NORTH DAKOTA
WELLHEAD
PROTECTION

Hydrologic Assessment and Delineation of Wellhead Protection Areas for the City of Stanley, North Dakota

By
Christopher D. Bader
and
Scott A. Radig

North Dakota Ground-Water Studies
Number 96
North Dakota State Water Commission

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INTRODUCTION

In 1986, the amendments to the Safe Drinking Water Act (SDWA) provided for the development of a Wellhead Protection (WHP) Program designed to protect groundwater derived public water systems from potential contaminant sources. The goal of the WHP Program is to promote the protection of groundwater resources through local governmental entities such as municipalities and regional water resource districts. As mandated by the 1986 SDWA requirements, the North Dakota State Department of Health and Consolidated Laboratories has developed and is implementing a WHP Program.

The North Dakota Wellhead Protection Program addresses each of the following elements required by the SDWA:

1. Roles and duties of State agencies, local governments, and public water systems, with respect to the development and implementation of WHP programs.
2. Delineation of a Wellhead Protection Area (WHPA) around each public water supply well, utilizing reasonably available hydrogeologic information.
3. Identification of potential contaminant sources within each WHPA that may have adverse effects on the groundwater environment or public health.
4. Development of management approaches to protect the groundwater resource within each WHPA from potential contaminant sources.
5. Development of contingency plans for use in the case of an emergency that could threaten the quality of the groundwater resource or affect its suitability as a public water supply.
6. Locating new wells in areas that have a low probability of being contaminated.
7. Public participation in the development and implementation of the WHP Program.

The city council of Stanley has chosen to participate in the North Dakota WHP Program. In October, 1989, the North Dakota State Department of Health and Consolidated Laboratories (NDSDHCL), the North Dakota State Water Commission (NDSWC), and the City of Stanley entered into a cooperative agreement to complete a hydrogeologic investigation of the area surrounding Stanley's municipal well field in order to delineate an appropriate WHPA.

Purpose and Objectives

The purpose of this report is to delineate a wellhead protection area for Stanley's municipal wells which will establish the basis for implementing a WHP program for the city of Stanley. In order to delineate a WHPA, an understanding of the hydrogeologic setting of the area surrounding Stanley's municipal wells is required, which includes:

1.) Size and shape of the aquifer systems contributing to Stanley's municipal water supply.

2.) Groundwater flow characteristics of the aquifer system and the physical relationship between the aquifer material and adjacent material, as well as, the interaction between the surficial aquifer system and the surface water reservoir located south of Stanley.

3.) Water quality characteristics of the surficial aquifer, the underlying bedrock aquifer material, and the surface water reservoir.

The establishment of a wellhead protection area for the City of Stanley will also require designation of the zone of contribution (ZOC) surrounding the municipal wells, which is defined as follows:

Zone of Contribution - is the area contributing water to the city's wells, which would include the entire groundwater flow system contributing water to the municipal wells, as well as, any components of the surface systems contributing to the municipal wells.

Description of Study Area

The study area consists of an approximate 36 square mile area surrounding the city of Stanley. The study area includes most of Township 156 North, Range 91 West; and parts of Township 156 North, Range 90 West, and Township 155 North, Range 91 West, which are located in Mountrail County, North Dakota (figure 1).

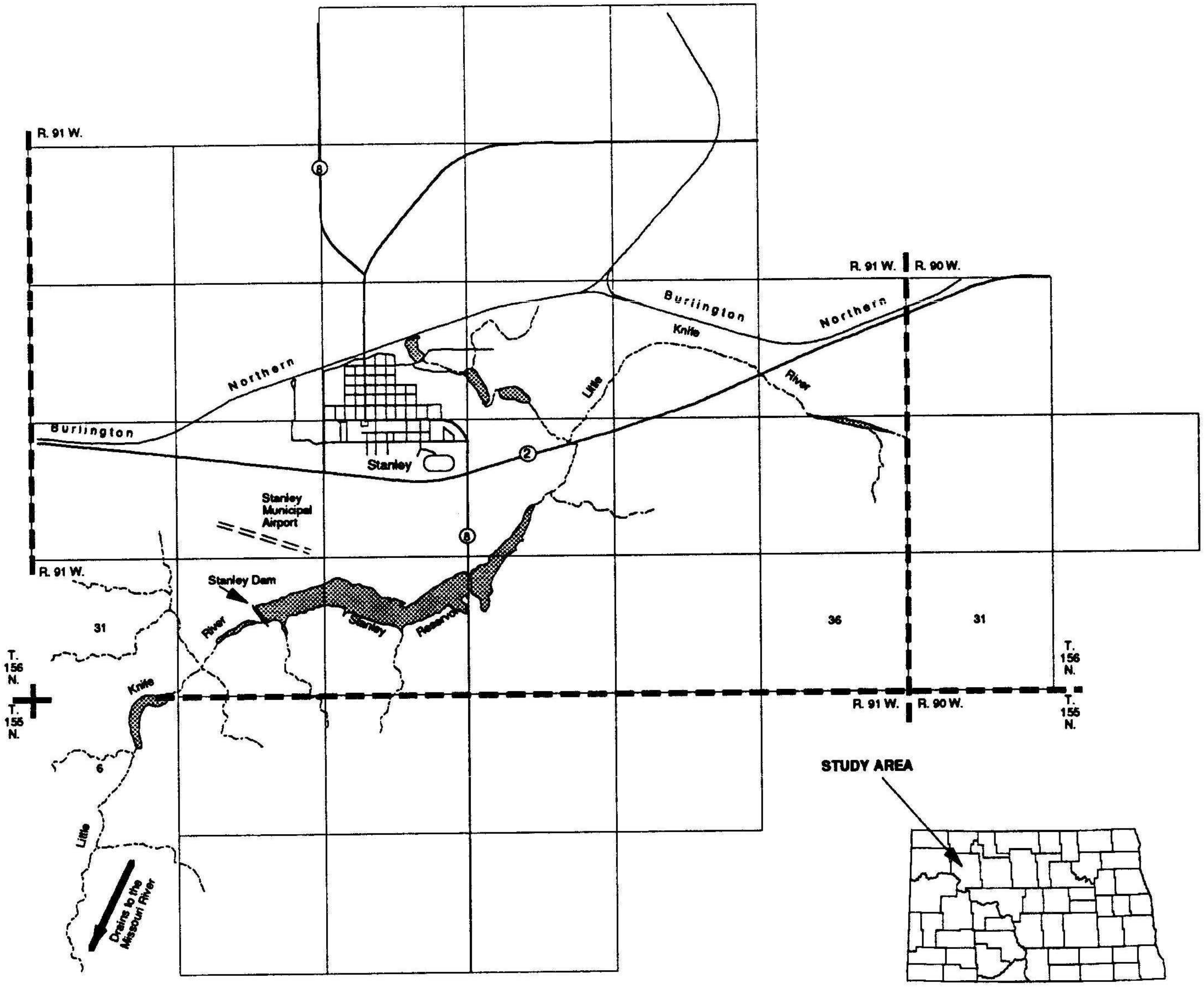

Figure 1 - Location of the study area.

The study area is situated on the upland side of the Coteau Slope District of the Great Plains physiographic province. The topography consists of hummocky terrain characterized by poorly to moderately integrated drainage and numerous small undrained depressions. The study area includes the headwaters of the Little Knife River which is a tributary to the Missouri River. The Little Knife River valley extends across the study area to the west, and land surface elevations range from approximately 2,150 feet in the river valley to over 2,350 feet in the northwestern portion of the study area.

An impoundment structure, known as the Stanley Dam, was constructed across the Little Knife River valley in approximately the center of Section 32, Township 156 North, Range 91 West (figure 1). The reservoir, created by the Stanley Dam, extends up the Little Knife River Valley across Sections 33, 34, and 27, all of Township 156 North, Range 91 West. The impoundment structure was constructed with a maximum pool elevation of 2155.4 feet, and at a pool elevation of 2155.4 feet, the surface area of the reservoir is approximately 250 acres.

Previous Investigations

The geology and groundwater resources of Mountrail County were first described by Simpson (1929, p. 174-177) as part of an overview of groundwater resources within the state of North Dakota. Alpha (1935) provided a more detailed description of the groundwater resources of Burke, Divide, Mountrail, and Williams Counties. Paulson (1954) described the groundwater resources within the Stanley area in relation to municipal development.

A county groundwater survey was completed for Burke and Mountrail Counties on a cooperative basis by the NDSWC, the North Dakota State Geological Survey (NDGS), and the United States Geological Survey (USGS). The groundwater survey was published in four parts. *Part I - Geology of Burke County, North Dakota* (Freers, 1973) describes the surface and subsurface geology in Burke County. *Part II - Groundwater Basic Data* (Armstrong, 1969) includes lithologic logs, chemical analyses, and water level records for wells and test holes within the two county area. *Part III - Groundwater Resources of Burke and Mountrail Counties* (Armstrong, 1971) describes the hydrogeology of Burke and Mountrail Counties including the water yielding potential and chemical properties of the water from the major bedrock, glacial, and alluvial aquifers. *Part IV - Geology of Mountrail County North Dakota* (Clayton, 1972) describes the surface and subsurface geology in Mountrail County.

Methodology

In addition to the available test hole information, test holes were drilled at 17 sites using a forward mud rotary drilling rig. Lithologic logs were prepared by the site geologist and driller's logs were completed by the driller for each site. Piezometers were installed at 7 of the 17 test hole locations. Water levels were measured at each of the piezometer sites, and water samples were collected from each piezometer for water quality analysis. The locations of all of the test holes and piezometers are presented in figure 2. Lithologic logs for all of the test holes and wells are included in Appendix A.

Piezometer Construction

The piezometers were constructed of 2 inch diameter SDR 21 polyvinyl chloride (PVC) pipe with either a 0.012 inch or 0.018 inch slot PVC screen. Piezometer lengths varied depending upon the aquifer depth at the site location. The majority of the piezometers were constructed with 5 feet of screen with the exception of the well located at 156-091-28ACA in which 20 feet of screen was installed. In each of the piezometers a check-valve was attached to the bottom of the screen. For the piezometers constructed in the surficial aquifer, the screens were typically placed in the basal 5 feet of the aquifer. For the piezometers constructed in the bedrock aquifer, the screens were typically placed in the basal portion of the bedrock aquifer interval. The piezometer casing and screens were assembled using a PVC solvent weld cement.

Upon installation of the casing, screen, and check valve assembly in the test hole, the test hole was back-washed with fresh water to remove the drilling fluid. A sand pack was placed around the screen using a 1.25-inch diameter PVC tremie pipe that was inserted in the annular area between the wall of the hole and the casing. The sand pack consisted of a #10, medium size quartzose sand. With the sand pack in place, the tremie pipe was used to inject a cement slurry, consisting of a Volclay grout mixture, from the top of the sand pack to land surface. After the cement was allowed to set, a bentonite grout was placed from the settled cement surface to land surface.

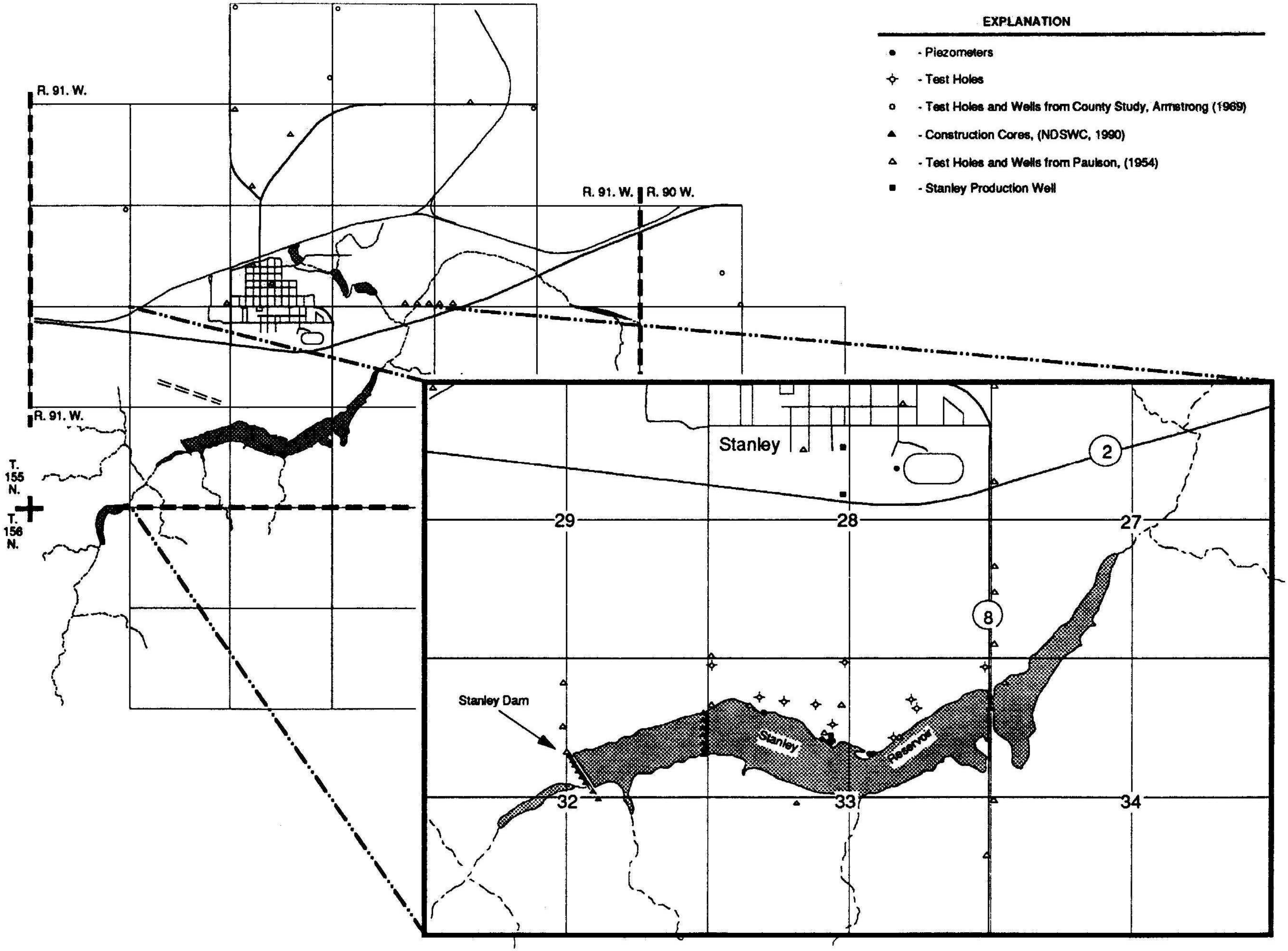

Figure 2 - Location of test holes and piezometers within the study area.

Upon completion of the installation of the piezometers, most of the piezometers were pumped with air using an air compressor. Some of the piezometers which could not be pumped using air-lift methods were bailed manually.

Water-Level Measurements

Beginning in November 1989, water levels were measured weekly in each of the piezometers. Weekly water-level measurements were made by Stanley's city maintenance personnel and were cross-referenced by monthly measurements made by NDSWC personnel. Water levels were measured by inserting a chalked, steel tape into the piezometers and recording the depth to water from the top of the piezometer to the nearest 0.01 foot. The elevation of the top of the piezometer or the M.P. (measuring point) was established to the nearest 0.01 foot using differential leveling techniques.

A staff gauge was installed in the reservoir in February 1990 for purposes of measuring reservoir stage. The reservoir stage was recorded to the nearest 0.1 foot. The staff gauge was surveyed to the nearest 0.01 foot using differential leveling techniques.

Chemical sampling procedures

Water samples were collected from the surface reservoir, the city production wells, and each of the piezometers and sent to the NDSDHCL and the NDSWC laboratories for major cation-anion analysis. Each piezometer was developed, prior to sampling, by air-lift or bailing to remove excess drilling fluid and potential contamination from the screen, sand-pack, and adjacent formation. The samples were collected after a volume equivalent to three times the static water column was purged from each well. Both the temperature and the electrical conductance were measured in the field as the samples were collected.

Water samples were collected from the majority of the piezometers using either a submersible pump or air-lift methods to pump the water. Water samples were also collected from the piezometers that could not be pumped with either the submersible pump or air-lift methods with a Teflon bailer. Water samples from the reservoir were collected approximately 6 inches above the bottom of the reservoir using a Kemmerer Sampler.

Water samples for major cation-anion analysis included 500 milliliters of raw water, 500 milliliters of filtered water, and 500 milliliters of filtered water which was acidified with nitric acid. A 0.45 micron filter was used to obtain the filtered samples. The water quality analyses are included in Appendix B.

Location-Numbering System

The description used to denote a well or test hole location is based upon the federal system of rectangular surveys of public land (figure 3). The first number identifies the township north of an established baseline, and the second number identifies the range west of the Fifth Principal Meridian. The third number identifies the section within the designated township and range in which the well or test hole is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section (160 acre tract), quarter-quarter section (40 acre tract), and quarter-quarter-quarter (10 acre tract). Therefore, a well identified as 156-091-4AAD would be located in the SE1/4 NE1/4 NE1/4 Section 33, Township 156 North, Range 91 West (figure 3). Consecutive terminal numbers are added if more than one well is located in a given 10 acre tract, i.e., 156-091-33ACB$_1$ and 156-091-33ACB$_2$

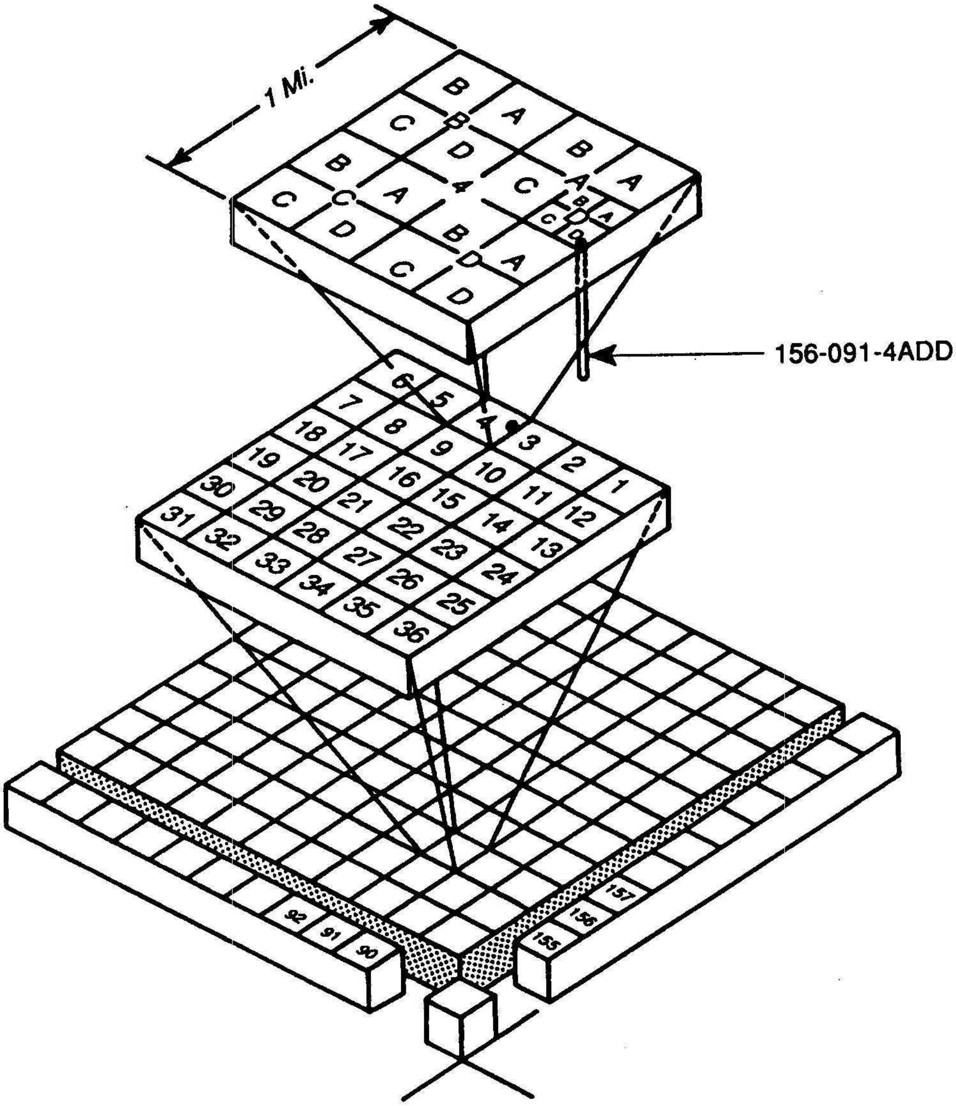

Figure 3 - Location numbering system.

Acknowledgements

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MUNICIPAL WATER SUPPLY

Prior to 1964, Stanley obtained it's water supply from three wells completed in the bedrock deposits of the Fort Union Group. The water quality associated with these three wells was fairly poor, and in the early 1950's, efforts were made to isolate a more suitable water supply for the city of Stanley. The geology and groundwater resources in the area surrounding Stanley were described by Paulson (1954), and the surficial sand and gravel outwash deposits along the Little Knife River valley were identified as a possible alternative for the city of Stanley.

In assessing the potential for developing a water supply from the surficial deposits, Paulson (1954) indicated that the aquifer by itself did not possess sufficient storage capabilities to meet Stanley's long term water supply demands. However, Paulson also pointed out that, if the city were to install a well or series of wells along the shore of the reservoir, pumping from the aquifer would likely induce recharge from the surface reservoir. The resulting storage available to Stanley would, therefore, be determined by the available storage in both the aquifer and the surface water reservoir.

At the time Paulson (1954) conducted his evaluation, the small surface reservoir was created by a dam constructed across the river valley along the section line between sections 32 and 33. The dam was constructed by Great Northern Railway for purposes of developing a water supply for use in steam locomotives (Paulson, 1954), and the storage capacity of the resulting reservoir was approximately 700 acre-feet.

In 1964, the city of Stanley installed a production well in the surficial sand and gravel deposits of the Little Knife River Valley aquifer. The production well was constructed to a depth of 26 feet and consists of an 86 inch porous concrete casing. The well is located in the NW 1/4 Section 33, Township 156 North, Range 91 West, along the northern shore of the reservoir created by the Stanley Dam (figure 2).

