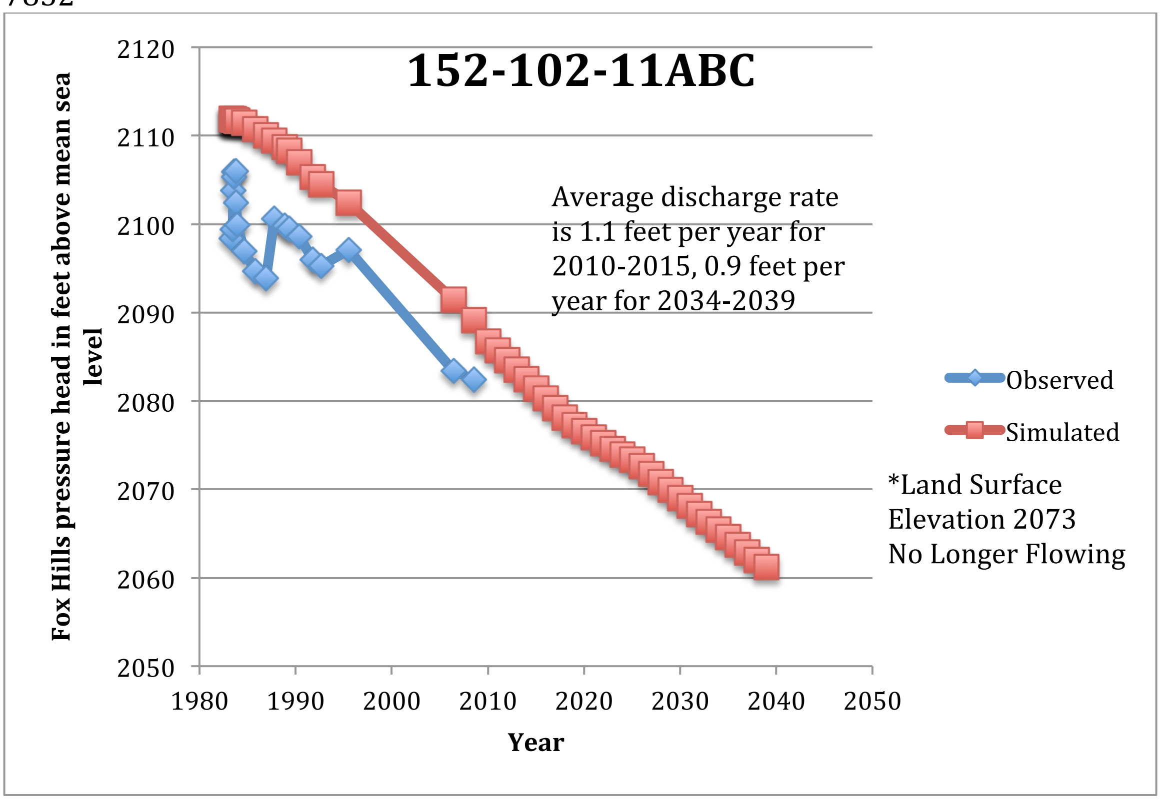
7842*


152-099-03ABC
Fox Hills pressure head in feet above mean sea level
2130
2120
2110
2100
2090
2080
2070
2060
2050
2040
2030
2020
1970
1980
1990
2000
2010
2020
2030
2040
2050
Year
Average discharge rate is 0.3 feet per year for 2010-2015, 0.4 feet per year for 2034-2039
Observed
Simulated
*Land Surface Elevation 1920

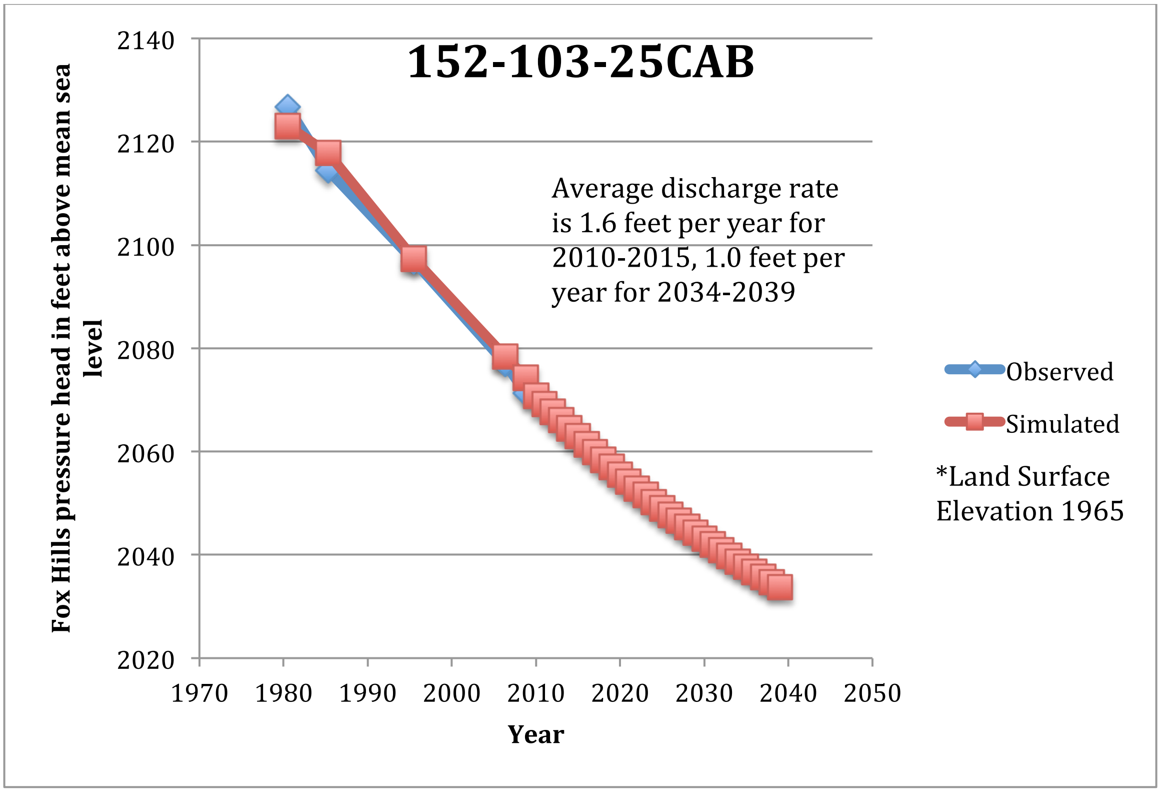
7848*


152-101-15ADD
Average discharge rate is 0.9 feet per year for 2010-2015, 0.8 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2120
2115
2110
2105
2100
2095
2090
2085
2080
2075
2070
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
*Land Surface Elevation 1995

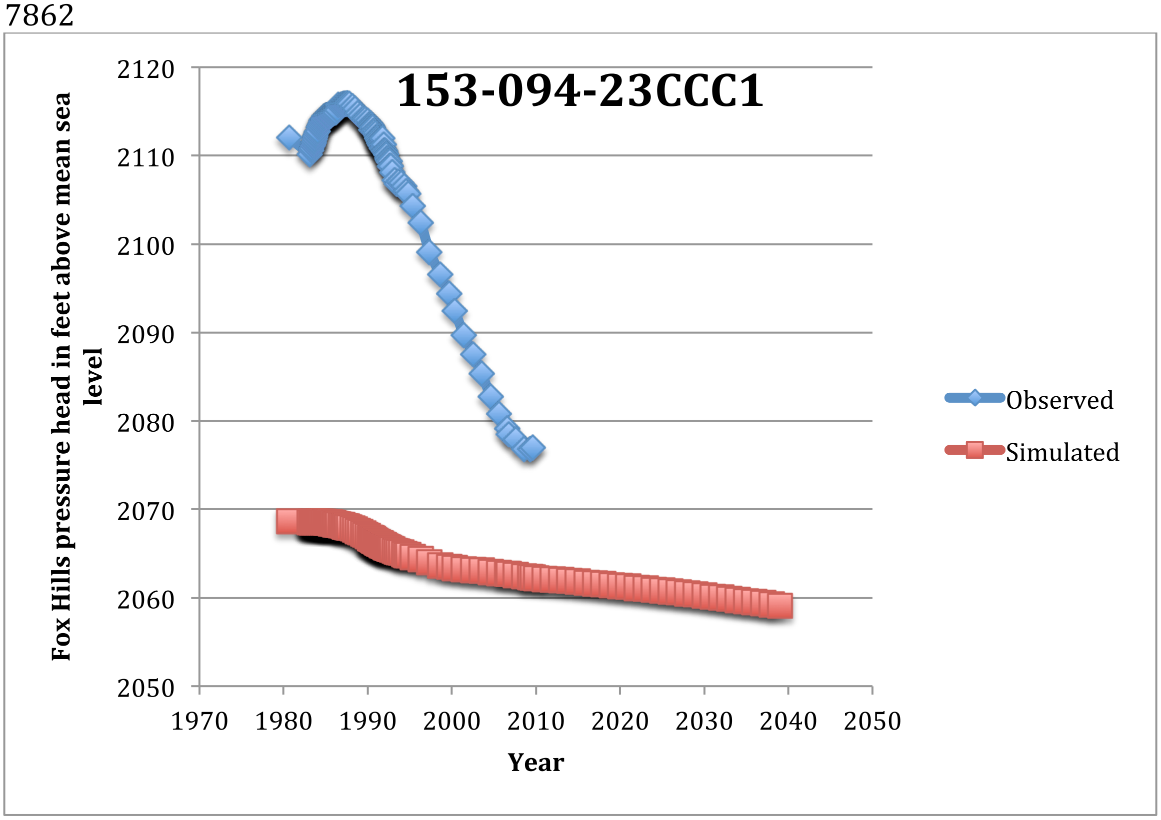
7852*


152-102-11ABC
Average discharge rate is 1.1 feet per year for 2010-2015, 0.9 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2120
2110
2100
2090
2080
2070
2060
2050
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
*Land Surface Elevation 2073
No Longer Flowing

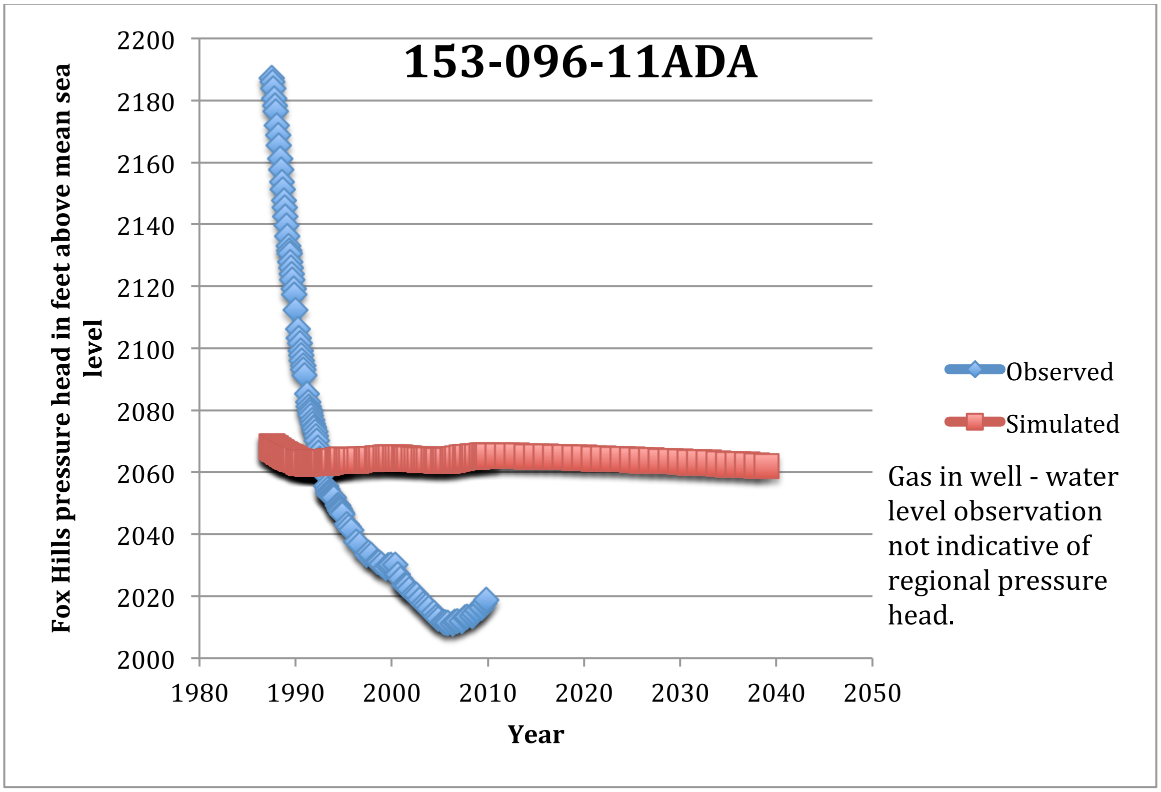
7855*


152-103-25CAB
Average discharge rate is 1.6 feet per year for 2010-2015, 1.0 feet per year for 2034-2039
Fox Hills pressure head in feet above mean sea level
2140
2120
2100
2080
2060
2040
2020
1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated
*Land Surface Elevation 1965

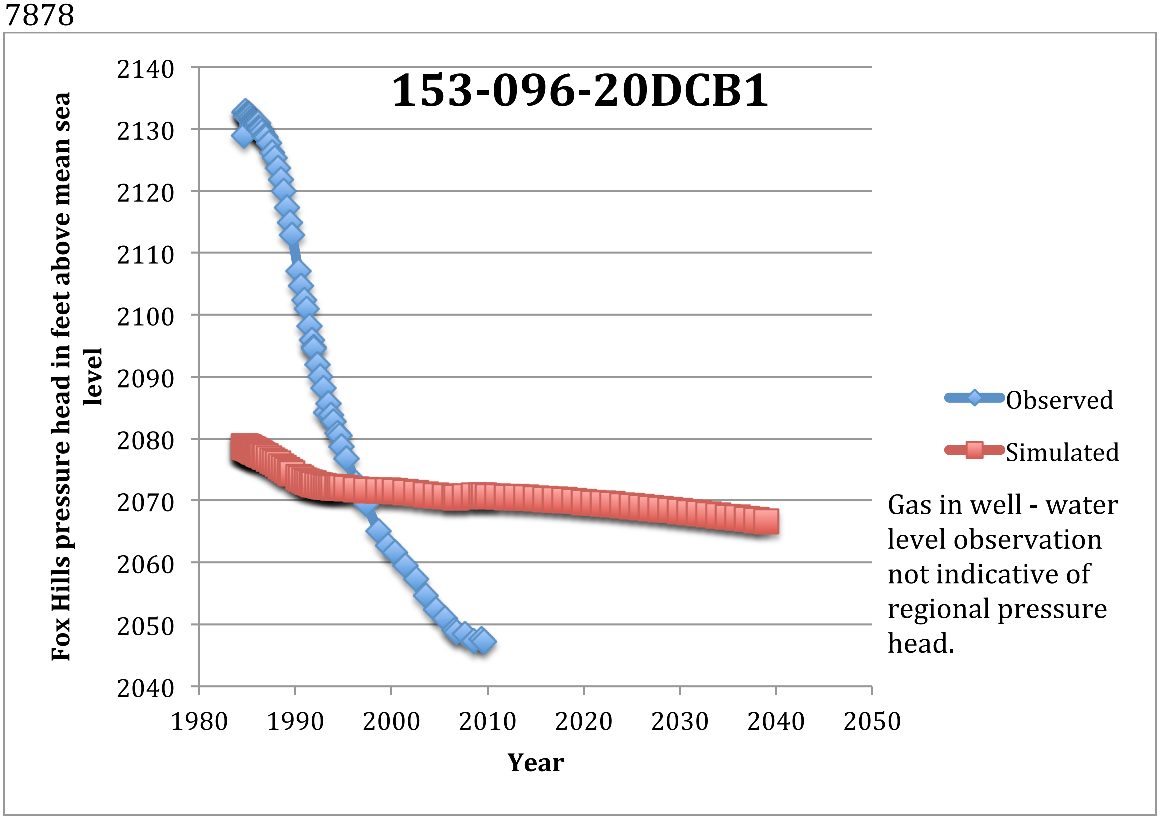
7862


153-094-23CCC1
Fox Hills pressure head in feet above mean sea level
2120
2110
2100
2090
2080
2070
2060
2050
1970 1980 1990 2000 2010 2020 2030 2040 2050
Year
Observed
Simulated

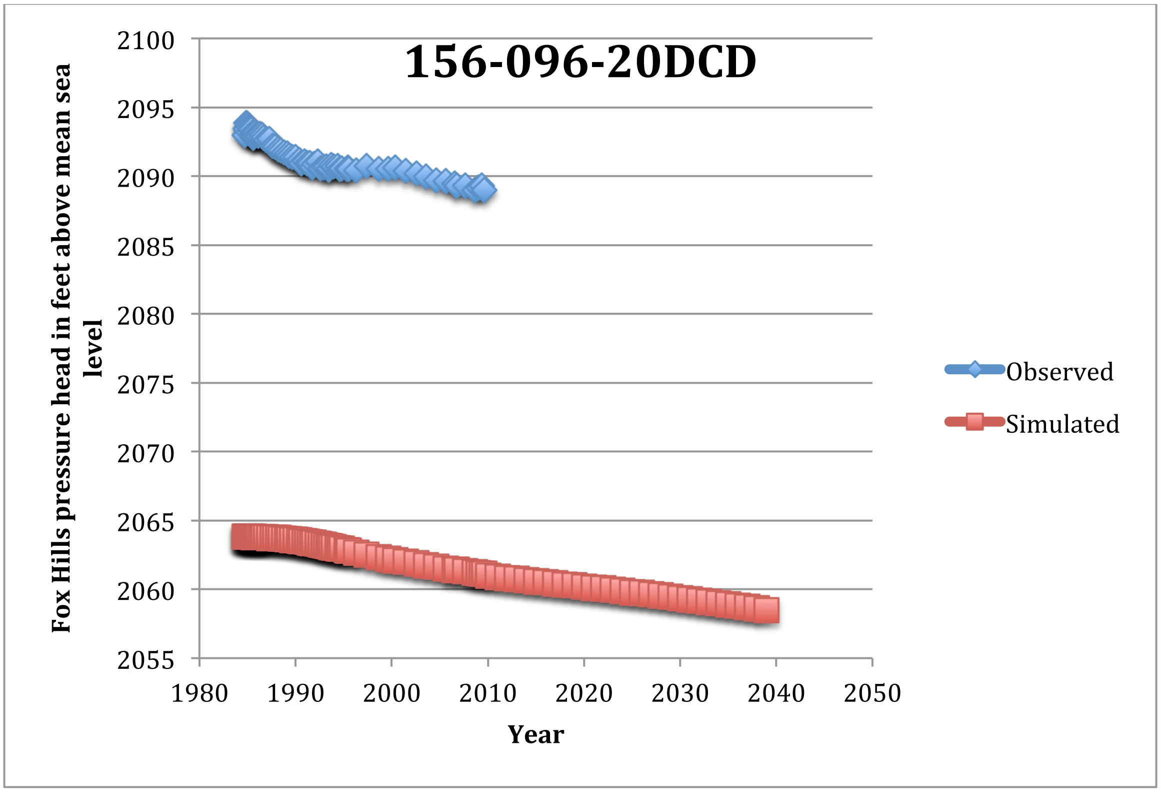
7877


153-096-11ADA
Fox Hills pressure head in feet above mean sea level
2200
2180
2160
2140
2120
2100
2080
2060
2040
2020
2000
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
Gas in well - water level observation not indicative of regional pressure head.

7878


153-096-20DCB1
Fox Hills pressure head in feet above mean sea level
2140
2130
2120
2110
2100
2090
2080
2070
2060
2050
2040
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated
Gas in well - water level observation not indicative of regional pressure head.

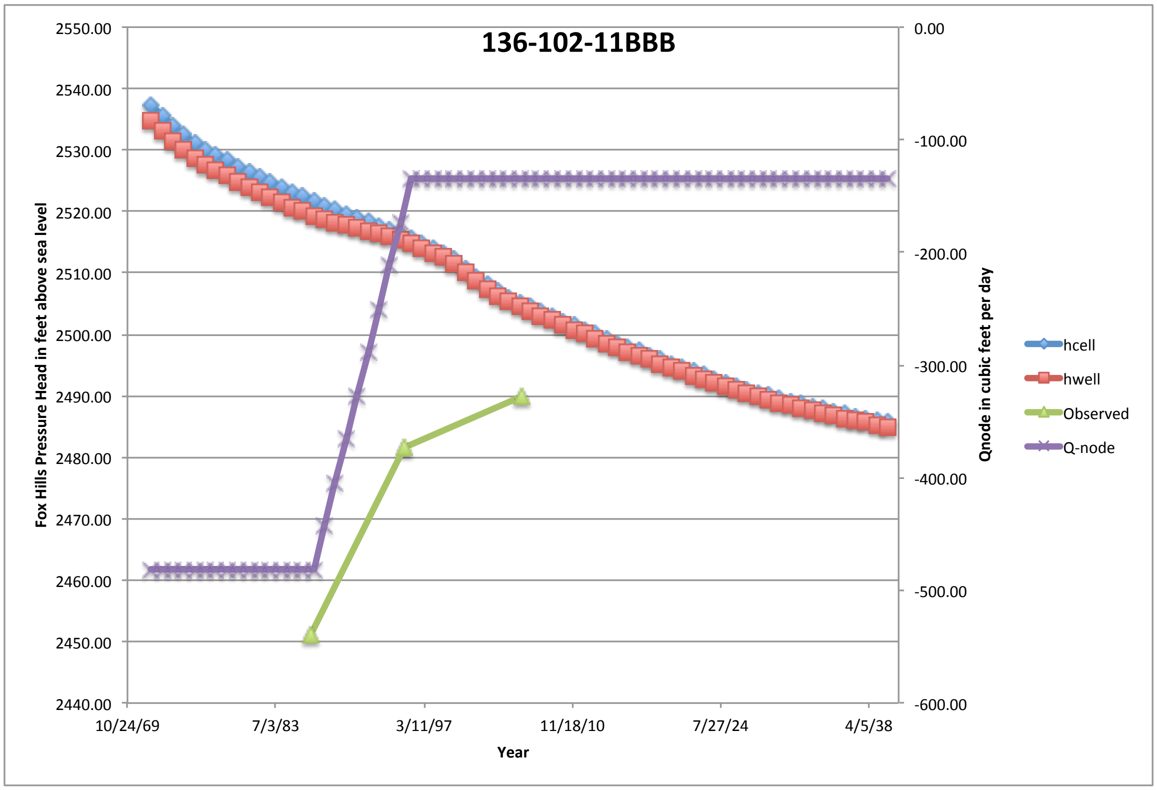
11893


156-096-20DCD
Fox Hills pressure head in feet above mean sea level
2100
2095
2090
2085
2080
2075
2070
2065
2060
2055
1980
1990
2000
2010
2020
2030
2040
2050
Year
Observed
Simulated

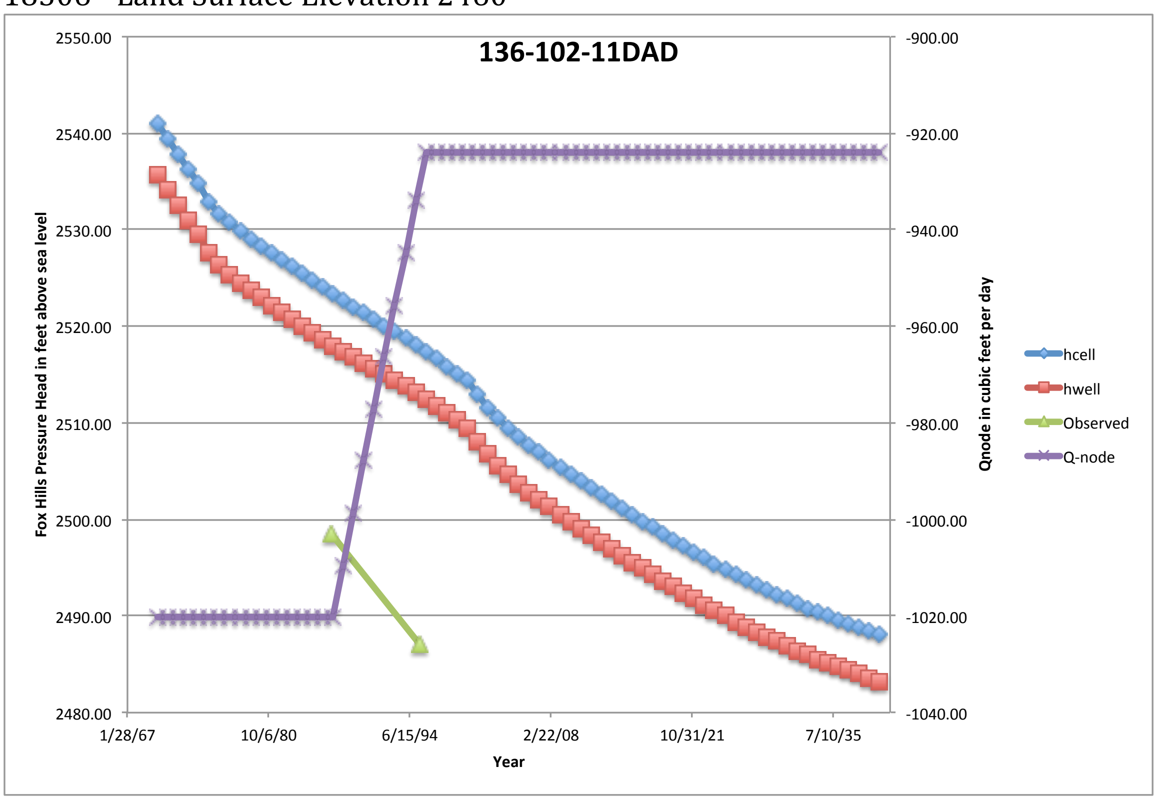
APPENDIX B

WATER LEVEL HYDROGRAPHS WITH DISCHARGE RATE

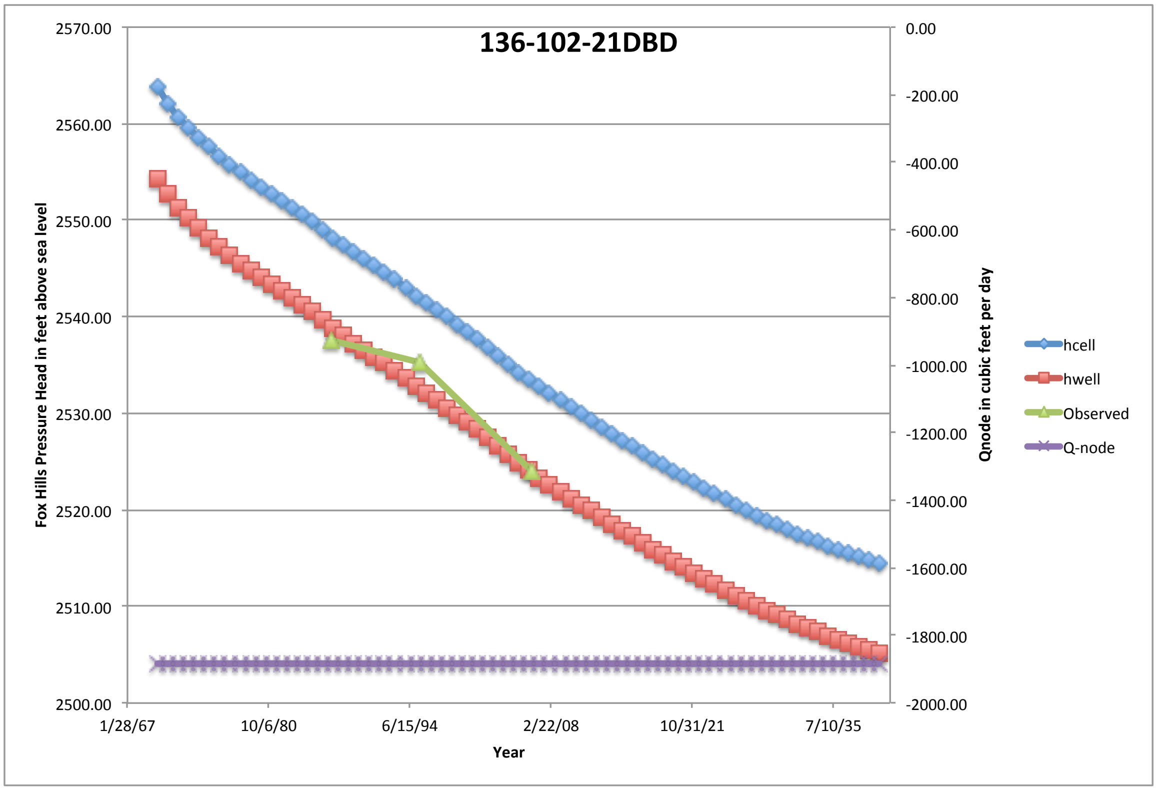
18305 - Land Surface Elevation 2410



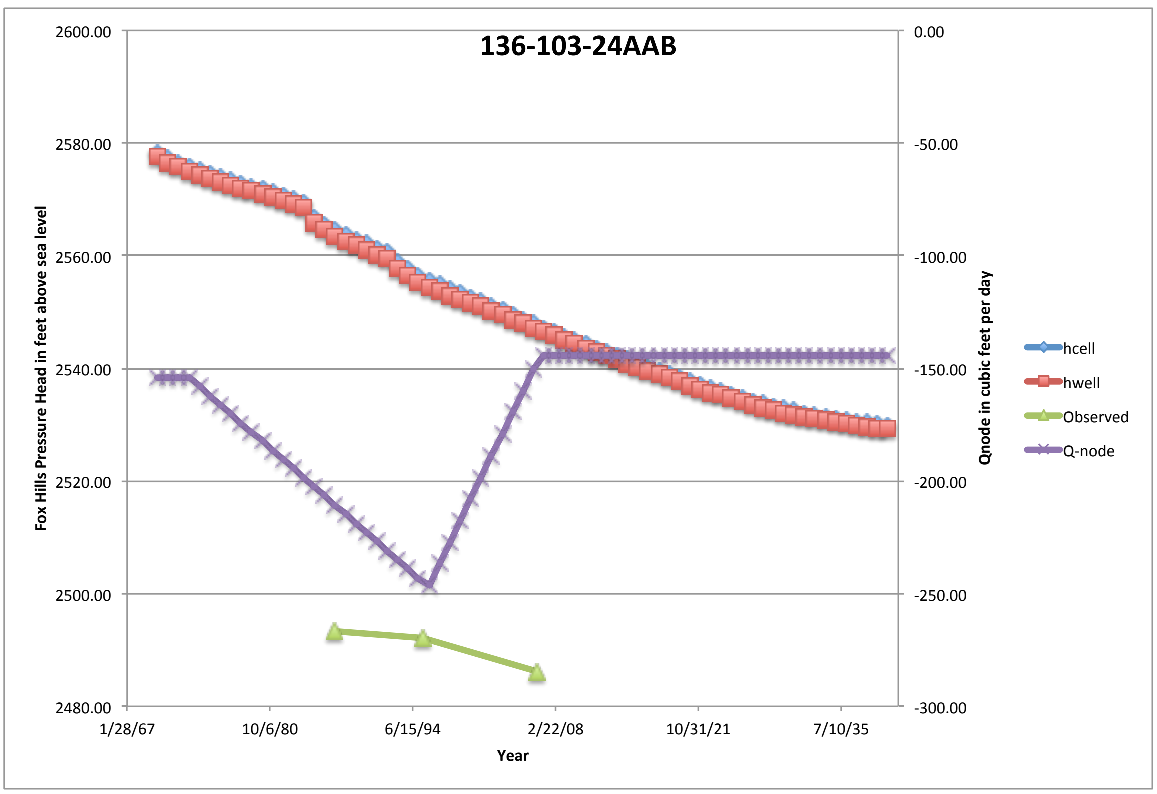
18306 - Land Surface Elevation 2460



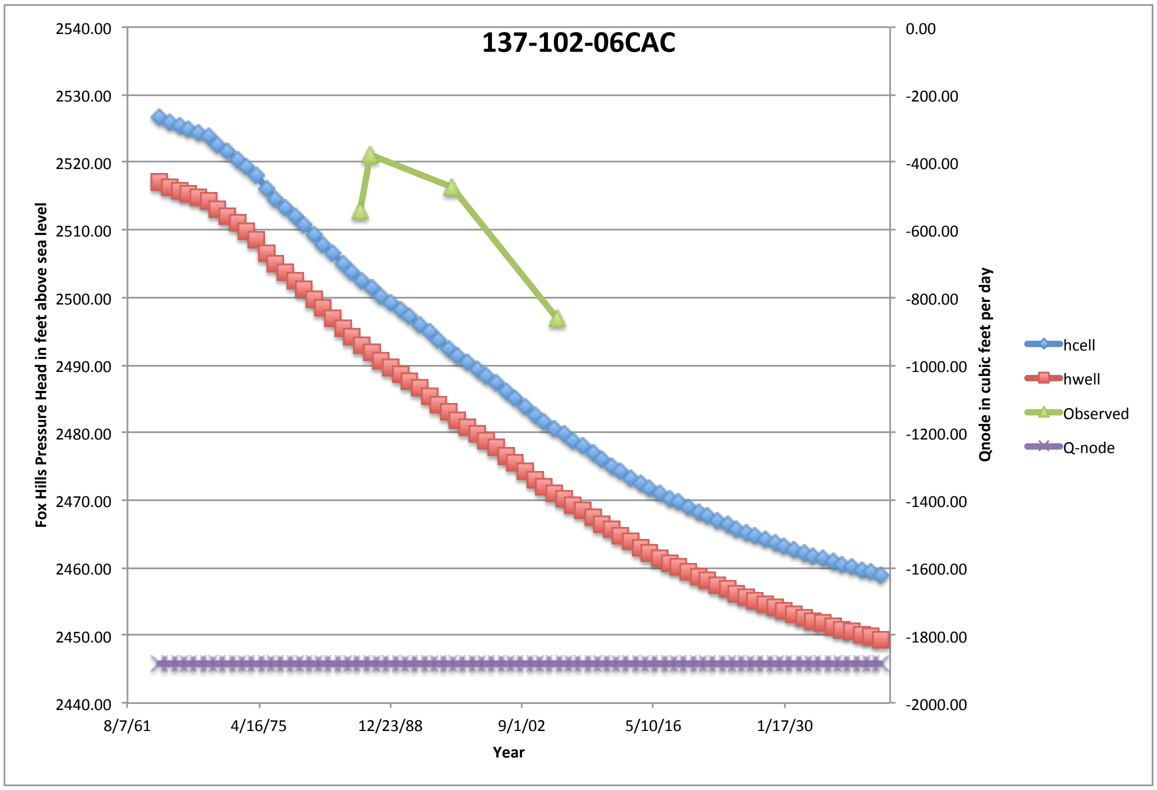
18307 - Land Surface Elevation 2480



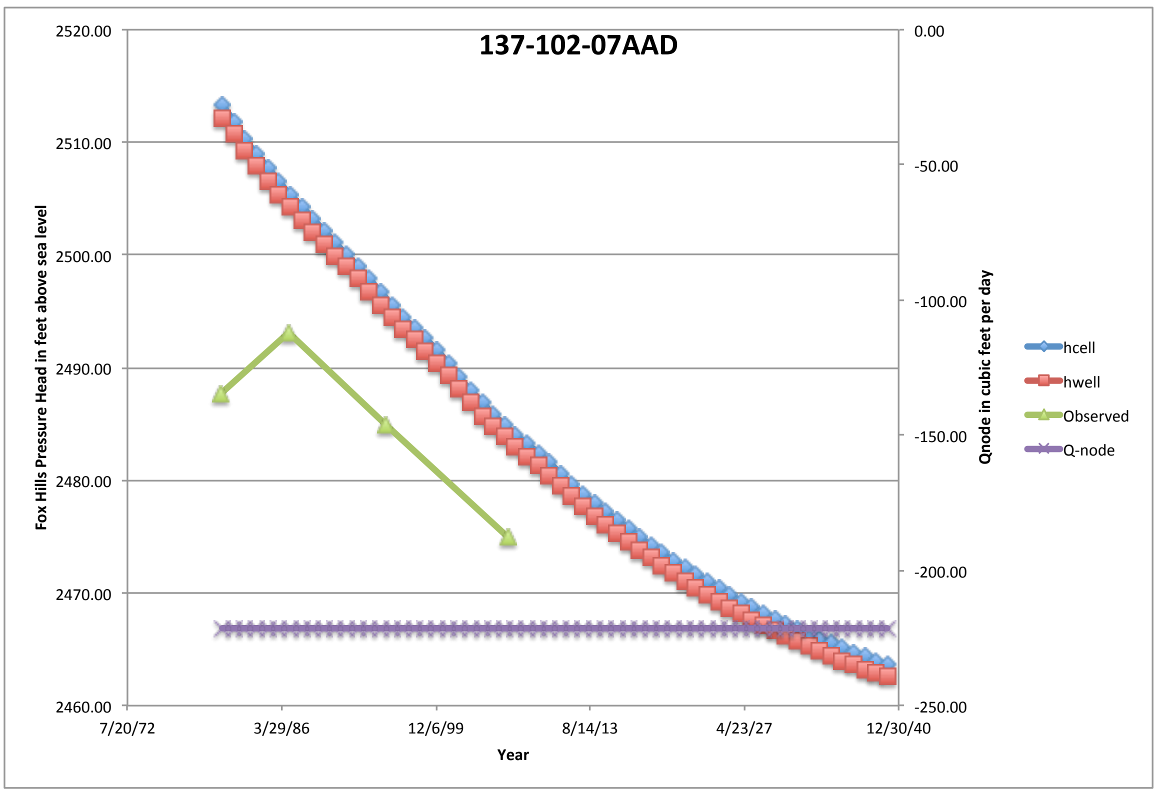
18304 – Land Surface Elevation 2480



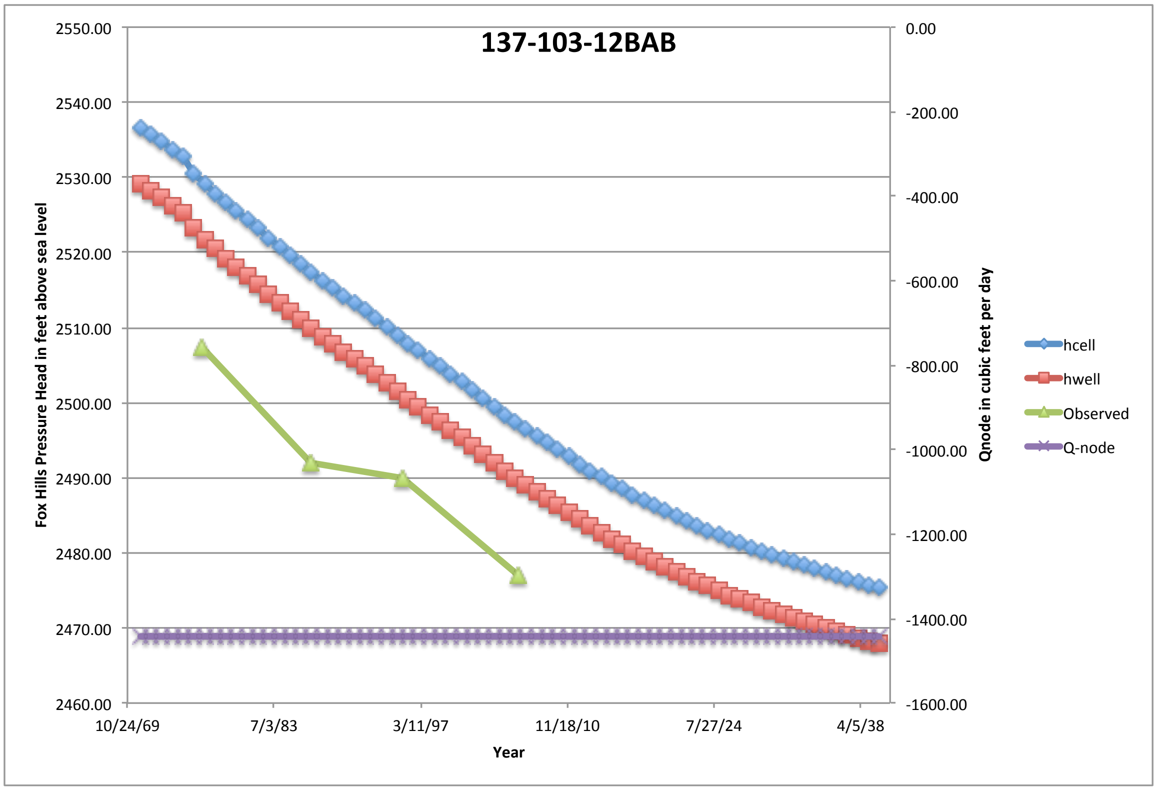
18309 – Land Surface Elevation 2370



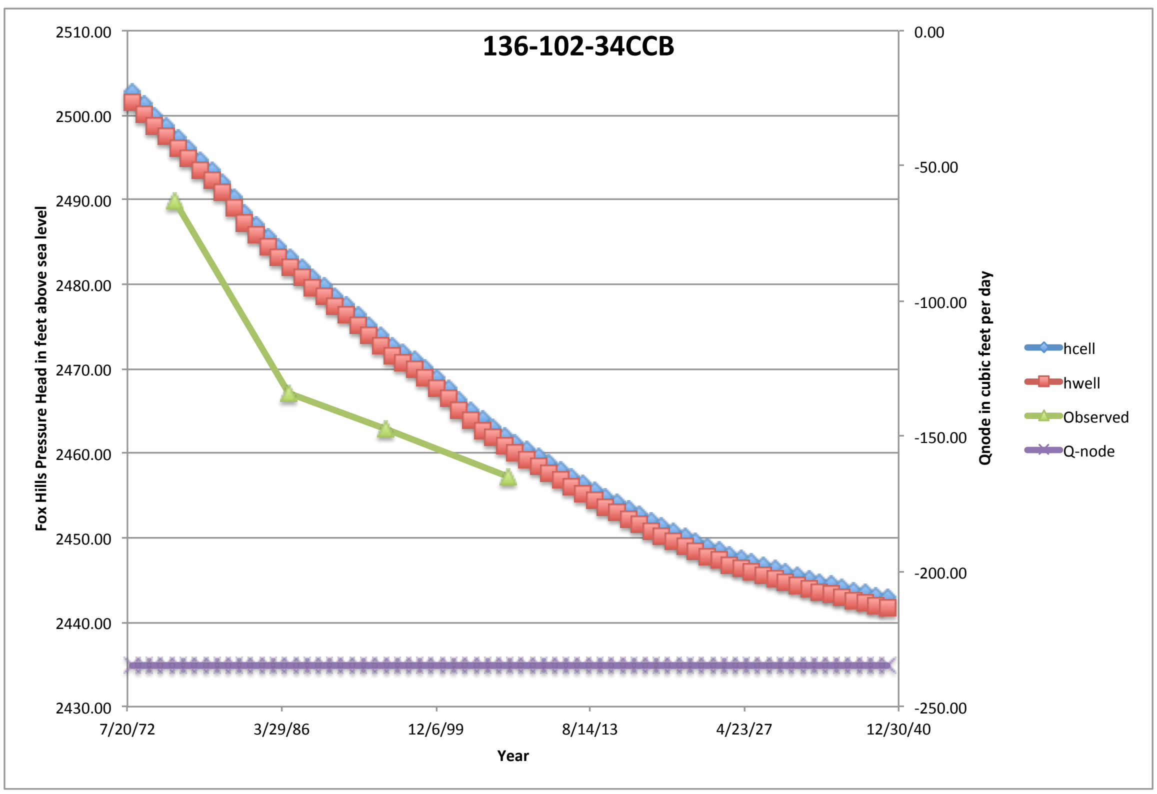
18310 – Land Surface Elevation 2460



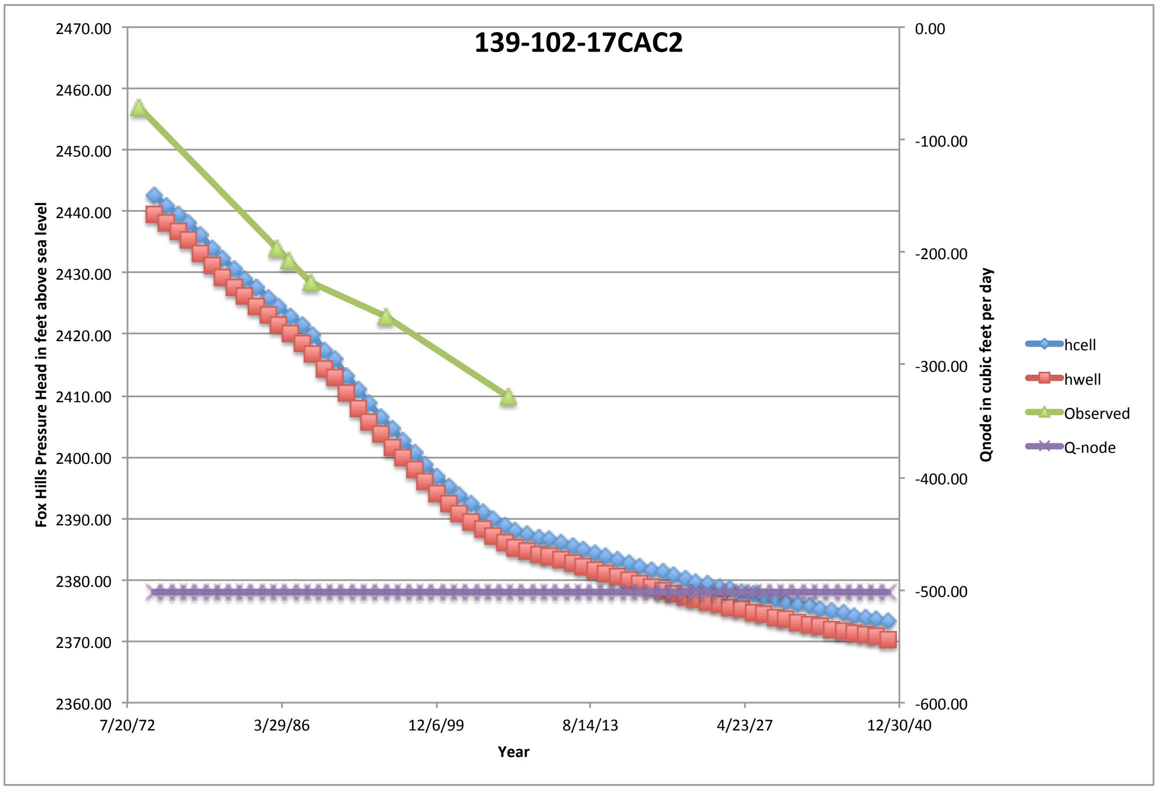
18311 – Land Surface Elevation 2410



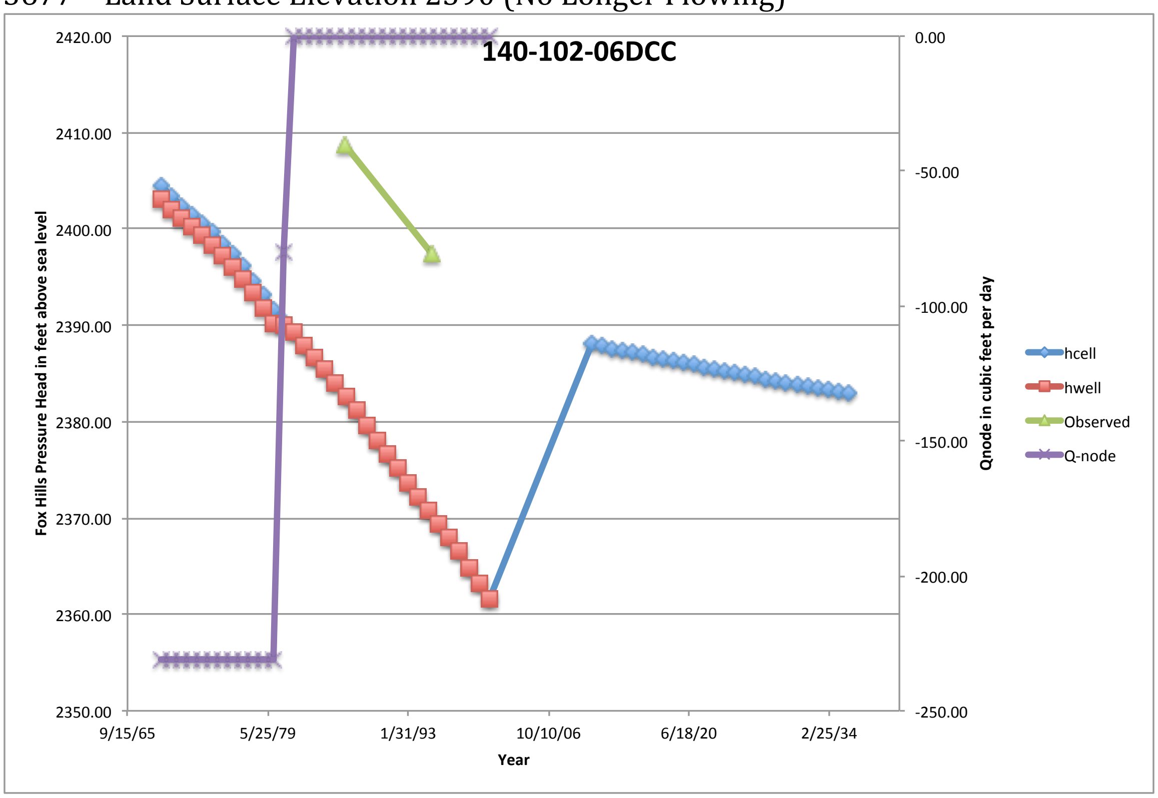
18308 – Land Surface Elevation 2400



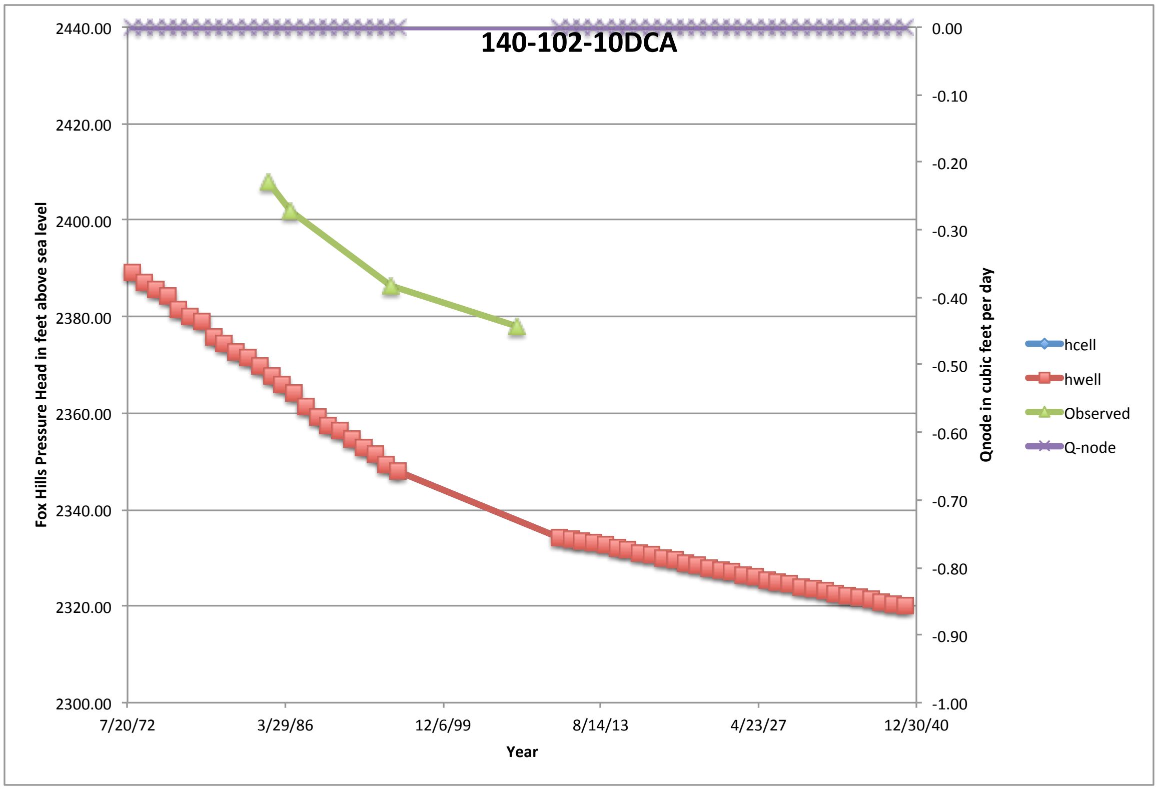
3671 – Land Surface Elevation 2365



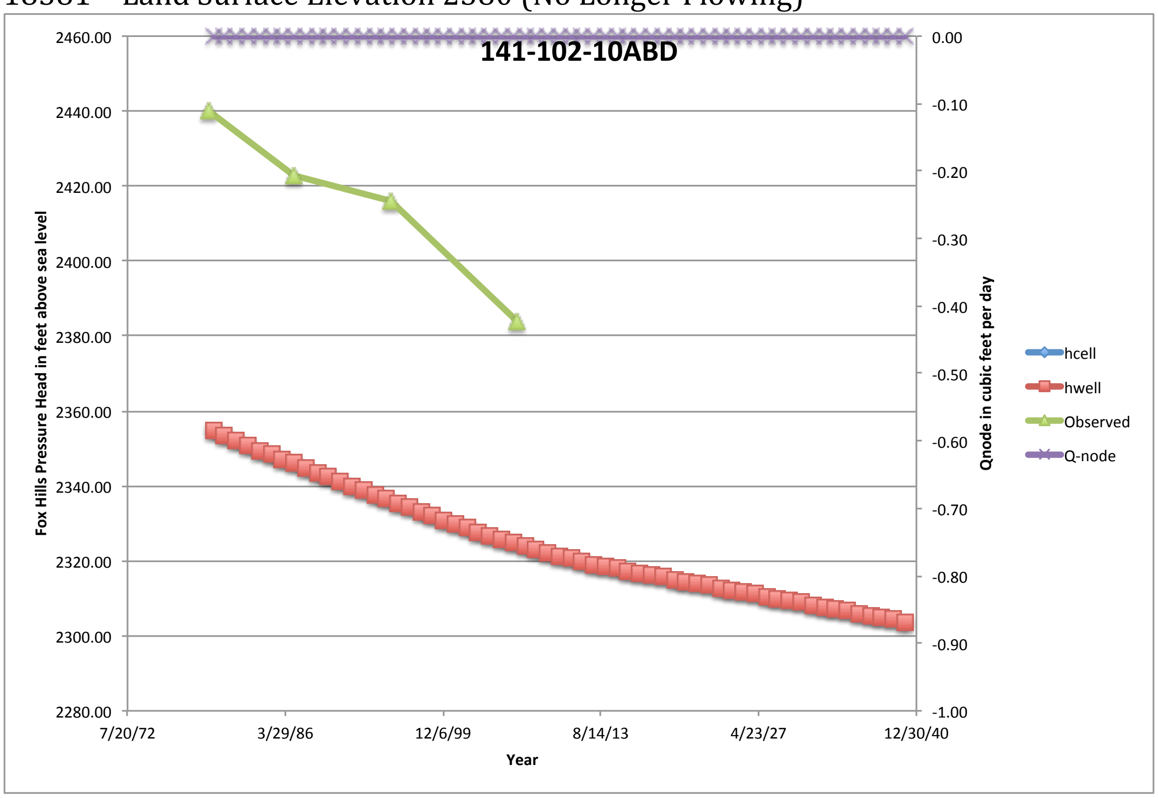
3677 – Land Surface Elevation 2390 (No Longer Flowing)



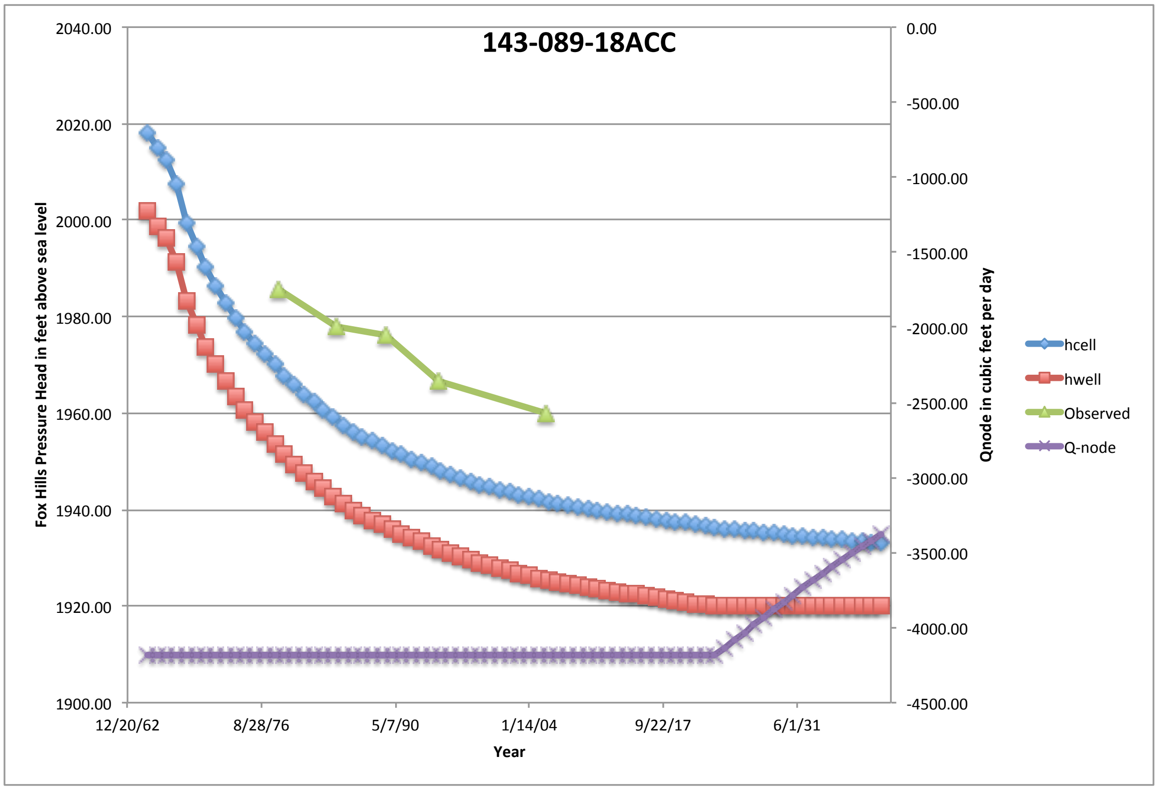
18313 – Land Surface Elevation 2258



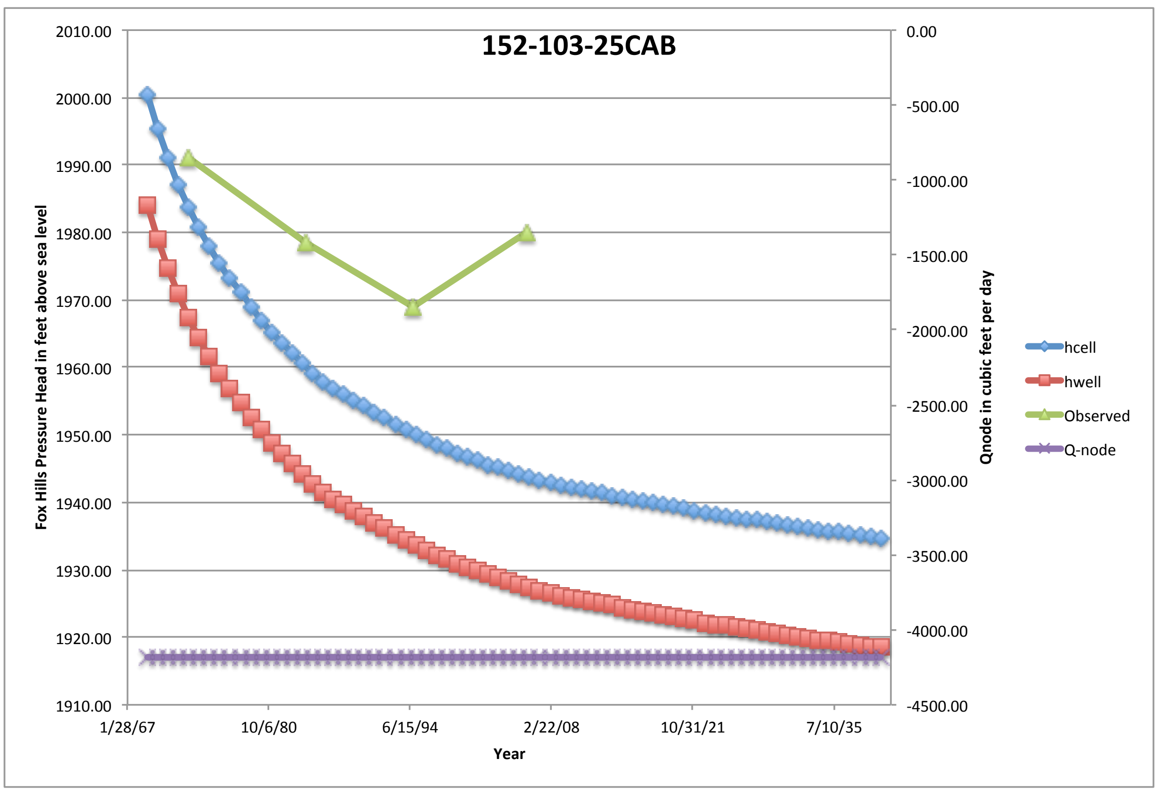
18381 – Land Surface Elevation 2380 (No Longer Flowing)



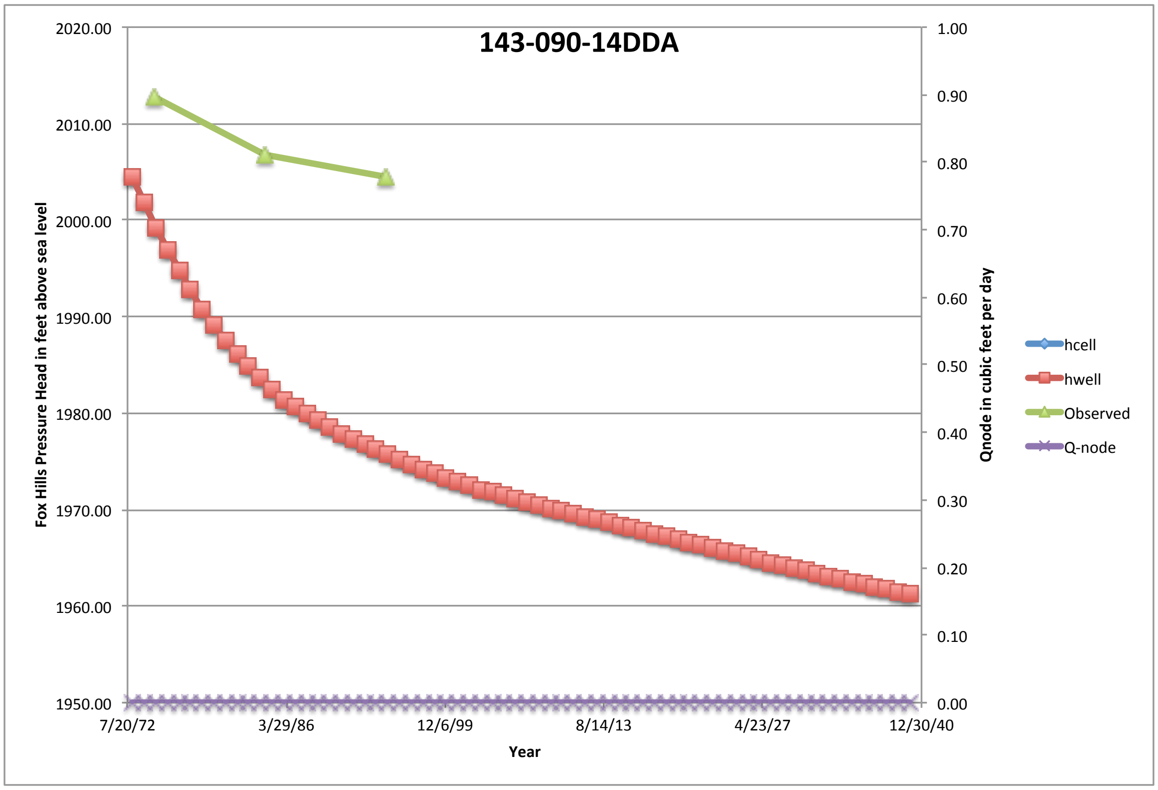
17570 – Land Surface Elevation 1920



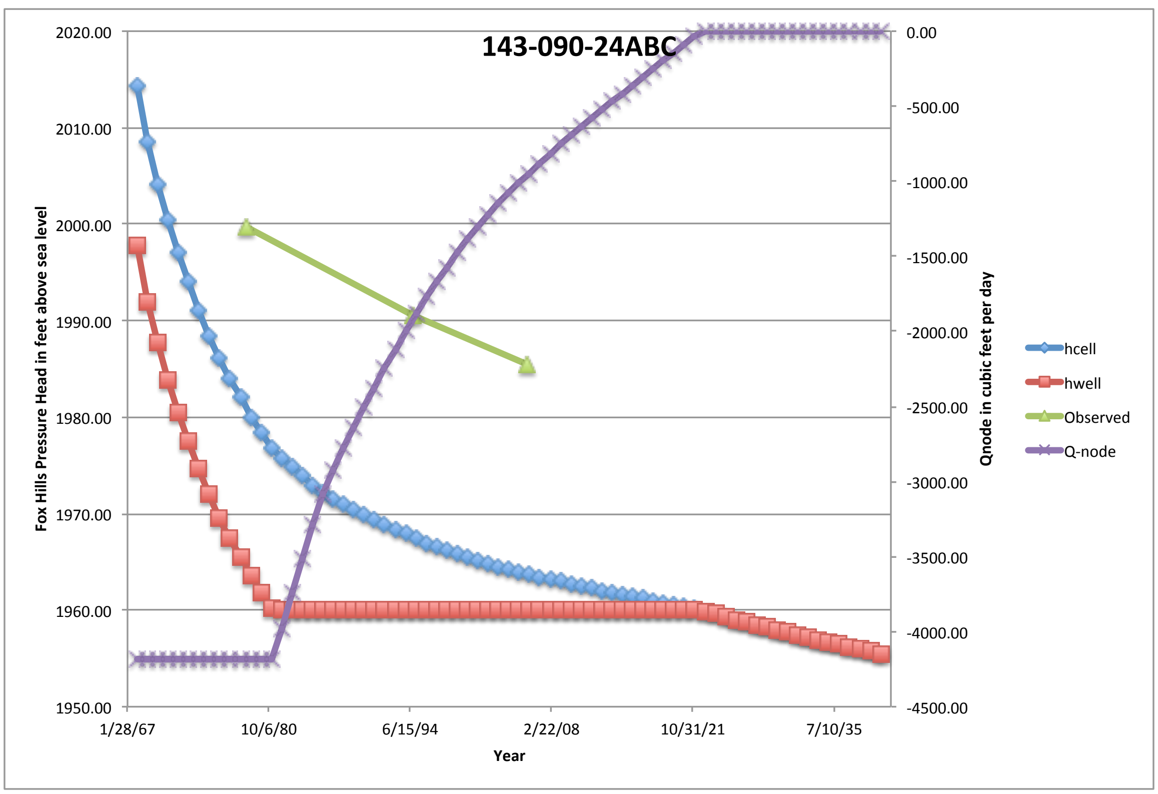
8485 – Land Surface Elevation 1897



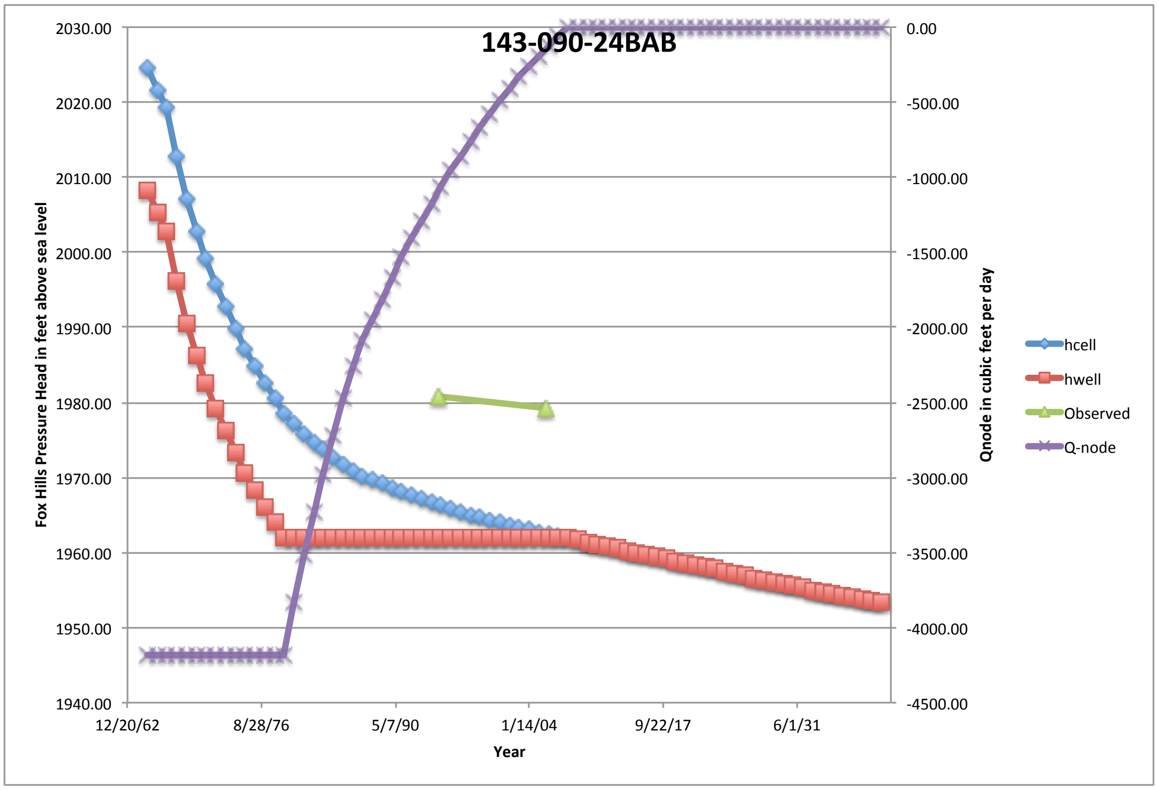
17571 – Land Surface Elevation 2000



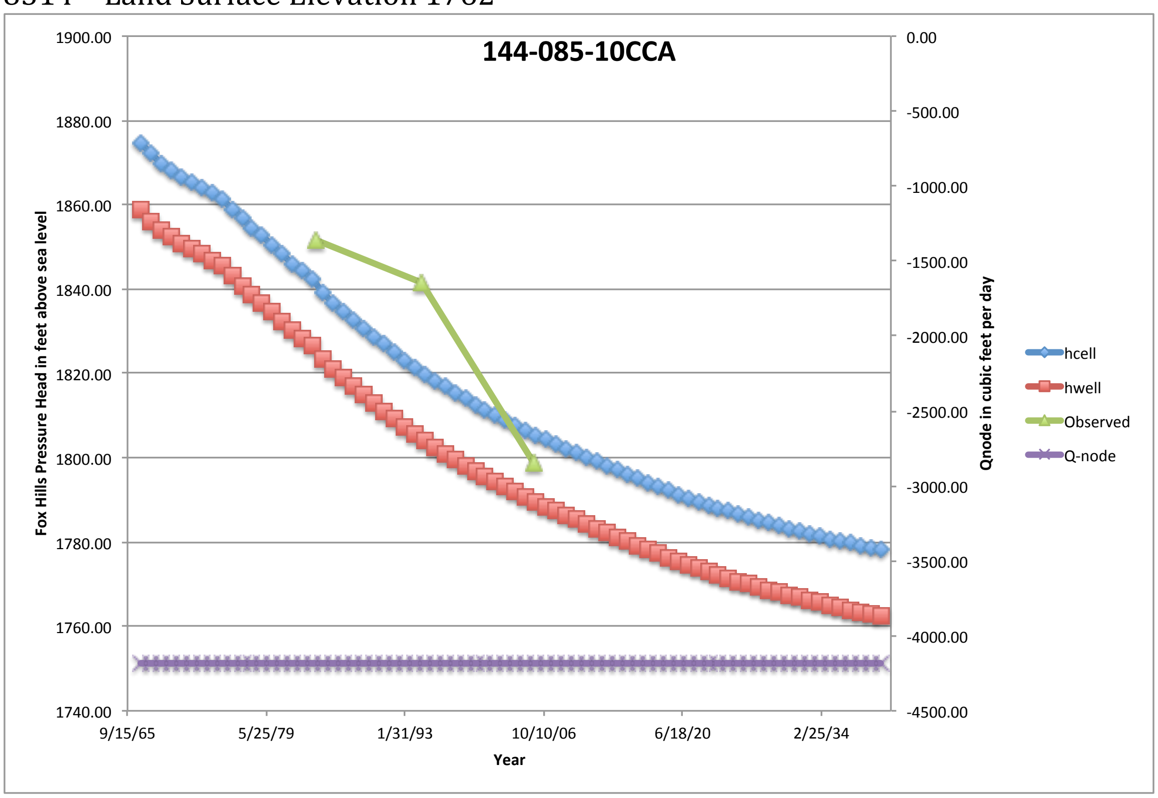
17572 – Land Surface Elevation 1960



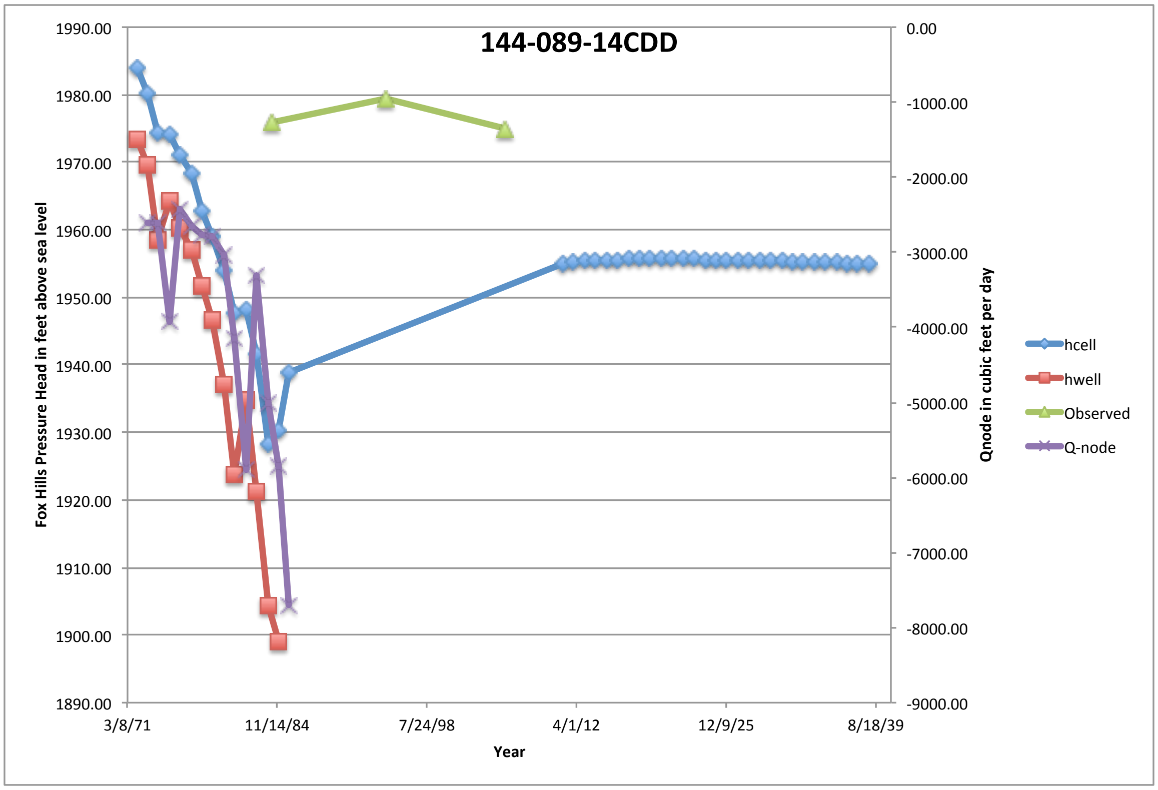
8486 – Land Surface Elevation 1962



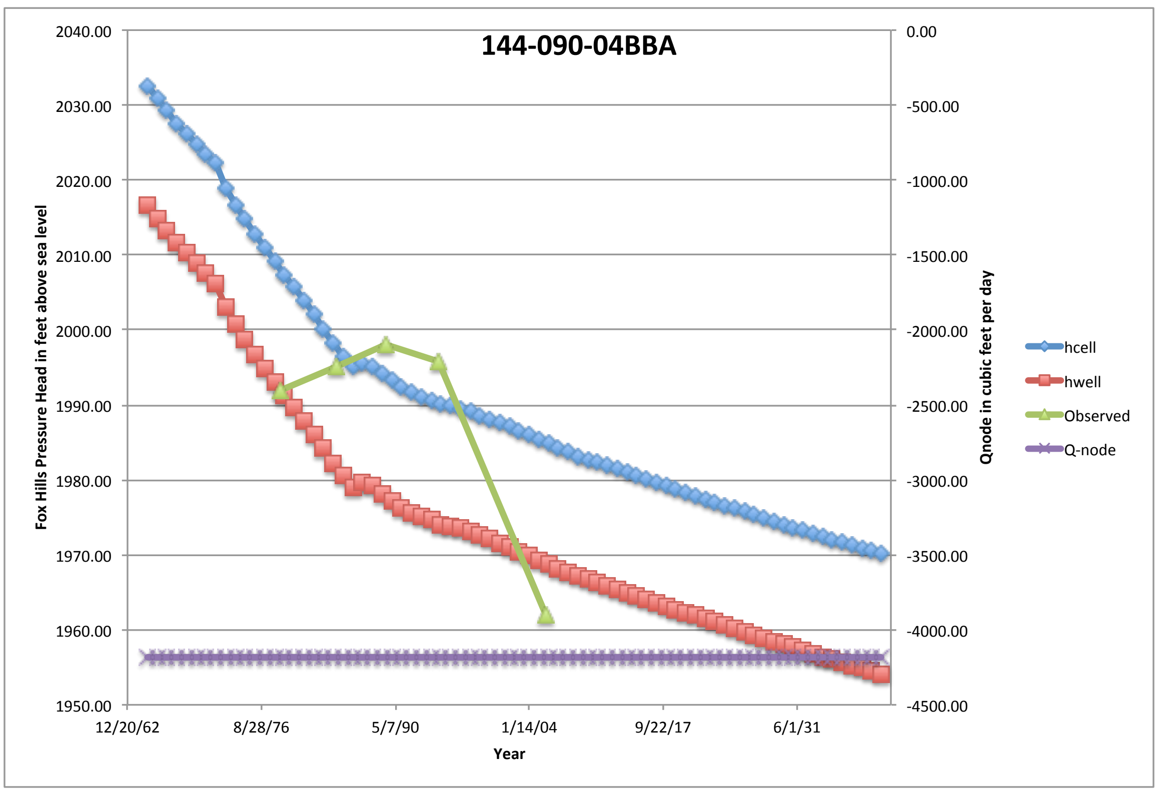
8514 – Land Surface Elevation 1762



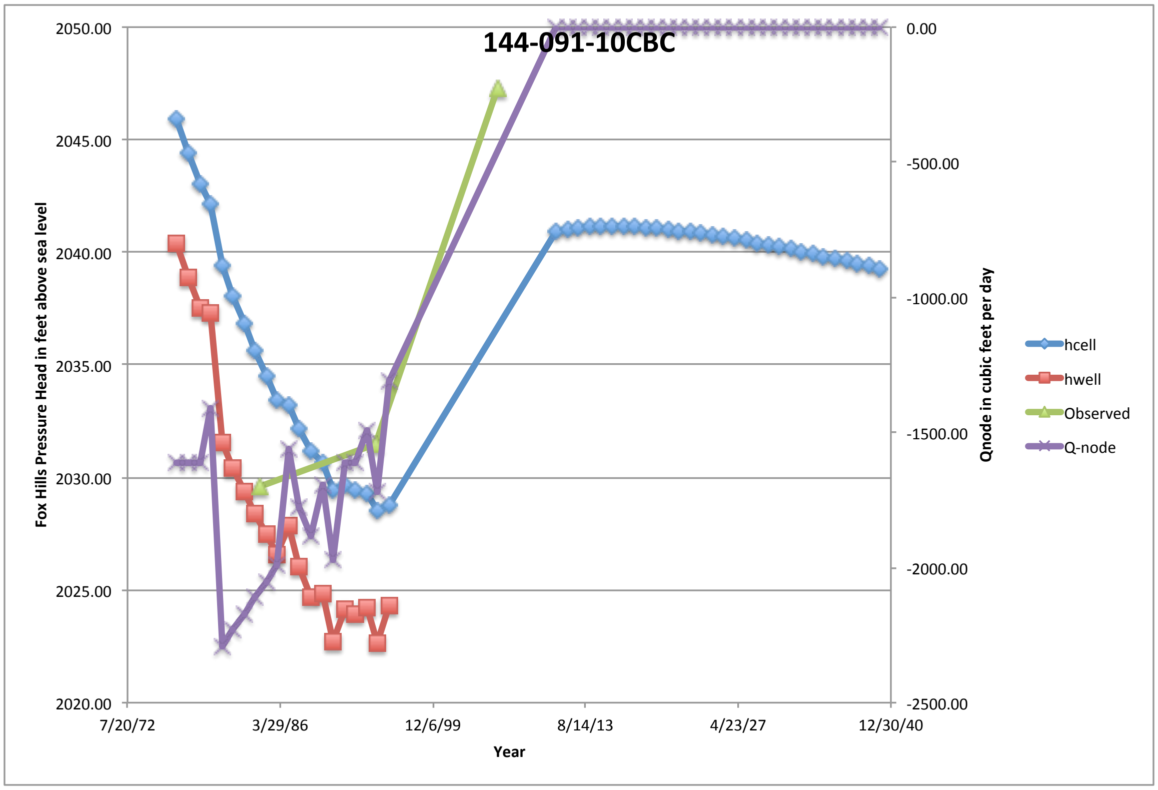
8561 – Land Surface Elevation 1845



10821 – Land Surface Elevation 1953

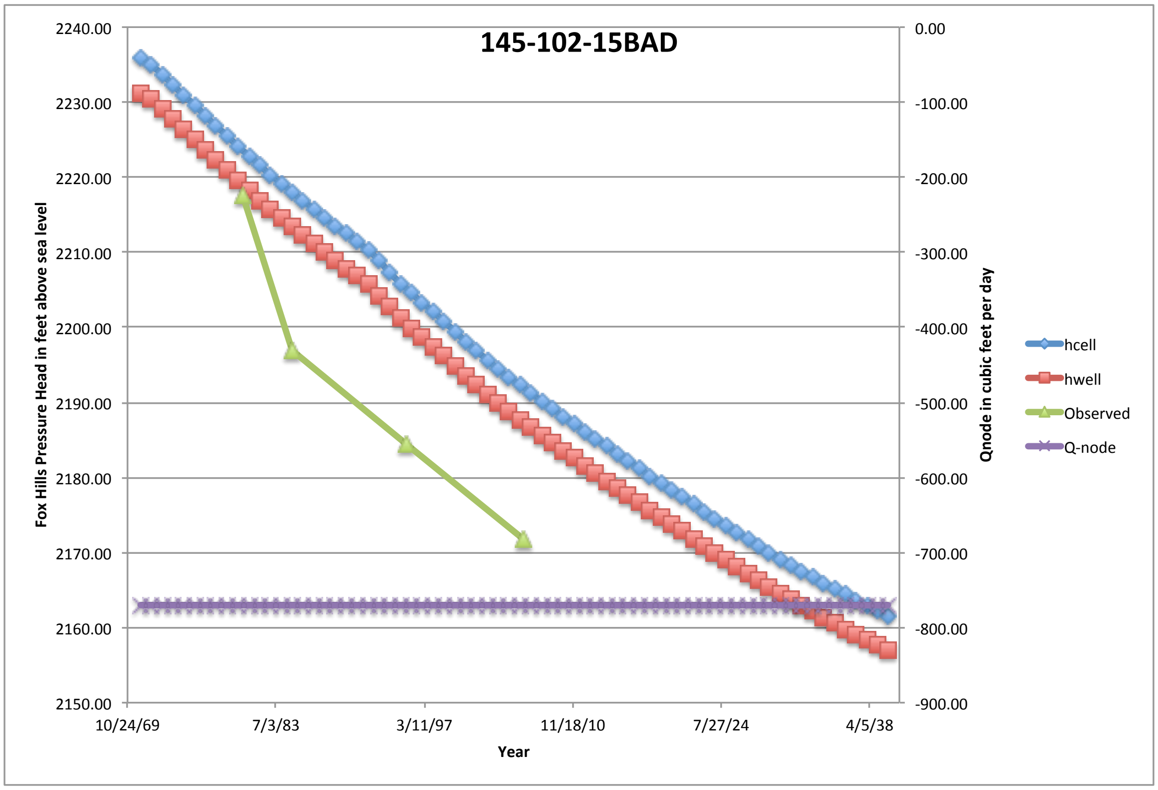


17573 – Land Surface Elevation 1995

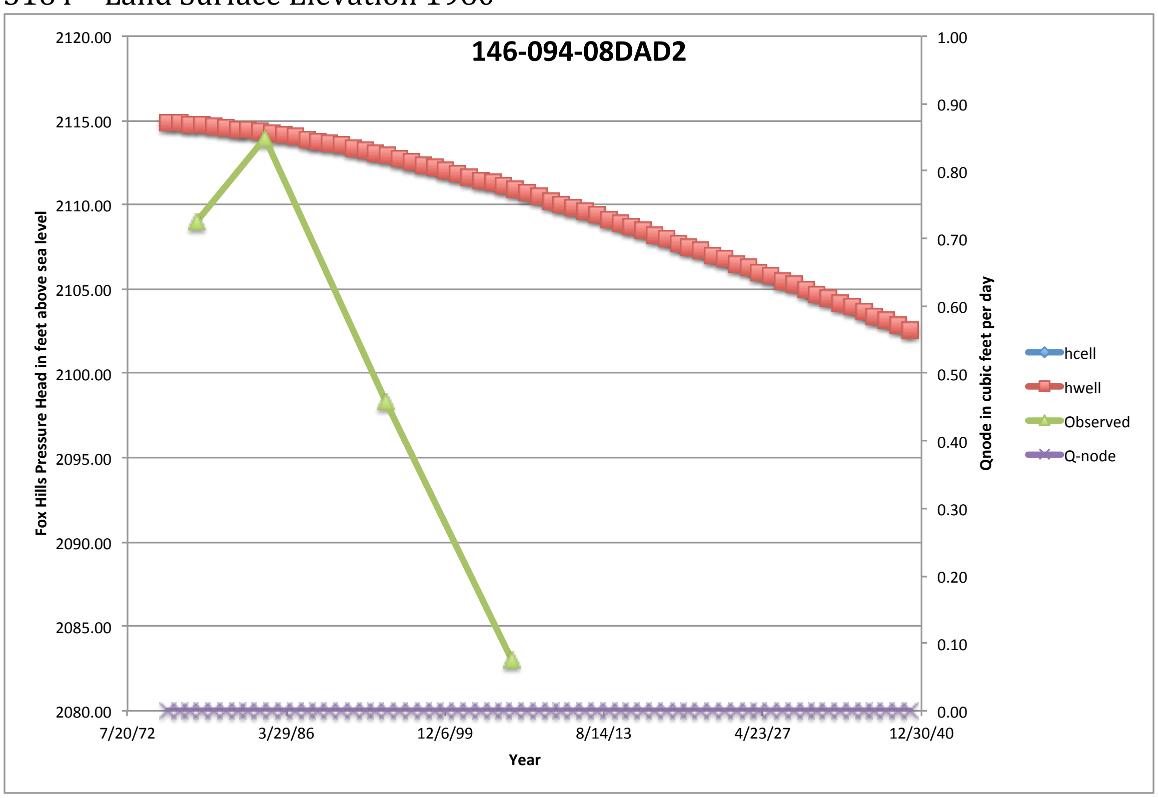


13095 – Land Surface Elevation 2210

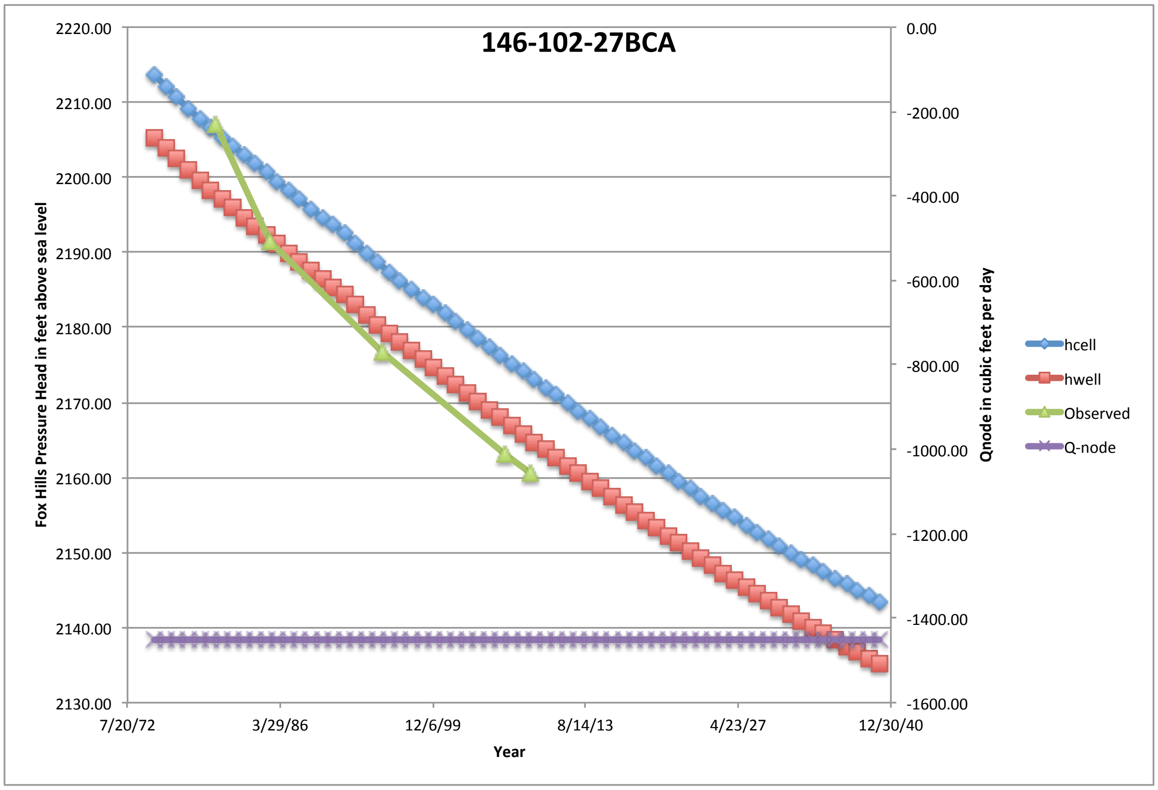
7570 – Land Surface Elevation 2160



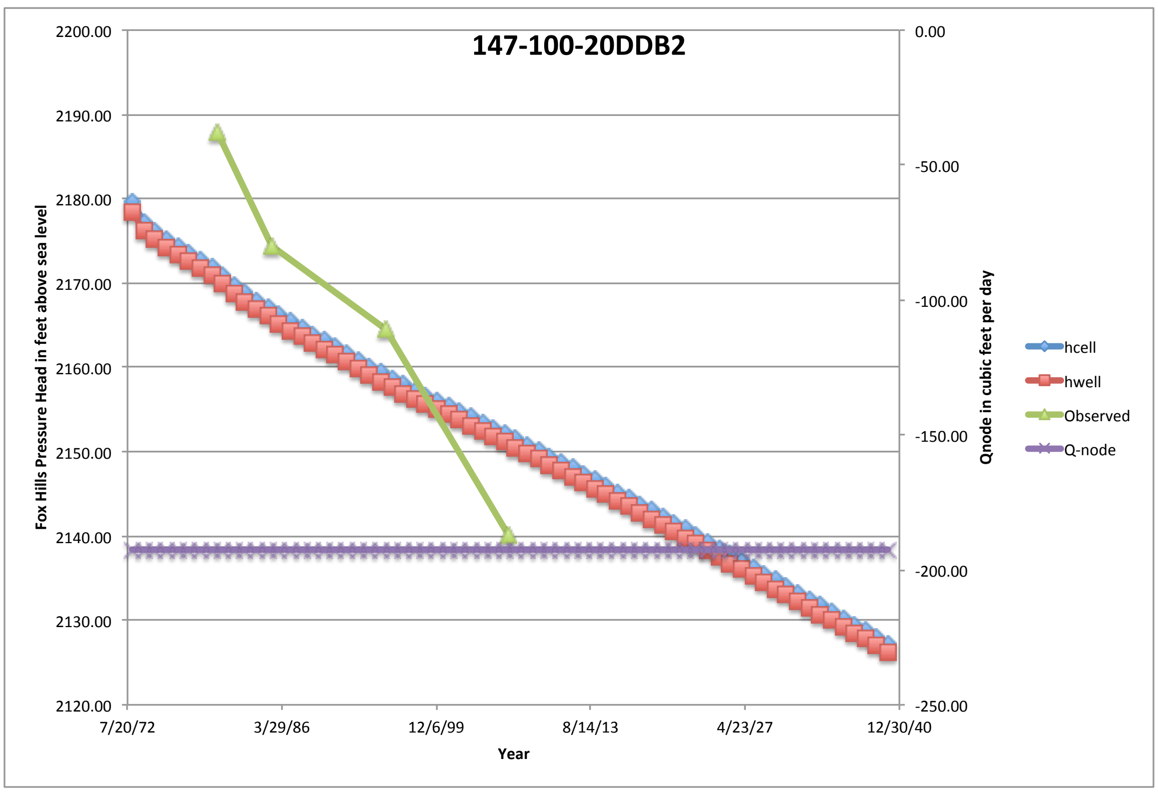
5164 – Land Surface Elevation 1960



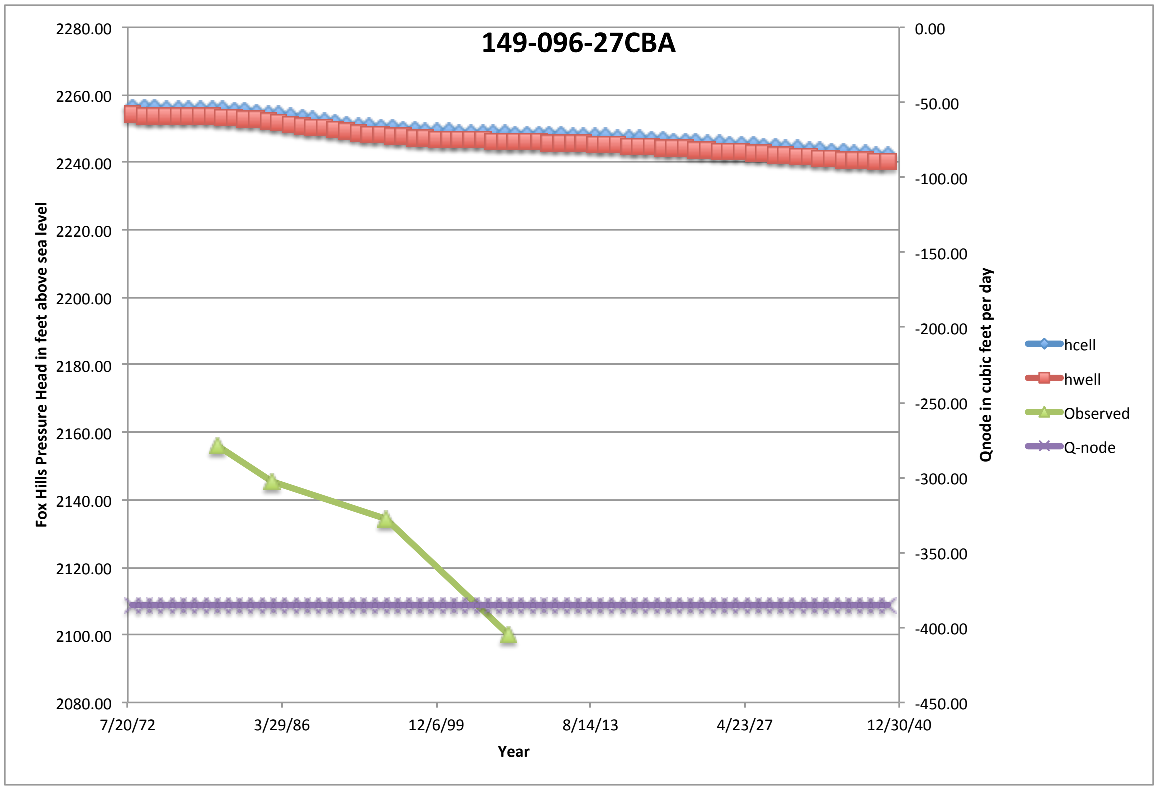
18315 – Land Surface Elevation 2127



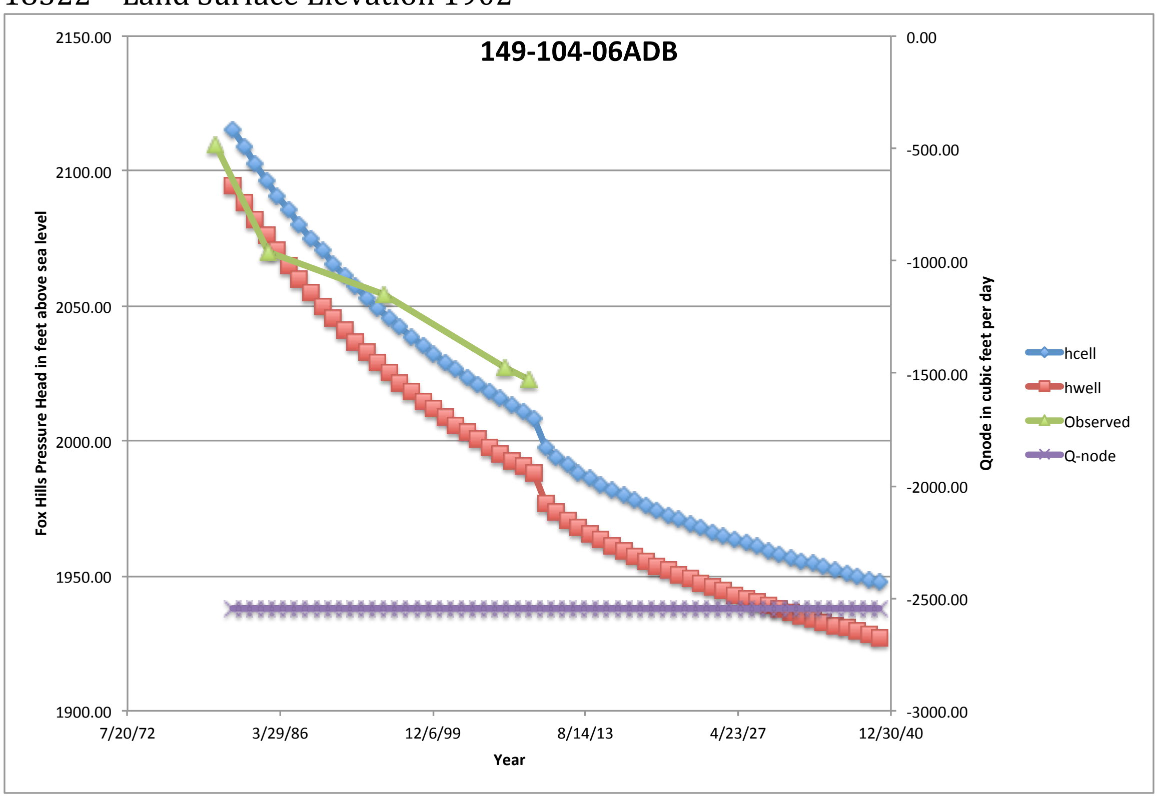
7598 – Land Surface Elevation 2010



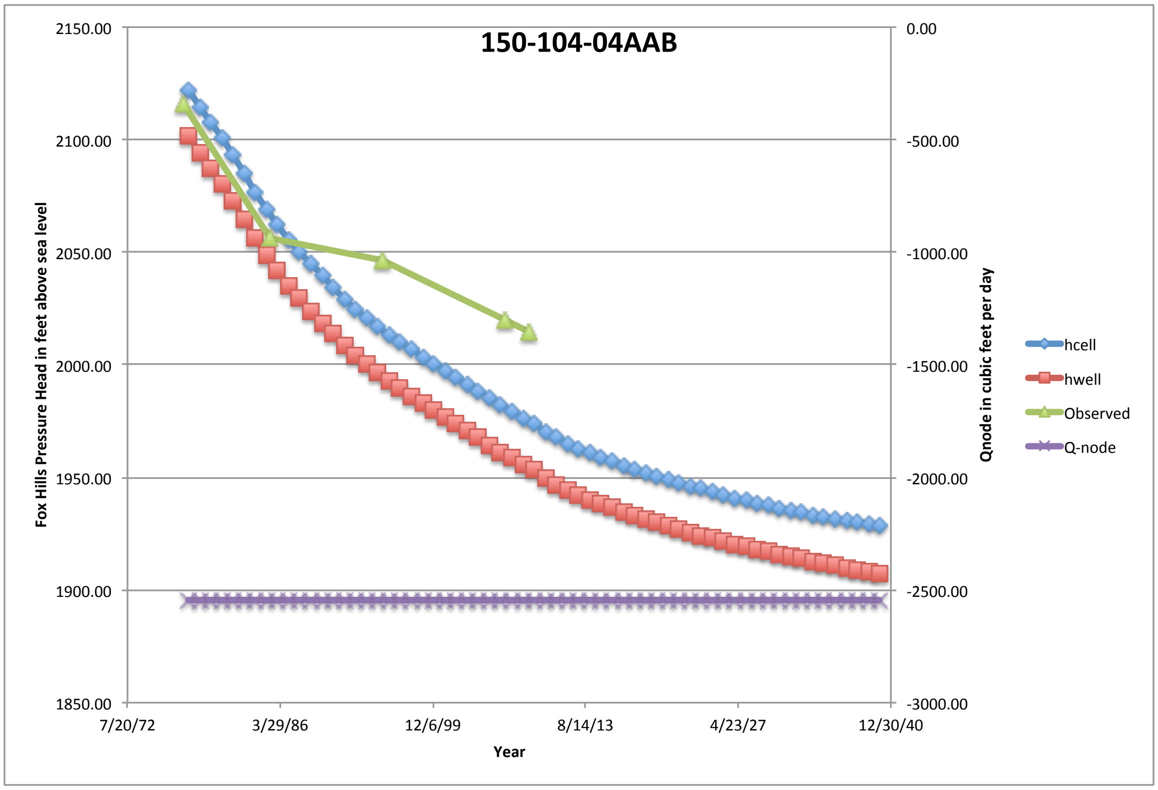
7644 – Land Surface Elevation 1995



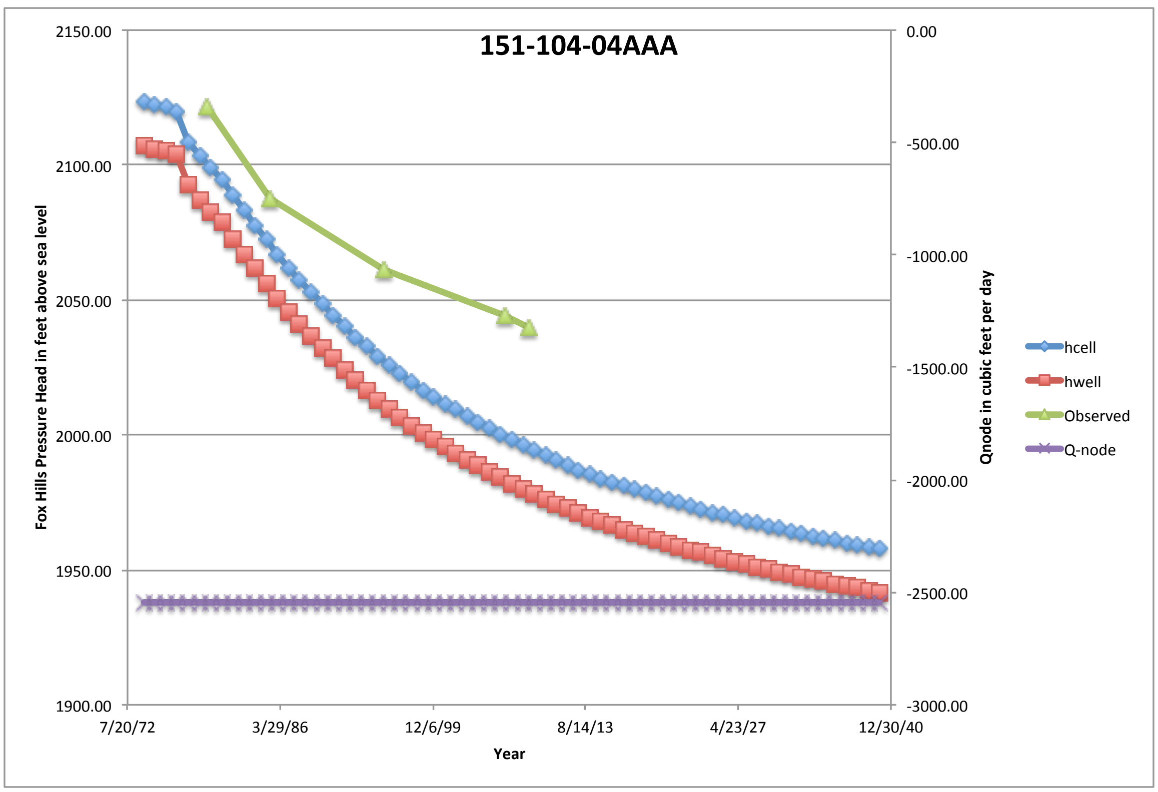
18322 – Land Surface Elevation 1902



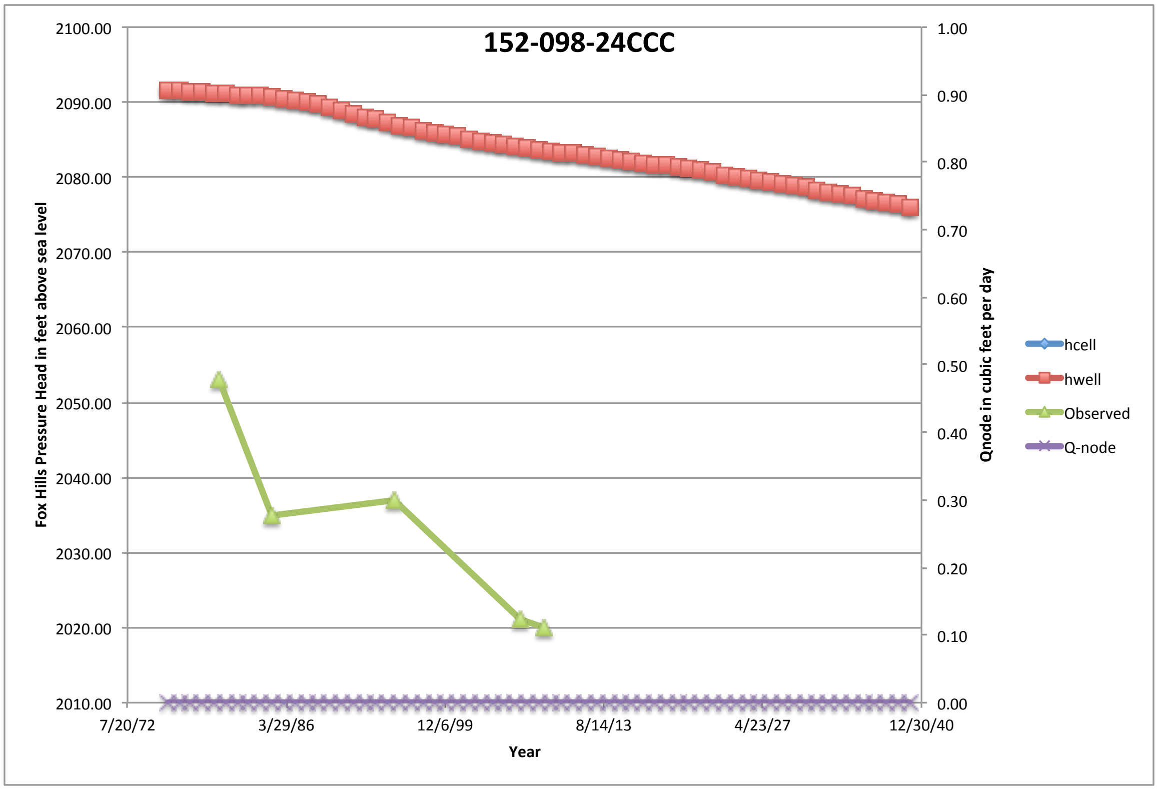
18317 – Land Surface Elevation 18317



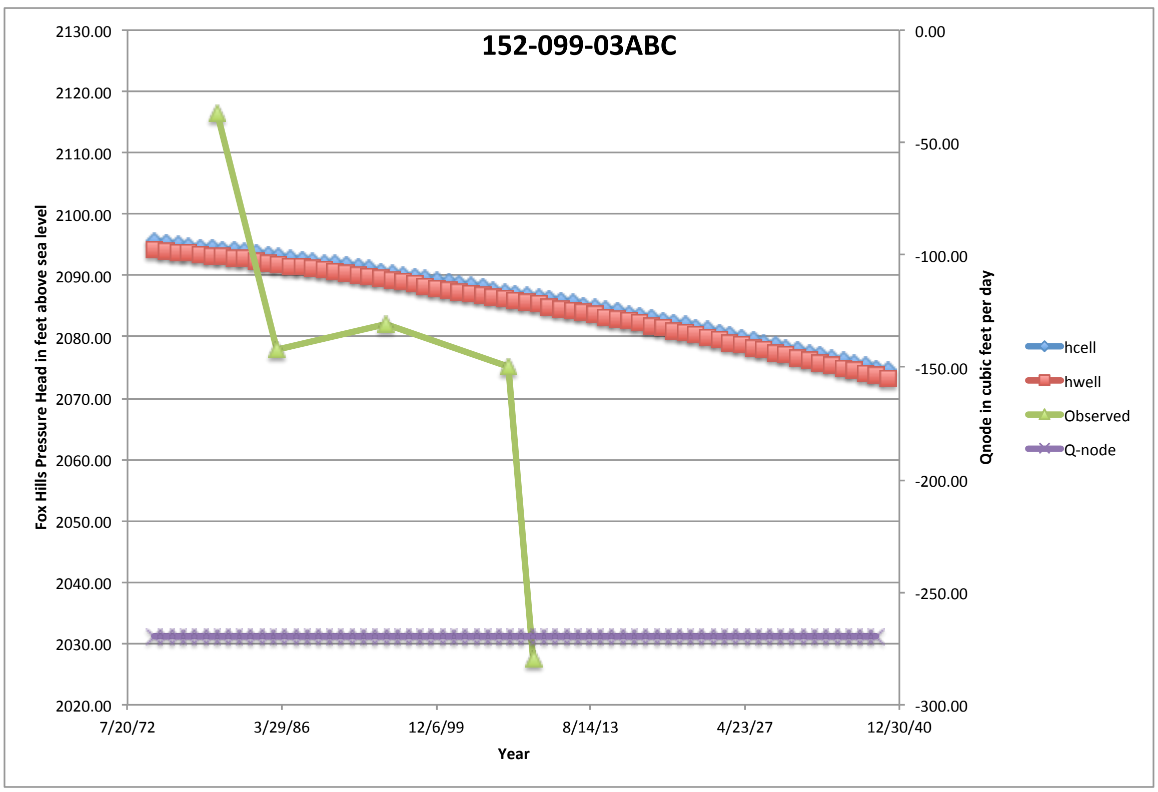
7804 – Land Surface Elevation 1879



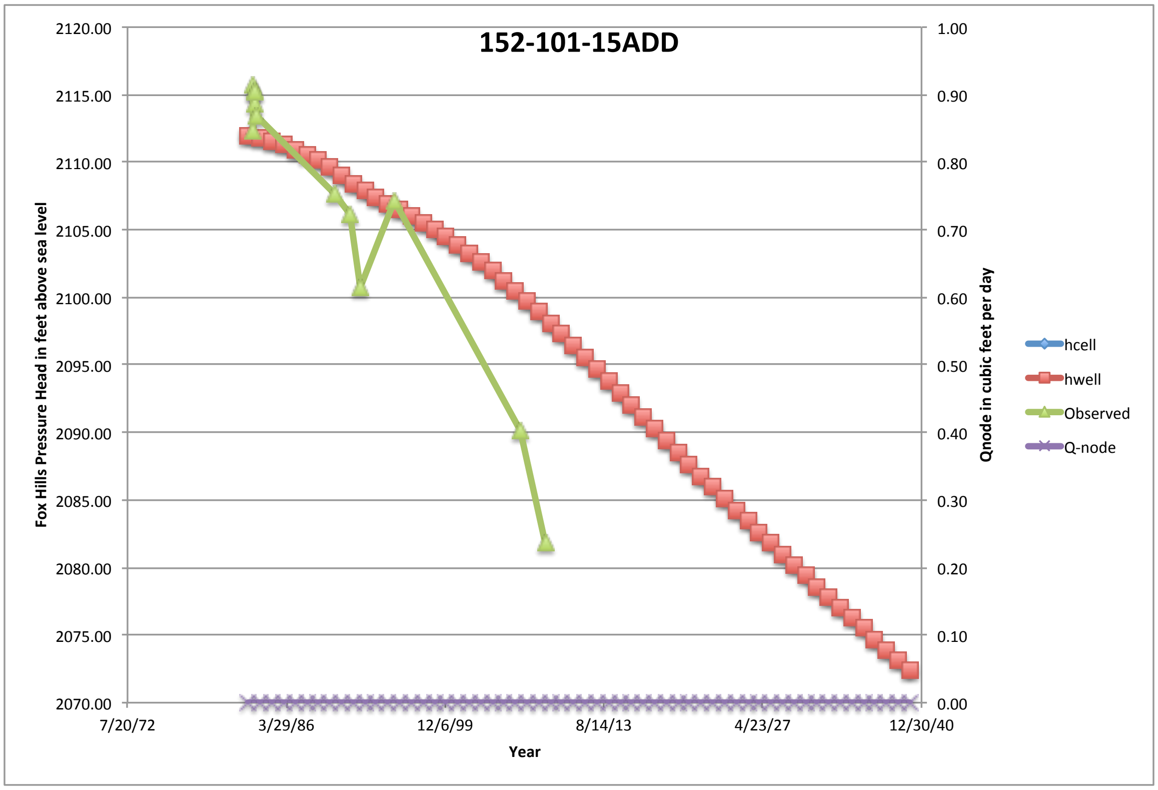
7838 – Land Surface Elevation 2000



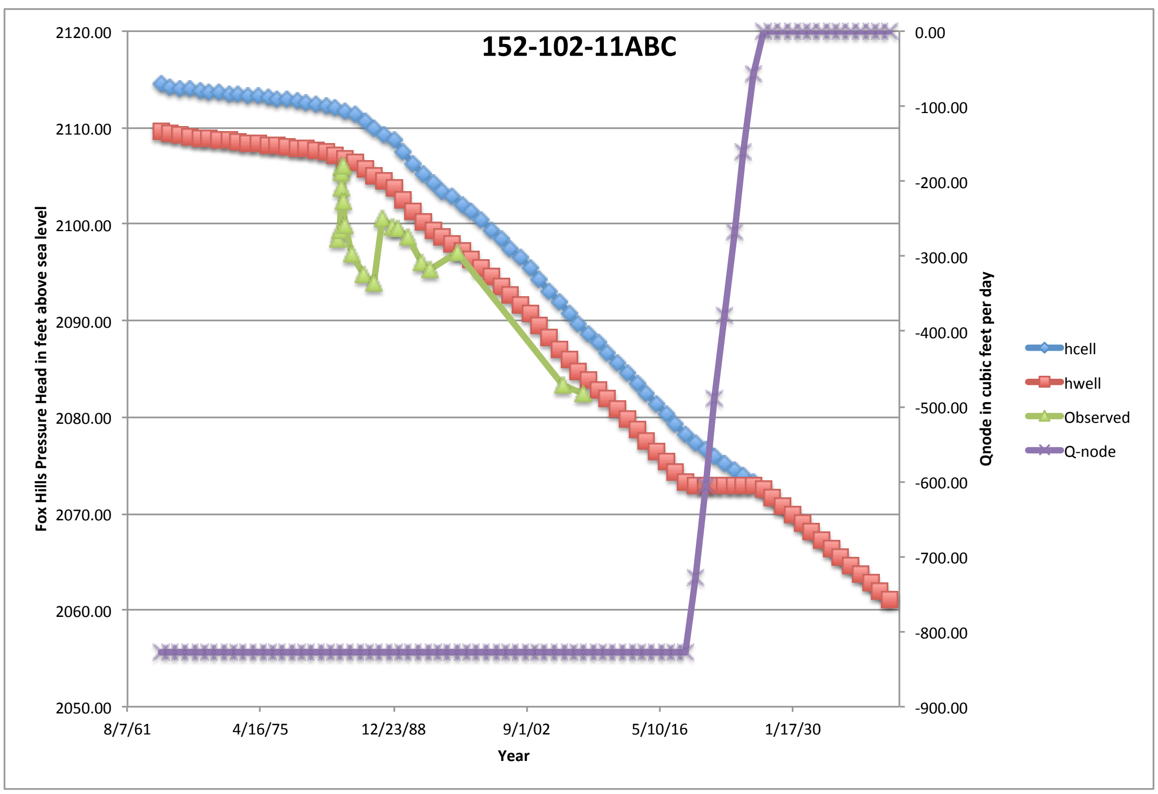
7842 – Land Surface Elevation 1920



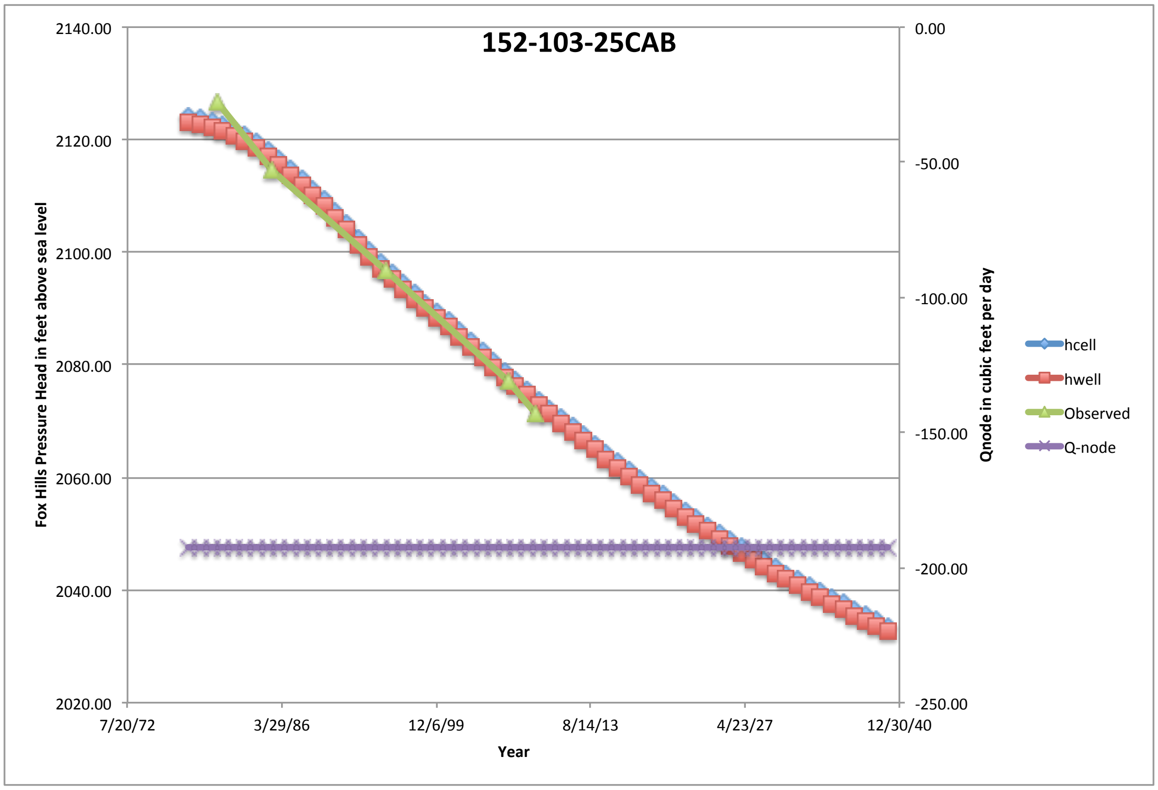
7848 – Land Surface Elevation 1995



7852 – Land Surface Elevation 2073



7855 – Land Surface Elevation 1965



APPENDIX C

ZONE BUDGET ANALYSIS FOR GROUNDWATER MODEL

Stress Period 1 (Year 1942)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	0	0	0	0	0	0	0	0	0	0	57
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	9	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	6	0	0	0	0	7	3	0	0	37
FROM ZONE 1	0	0	106	0	7	1	0	0	0	0	0
FROM ZONE 2	0	0	253	0	0	0	736	0	4	378	8
FROM ZONE 3	261	86	0	0	260	0	0	0	0	0	0
FROM ZONE 4	0	1141	0	0	0	0	0	0	0	0	609
FROM ZONE 5	156	0	60	0	0	108	25	25	0	0	0
FROM ZONE 6	56	0	0	0	2	0	0	84	0	0	0
FROM ZONE 7	0	32	0	0	127	0	0	91	515	0	0
FROM ZONE 8	0	0	0	0	0	33	2	0	23	169	0
FROM ZONE 9	0	0	0	0	0	0	0	299	0	313	0
FROM ZONE 10	0	33	0	0	0	0	0	4	69	0	577
FROM ZONE 11	0	0	0	0	0	0	0	0	0	222	0
Total IN	573	1387	606	2172	395	142	770	507	612	1082	1288
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	459	0	0	0	0	0	0	265	0	399	1008
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	422	0	0	0	0	0	0	0
MNW2	0	0	0	0	21	0	0	0	0	0	0
TO ZONE 0	0	7	0	0	0	0	5	14	0	0	57
TO ZONE 1	0	0	261	0	156	56	0	0	0	0	0
TO ZONE 2	0	0	86	1141	0	0	32	0	0	33	0
TO ZONE 3	106	253	0	0	60	0	0	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	7	0	260	0	0	2	127	0	0	0	0
TO ZONE 6	1	0	0	0	108	0	0	33	0	0	0
TO ZONE 7	0	736	0	0	25	0	0	2	0	0	0
TO ZONE 8	0	0	0	0	25	84	91	0	299	4	0
TO ZONE 9	0	4	0	0	0	0	515	23	0	69	0
TO ZONE 10	0	378	0	0	0	0	0	169	313	0	222
TO ZONE 11	0	8	0	609	0	0	0	0	0	577	0
Total OUT	573	1387	606	2172	395	142	770	507	612	1082	1288
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