Early in 1965, as Stanley began to utilize the well, it was discovered that the reservoir could not maintain storage levels sufficient to meet Stanley's water supply needs. The dam which was constructed along the section line between Sections 32 and 33 by Great Northern Railway had been constructed directly over the surficial sand and gravel deposits allowing significant loss of water through the sand and gravel deposits under the dam.

In order to improve the reliability of the water supply from the surficial system, the Stanley Dam, located approximately 1/2 mile west of the old Great Northern Railway dam, was constructed during the late fall of 1968 under NDSWC project #1407. The construction of the Stanley Dam increased the pool elevation of the reservoir by approximately 3.5 feet to 2155.4 feet above sea-level which increased total storage of the reservoir from approximately 700 acre-feet to the current capacity of 1550 acre-feet. The area-capacity curve for the reservoir is included in Appendix C.

The city of Stanley currently utilizes water from two different sources. The city's primary water supply, developed in 1964, is from the surficial sand and gravel deposits of the Little Knife River Valley aquifer. Two additional wells were installed in the bedrock deposits of the Fort Union Group in September of 1990. These wells were installed to provide the city of Stanley with an alternative water supply in response to low water levels in the existing well resulting from drought related stress. Both of the bedrock wells are 6 inches in diameter and are constructed to depths of 240 and 260 feet. The wells installed in the Fort Union Group are located in the NW 1/4 Section 28, Township 156 North, Range 91 West, near the southern edge of Stanley (figure 2).

BEDROCK GEOLOGY

Fox Hills Formation

The Fox Hills Formation consists of a sequence of sandstone, silty shales, and siltstones which were deposited in near-shore coastal marine or deltaic coastal marine environments. The Fox Hills Formation was deposited during a major late Cretaceous regression of the epicontinental seas that covered much of the western interior at the time (Cvancara, 1976). None of the wells in the study area penetrated the Fox Hills Formation; however, the log obtained from an abandoned oil well, the Milestone 32-33 BN, located in Section 33, Township 156 North, Range 91 West, places the Fox Hills Formation at a depth of 1,650 feet below land surface. The Fox Hills Formation rests conformably on the Cretaceous deposits of the Pierre Shale.

Hell Creek Formation

The Hell Creek Formation generally consists of an interbedded sequence of sandstone, siltstone, mudstone, and carbonaceous shales. The Hell Creek Formation was deposited in a near shore, flood-plain or swampy environment as the Late Cretaceous seas receded from the western continental interior (Carlson, 1985). The Hell Creek Formation rests conformably on the late Cretaceous deposits of the Fox Hills Formation.

Fort Union Group

The depth of the Fort Union Group in the study area ranges from a few feet in the Little Knife River Valley to approximately 318 feet in test hole 156-091-10BBB where the White Lake buried valley was incised into the bedrock surface by pre-glacial drainage (figure 4). None of the test holes in the study area completely penetrated the Fort Union Group. However, based upon a geophysical log obtained from an abandoned oil well, the Milestone 32-33 BN, located in Section 33, Township 156 North, Range 91 West, the Fox Hills Formation is approximately 1650 feet below land surface. The Hell Creek Formation is approximately 350 feet thick (Clayton, et al., 1980), and therefore, the thickness of the Fort Union Group within the study area is estimated at about 1,200 feet.

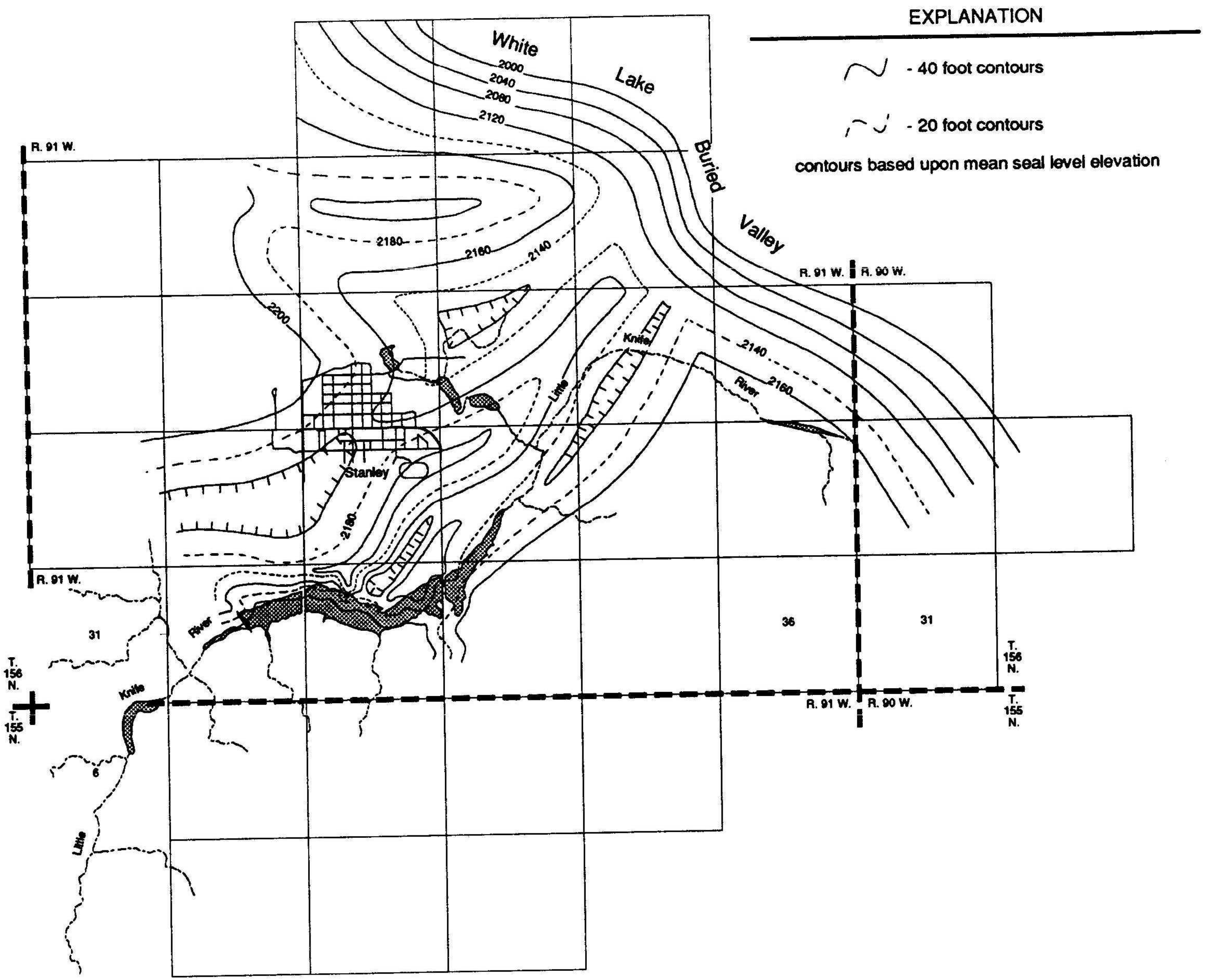


Figure 4 - Structural elevation of the top of the Fort Union Group.

The Fort Union Group was deposited during the Paleocene epoch of the Tertiary period, and it includes the Sentinel Butte Formation, the Bullion Creek Formation, the Cannonball Formation, and the Ludlow Formation (Bluemle, 1989) in descending order. The Ludlow, Bullion Creek , and Sentinel Butte Formations were deposited in either fluvial, lacustrine, or swampy environments (Clayton, et al., 1980) and consist predominantly of interbedded silts, sands, clays, sandstones, and lignite. The Cannonball Formation consists of alternating beds of sand and shale deposited in marine shore-line and off-shore marine environments, respectively.

QUATERNARY GEOLOGY

Surficial deposits in the study area are primarily related to Late Wisconsin Pleistocene glacial and glaciofluvial activity. Most of the surface deposits within the study area consist of silts and clays derived from glacial till deposited as the Late Wisconsin glaciers retreated past the Missouri Escarpment. Cross-sections which identify the relationship of the Quaternary deposits and the underlying Fort Union Group are presented in figures 5 and 6.

At the height of the Late Wisconsin glacial advance most of Mountrail County was covered by ice. Shortly after the Late Wisconsin glacial advance had reached its maximum extent, the ice sheet began to thin and recede to the northeast. Recession of the Late Wisconsin glacier was interrupted by brief periods of re-advancement of the ice sheet (Bluemle, 1989), but as the recession continued, the active ice margin was eventually confined by the Missouri Escarpment and restricted to the lowlands northeast of the Missouri Escarpment.

As glacial activity was confined northeast of the Missouri Escarpment, stagnant ice remained on the Missouri Coteau region. Meltwaters, derived from both the active ice sheet to the northeast and from the stagnant ice on the Coteau, drained across the stagnant ice on the Missouri Coteau southwestward over the Coteau Slope to the Missouri River (Clayton, et al., 1980). The fluvial activity associated with the melting and collapse of the stagnant ice was responsible for the development of the hummocky, collapse terrain with non-integrated drainage characteristic of the Missouri Coteau.

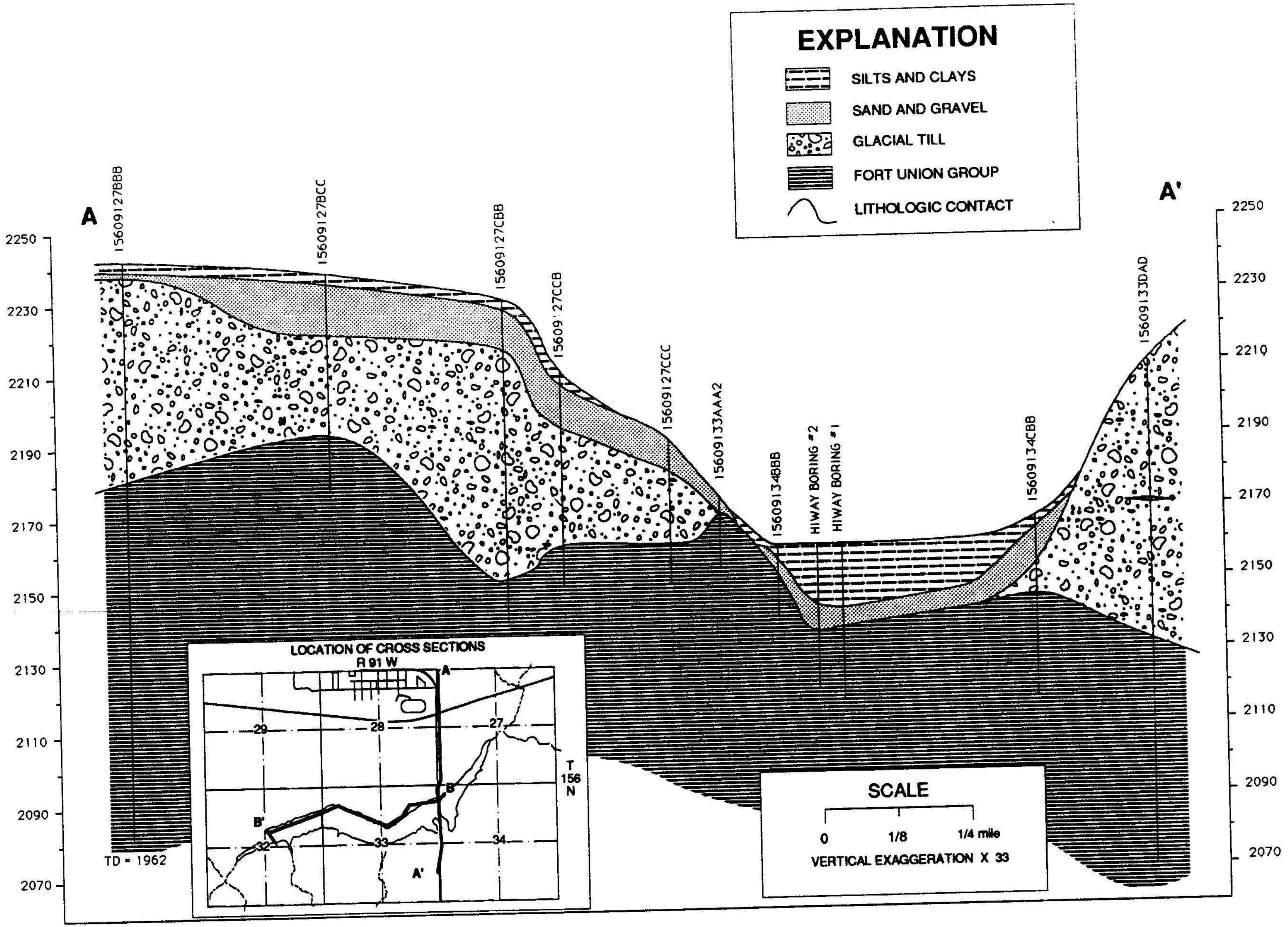


Figure 5 - Geologic section A-A' showing the Quaternary deposits and the upper Fort Union Group in the vicinity of Stanley, North Dakota.

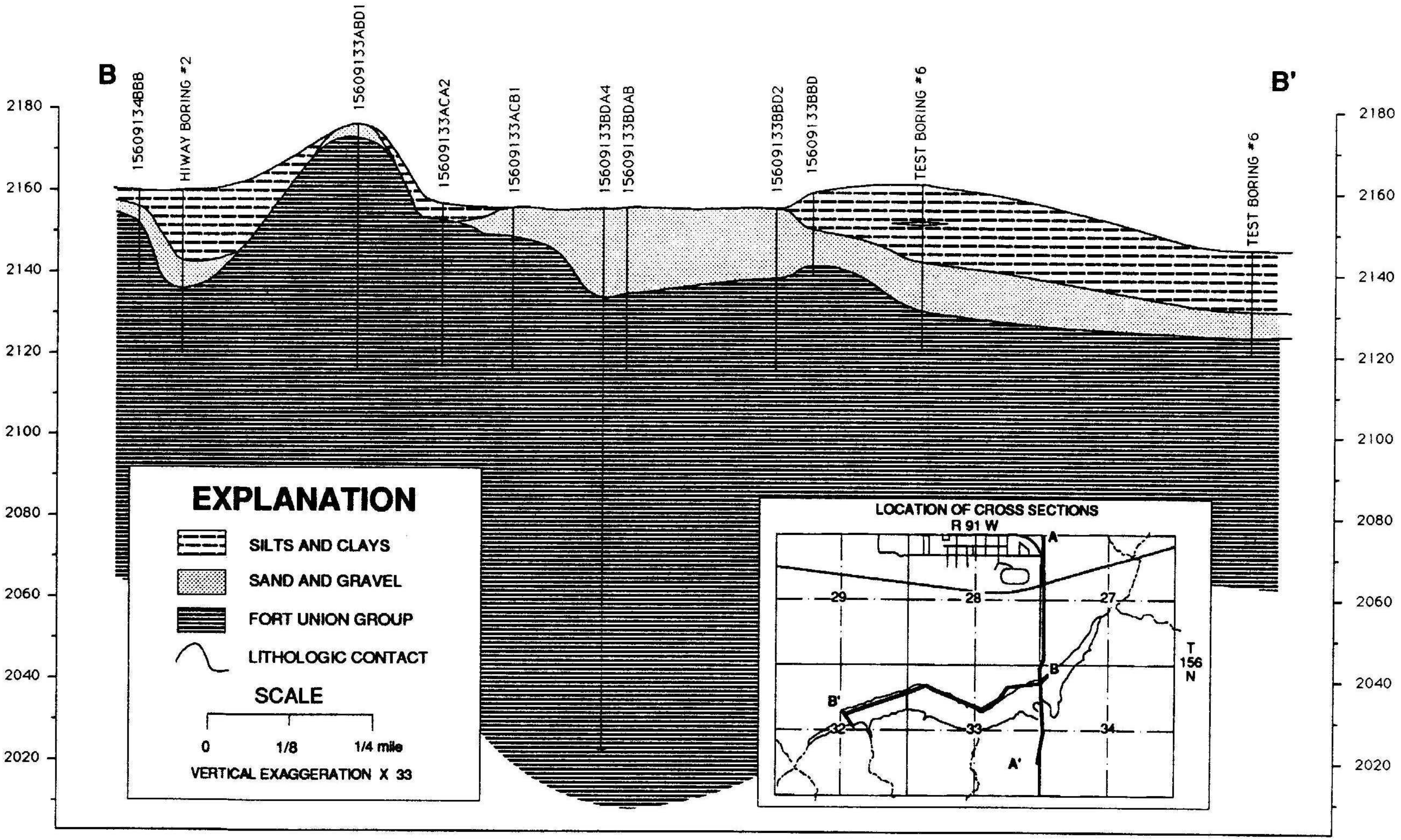


Figure 6 - Geologic section B-B' showing the Quaternary deposits and the upper Fort Union Group in the vicinity of Stanley, North Dakota.

Current drainage systems on the Coteau Slope were established by the meltwaters derived from the recession of the Late Wisconsin ice sheet. Paulson (1954) indicated that the sand and gravel outwash deposits in the Little Knife River valley, from which the city of Stanley currently obtains water, were deposited for the most part by these meltwater sources.

Unconsolidated deposits in the study area include the surficial sediment overlying the Fort Union Group. The majority of the unconsolidated deposits in the study area are of Pleistocene glacial origin with the exception of the Quaternary lake clays, silts, and fine sands, deposited by post-glacial drainage which are commonly referred to as the Oahe formation. Pleistocene sediments deposited by glacial ice or subsequent glacial activity are commonly referred to as the Coleharbor Group.

Coleharbor Group

The Coleharbor Group is generally subdivided into three main facies, including the till, sand and gravel, and silt and clay facies (Bluemle, 1982), and all three facies are represented in the study area. The till facies of the Coleharbor Group is widespread in the study area. Most of the till was deposited as it slumped or flowed to its present position as the last of the glacial ice melted (Clayton, 1972). The till is generally thinner toward the Little Knife River valley where in places it is absent and sand and gravel outwash deposits directly overlie bedrock. Approaching the northern portion of the study area along the flanks of the White Lake buried valley, the till reaches a thickness of approximately 200 feet in test hole 156-091-10BBB.

The till within the study area consists of a poorly sorted mixture of clay to boulder size particles with a predominate clay matrix. The pebble size particles consist predominantly of carbonates, detrital shales, and various igneous and metamorphic rocks, while the cobble and boulder size particles consist predominantly of various types of metamorphic and igneous rocks (Clayton, 1972). Weathering in the till is apparent in several of the test holes in the study area, and the weathered till is characterized by an orangish, yellowish, or brown mottled appearance. Unweathered till is typically a medium to dark gray or olive gray.

The sand and gravel facies of the Coleharbor Group occurs primarily as meltwater outwash deposits along the Little Knife River valley. Sand and gravel also occurs as thin discontinuous lenses dispersed throughout the till and as thicker units within the till. The majority of the sand and gravel deposits within the study area are glaciofluvial. The sand and gravel deposits range in thickness from less than 1 foot to approximately 27 feet in test hole 156-091-33CAB where it is overlain by approximately 32 feet of till. In test hole 156-091-10BBB located along the flanks of the White Lake buried valley in the northern portion of the study area, a total of 92 feet of sand and gravel was identified. However, the well log identifies interbedded silts, clays, sand, and gravel, and the maximum continuous thickness of sand and gravel is 34 feet.

Most of the sand and gravel within the study area, particularly along the Little Knife River valley, consists of poorly to moderately sorted, subangular to rounded, fine sand to very coarse sand and gravel sized particles. In contrast the sand and gravel within test hole 156-091-10BBB consists predominantly of fine, well sorted sands with little or no gravel. The mineralogical composition of the sand and gravel consists of a mixture of carbonates and various igneous and metamorphic rocks.

The silt and clay facies of the Coleharbor Group is not common in the study area. The silt and clay facies was generally deposited in ice-marginal contact lakes which were surrounded by stagnant glacial ice (Clayton, 1972). The silt and clay facies occurs in the northern portion of the study area along the flanks of the White Lake buried valley in both sections 9 and 10. The silt and clay deposits reach a maximum thickness of 42 feet in test hole 156-091-9DAD. Approximately 14 feet of the ice marginal lake deposits, consisting mostly of clay also occur just west of the study area at 156-092-26ADD (Paulson, 1954).

Oahe Formation

Post-glacial deposits of the Oahe Formation include lake clays and alluvial clays, silts, and fine sands which overlie the Coleharbor Group in parts of the study area. Deposits of the Oahe Formation are primarily the result of erosion and re-deposition of the glacial sediments of the Coleharbor Group, and the Oahe Formation is generally confined to the Little Knife River valley, the adjoining tributaries, and local sloughs in the study area. For the most part, the Oahe Formation is rather thin and discontinuous. The

Oahe Formation reaches its maximum thickness in the Little Knife River valley where a sequence of silts and clays approximately 30 feet thick was identified by the test boring completed prior to the construction of the Stanley Dam in 1968.

GROUND WATER HYDROLOGY

Within the study area, there are four different aquifers with sufficient transmitting capacity for the development of a municipal water supply for the city of Stanley. These are: 1) the Fox Hills aquifer, 2) the Fort Union aquifer, 3) the White Lake branch of the Shell Creek aquifer, and the Little Knife River Valley aquifer. The Fort Union aquifer and the Fox Hills aquifer are bedrock aquifers that underlie the entire study area. The White Lake branch of the Shell Creek aquifer occupies the White Lake buried valley located along the northeastern flank of the study area (figure 7). The Little Knife River Valley aquifer is located in the Little Knife River valley south and east of Stanley (figure 7).

Fox Hills Formation

The Fox Hills Formation conformably underlies the Hell Creek Formation which conformably underlies the Fort Union Group throughout the study area. The Fox Hills Formation consists of a sequence of sandstone, silty shales, siltstones, sand, and silts. The upper 40 to 65 feet of the Fox Hills Formation is typically characterized by shoreline deposits generally consisting of fairly clean, fine to medium grained sand deposits which provides much more suitable aquifer material than the underlying material within the Fox Hills Formation (Wanek, 1990). Groundwater in the Fox Hills formation occurs under confined conditions.

None of the test holes completed as part of this study or any previous studies penetrated the Fox Hills Formation in the study area. However, based upon a log obtained from the Milestone 32-33 BN, the depth to the Fox Hills Formation in the vicinity of Stanley is estimated at 1,650 feet below land surface.

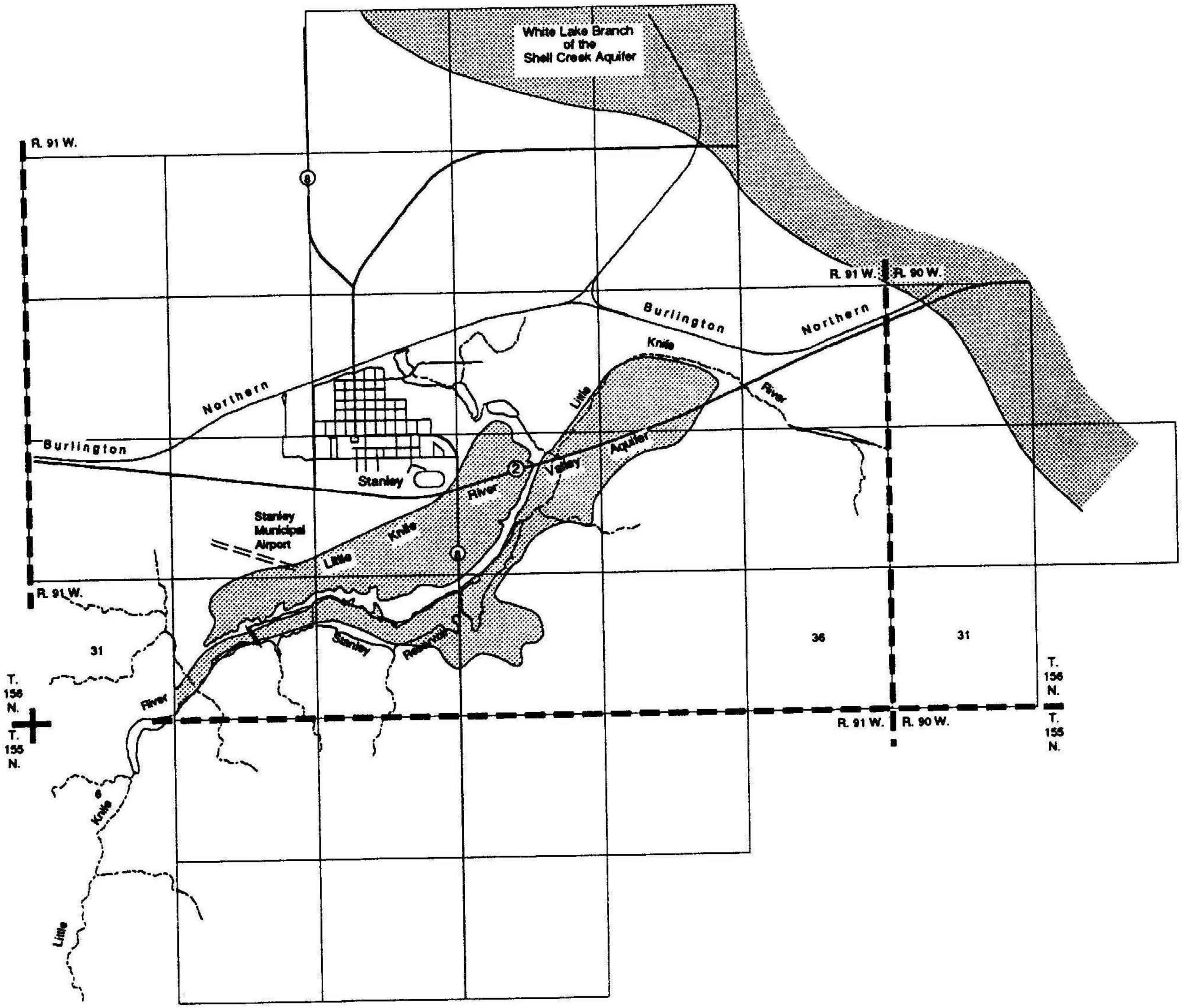


Figure 7 - Location of major glacial-drift aquifers within the study area.

In 1984, a 4-inch diameter observation well was installed by the NDSWC in the Fox Hills aquifer approximately 25 miles west of Stanley, near the city of Tioga. In 1985, a pump test was completed on this well (Wanek, 1985). The well was pumped at a rate of 18.75 gallons per minute for 300 minutes, and both the drawdown and the recovery were monitored. Total drawdown in the well was 74.58 feet. The specific capacity of the well after 300 minutes of pumping was 0.251 gallons per minute per foot of drawdown. The transmissivity (T) was calculated at 41 ft^2/day, and the storage coefficient (S) was estimated to be 10^{-4} based upon the matrix grain size of the aquifer matrix.

The potentiometric surface of the Fox Hills aquifer is illustrated in figure 8 (NDSWC, 1990). The elevation of the potentiometric surface in the Fox Hills Formation near Stanley is estimated to be approximately 2,050 feet above sea level. Depending upon variation in land-surface elevation, the depth to water in the vicinity of Stanley would be approximately 190 feet.

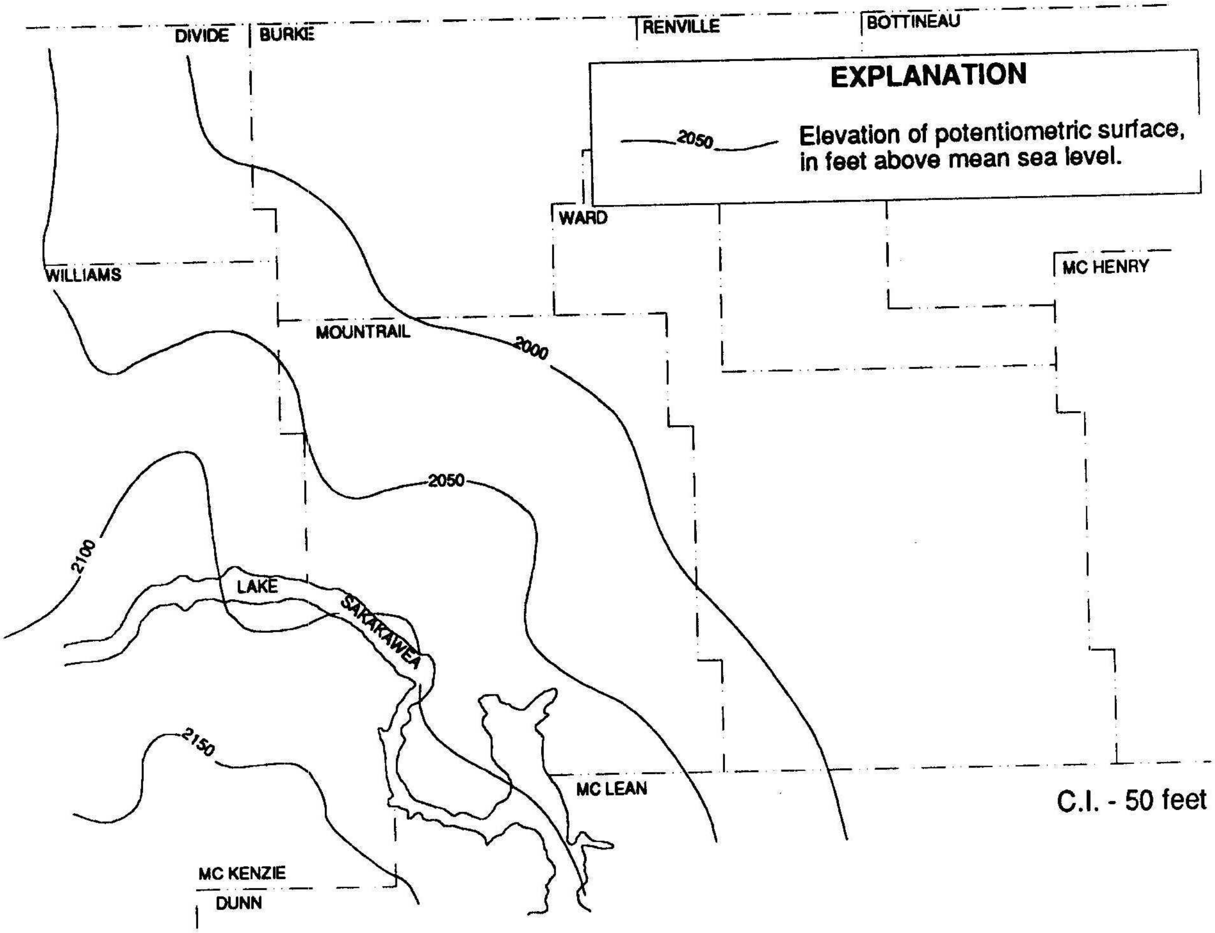


Figure 8 - Potentiometric surface of the Fox Hills aquifer in northwestern North Dakota.

Fort Union Group

The Fort Union Group unconformably underlies the Quaternary deposits throughout the study area (figures 5 and 6). As stated earlier, the Fort Union Group consists predominantly of interbedded silts, sands, clays, sandstones, and lignite. The interbedded sand lenses, sandstone beds, and lignite beds will generally yield less than 200 gallons per minute and are found at various depths throughout the Fort Union Group.

Most of the domestic wells completed in the Fort Union Group near Stanley have been completed within the upper 300 feet of Fort Union sediments. Prior to the development of a water supply from the Little Knife River Valley aquifer, the city of Stanley obtained water from three wells completed in the Fort Union Group. The Stanley #1 was drilled to a depth of 200 feet and had a static water level of 128 feet below land surface (Paulson, 1954). The Stanley #2 was drilled to a depth of 190 feet and had a static water level of 95 feet below land surface. The Stanley #3 was drilled to a depth of 185 feet and had a static water level of 85 feet below land surface. Pumping rates were reported for the Stanley #2 and the Stanley #3 at 50 and 70 gallons per minute, respectively.

Paulson (1954) completed a pump test on the Stanley #3 well which was used to calculate aquifer properties. The Stanley #3 well was pumped at a constant rate of 100 gallons per minute for 24-hours. Water levels in the production well were monitored during pumping and recovery. The transmissivity reported by Paulson (1954) was approximately 800 ft^2/day. The specific capacity of the production well after 24 hours of pumping was approximately 2.6 gallons per minute per foot of drawdown.

In September of 1990, Gregory Drilling installed two production wells for the city of Stanley in the Fort Union Group to provide the city with an alternative water supply. The two new wells, the Stanley #4 and the Stanley #6, were completed to depths of 240 and 260 feet, respectively. Both wells were constructed with 60 feet of #18 slot (0.018 inch) screen which was sand packed throughout the screened interval. Static water levels reported for the Stanley #4 and the Stanley #6 wells were 75 and 85 feet below land surface, respectively. Pump test were completed on both wells, and water levels were monitored during pumping and recovery.

The method of Jacob (in Lohman, 1972) was applied to the pump test data to calculate aquifer properties. Transmissivity (T) and storage coefficient (S) of the aquifer can be determined using the following equations in conjunction with a semi-logarithmic plot of the time-drawdown data observed during pumping.

$$T = \frac{2.3\,Q}{4\pi\Delta s}$$

where Q = rate of discharge in gallons per minute
Δs = change in drawdown over one full log cycle

$$S = 2.25\,T\left(\frac{t_0}{r^2}\right)$$

where T = transmissivity in square feet per day
t_0 = intercept of the straight line at zero drawdown, in days
r = distance from the pumped well, in feet

It is not possible to determine the storage coefficient when evaluating drawdown from the production well because well efficiency is generally indeterminate. Therefore, the storage coefficient is estimated based upon the matrix grain size of the aquifer. Given, the high clay matrix material and the thickness of the aquifer, the storage coefficient for the Fort Union Group is estimated to range from 10^{-5} to 10^{-4}.

In addition to using the time-drawdown data to calculate the transmissivity, a semi-logarithmic plot of the residual drawdown versus the ratio of the total pumping time to the recovery time (t/t') used in conjunction with the following equation can also be used to determine aquifer transmissivity.

$$T = \frac{264\,Q}{\Delta s'}$$

where Q = rate of discharge in gallons per minute
$\Delta s'$ = change in residual drawdown over one log cycle, in feet

Therefore, to better evaluate the transmissivity for the interval in which the city's production wells are completed, both the time-drawdown data and the recovery data were used to calculate aquifer transmissivity.

The Stanley #4 well was pumped at a constant rate of 105 gallons per minute for 1,200 minutes. Total drawdown measured during the test was 46.6 feet, and the specific capacity of the well after 1,200 minutes was 2.25 gallons per minute per foot of drawdown. The transmissivity calculated from the time-drawdown plot using the method of Jacob was approximately 1,630 ft^2/day (figure 9). The transmissivity calculated from the residual-drawdown plot using the method of Jacob was approximately 900 ft^2/day (figure 10).

The differences between the transmissivity calculated the time-drawdown data and the transmissivity calculated from the recovery-drawdown data would tend to suggest that the basic assumptions applied to the Jacob method were not met in this pump test. The plot of the time-drawdown data shows a flattening in the time-drawdown curve nearing the end of the test (figure 9). The flattening observed in the time-drawdown curve indicates that either a recovery boundary or leakage may have influenced drawdown during the pump test. The plot of the residual-drawdown (figure 10) also suggests that a recovery boundary of leakage may be influencing drawdowns because the data trace intersects the 0 drawdown line to the right of the origin. Ideally, the trace should pass through the zero drawdown point where t is equal to t'.

The interval of the Fort Union Group in which the Stanley #4 was completed consists of a sequence of interbedded sands, silts, clays, sandstones, and lignite. Given the nature of the stratigraphy in which the well is completed, it is likely that pumping of the Stanley #4 well induced leakage from the surrounding material which influenced the results of the pump test.

The Stanley #6 well was pumped at a constant rate of 83 gallons per minute for 1,200 minutes, and total drawdown observed at the end of 1,200 minutes was 69.3 feet. The specific capacity of the well after 1,200 minutes of pumping was approximately 1.2 gallons per minute per foot of drawdown. Using the method of Jacob, transmissivity was calculated at 836 ft^2/day (figure 11). Transmissivity calculated from the residual-drawdown plot is approximately 751 ft^2/day (figure 12). The close agreement of the two transmissivity values suggests that the average value of 790 ft^2/day is representative of the aquifer interval tested.

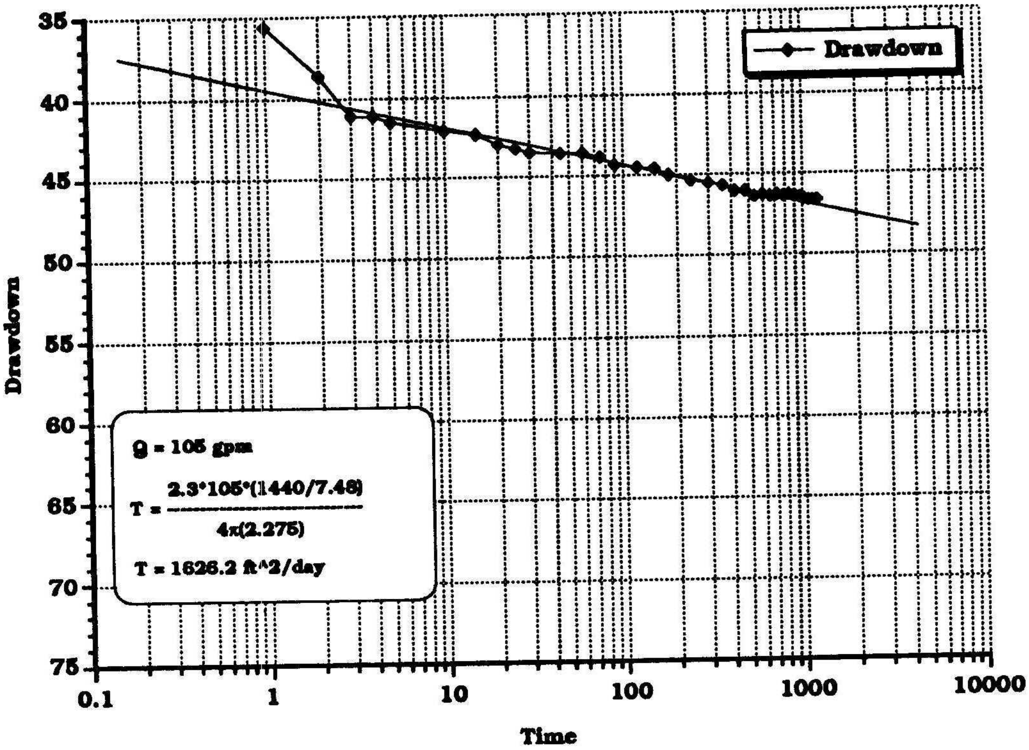


Figure 9 - Time-drawdown curve from the pump test conducted on the Stanley #4 well.

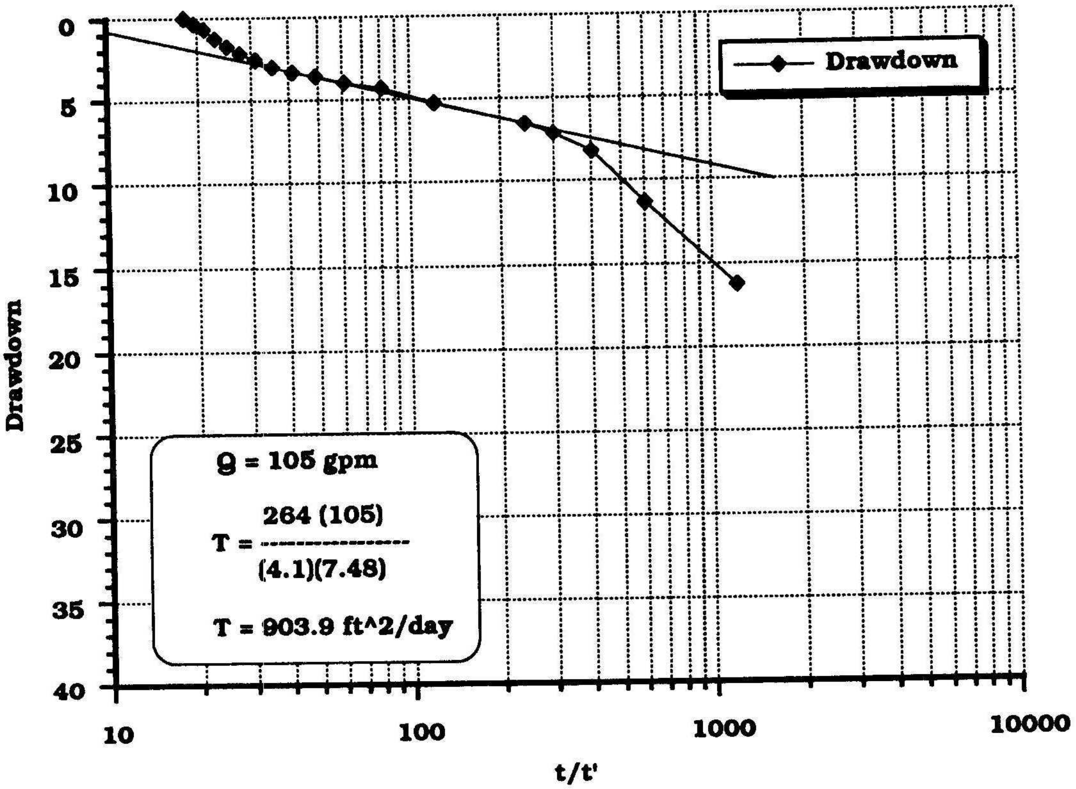


Figure 10 - Recovery versus t/t' curve from the pump test conducted on the Stanley #4 well.

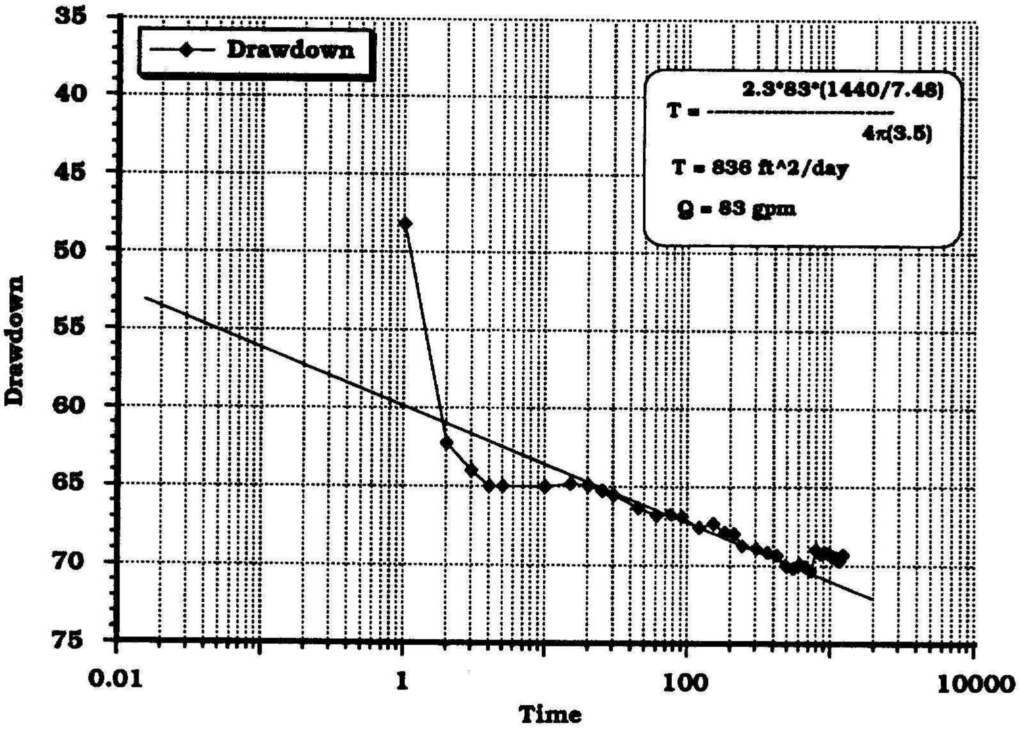


Figure 11 - Time-drawdown curve from the pump test conducted on the Stanley #6 well.