Stress Period 10 (Year 1952)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
STORAGE	16	0	42	0	1	0	0	7	6	28	0
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	0	0	0	0	0	0	0	0	0	0	57
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	9	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	6	0	0	0	0	7	3	0	0	37
FROM ZONE 1	0	0	106	0	7	1	0	0	0	0	0
FROM ZONE 2	0	0	253	0	0	0	736	0	4	378	8
FROM ZONE 3	270	86	0	0	259	0	0	0	0	0	0
FROM ZONE 4	0	1141	0	0	0	0	0	0	0	0	609
FROM ZONE 5	156	0	60	0	0	108	25	25	0	0	0
FROM ZONE 6	56	0	0	0	2	0	0	84	0	0	0
FROM ZONE 7	0	32	0	0	127	0	0	91	515	0	0
FROM ZONE 8	0	0	0	0	0	33	2	0	23	169	0
FROM ZONE 9	0	0	0	0	0	0	0	299	0	318	0
FROM ZONE 10	0	33	0	0	0	0	0	4	68	0	577
FROM ZONE 11	0	0	0	0	0	0	0	0	0	222	0
Total IN	598	1387	648	2172	395	142	770	514	617	1116	1288
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
STORAGE	0	0	0	0	0	0	0	0	0	0	0
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	452	0	0	0	0	0	0	265	0	399	1008
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	422	0	0	0	0	0	0	0
MNW2	33	0	33	0	21	0	0	7	0	35	0
TO ZONE 0	0	7	0	0	0	0	5	14	0	0	57
TO ZONE 1	0	0	270	0	156	56	0	0	0	0	0
TO ZONE 2	0	0	86	1141	0	0	32	0	0	33	0
TO ZONE 3	106	253	0	0	60	0	0	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	7	0	259	0	0	2	127	0	0	0	0
TO ZONE 6	1	0	0	0	108	0	0	33	0	0	0
TO ZONE 7	0	736	0	0	25	0	0	2	0	0	0
TO ZONE 8	0	0	0	0	25	84	91	0	299	4	0
TO ZONE 9	0	4	0	0	0	0	515	23	0	68	0
TO ZONE 10	0	378	0	0	0	0	0	169	318	0	222
TO ZONE 11	0	8	0	609	0	0	0	0	0	577	0
Total OUT	598	1387	648	2172	395	142	770	514	617	1116	1288
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

Stress Period 20 (Year 1962)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
STORAGE	90	23	277	409	41	4	18	23	30	71	33
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	0	0	0	0	0	0	0	0	0	0	57
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	9	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	6	0	0	0	0	7	3	0	0	37
FROM ZONE 1	0	0	107	0	5	1	0	0	0	0	0
FROM ZONE 2	0	0	253	0	0	0	735	0	4	378	8
FROM ZONE 3	241	85	0	0	241	0	0	0	0	0	0
FROM ZONE 4	0	1140	0	0	0	0	0	0	0	0	576
FROM ZONE 5	153	0	61	0	0	105	25	25	0	0	0
FROM ZONE 6	56	0	0	0	2	0	0	85	0	0	0
FROM ZONE 7	0	32	0	0	127	0	0	93	516	0	0
FROM ZONE 8	0	0	0	0	0	33	2	0	23	169	0
FROM ZONE 9	0	0	0	0	0	0	0	298	0	313	0
FROM ZONE 10	0	33	0	0	0	0	0	4	70	0	577
FROM ZONE 11	0	0	0	0	0	0	0	0	0	222	0
Total IN	640	1408	885	2581	415	142	787	531	643	1153	1288
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
STORAGE	0	0	0	0	0	0	0	0	0	0	0
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	428	0	0	0	0	0	0	265	0	399	1008
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	422	0	0	0	0	0	0	0
MNW2	99	22	318	443	46	0	15	24	33	70	0
TO ZONE 0	0	7	0	0	0	0	5	14	0	0	57
TO ZONE 1	0	0	241	0	153	56	0	0	0	0	0
TO ZONE 2	0	0	85	1140	0	0	32	0	0	33	0
TO ZONE 3	107	253	0	0	61	0	0	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	5	0	241	0	0	2	127	0	0	0	0
TO ZONE 6	1	0	0	0	105	0	0	33	0	0	0
TO ZONE 7	0	735	0	0	25	0	0	2	0	0	0
TO ZONE 8	0	0	0	0	25	85	93	0	298	4	0
TO ZONE 9	0	4	0	0	0	0	516	23	0	70	0
TO ZONE 10	0	378	0	0	0	0	0	169	313	0	222
TO ZONE 11	0	8	0	576	0	0	0	0	0	577	0
Total OUT	640	1408	885	2581	416	142	787	531	643	1153	1288
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

Stress Period 30 (Year 1972)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
STORAGE	115	432	786	428	442	49	269	82	54	1035	74
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	0	0	0	0	0	0	0	0	0	0	57
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	9	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	6	0	0	0	0	7	3	0	0	37
FROM ZONE 1	0	0	107	0	2	1	0	0	0	0	0
FROM ZONE 2	0	0	252	0	0	0	706	0	4	378	8
FROM ZONE 3	223	102	0	0	143	0	0	0	0	0	0
FROM ZONE 4	0	1136	0	0	0	0	0	0	0	0	553
FROM ZONE 5	142	0	103	0	0	99	26	25	0	0	0
FROM ZONE 6	56	0	0	0	2	0	0	85	0	0	0
FROM ZONE 7	0	32	0	0	126	0	0	87	515	0	0
FROM ZONE 8	0	0	0	0	0	37	2	0	23	169	0
FROM ZONE 9	0	0	0	0	0	0	0	294	0	335	0
FROM ZONE 10	0	33	0	0	0	0	0	3	66	0	577
FROM ZONE 11	0	0	0	0	0	0	0	0	0	222	0
Total IN	636	1830	1435	2599	716	186	1010	580	662	2139	1306
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
STORAGE	0	0	0	0	0	0	0	0	0	0	0
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	362	0	0	0	0	0	0	265	0	396	990
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	420	0	0	0	0	0	0	0
MNW2	164	475	967	491	321	43	245	69	33	1064	37
TO ZONE 0	0	7	0	0	0	0	5	14	0	0	57
TO ZONE 1	0	0	223	0	142	56	0	0	0	0	0
TO ZONE 2	0	0	102	1136	0	0	32	0	0	33	0
TO ZONE 3	107	252	0	0	103	0	0	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	2	0	143	0	0	2	126	0	0	0	0
TO ZONE 6	1	0	0	0	99	0	0	37	0	0	0
TO ZONE 7	0	706	0	0	26	0	0	2	0	0	0
TO ZONE 8	0	0	0	0	25	85	87	0	294	3	0
TO ZONE 9	0	4	0	0	0	0	515	23	0	66	0
TO ZONE 10	0	378	0	0	0	0	0	169	335	0	222
TO ZONE 11	0	8	0	553	0	0	0	0	0	577	0
Total OUT	636	1830	1435	2599	716	186	1010	580	662	2139	1306
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

Stress Period 40 (Year 1982)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
STORAGE	216	671	908	561	1213	957	606	233	129	1562	149
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	0	0	0	0	0	0	0	0	0	5	68
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	9	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	7	0	0	0	0	5	3	0	0	37
FROM ZONE 1	0	0	121	0	0	1	0	0	0	0	0
FROM ZONE 2	0	0	254	0	0	0	664	0	4	363	8
FROM ZONE 3	201	107	0	0	100	0	0	0	0	0	0
FROM ZONE 4	0	1144	0	0	0	0	0	0	0	0	539
FROM ZONE 5	120	0	241	0	0	71	15	23	0	0	0
FROM ZONE 6	56	0	0	0	32	0	0	77	0	0	0
FROM ZONE 7	0	32	0	0	131	0	0	68	507	0	0
FROM ZONE 8	0	0	0	0	12	75	3	0	22	175	0
FROM ZONE 9	0	0	0	0	0	0	0	288	0	391	0
FROM ZONE 10	0	33	0	0	0	0	0	0	62	0	593
FROM ZONE 11	0	0	0	0	0	0	0	0	0	238	0
Total IN	692	2084	1711	2733	1489	1105	1292	692	724	2733	1395
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
STORAGE	0	96	0	0	0	0	0	0	0	0	7
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	241	0	0	0	0	0	0	265	0	346	967
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	405	0	0	0	0	0	0	0
MNW2	329	691	1304	644	1019	940	547	125	45	1699	126
TO ZONE 0	0	5	0	0	0	0	6	14	0	0	57
TO ZONE 1	0	0	201	0	120	56	0	0	0	0	0
TO ZONE 2	0	0	107	1144	0	0	32	0	0	33	0
TO ZONE 3	121	254	0	0	241	0	0	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	0	0	100	0	0	32	131	12	0	0	0
TO ZONE 6	1	0	0	0	71	0	0	75	0	0	0
TO ZONE 7	0	664	0	0	15	0	0	3	0	0	0
TO ZONE 8	0	0	0	0	23	77	68	0	288	0	0
TO ZONE 9	0	4	0	0	0	0	507	22	0	62	0
TO ZONE 10	0	363	0	0	0	0	0	175	391	0	238
TO ZONE 11	0	8	0	539	0	0	0	0	0	593	0
Total OUT	692	2084	1711	2733	1489	1105	1292	692	724	2733	1395
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

Stress Period 50 (Year 1992)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
STORAGE	209	784	919	567	1148	1047	696	604	189	1658	185
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	46	0	0	0	0	0	0	0	0	82	75
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	10	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	7	0	0	0	0	5	3	0	0	37
FROM ZONE 1	0	0	125	0	0	1	0	0	0	0	0
FROM ZONE 2	0	0	258	0	0	0	626	0	4	354	8
FROM ZONE 3	212	113	0	0	105	0	0	0	0	0	0
FROM ZONE 4	0	1151	0	0	0	0	0	0	0	0	528
FROM ZONE 5	91	0	313	0	0	66	0	31	0	0	0
FROM ZONE 6	55	0	0	0	70	0	0	63	0	0	0
FROM ZONE 7	0	33	1	0	160	0	0	62	489	0	0
FROM ZONE 8	0	0	0	0	39	164	2	0	24	191	0
FROM ZONE 9	0	0	0	0	0	0	0	301	0	425	0
FROM ZONE 10	0	34	0	0	0	0	0	0	63	0	583
FROM ZONE 11	0	0	0	0	0	0	0	0	0	254	0
Total IN	712	2211	1804	2740	1523	1278	1329	1064	769	2963	1416
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
STORAGE	0	103	0	71	0	0	0	0	0	5	0
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	159	0	0	0	0	0	0	265	0	257	937
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	394	0	0	0	0	0	0	0
MNW2	427	853	1373	595	1022	1090	578	364	42	2021	168
TO ZONE 0	0	5	0	0	0	0	6	14	0	0	57
TO ZONE 1	0	0	212	0	91	55	0	0	0	0	0
TO ZONE 2	0	0	113	1151	0	0	33	0	0	34	0
TO ZONE 3	125	258	0	0	313	0	1	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	0	0	105	0	0	70	160	39	0	0	0
TO ZONE 6	1	0	0	0	66	0	0	164	0	0	0
TO ZONE 7	0	626	0	0	0	0	0	2	0	0	0
TO ZONE 8	0	0	0	0	31	63	62	0	301	0	0
TO ZONE 9	0	4	0	0	0	0	489	24	0	63	0
TO ZONE 10	0	354	0	0	0	0	0	191	425	0	254
TO ZONE 11	0	8	0	528	0	0	0	0	0	583	0
Total OUT	712	2211	1804	2740	1523	1278	1329	1064	769	2963	1416
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

Stress Period 60 (Year 2002)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
STORAGE	161	722	644	441	936	909	695	588	175	1260	160
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	114	0	0	0	0	0	0	0	0	108	77
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	10	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	6	0	0	0	0	7	3	0	0	37
FROM ZONE 1	0	0	128	0	2	0	0	0	0	0	0
FROM ZONE 2	0	0	267	0	0	0	653	0	4	370	8
FROM ZONE 3	222	109	0	0	115	0	0	0	0	0	0
FROM ZONE 4	0	1158	0	0	0	0	0	0	0	0	547
FROM ZONE 5	61	0	357	0	0	68	0	34	0	0	0
FROM ZONE 6	52	0	0	0	73	0	0	56	0	0	0
FROM ZONE 7	0	33	2	0	205	0	0	65	484	0	0
FROM ZONE 8	0	0	0	0	51	216	1	0	26	211	0
FROM ZONE 9	0	0	0	0	0	0	0	305	0	444	0
FROM ZONE 10	0	34	0	0	0	0	0	0	60	0	578
FROM ZONE 11	0	0	0	0	0	0	0	0	0	266	0
Total IN	710	2151	1586	2614	1381	1194	1355	1052	750	2659	1407
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
STORAGE	0	3	0	141	0	0	3	0	0	33	23
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	120	0	0	0	0	0	0	265	0	215	937
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	379	0	0	0	0	0	0	0
MNW2	460	838	1139	389	861	1013	558	267	2	1738	124
TO ZONE 0	0	7	0	0	0	0	6	14	0	0	57
TO ZONE 1	0	0	222	0	61	52	0	0	0	0	0
TO ZONE 2	0	0	109	1158	0	0	33	0	0	34	0
TO ZONE 3	128	267	0	0	357	0	2	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	2	0	115	0	0	73	205	51	0	0	0
TO ZONE 6	0	0	0	0	68	0	0	216	0	0	0
TO ZONE 7	0	653	0	0	0	0	0	1	0	0	0
TO ZONE 8	0	0	0	0	34	56	65	0	305	0	0
TO ZONE 9	0	4	0	0	0	0	484	26	0	60	0
TO ZONE 10	0	370	0	0	0	0	0	211	444	0	266
TO ZONE 11	0	8	0	547	0	0	0	0	0	578	0
Total OUT	710	2151	1586	2614	1381	1194	1355	1052	750	2659	1407
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

Stress Period 68 (Year 2009)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
STORAGE	126	525	501	375	802	869	657	679	188	1097	144
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	147	0	0	0	0	0	0	0	0	151	79
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	11	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	6	0	0	0	0	7	3	0	0	37
FROM ZONE 1	0	0	128	0	5	0	0	0	0	0	0
FROM ZONE 2	0	0	274	0	0	0	672	0	5	377	8
FROM ZONE 3	226	105	0	0	123	0	0	0	0	0	0
FROM ZONE 4	0	1168	0	0	0	0	0	0	0	0	570
FROM ZONE 5	43	0	342	0	0	72	0	37	0	0	0
FROM ZONE 6	48	0	0	0	76	0	0	54	0	0	0
FROM ZONE 7	0	33	3	0	225	0	0	68	483	0	0
FROM ZONE 8	0	0	0	0	52	241	0	0	25	225	0
FROM ZONE 9	0	0	0	0	0	0	0	305	0	455	0
FROM ZONE 10	0	34	0	0	0	0	0	0	61	0	574
FROM ZONE 11	0	0	0	0	0	0	0	0	0	277	0
Total IN	690	1960	1435	2548	1283	1183	1336	1145	762	2581	1411
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
STORAGE	0	43	1	97	0	0	1	2	0	0	34
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	97	0	0	0	0	0	0	265	0	180	925
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	369	0	0	0	0	0	0	0
MNW2	460	574	980	345	789	1005	518	320	2	1733	119
TO ZONE 0	0	8	0	0	0	0	5	14	0	0	57
TO ZONE 1	0	0	226	0	43	48	0	0	0	0	0
TO ZONE 2	0	0	105	1168	0	0	33	0	0	34	0
TO ZONE 3	128	274	0	0	342	0	3	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	5	0	123	0	0	76	225	52	0	0	0
TO ZONE 6	0	0	0	0	72	0	0	241	0	0	0
TO ZONE 7	0	672	0	0	0	0	0	0	0	0	0
TO ZONE 8	0	0	0	0	37	54	68	0	305	0	0
TO ZONE 9	0	5	0	0	0	0	483	25	0	61	0
TO ZONE 10	0	377	0	0	0	0	0	225	455	0	277
TO ZONE 11	0	8	0	570	0	0	0	0	0	574	0
Total OUT	690	1960	1435	2548	1283	1183	1336	1145	762	2581	1411
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

Prediction Stress Period 10 (Year 2019)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
STORAGE	100	510	410	330	691	766	656	693	196	931	148
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	178	0	0	0	0	0	0	0	0	173	80
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	2	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	6	0	0	0	0	7	3	0	0	37
FROM ZONE 1	0	0	128	0	12	0	0	0	0	0	0
FROM ZONE 2	0	0	284	0	0	0	698	0	5	379	8
FROM ZONE 3	227	87	0	0	132	0	0	0	0	0	0
FROM ZONE 4	0	1183	0	0	0	0	0	0	0	0	579
FROM ZONE 5	26	0	318	0	0	74	0	41	0	0	0
FROM ZONE 6	41	0	0	0	81	0	0	54	0	0	0
FROM ZONE 7	0	34	3	0	241	0	0	76	481	0	0
FROM ZONE 8	0	0	0	0	54	252	0	0	24	241	0
FROM ZONE 9	0	0	0	0	0	0	0	302	0	463	0
FROM ZONE 10	0	34	0	0	0	0	0	0	62	0	563
FROM ZONE 11	0	0	0	0	0	0	0	0	0	296	0
Total IN	671	1944	1331	2494	1211	1092	1361	1169	767	2482	1415
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
STORAGE	0	0	0	40	0	0	0	0	0	0	14
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	71	0	0	0	0	0	0	265	0	152	927
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	347	0	0	0	0	0	0	0
MNW2	460	562	885	345	753	917	520	319	2	1672	120
TO ZONE 0	0	8	0	0	0	0	5	14	0	0	57
TO ZONE 1	0	0	227	0	26	41	0	0	0	0	0
TO ZONE 2	0	0	87	1183	0	0	34	0	0	34	0
TO ZONE 3	128	284	0	0	318	0	3	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	12	0	132	0	0	81	241	54	0	0	0
TO ZONE 6	0	0	0	0	74	0	0	252	0	0	0
TO ZONE 7	0	698	0	0	0	0	0	0	0	0	0
TO ZONE 8	0	0	0	0	41	54	76	0	302	0	0
TO ZONE 9	0	5	0	0	0	0	481	24	0	62	0
TO ZONE 10	0	379	0	0	0	0	0	241	463	0	296
TO ZONE 11	0	8	0	579	0	0	0	0	0	563	0
Total OUT	671	1944	1331	2494	1211	1092	1361	1169	767	2482	1415
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

Prediction Stress Period 20 (Year 2029)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
STORAGE	83	504	357	316	583	705	642	690	206	795	154
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	202	0	0	0	0	0	0	0	0	186	82
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	3	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	6	0	0	0	0	7	3	0	0	37
FROM ZONE 1	0	0	127	0	21	0	0	0	0	0	0
FROM ZONE 2	0	0	291	0	0	0	711	0	5	379	8
FROM ZONE 3	227	79	0	0	139	0	0	0	0	0	0
FROM ZONE 4	0	1197	0	0	0	0	0	0	0	0	583
FROM ZONE 5	14	0	292	0	0	71	0	42	0	0	0
FROM ZONE 6	32	0	0	0	88	0	0	54	0	0	0
FROM ZONE 7	0	34	4	0	251	0	0	81	475	0	0
FROM ZONE 8	0	0	0	0	54	258	0	0	23	253	0
FROM ZONE 9	0	0	0	0	0	0	1	300	0	469	0
FROM ZONE 10	0	34	0	0	0	0	0	0	63	0	556
FROM ZONE 11	0	0	0	0	0	0	0	0	0	312	0
Total IN	658	1945	1259	2481	1136	1034	1361	1170	772	2394	1420
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
STORAGE	0	0	0	20	0	0	0	0	0	0	10
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	50	0	0	0	0	0	0	264	0	132	922
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	336	0	0	0	0	0	0	0
MNW2	460	543	814	345	717	860	510	304	2	1610	119
TO ZONE 0	0	8	0	0	0	0	5	14	0	0	57
TO ZONE 1	0	0	227	0	14	32	0	0	0	0	0
TO ZONE 2	0	0	79	1197	0	0	34	0	0	34	0
TO ZONE 3	127	291	0	0	292	0	4	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	21	0	139	0	0	88	251	54	0	0	0
TO ZONE 6	0	0	0	0	71	0	0	258	0	0	0
TO ZONE 7	0	711	0	0	0	0	0	0	1	0	0
TO ZONE 8	0	0	0	0	42	54	81	0	300	0	0
TO ZONE 9	0	5	0	0	0	0	475	23	0	63	0
TO ZONE 10	0	379	0	0	0	0	0	253	469	0	312
TO ZONE 11	0	8	0	583	0	0	0	0	0	556	0
Total OUT	658	1945	1259	2481	1136	1034	1361	1170	772	2394	1420
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

Prediction Stress Period 30 (Year 2039)

	ZONE 1	ZONE 2	ZONE 3	ZONE 4	ZONE 5	ZONE 6	ZONE 7	ZONE 8	ZONE 9	ZONE 10	ZONE 11
	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN	IN
STORAGE	68	483	309	305	493	659	604	693	214	689	157
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	223	0	0	0	0	0	0	0	0	197	83
RECHARGE	100	89	188	2163	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	3	0	0	0	0	0	0	0
MNW2	0	0	0	0	0	0	0	0	0	0	0
FROM ZONE 0	0	6	0	0	0	0	7	3	0	0	37
FROM ZONE 1	0	0	127	0	31	0	0	0	0	0	0
FROM ZONE 2	0	0	296	0	0	0	722	0	5	378	8
FROM ZONE 3	227	75	0	0	145	0	0	0	0	0	0
FROM ZONE 4	0	1207	0	0	0	0	0	0	0	0	585
FROM ZONE 5	8	0	268	0	0	70	0	42	0	0	0
FROM ZONE 6	23	0	0	0	92	0	0	54	0	0	0
FROM ZONE 7	0	34	4	0	258	0	0	84	470	0	0
FROM ZONE 8	0	0	0	0	54	257	0	0	21	263	0
FROM ZONE 9	0	0	0	0	0	0	2	298	0	473	0
FROM ZONE 10	0	34	0	0	0	0	0	0	64	0	551
FROM ZONE 11	0	0	0	0	0	0	0	0	0	324	0
Total IN	650	1929	1191	2471	1073	987	1336	1174	774	2324	1420
	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
STORAGE	0	0	0	9	0	0	0	0	0	0	6
CONSTANT HEAD	0	0	0	0	0	0	0	0	0	0	0
HEAD DEP BOUNDS	32	0	0	0	0	0	0	264	0	116	916
RECHARGE	0	0	0	0	0	0	0	0	0	0	0
STREAM LEAKAGE	0	0	0	325	0	0	0	0	0	0	0
MNW2	460	511	744	345	685	818	480	301	2	1558	117
TO ZONE 0	0	8	0	0	0	0	5	14	0	0	57
TO ZONE 1	0	0	227	0	8	23	0	0	0	0	0
TO ZONE 2	0	0	75	1207	0	0	34	0	0	34	0
TO ZONE 3	127	296	0	0	268	0	4	0	0	0	0
TO ZONE 4	0	0	0	0	0	0	0	0	0	0	0
TO ZONE 5	31	0	145	0	0	92	258	54	0	0	0
TO ZONE 6	0	0	0	0	70	0	0	257	0	0	0
TO ZONE 7	0	722	0	0	0	0	0	0	2	0	0
TO ZONE 8	0	0	0	0	42	54	84	0	298	0	0
TO ZONE 9	0	5	0	0	0	0	470	21	0	64	0
TO ZONE 10	0	378	0	0	0	0	0	263	473	0	324
TO ZONE 11	0	8	0	585	0	0	0	0	0	551	0
Total OUT	650	1929	1191	2471	1073	987	1336	1174	774	2324	1420
IN-OUT	0	0	0	0	0	0	0	0	0	0	0
Percent Error	0	0	0	0	0	0	0	0	0	0	0

APPENDIX D

RECOMMENDED DECISION FOR CITY OF ALEXANDER WATER PERMIT APPLICATION NO. 5990 (WANEK, 2009)

Office of the State Engineer

Recommended Decision

City of Alexander Water Permit Application No. 5990

June 24, 2009

Office of the State Engineer
Recommended Decision

To: Dale L. Frink, State Engineer, through 6-26-2009
Jon Patch, Section chief, Ground Water Management, and
Robert Shaver, Director, Water Appropriations Division JP 6/25/09
From: Alan Wanek, Hydrologist Manager
Subject: City of Alexander Water Permit Application No. 5990
Date: June 24, 2009

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Fox Hills water permit applications:

Nine water permit applications are pending in western North Dakota for which the Fox Hills-Hell Creek (FH-HC) aquifer is expected to be the source of water (Table 1).

Table 1. Pending water permit applications where the expected source is the FH-HC aquifer

No.	*Applicant*	*Priority date*	*Comment date*	*Ac-ft/gpm*	*Location*	*Nearest city*
5934	Linda Monson	July 17, 2007	Sep 24, 2007	50/75	150-102-33B	Alexander 7SW
5963	Lyle Bratcher	Nov 5, 2007	Apr 5, 2008	250/300	149-101-17B	Alexander 8S
5965	Petro-Hunt	Nov 16, 2007	Jan 21, 2008	10/6	144-98-04A	Gassy Bt 8SE
5966	Energy Equity	Nov 16, 2007	Mar 10, 2008	20/50	152-88-13BC	Parshall 8E
5967	Energy Equity	Nov 19, 2007	Mar 10, 2008	20/50	156-91-12DD	Stanley 5NE
5990	Alexander	Jan 11, 2008	May 12, 2008	170/500	150-101-5B	Alexander
6018	Dunn Center	Apr 2, 2008	Sept 22, 2008	325/200	145-94-26CA	Dunn Center
6052	Halliday	Sep 15, 2008	Dec 8, 2008	310/300	145-92-24BC & 25AB	Halliday
6056	Fred Berger	Sep 23, 2008	Dec 22, 2008	120/100	140-83-25S	Mandan 9NW

Linda Monson Application No. 5934, Lyle Bratcher Application No. 5963, and City of Alexander Application No. 5990, are all located in western McKenzie County (Fig. 1) and will be discussed together. Similarly, the two Energy Equity applications can be discussed together and the Dunn Center and Halliday applications can be discussed together. Because each application has different parties of record and possible appeals, a separate memo heading and recommendation will be written for each of the three McKenzie County applications, although the body of the memo will be the same.

On July 16, 2007, Linda Monson applied for 50 acre-feet of water per year for industrial use, at a maximum pumping rate of 75 gallons per minute (gpm). From telephone discussions with Ms. Monson in 2007 and 2009, it is understood that the intention, at least at the time of application, was to sell water to the oil industry, primarily for brine dilution in nearby producing oil wells. The proposed ground-water source is Ms. Monson's existing Fox Hills well at her farmstead, 5 miles south and 4.5 miles west of Alexander. Ms. Monson's 5-inch diameter Fox Hills well is completed between 1,564 and 1,645 feet below land surface. Water from the well supplies the farmstead and is piped to pastures. Letters were received regarding the application from Rodney Wolf and Cindy Klein, representing the Dakota Resource Council.

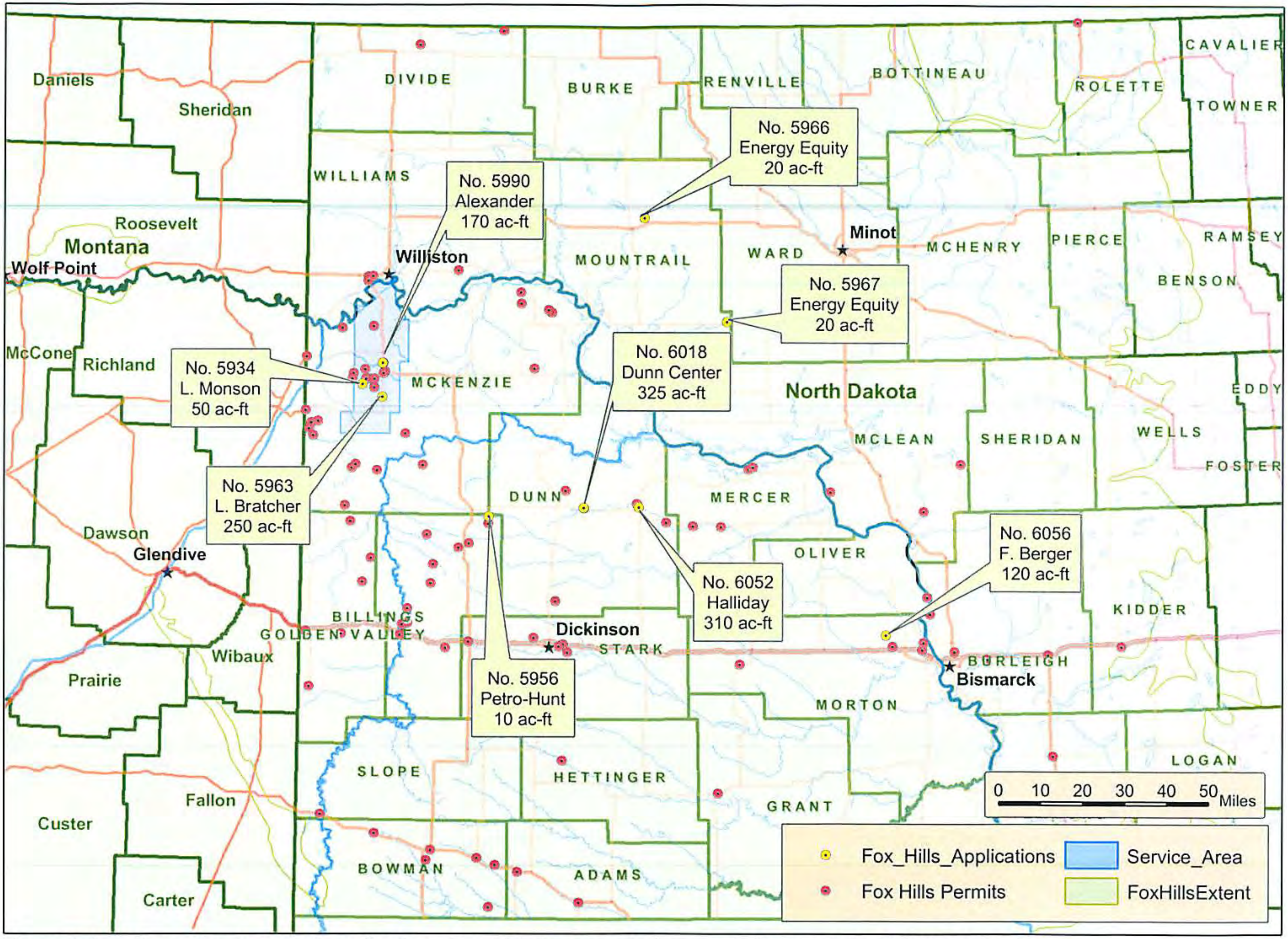


Figure 1. Locations of water permit applications for which the expected source is the Fox Hills-Hell Creek aquifer

On October 12, 2007, Lyle Bratcher applied for 250 acre-feet of water per year for industrial use, at a maximum pumping rate of 300 gpm, from a location about eight miles south of Alexander. Lyle Bratcher Application No. 5963 is signed by Lyle Bratcher, his wife, Sharon, son, Troy, and Gene W. Koch, Trustee of the James R. Chitwood and Beulah B. Chitwood Family Trusts. Landowners at the proposed point of diversion are listed on the application as the James R. Chitwood Family Trust and the Beulah B. Chitwood Family Trust (Sharon Bratcher is the daughter of James Chitwood). Included with the application are copies of deeds putting the land in a family trust and a copy of an agreement for Gene W. Koch to serve as trustee. Eleven letters were received regarding the Bratcher application. The proposed project was discussed with Lyle Bratcher in an April 27, 2009 telephone conversation. The proposed water use is sales, primarily oil industry-related, for the dilution of brine entrained with oil produced from the Ratcliffe interval. The FH-HC aquifer is very likely the only fresh ground water source at the proposed well location capable of producing the requested quantity of water.

On February 15, 2008, the City of Alexander (City) applied for 170 acre-feet of water per year at a maximum pumping rate of 200 gallons per minute for Rural-Domestic use. City of Alexander Application No. 5990 proposes to supply water to a planned rural water district, the 'System IV Service Area,' consisting of about 100 connections, approximately centered around Alexander in western McKenzie County (Fig. 2). The City's application replaces a January 8, 2008 application for 270 acre-feet of water per year at 500 gpm for Municipal, Rural-Domestic, and Industrial types of use. The City's January 8, 2008 application was returned because multiple types of water use were listed. No letters of concern were filed regarding the City of Alexander's application. The City proposes to use two existing municipal wells and a planned third well for the rural water supply. The City's Fox Hills wells are located about 320 feet apart in the western part of Alexander. The wells are completed between 1,676 and 1,760 feet below land surface (a 1982 well) and between 1,690 and 1,770 feet below land surface (a 2004 well). A third well is proposed about 440 and 760 feet northwest of the two existing city wells. City of Alexander water systems operator James Fixen said that the reverse osmosis treatment process used for the city water requires between 13% and 18% of the water pumped.

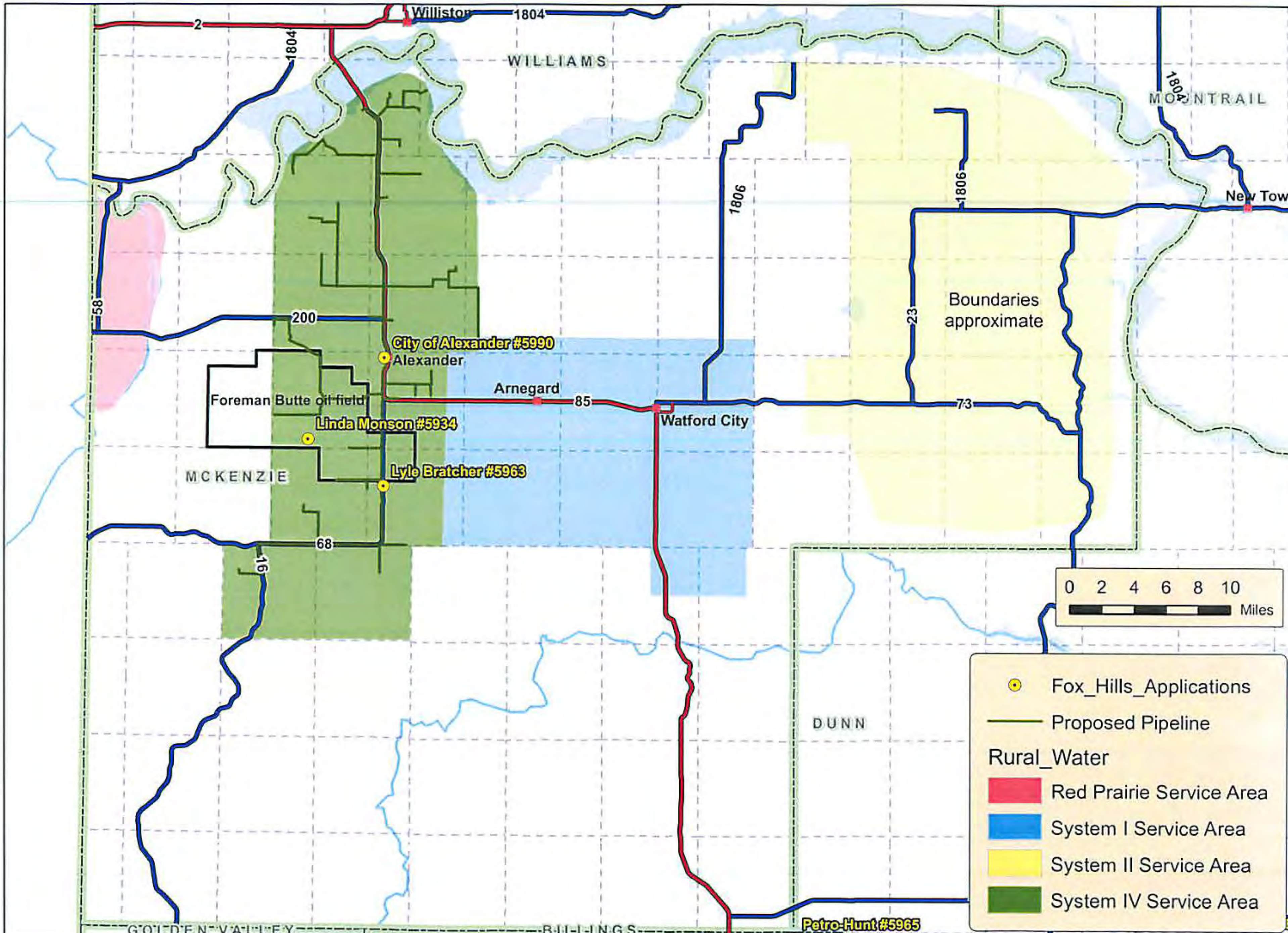


Figure 2. Locations of three industrial water permit applications in western McKenzie County (expected source is FH-HC aquifer)

Supplying water to the Foreman Butte oil field:

The Monson and Batcher industrial water permit applications were requested to supply water to recently installed oil wells in the Foremen Butte oil field. The rural water pipeline to be supplied by the City of Alexander also proposes to supply water to oil wells in the Foreman Butte field.

In early 2004, the Ruth 1-23H oil well was completed in the Ratcliffe interval of the Charles Formation, in what came to be the Forman Butte oil field, which is located between two and ten miles southwest of Alexander. There are currently about 42 Ratcliffe oil wells operating in the Foreman Butte field, plus a few other Ratcliffe wells in smaller oil fields north and east of the Foreman Butte field. The Ratcliffe oil-producing zone is in close proximity to the Charles salt and the oil wells completed in the interval require up to about one gpm of fresh water to prevent precipitating salt from plugging up production tubing and other equipment. Reported water use at a commercial oil depot east of the Foremen Butte field increased in 2004 and 2005, then dropped off in 2006. The City of Alexander's reported water use increased in July 2005. When the City of Alexander began treating its Fox Hills water by reverse osmosis, the city's water supply became a preferred water source, requiring less chemical treatment for use in the producing oil wells.

As a possible alternative to serve the fresh water requirements of the Ratcliffe oil wells southwest of Alexander, Linda Monson, in July 2007, applied for an industrial water permit. The source would be a Fox Hills well recently installed for Ms. Monson as a replacement stock water source following leakage from a break in a salt water disposal line. A stock distribution line from Ms. Monson's Fox Hills well traverses within a few hundred feet of one of the Foreman Butte oil wells in the southern part of the oil field.

A second possible water supply source for the Foreman Butte field Ratcliffe oil wells were proposed in an October 2007 water permit application by Lyle Bratcher. Mr. Bratcher, working with an oil field service company acting as an agent for the primary developer of the Ratcliffe oil wells, applied for an industrial water permit from a location near the southeast corner of the oil field. While no Fox Hills well exists at the location proposed by Mr. Bratcher for the point of diversion, the FH-HC aquifer is likely the only source capable of producing the requested quantity of water.

A third possible water source for the Foremen Butte and nearby Ratcliffe oil wells is a proposed rural water line traversing through the field. In a January 9, 2008 letter, Keith Hill, Operations Manager with Zenergy, the primary operator of Ratcliffe oil wells in the Foreman Butte field, wrote of the oil company's involvement in the proposed rural water system. The proposed water source for the rural water system would be reverse-osmosis treated Fox Hills water supplied by the City of Alexander. In a recent telephone conversation, Mr. Hill has reiterated his interest in possibly having even more of the Foremen Butte oil field wells served with the high-quality, treated Fox Hills water supplied by the City of Alexander.

The southeast portion of the Foreman Butte Oil Field has not been developed as much as originally envisioned, with a number of oil drilling permits being cancelled. Additionally, Zenergy has had its own Fox Hills wells installed at five locations in the southeast part of the Foreman Butte oil field and has shown a preference for the reverse osmosis-treated, City of Alexander Fox Hills water to serve other oil wells. However, since they have completed the submitted applications, both Ms. Monson and Mr. Bratcher expressed an interest in having the water permit application process continue for their applications. The development of oil wells in the Bakken Formation in Mountrail and Dunn counties, requiring water for formation stimulation as part of the oil well completion process and generating interest in developing commercial water depots, has not extended as far west as western McKenzie County.

Other Fox Hills water permit applications:

Petro-Hunt Application No. 5965 is for 10 acre-feet of water per year to dilute brine in the Zabolotny 8-4 gas well in northeastern Billings County. Currently water is being hauled from a permitted Fox Hills well at a gas plant 1.7 miles south of the Zabolotny 8-4 well. Granting the permit is not expected to result in any more water being drawn from the FH-HC aquifer, but rather, water would not have to be hauled 1.7 miles.

Energy Equity Water Permit Applications No. 5966 and 5967 are each for 20 acre-feet per year, primarily for water sales associated with development of Bakken oil wells in Mountrail County. The proposed point of diversion for Energy Equity Water Permit Application No. 5966, near Plaza, east of Parshall, is the location of an Energy Equity oil well currently shut-in. Energy Equity proposes to plug the lower portion of the well and perforate the casing opposite the FH-HC aquifer. The proposed point of diversion for Energy Equity Water Permit Application No. 5967, near Stanley, is the location of a 'dry hole' oil test. Energy Equity proposes to reenter and perforate the casing opposite the FH-HC aquifer.

The City of Dunn Center Application No. 6018 is for 325 acre-feet of water per year for industrial water sales. The City of Dunn Center proposes to sell water from its two existing wells completed in the FH-HC aquifer. The city obtained its municipal water from the Fox Hills wells until switching to the Southwest Pipeline for its water in 1994.

The City of Halliday Application No. 6052 is for 310 acre-feet of water per year for industrial water sales. The City of Halliday, like the City of Dunn Center, proposes to sell water from its former municipal water supply. The city obtained its municipal water, at least in part, from a Fox Hills well until switching to the Southwest Pipeline for its water in 1994. On Line 5 of the city's application, 'Proposed construction, the city auditor has written, "Existing well, current permit #2136." The City of Halliday also lists a spring location ¾-mile northwest of the city as a proposed point of diversion on the industrial application. It is understood that at least at one time the spring formed part of the city's water supply. I have not asked the city if they plan to sell water from the spring, should their industrial water permit application be granted.

Fred Berger Water Permit Application No. 6056 is for 120 acre-feet of water per year for a proposed cattle feedlot nine miles northwest of Mandan. As far as is known, there is not an alternative fresh ground-water source other than the FH-HC aquifer capable of supplying the required quantity of water for Mr. Berger's proposed feedlot.

Fox Hills-Hell Creek aquifer:

Origin:

The Fox Hills-Hell Creek aquifer underlies western North Dakota and adjacent areas (Fig. 3), extending north into Saskatchewan, where it is known as the Eastend Formation, and south through South Dakota, Wyoming and much of Colorado. The FH-HC aquifer was formed when the Rocky Mountain uplift drained a mid-continent sea. As the western shoreline of the sea retreated to the east, a continuous, eastward moving line of deltaic and beach deposits formed in which the finer and more argillaceous or clayey sediments were winnowed out to sea.

The upper, Colgate Member of the Fox Hills Formation, along with occasional lenses of sand in the overlying Hell Creek Formation, forms the FH-HC aquifer. Sediments comprising the lower Fox Hill Formation become finer with depth, grading to the underlying Pierre Formation, comprised of clay deposited offshore in a sea. The Pierre Formation and underlying Cretaceous shales form an aquitard up to a few thousand feet thick separating the Fox Hills Formation and overlying sediments containing 'fresh' or potable water from the Dakota Group and underlying rock and sediment containing water with elevated dissolved mineral concentrations, particularly of sodium and chloride.

The FH-HC aquifer is overlain by fine and clayey sediments that were eroded from the rising Rocky Mountains and deposited onto a low-lying landscape where, unlike the modern setting, deposition of sediments exceeded erosion. The fine and clayey sediments were deposited on a low-relief landscape of braided streams, broad floodplains, and marshes. Sand was deposited in braided stream channels while finer sand, silt, and clay was deposited over a broader landscape by flooding streams. In swamps organic material was buried and was eventually compressed into lignite.

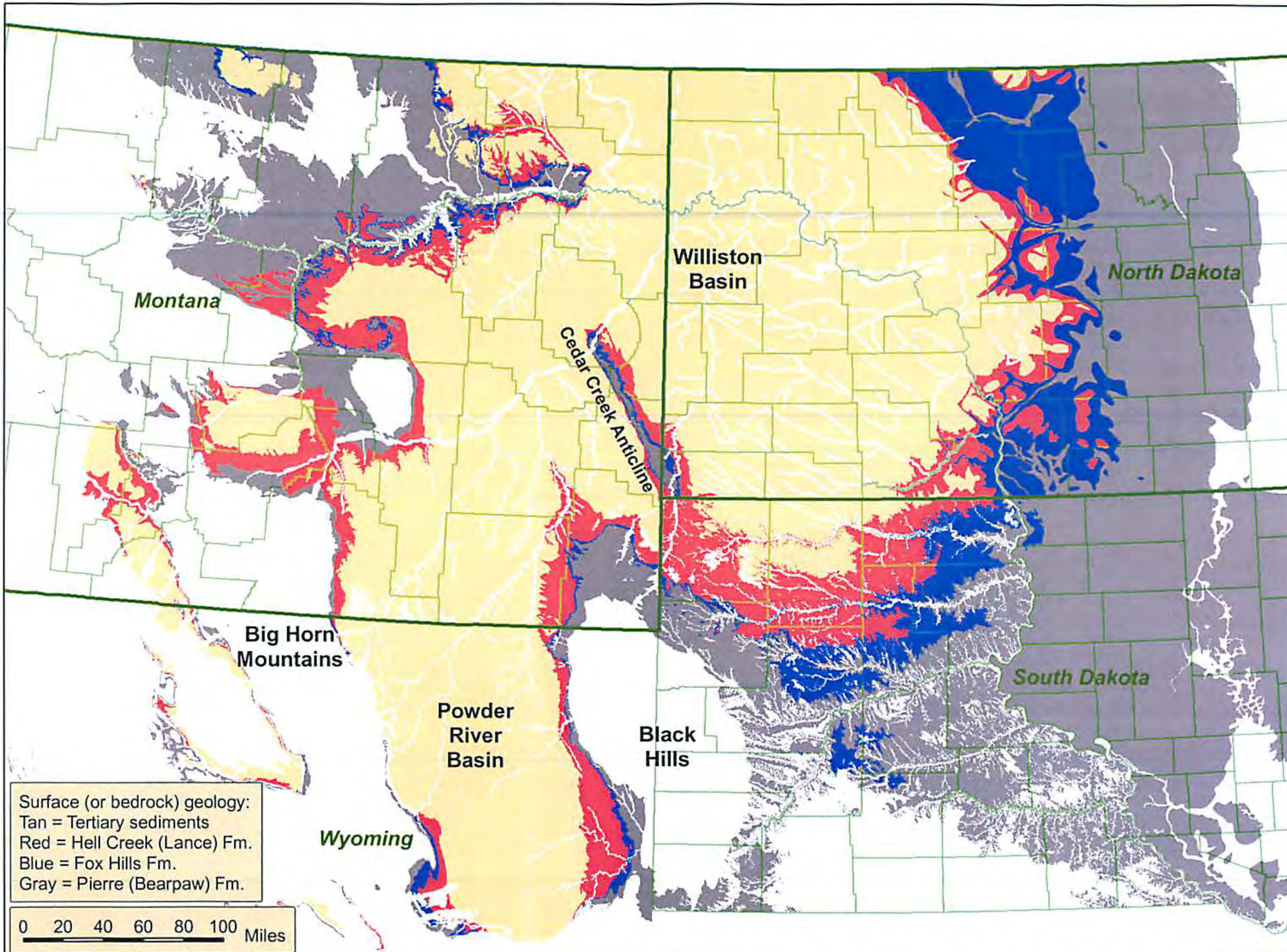


Figure 3. Aerial extent of the Fox Hills Formation (outcrop/subcrop area in blue) in the Williston and Powder River basins

Over time, deposition during flooding caused the area near a stream to become slightly higher than the surrounding landscape and when the stream cut through the bank it shifted laterally to a new, slightly lower-lying course. The depositional process then resumed with the same sediment types being deposited but shifted laterally across the landscape. The nature of the depositional process resulted in the lenticular, fine-grained and clayey sediments that make up the Hell Creek Formation and the Fort Union Group.

The lenticular sediments comprising the Hell Creek Formation and overlying Fort Union Group consist of varying proportions of clay, silt, and sand, the sand usually being fine or very fine grained, and beds of lignite. The sediments are occasionally cemented, but are more often not. A great extinction and different fossil assemblage separate the Cretaceous Hell Creek Formation from the overlying Tertiary Fort Union Group; however, sediment deposition in what is now western North Dakota was continuous, with similar lenticular sediments being deposited across the Cretaceous-Tertiary boundary.

Lenses of sand or lignite beds in the Fort Union Group and Hell Creek Formation sediments are sometimes capable of yielding the quantities of water sufficient for a farm or ranch well; however, they will seldom provide sufficient water for larger demands, as that of a municipality. The underlying beach/deltaic sand of the FH-HC aquifer is distinguished from overlying sediments not only in having less silt and clay, but also by extending hundreds of miles laterally as compared to the lenticular nature of the overlying sediments.

Depth:

The uplift of the Rocky Mountains and associated folding caused sediments, including those of the FH-HC aquifer, to be differentially uplifted. Sand of the FH-HC aquifer occurs at land surface in southwestern Bowman County, at about 2,600 feet above sea level, and at up to about 2,000 feet below land surface, or about 400 feet above sea level, in the central part of the Williston Basin (Fig. 4). Figure 4 is based on the completion intervals of 356 upland Fox Hills wells (R. Honeyman 2007). Figure 5 is adapted from a map of the elevation of the top of the Pierre Formation (C.G. Carlson

1982), which is also the bottom of the overlying Fox Hills Formation. The lower part of the Fox Hills Formation, underlying the FH-HC aquifer, is about 150 to 200 feet thick and grades finer and more clayey with depth to the clay/shale of the underlying Pierre Formation.

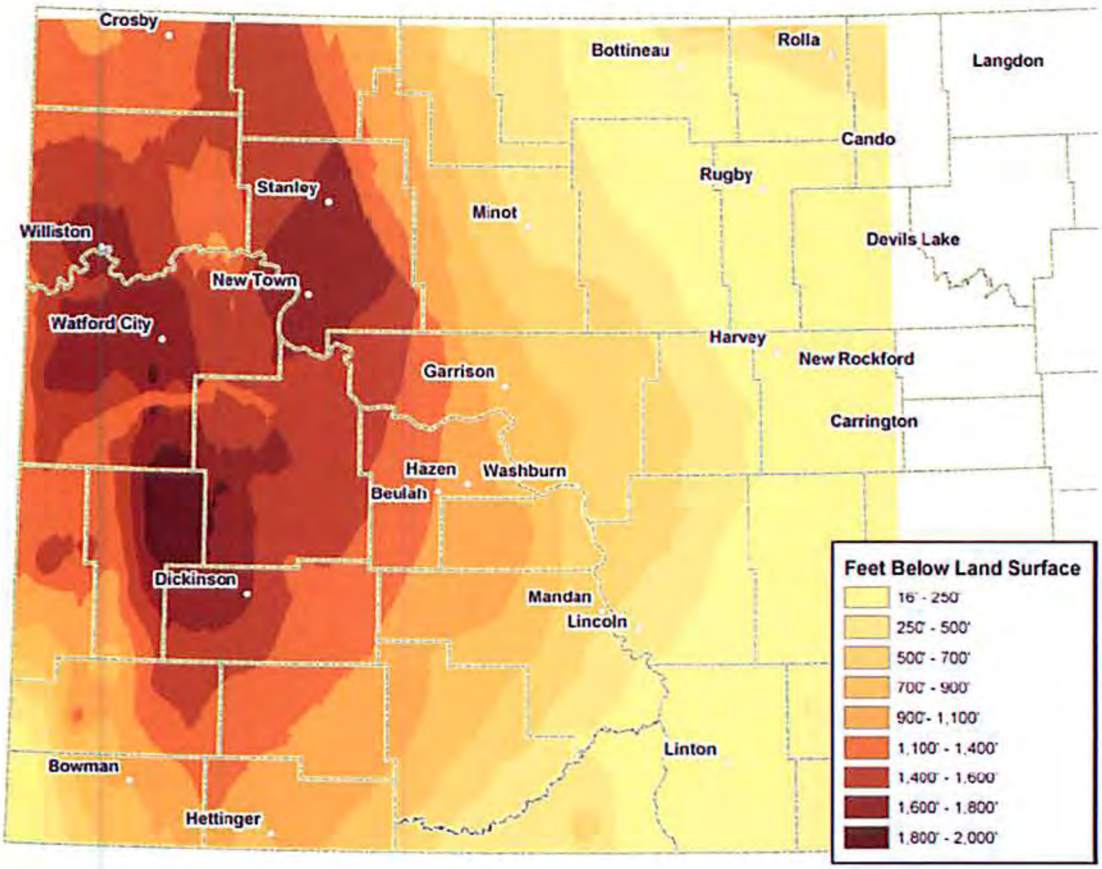


Figure 4. Approximate depth to the FH-HC aquifer

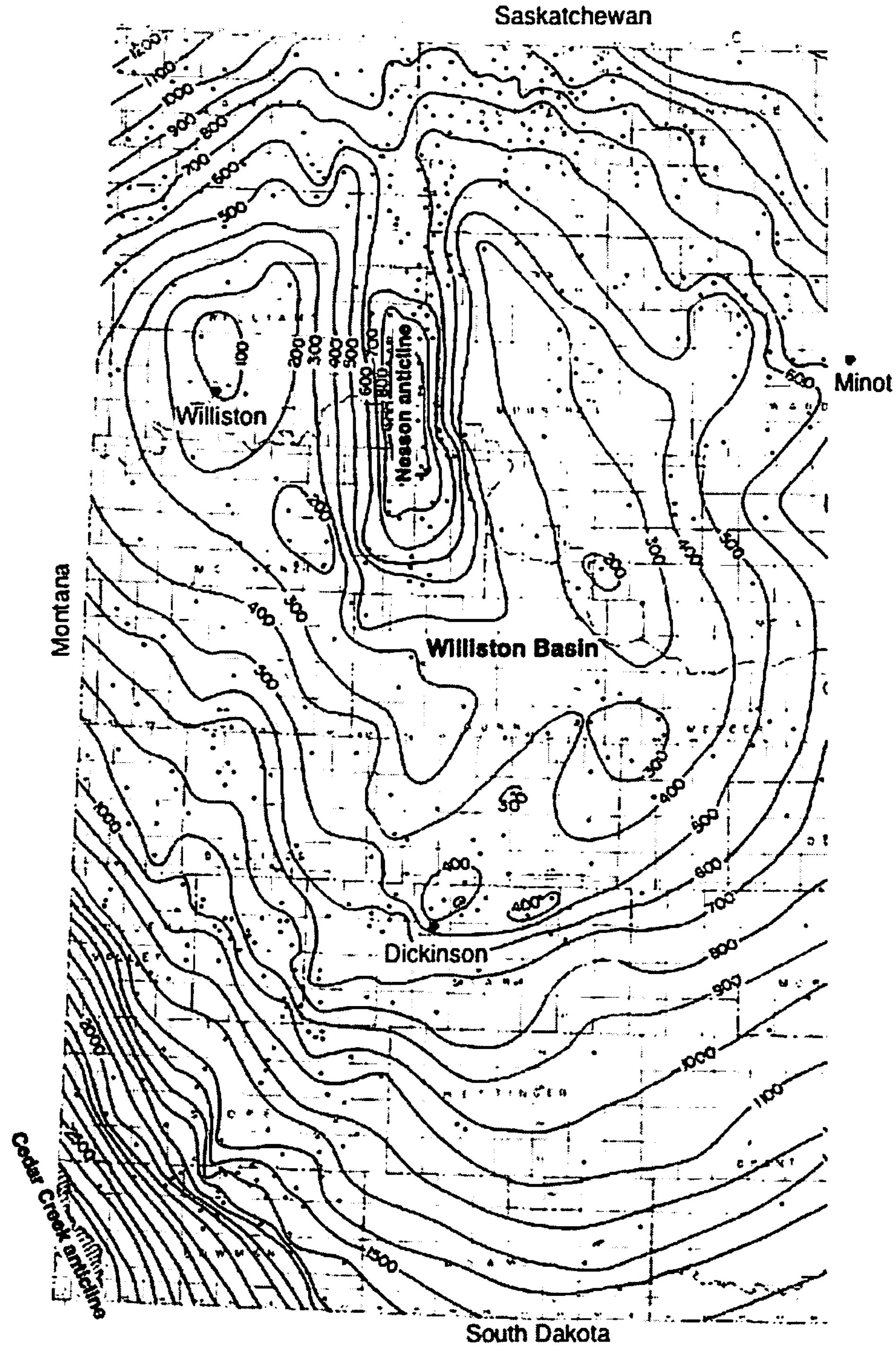


Figure 5. Elevation of the top of the Pierre Formation in feet above sea level

Hydraulic Properties:

Transmissivity is a measure of the ability of an aquifer to transmit water. By definition, it is the amount of water that moves through a unit vertical column of an aquifer under a unit (one-to-one) hydraulic gradient. The transmissivity of the FH-HC aquifer is about 300 feet squared per day, plus or minus about 200 ft2/day (Fig. 6). The transmissivity values in Figure 6 were adapted from maps included in four county groundwater studies, with adjustments made near the county boundaries. The transmissivity the FH-HC aquifer was determined from single well pumping and recovery tests and from interpretation of geophysical logs.

Hydraulic conductivity is a measure of an aquifer's ability to transit water through a unit area under a unit hydraulic gradient. By definition, it is transmissivity divided by aquifer thickness. There is commonly between 50 and 150 feet of sand in the FH-HC aquifer interval, with partings of finer and more clayey sediment. The hydraulic conductivity of the FH-HC aquifer is commonly between about one and five feet per day.

Specific storage and storativity: Specific storage of an aquifer is by definition the amount of water taken into or released from storage per unit volume of aquifer per unit change in hydraulic head. Storativity is the specific storage multiplied by the aquifer's thickness. The storativity of the FH-HC aquifer is less frequently determined, most of the testing of the aquifer being done on a single, pumped well. The depth at which the FH-HC aquifer commonly occurs makes it impractical to install monitoring wells around a pumped well, useful in determining storativity. In areas where the FH-HC aquifer is confined by overlying sediments, the storativity of the FH-HC aquifer has been estimated at about 0.0003 (3×10^{-4}), plus or minus 0.0001 (1×10^{-4}).

Specific capacity is a measure of well yield per unit drawdown after pumping for a specified period of time. Reported specific capacities of Fox Hills wells often are about one or two gallons per minute per foot of pressure head drawdown.

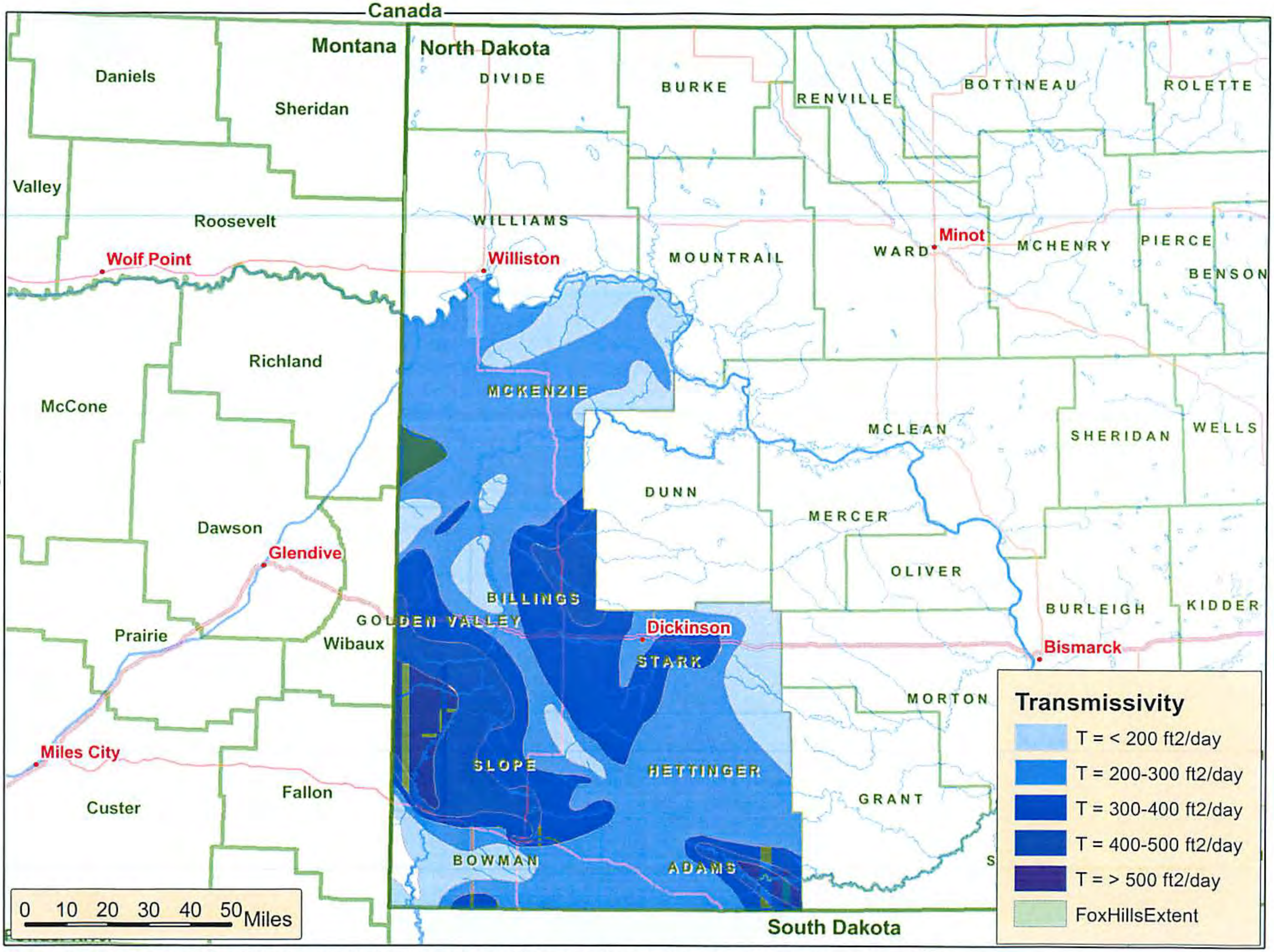


Figure 6. Transmissivity of the Fox Hills-Hell Creek aquifer, as estimated in county groud-water studies

Water quality:

Away from surface outcrop areas, water from the FH-HC aquifer is typically sodium bicarbonate type with total dissolved solid concentrations over 1,000 milligrams per liter (mg/l). Fox Hills water is soft, nearly all of the dissolved calcium and magnesium ions being replaced by sodium from clayey sediments. In western North Dakota Fox Hills waters, away from the outcrop area in Bowman County and southern Slope County, sodium typically comprises 98 or 99 percent of the cations.

In western North Dakota the concentration of dissolved solids in water from the FH-HC aquifer increases to the north-northeast, away from recharge areas. Dissolved sodium increases from about 400 mg/l in southwestern North Dakota to about 700 mg/l along the Missouri River to about 900 mg/l in northwestern North Dakota. Chloride concentrations, less than 100 mg/l in southwestern North Dakota, increase to about 200 mg/l along the Missouri River to about 800 mg/l in northwestern North Dakota.

The concentration of fluoride in Fox Hills waters is commonly near the primary drinking water standard of 4 mg/l. The concentration of fluoride in Fox Hills waters was a consideration in southwestern North Dakota communities switching to alternative water sources in or about the 1990's.

Analyses from 15 Fox Hills wells in western North Dakota, collected between 2005 and 2008, are represented in a Piper diagram, which shows the percentage of different dissolved ions present in the waters (Fig. 7). Samples from southern wells, nearer the outcrop area along the Cedar Creek anticline, are shown in lighter colors (yellow, red) on the diagram. Samples from northern wells, more distant from recharge areas, are shown in darker colors (blue, purple) in the Piper diagram. Sodium is the dominant cation. One shallow, southerly Fox Hills well has some dissolved sulfate. In deeper wells bicarbonate is the dominant anion, and sulfate concentrations are commonly less than one milligram per liter. Farther north, across the Missouri River the concentration of chloride increases.

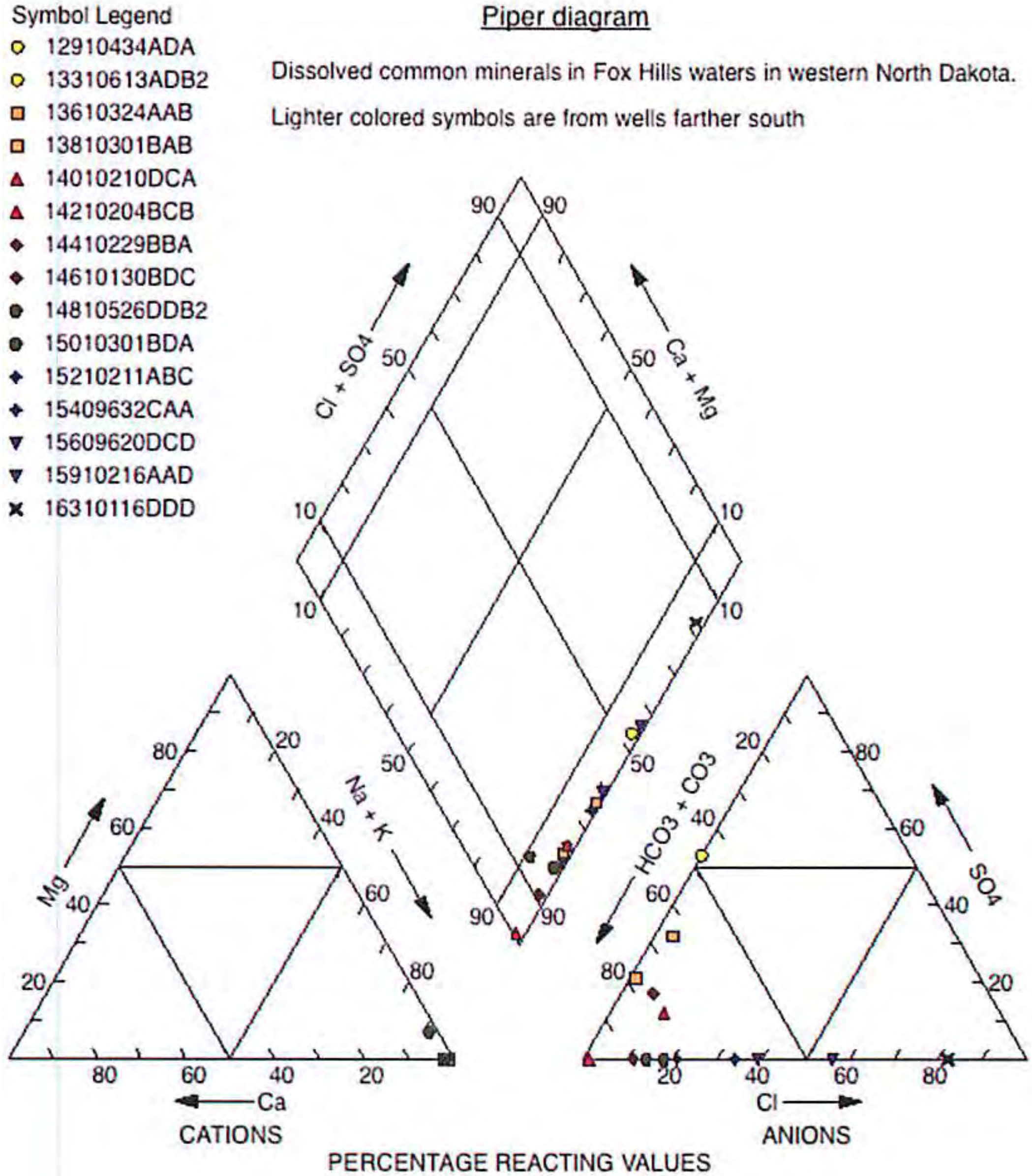


Figure 7. Piper diagram using water from 15 western ND Fox Hills wells

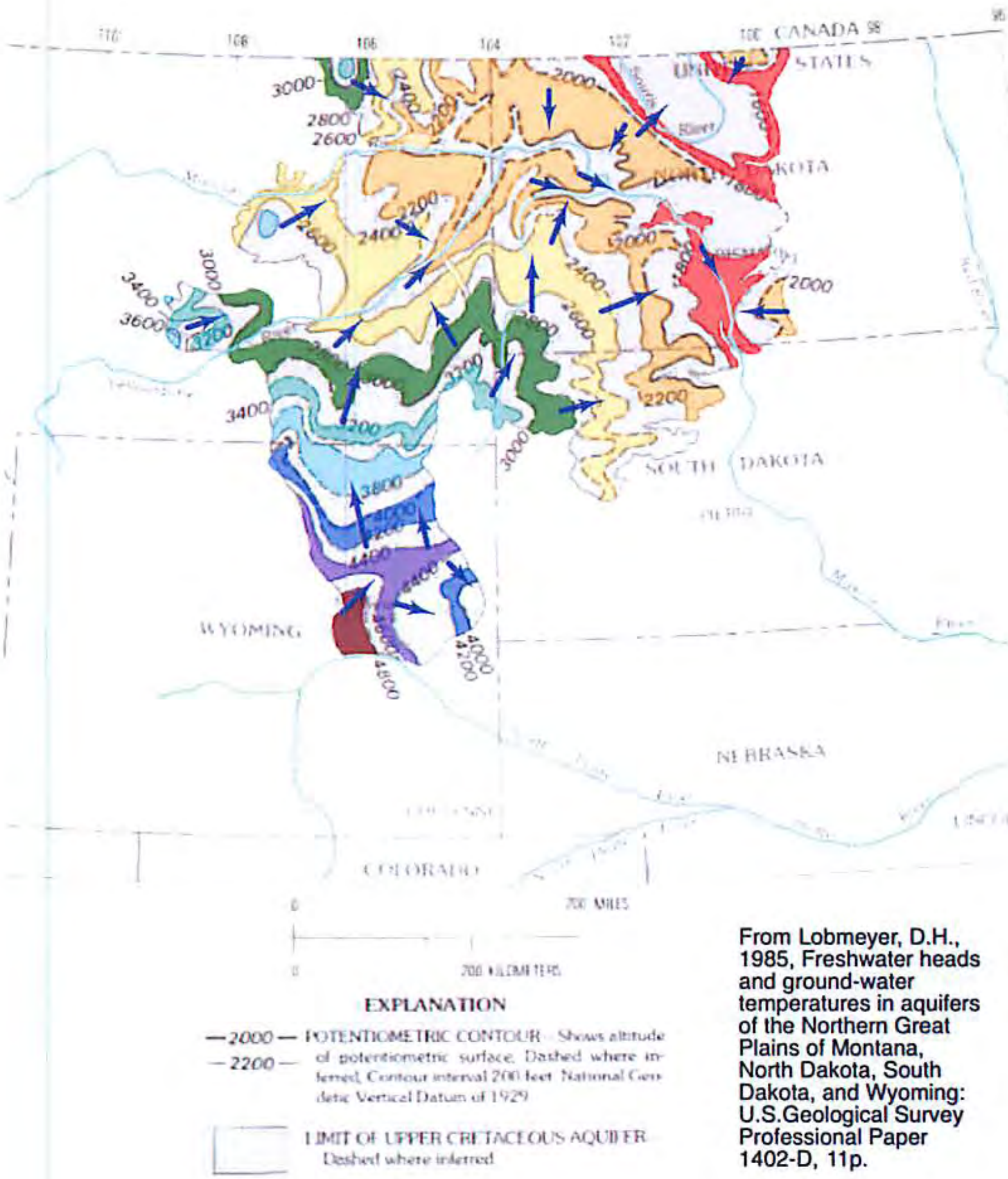
Water movement in the FH-HC aquifer:

The FH-HC aquifer is recharged by precipitation falling on upland areas to the south and west where the aquifer is at or near land surface. The FH-HC aquifer is at land surface along the margins of the Williston and Powder River basins (Fig. 3). Within the

Williston Basin, folding along the Cedar Creek anticline brings the FH-HC aquifer (and the upper Pierre Formation) to land surface along a 90-mile line from near Glendive, Montana to near the southwestern corner of Bowman County. Along the Cedar Creek anticline, recharge to the FH-HC aquifer occurs from infiltrating precipitation on upland areas, and discharge from the FH-HC aquifer occurs along the Yellowstone and Little Missouri Rivers.

Because of the hydraulic continuity of the FH-HC aquifer across the Williston Basin, recharge to the aquifer in topographically higher areas in Montana, Wyoming, western South Dakota, and southwestern North Dakota has, over long periods of time, given the aquifer an elevated pressure head in North Dakota. The water levels in wells completed in aquifers confined by overlying, less permeable sediments, are commonly above the top of the aquifer, water being slightly compressible. Confined water levels above the top of an aquifer are called pressure heads. The surface formed by an aquifer's pressure head is its potentiometric surface, similar to an unconfined aquifer's water table. Groundwater moves from areas of high pressure to low pressure. In the FH-HC aquifer water moves from east-central Wyoming north and northeast to the Missouri River valley, as shown in Figure 8, adapted from a regional map of the aquifer by D.H. Lobmeyer, 1985.

A map showing the potentiometric surface of the FH-HC aquifer in North Dakota was prepared from measurements made in 94 monitoring wells (Fig. 9), plus 4 wells in Montana. While giving some regional perspective, not enough pressure head data from Montana are included to accurately portray the potentiometric surface in that state. Hydrographs of pressure head measurements in each well over time were prepared and the pressure head was extrapolated to January 1, 2009 for use in Figure 9. The direction of water movement in the FH-HC aquifer is to the north and east. In the eastern part of North Dakota, where the FH-HC aquifer subcrops (forms the bedrock surface under glacial sediments), the direction of water movement is to the Missouri River or Souris River.



From Lobmeyer, D.H., 1985, Freshwater heads and ground-water temperatures in aquifers of the Northern Great Plains of Montana, North Dakota, South Dakota, and Wyoming: U.S.Geological Survey Professional Paper 1402-D, 11p.

Figure 8. Regional potentiometric surface of the FH-HC aquifer

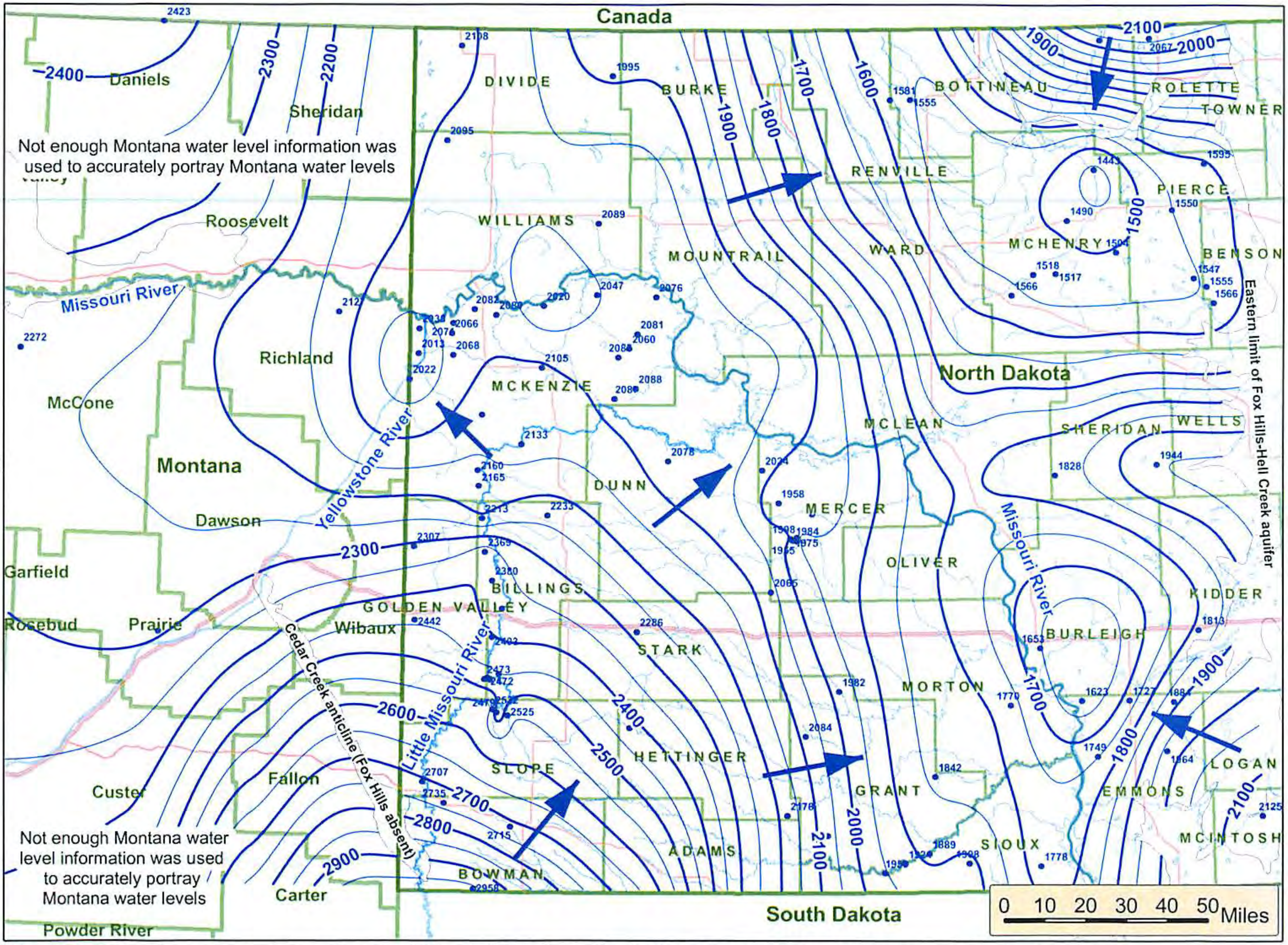


Figure 9. Potentiometric surface of the Fox Hills-Hell Creek aquifer in feet above sea level (as projected to Jan 1, 2009)

The pressure head of the FH-HC aquifer is in places about 200 feet higher than the pressure head of overlying sediments in the lower part of the Fort Union Group. In low-lying areas along the Little Missouri, Yellowstone, and Missouri Rivers and their immediate tributaries in western North Dakota, the FH-HC aquifer has a pressure head above land surface, reaching up to about 200 feet above land surface in the lower part of the Yellowstone Valley.

Discharge from the FH-HC aquifer occurs naturally by northern and eastern outflow and to upward leakage to overlying sediments. The natural quasi-equilibrium of the FH-HC pressure head is being changed by discharge to wells tapping the aquifer, causing a decline in the aquifer pressure head.

Wells completed in the Fox Hills-Hell Creek aquifer:

An inventory of Fox Hills wells was made to evaluate the water permit applications for which the expected source is the FH-HC aquifer (Fig. 10). Fox Hills well information was compiled from available sources in 16 counties in western North Dakota that are shown within a light yellow line in Figure 10. Given time, Adams, Grant, Morton, Burleigh, Sheridan, Ward, and Renville counties, could be inventoried for Fox Hills wells. Outside of that area, more or less, the FH-HC aquifer occurs within a few hundred feet of land surface and is the near-surface ground-water source in which many wells are completed.

Most of the inventoried Fox Hills wells were installed in the 1960's, 1970's, and 1980's. About 70% of the inventoried flowing-head Fox Hills and Hell Creek wells were installed between 1960 and 1990. The flowing-head wells were commonly installed using casing two inches or less in diameter. The annular space outside the well casing was typically not filled with cement over its entire length.

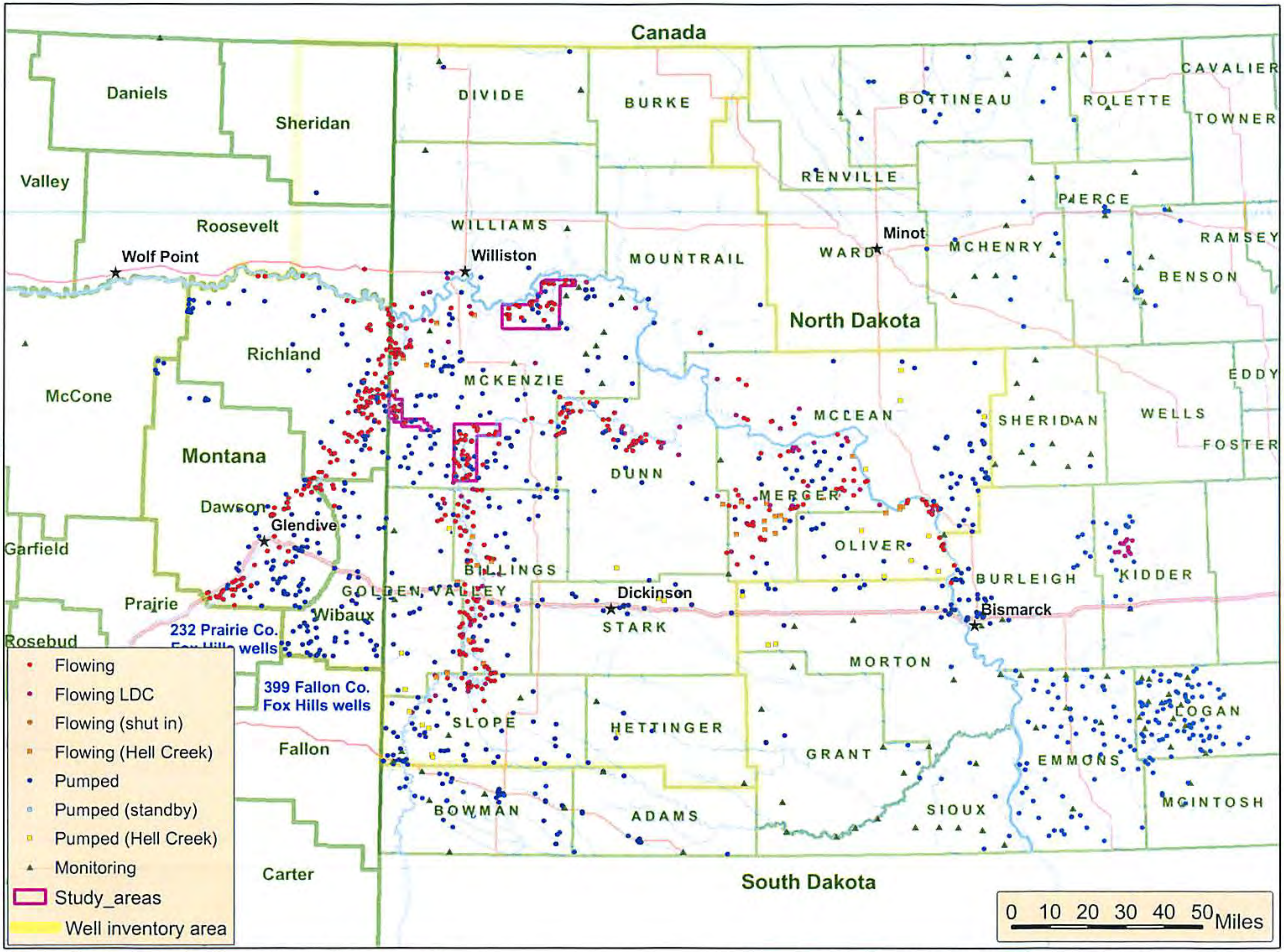


Figure 10. Location of Fox Hills-Hell Creek wells

LDC = Large diameter casing (capable of being pumped)

Well driller's reports of completed wells and test holes have been required by the North Dakota Board of Water Well Contractors since 1972. Well driller's reports were reviewed for Fox Hills wells in the 16 counties. Well depth, land surface elevation at the well site, and the expected elevation of the FH-HC aquifer were compared to information in the well driller's reports to determine which wells are thought to be completed in the FH-HC aquifer. Other sources of information reviewed for existing Fox Hills wells include county ground-water studies, the State Water Commission's well and water permit databases, registered wells, and information supplied by the US Forest Service. The locations of wells as indicated on well driller's reports have not been field-checked for accuracy and may be in error. Particularly in areas where roads and trails diverge from section lines, the indicated well locations on well driller's reports are approximate.

The Montana Bureau of Mines and Geology and the University of Montana maintain a Ground-Water Information Center (GWIC) web site on which private well information is available for wells completed in Montana. Included on Figure 9 are the GWIC's locations of Fox Hills wells in three Montana counties west of McKenzie and Golden Valley counties in North Dakota. Wells categorized on the GWIC web site as being completed in the 'Fox Hills-Hell Creek aquifer', the 'Fox Hills Formation or Sandstone', and the 'Colgate Sandstone Member of the Fox Hills Formation' was considered completed in the FH-HC aquifer.

Information about the 1,579 wells in Figure 9 is included in Appendix 1 at the back of this recommendation memo. The well locations are color-coded in Figure 9 with flowing pressure head wells shown in red and pumped wells in blue. Unused flowing-head wells are designated as 'shut-in' and unused non-flowing wells are designated as 'standby.' Some Hell Creek wells are included if it is not certain whether the completion zone is hydraulically separated from the FH-HC aquifer. The number of wells in each category is listed in Tables 2a and 2b. Water level/pressure head information is available for about half the Montana Fox Hills wells. For designating the remaining Montana Fox Hills wells as either 'flowing' or 'pumped,' land surface elevation was compared to the estimated pressure head of the FH-HC aquifer.

Table 2a. Fox Hills Wells by type, primarily from sixteen North Dakota and three Montana counties

Well type	North Dakota	Montana	Total
Flowing	281	149	430
Flowing LDC	89	0	89
Flowing shut in	15	4	19
Pumped	634	183	817
Pumped standby	53	3	56
Flowing Hell Creek	31	0	31
Pumped Hell Creek	24	0	24
Monitoring	110	3	113
Total	1,237	342	1,579

'LDC' stands for 'large diameter casing,' capable of holding a submersible pump (not specified for the Montana wells).
22 of the 110 North Dakota monitoring wells have been plugged.
The 56 wells listed as 'Hell Creek' may be part of the FH-HC aquifer, but more likely have some hydraulic separation from the underlying aquifer.

Table 2b. Fox Hills wells (as listed above in Table 2a) in use:

Well type	North Dakota	Montana	Total
Flowing	281	149	430
Flowing LDC	89	0	89
Pumped	634	183	817
Total	1,004	332	1,336

'LDC' in the tables and figures refers to wells that have 4-inch or larger diameter casing, large enough for installing a submersible pump. About ¾ of the North Dakota flowing-head Fox Hills wells listed in Table 2 have 1.25 or 2-inch diameter casing, too small for installing a submersible pump. Over 1/3 (37%) of the 1,004 in-use North Dakota Fox Hills wells listed in Table 2b have flowing heads (or had flowing heads when the well was installed). Part of the value of flowing-head wells is they can be installed in remote pastures without the need to bring electrical power to the location. As listed in Table 3, stock wells make up 61% of the North Dakota flowing-head wells, but only 35% of the pumped wells. A more detailed breakdown of the type of wells is included in Table 3. The number of inventoried Fox Hills wells in each county is listed in Table 4.

Table 3. Use of the listed Fox Hills wells

Well type	ND wells	MT wells	Total
Flowing domestic/stock	47	2	49
Flowing domestic/stock LDC	13	-	13
Flowing domestic	38	74	112
Flowing domestic LDC	20	-	20
Flowing stock	194	60	254
Flowing stock LDC	42	-	42
Flowing municipal LDC	8	1	9
Flowing rural water LDC	3	-	3
Flowing industrial	2	6	8
Flowing industrial LDC	3	-	3
Flowing shut-in	12	4	16
Flowing shut-in LDC	3	-	3
Flowing unknown	-	6	6
Flowing Hell Creek	31	-	31
Pumped Hell Creek	24	-	24
Pumped domestic/stock	64	0	64
Pumped domestic	264	69	333
Pumped stock (+1 'wildlife' well)	239	87	326
Pumped municipal	30	3	33
Pumped rural water	1	0	1
Pumped industrial	35	16	51
Pumped standby	53	3	56
Pumped unknown	-	7	7
Pumped irrigation*	1	1	2
Monitoring	88	3	91
Monitoring – plugged	22	0	22
Total	1,237	342	1,579

* The Fox Hills irrigation wells, one in Montana and one in North Dakota, are near areas where the Fox Hills Formation outcrops and are for use at a golf course and/or an athletic field not requiring a high pumping rate.

Table 4. 1,579 identified Fox Hills (and a few Hell Creek) wells, by county

County	Wells	County	Wells
Adams	15	Morton	30
Benson	12	Mountrail *	5
Billings *	113	Oliver *	38
Bottineau	20	Pierce	14
Bowman	42	Renville	2
Burke *	0	Rolette	4
Burleigh	43	Sheridan	12
Divide *	4	Sioux	14
Dunn *	68	Slope *	80
Emmons	77	Stark *	22
Golden Valley *	48	Williams *	13
Grant	13	Custer, MT	1
Hettinger *	7	Daniels, MT	1
Kidder	30	Dawson, MT *	171
Logan	91	McCone MT	1
McHenry	14	Prairie, MT	1
McIntosh	11	Richland, MT *	90
McKenzie *	236	E. Roosevelt MT	1
McLean *	62	E. Sheridan MT	1
Mercer *	98	Wibaux, MT *	74

* = Counties in which well driller's reports (or the Montana's GWIC web site) were reviewed for Fox Hills wells

The requirement that water well contractors in North Dakota file reports of wells installed began in 1972. Information from older wells, unless available from other sources, is not part of the Water Commission's data set of known wells. To get a better idea of how many Fox Hills wells there are in flowing-head areas, as compared to the number of wells for which information is available, three flowing-head well areas in McKenzie County were selected for field checking in 2008 (Fig. 11). The areas selected to check were 1) north and north-northeast of Watford City, along lower Tobacco Garden Creek valley and the nearby Missouri River valley breaks, 2) southeast of Sidney, MT, along Bennie-Peer Creek, and 3) southwest of the north unit of Theodore Roosevelt National Park, along the Little Missouri River valley (Table 5).

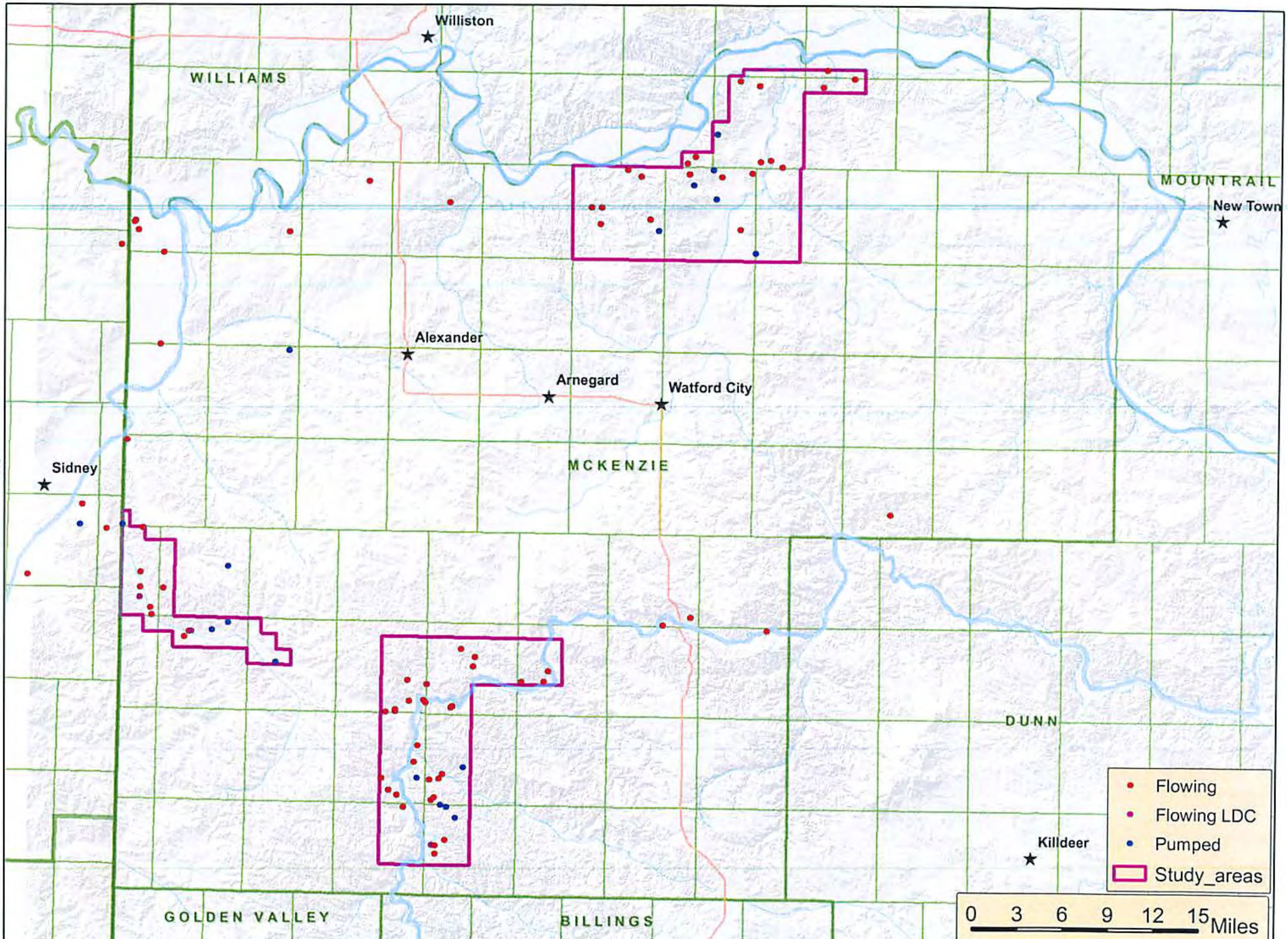


Figure 11. Locations of Fox Hills wells visited in 2008

LDC = Large diameter casing (capable of being pumped)

Table 5. Three areas visited in 2008 to check for Fox Hills wells
(Not all of the wells listed in the table were visited)

	North of Watford City - Missouri & Tobacco Garden	Bennie-Peer Creek near Sidney	Little Missouri west of TR Park	Total
Area (sq. mi.)	122	38	108	268
Known wells	20	18	23	61
'Found' wells	11	2	20	33
% more wells (total-known) -1	65%	11%	87%	54%
Unused wells (included in known & found, above)	0	6	3	9 (10%)
% more wells used (total-unused)/known	65%	-22%	74%	39%

In the three areas, owners or renters having flowing head wells were contacted and arrangements were made to visit their Fox Hills wells. The wells were photographed and their locations were determined using a handheld Global Positioning System (GPS) receiver. If flowing, the flow rates from the wells were measured or estimated. If practical, water samples were collected for chemical analysis. The owners or renters were questioned about other Fox Hills wells in the area.

In the three areas visited in 2008, in addition to the 61 known Fox Hills wells, another 33 Fox Hills wells were found, 54% more wells than were previously known. Nine of the 94 Fox Hills wells in the visited areas were not being used, leaving 85 wells in use, which is 39% more wells than the 61 wells that were previously known in the three areas. In all likelihood, the 2008 field investigation did not find every existing Fox Hills well in the field-checked areas. Another six 'undiscovered' Fox Hills wells in use in the three areas visited would make 50% more Fox Hills in use in the areas than were previously known.

The purpose of the 2008 field work in flowing-head areas was to get a better understanding, or estimation, of about how many Fox Hills wells are in use, as compared to the number of known wells from well driller's reports and other sources. Based on the

2008 field work, probably over half and perhaps about 2/3 of the Fox Hills wells in the central Williston Basin have been identified in well driller's reports, county studies, etc. The hydrogeologist performing the 2008 well inventory reported that the well owners were very aware of the declining pressure head in their wells and for the most part had their wells valved back to that needed for their use.