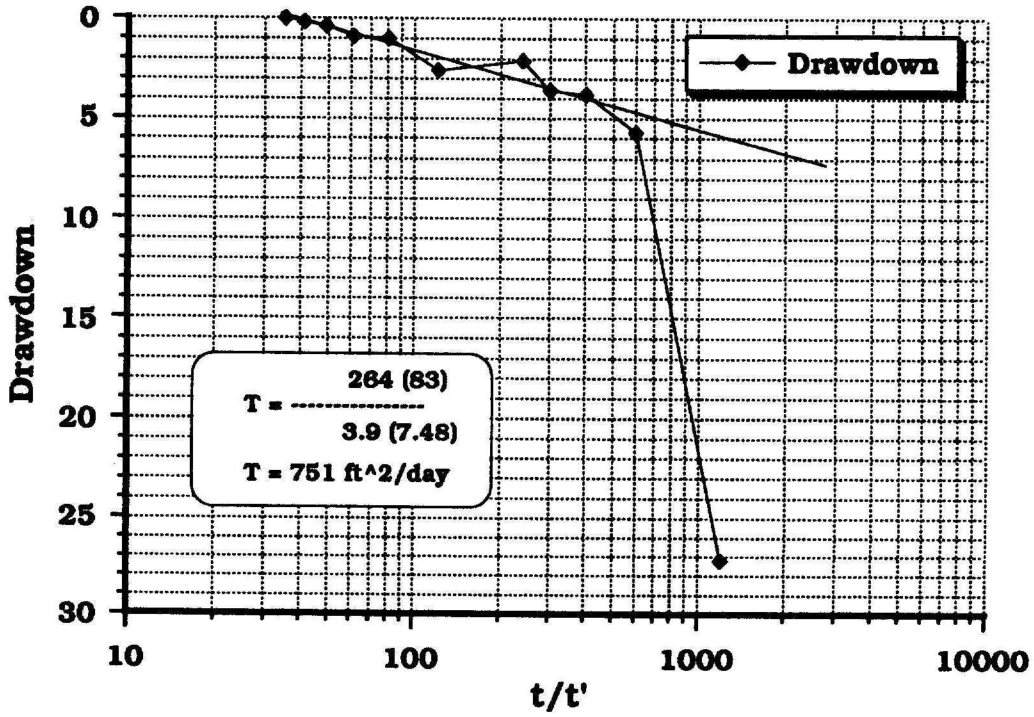


Figure 12 - Recovery versus t/t' curve from the pump test conducted on the Stanley #6 well.

Two piezometers, 156-091-33ACB1 and 156-091-33BDA4, were installed in the Fort Union Group for purposes of establishing the relationship between the Little Knife River Valley aquifer and the underlying sediments of the Fort Union Group. Both piezometers were installed along the northern shore of the Stanley Reservoir adjacent to the wells completed in the Little Knife River Valley aquifer. Well 156-091-33ACB1 was screened over an interval from 25 to 30 feet, and 156-091-33BDA4 was screened from 122 to 127 feet.

The water level in 156-091-33BDA4 is approximately 2 feet above land surface. Water levels in 156-091-33ACB1 are between 6 and 7 feet below the water level observed in 156-091-33BDA4, which indicates an upward gradient in the Fort Union Group (figure 13).

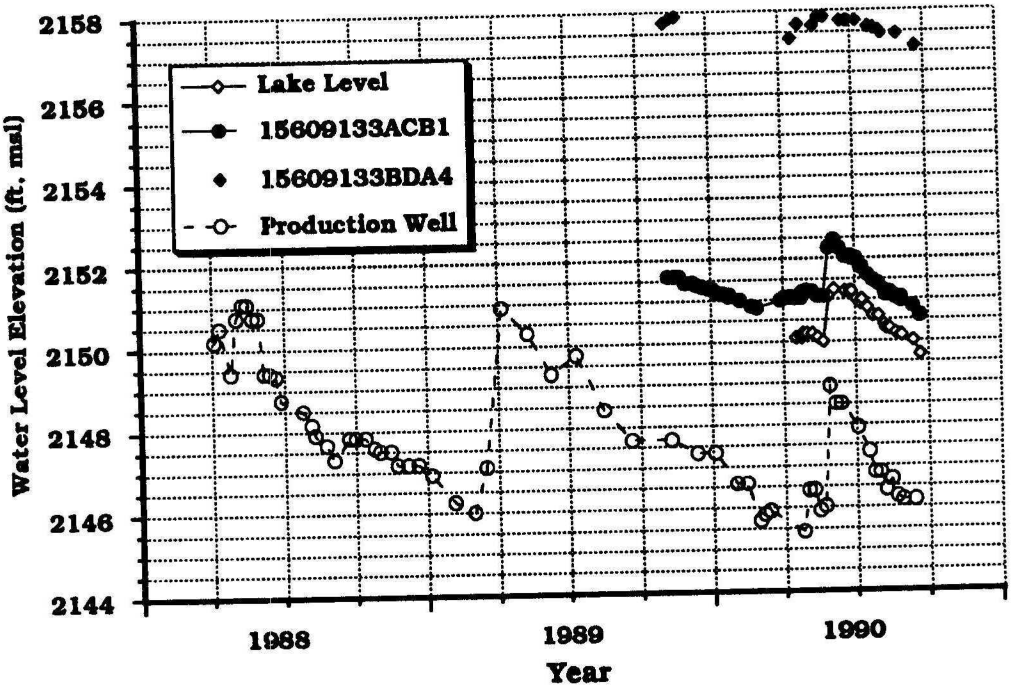


Figure 13 - Hydrograph comparing water levels in the Fort Union Group with water levels in the Stanley Reservoir and the 86-inch production well completed in the Little Knife River Valley aquifer.

Water level fluctuations in 156-091-33ACB1 are very similar to the fluctuations observed in both the reservoir and in the Little Knife River Valley aquifer, while water level fluctuations in 156-091-33BDA4 show very little similarity to the water level fluctuations in either the reservoir or the Little Knife River Valley aquifer. The similarity in water level fluctuations between 156-091-33ACB1, which is screened in the Fort Union Group just below the Little Knife River Valley aquifer, and the wells completed in the Little Knife River Valley aquifer indicates that the surficial aquifer is fairly well connected to the surrounding sediment of the Fort Union Group.

Armstrong (1971) noted the occurrence of numerous springs along the Little Knife River valley, and it is likely that the Little Knife River valley represents a regional discharge area for the Fort Union Group. Water levels observed in 156-091-33ACB1 range from 1 to 4 feet higher than the corresponding water levels in the wells completed in the Little Knife River Valley aquifer which also tends to suggest that water generally moves from the Fort Union Group to the Little Knife River Valley aquifer.

White Lake Branch of the Shell Creek Aquifer

The White Lake branch of the Shell Creek aquifer consists of a sand and gravel channel sequence deposited in the White Lake buried valley situated along the northeastern flank of the study area. The White Lake branch of the Shell Creek aquifer is approximately one half mile wide and 22 miles long (Armstrong, 1971), and it extends from the White Lake region north of the study area to the junction with the east branch of the Shell Creek aquifer southeast of the study area. The aquifer generally is confined by glacial till in the study area.

Water samples collected as part of the county groundwater study indicate the overall water quality of the White Lake branch of the Shell Creek aquifer is similar to that of the Fort Union bedrock deposits in which the valley was incised. Because the water quality of the White Lake Branch is similar to that found in the Fort Union aquifers, and wells completed in the Fort Union Group could be more strategically placed in relation to Stanley's current water distribution system, the White Lake Branch of the Shell Creek aquifer was dismissed as a possible alternative available to the city of Stanley.

The White Lake Branch of the Shell Creek aquifer does provide significant possibilities as a water supply. However, additional test drilling would be required to ascertain the yield potential and water quality associated with the aquifer. Since the development of alternative sources was not the primary intent of this study, the White Lake Branch of the Shell Creek aquifer will not be discussed further in this report. For more detailed information regarding the White Lake aquifer refer to the work completed by Paulson (1954), and Armstrong (1971).

Little Knife River Valley Aquifer

The outwash deposits comprising the Little Knife River Valley aquifer were deposited by meltwaters derived as the Late Wisconsin glacier retreated to the northeast. The aquifer is predominantly composed of a poorly sorted, subangular to rounded, fine to very coarse sand and gravel. The sand and gravel consists predominantly of carbonates with various percentages of igneous and metamorphic rocks.

In the study area, the Little Knife River Valley aquifer reaches a maximum thickness of approximately 20 feet in test wells 156-091-33BDAB and 156-091-33BDA4 located adjacent to the Stanley Reservoir (figure 14). The aquifer was generally incised into the till and in many places sand and gravel directly overlies the Fort Union Group (figure 5). In the Little Knife River valley, the aquifer material is overlain by as much as 20 feet of lake clays and silts (figure 6). However, much of the aquifer is either exposed at land surface or is covered by a thin veneer of soil and recent alluvium. For the most part, the aquifer is unconfined within the study area.

The Little Knife River Valley aquifer was originally identified by Paulson (1954) as a continuous sequence of sand and gravel outwash deposits extending from the reservoir north. However, the test boring completed prior to the construction of the Stanley Dam in 1968 and the recent drilling completed as part of this study identified no appreciable deposits of sand and gravel along the terrace slope lying north of the reservoir (figure 14). Based upon the available test hole information, the sand and gravel outwash sequence does not appear to be continuous over the area defined by Paulson (1954). The sand and gravel deposits on the terrace north of the Stanley Reservoir do not appear to be connected with the sand and gravel deposited adjacent and beneath the reservoir in which Stanley's 86 inch production well was installed.

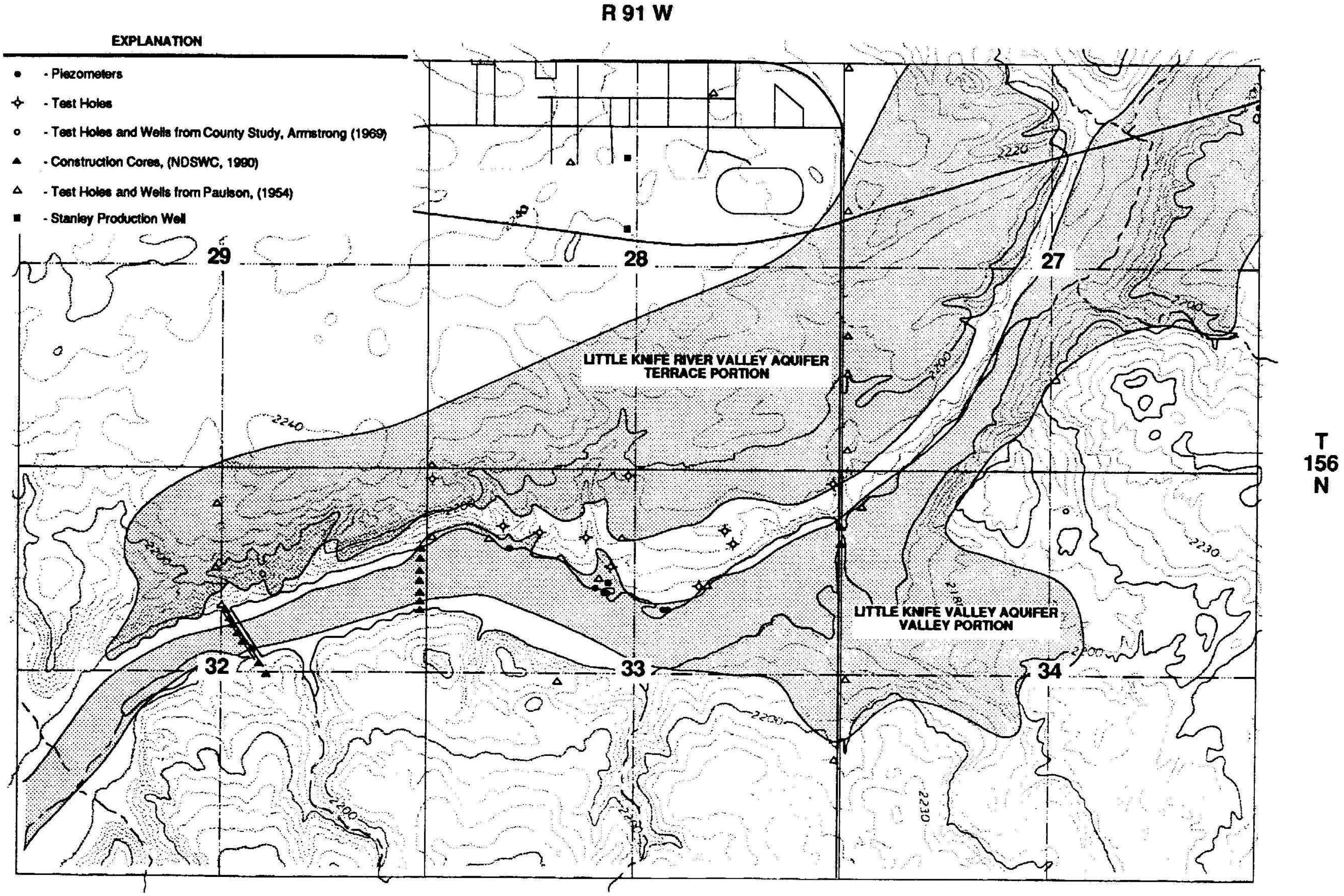
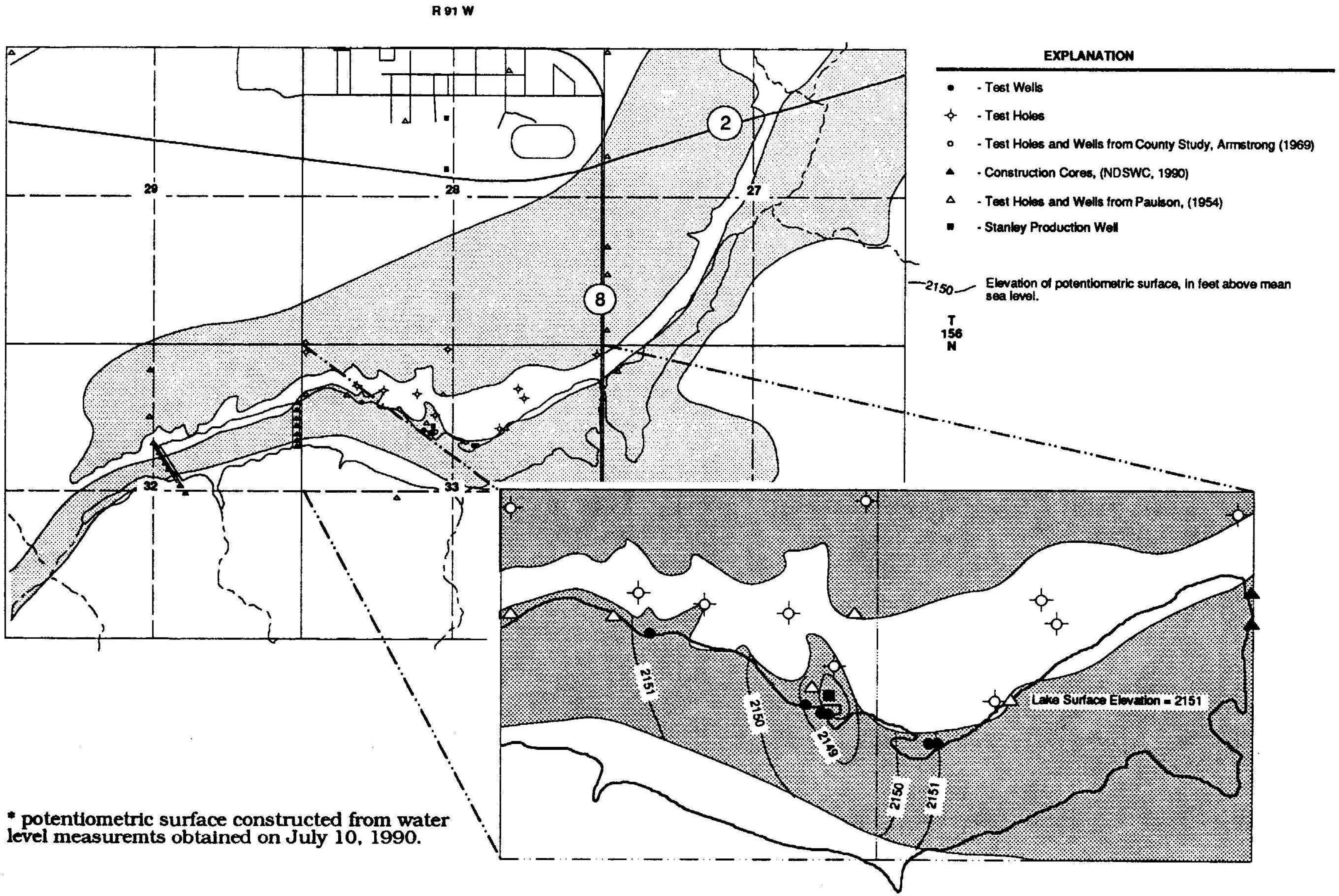


Figure 14 - Areal extent of the Little Knife River Valley aquifer.

The flow system within the Little Knife River Valley aquifer would generally be expected to follow the current surface drainage pattern of the Little Knife River valley, and based upon the topographic configuration of the aquifer material, water within the aquifer would generally move down slope from the terrace deposits to the valley floor. However, the absence of the aquifer material along the terrace slope would tend to isolate the terrace portion of the aquifer system from the valley portion of the aquifer (figure 14). Most of the sand and gravel deposits on the terrace overlie clays of the till facies. Groundwater flow within the terrace system would possibly discharge through seeps and springs along the southern extent of the aquifer material where it is more than likely lost through evapotranspiration. The till underlying the terrace deposits was oxidized in places suggesting a possible downward groundwater flow from the terrace deposits into the till. In either case, groundwater flow in the northern terrace deposits probably has little effect on the overall flow system of the valley portion of the Little Knife River Valley aquifer.

The valley portion of the Little Knife River Valley aquifer in the vicinity of Stanley's 86-inch production well is a relatively narrow linear feature oriented in an approximate east-west direction along the northern edge of the valley floor (figure 14). The aquifer is exposed at land surface along the northern shore of the reservoir. However, a significant portion of the aquifer is overlain by lake clays and silts which are for the most part overlain by the reservoir. The potentiometric surface in the valley portion of the aquifer reflects groundwater withdrawals from the 86-inch production well (figure 15). The hydraulic gradient ranges from approximately 8 feet per mile west of the production well to approximately 16 feet per mile east of the production well.

In the absence of the Stanley Dam, surface run-off in the vicinity of Stanley would be lost as discharge down the Little Knife River valley to the Missouri River. In 1954, when the Little Knife River Valley aquifer was evaluated as a potential water supply for the city of Stanley, Paulson identified the importance of the reservoir as a possible source of recharge to the aquifer which could enhance the storage available from the aquifer system. The effective radius of the cone of depression established by the production well is relatively small (figure 15) suggesting that the aquifer in the vicinity of the production well is receiving a significant amount of recharge from the reservoir. Currently, wells 156-091-33BBD2 and 156-091-33ACB2, which are furthest from the



* potentiometric surface constructed from water level measuremts obtained on July 10, 1990.

Figure 15 - Potentiometric surface of the Little Knife River Valley aquifer in the vicinity of Stanley's 86-inch production well.

production well, reflect water levels that are at or near lake surface elevation, and it is likely that in the absence of pumping the water levels in the aquifer would reflect reservoir water levels and the gradient within the aquifer would be fairly flat.

If the aquifer is well connected to the reservoir, water levels in the aquifer and the reservoir would be expected to rise and fall in a similar manner. Since the installation of the staff gage in the reservoir in April of 1990, water levels in wells 156-091-33BBD2 and 156-091-33ACB2, which are furthest from the production well, have been at or near the lake surface elevation (figure 16). The similarity in the water level fluctuations in the reservoir, the observation wells, and the production well indicates that the aquifer and the reservoir are fairly well connected.

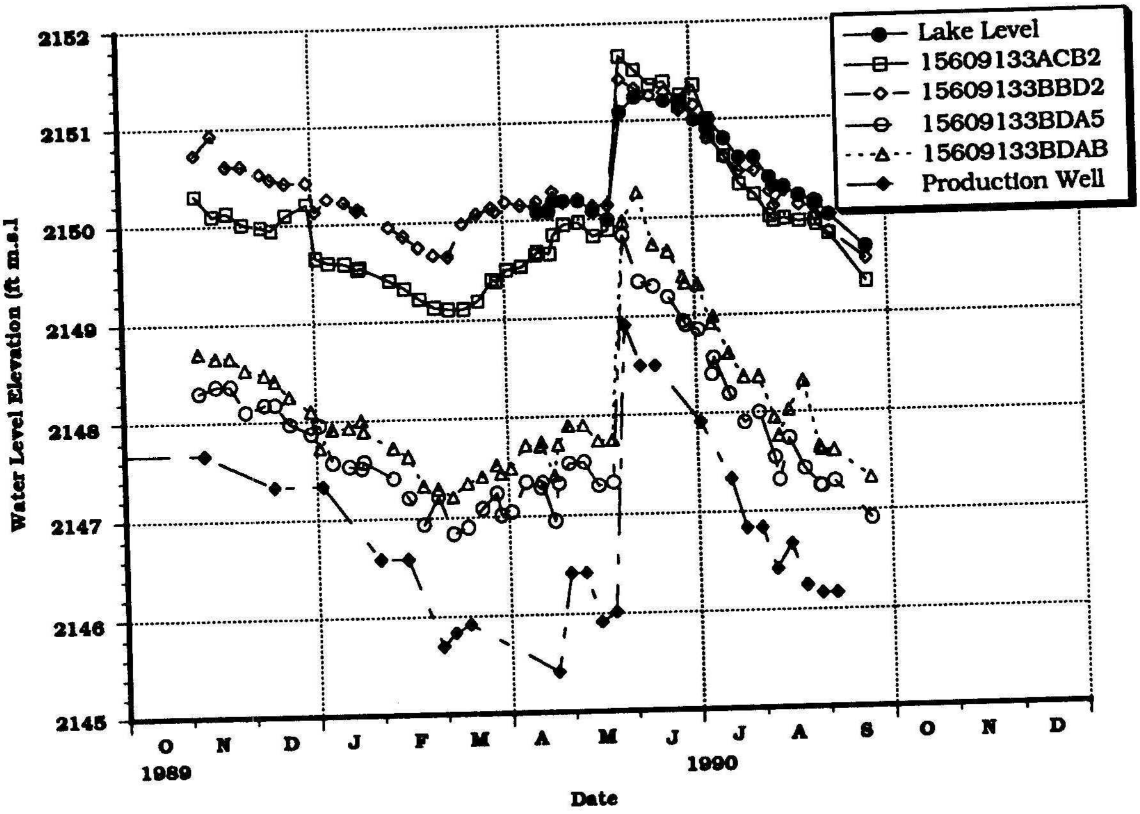


Figure 16 - Hydrograph comparing water levels in the wells completed in the Little Knife River Valley aquifer and the lake surface elevation of the Stanley Reservoir.

Even though it may appear that water levels in the aquifer are generally maintained by the reservoir, a certain amount of recharge in the aquifer is derived from direct infiltration along the exposed portion of the aquifer north of the reservoir. During large recharge periods, water will move from the aquifer into the reservoir. In May of 1990, more than 5 inches of rainfall was recorded which resulted in an approximate 1 foot rise in reservoir levels (NOAA, 1990). During this same precipitation event, water levels in wells 156-091-33BBD2 and 156-091-33ACB2 increased by slightly more than 1 foot causing water levels in both wells to rise above the water level in the reservoir (figure 16). Over a period of approximately 3 weeks, water levels in both wells declined with respect to the lake levels to re-assume relative positions similar to those prior to the May rainfall events.

Based upon observed water-level fluctuations the valley portion of the Little Knife River Valley aquifer and the Stanley reservoir can be treated as a single hydrologic system. Since the valley portion of the aquifer is relatively small in comparison to reservoir storage and the contributing drainage area, the hydrologic response of the aquifer will primarily be caused by hydrological factors controlling the reservoir.

Because the aquifer-reservoir system is dominated by the surface reservoir, climatic conditions controlling precipitation, run-off, and evapotranspiration are important constraints on the water yielding capacity. Average annual precipitation within the Stanley area, recorded at a National weather station located approximately 3 miles northwest of Stanley, is 17.72 inches, with most of the precipitation occurring as rainfall during the spring and summer months (NOAA, 1990). Based upon the Soil Conservation Service (SCS) Hydrology Manual for North Dakota, annual evaporative losses within the vicinity of Stanley could approach 35 inches from the reservoir. However, the relationship between the precipitation and evapotranspiration is clearly demonstrated when comparing water levels in the production well with precipitation over the same period (figure 17). The aquifer is clearly characterized by rapid recharge events in the spring resulting from spring snowmelt and early spring rainfall followed by water-level declines throughout the rest of the year caused by evapotranspiration and withdrawals from Stanley's production well.

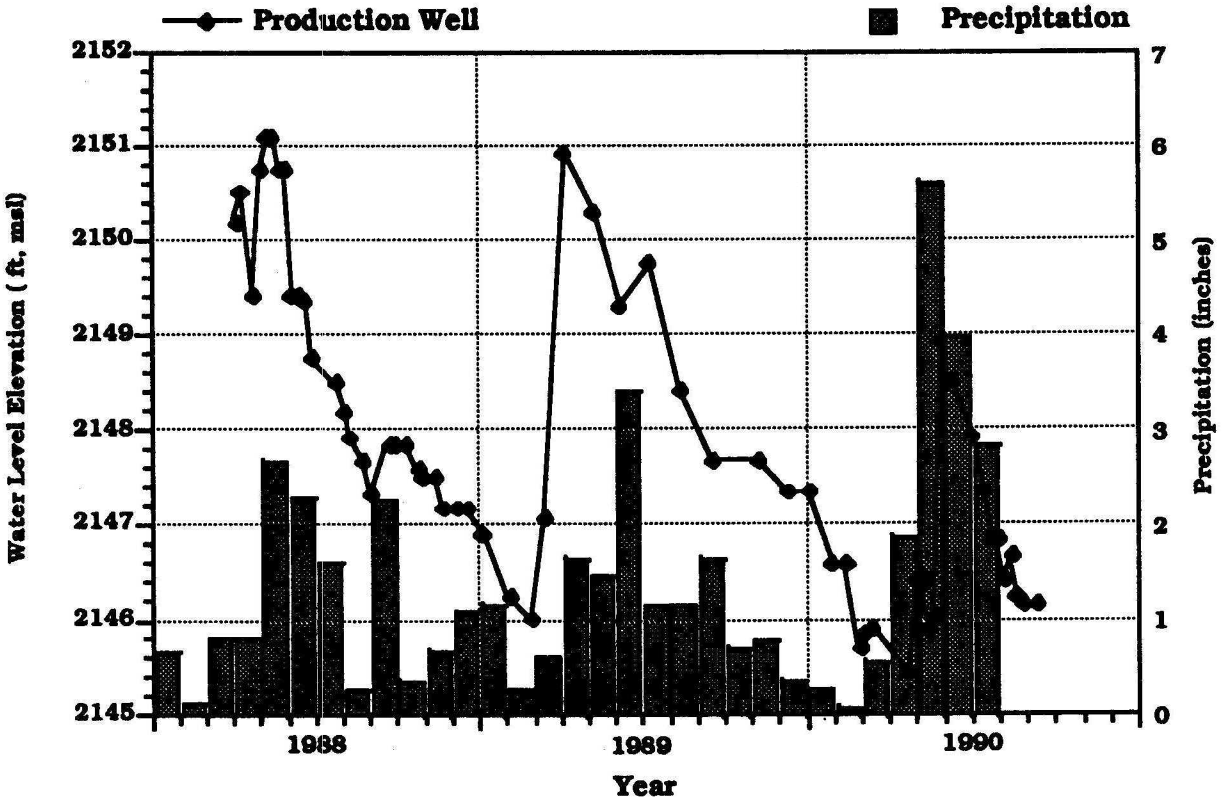


Figure 17 - Comparisons of water levels in Stanley's 86-inch production well in the Little Knife River Valley aquifer and monthly precipitation in the vicinity of Stanley.

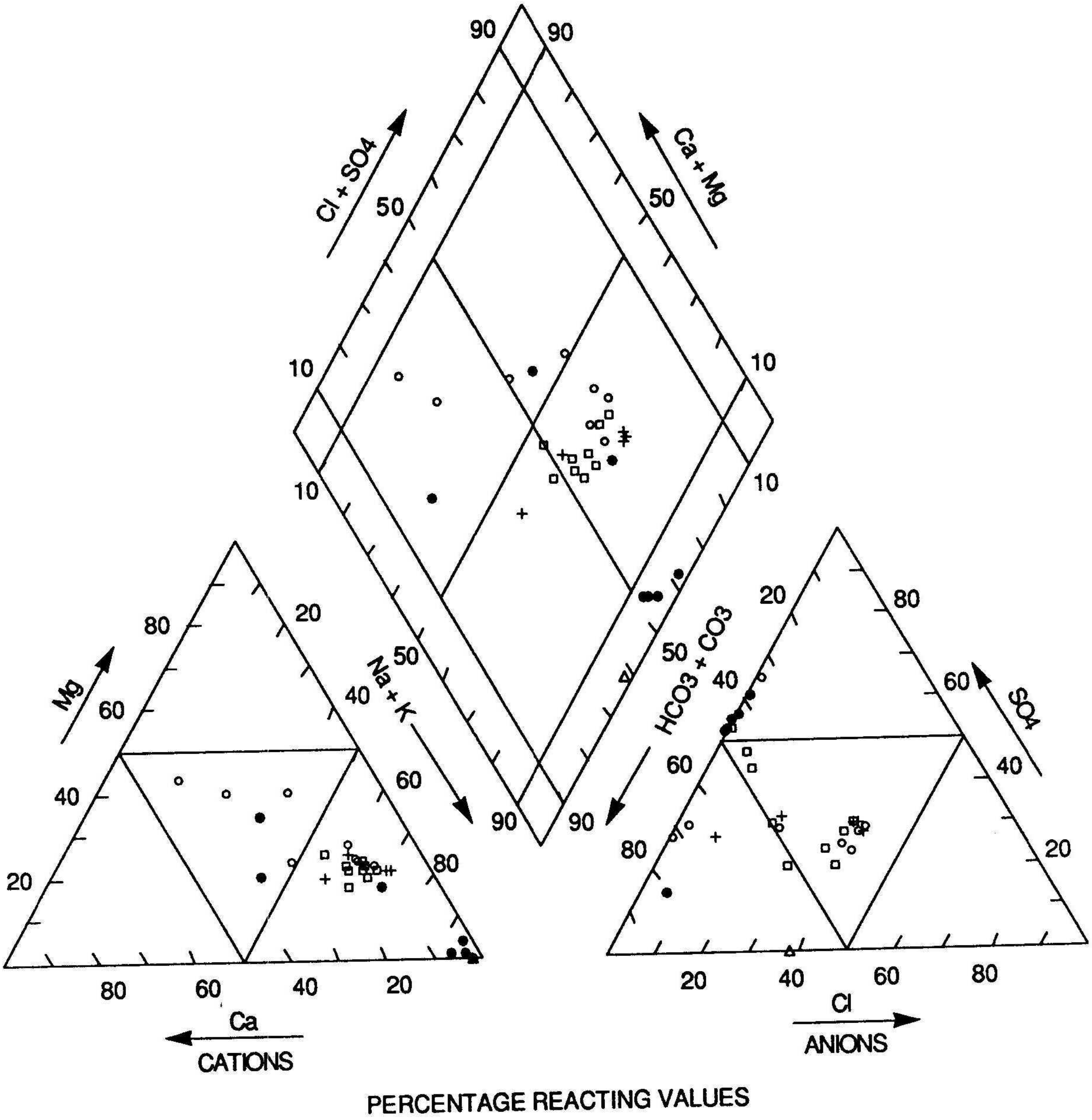
Discharge from the aquifer and the reservoir is dominated by evapotranspiration and Stanley's municipal withdrawals. Evapotranspiration will occur in the form of evaporation from the surface of the reservoir and the aquifer and transpiration from vegetation overlying the aquifer. Assuming a potential annual evapotranspiration rate of 35 inches, and an average annual precipitation of 18 inches, the net evaporative loss from the reservoir is estimated at 17 inches.

Evaporative losses from the reservoir will vary depending upon the elevation of the lake surface, but based upon the area capacity curve (See Appendix C) an evaporative loss of 17 inches could range from less than 150 acre-feet of water to approximately 400 acre-feet of water at maximum pool elevation. In contrast, the average annual groundwater withdrawal reported by the city of Stanley over the last 6 years is approximately 160 acre-feet (NDWUDP, 1990). It is clear from the comparison of municipal withdrawals with the estimated evaporative losses from the lake surface that evapotranspiration is the dominant form of discharge from the aquifer-reservoir system.

WATER QUALITY

Analysis from a total of 34 water samples were available within the study area which includes water samples obtained from the Stanley Reservoir, the Little Knife River Valley aquifer, and the Fort Union Group. The water samples for the analysis included in this report were collected over a period of several years, and the earliest samples were obtained during the early 1950's by Paulson (1954). Additional samples were included from the county study (Armstrong, 1969) and the NDSDHCL (Kern, 1990). In addition to the samples that were available from within the study area, a sample collected from the NDSWC observation well (156-096-20DCD) near Tioga, North Dakota, which is completed in the Fox Hills Formation, was also included for purposes of presenting the water quality associated with the Fox Hills Formation. The chemical analysis for all of the samples are included in Appendix B.

The distribution of the hydrochemical facies for the available sources within the study area are shown in figure 18. The distribution of the cation constituents ranges from a sodium (Na) type to a mixed type with the sodium (Na) type predominating. The distribution of the anion constituents includes a bicarbonate (HCO_3) type, a sulfate (SO_4) type, and a mixed anion type with the mixed type predominating. Water samples from both the reservoir and the Little Knife River Valley aquifer are fairly similar with no dominant anion constituents and relatively high chloride (Cl) concentrations. Sulfate (SO_4) is the dominant anion in waters from the Fort Union Group, and bicarbonate (HCO_3) is the dominant anion in water from the Fox Hills Formation.



EXPLANATION

\+ - Stanley Reservoir

□ - Stanley 86-inch Production Well in the Little Knife River Valley aquifer

○ - Little Knife River Valley Aquifer

● - Fort Union Group

△ - Fox Hills Formation

Figure 18 - Piper diagram showing chemical characteristics of waters from the available sources within the study area.

Fox Hills Formation

The water from the Fox Hills Formation is clearly unlike the water obtained from any of the other three aquifers within the study area. Water from the Fox Hills Formation is a sodium (Na) bicarbonate (HCO_3) type water (figures 18 and 19). Total dissolved solids (TDS) in the sample from the Fox Hills Formation was 2,070 mg/l with a very high sodium (Na) concentration of 850 mg/l. The bicarbonate (HCO_3) concentration is 1,290 mg/l, and the chloride (Cl) concentration is 530 mg/l. The sulfate (SO_4) concentration is 4.1 mg/l.

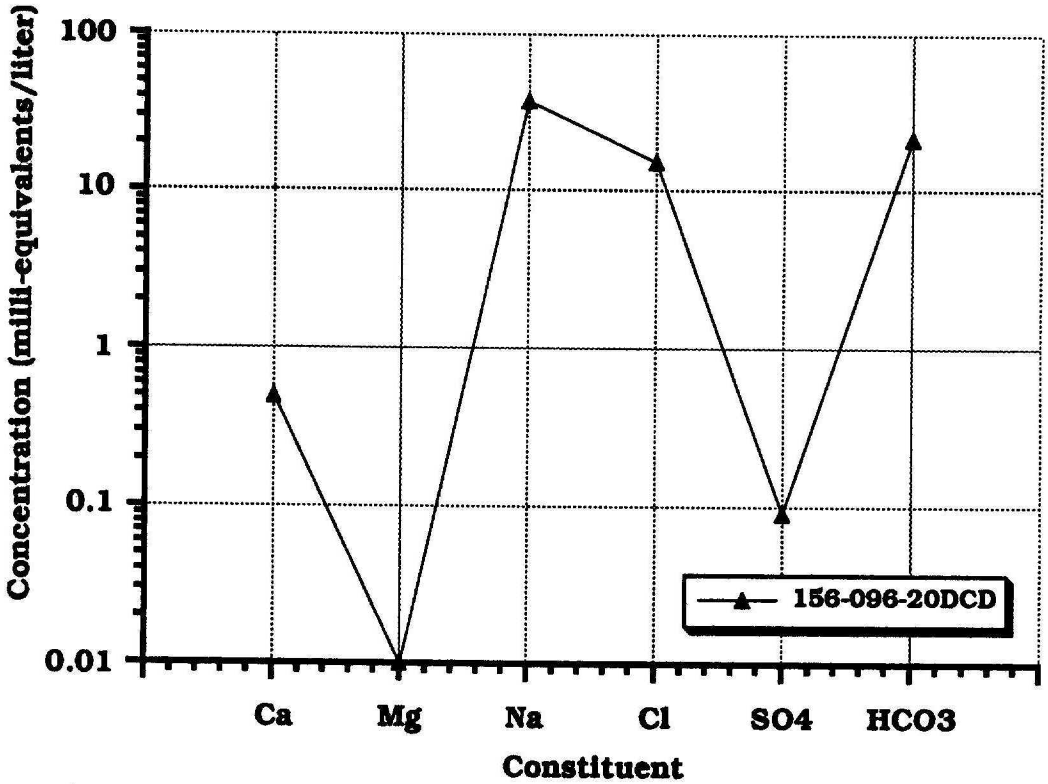


Figure 19 - Schoeller diagram of sample obtained from the well completed in the Fox Hills Formation near Tioga, North Dakota.

Fort Union Group

Water samples obtained from wells completed in the Fort Union Group include wells screened in several different intervals within the upper 300 feet. Water from the Fort Union Group is a sodium (Na) sulfate (SO_4) type (figures 18 and 20). TDS range from 716 mg/l to 2,970 mg/l with an average TDS of approximately 2,290 mg/l.

Concentrations of both sodium (Na) and sulfate (SO_4) are very high with an average sodium (Na) concentration of approximately 687 mg/l and an average sulfate (SO_4) concentration of 950 mg/l. Sodium (Na) concentrations range from 115 mg/l to 1,080 mg/l, and sulfate (SO_4) concentrations range from 97 mg/l to 1,410 mg/l.

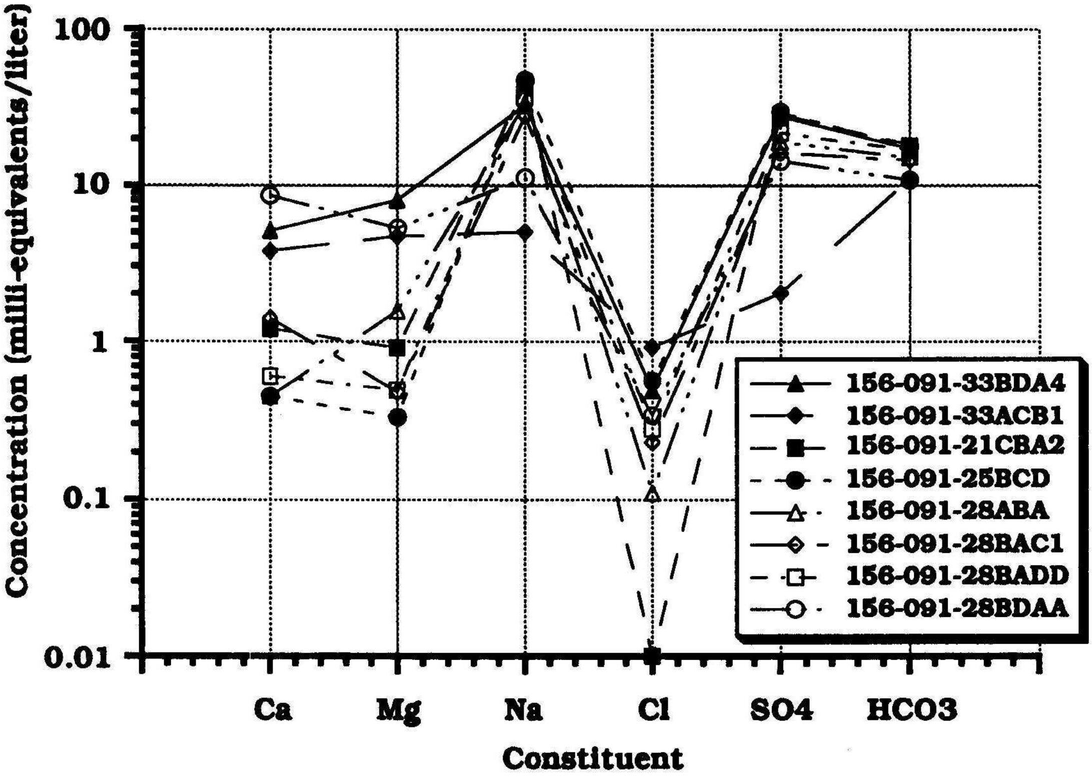


Figure 20 - Schoeller diagram of samples obtained from wells completed in the Fort Union Group.

Little Knife River Valley Aquifer

Water from the Little Knife River Valley aquifer has a variable composition ranging from a sodium (Na) to a mixed cation with a bicarbonate (HCO_3), sulfate (SO_4), or mixed anion type (figures 18 and 21). The sodium (Na) mixed anion type predominates. The chloride(Cl) concentration in water from the Little Knife River Valley aquifer is generally high as compared to the chloride (Cl) concentration in groundwater from either the Fox Hills or the Fort Union aquifers.

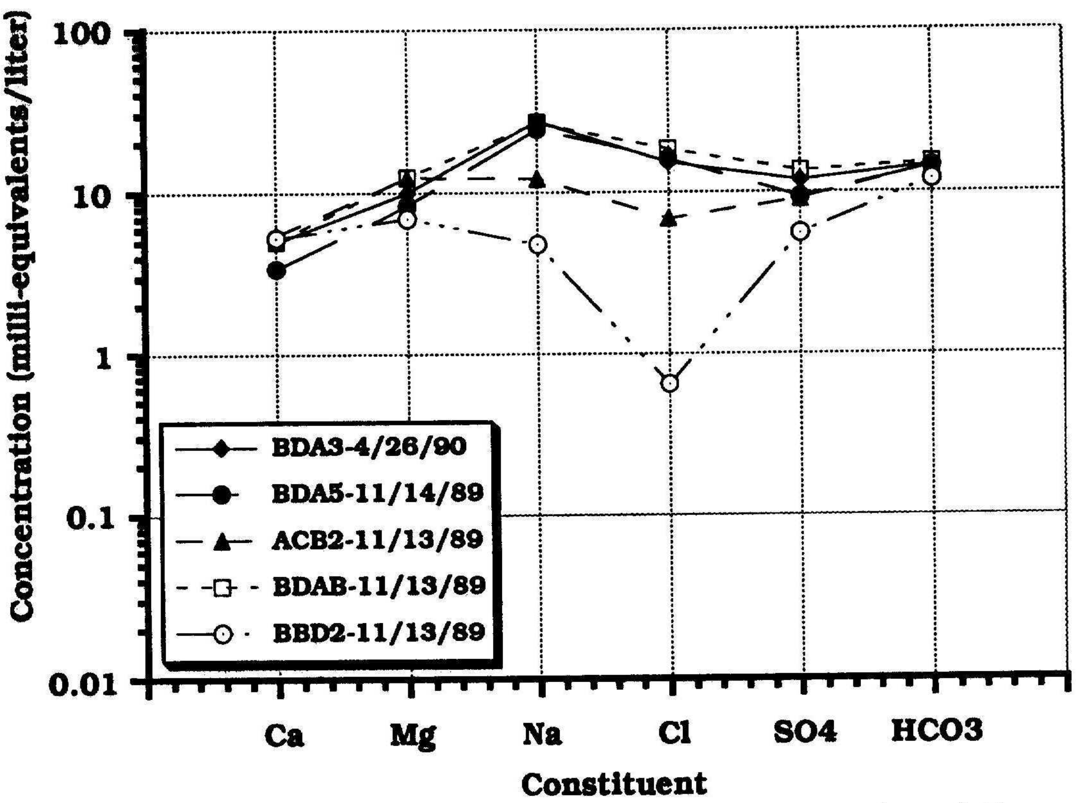


Figure 21 - Schoeller diagram of representative samples from the Little Knife River Valley aquifer

TDS range from 717 mg/l to 2,790 mg/l. Paulson included three samples from wells completed in the Little Knife River Valley aquifer prior to 1954 with TDS when collected ranging from 200 mg/l to 450 mg/l which would create an even greater variability in the range of TDS. However, the TDS reported for each of the three samples was based upon an incomplete analysis, and therefore, the samples were not entirely representative of the actual TDS at the time the samples were collected. Even though the TDS for each of the three samples reported by Paulson was not based upon a complete analysis, most of the major cation and anion constituents were significantly lower than samples collected later, which tends to indicate that the TDS in the Little Knife River Valley at one time was below the range of 717 mg/l to 2,790 mg/l currently indicated.