Ninety-three Fox Hills wells were visited in McKenzie County in 2008, including 78 of the 94 wells in the three areas discussed above and 15 wells from other parts of the county. Additionally, five Fox Hills wells in Montana were visited, for comparison. Of the 93 North Dakota Fox Hills wells visited, 76 had flowing heads and 17 were pumped. Four of the 76 flowing-head wells had 4-inch or more diameter casing in their upper portion, capable of holding a submersible pump. Six of the 76 flowing-head wells visited in 2008 in McKenzie County appeared to be leaking water around the well casing.

Ongoing water flow rates were measured or estimated in 40 of the 76 flowing-head wells visited in McKenzie County in 2008 (Table 6). The remaining 36 wells were either plumbed to a household, controlled by a float valve in a tank, shut-in, or otherwise not measured. The average flow rate of the 40 measured flowing wells was 1.9 gpm. Twenty of the 40 measured wells had flow rates less than 1.5 gpm.

Table 6. Measured or estimated flow rates in 40 Fox Hills wells in McKenzie County

Flow rate	Number of wells
Less than 1 gpm	10
About 1 gpm	8
1-2 gpm	3
About 2 gpm	5
2-3 gpm	7
3-4 gpm	2
4-5 gpm	3
5-6 gpm	1
About 6 gpm	1

For a quick comparison of Montana and North Dakota flowing-head wells, one stock well and four domestic wells were visited in Montana. Four of the Montana wells visited were in the Sidney area, three of those in the Yellowstone River valley and one in the Bennie-Peer Creek valley. The remaining Montana well is farther north, in the vicinity of the confluence of the Yellowstone and Missouri Rivers. The stock well was flowing at about one gpm. The four domestic wells consisted of three flowing and one pumped well. The three domestic flowing wells were plumbed into houses. One of the domestic wells also supplied two stock tanks. From a very limited sampling, the Fox Hills wells in Montana were being maintained in a similar manner to those in North Dakota.

In addressing water permit applications where the FH-HC aquifer is the expected source, the effect of the proposed development on flowing-head wells is a primary issue. Additional water withdrawals from the FH-HC aquifer will increase the rate of aquifer pressure head decline, causing flowing wells to stop flowing sooner than they would otherwise. The locations of 526 flowing-head Fox Hills wells and 31 flowing-head Hell Creek wells are shown in Figure 12. An additional 12 shallow, large diameter casing flowing-head Fox Hills wells are located east of the area shown on the map, 17 miles north of Steele, in Kidder County.

The flowing-head Fox Hills wells indicated in Figure 12 consist of 153 wells in Montana, mostly in or near the Yellowstone River valley and 373 wells in North Dakota (296 with small diameter casing and 77 with large diameter casing), mostly along or near the valleys of the Little Missouri, Yellowstone, Missouri, and Knife rivers. Based on the 2008 fieldwork, there may be about half again as many flowing-head Fox Hills wells (in North Dakota) as are shown in Figure 12 (with the exception of the visited areas in McKenzie County where a higher percentage of the Fox Hills wells have now been identified). Some of the Fox Hills wells that originally had a flowing head (and are listed in this memo as flowing-head wells) will have stopped flowing because of the declining pressure head of the aquifer.

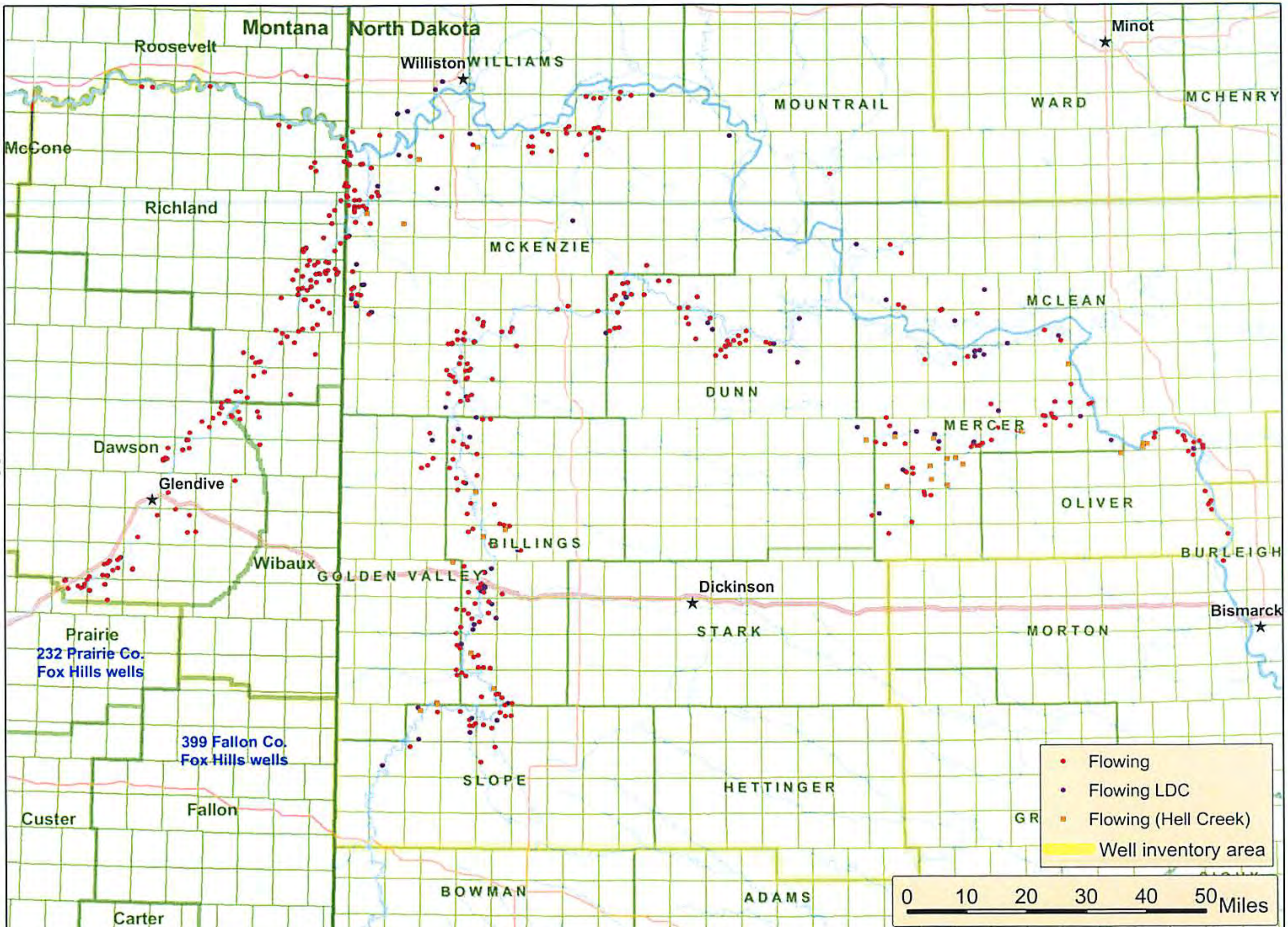


Figure 12. Locations of flowing-head Fox Hills-Hell Creek wells LDC = Large diameter casing (capable of being pumped)

Water Use From The Fox Hills-Hell Creek Aquifer:

Probably the earliest use of water from the FH-HC aquifer in North Dakota was from shallow wells around the perimeter of the Williston Basin and along the Cedar Creek anticline where folding has brought the aquifer to land surface (Fig. 3). In or about the 1930's, communities in southwestern North Dakota began switching from surficial or shallow water sources to FH-HC aquifer for municipal water supplies. In or about the 1990's, most of those communities converted back to surface water (Lake Sakakawea via Southwest Pipeline) for their municipal supply, in part because in 1985 the primary drinking water standard for dissolved fluoride was set at 4 mg/l, which is about the naturally occurring concentration of fluoride in western North Dakota Fox Hills waters.

Most rural domestic and stock wells in western North Dakota are completed in Fort Union Group sediments occurring within a few hundred feet of land surface, in a relatively sandy interval or a fractured lignite bed, capable of producing at least a few gallons of water per minute. However, in low-lying areas where the FH-HC aquifer has a flowing pressure head, ranchers have installed wells in the FH-HC aquifer, the extra cost of the deeper well being offset by not needing to pay for installing electrical power lines to remote pasture locations. The average depth of 299 flowing-head Fox Hills wells in western North Dakota, for which the well depth or completion interval was known, is 1,111 feet. Not requiring a pump, ranchers often reduce the cost of flowing-head Fox Hills wells by having 1.25 or 2 inch diameter casing installed instead of larger casing capable of holding a submersible pump.

In North Dakota, 110 water permits have been identified at 98 locations for which the ground water source is the FH-HC aquifer (Fig. 13). At 12 of the 98 locations a second permit for additional water was granted at a later date. In Figure 13, one location is shown representing a community's municipal Fox Hills water source, even though cities usually have more than one well, sometimes a mile or more apart.

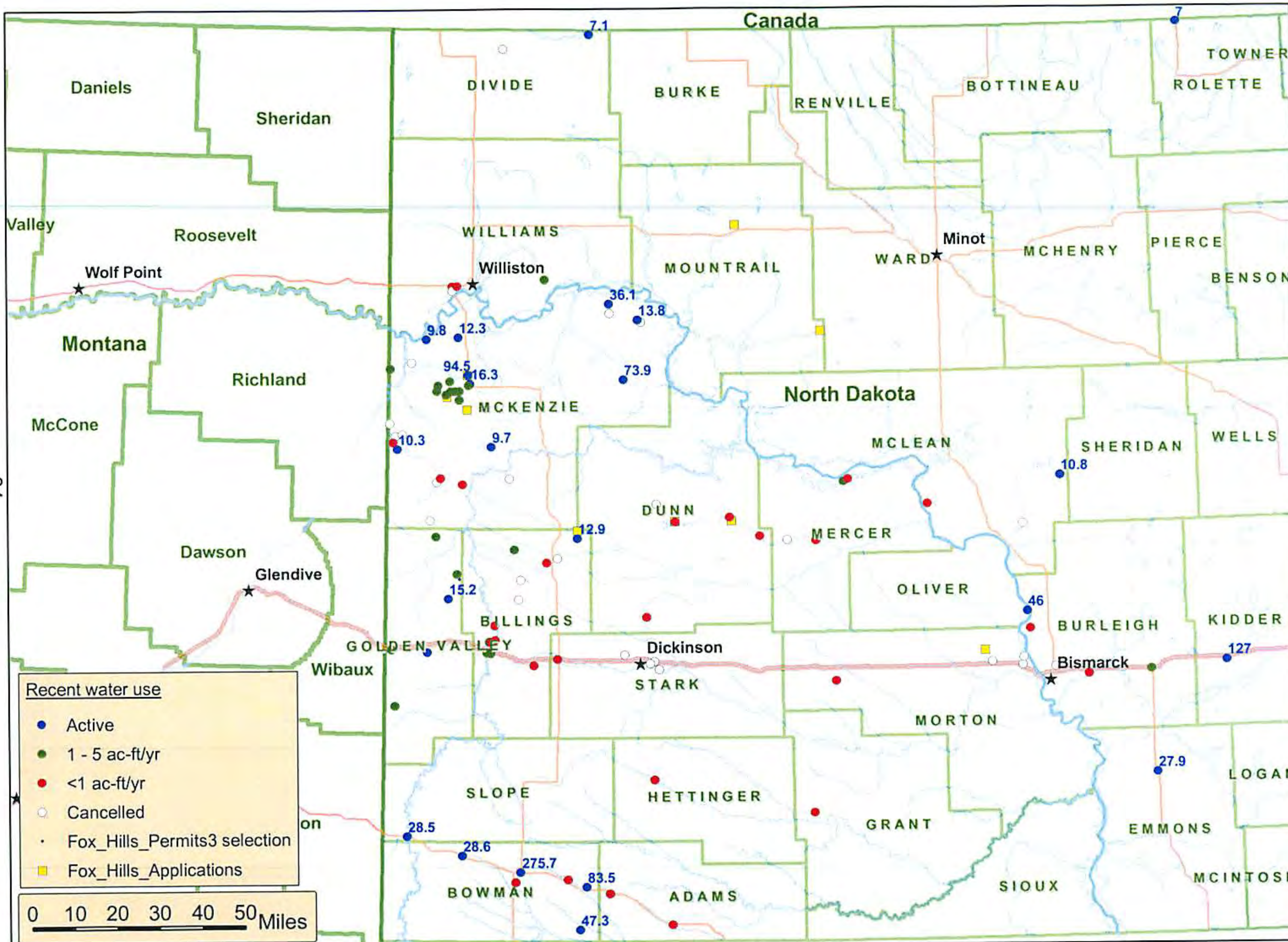


Figure 13. Locations of water permits and applications from the FH-HC aquifer Blue number is average annual reported acre-feet of use 2006-2008

A listing of the 110 water permits accessing the FH-HC aquifer is included as Appendix 2 at the end of the memo. Thirty-four of the 110 'Fox Hills permits' have been cancelled. Less than one acre-foot of water has been reported recent years for 31 of the remaining 76 Fox Hills permits, including 17 permits reporting no water use in the past five years. Between one and five acre-feet of water, on average, have been reported in recent years for 21 of the permits (including eight Zenergy permits from which between one and five acre-foot per year of water use is expected). More than five acre-feet of water per year, on average, have been reported in recent years under the remaining 24 water permits accessing the FH-HC aquifer. For those 24 water permits with more than five acre-feet of annual use recently, the average annual use reported during the past three years is shown in blue numbers on Figure 13.

In southwestern North Dakota, three cities, Bowman, Rhame, and Marmarth, continue use Fox Hills water for their municipal water supply. Two feedlots in eastern Bowman County use Fox Hills water for livestock watering, as does a feedlot north of Bismarck. The cities of Steele and Hazelton, located east and southeast of Bismarck where the Fox Hills occurs near land surface, use Fox Hills water for their municipal supplies. In western North Dakota, particularly McKenzie County, the oil industry uses Fox Hills water for brine dilution in oil wells.

The annual reported water use in North Dakota from the FH-HC aquifer generally increased between 1976 and 1990, reaching a maximum annual reported use of 2,267 acre-feet in 1990 (Fig. 14). Since 1990, Fox Hills water use has generally been declining, primarily due to communities switching to alternative sources for their municipal supply. Permitted water use information prior to about 1976 is incomplete.

Fox Hills water use in McKenzie County:

The percentage of permitted Fox Hills water use in North Dakota that is taking place in McKenzie County has increased from 18% of reported use during 1987-2004 to 27% of reported use during 2005-2008, as southwestern North Dakota communities have switched to alternative water sources for their municipal supplies and McKenzie County industrial use has increased. Reported Fox Hills use in McKenzie County is about 4/5 industrial and 1/5 municipal (Fig. 15).

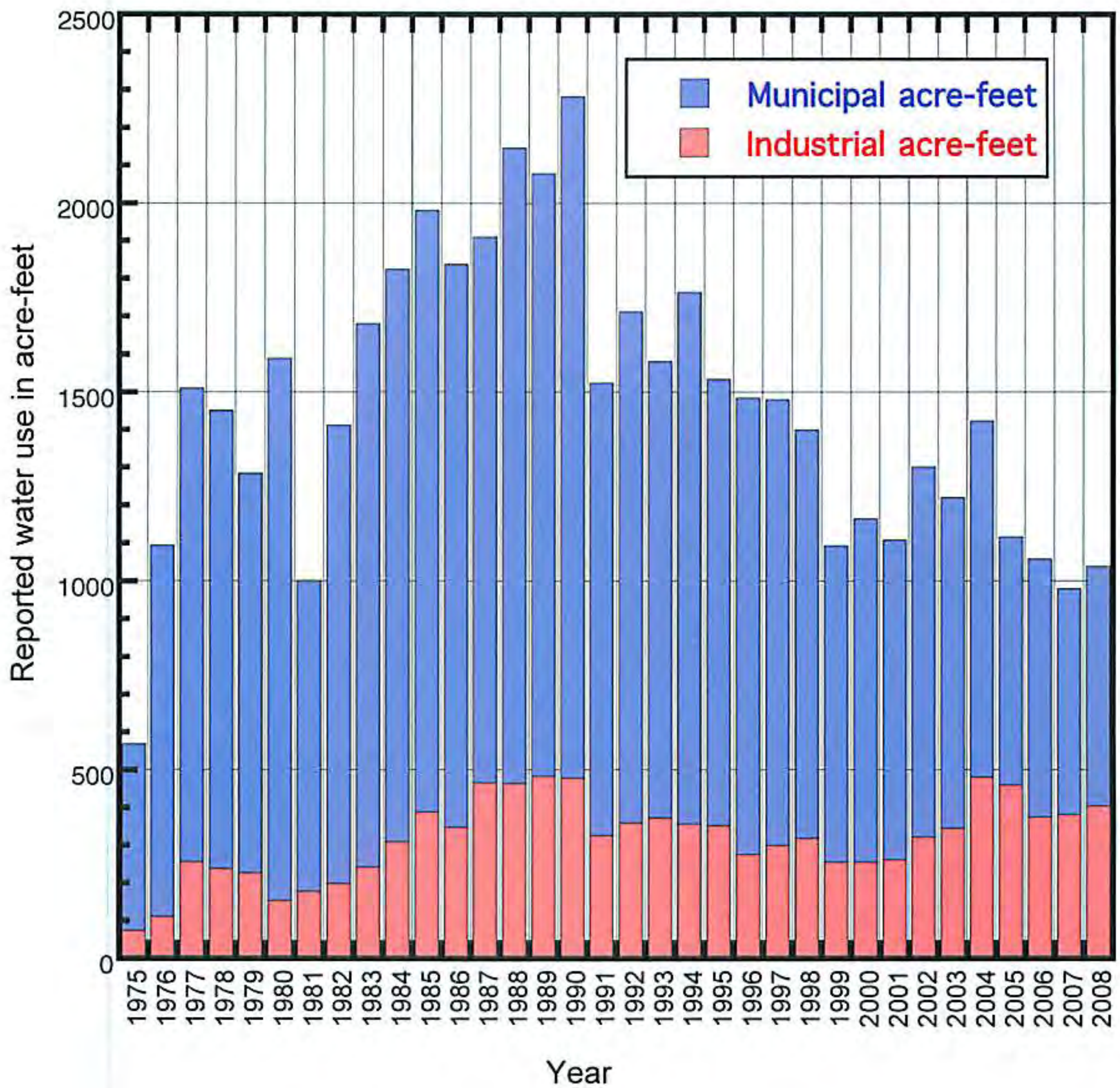


Figure 14. Annual reported water use from the Fox Hills-Hell Creek aquifer

Permitted Fox Hills water use reported in McKenzie County has averaged 275 acre-feet annually over the past 25 years, 254 acre-feet annually over the past 10 years, and was 283 acre-feet in 2008. The 2008 fieldwork and well inventory in McKenzie County was used to develop a general sense, or estimation, of how the magnitude of ongoing permitted (municipal and industrial) Fox Hills water use compares with Fox Hills water use (domestic and stock) that does not require a permit.

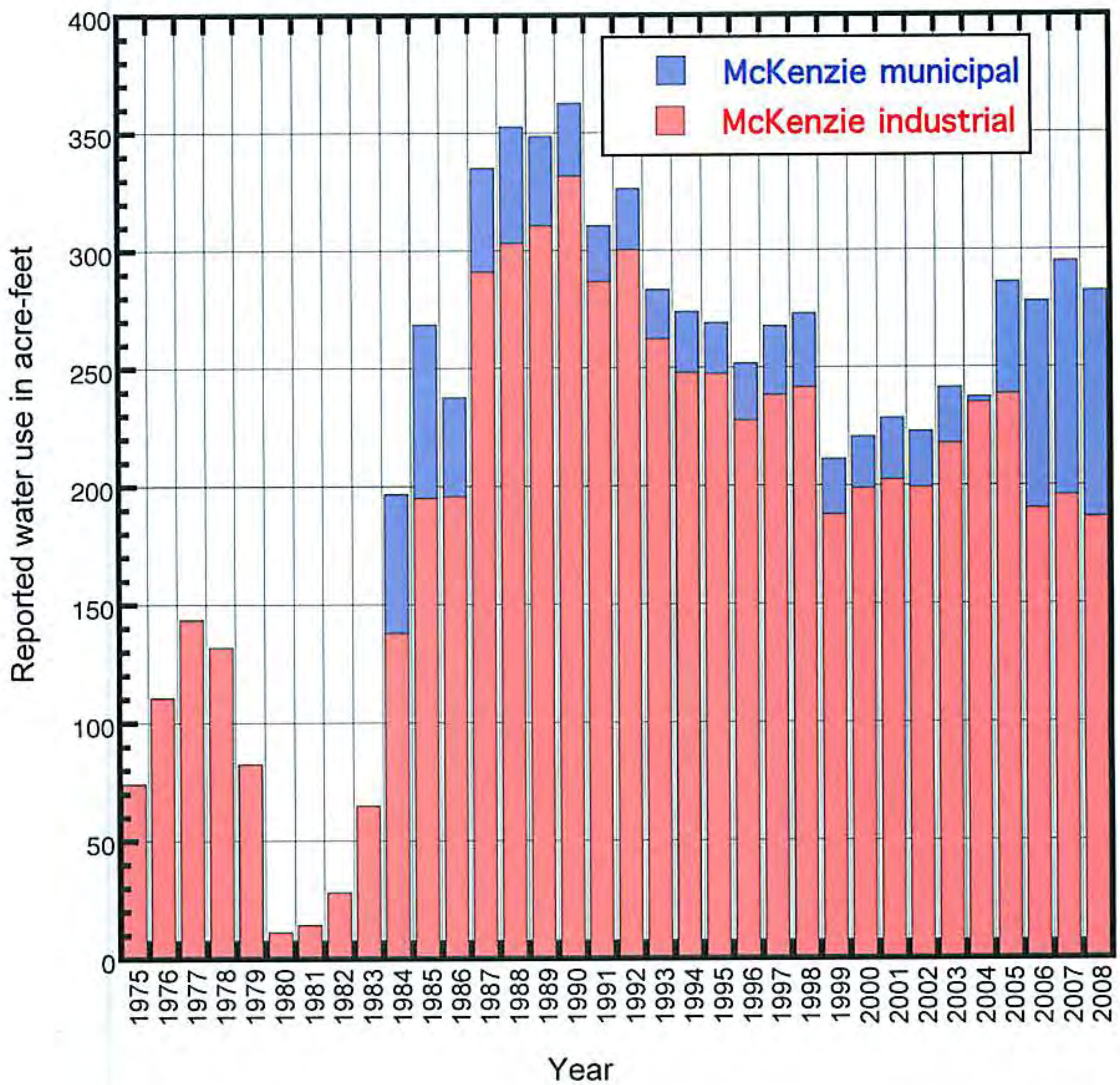


Figure 15. Annual reported McKenzie County water use from the FH-HC aquifer

Between June and October 2008, 187 domestic, stock, or combined domestic-stock Fox Hills wells were inventoried in McKenzie County, 111 wells with flowing heads and 76 that are pumped. Reviewing the 2008 site visit information, I estimated there might be about half again as many Fox Hills wells in use as wells we have records of. However, having now done the work in McKenzie County and added the previously unrecorded wells in three study areas to our database, for estimating the number of Fox Hills wells in McKenzie County I adjusted that 'multiplier' from 1.5 to 1.25 because we now know about more of the wells in use in the county. About two-thirds of the flowing-head wells (47 of 71 or 66%) are flowing, that is, the excess water is being discharged to land surface rather than being contained (by using a float valve in a tank, for instance). Flow rates were measured or estimated for 40 of the 47 flowing wells and the rate averaged 1.9 gallons per minute. The quantity of water flowing from the Fox Hills wells in McKenzie County was therefore estimated as (111 wells) (1.25 multiplier) (47/71 discharging wells) (1.9 gpm flow rate) (1.61 ac-ft/yr per 1 gpm) = 281 acre-feet per year.

Estimates of the water used from the pumped wells and the flowing wells controlled by float valves or plumbed into households rather than allowed to discharge to surface were made for McKenzie County. An average use of 90 gallons per day per person and 3 people per domestic well was assumed. An average of 50 head of livestock per stock well drinking 8 gallons per day for three months of the year was made for the stock wells. Both stock and domestic use estimates were applied to wells described as being for both domestic and stock use. An estimated 30 acre-feet of Fox Hills water per year is used by the pumped and contained or float-valved flowing-head wells, slightly more than 1/10 the quantity of water estimated from the surface discharging (flowing) wells. Even if the estimation of the quantity of water typically used from pumped stock or domestic wells is somewhat inaccurate, the exercise suggests that most (90% in the estimation, above) of the domestic/stock Fox Hills water use is from wells allowed to flow water constantly, discharging the excess water to land surface.

Six of 76 flowing wells visited in 2008, or 8% of the wells, appeared to be leaking water to surface. If 8% of the flowing-head stock and domestic wells in McKenzie County are leaking an average of 5 gpm, 55 gpm or 89 acre-feet of water annually are being lost to surface leakage. The actual quantity of Fox Hills water being lost to surface leakage may be significantly higher. Two wells with a fair amount of pressure head flowing uncontrolled could be discharging the total estimated 55 gpm to land surface.

The FH-HC aquifer has a greater pressure head than overlying formations, about 240 feet, equal to 104 pounds per square inch (psi), higher head than that of the basal Tongue River in southwest McKenzie County, which occurs about 900 feet above the FH-HC aquifer, and about 200 feet (87 psi) higher than a sandy zone, possibly the Cannonball Formation, which occurs about 500 feet above the FH-HC aquifer in northeastern McKenzie County. An unknown quantity of water is being discharged from Fox Hills wells to overlying formations by water moving up the annular space between well casings and the walls of the drilled holes, if left open, and through holes corroded into well casings. Because the overlying formations are much less permeable than the FH-HC aquifer, as the overlying zones around the well become pressured up with Fox Hills water, the discharge of Fox Hills water to overlying formations may be significantly reduced. Fox Hills wells discharging water to shallow zones that may 'daylight,' or surface, in the vicinity of the well, may continue to lose water because the receiving zone, having an outlet, does not pressure up nearly as much. If water is leaking upward in 90% of the Fox Hills wells in McKenzie County at as little at 0.1 gpm (144 gallons per day), 42 acre-feet of water per year are being lost to upward leakage. When added to the estimated 89 acre-feet of water leaking to surface in McKenzie County Fox Hills wells, 131 acre-feet of water are being lost annually to surface and subsurface well leakage. In reality, it is unknown how much water is being lost to well leakage, but the evaluation suggests the quantity may very well be over 100 acre-feet annually.

In round numbers, the water discharged annually from Fox Hills stock and domestic wells in McKenzie County is very roughly estimated as 30 acre-feet from pumped and float valved flowing-head wells, 280 acre-feet from flowing wells discharging water to surface and (probably conservatively) 130 acre-feet to well leakage, for a total of 440 acre feet of water per year. The reported, permitted water use from Fox Hills wells in the county was 283 acre-feet in 2008, a bit higher than the average of the past 10 years (253 acre-feet/year) and past 25 years (275 acre-feet/year). Using the very rough estimate of 440 acre-feet per year from (primarily losses associated with) Fox Hills domestic and stock wells and the 25-year average reported use figure of 275 acre-feet per year, about 62% of McKenzie County Fox Hills water use is to domestic and stock wells and 38% is to industrial and municipal pumping. Based on this evaluation, it can be said that in McKenzie County, municipal and industrial (i.e. permitted) Fox Hills water use is likely to be somewhat less than the expected level of water discharge associated with domestic and stock wells in the county. If the losses to leakage are somewhat higher than estimated above, the municipal and industrial use may account for about 1/3 of the Fox Hills water use/discharge in McKenzie County, and water use and losses associated with stock and domestic wells about 2/3 of the Fox Hills use/discharge in the county. Again, the evaluation was undertaken to gain an idea of the general magnitude of the various Fox Hills water uses for comparative purposes. While the municipal and industrial water use from the FH-HC aquifer in McKenzie County is likely less than that associated with stock and domestic wells, primarily from discharge of flowing wells, it appears to be not so much less as to be insignificant by comparison.

Montana Fox Hills water well information reviewed for this report, almost all from three eastern counties, includes 89 flowing-head wells, primarily in the Yellowstone River valley, within 10 miles of McKenzie County. As is the case in North Dakota, probably not all of the existing Fox Hills wells are accounted for in Montana. From the available well information, the density of flowing wells appears be a bit higher in the Yellowstone River valley than along the Little Missouri River valley. In the vicinity of the Montana-North Dakota border, in western McKenzie and eastern Richland counties, water discharge from the FH-HC aquifer in the Yellowstone River valley is probably taking place at generally similar levels from either side of the state boundary line, judging by the general density of Fox Hills wells (figs. 10 and 12).

McKenzie County municipal water use:

Two cities in McKenzie County, Watford City and Alexander, have municipal water-use permits, each city having two permits. Watford City's municipal water source is from wells completed in the Tobacco Garden aquifer, comprised of coarse-grained sediments deposited along the preglacial course of the Little Missouri River. Smaller communities in McKenzie County do not have municipal water systems.

City of Alexander Water Permit No. 1209, granted in 1964, allows for the appropriation of 95 acre-feet of water annually for municipal use. City of Alexander Permit No. 3586, granted in 1983 to supplement the earlier permit, allows for the appropriation of 35 acre-feet of water annually. On February 4, 1982, Garvin Jacobson, on behalf of the Mayor of Alexander, contacted the State Water Commission requesting information on additional water sources to supplement the city's shallow ground water supply. The city's reported annual water use had increased to 64.0 acre-feet in 1981, 2/3 of the permitted quantity. Responded to the request in the City in a February 17, 1982 letter to the mayor, I suggested as possible municipal water sources, either a shallow well in the alluvium along Lonesome Creek just south of Alexander, or a well completed in the FH-HC aquifer. On July 16, 1982, a municipal well was installed for the City of Alexander, completed in the FH-HC aquifer between 1,676 and 1,760 feet below land surface. In 2001, a second Fox Hills well was installed for the city. The second well was replaced in 2004. The City of Alexander's reported water use between 1984 and 2008 has varied between 21.7 acre-feet in 1995 and 2000 and 99.4 acre-feet in 2007 and has averaged 40.4 acre-feet per year. For the Fox Hills water use shown in figures 14 and 15, the City of Alexander's reported use in 1982 was assumed to come from shallow sources and not the FH-HC aquifer; although, the city's first Fox Hills municipal well probably came on line sometime in late 1982. We do not have the City's water use from 1983. The City of Alexander's reported water use from 1984 to the present time is all assumed to come from the FH-HC aquifer for figures 14 and 15; although, some of the city's municipal water use in the 1980's may have been from shallow sources.

The City of Mandaree in southeastern McKenzie County, with an estimated 2007 population of 548, had an eight-inch diameter, 1,705 feet deep, Fox Hills well installed in 1970 for their municipal water supply. In or about the early 1980's, the Fox Hills municipal source was replaced with water from Lake Sakakawea. In the 1970's, the City of Mandaree may have used about 70 acre-feet of water per year, based on reported use by nearby cities. The City of Mandaree, located on the Fort Berthold Indian Reservation, does not require a water permit for their municipal use and their use is not included in the graphs of Fox Hills permitted water use.

The National Park Service has two water permits for use listed as 'domestic'. The National Park Service water permits were granted in 1964 for use at their North Unit Park Headquarters and at Juniper Campground, with annual reported water use of about one acre-foot at each of the locations. Wells at the two national park permitted locations are completed about 1,000 feet above the FH-HC aquifer.

McKenzie County industrial ground-water use:

The State Water Commission water permit database lists 148 industrial ground water permit applications or ground water permits that have been issued in McKenzie County, including:

3 applications that are void (the application process never completed)
3 applications denied
1 application held in abeyance
4 applications in processing
11 total applications

73 permits cancelled
24 permits conditionally approved (including 22 for Zenergy)
40 permits perfected (including one restricted to deeper than 4,000 feet)
137 total permits

The 137 industrial groundwater permits issued in McKenzie includes one permit requiring the well to be completed deeper than 4,000 feet below land surface (for Dakota aquifer water use in an oil field waterflood). Of the remaining 136 permits, 82 permits (60%) have depth restrictions requiring the well to be completed above the FH-HC aquifer, and 54 permits (40%) allow access to the FH-HC aquifer (including at least 5 permits for which a Fox Hills depth restriction was waived when a satisfactory shallower source could not be found). Twenty-six of the 54 McKenzie County industrial water permits allowing Fox Hills access have been canceled. Of the remaining 28 conditionally approved or perfected water permits in McKenzie County that allow Fox Hills access, 21 have wells completed in the FH-HC aquifer (Fig. 16).

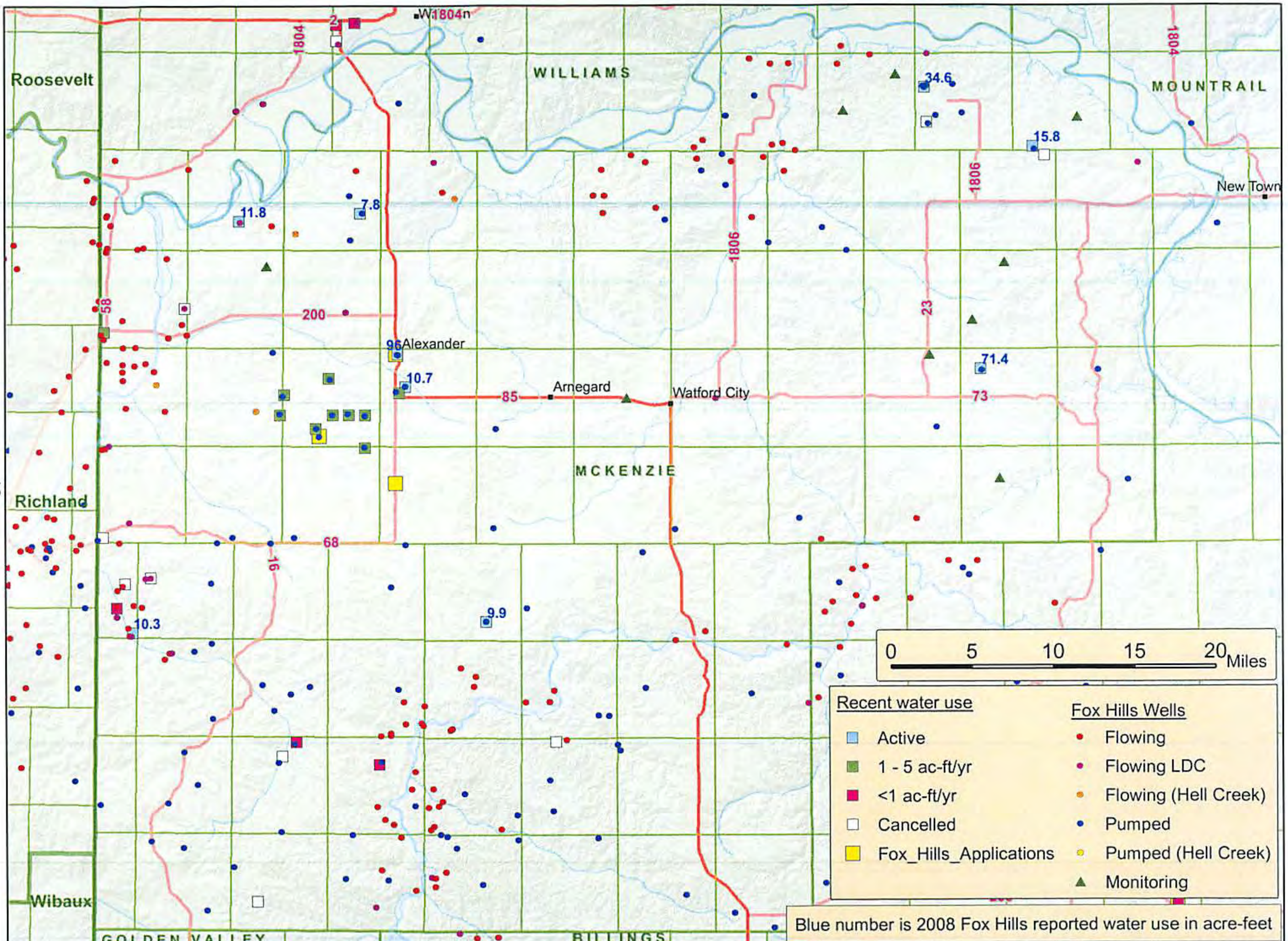


Figure 16. Locations of Fox Hills permitted water use, applications, and wells in McKenzie County

Many industrial water permits in McKenzie Couny date from the early 1980's when oil wells completed in the Interlake Formation in northeastern McKenzie County required water to dilute salt-saturated brine entrained with produced oil. Ninety-four of the 148 applications/permits in McKenzie County (64%) have priority dates in the 1980's. Beginning in the early 1980's, depth conditions requiring the water supply well to be completed above the FH-HC aquifer were commonly added to industrial water permits in flowing-head Fox Hills well areas. As an example, in a November 10, 1981 memo regarding Water Permit Application No. 3485 for 25 acre-feet of water per year from a location about eight miles northwest of Alexander, I wrote, "It is the policy of the State Engineer to restrict industrial use of the Lower Hell Creek-Fox Hills aquifer in order to maintain the flowing artesian pressure head for stock and domestic use." Permit No. 3485 was conditioned that "the well shall be screened between a depth of 400 and 1400 feet below ground surface." A well was completed between 837 and 877 feet below surface and up to 3.3 acre-feet of water use was reported annually between 1982 and 1992. Permit No. 3485 was cancelled in 1995.

The policy of restricting access to the FH-HC aquifer was the subject of an April 5, 1984 memo to the State Engineer written by Milton O. Lindvig, Director of the Hydrology (now Water Appropriations) Division of the North Dakota State Water Commission (Lindvig, 1984). Mr. Lindvig wrote that in response to rancher's concerns for preserving its flowing pressure head, the State Engineer has controlled access to permitted water use from the FH-HC aquifer, requiring industrial wells to be completed in overlying zones. If the overlying zones do not produce sufficient water for the intended industrial use, the FH-HC aquifer may then be considered as a source. Mr. Lindvig discussed the difficulty in assigning economic value to ranchers' flowing head Fox Hills wells and comparing their value to oil company's having access to the FH-HC aquifer. Mr. Lindvig considered approaching the allocation of Fox Hills water based on an acceptable rate of the pressure head decline, writing that, "it seems that the emphasis should be placed on preserving the flow from the largest number of wells for a reasonable period of time."

Two industrial water permits were granted in the 1980's in the vicinity of the Monson, Bratcher, and Alexander applications for which Fox Hills water is used. In 1985 Landtech Corporation applied for 60 acre-feet of water per year from a location 1.8 miles south (and slightly east) of Alexander, for water sales. A permit was granted that included a condition that the well be completed no deeper than 1,300 feet below land surface. The condition was later waived, allowing access to the FH-HC aquifer. Reported water use under Permit No. 3792 has ranged between 5.4 acre-feet in 1994 and 42.6 acre-feet in 2005 and has averaged 13.3 acre-feet per year between 1986 and 2008. Reported water use in 2008 for Permit No. 3792 was 10.7 acre-feet.

In 1986, Mobil Oil was granted an industrial water permit for 16.1 acre-feet of water per year from the location of their field office two miles south of Alexander. A domestic well was completed for the field office in 1982 for owner at the time, Sumbehm Oil & Gas. Mobil Oil applied for the industrial permit to use water from the Fox Hills well for brine dilution in four of their producing oil wells located within ten miles of the field office. Reported annual water use has ranged between 0.1 acre-feet in 1992 and 7.1 acre-feet in both 2007 and 2008, and has averaged 1.7 acre-feet annually.

In 2007, twenty water permits were granted, each for five acre-feet of water per year, from locations in the Foreman Butte oil field between 2.5 and 8 miles southwest of Alexander. The 20 permits granted in 2007 each included a depth restriction requiring the well to be completed below the interval in which most area wells were completed. The minimum depth restriction for the 20 locations ranges from 580 feet below land surface to 930 feet below land surface. A maximum depth restriction was not included on the 20 permits. After reviewing the gamma-ray logs from the holes drilled for oil wells at the locations, it was thought that at some locations a suitable well completion zone may not be found below the minimum depth allowed and above the FH-HC aquifer. After three water supply wells were successfully completed in or slightly below the basal Tongue River aquifer, occurring about 900 feet above the FH-HC aquifer, eight water source wells were then completed in the FH-HC aquifer following difficulties in completing shallower wells at the locations. On January 22, 2009, a condition was added to the remaining 12 permits not already having a Fox Hills well installed at the location, requiring approval by the State Engineer before a well can be completed deeper than 1,300 feet below land surface (i.e. in the FH-HC aquifer).

Besides the Zenergy use, Fox Hills industrial water use is ongoing in McKenzie County under 10 other water permits. While most of the Fox Hills use in McKenzie County is for brine dilution in oil wells, one of the ten permits is for water use in a gas processing plant and another is for use in the manufacture of fertilizer. Five of the ten other permits in McKenzie County were granted for a smaller quantity of water per year than had been applied for. In a February 17, 1983 recommendation for a permit in southeastern McKenzie County, I wrote, "Limited conditional access to the Fox Hills aquifer is being recommended in this memo for the following reasons, 1) Nearby flowing Fox Hills wells are more than ten miles from the proposed site, 2) The oil field for which the supply water is required has a limited practical production period of from 10 to 20 years, 3) Projections of head decline from a partial appropriation of the application show that only a moderate effect may be expected at the flowing well sites, and 4) A lack of viable alternate sources of water supply has been demonstrated." Similar reasoning was cited on other recommendations where Fox Hills access was allowed. Also discussed in some recommendations for Fox Hills water use was the relatively small quantity of water requested and in one case that the applicant intended to replace the current water source, which was a Fox Hills well on the Montana side of the state boundary line. The recommendation memos commonly include projections of the increase in the rate of pressure head decline at locations of nearby flowing-head Fox Hills wells, expected from pumping for the proposed project.

A proposed rural water system for Eastern McKenzie County is expected to be completed in about 2011. An oil company whose average 2006-2008 Fox Hills water use, as shown in Figure 13, was 13.8 acre feet at one location and 73.9 acre-feet at a second location, is interested in replacing the Fox Hills water with rural water, reducing the Fox Hills water use in eastern McKenzie County by about 87 acre-feet annually.

Proposed water use:

<u>Industrial water use:</u>

As discussed near the beginning of this memo, Linda Monson App. No. 5934 is for 50 acre-feet annually (industrial), Lyle Bratcher App. No. 5963 is for 250 acre-feet annually (industrial), and the City of Alexander App. No. 5990 for 170 acre-feet annually (rural water). The Monson and Bratcher applications are for water to serve oil wells in the Foreman Butte field for brine dilution (Fig 17).

Zenergy, Inc., at the time of writing, has 46 oil wells completed in the Ratcliffe interval of the Charles Formation in or near the Foreman Butte field southwest of Alexander, each requiring about one gallon per minute (1.61 acre-feet/year) of fresh water for brine dilution. Fox Hills wells supply water to the oil wells at eight of Zenergy's locations, including one well that supplies a second oil well. Three Zenergy basal Tongue River wells supply water to seven oil wells. Seven oil wells are temporarily supplied with fresh water from shallow wells. It is understood from an April 22, 2009 telephone conversation with Zenergy Operations Manager Keith Hill that water trucked from the City of Alexander's water depot supplies the remaining 23 Zenergy oil wells.

In the April 22, 2009 telephone conversation, Mr. Hill said Zenergy would like to supply the Foreman Butte field oil wells with pipeline water originating from the City of Alexander's treated water supply. The 23 Zenergy oil wells to which water is being trucked and the seven wells temporarily being served by shallow water wells require about 48 acre-feet of water annually. In summary, the Monson and Bratcher applications in large part are for water to serve the needs now being met from the City of Alexander's water sales, much of which could ultimately be met by a proposed rural water line through the area that would also serve about 93 farmsteads.

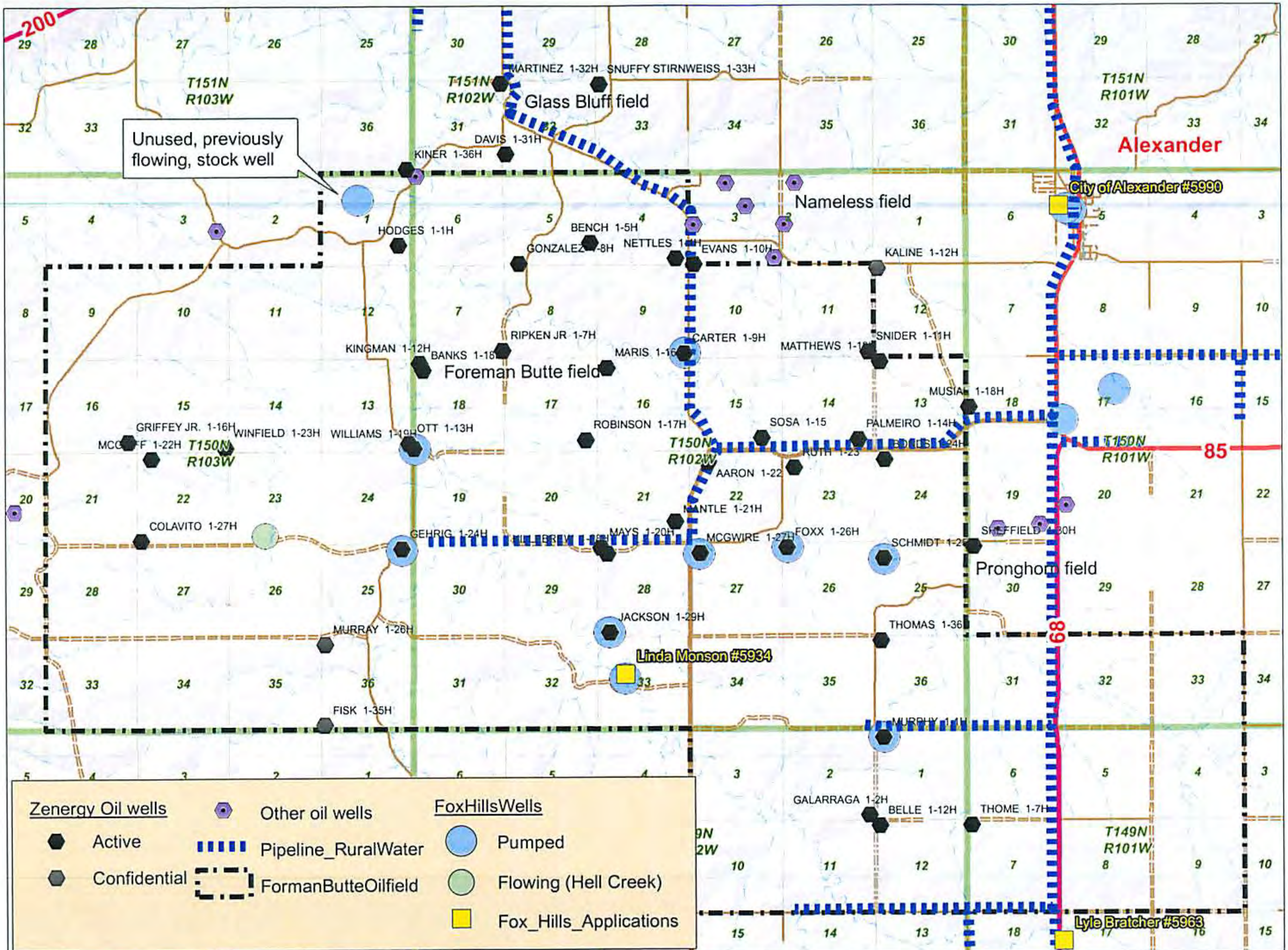


Figure 17. Locations of oil wells southwest of Alexander

On May 29, 2009, I reviewed information on the website of the North Dakota Industrial Commission, Oil and Gas Division, about oil wells in the Foreman Butte oil field. Forty-one oil wells were identified in the Foreman Butte field (including three locations on confidential status assumed to be Zenergy Ratcliffe oil wells), plus five nearby Zenergy oil wells in the Glass Bluff and Pronghorn fields. Shown within the Foreman Butte field boundaries on the website map were 20 cancelled or expired oil well permit locations and three 'dry holes'. Within the Foreman Butte field I did not see any proposed oil well locations that were permitted but not developed. The website map showed no drilling rigs operating in the Foreman Butte field. Zenergy's 46 existing Ratcliffe oil wells in and near the Foreman Butte field appear to be the extent of the company's development in the area at this time. There are two oil wells in the Foreman Butte field not operated by Zenergy and a few more in nearby fields that may require brine dilution and may be supplied by water from the City of Alexander.

The City of Alexander's reported water use the past three years has been 88 acre-feet (2006), 99.4 acre-feet (2007), and 96 acre-feet (2008), or an average of 94.5 acre-feet per year. The City's reported use the previous four years (2002-2005) averaged 24.5 acre-feet per year or 70 acre-feet less that the reported use the past three years. City of Alexander water systems operator Jim Fixen said the City's municipal water use has increased the past few years, in part because of the better quality, reverse osmosis treated water now being supplied by the City. The City's municipal use may have been about 35 acre-feet per year in recent years, leaving about 60 acre-feet, in round numbers, for sales from the City's water depot. From 60 acre-feet of the City's Fox Hills water, assuming an extra 15% of water is needed for the reverse osmosis treatment process, about 52 acre-feet of processed water can be produced.

The 23 Zenergy oil wells being supplied by water trucked from Alexander, each requiring about one gallon of water per minute (1.61 acre-feet per year), require about 37 acre-feet of water annually, leaving about 15 acre-feet of water annually being used by customers other than Zenergy. Seven Zenergy oil wells, requiring about 11 acre-feet of water annually, are temporarily being supplied with water from shallow wells. These seven oil wells will eventually need an alternative water source. About 63 acre-feet of water (37 + 11 + 15 acre-feet) are currently required in the Alexander area for industrial use.

Rural water use:

The city of Alexander has applied for 170 acre-feet of water annually. As I understand it, with input from Zenergy as a potential customer, a proposal was made for a rural water service area, now designated as the proposed McKenzie Rural Water System 4 Service Area (Fig. 2). Mr. Fixen has estimated about 100 rural water connections, including seven for Zenergy, requiring between about 70 and 100 acre-feet of water per year (between 23 and 33 million gallons/year). Sixteen Zenergy water connections were also mentioned as a possibility for rural water service.

Based on conversations with Mr. Fixen, the McKenzie County Water Resource District estimated monthly water use for a connection as 10,000 gallons, while Mr. Fixen suggested a figure of 8,000 gallons per month per connection as being a better estimate of actual rural water use. Rural water use in North Dakota was reviewed to better estimate likely level of use from rural water systems. Reported annual water use in 2006 and 2007 by ten rural water systems was reviewed. The two rural water systems with the highest reported use per connection and two with the lowest use per connection were removed and the water use of the middle six systems was reviewed. The estimated population per water connection or hookup averaged 3.1 people per connection. The average water use per connection was 96,676 gallons per year (8,056 gallons per month). The average daily use in 2006 and 2007 for the six reviewed rural water systems was 87 and 84 gallons per person respectively (in reviewing the use data, the number of connections is typically known while the number of people served is estimated). Jaret Wirtz, Manager of the McKenzie County Water Resource District, supplied rural water use information for the System 1 Service Area, a similar sized rural water system in the Watford City-Arnegard area (Fig. 2). Over the past four years System 1 has grown from 60 to 120 connections, serving an average of 6,129 gallons of water per month per connection, or about 67 gallons per day per person (Mr. Wirtz estimated three people per connection). An average of 6,129 gallons per month per connection is equal to 0.226 acre-feet per year per connection, or 22.6 acre-feet for 100 connections. In 2007, an estimated 100 connections were served from System 1, using 23.9 acre-feet of water.

Mr. Wirtz estimated the proposed System 4 Service area to have 100+ connections serving 300 people, similar to Mr. Fixen's earlier estimate of 100 connections including seven for Zenergy. One hundred rural water connections averaging 8,000 gallons per month will use 9.6 million gallons (29.5 acre-feet) of water annually. At least two of the farmsteads interested in signing up for rural water have Fox Hills wells for their ongoing supply. A small amount of the proposed rural water use would be substituting Fox Hills water for Fox Hills water.

Total estimated water use:

As estimated above, about 63 acre-feet of water annually are expected to be required for industrial use in and around the Foremen Butte oil field, about ¾ of that by Zenergy. About 30 acre-feet of water annually are expected to be required for 100 rural water connections in western McKenzie County; although, judging by the System 1 area around Watford City, between 20 and 25 acre-feet may be closer to the actual annual rural water use for 100 connections. The City of Alexander's municipal use is probably about 35 acre-feet annually. The estimated annual use for the City, the oil field, and the proposed rural water system is therefore 35 + 63 + 30 = 128 acre-feet. If the reverse-osmosis process uses an extra 15% of water, about 147 acre-feet of raw water would be needed yearly from the Alexander Fox Hills wells, 17 acre-feet more annually than the city is authorized.

As it has since 1982, the City of Alexander's municipal water use will continue to come from their Fox Hills wells. The City's annual water use is therefore not part of the discussion of additional water use for a the proposed rural water system. If Zenergy's oil wells are supplied with water from a rural water line, the City will probably continue to sell a smaller quantity of water from their depot. The estimated 15 acre-feet annually sold to customers other than those trucking water to Zenergy wells would continue under the city's municipal permit. The estimated additional annual water for the proposed rural water system is therefore about 30 acre-feet for the 100 connections plus whatever portion of Zenergy's 48 acre-feet of area water use is served by the rural water system.

Of the 30 Zenergy oil wells requiring about one gpm per well, Mr. Fixen included sales for 7 and 16 oil wells in estimates while Mr. Wirtz included ten, with potential for more Zenergy oil wells being added once the system is operational. Mr. Wirtz estimated an expected annual use of 32 million gallons (98 acre-feet) of water for proposed System 4 in the Alexander area. Mr. Fixen estimated between 70 and 100 acre-feet of water needed annually for the proposed Alexander rural water. The estimated water use for 100 connections averaging 8,000 gallons per month plus 10 Zenergy connections using 1 gallon per minute (44,000 gallons per month) is 46 acre-feet (15 million gallons) annually. Estimating 10,000 gallons per month per connection (other than Zenergy's) increases the above System 4 water use to 53 acre-feet or 17 million gallons annually. The estimated 32 million gallons (98 acre-feet) of water annually for System 4 is therefore about twice the initial annual water need, providing plenty of extra water for future growth.

The expected water sales to a rural water system serving 100 connections is about 30 acre-feet annually (8,146 gallons per month per connection); although, use in the System 1 Service Area around Watford City suggests about 23 or 24 acre-feet annually may be closer to the actual use. The City of Alexander's municipal water use is estimated at 35 acre-feet per year. Allowing for annual City water depot sales of 15 acre-feet, totals 30 + 35 + 15 acre-feet = 80 acre-feet treated water, requiring about 92 acre-feet raw water. The city is permitted for 130 acre-feet of municipal water. The city, under its existing permits, could accommodate the proposed rural water line's non-Zenergy needs and still have 38 acre-feet of water per year available for future growth in any of the three use areas (municipal, sales, rural water).

The effect of granting some of the City of Alexander's rural water application would be an additional about 30 acre-feet of treated (34.5 acre-feet raw) Fox Hills water use for the farmstead connections, possibly increasing with time, plus whatever water

Zenergy uses. Zenergy's Foreman Butte field water use has been restricted from the shallow water zones, except temporarily at seven locations, and from the FH-HC aquifer at all but eight locations. Intermediate depth intervals, including the basal Tongue River, have not been productive. Were Zenergy to be left out of the rural water line, possible alternative fresh water sources for the Foreman Field oil wells are Alexander's water depot or the existing water depot south of Alexander, or their own Fox Hills wells (the average oil well requirement of 1.6 acre-feet of water annually is about 1/3 of the appropriated 5 acre-feet at each of eight locations having Fox Hills wells). If a portion of either the Monson or Bratcher applications were granted, they could also provide Zenergy with Fox Hills water. Other than the FH-HC aquifer, the only available fresh water supply for Zenergy's Foreman Butte field oil wells that comes to mind is a rural water system not using Fox Hills water.

Although the City of Alexander applied for an additional 170 acre-feet of water annually, less additional water would need to be appropriated. The City is currently supplying their municipal water needs, about 23 of the 30 Zenergy wells, and a few other customers using its water depot, with about 95 acre-feet of water annually the past three years. The City is allocated 130 acre-feet annually, or 35 acre-feet more than is currently being used. The initial 100 connections for rural water, at 8,000 gallons per month per connection, require 29.5 acre-feet of processed water annually, produced from 34 acre-feet of raw water, which would approximately use the remaining 35 acre-feet appropriated to the City. The remaining seven Zenergy wells, temporarily supplied by shallow wells, require 10.34 acre-feet of water annually (as determined from water use monitoring), or about 12 acre-feet of 'raw' water, which if supplied by the City would put them about 11 acre-feet over their currently appropriated 130 acre-feet. Allowing for a 50% growth in water use by the city and by the rural water served and a 20% growth in the industrial water supplied and factoring in the 15% extra water needed for reverse osmosis treatment, and including the 11 acre-feet discussed in the previous sentence, another 62 acre-feet of water may be needed to be appropriated annually to the City of Alexander to meet the proposed rural water systems water requirement. Seventy acre-feet per year of the requested 170 acre-feet per year would therefore probably be sufficient to meet expected water need, allowing for moderate growth.

For discussion purposes, the effect of pumping water for a rural water system to serve 200 non-Zenergy connections with 8,000 gallons of water per month (allowing for a doubling of rural water use over time), plus 48 acre-feet of water to serve 30 Zenergy oil wells for a total of 107 acre-feet of treated water, requiring 123 acre-feet of raw water annually will be considered. The 123 acre-feet of raw water could also supply water for a 50% growth of the rural water service and a 30% growth in the industrial water supplied. The estimated 123 acre-feet of water required annually is equal to 40 million gallons, or constant pumping at 76.4 gpm. The estimated quantity of water to serve the initial 100 non-Zenergy connections plus the Zenergy wells is 89 acre-feet annually, 72% of the 123 acre-feet figure allowing for estimated growth. Of the 123 acre-feet of annual Fox Hills water use, about 55 acre-feet, or 45% of the total, serving Zenergy oil wells, are currently supplied from the City's water depot. Zenergy's water use will fluctuate over time as the oil field 'ages'. Some time in the future the economically recoverable oil from the Foreman Butte Ratcliffe wells will be depleted, oil production will cease, and with it the demand for fresh water will come to an end. While the City of Alexander has available appropriated water for much of that required by a rural water system, it makes sense to review the effect of pumping 89 possibly growing to 123 acre-feet of raw Fox Hills water because that is about how much water will be provided to the proposed rural water system serving Zenergy and rural customers, either by the City of Alexander, or by some other source.

Ongoing pressure head decline in the FH-HC aquifer:

The pressure head in a confined aquifer is comparable to the water level in an unconfined aquifer. Similarly, the potentiometric surface of a confined aquifer is comparable to an unconfined aquifer's water table surface. As water is pumped or allowed to flow from a well completed in a confined aquifer, a cone-shaped depression in the aquifer's potentiometric surface is created around the production well. The magnitude of the cone of depression increases over time with continued pumping and flowing of water from the aquifer. The decline of an aquifer's pressure head at a particular location is the net effect of the cones of depression created by water being taken from the aquifer at different locations (plus or minus other aquifer influences such as changes in recharge or discharge).

Periodic pressure head measurements have been made over varying periods of time in 107 Fox Hills wells in North Dakota, including 39 flowing-head wells in which the water pressure is checked at 10-year intervals (Fig. 18). Ten of the 107 measured Fox Hills wells have been plugged. Twenty of the Fox Hills monitoring wells, mostly in eastern and south-central North Dakota, have not been measured for over 12 years. Hydrographs from measurements made in wells are included as Appendix 3. Included in Appendix 3 are hydrographs from measurements made in two wells in Montana. On the hydrographs in Appendix 3, while the horizontal ('x') axis (date measured) is, with a few exceptions, 40 years (usually 1970 – 2010), the vertical ('y') axis (pressure head elevation from measurements made in a well) varies, depending on the magnitude of pressure head change measured in the well. The magnitude of the pressure head changes in the measured wells varies enough that it is not practical to use the same vertical scale for all the wells.

A red dashed red line on the hydrographs is a linear curve fit of the pressure head measurements shown on the graph. A thin, solid red line extends the curve fit line to the edges of the graph for calculating the rate of pressure head change over time. A thin blue diagonal line is linear curve fit for the pressure head measurements since January 1, 1995.

Using the information from the individual well hydrographs, the rate at which the FH-HC aquifer pressure head is changing (usually declining) was determined for the well locations. Pressure heads have been measured for different periods of time from well to well. A second pressure head rate of change was determined for individual wells using only pressure head measurements made after January 1, 1995.

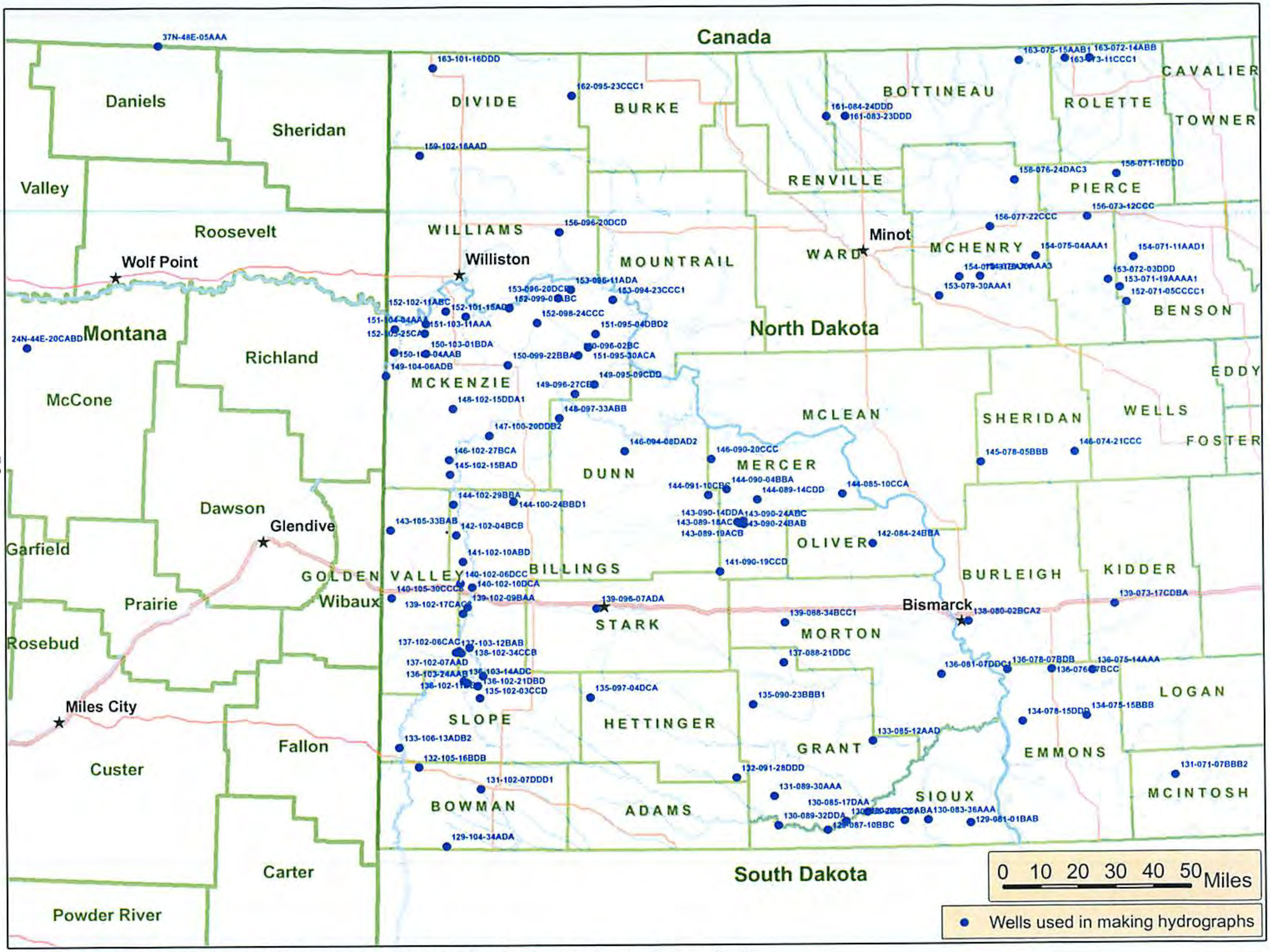


Figure 18. Location of Fox Hills wells used in making hydrographs in Appendix 3

Erratic pressure head changes in some of the Fox Hills wells suggest that holes have developed in the well casings causing the pressure head in the well to be influenced by the pressure heads in overlying beds. Gas accumulating in the FH-HC aquifer along the Nesson anticline in northeastern McKenzie County has, at times, elevated the aquifer's pressure head above expected levels. Pressure head measurements in flowing-head domestic and stock wells are somewhat less accurate than those made in monitoring wells because the rate at which the well has been flowing water is slightly different prior to each measurement. Additionally, the pressure head measurements in flowing head wells are generally made at 10 or 11-year intervals as compared to annual or quarterly measurements made in wells installed for water level monitoring.

The FH-HC aquifer rate of pressure head change at well locations was plotted on a map of western North Dakota. The rates of change were contoured, producing a map showing the estimated annual pressure head decline rate in the FH-HC aquifer for any particular location (Fig. 19). A second contour map was made of the rate of pressure change in the FH-HC aquifer since January 1, 1995 (Fig. 20). If pressure head measurements ended in a well before about 1997, the location was not used in constructing Figure 20. For easier visualization in figures 19 and 20, areas where the FH-HC aquifer pressure head is increasing or is showing no change are shown with blue contour lines. Areas where the pressure head in the FH-HC aquifer is declining are shown with red contour lines. Black numbers on Figures 18 and 19 indicate the pressure head change rate in feet per year determined for individual well locations.

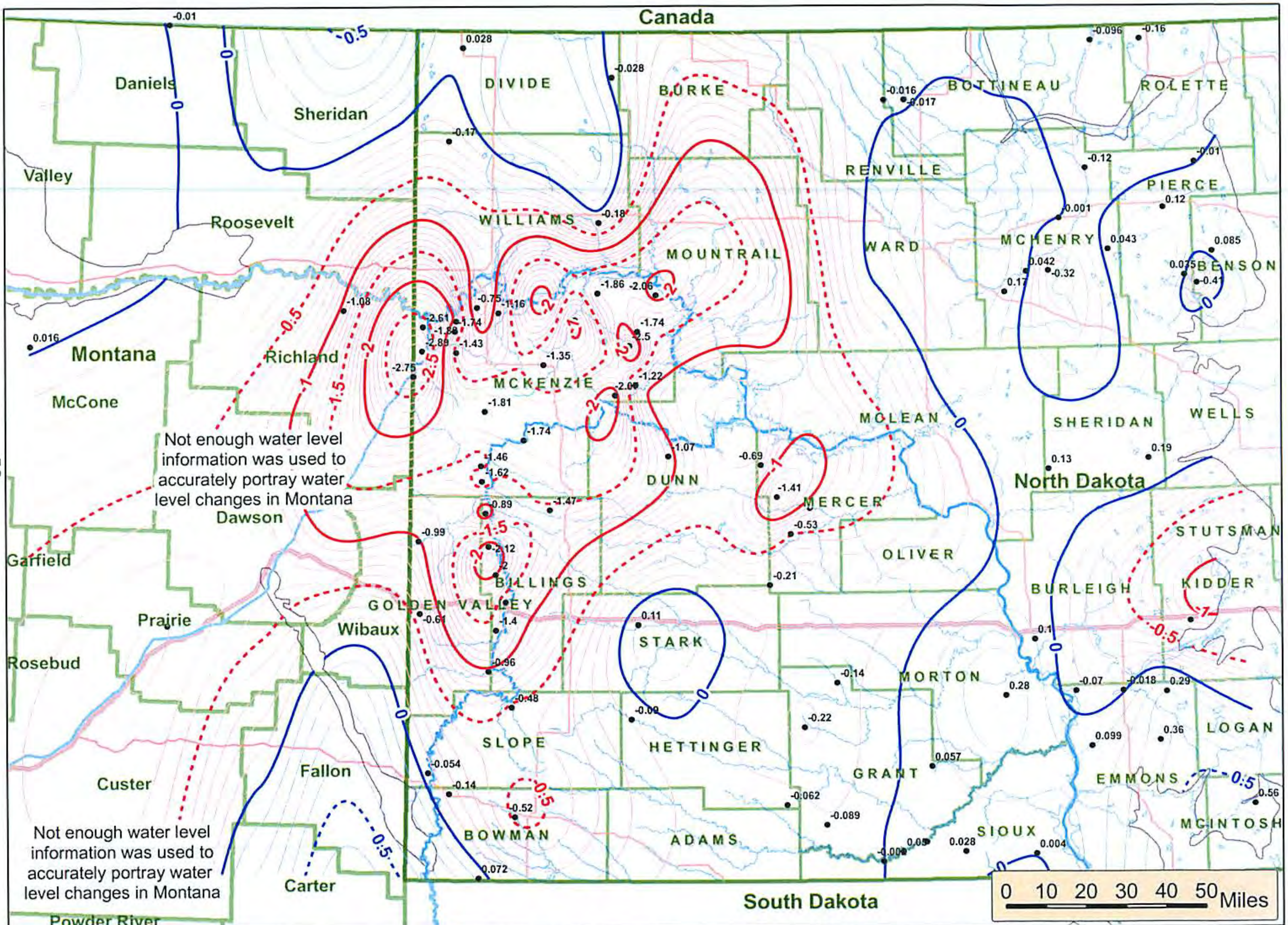


Figure 19. Pressure head rate of change in the Fox Hills-Hell Creek aquifer in feet per year over the period of recorded measurements

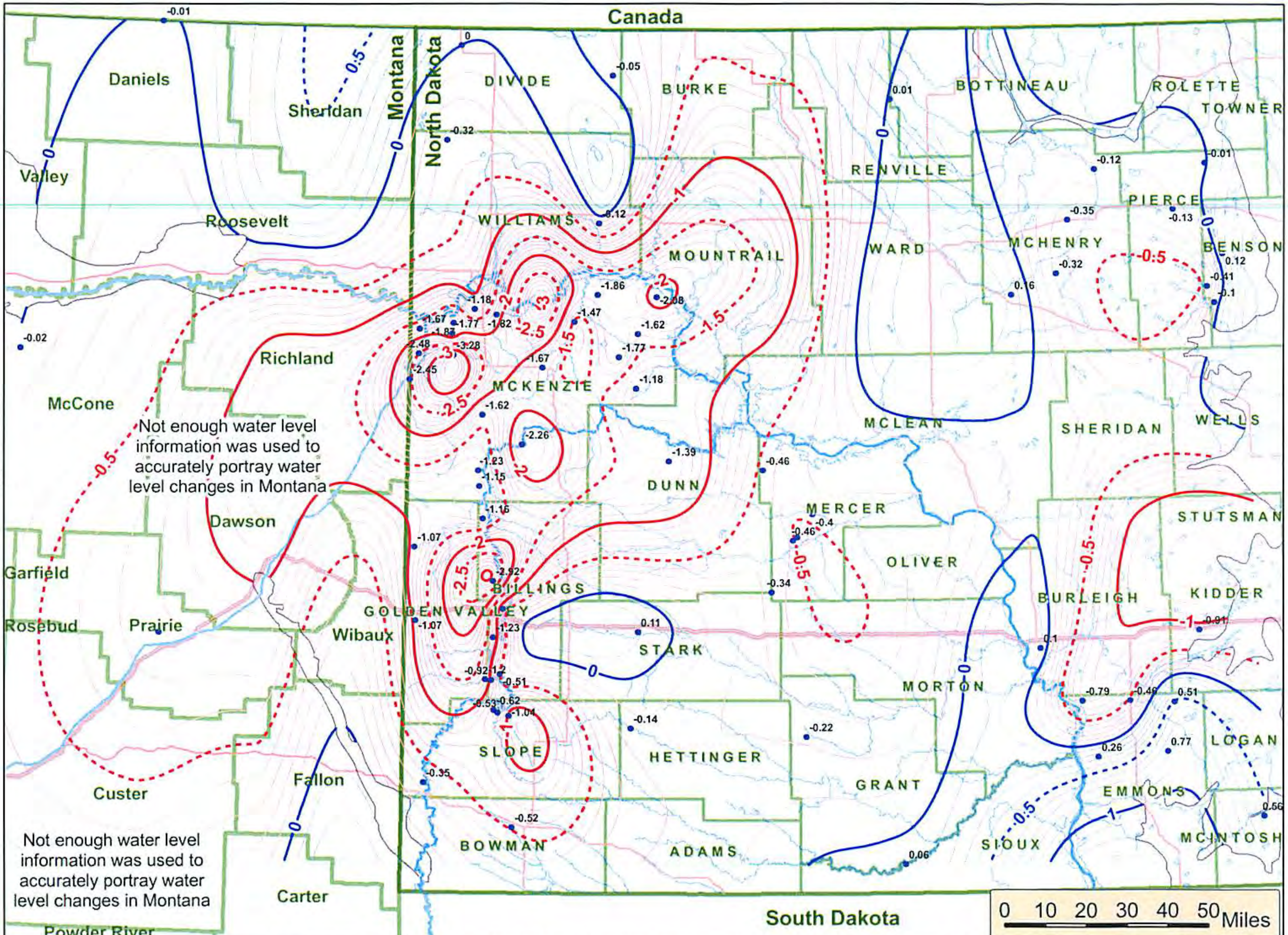


Figure 20. Pressure head rate of change in the Fox Hills-Hell Creek aquifer in feet per year between 1995 and 2009

The FH-HC aquifer pressure head is undergoing little change in eastern and central North Dakota where rates of change are generally plus or minus a few tenths of one foot per year. An exception is near the City of Steele, 40 miles east of Bismarck, where pressure heads are measured in a monitoring well within a few hundred feet of the City's two Fox Hills municipal wells. Because there are no pressure head change measurements from Fox Hills wells in Mountrail, Burke, Renville, Ward, and McLean counties, the northeast McKenzie County Fox Hills rate-of-change data are interpolated over that 'east river' area by the contouring program used. The actual rate of FH-HC aquifer pressure head change is probably smaller than indicated on the contour maps in those counties immediately northeast of the Missouri River, where there is little use of the poor-quality water found there in the FH-HC aquifer.

Because the Monson, Bratcher, and City of Alexander pending application areas are not far from Montana, about 100 miles of eastern Montana are included on the maps used in this memo so that the area of interest is not shown on the left edge of the map. Pressure head change information from the Ground Water Information Center web site for three Montana locations is included on the map. However, the map in no way accurately portrays pressure head changes taking place in the FH-HC aquifer in Montana. The many flowing wells in the Yellowstone River valley are expected to be causing the FH-HC aquifer to decline along the valley similar to declines taking place in and near the valley in North Dakota.

The pressure head of the FH-HC aquifer is declining at more than one foot per year in much of McKenzie, Billings, and Golden Valley counties, with decline rates of more than two feet per year in or near the Yellowstone, Little Missouri, and Missouri river valleys. In a few locations the FH-HC aquifer pressure head decline rate has exceeded three feet per year. Although not shown in figures 19 and 20, elevated decline rates of the FH-HC aquifer in Montana probably track up the Yellowstone River valley, and to a lesser extent, the up Missouri River valley.

The pressure head of the FH-HC aquifer is declining because of water leaving the aquifer. As discussed earlier, in McKenzie County it is estimated that more water is being allowed to flow from the aquifer, or is leaking upwards in wells, than is being pumped for industrial and municipal use; however, not so much that the municipal/industrial water use is insignificant by comparison. In Figure 21, the contour lines from Figure 20, showing the pressure head change in the FH-HC aquifer since the beginning of 1995, are included with the locations of water extraction from the aquifer, that is, the locations of flowing head wells and the locations where, on average, more than five acre-feet of permitted water use have been reported for the past three years (2006 – 2008).

As can be seen on Figure 21, the FH-HC aquifer pressure head is declining at between about 1.5 and 3 feet per year along the Little Missouri River valley, probably largely from flowing-head domestic and stock wells, permitted water use in the area being low. Pressure head rates of decline in the FH-HC aquifer between 1.5 and 2 feet per year that are occurring in eastern McKenzie County are probably more influenced by permitted Fox Hills use, there being fewer flowing head wells in the area, but more industrial use. The two to three feet per year FH-HC aquifer pressure head rate of decline occurring in western McKenzie County is probably due to both flowing head wells and permitted water use in the area.

Comparing the spatial distribution of both flowing-head wells and permitted water use with the mapped pressure head decline in the FH-HC aquifer provides some insight into the relative influence of the two types of Fox Hills water use on the aquifer's pressure head. Judging by the information in Figure 21, flowing wells are probably the larger source of water extraction from the FH-HC aquifer and therefore pressure head decline, but permitted use is also significant. A similar conclusion was reached in the discussion of Fox Hills water use in McKenzie County, where most, perhaps about 2/3 of Fox Hills water use in the county was estimated to come primarily from flowing domestic and stock wells, with lesser amounts coming from industrial and municipal use.

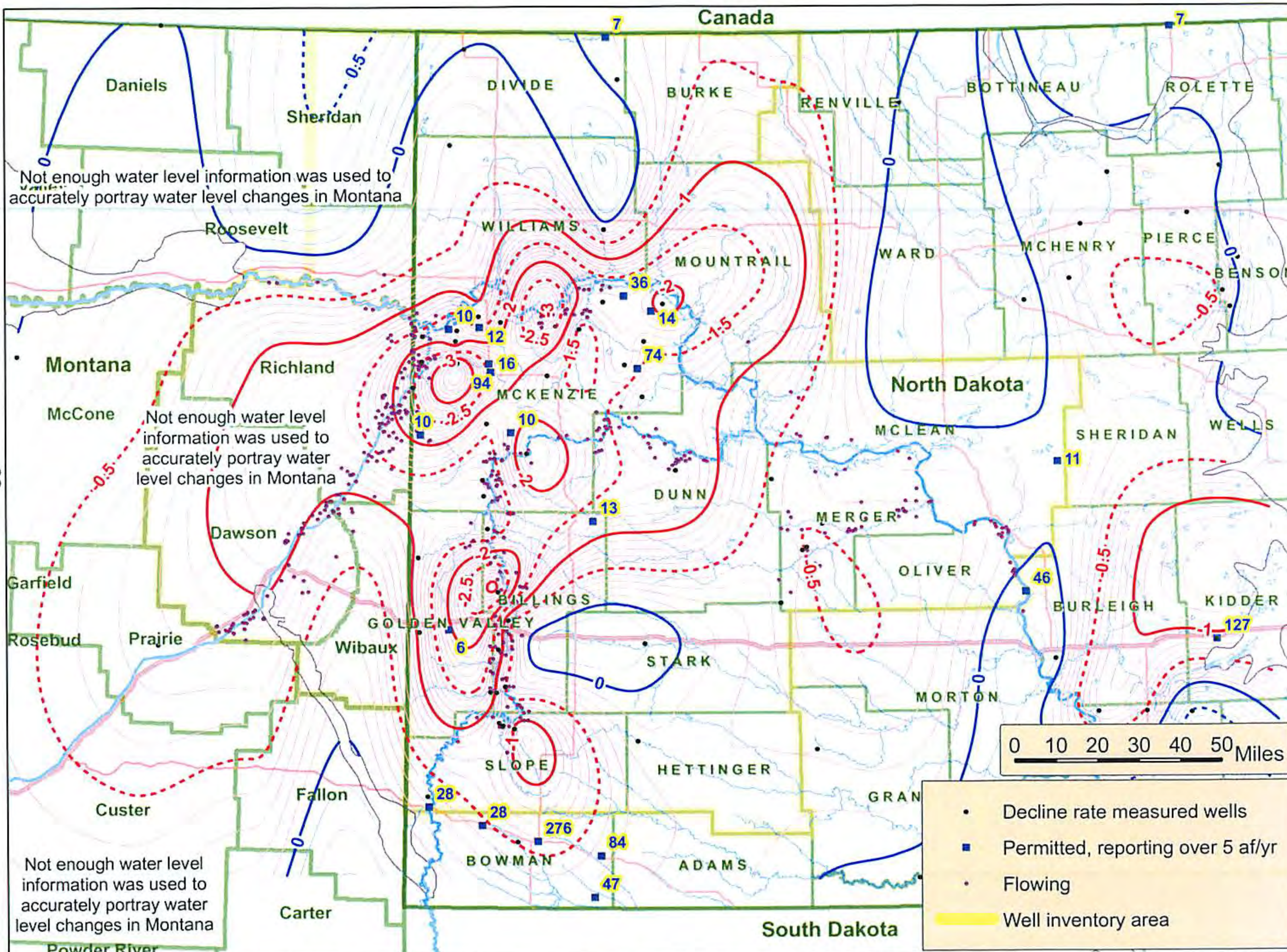


Figure 21. Pressure head rate of change in the FH_HC aquifer in ft/yr, 1995 - 2009, and location of flowing head wells and permitted wells using > 5 a-f/yı

Projected pressure head decline in the FH-HC aquifer from proposed System 4:

If the Monson, Bratcher, and City of Alexander pending applications are granted, all or in part, and the proposed rural water line is built, about 89 acre-feet of raw water per year will be initially required to supply the rural water customers, including Zenergy, possibly growing to 123 acre-feet if the non-Zenergy use increases over time. Projections will therefore be made of the effect of pumping 123 acre-feet of water per year. The effect of only pumping 89 acre-feet of water is 89/123 or 72% of the effect of pumping 123 acre-feet year, the pressure head decline being proportional to the quantity of water pumped. The projection will be made as if all the water is coming from the City of Alexander wells. The effect of some of the water coming from the locations proposed by Ms. Monson and Mr. Bratcher would be to shift the pressure head decline in that direction.

Theis (1935) developed a method of relating the lowering of an aquifer's potentiometric surface to the rate and duration of discharge of water from the aquifer. The transmissivity of the FH-HC aquifer in the Alexander area is about 220 feet^2/day (Fig. 6), and the storativity is about 0.0003 (from the 'Fox Hills-Hell Creek aquifer' section, properties subsection, of this memo). Using a Theis analytic program, the projected FH-HC aquifer pressure head decline was determined at varying distances from a well being pumped at 123 acre-feet of water per year (76.4 gpm) for 5, 10, 15, 20, 30, 40, and 50 years (Fig. 22).

Knowing the current flowing pressure head of a Fox Hills well and the rate at which the pressure head is declining in that area (Figs. 20 or 21), an estimate can be made of when the well will stop flowing if the current decline rate continues. Using information from Figure 22 (or the Theis analytic method from which it was produced), an estimate can be made of how much the added pumping of 123 acre-feet per year will reduce the time the well will continue to flow.

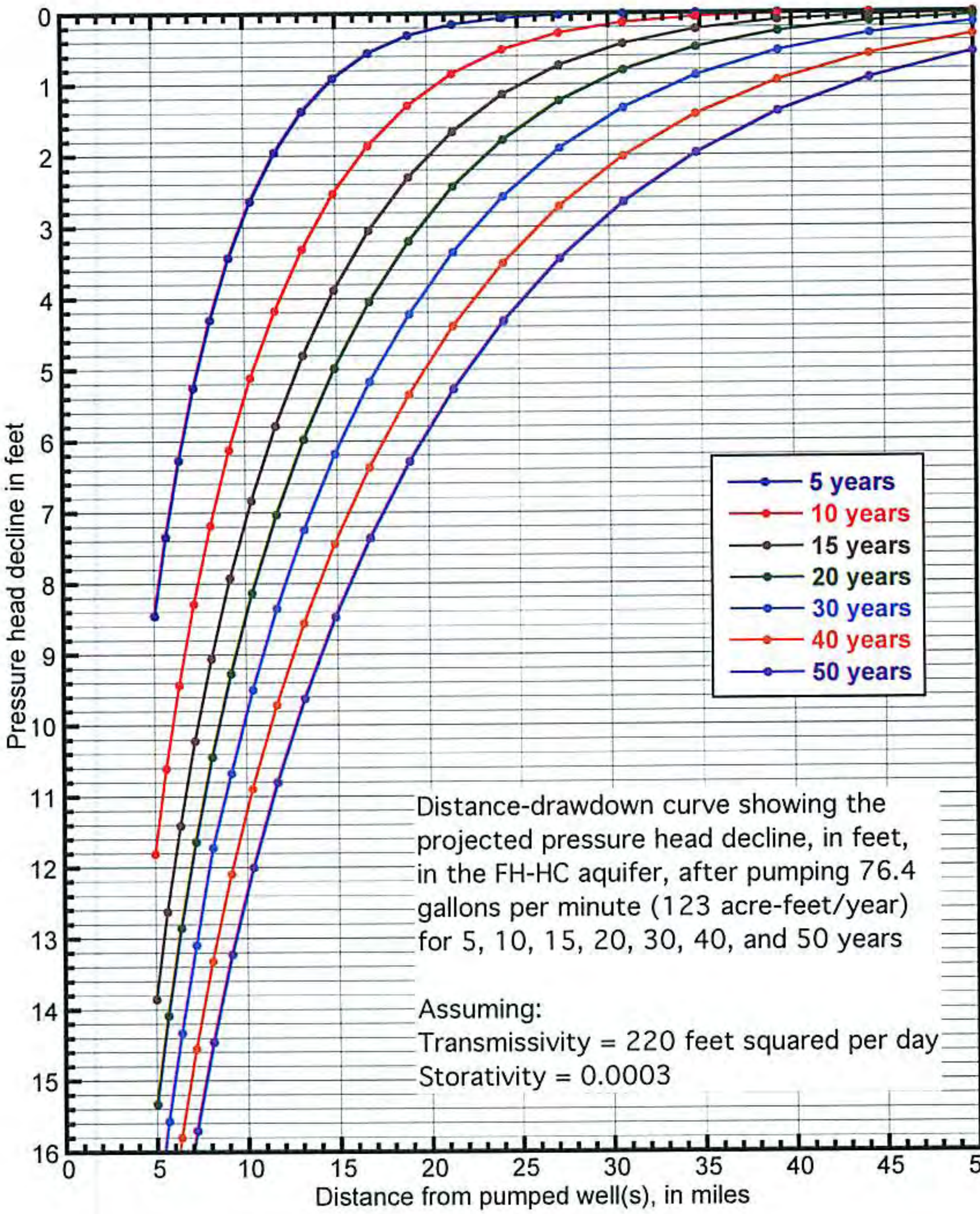


Figure 22. Projected FH-HC aquifer pressure head decline from pumping 123 af-ft/yr

For instance, a flowing-head Fox Hills well 16 miles northeast the pumped well, in the Missouri breaks area north of Arnegard, had a pressure head measured as 27.5 psi (63.5 feet above land surface) on August 6, 2008, and is in an area with an estimated pressure head decline rate of 2.88 feet per year. At the current rate of pressure head decline the well will stop flowing in 22.1 years. From Figure 22, pumping 123 ac-ft/yr for 20 years will result in 4.5 feet of additional drawdown at 16 miles from the pumped well. The drawdown in 20 years will therefore be 20 years times 2.88 feet per year (from the 'background' or ongoing FH-HC aquifer pressure head decline) plus 4.5 feet (projected from the proposed additional pumping) equals 62.1 feet, which, when subtracted from the original 63.5 feet of pressure head, leaves 1.4 feet of flowing pressure head remaining. Using slightly longer times and calculating the projected pressure head declines from both sources, after 20.5 years the pressure head of the well is expected to decline 63.5 feet, to land surface, 1.6 years earlier than the 22.1 years expected without the added effect of pumping 123 acre-feet per year, a 7% reduction in the remaining time the well will have a flowing pressure head. In a similar manner, the reduction in the time 15 other flowing-head Fox Hills wells are expected to continue to flow, if 123 acre-feet of water per year are pumped from Alexander, was calculated, Table 7. The projected percent reduction in the time the wells are expected to flow is shown in Figure 23.

Table 7. Reduction in time 16 Fox Hills wells are projected to flow, if 123 ac-ft/yr are pumped from Alexander

Location of flowing well	Distance from Alexander	Flowing head (feet above land)	Head decline rate (feet/year)	Years water will flow from well	Fewer years flow w/add. pumping	% reduction in remaining flow years
145-101-18DBC	32.4 miles	73.9 feet	-1.30 ft/yr	56.85 years	2.29 years	4.0%
146-102-35BCD	28.9 miles	78.5 feet	-1.23 ft/yr	63.82 years	3.34 years	5.2%
147-100-21BBB	22.8 miles	155.9 feet	-2.20 ft/yr	70.86 years	2.95 years	4.2%
147-101-30BBB	21.7 miles	97.0 feet	-1.50 ft/yr	64.67 years	4.29 years	6.6%
147-102-34DDD	23.5 miles	68.1 feet	-1.38 ft/yr	49.35 years	3.38 years	6.8%
147-104-08ADB	23.7 miles	53.1 feet	-2.08 ft/yr	25.53 years	1.15 years	4.5%
148-099-34DCD	24.7 miles	171.0 feet	-2.02 ft/yr	84.65 years	3.29 years	3.9%
148-105-36DCC	24.1 miles	92.4 feet	-2.12 ft/yr	84.58 years	1.93 years	4.4%
149-104-06ADB	19.3 miles	120.7 feet	-2.43 ft/yr	49.67 years	2.62 years	5.3%
150-104-04AAB	16.2 miles	129.4 feet	-2.48 ft/yr	52.18 years	3.27 years	6.3%
151-104-04AAA	17.3 miles	160.5 feet	-1.68 ft/yr	95.54 years	6.16 years	6.4%
152-098-01ADB	25.7 miles	41.1 feet	-1.73 ft/yr	23.76 years	1.04 years	4.4%
152-099-17DAD	16.1 miles	63.5 feet	-2.88 ft/yr	22.06 years	1.55 years	7.0%
152-101-15ADD	10.3 miles	83.2 feet	-1.80 ft/yr	46.22 years	6.39 years	13.8%
152-102-11ABC	11.6 miles	9.0 feet	-1.20 ft/yr	7.50 years	1.92 years	25.5%
152-103-25CAB	10.9 miles	106.3 feet	-1.85 ft/yr	57.44 years	6.55 years	11.4%

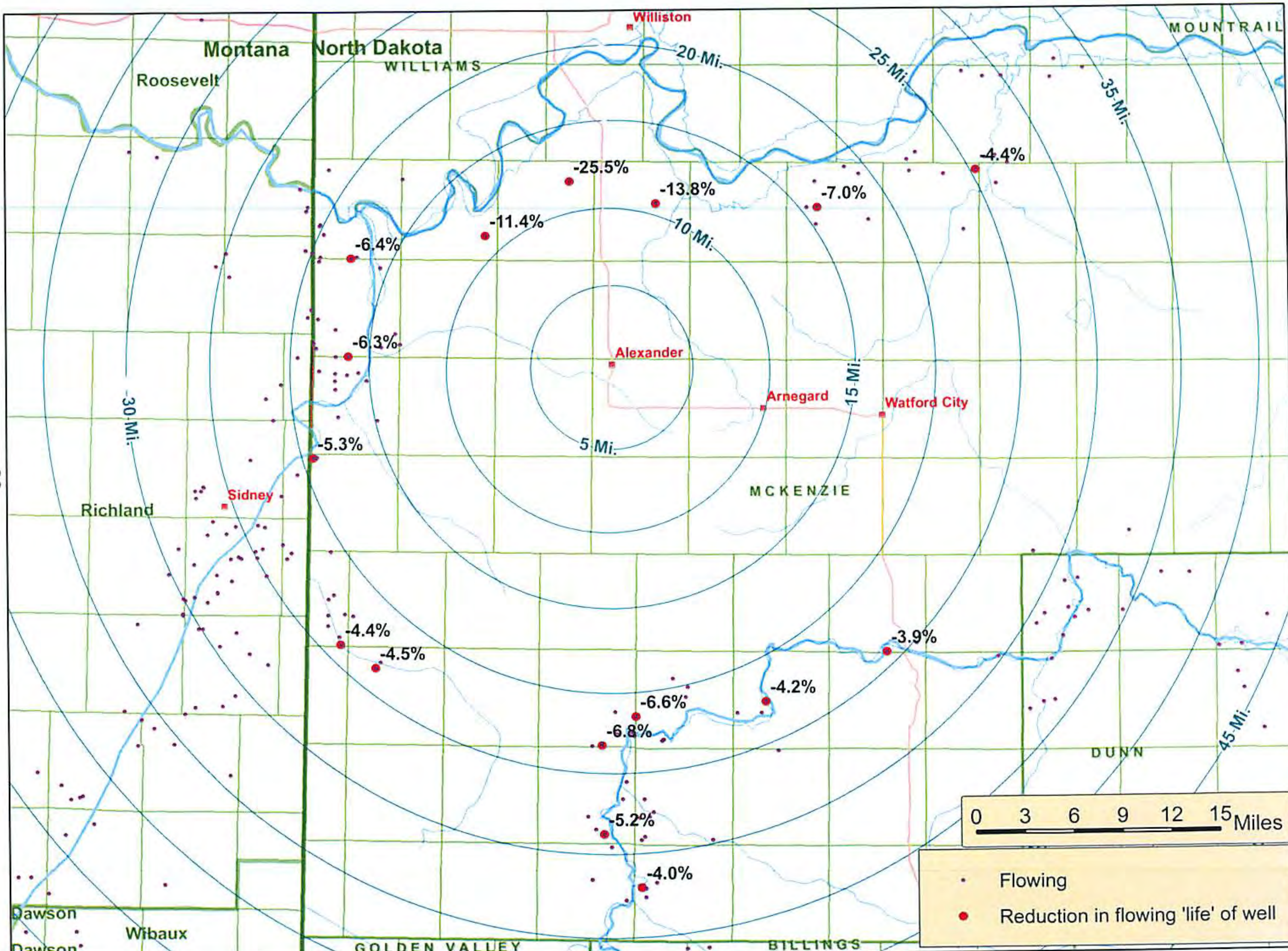


Figure 23. Projected percent reduction in the remaining time water will flow from selected Fox Hills wells if 123 ac-ft/yr is pumped at Alexander

The selected wells located between 15 and 30 miles from Alexander have a projected 4 to 7% reduction in the remaining time the wells are expected to flow. Two wells between 10 and 15 miles from Alexander have projected reductions in the remaining time the wells will have a flowing pressure head of about 11 and 14%. An 11.6 mile distant well, expected to stop flowing in 7.5 years, is projected to stop flowing in 5.6 years with the additional pumping, a 25% reduction.

The projected number of "Years water is expected to flow from well," the fifth column in Table 7, is in most cases longer than the expected economic 'lifetime' of the oil wells in the Foreman Butte field, which is probably a few decades. The industrial component of water use by an Alexander-area rural water system may therefore be reduced over time as the oil field 'ages'. However, similar observations were made regarding oil field water use in eastern McKenzie in the 1980's and much of that area's oil field water use is still ongoing. It is not prudent to assume that other use will not be found for available water as the Forman Butte oil wells come to the end of their economic 'life'.

Another way to show the projected effect of pumping at a specified time in the future is to calculate the shape of the cone of depression created in the FH-HC aquifer potentiometric surface. After 20 years of pumping at 76.4 gpm (123 ac-ft/yr) from the City of Alexander, using the assumed aquifer properties of a transmissivity = 220 ft^2/day and a storativity = 0.0003, the projected feet of pressure head decline in the FH-HC aquifer potentiometric surface is shown in Figure 24. If less water is pumped, the volume of the cone of depression is proportionally less. The projected pressure head decline at some location within the area of influence would also be less, but not in a direct, linear proportion. As more time passes and more water is pumped, the volume of the cone of depression increases.

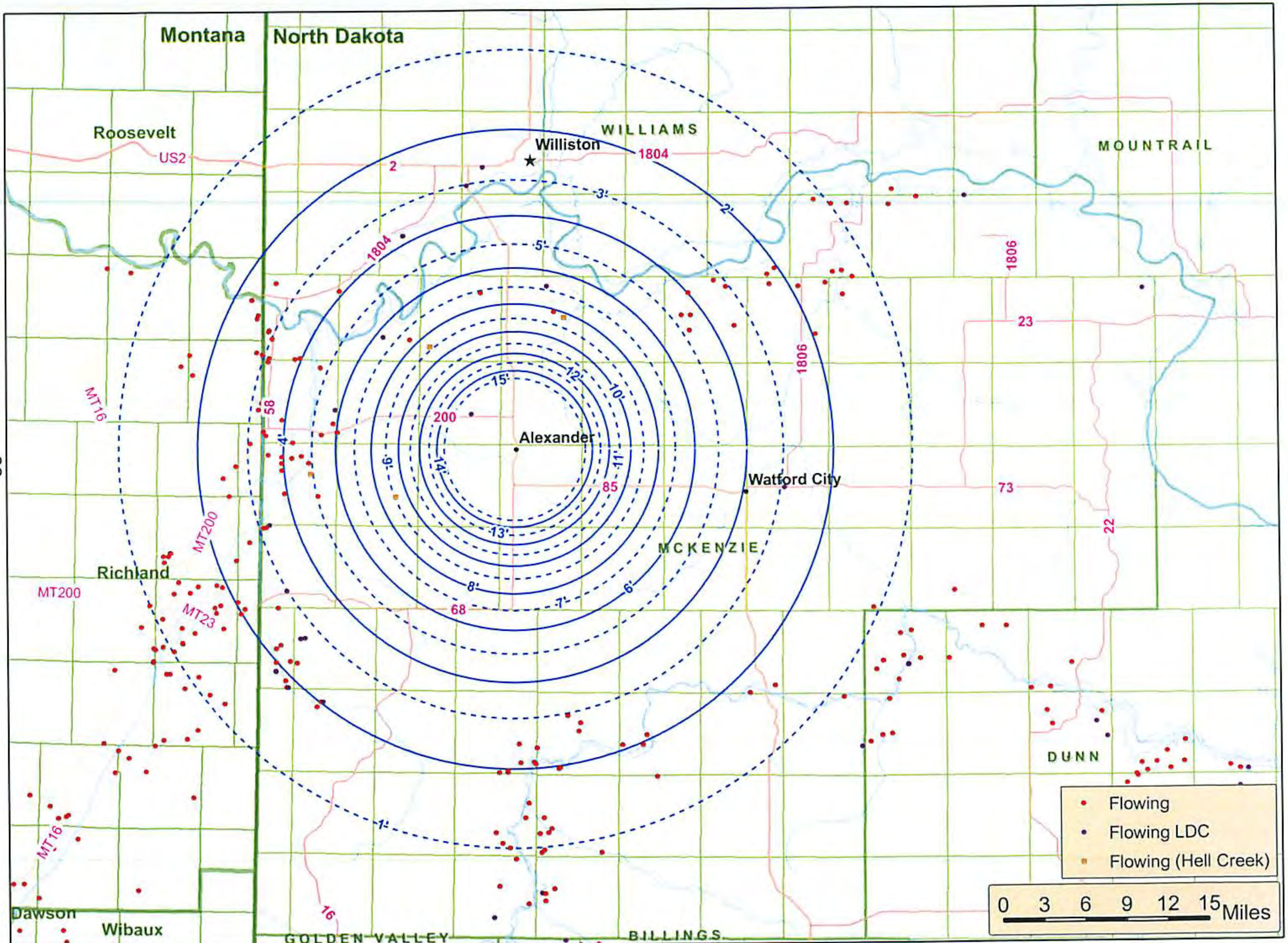


Figure 24. Projected FH-HC aquifer pressure head decline, in feet, after 20 years of pumping at 123 ac-ft/yr (76.4 gpm)

Water quality comparison:

Jim Fixen, the operator of the City of Alexander's water system, said in a telephone conversation that one of the advantages of using the City of Alexander's water for supplying a rural water system is the quality of the City's treated water. For comparison purposes, the dissolved concentrations of selected ions in water samples collected from three area municipal water supplies and a Fox Hills well are listed in Table 8. In or about 2005, the City of Alexander began treating its Fox Hills municipal water by reverse osmosis. The City of Williston's municipal supply is from the Missouri River. Watford City's municipal supply is from wells completed in the Tobacco Garden aquifer, screened within about 100 feet of land surface. Analyses of municipal water samples were provided by the Department of Health and are for treated water. Included in Table 7, for comparison, is an analysis of untreated water from a Fox Hills well seven miles west of Alexander.

Table 8. Dissolved solids concentrations from selected water supplies

Constituent	Alexander	Williston	Watford City	150-103-01BDA
Source	Fox Hills, treated	Missouri River	Tobacco Garden aq.	Fox Hills, untreated
Sample date	May 14, 2007	May 20, 2002	June 4, 2007	Nov 7, 2005
Total dissolved solids	142 mg/l	319 mg/l	1,210 mg/l	1,260 mg/l
Sodium	56 mg/l	54 mg/l	198 mg/l	538 mg/l
Calcium	Not detected	37.5 mg/l	54 mg/l	< 2 mg/l
Magnesium	Not detected	8.2 mg/l	20 mg/l	< 1 mg/l
Sulfate	0 mg/l	162 mg/l	437 mg/l	< 0.3 mg/l
Chloride	22 mg/l	13 mg/l	16 mg/l	151 mg/l
Fluoride	0.45 mg/l	1.45 mg/l	1.07 mg/l	5.42 mg/l
Iron	0.05 mg/l	Not detected	0.1 mg/l	0.025 mg/l
Manganese	Not detected	Not detected	0.01 mg/l	< 0.01 mg/l
Total alkalinity	96.5 mg/l	81 mg/l	473 mg/l	937 mg/l
pH	8.3	9.2	7.2	8.7

The City of Alexander's treated water is very low in the concentration of dissolved solids, 142 milligrams per liter (mg/l), as compared to Williston's 319 mg/l, which is also low. Watford City's 1,210 mg/l dissolved solids and the Fox Hills well's 1,260 mg/l dissolved solids are more typical of western North Dakota groundwater sources. Dissolved calcium and magnesium, associated with 'hardness' in water, are below detection limits in the City of Alexander's treated water, but present is Williston's and Watford City's municipal supplies.

With respect to the relative costs of water from the City of Alexander and an alternative water source, water from the City of Williston, one estimate was that water from Alexander would be less expensive. Another estimate was that the costs of water from the City of Williston's water treatment plant and reverse osmosis water from the City of Alexander would be close to the same.

Letters filed with the applications:

City of Alexander Application No. 5990:

No letters of concern were filed with the City of Alexander Water Permit Application No. 5990, for 170 acre-feet of water per year for rural water use.

Linda Monson Application No. 5934:

Two letters of concern were filed with Linda Monson's application for 50 acre-feet of water per year for industrial use from her farmstead location 6.5 miles southwest of Alexander. Rodney Wolf, Killdeer, who owns neighboring land, wrote a letter regarding road use associated with a Monson water depot. Cindy Klein, Dakota Resource Council (DRC) Oil & Gas Task Force, wrote a letter regarding use of the water by the oil industry.

Rodney Wolf's letter:

Rodney Wolf writes in an August 8, 2007 letter, "This is to inform you I have no objection to Linda's request."

"However, I do have a concern that any water for industrial use is not transported over the road going to and from the Jackson oil well site, traveling through NE1/4-33-150-102."

Response to Mr. Wolf's letter:

A road has been constructed along the section line between Sections 28 and 33 of Township 150 North, Range 102 West (Fig. 16), to Zenergy's Jackson 1-29H oil well in southwestern Section 28. The first ¼-mile of the road (from the east) is about 200 feet south of the section line, on Mr. Wolf's land. It is understood from a telephone discussion with Mr. Wolf that Zenergy has an easement for use of the road on his land to access the Jackson site and a proposed oil well site, but the township or county does not have an easement with him. Mr. Wolf writes he would like the road land to eventually be reclaimed.

Since the letter was written, Zenergy has had a Fox Hills well installed at the Jackson 1-29H oil well location for a source of water. A proposed Dawson 1-33H oil well immediately south of the Jackson site has not been installed. Should Ms. Monson's application be granted, the access to the Fox Hills well on her farmstead would likely be from the east, along the road leading to her farmstead, ½-mile south of the section line road described above. In any case, the issues raised by Mr. Wolf were truck-travel-related rather than water-related. Mr. Wolf, for a water supply on his farm, has springs on his land, emanating from the lower Sentinel Butte Formation in addition to lower Sentinel Butte or upper Tongue River (Bullion Creek) wells, and access to a Zenergy water supply well completed about 800 feet above the FH-HC aquifer. Neither of Mr. Wolf's water sources would be affected by the proposed pumping in the FH-HC aquifer.

Cindy Klein's letter:

A letter was received on September 24, 2007 by fax from Cindy Klein, DRC. The letter was time-stamped 19:23, two hours and 23 minutes after the 5 PM comment deadline for the application. Ms. Klein subsequently informed the State Engineer's office that the time on the DRC fax machine was not set correctly, and telephone billing records, which she provided, show the connection for the 1.3 minute fax transmission was made at 3:59 pm, Mountain Daylight Time, one minute before the comment period deadline expired.

In her letter, Ms. Klein writes that she understands Zenergy has offered to purchase brine dilution water from Ms. Monson, should her application be granted. Ms. Klein writes that the DRC is opposed to water use for this purpose, where the water is ultimately injected deep underground. Ms. Klein writes that one positive aspect of Ms. Monson's application is the potential water right being retained locally, rather than by out-of-state corporations.

Ms. Klein goes on to write that ranchers could be affected by the amount of Fox Hills water proposed to be used, citing the declining head of the FH-HC aquifer. Ms. Klein writes that the 1985 McKenzie County groundwater study should be updated before any more water permits are issued, noting recent water use related to oil and gas production. Ms. Klein writes that more monitoring wells should be installed where water is used for production of oil and gas.

Response to Ms. Klein's letter:

Ms. Klein raises the issue that the use of fresh water for brine dilution, requiring the water to be disposed of, is a waste of water. When water entrained with produced oil is saturated with respect to salt, it is necessary to dilute the brine to prevent it precipitating onto production tubing and equipment. The slightly diluted saltwater is injected into the Dakota aquifer, at about a mile depth in the Williston Basin. The use of water, when necessary, to produce oil, a commodity of value, is considered a beneficial use.

Ms. Klein writes of the declining head of the FH-HC aquifer and the need to update the 1985 county groundwater study, and install more monitoring wells. As described in this memo, over the past year water use from the FH-HC aquifer has been updated and the issue of permitted use from the aquifer addressed. Parts 1 and 3 of the county ground water studies, a description of the geology and ground water resources respectively, do not need updating. The boundaries drawn for glacial aquifers may be adjusted in areas where additional test drilling has taken place. The type of information available in Part 2 of the county ground water studies, a compilation of basic data (wells, test holes, water quality, water levels), is continuously updated on the State Water Commission web site, www.swc.nd.gov. Additional monitoring wells have been installed in water use areas. Monitoring in the FH-HC aquifer has been discussed in this memo.

Lyle Bratcher Application No. 5963:

Eleven letters were received in response to Lyle Bratcher's application for 250 acre-feet of water per year for industrial use, from a location about eight miles south of Alexander. Letters were received from the City of Alexander, Alan Sims, Jesse Monson, Jaret Wirtz, Manager, McKenzie County Water Resources District Board, Cindy L. Klein, DRC Staff, Oil and Gas Task Force, Ned Hermanson, Kit James, Milton and Clarice Madison, Craig and Denise Wahlstrom, Les Haugen, and Ray Powell.

City of Alexander's letter:

A January 4, 2008 letter was received from the City of Alexander, signed by Mayor Kay Glick, council members Lance Powell, Chad Simonson, Joe Mrachek, and Terrille Jacobson, and Operator Jim Fixen. The letter states, "Hence the City of Alexander's only source of water supply is the Fox Hills aquifer. Therefore would like to record a Registration of Concern for the following Water Permits:" followed by a listing of four water permit applications, including Lyle Bratcher's Permit Application No. 5963.

Response to the City of Alexander's letter:

The City's concern is noted. The proposed Bratcher depot is slightly less than eight miles south of the city's wells. Use of the entire 250 acre-feet of water requested would result in an accelerated decline in the FH-HC aquifer pressure head in Alexander. The City's 1982 Fox Hills well has 6-inch diameter casing to 520 feet below land surface and 2-inch diameter casing starting at 504 feet and extending to 1,760 feet below land surface, with 84 feet of casing perforated. The static water level of the FH-HC aquifer at Alexander's city wells is probably about 150 feet below land surface.

Alan Sims' letter:

Alan Sims writes in a January 16, 2008 letter that water has always been a big concern in western North Dakota, and that the oil industry is competing with agriculture for water. Mr. Sims asks what our studies indicate and states that he is against the application.

Response to Mr. Sims' letter:

Fox Hills aquifer water use for stock and domestic purposes and by industry is discussed at length in this memo and will be a primary consideration in making a recommendation on the application. The Sims Farmsteads are located about 4.5 miles south and slightly east of Mr. Bratcher's proposed depot. One well driller's report is available, for a 182 feet deep domestic well, at the Sims farmstead, installed in 1984.

Jesse Monson's letter:

Jesse Monson writes in a January 21, 2008 letter about his concern for the quantity of water Lyle Bratcher has requested. Mr. Monson goes on to write that Mr. Bratcher has located the proposed depot, and therefore the associated disruption caused by tanker truck traffic, away from his farmstead but near a neighbor's home. The Artie Weber farmstead is located ¼-mile north of Mr. Bratcher's proposed depot location.