Sodium (Na) concentrations are generally high to very high ranging from 27 mg/l to 710 mg/l, with an average concentration of approximately 420 mg/l. Sulfate (SO_4) concentrations range from 10 mg/l to 795 mg/l with an average concentration of approximately 430 mg/l. Bicarbonate (HCO_3) concentrations range from 220 mg/l to

956 mg/l. Chloride (Cl) concentrations in the samples obtained from the Little Knife River Valley aquifer are variable ranging from 2 mg/l to 690 mg/l. Chloride (Cl) concentrations are generally larger in samples obtained from the wells completed near Stanley's 86-inch production well. Chloride (Cl) concentrations in the 86-inch production well increased from 90 mg/l in 1966 to over 500 mg/l in 1990, while the chloride (Cl) concentrations in piezometers furthest from the production well generally remained below 100 mg/l.

Stanley Reservoir

Water from the Stanley reservoir is a sodium (Na) - mixed anion type (figures 18 and 22). TDS range from approximately 752 mg/l to 2,370 mg/l with the TDS generally increasing over time. Sodium (Na) concentrations range from 162 mg/l to 629 mg/l with an average concentration of 472 mg/l. Sulfate (SO_4) concentrations are generally high with concentrations ranging from 170 mg/l to 567 mg/l, and an average concentration of 441 mg/l. Bicarbonate (HCO_3) concentrations range from 492 mg/l to 719 mg/l with an average concentration of 644 mg/l, and chloride (Cl) concentrations range from 47 mg/l to 602 mg/l with an average concentration of 368 mg/l.

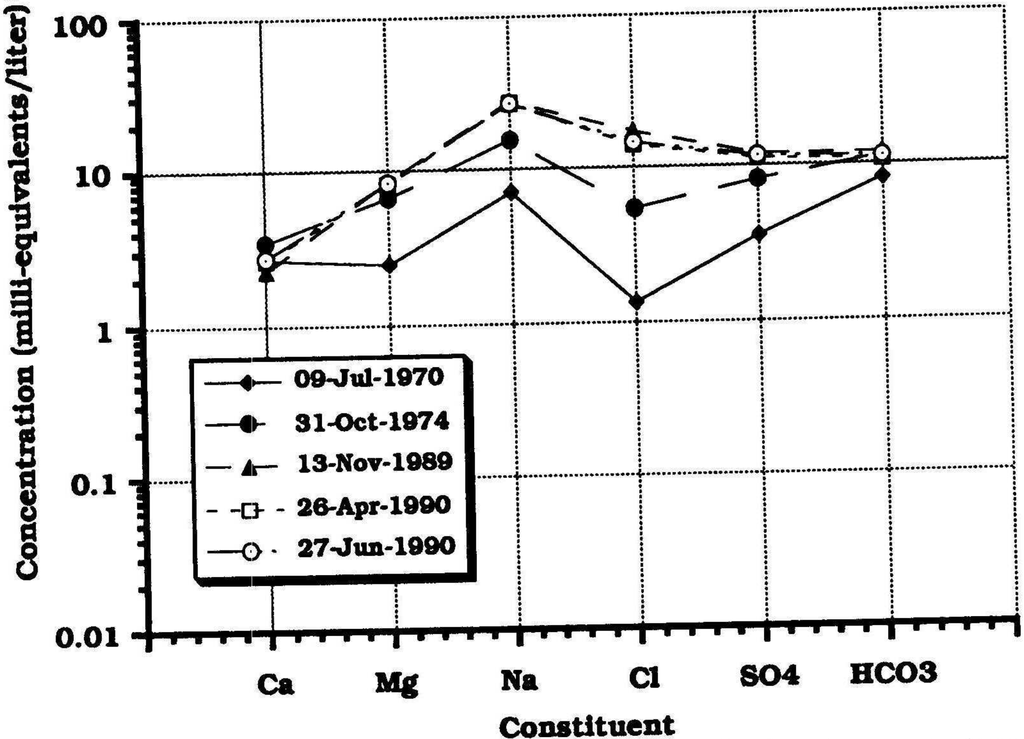


Figure 22 - Schoeller diagram of samples collected from the Stanley reservoir over time.

Head relationships previously described indicate that water is generally moving upward from the Fort Union Group into the Little Knife River Valley aquifer. However, water from the Little Knife River Valley aquifer is clearly different than the water from the Fort Union Group (figure 23). Chloride (Cl) concentrations in water from the Little Knife River Valley aquifer is generally between one to three orders of magnitude larger than the chloride (Cl) concentrations in water from the Fort Union Group. The similarity in the water quality observed in both the Little Knife River Valley aquifer and the Stanley Reservoir and the associated high chlorides in both provides further evidence to suggest that the Stanley Reservoir and the Little Knife River Valley aquifer are hydraulically connected.

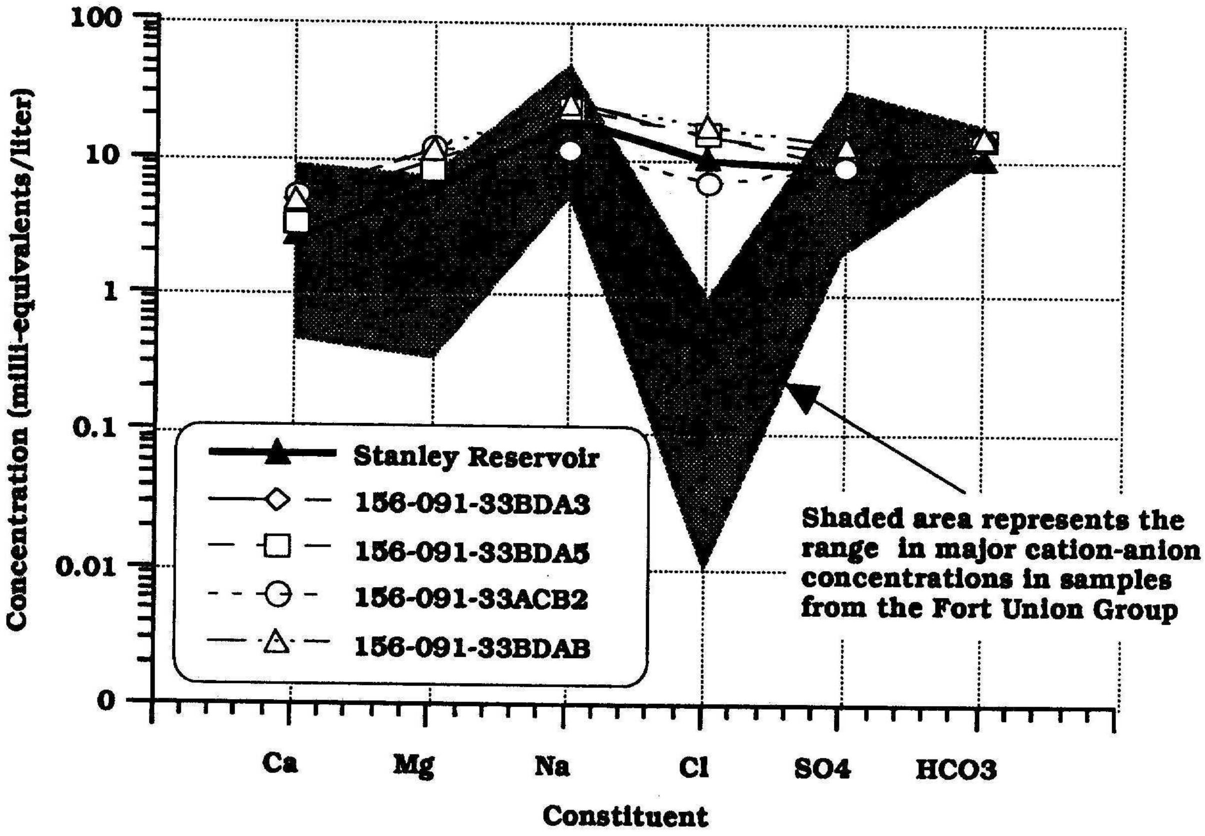


Figure 23 - Schoeller diagram comparing representative samples from the Little Knife River Valley aquifer with samples from both the Stanley reservoir and the Fort Union Group.

WELL HEAD PROTECTION AREA

The WHP program is designed to protect groundwater around public water supply well fields from various possible threats. These threats include: direct introduction of contaminants to the area immediately surrounding the well through improper well construction, road runoff, or spills; microbial contaminants such as bacteria or viruses; and a broad range of chemical contaminants, both naturally occurring and man-made. A major element of the WHP program is the determination of zones within which contaminant source assessment and management will be addressed. These zones, called Wellhead Protection Areas (WHPAs), are defined by the Safe Drinking Water Act amendments of 1986 as "The surface and subsurface area surrounding a water well or well field, supplying a public water system, through which contaminants are likely to move toward and reach such water well or well field.".

A WHPA protects the groundwater entering public water supply (PWS) wells by performing these three functions:

1. Provides a remedial action zone to protect wells from unexpected contaminant releases.
2. Provides a management zone for all or part of a well's recharge or contribution area.
3. Provides an attenuation zone in which the concentration of a contaminant in the groundwater is reduced before entering the well.

Wellhead Protection Area Delineation

A number of factors or "criteria" form the technical basis for the delineation or mapping of WHPAs. The North Dakota WHP program uses a combination of the following criteria for delineating WHPAs:

1. Distance to the well.
2. Time of travel (TOT) which is the length of time it takes for water to travel through the aquifer from the WHPA boundary to the well.
3. Flow boundaries which are groundwater divides or other physical hydrologic features that control groundwater flow.

Methods used to delineate a WHPA using these criteria include the arbitrary fixed radius method, the calculated fixed radius method, the analytical zone of contribution method, and the hydrogeologic mapping method.

The North Dakota WHP program has also selected minimum standards, called criteria thresholds, by which these criteria are implemented. As a guideline, thresholds have been set at a minimum distance of 500 feet, and 10 years TOT if the WHPA is delineated using the zone of contribution method or 15 years TOT if the WHPA is delineated using the calculated fixed radius method. These thresholds may be modified on a case-by-case basis due to flow boundaries or other site specific conditions.

In some instances, it may be advantageous to delineate more than one zone within the WHPA. This would be done if varying levels of protection or management was desired around the well. The zone closest to the well, with the most stringent protection is called the primary WHPA and the zone of less stringent protection is called the secondary WHPA.

Arbitrary Fixed Radius Method

The Arbitrary Fixed Radius method is the simplest method of delineating a WHPA. It involves drawing a circle with a specific radius around the well to be protected (figure 24). The Arbitrary Fixed Radius method is simple and inexpensive, but due to the lack of any quantitative basis for choosing the radius there is much uncertainty about the effectiveness in any specific setting. This method could be employed in situations where it is necessary to define a WHPA before it is possible to collect more definitive site specific information for delineation by other methods.

The North Dakota WHP program has established a minimum distance of 500 feet as the distance threshold to be used for WHPA delineation using the Arbitrary Fixed Radius method. The minimum distance of 500 feet is to be used in situations where the wells are completed in a confined aquifer with unknown or undefined recharge areas or in systems where no other method can be applied.

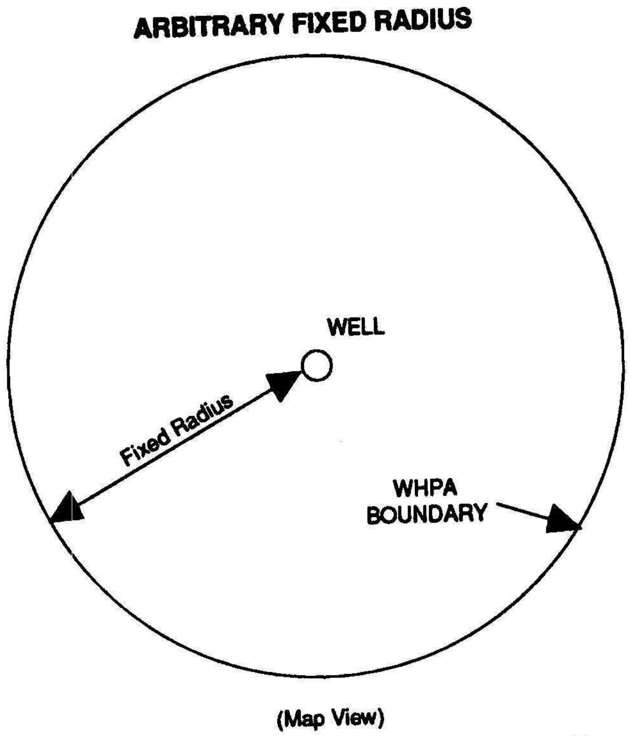
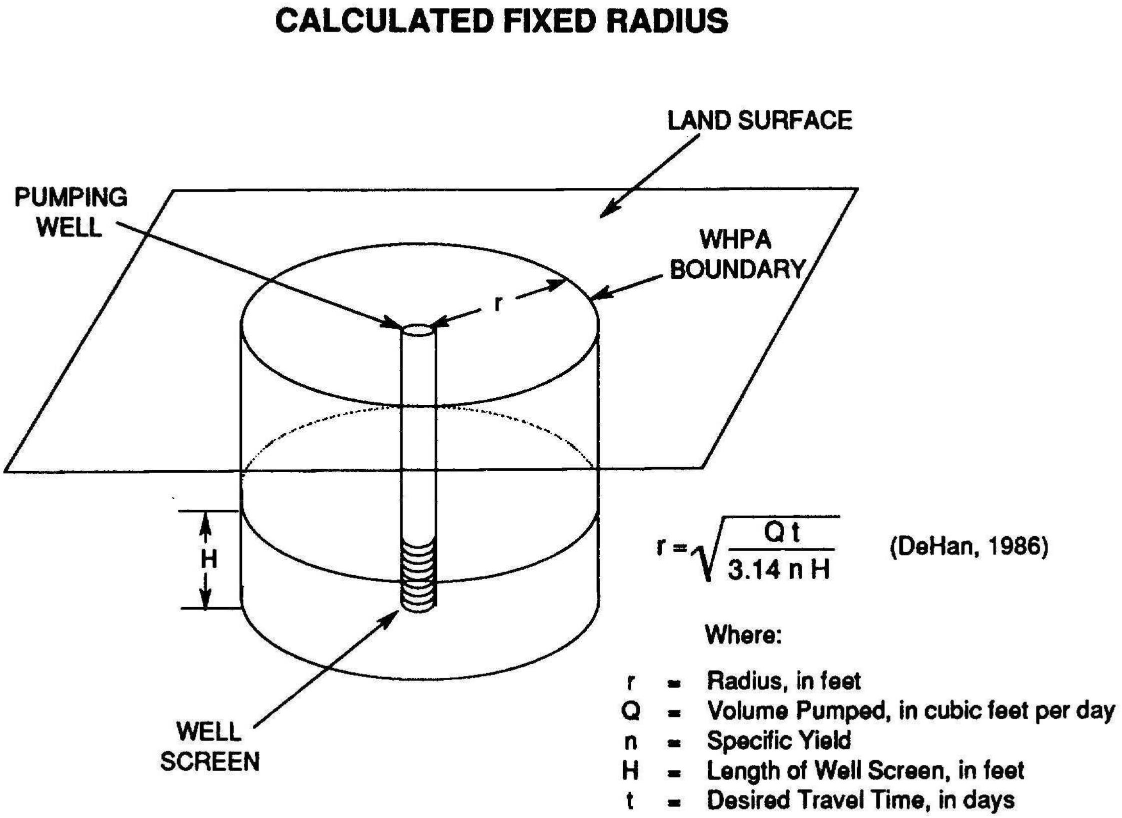


Figure 24 - Arbitrary Fixed Radius method of Wellhead Protection Area Delineation.

Calculated Fixed Radius Method

The Calculated Fixed Radius method involves drawing a circle around the well with a radius tied to a TOT , which under the North Dakota WHP program is generally 15 years. The radius is calculated using a volumetric equation (DeHan, 1986), based on the volume of water that will be drawn to the well in the specified time, specific yield of the aquifer, and length of the well screened (figure 25). It provides more accuracy than the Arbitrary Fixed Radius method but still does not account for hydrogeologic factors that may influence contaminant transport.

In the case of a well that is completed in a confined aquifer with an arbitrary WHPA of 500 foot radius, it is recommended that a secondary WHPA be established using a calculated fixed radius with a TOT of 15 years. The secondary WHPA would then be checked for abandoned or improperly constructed wells or other artificial penetrations that could provide a direct conduit for contaminants to enter the aquifer.



$$r = \sqrt{\frac{Q\,t}{3.14\,n\,H}}$$ (DeHan, 1986)

Where:

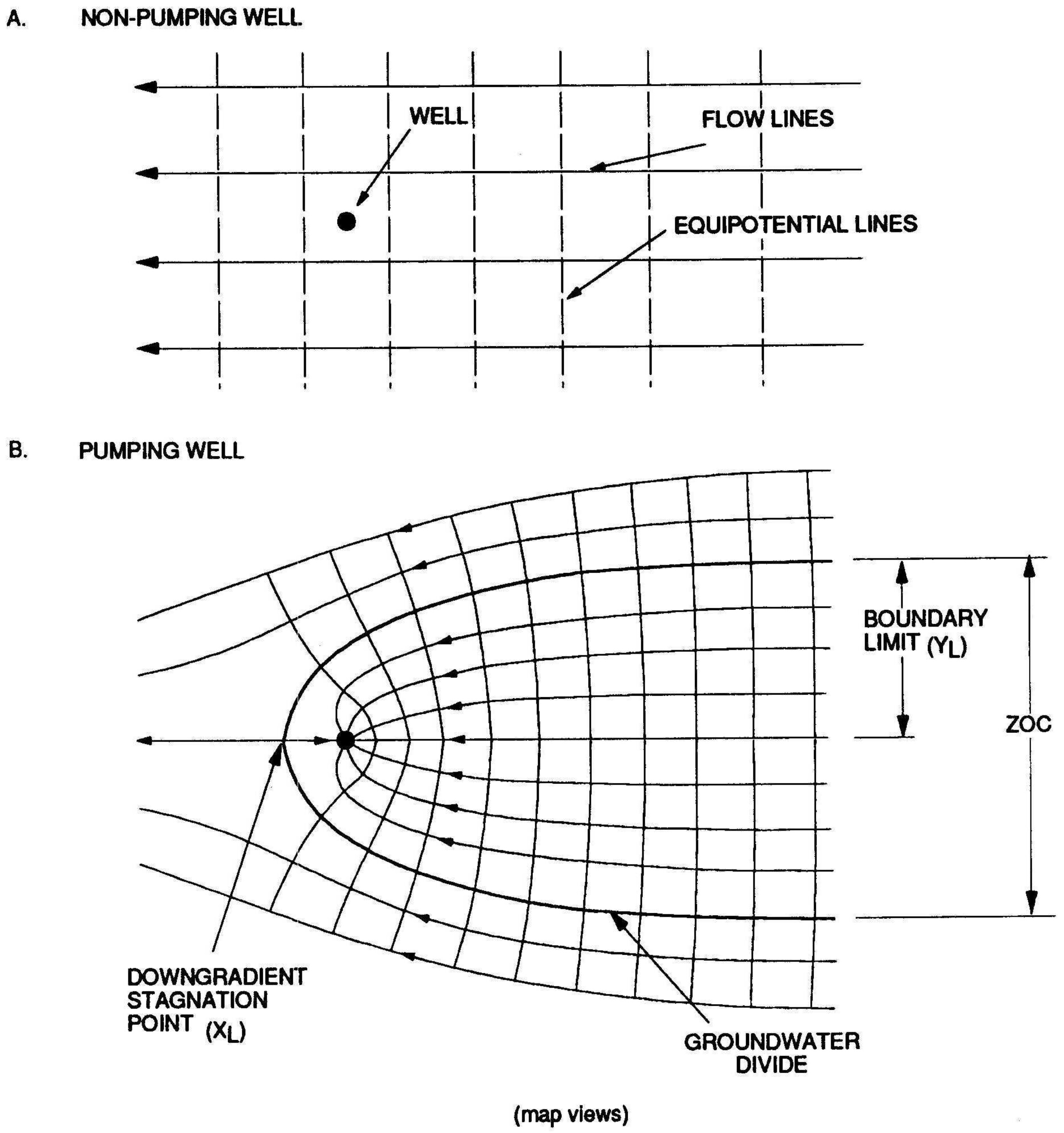
r = Radius, in feet
Q = Volume Pumped, in cubic feet per day
n = Specific Yield
H = Length of Well Screen, in feet
t = Desired Travel Time, in days

Figure 25 - Calculated Fixed Radius method of Wellhead Protection Area delineation.

Analytical Zone Of Contribution Method

The Zone of Contribution (ZOC) for a well is the land surface, including recharge areas, and subsurface areas through which water flows, that will contribute water to the well. One method of delineating the ZOC involves the use of the uniform flow equation (Todd, 1980) to determine the stagnation point down-gradient from a well and the width of the up-gradient zone that contributes flow to the well (figure 26). The stagnation point marks the distance beyond which flow in the aquifer will not be drawn into the well under the influence of pumping. The boundary limits of the ZOC in the up-gradient direction define the width of the aquifer required to supply flow to the pumping well. The distance to the up-gradient WHPA boundary within the ZOC is tied to the desired time of travel (TOT) chosen to protect the well or wellfield. The distance groundwater will move through the aquifer during the specified TOT is calculated using a derivation of Darcy's law:

ZONE OF CONTRIBUTION



DISTANCE TO DOWN-GRADIENT STAGNATION POINT

$$(X_L) = \frac{Q}{6.28\,K\,b\,i}$$

DISTANCE TO BOUNDARY LIMIT

$$(Y_L) = \frac{Q}{2\,K\,b\,i}$$

WHERE :

Q = VOLUME PUMPED, in cubic feet / day
K = HYDRAULIC CONDUCTIVITY, in feet / day
b = SATURATED THICKNESS, in feet
i = HYDRAULIC GRADIENT

Figure 26 - Zone of Contribution method of Wellhead Protection Area delineation (modified from Todd, 1980).

$$x_t = \frac{(K)\,(i)\,(t)}{(n)}$$

where:
x_t = up-gradient distance to WHPA boundary, in feet
K = hydraulic conductivity, feet / day
i = hydraulic gradient
t = desired TOT, in years
n = porosity

The use of this equation assumes that the well is completed in an aquifer that has a sloping water table or regional hydraulic gradient. The effects of the pumping well are also ignored.