Response to Mr. Monson's letter:

Part of the concern raised regarding the Bratcher application probably is because he has requested 250 acre-feet of water per year, as compared to the Monson's request for 1/5 as much water. Jesse Monson is the son of Linda Monson, who has a pending request for 50 acre-feet of water per year for industrial use. The disruption created relating to an industry, as the truck traffic, is a zoning issue, governed locally by the township or county zoning board. In considering applications for water the State Engineer's office must consider the effect of the proposed use of water on the water source.

Jaret Wirtz' letter:

Mr. Wirtz, writing for the McKenzie County Water Resource District Board in a January 10, 2008 letter, asks for more information regarding Mr. Bratcher's application. Mr. Wirtz asks for the purpose of the proposal and the expected aquifer.

Response to Mr. Wirtz' letter:

I responded to Mr. Wirtz' letter in a February 19, 2008 letter, writing that the Bratcher application is for industrial use, from ground water. I wrote that I had not contacted Mr. Bratcher for details of his proposed project. I wrote that the FH-HC aquifer is the one known ground-water source underlying the location likely to (possibly) be capable of supplying fresh water in the quantity requested. I went on to say that with respect to accessing the FH-HC aquifer, we consider the quantity of water requested, the proximity of the proposed well to flowing-head wells, and possible alternative water sources.

Jaret Wirtz' second letter:

Mr. Wirtz responded for the water resource board in a March 26, 2008 letter, opposing Bratcher Application No. 5963. Mr. Wirtz writes that granting the application would jeopardize domestic supplies in and around Alexander and would conflict with a planned rural water system near Alexander.

Response to Mr. Wirtz' second letter:

Granting the Bratcher application in its entirety would create the potential, particularly if all the appropriated water were pumped from the FH-HC aquifer, to reduce the length of time nearby flowing-head Fox Hills wells flowed. The only known fresh water source from the location capable of producing the requested quantity of water, the FH-HC aquifer, is also the source the City of Alexander proposes to use to serve a rural water system.

Cindy Klein's letter:

Cindy Klein, writing for the DRC in a January 21, 2008 letter, makes the following points and asks that the application be denied:

1 Ms. Klein writes that residents within one mile of the proposed appropriation were not given notice.

Response: Area residents Kit James, Craig and Denise Wahlstrom, and Ray Powell also wrote that they had not received notification. Notices were later sent to five additional landowners not contacted when notices were originally sent out: Henry and Laura Lebak, Kit and Fredrick Kole James, Randy and Patricia Adler, Leland and Beverly Evjen, and Craig and Denise Wahlstrom. The comment deadline was reset to April 5, 2008. Ray Powell's land, as shown in the 2004 McKenzie County Atlas, begins one mile west of the quarter section proposed for the point of diversion, just beyond the required notification area.

2 Ms. Klein writes that the application does not state the depth, or aquifer from which the applicant intends to take water, which DRC believes is a violation of due process.

Response: The conditional ground water permit application process does not require specifying the intended water source. Depending on the setting, more than one source of water may be possible and it may not be known until more extensive testing is performed which source (aquifer, formation) will be used. In considering an application for water use, the State Engineer can restrict appropriation to a specific aquifer to protect the rights of prior appropriators.

3 Ms. Klein writes that line 7(c) of the application, describing the arrangement made with the landowner to access the proposed point of diversion, was not completed.

Response: Line 7, Ownership, of the application has parts a, b, and c. Line 7(a) is for listing the owner at the point of diversion, line 7(b), applicable to irrigation applications, is for listing the owner at the point of use (irrigated land), and line 7(c) is for describing the arrangement made with the landowner, if other than the applicant. On line 7(a) of Bratcher Application No. 5964 the property owners are listed as the James R.

Chitwood Family Trust UDT 4/17/1990 and the Beulah B. Chitwood Family Trust UDT 4/17/1990. Line 7(c) of the application was left blank. Although the applicant is listed on Line 1 of the application as Lyle Bratcher, the application is signed by Lyle, his wife, Sharon, son, Troy, and Gene Koch, Trustee for the Chitwood Family Trusts. In a December 4, 2007 letter to the State Engineer, Gene Koch writes that he is Trustee for the two Chitwood family trusts, notes cosigning the permit application, and writes that he is in favor of the application. A copy of the agreement for Gene Koch to serve as trustee for the two Chitwood family trusts has been included in the Bratcher permit application file, along with quit claim and trustee's deeds that include in the family trusts the land proposed in the permit application for the point of diversion.

4 Ms. Klein writes that water levels in McKenzie County have been declining, particularly in the FH-HC aquifer as shown in monitoring wells completed in the aquifer, putting users in danger, particularly users with flowing-head, small diameter wells. Ms. Klein writes that granting the large appropriation requested by Mr. Bratcher would not protect water users with priority use rights.

Response: The pressure head of the FH-HC aquifer has been declining, as discussed in this memo. While there is about 1,500 feet of pressure head above the top of the FH-HC aquifer, available to efficiently completed wells, in considering the public interest, further pumping of water from the aquifer will shorten the time until flowing head wells stop flowing. Most of the flowing head wells are completed with small diameter casings that cannot accommodate installation of a pump and many are in remote locations, away from electrical power. The degree to which further use of water from the FH-HC aquifer should be curtailed so as to not shorten the time until pressure heads decline below land surface, is a primary consideration when evaluating applications where the FH-HC aquifer is the likely water source.

5 Ms. Klein writes that conservation measures to reduce the pressure head decline in aquifers with a flowing head are recommended in the county ground-water study, brochures discussing flowing-head wells, and the most recent report describing pressure head changes in the FH-HC aquifer. Ms. Klein asks why are conservation measures [not] being put into practice and writes that issuing the Bratcher application would not be in the spirit of conservation.

Response: As discussed in this memo, much of the water extracted from the FH-HC aquifer is the excess water flowing from wells. Owners of flowing wells are encouraged to minimize the amount of water allowed to flow. Bratcher application considerations are more applicable to Point 4, above.

6 Ms. Klein writes that diluting brine in oil production is wasting water and is not a beneficial use.

Response: The same point was made in Ms. Klein's letter addressing the Monson application, and was discussed above. As a necessary part of crude oil extraction, water used for brine dilution in oil wells is considered a beneficial use.

7 Ms. Klein writes that the Winters Doctrine reserves water on National Grasslands.

Response: Water from the FH-HC aquifer is commonly used in stock wells on federal land, often piping water to multiple pastures. Like private wells, water from the FH-HC aquifer is available and will continue to be available to efficiently completed wells. Like private wells, the use of the FH-HC aquifer's flowing head will be a public interest consideration. Of 55 Fox Hills (or, in a few cases, probably Hell Creek) wells inventoried that are associated with the Little Missouri, Medora, or McKenzie County grazing associations and presumably on federal land, 25 at least initially had flowing heads.

8 Ms. Klein writes that the Public Trust Doctrine requires a determination of the effect of a proposed appropriation on present and future needs of the state.

Response: The effect of the proposed water use, lowering the pressure head of the presumed target aquifer, and its expected effect on other water users, was discussed in this memo and is a consideration in making a recommendation on the application.

9 Reiterating Point 6, above, Ms. Klein writes that a new county ground-water study needs to be done to determine if prior water rights will be unduly affected.

Response: The same point was made in Ms. Klein's letter addressing the Monson application, and was discussed above. The well inventory comprising part two of the county ground water studies is continuously updated on the State Water Commission internet web site. Available data is sufficient to provide the basis for evaluating these water permit applications.

10 Ms. Klein writes that the Bratcher application, if granted, would affect the City of Alexander's water right and the City's pending application.

Response: Water is available to the City from efficiently completed wells. The City's application is a consideration with respect to the Bratcher application.

11 Ms. Klein writes that the initial comment period expired on January 21, 2008, a holiday.

Response: The comment expiration day was inadvertently set on Martin Luther King Jr. Day. A letter received the following day would have been considered part of the record for Mr. Bratcher's permit application. In any case, when it was determined that not all landowners within one mile of the proposed point of diversion area had been notified, the comment deadline was extended until April 5, 2008.

Many of the points made in Ms. Klein's letter were reiterated in letters of concern from Ned Hermanson, Kit James, Milton and Clarice Madison, Craig and Denise Wahlstrom, Les Haugen, and Ray Powell, and were discussed above. Concerns or information from these parties that have not been previously discussed will be addressed below.

Ned Hermanson's letter:

1 Mr. Hermanson writes that the state should not overly rely on water modeling to predict the effect of a proposed appropriation.

Response: I have not overly relied on modeling in my analysis.

2 As an example of the oil industry's negative impact on ranchers, Mr. Hermanson cites a US Forest Service/McKenzie County Grazing Association well in Section 1 of 150-103, in which the flowing head had declined to a trickle by 2006. Mr. Hermanson writes that that I had projected the well to flow until 2014.

Response: Using a rate of pressure head decline determined from the well's pressure head as listed on the well driller's report and a measured pressure head in 2005, the well was projected to flow until late 2012. The pressure head of the well was measured in May 2009 at three feet below land surface, for a rate of decline the past 3.5 years at 3.28 feet per year, probably about double the earlier pressure head decline rate, based on monitored wells to the north and south.

Kit James' letter:

Kit James writes that he has four Fox Hills wells, one of which has stopped flowing. Mr. James writes, "One of these wells is being used for my domestic household use. The others supply water for my cattle herd. There is no electricity out in the areas of those wells and they are flowing artesian wells, therefore there is only 1.25" casing. There is no way to submerse any pumps. Should the head pressure decline in such a way that makes those wells unusable, the only alternative is to drill an entirely new well. That is not feasible for my ranching operation." Mr. James writes that he lives near the proposed water use and is concerned for the viability of his water source.

Response to Mr. James' letter:

Mr. James sums up the situation ranchers with flowing head wells are facing.

Milton and Clarice Madison's letter:

The Madisons, who live about five miles south of the proposed appropriation, write that they depend on Fox Hills well for watering cattle, their shallower wells no longer providing enough water for the ranching operation.

Response to Mr. and Mrs. Madison's letter:

The Madisons' Fox Hills well, located about four miles south of the proposed Bratcher appropriation, 11.5 miles south of Alexander, is completed with 9 5/8" casing set to about 3,100 feet and plugged back to about 3,050 feet, then perforated opposite the FH-HC aquifer. Based on the surface elevation, the pressure head in the Madison's well is expected to be about 150 or 200 feet below land surface, leaving the Madisons adequate pressure head in their well for their use.

Craig and Denise Wahlstrom's letter:

The Wahlstrom's write that they have a new Fox Hills well on land they own in Sections 7 and 18 of 149-101 (nearby west and northwest of the Bratcher proposed appropriation), as well as a spring they use.

Response to the Wahlstrom's letter:

A well driller's report was not found for the Wahlstrom's new Fox Hills well (it may not have been processed yet or the well driller may not have filed it yet). With an expected pressure head about 100 or 200 feet below land surface, a Fox Hills well should have been installed with sufficient large diameter casing in its upper portion to meet future needs. Mr. Wahlstrom may have been thinking of a shallower well, completed in October 2005 in Section 7 of 149-101, with perforated pipe between 18 and 26 feet below land surface. The FH-HC aquifer underlies Mr. Wahlstrom's land at an estimated 1,600 feet below surface.

Les Haugen's letter:

Les Haugen writes that his family uses a Fox Hills well for his grazing operation in Section 16 of 148-102, adding that 900 head of cattle are watered from this well, which has shown a significant pressure head decline.

Response to Mr. Haugen's letter:

Mr. Haugen manages a McKenzie County Grazing Association/US Forest Service Fox Hills well in Section 15 of 148-102, 6.5 miles south of the Bratcher application area and 14 miles south of Alexander. The hole for the well was drilled in 1979 as part of the McKenzie County ground water study. The McKenzie County Grazing Association and/or the US Forest Service had casing installed and a well completed in the drilled hole. Pressure heads were measured in the well in the 1980's and 1990's, and again in 2008 and 2009. On May 4, 2009 the pressure head in the well was 264.9 feet below the well top. The pressure head in the well is declining at a rate of about 1.8 feet per year. The well was completed with 4-inch diameter casing set to 1,695 feet below land surface, with an open-hole completion and the casing annulus cemented. By lowering the pump in the well if necessary (and possible), the aquifer has sufficient pressure head for continued operation. If the pump is stuck in the relatively small diameter well for holding a pump, future use of the well may be problematic.

Ray Powell's letter:

Ray Powell writes that he has a farm in Sections 12 and 13 of 149-102, about one mile from the proposed appropriation and that he raises cattle reliant on groundwater.

Response to Mr. Powell's letter:

Well driller's reports are available for wells at the Dennis and Ray Powell farm(s) at depths of 40, 55, 56, and 105 feet. Mr. Powell has registered a spring, which is used for watering stock. The FH-HC aquifer is expected about 1,550 feet below land surface at the Powell's farm(s).

Criteria for issuance of a permit:

Section 61-04-06 of the North Dakota Century Code lists the criteria to be considered when evaluating a water permit application. As stated in Section 61-04-06, *The state engineer shall issue a permit if he finds all of the following:*

1. The rights of a prior appropriator will not be unduly affected.

North Dakota Century Code, Section 61-04-06.3 Priority, states, in part,

"Priority of appropriation does not include the right to prevent changes in the condition of water occurrence, such as the increase or decrease of streamflow, or the lowering of a water table, artesian pressure, or water level, by later appropriators, if the prior appropriator can reasonably acquire the prior appropriator's water under the changed conditions."

In Ms. Monson's and City of Alexander's wells the pressure head of the FH-HC aquifer is about 1,500 feet above the top of the aquifer. Water is available from efficiently completed wells in the FH-HC aquifer in the vicinity of the water use proposed in the Monson, Bratcher, and City of Alexander applications.

2. The proposed means of diversion or construction are adequate.

The wells must be constructed by a North Dakota certified water well contractor (or by the applicant) in compliance with the construction rules of the North Dakota Health Department and the North Dakota Board of Water Well Contractors. Certified water well contractors have constructed the in-place wells.

3. The proposed use of water is beneficial.

The proposed water use for the Monson and Bratcher applications is industrial, primarily for brine dilution in oil wells completed in the Ratcliffe interval, necessary for operation of the wells and the extraction of crude oil, a commercial product having economic value. The City of Alexander's application is to supply a rural water system, also a beneficial water use. The proposed rural water supply would include supplying an industrial customer, Zenergy, with water to be used for brine dilution.

4. The proposed appropriation is in the public interest. In determining the public interest, the state engineer shall consider all of the following:

a. The benefit to the applicant resulting from the proposed appropriation.

The applicants would benefit by revenue from the sale of water.

b. The effect of the economic activity resulting from the proposed appropriation.

The water that would be provided is necessary for an area industry and would be a better quality water for area residents. However, the reduction in the time flowing-head wells continue to flow would negatively affect the area's ranching industry.

c. The effect on fish and game resources and public recreational opportunities.

No effect is expected on fish and game resources and public recreational opportunities from the proposed water use.

d. The effect of loss of alternate uses of water that might be made within a reasonable time if not precluded or hindered by the proposed appropriation.

Possible alternative uses are similar to the proposed uses, that is, stock and domestic water supplies and industrial use.

e. Harm to other persons resulting from the proposed appropriation.

The proposed use of Fox Hills water would reduce the time flowing head wells completed in the aquifer will continue to flow. For this reason, industrial water use has, at times, been restricted from the FH-HC aquifer, depending on the quantity of water expected to be needed, the proximity of the proposed supply wells to flowing head wells, and possible alternative water sources.

f. The intent and ability of the applicant to complete the appropriation.

The City of Alexander has the intent and ability to complete the appropriation. A third municipal well is planned. The reverse osmosis water treatment is ongoing.

The intent and ability of the Monson and Bratcher applications to complete the appropriation are a little more complicated. Ms. Monson's stock water supplies were affected by saltwater from a leaking pipeline and a Fox Hills well was installed as a replacement supply. Water is now piped from Ms. Monson's Fox Hills well to pastures, passing within a few hundred feet of Zenergy's Jackson 1-29H oil well. In the summer of 2007, when Ms. Monson applied for a water permit, Zenergy was considering purchasing water from her for the Jackson well, and possibly other area oil wells. Since that time, Zenergy has had a Fox Hills well installed at the Jackson location, and four other locations in the southeastern part of the Foreman Butte field (Fig. 17). Other drilling locations originally proposed for the southern part of the Foreman Butte oil field have been withdrawn or allowed to lapse. In a telephone conversation, Keith Hill, Operations

Manager with Zenergy, expressed a preference for the treated water from Alexander for use in their oil wells. Therefore, while the proposed water source, Ms. Monson's recently installed Fox Hills well, is in place, there seems to be little prospective water sales market for Ms. Monson.

Lyle Bratcher's situation is similar to Ms. Monson's in that the intention was primarily to supply water to Zenergy's Ratcliffe oil wells from a location slightly south of the southeastern part of the Foreman Butte field. Mr. Bratcher's application was made working with an attorney retained by Zenergy and with an officer of an oil service company acting as an agent for Zenergy. One difference between Mr. Bratcher's situation and Ms. Monson's is that Mr. Bratcher does not have an in-place well that could serve as a water source, should the application be granted. For the 250 acre-feet per year of water requested by Mr. Bratcher, or for even 1/10 of that quantity of water, Mr. Bratcher's only likely water source is the FH-HC aquifer, expected between about 1,600 and 1,700 feet below land surface at the proposed well location. As is the case with Ms. Monson's application, the planned market for the proposed water sales has changed since the time of the application. However, having completed the water permit application process, both Ms. Monson and Mr. Bratcher preferred to have their applications considered rather than to request they be withdrawn.

The public interest criteria have been considered. Taking the last public interest criterion first, the intent and ability of Ms. Monson and Mr. Bratcher to complete their requested appropriations is somewhat in doubt, in that since the applications were made the primary customer for the water, Zenergy, has participated in a planned pipeline for the area, as a potential water source.

The public interest criterion to be addressed in more detail is Criterion 4e, harm to others from the proposed appropriation. As has been the case with other applications for water in which the FH-HC aquifer is a possible source, the effect of the proposed pumping on the flowing pressure head of the aquifer is considered along with possible alternative sources, the quantity of water requested, and the proximity of the proposed water supply source to the flowing head wells. The effect of the proposed appropriations on the flowing pressure head will be reviewed in the following section.

Discussion of public interest criterion 4e, harm to others:

Ongoing Fox Hills water use:

As has been the case with other applications from the FH-HC aquifer, while there is sufficient pressure head above the top of the aquifer so that efficiently completed wells will not be adversely affected, the value to ranchers of the flowing pressure head is recognized as worthy of consideration under the public interest. To address nine pending water permit applications for a total of 1,325 acre-feet of water annually, for which the FH-HC aquifer is the expected water source, Fox Hills wells have been inventoried, water use from the aquifer has been reviewed, the effects of ongoing use compiled, and projections made of the effect of additional water use. It was found that, while more water is likely to be discharging from the FH-HC aquifer through stock and domestic wells, primarily flowing head stock wells, than is being pumped for municipal and industrial use, the municipal and industrial use still makes up a significant portion of the water taken from the aquifer. Further, it was found that while there are well integrity problems and the flow from some Fox Hills wells could be reduced, nearly half the flowing head stock wells were valved to one gpm flow, or less, and the stockmen are very aware of the declining pressure head of the aquifer and that their wells will eventually stop flowing.

Proposed water use:

The proposed water use under the three applications in western McKenzie County was reviewed in greater detail. The Monson and Bratcher applications, for 50 and 250 acre-feet per year were made, as I understand it, working with Zenergy to serve their Ratcliffe oil wells in and near the Foremen Butte oil field southwest of Alexander. The City of Alexander application for 170 acre-feet annually for rural water also includes supplying water to at least some of the Zenergy wells, as well as about 100 connections for domestic and stock water use, the inclusion of Zenergy helping to make the planned rural water system viable.

From a review of reported water use by other rural water systems in the state, including a system around Watford City, it is estimated that 25 or 30 acre-feet of water annually is likely required for the 100 rural water connections around Alexander proposed to be initially supplied by System 4. If that were all the water required, the City of Alexander could supply the water under authority of its two water permits with room for growth, if the City were not supplying water through its sales depot, much of which is being trucked to Zenergy's oil wells. For the City of Alexander to supply its municipality, area brine dilution needs, and the proposed rural water customers and allow for some growth, the City would require about 70 more acre-feet of water annually than is currently appropriated to the City.

Sixteen of 46 Zenergy oil wells southwest of Alexander are supplied by permitted wells completed in the basal Tongue River aquifer, a deeper sandy interval, or in the FH-HC aquifer. The source of water for the remaining 30 Zenergy oil wells in the Foreman Butte field, requiring about 48 acre-feet of water annually, is a primary consideration in addressing the three applications. If water for Zenergy's oil wells was excluded from the planned rural water system, the alternative water sources available to Zenergy are other area Fox Hills wells (water they could purchase from the City of Alexander or the water depot south of Alexander, or from their own wells having a little available appropriated capacity). The only known, practical alternative water supply to the FH-HC aquifer for Zenergy's Foreman Butte oil wells is a pipeline with a source other than Fox Hills water.

In any case, a rural water system is expected to supply 20 or 30 acre-feet to about 100 rural connections, probably increasing in the future, plus much of the about 48 acre-feet of water required for Zenergy. The water source for the proposed rural water system is to be either the FH-HC aquifer, or some other water source, such as the Missouri River.

Proximity to flowing-head Fox Hills wells:

In western McKenzie County there are flowing-head Fox Hills wells in and near three river valleys, the Little Missouri, the Yellowstone, and the Missouri (Fig. 11). The City of Alexander, as well as the proposed points of diversion of the Monson and Bratcher applications, are somewhat centrally spaced in western McKenzie County, being between about 15 and 20 miles from the valleys (Fig. 15). However, the presence of flowing-head Fox Hills wells along the three valleys make the general area one where additional water use from the FH-HC aquifer will affect many wells.

Effect of pumping for the planned appropriation:

The pressure head of the FH-HC aquifer is declining in western McKenzie County at between about 1.5 and 3 feet per year (Fig. 19). The flowing-head Fox Hills wells in western North Dakota will eventually stop flowing as the pressure head declines to land surface at the locations of the wells. Additional pumping from the FH-HC aquifer will increase the rate of pressure head decline, causing wells to stop flowing earlier than they would have otherwise. In 16 flowing-head wells reviewed, the projected effect of pumping 123 acre-feet of water per year was to shorten the remaining time the wells would flow by between about 4 and 7% for wells located between 15 and 30 miles from Alexander, with larger projected reductions (11 and 14%) for wells between 10 and 15 miles from Alexander (Fig. 23). Initial water use serving 100 connections, plus Zenergy, may require about 2/3 of the projected 123 acre-feet of water considered. The effect of less water use would be proportionally less.

Cost of replacing a flowing-head Fox Hills well:

Once the flowing pressure head of a small-diameter Fox Hills well declines below land surface, it may be possible to drill over the well to 200 or more feet below surface, install larger-diameter casing, and cut off the upper small-diameter casing. The cost of the retrofit would be similar to that of a well the depth of the large-diameter casing. The condition of the remaining small-diameter casing may be a concern when considering a retrofit. Alternatively, the Fox Hills well could be replaced with a shallower well, installed in a sandy interval or a shallow lignite bed. In either case, a power source to operate a pump would be needed.

The cost of replacing the Fox Hills well with another Fox Hills well would be between $50,000 and $100,000, probably closer to the latter than the former, if properly installed. An area water well contractor estimated the cost of a Fox Hills well installed with 1,100 feet of five-inch diameter steel casing, cemented in place for its entire length. The well would be completed with two-inch diameter screen set between 1,100 and 1,150 feet, attached to a two-inch diameter riser pipe extending from the top of the screen up into the five-inch diameter casing. Including a pump and works, the cost of the well was estimated as $73,700. The estimate did not include the cost of supplying electrical power to the location. For a well completed as described above, but screened between 1,500 and 1,550 feet, the cost was estimated as $86,600.

Alternative water supplies:

For Ms. Monson, Mr. Bratcher, and the City of Alexander, their only likely source of water sufficient to supply the proposed uses is the FH-HC aquifer. However, and given that the operator's preferred alternative to supply the oil field is a pipeline through the area, the proposed rural water system does have alternatives. The system 4 service area butts up against the System 1 service area supplied out of Watford City, crosses the Charbonneau aquifer, and extends north to the breaks of the Missouri River valley, across the valley from Williston's water treatment plant. While not as low in total dissolved solids as the City of Alexander's treated water, the treated Missouri River water is still of high quality, one of the principal difference to consumers being the presence of calcium and magnesium in the Williston treated water, contributing to hardness.

Summary:

Since the early 1980's, industrial water permit applications in the vicinity of flowing-head Fox Hills wells have, at times and on a case-by-case basis, been directed to alternate sources, if available, depending on the quantity of water requested. The planned Alexander-area rural water system, including some industrial use, requires a significant amount of water, probably initially somewhat less than 100 acre-feet annually, but possibly growing to over 100 acre-feet annually, at least during the remaining economic 'life' of the Foreman Butte oil wells, which is probably a few decades. The location of the proposed use, while centrally spaced from the flowing head wells along the Little Missouri, Yellowstone, and Missouri river valleys, is generally located in one of the larger concentrations of flowing-head Fox Hills wells. Although area Fox Hills wells will stop flowing eventually, the additional proposed water use is expected to reduce that remaining time, generally speaking, by a few years, or between about 4 and 7% for wells in McKenzie County along the Little Missouri, Yellowstone, and Missouri river valleys, with larger reductions in the few flowing-head wells within 15 miles of Alexander. While the City of Alexander, as well as Ms. Monson and Mr. Bratcher, do not have alternative water sources to the FH-HC aquifer available on their properties that could realistically meet the needs of the proposed water projects, a rural water system serving western McKenzie County does have available alternatives.

In considering the public interest criteria, the benefits of the proposed water use are compared with, or balanced against, the harm caused by that same proposed water use. The benefits from the City of Alexander supplying a proposed rural water system would be added revenue to the City and a quality of water to customers very low in dissolved solids and essentially absent hardness. The harm from the same proposed use would be locally increasing the rate of pressure head decline in the FH-HC aquifer and shortening the remaining time flowing head wells will continue to flow.

Because of the quantity of water required, the large number of flowing-head Fox Hills wells in the general area, and the existence of alternative sources of water for a planned rural water system, it is my judgment that the benefits to the City of Alexander and potential rural water line customers do not outweigh the harm caused by a reduction in the useful 'lifetime' of flowing-head Fox Hills wells in the area. Similarly, the benefits in water sales revenue to Ms. Monson or Mr. Bratcher do not outweigh the harm to area ranchers with flowing-head Fox Hills wells. Therefore, it will be my recommendation that access to the FH-HC aquifer not be allowed.

While alternative water sources to the FH-HC aquifer exist for a planned rural water system in western McKenzie County, they do not practically exist under points of diversion proposed by Ms. Monson, Mr. Bratcher, or the City of Alexander in Water

Permit Applications No. 5934, 5963, and 5990. There is therefore little point in granting any of the three applications, but including depth conditions on the permits not allowing access to the FH-HC aquifer. It will therefore be recommended that each of the three applications be denied.

In separate memos it will be recommended that Linda Monson Application No. 5934, for 50 acre-feet of water annually at a pumping rate of 75 gpm, and Lyle Bratcher Application No. 5963 for 250 acre-feet of water annually at a pumping rate of 300 gpm, be denied.

Recommendation:

It is recommend that the City of Alexander Application No. 5990 for 170 acre-feet of water annually at 500 gpm, be denied.

Alan Wanek

Alan Wanek, Hydrologist Manager

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Appendix 1:

Fox Hills wells and a few Hell Creek wells as shown in Figure 9

Explanation of column headings:

Well location: Wells are listed by state (1,239 North Dakota wells followed by 340 Montana wells), then by well location (Township, Range, Section, quarter (A=NE, B=NW, C=SW, D=SE), quarter-quarter, and quarter-quarter-quarter (10-acre parcel).

Land elev.: The elevation is in feet above sea level, as estimated from topographic maps in all but a few instances.

Screened interval: The screened interval is in feet below land surface. Most Fox Hills domestic and stock wells in North Dakota are not screened, but instead completed with slotted or perforated well casing, or by open, drilled hole below the bottom of the open well casing. Sometimes only the depth of the well is listed, which may be either the drilled depth or the depth casing was set in the well.

Pressure head: A negative number in this column is the feet the pressure head in the well is below land surface. A positive number is the feet the flowing pressure head is above land surface (2.31 feet of head is equal to 1 psi pressure).

Head cng ft/yr: Is the rate of pressure head change in feet per year, as determined from a hydrograph of pressure heads measured over time in the well. A negative number indicated a declining pressure head.

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
129-074-01BCB	Emmons	B. Weigel	Pumped	Domestic		2000	130			
129-075-20CBB	Emmons	Nieuwsma	Pumped	Domestic		1855	170			
129-076-04ABB	Emmons	Hope Chrch	Pumped	Domestic		2000	150			
129-077-05DAD	Emmons	Vander Laan	Pumped	Domestic		1990	120			
129-077-09DBC	Emmons	Ryckmann	Pumped	Domestic		2000	145-160			
129-078-01DAA	Emmons	Becker	Pumped	Domestic		1820	100-120			
129-078-11DCC1	Emmons	Ryckman	Pumped	Domestic		1900	70			
129-079-07CBD	Sioux	Anton Silbernagel	Pumped	Domestic		1920	210			
129-080-23DDD	Sioux	NDSWC	Monitoring	Monitoring	1973	1927	138-142	-68	1973	
129-081-01BAB	Sioux	NDSWC Ft Yates Sw	Monitoring	Monitoring	1973	1840	98-104	-62	1994	
129-081-25DCC	Sioux	Donald Scheffer	Pumped	Domestic		2210	420			
129-087-10BBC	Grant	NDSWC West Sioux	Monitoring	Monitoring	1972	2060	342-361	-107	1989	
129-092-35S	Adams	City Of Lemmon	Pumped	Municipal		2642	813-913			
129-094-26DDD	Adams	NDSWC	Monitoring	Monitoring	1972	2500	938-948	-200	1972	
129-096-04DCB	Adams	Alfred Rose	Pumped	Domestic		2711	800-880			
129-096-12DBB	Adams	City Of Hettinger	Pumped	Unused	1965	2812	1010-1314	-670	1971	
129-096-13ACA	Adams	City Of Hettinger	Pumped	Unused	1965	2719	940-1140			
129-096-13ADD	Adams	City Of Hettinger	Pumped	Unused	1940	2670	1050	-359		
129-096-13BBB1	Adams	City Of Hettinger	Pumped	Unused	1948	2658	1180	-397		
129-096-13BDD1	Adams	City Of Hettinger	Pumped	Unused	1935	2681	1182	-386		
129-098-31ABB	Adams	Frank Smyle	Pumped	Domestic		2690	800			
129-099-04ABA2	Bowman	V. Czywczynski	Pumped	Domestic		2765	940			
129-099-04CBB	Bowman	W. Kralicek	Pumped	Stock		2730	925			
129-099-20AAB	Bowman	Nordak	Pumped	Industrial	1996	2750	760-930	-180	1996	
129-099-20ABA	Bowman	Nordak	Pumped	Industrial	1996	2750	750-940	-170	1996	
129-104-34ADA	Bowman	NDSWC Bowman Sw	Monitoring	Monitor plug	1971	3013	525-543	-54	1998	
130-072-02ACC	McIntosh	Delmar Schilling	Pumped	Domestic		2190	130-170			
130-072-03BBB	McIntosh	Howard Kaseman	Pumped	Stock		2130	45			
130-072-10ABD	McIntosh	Alvin Wiest	Pumped	Domestic		2210	85			
130-076-18DDA	Emmons	E. Kramer	Pumped	Stock		2060	280			
130-077-01CCC	Emmons	NDSWC Strasburg	Monitoring	Monitoring	1972	1930	37-43	-8	2007	
130-077-23AB	Emmons	M. Wagner	Pumped	Domestic		1980	120			
130-077-23ABC	Emmons	Wagner	Pumped	Domestic		1980	130			
130-078-20AAD	Emmons	Kieffer	Pumped	Stock		1780	80-100			
130-079-09DDA	Emmons	Paul	Pumped	Stock		1710	90-110			
130-080-16DDD	Burleigh	Franky Steel	Pumped	Domestic	1979	1830	430-450	-162	1979	
130-082-36BBC	Sioux	NDSWC Selfridge	Monitoring	Monitoring	1972	2197	480-498	-319	1972	
130-083-36AAA	Sioux	NDSWC Selfridge	Monitoring	Monitoring	1973	2247	504-522	-432	1980	
130-084-36ABA	Sioux	NDSWC Cen Sioux	Monitoring	Monitor plug	1972	2148	399-417	-112	1989	
130-085-17DAA	Sioux	NDSWC Cen Sioux	Monitoring	Monitoring	1972	1910	219-244	-22	1994	
130-086-28CCC1	Sioux	NDSWC West Sioux	Monitoring	Monitoring	1973	2062	406-424	-138	2007	+0.06
130-089-32DDA	Sioux	NDSWC Sioux West	Monitoring	Monitoring	1972	2165	525-543	-57	1981	
130-098-04DBB	Adams	City Of Reeder	Pumped	Unused	1971	2850	1204-1274	-306	1971	
130-098-04DCC	Adams	City Of Reeder	Pumped	Unused	1950	2825	1200			
130-100-14CDD	Bowman	Selma Hedman	Pumped	Domestic	1986	2850	1250	-195	1986	
130-103-11CCC	Bowman	Harley Davis	Pumped	Domestic		3090	651-687			
130-104-03DDD1	Bowman	Ole Oakland	Pumped	Domestic		3138	700			
130-104-21BBA	Bowman	M. Susag	Pumped	Stock		3128	406			
130-104-26DCD	Bowman	Selmer Njos	Pumped	Stock		3123	600			
131-071-07BBB2	McIntosh	NDSWC Wishek W	Monitoring	Monitoring	1977	2166	115-121	-42	2008	+0.56
131-072-12BAA	McIntosh	Wilbert Neis	Pumped	Stock		2160	100-140			
131-073-23DBB2	McIntosh	Arndt Ketterling	Pumped	Stock		2050	47			
131-073-26ABB	McIntosh	Isadore Meidinger	Pumped	Stock		2035	37			

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
131-077-21CAD	Emmons	H. Heidrich	Pumped	Stock		1825	82-122			
131-078-30DBD	Emmons	C. Jochim	Pumped	Domestic		1980	210			
131-079-12BBC	Emmons	H. Nagel	Pumped	Domestic		1860	105			
131-079-15ADD	Emmons	A. Nagel Etal	Pumped	Domestic		1810	120			
131-080-21AAC	Sioux	Joe Running Bear	Pumped	Domestic		1680	240			
131-089-30AAA	Grant	NDSWC Sw Grant	Monitoring	Monitoring	1973	2395	791-809	-323	1994	
131-096-11DAD	Bowman	City Of Bowman	Pumped	Municipal	1943	2959	969-1050			
131-096-14AAB	Bowman	City Of Bowman	Pumped	Municipal	1968	2948	887-1096	-305	1971	
131-096-14ADD	Bowman	City Of Bowman	Pumped	Municipal	1983	2950	876-1200	-383	1983	
131-096-26A	Bowman	Bowman Golf	Pumped	Irrigation	1984	2880	844	-268	1984	
131-099-27CCD	Bowman	Dakota Prairie Beef	Pumped	Industrial	2000	2760	950-1060	-230	2000	
131-099-34BAD	Bowman	Gascoyne Materials	Pumped	Domestic	1973	2750	1244	-160	1973	
131-099-34DAA	Bowman	NDSWC Gascoyne	Monitoring	Monitoring	1973	2760	1254	-160	1973	
131-100-09CCD	Bowman	Archie Frietag	Pumped	Domestic		2845	1068			
131-100-23D	Bowman	City Of Scranton	Pumped	Unused	1936	2800	1180			
131-100-26AA	Bowman	City Of Scranton	Pumped	Unused	1969	2774	1030-1293			
131-101-18BCC1	Bowman	Pearl Lewton	Pumped	Domestic		1985	900			
131-102-02DDA	Bowman	City Of Bowman	Pumped	Municipal	1961	3023	965-1067	-359	1971	
131-102-07DDD1	Bowman	NDSWC Bowman	Monitoring	Monitoring	1972	2945	951-963	-227.5	2003	-0.52
131-102-11CAB	Bowman	City Of Bowman	Pumped	Municipal	1930	2977	962-1042			
131-102-12DD	Bowman	City Of Bowman	Pumped	Unused		2965				
131-102-23BBB	Bowman	Jim Peters	Pumped	Domestic	2000	2960	848	-308	2000	
131-103-08CAC1	Bowman	Jim Lutz	Pumped	Domestic		3141	907-927			
131-104-22CCC	Bowman	Roger Getz	Pumped	Domestic	1996	3185	800-920	-380	1996	
131-104-28AAA2	Bowman	Melvin Miller	Pumped	Domestic		3140	700-765			
131-105-18DCC	Bowman	Garid Larkin	Pumped	Domestic		2800	80-126			
131-105-21ACC	Bowman	Garid Larkin	Pumped	Stock		2990	287			
131-105-23CDD	Bowman	NDSWC	Monitoring	Monitoring	1972	2995	483-495	-66	1972	
131-106-03DAA	Bowman	Laverne Miller	Pumped	Stock		2760	76-96			
131-106-04DCC	Bowman	Laverne Miller	Pumped	Domestic		2920	56-66			
132-073-04CAB	McIntosh	Peter Wald	Pumped	Stock		1940	57			
132-073-07BAA	McIntosh	Kasmer Wald	Pumped	Domestic		1900	14			
132-073-08CBC	McIntosh	Joe Wald	Pumped	Stock		1935	48-52			
132-073-28BAB	McIntosh	Marvin Meidinger	Pumped	Stock		2050	120-160			
132-074-14CDD1	Emmons	J. Aberle	Pumped	Domestic		1870	85			
132-074-14CDD2	Emmons	J. Aberle	Pumped	Stock		1870	85			
132-074-18DCC	Emmons	C. Rohrich	Pumped	Stock		1880	56			
132-076-35ADD	Emmons	M. Wolf	Pumped	Domestic		1910	57			
132-078-34AAB	Emmons	S. Vetter	Pumped	Stock		1710	70			
132-079-01BDC	Emmons	A. Ohlhauser	Pumped	Domestic		1860	200			
132-079-03CDD	Emmons	A. Ohlhauser	Pumped	Stock		1700	100-105			
132-079-14ADB	Emmons	T Walther	Pumped	Domestic		1770	80-90			
132-082-30ADB	Sioux	Joe Kraft	Pumped	Domestic		1930	400			
132-083-29BBB	Grant	Weinhandl Bros.	Pumped	Stock		1780	400			
132-084-16DAA	Grant	NDSWC	Monitoring	Monitoring	1973	1973	378-396	-146	1973	
132-091-28DDD	Hettinger	NDSWC Mott Se	Monitoring	Monitoring	1968	2469	1030	-292	1994	
132-096-20BAA1	Adams	Fred Paulson	Pumped	Stock	1973	2650	997	-157	1973	
132-096-20BAA2	Adams	Fred Paulson	Pumped	Stock	1979	2650	996	-170	1979	
132-097-09CCC	Adams	Lewoin Schoeder	Pumped	Dom/stk	1974	2630	994	-130	1974	
132-097-09CCC2	Adams	NDSWC	Monitoring	Monitoring	1974	2630	1080	-130	1974	
132-100-35DDD	Bowman	Kenneth Freitag	Pumped	Domestic		2904	1050-1200			
132-104-17CCC	Bowman	Richard Izler	Pumped	Domestic		3037	600-630			
132-104-21AAA	Bowman	D B Messers	Pumped	Domestic		3190	750			

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
132-104-26BAB	Bowman	City Of Rhame	Pumped	Municipal		3180	800			
132-104-32DA	Bowman	Jerome Fischer	Pumped	Stock	2005	3240	663 - 698	-310	2005	
132-104-35BBB	Bowman	Albert Bowman	Pumped	Domestic		3130	895			
132-105-16BDB	Bowman	NDSWC Rhame W	Monitoring	Monitor plug	1971	3010	441-459	-27	1997	
132-106-26BDC	Bowman	J Peterson	Pumped	Domestic		2881	229			
133-069-12BCD	Logan	Lydia Bucholz	Pumped	Stock		2035	120-140			
133-069-22BBB1	Logan	John Bellon	Pumped	Stock		2035	100-140			
133-070-04DDD	Logan	Edwin Kautz	Pumped	Stock		1980	59			
133-070-05CAA2	Logan	Don Diede	Pumped	Domestic		1990	41-45			
133-070-05CAA4	Logan	Don Diede	Pumped	Domestic		1990	45			
133-070-08BBD	Logan	Art Pudwill	Pumped	Stock		2030	28			
133-070-14DDB	Logan	Darvin Goebel	Pumped	Domestic		2070	110-180			
133-070-29CAB	Logan	John Stock	Pumped	Domestic		2090	60			
133-070-30CCD	Logan	NDSWC	Monitoring	Monitoring		2109	41-47			
133-071-01BCC	Logan	Clifton Herr	Pumped	Stock		2115	200-280			
133-071-04AAD	Logan	Rod Burgad	Pumped	Stock		2050	160-180			
133-071-09BBB	Logan	Rod Burgad	Pumped	Domestic		2005	160-260			
133-071-12DCA	Logan	Harley Herr	Pumped	Stock		2100	240-260			
133-071-23DDC1	Logan	William Wanner	Pumped	Stock		2060	40			
133-071-23DDC2	Logan	William Wanner	Pumped	Domestic		2060	39			
133-071-25BCD	Logan	Elmer Meidinger	Pumped	Domestic		2075	58			
133-072-04BBC	Logan	George Becker	Pumped	Domestic		1980	100-145			
133-072-06DDD	Logan	Alvin Gross	Pumped	Domestic		2050	280-300			
133-072-07BBC	Logan	Joe Glatt	Pumped	Stock		2000	250-260			
133-072-15CCC	Logan	NDSWC	Monitoring	Monitoring		2110	108-114			
133-072-34CBB	Logan	Albert Brendel	Pumped	Stock		2165	240-280			
133-073-04BBB	Logan	Martin Leier	Pumped	Domestic		2030	160			
133-073-08ADD	Logan	Frank Fettig	Pumped	Domestic		2000	70-100			
133-073-34CAD	Logan	Joe Wald	Pumped	Stock		1945	50			
133-074-04DDB	Emmons	M. Jacob Jr.	Pumped	Domestic		2130	185-210			
133-074-14CAA	Emmons	V. Huber	Pumped	Domestic		2100	140			
133-074-20DDD	Emmons	P. Kramer	Pumped	Domestic		1885	120-130			
133-074-24B	Emmons	Vetter	Pumped	Domestic		2100	80			
133-075-10DCD	Emmons	S. Loebs	Pumped	Stock		2010	80			
133-075-28ACD1	Emmons	J. Schwab	Pumped	Domestic		1900	104			
133-076-07BBA	Emmons	F. Deis	Pumped	Domestic		1930	108			
133-076-25DDC	Emmons	T. Ackerman	Pumped	Domestic		2025	180			
133-080-31CCD1	Sioux	NDSWC	Monitoring	Monitoring	1973	1770	168-180	-67	1973	
133-081-35-DCB	Sioux	John Kary	Pumped	Domestic		1800	210			
133-083-06CDD	Grant	Emil Bornhoeft	Pumped	Domestic		1900	307			
133-083-12ADA1	Grant	NDSWC	Monitoring	Monitoring	1973	1764	218-230	+1	1973	
133-083-34CBC	Grant	Earl Laduke	Pumped	Domestic		1890	310			
133-085-12AAD	Grant	NDSWC Raleigh	Monitoring	Monitoring	1972	2020	510-522	-179	1994	
133-097-30DC	Hettinger	Darrell Jelbert	Pumped	Dom/stk	1974	2720	1050	-225	1974	
133-098-20B	Slope	Robert Schaar	Pumped	Stock	1974	2755	1228	-240	1974	
133-099-02CBB	Slope	Floyd Pierce	Pumped	Dom/stk	1974	2840	1364	-251	1974	
133-099-32BBA	Slope	Frank Dilse	Pumped	Dom/stk	1972	2871	1252	-251	1974	
133-100-24CCC	Slope	Harry Flatz	Pumped	Stock	1973	2850	1165	-160	1973	
133-101-20BCC	Slope	Maurice Hansen	Pumped	Dom/stk	1979	2880	1100	-335	1979	
133-102-10	Slope	Donald Burke	Pumped	Stock	1977	2850	1031	-240	1977	
133-102-25DDD	Slope	Robert Folske	Pumped	Stock	1982	2890	1018	-312	1982	
133-103-02A	Slope	William Martian	Pumped	Stock	2001	2910	937-1000	-320	2001	
133-103-23BBC	Slope	John Goetz	Pumped	Stock	1961	2910	634-671			

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
133-103-26C	Slope	Allen Henke	Pumped	Stock	1977	2990	926	-410	1977	
133-104-12DD	Slope	Larry Fischer	Pumped	Stock	1990	3070	1112-1182	-380	1990	
133-104-14A	Slope	Arnold Meggers	Pumped	Stock	1972	3090	1120-1160	-441	1972	
133-104-14BBB	Slope	Arnold Meggers	Pumped	Domestic	1978	3150	1080-1140	ap-500		
133-104-20ABB	Slope	Howard Brooks	Pumped hc	Dom/stk	1989	3000	670	-280	1989	
133-104-20DD	Slope	Howard Merz	Pumped hc	Domestic	1977	2950	503	-291	1977	
133-105-30ABB	Slope	Henry Bradak	Pumped	Stock	1997	2700	100-120	-30	1997	
133-105-30CCC	Slope	City Of Marmarth	Pumped	Municipal		2710	215			
133-105-31BAA	Slope	City Of Marmarth	Pumped	Municipal		2708	270			
133-105-32C	Slope	M. R. Rost	Pumped	Stock	1981	2800	245	-210	1981	
133-106-12CA	Slope	Robert Hadley	Pumped	Stock	1993	2750	120-190	-65	1993	
133-106-13ADB2	Slope	NDSWC Marmarth	Monitoring	Monitoring	1977	2750	223-229	-44	2006	-0.35
133-106-21CBB	Slope	Little Mo Grazing	Pumped	Stock	1988	2850	260-300	-196	1988	
133-106-22ACC	Slope	Mike Sonsalla	Pumped	Stock	1988	2800	80-100	-25	1988	
133-106-25CBB	Slope	George Rankin	Pumped	Stock		2755	237	-130		
133-106-32BBB	Slope	Elwood Miner	Pumped	Stock	1996	2750	150-170	-50	1996	
133-106-34AAA	Slope	Joseph Sunsalla	Pumped	Stock		2750	120			
133-106-34BAA	Slope	NDSWC	Monitoring	Monitoring	1975	2750	98-104	+3	1975	
133-106-34D	Slope	Mike Sonsalla	Pumped	Dom/stk	1981	2750	54	-3	1981	
134-070-27ADA	Logan	John Mehuler	Pumped	Stock		1975	140-160			
134-070-30ACD	Logan	Oscar Bechtle	Pumped	Domestic		2075	200			
134-071-13ACB	Logan	Wilbert Wanner	Pumped	Stock		2070	105			
134-071-18AAD	Logan	Mike Feist	Pumped	Domestic		2080	165-194			
134-071-20CBB	Logan	NDSWC	Monitoring	Monitoring		1994	92-98			
134-071-21BCC	Logan	George Lubbers	Pumped	Stock		1970	148-158			
134-071-21CDC	Logan	State Park Service	Pumped	Domestic		2010	172-202			
134-071-22BBA	Logan	Robin Auch	Pumped	Stock		2000	140-160			
134-071-28BAD	Logan	Gordon Nuberg	Pumped	Stock		1980	85-123			
134-071-31-ABA	Logan	Peter Horner	Pumped	Stock		2040	160-180			
134-072-10DAA	Logan	NDSWC	Monitoring	Monitoring		2038	198-204			
134-072-18CBC	Logan	Andrew Johs	Pumped	Stock		2075	240-260			
134-072-22BBC	Logan	Anton Glatt	Pumped	Stock		2030	260-280			
134-072-26DDD	Logan	Christ Leier	Pumped	Domestic		1960	90-110			
134-073-05AAD	Logan	Peter Reis	Pumped	Domestic		2030	160-178			
134-073-05CCC	Logan	NDSWC	Monitoring	Monitoring		2070	128-134			
134-073-12CDC	Logan	Simon Piatz	Pumped	Domestic		2000	230-260			
134-073-15BDB	Logan	Baltzer Weigel	Pumped	Stock		1970	200			
134-073-21CDD	Logan	NDSWC	Monitoring	Monitoring		1988	68-74			
134-073-32ACC	Logan	Julius Vetter	Pumped	Domestic		2020	170			
134-073-35CBD	Logan	Charles Johs	Pumped	Domestic		1940	100			
134-074-06DDA	Emmons	A. Olson Sr.	Pumped	Domestic		1980	70			
134-074-11CDD	Emmons	C. Laine	Pumped	Domestic		2060	120-130			
134-074-32CCD	Emmons	H. Kundert	Pumped	Domestic		2130	280			
134-075-08DCB	Emmons	E. Jensen	Pumped	Stock		2025	80			
134-075-15BBB	Emmons	NDSWC Hazelton Se	Monitoring	Monitoring	1972	2010	97-103	-48	2007	+0.77
134-075-20CCC1	Emmons	B. Buck	Pumped	Domestic		2050	240			
134-075-34BAA	Emmons	L. Witikko	Pumped	Stock		2080	130			
134-076-02DDD1	Emmons	R. Schatz	Pumped	Domestic		1995	160-200			
134-076-05CBC1	Emmons	L Buck	Pumped	Domestic		2040	165			
134-076-08BBD	Emmons	E. Brindle	Pumped	Stock		2020	270-350			
134-076-28CDC	Emmons	N. Wilhelm	Pumped	Domestic		1975	100			
134-077-14CDD1	Emmons	E. Flegel	Pumped	Domestic		1980	65			
134-077-18CCB1	Emmons	H. Well Jr	Pumped	Stock		1850	220-230			

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
134-077-18CCB2	Emmons	H. Will	Pumped	Domestic		1850	154-220			
134-077-34CAB	Emmons	E. Gimbel	Pumped	Domestic		1880	86-96			
134-078-08ADD	Emmons	C. Watkinson	Pumped	Stock		1990	320-360			
134-078-15DDD	Emmons	NDSWC Hazelton W	Monitoring	Monitor plug	1972	1775	117-123	-24	2002	+0.26
134-089-27AA	Grant	Abrasives, Inc.	Pumped	Industrial	1998	2360	800-1056	-300	1998	
134-090-36CBC	Grant	New Leipzig	Pumped	Unused mun	1967	2350	820-880	-297	1967	
134-090-36CC	Grant	City Of New Leipzig	Pumped	Unused mun	1976	2350	770-860	-246.5	1976	
134-095-013CA	Hettinger	City Of Regent	Pumped	Municipal	1972	2490	1032-1150	-152	1972	
134-096-21ABB	Hettinger	Archie Wolf	Pumped hc	Domestic	1974	2640	1159	-181	1974	
134-096-29ACC	Hettinger	Richard Lultz	Pumped	Dom/stk	1975	2700	1220-1263	-228	1975	
134-099-02CC	Slope	Alex Stockert	Pumped	Domestic	1981	2840	1420		1981	
134-099-27DAA	Slope	Gordon Olson	Pumped	Domestic	1993	2825	1400-1500	-280	1993	
134-100-2BB	Slope	Don Stegner	Pumped	Domestic	1975	2810	1200-1260	-227	1975	
134-101-17D	Slope	Stanley Pope	Pumped	Stock	1995	2900	1100-1160	-240	1995	
134-104-18A	Slope	Jackoldis	Pumped hc	Stock	1976	3030	725	-360	1976	
134-104-24DD	Slope	NDSWC	Monitoring	Monitoring	1975	1976	1252-1254	406	1976	
134-104-9D	Slope	Jerry Lambourn	Pumped	Stock	1983	2900	665-705	-225	1983	
134-105-09BA	Slope	Little Mo Grazing	Pumped	Stock	1970	2700	463			
134-105-12BCC	Slope	Dick Bowman	Pumped hc	Stock	1987	2920	578	-254	1987	
134-105-15BCC	Slope	Forrest Hodges	Pumped	Stock	2000	2840	439-447	-304	2000	
134-105-24A	Slope	Jack Oldis	Pumped	Stock	1994	2900	543-660	-247	1994	
134-105-25AD	Slope	Patrick Pafferty	Pumped	Stock	1998	2930	614-656	-260	1998	
134-105-26BAA	Slope	Allan Henke	Pumped	Domestic	1961	2850	445-536	-175	1961	
134-106-17AC	Slope	Horsecreek Coop	Pumped	Stock	1981	2900	105-155	-105	1981	
134-106-22AC	Slope	H. R. Bradac	Pumped	Stock	1985	2740	175	-80	1985	
134-106-26C	Slope	H. R. Bradac	Pumped	Stock	1985	2780	175	-95	1985	
135-070-02BCC1	Logan	Roland Becker	Pumped	Domestic		1960	250			
135-070-12CDD	Logan	Lonnie Freier	Pumped	Domestic		1950	135			
135-070-14CAD	Logan	Marvin Grenz	Pumped	Domestic		2000	180-200			
135-071-08BDC	Logan	Delane Rau	Pumped	Stock		2125	196-268			
135-071-13ABC	Logan	Marvin Wentz	Pumped	Stock		1930	100-113			
135-071-15BBD	Logan	Marvin Wentz	Pumped	Stock		2050	203-204			
135-071-17BAB	Logan	Lorraine Kuhn	Pumped	Stock		2080	180-221			
135-071-20ABA	Logan	Robert Hammond	Pumped	Domestic		2060	180-23			
135-071-21BCB	Logan	Allen Hammund	Pumped	Stock		2080	184-208			
135-071-30-BBB	Logan	NDSWC	Monitoring	Monitoring		2087	188-194			
135-072-01CDC	Logan	Mike Schumacher	Pumped	Stock		2090	290			
135-072-02DAA	Logan	M. Hilzendrager	Pumped	Stock		2075	260-280			
135-072-09AAD	Logan	NDSWC	Monitoring	Monitor plug	1979	2007	138-144	-28	2008	
135-072-15CCC	Logan	Ted Schumacher	Pumped	Domestic		2025	73-93			
135-072-20BCB	Logan	NDSWC	Monitoring	Monitoring		1953	142-148			
135-072-20CBB	Logan	Carl Wentz	Pumped	Domestic		1960	100-160			
135-072-21BCB3	Logan	Mike Schumacher	Pumped	Domestic		2080	140-160			
135-072-22BBB	Logan	Ted Schumacher	Pumped	Domestic		2025	140-168			
135-072-27BBD	Logan	Sebastian Reis	Pumped	Stock		2000	140-60			
135-072-27BD	Logan	Sebastian Reis	Pumped	Stock		2000	160			
135-072-32BAB	Logan	John Kunz	Pumped	Stock		2075	160-224			
135-073-20ADD	Logan	Tony Braun	Pumped	Domestic		2030	180-200			
135-073-20BAA	Logan	Gary Volk	Pumped	Stock		2050	180-220			
135-073-22CCC	Logan	Mike Jacob	Pumped	Domestic		2020	170-180			
135-073-29AAC	Logan	Baltzer Weigel	Pumped	Stock		2080	200-220			
135-073-36DAC	Logan	Raymond Wentz	Pumped	Stock		1960	340-364			
135-074-30BAA	Emmons	G. Pearson	Pumped	Domestic		1975	100			

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
135-075-15DCC	Logan	NDSWC - Napoleon	Monitoring	Monitoring	1978	1952	99-105	-13	2008	
135-075-30AAA2	Emmson	City Of Hazelton	Pumped	Municipal	2004	1990	120-360	-100	2004	
135-076-19CCC1	Emmons	NDSWC Hazelton	Monitoring	Monitor plug	1971	1975	125-137	-59	1977	
135-076-29BCB	Emmons	Hazelton	Pumped	Municipal		1980	98-140			
135-076-30AAA1	Emmons	City Of Hazelton	Pumped	Municipal	2004	1990	130-300	-120	2004	
135-077-10ADA	Emmons	H.Schmidt	Pumped	Domestic		1980	120			
135-077-28BCA1	Emmons	E. Schmitcke	Pumped	Domestic		2030	220			
135-090-23BBB1	Grant	NDSWC New Leipzig	Monitoring	Monitoring	1973	2362	1029-1047	-277	2003	-0.22
135-096-22DDD	Hettinger	Doug Buzalsky	Pumped	Unused	1985	2550	1280-1330	-168	1985	
135-097-04DCA	Hettinger	NDSWC New England	Monitoring	Monitoring	1968	2567	1320-1360	-146	2003	-0.14
135-101-23DD	Slope	H-T Enterprises	Pumped	Domestic	1975	2900	1040-1052	-12	1975	
135-102-03CCD	Slope	Caroline Klewin	Flowing	Stock	1964	2560	905-945	+18	1995	
135-102-19DAA	Slope	Ht Enterprises	Flowing	Domestic	1975	2620	1040-1080	+3	1976	
135-104-02DDD	Slope	Todd Seymansky	Pumped	Stock	1988	2800	1005	-178	1988	
135-104-08BBA	Slope	Davis Rusch	Flowing	Stock	1977	2600	628-662	+14	1977	
135-104-19CDD	Slope	Glenn Strum	Pumped	Stock	1975	2820	713-740	-200	1975	
135-104-25ACA	Slope	Met Mitchell	Pumped	Stock	1988	3040	1002	-411	1988	
135-105-04ACC	Slope	Little Mo Grazing	Pumped	Stock	1984	2700	783-813	-90	1984	
135-105-15CDD	Slope	C. Berk Bowman	Pumped	Stock	1980	2610	329	-150	1980	
135-105-28B	Slope	Merle Clark	Pumped hc	Stock	1976	2750	456	-180	1976	
135-105-28B	Slope	Vern Brown	Flowing Idc	Domestic	2001	2600	240-270	+9	2001	
135-106-09DDD	Slope	Horse Creek Ga	Pumped	Stock	1992	2990	508-520	-262	1992	
136-070-29DDA	Logan	Reinhold Opp	Pumped	Stock		1882	190			
136-071-02CDD	Logan	Dwight Rau	Pumped	Domestic		1920	200			
136-071-10DBA	Logan	Emma Rau	Pumped	Stock		1890	100			
136-071-16CCC	Logan	NDSWC	Monitoring	Monitoring		1980	158-164			
136-071-18BCB	Logan	Ed Wanner	Pumped	Domestic		2030	182-208			
136-071-28CCC	Logan	Eugene Rau	Pumped	Domestic		2050	220			
136-071-34-CBB	Logan	Kenneth Bolstad	Pumped	Domestic		2050	140-193			
136-071-35-AAA	Logan	Ruben Wentz	Pumped	Stock		1932	61-73			
136-072-13BBB	Logan	William Johnson	Pumped	Domestic		2060	210			
136-072-17BBB	Logan	Marvin Schnabel	Pumped	Domestic		2020	180-204			
136-072-19DAB	Logan	Jim Harrison	Pumped	Domestic		2040	160-238			
136-072-22CCA	Logan	Andrew Gross	Pumped	Stock		2010	210-240			
136-072-22CCC	Logan	Andrew Gross	Pumped	Domestic		2010	195-230			
136-073-12BBD	Logan	William Foster Jr.	Pumped	Stock		2050	200-313			
136-073-16CBC1	Logan	NDSWC	Monitoring	Monitoring	1979	1953	158-164	-28	2008	
136-073-20DDC	Logan	Harold Sunde	Pumped	Domestic		1960	140-153			
136-073-22AAA	Logan	NDSWC	Monitoring	Monitoring	1978	2019	197-203	-87	2008	
136-073-27DDB	Logan	Alfred Schumacher	Pumped	Domestic		1960	170-193			
136-073-30AAA	Logan	Jack Roth	Pumped	Domestic		1960	133			
136-074-10BBC	Emmons	A. Feyereison	Pumped	Domestic		1920	150			
136-075-14AAA	Emmons	NDSWC Braddock	Monitoring	Monitor plug	1971	1910	107-113	-26	2002	+0.51
136-075-18AAD	Emmons	Saville Bros.	Pumped	Domestic		1900	100			
136-075-27D	Emmons	Bender	Pumped	Domestic		1860	80			
136-075-27DAC2	Emmons	J. Hammer	Pumped	Domestic		1860	45-80			
136-075-27DBD1	Emmons	T. Mock	Pumped	Domestic		1860	73			
136-075-27DBD2	Emmons	J. Wolbaum	Pumped	Domestic		1860	70-80			
136-075-35CBD	Emmons	F. Vetter	Pumped	Domestic		1910	85			
136-076-01ACA	Emmons	L&R Ranch	Pumped	Stock		1820	270-330			
136-076-02ADB	Emmons	L&R Ranch	Pumped	Stock		1840	180			
136-076-07BCC	Emmons	NDSWC Moffit	Monitoring	Monitoring	1972	1733	77-83	-6	2008	-0.46
136-076-18CCA	Emmons	R. Schlittenhart	Pumped	Domestic		1760	150			

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
136-076-26CAA	Emmons	J. Vetter	Pumped	Domestic		1910	280			
136-077-04BAB	Emmons	J. Vetter	Pumped	Stock		1940	185			
136-077-21DCD	Emmons	P. Moch	Pumped	Domestic		1830	190			
136-077-32CDB	Emmons	R. Dahl	Pumped	Domestic		1770	180			
136-078-07BDB	Emmons	NDSWC Ne Emmons	Monitoring	Monitoring	1971	1696	227-239	-75	2008	-0.79
136-078-14CDC	Emmons	M. Marquart	Pumped	Domestic		1860	310			
136-078-34ABC	Emmons	Wahl	Pumped	Stock		1820	200-220			
136-079-02AAD	Emmons	H. Woodland	Pumped	Stock		1680	140			
136-079-05CCC	Morton	NDSWC - Huff	Monitoring	Monitoring	1974	1675	188-200	-45	1974	
136-081-07DDC1	Morton	NDSWC St. Anthony	Monitoring	Monitoring	1974	1813	445-475	-46	1994	
136-100-26BCB	Slope	Joseph Schaffer	Pumped	Unused	1971	2820	1330-1394	-230	1975	
136-100-31DDC1	Slope	NDSWC	Monitoring	Monitoring	1975	2870	1388	299.5	1975	
136-101-04CB	Slope	Al Schoeffer	Pumped	Dom/stk	1998	2500	1194-1236	0	1998	
136-102-02AA	Slope	Cary Hande	Flowing	Stock	1985	2450	903-945	Flow	1985	
136-102-11BBB	Slope	Robert Hanson	Flowing	Stock		2410	1060	+80	2006	+0.69
136-102-11DAD	Slope	Robert Hanson	Flowing	Stock	1969	1995	1120	+27	1995	
136-102-12DA	Slope	Little Mo Grazing	Flowing	Stock	1974	2520	1100			
136-102-15ACC	Slope	Logging Camp R	Flowing ldc	Stock	1973	2560	1061-1091	+1	1973	
136-102-20BBD	Slope	Robert Hanson	Flowing	Stock	1969	2510	1120	+40	1975	
136-102-21DBD	Slope	John & Jen Hanson	Flowing	Stock	1969	2480	1100	+44	2006	-1.04
136-103-10ABA	Slope	Dennis Walser	Flowing	Stock	1977	2470	671-713	Flow	1977	
136-103-13B	Slope	Tom Burke	Flowing ldc	Stock	1992	2510	1020-1120	+32	1992	
136-103-14ADC	Slope	Tom Burke	Flowing	Stock	1969	2525	840	+8	2006	-0.62
136-103-18CC	Slope	Louis Hafele	Pumped	Stock	1973	2680	840	-80	1973	
136-103-20C	Slope	US Forest Service	Pumped	Stock	1977	2800	989-1055	-216	1977	
136-103-23ADB	Slope	Vern Jacobson	Flowing	Stock	1969	2570	850-1010	+11	1969	
136-103-24AAB	Slope	Lavonia Hafele	Flowing	Stock	1969	2480	800-840	+6	2006	-0.51
136-103-24ACC	Slope	Lavonia Hafele	Flowing	Dom/stk		2510		+16	2006	
136-103-26DAA	Slope	Vern Jacobson	Flowing ldc	Stock	1984	2530	924	+40	1984	
136-104-01BAA	Slope	Gary Van Daele	Flowing hc	Stock	2000	2500	530-650	+35	2000	
136-104-04CB	Slope	Todd Seymansky	Flowing ldc	Stock	1985	2530	680	+9	1985	
136-104-04CD	Slope	Gary Van Daele	Flowing hc	Stock	2001	2530	380-470	+42	2001	
136-104-12BAD	Slope	Edith Wojohn	Flowing	Stock	1972	2510	945-987	+27	1976	
136-104-33CA	Slope	Gene Davis	Flowing ldc	Stock	1991	2600	850	+5	1991	
136-105-30B	Golden Val	Little Mo Grazing	Pumped hc	Stock	1977	2820	665	-150	1977	
136-106-26	Golden Val	(Betty) Davis Ranch	Pumped	Stock	1972	2950	1104-1106	-200	1972	
137-081-28CBC	Morton	W. Graner	Pumped	Domestic		1770	486			
137-088-21DDC	Grant	NDSWC Lake Tschida	Monitoring	Monitoring	1972	2110	905-923	-126	1994	
137-101-12AAD	Billings	Larry Fritz	Pumped	Dom/stk	1981	2900	1575	450	1981	
137-101-29CCA	Billings	Morris Gerbig	Flowing	Stock	1969	2450	865	+38	1976	
137-101-30ABC	Billings	Morris Gerbig	Flowing	Dom/stk	1966	2415	883-925	+112	1969	
137-101-30BBC	Billings	Morris Gerbig	Flowing	Stock	1967	2393	807-820	Flowing		
137-101-33CBA	Billings	Cory Hande	Flowing ldc	Stock	2000	2420	1029-1071	+53	2000	
137-101-33DDB	Billings	John Gurbig	Flowing	Stock	1972	2450	860-900	+83	1972	
137-102-06CAC	Billings	Robert Griffin	Flowing	Stock	1964	2370	940	+102	2006	-1.79
137-102-07AAD	Billings	Robert Griffin	Flowing	Stock	1980	2460	1010-1040	+15	2006	-0.92
137-102-24ACA	Billings	Medora Graz (Gerbig)	Flowing hc	Stock	1999	2440	505-650	+23	1999	
137-102-31DDD	Billings	Dennis Walker	Pumped	Stock	1999	2610	948-990	+5	1999	
137-102-34ABA	Billings	Medora Grazing	Flowing	Stock	1979	2580	845-990			
137-103-01B	Golden Val	Al Wasepka	Flowing	Stock	1975	2400	900-960	Flowing	1975	
137-103-03ACA	Golden Val	Medora Grazing	Pumped	Stock	1979	2560	946-952	-30	1979	
137-103-12BAB	Golden Val	Alan Wosepka	Flowing	Dom/stk	1960	2410	950	+67	2006	-1.20
137-103-33CC	Golden Val	Gary Van Dhele	Flowing hc	Stock	2002	2510	720-740	+51	2002	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
137-104-23A	Golden Val	Don Maus	Pumped	Stock	2002	2640	960-980	-80	2002	
137-105-04CCC	Golden Val	Gerald Hall	Pumped hc	Dom/stk	1975	2800	800-860	-250	1975	
137-105-10ABB	Golden Val	Mel Basserman	Pumped	Dom/stk	1974	2760	880-940	-160	1974	
138-080-02BCA2	Burleigh	NDSWC Bismarck	Monitoring	Monitoring	2006	1665	433-453	-12	2008	
138-089-26BBB	Morton	Helfrick Bros.	Pumped hc	Domestic	1974	2240	920	-250	1974	
138-089-28BC	Morton	Michael Schaaf	Pumped hc	Dom/stk	1981	2280	933	-235	1981	
138-100-32BAA	Billings	James Fritz	Pumped	Stock	1983	2730	1808-1850	-121	1983	
138-101-19ACC	Billings	US Forest Service	Pumped	Stock	1973	2560	1408-1450	-58	1973	
138-102-07CCD	Billings	Sidney Connell	Flowing ldc	Dom/stk	1997	2340	931-995	+81	1997	
138-102-16ADD	Billings	Sidney Connell	Pumped	Stock	1974	2520	1138-1200	-47	1974	
138-102-18CBB	Billings	Sid Chamberlin	Flowing	Stock	1992	2330	956-998	+104	1992	
138-102-20AD	Billings	Little Mo Grazing	Flowing hc	Stock	1969	2400	777			
138-102-22CC	Billings	Ray Paasch	Flowing	Stock	1972	2440	955-997	+88		
138-102-28BBA	Billings	Ms. Sutherland	Flowing	Domestic	1981	2450	898-930			
138-102-34CCB	Billings	David Paasch	Flowing	Stock	1972	2400	955-997	+57	2006	-0.51
138-102-34DDA	Billings	Ray Paasch	Flowing	Stock	1961	2435	968-988	+69	1976	
138-102-36CCB	Billings	Ray Paasch	Flowing	Stock	1981	2500	903-945			
138-103-01BAB	Golden Val	Ted Tescher	Flowing	Stock		2390		+40	2006	
138-103-13BAA	Golden Val	Sid Connell	Flowing	Stock	1974	2370	880	+92	1976	
138-106-25DDA1	Golden Val	City Of Golva	Pumped	Municipal	1970	2819	942-967	-315		
138-106-25DDA2	Golden Val	City Of Golva	Pumped	Municipal	1978	2820	862-906	-160	1978	
139-073-05DCC	Kidder	Glen Dekrey	Pumped	Domestic		1880	160			
139-073-17CD	Kidder	City Of Steele	Pumped	Municipal	1978	1855	138-156	-57	1978	
139-073-17CDA	Kidder	City Of Steele	Pumped	Municipal	2000	1855	104-124	-34	2000	
139-073-17CDBA	Kidder	NDSWC Steele	Monitoring	Monitoring	1998	1854	228-238	-41	2008	-0.91
139-079-27DCA	Burleigh	NDSWC	Monitoring	Monitoring		1735	412-418			
139-079-31CDA	Burleigh	Walter Kruger	Pumped	Domestic	1972	1680	420-496	-66	1972	
139-079-36BBA	Burleigh	Apple Valley Coop	Pumped	Unused		1680				
139-080-16D2	Burleigh	Bergen Florists	Pumped	Industrial	1980	1870	310-420	-227	1980	
139-080-16D3	Burleigh	Bergen Florists	Pumped	Industrial	1981	1870	418	-215	1981	
139-080-22AA	Burleigh	Hay Creek Court	Pumped	Domestic	1977	1750	350-375			
139-080-22CCC	Burleigh	Martin Bauer	Pumped	Domestic	1986	1800	305-345	-170	1986	
139-080-23AD	Burleigh	Kurt Strigel (Koa)	Pumped	Domestic	1972	1850	360-380	-200	1972	
139-080-23DAC	Burleigh	Paul Breen	Pumped	Domestic	1984	1800	250-330			
139-080-23DDB	Burleigh	Mr. B's Estate	Pumped	Domestic	1992	1800	230-330			
139-080-26ABC	Burleigh	Milton Brown	Pumped	Stock	1973	1750	420	-132	1973	
139–080-30	Burleigh	Lawrence Klemine	Pumped	Domestic	1978	1800	420-480	-82	1978	
139-080-30AB	Burleigh	Geo. Orentenko	Pumped	Domestic	1973	1800	360	-160	1973	
139-080-30BA	Burleigh	Strand Construction	Pumped	Domestic	1973	1750	360	-160	1973	
139-080-30CDD	Burleigh	Farwest Riverboat	Pumped	Domestic	1984	1750	300-420	-3	1984	
139-081-04BDA	Morton	Jack Hauphof	Pumped	Rural water		1710	600-680	-39		
139-081-09DBA	Morton	Don Vogel	Pumped	Domestic	1983	1740	350-390			
139-081-10C	Morton	Paul Orset	Pumped	Domestic	1972	1720	300	-98	1972	
139-081-10CD	Morton	Gus Voegele	Pumped	Domestic	1987	1710	260-330		1987	
139-081-16C	Morton	Jack Hauphauf	Pumped	Domestic	1972	1850	500-520	-230	1972	
139-081-18AAA	Morton	Jim Wolf	Pumped	Domestic	1984	1960	405-525		1984	
139-081-20AA	Morton	Lastrotor Brothers	Pumped	Stock	1974	1890	320-480	-80	1974	
139-082-08BC1	Morton	Crown Butte Coop	Pumped	Unused	1991	2040	747-814	-398	1991	
139-082-08BC2	Morton	Crown Butte Coop	Pumped	Unused	1992	2020	712-813	-440	1992	
139-082-08BDD	Morton	Monte Rancheros	Pumped	Unused	1977	2020	720-820	-408	1977	
139-082-11A (?)	Morton	Ralph Kary	Pumped	Domestic	1974	1855	660-800	-212	1974	
139-082-24DDD	Morton	Arnie Kuhn	Pumped	Domestic	1973	1675	400	0	1973	
139-085-30AAB1	Morton	NDSWC New Salem	Monitoring	Monitoring	1974	2065	950-962	-245.3	1977	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened Interval ft	Pressure head ft	Year meas.	Head cng ft/yr
139-088-31B	Morton	City Of Glen Ulllin	Pumped	Unused mun	1977 ('	2080	1120		1977	
139-088-34BCC1	Morton	NDSWC Glen Ullin	Monitoring	Monitoring	1974	2070	1044-1062	-133	1997	
139-091-11DCD1	Stark	ND St. DOT	Pumped	unused dom	1967	2432	1717-1837	-307	1967	
139-091-11DCD2	Stark	ND St. DOT	Pumped	unused dom	1969	2432	1512			
139-093-08AAA	Stark	Jim Broom	Pumped	Domestic	1976	2480	1720-1790	-255	1978	
139-095-01DAB	Stark	ND St. DOT	Pumped	Stock	1967	2322	1776	-20	1967	
139-095-06BB	Stark	Amerigas	Pumped	Unused	1981	2450	1810-1890	-239 ?	1981	
139-095-06BB	Stark	Wasteco Mfng.	Pumped	Unused	1980	2480	1926-2002	-260	1980	
139-095-17BAC	Stark	Husky	Pumped	Unused	1976	2410	1757-1860	-160	1976	
139-096-01CBA	Stark	Dickinson Energy C	Pumped	Domestic		2440	1690-1986	-164		
139-096-07ADA	Stark	City Of Dickinson	Pumped	Unused mun	1981	2430	1713-1962	-143	1981	+0.11
139-099-05A	Stark	City Of Belfield	Pumped	Unused mun	1977	2600	1570-1747	-185	1977	
139-099-05A	Stark	City Of Belfield	Pumped	Unused mun	1983	2600	1598-1800	-400	1983	
139-100-04BCD	Billings	Russel Logan	Pumped	Domestic	1990	2770	1658-1678	-325	1990	
139-100-09DBB	Billings	Billings Co. Sch. #1	Pumped	Municipal	1986	2800	1806-1366	-400	1986	
139-101-14CAA	Billings	Morris O'connel	Pumped	Domestic	1975	2500	1513-1555	-70	1975	
139-101-17DD	Billings	Little Mo Grazing	Pumped	Stock	1973	2500	1248-1290	-98	1973	
139-102-02DCA	Billings	Leon Hellickson	Flowing	Dom/stk		2330	1100	+115	1969	
139-102-09BAA	Billings	Douglas Tescher	Flowing	Stock	1988	2350	1008-1050	+62	1995	
139-102-12BBA	Billings	Patrick Lavelle	Flowing ldc	Dom/stk	1990	2360	1103-1260	+46		
139-102-14DBD	Billings	US Forest Service	Flowing	Stock		2340	1096	+145	1969	
139-102-17CAC2	Billings	Tom Tescher	Flowing	Dom/stk	1973	2365	1054-1104	+45	2006	-1.23
139-102-18ABD	Billings	Adolph Burkhardt	Flowing	Stock	1973	2445	1120-1180	+2	1975	
139-102-20DAD	Billings	Ted Tescher	Flowing	Stock		2300		+72	2006	
139-102-24ADD	Billings	Tim Wilhelmi	Flowing ldc	Dom/stk	1990	2380	1321-1363			
139-102-27CC	Billings	Albert Wolff	Flowing	Stock	1977	2400	1042-1080			
139-102-28CAB	Billings	John Hild	Flowing ldc	Stock	1990	2311	1055-1085	Flow	1991	
139-102-31BBB	Billings	Ted Tescher	Flowing	Stock		2400		+37	2006	
139-102-33	Billings	George Wolf	Flowing ldc	Stock	1996	2330	1368-1405	+30	1996	
139-102-35	Billings	Medora Grazing	Pumped	Stock	1979	2500	1288	-100	1979	
139-103-13BBA	Golden Val	Medora Grazing	Flowing	Stock	19974	2600	1260	Flow	1974	
139-104-07	Golden Val	Pat Ueckert	Pumped	Domestic	1997	2980	1407-1449	-526	1997	
139-105-13BBC	Golden Val	Darrell Uechert	Pumped	Dom/stk	1973	2800	1020-1200	-380	1973	
139-105-14CBB	Golden Val	Les Strum	Pumped	Domestic	1979	2825	1215-1245	-200	1979	
139-106-24AA	Golden Val	Henry Strum	Pumped	Dom/stk	1978	2900	1080-1170	-350	1978	
140-074-12BCC	Kidder	Charles Shipley	Pumped	Stock		1895	146-186			
140-074-34CCC	Kidder	David Martin	Pumped	Domestic		1870	150			
140-079-31AAD	Burleigh	Dave Schwalbe	Pumped	Domestic	1991	1930	520-580	-220	1991	
140-080-03DDD	Burleigh	Leroy Clooten	Pumped	Stock	1976	1860	360-405	-251	1976	
140-080-09BB	Burleigh	Cl Sanders	Flowing	Dom/stk	1941	1660	376	Flow		
140-080-27B	Burleigh	Lawrence Klemin	Pumped	Domestic	1979	1900	460-480	-252	1979	
140-080-31DA	Burleigh	Edward Rittenbach	Pumped	Domestic	1979	1780	319	-110	1979	
140-080-34BDC	Burleigh	Delane Meeres	Pumped	Domestic	1973	1875	440-480	-180	1973	
140-080-36	Burleigh	Lloyd Miller	Pumped	Domestic	1978	1965	510			
140-080-36DCC	Burleigh	Leroy Clooten	Pumped	Domestic	1979	1940	640	-284	1940	
140-081-01CCD	Burleigh	Tom Gunderson	Pumped	Domestic	1990	2080	700-760	-460	1990	
140-081-02AC	Burleigh	Wally Suko	Pumped	Domestic	1986	1880	445-525			
140-081-03	Burleigh	Dakota Adventist	Pumped	Domestic	1976	1810	365-465			
140-081-03A	Burleigh	Dakota Adventist	Pumped	Domestic	1977	1810	402-482	-129	1977	
140-081-03B	Burleigh	Larry Wall	Pumped	Domestic	1992	1750	310-390			
140-081-04AC	Burleigh	Curt Stanley	Pumped	Domestic	1983	1655	310-350			
140-081-07CBD	Morton	Wachter Ranch	Pumped	Stock	1984	1725	555-635	-1	1984	
140-081-25CA	Burleigh	Bill Rotenberger	Pumped	Domestic	1989	1680	300-340	-60	1989	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
140-085-03DDD	Morton	W. Rusch	Pumped	Dom/stk	1965	2100	980-1040	-278	1965	
140-085-09DB	Morton	Terry Wilkens	Pumped	Dom/stk	1980	2080	930	-265	1980	
140-086-09CCC	Morton	Lester Doll	Pumped	Domestic	1977	2220	1050-1200		1977	
140-086-17AAA	Morton	Myron Conetz	Pumped	Domestic	1981	2240	1060-1180		1981	
140-089-05DAA	Morton	Amoco	Pumped	Industrial	1980	2271	1368-1410	-173	1980	
140-089-09CAC	Morton	Wehri Bros.	Pumped	Dom/stk	1979	2135	1226-1251	-130	1979	
140-089-11CCC	Morton	Ida Kottenbroch	Pumped	Unused d/s	1985	2180	1140-1160	-220	1985	
140-090-17ACB	Morton	N. Underdahl	Pumped	Dom/stk	1969	2180	1274-1500 ?	-146	1969	
140-090-20DBA1	Morton	A. Rehm	Pumped hc	Dom/stk	1963	2105	1200-1200	-10	1963	
140-092-31CC	Stark	Benedictine Priory	Pumped	Domestic	1967	2490	1100			
140-093-05DAA	Stark	James Bernhardt	Pumped	Domestic	1998	2260	1525-1585	-100	1998	
140-093-15CDC	Stark	Tony Kolar	Pumped	Domestic	1994	2470	1540-1600	-330	1994	
140-094-26DDA	Stark	Bob Jurgens	Pumped hc	Domestic	1973	2360	1200-1250	-93	1973	
140-094-27BA	Stark	Clarence Dohrmann	Pumped hc	Dom/stk	1972	2320	1110-1150	-50	1972	
140-095-31DCD	Stark	Decker Dairy	Pumped	Dom/stk	1974	2500	1856-1936	-220	1974	
140-095-32DCB	Stark	John Krous	Pumped	Dom/stk	1981	2530	1739-2010	-85	1981	
140-097-25CB	Stark	Slope Estates	Pumped	Unused mun	1981	2590	1744-1935	-26	1981	
140-098-23AAB	Stark	Vincent Tuhy	Pumped	Domestic	1992	2620	1739-1799	-305	1992	
140-098-24D	Stark	Bernard Pavlish	Pumped	Stock	1988	2600	1800-1805			
140-099-28DAD	Stark	Boyd Matteson	Pumped	Stock	1984	2588				
140-100-28CAB	Billings	Jerry Redmund	Pumped	Stock	1967	2740	1770			
140-101-32BCC	Billings	USFS O'connel	Flowing	Stock	1973	2420	1300-1320			
140-101-32D	Billings	USFS O'connel	Pumped	Stock	1973	2500	1458-1490	-122	1973	
140-101-35DAC	Billings	Nat Park Svc	Pumped	Domestic	1973	2780	1801-1871	-336	1973	
140-102-06DCC	Billings	Robert Myers	Flowing	Dom/stk		2390		+7	1995	
140-102-10DCA	Billings	US Park Service	Flowing ldc	Domestic	1984	2257	1115-1280	+120	2006	-0.78
140-102-10DDA	Billings	US Park Service	Flowing	Domestic	1976	2260	119601233	28	1976	
140-102-11CCB	Billings	US Nat Part Service	Flowing ldc	Domestic	1961	2400	1215	Flow		
140-102-12BB	Billings	US Park Service	Flowing ldc	Domestic	1998	2250	1250-1290	+129	1998	
140-102-18CD	Billings	Medora Grazing	Flowing	Stock	1968	2380	1200			
140-102-22	Billings	Doug Burk & Kurt D	Flowing	Domestic	1973	2260	1003-1042	+129		
140-102-22DBD	Billings	Gold Seal Co.	Flowing ldc	Domestic	1976	2260	1000-1050	+111	1976	
140-102-26BBD	Billings	US Park Service	Flowing ldc	Domestic	1986	2270	1152-1212	+109	1986	
140-102-26BCB	Billings	City Of Medora	Flowing ldc	Municipal	1968	2270	1080			
140-102-27	Billings	Burning Hills Amp.	Flowing	Domestic	1990	2280	950-1010	+88	1990	
140-102-27A	Billings	City Of Medora	Flowing ldc	Municipal	1989	2270	1055-1096	+95	1989	
140-102-27BAB	Billings	Adolph Burkart	Pumped	Domestic	1976	2380	1000-1060	+2	1976	
140-102-27CDD	Billings	Cil Kelly Schaffer	Flowing ldc	Stock	1987	2280	1191	+116	1987	
140-102-28ADD	Billings	Medora Grazing	Flowing	Stock	1977	2360	1036-1078	+74		
140-102-32	Billings	Medora Grazing	Flowing	Stock	1973	2420	1490			
140-103-02ACA	Billings	M. Hellickson	Flowing	Stock		2355	1100	+60	1976	
140-103-02ACA	Golden Val	Rodger Meyers	Flowing hc	Stock	1974	2500	1233-1275	Weak f	1974	
140-103-02CCD	Golden Val	Ollie Golberg	Pumped	Dom/stk	1997	2050	1449-1486	-115	1997	
140-103-02CDD	Golden Val	Robert Meyers	Pumped	Dom/stk		2480	1415-1455	-59	1973	
140-103-09BDD	Golden Val	Medora Grazing	Pumped	Stock	1967	2620	1445			
140-103-33DAC	Golden Val	US Forest Service	Pumped	Stock	1969	2598	About 1300			
140-104-12ADB	Golden Val	ND St. Hwy. Dept.	Pumped	Domestic	1969	2668	1268-1350			
140-104-15ABB	Golden Val	ND St. Hwy. Dept.	Pumped	Domestic	1969	2742	1351-1400	-360	1969	
140-104-19DDD	Golden Val	Sentinel Butte	Pumped	Unused mun	1981	2720	1100-1300	-160	1981	
140-105-14ABB	Golden Val	Home On Range	Pumped	Domestic	1975	2900	1494-1553	-419	1975	
140-105-14ABB2	Golden Val	Home On Range	Pumped	Domestic	1982	2900	1520-1589	-469	1982	
140-105-30CCC6	Golden Val	NDSWC Beach	Monitoring	Monitoring	1984	2770	1050-1130	-331	2007	-1.07
140-106-14DDD	Golden Val	Forest Hodges	Pumped	Domestic	1976	2770	1180	-310	1976	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
140-106-22AA	Golden Val	Larry Jandt	Pumped	Domestic	1976	2820	1120-1220	-390	1976	
140-106-23ADD	Golden Val	City Of Beach	Pumped	Municipal	1982	2820	1180-1400	-440	1982	
140-106-23DCC	Golden Val	City Of Beach	Pumped	Municipal	2003	2790	1215-1355	-411	2003	
140-106-25CBB1	Golden Val	City Of Beach	Pumped	Municipal	1961	2610	1157-1259	-332	1962	
141-073-03DBB	Kidder	Tracy Magstadt	Flowing ldc	Stock	2006	1790	106-116	+24	2006	
141-073-06A	Kidder	Albert Schuler	Flowing ldc	Stock	1988	1800	84-94	Flowing	1988	
141-073-09B	Kidder	Tim Whitmore	Flowing ldc	Stock	1978	1800	97-150	Flowing	1978	
141-073-14CA	Kidder	Eugene Horn	Pumped	Stock		1845	120-180			
141-074-01ABB	Kidder	Leon Haverkamp	Flowing ldc	Stock	2003	1800	91-116	Flowing	2003	
141-074-14ABC	Kidder	Glen Gorder	Pumped	Stock		1825	175-195			
141-074-25DBDA	Kidder	Robert Kellam	Pumped	Stock		1920	200-220			
141-075-02DDD	Burleigh	Mark Mehlhoff	Pumped	Domestic		1910	245-320			
141-075-19CADD	Burleigh	Clarence Wolfe	Pumped	Stock		1970	270-340			
141-075-20BAD	Burleigh	Clarence Wolfe	Pumped	Stock		2005	255-315			
141-080-19CBD	Burleigh	Darrel Simons	Pumped	Domestic	1987	1700	340-380	-70	1987	
141-080-21DAA	Burleigh	D. Heger	Pumped	Stock	1994	2070	660-767	-350	1994	
141-080-29CB	Burleigh	Chuck Peterson	Pumped	Stock	1984	1950	335-415			
141-081-13CBB	Oliver	J. Wachter/Price	Flowing	Stock		1645		+23	1968	
141-081-20CC	Oliver	Tom Gunderson	Pumped hc	Stock	1998	1900	400-440	-68	1998	
141-082-07BBB	Oliver	Mike Keller	Pumped hc	Domestic	2003	1900	430-470	-145	2003	
141-082-15DDC	Oliver	Pennzoil	Pumped	Industrial	1981	1950	710	-240	1981	
141-084-11AAA	Oliver	Nick Bergen	Pumped	Domestic	1973	2000	903-1176	-206	1973	
141-084-26DDD	Oliver	Raymond Phlegr	Pumped hc	Domestic	1972	2165	770-900	-360	1972	
141-084-35ADD	Oliver	Donald Erhardt	Pumped	Domestic	1975	2161	920	-270	1975	
141-085-27DAA	Oliver	Roger Beliga	Pumped	Domestic	1975	2170	1090-1160	-382	1975	
141-085-30CAD	Oliver	George Dall	Pumped	Domestic	1978	2170	970	-380	1975	
141-089-11BC	Mercer	J. Woroniecki	Pumped	Stock	1964	2065	1318-1400	-81	1968	
141-089-20CBC	Mercer	J. Woroniecki	Pumped	Dom/stk		2213	1340	-141	1984	
141-090-09DB	Mercer	S. Jaeger	Flowing	Stock	1964	2051	1300	+14	1968	
141-090-19CCD	Mercer	NDSWC Hebron	Monitoring	Monitoring	1967	2080	1142-1790 C	-15	2008	-0.34
141-094-34CAD	Dunn	M. Dillinger	Pumped	Dom/stk	1971	2200	1340-1380	-80	1971	
141-095-18AD	Dunn	Armstrong	Pumped hc	Industrial	1991	2578	1480-1724			
141-100-02BCD	Billings	Edwin Cerkoney	Pumped	Stock	1991	2717	1870-1930	about 400'		
141-100-30ACA	Billings	Vern Thompson	Flowing	Stock		2380	1365			
141-100-30B	Billings	Vernon Tompson	Flowing ldc	Stock	1979	2380	1333-1375			
141-101-02AAC	Billings	Dorothy Meschke	Flowing	Stock		2355	1300	-35	1969	
141-101-02BBD	Billings	Floyd Oyhus	Flowing hc	Domestic	1985	2320	923-943	+55	1985	
141-101-02CCC	Billings	Floyd Oyhus	Flowing hc	Stock	1988	2345	965-995	+32	1988	
141-101-03AAB	Billings	Floyd Uhyus	Flowing	Stock		2322		+71	1976	
141-101-18BAA	Billings	John Griggs	Flowing hc	Stock	1974	2220	640-720		1974	
141-101-20A	Billings	Ralph Mosser	Flowing	Stock	1977	2280	1108-1230			
141-101-21BCB	Billings	State Of ND	Flowing	Stock		2252	1280 OH	+95	1967	
141-101-21CAC	Billings	Ralph Mosser	Flowing	Stock	1963	2270	1130-1200	+59	1976	
141-101-26ACB	Billings	Ralph Mosser	Pumped	Stock	1974	2370	1295-1340	+23	1976	
141-101-29ABD	Billings	US Park Service	Pumped	Domestic	1996	2380	1295-1325	+3	1996	
141-102-02DDB	Billings	Arnold Kadramas	Flowing	Stock	1973	2260	1150-1280	+79	1973	
141-102-03DAC	Billings	US Forest Service	Pumped	Domestic	2001	2420	1428-1554	-58	2001	
141-102-10ABD	Billings	Medora Grazing	Flowing	Stock	1979	2320	1365-1428	+4	2006	-2.92
141-105-28BCC	Golden Val	Pearl Odland	Pumped	Domestic	1980	2700	1120-1155	-220	1980	
142-073-16D	Kidder	Dennis Price	Flowing ldc	Stock	1990	1790	123-140	+5	1990	
142-073-20C	Kidder	Clarance Solheim	Flowing ldc	Stock	1979	1800	100-170	Flowing	1979	
142-073-20D	Kidder	Norman Beckel	Flowing ldc	Stock	1985	1800	95-125	Flowing	1985	
142-073-20DD	Kidder	Manfred Solheim	Flowing ldc	Stock	1990	1800	140	+14	1990	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
142-073-23B	Kidder	Clarence Solheim	Flowing ldc	Stock	1990	1790	138-160	+9	1990	
142-073-27C	Kidder	Marvin Dehne	Flowing ldc	Stock	1988	1790	100-140	Flowin(	1988	
142-073-34CC	Kidder	Tracy Magstadt	Flowing ldc	Stock	1992	1985	90-130	+12	1992	
142-074-01ADDC	Kidder	Jewell Mehlhoff	Pumped	Domestic		1870	150-180			
142-074-12AAB	Kidder	Darin Witt	Pumped	Domestic		1855	150-185			
142-074-26CBC	Kidder	Gilbert Bernhardt	Pumped	Domestic		1825	168-180			
142-075-08DDBA	Burleigh	Gene Eide	Pumped	Stock		1855	205-235			
142-075-10BBC	Burleigh	Gene Eide	Pumped	Stock		1890	383-423			
142-075-34DC	Burleigh	Ray Hinkel	Pumped	Domestic		1910	142-268			
142-081-04ADC	Burleigh	USGS	Monitoring	Monitoring		1666	415-435			
142-081-08ACB	Oliver	Kenneth Porsborg	Flowing	Dom/stk	1979	1675	490-688	+60	1979	
142-081-16DCB	Oliver	Tom Price Ranch	Flowing	Unused	1975	1665	389-620	+69	1975	
142-081-21BDB	Oliver	Price Brohers	Flowing	Unused	1984	1650	572-666	+69	1984	
142-081-21CB	Oliver	Ray Price	Flowing	Domestic	1979	1710	632-712	+39	1979	
142-081-28ACC	Oliver	Price Brothers	Flowing	Stock	1984	1660	564-660	Flowing		
142-082-02DCA	Oliver	Cross Ranch	Pumped hc	Stock	1990	1960	540-600	-170	1990	
142-083-13DCC	Oliver	Tom Hoag	Pumped	Domestic	1988	2150	1010-1030	-360	1988	
142-084-24BBA	Oliver	NDSWC Center	Monitoring	Monitoring	1967	2006	966-1295 OI	-204	2007	-0.33
142-086-32CBD	Oliver	D. Unterseher	Pumped	Stock	1967	2180	1320	-284	1968	
142-089-04CA	Mercer	F. Unruh	Flowing	Stock	1964	1950	1260	+28	1968	
142-089-09AB	Mercer	F. Unruh	Flowing	Stock	1966	1948	1250	+28	1968	
142-089-10AB	Mercer	E. Unruh	Flowing	Stock		1965	1480	Flow		
142-089-31CAC	Mercer	W. Opp	Flowing	Stock		1980		+19	1978	
142-090-30AAA	Mercer	Gary Gierke	Flowing ldc	Domestic	1990	1975	1190-1250	Flow	1990	
142-091-25DBB	Dunn	A. Schnaidt	Flowing	Stock	1966	2010	1230-1290	+22	1966	
142-100-21BBD	Billings	Ed Eagly	Pumped	Stock	1983	2540	1672-1735	-220	1983	
142-101-01BDB1	Billings	Paul Kessel	Pumped	Dom/stk	1967	2720	1816-1860	-385	1967	
142-101-16CAC	Billings	Warren Myers	Flowing	Stock	1991	2300	1342-1386	+28	1991	
142-101-33DBA	Billings	Medora Grazing	Pumped	Stock	1976	2320	1333	-2	1976	
142-101-34C	Billings	Medora Grazing	Flowing	Stock	1977	2300	1220-1280	+55	1977	
142-102-01B	Billings	Con Short	Flowing hc	Stock	1977	2175	720-820	+115	1977	
142-102-04BCB	Billings	USFS/K Obrigewitch	Flowing	Stock		2230	817 +?	+45	2006	-4.00
142-102-14BDC	Billings	Geo Wolf	Flowing	Stock	1985	2180	1180-1220			
142-102-27AAB	Billings	Medora Grazing	Flowing	Stock	1979	2300	1302-1365	+92	1979	
142-103-28A	Golden Val	Energy Equity	Pumped	Industrial	2006	2640	1498-1578	-340	2006	
142-73-21B	Kidder	Norman Boechel	Flowing ldc	Stock	1980	1800	100	Flowin(	1980	
143-073-15D	Kidder	Melvin Nordgaard	Pumped	Stock		1875	245-260			
143-073-26BA	Kidder	Douglas Landenburg	Pumped	Domestic		1875	180-285			
143-073-28DCD	Kidder	Robert Gerr	Pumped	Stock		1830	168-180			
143-073-33A	Kidder	Chris Gerr	Pumped	Stock		1830	100-195			
143-073-34BDCC	Kidder	Chris Gerr	Pumped	Domestic		1830	96-150			
143-074-27s	Kidder	James Weinman	Pumped	Stock		1915	180-220			
143-075-25AAA	Burleigh	Zerr Farms	Pumped	Stock		1870	170-185			
143-080-16CCB1	McLean	P. Patrick	Pumped	Dom/stk	1958	1960	530	-200	1958	
143-080-16CCB3	McLean	Wesley Newmiller	Pumped	Dom/stk	2004	1960	505-555	-275	2004	
143-080-26BAB	McLean	Steve Desciak	Pumped	Domestic	1988	2100	570-710	-380	1988	
143-080-30AAC	McLean	Ray Burck	Pumped	Dom/stk	1982	1940	395-495			
143-080-35CC	McLean	Earl Aune	Pumped	Domestic	1980	2170	670-707	-270	1980	
143-081-05BAA	McLean	Jason Shower	Flowing	Domestic	1998	1665	515-555	+97	1998	
143-082-01AAA	Oliver	Price Brothers	Flowing	Unused	1982	1670	550-726	+81	1982	
143-082-02ADD	Oliver	Price Brothers	Flowing	Unused	1982	1720	734-782	+51	1982	
143-082-12AAB	Oliver	Price Brothers	Flowing	Unused	1984	1680	478-526	+42	1984	
143-084-01AC	Oliver	Zach Mcnaulty	Flowing hc	Stock	1994	2060	495-763	+16	1994	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
143-085-25CCC	Oliver	Preston Beckman	Pumped hc	Domestic	1984	2130	751-796	-370	1984	
143-086-20BBB	Oliver	Erwin Unteraler	Pumped	Domestic	1974	2100	1211-1358	-198	1974	
143-087-08ACC	Oliver	Dale Neuberger	Pumped	Domestic	1987	2020	1275-1425	-110	1987	
143-087-25BB	Oliver	J. Borneman	Pumped	Stock	1966	1967	1380	-16	1968	
143-087-27ADD	Oliver	Lincoln Reinhiller	Pumped	Stock	1974	1960	1053-1179	-65	1974	
143-088-05DD	Mercer	Forrest Murray	Flowing hc	Stock		1860	798			
143-088-06CDD	Mercer	Forrest Murray	Flowing hc	Stock	1967	1835	945	+105	1968	
143-088-10C	Mercer	Bob Keogh	Flowing hc	Stock		1935	960	+108	1968	
143-088-14BDB	Mercer	Knife River Coal	Pumped	Industrial	1979	1965	1180-1220	-80	1979	
143-088-28AAA	Mercer	Earl Erdmann	Pumped	Domestic	1985	2095	1390-1450	-210	1985	
143-088-31AC	Mercer	Ralph Murray	Flowing hc	Stock	1966	1910	1040	+43	1968	
143-088-31ACC	Mercer	Casey Voegt	Flowing ldc	Stock	2004	1910	1190-1250	+32	2004	
143-089-15AB	Mercer	Ralph Johnson	Flowing hc	Stock	1964	1857	1000	Flow		
143-089-18ACC	Mercer	Hauck Bros.	Flowing	Stock	1964	1920	1380	+40	2005	-0.58
143-089-19ACB	Mercer	Hauck Bros.	Flowing	Stock		1897	1280	+83	2005	+1.0 ft/yı
143-089-27ADC	Mercer	Ed Unruh	Flowing hc	Stock	1967	1910	1100	+45	1968	
143-090-08D	Mercer	Marvin Faut	Pumped	Stock	1979	2230	1384-1432	-254	1979	
143-090-14DDA	Mercer	Albert Hauck	Flowing ldc	Stock	1974	2000	1361-1445	+4.5	1994	
143-090-24ABC	Mercer	Albert Hauck	Flowing	Stock		1960		+25	2005	-0.46
143-090-24BAB	Mercer	Albert Hauck	Flowing	Stock	1994	1962	1280-1300	+17	1967	-0.14
143-090-33CBD	Mercer	Robert Backfish	Flowing hc	Stock		1980	890	+17	1968	
143-099-02CC	Billings	Missouri Basin	Pumped	Unused	1981	2700	1955-2100			
143-099-08DDA	Billings	Chimney Butte Land	Pumped	Industrial	1980	2670	1922-2080	445	1980	
143-100-32DBA	Billings	Koch Exploration	Pumped	Unused	1986	2695	1878-1918	-390	1986	
143-102-01BBD	Billings	Byron Connell	Flowing	Stock		2235	1300-1335	+51	1967	
143-102-08BBD	Billings	Medora Grazing	Flowing	Stock	1972	2200	1320-1380	+51	1972	
143-102-10ACA	Billings	Randy Mosser	Pumped	Stock	1968	2220		-19	1990	
143-102-18	Billings	Douglas Mosser	Flowing	Stock	1977	2400	1280-1360	+12	1977	
143-102-24CCA	Billings	US Forest Service	Flowing	Stock		2220	1240-1280			
143-102-27CC	Billings	Con Short	Flowing	Stock	1973	2220	1060-1120	+157	1973	
143-102-29AAD	Billings	US Forest Service	Flowing	Stock		2195	1200	+139	1968	
143-102-34ABB	Billings	Byron Connell	Flowing ldc	Stock	1973	2160	1040-1120	+175	1976	
143-103-01DDA	Golden Val	US Forest Service	Pumped	Domestic	2003	2320	1390-1470	-37	2003	
143-103-03DDC	Golden Val	Medora Grazing	Flowing	Stock	1972	2320	1320-1440	+25	1972	
143-103-16AAB	Golden Val	Medora Grazing	Flowing	Stock	1981	2300	1452-1515	+35	1981	
143-103-17DD	Golden Val	Medora Grazing	Flowing	Stock	1972	2300	1420-1480	+30	1972	
143-103-26ADD	Golden Val	Summit Resources	Pumped hc	Industrial	1979	2600	About 1200?	336	1989	
143-105-18BBB	Golden Val	Ronald Hollar	Pumped	Dom/stk	1977	2700	1430-1540	-340	1975	
143-105-33BAB	Golden Val	NDSWC Beaver Ck	Monitoring	Monitoring	1975	2385	1153-1177	-76	2007	-1.07
144-080-12AAA	McLean	Arlen Helm	Pumped	Domestic	1997	1890	500-530	-200	1997	
144-080-19CBD	McLean	Steve Dennison	Pumped	Domestic	2005	1820	610-630	-60	2005	
144-080-34CCD	McLean	Bill Sawicki	Pumped	Stock	1988	1950	455-595			
144-081-24BBB	McLean	Leo Carlson	Pumped	Dom/stk	1975	1810	373-495	-70	1975	
144-081-30DD	McLean	Harry Sheldon	Flowing	Domestic	1999	1660	435-455	+97	1999	
144-081-32	McLean	Keith Radomski	Flowing	Domestic	2002	1660	533-573	+97	2002	
144-081-32DAA	McLean	Larry Walfred	Pumped	Domestic	1979	1730	410-430			
144-082-22BBD	Oliver	Lewis Price	Flowing	Domestic	1998	1670	495-535	+97	1998	
144-082-23CCA	Oliver	Douglas Price	Flowing	Stock	1973	1665	440-503	+42	1973	
144-082-23CCD	Oliver	Doug Price	Flowing	Stock	2003	1665	435-505	Flow		
144-082-25DDD	Oliver	Steve Martin	Flowing	Stock	1985	1660	610-630	+28	1985	
144-082-26CAA	Oliver	Price Brothers	Flowing	Stock	1984	1665	360-430	Flow		
144-082-36DDC	Oliver	Nature Conservancy	Flowing ldc	Stock	1984	1690	453-533	+25	1984	
144-083-24BAD	Oliver	Rob Tweeten	Flowing	Domestic	2005	1670	530-570	+81	2005	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
144-083-24CCD	Oliver	Rob Tweeten	Flowing	Dom/stk	2003	1670	534-574	+53	2003	
144-083-26CCC	Oliver	Vernon Smith	Flowing hc	Stock	2004	1670	310-330	+28	2004	
144-083-27CCA	Oliver	Vernon Smith	Flowing hc	Stock	1994	1665	302-350	+28	1994	
144-083-34CAA	Oliver	Vernon Smith	Flowing hc	Domestic	2000	1665	300-340	+28	2000	
144-084-26BBC	Mercer	Clarence/Orv Fretty	Flowing ldc	Domestic	1975	1700	613-655	+46	1975	
144-085-02	Mercer	Jim Berg	Flowing ldc	Stock	1984	1710	796-850	+69	1984	
144-085-06AD	Mercer	Cook Ranch	Flowing	Stock	1975	1755	850	Flow	1975	
144-085-06BD	Mercer	Cook Ranch	Flowing	Stock	1967	1725	882-903	Flow	1967	
144-085-10CCA	Mercer	J. Schultz Ranch	Flowing	Stock	1966	1762	900	+37	2005	
144-085-32ABB	Mercer	Gary Boeckel	Pumped	Domestic	1986	1920	1098-1161	-73	1986	
144-086-02AAA	Mercer	Jeff Boehm	Flowing	Dom/stk	1988	1720	840-880	+125	1988	
144-086-11DAA	Mercer	E. Oster	Flowing	Stock		1784	1000	Flow		
144-086-17	Mercer	Fred Hoffman	Flowing hc	Stock	1968	1732	730	+60	1968	
144-086-17BCC	Mercer	Henry Orster	Flowing hc	Stock	1974	1740	735-798	+88	1974	
144-086-18B	Mercer	Glenn Miller	Flowing	Domestic	1979	1750	796-828	+92	1979	
144-087-09DDD	Mercer	Herb Oster	Flowing	Stock	1975	1860	1092-1229	+51	1975	
144-087-20DDD	Mercer	E. Sasse	Flowing	Dom/stk	1964	1865	1144	Flow	1964	
144-087-30	Mercer	Reuben Voegele	Flowing	Domestic	1988	1770	840-900	+99	1988	
144-088-13BBB	Mercer	Beulah Lumber	Pumped	Domestic	1980	2040	1315	-107	1980	
144-088-14DAA	Mercer	Industrial Builders	Pumped	Industrial	1978	1960	1210-1280	-20	1978	
144-088-25CDD	Mercer	Jack Helm	Flowing	Domestic	1986	1780	846-886	+99	1986	
144-088-25DD	Mercer	Morris Erickson	Flowing	Domestic	1974	1770	840-882	+139	1974	
144-088-26A	Mercer	Ernest Skarsky	Flowing	Domestic	1986	1850	875-915	+92	1986	
144-088-26AAD	Mercer	Doug Neuberger	Flowing ldc	Domestic	1985	1800	840			
144-088-35ABB	Mercer	Noel Helm	Flowing	Domestic	1984	1775	864-884	+92	1984	
144-089-14CDD	Mercer	City Of Zap	Flowing ldc	Municipal	1969	1845	1241-1281	+130	2005	-0.40
144-089-17B	Mercer	A. J. Dollman	Flowing ldc	Stock	1972	1885	918	Flow	1972	
144-089-23CB	Mercer	Dick Lange	Flowing hc	Stock		1883	1060	+68	1968	
144-089-25	Mercer	Werner Benfit	Flowing ldc	Domestic	1977	1920	1314-1334	Flow	1977	
144-089-35AAD	Mercer	Joe Baldwon	Flowing	Stock	1977	1980	1354	+28	1977	
144-090-04BBA	Mercer	Dean Brecht	Flowing	Stock	1964	1953	1265	+9	2005	-3.12
144-090-09ADB	Mercer	Reben Schiebre	Flowing	Dom/stk	1972	1930	1050-1340	+18	1972	
144-090-15DB	Mercer	Golden Vallley City	Flowing ldc	Municipal	1968	1925	1275-1325	+94	1968	
144-090-22AB	Mercer	T. Braun	Flowing hc	Stock	1968	1890	1140	+95	1968	
144-090-25BD	Mercer	Hauck Bros.	Flowing	Stock	1967	1990	1360	+3	1971	
144-090-29AD	Mercer	V Entze	Flowing	Stock	1964	1988	1400	+30	1968	
144-090-30BA	Mercer	V. Entze	Flowing	Stock	1967	1958	1428-1443	+31	1968	
144-091-10CBC	Dunn	City Of Dodge	Flowing ldc	Municipal	1975	2000	1450-1515	+52	2005	+1.23
144-091-18B	Dunn	Frank Neuhor	Pumped	Stock	1978	2120	1344	-42	1978	
144-091-23D	Dunn	E. Stuhmiller	Flowing hc	Stock	1963	1963	1232-1300	+15	1972	
144-096-06ADB	Dunn	Irving Katrmas	Pumped	Domestic	1974	2430	1995-2049	-225	1974	
144-098-04ADD	Billings	Petro-Hunt	Pumped	Industrial	2007	2532	1998-2028	-339	2007	
144-098-15BBB	Billings	Petro-Hunt	Pumped	Industrial	1980	2560	1928-1978	-338	1980	
144-098-16AA	Billings	Petro-Hunt	Pumped	Unused ind	1978	2560	1940-1982	-320	1978	
144-099-10CCA2	Billings	William Palanuk	Pumped	Unused	1966	2568	2025-2065	-378	1966	
144-099-14ABB	Billings	Sc Tachenko	Pumped	Dom/stk	1967	2690	2046-2106	-300		
144-100-24BBD1	Billings	Robert Lillibridge	Pumped	Stock	1975	2260	1993		2007	
144-100-30CCB	Billings	Koch Exploration	Pumped	Industrial	1984	2600	1618-1678	-317	1984	
144-101-05BDB	Billings	Medora Grazing	Flowing	Stock	1977	2200	1300-1352	+51	1977	
144-101-06BCC	Billings	Medora Grazing	Flowing	Stock	1977	2200	1255-1300	+74	1977	
144-101-15BCD	Billings	Willis Northrup	Pumped	Dom/stk	1968	2260	1440-1540	Flow		
144-101-27BDD	Billings	Elbert Brothers	Pumped	Stock	1997	2320	1448-1490	-90	1997	
144-102-01BBC	Billings	US Forest Service	Flowing ldc	Stock	1971	2180	1300-1335			