The Analytical Zone of Contribution method is fairly accurate and provides excellent protection for a water supply. However, the use of this method does require a significant amount of site specific data that may not be available.

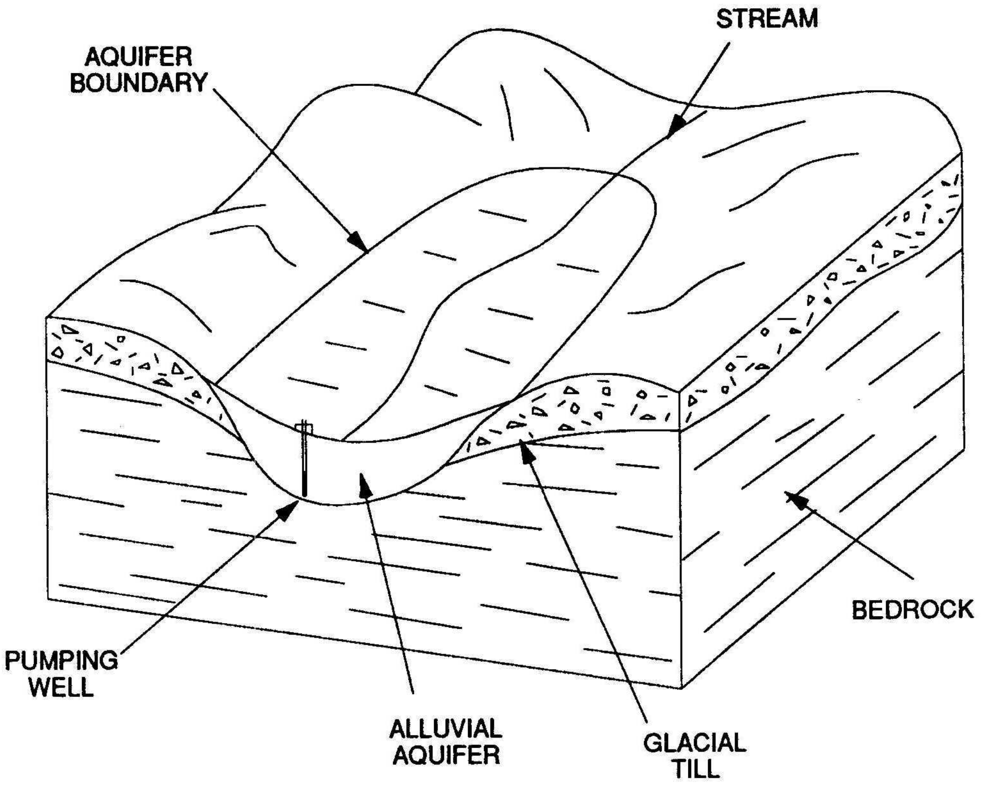
Hydrogeologic Mapping Method

Hydrogeologic mapping is the determination of aquifer characteristics, flow boundaries and flow directions (figure 27). It is well suited to hydrogeologic settings dominated by near surface flow boundaries as are many glacial and alluvial aquifers. It provides for site specific modification to WHPAs calculated using the other methods or can be used alone if the whole aquifer is to be the WHPA.

Stanley Wellhead Protection Areas

Stanley's 86-inch diameter production well was completed in the surficial deposits of the Little Knife River Valley aquifer adjacent to the Stanley Reservoir, and the Stanley #4 and Stanley #6 wells were completed in the Fort Union Group. The setting for the well completed in the surficial deposits is very different from the setting associated with the two wells completed in the Fort Union Group. Both settings are unique with regard to the level of susceptibility and vulnerability to contamination. The surficial deposits of the Little Knife River Valley aquifer are generally unconfined, and the aquifer is hydraulically connected to the adjacent reservoir. Water withdrawn from the 86-inch production well would therefore be directly influenced by local precipitation events and

HYDROGEOLOGIC MAPPING



WHPA DRAWN AS CONTACT BETWEEN AQUIFER AND NON-AQUIFER MATERIAL

Figure 27 - Hydrologic Mapping method of Wellhead Protection Area delineation.

the resulting infiltration and run-off to the reservoir which would make it vulnerable to contamination from surface activity. In contrast, the Fort Union Group ranges from semi-confined to confined, and for the most part water withdrawn from the Fort Union Group will not be greatly affected by surface activity. Therefore, the delineation of the WHPA will require the use of different methods to address the differences associated with the systems in which the wells are completed.

Little Knife River Valley Aquifer

The Little Knife River Valley aquifer is unconfined in the vicinity of Stanley's 86-inch production well, and the aquifer is hydraulically connected to the Stanley Reservoir. Because the aquifer is unconfined, it is vulnerable to contamination from surface activity, and the protection area was defined using the analytical zone of contribution method combined with hydrogeologic mapping methods to provide an appropriate WHPA.

The potentiometric surface identified in the Little Knife River Valley aquifer clearly identifies the influence from Stanley's pumping of the 86-inch production well. Based upon the potentiometric surface identified in figure 9, the ZOC for the 86 inch production well would extend to both the northern and southern boundaries of the aquifer. However, water level and water quality data suggest that the Little Knife River Valley aquifer and the reservoir are hydraulically connected in the vicinity of the 86-inch production well, and the ZOC would need to be expanded to include the reservoir. Therefore, the Stanley Reservoir and the entire lower terrace of the Little Knife River Valley aquifer throughout the reach of the Stanley Reservoir will be designated as the primary WHPA for Stanley's 86-inch production well (figure 28).

The drainage area for the Stanley Reservoir is approximately 22 square miles. Any contamination introduced into the drainage area that recharges the reservoir could ultimately impact Stanley's water supply from the Little Knife River Valley aquifer. Therefore, it will be necessary to provide a secondary WHPA for purposes of providing an additional level of protection for Stanley's water supply from the 86-inch production well.

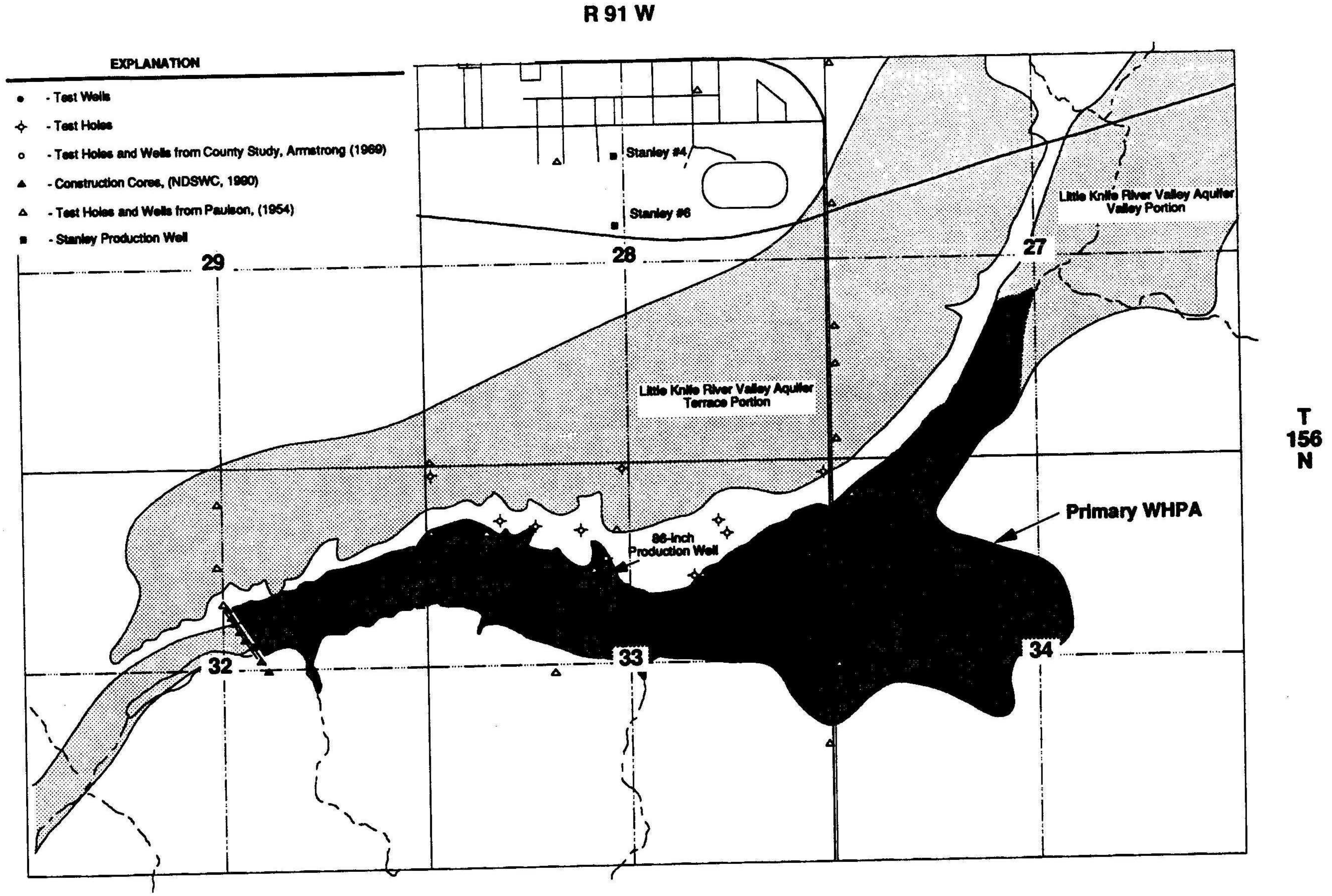


Figure 28 - Primary wellhead protection area for Stanley's 86 inch production well completed in the Little Knife River Valley aquifer.

Much of the drainage area that supplies the Stanley Reservoir is non-integrated. In order for the contaminants introduced into the non-integrated drainage areas to reach the reservoir and subsequently Stanley's 86-inch production well, either an extreme anomalous precipitation event or above average precipitation over several years would be required. In any event, the non-integrated drainage area should provide a level of attenuation sufficient to minimize any impacts of contamination of Stanley's water supply from the 86 inch production well. Therefore, only the portion of the drainage area that is fairly well integrated will be included in the secondary WHPA for the 86 inch production well completed in the Little Knife River Valley aquifer (figure 29).

Fort Union Group

The Stanley #4 and the Stanley #6 wells were both completed in the Fort Union Group. The Fort Union Group is confined or semi-confined in the area around the Stanley's water supply wells with approximately 125 to 135 feet of silts and clays above the zone in which Stanley's municipal wells were completed. The potential for contamination of these wells is much less than for 86-inch production well completed in the Little Knife River Valley aquifer. Therefore the calculated fixed radius method of delineation was considered adequate for protecting the Stanley #4 and the Stanley #6 wells.

A 15 year TOT was established by the North Dakota WHP program for delineating a WHPA when using calculated fixed radius methods. The 15 year TOT is used for the WHPA's delineated with the calculated fixed radius rather than the 10 year TOT that is used with the zone of contribution in order to provide additional protection because less site specific data is used to delineate the WHPA. Because the Stanley #4 and the Stanley #6 wells are relatively close together, they can be treated as one pumping point for the purposes of calculating the WHPA.

Stanley's annual pumping varies from year to year, but over the past 6 years Stanley has reported an average annual municipal withdrawal of approximately 52 million gallons of water (NDWUDP, 1990). Based upon the assumptions that Stanley's total annual withdrawal of 52 million gallons was obtained from the Stanley #4 and the Stanley #6 wells, a radius of 1,920 feet would establish a WHPA that would provide a level of protection reflecting a TOT of 15 years. The primary WHPA for the Stanley #4 and the Stanley #6 wells will therefore be defined as the area surrounding both wells

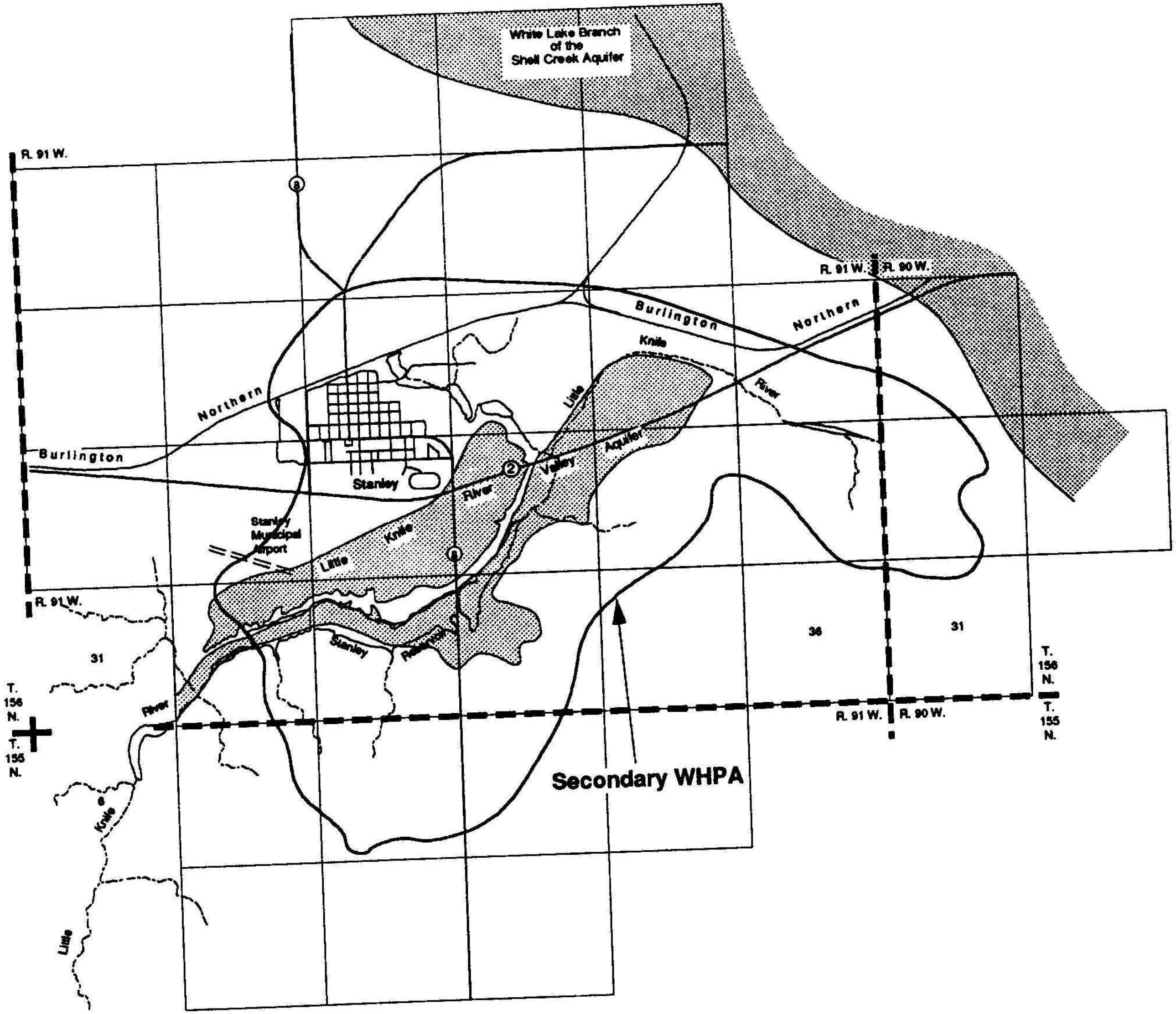


Figure 29 - Secondary wellhead protection area for Stanley's 86 inch production well completed in the Little Knife River Valley aquifer.

with a radius from the mid-point between the two wells of 1920 feet (figure 30). The secondary WHPA for the 86-inch production well completed in the Little Knife River Valley aquifer includes the area surrounding the primary WHPA established for the Stanley #4 and the Stanley #6 wells; therefore, a secondary WHPA was not specifically delineated for the Stanley #4 and the Stanley #6 wells.

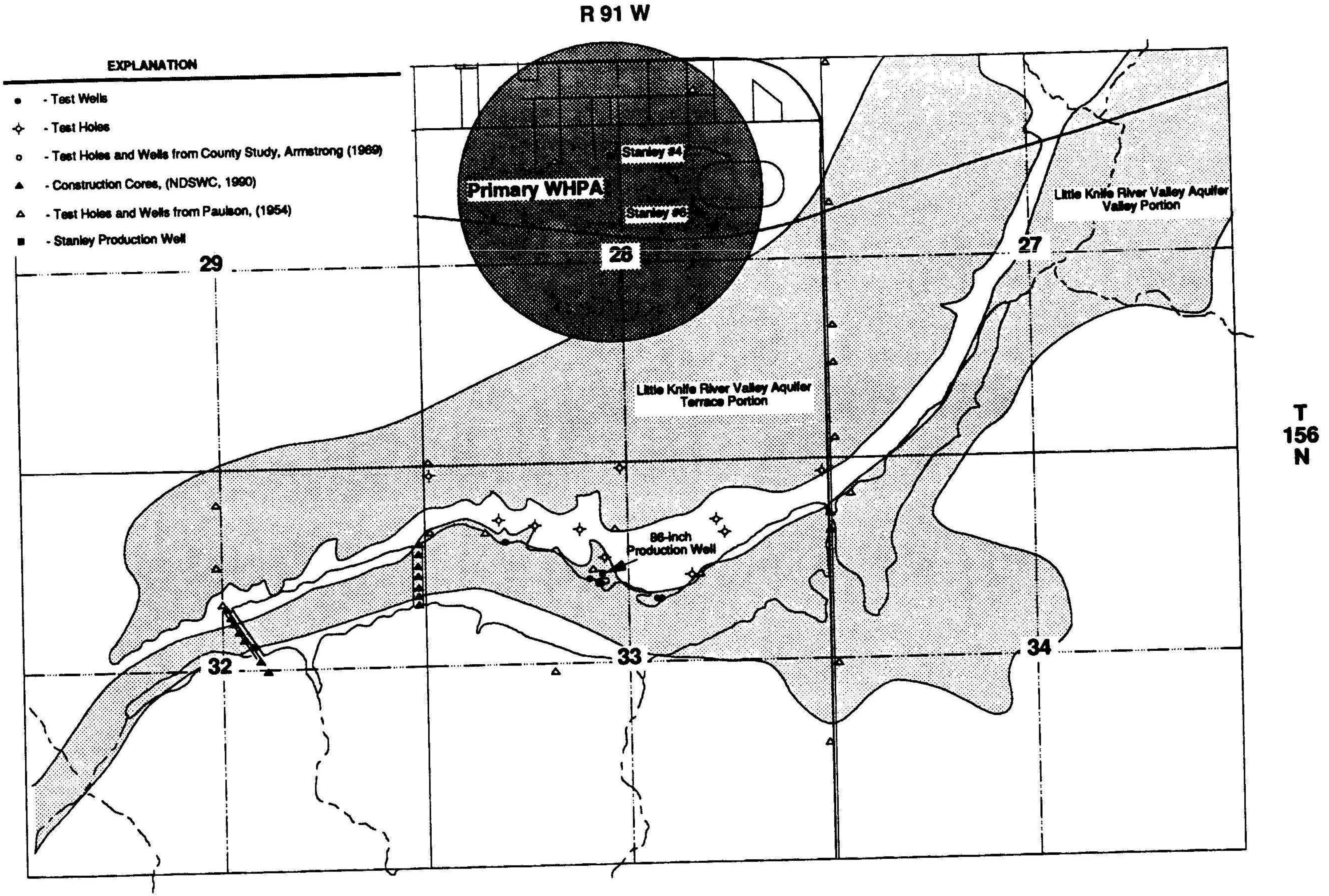


Figure 30 - Primary wellhead protection area for Stanley #4 and the Stanley #6 production wells completed in the Fort Union Group.

SUMMARY AND CONCLUSIONS

The city of Stanley obtains its municipal water supply from three wells. One well is completed in the surficial outwash deposits of the Little Knife River Valley aquifer, and the other two wells are completed in the bedrock deposits of the Fort Union Group.

The sand and gravel outwash deposits which comprise the Little Knife River Valley aquifer were deposited by meltwaters derived from the retreat of the Late Wisconsin glaciers to the northeast. Within the study area the Little Knife River Valley aquifer is separated into two distinct units; a terrace unit that extends north of the Stanley Reservoir, and a valley portion which is generally situated along the Little Knife River valley adjacent to the Stanley Reservoir. Stanley's 86-inch production well is completed in the valley portion of the Little Knife River Valley aquifer, and the valley portion is generally not hydraulically connected to the northern terrace portion of the aquifer.

The horizontal hydraulic gradient suggests that groundwater generally flows toward the 86-inch production well. Water level data from both the aquifer and the Stanley Reservoir suggest that water is generally moving from the Reservoir to the aquifer. In addition to recharge from the adjacent reservoir, the valley portion of the Little Knife River Valley aquifer also receives some recharge from direct infiltration of precipitation. Since the Little Knife River Valley aquifer is small in comparison to the reservoir storage and the contributing drainage area, the hydrologic response in the aquifer will be caused primarily by hydrological factors controlling the reservoir. These factors include precipitation, runoff, and evapotranspiration and other climatic conditions.

The Fort Union Group subcrops beneath the surficial deposits throughout the study area. The Fort Union Group consists of interbedded silts, sands, clays , sandstones, and lignites, and due to these lithologic differences, aquifer properties will vary greatly within the Fort Union Group. The transmissivity (T) for the interval in which both the Stanley #4 and the Stanley #6 wells are completed was calculated at 790 ft^2/day, and the storage coefficient (S) was estimated to range from 10^{-5} to 10^{-4}. The Little Knife River valley represents a regional discharge area for the Fort Union Group, and water within the Fort Union Group is generally moving upward into the Little Knife River Valley aquifer.

Water from the Stanley Reservoir can generally be classified as a sodium (Na) mixed anion type. Water from the Little Knife River Valley aquifer has a variable composition ranging from a sodium (Na) to a mixed cation with a bicarbonate (HCO_3), sulfate (SO_4), or mixed anion type, and the sodium (Na) mixed anion type predominates. Water in the Fort Union Group is generally a sodium (Na) sulfate (SO_4) type. Chloride (Cl) concentrations are generally significantly larger in both the reservoir and the Little Knife River Valley aquifer than the chloride (Cl) concentrations in the underlying Fort Union Group. Similarities in the water quality from both the reservoir and the Little Knife River Valley aquifer suggest that the reservoir and the aquifer are hydraulically connected.