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144-102-08DDD	Billings	Francis Boyce Trust	Flowing ldc	Dom/stk	1996	2110	1197-1239	+104	1996	
144-102-22ADD	Billings	Ebrats Bros	Flowing ldc	Stock	1994	2120	1216-1258	+88	1994	
144-102-27DCC	Billings	Byron Connell	Flowing	Domestic	1964	2180		+104	1967	
144-102-28DAA	Billings	Jim Tescher	Flowing	Domestic	1970	2140		+124	1970	
144-102-29BBA	Billings	Ken Johnson	Flowing	Stock	1960	2210	1200-1220	+5	2006	-1.16
144-103-15CBD	Golden Val	Donald Hall	Flowing	Dom/stk	1979	2200	1385-1415	+51	1979	
144-103-22CCD	Golden Val	Hall Brothers	Flowing ldc	Stock		2220	1239-1280	+89	1976	
144-103-29AA	Golden Val	Boyce Family	Pumped	Stock	1981	2280	1302-1344	-2	1981	
144-103-33BAA	Golden Val	Banner Res Mgmt	Pumped	Stock	2004	2425	about 1500			
144-104-12DDC	Golden Val	Wesco	Pumped	Industrial	1979	2511				
145-074-08AAD	Sheridan	Arnold Berreth	Pumped	Domestic	1974	2020	505	-80	1974	
145-075-09BBB	Sheridan	NDSWC Goodrich Sw	Monitoring	Monitor plug	1977	1945	451-457	+3	1996	
145-078-05BBB	Sheridan	NDSWC Mercer Se	Monitoring	Monitor plug	1978	1910	617-623	-86	1993	
145-079-10BDA	McLean	Larry Gessele	Pumped	Domestic	1988	1980	550	-35	1988	
145-079-14BAA	McLean	Edwin Gessele	Pumped	Domestic	1976	1905	575	-70	1976	
145-079-20CCB	McLean	J. Laib	Pumped	Domestic		1880	605			
145-079-23ADD	McLean	Larry Gessele	Pumped	Dom/stk	1999	1860	548-588	-20	1999	
145-079-23CBA	McLean	J. Laib	Pumped	Dom/stk		1870	605			
145-079-24CCD	McLean	Gene Kurle	Pumped	Domestic	2004	1975	542-582			
145-079-29DCC	McLean	Jeff Walker	Pumped	Stock	1990	1885	584-635	-94	1990	
145-080-22AAA	McLean	E. Wagner	Pumped	Dom/stk	1952	1970	694			
145-080-28DDD	McLean	Chris Pfleiger	Pumped	Domestic	2005	1850	470-550	-70	2005	
145-080-32CDC	McLean	Schirados Exc	Pumped	Unused	1977	1770	265-360	-55	1977	
145-081-24BBB	McLean	Steve Reiser	Pumped	Domestic	1982	1975	430-490	-190	1982	
145-084-03CCC	McLean	Wachter Develop	Pumped hc	Industrial		1720	385-425	-1	1986	
145-084-06BBC	Mercer	Willis Weiderich	Flowing	Dom/stk		1870	1260	Flow		
145-084-22DCC	Mercer	Terry Grannis	Flowing	Domestic	2001	1690	555-655	+127	2001	
145-084-27BBC	Mercer	William Russell	Flowing	Dom/stk	1974	1690	483-630	+32	1974	
145-085-22CAC	Mercer	E. Zieman	Flowing	Stock	1967	1765	891-903	+107	1971	
145-085-24DDA	Mercer	H. Galster	Flowing	Dom/stk		1815	1058	+76	1971	
145-085-32CDC	Mercer	Leo Mittlested	Flowing	Domestic	1972	1725	710-860	+185	1972	
145-085-33DD	Mercer	Logh Ranch	Flowing	Stock	1979	1715	830	Flow	1979	
145-086-01DDD	Mercer	Harold Richenberg	Pumped	Stock	1979	2015	1118-1138	-120	1979	
145-086-19DDA	Mercer	Robert Mettler	Pumped	Domestic	1985	2010	1390-1420	-95	1985	
145-086-22AAA	Mercer	Harold Benz	Pumped	Stock	1972	1990	950-1260	-76	1972	
145-086-35CCA	Mercer	William Rahn	Pumped	Domestic	1975	1930	993-1119	-35	1975	
145-087-04DDD	Mercer	Art Oberlander	Pumped	Domestic	1972	1975	1162-1316	-20	1975	
145-087-06CBB3	Mercer	E. Boechel	Pumped	unused dom/s	1966	2069	1370	-99	1966	
145-087-17DCD	Mercer	Floyd Weigum	Pumped	Domestic	1973	1960	970-1138	-9	1973	
145-087-23DCC	Mercer	John Galster	Flowing	Dom/stk	1972	1870	920-960	+46	1972	
145-087-36ABA	Mercer	Clarence Zuern	Flowing ldc	Domestic	1975	1840	830-1187	+51	1975	
145-089-25DBA	Mercer	A. Mittelsteadt	Pumped	Stock	1964	2118	1507	-132		
145-092-25ABC	Dunn	City Of Halliday	Pumped	Unused mun	1974	2046	1480-1555	Flow	1974	
145-094-06BB	Dunn	Amoco Production	Pumped	Domestic	1979	2350	1680-1740	-200	1979	
145-094-26B	Dunn	City Of Dunn Center	Pumped	Unused mun	1975	2180	1742-1822	-94	1975	
145-094-26B	Dunn	City Of Dunn Center	Pumped	Unused mun	1983	2200	1565-1835	-42	1983	
145-097-19AA	Dunn	Gulf Exploration	Pumped	Domestic	1978	2600	1940-2115		1978	
145-098-29CCD	McKenzie	Roger Chinn	Pumped	Stock	1993	2640	about 2000			
145-098-34DCA	McKenzie	Pete Glovatsky	Pumped	Stock	1977	2585	1933-1993	-343	1977	
145-099-23CCA	McKenzie	McKenzie Grazing	Pumped	Stock	1981	2540	1920-1980	-360	1981	
145-100-01ADB	McKenzie	Edgar Storm	Pumped	Stock	1989	2422	1620			
145-100-02AAC	McKenzie	McKenzie Grazing	Pumped	Unused	1980	2620	1891-1937	-409	1980	
145-100-02AAC2	McKenzie	McKenzie Grazing	Pumped	Stock	2008	2620	1850-1940	-444	2008	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
145-101-04CCC	McKenzie	Ed Trotter	Pumped	Stock	1957	2220				
145-101-05BAD	McKenzie	Ed Trotter	Pumped	Dom/stk	1981	2190	1438-1470	+23	1981	
145-101-05BBB	McKenzie	Eleanor Trotter	Pumped	Stock	1979	2170	1344-1407	+35	1979	
145-101-17BDA	McKenzie	Dan Brockman	Flowing	Stock	1977	2140	1250-1300	+74	1977	
145-101-18DAC	McKenzie	Dan Brockman	Flowing	Stock		2090				
145-101-18DBC	McKenzie	Dan Brockman	Flowing Idc	Dom/stk	1999	2085	1260-1354	+74	2008	
145-101-19ACA	McKenzie	Dan Brockman	Flowing	Stock	1975	2120	1230-1305	+104	1975	
145-101-22ABD	McKenzie	McKenzie Grazing	Pumped	Stock	1983	2360	1562-1702	-160	1983	
145-102-02ACB	McKenzie	Milo Wisness	Flowing	Stock	1992	2150	1239-1281	+62.5	1992/2008	
145-102-05ABB	McKenzie	Pennzoil	Pumped	Unused	1981	2400	1670-1730	-277	1981	
145-102-15BAD	McKenzie	Milo & Paul Wisness	Flowing	Stock	1970	2160	1212-1255	+12	2006	-1.15
145-102-15DDD	McKenzie	Pennzoil To Owner	Pumped	Unused	1981	2380	1365-1407	-60	1981	
145-102-17CCA	McKenzie	Pennzoil To Owner	Pumped	Unused	1980	2400	1582-1645	-180	1980	
145-102-24DBB	McKenzie	Lee Trotter	Flowing	Stock	1993	2100	1260-1340	+74	1993	
145-102-27CBB	McKenzie	Goldsbury	Flowing Idc	Stock	1965	2170	1206-1240	Flow		
145-103-18BAB	McKenzie	Belle Fourche Pipe	Pumped	Domestic	1979	2570	1640-1720	-370	1979	
145-104-03CCC	McKenzie	McKenzie Grazing	Pumped	Stock	1980	2540	1613-1643	-324	1980	
145-104-05CBB	McKenzie	Plainview School	Pumped	Domestic	1984	2370	1486-1526	-150	1984	
145-104-26DCC	McKenzie	McKenzie Grazing	Pumped	Stock	1979	2380	1440-1485	-115	1979	
146-074-21CCC	Sheridan	NDSWC Goodrich Se	Monitoring	Monitoring	1977	1980	399-405	-42	1978	
146-076-03DDD	Sheridan	NDSWC Mcclusky E	Monitoring	Monitor plug	1978	1980	652-658	-22	1978	
146-077-11ADB	Sheridan	Mcclusky N.D.	Pumped	Municipal		1920	377-445			
146-077-21BBB	Sheridan	NDSWC Mcclusky Sw	Monitoring	Monitor plug	1977	1870	399-405	-37	1978	
146-077-36CCC	Sheridan	NDSWC Mcclusky S	Monitoring	Monitor plug	1977	2020	560-566	-153	1978	
146-079-02BCD	McLean	Lloyd Westerlind	Pumped	Dom/stk	1965	1940	580			
146-079-02C	McLean	City Of Mercer	Pumped	Municipal	1978	1920	554-584	-108	1978	
146-079-02CCA2	McLean	City Of Mercer	Pumped	Unused		1926	585	-100		
146-079-06ACC1	McLean	R. O'shea	Pumped	Dom/stk	1959	1860	530			
146-079-06CDD	McLean	Darrell O'shea	Pumped	Domestic	1977	1880	610		1977	
146-079-18DAB1	McLean	L. Brunner	Pumped	Domestic	1951	1950	600-635			
146-079-25BDA	McLean	A. Wardner	Pumped	Stock		1890	590			
146-080-17A	McLean	Leo Reiser	Pumped	Stock	1979	1850	644-665	-61	1979	
146-081-10BDD	McLean	Dale Hanson	Pumped	Domestic	1982	1990	545-625	-170	1982	
146-081-10DAD	McLean	Robert Hanson	Pumped	Domestic	1986	1980	590-650	-145	1986	
146-085-04DAA2	Mercer	A Knell	Pumped	Dom/stk	1965	2016	1192	-90	1965	
146-085-21CDC	Mercer	Ben Scheid	Pumped	Dom/stk	1983	2050	1348-1358	-95	1983	
146-085-24AC	Mercer	Ludwig Kruckenberg	Flowing hc	Stock	1972	1750	480-671	+58	1972	
146-086-14BBA1	Mercer	Harold & Max Miller	Pumped	Dom/stk	1989	2055	1265-1315	-140	1989	
146-086-14BBA2	Mercer	Max Miller	Pumped	Dom/stk	2001	2055	1260-1310	-145	2001	
146-086-17AAB	Mercer	Theo Weidrich	Pumped	Domestic	1979	2040	1008-1205	-136	1975	
146-086-28DAD	Mercer	Roger Rasch	Pumped	Dom/stk	1982	2140	1140-1160	-230	1982	
146-086-33CBD	Mercer	Scott Clooten	Pumped	Dom/stk	2003	2120	1340-1400	-206	2003	
146-087-04DDC	Mercer	Vernon Boeshans	Flowing Idc	Rural Water	2008	1880	1165-1250	Flow	2008	
146-087-07DDC	Mercer	Hemmuth Pfenning	Flowing	Domestic	1978	1875	1090-1130	+74	1978	
146-087-08AAB	Mercer	Lakeshore Subdiv.	Flowing Idc	Domestic	1986	1860	1124-1236	+51	1986	
146-087-08DDD2	Mercer	H. Hafner	Flowing Idc	Dom/stk	1964	1915	1140-1205	+48	1968	
146-087-09BBB	Mercer	Lakeshore Subdiv.	Flowing Idc	Municipal	2002	1860	1120-1220	+51	2002	
146-087-10DBC	Mercer	H. Hafner	Flowing Idc	Dom/stk	1967	1923	1299-1320	+40	1968	
146-087-23CA	Mercer	Jerome Boeshans	Pumped	Domestic	1980	2040	936-1036	-96	1980	
146-088-23ABB	Mercer	Helmuth Phenning	Flowing	Domestic	1986	1895	920-960	Flow	1986	
146-089-13ACC	Mercer	Victor Walker	Flowing	Stock	1974	1880	952-1225	+115	1974	
146-089-24CBC	Mercer	Eugene Sailer	Pumped	Dom/stk	1972	2055	1168-1357	-120	1972	
146-090-20CCC	Mercer	NDSWC Dodge	Monitoring	Monitoring	1968	2120	1540-1576	-94	2007	-0.46

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
146-092-16CC	Dunn	Marvin Voight	Flowing Idc	Stock	1988	2100	1611	+127	1988	
146-093-03CDD	Dunn	Andrew Voight	Flowing Idc	Stock	1972	2060	1485-1525	+46	1972	
146-094-04BBC	Dunn	Ray Hammel	Flowing	Stock	1969	1980	1590-1600	Flow	1969	
146-094-05AA	Dunn	Ray Hammel	Flowing	Stock	1972	1960	1415-1500	+78	1972	
146-094-05CBD	Dunn	Ray Hammel	Flowing	Stock	1968	1905	1340-1410	+32	1972	
146-094-07CAB	Dunn	Ray Hammel	Flowing	Stock	1974	1980	1495-1570	+68	1974	
146-094-08DAD2	Dunn	Mark Reddig	Flowing	Stock	1974	1960	1660-1730	+123	2005	-1.39
146-095-03CDA	Dunn	Johnny Kupper	Pumped	Stock	1972	2130	1520-1600	-1	1972	
146-099-06BCC	McKenzie	Wallace Carson	Pumped	Stock		2200	1300	+12	1978	
146-099-06CCA	McKenzie	US Forest Service	Pumped	Domestic	2000	2200	1375-1417	-12	2000	
146-100-04AAC	McKenzie	McKenzie Grazing	Flowing	Stock	1980	2096	1337-1400	+97	1985	
146-100-17DAD	McKenzie	Frank Dillman	Pumped	Stock	1996	2574	about 1820			
146-100-28CBB	McKenzie	Bob Christopherson	Pumped	Unused	2004	2480	about 1800?			
146-101-19AB	McKenzie	McKenzie Grazing	Flowing	Stock		2170	1425			
146-101-21DBB	McKenzie	Kevin Hartman	Pumped	Stock		2180		about (	2008	
146-101-25D	McKenzie	McKenzie Grazing	Pumped	Stock		2225	1500	-25		
146-101-29BBA	McKenzie	Kevin Hartman	Flowing	Stock		2190		Flowin(	2008	
146-101-30ADA	McKenzie	Kevin Hartman	Flowing	Dom/stk	1980	2120	1400-1500	+81	1980	
146-101-30BDC	McKenzie	Kevin Hartman	Flowing	Dom/stk	1974	2100	1260-1320	+58	1974, 2008	
146-101-31CDA	McKenzie	Eleanor Trotter	Flowing	Unused	1975	2170	1329-1435	+58	1975	
146-101-31DBA	McKenzie	Ed Trotter	Flowing	Stock		2150				
146-101-35D	McKenzie	Mck Gz - Hartman	Flowing	Stock		2180		Flow		
146-102-10CAB	McKenzie	Petro-Hunt	Pumped	Industrial	1984	2233	1605-1665	-60	1984	
146-102-13BAD	McKenzie	Ross Sundeen	Flowing	Stock		2060				
146-102-24BDB	McKenzie	Alvin Nelson	Flowing	Dom/stk		2060		+104	2008	
146-102-25BDA	McKenzie	Kevin Hartman	Pumped	Stock		2190				
146-102-27BCA	McKenzie	Alvin Nelson	Flowing	Stock	1974	2127	1260-1310	+34	2006	-1.23
146-102-34ABD	McKenzie	Lloyd Rocheman	Flowing	Stock	1977	2120	1352-1395	+97	1977	
146-102-35BCD	McKenzie	Milo & Paul Wisness	Flowing	Stock		2080		+79	2008	
146-103-02BCC	McKenzie	Charles Fitzgerald	Pumped	Domestic	1977	2240	1455-1520	-41	1977	
146-103-10BCC	McKenzie	Shell Oil/N Mitten	Pumped	Stock	1981	2270	1493-1533	-48	1981	
146-103-34CCD	McKenzie	McKenzie Grazing	Pumped	Stock	1973	2455	1663	-260	1973	
146-104-10BBB	McKenzie	Squaw Gap School	Pumped	Domestic	1980	2280	1495-1535	-70	1980	
146-104-22AAA	McKenzie	Hall Brothers	Pumped	Stock	1983	2345	1533-1617	-100	1983	
146-104-28BBC	McKenzie	Melvin Leland	Pumped	Dom/stk	1981	2440	1556-1596	-200	1981	
146-105-27A	McKenzie	McKenzie Grazing	Pumped	Stock	1979	2370	1482-1525	-77	1979	
147-075-03CCC1	Sheridan	NDSWC Sheridan E	Monitoring	Monitor plug	1977	1850	459-456	-137	1996	
147-079-10DA	McLean	Rusal Makoff	Pumped	Domestic	1993	1910	332-370	-83	1993	
147-079-11CD	McLean	Joel Stredinger	Pumped	Domestic	1995	1880	305-345	-43	1995	
147-079-34DD	McLean	Myron Maheeff	Pumped	Domestic	1972	1910	575	-108	1972	
147-080-30DBC	McLean	Leon Schlofram	Pumped	Dom/stk	1986	1900	425-445	-80	1986	
147-080-31BAB	McLean	Don Pickett	Pumped	Stock	1998	1900	410-460	-85	1998	
147-085-20DBD3	Mercer	F. Isaak	Flowing	Dom/stk	1965	1915	1403-1440	+19	1968	
147-085-26C	Mercer	Leonard Sailer	Flowing Idc	Domestic	1971	1920	1040	Flow	1971	
147-085-35	Mercer	William Richter	Flowing	Stock	1982	1950	1055-1080	Flow		
147-086-32DCB	Mercer	Kevin Schulte	Flowing Idc	Domestic	1998	1880	1162-1204	+53	1998	
147-087-04CD	McLean	Oscar Whitecalf	Flowing	Stock	1972	1920	1220	Flowing		
147-088-04ABB	McLean	Almit Brever	Flowing	Stock	1994	1950	1289-1339	+39	1994	
147-088-04BDB	McLean	Almit Brever	Flowing	Stock	1990	1930	1300-1350	+42	1990	
147-088-11DCD	McLean	Pearl Howard	Flowing Idc	Domestic	1994	1950	1275-1305	+35	1994	
147-092-09BDC	Dunn	Jim Mosset	Flowing Idc	Stock	1998	1880	1250-1295	+171	1998	
147-093-33ACD	Dunn	Andrew Voight	Flowing	Stock	1989	1880	1340-1390	Flow	1989	
147-093-34CAD	Dunn	Andrew Voight	Flowing	Stock	1989	1880	1190-1250	+162	1989	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
147-093-35CBC	Dunn	Corps Of Eng.	Flowing Idc	Municipal	1989	1860	1166-1292	+224	1989	
147-094-24C	Dunn	Earl Pelton	Flowing	Stock	1989	2000	1370-1420	+69	1989	
147-094-26BCB	Dunn	K. Knutson	Flowing	Stock	1969	1940	1470-1502	+72	1972	
147-094-33B	Dunn	Bob Larsen	Flowing	Stock	1989	2020	1420-1470	+104	1989	
147-094-33DB	Dunn	H. Larson	Flowing	Stock	1969	2210	1590-1665	Flow	1969	
147-094-34BAD	Dunn	K. Knutson	Flowing	Stock	1968	1980	1465-1510	+78	1972	
147-094-35C	Dunn	Kim Knutson	Flowing	Stock	1989	2140	1495-1560	+32	1989	
147-094-35CAA	Dunn	Kenneth Knutson	Pumped	Stock	1974	2190	1550-1610	0	1974	
147-094-36B	Dunn	Earl Pelton	Flowing	Stock	1989	1990	1390-1450	+79	1989	
147-095-08BDC	Dunn	G. Tabor	Flowing	Stock	1966	1990	1385-1490	+51	1972	
147-095-12CAD	Dunn	T. Sandvick	Flowing	Stock	1969	1860	1386-1410	+118	1972	
147-095-13BCC	Dunn	ND Park & Rec.	Pumped	Domestic	1979	2425	1896-1983	-310	1979	
147-095-13CCC2	Dunn	ND St. Park Svc.	Pumped	Domestic	1971	2420	1935-1950	-299	1973	
147-095-14AAA	Dunn	ND St. Park Svc.	Flowing Idc	Domestic	1968	1980	1410-1430	+71	1972	
147-095-17ACA	Dunn	G. Tabor	Flowing	Stock	1968	2100	1510-1570	+40	1972	
147-095-18D	Dunn	George Tabor	Pumped	Stock	1974	2530	1987-2052	-415	1974	
147-095-19BBA	Dunn	Cody Kleemann	Pumped	Unused	2007	2524	about 1900			
147-095-24AAC	Dunn	T. Sandvick	Flowing Idc	Stock	1969	1990	1580	+146	1969	
147-095-26BBB1	Dunn	A. Schwalbe	Pumped	Stock	1969	2280	1850	-164	1972	
147-095-28DDD	Dunn	Bob Larsen	Flowing	Stock	1989	2220	1330-1380	+104	1989	
147-097-05ADD	Dunn	D. Harris	Flowing	Stock	1973	1954	1400	Flow		
147-097-07	Dunn	Lazy T Ranch	Pumped	Stock	1988	2000	1350-1400			
147-097-16CC	Dunn	Gene Harris	Flowing	Stock	1981	2000	1423-1465	Flow		
147-097-17AAC	Dunn	Gene Harris	Pumped	Stock	1981	2430	1820	-360	1981	
147-097-19	Dunn	Lazy T Ranch	Flowing	Stock	1988	2050	1465-1540	+62	1988	
147-097-20BAB	Dunn	D. Harris	Flowing	Stock	1972	2002	1425	+116	1972	
147-098-02ACB	McKenzie	Darlene Haugland	Flowing	Stock	1975	1928	1190-1265	+150	1975	
147-098-21BDB	McKenzie	US Forest Service	Pumped	Stock	1982	2171				
147-098-24DDD	McKenzie	Encore Operating	Flowing Idc	Industrial	1982	2128	1615-1700	+173	1982	
147-099-17DDC	McKenzie	McKenzie Grazing	Pumped	Stock	1976	2570	1808-1955	-360	1976	
147-100-19CDB	McKenzie	William Ceynar	Flowing	Unused	1981	2010	1342-1386	+150	1981	
147-100-20DDB2	McKenzie	William Ceynar	Flowing	Stock	1972	2010	1290-1330	+130	2006	-2.26
147-100-21BBB	McKenzie	Arnold Ceynor	Flowing	Dom/stk	1973	1995	1273-1323	+156	2008	
147-100-25DBC	McKenzie	Joyce Byerly	Pumped	Stock	1981	2560	1869-1911	-350	1981	
147-100-26DAD	McKenzie	Howard Lange	Pumped	Dom/stk	1982	2560	1911-1974	-350	1982	
147-101-09CAC	McKenzie	Fredrick (Kit) James	Flowing	Dom/stk		2100		+183s	2008	
147-101-15BBD	McKenzie	Kit James	Flowing	Stock		2100		+217	2008	
147-101-15CCB	McKenzie	Kit James	Flowing	Stock		2087				
147-101-30BBB	McKenzie	Ron Crighton	Flowing	Dom/stk		2045		+97	2008	
147-101-32ACD	McKenzie	Bill & Carol Russell	Flowing	Stock		2035				
147-101-32ADC	McKenzie	Bill & Carol Russell	Flowing	Stock		2035				
147-101-32DBA	McKenzie	Bill & Carol Russell	Flowing	Dom/stk	1973	2035	1321-1376	+102	2008	
147-102-23BAC	McKenzie	McKenzie Grazing	Pumped	Stock	1981	2247	1533-1596	-75	1981	
147-102-23DDC	McKenzie	D & R Crighton Fed	Flowing	Stock		2105				
147-102-34CDC	McKenzie	David Crighton	Flowing	Stock		2100		+32	2008	
147-102-34DDA	McKenzie	David Crighton	Flowing	Dom/stk		2065		+64	2008	
147-102-34DDD	McKenzie	Stephenson School	Flowing	Domestic	1984	2070	1323-1365	+79	2008	
147-102-35ADA	McKenzie	Crighton W Bar	Flowing	Stock		2050				
147-102-36AAD	McKenzie	River Ghost Ranch	Flowing	Dom/stk	1973	2060	1340-1380	+115	1973	
147-102-36ADA	McKenzie	Ross Sundeen	Flowing	Stock		2100				
147-103-14DDD	McKenzie	Arne Skedsvold	Pumped	Dom/stk	1994	2260	1491-1554	-95	1994	
147-103-16CCB	McKenzie	Leland School	Pumped	Dom/stk	1979	2165	1397-1460	Pumpe	1979	
147-103-22ADC	McKenzie	William Lewis	Pumped	Dom/stk	1979	2165	1431-1491	0	1979	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
147-103-28ACD	McKenzie	Everett Johnson	Pumped	Dom/stk	2004	2185	1428-1470	-51	2004	
147-104-02ACA	McKenzie	Tim Dwyer	Pumped	Unused stk	1985	2138	1406-1456		2008	
147-104-03DCA	McKenzie	David Hatter	Pumped	Dom/stk	1974	2120	1354		1974	
147-104-04CCC	McKenzie	Tim Dwyer	Flowing	Dom/stk	1976	2055	1247-1290	+65	2008	
147-104-04CCD	McKenzie	Tim Dwyer	Flowing ldc	Dom/stk	2004	2050	1219-1300	+46	2004	
147-104-08ADB	McKenzie	Mark Voll	Flowing	Dom/stk	1980	2060	1240-1280	+53	2008	
147-104-26DDC	McKenzie	Russell Hatter	Pumped	Dom/stk	1979	2200	1417-1490	+9	1979	
148-077-02DDD	Sheridan	NDSWC Sheridan W	Monitoring	Monitor plug	1978	1955	570-576	-145	1978	
148-079-28ADA	McLean	Cliff Alexander	Pumped	Domestic	1993	2010	680-720	-152	1993	
148-079-35CAD1	McLean	Herbert Rauser	Pumped	Stock	1973	1950	555	-136	1973	
148-079-35CAD2	McLean	Herbert Rauser	Pumped hc	Domestic	1973	1950	385-400	-110	1973	
148-082-07N	McLean	Tony Mann	Pumped hc	Domestic	1985	1860	460	-50	1985	
148-085-23CDC	McLean	Re Weber	Pumped	Dom/stk	1968	1945	1240-1323	-44	1969	
148-087-15DCD	McLean	Jack Iglehart	Flowing ldc	Dom/stk	1982	1930	1132-1152	Flow	1982	
148-087-33BBB	McLean	Leo Ruhland	Pumped	Dom/stk	1986	2000	1280-1316	-35	1986	
148-089-32	McLean	Almit Breuer	Flowing	Stock	1978	1870	1040	Flowing		
148-089-33CC	McLean	Almit Breuer	Flowing	Stock	1986	1970	1315-1387	Flowing		
148-090-25B	McLean	Byron Holtan	Flowing ldc	Stock	2000	1900	1386-1436	+39	2000	
148-094-06CBB	Dunn	Gabe Fettig	Pumped	Stock	2002	2440	1808-1848	-331		
148-095-22CCA	Dunn	Emerson Chase	Flowing	Dom/stk		1925	1372-1430	+37	1972	
148-095-31CCA	Dunn	George Tabor	Flowing	Stock	1971	1920	1317-1350	+149	1972	
148-095-32DBD	Dunn	George Tabor	Flowing	Stock	1971	1910	1335-1365	+82	1972	
148-096-09ABD	Dunn	Einer Jorgenson	Flowing	Stock	1969	1950	1460	+125	1972	
148-096-10	Dunn	Einer Jorgenson	Pumped	Stock	1977	2300	1850-1888	-250	1977	
148-096-11BDA	Dunn	Einer Jorgenson	Flowing	Stock	1972	2020	1405-1455	+42	1972	
148-096-15AAA	Dunn	Einer Jorgenson	Pumped	Stock	1970	2400	1665-1675	-289	1973	
148-096-19CAA	Dunn	George Fenton	Flowing	Stock	1975	1960	1297-1335	+58	1975	
148-097-09DBD	Dunn	Gordon Olson	Flowing	Stock	1966	1935	1350-1450	+196	1973	
148-097-10	Dunn	George Fenton	Flowing	Stock	1986	1900	1269-1320			
148-097-17DAA	Dunn	Orvel Thorp	Pumped	Stock	1964	2390	1978-1998	-277	1973	
148-097-20CAD	Dunn	Clarence Dannielson	Flowing	Stock	1970	2140	1630-1693	+49	1973	
148-097-21ADA	Dunn	Clarence Danielson	Flowing	Stock	1975	1910	1370-1435	+104	1975	
148-097-22CDC1	Dunn	R. Menroe	Flowing	Domestic	1968	1920	1381-1401	+220	1972	
148-097-22CDC2	Dunn	Alvin Carus	Flowing ldc	Dom/stk	1980	1920	1420	Flow		
148-097-23	Dunn	Louie Hunt	Flowing	Stock	1988	2000	1360-1420			
148-097-30ADA	Dunn	Gordon Olson	Flowing	Stock	1964	2080	1523-1565	+33	1973	
148-097-33ABB	Dunn	Robert Menroe/NDSWC	Flowing	Stock	1972	1920	1325	+187	1992	
148-099-05DBA	McKenzie	McKenzie Grazing	Pumped	Stock	1977	2365	1890-1940	-210	1977	
148-099-34DCD	McKenzie	Morris Tarnausky	Flowing	Dom/stk	1955	1960		+171	2008	
148-099-36BDD	McKenzie	T. Martin/A. Olson	Flowing	Stock	1975	2010	1435-1475	+58	1975	
148-100-30BAA	McKenzie	McKenzie Grazing	Pumped	Stock	1994	2255	1638-1680	-114	1994	
148-101-27DD	McKenzie	True Oil	Pumped	Industrial	1976	2167	1563-1663			
148-102-02AAB	McKenzie	Milton Madison	Pumped	Stock	2000	2270	about 1700			
148-102-15DDA1	McKenzie	McKenzie Grazing	Pumped	Stock	1979	2389	1695-1756	-264	2007	-1.62
148-103-04BAA	McKenzie	US Forest Service	Pumped	Domestic	2004	2260	1640-1680	-121	2004	
148-104-14DBD	McKenzie	Marvin Wambach	Pumped	Stock	1980	2381	1730-1764	-150	2005	
148-104-18ACC	McKenzie	McKenzie Grazing	Flowing ldc	Stock	1979	2150	1452-1495			
148-104-18ADB	McKenzie	ANR Prod	Flowing ldc	Unused	1981	2150	1496-1580	+58		
148-104-30BAC	McKenzie	McKenzie Grazing	Flowing	Stock	1977	2040	1402-1460	+92	1977	
148-105-02AAB	McKenzie	McKenzie Grazing	Flowing	Stock	1978	2065	1334-1386	+92	1978	
148-105-13CC	McKenzie	McKenzie Grazing	Flowing	Unused	1980	2092	1420-1460	+51	1980	
148-105-23AAC	McKenzie	Greg Pennington	Flowing	Stock		2000		Flow		
148-105-25A	McKenzie	Marvin Wambach	Flowing	Stock	1975	2050	1375	Flow		

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
148-105-26AAC	McKenzie	Greg Pennington	Flowing	Unused	1982	2005	1260-1302	+92	1982	
148-105-26DDB1	McKenzie	Klandl Brothers	Flowing	Unused	1973	2030	1230-1290	+162	1973	
148-105-26DDB2	McKenzie	Greg Pennington	Flowing ldc	Dom/stk	2003	2030	1260-1302	+92	2003	
148-105-36BDD2	McKenzie	Greg Pennington	Flowing	Stock		1995		Flow		
148-105-36DCC	McKenzie	Bear Paw Energy	Flowing	Industrial	1980	2000	1220-1260	+92	2008	
148-105-36DCD	McKenzie	Bear Paw Energy	Flowing ldc	Industrial	1991	2000	1197-1260	+88	1991	
149-077-15CCC	Sheridan	NDSWC Sheridan Nw	Monitoring	Monitor plug	1978	2013	642-648	-110	1978	
149-089-09BBA	McLean	Harvey Biladeau	Flowing	Stock	1990	1900	1268-1318	+85	1990	
149-090-04DCC	McLean	Dickle Clair	Flowing ldc	Domestic	2000	1865	1123-1166	+97	2000	
149-094-14BA	McKenzie	Mandaree #3	Pumped	Municipal	1970	2200	1605-1705	-111	1970	
149-095-09CDD	McKenzie	NDSWC Linseth	Monitoring	Monitoring	1984	2226	1539-1564	-138	2009	-1.18
149-096-27CBA	McKenzie	William Jorgenson	Flowing	Unused stk	1972	1995	1380-1440	+55	2006	-3.18
149-097-29AD	McKenzie	McKenzie Grazing	Pumped	Stock	1976	2220	1690	-120	1976	
149-097-34CD	McKenzie	McKenzie Grazing	Flowing	Stock	1981	2030	1490-1520	+92	1981	
149-098-14CBB	McLean	Donald Roberts	Flowing	Dom/stk	1985	1925	1305-1370	+79	1985	
149-098-31BAB	McKenzie	Denton Zubke	Pumped	Domestic	1994	2260	1750-1840	-150	1994	
149-100-32BBB	McKenzie	Eugene Braaten	Pumped	Domestic	1982	2230	1743-1806	-90	1982	
149-102-01BBB	McKenzie	Zenergy (Murphy)	Pumped	Industrial	2008	2294	1690-1760	-198.8	2008	
149-102-31D	McKenzie	Faa Watford City	Pumped	Domestic	1975	2500	1805-1910	-330	1975	
149-103-33DA	McKenzie	McKenzie Grazing	Pumped	Stock	1971	2250	1400			
149-104-02AA	McKenzie	McKenzie Grazing	Pumped	Stock	1963	2210	1520			
149-104-05BBA	McKenzie	Prewitt Cattle Co.	Flowing ldc	Domestic	1981	1880	1347-1407	+58	1981	
149-104-06ADA	McKenzie	Prewill Cattle Co.	Flowing	Dom/stk	1981	1900	1220-1260	+173	1981	
149-104-06ADB	McKenzie	James Kuykdendall	Flowing	Domestic	1971	1902	1192-1220	+121	2008	-2.45
149-104-28DCB	McKenzie	Chris Christenson	Flowing ldc	Dom/stk	1980	2080	1387-1450	+51	1980	
149-104-31DCC	McKenzie	Headington Oil	Pumped	Unused	1981	2120	1323-1428	0	1981	
150-076-21BBB	Sheridan	NDSWC Sheridan N	Monitoring	Monitor plug	1977	1676	356-362	-49	1996	
150-079-23C	McLean	Barry Dossenko	Pumped	Stock	1974	1980	460	-200	1974	
150-081-30CA	McLean	Tom Kohler	Pumped	Stock	2005	2000	590-620	-175	2005	
150-082-15CCC	McLean	Robin Plesuk	Pumped	Dom/stk	1987	2050	570-780	-210	1987	
150-082-33AA	McLean	Robert Olson	Pumped hc	Domestic	1974	2040	590	-225	1974	
150-085-15CBB	McLean	Zack Roberts	Pumped	Dom/stk	1985	2100	1206-1260	-200	1985	
150-094-09ACC	McKenzie	Howard Fettig	Pumped	Stock	2001	2200	1533-1617	-140	2001	
150-095-08BDB	McKenzie	Amerada Hess	Pumped	Industrial	1983	2318	1410-1560	-220	1983	
150-096-02BC	McKenzie	Larry Signalness	Monitoring	Monitoring	1958	2369	1400-1500	-286	2009	-1.77
150-096-26DCB	McKenzie	Delmer Rink	Pumped	Stock	1980	2325	1583-1604	-214	1980	
150-098-21AAB	McKenzie	Black Hills Trucking	Flowing ldc	Domestic	1980	2090	1730-1810	+46	1980	
150-099-22BBA1	McKenzie	NDSWC Watford Cty	Monitoring	Monitoring	1980	2188	1742-1772	-83	2009	-1.67
150-100-29CCD	McKenzie	Phillip Moen	Pumped	Dom/stk	1982	2380	1818-1860	-135	1982	
150-101-05BCA1	McKenzie	City Of Alexander	Pumped	Municipal	1982	2200	1676-1760	-60	1982	
150-101-05BCA2	McKenzie	City Of Alexander	Pumped	Municipal	2004	2190	1690-1770	-120	2004	
150-101-17ACA	McKenzie	Landtech Ent.	Pumped	Industrial	1985	2180	1643-1706	-50	1985	
150-101-17CBC	McKenzie	Encore Op.	Pumped	Industrial	1982	2220	1705-1762	-90	1982	
150-102-09DDD	McKenzie	Zenergy (Carter)	Pumped	Industrial	2008	2126	1550-1610	-42	2008	
150-102-18CCC	McKenzie	Zenergy (Williams)	Pumped	Industrial	2008	2088			2008	
150-102-25BB	McKenzie	Zenergy (Schmidt)	Pumped	Industrial	2008	2155	1610-1680	-66	2008	
150-102-26BB	McKenzie	Zenergy (Foxx)	Pumped	Industrial	2008	2233	1690-1760	-148	2008	
150-102-27BBB	McKenzie	Zenergy (Mcgwire)	Pumped	Industrial	2008	2231	1660-1720	-148.7	2008	
150-102-28CCC	McKenzie	Zenergy (Jackson)	Pumped	Industrial	2008	2149			2009	
150-102-33BDC	McKenzie	Linda Monson	Pumped	Dom/stk	2007	2123	1564-1624	-30	2007	
150-103-01BDA	McKenzie	McKenzie Grazing	Pumped	Unused stk	1979	2075	1603-1645	-2	2009	-3.28
150-103-23CDD	McKenzie	McKenzie Grazing	Flowing hc	Stock	1970	2160	1414-1450	Flow	1970	
150-103-25AA	McKenzie	Zenergy (Gehrig)	Pumped	Industrial	2008	2124	1600-1680	-48	2008	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
150-104-04AAB	McKenzie	Harold Schlothauer	Flowing	Domestic	1977	1885	1340-1380	+129	2008	-2.48
150-104-04BBB	McKenzie	Clayton Falkenhagen	Flowing	Domestic	1977	1890	1305-1340	+196	1977	
150-104-05CCC	McKenzie	Carl Miller	Flowing	Domestic	1981	1895	1323-1344	+185	1981	
150-104-09AAC	McKenzie	Marlin Norby	Flowing	Dom/stk	1981	1890	1302-1344	+162	1981	
150-104-09BBB	McKenzie	Bernard Langwold	Flowing	Domestic	1998	1890	1311-1353	+102	1998	
150-104-09CBB	McKenzie	Donald Helm	Flowing	Stock	1975	1886	1340-1365	+224	1975	
150-104-10BAA	McKenzie	Eldon Johnson	Flowing	Dom/stk	1977	1890	1330-1380	+185	1975	
150-104-11CAB	McKenzie	William Lassey	Flowing	Dom/stk	1979	1990	1344-1365	+81	1979	
150-104-14BCA	McKenzie	Annie Walker	Flowing hc	Stock	1967	2092	943-960	+29	1995	
150-104-16BBB	McKenzie	E. Denoough	Flowing	Dom/stk	1977	1889	1287-1335	+208	1977	
150-104-21CCA	McKenzie	Melody Ranch/Flinn	Flowing	Dom/stk	1977	1900	1300-1323	+208	1977	
150-104-23DCD	McKenzie	McKenzie Grazing	Flowing	Stock	1970	2015	1414-1450	Flow		
151-077-01BCC	McHenry	Alfred Martin	Pumped	Domestic		1605	262-270			
151-090-29BBB	Mountrail	Tom Miller	Pumped	Dom/stk	1982	2150	1590-1620	-125	1982	
151-091-11BBB	Mountrail	Ralph Brendle	Flowing	Domestic	1985	1890	1295-1340	Flow		
151-095-04DBD2	McKenzie	NDSWC Chimney Bt.	Monitoring	Monitoring	1983	2309	1407-1432	-228	2009	-1.62
151-095-30ACA	McKenzie	Johnson 3	Monitoring	Monitor plug	1983	2320	1371-1402	-233	2003	
151-102-22DDD	McKenzie	John Mrachek	Flowing ldc	Dom/stk	1982	2110	1617-1659	+12	1982	
151-103-11AAA	McKenzie	NDSWC Elk	Monitoring	Monitoring	1985	2187	1680-1753	-121	2009	-1.77
151-103-31BCB1	McKenzie	Arthur Paulson	Flowing	Unused	1982	1900	1352-1394	+173	1982	
151-103-31BCB2	McKenzie	Elizabeth Paulson	Flowing	Domestic	2003	1900	1358-1460	+139	2003	
151-104-02AA	McKenzie	Marie Isley	Flowing	Dom/stk	1977	1880	1400-1435	+127	1977	
151-104-04AAA	McKenzie	Harlow Bieber	Flowing	Domestic	1973	1879	1342-1405	+161	2008	-1.67
151-104-06ADA	McKenzie	Dick Johnson	Flowing	Domestic	1981	1890	1323-1365	+208	1981	
151-104-19DDA	McKenzie	Robert Stepan	Flowing	Domestic	1982	1910	1332-1374	+173	1982	
151-104-24DA	McKenzie	St. Mary Land & Exp	Flowing ldc	Unused	1983	2090	1515-1575	+23	1983	
151-104-25DBD	McKenzie	Math Koch	Flowing	Domestic	1971	1950	1411-1450	Flow		
151-104-28BCC	McKenzie	Jack Hardy	Flowing	Dom/stk	1979	1890	1367-1400	+201	1979	
151-104-31A	McKenzie	Mon-Kota, Inc.	Flowing	Industrial	1980	1905	1320-1385	+189	1980	
151-104-31DAA	McKenzie	Melvin Simmons	Flowing	Dom/stk	1978	1895	1350-1380	+185	1978	
151-104-35ADD	McKenzie	RA Shaide, Inc.	Flowing	Dom/stk	1982	1900	1307-1370	+201	1982	
152-071-05CCCC1	Benson	NDSWC Esmond Sw	Monitoring	Monitoring	1998	1570	72-77	-1	2008	-0.095
152-071-15AAA	Benson	Leon Arnold	Pumped	Domestic		1640	98-125			
152-093-26BCC	Mountrail	D. Pennington	Pumped	Stock	1967	2100	1805	-11	1967	
152-094-01CB	McKenzie	Rae Hendrickson	Flowing ldc	Stock	1966	1910	1620			
152-097-08BBA	McKenzie	Lawrence Grantier	Flowing	Stock	1972	1970	1485-1530	+53	1972	
152-097-27CAA	McKenzie	McKenzie Grazing	Pumped	Stock	1981	2170	1407-1449	-65	1981	
152-097-31CBB	McKenzie	Thomas Kellogg	Pumped	Dom/stk	1982	2100	1512-1554	0	1982	
152-097-35CCC	McKenzie	D & D Rolfsrud	Pumped	Stock		2275	1465			
152-098-01ADB	McKenzie	Gary Wold	Flowing	Stock		1980		+41	2008	
152-098-03BAC	McKenzie	Gary Nottested	Pumped	Wildlife		2095				
152-098-03DAB	McKenzie	John Steelman, Est.	Flowing	Domestic	1973	2020	1625-1730	+29	1973	
152-098-05ACD	McKenzie	Delores Maston	Flowing	Stock		2080				
152-098-08AAA	McKenzie	Delores Maston	Pumped	Stock		2125		-129	2008	
152-098-10CDD	McKenzie	Anthony Gunderson	Pumped	Stock	1974	2060	1660-1750	+35	1974	
152-098-24CCC	McKenzie	Madeline Miller	Flowing	Stock	1975	2000	1680-1730	+20	2006	-1.47
152-099-02CAA	McKenzie	Ben Johnson	Flowing	Stock		1900		Flow		
152-099-03ABC	McKenzie	Larry Widder	Flowing	Stock	1974	1920	1560-1610	107	2008	-3.02
152-099-08AA	McKenzie	Evelyn Jerminson	Flowing	Stock	1981	1960	1615-1675	+148	1981	
152-099-17CAC	McKenzie	Glen Lawler	Flowing	Stock	1983	2020	1690-1750	+81	1983	
152-099-17DAD	McKenzie	John Lawler	Flowing	Stock	1992	2040	1680-1995	+64	2008	
152-099-20DAC	McKenzie	John Lawlar	Flowing	Stock		2035		Flow		
152-099-24BCB	McKenzie	Ben Johnson	Flowing	Stock	1975	2030	1735-1795	+81	1975	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
152-099-25ABA	McKenzie	Ben Johnson	Pumped	Stock	1976	2110	1730-1800	+35	1976	
152-101-03CA	McKenzie	John & Don Lindvig	Flowing ldc	Stock	1982	2130	1464	-35	1982	
152-101-14DCA	McKenzie	Don Lindvig	Flowing hc	Stock	1976	2017	1735-1855	+13	2006	
152-101-15ADD	McKenzie	Don Lindvig	Flowing	Stock	1982	1995	1532-1547	+95	2008	-1.82
152-102-11ABC	McKenzie	Don Lindvig	Flowing	Stock		2073		+10	2009	-1.18
152-102-14CCC	McKenzie	Clayton Roen	Pumped	Stock	1982	2220	1816	-80	1982	
152-102-23DDB	McKenzie	Encore Operating	Pumped	Industrial	1982	2220	1728-1770	-85	1982	
152-102-31AAB	McKenzie	Matt Iverson	Flowing hc	Stock		2165				
152-102-35BC	McKenzie	Donald Link	Pumped	Stock	1994	2253	about 1825-1950			
152-103-07BBB	Williams	Arthur Anderson	Flowing	Dom/stk	1981	1920	1457-1499	+185	1981	
152-103-25CAB	McKenzie	Steven Erickson	Flowing	Stock	1977	1965	1485-1530	+106	2008	-1.87
152-103-27BDC	McKenzie	Stanley Anderson	Flowing ldc	Stock	1982	2710	1540-1596	+21	1982	
152-104-05CA	Williams	Wayne Denough	Flowing	Stock	1980	1960	1496-1538	+134	1980	
152-104-20CCC	McKenzie	Charles Rambel	Flowing	Dom/stk	1977	1930	1441-1485	+150	1977	
152-104-29CBA	McKenzie	Paul Eldridge	Flowing	Dom/stk	1981	1890	1399-1441	+208	1981	
152-104-30AAA	McKenzie	Tim Langwold	Flowing	Dom/stk	1984	1990	1449-1512	Flow	1984	
152-104-32CCC	McKenzie	Kevin Martin	Flowing	Domestic	1976	1885	1360-1385	+222	1976	
152-104-34CCD	McKenzie	John Cayko	Flowing	Dom/stk	1977	1875	1396-1425	+254	1977	
153-071-19AAAA1	Benson	NDSWC Esmond Nw	Monitoring	Monitoring	1998	1577	74-79	-22	2008	-0.41
153-071-19DCC2	Benson	Victor Wolf	Pumped	Domestic		1580				
153-071-28BBC1	Benson	Kenny Streifel	Pumped	Domestic		1562	40			
153-071-29-CBB1	Benson	David Lauinger	Pumped	Domestic		1600				
153-071-30-DAA1	Benson	Ron Lauinger	Pumped	Domestic		1595	53-117			
153-072-03DDD	Pierce	NDSWC Esmond Nw	Monitoring	Monitoring	1968	1553	58-61	-5	2008	0
153-077-34ACD	McHenry	Paul Roe	Pumped	Stock		1580	297-325			
153-079-30AAA1	McHenry	NDSWC Velva	Monitoring	Monitor plug	1976	1595	456-467	-31	2001	+0.16
153-088-35CCD	Mountrail	City Of Plaza	Pumped	Municipal	1997	2095	1440-1543	-155	1997	
153-093-25BCC	Mountrail	B. Roggenbuck	Pumped	Dom/stk	2000	2150	1744-1840	-70	2000	
153-094-23CCC1	McKenzie	NDSWC Antelope S.	Monitoring	Monitoring	1980	2186	1743-1767	-109	2009	-2.08
153-094-32CDC	McKenzie	Amerada Hess	Pumped	Industrial	1989	2266	1404-1509	-176	1989	
153-095-06AAB	McKenzie	Harley Thompson	Flowing ldc	Stock	1996	1900	840-880	+92	1996	
153-095-09CDD	McKenzie	McKenzie Grazing	Pumped	Stock	1979	2400	1420-1500	-138	1979	
153-095-18AB	McKenzie	Petro Hunt	Pumped	Unused ind	1992	2270	1085-1295			
153-095-18ABA	McKenzie	Petro Hunt	Pumped	Industrial	1988	2295	1110-1350	-256	1988	
153-095-18ABB	McKenzie	McKenzie Grazing	Pumped	Stock	1979	2255	1445-1500	-138	1979	
153-095-20CDB	McKenzie	Universal Resources	Pumped	Unused	1984	2325	1055-1380	-200	1984	
153-095-21DDA	McKenzie	Lewell Thompson	Pumped	Dom/stk	1989	2350	1270	-200	1989	
153-095-30ADB	McKenzie	St. Mary Land Tk30	Pumped	Unused	1983	2263				
153-096-03BAB	McKenzie	Craig Sorenson	Flowing	Stock	1977	1940	1053-1075	+60	1977	
153-096-05CAC	McKenzie	Craig Sorenson	Flowing	Stock	1976	1912	1272-1290	Flow		
153-096-11ADA	McKenzie	NDSWC Sand Creek	Monitoring	Monitoring	1987	2340	1289-1370	-324	2009	-3.06
153-096-20DCB1	McKenzie	NDSWC Tobacco G	Monitoring	Monitoring	1984	2282	1433-1500	-234	2009	-1.86
153-097-02CBD	McKenzie	Lynn Wold	Flowing	Stock	1976	1940	1404-1467	+92	1976	
153-097-03CBC	McKenzie	Flatland 2	Flowing	Stock		2017		Flow		
153-097-05ADB	McKenzie	Weston Wold	Flowing	Stock		1960		Flow		
153-097-16CBC	McKenzie	State Of ND	Pumped	Stock	1980	2032				
153-097-19CDB1	McKenzie	Henry Garmann	Pumped	Stock	1973	2125	1770-1840	-30	1973	
153-097-19CDB2	McKenzie	Jay Garmann	Pumped	Stock	2003	2125	1785-1848	-83	2003	
153-097-34CBD	McKenzie	Myron Wold	Flowing	Stock	1974	1995	1600-1660	+88	1974	
153-097-34DAB2	McKenzie	Myron Wold	Flowing	Stock	1985	1910	1650-1700			
153-097-35DCC	McKenzie	Olaf Flatland	Flowing	Stock	1976	1940	1360-1465	+96	2008	
153-098-35ADA	McKenzie	Thoral Sax	Flowing	Stock	1975	1920	1609-1665	+88	1975	
153-098-35CDB	McKenzie	Gary Nottestad	Flowing	Stock		2000				

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressuro head ft	Year meas.	Head cng ft/yr
153-101-23BBB	McKenzie	L. Heen/J. Rider	Pumped	Stock	2008	2131	about 1800			
153-102-19CBA	Williams	Trenton Indian Svc	Flowing Idc	Municipal	1984	1940	1535-1620	+120	1984	
153-102-19CBC	Williams	Trenton Indian Svc	Flowing Idc	Domestic	1984	1940	1509-1615	+150	1984	
153-102-20ABD1	Williams	Trenton Water Users	Flowing Idc	Rural Water		1860				
153-102-20ABD2	Williams	Trenton Water Users	Flowing Idc	Rural Water		1860				
154-071-11AAD1	Benson	NDSWC Esmond N	Monitoring	Monitoring	1968	1590	42-45	-7	2007	+0.12
154-071-20DDD	Benson	S. Hoffert	Monitoring	Monitoring	1967	1640	113	-62		
154-072-01BBB	Pierce	N. Duscher	Pumped	Stock		1605				
154-073-12CCC	Pierce	A. Schiff	Pumped	Domestic		1550	30			
154-075-04AAA1	McHenry	NDSWC Mchenry E	Monitoring	Monitor plug	1976	1508	102-108	-4	2005	
154-077-35DAD	McHenry	Pius Black	Pumped	Stock		1535	240-270			
154-078-31BAA1	McHenry	NDSWC Verendrye	Monitoring	Monitor plug	1976	1550	336-345	-32	1996	
154-078-36AAA3	McHenry	NDSWC Karlsruhe	Monitoring	Monitoring	2000	1547	282-292	-30	2008	-0.32
154-096-32CAA	McKenzie	Craig Sorenson	Flowing	Stock		1980		+145		
154-098-15DAB	Williams	T And T Coop.	Pumped	Stock	2003	2160	1360-1560	-183	2003	
154-100-34BBD	Williams	Mark Brunelle	Pumped	Unused	2001	2113	1760-1860			
154-101-29ABA	Williams	Kevin Satermo	Flowing Idc	Industrial	1997	1940	1647-1800	+139	1997	
154-101-30BBA	Williams	Tractor & Equipment	Pumped	Industrial	1981	2080	1721-1880	0	1981	
154-101-31BDD	Williams	Behm's	Flowing Idc	Unused	1985	2020	1730-1790	+74	1985	
155-075-03ADD	McHenry	Ronald Carpenter	Pumped	Stock		1525	56-61			
155-075-23ABB	McHenry	John Burckhard	Pumped	Domestic		1520	99			
155-079-08AA	McHenry	NDGS Bull #11	Pumped	Domestic		1530	103			
155-080-19CCB2	McHenry	G. Lenton	Pumped	Stock		1570	330			
156-069-30AA	Benson	A.Sebelias	Pumped	Domestic		1590	98			
156-070-02CCC	Benson	NDSWC Knox	Monitoring	Monitoring		1660	108	-49	1967	
156-070-09AAB	Benson	Walt & Don Mears	Pumped	Stock		1597	55			
156-073-01CCC1	Pierce	A. Buchl	Pumped	Domestic		1550	85-118			
156-073-01CCC2	Pierce	A. Buchl	Pumped	Domestic		1550	63-75			
156-073-01CDC	Pierce	Rugby Mfg. Co.	Pumped	Industrial		1550	100			
156-073-01DDD	Pierce	L. Johnson	Pumped	Domestic		1555	92-100			
156-073-11AAB	Pierce	Phil Fossum	Pumped	Stock		1545	85			
156-073-12CCC	Pierce	NDSWC Rugby	Monitoring	Monitoring	1967	1550	73-78	-3	2007	-0.13
156-077-22CCC	McHenry	NDSWC Granville	Monitoring	Monitoring	1975	1496	78-81	-6	2008	-0.35
156-096-20DCD	Williams	NDSWC Ray	Monitoring	Monitoring	1984	2177	1302-1350	-88	2009	-0.12
157-072-31DC	Pierce	City Of Rugby	Pumped	Municipal		1550	135			
157-072-31DDC	Pierce	City Of Rugby	Pumped	Municipal		1550				
157-074-22DDA	Pierce	M. Thompson	Monitoring	Monitoring		1480		-5	1967	
157-076-22DCC	McHenry	O. Sveund	Pumped	Domestic		1490	87			
158-071-16DDD	Pierce	NDSWC Wolford-W	Monitoring	Monitoring	1968	1593	67-73	+2	2008	-0.01
158-074-19DCB	Pierce	Bjarne Engeland	Pumped	Domestic		1970	118			
158-076-24DAC3	McHenry	NDSWC Bantry Se	Monitoring	Monitoring	2003	1458	70-80	-16	2008	-0.12
158-085-03CDC	Renville	Helseth Bros	Pumped	Stock	1977	1780	900-930	-95	1977	
159-102-16AAD	Williams	NDSWC Grenora	Monitoring	Monitoring	1985	2160	1302-1372	-66	2008	-0.32
160-074-12BAB	Bottineau	Richard Rude	Pumped	Domestic		1550	70-188			
160-080-02DDD	Bottineau	Ervin Hunskor	Pumped	Domestic		1475	159-170			
160-083-27CD	Bottineau	Hortense Hammer	Pumped	Domestic		1570	500			
161-072-23CCC	Rolette	NDSWC Dunseith Se	Monitoring	Monitoring	1978	1633	60-66	-9	1981	
161-075-13BBB	Bottineau	David Kyle	Pumped	Domestic		1590	102-162			
161-078-25AAA1	Bottineau	Lloyd Koster	Pumped	Dom/stk		1470	108-164			
161-079-28CCC	Bottineau	Larry Kersten	Pumped	Domestic		1465	129-164			
161-080-12AAA	Bottineau	Ron Wyman	Pumped	Stock		1490	120-180			
161-080-22DDD	Bottineau	Ross Morison	Pumped	Domestic		1485	190			
161-080-23CCC	Bottineau	Larry Wyman	Pumped	Domestic		1489	180			

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
161-083-23DDD	Bottineau	NDSWC Mohall Se	Monitoring	Monitoring	1978	1585	444-450	-30	1994	
161-084-24DDD	Renville	NDSWC Mohall	Monitoring	Monitoring	1979	1619	470-488	-37	2006	+0.005
162-074-29DAD	Bottineau	Laurel Hiatt	Pumped	Stock		1785	107-127			
162-076-05DAA	Bottineau	NDSWC	Monitoring	Monitoring	1979	1661	78-84	-23	1981	
162-080-35ADD	Bottineau	Don Stratton	Pumped	Domestic		1490	155			
162-080-35BBB	Bottineau	C.M. Huber	Pumped	Dom/stk		1491	166-200			
162-082-16AAB	Bottineau	Don Peterson	Pumped	Stock		1547	300			
162-082-17ABB1	Bottineau	Percy Thorp	Pumped	Stock		1550	200			
162-095-23CCC1	Divide	NDSWC Noonan	Monitoring	Monitoring	1985	2203	1440-1475	-208	2007	-0.05
163-072-14ABB	Rolette	NDSWC Dunseith Ne	Monitoring	Monitoring	1978	2250	590-596	-251	2008	
163-073-11CCC1	Rolette	NDSWC Dunseith Nw	Monitoring	Monitoring	1978	2123	406-412	-38	2008	
163-074-15ABA1	Bottineau	NDSWC	Monitoring	Monitor plug	1978	2190	510-516	-144	1989	
163-075-15AAB1	Bottineau	NDSWC Bottineau Nw	Monitoring	Monitoring	1978	2150	509-515	-104	1989	
163-076-16BAD1	Bottineau	NDSWC	Monitoring	Monitor plug	1979	2110	470-490	-157	1981	
163-078-15AAB	Bottineau	Sigurd Kjelshus	Pumped	Stock		1515	78-84			
163-080-26DDC	Bottineau	City of Westhope	Pumped	Municipal	1963	1490	159-160			
163-101-16DDD	Divide	NDSWC Fortuna	Monitoring	Monitoring	1982	2238	1055-1079	-132	2008	+0.004
163-101-26BCC	Divide	Steven Feil	Pumped	Domestic	2000	2190	1029-1090	-78	2000	
164-073-25D	Rolette	Int Peace Garden	Pumped	Municipal	1995	2255	577-627	-220	1995	
164-095-32CCC	Divide	Nordak	Pumped	Industrial	2001	1900	930-960	-1	2001	
Montana										
04N-53E-04CAA	Custer	Charlie Niles	Pumped	Stock	1976	2588	390 - 480			
10N-60E-02CDD	Wibaux	Scott Abrahms	Pumped	Stock	1988	3045	614-660	-346	1995	
11N-57E-05DD	Wibaux	NG Tex	Pumped	Unknown	1962	2710	1000			
11N-57E-06CC	Wibaux	Shell Oil	Pumped	Industrial	1962	2801	1263	-308	1962	
11N-57E-08AA	Wibaux	Union Tex Petrol	Pumped	Unknown		2645	1190			
11N-57E-12AB	Wibaux	Union Texas Petrol	Pumped	Unknown	1962	2697	300	-104	1962	
11N-57E-17BC	Wibaux	Union Texas Petrol	Pumped	Industrial		2652	1190			
11N-57E-21CB	Wibaux	Shell Oil	Pumped	Industrial		2695	710			
11N-57E-21CBA	Wibaux	Shell Oil	Pumped	Industrial		2690	710	-133	1995	
11N-57E-21CDB	Wibaux	Shell Oil	Pumped	Industrial	1954	2617	480-620	-72	1992	
11N-58E-05ACB	Wibaux	Smith Cattle Co.	Pumped	Domestic	1988	2673	60-80	-77	1995	
11N-58E-05C	Wibaux	Smith Cattle Co.	Pumped	Stock	1976	2700	70-90	-50	1976	
11N-58E-14CB	Wibaux	Steve Gansiorouski	Pumped	Stock	1993	2950	260-280	-265	1993	
11N-58E-19AA	Wibaux	Northern Pacfic Rr	Pumped	Stock	1946	2700	30	-10	1946	
11N-58E-20DBD	Wibaux	Maurice Tunby	Pumped	Stock	1993	2860	130-150	-130	1993	
11N-58E-22ADB	Wibaux	Tobin Ranch	Pumped	Stock	1950	2800	200	-100	1950	
11N-58E-22DBB	Wibaux	Smith Cattle Co.	Pumped	Stock		2778	76	-56	1995	
11N-58E-22DCB	Wibaux	Tobin Ranch	Pumped	Stock	1959	2750	100	-50	1959	
11N-58E-24BA	Wibaux	Smith Cattle Co.	Pumped	Stock	1988	2950	240-300	-200	1988	
11N-59E-01BCB	Wibaux	Connie Brungard	Pumped	Unknown	1980	2910	38-700	-280	1980	
11N-59E-04BBB	Wibaux	Art Peters	Pumped	Stock	1969	3150	720	-400	1969	
11N-59E-20DCA	Wibaux	Max Lerbiecke	Pumped	Domestic	1994	3300	720-780	-480	1994	
11N-61E-06DDA	Wibaux	Robert Debrowski	Pumped	Domestic	1975	3050	800-940	-420	1975	
11N-61E-18BAB	Wibaux	Douglas Herford Ran	Pumped	Domestic	1974	3056	785-900	-370	1974	
11N-61E-20CBB	Wibaux	Floyd Weyer	Pumped	Stock	1975	3150	840-940	-320	1975	
12N-57E-12ADD	Wibaux	Raymond Herigstad	Pumped	Stock	1926	2700	64			
12N-57E-12DAA	Wibaux	Raymond Herigstad	Pumped	Domestic	1949	2700	90			
12N-57E-14ADD	Wibaux	Raymond Herigstad	Pumped	Stock	1915	2600		-14	1915	
12N-57E-22CCB	Wibaux	O Wing & B Jackson	Pumped	Unused		2660				
12N-58E-04DBB	Wibaux	Bob Petermann	Pumped	Stock	1974	2842	420-480	-272	1995	
12N-58E-15CBC	Wibaux	Glenn Hutchinson	Pumped	Stock	1980	2750	1050-1070	-245	1980	
12N-58E-18ACA	Wibaux	Raymond Herigstad	Pumped	Stock	1960	2700	180			

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
12N-58E-19DAC	Wibaux	Lost In Time Ranch	Pumped	Stock	1972	2638	80-100	-25	1993	
12N-58E-34BBD	Wibaux	Smith Cattle Co	Pumped	Stock	1976	2711	120-160	-80	1995	
12N-59E-23DAA	Wibaux	David Watembach	Pumped	Domestic	1994	2922	636-676	-329	1995	
12N-59E-32AAD	Wibaux	Duane Hanson	Pumped	Domestic	1949	3123	650	-491	1995	
12N-60E-03DAA	Wibaux	St. Phillips Church	Pumped	Domestic		2935	900	-380	1995	
12N-60E-11ABB	Wibaux	Joe Bruski	Pumped	Domestic	1969	2935	800-950	-380	1969	
12N-60E-28AAD	Wibaux	DI Morris	Pumped	Stock	1955	3086	1000	-60	1955	
12N-60E-36CAC	Wibaux	Theresa Wicka	Pumped	Domestic	1973	2995	820 0 900	-404	1995	
13N-51E-31BDCB	Prairie	USGS Terry 1a	Monitoring	Monitoring M1	1979	2341	973	-44	2008	-0.77
13N-53E-04CAB	Dawson	Edwin Roseler	Flowing	Domestic	1987	2350	875-9090	+14	1987	
13N-53E-04CBA	Dawson	B & L Mittmayer	Flowing	Stock	1967	2310	875-1210	-6	1995	
13N-53E-09DDC	Dawson	Carl Rein	Flowing	Domestic	1975	2195	983-1018	+111	1975	
13N-53E-11ACC	Dawson		Flowing	Domestic		2194	722			
13N-53E-12	Dawson	Arthur Bouchard #2	Flowing	Domestic	1950	2170	910			
13N-53E-12AB	Dawson	E Haft	Flowing	Domestic		2191	820			
13N-53E-12CBC	Dawson	Donald Bouchard	Flowing	Domestic	1940	2170	910			
13N-54E-06BC	Dawson	J Baxdaum	Flowing	Stocik		2183	836			
13N-54E-10BAA	Dawson	Thomas Ulrich	Flowing	Domestic	1995	2150	685-883	+125	1995	
13N-54E-10BB	Dawson	Elsie Schock	Flowing	Domestic		2223	880-1050			
13N-54E-10BBB	Dawson	Erwin Schock	Flowing	Domestic	1973	2230	1100			
13N-54E-18ABC	Dawson	Marsh School	Flowing	Unused		2194	800			
13N-54E-22DBB	Dawson	Lee Gibs	Flowing	Stock	1964	2200				
13N-55E-23DBB	Dawson	Cedar Creek Graz	Pumped	Stock	1968	2659	290	-252	1995	
13N-56E-01BDA	Dawson	Cedar Crek Graz	Pumped	Stock	1968	2684	221	-182	1995	
13N-56E-02ACA	Dawson	Cedar Creek Graz	Pumped	Stock	1973	2680	218-230	-184	1995	
13N-56E-02BBD	Dawson	Cedar Creek Graz	Pumped	Stock	1968	2684	260			
13N-57E-05	Dawson	Phelps & Fleming	Pumped	Domestic	1933	2650	75			
13N-57E-15B	Dawson	Helen Botch	Pumped	Domestic	1961	2750	175	-170	1961	
13N-57E-20BBD	Dawson	Cedar Creek Graz	Pumped	Stock		2700	195	-168	1995	
13N-57E-21CA	Dawson	Cedar Creek Graz	Pumped	Stock	1968	2600	57			
13N-57E-25ADD	Wibaux	Charles Kahl	Pumped	Stock	1976	2700	174-214	-174	1976	
13N-59E-01BAA	Wibaux	Stanley Dobrowski	Pumped	Domestic	1977	2738	805	-313	1995	
13N-59E-10DAA1	Wibaux	Louis Dobrowski	Pumped	Domestic		2791	980	-322	1995	
13N-59E-10DAA2	Wibaux	Louis Dobrowski	Pumped	Domestic	1976	2790	784-920	-260	1976	
13N-59E-13BCB	Wibaux	Alfred Nunberg	Pumped	Domestic	1976	2765	715-841	-294	1995	
13N-59E-20BAC	Wibaux	Albert Rojie	Pumped	Domestic	1973	2964	1080-1100			
13N-5E-08BDA	Dawson	Big 4 Ranch	Pumped	Domestic	1977	2400	805-1120	-58	1977	
13N-60E-02DAA	Wibaux	Ernie Wojohn	Pumped	Domestic	1975	2840	1008-1086	-400	1975	
14N-54E-02DAC	Dawson	J & D Buxbaum	Pumped	Stock	1992	2200	840-940	-27	1992	
14N-54E-13AC	Dawson	L. Leivestad	Flowing	Stock		2156	703			
14N-54E-13CC	Dawson	Jacob Neiffer	Flowing	Domestic	1942	2140	860			
14N-54E-13DBB	Dawson	Leivestad Farms	Flowing	Domestic		2158	710			
14N-54E-13DBBB	Dawson	Melvn Deines	Flowing	Domestic	1941	2160	713			
14N-54E-21DDB	Dawson	J & D Buxbaum	Flowing	Stock	1993	2275	945-1134	+25	1993	
14N-54E-22AAB	Dawson	Alex Kaufman	Flowing	Stock	1963	2180	917-1010	+113	1963	
14N-54E-22BDD	Dawson	Larry Heimbauch	Flowing	Domestic	1963	2182	900-1100	+63	1995	
14N-54E-25BB	Dawson	Krug Ranch	Flowing	Stock	1960	2118	816			
14N-54E-26CA	Dawson	G. Krug	Flowing	Stock		2179	813			
14N-54E-29ACC	Dawson	Rudy Diegle	Pumped	Domestic	1969	2265	925-1050			
14N-54E-31CDB	Dawson	Donald Burbaum	Flowing	Domestic	1994	2200	885-990			
14N-54E-32BAD	Dawson	Rudy Diegel	Pumped	Stock	1972	2220	870-1030	0	1972	
14N-54E-33DBA	Dawson	Christ Diegel	Flowing	Domestic	1940	2120	800			
14N-54E-34CA	Dawson	Krug Ranch #2	Flowing	Stock	1980	2120	830	+139	1980	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
14N-54E-34CAA	Dawson	Lee Gibbs	Flowing	Domestic	1970	2125	850			
14N-54E-34CB	Dawson	Krug Ranch	Flowing	Domestic		2129	818			
14N-55E-22CD	Dawson	Frank Giarratana	Pumped	Stock	1949	2500	300			
14N-55E-29A	Dawson	Shell Oil	Flowing	Industrial	1955	2120	250-320	-70	1955	
14N-55E-29ACD	Dawson	Cedar Creek Graz	Flowing	Stock	1973	2160	570	-210	1973	
14N-55E-31CBB1	Dawson	Lee Gibbs	Pumped	Stock		2210	1010			
14N-56E-11CDC	Dawson	Jack Eaton	Pumped	Stock	1977	2475	350			
14N-56E-15BB	Dawson	Frank Giarratana	Pumped	Stock	1949	2500	300			
14N-56E-17BDD	Dawson	Cedar Creek Graz	Pumped	Stock	1973	2540	240-248	-202	1995	
14N-56E-21ABA	Dawson	Cedar Creek Graz	Pumped	Stock	1968	2415	66	-58	1995	
14N-56E-21AC	Dawson	Cedar Creek Graz	Pumped	Stock	1973	2400	190			
14N-56E-31CBB2	Dawson	Lee Gibbs	Pumped	Stock		2205	1010			
14N-56E-32B	Dawson	Phelps Flemming	Pumped	Stock	1975	2500	120-180	-140	1975	
14N-56E-35DB	Dawson	Cedar Creek Graz	Pumped	Stock	1973	2600	240			
14N-57E-15BCB	Dawson	Walt Hinebauch	Pumped	Stock	1963	2379	101	-66	1995	
14N-57E-21ACC	Dawson	Walt Hinebauch	Pumped	Stock	1963	2481	199	-143	1995	
14N-57E-26CDC	Dawson	Walt Hinebauch	Pumped	Stock		2462	165	-91	1995	
14N-57E-28BBB	Dawson	Al Phelps	Pumped	Unused	1963	2490				
14N-57E-33BDC	Dawson	Walt Hinebauch	Pumped	Stock	1963	2538	104	-82	1995	
14N-59E-10BBA	Wibaux	Terry Hall	Pumped	Domestic	1962	2783	1000			
14N-59E-11DAD	Wibaux	Norbert Job	Pumped	Domestic	1973	2700	865-980	-200	1973	
14N-59E-12BDD	Wibaux	City Of Wibaux	Pumped	Municipal	1956	2640	916			
14N-59E-36C	Wibaux	Harold Goodale	Pumped	Domestic	1972	2760	790-900	-380	1973	
15N-54E-26CAB	Dawson	Shell Oil	Pumped	Industrial	1952	2375	1042-1219			
15N-54E-34DDC	Dawson	Maude Reynolds	Pumped	Domestic	1960	2395	1200			
15N-55E-06ACA	Dawson	Joe Leal	Pumped	Domestic	1986	2318	310-330	-201	1993	
15N-55E-12ABD	Dawson	State Of Montana	Flowing	Unused	1977	2160	675	-59	1992	
15N-55E-25ABC	Dawson	Marvin Nemitz	Pumped	Unused	1960	2490	440	-250	1960	
15N-55E-28CDD	Dawson	Carl Jimison	Flowing	Stock	1977	2070	187-202	-155	1977	
15N-56E-04AAC	Dawson	Jack Eaton	Flowing	Stock		2120	150			
15N-56E-12BBB	Dawson	Jack Eaton	Flowing	Stock	1977	2195	132			
15N-56E-20	Dawson	Glendive Noon Lions	Pumped	Domestic	1978	2600	560-622	-520	1978	
15N-56E-23DDC	Dawson	Jack Eaton	Flowing	Stock	1950	2190	150			
15N-56E-26	Dawson	Obert Karterold	Pumped	Stock	1956	2300	720			
15N-56E-31DD	Dawson	J & E Engle	Pumped	Stock	1952	2380	175	-145	1952	
15N-56E-32B	Dawson	J & E Engle	Pumped	Stock	1952	2290	200	-155	1952	
15N-57E-04DCC	Dawson	Charles Casey	Pumped	Stock		2442	262			
15N-57E-05BCD	Dawson	Tom Rie	Pumped	Stock	1977	2440	398-440	-210	1977	
15N-57E-05D	Dawson	Mt Hwy Dept	Pumped	Domestic	1975	2400	481	-159	1975	
15N-57E-06AA	Dawson	Blm - Justin	Pumped	Stock	1995	2400	340-370			
15N-57E-06ADB	Dawson	Jack Eaton	Pumped	Stock	1977	2400	350			
15N-57E-18ADD	Dawson	Jack Eaton	Pumped	Stock	1964	2400	270-300	-190	1964	
15N-57E-19CCA	Dawson	Jack Eaton	Flowing	Stock		2220	135			
15N-58E-08BCA	Dawson	Schultz Bros	Pumped	Stock	1992	2800	835-898	-365	1992	
15N-58E-36B	Wibaux	Alida Hergstad	Pumped	Stock	1976	2800	440-500	-300	1976	
15N-59E-36CCD	Wibaux	Harold Goodale	Pumped	Domestic	1972	2641	790-900	-180	1972	
16N-55E-09	Dawson	John Rahr #2	Pumped	Industrial	1953	2230	784	-40	1953	
16N-55E-09	Dawson	John Rahr #3	Pumped	Industrial	1957	2220	503	-80	1957	
16N-55E-22BD	Dawson	Cotonwood Cc	Pumped	Domestic	1961	2170	410			
16N-560E-02DBC	Wibaux	Marian Dahl	Pumped	Domestic	1973	2700	1120-1320	-280	1973	
16N-56E-20CBA	Dawson	Ch Swenson	Flowing	Unused	1960	2190	260			
16N-57E-11DAC	Wibaux	E. Woodworth	Flowing	Stock	1969	2055	660-688	+1	1969	
16N-57E-18	Dawson	Godron Mullendore	Pumped	Stock	1943	2500	920			

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16N-57E-27AAC	Dawson	Mid River Telephone	Pumped	Domestic	1968	2700	1200			
16N-57E-33DDC	Dawson	Charles Casey Jr	Pumped	Domestic	1980	2554	450-560			
16N-57E-34DD	Dawson	Mobil Prod.	Pumped	Industrial	1957	2600	798-893			
16N-57E-34DDC	Dawson	Norman Berman	Pumped	Stock	1958	2600	1100			
16N-57E-34DDD	Dawson	Norman Berman	Pumped	Domestic	1957	2621	340			
16N-58E-30DBC	Dawson	NW Burman	Pumped	Domestic	1953	2600	550			
16N-59E-13CCB	Wibaux	W. Dahemann	Pumped	Domestic	1971	2577	1055-1120	-235	1971	
16N-60E-02DBC	Wibaux	Marvin Dahl	Pumped	Domestic	1973	2645	1120-1220	-280	1973	
16N-60E-02DBC	Wibaux	Marvin Dahl	Pumped	Domestic	1975	2645	1120-1200	-400	1975	
17N -58E-09BAB	Wibaux	Glenn Hutchinson	Flowing	Stock	1970	2199	810-845			
17N-54E-17ACD	Dawson	Emma Schipman	Pumped	Stock	1977	2520	760-840	-460	1977	
17N-55E-10CBD	Dawson	Sam Undeum	Pumped	Stock	1990	2160	540-700	-41	1993	
17N-55E-11DDD	Dawson	Sam Undem	Flowing	Stock	1988	2075	550-600	+77	1995	
17N-55E-19CBB	Dawson	Joeseph Undem	Pumped	Stock	1969	2608	1240-1260			
17N-55E-23BDD	Dawson	Vernon Heinrich	Flowing	Stock	1977	2083	527-567	+10	1993	
17N-55E-23CC1	Dawson	Herb Sharbano	Flowing	Domestic	1968	2100	565-595			
17N-55E-23CC2	Dawson	Herb Sharbano	Flowing	Domestic	1977	2080	566-590	+46	1977	
17N-55E-23CDD	Dawson	Clarence Vallard	Flowing	Unused		2055	325			
17N-55E-23DAC	Dawson	Patrick Hogel	Flowing	Domestic	1976	2065	570-610	+58	1976	
17N-55E-26BBA	Dawson	Carl Roe	Flowing	Stock		2083		+30	1993	
17N-56E-04BDC	Dawson	Gentry Land & Stock	Flowing	Stock	1955	2015	390			
17N-56E-04CAB	Dawson	Gentry Livestock	Flowing	Domestic	1988	2020	470-505	+81	1988	
17N-56E-09DCC	Dawson	Jim Gentry	Flowing	Stock	1988	2060	560-600	+46	1988	
17N-56E-17BAD	Dawson	Genrty Livestock	Flowing	Stock	1967	2025	462			
17N-56E-17BDA	Dawson	Ethel Genrty	Flowing	Stock		2024		+98	1993	
17N-56E-22	Dawson	Hn Dion	Pumped	Stock	1911	2400	125-185			
17N-57E-23BBA	Dawson	Jim Williams	Pumped	Stock	1988	2216	840-900	-7	1993	
17N-58E-07ABD	Dawson	Glacier Park Co.	Flowing	Stock	1988	2201	756-840	+5	1988	
17N-58E-10ACA	Wibaux	Glenn Hutchinson	Pumped	Domestic	1970	2260	805-840			
17N-58E-10ADB	Wibaux	Glenn Hutchinson	Pumped	Stock	1971	2260	830-855			
17N-58E-24CCA	Wibaux	Diamond A Ranch	Pumped	Domestic	1978	2305	960	-35	1978	
17N-58E-35DDD	Wibaux	Million	Pumped	Domestic		2450	835			
17N-59E-33BBC	Wibaux	Roy Amunrud	Pumped	Domestic	1953	2418	1020			
17N-5E-23DCB	Dawson	Leonard Chouinard	Flowing	Domestic	1957	2062	310			
18N-56E-23	Dawson	Joe Tomalino	Flowing	Stock	1961	2200	630-670	+51	1961	
18N-56E-25ADB	Dawson	Bob Buxbaum	Flowing	Stock	1972	2010	555-570	+120	1993	
18N-56E-29ADB	Dawson	Donald Tague	Pumped	Stock	1967	2225	904-940	-60	1967	
18N-56E-33ACB	Dawson	Bob Buxbaum	Flowing	Stock	1966	2075	522-578	+14	1995	
18N-57E-05AAD	Dawson	August Sobotka	Flowing	Stock	1964	2120	760			
18N-57E-05DDC	Dawson	August Sobotka	Flowing	Stock		2070	680			
18N-57E-06ADD	Dawson	August Sobotka	Pumped	Stock	1964	2165	1000			
18N-57E-06BDD	Dawson	August Sobotka	Pumped	Stock		2260	1310	-10		
18N-57E-07DCC	Dawson	August Sobotka	Pumped	Stock		2150	740			
18N-57E-13CC	Wibaux	Lester Woodsworth	Flowing	Unknown	1969	2040	593-617			
18N-57E-15ACB	Wibaux	Dan Cahill	Flowing	Domestic		2028		106	1994	
18N-57E-15ADC	Wibaux	K & W Ranch	Flowing	Stock	1971	2020	606-660			
18N-57E-17AB	Dawson	August Sobotka	Flowing	Domestic	1986	2000	580-620	+104	1986	
18N-57E-18AAA	Dawson	August Sobotka	Flowing	Stock	1988	2050	729-792	+92	1988	
18N-57E-18CBD	Dawson	Joe Tomalino	Flowing	Stock	1962	2040	710-750			
18N-57E-21	Dawson	Hotbar Land & Cattle	Flowing	Stock	1960	1990	400			
18N-57E-35ACC	Dawson	Du Bar Inc.	Pumped	Domestic	1994	2280	925-1052	-211	1994	
18N-58E-01CCC	Wibaux	Smith Creek Graz	Pumped	Stock	1972	2370	1160-1220	-110	1972	
18N-58E-02DAD	Wibaux	Smith Cr Grazing	Pumped	Domestic	1973	2360	1220	-121	1973	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
18N-58E-08DAB	Wibaux	Minerva Townley	Flowing	Stock	1971	2120	745-790			
18N-58E-14DDA	Wibaux	D & L Roberts	Pumped	Domestic	1987	2230	1054-1120	-36	1987	
18N-58E-16BCD	Wibaux	Lg Roberts	Flowing	Domestic	1993	2150	960-1018	+16	1993	
18N-59E-20BDC	Wibaux	John Moerman	Pumped	Domestic	1979	2322	1200-1263	-60	1979	
19N-57E-26ADA	Richland	Harold Eetzel	Flowing	Domestic	1980	2000	723-770			
19N-57E-26BCA	Richland	Brian & Anne Carr	Flowing	Domestic		2040	800	+97	1995	
19N-57E-33DCA	Richland	George Rice Jr	Flowing	Stock	1980	2040	705-740	+72	1995	
19N-57E-34CC	Richland	D Davies	Flowing	Domestic		2000	582			
19N-58E-04DDC	Richland	John Redman	Flowing	Domestic	1971	1960	915	+21	1971	
19N-58E-08CBD	Richland	Herigstad Ranch	Flowing	Domestic	1973	1961	800-840	+167	1993	
19N-58E-31BBD	Richland	Dave Roberts	Flowing	Stock	1992	2040	737-835	-111	1992	
19N-59E-07AAD	Richland	Roy Sult	Pumped	Stock	1968	2165	102-1110			
19N-59E-29BDD	Richland	Smith Creek Grazing	Flowing	Unknown	1980	2070	1013-1070			
20N-57E-14	Richland	Covered Wagon Ranch	Pumped	Stock	1970	2220	1067-1097			
20N-57E-24CDB	Richland	Coverred Wagon Ranch	Flowing	Stock	1969	2130	1050-1110	+10	1993	
20N-58E-14DBC	Richland	Leonard Hagler	Flowing	Stock	1974	1935	1117-1247	+162	1993	
20N-58E-30DA	Richland	Covered Wagon Ranch	Flowing	Domestic	1970	2080	1083			
20N-58E-32	Richland	Lawrence Deshaw	Flowing	Domestic	1976	2000	965-1000	+155	1995	
20N-58E-32ADA	Richland	Lawrence Deshaw	Flowing	Domestic	1978	1980	950-1008			
20N-58E-33B	Richland	Leo Lang	Flowing	Domestic	1976	1970	965-1000			
20N-59E-02ADC	Richland	Lewis Albert	Pumped	Domestic		2280	1505-1550			
20N-59E-03AC	Richland	Nj Hoctetter	Pumped	Stock	1972	2100	1275-1320			
20N-59E-03DBA	Richland	M. Hostetter	Pumped	Stock	1972	2180	1320			
20N-59E-04ABB	Richland	Thomas Hastetter	Flowing	Stock	1974	2025	1160-1200			
20N-59E-06BCC	Richland	Balducke Bros.	Flowing	Stock	1973	1990	1022-1240			
20N-59E-07ABA	Richland	Joe Leland	Flowing	Domestic	1979	2000	1045			
20N-59E-08DDD	Richland	Ernest Leland	Flowing	Stock	1973	2025	1057-1120			
20N-59E-11BDC	Richland	Ms. Charles Clark	Pumped	Stock	1971	2140	1360-1390			
20N-59E-14CCD	Richland	Sult Land Livestock	Pumped	Unknown	1980	2094	1220-1280			
20N-59E-24CAD	Richland	Lloyd Wick	Flowing	Stock	1982	2148	1302-1362	+5	1993	
20N-59E-27BA	Richland	Ray Sult	Pumped	Stock	1971	2200	1160-1190			
20N-60E-28DAA	Richland	Ronald F. Whited	Pumped	Domestic	1978	2910	1233-1360	-18	1978	
21N-57E-23AAA	Richland	Moo Juice Dairy	Pumped	Stock	1999	2250	1211-1575	-141	1999	
21N-58E-01AAA	Richland	Harlan Stane	Flowing	Stock	1978	1920	1085-1120			
21N-58E-01BB	Richland	Charles Nelson	Pumped	Stock	1968	2110	1064-1090			
21N-58E-03CB	Richland	Melvin Bakker	Flowing	Stock	1972	2057	1135-1325			
21N-58E-33CDD	Richland	Henry Nollmeyer	Flowing	Dom/stk	1976	1935	945-990	+179	1993	
21N-59E-06DDA	Richland	Todd Gorder	Flowing	Domestic	1979	1930	1198-1222	+134	1993	
21N-59E-08BCD	Richland	Todd Gorder	Flowing	Domestic	1968	1970	1240-1270	+102	1993	
21N-59E-09CD	Richland	Dr Nj Hastetter	Flowing	Stock	1970	2065	1250-1278			
21N-59E-10BAA	Richland	Tom Franzen	Flowing	Domestic	1980	2010	1193-1235			
21N-59E-13CDC	Richland	Buxbaum Bros.	Flowing	Stock	1970	2080	1328-1368			
21N-59E-14BCA	Richland	Alford Franzen	Flowing	Stock	1969	2065	1305-1330			
21N-59E-14CBD	Richland	Ronald F Prevost	Pumped	Domestic	1982	2110	1354-1400			
21N-59E-27CD	Richland	NJ Hastetter	Flowing	Stock	1971	2085	1265-1310			
21N-59E-31DA	Richland	Thomas Hastetter	Flowing	Stock	1974	2080	1302			
21N-59E-33DBB	Richland	Halversen Bros	Flowing	Stock	1971	2100	1262-1300			
21N-60E-05BBB	Richland	Tom Franzen	Pumped	Stock	1977	2200	1223-1258			
21N-60E-30DC	Richland	Daryl W. Bauxbaum	Pumped	Domestic	1979	2180	2180-1470			
22N-29E-14AC	Richland	Ray Thiel Jr.	Pumped	Domestic	1961	2150	1382-1431	-124	1961	
22N-51E-27BAB	Dawson	Robert Delp	Pumped	Domestic	1983	2320	1146	-214	1995	
22N-52E-20DC	Dawson	Richey 3	Pumped	Municipal	1970	2473	1180-1220			
22N-52E-28B	Dawson	Richey 2	Pumped	Municipal	1955	2495	1150-1180	-325	1995	

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
22N-52E-29	Dawson		Pumped	Domestic	1935	2350	1140-1180	-400	1935	
22N-52E-29ADD	Dawson	City Of Richey	Pumped	Domestic		2500	1036-1189	-325		
22N-58E-09ABB	Richland	Dean Youngquist	Flowing	Domestic	1980	1910	1190-1240			
22N-58E-12ABA	Richland	Ted Goss	Pumped	Domestic	1978	2020	1237-1267	+35	1995	
22N-58E-12DCC	Richland	George Haffner	Flowing	Stock	1972	1980	1117-1140			
22N-58E-23DAA	Richland	Eddie Ault	Flowing	Domestic	1979	1960	1235-1260			
22N-58E-36AAA	Richland	Steinbeisser & Sons	Flowing	Domestic	1983	1910	1050-1134			
22N-58E-36DDD	Richland	Matt Rambur	Flowing	Domestic	1971	1915	1080-1120			
22N-59E-02	Richland	Clara Lien	Flowing	Stock	1930	1920	900			
22N-59E-02DAA	Richland	Bell Land	Flowing	Stock	1993	1900	1153-1216	+120	1993	
22N-59E-03CB	Richland	Tenderlain Ind.	Flowing	Stock	1974	1930	1220 OH			
22N-59E-05DCD	Richland	Nick Youngkin	Flowing	Industrial	1980	1940	1073-1220			
22N-59E-08BA	Richland	Victor Buxbaum	Flowing	Domestic	1979	1935	1170-1240			
22N-59E-11DDC	Richland	Wh Hertz	Flowing	Domestic	1978	2030	1410 OH	+81	1980	
22N-59E-14	Richland	Arnold Thiel	Flowing	Industrial	1980	1940	1350-1410	+108	1977	
22N-59E-14BAB	Richland	Raymond Thiel Jr	Flowing	Domestic	1977	2040	1220-1345			
22N-59E-14CDD	Richland	Larson Co.	Pumped	Unknown	1981	2150	1295-1407	-80	1981	
22N-59E-14DBA	Richland	Alan & Pat Whitford	Pumped	Domestic	1994	2100	1396-1500	-75	1994	
22N-59E-15ACB	Richland	Trodingond Getty	Pumped	Industrial	1984	1910	1168-1191	-120 ?:	1984	
22N-59E-15BDC	Richland	Mark Gullickson	Flowing	Domestic	1989	1915	1130-1195			
22N-59E-15CAA	Richland	Pennzoil	Flowing	Unknown	1980	1940	1163-1210			
22N-59E-16DAB	Richland	Rau School Dist.	Flowing	Municipal	1983	1910	1194-1380	+109	1994	
22N-59E-18DCC	Wibaux	Hi Line Trucking	Flowing	Industrial	1978	1940	1170-1286			
22N-59E-20DAA	Richland	Victor Marker	Flowing	Domestic		1940	1277	+106	1995	
22N-59E-21DDD	Richland	Willmer Lorenz	Flowing	Domestic	1978	2030	1270-1320			
22N-59E-23DD	Richland	Willmer Rau	Pumped	Stock	1974	2100	1194-1233			
22N-59E-24CBB	Richland	W. Rau	Flowing	Domestic		2040	1300			
22N-59E-25DBD	Richland	Rau Brothers	Pumped	Stock	1977	2080	1328-1375			
22N-59E-28CBC	Richland	Shell Oil	Flowing	Unknown	1981	1990	1305			
22N-59E-28CBCB	Richland	Andrew Petersen	Flowing	Domestic	1970	1965	1105-1172	+83	1995	
22N-59E-30BBC	Richland	Simard Farms	Flowing	Domestic	1984	1920	1113-1180			
22N-59E-30DC	Richland	Seib Sulbranang	Flowing	Domestic	1976	1910	1221-1270			
22N-59E-32BAD	Richland	Jim Iverson	Flowing	Dom/stk	1971	1920	1109-1140	+115	2008	
22N-60E-18ABC	Richland	Laurna Kelly	Flowing	Domestic		1960	1200-1260	+97	2008	1 ft/yr
22N-60E-18CAB	Richland	Mike Williams	Flowing	Domestic	1979	1950	1188-1240			
22N-60E-7CBC	Richland	Shell Oil	Flowing	Industrial	1978	1975	1200-1240			
23N-50E-06BDB	Dawson	August Normand	Pumped	Irrigation	1951	2450	1000			
23N-50E-09B	Dawson	Shell Oil	Pumped	Industrial	1952	2400	943-1080	-325	1952	
23N-50E-19BBB	Dawson	Shell Oil	Pumped	Industrial	1952	2495	1037-1156	-445	1952	
23N-50E-19DCC	Dawson	Shell Oil	Pumped	Industrial	1952	2490	956-1096	-325	1952	
23N-56E-11DCC	Dawson	Diana Bahl	Pumped	Domestic	1981	2600	1716-1760	-480	1981	
23N-58E-34BDD	Richland	Rocky Gorder	Pumped	Industrial	1983	2240	1446-1540	-179	1995	
23N-59E-01BAB	Dawson	Neil Williams	Flowing	Unknown	1982	1910	1219-1320			
23N-59E-15ADD	Dawson	Charles Lowman	Flowing	Domestic	1980	1950	1227-1370			
23N-59E-17AD	Dawson	Terry Williams	Pumped	Domestic	1979	2100	1350-1385			
23N-59E-25DAD	Dawson	Leslie Schiling	Flowing	Unknown	1980	2000	1170-1200			
23N-59E-29BBC	Dawson	Harmon Pigg	Flowing	Domestic	1978	2020	1313-1380			
23N-59E-29BBC	Richland	Roger Kimble	Flowing	Domestic	1978	2303	1315-1420	+32	1995	
23N-59E-30	Dawson	Wl Mercier	Pumped	Domestic	1979	2100	1268-1320			
23N-59E-30ACC	Dawson	Robert Boyce	Flowing	Domestic	1979	2050	1243-1285			
23N-59E-30ADD	Dawson	Clarence Pedersen	Flowing	Domestic	1978	1995	1260-1290			
23N-59E-30DAD	Richland	Gordon & Ike Rambur	Pumped	Domestic	1978	1980	1214-1265	-68	1984	
23N-59E-30DC	Dawson	Walter Mcnutt	Flowing	Domestic	1976	1910	1221-1250			

Well location	County	Owner Usually at time of instal.	Well type	Purpose	Install year	Land elev. Ft	Screened interval ft	Pressure head ft	Year meas.	Head cng ft/yr
23N-60E-19ADB	Richland	Dennis Dahl	Flowing	Domestic	1978	1900	1240-1290	+450	1995	
23N-60E-31DAC	Dawson	Shell Oil	Pumped	Unknown	1980	2150	1490			
24N-44E-20CABD	McCone	USGS-Blm	Monitoring	Monitoring MT		2450	300	-178	2008	-0.02
24N-56E-07BCA	Dawson	Clement Jambor	Pumped	Stock	1976	2304	1400			
24N-58E-09BAB	Dawson	Landtech Corp	Pumped	Industrial	1985	2275	1660-1720	-187	1976	
24N-59E-24DD	Dawson	James A. Bieber	Flowing	Domestic	1977	1900	1320-1370			
24N-59E-26DAC	Richland	Gary &Karen Candee	Flowing	Domestic	1982	1950	1302-1348	+104	1995	
24N-59E-28CCD	Richland	Gladys Levno	Pumped	Domestic	1984	2100	1410-1480	-45	1995	
24N-60E-18AAC	Dawson	Roger Johnson	Flowing	Domestic	1977	1949	1306-1360			
25N-57E-11ADB	Dawson	Charles Mcginnis	Pumped	Domestic	1979	2305	1775-1815	-225	1979	
25N-57E-23DAC	Dawson	Larry Tuiet	Pumped	Domestic	1978	2360	1661-1945	-270	1978	
25N-58E-12CDDD	Richland	Marian Christiansen	Flowing	Domestic	1977	2050	1400-1500	+71	1995	
25N-59E-01CCC	Dawson	Sam/Dick Shannon	Flowing	Domestic	1977	1955	1408-1445	+245	2008	
25N-59E-07BBC	Richland	Vincent Wheeler	Flowing	Domestic	1977	2050	1410-1505	+30	1995	
25N-59E-12	Dawson	Rex Niles	Flowing	Domestic	1977	1950	1380-1420			
25N-59E-18CAB	Dawson	Vanderhoof Bros	Flowing	Domestic	1977	2040	1448-1488			
25N-59E-25CAA	Dawson	Valley View Feed Lot	Flowing	Stock	1989	1950	1370-1405			
25N-59E-36ABA	Dawson	Dale Reidle	Flowing	Stock	1980	1950	1400			
26N-51E-07CDD	Dawson	Sarah Woods	Pumped	Domestic	1916	2205	212	-70	1916	
26N-51E-13DC	Dawson	Frank Marottek	Pumped	Stock	1910	2250	60			
26N-51E-17ABB	Dawson	William Woods	Pumped	Domestic	1918	2240	212	-70	1918	
26N-51E-19BAAC	Dawson	William Voorhees	Pumped	Stock	1918	2280	280	-200	1918	
26N-51E-20CCC	Dawson	Leonard Alexander	Pumped	Domestic	1958	2305	298	-162	1958	
26N-51E-29BA	Dawson	Melvin Bogar	Pumped	Industrial	1952	2400	348-492	-300	1952	
26N-51E-30BDCC	Dawson	Victor Rhines	Pumped	Domestic	1958	2260	311			
26N-51E-31BBB	Dawson	William Voorhees	Pumped	Stock	1955	2275	300	-200	1955	
26N-52E-14DAA	Dawson	Tom Ruffatto	Pumped	Stock	1990	2250	342-353	-237	1995	
26N-54E-09CAD	Richland	Henry Milller Jr.	Pumped	Domestic	1981	2075	885	-57	1995	
26N-56E-24DAD	Richland	Hackley	Pumped	Domestic	1983	2230	760-880	-89	1995	
26N-56E-334BBD	Dawson	Don Palmer	Pumped	Domestic	1980	2170	800-850	-75	1980	
26N-57E-01DDD	Richland	Trudell Brothers	Flowing	Domestic	1979	1915	1293-1335	+103	1995	
26N-58E-08ACA	Dawson	Boyd Hardy	Flowing	Domestic	1980	1895	1370-1434			
26N-59E-23ABC	Dawson	Nickie Cayko	Flowing	Domestic	1977	1880	1385-1430	+213	1977	
26N-59E-25B	Dawson	Elmer Herdt	Flowing	Domestic	1979	1989	1385-1440			
26N-59E-26ADD	Dawson	Alvin Filler	Flowing	Domestic	1977	1989	1387-1442	+104	1995	
27N-53E-33AA	Dawson	Schmitz Trust	Pumped	Stock	1991	2260	400-426			
27N-54E-07BAD	Dawson	Elmer Foss	Flowing	Stock		1935	684	+52	1995	
27N-54E-09BAC	Dawson	Gene Foss	Flowing	Stock	1981	1922	795-900	+68	1995	
27N-56E-06CCC	Dawson	Gustafson	Flowing	Stock	1944	1905		+52	1995	
27N-56E-23CDB	Dawson	Raaum	Pumped	Stock		2005		-142	1995	
28N-58E-26CDB	Roosevelt	Landtech	Flowing	Industrial		1975	1340-1370	+58		
31N-56E-19ABA	Sheridan	Mccabe Farms	Pumped	Stock	1970	2050	850-1160			
37N-48E-05AAA	Daniels	Mbmg Research -11	Monitoring	Monitoring M1	1961	2422	212-218	+1	2008	-0.01

Appendix 2:

Water permits where the source is the Fox Hills-Hell Creek aquifer

County: Permits are listed alphabetically by county, then by point of diversion (area in which the well or wells is located).

Point of diversion: - Township, Range, Section, quarter (A=NE, B=NW, C=SW, D=SE), quarter-quarter, and quarter-quarter-quarter (10-acre parcel).

Ac-ft/yr: Is the quantity of water authorized to be pumped annually. An acre-foot (one rod by ½-mile by one foot) is equal to 325,851 gallons.

No.	Permit holder	County	Well POD	Purpose	Status	Ac-ft/yr
2519	Hettinger, City of*	Adams	129-095-17A	Municipal	Perfected	160
1297	Hettinger, City of	Adams	129-096-13BD4	Municipal	Perfected	624.8
1115	Reeder, City of	Adams	130-098-04DC	Municipal	Perfected	109.2
3886	Billings County School	Billings	139-100-09D	Municipal	Perfected	4.3
3680	U.S. National Park Service*	Billings	140-102-10D	Domestic	Perfected	0.4
1192	U.S. National Park Service	Billings	140-102-10DC	Domestic	Perfected	0.8
1196	U.S. National Park Service	Billings	140-102-11CC	Domestic	Perfected	4
1191	U.S. National Park Service	Billings	140-102-12BC	Domestic	Perfected	4
1198	U.S. National Park Service	Billings	140-102-26BB	Domestic	Perfected	13.4
1560	Medora, City of	Billings	140-102-26BC	Municipal	Perfected	126
4230	Theodore Roosevelt Medora	Billings	140-102-27B	Rural Water	Perfected	5
5017	U.S. National Park Service	Billings	141-101-29A	Rural Water	Perfected	2
3290	Missouri Basin, Inc.	Billings	143-099-02C	Industrial	Cancelled	0
3308	Chimney Butte Land, LLP	Billings	143-099-08D	Industrial	Perfected	67.8
3289	Amoco Production Co.	Billings	143-100-29B	Industrial	Cancelled	0
3833	Koch Exploration Co.	Billings	143-100-32D	Industrial	Cancelled	0
3641	Petro-Hunt, LLC*	Billings	144-098-16A	Industrial	Cancelled	
3270	Petro-Hunt, LLC	Billings	144-098-16AA	Industrial	Perfected	29
3711	Encore Operating, LLC	Billings	144-100-30C	Industrial	Perfected	1.7
5008	Nordak, LLP	Bowman	129-099-20A	Industrial	Perfected	40
5259	Dakota Prairie Beef	Bowman	131-099-27C	Industrial	Abeyance	255
3732	Scranton, City of*	Bowman	131-100-23A	Municipal	Perfected	66
1208	Scranton, City of	Bowman	131-100-23DA	Municipal	Cancelled	0
2810	Bowman, City of*	Bowman	131-101-12DD	Municipal	Cancelled	0
725	Bowman, City of	Bowman	131-102-11,12,	Municipal	Perfected	730
3766	Bowman Golf Assoc.	Bowman	131-102-26A	Irrigatio	Perfected	28.2
3117	Rhame, City of	Bowman	132-104-26BAB	Municipal	Perfected	63
2950	Wolt, Clayton	Burleigh	139-076-29A	Rural Water	Perfected	8
1818	Apple Valley Coop.	Burleigh	139-079-36BABB	Rural Water	Perfected	65
2733	Kurtz, Phillip J.	Burleigh	139-080-22AB2	Rural Water	Cancelled	0
2575	Dakota Adventist Academy	Burleigh	140-081-03B	Municipal	Perfected	45
3832	Balco Three, Inc.	Divide	163-099-24B	Industrial	Cancelled	0
5501	Nordak, Llp	Divide	164-095-32C	Industrial	Conditional	20
4423	Armstrong Op	Dunn	141-095-18A	Industrial	Perfected	47
2392	Dodge, City of	Dunn	144-091-10C	Municipal	Perfected	60
2136	Halliday, City of	Dunn	145-092-25ABB	Municipal	Perfected	82
3210	Koch Hydrocarbon Co.	Dunn	145-094-06B	Industrial	Cancelled	0
2387	Dunn Center, City of	Dunn	145-094-26AC	Municipal	Perfected	50
3100	Hazelton, City of	Emmons	135-076-30AC	Municipal	Perfected	65
3110	Golva, City of	Golden Valley	138-106-25D2	Municipal	Perfected	49
3354	Sentinel Butte, City	Golden Valley	140-104-29B	Municipal	Perfected	50
1034	Beach, City of	Golden Valley	140-106-23, 25	Municipal	Perfected	322.6

No.	Permit holder	County	Well POD	Purpose	Status	Ac-ft/yr
4023	Summit Resources	Golden Valley	143-103-26A	Industrial	Perfected	9
5779	Energy Equity Company	Golden Valley	143-103-28AA	Industrial	Conditional	20
3719	Wesco Operating, Inc.	Golden Valley	144-104-12D	Industrial	Perfected	8
1520	New Leipzig, City of	Grant	134-090-36CCB	Municipal	Perfected	60
3843	Buzalsky, Doug A.*	Hettinger	135-096-22D	Industrial	Perfected	2.9
5620	Buzalsky, Doug A.	Hettinger	135-096-22D	Industrial	Conditional	3
1232	Steele, City of	Kidder	139-073-17CD	Municipal	Conditional	570
4723	Burlington Resources	McKenzie	145-103-29A	Industrial	Cancelled	0
3345	U.S. Forest Servicee	McKenzie	146-100-04A	Industrial	Cancelled	0
3896	Petro-Hunt, LLC	McKenzie	146-102-10C	Industrial	Perfected	3
3887	Fitzgerald, Charles P	McKenzie	146-103-02CB	Industrial	Perfected	6
3302	Mitten, Norma	McKenzie	146-103-10B	Industrial	Cancelled	0
2344	True Oil LLC	McKenzie	148-101-27DD	Industrial	Perfected	24.2
3503	ANR Production Co.	McKenzie	148-104-18A	Industrial	Cancelled	16
3222	ANR Production Co.	McKenzie	148-105-13C	Industrial	Cancelled	0
3474	ANR Production Co.	McKenzie	148-105-26A	Industrial	Perfected	16
4532	Bear Paw Energy (Koch)	McKenzie	148-105-36D	Industrial	Cancelled	
4794	Bear Paw Energy (Koch)*	McKenzie	148-105-36D	Industrial	Perfected	25
5784	Zenergy, Murphy	McKenzie	149-102-01BB	Industrial	Conditional	5
3357	ANR Production Co.	McKenzie	149-104-31D	Industrial	Cancelled	0
3587	Amerada Hess Corp.	McKenzie	150-095-08B	Industrial	Perfected	118
3653	Tipperary Oil & Gas*	McKenzie	150-095-30A	Industrial	Cancelled	
3586	Alexander, City of*	McKenzie	150-101-05B	Municipal	Perfected	35
1209	Alexander, City of	McKenzie	150-101-05BC	Municipal	Perfected	95
3792	Landtech Enterprises	McKenzie	150-101-17AC	Industrial	Perfected	60
3864	Encore Operating, LLC	McKenzie	150-101-17C	Industrial	Perfected	16.1
5782	Zenergy, Carter	McKenzie	150-102-09DD	Industrial	Conditional	5
5778	Zenergy, Williams	McKenzie	150-102-18CC	Industrial	Conditional	5
5777	Zenergy, Schmidt	McKenzie	150-102-25BB	Industrial	Conditional	5
5774	Zenergy, Foxx	McKenzie	150-102-26BB	Industrial	Conditional	5
5775	Zenergy, McGwire	McKenzie	150-102-27BB	Industrial	Conditional	5
5776	Zenergy, Jackson	McKenzie	150-102-28CC	Industrial	Conditional	5.0
5783	Zenergy, Gehrig	McKenzie	150-103-25AA	Industrial	Conditional	5
3618	Nance Petroleum	McKenzie	151-104-24D	Industrial	Cancelled	8.0
3846	Mon-Kota, Inc.	McKenzie	151-104-31AB	Industrial	Perfected	2
3939	Amerada Hess Corp.	McKenzie	152-095-01B	Industrial	Cancelled	0
3562	Encore Operating	McKenzie	152-102-23D	Industrial	Perfected	2.4
3596	Encore Operating*	McKenzie	152-102-23D	Industrial	Cancelled	
3889	Anderson, Stanley	McKenzie	152-103-27B	Industrial	Perfected	20
3960	Amerada Hess Corp.	McKenzie	153-094-32C	Industrial	Perfected	24.2
1769	Petro-Hunt, L.L.C.	McKenzie	153-095-07, 18	Industrial	Perfected	180
3608	Tipperary Oil & Gas	McKenzie	153-095-30A	Industrial	Cancelled	0

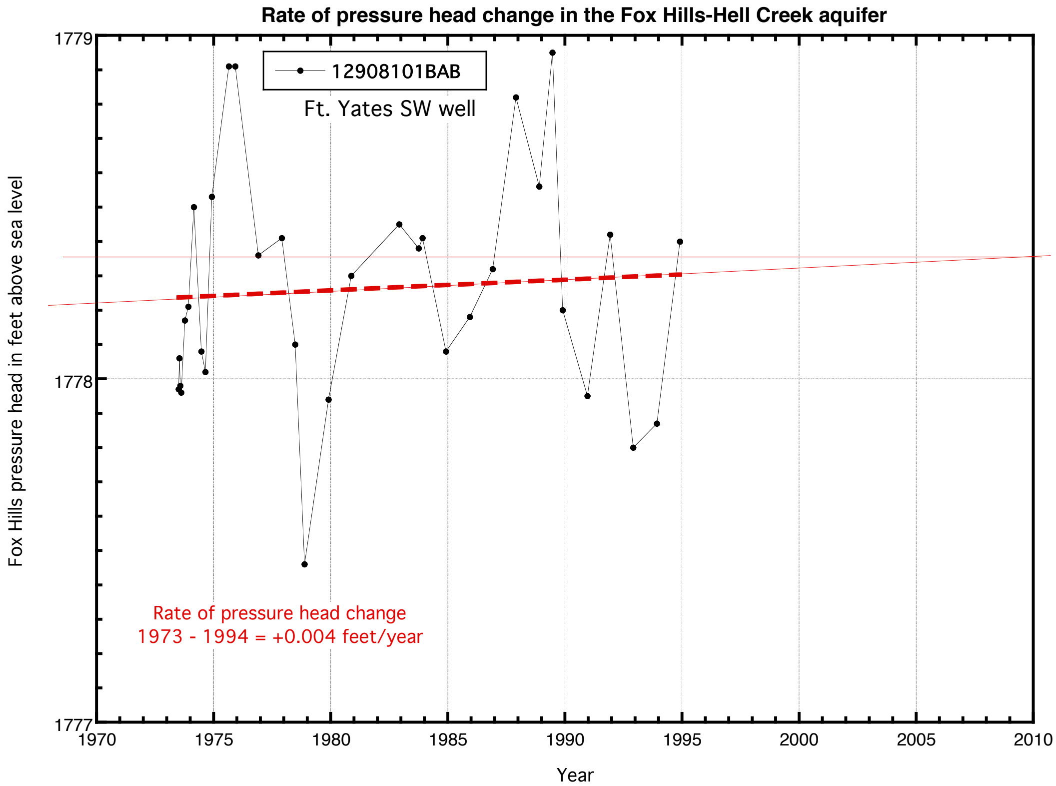
No.	Permit holder	County	Well POD	Purpose	Status	Ac-ft/yr
3047	Schirado's Excavation	McLean	145-080-32C	Industrial	Cancelled	0
3915	Wachter Development Inc.	McLean	145-084-03C	Industrial	Perfected	20
3617	Mercer, City of	McLean	146-079-02C	Municipal	Perfected	25.0
2978	Mercer, City of*	McLean	146-079-02C	Municipal	Cancelled	0
1659	Zap, City of	Mercer	144-089-14CD	Municipal	Cancelled	0
3286	Zap, City of*	Mercer	144-089-15D	Municipal	Perfected	140
1851	Golden Valley, City of	Mercer	144-090-15DB	Municipal	Cancelled	0
5921	Boeshans, Vernon	Mercer	146-087-04D	Rural Water	Conditional	6.7
3984	Lakeshore Estates	Mercer	146-087-08A	Rural Water	Cancelled	0
5477	Lakeshore Estates*	Mercer	146-087-09N	Rural Water	Conditional	35
1821	Riverview Heights Co-Op	Morton	139-081-04CAD	Rural Water	Cancelled	0
1632	Porsborg, Kenneth	Morton	139-081-16BC	Rural Water	Cancelled	0
2759	Crown Butte Co-Op	Morton	139-082-08BC	Rural Water	Cancelled	0
2229	Glen Ullin, City of	Morton	139-088-31BA	Municipal	Perfected	180
5657	Price Cattle Ranch, LLD	Oliver	141-081-13B	Industrial	Conditional	100
4976	International Peace Garden	Rolette	164-073-25D	Rural Water	Conditional	50
2703	Marmarth, City of	Slope	133-105-31BA	Municipal	Perfected	42
3287	Wasteco Manufacturing	Stark	139-095-06B	Industrial	Cancelled	0
2696	Wolf, Mike	Stark	139-095-17BA	Industrial	Cancelled	0
3319	Dickinson Energy Center	Stark	139-096-01C	Industrial	Cancelled	0
2513	Belfield, City of	Stark	139-099-05A	Municipal	Perfected	200
3372	Slope Estates Partnership	Stark	140-097-25C	Rural Water	Cancelled	0
5331	T & T Pipeline Coop.	Williams	153-099-14B	Industrial	Perfected	16
4767	Satermo, Kevin	Williams	154-101-29AB	Industrial	Conditional	130
3483	Tractor & Equipment Co.	Williams	154-101-30B	Industrial	Perfected	10
3840	Behm Investments, Inc.	Williams	154-101-31B	Industrial	Cancelled	0

Appendix 3:

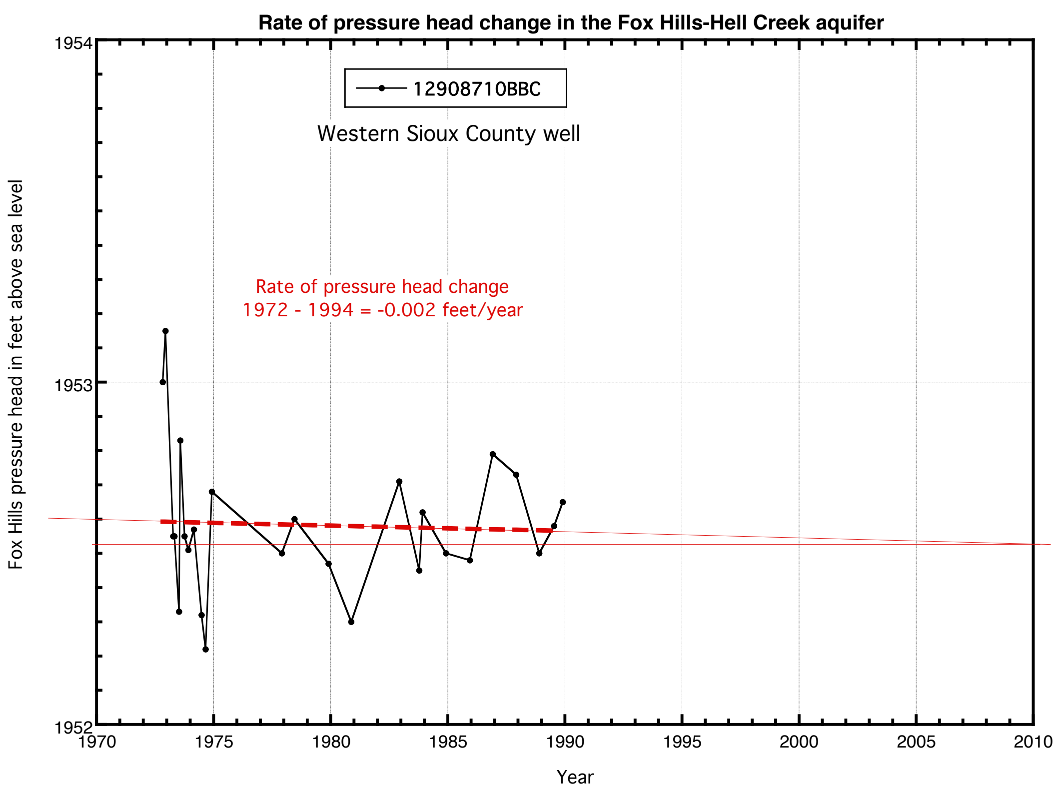
Hydrographs of measured pressure heads in Fox Hills wells

The thick red dashed line on the hydrographs is a linear curve fit of the hydrograph. The line is extended to the edges of the graph and used to determine the pressure head change over time.

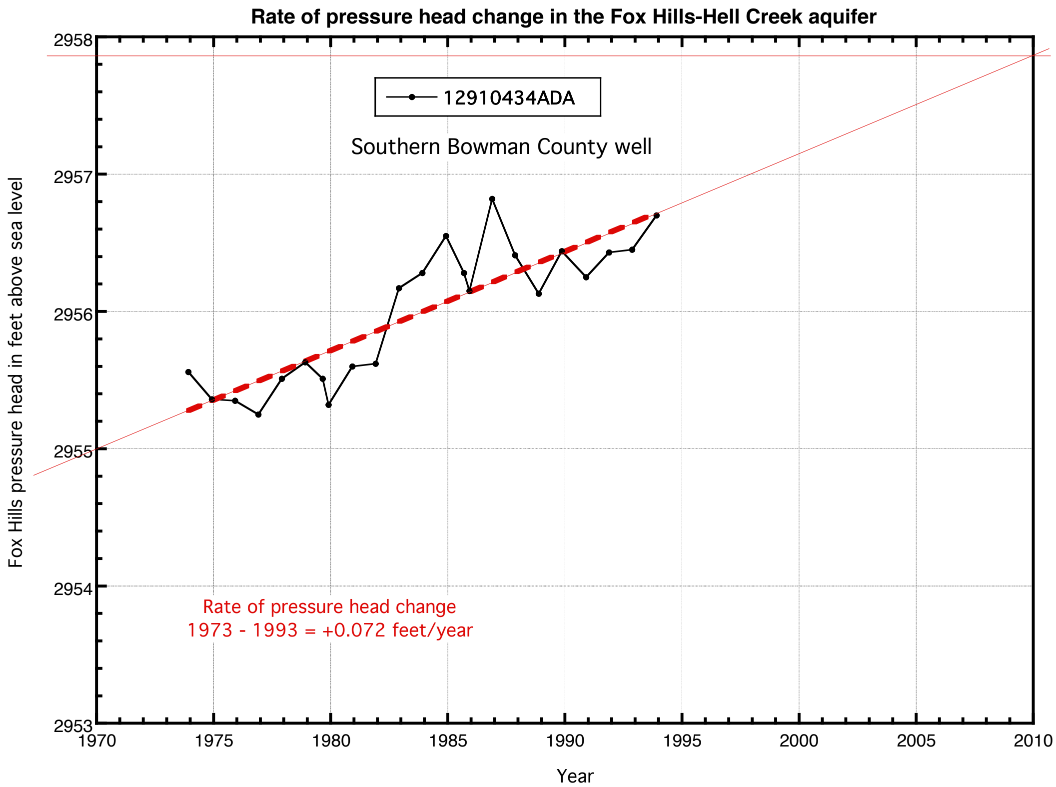
If enough water level measurements are available after January 1, 1995, a thin blue diagonal line on the hydrographs is the linear curve fit of those measurements.



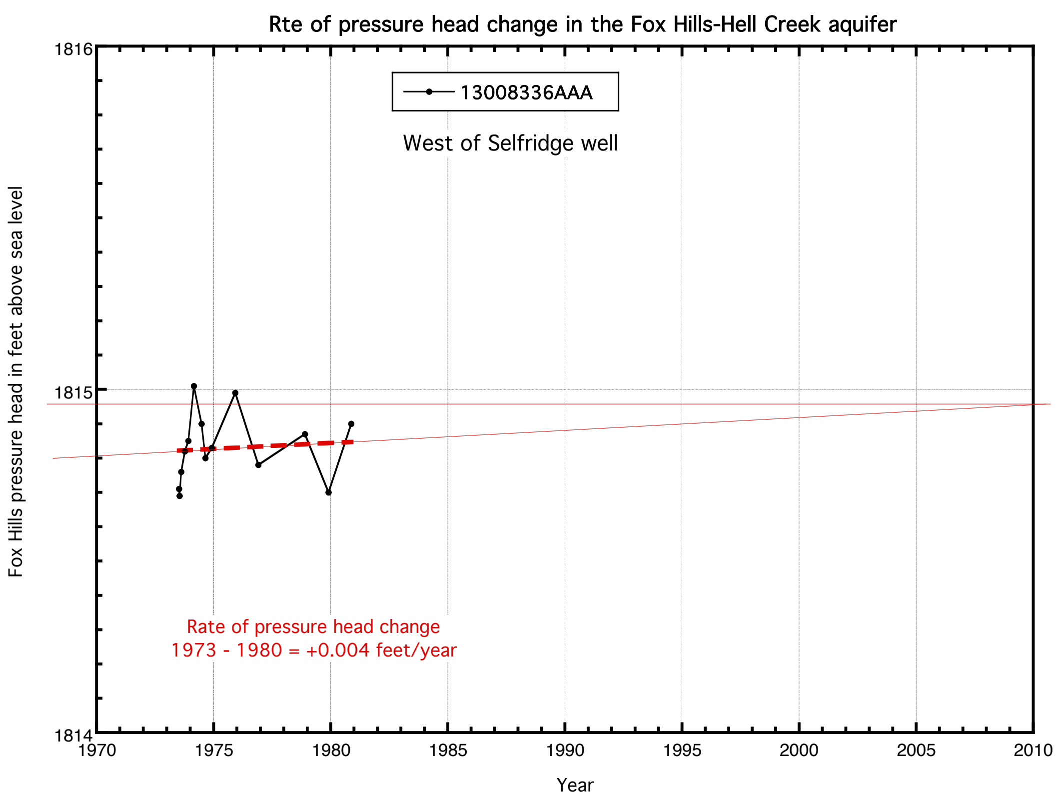
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
1779
1778
1777
12908101BAB
Ft. Yates SW well
Rate of pressure head change
1973 - 1994 = +0.004 feet/year
Fox Hills pressure head in feet above sea level
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year



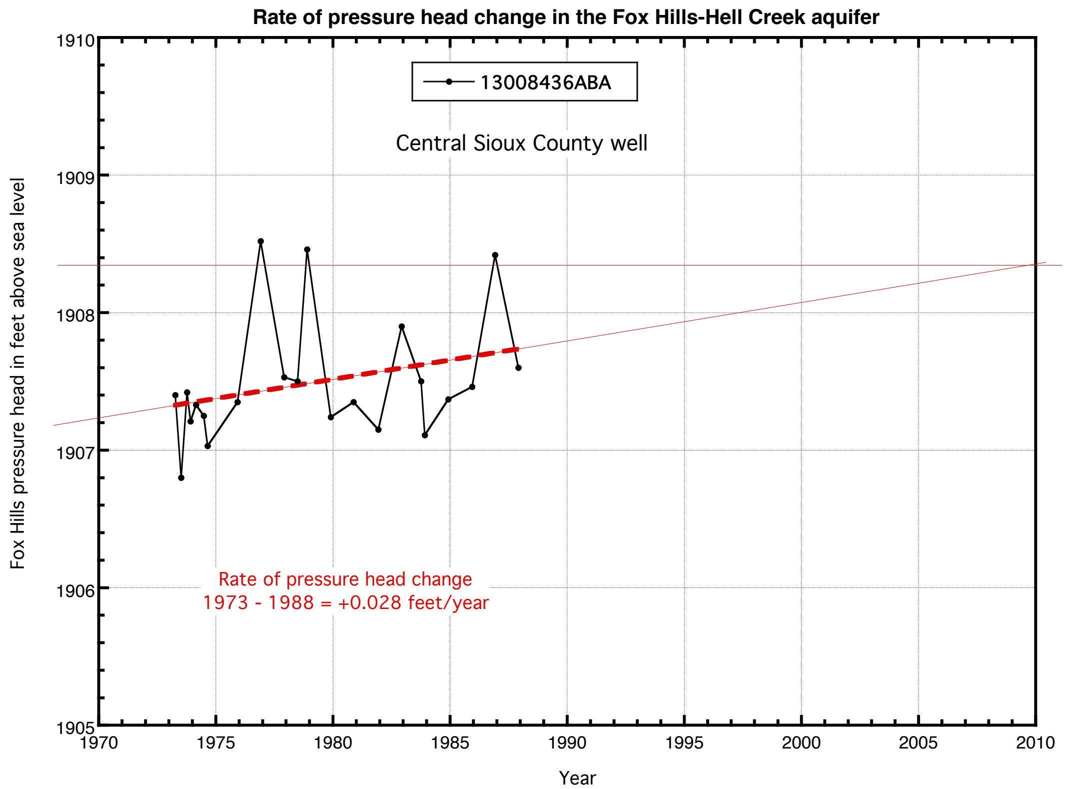
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
1954
1953
1952
12908710BBC
Western Sioux County well
Rate of pressure head change
1972 - 1994 = -0.002 feet/year
Fox Hills pressure head in feet above sea level
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year



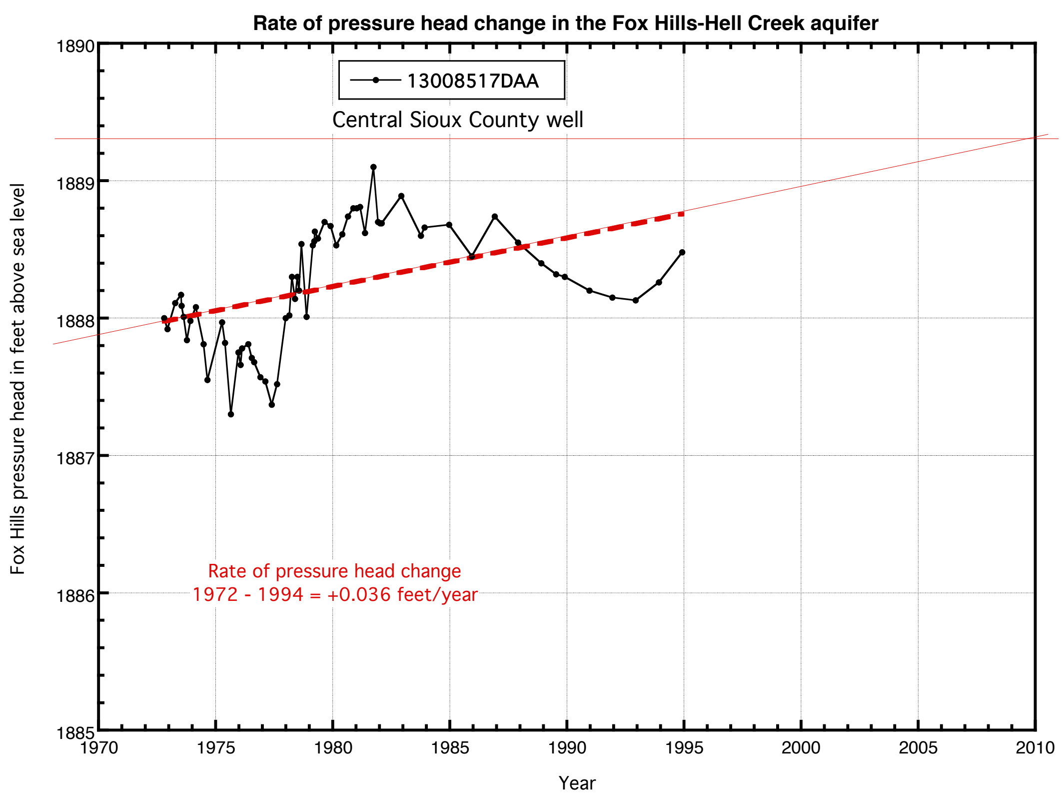
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
12910434ADA
Southern Bowman County well
Fox Hills pressure head in feet above sea level
2958
2957
2956
2955
2954
2953
Rate of pressure head change
1973 - 1993 = +0.072 feet/year
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year



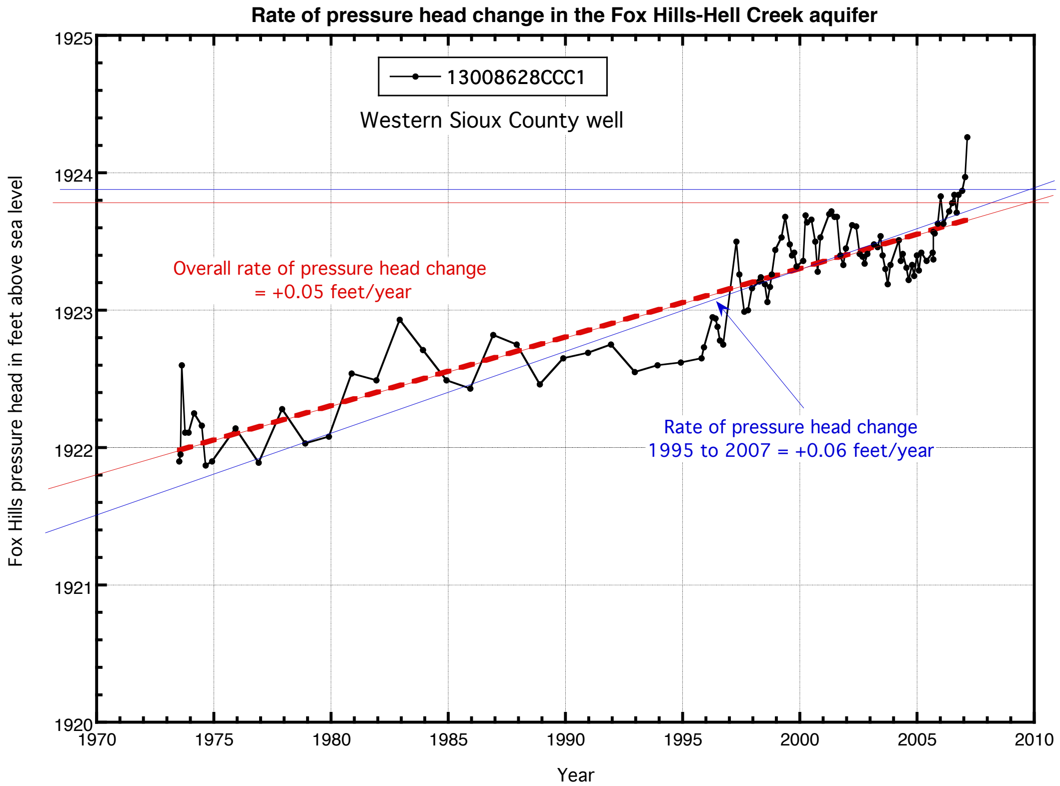
Rte of pressure head change in the Fox Hills-Hell Creek aquifer
13008336AAA
West of Selfridge well
Fox Hills pressure head in feet above sea level
1816
1815
1814
Rate of pressure head change
1973 - 1980 = +0.004 feet/year
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

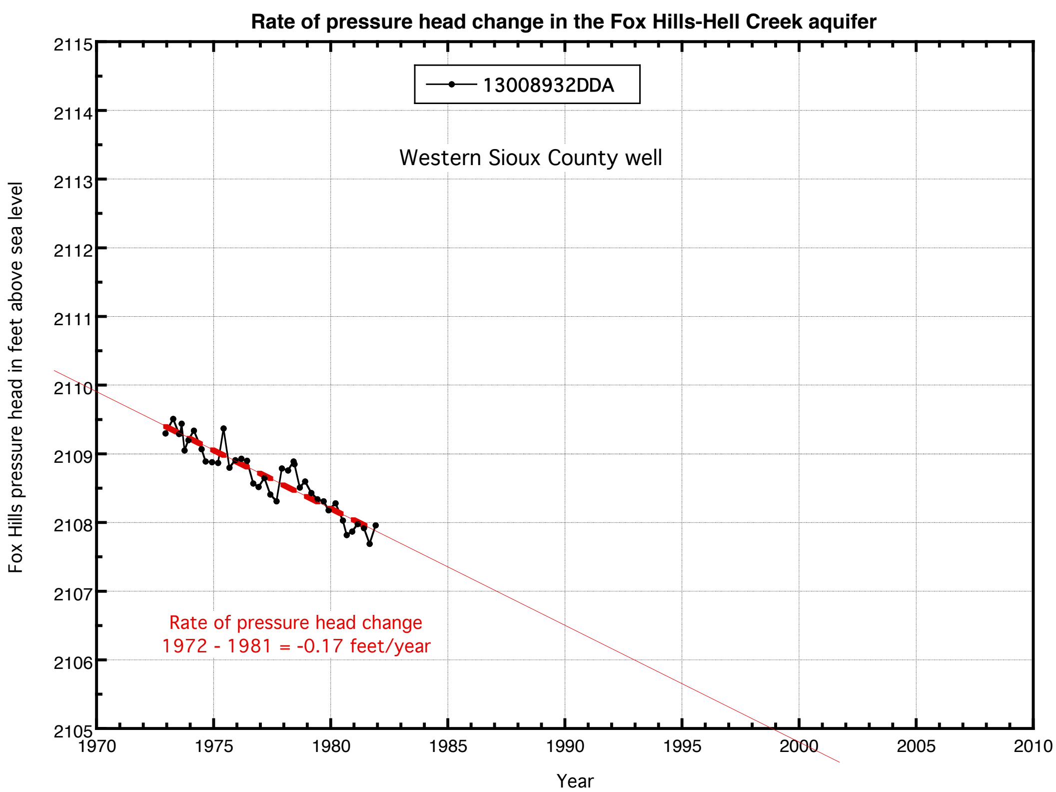


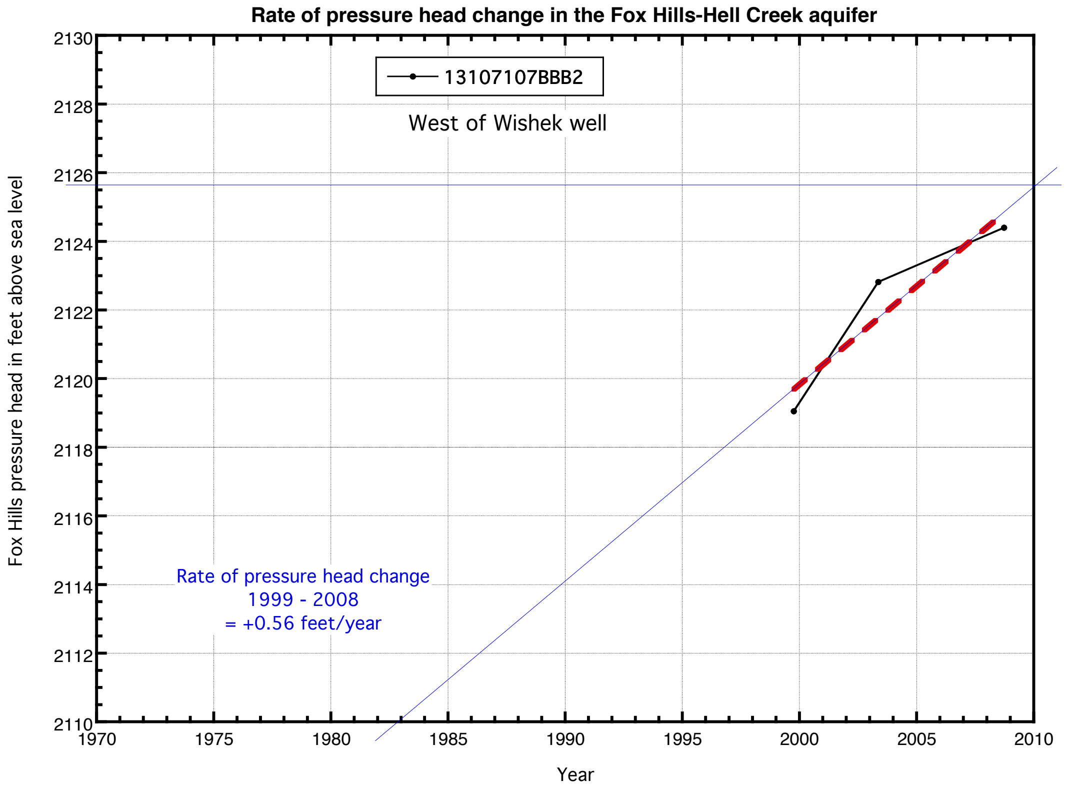
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13008436ABA
Central Sioux County well
Fox Hills pressure head in feet above sea level
1910
1909
1908
1907
1906
1905
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
Rate of pressure head change
1973 - 1988 = +0.028 feet/year

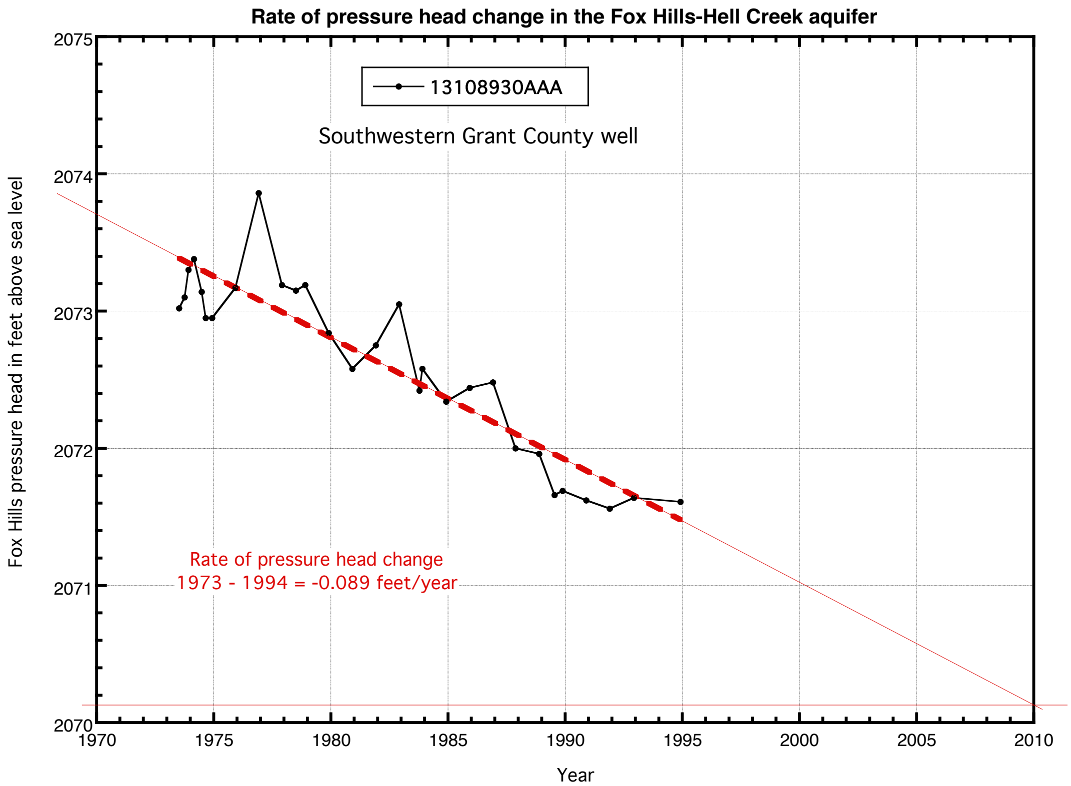


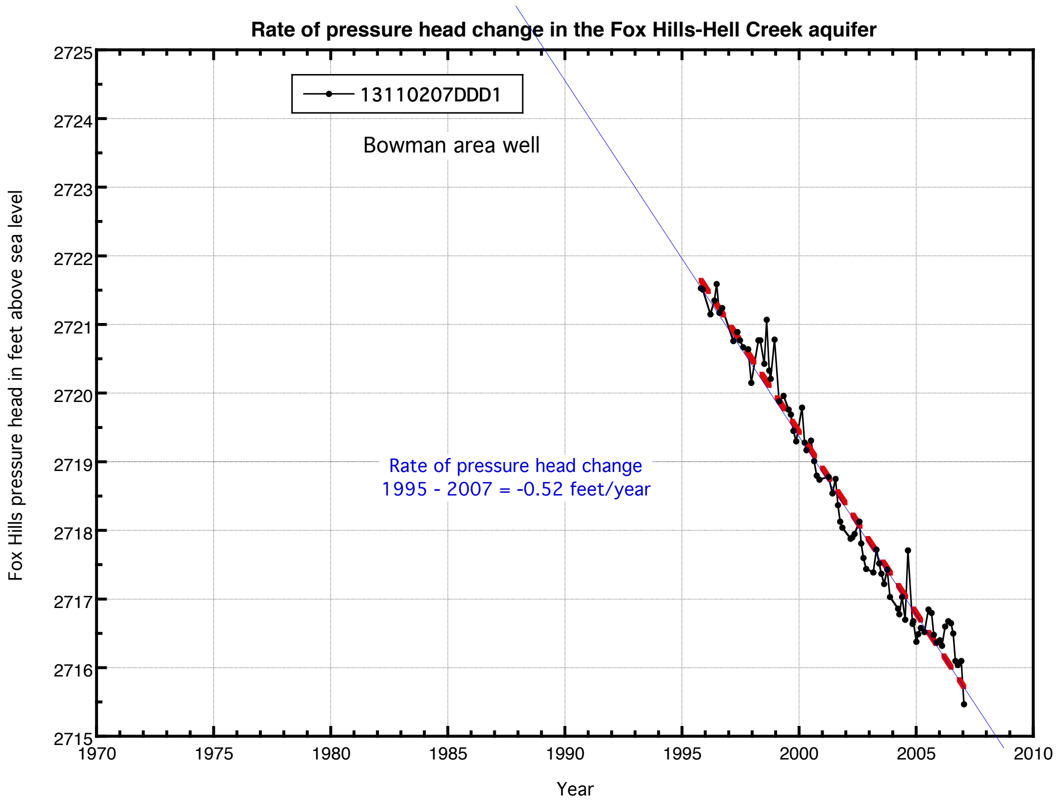
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13008517DAA
Central Sioux County well
Fox Hills pressure head in feet above sea level
1890
1889
1888
1887
1886
1885
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year
Rate of pressure head change
1972 - 1994 = +0.036 feet/year

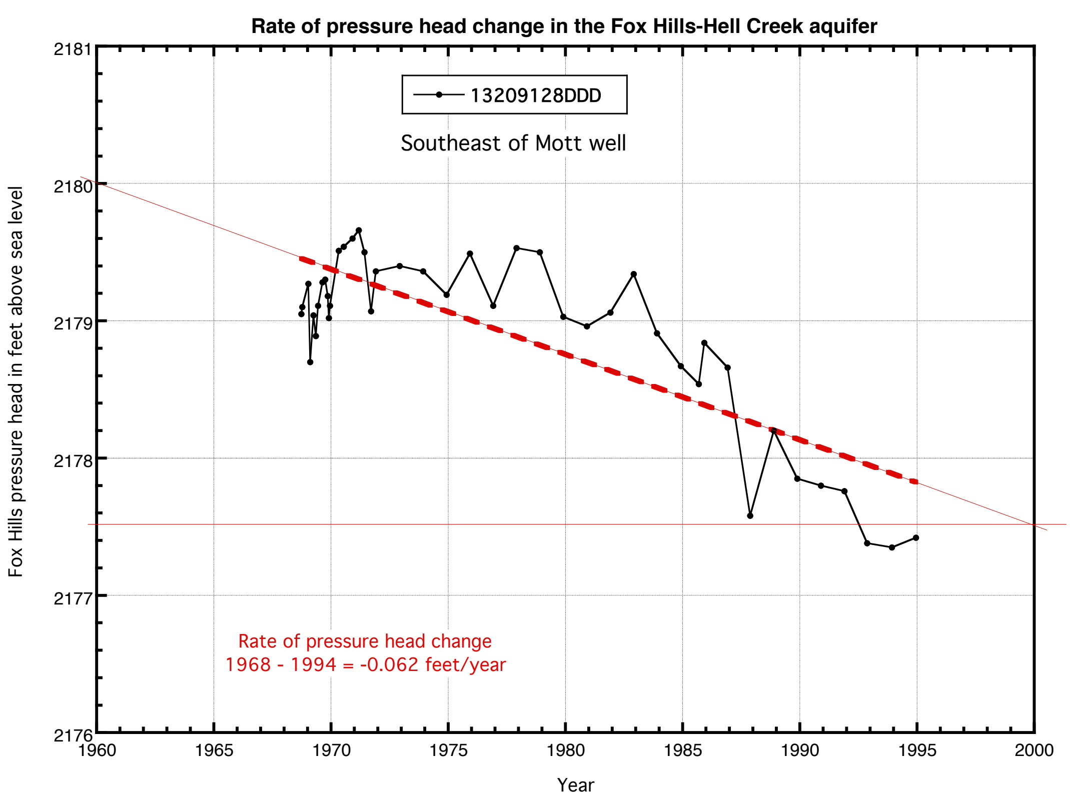

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13008628CCC1
Western Sioux County well
Overall rate of pressure head change
= +0.05 feet/year
Rate of pressure head change
1995 to 2007 = +0.06 feet/year
Fox Hills pressure head in feet above sea level
1925
1924
1923
1922
1921
1920
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

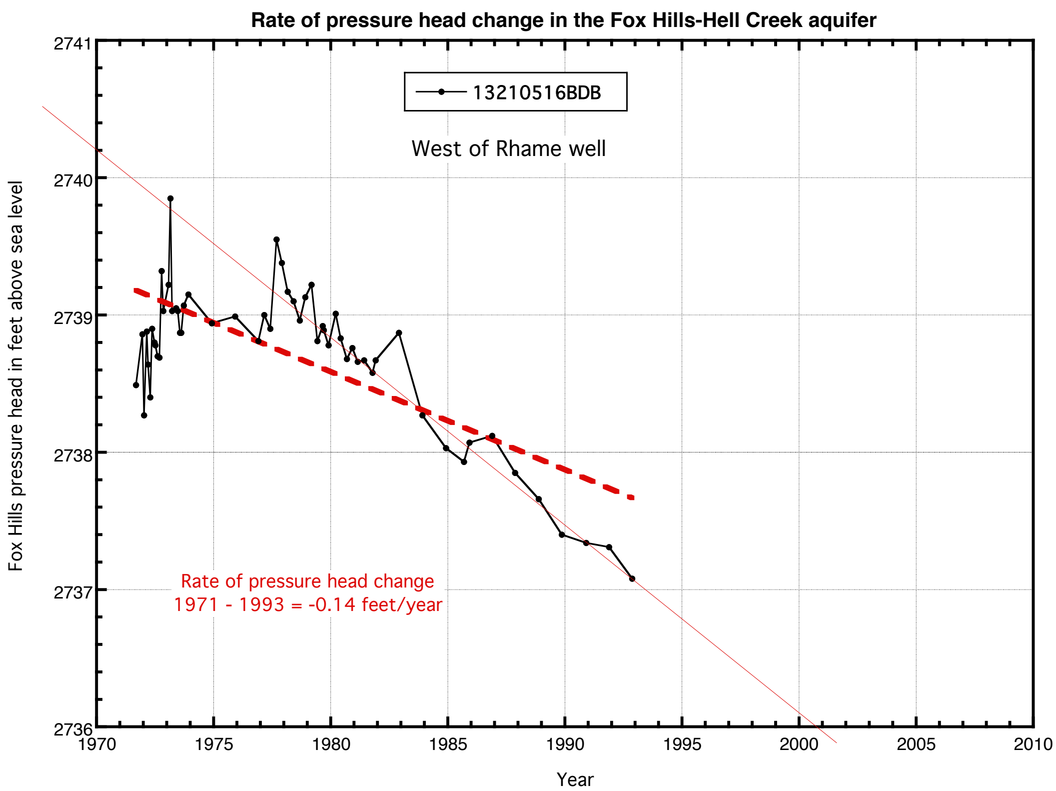

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13008932DDA
Western Sioux County well
Rate of pressure head change
1972 - 1981 = -0.17 feet/year
Fox Hills pressure head in feet above sea level
2115
2114
2113
2112
2111
2110
2109
2108
2107
2106
2105
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

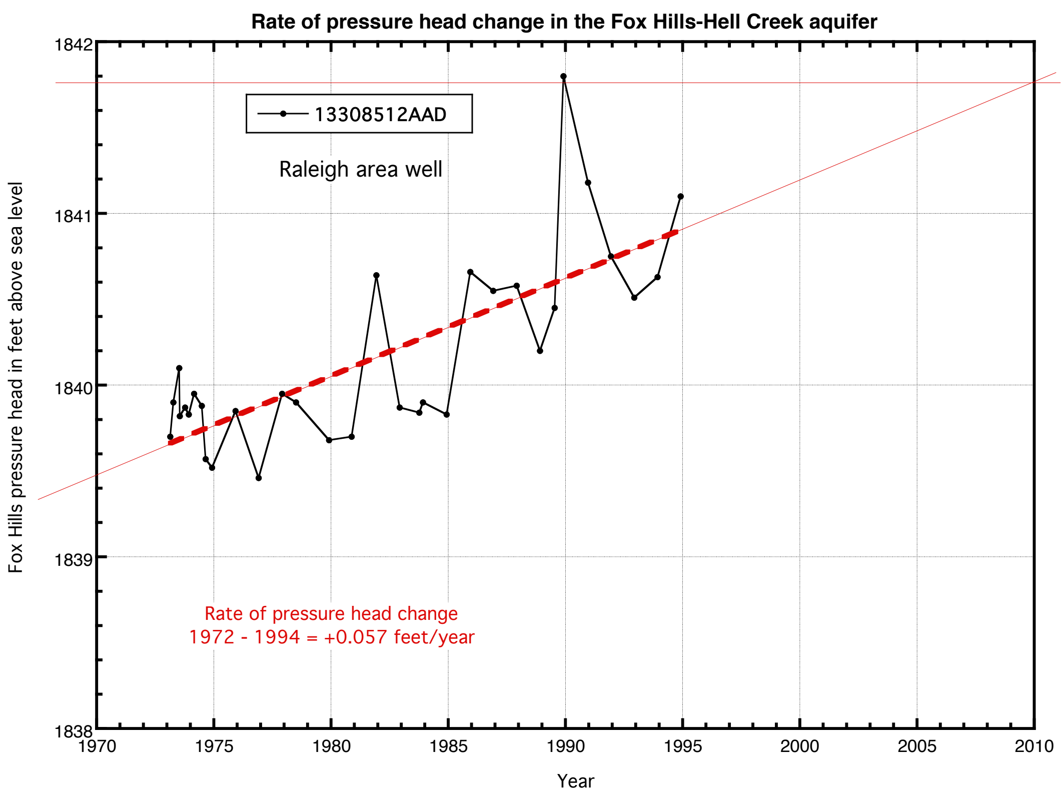

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13107107BBB2
West of Wishek well
Rate of pressure head change
1999 - 2008
= +0.56 feet/year
Fox Hills pressure head in feet above sea level
Year
2110
2112
2114
2116
2118
2120
2122
2124
2126
2128
2130
1970
1975
1980
1985
1990
1995
2000
2005
2010

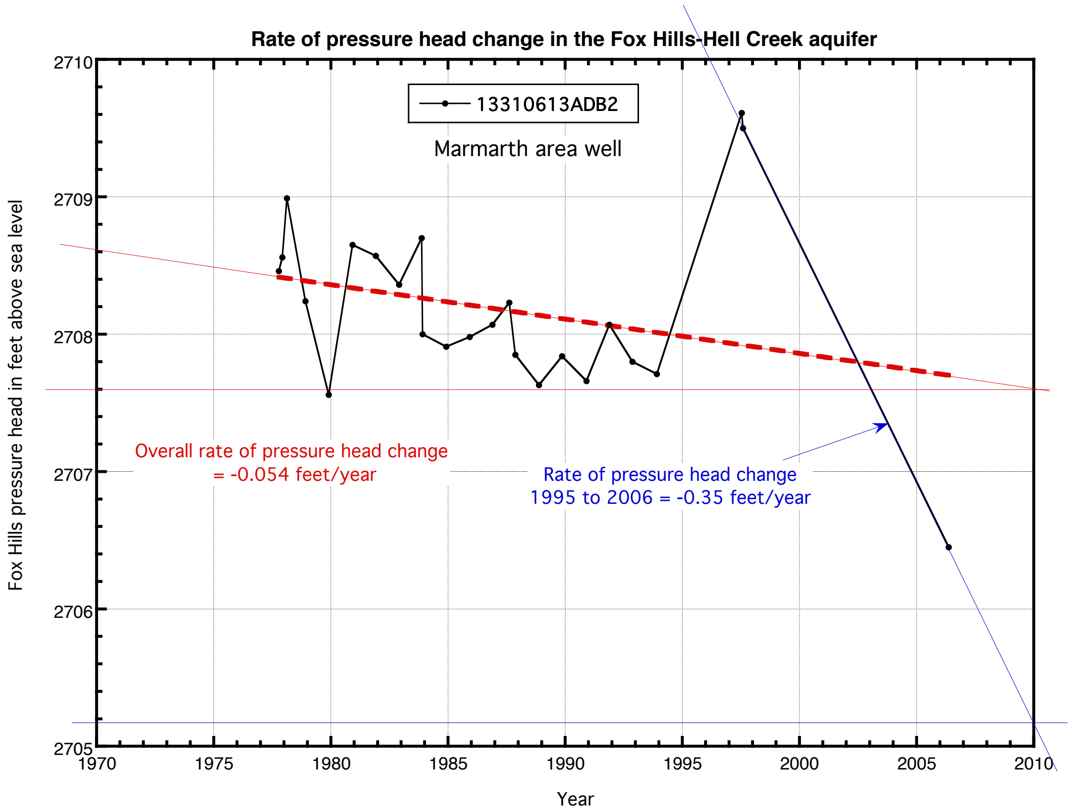

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13108930AAA
Southwestern Grant County well
Rate of pressure head change
1973 - 1994 = -0.089 feet/year
Fox Hills pressure head in feet above sea level
Year
2070
2071
2072
2073
2074
2075
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13110207DDD1
Bowman area well
Rate of pressure head change
1995 - 2007 = -0.52 feet/year
Fox Hills pressure head in feet above sea level
Year
2725
2724
2723
2722
2721
2720
2719
2718
2717
2716
2715
1970
1975
1980
1985
1990
1995
2000
2005
2010

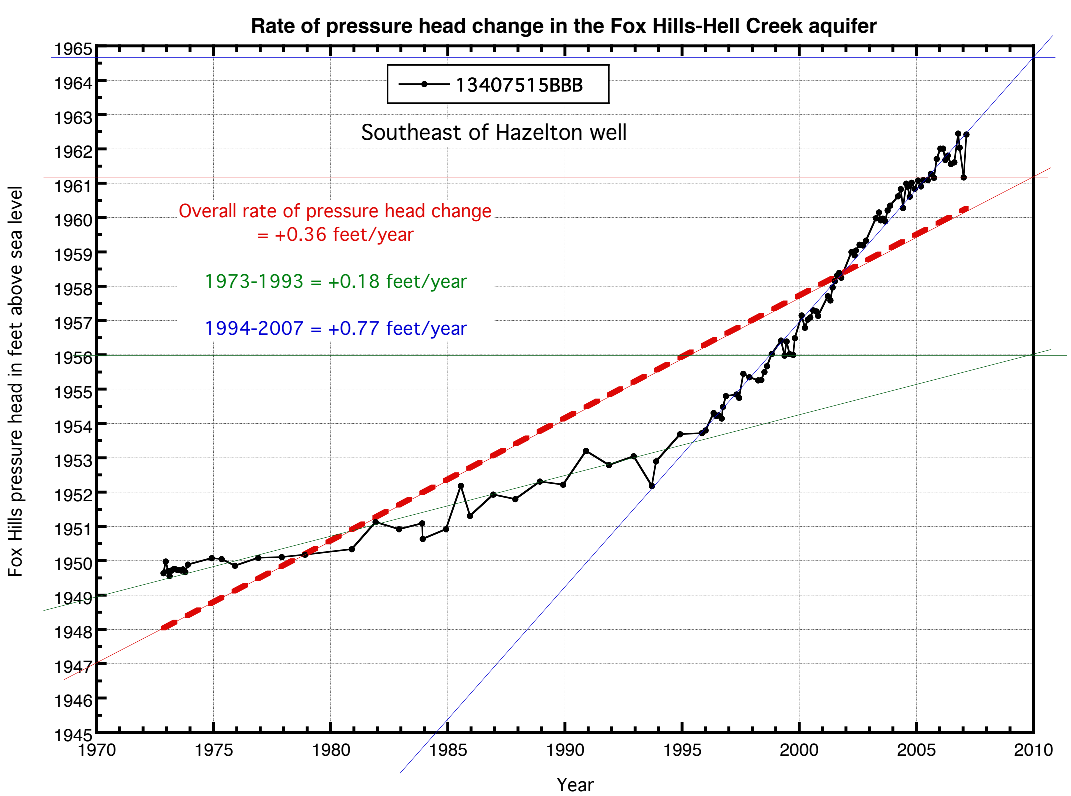

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13209128DDD
Southeast of Mott well
Rate of pressure head change
1968 - 1994 = -0.062 feet/year
Fox Hills pressure head in feet above sea level
Year
2181
2180
2179
2178
2177
2176
1960
1965
1970
1975
1980
1985
1990
1995
2000


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13210516BDB
West of Rhame well
Fox Hills pressure head in feet above sea level
Rate of pressure head change
1971 - 1993 = -0.14 feet/year
2741
2740
2739
2738
2737
2736
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

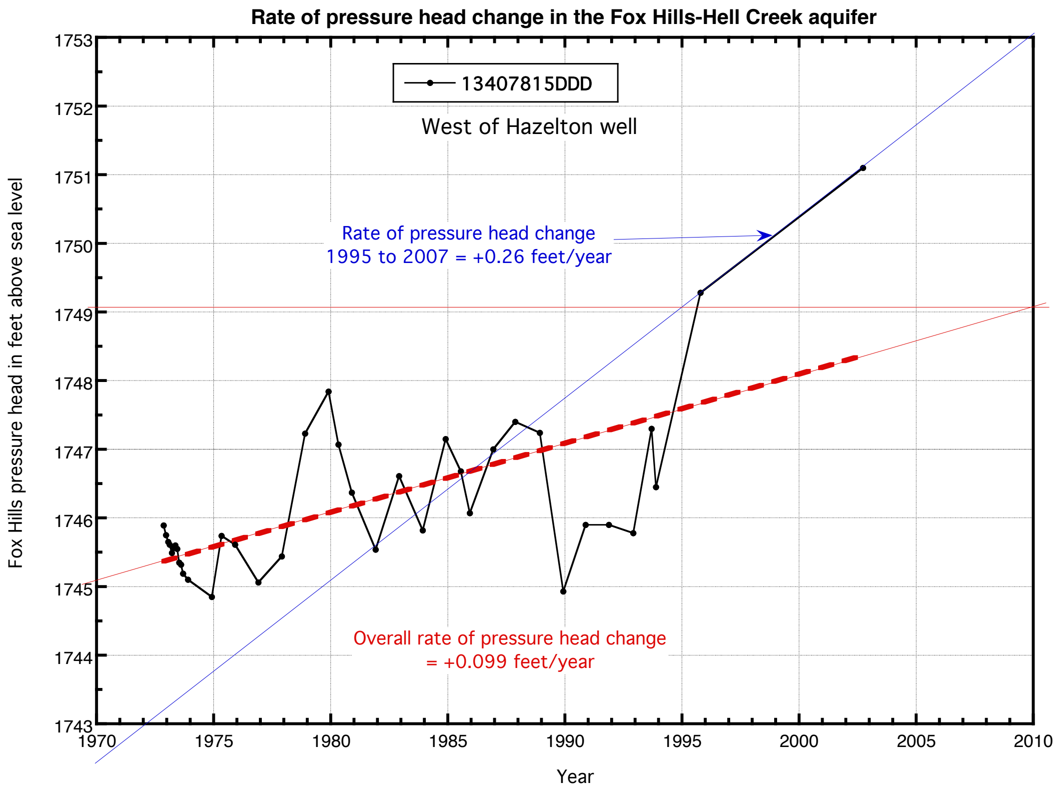

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13308512AAD
Raleigh area well
Fox Hills pressure head in feet above sea level
Rate of pressure head change
1972 - 1994 = +0.057 feet/year
1842
1841
1840
1839
1838
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

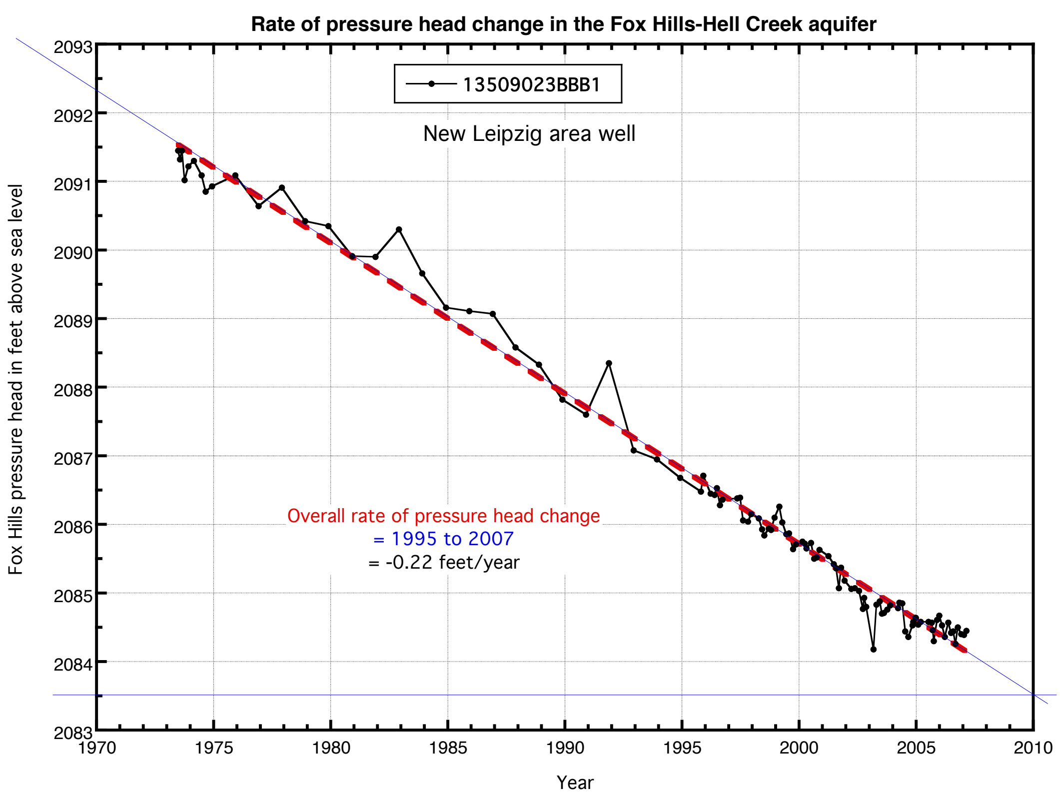


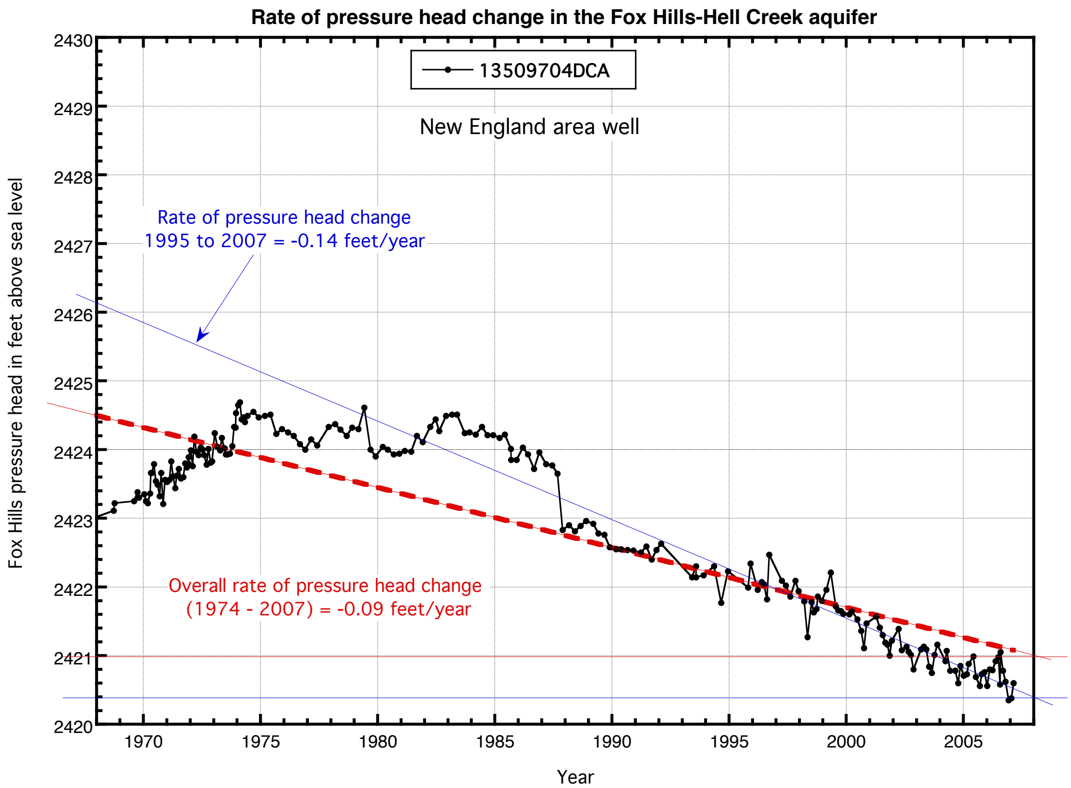
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13310613ADB2
Marmarth area well
Overall rate of pressure head change
= -0.054 feet/year
Rate of pressure head change
1995 to 2006 = -0.35 feet/year
Fox Hills pressure head in feet above sea level
Year
2710
2709
2708
2707
2706
2705
1970
1975
1980
1985
1990
1995
2000
2005
2010



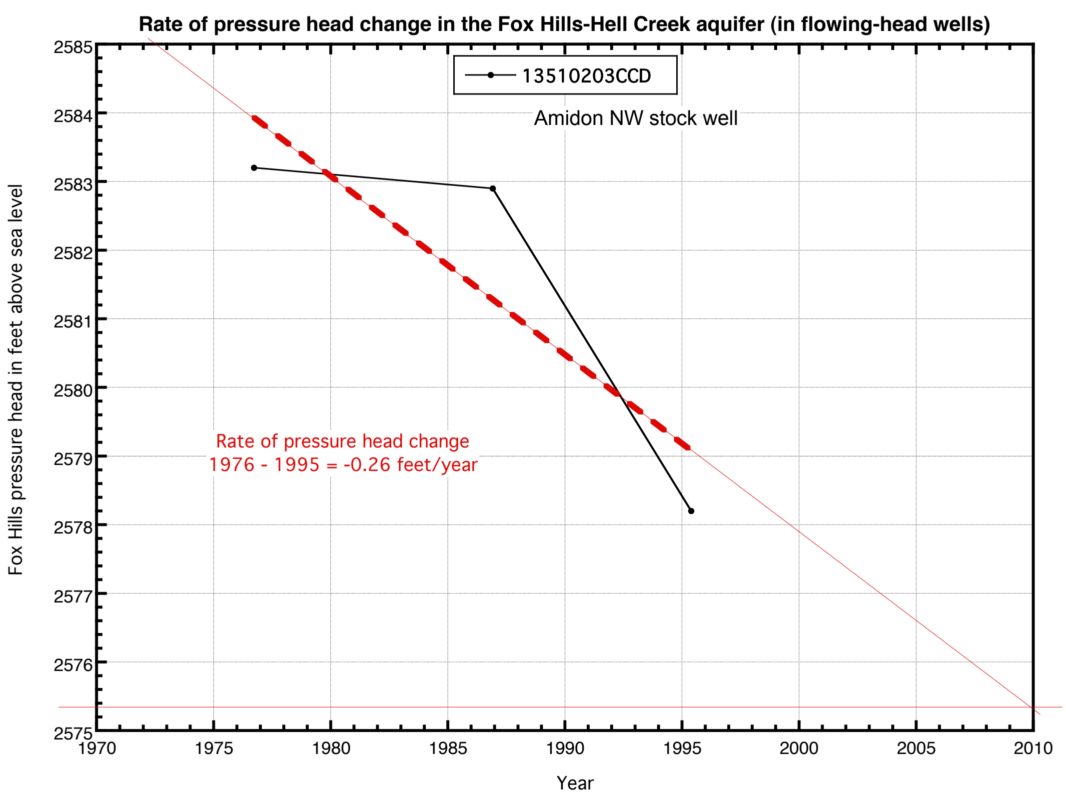
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13407515BBB
Southeast of Hazelton well
Overall rate of pressure head change
= +0.36 feet/year
1973-1993 = +0.18 feet/year
1994-2007 = +0.77 feet/year
Fox Hills pressure head in feet above sea level
Year
1965
1964
1963
1962
1961
1960
1959
1958
1957
1956
1955
1954
1953
1952
1951
1950
1949
1948
1947
1946
1945
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13407815DDD
West of Hazelton well
Rate of pressure head change
1995 to 2007 = +0.26 feet/year
Overall rate of pressure head change
= +0.099 feet/year
Fox Hills pressure head in feet above sea level
Year
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1970
1975
1980
1985
1990
1995
2000
2005
2010

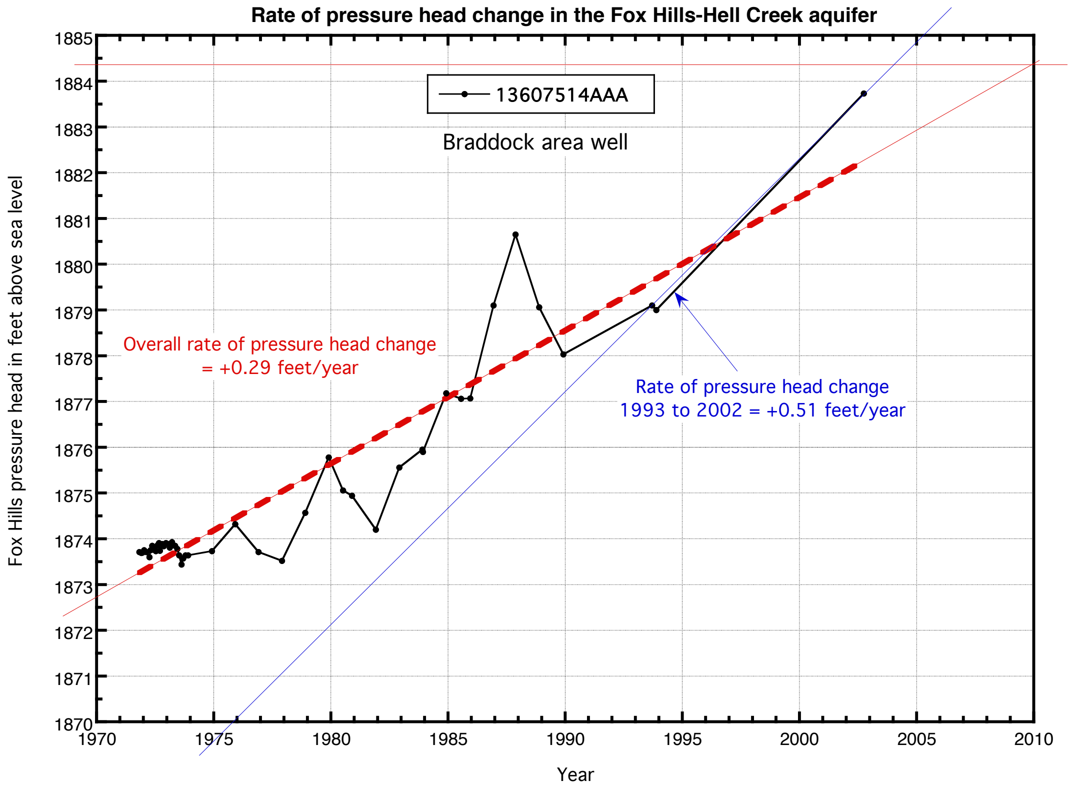

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13509023BBB1
New Leipzig area well
Overall rate of pressure head change
= 1995 to 2007
= -0.22 feet/year
Fox Hills pressure head in feet above sea level
Year
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
1970
1975
1980
1985
1990
1995
2000
2005
2010



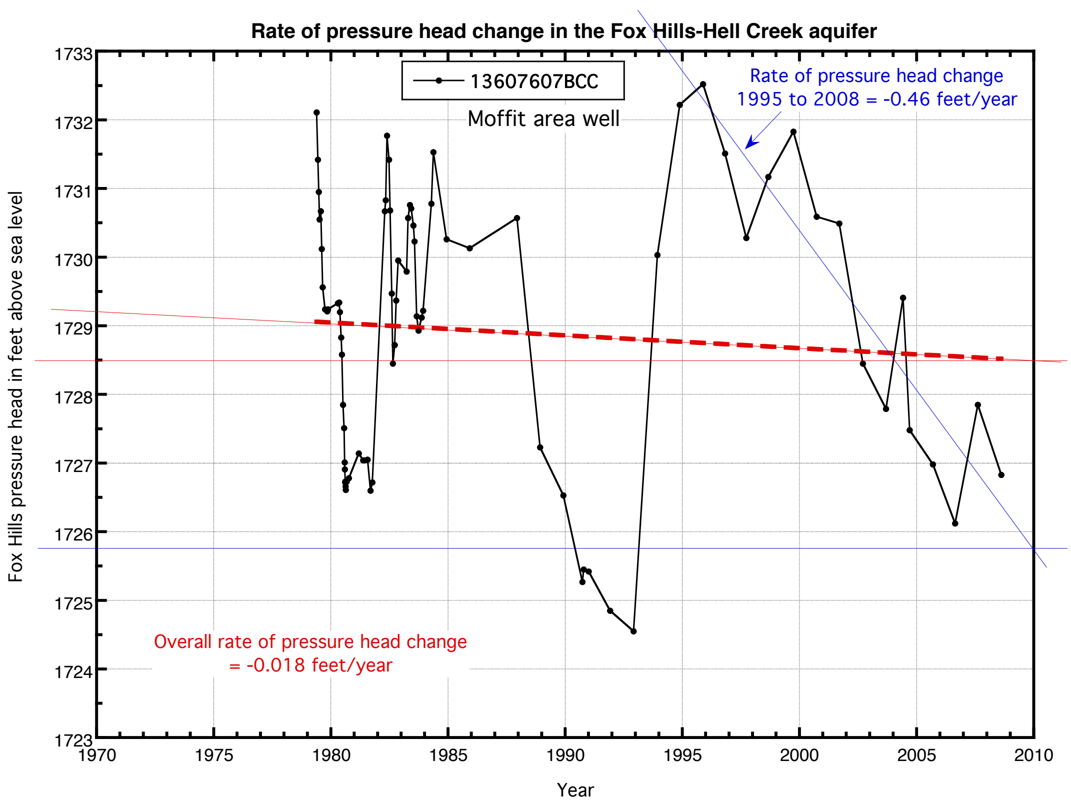
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13509704DCA
New England area well
Rate of pressure head change
1995 to 2007 = -0.14 feet/year
Overall rate of pressure head change
(1974 - 2007) = -0.09 feet/year
Fox Hills pressure head in feet above sea level
Year
2430
2429
2428
2427
2426
2425
2424
2423
2422
2421
2420
1970
1975
1980
1985
1990
1995
2000
2005



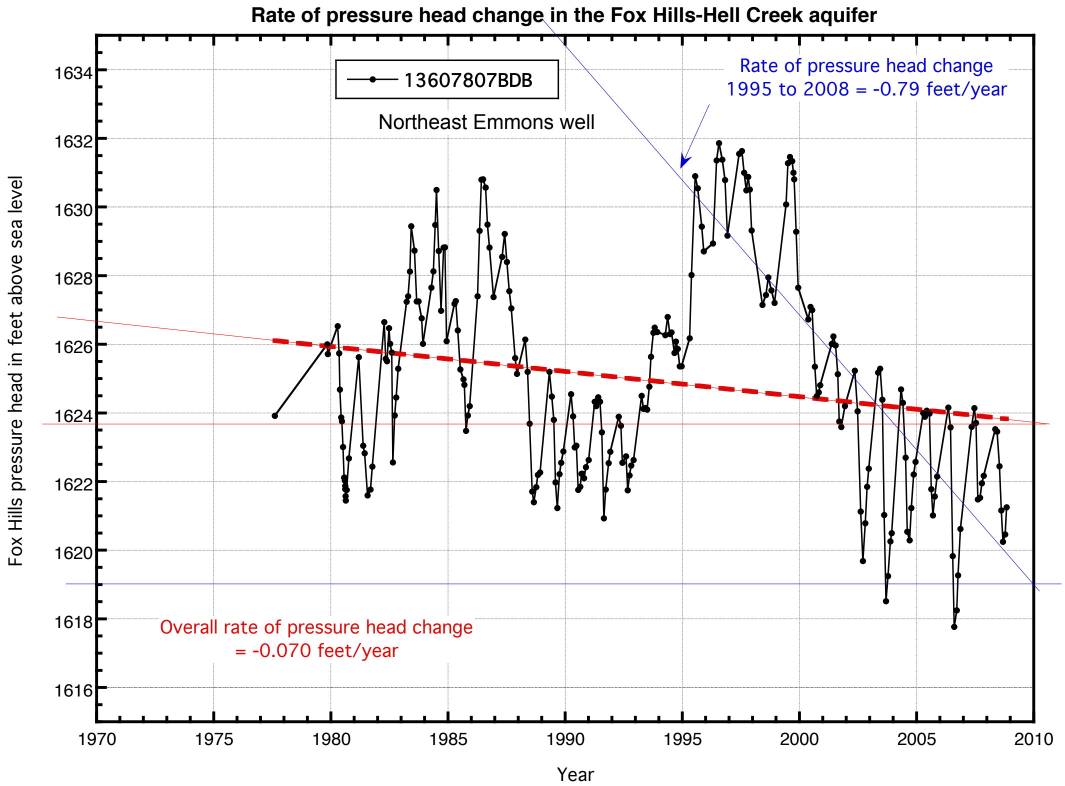
Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13510203CCD
Amidon NW stock well
Rate of pressure head change
1976 - 1995 = -0.26 feet/year
Fox Hills pressure head in feet above sea level
Year
2585
2584
2583
2582
2581
2580
2579
2578
2577
2576
2575
1970
1975
1980
1985
1990
1995
2000
2005
2010

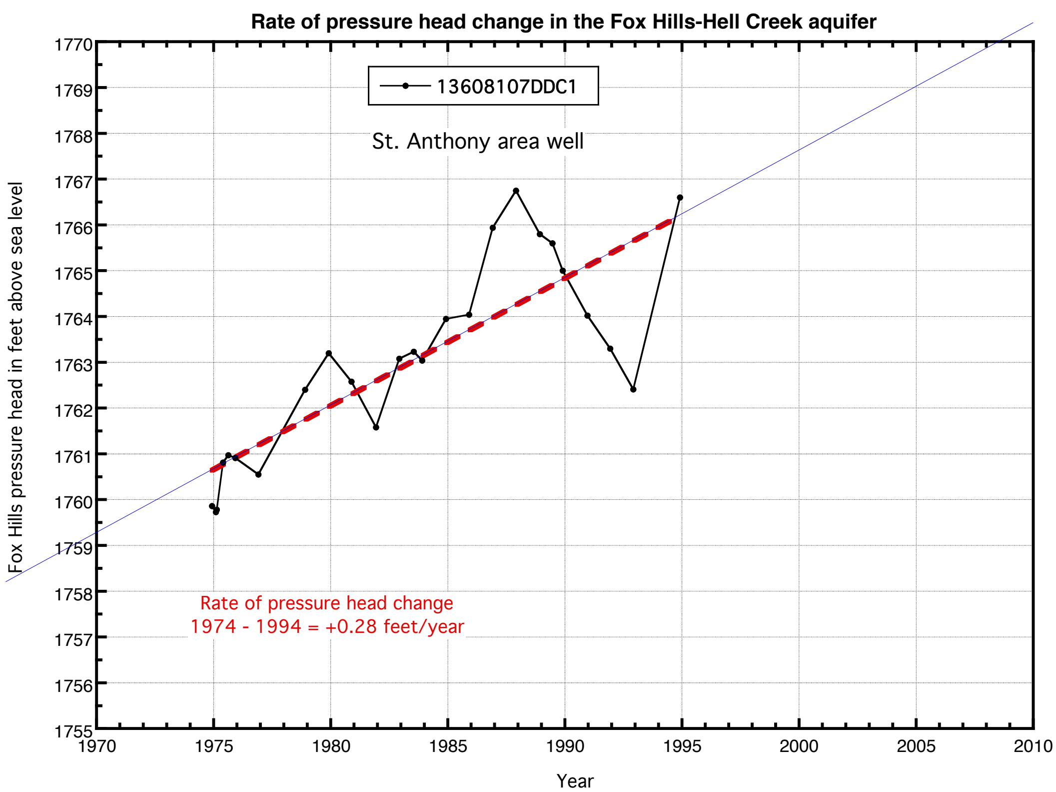


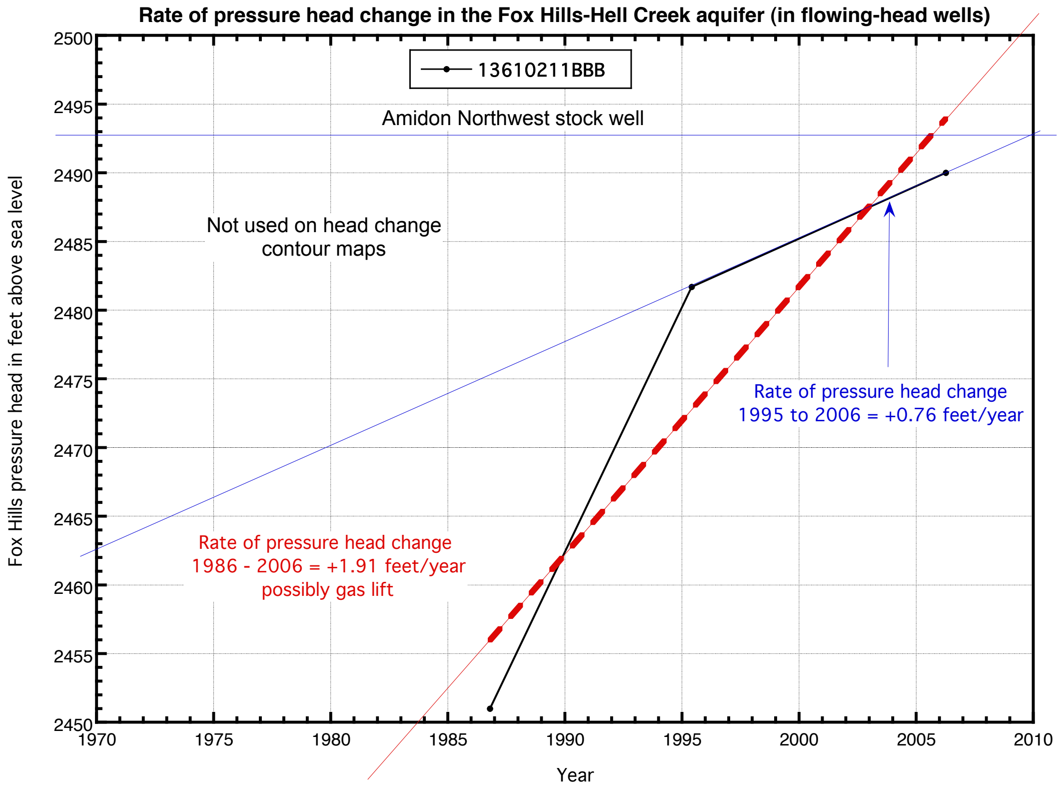
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13607514AAA
Braddock area well
Overall rate of pressure head change
= +0.29 feet/year
Rate of pressure head change
1993 to 2002 = +0.51 feet/year
Fox Hills pressure head in feet above sea level
Year
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1970
1975
1980
1985
1990
1995
2000
2005
2010

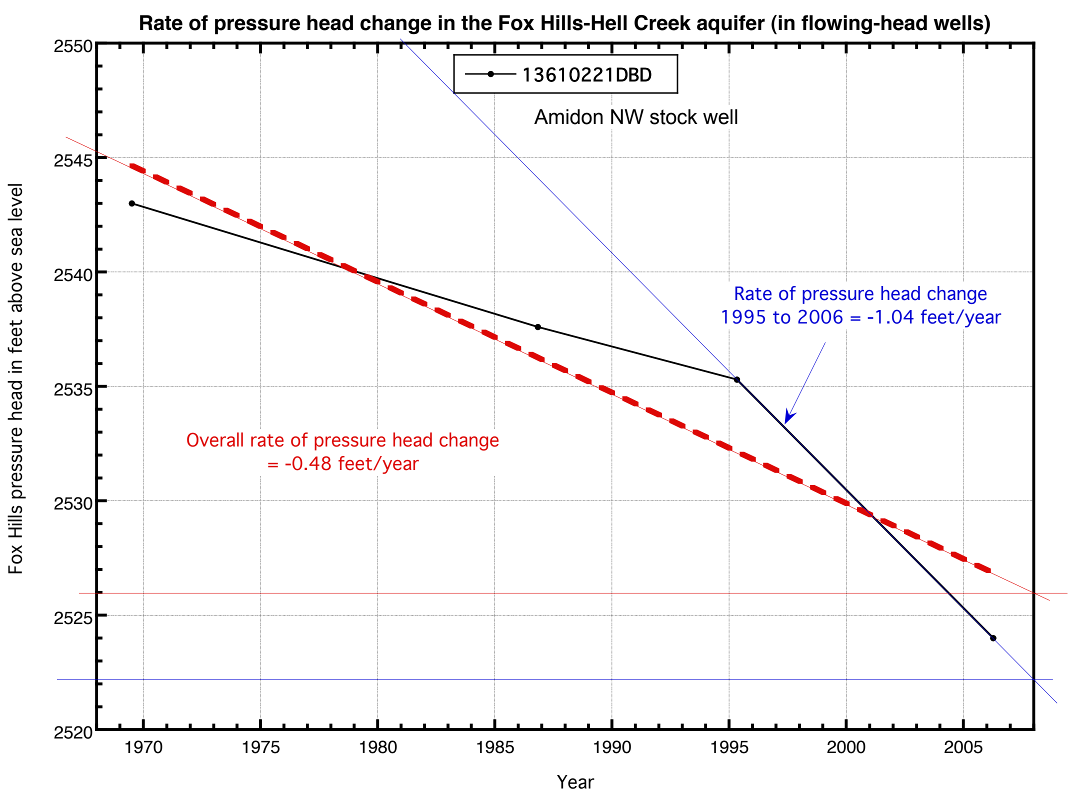


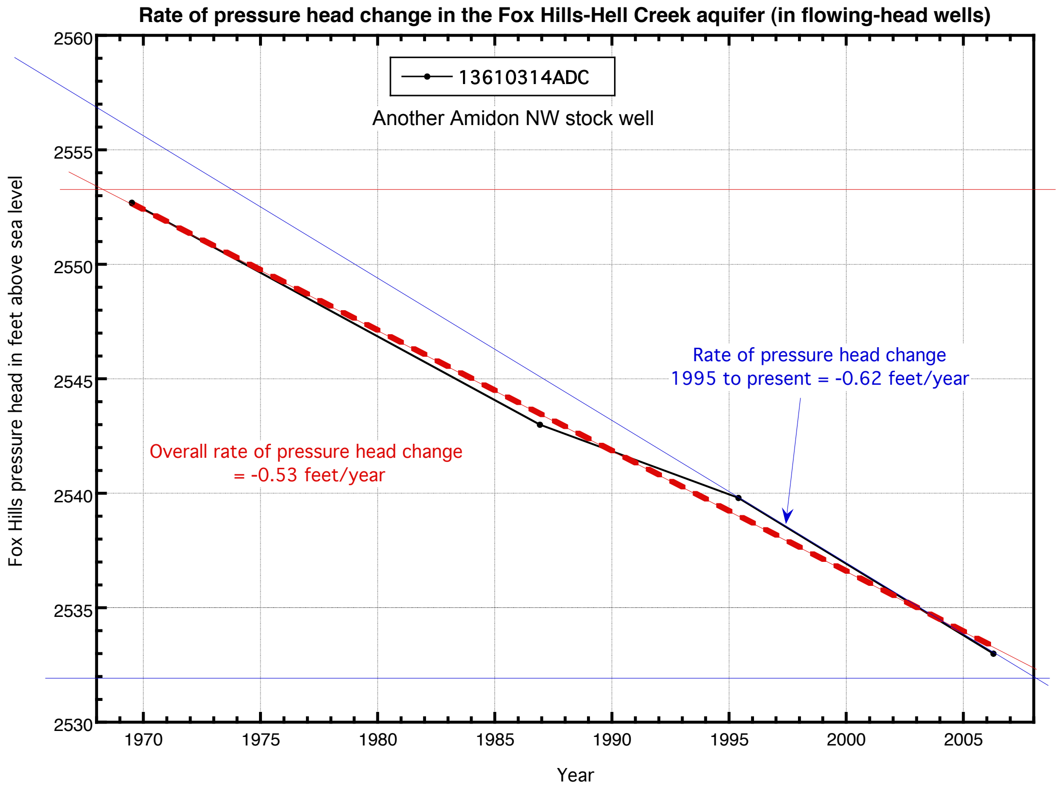
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13607607BCC
Moffit area well
Rate of pressure head change
1995 to 2008 = -0.46 feet/year
Overall rate of pressure head change
= -0.018 feet/year
Fox Hills pressure head in feet above sea level
Year
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1970
1975
1980
1985
1990
1995
2000
2005
2010

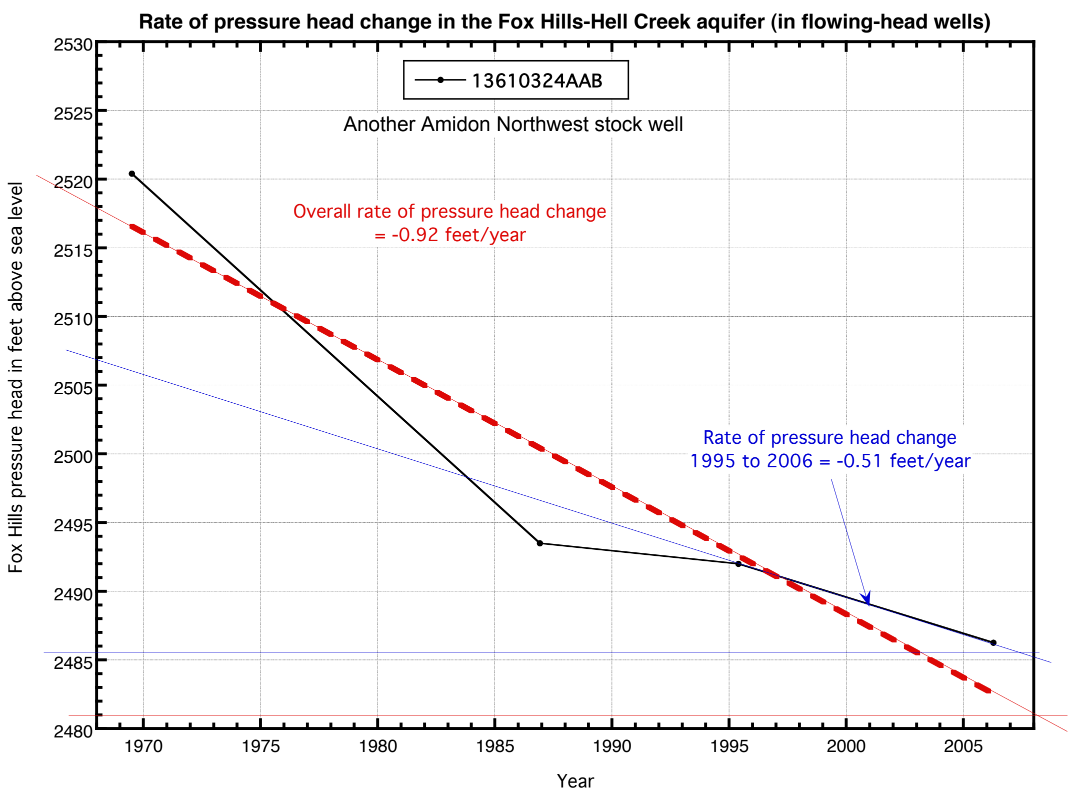

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13607807BDB
Northeast Emmons well
Rate of pressure head change
1995 to 2008 = -0.79 feet/year
Overall rate of pressure head change
= -0.070 feet/year
Fox Hills pressure head in feet above sea level
Year
1616
1618
1620
1622
1624
1626
1628
1630
1632
1634
1970
1975
1980
1985
1990
1995
2000
2005
2010

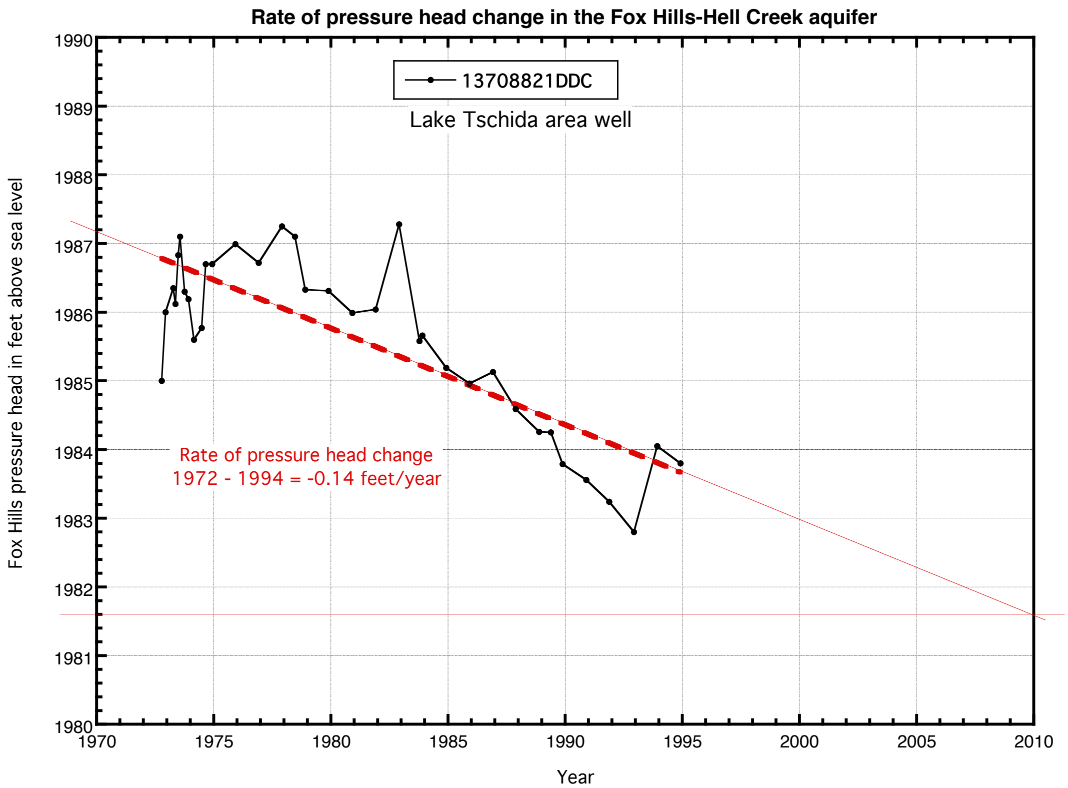

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13608107DDC1
St. Anthony area well
Rate of pressure head change
1974 - 1994 = +0.28 feet/year
Fox Hills pressure head in feet above sea level
Year
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1970
1975
1980
1985
1990
1995
2000
2005
2010

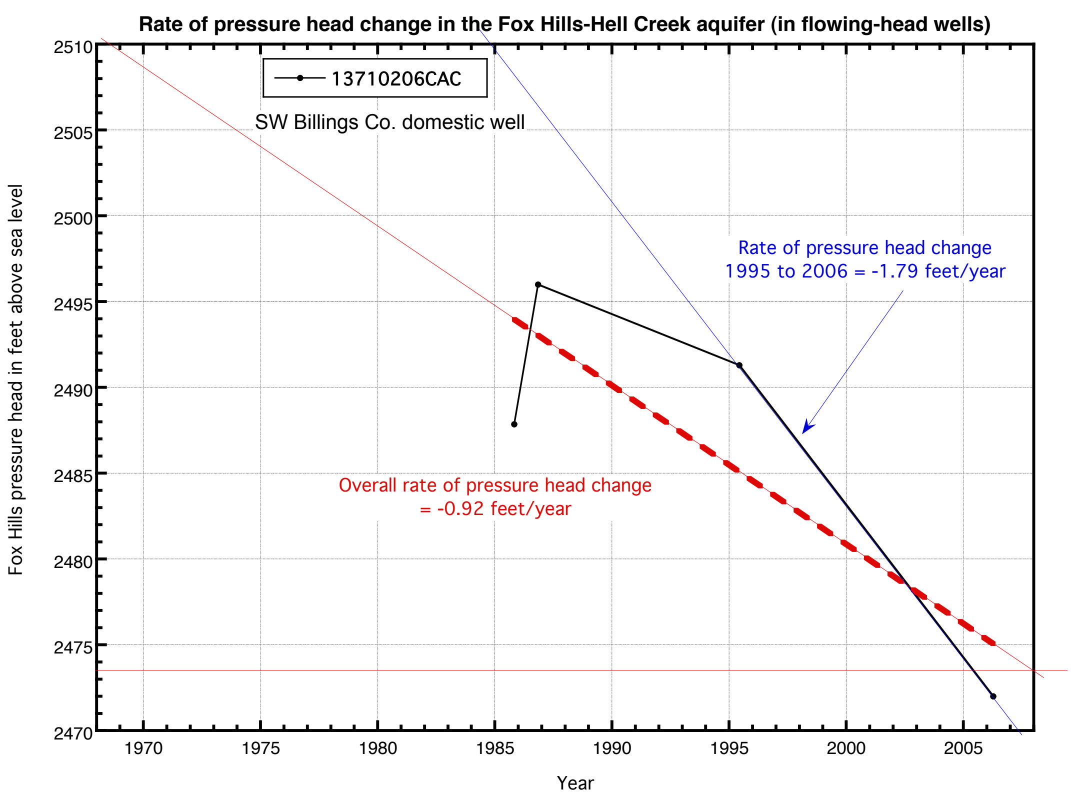

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13610211BBB
Amidon Northwest stock well
Not used on head change contour maps
Rate of pressure head change 1995 to 2006 = +0.76 feet/year
Rate of pressure head change 1986 - 2006 = +1.91 feet/year possibly gas lift
Fox Hills pressure head in feet above sea level
Year
2500
2495
2490
2485
2480
2475
2470
2465
2460
2455
2450
1970
1975
1980
1985
1990
1995
2000
2005
2010

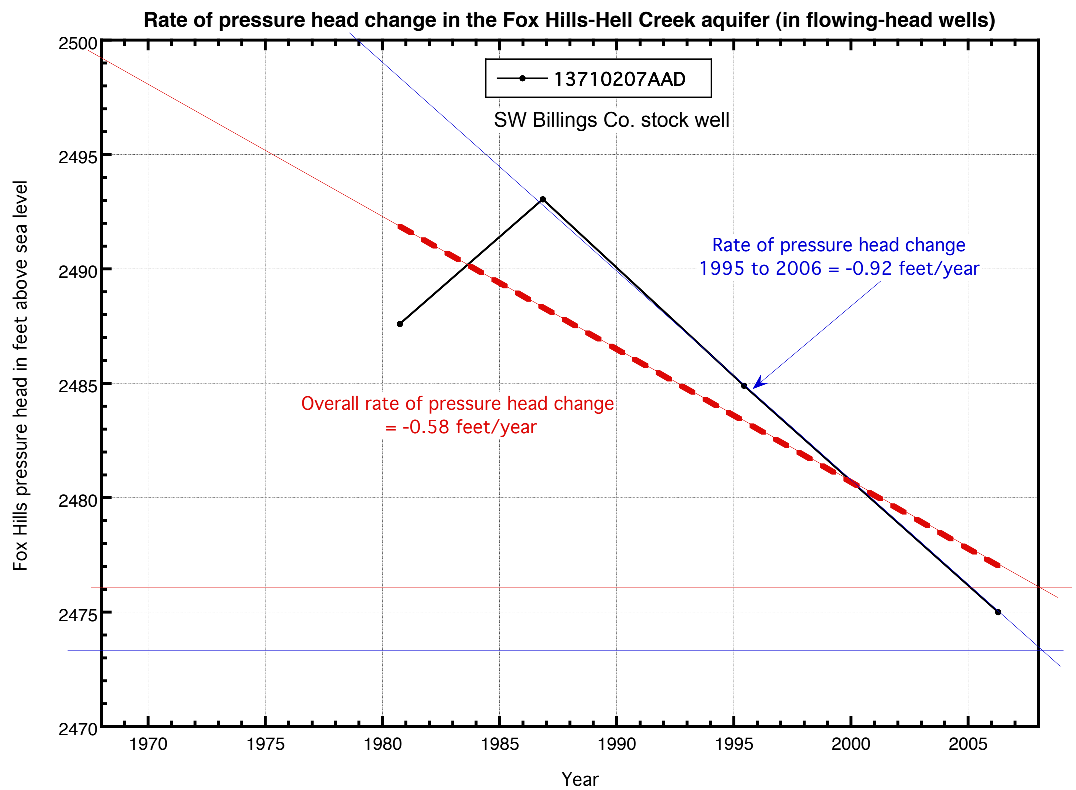

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13610221DBD
Amidon NW stock well
Rate of pressure head change 1995 to 2006 = -1.04 feet/year
Overall rate of pressure head change = -0.48 feet/year
Fox Hills pressure head in feet above sea level
Year
2550
2545
2540
2535
2530
2525
2520
1970
1975
1980
1985
1990
1995
2000
2005

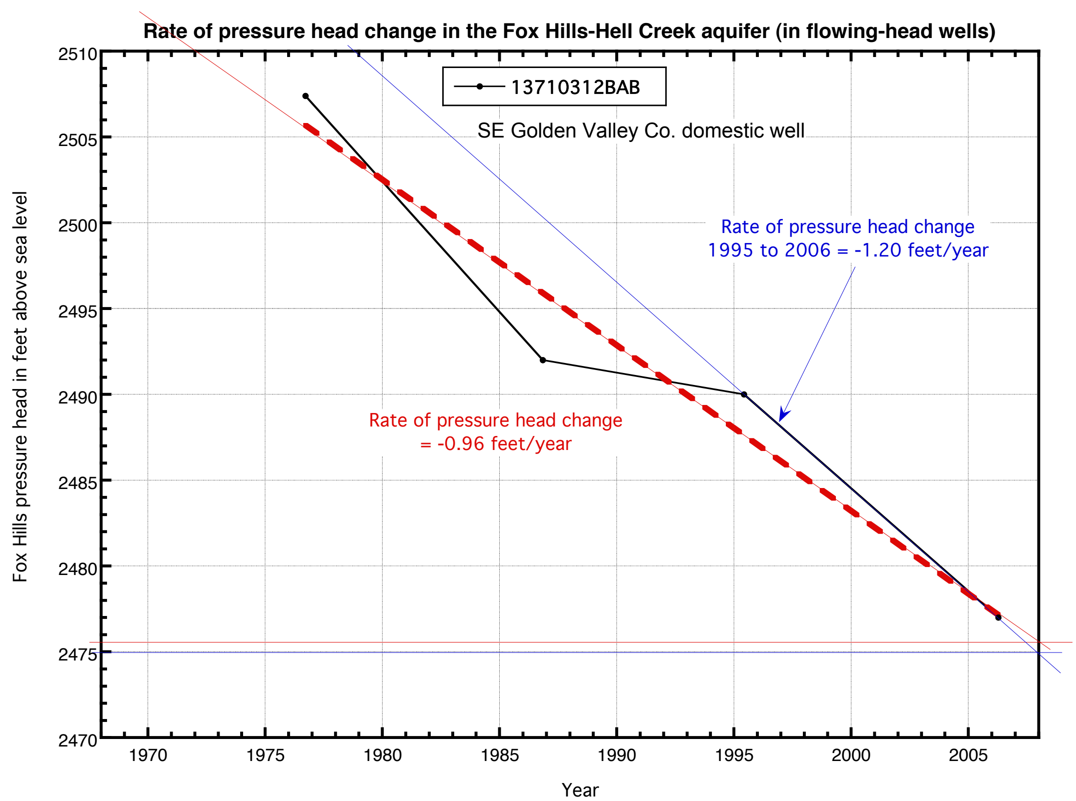

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13610314ADC
Another Amidon NW stock well
Rate of pressure head change
1995 to present = -0.62 feet/year
Overall rate of pressure head change
= -0.53 feet/year
Fox Hills pressure head in feet above sea level
2560
2555
2550
2545
2540
2535
2530
1970
1975
1980
1985
1990
1995
2000
2005
Year

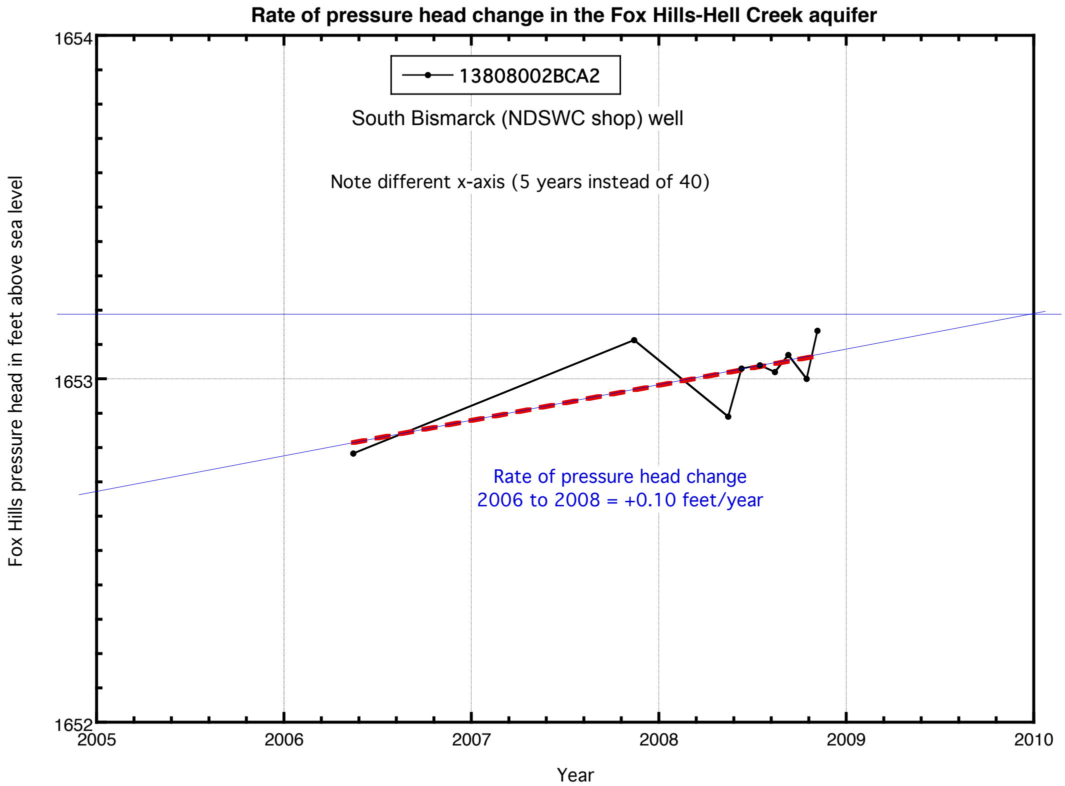

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13610324AAB
Another Amidon Northwest stock well
Overall rate of pressure head change
= -0.92 feet/year
Rate of pressure head change
1995 to 2006 = -0.51 feet/year
Fox Hills pressure head in feet above sea level
2530
2525
2520
2515
2510
2505
2500
2495
2490
2485
2480
1970
1975
1980
1985
1990
1995
2000
2005
Year

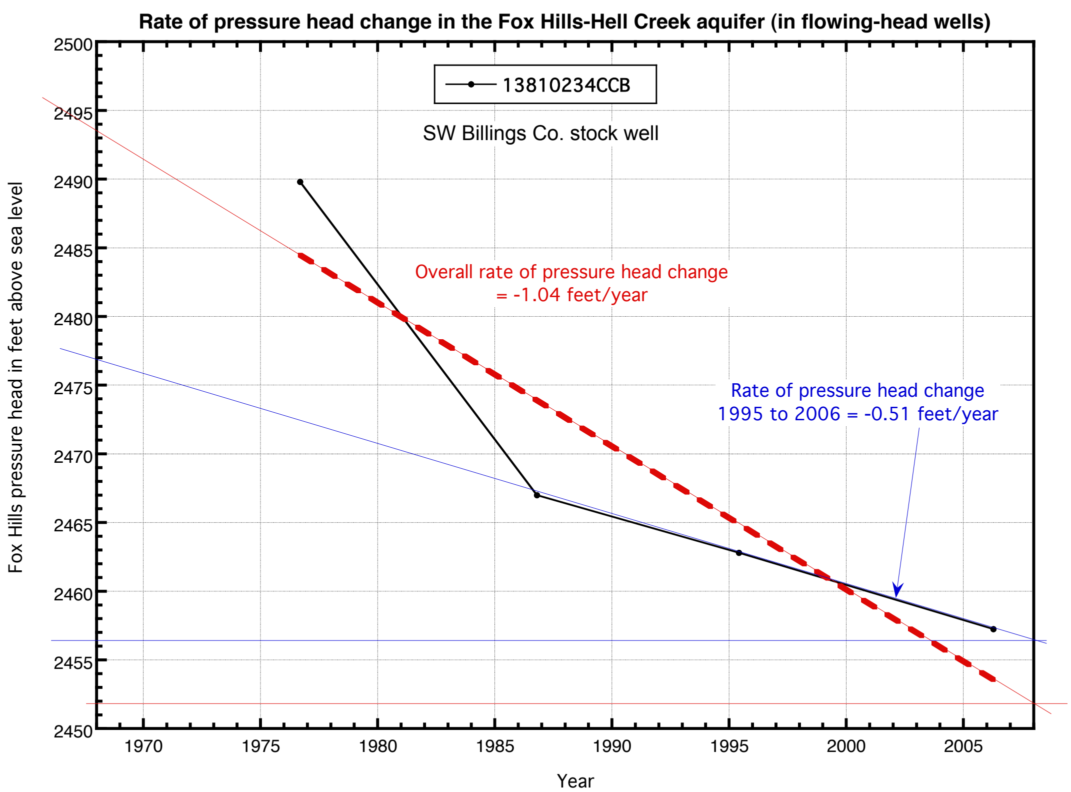

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13708821DDC
Lake Tschida area well
Rate of pressure head change
1972 - 1994 = -0.14 feet/year
Fox Hills pressure head in feet above sea level
Year
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1970
1975
1980
1985
1990
1995
2000
2005
2010

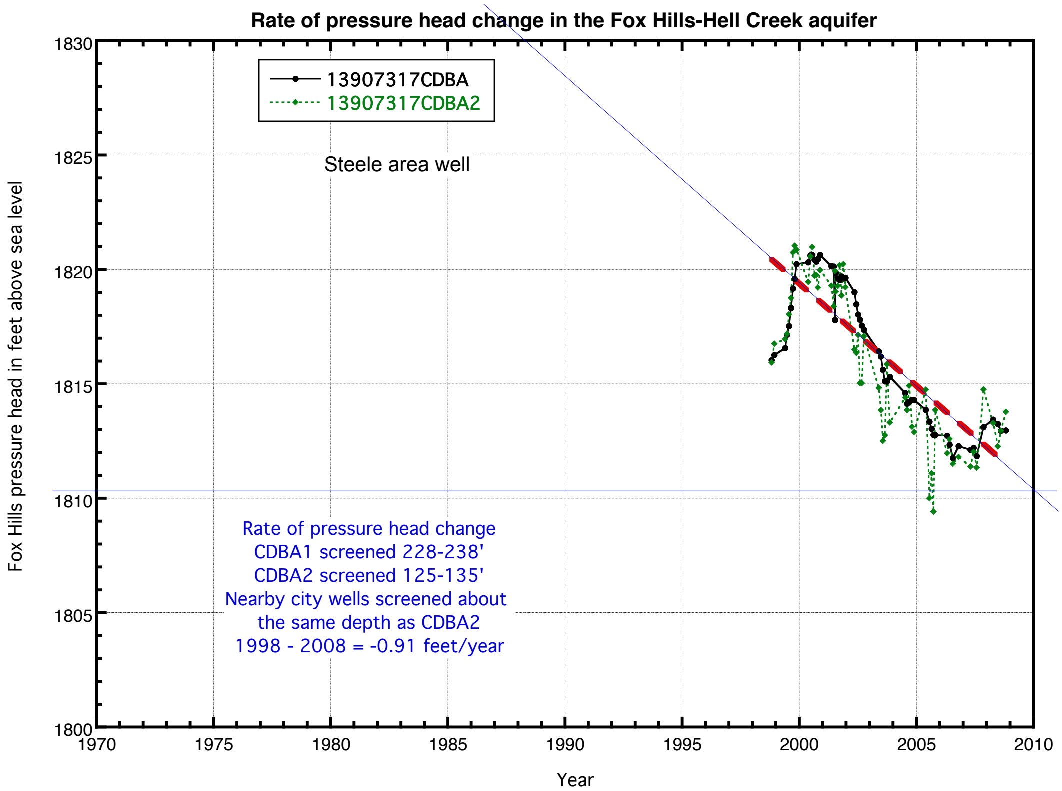

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13710206CAC
SW Billings Co. domestic well
Rate of pressure head change
1995 to 2006 = -1.79 feet/year
Overall rate of pressure head change
= -0.92 feet/year
Fox Hills pressure head in feet above sea level
Year
2470
2475
2480
2485
2490
2495
2500
2505
2510
1970
1975
1980
1985
1990
1995
2000
2005

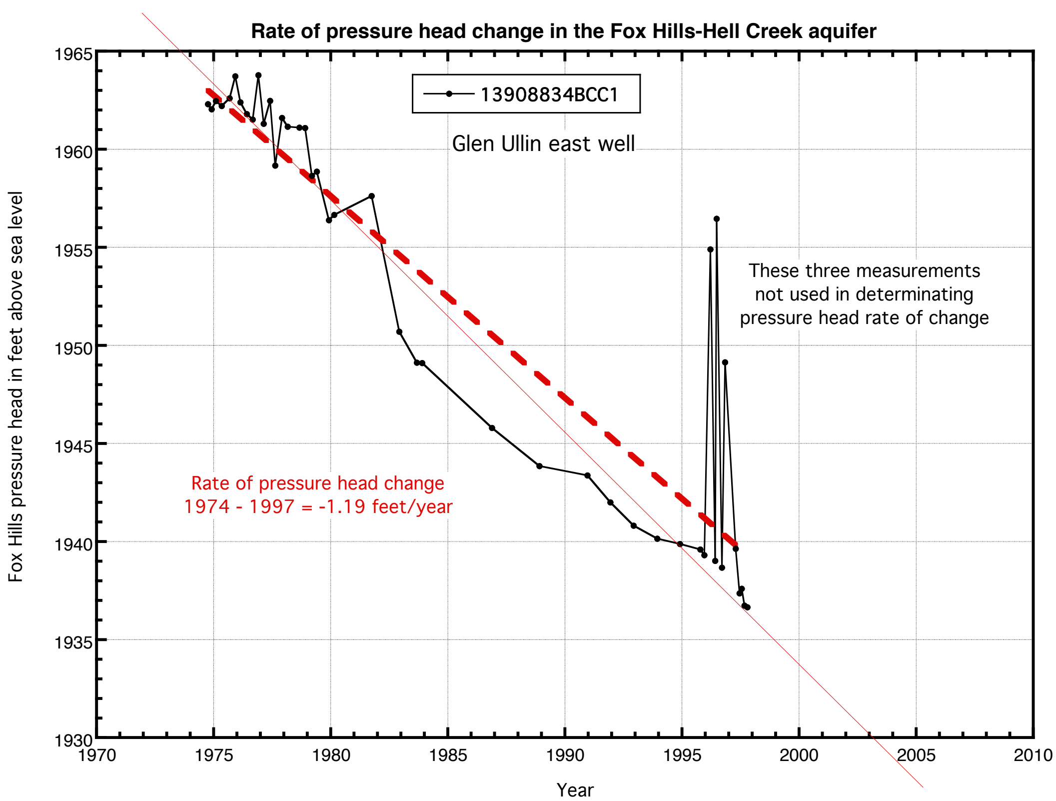

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13710207AAD
SW Billings Co. stock well
Rate of pressure head change
1995 to 2006 = -0.92 feet/year
Overall rate of pressure head change
= -0.58 feet/year
Fox Hills pressure head in feet above sea level
Year
2500
2495
2490
2485
2480
2475
2470
1970
1975
1980
1985
1990
1995
2000
2005

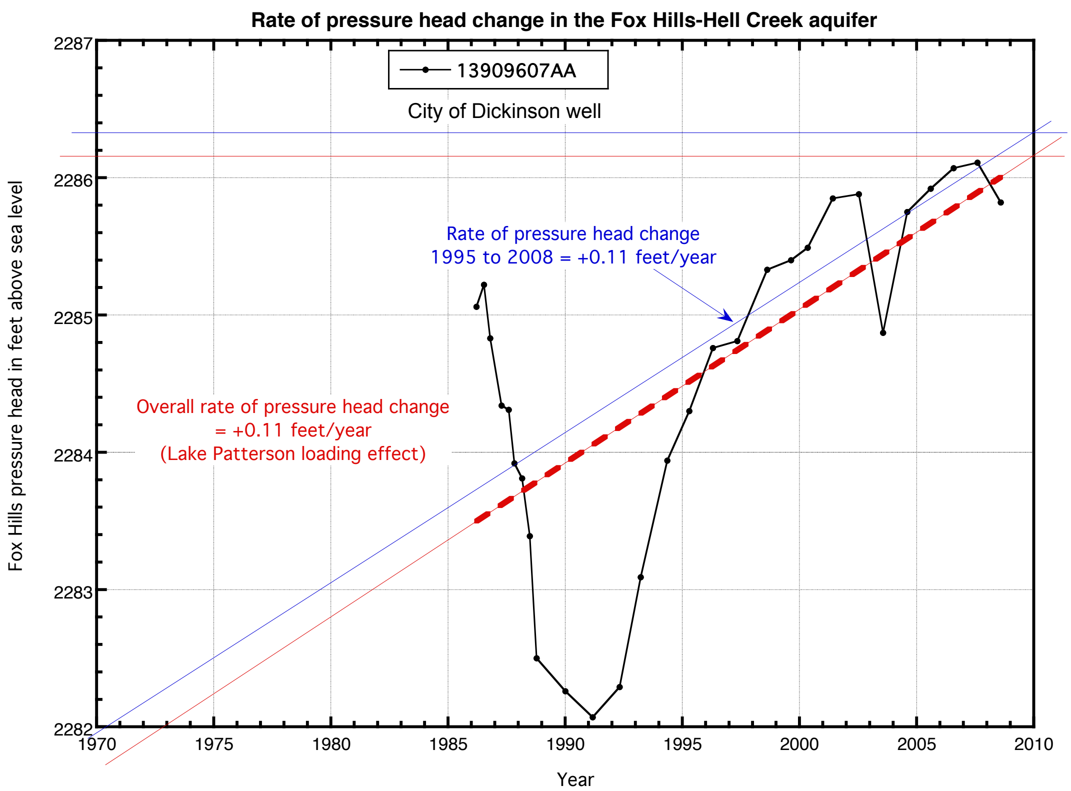

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13710312BAB
SE Golden Valley Co. domestic well
Rate of pressure head change
1995 to 2006 = -1.20 feet/year
Rate of pressure head change
= -0.96 feet/year
Fox Hills pressure head in feet above sea level
Year
2510
2505
2500
2495
2490
2485
2480
2475
2470
1970
1975
1980
1985
1990
1995
2000
2005

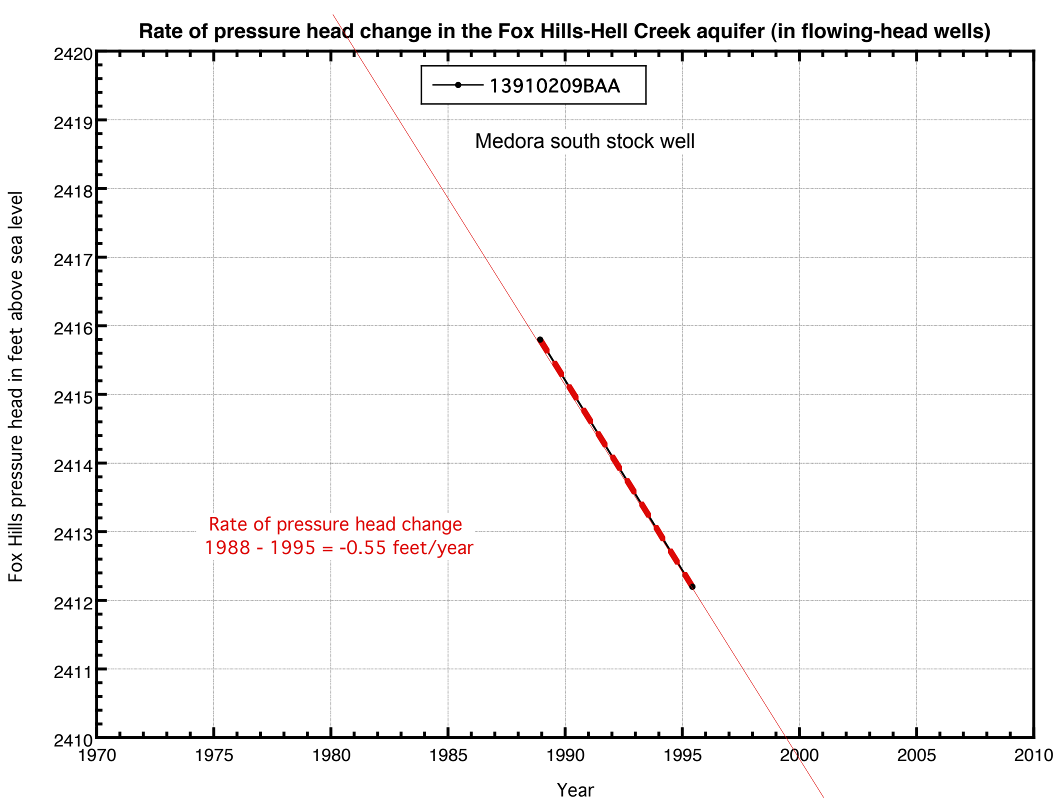

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13808002BCA2
South Bismarck (NDSWC shop) well
Note different x-axis (5 years instead of 40)
Rate of pressure head change
2006 to 2008 = +0.10 feet/year
Fox Hills pressure head in feet above sea level
Year
1654
1653
1652
2005
2006
2007
2008
2009
2010

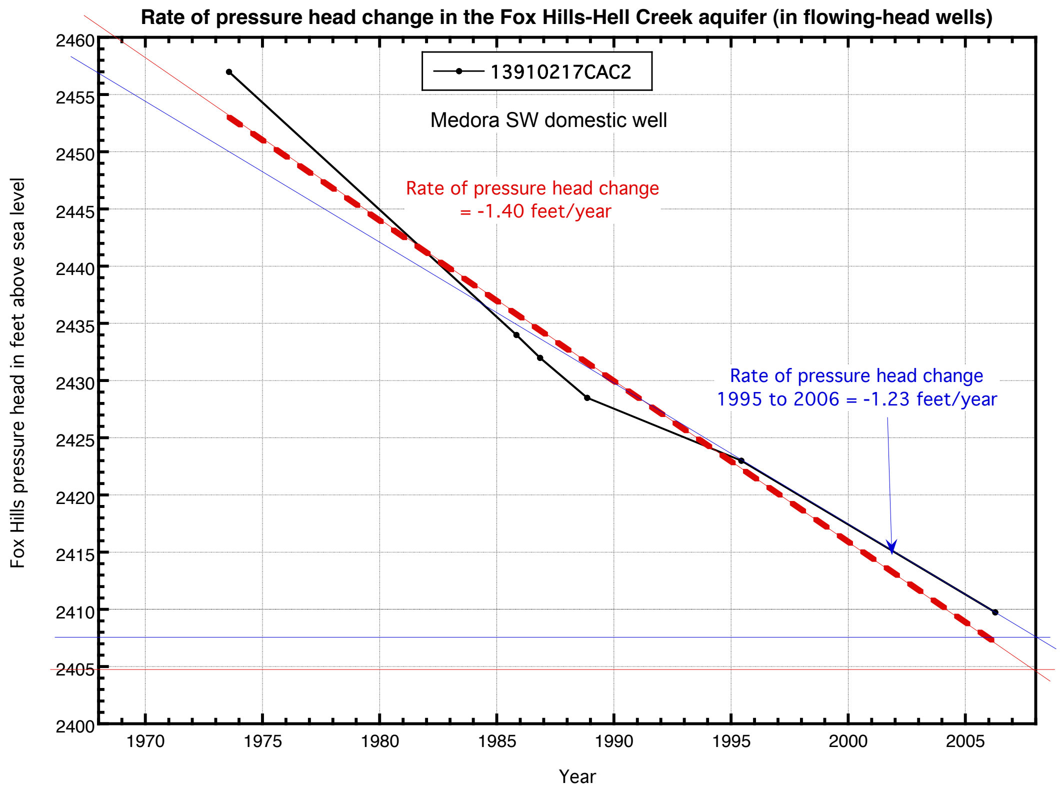

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13810234CCB
SW Billings Co. stock well
Overall rate of pressure head change
= -1.04 feet/year
Rate of pressure head change
1995 to 2006 = -0.51 feet/year
Fox Hills pressure head in feet above sea level
Year
2500
2495
2490
2485
2480
2475
2470
2465
2460
2455
2450
1970
1975
1980
1985
1990
1995
2000
2005

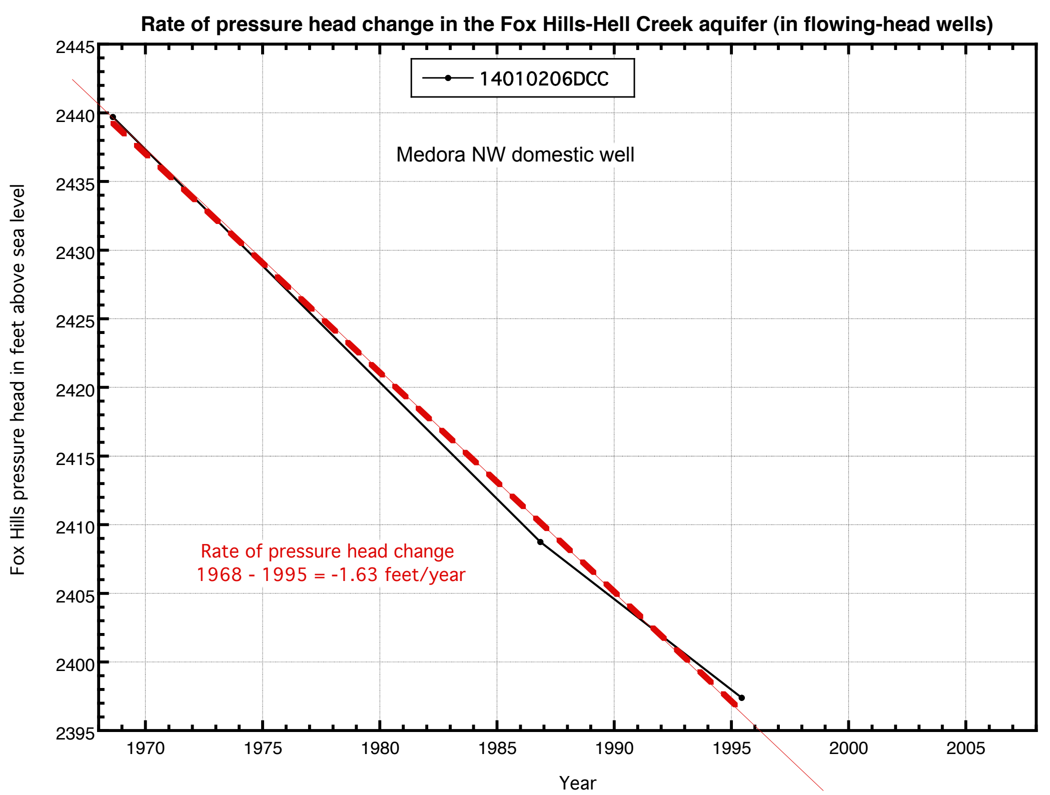

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13907317CDBA
13907317CDBA2
Steele area well
Rate of pressure head change
CDBA1 screened 228-238'
CDBA2 screened 125-135'
Nearby city wells screened about
the same depth as CDBA2
1998 - 2008 = -0.91 feet/year
Fox Hills pressure head in feet above sea level
Year
1800
1805
1810
1815
1820
1825
1830
1970
1975
1980
1985
1990
1995
2000
2005
2010

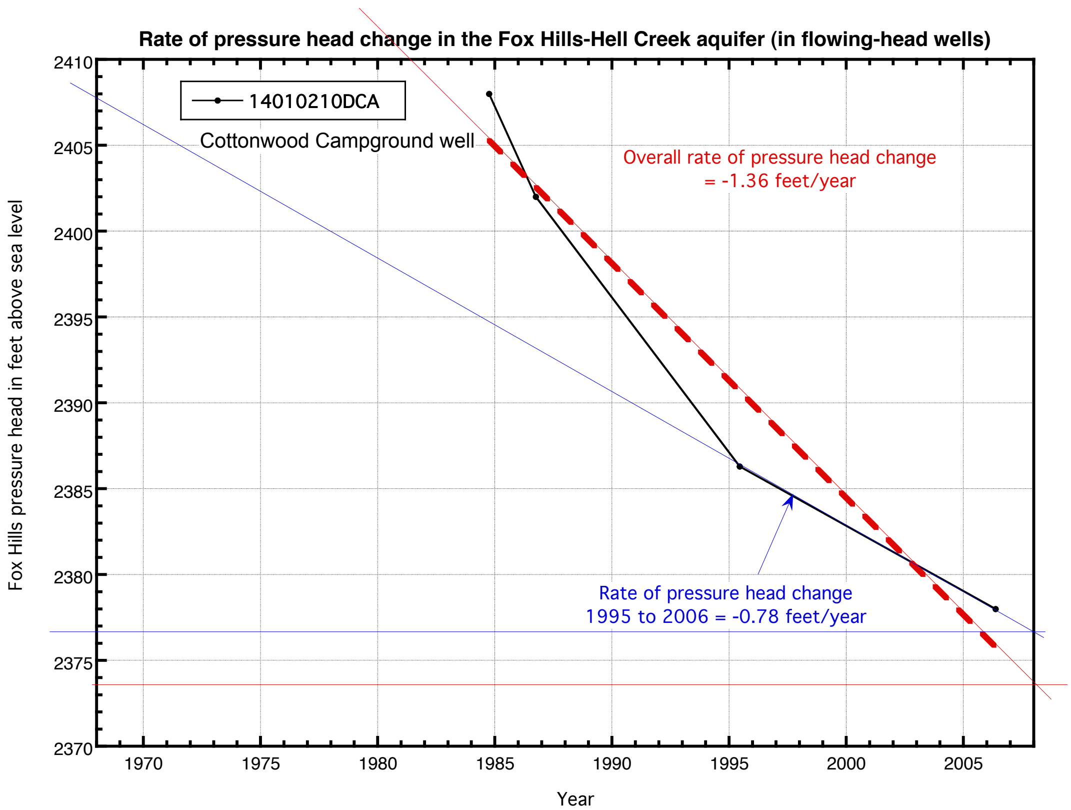

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13908834BCC1
Glen Ullin east well
These three measurements
not used in determinating
pressure head rate of change
Rate of pressure head change
1974 - 1997 = -1.19 feet/year
Fox Hills pressure head in feet above sea level
Year
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
13909607AA
City of Dickinson well
Rate of pressure head change
1995 to 2008 = +0.11 feet/year
Overall rate of pressure head change
= +0.11 feet/year
(Lake Patterson loading effect)
Fox Hills pressure head in feet above sea level
2287
2286
2285
2284
2283
2282
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year

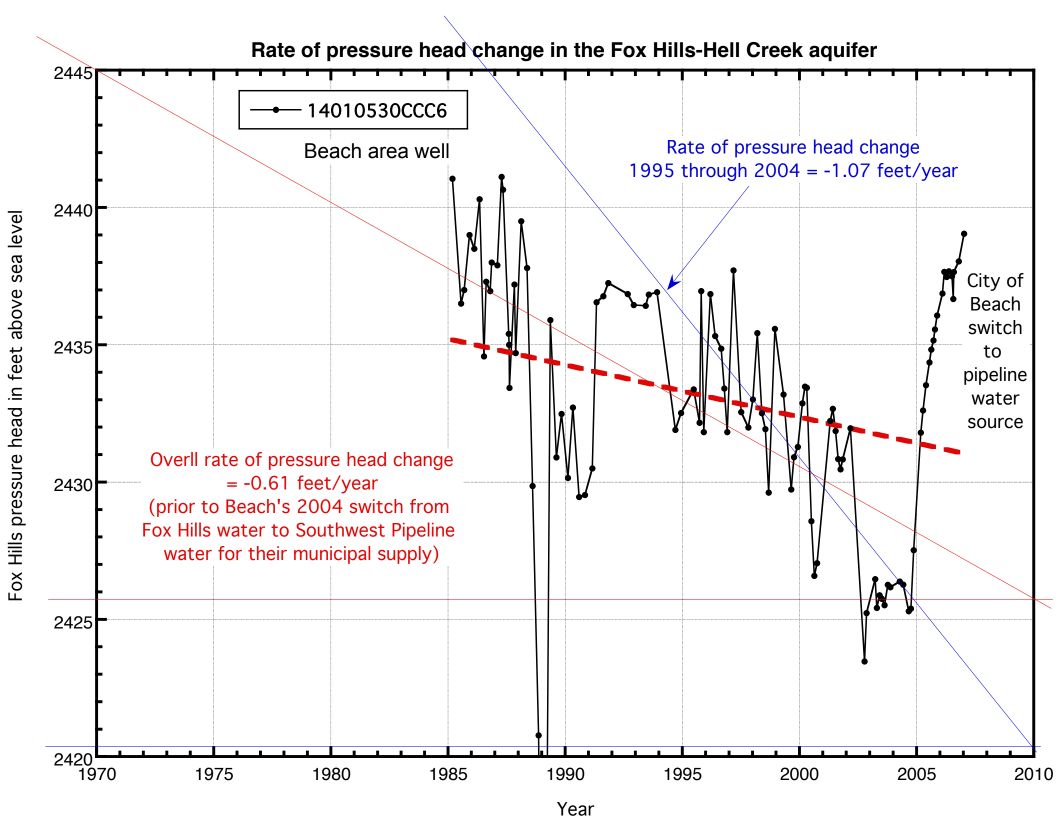

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13910209BAA
Medora south stock well
Rate of pressure head change
1988 - 1995 = -0.55 feet/year
Fox Hills pressure head in feet above sea level
2420
2419
2418
2417
2416
2415
2414
2413
2412
2411
2410
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year


Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
13910217CAC2
Medora SW domestic well
Rate of pressure head change
= -1.40 feet/year
Rate of pressure head change
1995 to 2006 = -1.23 feet/year
Fox Hills pressure head in feet above sea level
Year
2460
2455
2450
2445
2440
2435
2430
2425
2420
2415
2410
2405
2400
1970
1975
1980
1985
1990
1995
2000
2005

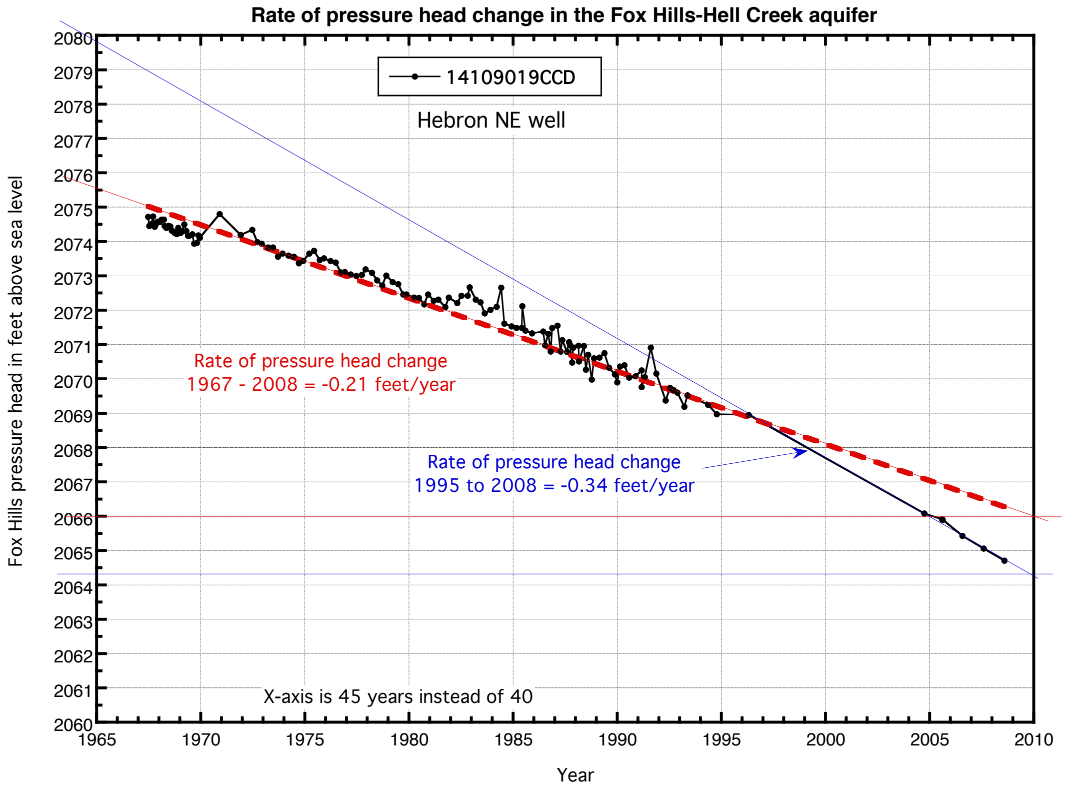

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14010206DCC
Medora NW domestic well
Rate of pressure head change
1968 - 1995 = -1.63 feet/year
Fox Hills pressure head in feet above sea level
Year
2445
2440
2435
2430
2425
2420
2415
2410
2405
2400
2395
1970
1975
1980
1985
1990
1995
2000
2005

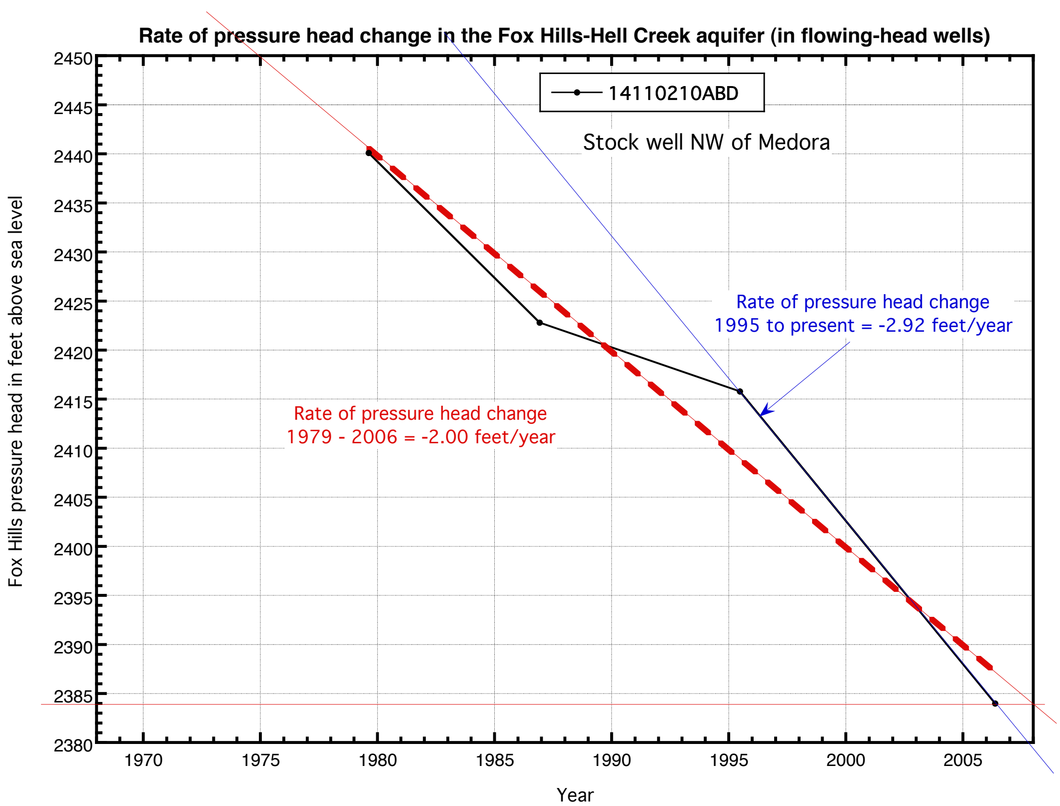


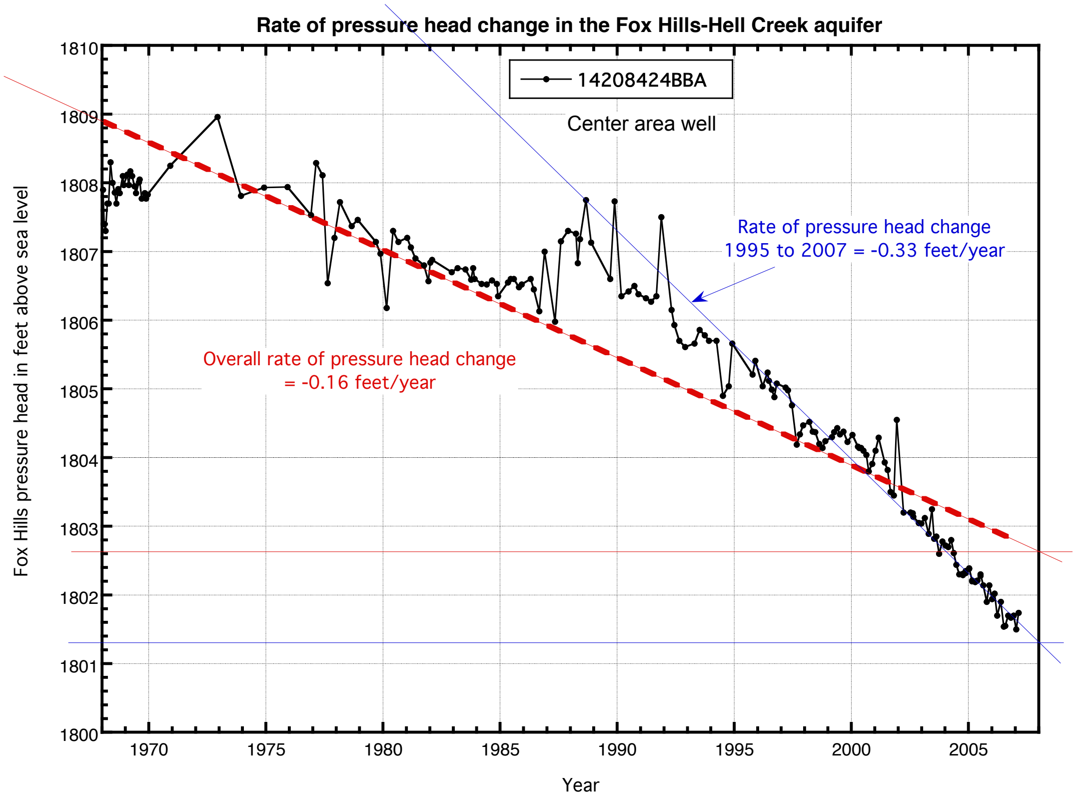
Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14010210DCA
Cottonwood Campground well
Overall rate of pressure head change
= -1.36 feet/year
Rate of pressure head change
1995 to 2006 = -0.78 feet/year
Fox Hills pressure head in feet above sea level
Year
2410
2405
2400
2395
2390
2385
2380
2375
2370
1970
1975
1980
1985
1990
1995
2000
2005

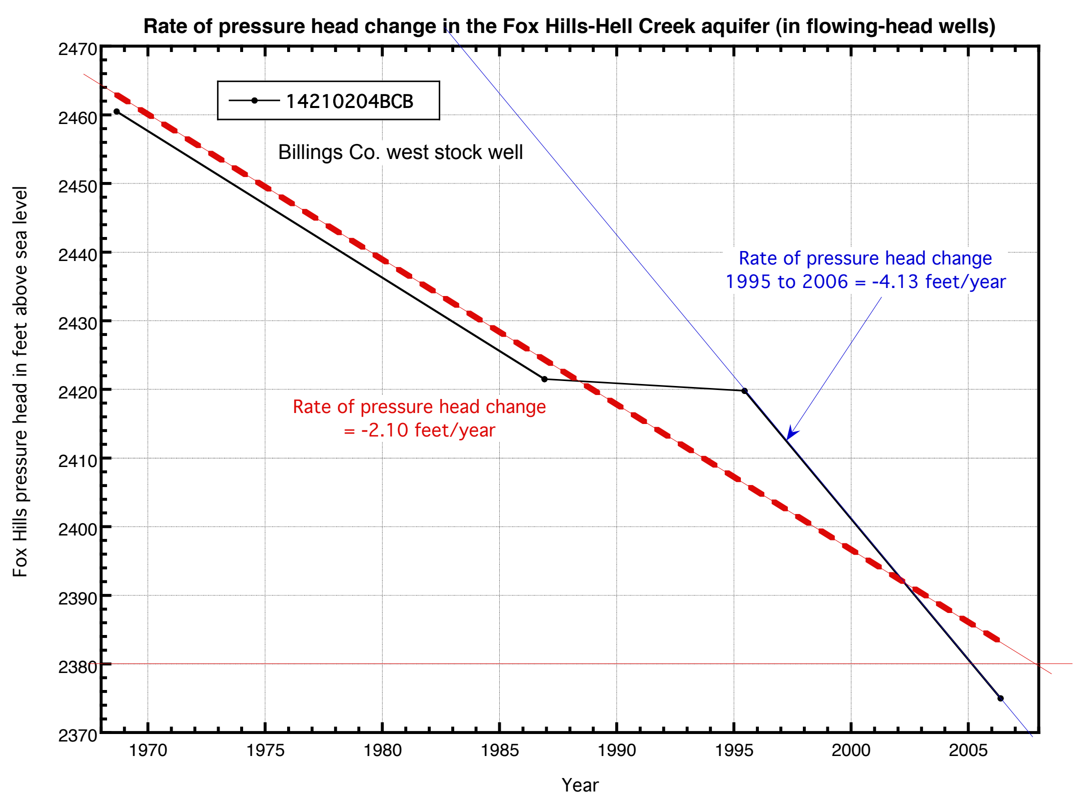


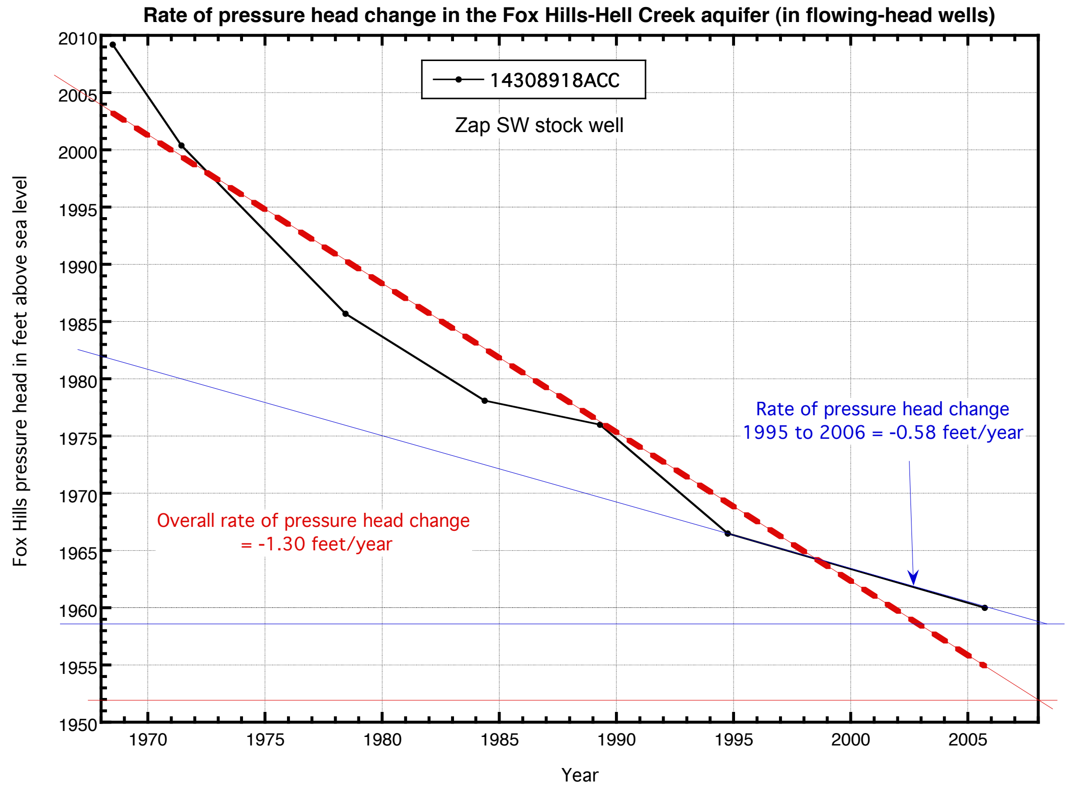
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14010530CCC6
Beach area well
Rate of pressure head change
1995 through 2004 = -1.07 feet/year
City of
Beach
switch
to
pipeline
water
source
Overll rate of pressure head change
= -0.61 feet/year
(prior to Beach's 2004 switch from
Fox Hills water to Southwest Pipeline
water for their municipal supply)
Fox Hills pressure head in feet above sea level
Year
2445
2440
2435
2430
2425
2420
1970
1975
1980
1985
1990
1995
2000
2005
2010

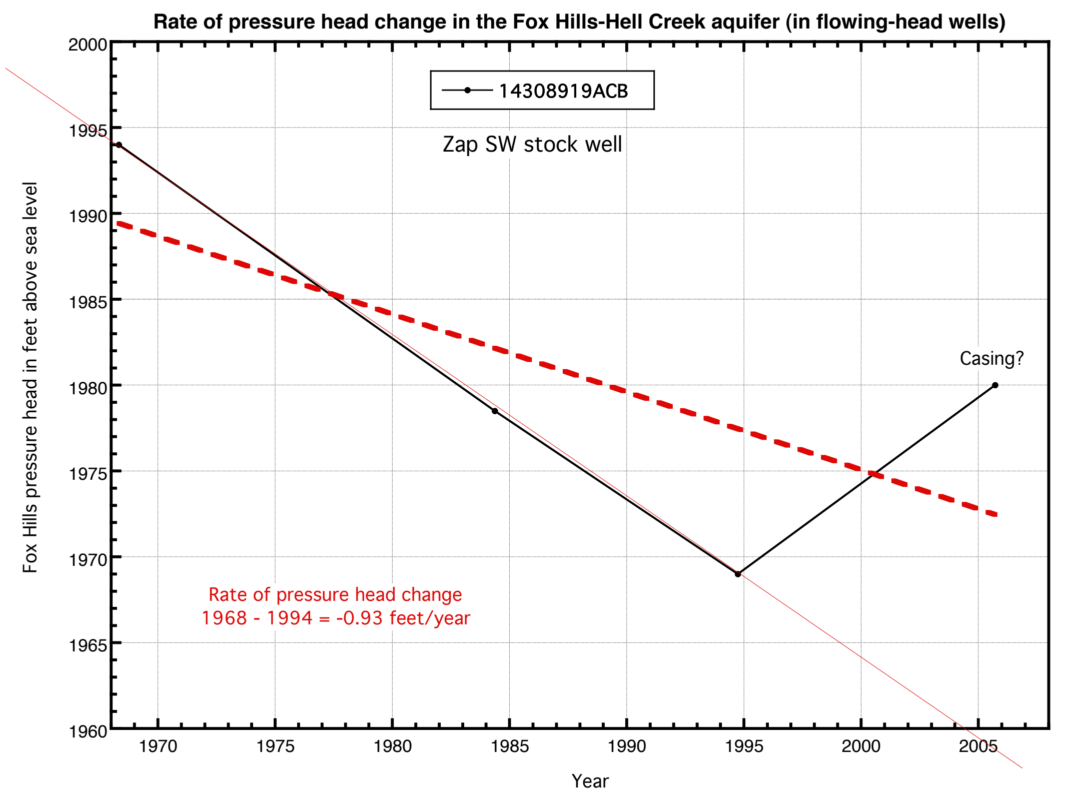

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14109019CCD
Hebron NE well
Rate of pressure head change
1967 - 2008 = -0.21 feet/year
Rate of pressure head change
1995 to 2008 = -0.34 feet/year
X-axis is 45 years instead of 40
Fox Hills pressure head in feet above sea level
Year

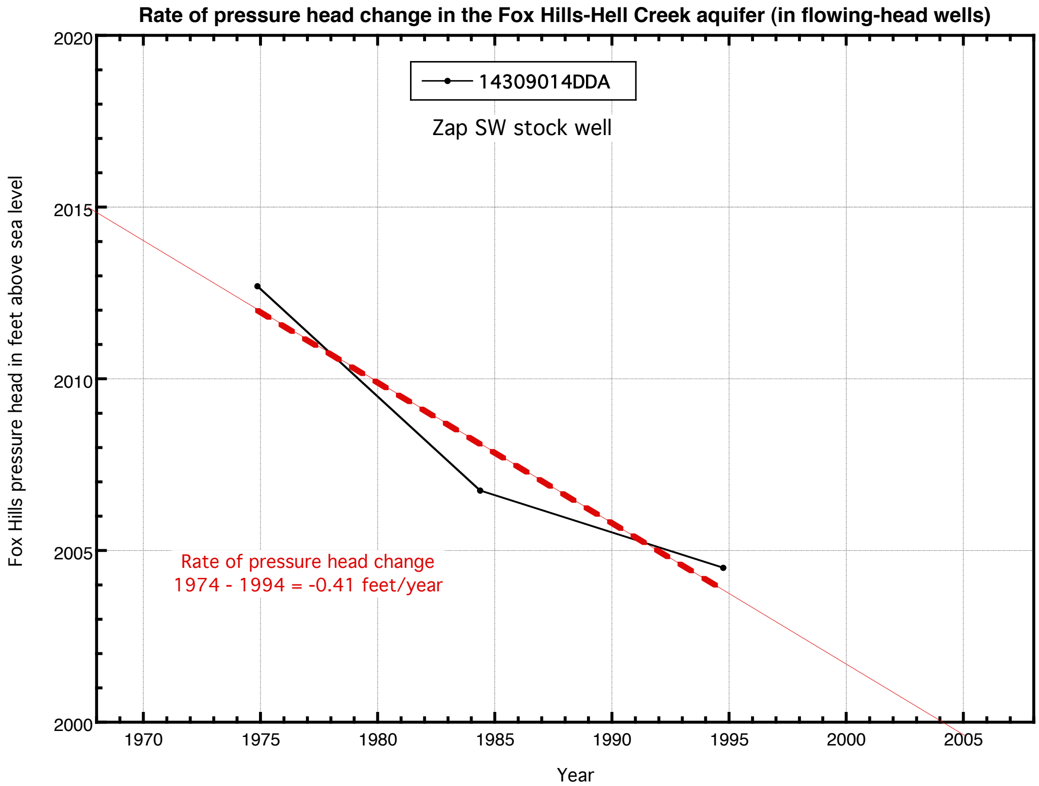

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14110210ABD
Stock well NW of Medora
Rate of pressure head change
1995 to present = -2.92 feet/year
Rate of pressure head change
1979 - 2006 = -2.00 feet/year
Fox Hills pressure head in feet above sea level
Year

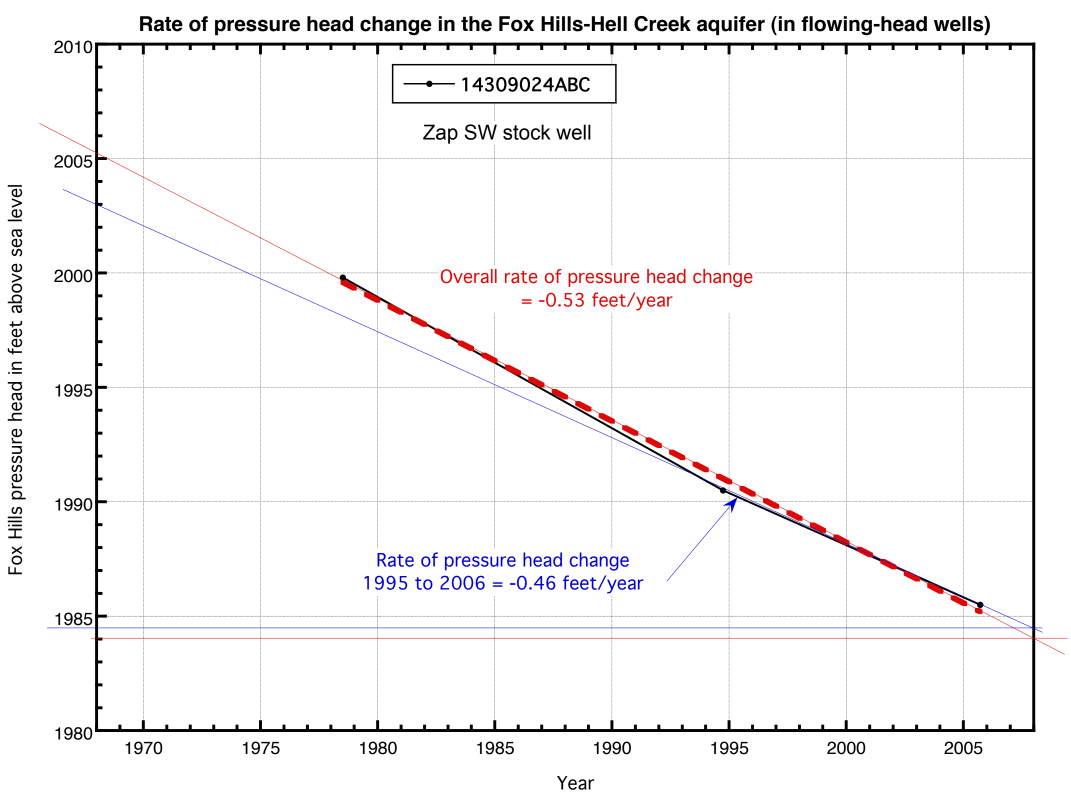

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14208424BBA
Center area well
Rate of pressure head change
1995 to 2007 = -0.33 feet/year
Overall rate of pressure head change
= -0.16 feet/year
Fox Hills pressure head in feet above sea level
Year
1810
1809
1808
1807
1806
1805
1804
1803
1802
1801
1800
1970
1975
1980
1985
1990
1995
2000
2005

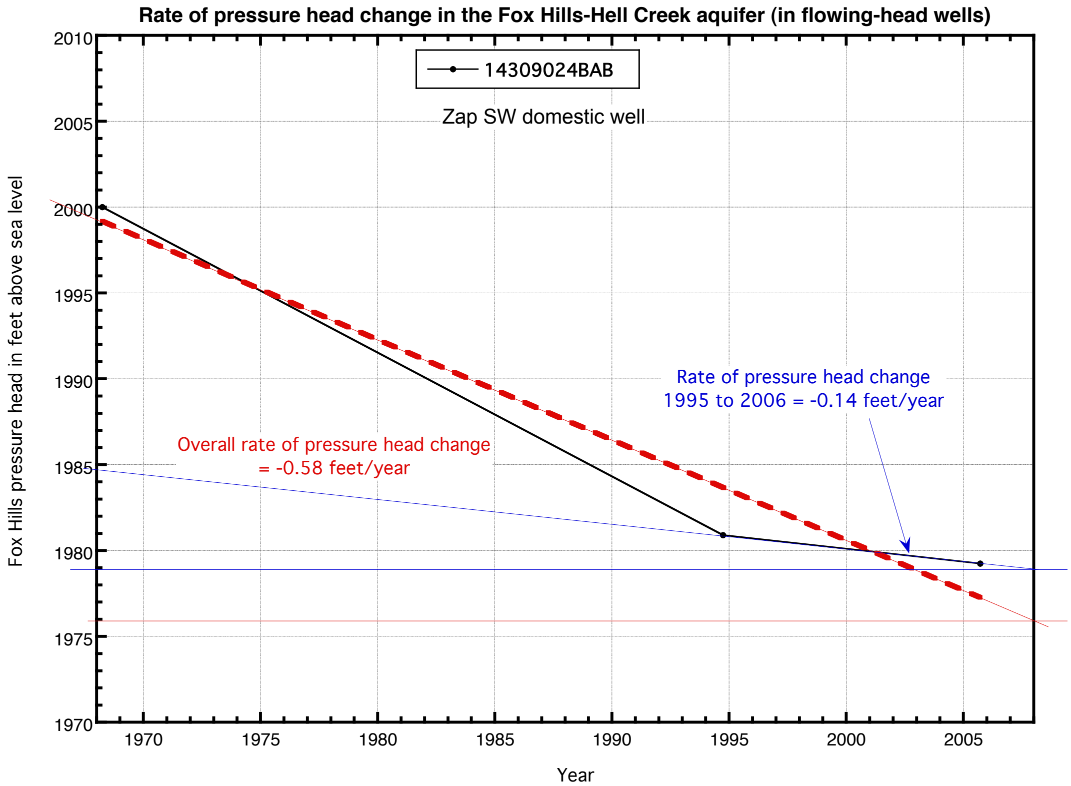

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14210204BCB
Billings Co. west stock well
Rate of pressure head change
1995 to 2006 = -4.13 feet/year
Rate of pressure head change
= -2.10 feet/year
Fox Hills pressure head in feet above sea level
Year
2470
2460
2450
2440
2430
2420
2410
2400
2390
2380
2370
1970
1975
1980
1985
1990
1995
2000
2005

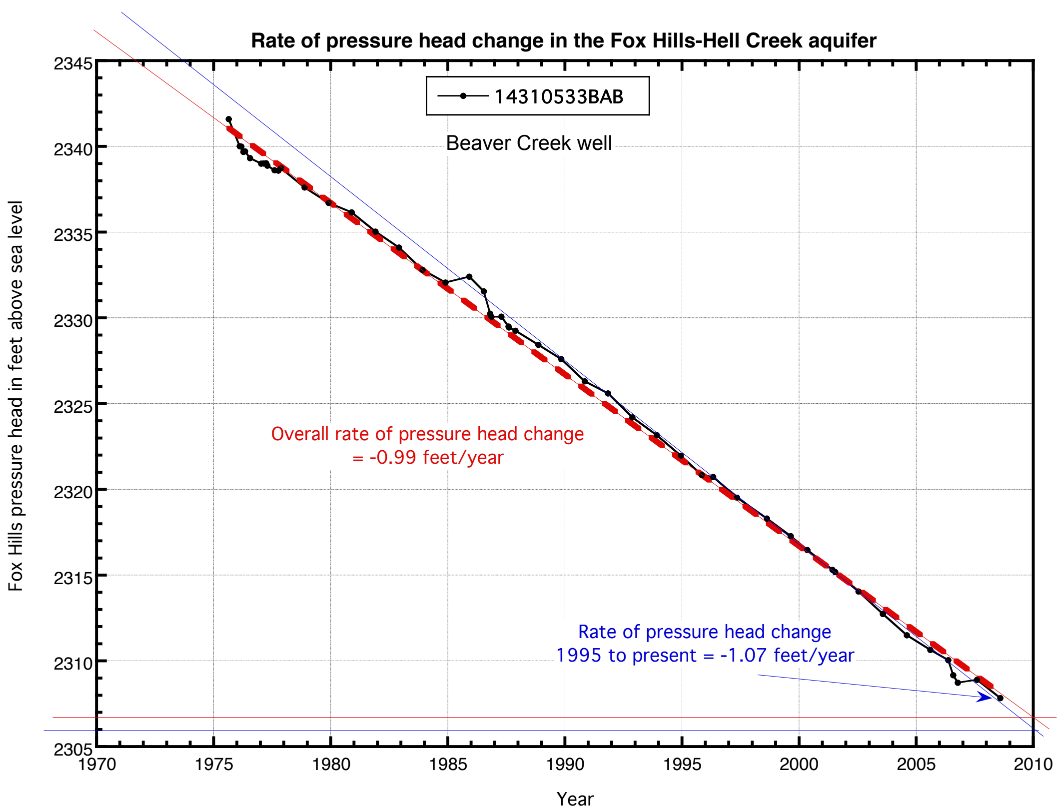

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14308918ACC
Zap SW stock well
Rate of pressure head change
1995 to 2006 = -0.58 feet/year
Overall rate of pressure head change
= -1.30 feet/year
Fox Hills pressure head in feet above sea level
Year
2010
2005
2000
1995
1990
1985
1980
1975
1970
1965
1960
1955
1950
1970
1975
1980
1985
1990
1995
2000
2005

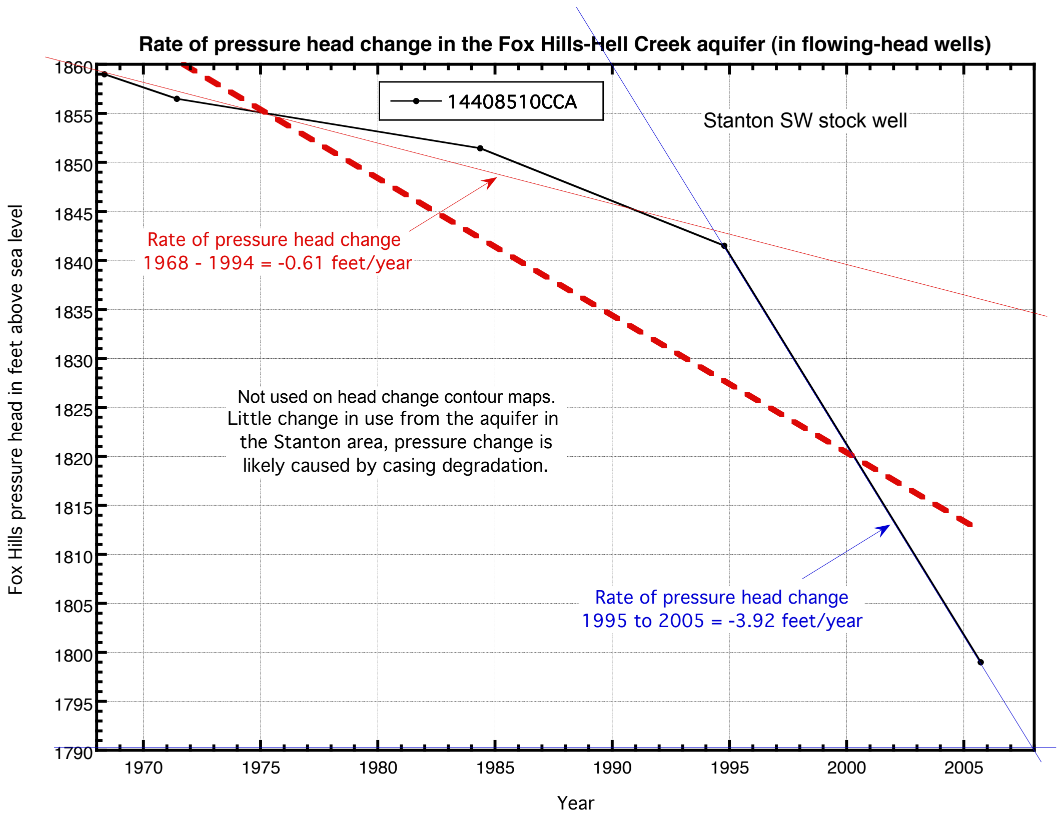

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14308919ACB
Zap SW stock well
Casing?
Rate of pressure head change
1968 - 1994 = -0.93 feet/year
Fox Hills pressure head in feet above sea level
Year
2000
1995
1990
1985
1980
1975
1970
1965
1960
1970
1975
1980
1985
1990
1995
2000
2005

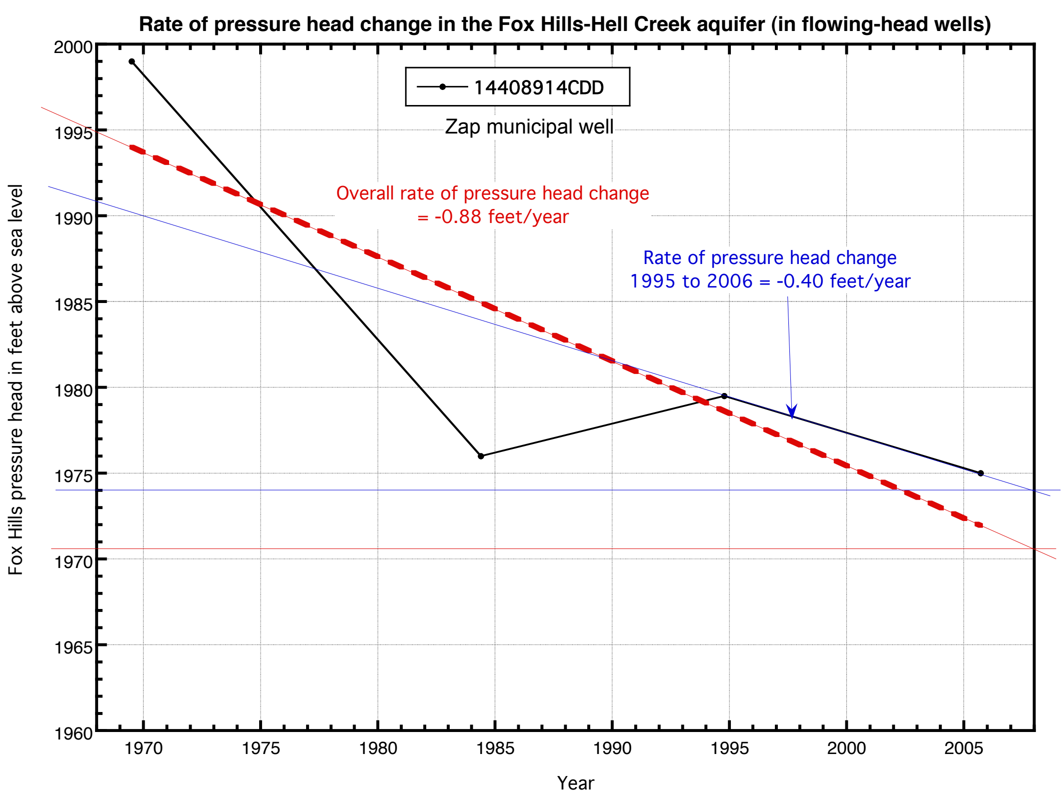

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14309014DDA
Zap SW stock well
Rate of pressure head change
1974 - 1994 = -0.41 feet/year
Fox Hills pressure head in feet above sea level
Year
2020
2015
2010
2005
2000
1970
1975
1980
1985
1990
1995
2000
2005

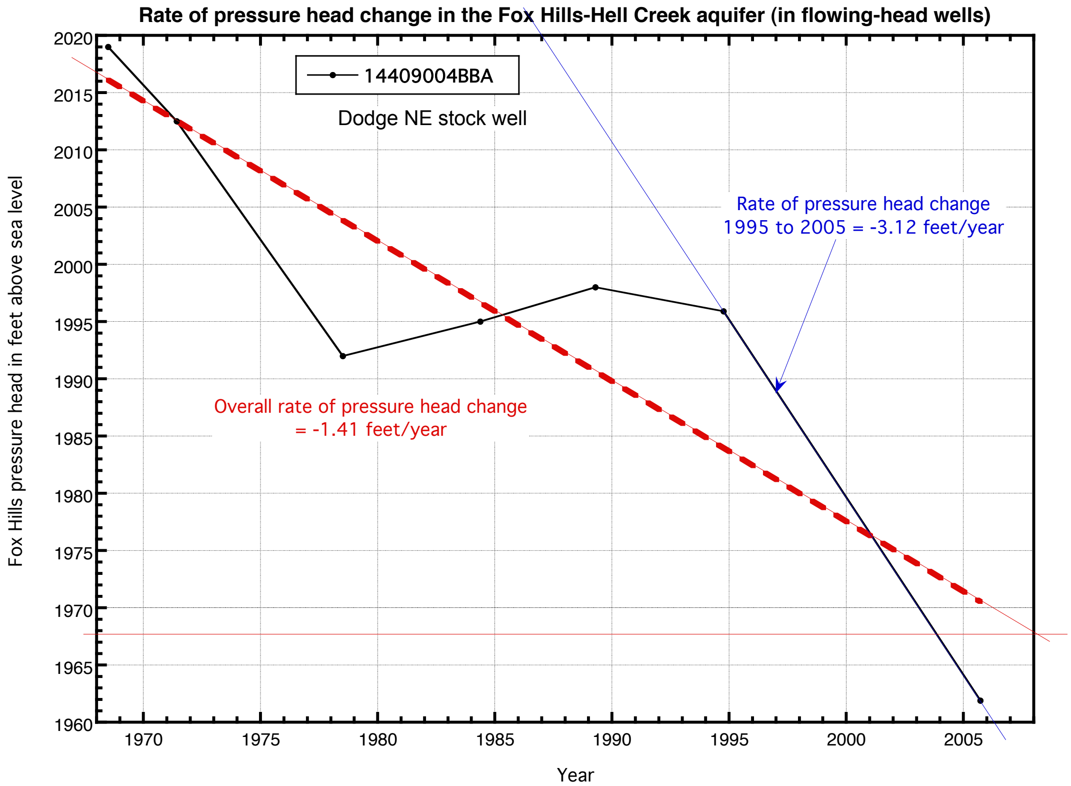

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14309024ABC
Zap SW stock well
Overall rate of pressure head change
= -0.53 feet/year
Rate of pressure head change
1995 to 2006 = -0.46 feet/year
Fox Hills pressure head in feet above sea level
Year
2010
2005
2000
1995
1990
1985
1980
1970
1975
1980
1985
1990
1995
2000
2005

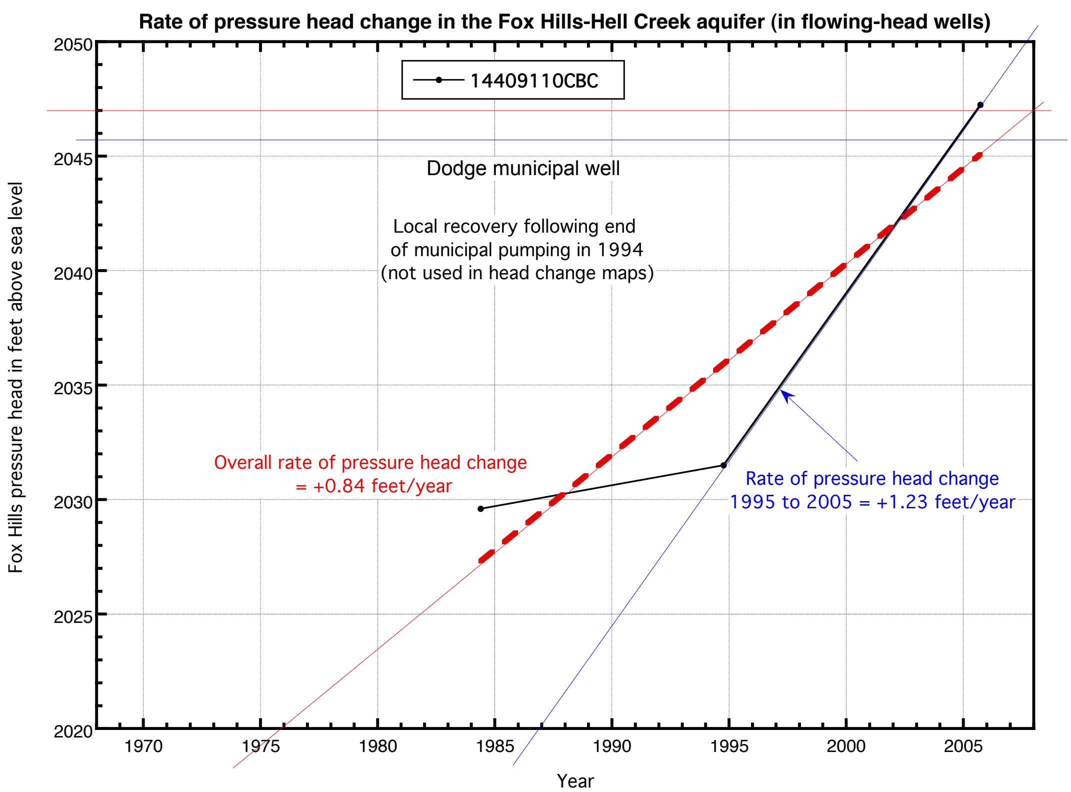

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14309024BAB
Zap SW domestic well
Rate of pressure head change
1995 to 2006 = -0.14 feet/year
Overall rate of pressure head change
= -0.58 feet/year
Fox Hills pressure head in feet above sea level
Year
2010
2005
2000
1995
1990
1985
1980
1975
1970
1970
1975
1980
1985
1990
1995
2000
2005

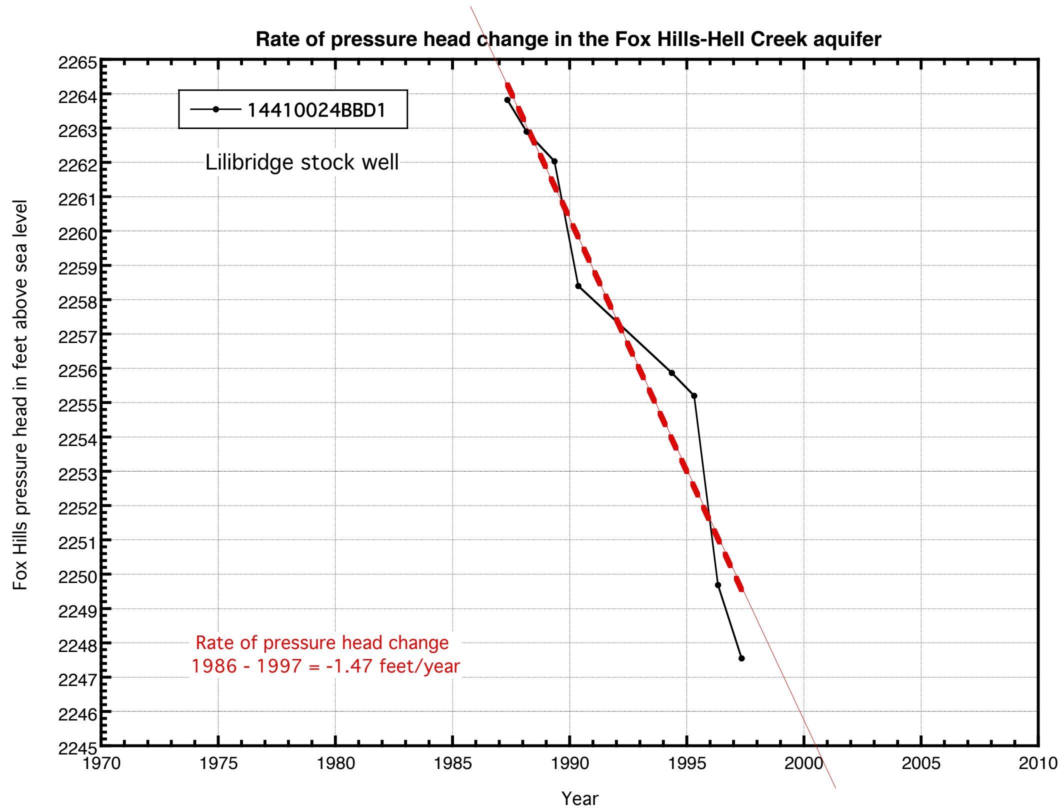

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14310533BAB
Beaver Creek well
Overall rate of pressure head change
= -0.99 feet/year
Rate of pressure head change
1995 to present = -1.07 feet/year
Fox Hills pressure head in feet above sea level
Year
2345
2340
2335
2330
2325
2320
2315
2310
2305
1970
1975
1980
1985
1990
1995
2000
2005
2010

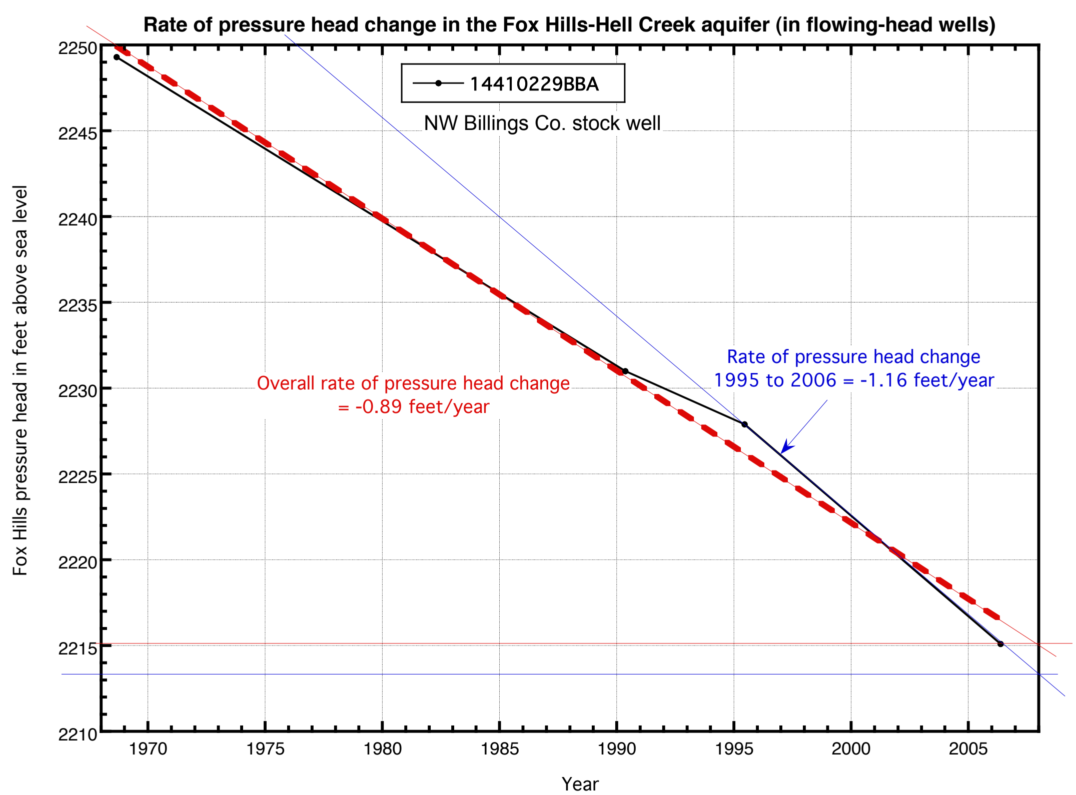

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14408510CCA
Stanton SW stock well
Rate of pressure head change
1968 - 1994 = -0.61 feet/year
Not used on head change contour maps.
Little change in use from the aquifer in
the Stanton area, pressure change is
likely caused by casing degradation.
Rate of pressure head change
1995 to 2005 = -3.92 feet/year
Fox Hills pressure head in feet above sea level
Year

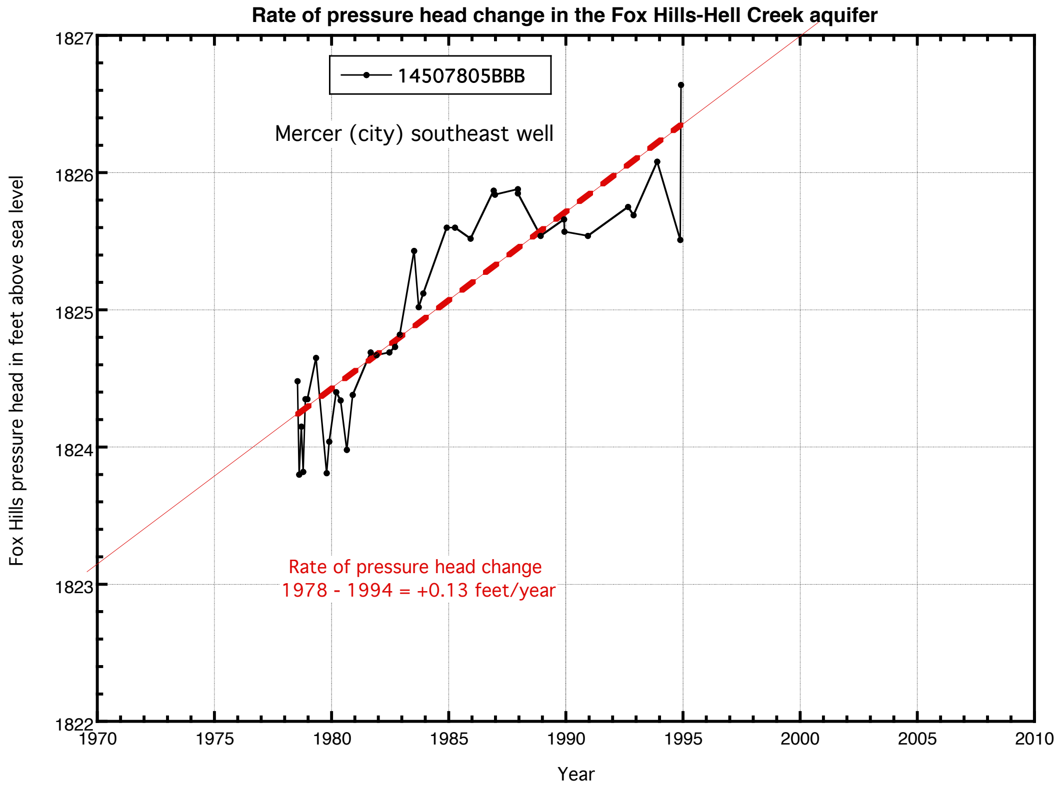

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14408914CDD
Zap municipal well
Overall rate of pressure head change
= -0.88 feet/year
Rate of pressure head change
1995 to 2006 = -0.40 feet/year
Fox Hills pressure head in feet above sea level
Year

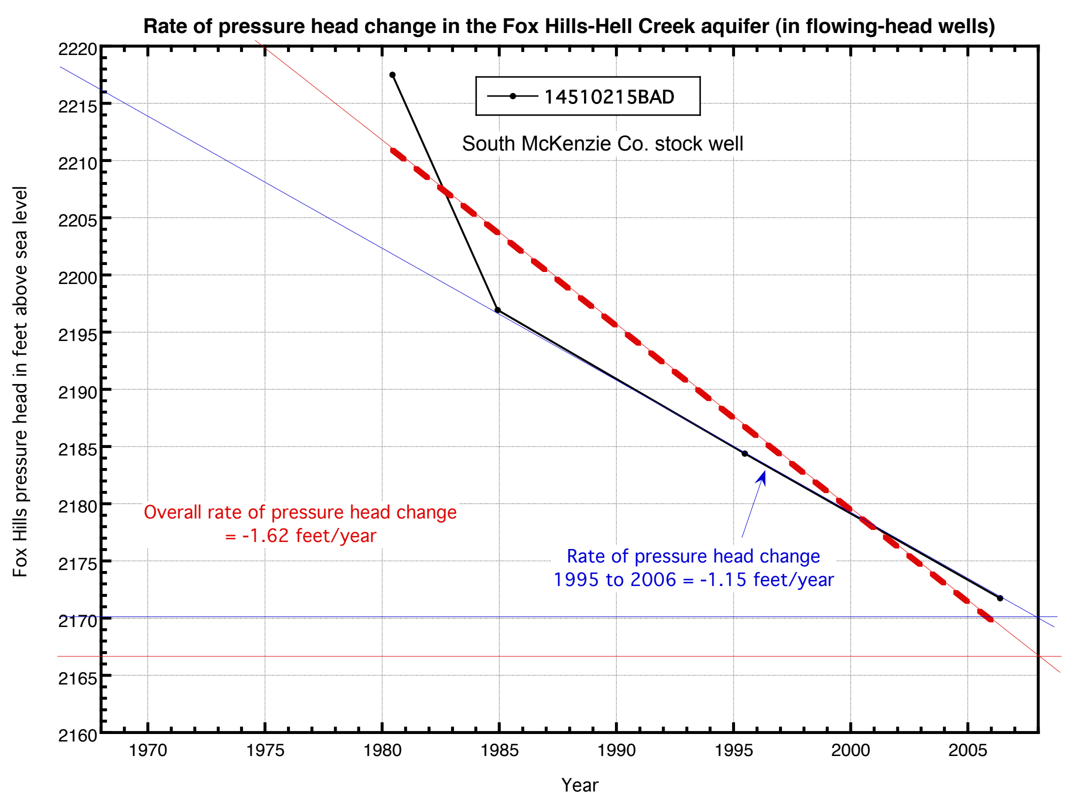

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14409004BBA
Dodge NE stock well
Rate of pressure head change
1995 to 2005 = -3.12 feet/year
Overall rate of pressure head change
= -1.41 feet/year
Fox Hills pressure head in feet above sea level
Year
2020
2015
2010
2005
2000
1995
1990
1985
1980
1975
1970
1965
1960
1970
1975
1980
1985
1990
1995
2000
2005

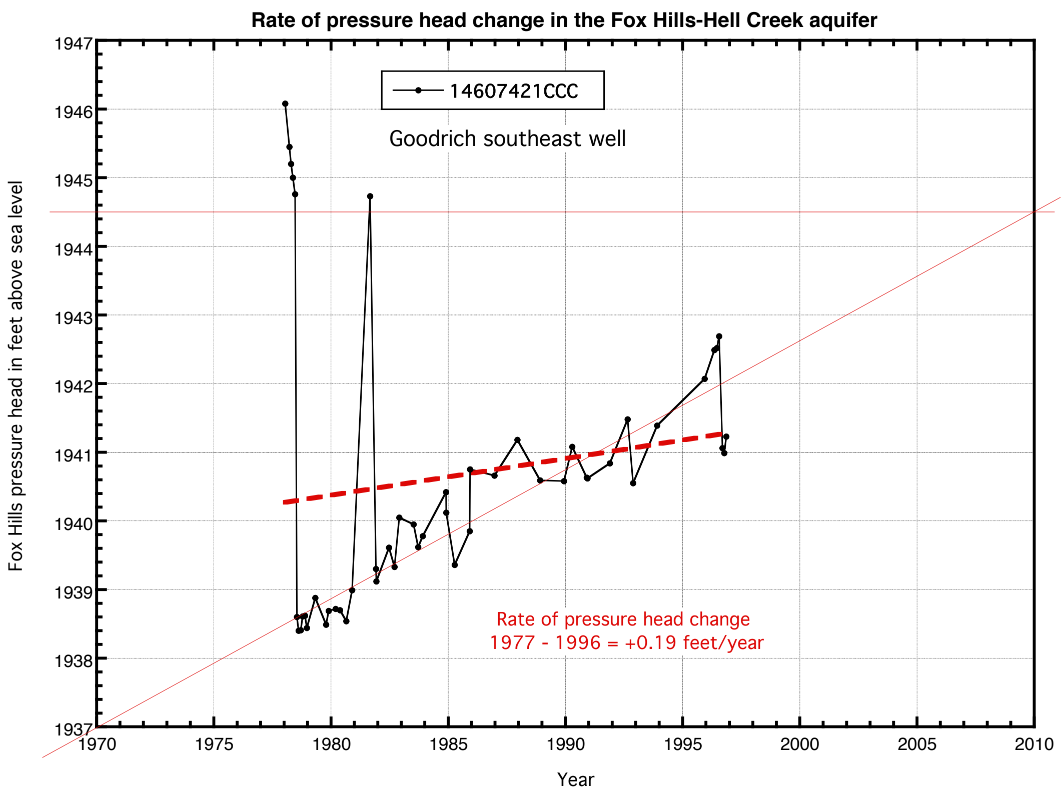

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14409110CBC
Dodge municipal well
Local recovery following end
of municipal pumping in 1994
(not used in head change maps)
Overall rate of pressure head change
= +0.84 feet/year
Rate of pressure head change
1995 to 2005 = +1.23 feet/year
Fox Hills pressure head in feet above sea level
Year
2050
2045
2040
2035
2030
2025
2020
1970
1975
1980
1985
1990
1995
2000
2005

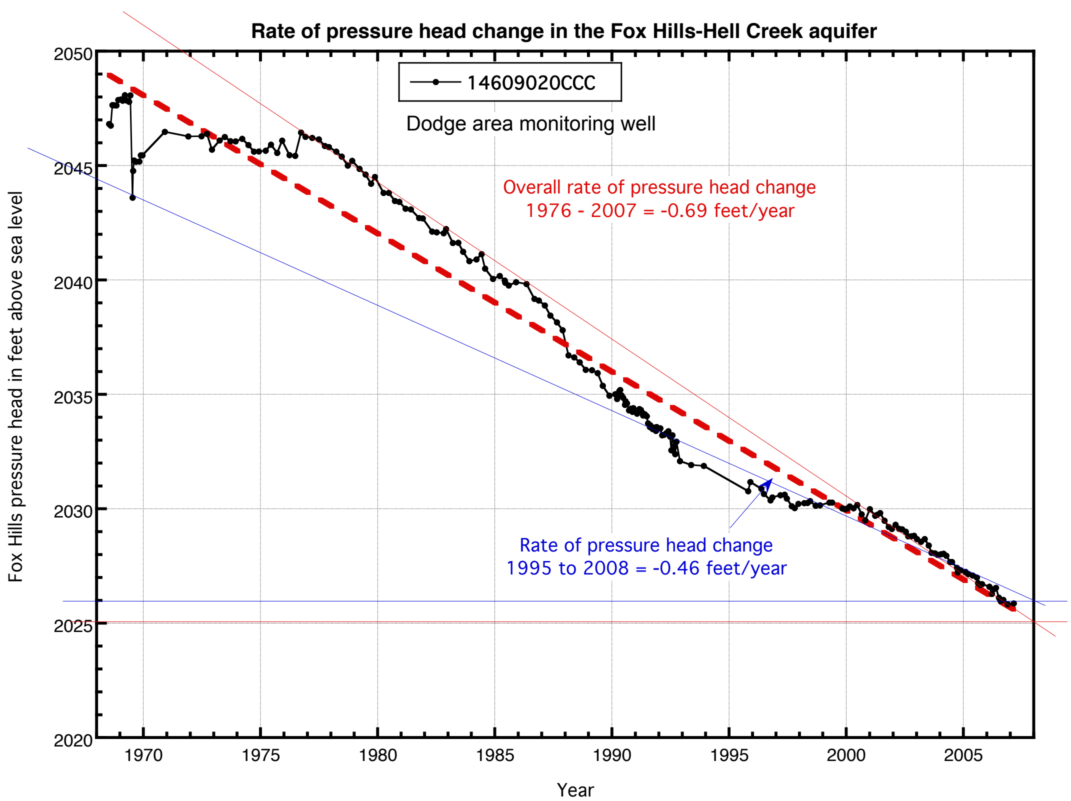

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14410024BBD1
Lilibridge stock well
Fox Hills pressure head in feet above sea level
Rate of pressure head change
1986 - 1997 = -1.47 feet/year
Year

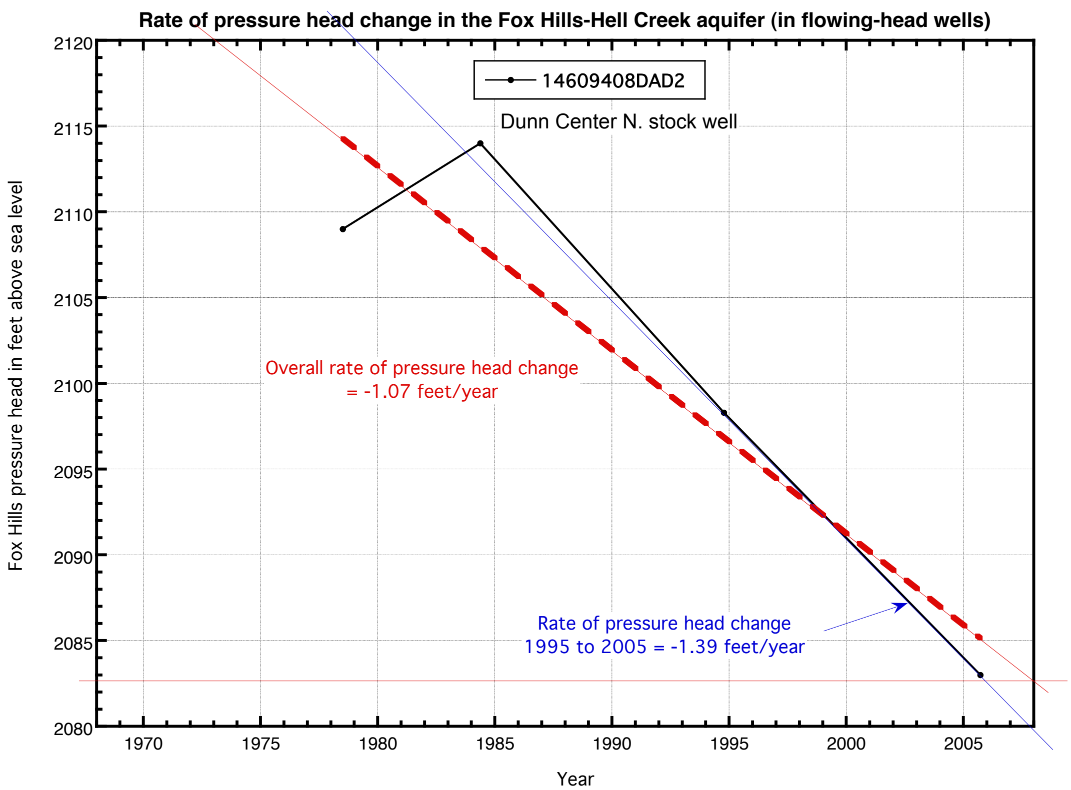

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14410229BBA
NW Billings Co. stock well
Fox Hills pressure head in feet above sea level
Rate of pressure head change
1995 to 2006 = -1.16 feet/year
Overall rate of pressure head change
= -0.89 feet/year
Year

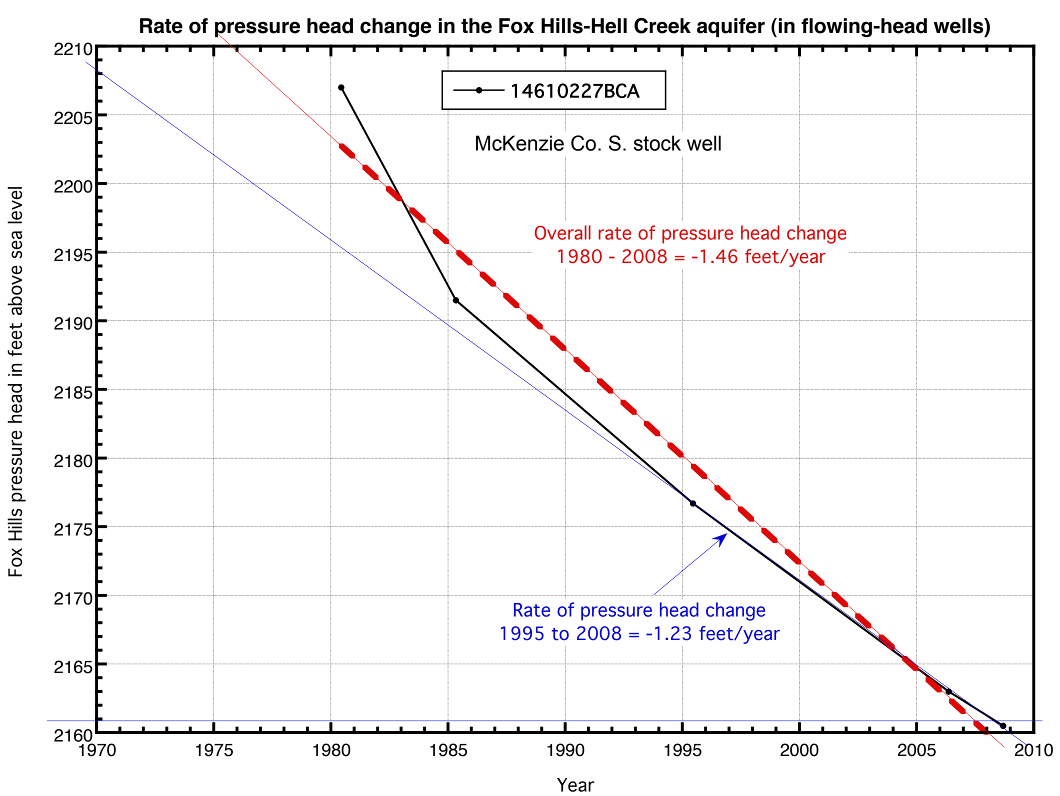

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14507805BBB
Mercer (city) southeast well
Rate of pressure head change
1978 - 1994 = +0.13 feet/year
Fox Hills pressure head in feet above sea level
Year
1822
1823
1824
1825
1826
1827
1970
1975
1980
1985
1990
1995
2000
2005
2010

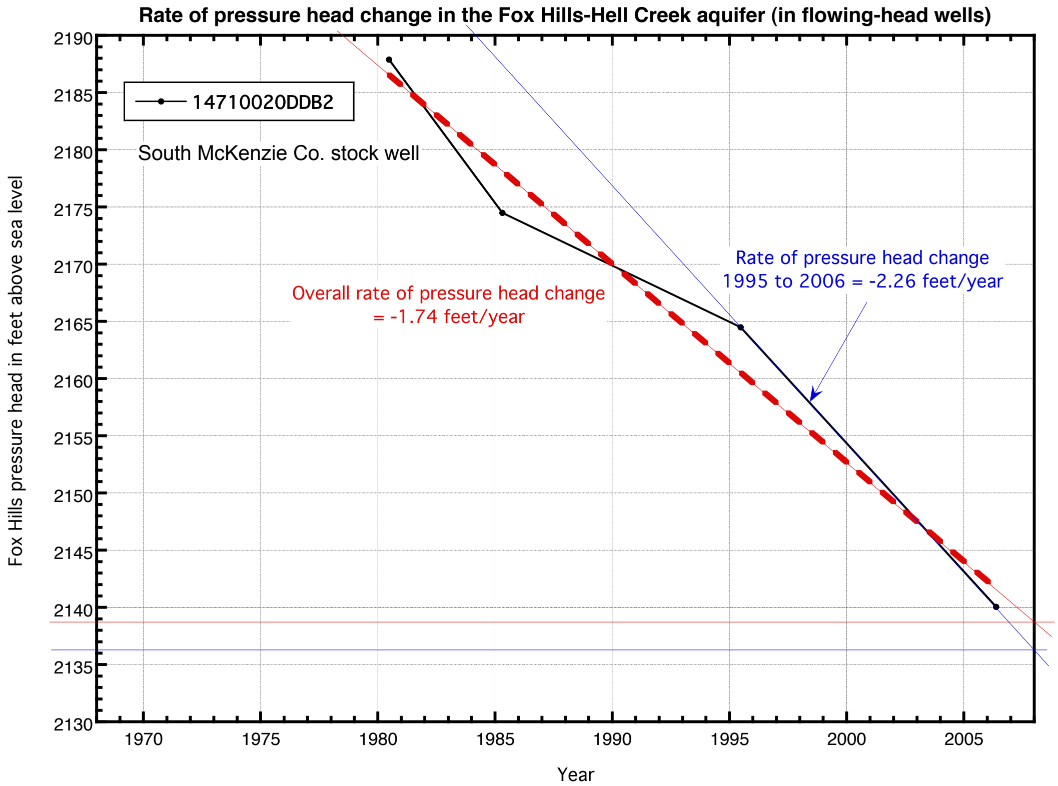

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14510215BAD
South McKenzie Co. stock well
Overall rate of pressure head change
= -1.62 feet/year
Rate of pressure head change
1995 to 2006 = -1.15 feet/year
Fox Hills pressure head in feet above sea level
Year
2160
2165
2170
2175
2180
2185
2190
2195
2200
2205
2210
2215
2220
1970
1975
1980
1985
1990
1995
2000
2005

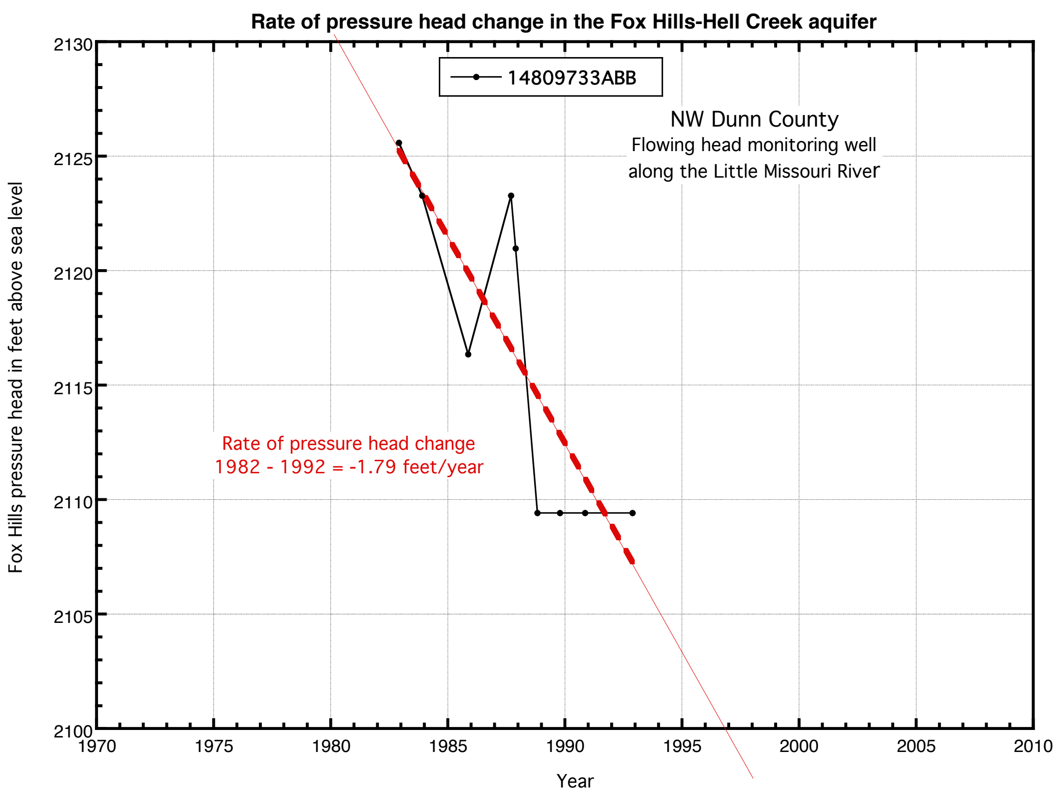

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14607421CCC
Goodrich southeast well
Rate of pressure head change
1977 - 1996 = +0.19 feet/year
Fox Hills pressure head in feet above sea level
Year
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1970
1975
1980
1985
1990
1995
2000
2005
2010

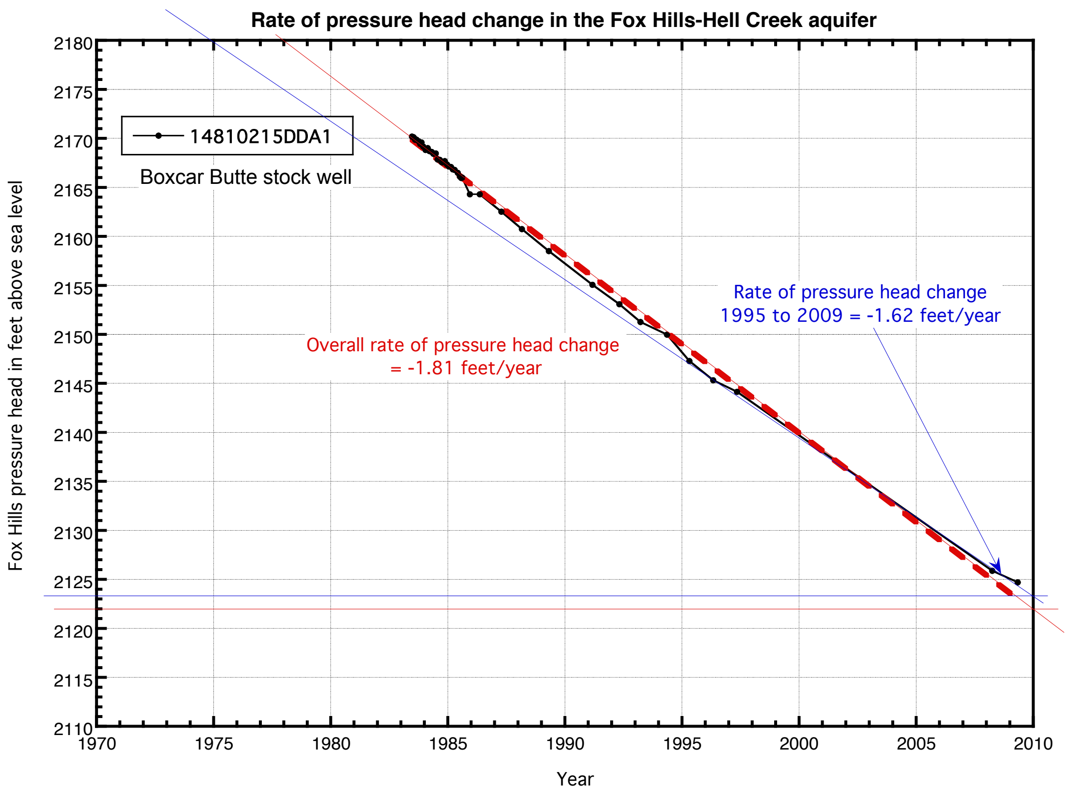

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14609020CCC
Dodge area monitoring well
Overall rate of pressure head change
1976 - 2007 = -0.69 feet/year
Rate of pressure head change
1995 to 2008 = -0.46 feet/year
Fox Hills pressure head in feet above sea level
Year
2020
2025
2030
2035
2040
2045
2050
1970
1975
1980
1985
1990
1995
2000
2005

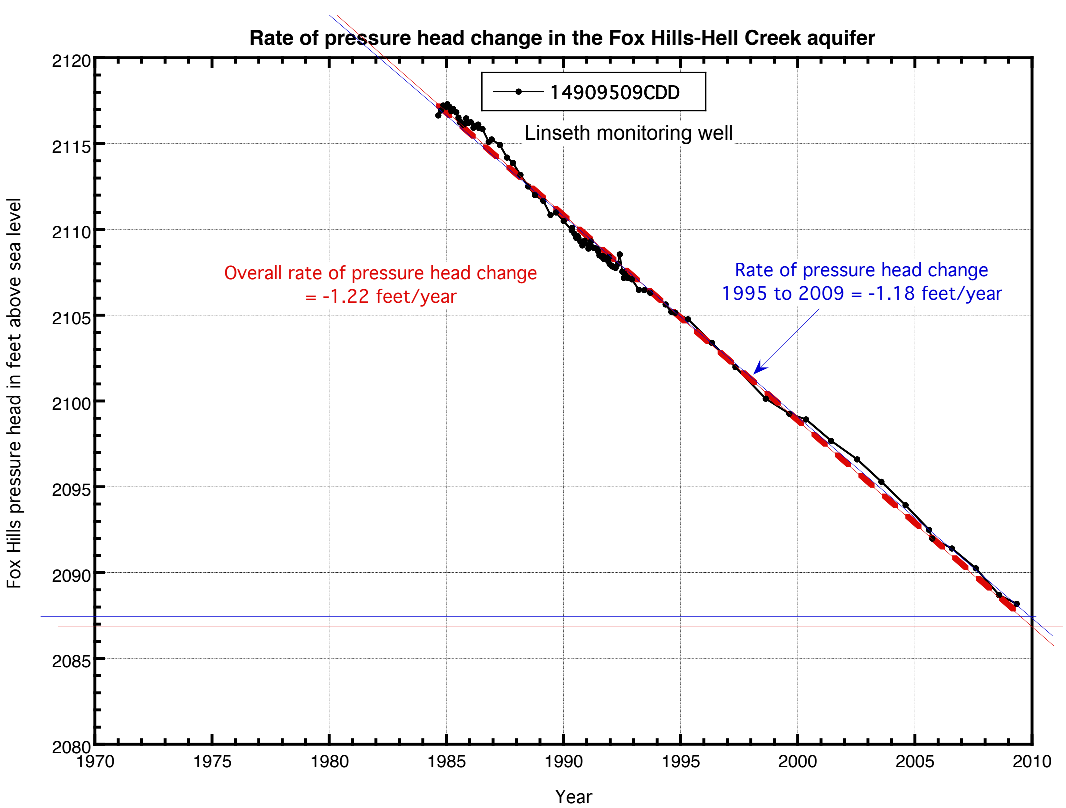

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14609408DAD2
Dunn Center N. stock well
Overall rate of pressure head change
= -1.07 feet/year
Rate of pressure head change
1995 to 2005 = -1.39 feet/year
Fox Hills pressure head in feet above sea level
Year
2120
2115
2110
2105
2100
2095
2090
2085
2080
1970
1975
1980
1985
1990
1995
2000
2005

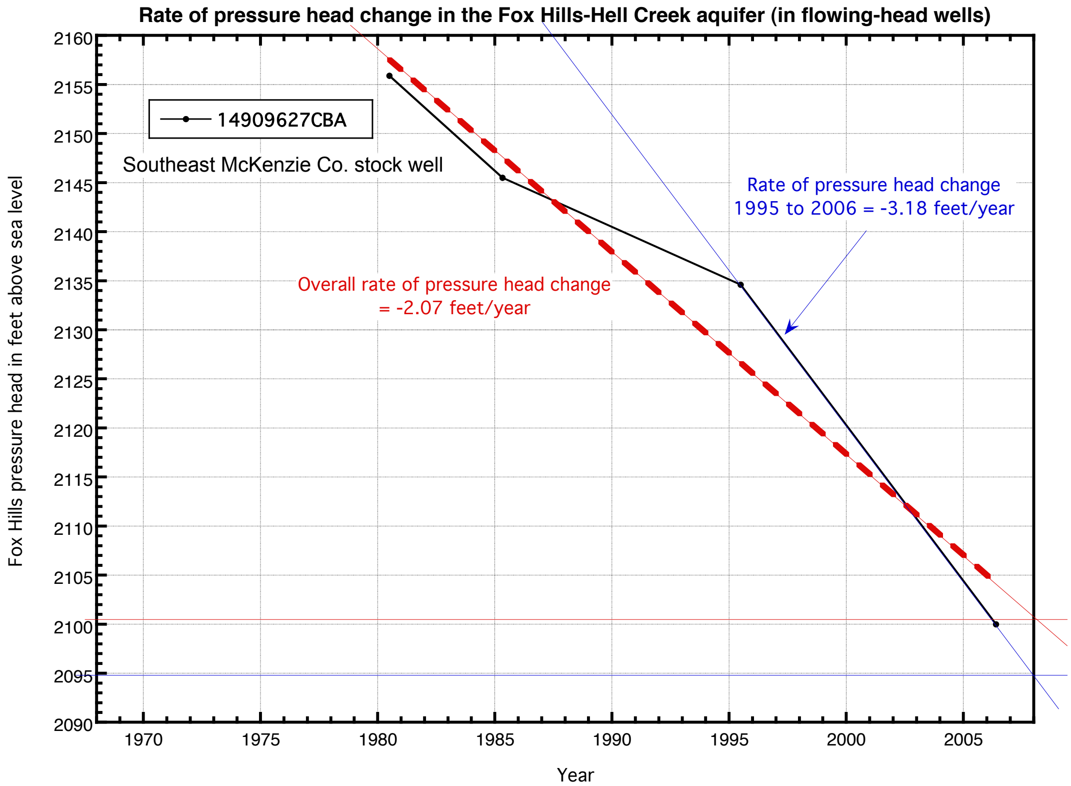

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14610227BCA
McKenzie Co. S. stock well
Overall rate of pressure head change
1980 - 2008 = -1.46 feet/year
Rate of pressure head change
1995 to 2008 = -1.23 feet/year
Fox Hills pressure head in feet above sea level
Year
2210
2205
2200
2195
2190
2185
2180
2175
2170
2165
2160
1970
1975
1980
1985
1990
1995
2000
2005
2010

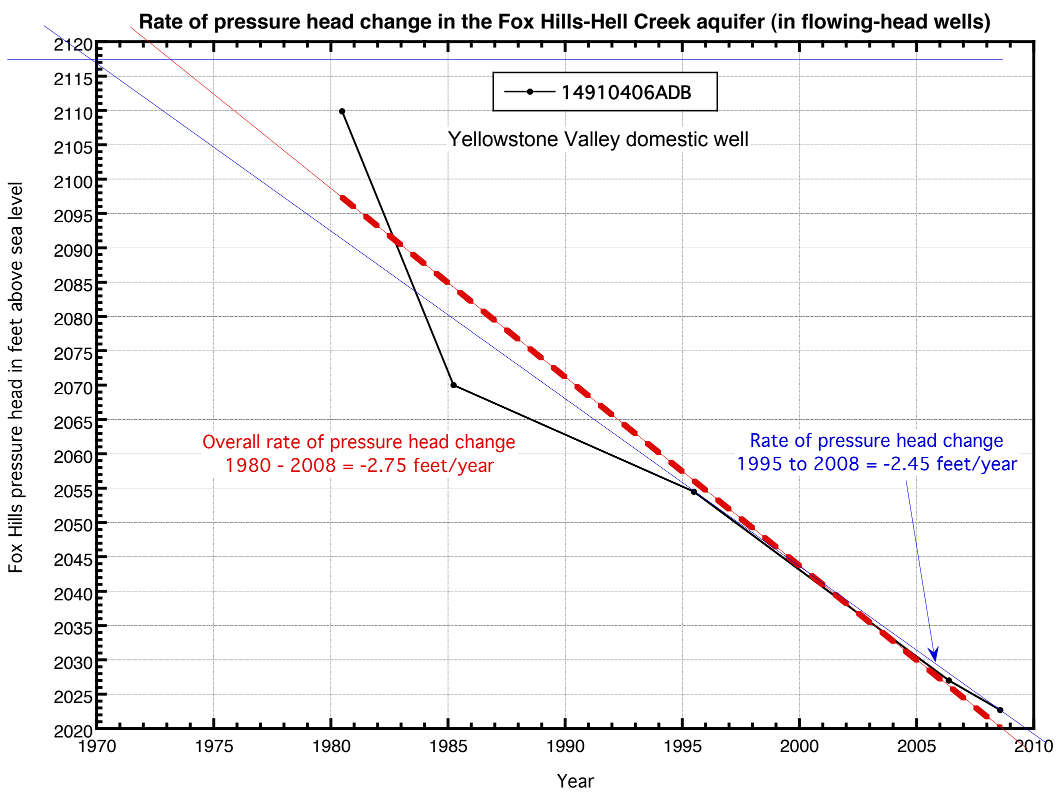

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14710020DDB2
South McKenzie Co. stock well
Overall rate of pressure head change
= -1.74 feet/year
Rate of pressure head change
1995 to 2006 = -2.26 feet/year
Fox Hills pressure head in feet above sea level
Year
2190
2185
2180
2175
2170
2165
2160
2155
2150
2145
2140
2135
2130
1970
1975
1980
1985
1990
1995
2000
2005

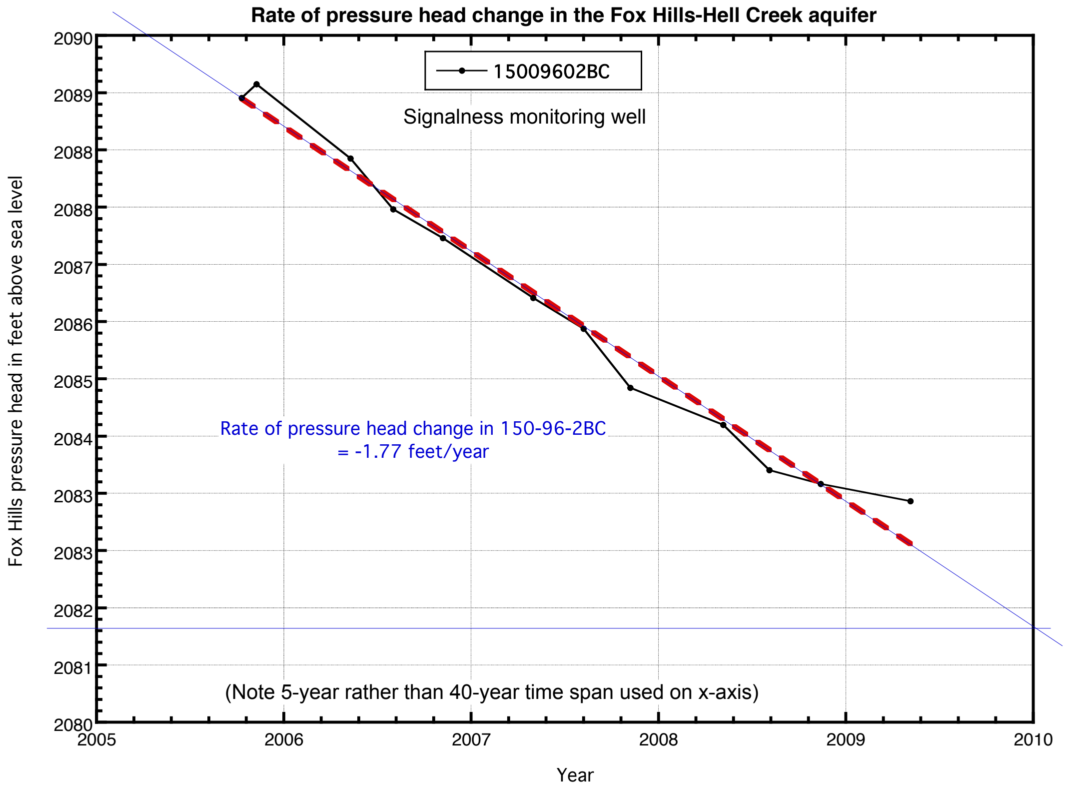

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14809733ABB
NW Dunn County
Flowing head monitoring well
along the Little Missouri River
Rate of pressure head change
1982 - 1992 = -1.79 feet/year
Fox Hills pressure head in feet above sea level
Year
2130
2125
2120
2115
2110
2105
2100
1970
1975
1980
1985
1990
1995
2000
2005
2010

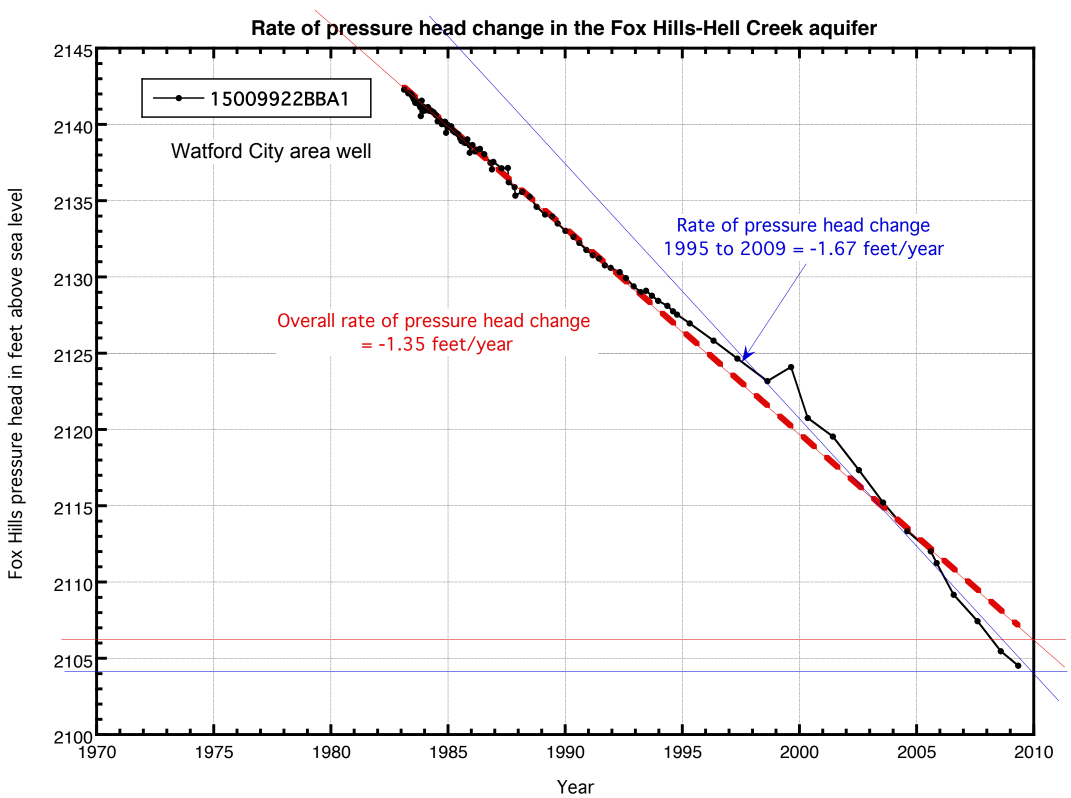

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14810215DDA1
Boxcar Butte stock well
Rate of pressure head change
1995 to 2009 = -1.62 feet/year
Overall rate of pressure head change
= -1.81 feet/year
Fox Hills pressure head in feet above sea level
Year
2180
2175
2170
2165
2160
2155
2150
2145
2140
2135
2130
2125
2120
2115
2110
1970
1975
1980
1985
1990
1995
2000
2005
2010

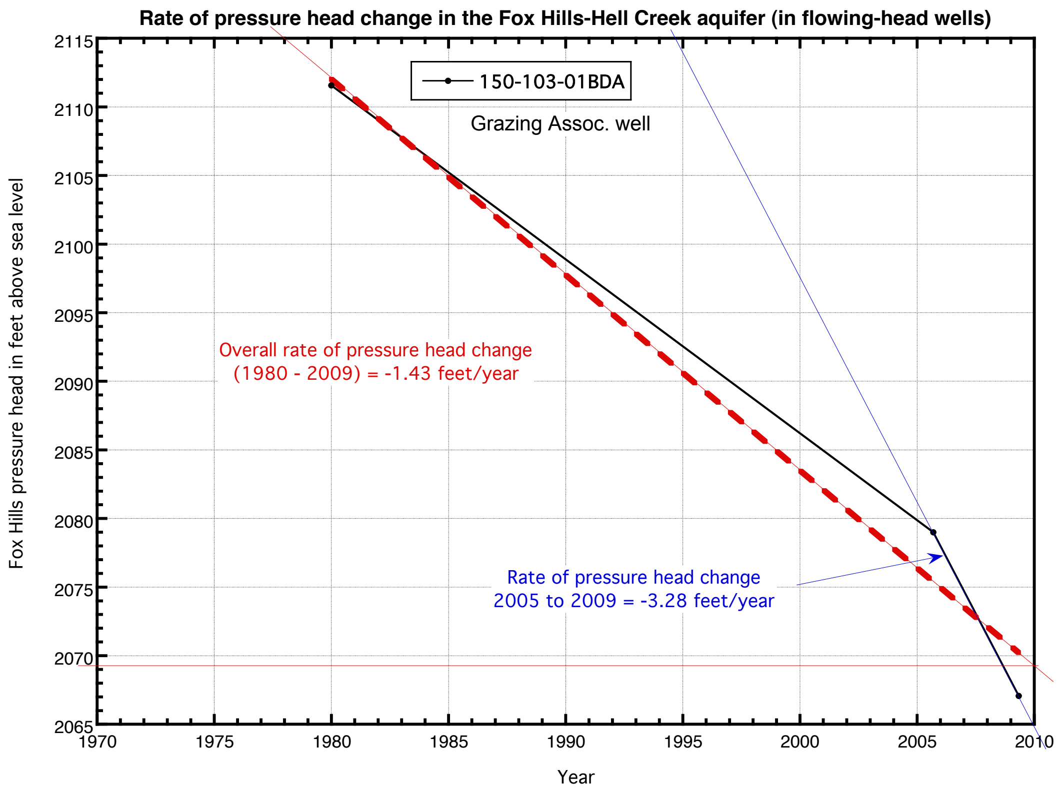

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
14909509CDD
Linseth monitoring well
Overall rate of pressure head change
= -1.22 feet/year
Rate of pressure head change
1995 to 2009 = -1.18 feet/year
Fox Hills pressure head in feet above sea level
Year
2120
2115
2110
2105
2100
2095
2090
2085
2080
1970
1975
1980
1985
1990
1995
2000
2005
2010

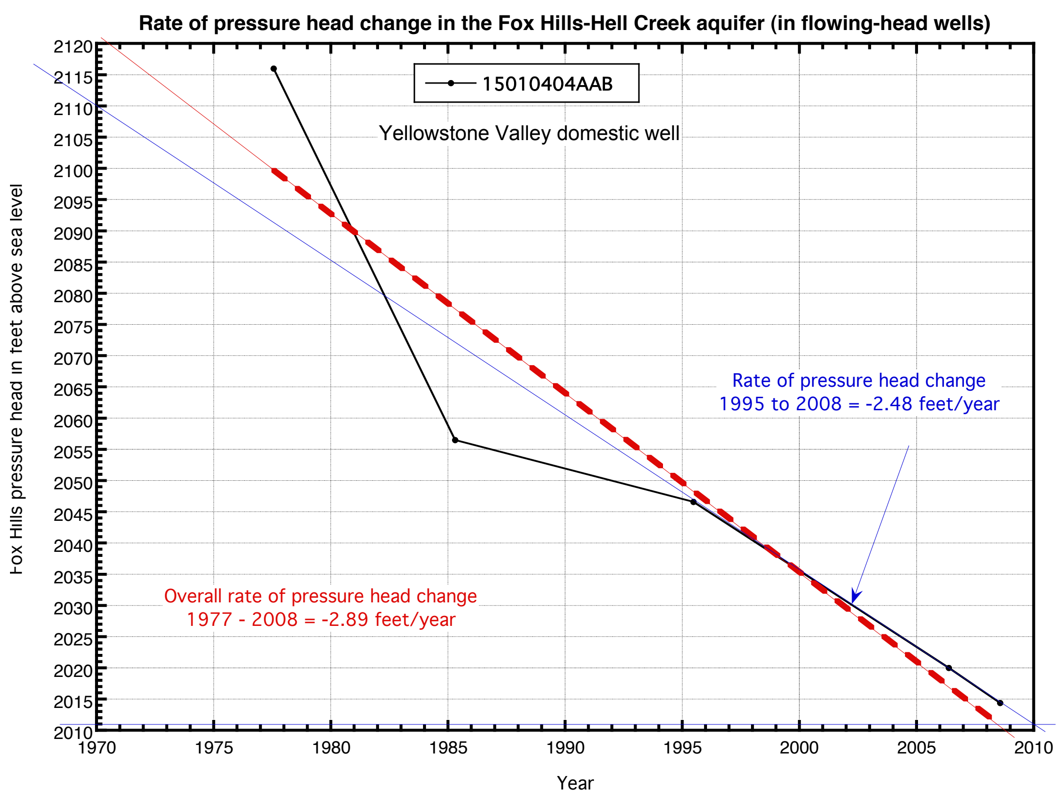

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14909627CBA
Southeast McKenzie Co. stock well
Rate of pressure head change
1995 to 2006 = -3.18 feet/year
Overall rate of pressure head change
= -2.07 feet/year
Fox Hills pressure head in feet above sea level
Year
2160
2155
2150
2145
2140
2135
2130
2125
2120
2115
2110
2105
2100
2095
2090
1970
1975
1980
1985
1990
1995
2000
2005

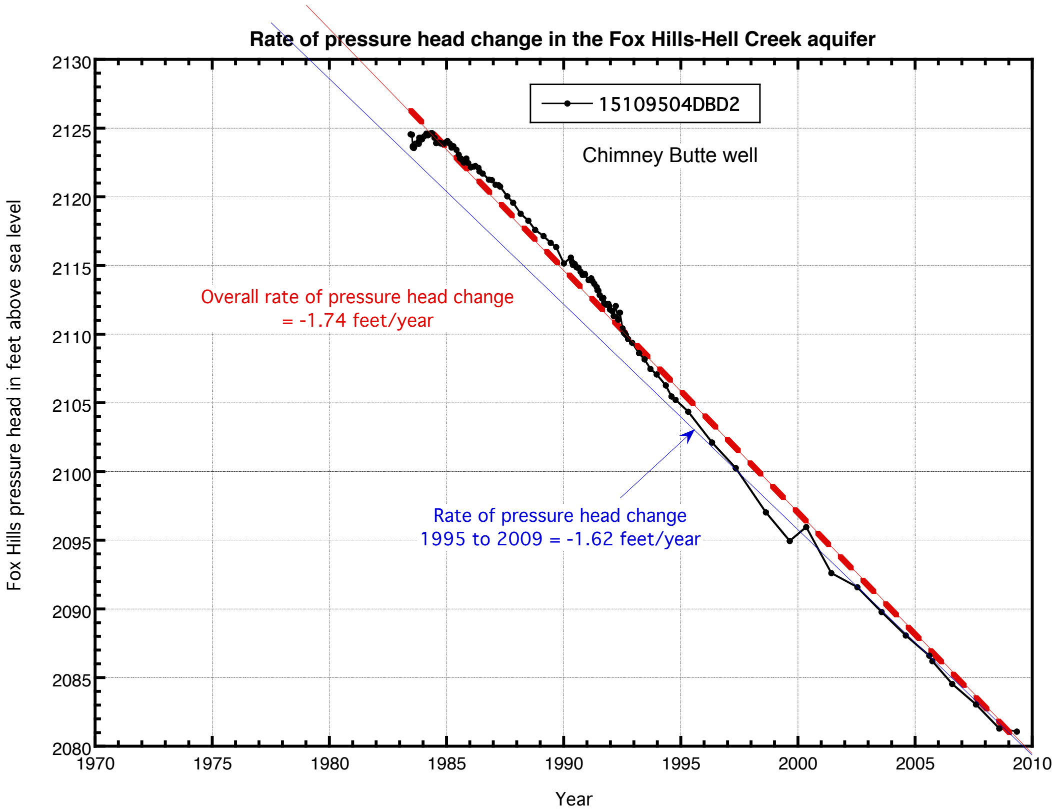

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
14910406ADB
Yellowstone Valley domestic well
Overall rate of pressure head change
1980 - 2008 = -2.75 feet/year
Rate of pressure head change
1995 to 2008 = -2.45 feet/year
Fox Hills pressure head in feet above sea level
Year
2120
2115
2110
2105
2100
2095
2090
2085
2080
2075
2070
2065
2060
2055
2050
2045
2040
2035
2030
2025
2020
1970
1975
1980
1985
1990
1995
2000
2005
2010

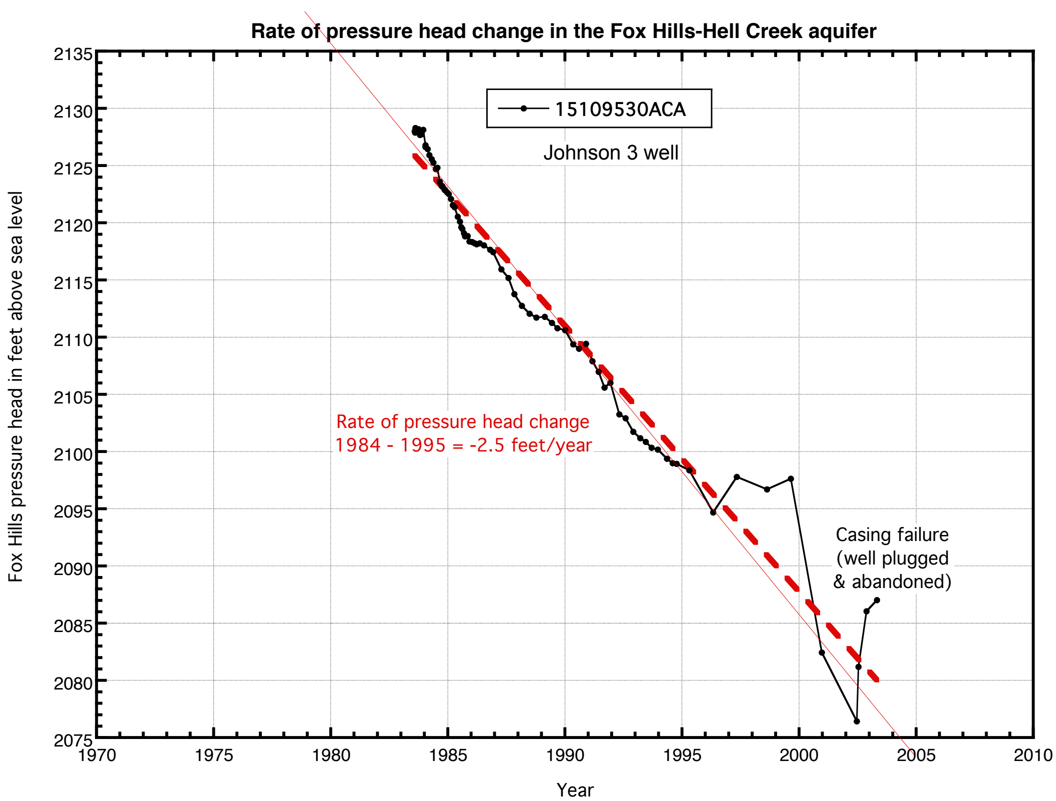

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15009602BC
Signalness monitoring well
Rate of pressure head change in 150-96-2BC
= -1.77 feet/year
(Note 5-year rather than 40-year time span used on x-axis)
Fox Hills pressure head in feet above sea level
Year
2090
2089
2088
2088
2087
2086
2085
2084
2083
2083
2082
2081
2080
2005
2006
2007
2008
2009
2010

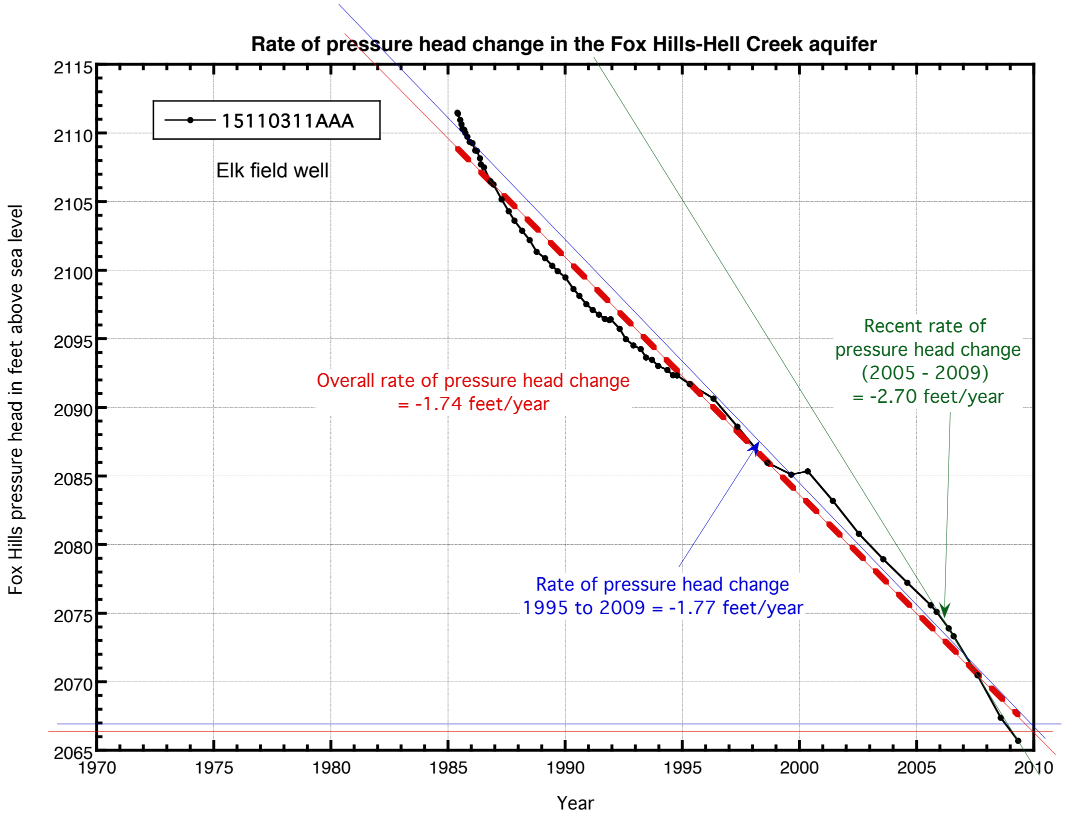

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15009922BBA1
Watford City area well
Rate of pressure head change
1995 to 2009 = -1.67 feet/year
Overall rate of pressure head change
= -1.35 feet/year
Fox Hills pressure head in feet above sea level
Year
2145
2140
2135
2130
2125
2120
2115
2110
2105
2100
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
150-103-01BDA
Grazing Assoc. well
Overall rate of pressure head change
(1980 - 2009) = -1.43 feet/year
Rate of pressure head change
2005 to 2009 = -3.28 feet/year
Fox Hills pressure head in feet above sea level
Year
2115
2110
2105
2100
2095
2090
2085
2080
2075
2070
2065
1970
1975
1980
1985
1990
1995
2000
2005
2010

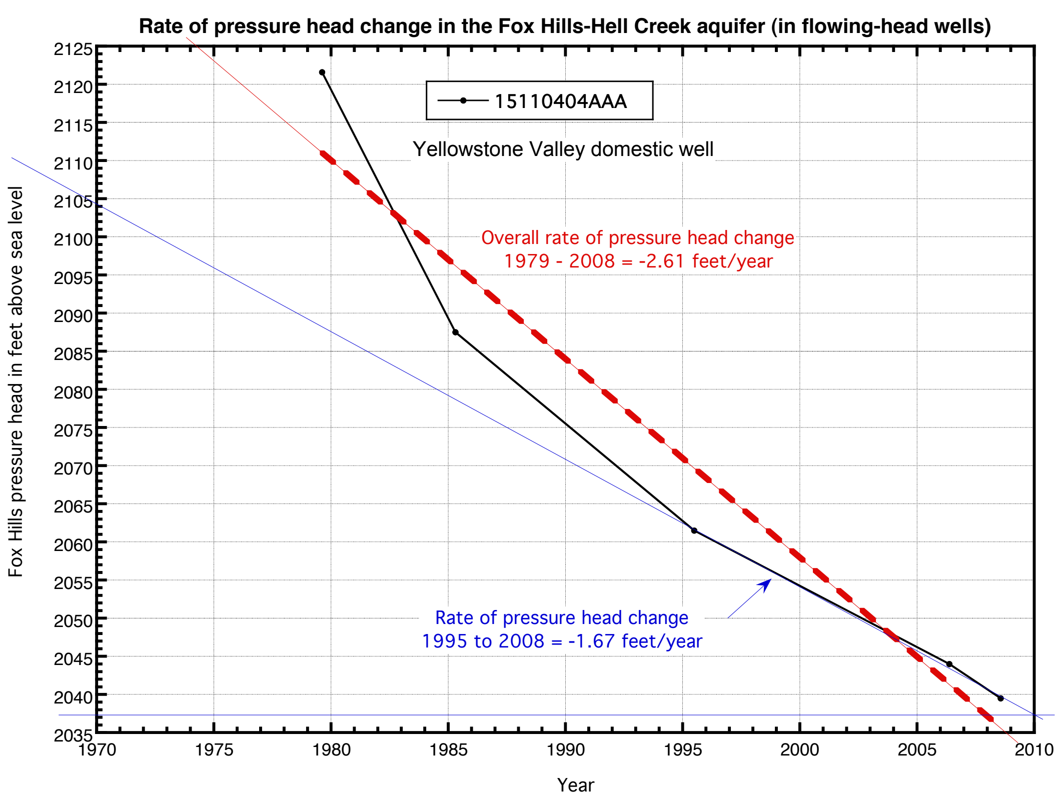

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
15010404AAB
Yellowstone Valley domestic well
Rate of pressure head change
1995 to 2008 = -2.48 feet/year
Overall rate of pressure head change
1977 - 2008 = -2.89 feet/year
Fox Hills pressure head in feet above sea level
Year
2120
2115
2110
2105
2100
2095
2090
2085
2080
2075
2070
2065
2060
2055
2050
2045
2040
2035
2030
2025
2020
2015
2010
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15109504DBD2
Chimney Butte well
Overall rate of pressure head change
= -1.74 feet/year
Rate of pressure head change
1995 to 2009 = -1.62 feet/year
Fox Hills pressure head in feet above sea level
Year
2130
2125
2120
2115
2110
2105
2100
2095
2090
2085
2080
1970
1975
1980
1985
1990
1995
2000
2005
2010

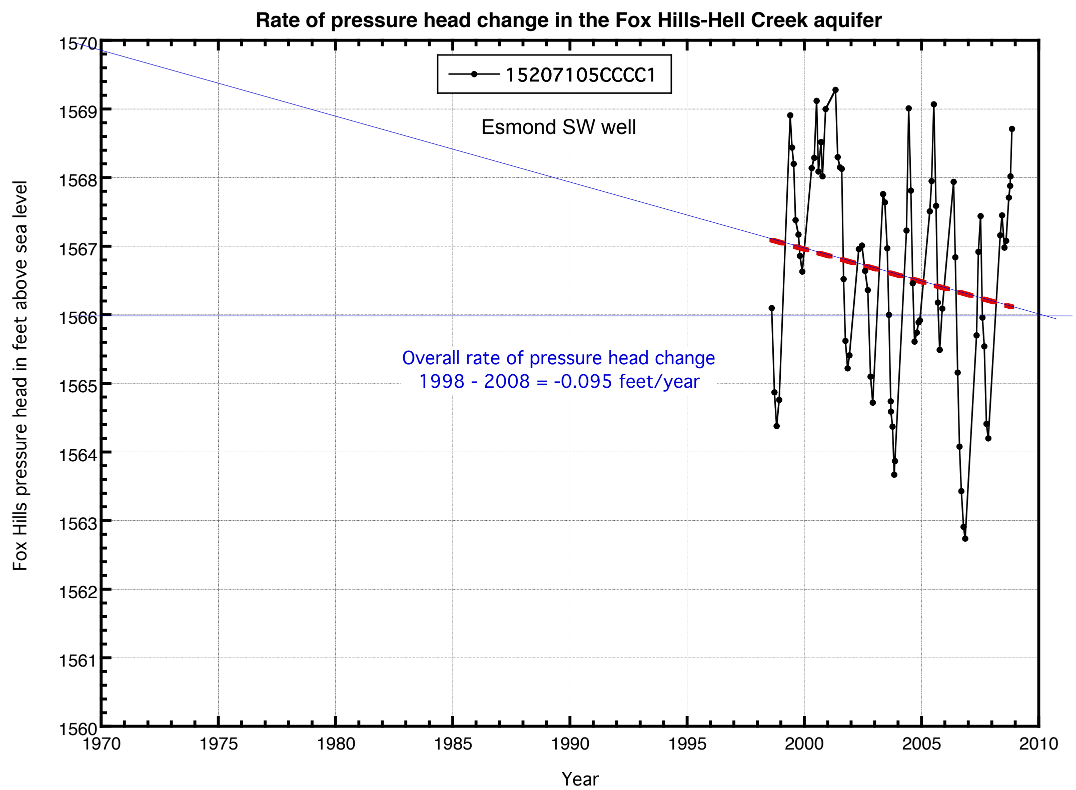

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15109530ACA
Johnson 3 well
Rate of pressure head change
1984 - 1995 = -2.5 feet/year
Casing failure
(well plugged
& abandoned)
Fox Hills pressure head in feet above sea level
Year
2135
2130
2125
2120
2115
2110
2105
2100
2095
2090
2085
2080
2075
1970
1975
1980
1985
1990
1995
2000
2005
2010

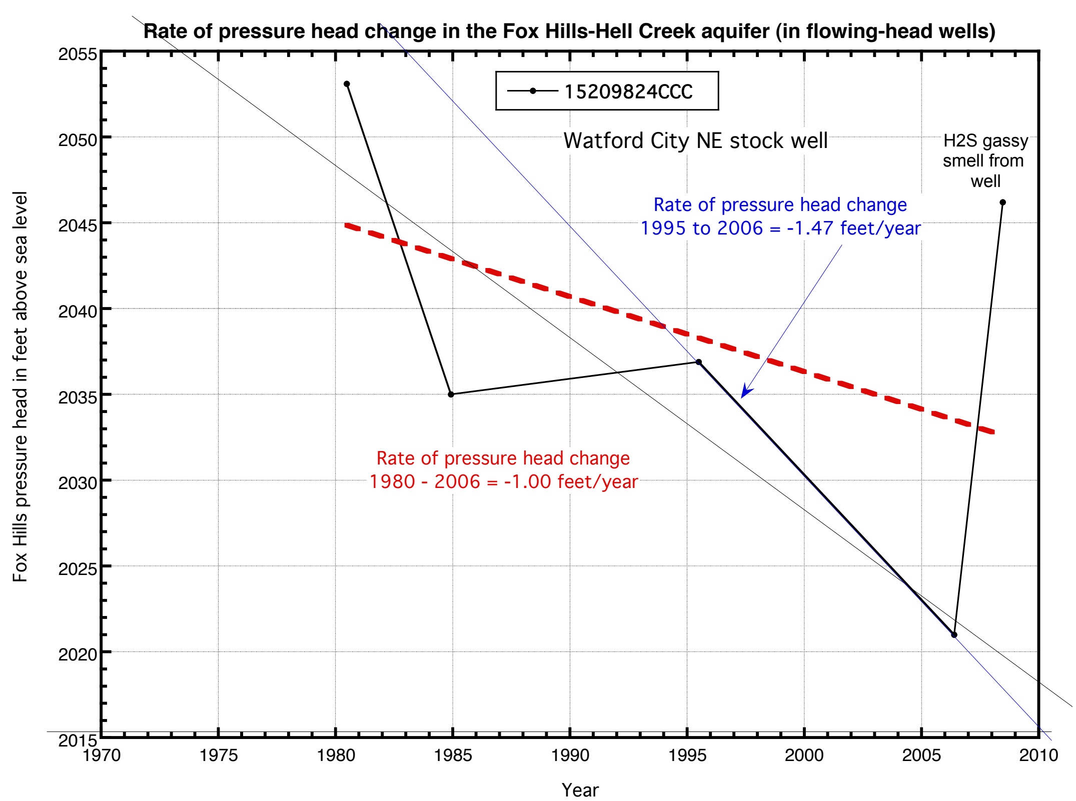


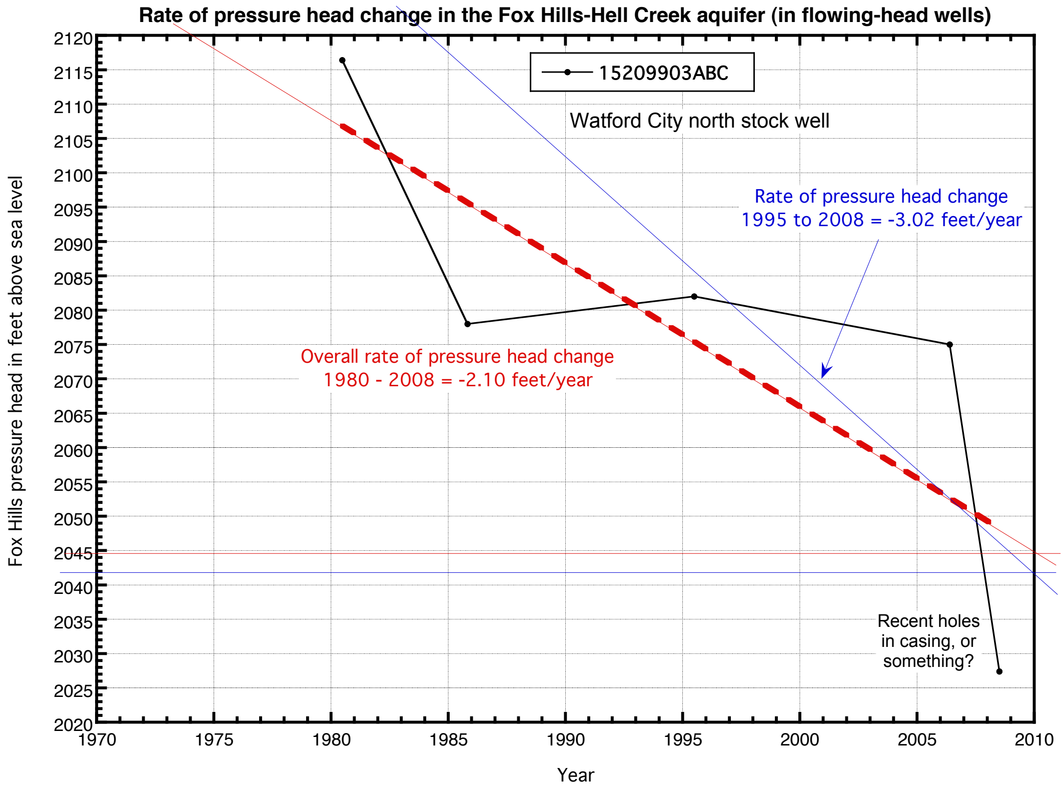
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15110311AAA
Elk field well
Overall rate of pressure head change
= -1.74 feet/year
Recent rate of
pressure head change
(2005 - 2009)
= -2.70 feet/year
Rate of pressure head change
1995 to 2009 = -1.77 feet/year
Fox Hills pressure head in feet above sea level
Year
2115
2110
2105
2100
2095
2090
2085
2080
2075
2070
2065
1970
1975
1980
1985
1990
1995
2000
2005
2010

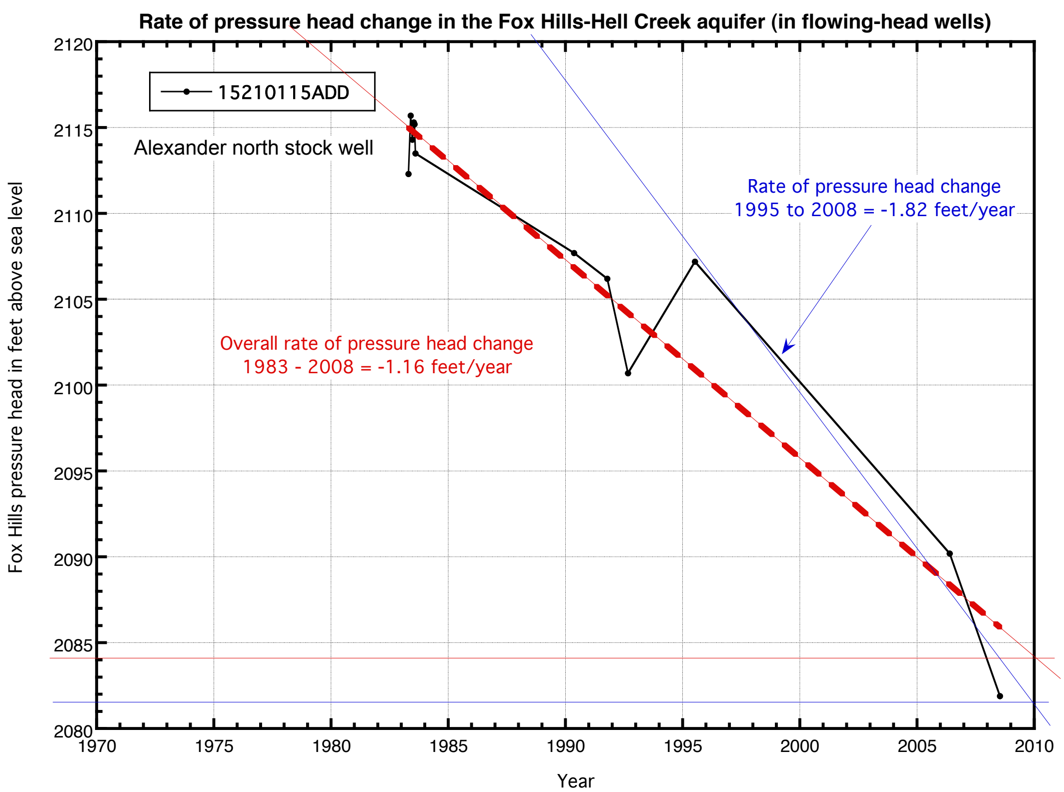


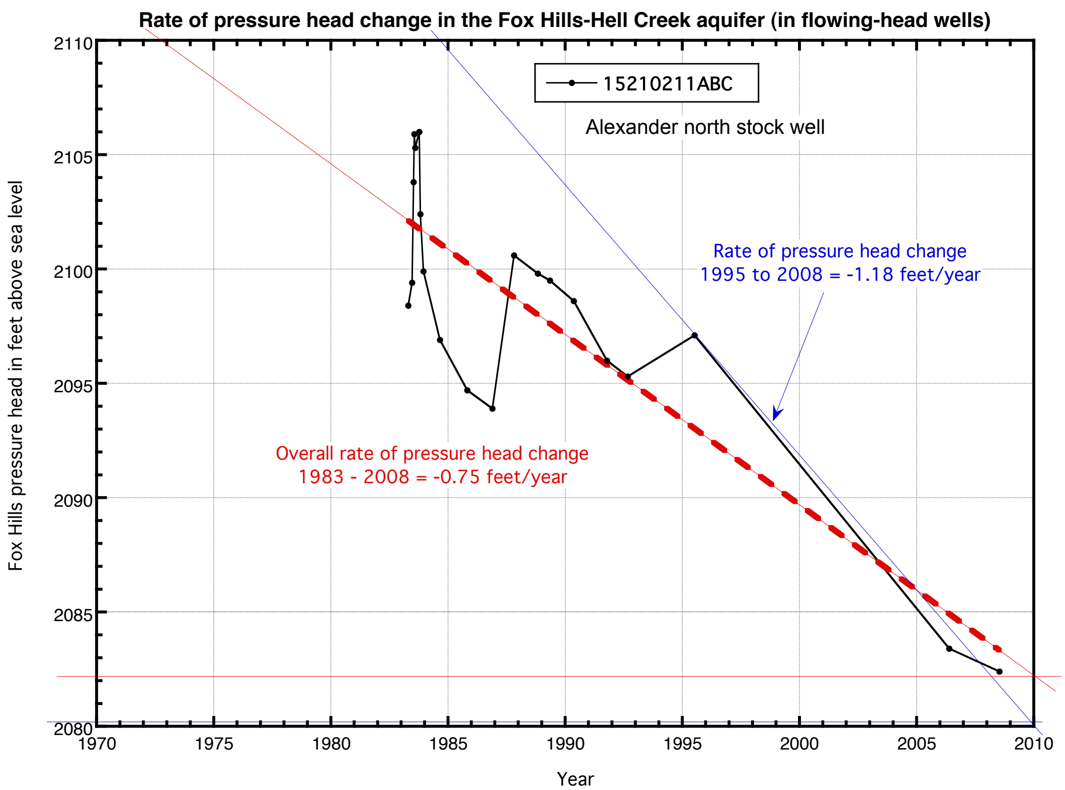
Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
15110404AAA
Yellowstone Valley domestic well
Overall rate of pressure head change
1979 - 2008 = -2.61 feet/year
Rate of pressure head change
1995 to 2008 = -1.67 feet/year
Fox Hills pressure head in feet above sea level
Year
2125
2120
2115
2110
2105
2100
2095
2090
2085
2080
2075
2070
2065
2060
2055
2050
2045
2040
2035
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15207105CCCC1
Esmond SW well
Overall rate of pressure head change
1998 - 2008 = -0.095 feet/year
Fox Hills pressure head in feet above sea level
Year
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1970
1975
1980
1985
1990
1995
2000
2005
2010

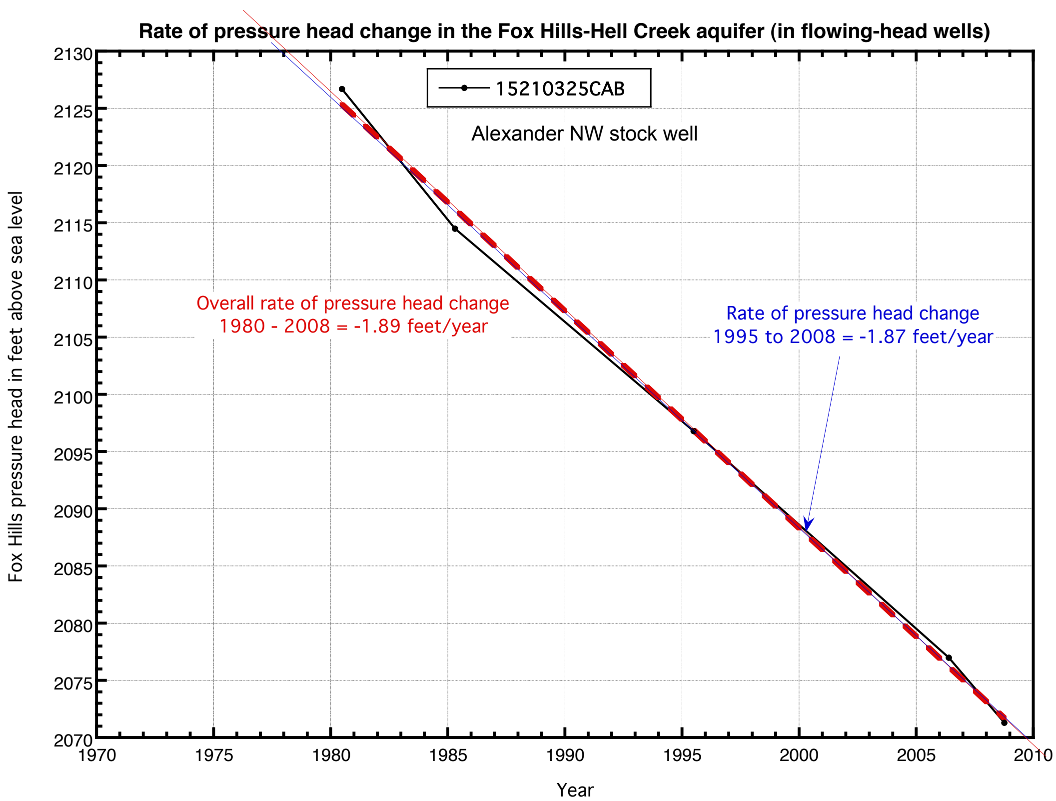

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
15209824CCC
Watford City NE stock well
H2S gassy
smell from
well
Rate of pressure head change
1995 to 2006 = -1.47 feet/year
Rate of pressure head change
1980 - 2006 = -1.00 feet/year
Fox Hills pressure head in feet above sea level
Year
2015
2020
2025
2030
2035
2040
2045
2050
2055
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
15209903ABC
Watford City north stock well
Rate of pressure head change
1995 to 2008 = -3.02 feet/year
Overall rate of pressure head change
1980 - 2008 = -2.10 feet/year
Recent holes
in casing, or
something?
Fox Hills pressure head in feet above sea level
Year

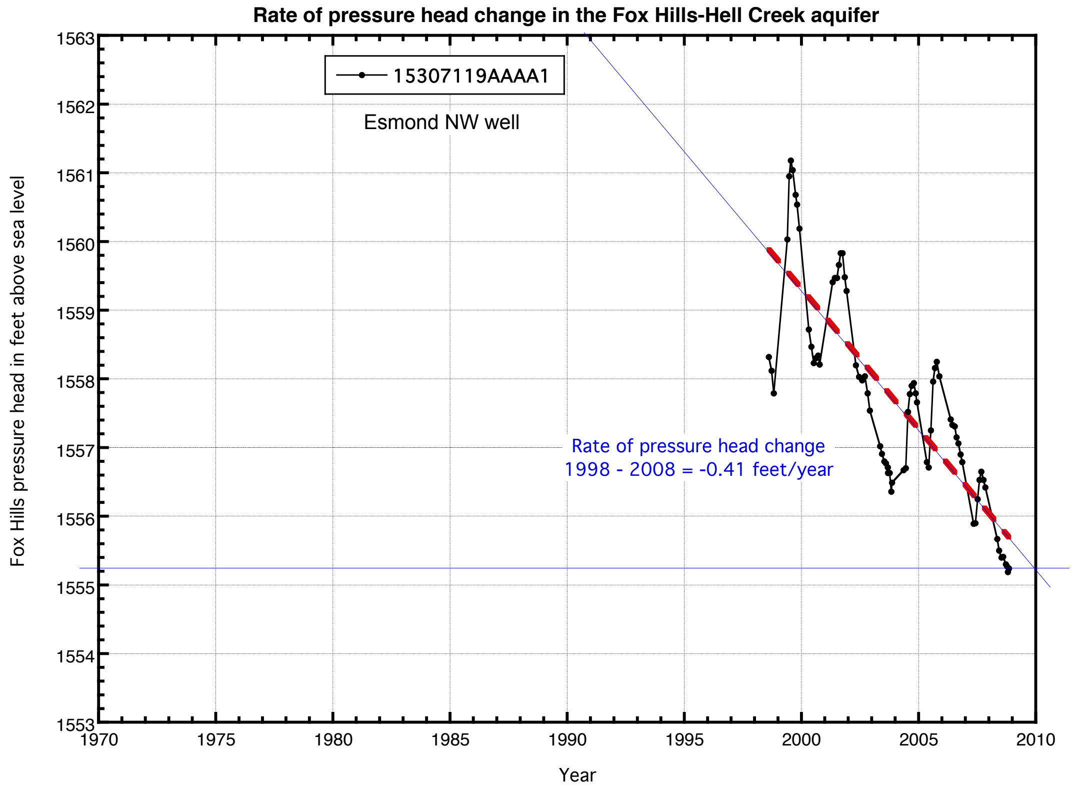

Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
15210115ADD
Alexander north stock well
Rate of pressure head change
1995 to 2008 = -1.82 feet/year
Overall rate of pressure head change
1983 - 2008 = -1.16 feet/year
Fox Hills pressure head in feet above sea level
Year

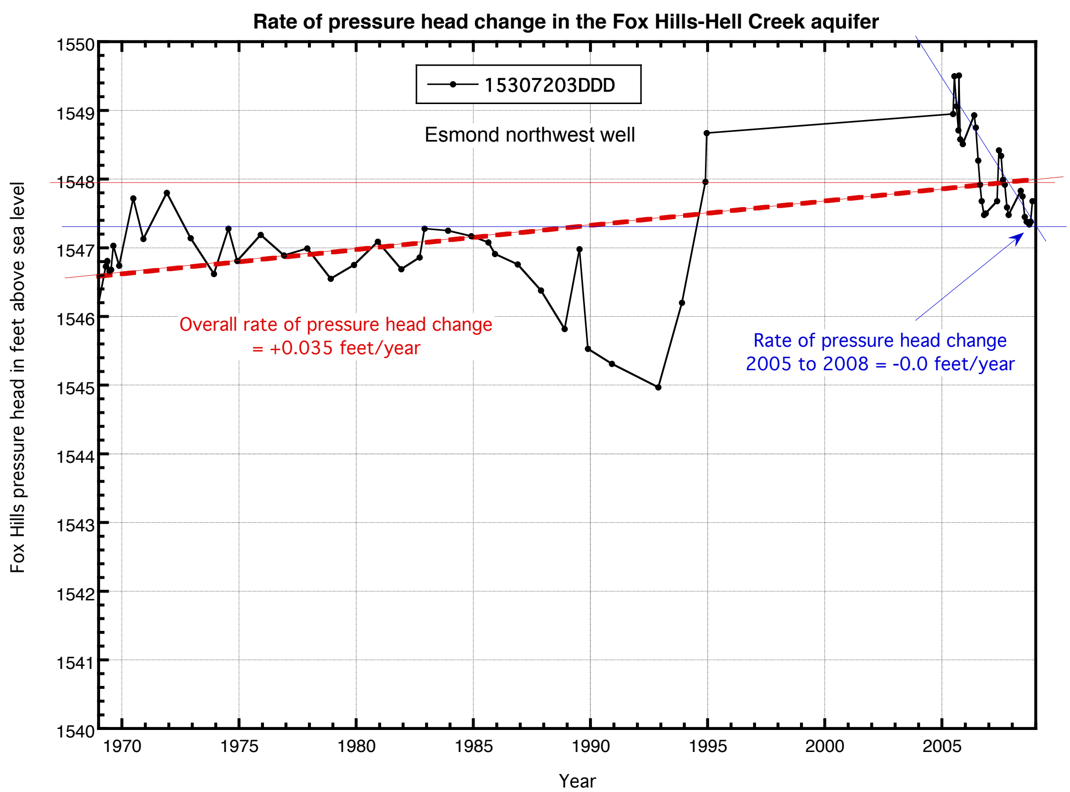


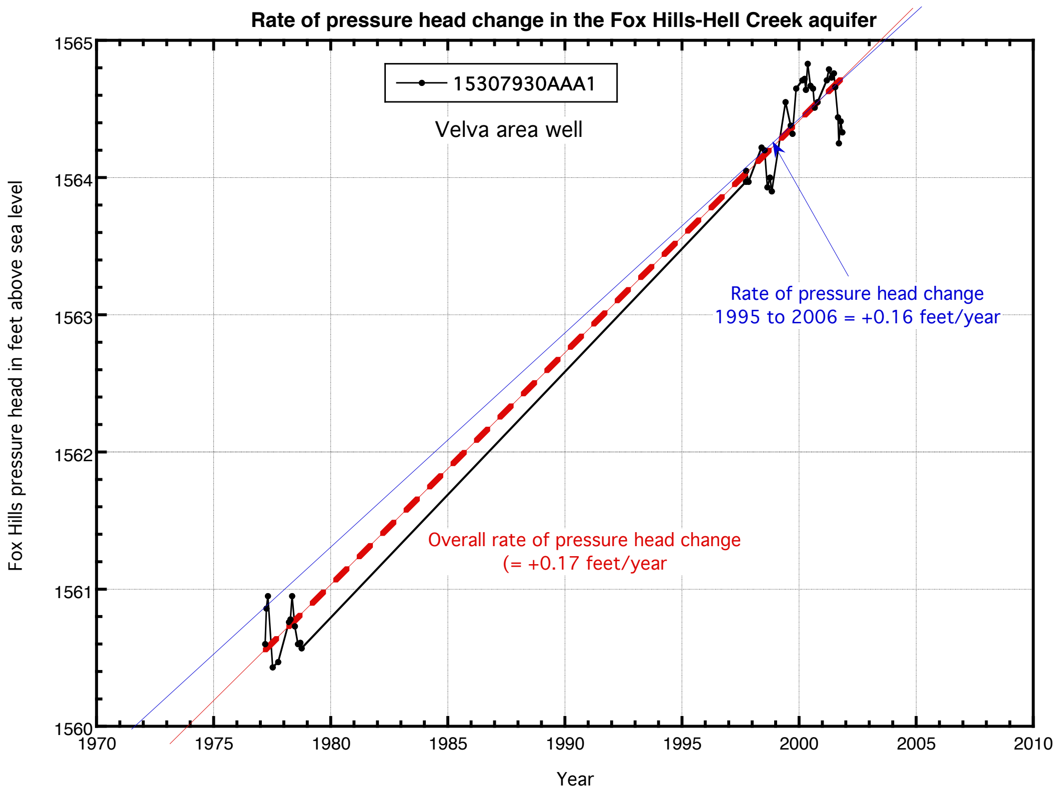
Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
15210211ABC
Alexander north stock well
Rate of pressure head change
1995 to 2008 = -1.18 feet/year
Overall rate of pressure head change
1983 - 2008 = -0.75 feet/year
Fox Hills pressure head in feet above sea level
Year
2110
2105
2100
2095
2090
2085
2080
1970
1975
1980
1985
1990
1995
2000
2005
2010



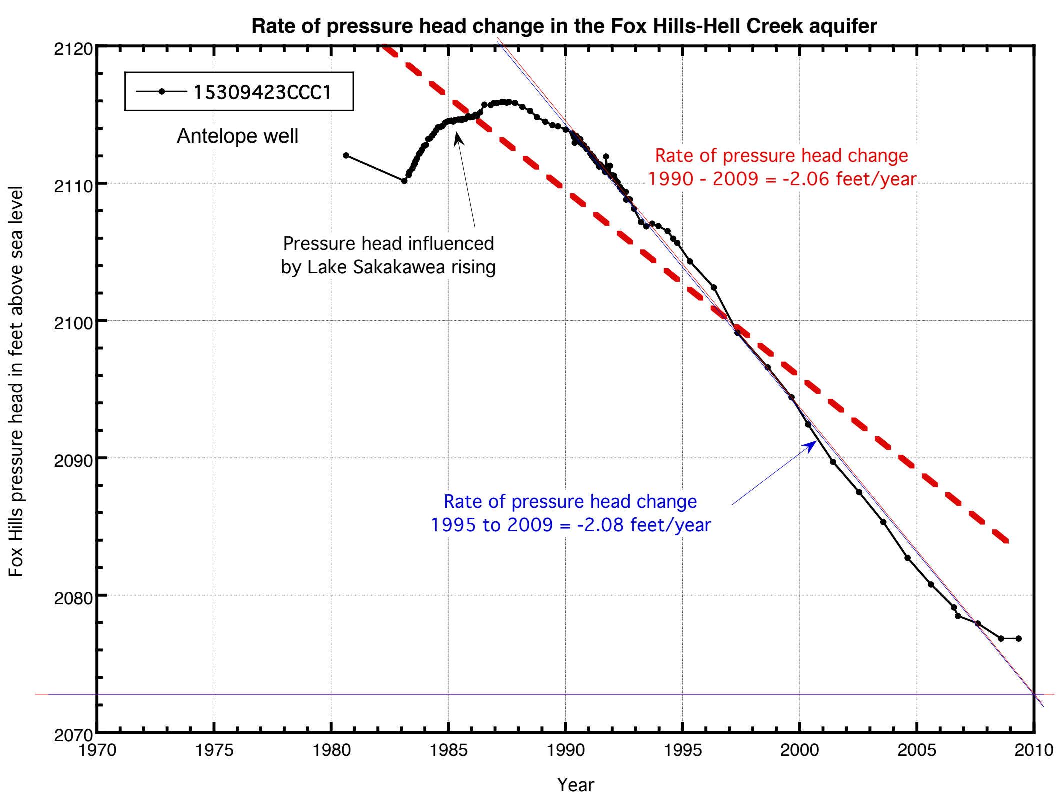
Rate of pressure head change in the Fox Hills-Hell Creek aquifer (in flowing-head wells)
15210325CAB
Alexander NW stock well
Overall rate of pressure head change
1980 - 2008 = -1.89 feet/year
Rate of pressure head change
1995 to 2008 = -1.87 feet/year
Fox Hills pressure head in feet above sea level
Year
2130
2125
2120
2115
2110
2105
2100
2095
2090
2085
2080
2075
2070
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15307119AAAA1
Esmond NW well
Rate of pressure head change
1998 - 2008 = -0.41 feet/year
Fox Hills pressure head in feet above sea level
Year
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1970
1975
1980
1985
1990
1995
2000
2005
2010

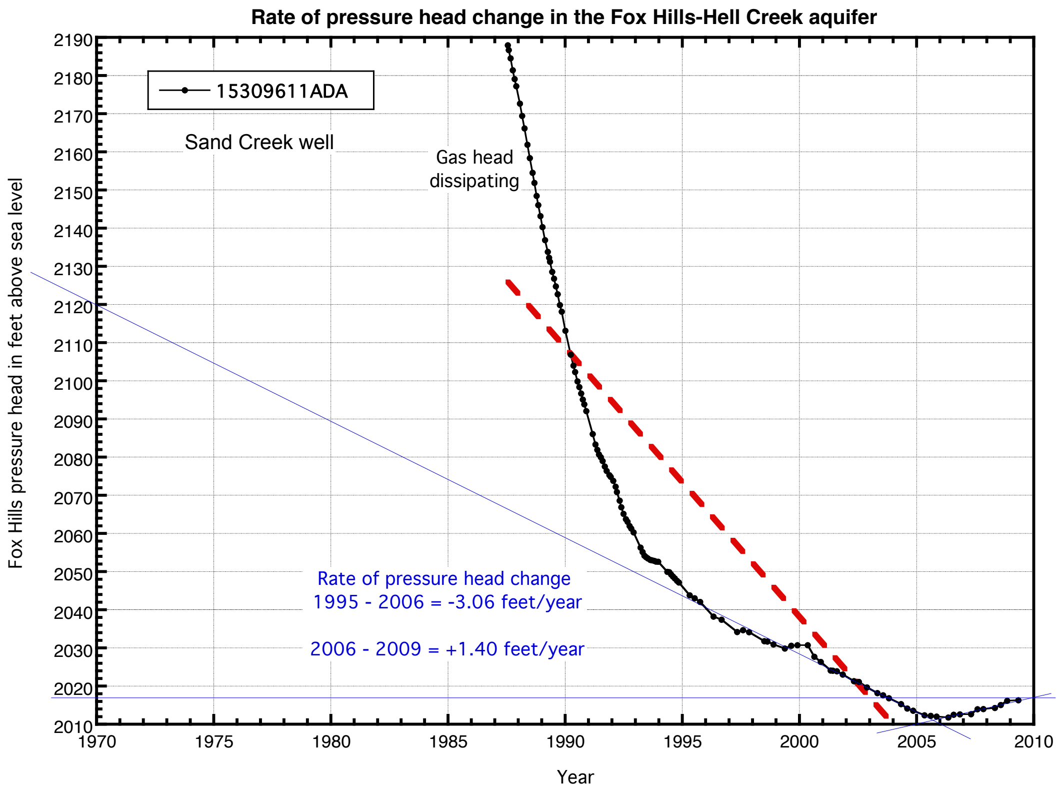

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15307203DDD
Esmond northwest well
Overall rate of pressure head change
= +0.035 feet/year
Rate of pressure head change
2005 to 2008 = -0.0 feet/year
Fox Hills pressure head in feet above sea level
Year
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1970
1975
1980
1985
1990
1995
2000
2005

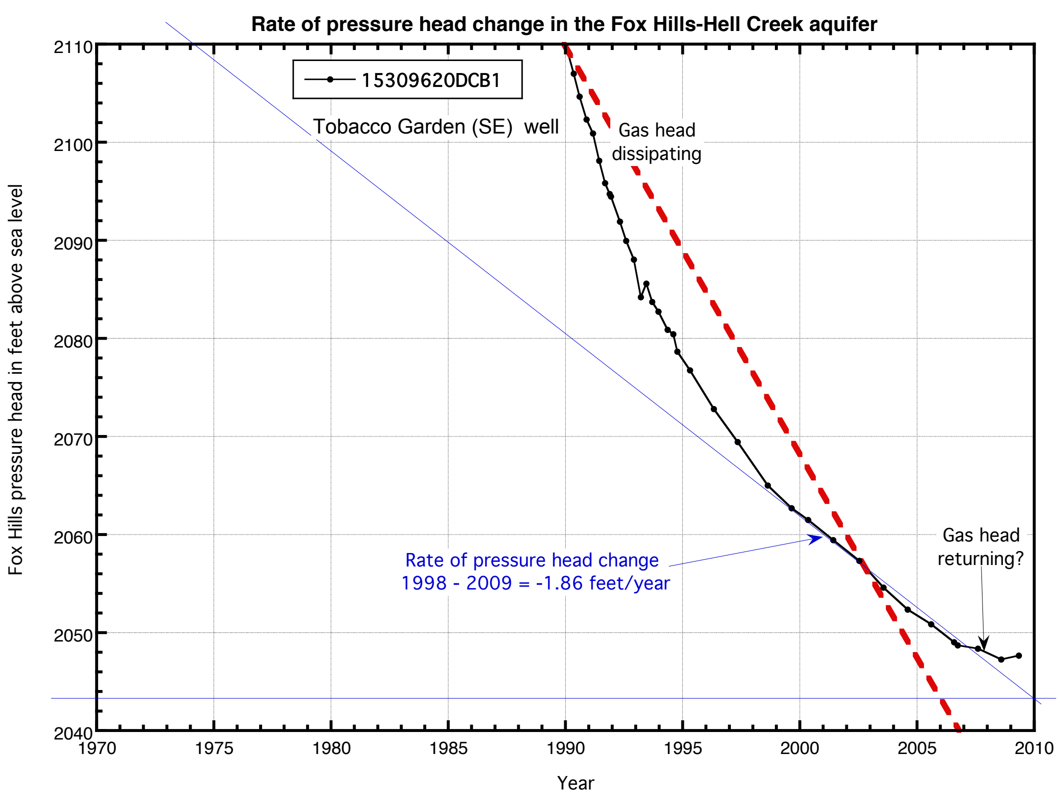


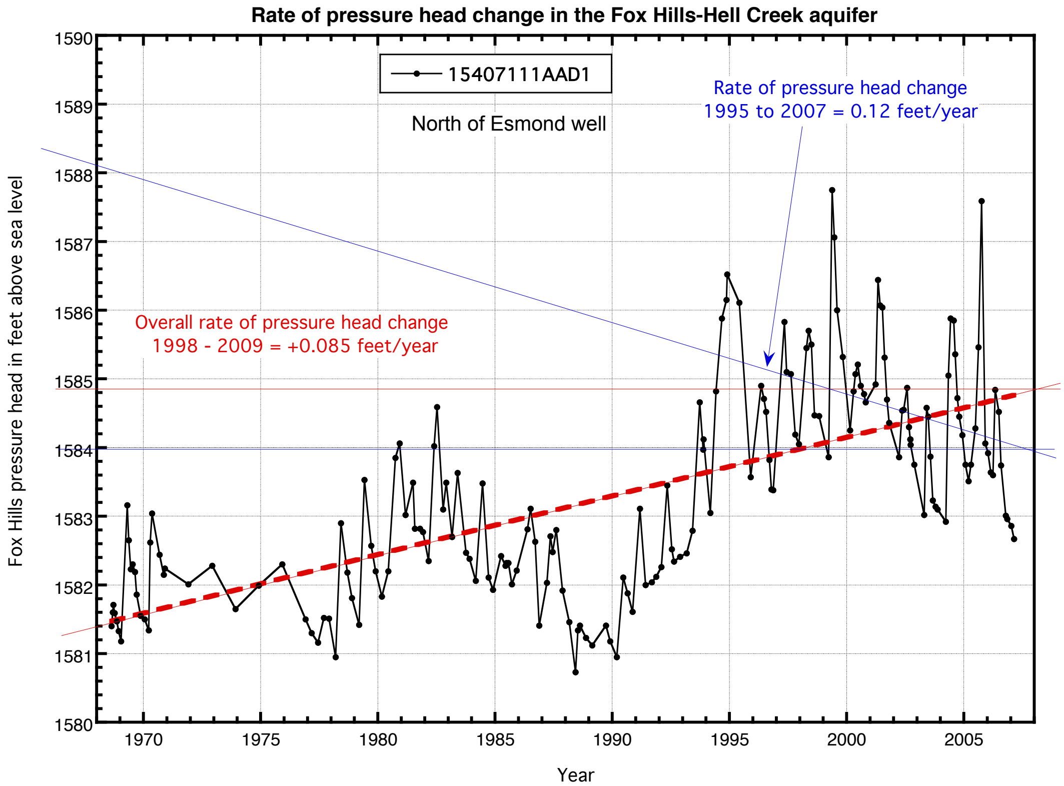
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15307930AAA1
Velva area well
Rate of pressure head change
1995 to 2006 = +0.16 feet/year
Overall rate of pressure head change
(= +0.17 feet/year
Fox Hills pressure head in feet above sea level
Year
1560
1561
1562
1563
1564
1565
1970
1975
1980
1985
1990
1995
2000
2005
2010

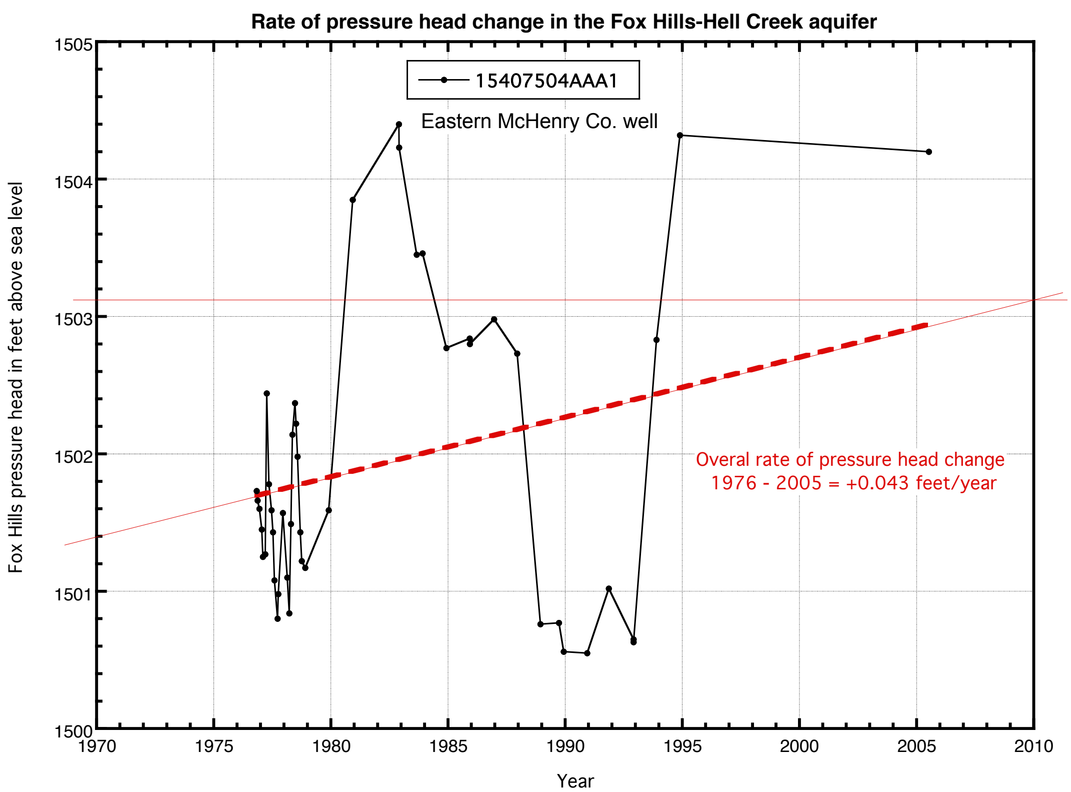


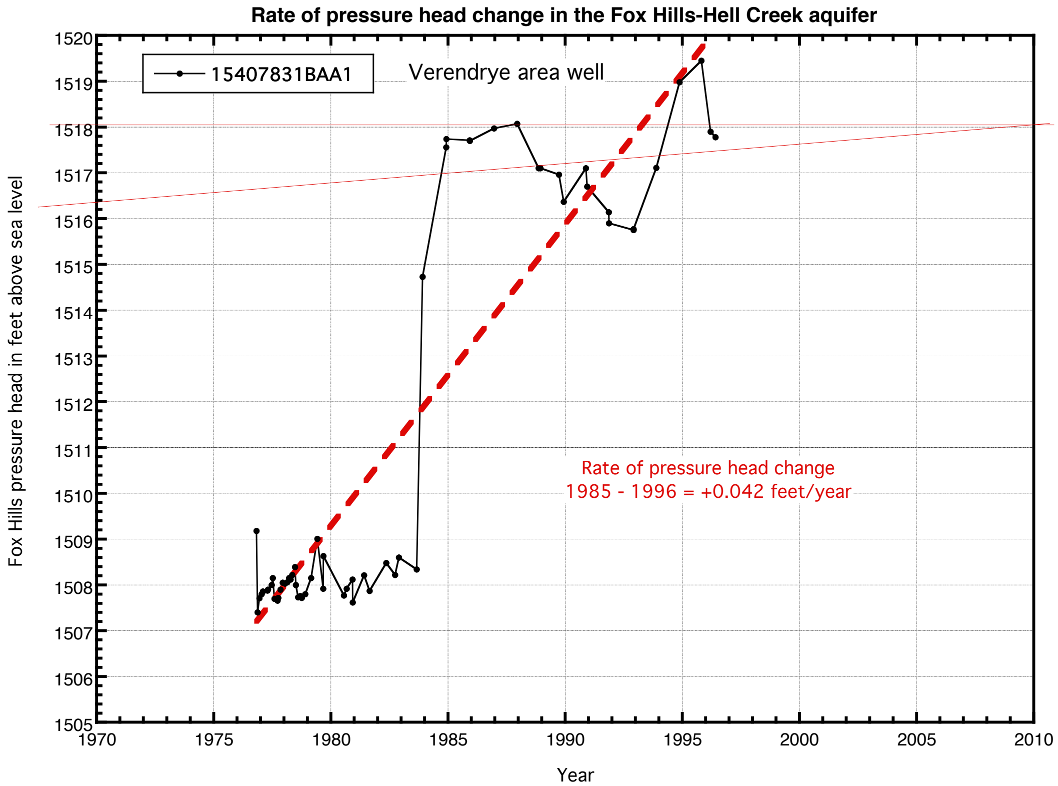
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15309423CCC1
Antelope well
Rate of pressure head change
1990 - 2009 = -2.06 feet/year
Pressure head influenced
by Lake Sakakawea rising
Rate of pressure head change
1995 to 2009 = -2.08 feet/year
Fox Hills pressure head in feet above sea level
Year
2070
2080
2090
2100
2110
2120
1970
1975
1980
1985
1990
1995
2000
2005
2010

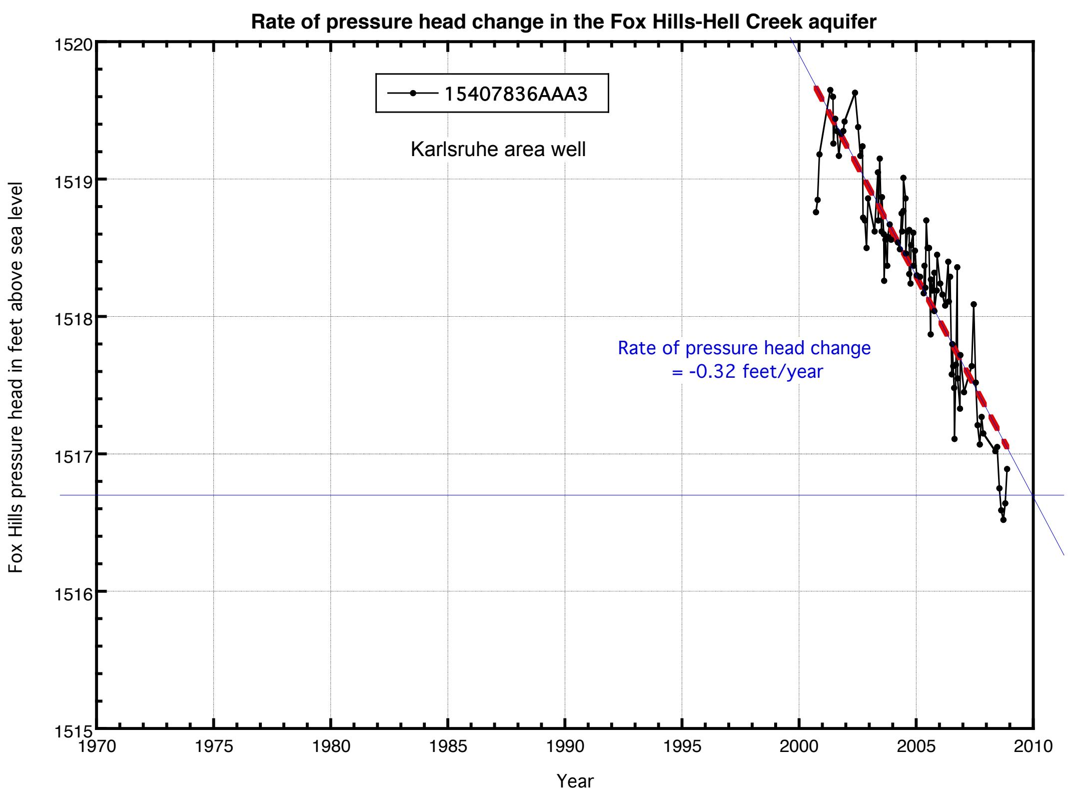

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15309611ADA
Sand Creek well
Gas head
dissipating
Rate of pressure head change
1995 - 2006 = -3.06 feet/year
2006 - 2009 = +1.40 feet/year
Fox Hills pressure head in feet above sea level
Year
2190
2180
2170
2160
2150
2140
2130
2120
2110
2100
2090
2080
2070
2060
2050
2040
2030
2020
2010
1970
1975
1980
1985
1990
1995
2000
2005
2010

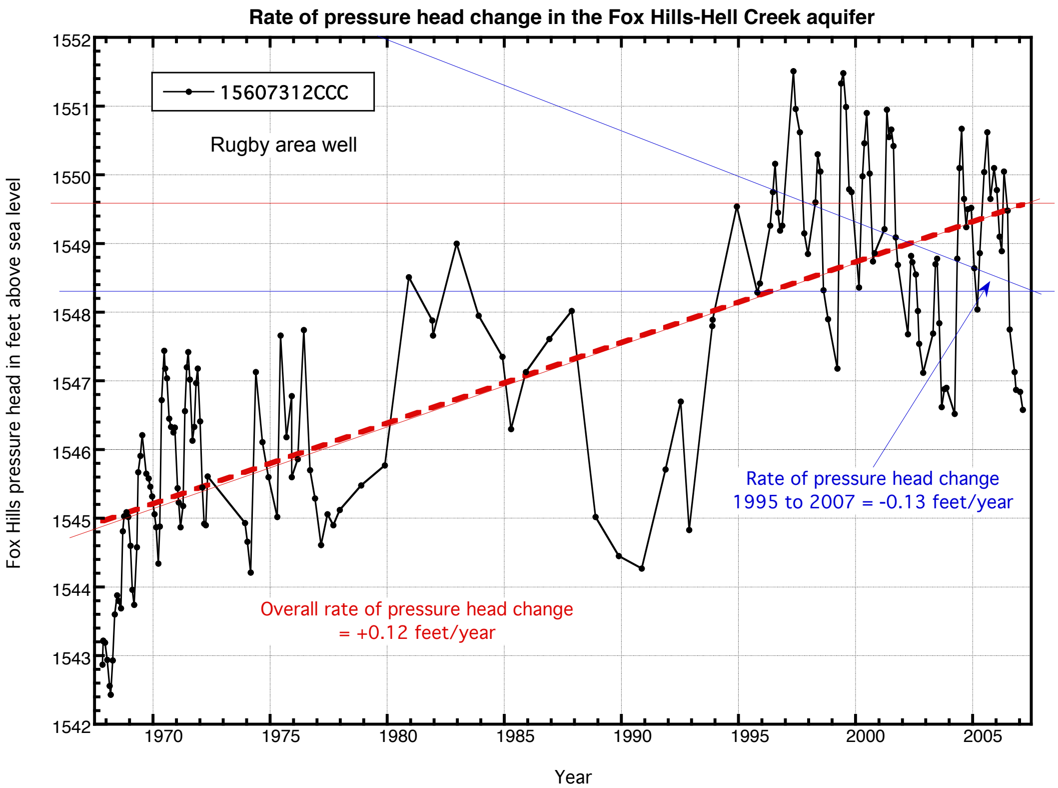

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15309620DCB1
Tobacco Garden (SE) well
Gas head
dissipating
Rate of pressure head change
1998 - 2009 = -1.86 feet/year
Gas head
returning?
Fox Hills pressure head in feet above sea level
Year
2110
2100
2090
2080
2070
2060
2050
2040
1970
1975
1980
1985
1990
1995
2000
2005
2010

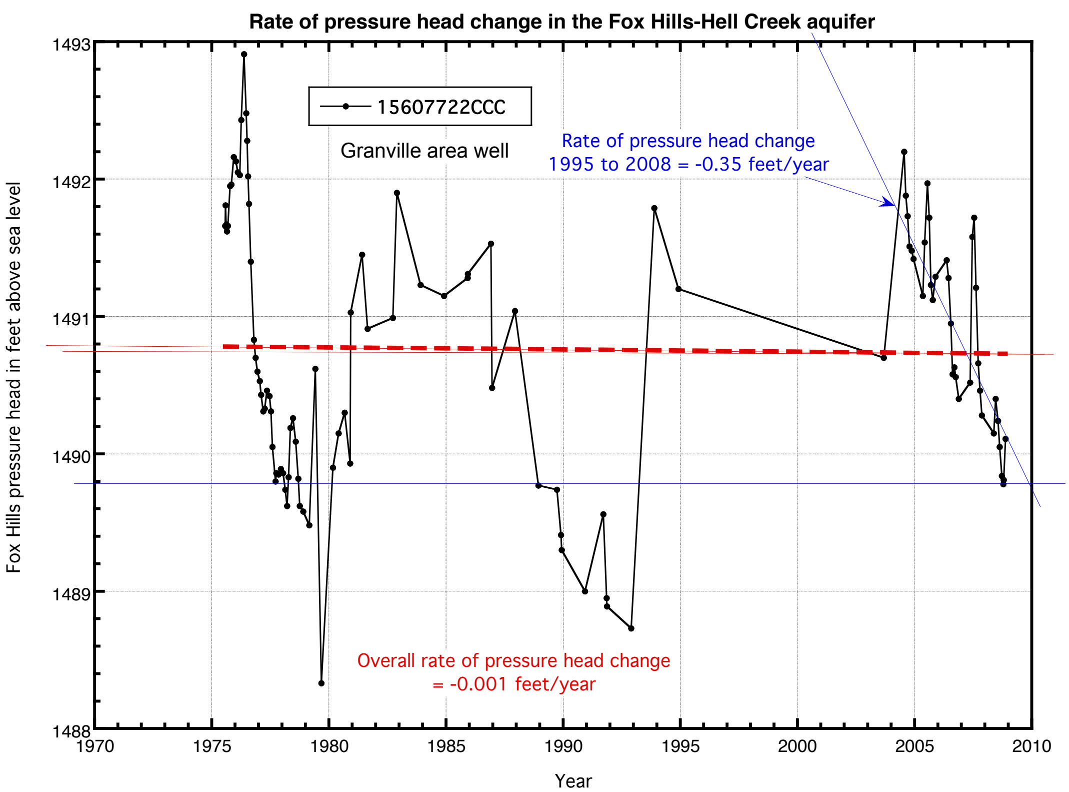

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15407111AAD1
North of Esmond well
Rate of pressure head change
1995 to 2007 = 0.12 feet/year
Overall rate of pressure head change
1998 - 2009 = +0.085 feet/year
Fox Hills pressure head in feet above sea level
1590
1589
1588
1587
1586
1585
1584
1583
1582
1581
1580
1970
1975
1980
1985
1990
1995
2000
2005
Year

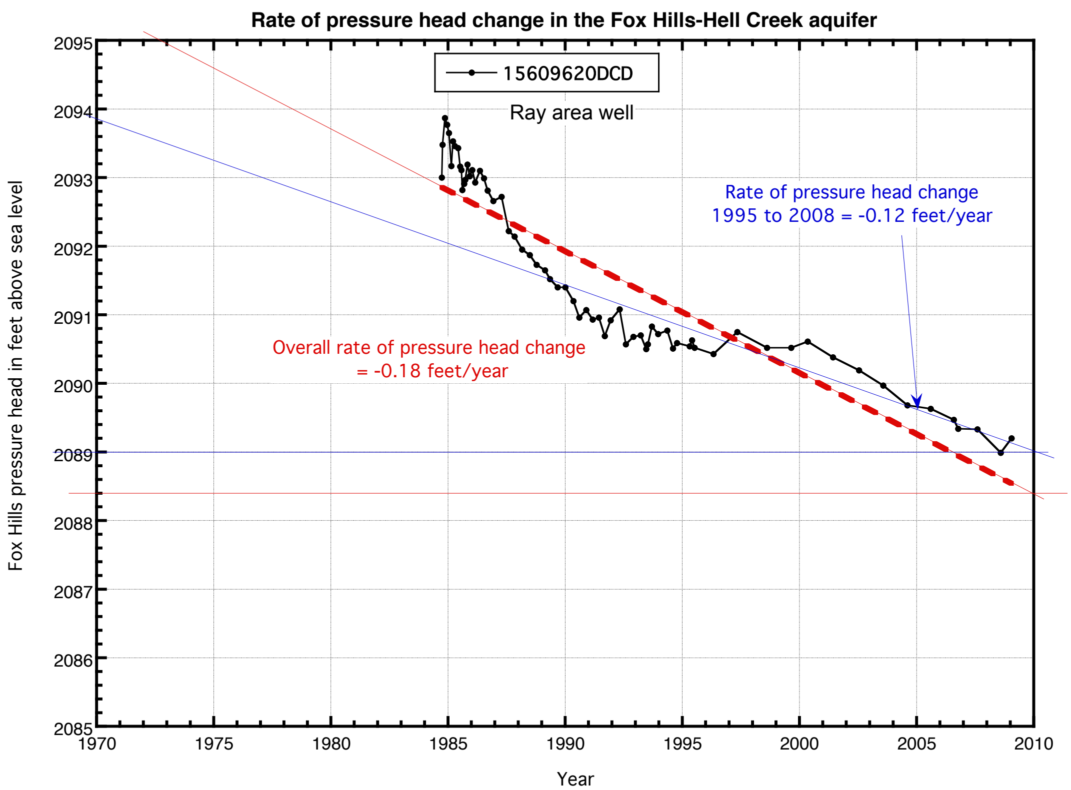

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15407504AAA1
Eastern McHenry Co. well
Overal rate of pressure head change
1976 - 2005 = +0.043 feet/year
Fox Hills pressure head in feet above sea level
1505
1504
1503
1502
1501
1500
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15407831BAA1
Verendrye area well
Rate of pressure head change
1985 - 1996 = +0.042 feet/year
Fox Hills pressure head in feet above sea level
Year
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1970
1975
1980
1985
1990
1995
2000
2005
2010

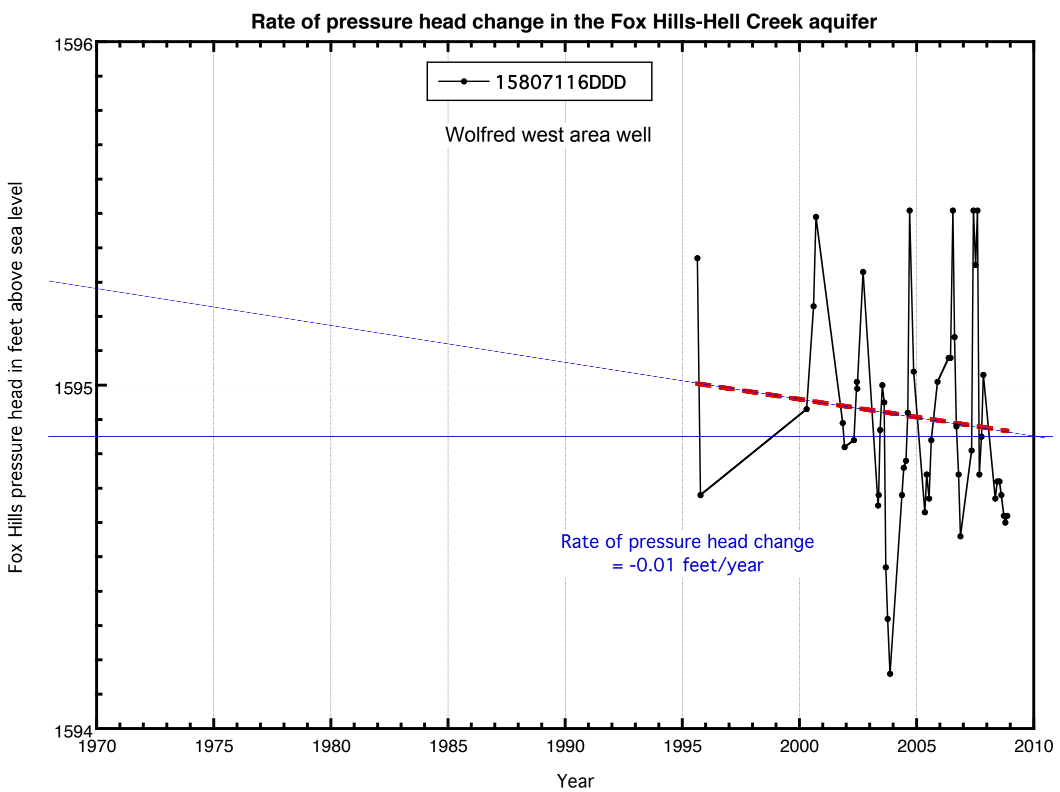

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15407836AAA3
Karlsruhe area well
Rate of pressure head change
= -0.32 feet/year
Fox Hills pressure head in feet above sea level
Year
1515
1516
1517
1518
1519
1520
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15607312CCC
Rugby area well
Rate of pressure head change
1995 to 2007 = -0.13 feet/year
Overall rate of pressure head change
= +0.12 feet/year
Fox Hills pressure head in feet above sea level
Year
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1970
1975
1980
1985
1990
1995
2000
2005

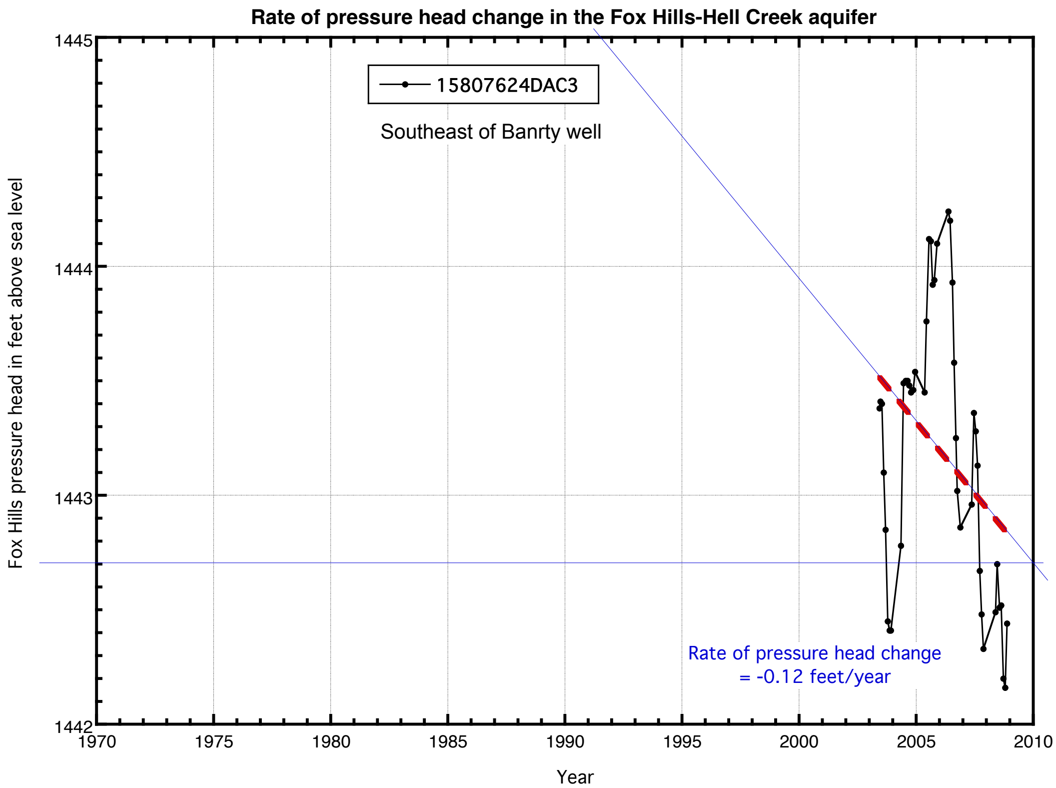

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15607722CCC
Granville area well
Rate of pressure head change
1995 to 2008 = -0.35 feet/year
Overall rate of pressure head change
= -0.001 feet/year
Fox Hills pressure head in feet above sea level
Year
1488
1489
1490
1491
1492
1493
1970
1975
1980
1985
1990
1995
2000
2005
2010



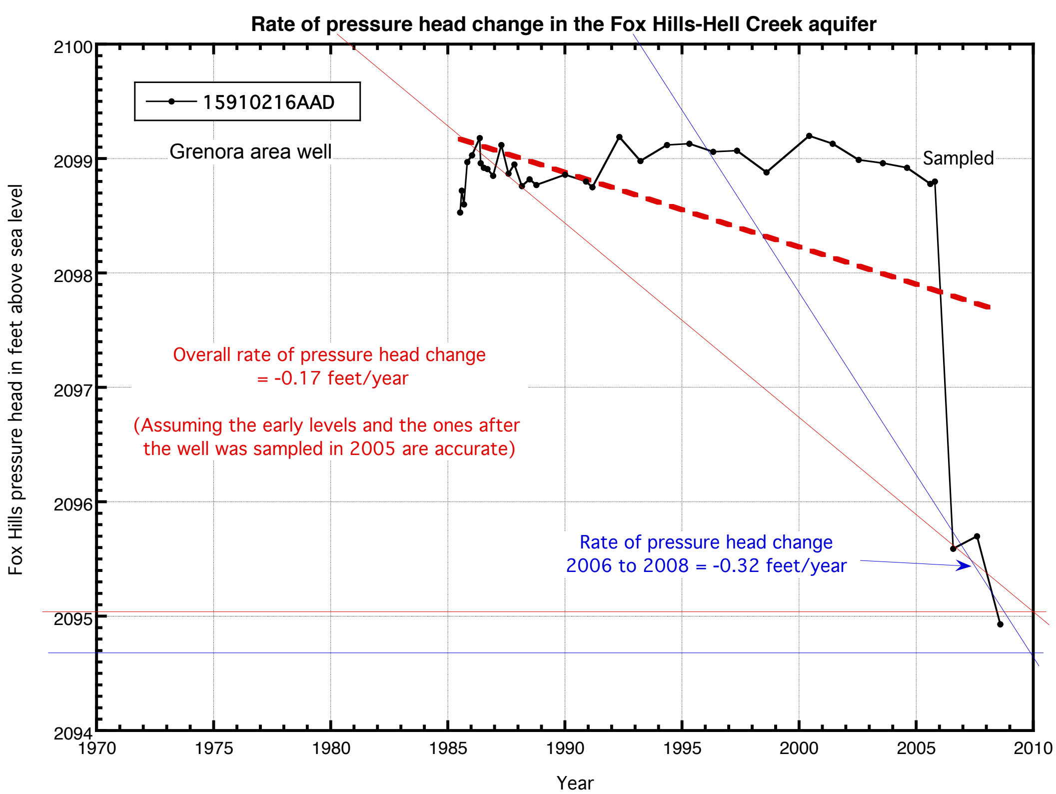
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15609620DCD
Ray area well
Rate of pressure head change
1995 to 2008 = -0.12 feet/year
Overall rate of pressure head change
= -0.18 feet/year
Fox Hills pressure head in feet above sea level
Year
2095
2094
2093
2092
2091
2090
2089
2088
2087
2086
2085
1970
1975
1980
1985
1990
1995
2000
2005
2010



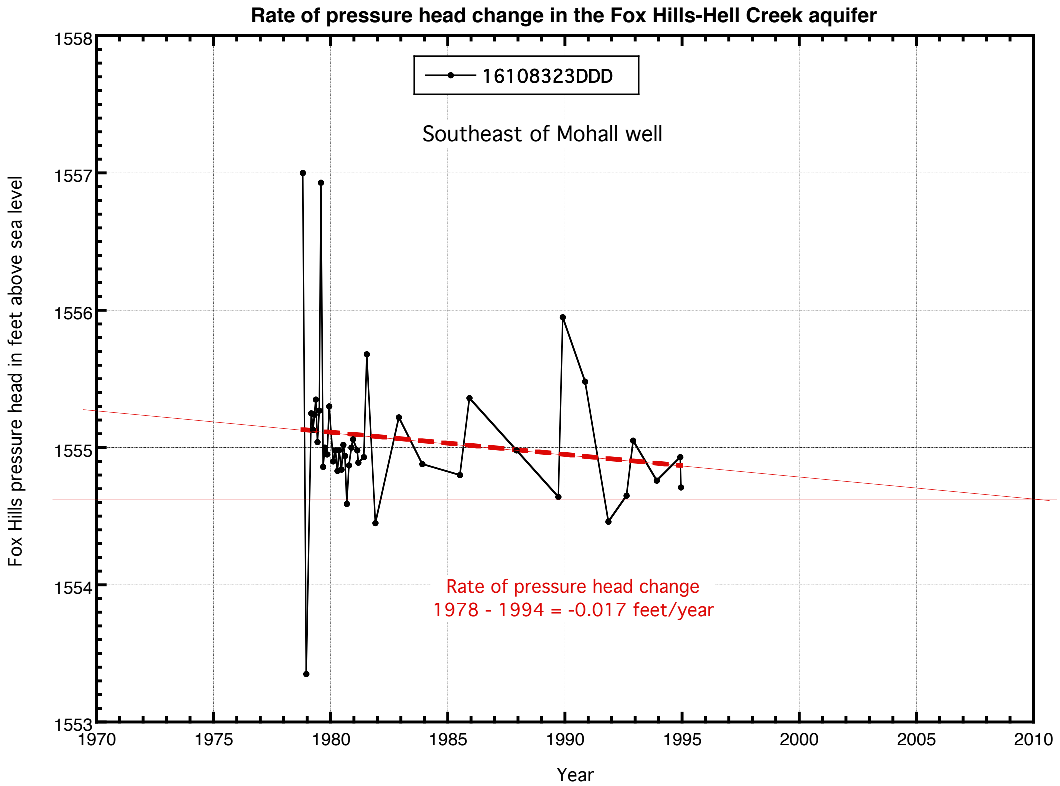
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15807116DDD
Wolfred west area well
Rate of pressure head change
= -0.01 feet/year
Fox Hills pressure head in feet above sea level
Year
1596
1595
1594
1970
1975
1980
1985
1990
1995
2000
2005
2010

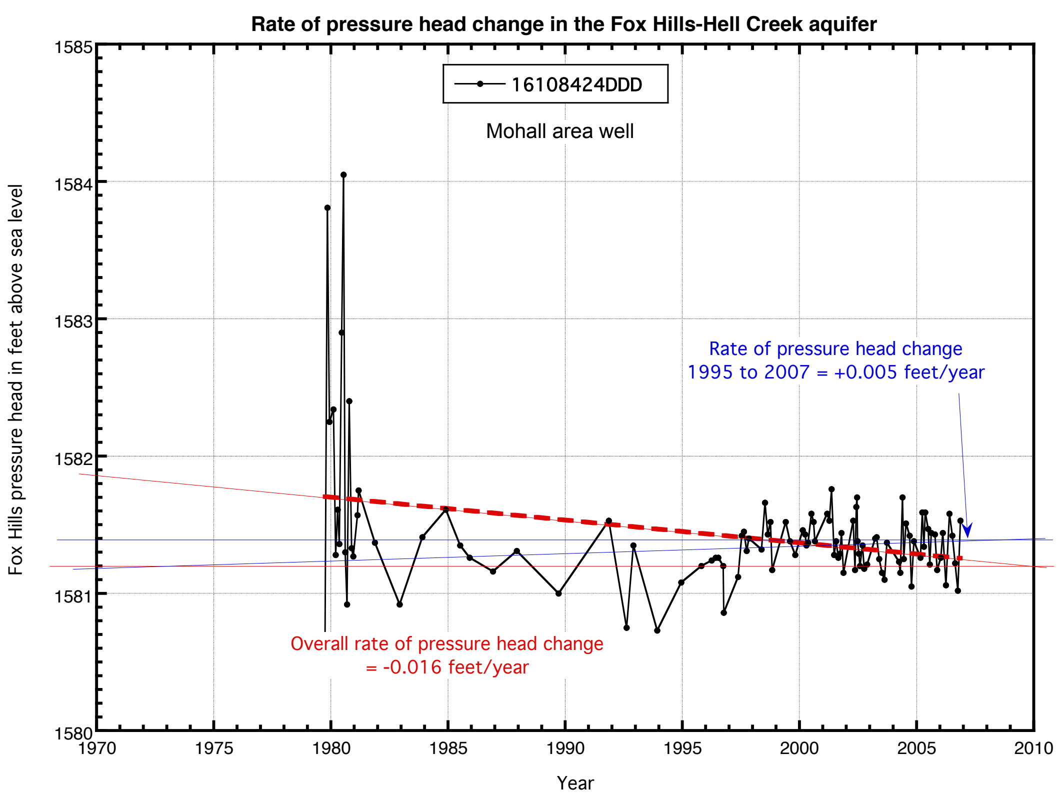


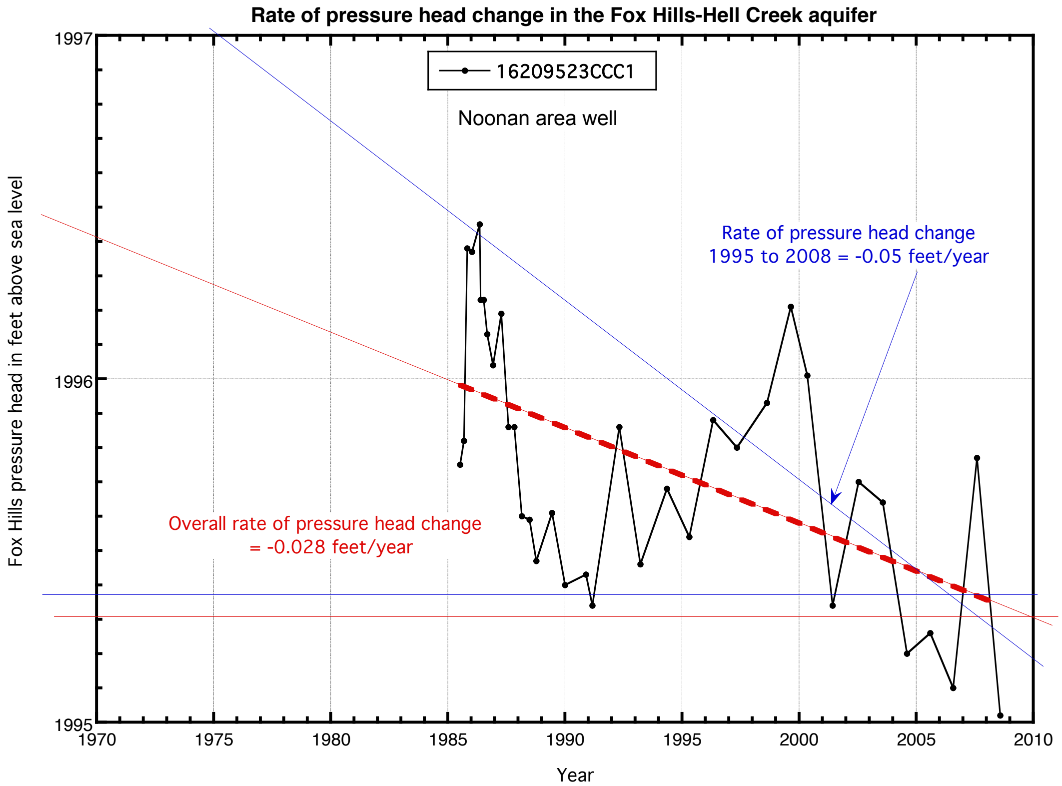
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15807624DAC3
Southeast of Banrty well
Rate of pressure head change
= -0.12 feet/year
Fox Hills pressure head in feet above sea level
Year
1445
1444
1443
1442
1970
1975
1980
1985
1990
1995
2000
2005
2010

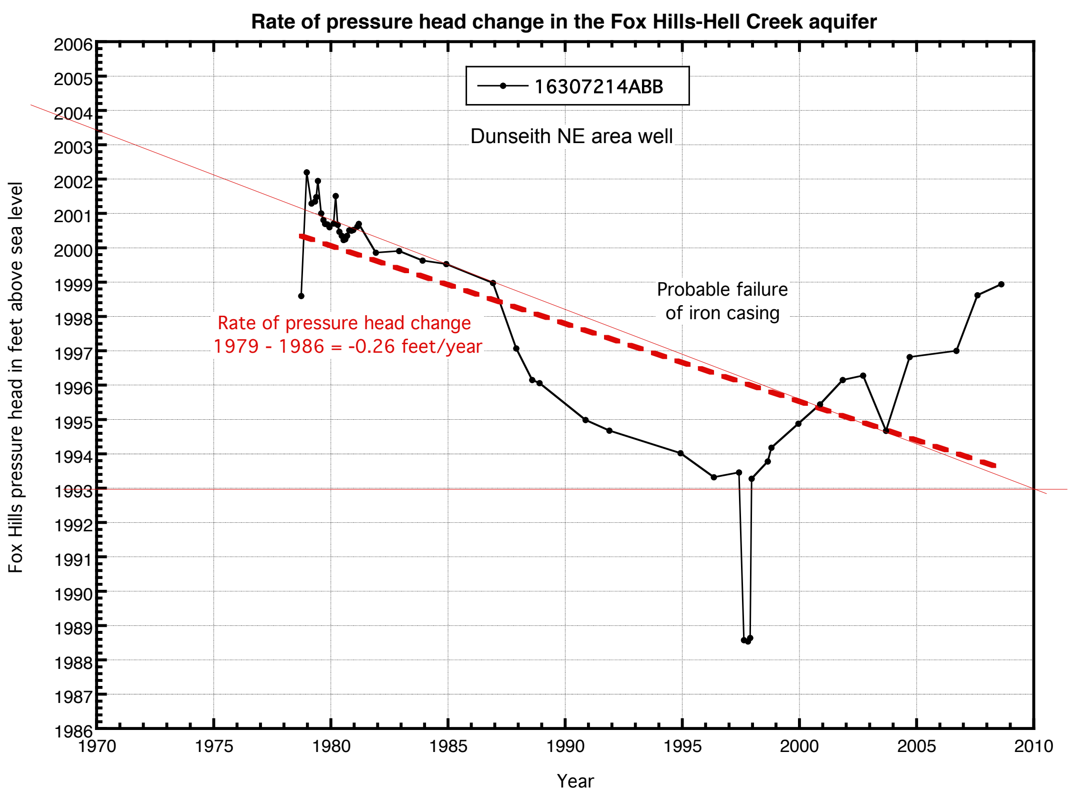


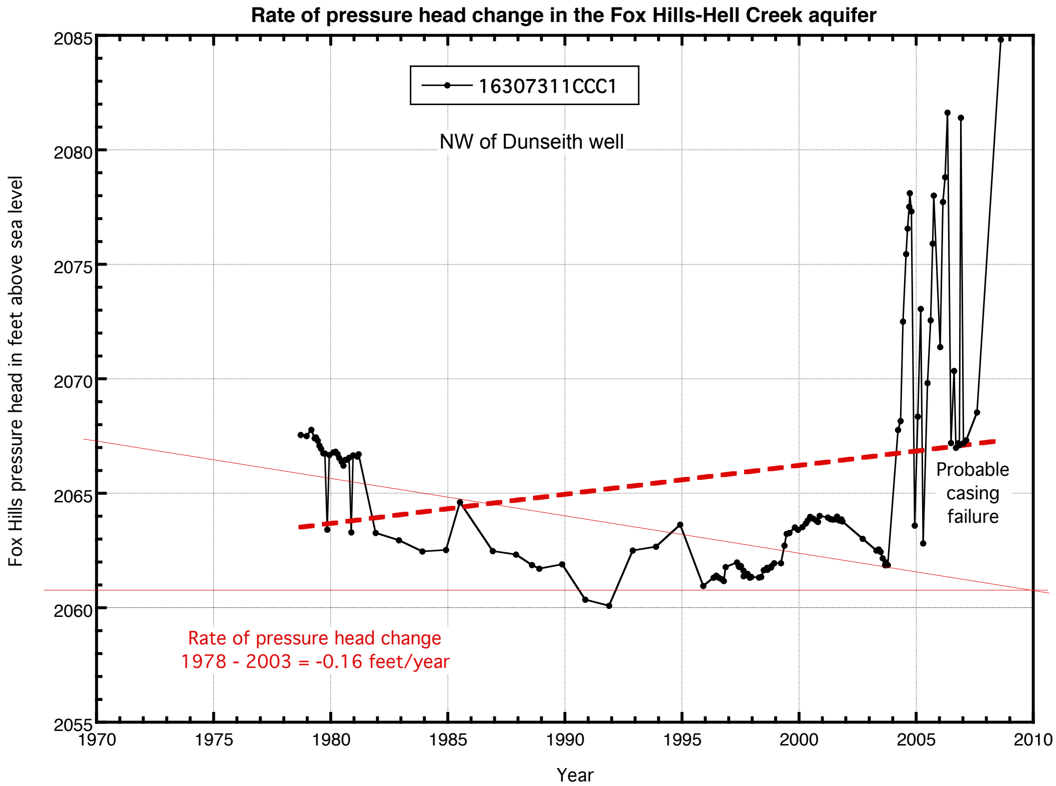
Rate of pressure head change in the Fox Hills-Hell Creek aquifer
15910216AAD
Grenora area well
Sampled
Overall rate of pressure head change
= -0.17 feet/year
(Assuming the early levels and the ones after
the well was sampled in 2005 are accurate)
Rate of pressure head change
2006 to 2008 = -0.32 feet/year
Fox Hills pressure head in feet above sea level
Year
2100
2099
2098
2097
2096
2095
2094
1970
1975
1980
1985
1990
1995
2000
2005
2010

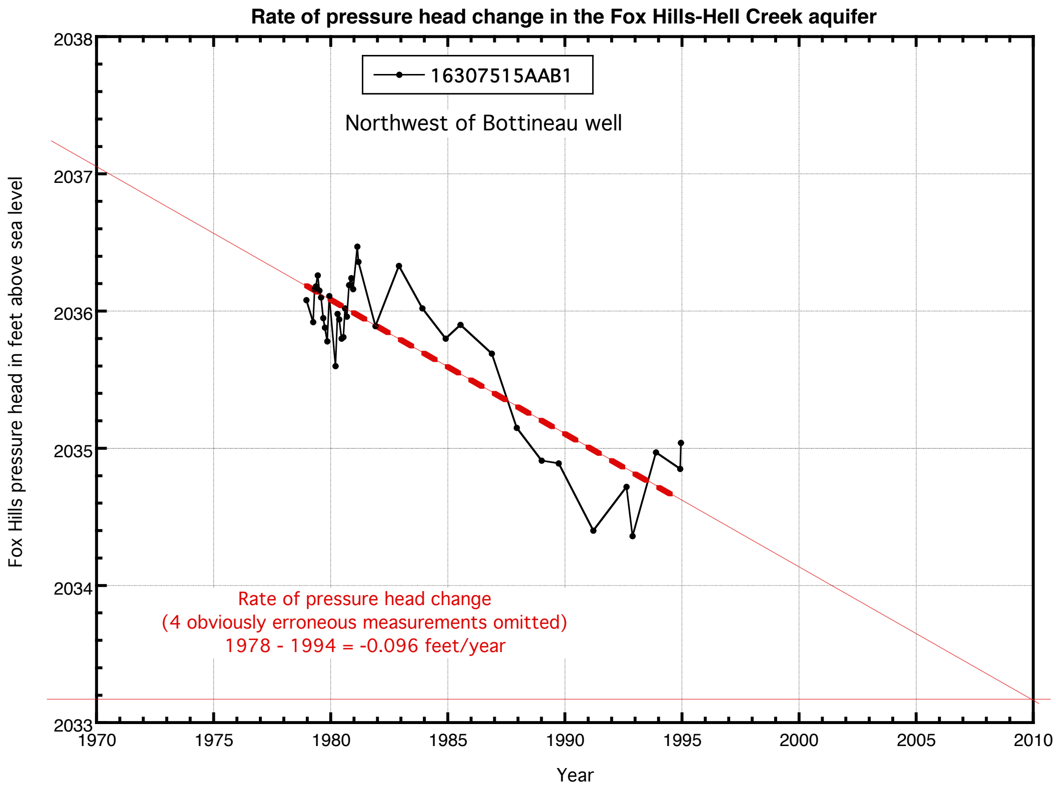

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
16108323DDD
Southeast of Mohall well
Rate of pressure head change
1978 - 1994 = -0.017 feet/year
Fox Hills pressure head in feet above sea level
Year
1553
1554
1555
1556
1557
1558
1970
1975
1980
1985
1990
1995
2000
2005
2010

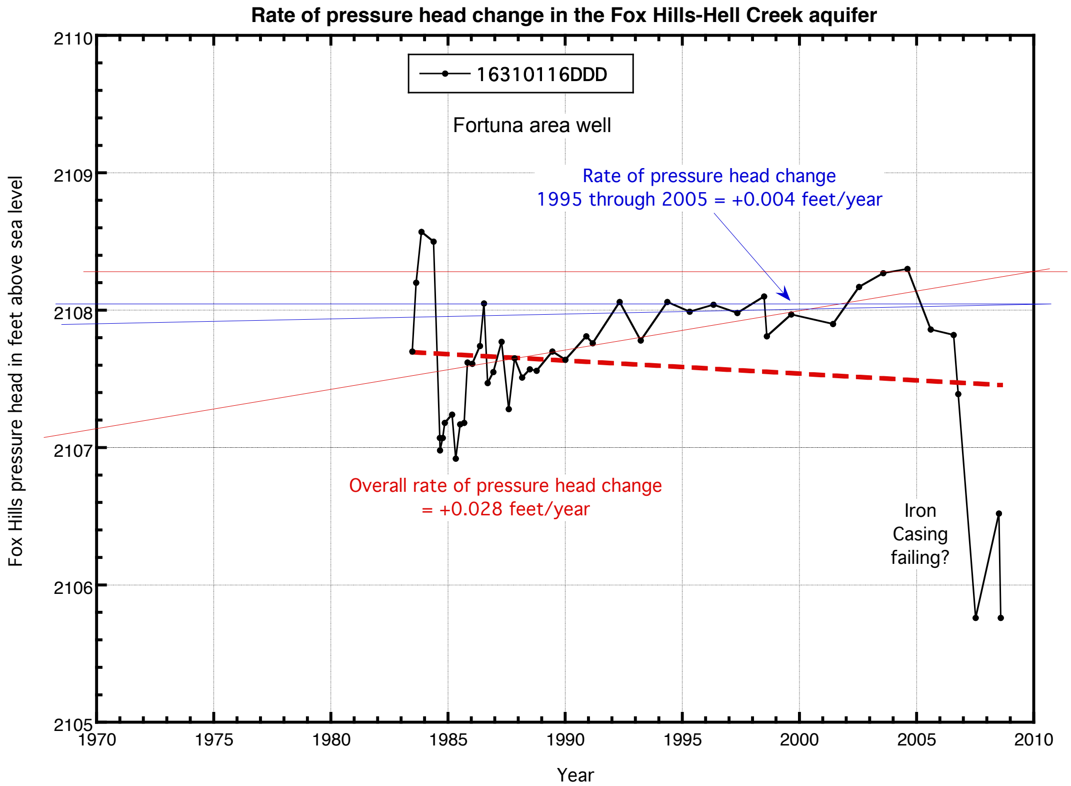

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
16108424DDD
Mohall area well
Rate of pressure head change
1995 to 2007 = +0.005 feet/year
Overall rate of pressure head change
= -0.016 feet/year
Fox Hills pressure head in feet above sea level
Year
1580
1581
1582
1583
1584
1585
1970
1975
1980
1985
1990
1995
2000
2005
2010

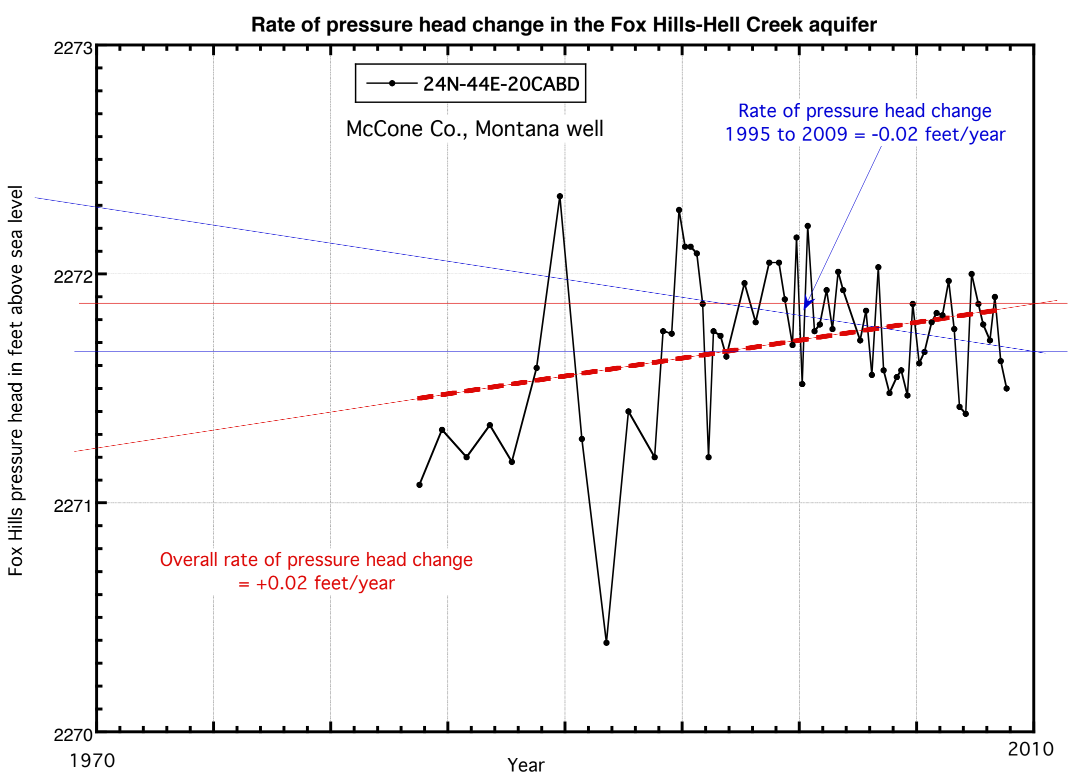

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
16209523CCC1
Noonan area well
Rate of pressure head change
1995 to 2008 = -0.05 feet/year
Overall rate of pressure head change
= -0.028 feet/year
Fox Hills pressure head in feet above sea level
Year
1997
1996
1995
1970
1975
1980
1985
1990
1995
2000
2005
2010

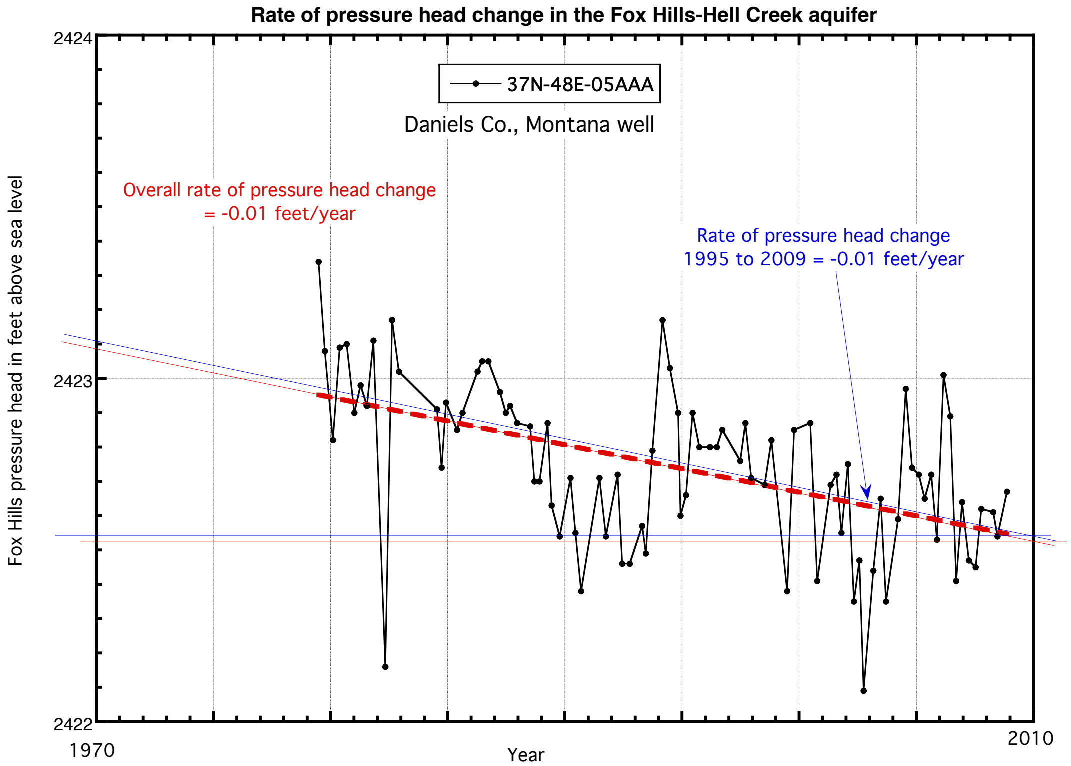

Rate of pressure head change in the Fox Hills-Hell Creek aquifer
16307214ABB
Dunseith NE area well
Probable failure
of iron casing
Rate of pressure head change
1979 - 1986 = -0.26 feet/year
Fox Hills pressure head in feet above sea level
Year
2006
2005
2004
2003
2002
2001
2000
1999
1998
1997
1996
1995
1994
1993
1992
1991
1990
1989
1988
1987
1986
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
16307311CCC1
NW of Dunseith well
Probable casing failure
Rate of pressure head change
1978 - 2003 = -0.16 feet/year
Fox Hills pressure head in feet above sea level
Year
2085
2080
2075
2070
2065
2060
2055
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
16307515AAB1
Northwest of Bottineau well
Rate of pressure head change
(4 obviously erroneous measurements omitted)
1978 - 1994 = -0.096 feet/year
Fox Hills pressure head in feet above sea level
Year
2038
2037
2036
2035
2034
2033
1970
1975
1980
1985
1990
1995
2000
2005
2010


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
16310116DDD
Fortuna area well
Rate of pressure head change
1995 through 2005 = +0.004 feet/year
Overall rate of pressure head change
= +0.028 feet/year
Iron
Casing
failing?
Fox Hills pressure head in feet above sea level
2110
2109
2108
2107
2106
2105
1970
1975
1980
1985
1990
1995
2000
2005
2010
Year


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
24N-44E-20CABD
McCone Co., Montana well
Rate of pressure head change
1995 to 2009 = -0.02 feet/year
Overall rate of pressure head change
= +0.02 feet/year
Fox Hills pressure head in feet above sea level
2273
2272
2271
2270
1970
2010
Year


Rate of pressure head change in the Fox Hills-Hell Creek aquifer
37N-48E-05AAA
Daniels Co., Montana well
Overall rate of pressure head change
= -0.01 feet/year
Rate of pressure head change
1995 to 2009 = -0.01 feet/year
Fox Hills pressure head in feet above sea level
2424
2423
2422
1970
2010
Year