Wellhead Protection Areas (WHPAs) were delineated for Stanley's municipal wells based upon the available hydrologic information. The primary WHPA for the 86-inch diameter production well completed in the Little Knife River Valley aquifer consists of the Stanley Reservoir and the entire lower terrace throughout the reach of the Stanley Reservoir. A secondary WHPA for this well consists of the portion of the drainage basin that directly contributes to the Stanley Reservoir.

The WHPA for the Stanley #4 and the Stanley #6 wells, which are both completed in the Fort Union Group, consists of a circular area with a radius of approximately 1,920 feet surrounding the two production wells.

Management of potential contaminant sources within the WHPA boundaries and additional care taken by persons performing activities within the WHPAs will greatly reduce the likelihood that the quality of water for the city of Stanley will be affected.

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APPENDIX A - Lithologic Logs of Test Holes and Wells

156-090-19DAC

Date Completed:	1959	Purpose:	Test Hole
Depth Drilled (ft):	157	Source of Data:	Armstrong, (1969)
L.S. Elevation (ft)	2150		

Lithologic Log

Unit	Description	Depth (ft)
CLAY	Brown	0-2
SAND & GRAVEL		2-15
CLAY	Brown	15-46
SAND & GRAVEL	Muddy	46-84
SAND & GRAVEL	With gray clay	84-108
SHALE	Gray	108-150
SHALE	Gray, sandy	150-152
SAND & GRAVEL		152-154
SAND	Gray	154-157

156-090-19DDD

Date Completed:	8/5/66	Purpose:	Test Hole
Depth Drilled (ft):	180	Source of Data:	Armstrong, (1969)
L.S. Elevation (ft)	2161		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	black	0-1
SILT	sandy and gravelly, yellowish gray to reddish brown	1-7
CLAY	(TILL) silty with sand grains, pebbles and occasional rocks, yellowish gray, soft to moderately soft, cohesive, oxidized	7-30
CLAY	(TILL) silty with sand grains, pebbles and occasional rocks, olive gray, light olive gray to about 40 feet, moderately soft, cohesive, drills fairly tight	30-65
TILL	as above, with streaks of fine and medium gray rounded quartzose sand	65-75
TILL	as above, with no sand, moderately soft, very cohesive and tough, drills good	75-138
SAND	coarse with fine gravel, moderately well sorted, subrounded, light brownish color	138-142
TILL	clayey, olive gray, gravelly near top of section	142-160
SHALE	(Ft. Union) very silty, medium gray, brownish gray, and brownish black, slightly hard, cohesive to slightly brittle	160-173
SAND	(Ft. Union) light greenish gray to greenish gray with carbonaceous streaks, fine grained, well sorted, lignitic	173-180

156-091-09BBB

Date Completed:	1967	Purpose:	Test Hole
Depth Drilled (ft):	180	Source of Data:	Armstrong, (1969)
L.S. Elevation (ft)	2260		

Lithologic Log

Unit	Description	Depth (ft)
CLAY	(TILL) silty and sandy, with pebbles, yellowish gray and dusky yellow, soft, moderately cohesive, oxidized	0-14
SAND	fine to medium, brown, well-sorted, subrounded	14-19
CLAY	(TILL) silty and sandy with pebbles, olive gray, soft, cohesive	19-25
SILT	clayey, laminated, moderate olive brown to light olive gray, occasional sand grains, soft, moderately cohesive	25-52
CLAY	(TILL) silty to sandy with numerous pebbles and occasional rocks, light olive gray to olive gray, soft, cohesive, moderately plastic, large samples	52-130
SAND	(Ft. Union) fine, slightly clayey, white, yellowish gray, yellowish green, and dusky yellow, soft, slightly cohesive, mostly quartz, highly lignitic, oxidized	130-159
SHALE	(Ft. Union) silty, greenish gray, smooth, slightly hard, slippery, tight	159-169
LIGNITE	(Ft. Union) black, fissile, hard	169-174
SHALE	medium gray, slightly hard, smooth, tight	174-180

156-091-09DAD

Date Completed:	1967	Purpose:	Test Hole
Depth Drilled (ft):	220	Source of Data:	Armstrong, (1969)
L.S. Elevation (ft)	2292		

Lithologic Log

Unit	Description	Depth (ft)
CLAY	(TILL) silty and sandy with numerous pebbles, yellowish gray, dusky yellow and moderate olive brown, soft, slightly to moderately cohesive, oxidized	0-38
CLAY	(TILL) silty with sand grains and pebbles, olive gray, moderately soft, cohesive	38-60
SILT	moderate olive brown, soft, slightly cohesive, slightly plastic, calcareous	60-80
SILT	as above, clayey and sandy	80-102
CLAY	(TILL) silty and sandy with pebbles and occasional rocks, olive gray, moderately soft, moderately cohesive, very slightly plastic, crumbly	102-166
SAND	(Ft. Union) very fine to fine, clayey, yellowish green, soft, slightly friable, oxidized, lignitic	166-181

156-091-09DAD (Cont.)

Date Completed:	1967	Purpose:	Test Hole
Depth Drilled (ft):	220	Source of Data:	Armstrong, (1969)
L.S. Elevation (ft)	2292		

Lithologic Log

Unit	Description	Depth (ft)
SHALE	(Ft. Union) very silty, moderately soft to slightly hard, medium gray with a bluish tint, noncalcareous	181-205
LIGNITE	(Ft. Union) black, hard, fissile	205-207
SHALE	(Ft. Union) as above	207-220

156-091-10BBB

Date Completed:	1966	Well Type:	1"
Depth Drilled (ft):	340	Source of Data:	Armstrong, (1969)
Screened Interval (ft):		Principal Aquifer:	Shell Creek
L.S. Elevation (ft)	2303		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	pebbly loam, dark yellowish brown	0-1
CLAY	(TILL) silty with pebbles, yellowish gray, soft, slightly cohesive	1-7
SILT	(TILL ?) clayey to sandy with some pebbles and rocks, yellowish gray, soft, slightly to moderately cohesive, oxidized	7-21
SAND	very fine to fine, well sorted, subrounded, some silty streaks, dry	21-40
SILT	clayey, sandy in upper portion, dusky yellow to moderate olive brown, moderately cohesive to very tight, drills fairly smooth, using rock bit, very good sample return	40-54
SAND	very fine and fine, very silty with streaks of clay, light olive gray to olive gray, soft, moderately cohesive	54-72
CLAY	silty, olive gray, moderately soft, cohesive and plastic	72-79
SILT	clayey with streaks of very fine sand, olive gray, soft to moderately soft, moderately cohesive, slightly plastic	79-97
SAND	very fine and fine, interbedded with silt and clay, light olive gray to olive gray, drills smooth	97-108
SAND	medium, well sorted, subrounded, quartzose, clean	108-114
GRAVEL	fine and medium, some sand and coarse gravel, moderately well sorted, generally subangular, about 25 percent well rounded. Mostly limestone, granitics and a little shale. No lignite. Drills fairly rough, taking lots of water	114-131
CLAY	(TILL) very sandy and gravelly, olive gray, moderately soft, cohesive, drills fairly light and rough	131-143

156-091-10BBB (Cont.)

Date Completed:	1966	Purpose:	Test Hole
Depth Drilled (ft):	340	Source of Data:	Armstrong, (1969)
L.S. Elevation (ft)	2303		

Lithologic Log

Unit	Description	Depth (ft)
CLAY	(TILL) silty with sand grains and pebbles, occasional rocks, olive gray, moderately soft, very cohesive and tough, drills tight, contains many specks of lignite, pebbles mainly limestone	143-256
CLAY	olive gray, slightly hard, very cohesive and tight	256-262
SAND	fine and medium, gray, clayey in spots, moderately sorted, poor sample return	292-303
CLAY	(TILL ?) silty, olive gray, tight	303-308
SAND	as above, with gravel, samples indicate the possibility it might be gravelly till	308-318
SILT	(Ft. Union) light gray, slightly hard, highly calcareous	318-322
SHALE	(Ft. Union) medium gray, slightly hard, cohesive, smooth	322-326
SAND	(Ft. Union) fine, greenish gray, moderately soft, slightly friable	326-330
SHALE	(Ft. Union) olive gray and dark greenish gray, slightly hard, smooth slippery, tight	330-334
SAND	(Ft. Union) fine, greenish gray to dark greenish gray, carbonaceous, drills tight	334-340
CLAY	(TILL) as above, very clayey, with lignitic sand grains, limestone, shale, and granitic pebbles and rocks, drills very tight and tough, excellent sample return	262-292

156-091-11CDC

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	140	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2240		

Lithologic Log

Unit	Description	Depth (ft)
TILL	pale yellowish brown, sandy	0-27
TILL	medium gray	27-82
TILL	moderate yellowish brown	82-88
TILL	light gray	88-131
CLAY	(Ft. Union) light gray, sandy	131-140

156-091-14AAA

Date Completed: 6/15/67
Depth Drilled (ft): 284
L.S. Elevation (ft) 2197
Purpose: Test Hole
Source of Data: Armstrong, (1969)

Lithologic Log

Unit	Description	Depth (ft)
ROAD FILL		0-9
CLAY	(TILL) silty and very sandy with pebbles, moderate olive brown, moderately soft, cohesive, oxidized	9-29
CLAY	(TILL) silty and sandy with pebbles and occasional rocks, olive gray, moderately soft, cohesive, easy drilling	29-54
SAND	medium to very coarse and fine gravel, moderately well sorted, subangular and subrounded, mostly quartz and limestone or dolomite, vert lignitic, appears to be fairly clean, no noticeable loss of drilling fluid	54-63
CLAY	(TILL) silty and sandy with pebbles, olive gray, moderately soft, cohesive	63-120
SILT	(Ft. Union) olive gray and light olive gray, slightly hard, shaley, calcareous, tight	240-260
SAND	(Ft. Union) fine, silty, olive gray, soft, moderately friable, highly calcareous, predominately quartz	260-280
SANDSTONE	(Ft. Union) light olive gray, indurated, calcareous cement	280-284
CLAY	(TILL) silty with sand grains and pebbles, olive gray, moderately soft, cohesive	120-240

156-091-16ACB

Date Completed: 1952
Depth Drilled (ft): 90
L.S. Elevation (ft) 2270
Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
TILL	yellowish gray	1-19
TILL	light gray	19-54
TILL	yellowish gray	54-60
TILL	yellowish gray	60-81
SHALE	(Ft. Union) gray, sandy	81-90

156-091-16BBB

Date Completed:	1952		
Depth Drilled (ft):	140	Purpose:	Test Hole
L.S. Elevation (ft)	2309	Source of Data:	Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-1
TILL	yellowish gray	1-43
TILL	light gray, sandy	43-64
SAND	medium; much clay	64-69
TILL	light gray, sandy	69-102
TILL	yellowish gray	102-126
TILL	gray, hard	126-137
SHALE	(Ft. Union) light gray	137-140

156-091-16CCA

Date Completed:	1952		
Depth Drilled (ft):	250	Purpose:	Test Hole
L.S. Elevation (ft)	2270	Source of Data:	Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-2
TILL	yellowish gray	2-18
SAND		18-20
TILL	yellowish gray	20-38
SAND & GRAVEL		38-48
TILL	yellowish gray	48-77
TILL	gray, harder than above	77-106
SHALE	(Ft. Union) light gray, sandy	106-115
SHALE	(Ft. Union) light gray, clayey	115-145
SHALE	(Ft. Union) light gray, hard	145-157
LIGNITE	(Ft. Union)	157-159
SHALE	(Ft. Union) light gray, clayey	159-208
Indurated Rock	(Ft. Union) probably a concretion	208-209
SHALE	(Ft. Union) light gray, hard	209-248
SHALE	(Ft. Union) brown	248-250

156-091-19AAA

NDSWC 3502

Date Completed:	7/25/67	Purpose:	Test Hole
Depth Drilled (ft):	120	Source of Data:	NDSWC
L.S. Elevation (ft)	2317		

Lithologic Log

Unit	Description	Depth (ft)
GRAVEL	sand, silt, and clay, yellowish gray and dusky yellow, soft, loose to slightly cohesive, interbedded, oxidized	0-11
CLAY	(TILL) silty with sand grains and pebbles, moderate olive brown, soft, cohesive, oxidized	11-22
CLAY	(TILL) silty to sandy with pebbles, olive gray, moderately soft, cohesive	22-46
CLAY	(TILL) silty and sandy with pebbles and gravel, olive gray,k moderately soft, cohesive	46-63
CLAY	olive gray, soft, smooth, plastic	63-72
CLAY	(TILL) silty to sandy with pebbles, olive gray, moderately soft, cohesive	72-84
TILL	as above, with limestone gravel, moderately rough drilling, sandy	84-94
SHALE	(Ft. Union) yellowish gray, yellowish green to light gray, slightly hard and brittle, smooth, slippery, tight	94-120

156-091-20DDD

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	70	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2248		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-1
TILL	yellowish gray	1-21
SAND & GRAVEL		21-27
TILL	yellowish gray	27-60
TILL	light gray	60-66
SHALE	(Ft. Union) light gray	66-70

156-091-21CBA2

Date Completed:	1947	Well Type:	8"
Depth Drilled (ft):	200	Source of Data:	Paulson, (1954)
Screened Interval (ft):		Principal Aquifer :	Fort Union Group
L.S. Elevation (ft)	2255		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
TILL	clay with cobbles	1-14
SAND	medium to coarse	14-18
GRAVEL	fine, clayey	18-22
SAND	medium to coarse, mostly shale fragments	22-30
SAND	medium to coarse, mostly shale fragments, clayey	30-38
CLAY	with sand	38-65
CLAY	(Ft. Union) gray, tough	65-114
SAND	(Ft. Union) clayey	114-118
CLAY	(Ft. Union) gray	118-153
CLAY	(Ft. Union) brown	153-160
CLAY	(Ft. Union) gray, sandy	160-170
SAND	(Ft. Union) gray, clayey, hard and soft layers	170-175
SANDSTONE	(Ft. Union) gray, fine	175-200

156-091-21CCA1

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	70	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2220		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	black	0-2
TILL	yellowish gray	2-47
SHALE	(Ft. Union) yellowish gray	47-58
SHALE	light gray	58-70

156-091-21CCA2

Date Completed: 1952
Depth Drilled (ft): 60
L.S. Elevation (ft) 2220
Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-2
TILL	yellowish gray	2-4
SAND		4-7
TILL	yellowish gray	7-49
SHALE	(Ft. Union) yellowish gray	49-54
SHALE	(Ft. Union) light gray	54-60

156-091-22DCD

Date Completed: 1952
Depth Drilled (ft): 40
L.S. Elevation (ft) 2190
Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark yellowish brown	0-3
TILL	yellowish gray	3-28
SHALE	(Ft. Union) light gray	28-40

156-091-22DDC

Date Completed: 1952
Depth Drilled (ft): 20
L.S. Elevation (ft) 2165
Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-1
CLAY	brown	1-3
SAND	very coarse	3-5
GRAVEL	very fine to coarse, average diameter about 1/4 inch	5-10
CLAY	carbonaceous, dark brown, contains bits of vegetation	10-14
SHALE	(Ft. Union) light gray	14-20

156-091-22DDD1

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	30	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2185		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
CLAY		1-3
SAND	very coarse	3-5
TILL	yellowish gray, much very coarse sand	5-10
TILL	yellowish gray	10-15
TILL	possibly lake clay, grayish orange, contains small amounts of pebbles or sand (could also be a weathered shale, more orange than oxidized till)	15-22
SHALE	(Ft. Union) light gray (streak of dark brown clay and lignite from 24-26)	22-30

156-091-22DDD2

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	50	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2185		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-1
CLAY	brown	1-3
SAND	fine to medium	3-7
TILL	yellowish gray	7-20
TILL	yellowish gray, much sandier than above	20-47
SHALE	(Ft. Union) light gray, sandy	47-50

156-091-23CCC

Date Completed: 1952
Depth Drilled (ft): 80
L.S. Elevation (ft) 2190
Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-1
CLAY	yellowish gray	1-3
SAND	medium to coarse	3-5
SAND	very coarse	5-8
GRAVEL	very fine to coarse, average diameter about 1/4 inch	8-16
TILL	yellowish gray	16-74
SHALE	(Ft. Union) brown	74-76
SHALE	(Ft. Union) light gray	76-77
LIGNITE	(Ft. Union)	77-78
SHALE	(Ft. Union) light gray	78-80

156-091-23CCD

Date Completed: 1952
Depth Drilled (ft): 100
L.S. Elevation (ft) 2209
Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown, sandy	0-1
CLAY	gray	1-3
SAND & GRAVEL		3-8
TILL	yellowish gray, sandy	8-88
LIGNITE	(Ft. Union)	88-89
SHALE	(Ft. Union) light gray, sandy	89-100

156-091-27BBB

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	280	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2242		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-1
CLAY	light gray, and gravel	1-3
SAND		3-4
TILL	yellowish gray, very gravelly	4-20
TILL	yellowish gray, streak of carbonaceous clay from 44 to 46 feet	20-61
SHALE	(Ft. Union) light gray	61-72
LIGNITE	(Ft. Union)	72-74
SHALE	(Ft. Union) light gray, hard	74-99
LIGNITE	(Ft. Union)	99-101
SHALE	(Ft. Union) light gray hard	101-113
LIGNITE	(Ft. Union)	113-114
SHALE	(Ft. Union) light gray, hard	114-128
SHALE	(Ft. Union) light gray, sandy	128-160
SHALE	(Ft. Union) sandy shale, light gray, (about 50% sand)	160-217
SHALE	(Ft. Union) gray, clayey	217-241
LIGNITE	(Ft. Union) with carbonaceous clay	241-243
SHALE	(Ft. Union) light gray, clayey	243-280

156-091-27BCC

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	60	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2238		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
CLAY	gray	1-3
SAND	very coarse	3-10
GRAVEL	medium	10-17
TILL	light olive gray, much gravel	17-45
SANDSTONE	(Ft. Union) very fine, very friable, yellowish gray	45-57
CLAY	(Ft. Union) light gray	57-60

156-091-27CBB

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	90	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2230		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	brown, sandy	0-1
CLAY	brown	1-3
GRAVEL		3-5
COBBLES	average diameter 2 to 3 inches	5-10
SAND & GRAVEL		10-14
TILL	yellowish gray, sandy	14-78
SHALE	(Ft. Union), light gray	78-90

156-091-27CCB

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	60	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2210		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
CLAY		1-4
SAND	very coarse, and gravel	4-10
GRAVEL	very fine to coarse	10-16
TILL	medium gray	16-28
TILL	yellow, gray, and orange (streaked); very sandy. Appears to be a weathered zone. Shows evidence of greater weathering than in the overlying till; contains limonitic nodules	28-49
SHALE	(Ft. Union), light gray	49-60

156-091-27CCC

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	40	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2190		

Lithologic Log

Unit	Description	Depth (ft)
SAND & GRAVEL		0-5
GRAVEL		5-9
TILL	medium gray	9-22
GRAVEL		22-26
TILL	medium gray	26-29
SHALE	(Ft. Union), light gray. Core, about 5% recovery	29-40

156-091-28ABA

Date Completed:	1949	Purpose:	Test Hole
Depth Drilled (ft):	200	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2235		

Lithologic Log

Unit	Description	Depth (ft)
TILL	yellowish gray	0-60
CLAY	(Ft. Union), yellowish gray, silty	60-70
CLAY	(Ft. Union), light gray	70-80
SILT	(Ft. Union), pale brown	80-90
SILT	(Ft. Union), yellowish gray	90-110
SILT	(Ft. Union), dark brown, carbonaceous	110-120
SILT	(Ft. Union), light gray	120-130
CLAY	(Ft. Union), dark grown, carbonaceous	130-140
CLAY	(Ft. Union), light gray, silty	140-150
SAND	(Ft. Union), very fine, clayey, loosely consolidated	150-162
SAND	(Ft. Union), very fine to fine, relatively clean, loosely consolidated	162-173
SAND	(Ft. Union), very fine, clayey	173-200

156-091-28ACA

NDSWC 12644

Date Completed: 10/2/90
Depth Drilled (ft): 240
Screened Interval (ft): 216-236
L.S. Elevation (ft) 2240

Well Type: 2" PVC
Source of Data: NDSWC
Principal Aquifer : Fort Union Group

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-3
TILL	(oxidized) - very silty, blocky, light brown to yellowish brown, dark brown mottled appearance in some samples, fine to very coarse sand with some cobbles, (coarse grains predominately carbonates and quartz), coarser cobbles generally carbonates.	3-19
TILL	(oxidized) - light brown to light gray, slightly silty, gradation in color and texture transitional from above, less silt than above, softer and more plastic toward the base, fewer sand and gravel material than above. Sandstone boulder @ 41'	19-45
LIGNITE		45-46
TILL	dark brown, silty, stiff and cohesive, clay significant carbonaceous material, with some fine to very coarse sand	46-50
SAND	(Ft. Union) silty, clayey, very fine to fine sand, predominately very fine, light yellowish gray, very soft, not lithified. (oxidized)	50-60
CLAY	(Ft. Union) light gray, with mottled yellowish stain in some samples, very stiff and cohesive, greasy, very little silt present	60-69
SILTSTONE	(Ft. Union) light gray, almost white, well indurated	69-71
SILT	(Ft. Union) clayey, soft, light greenish to dark gray	71-75
CLAY	(Ft. Union) mottled yellowish, brown and gray, fairly cohesive, greasy, slightly silty	75-77
SILT	(Ft. Union) clayey, dark gray, soft, slightly cohesive.	77-85
CLAY	(Ft. Union) dark brown to black, slightly silty, soft, extremely carbonaceous, with some lignite.	85-90
CLAY	(Ft. Union) silty, sandy, light to medium gray, soft, fairly plastic	90-92
CLAY	(Ft. Union) very sandy, light gray, soft	92-103
CLAY	(Ft. Union) light to medium gray, fairly cohesive and rigid	103-105
CLAY	(Ft. Union) dark grayish green, very cohesive and rigid, no silt or sand	105-111
SAND	(Ft. Union) clayey, silty, very fine to fine, predominately very fine, light greenish gray, soft, non-cohesive	111-123

156-091-28ACA (Cont.)

NDSWC 12644

Date Completed:	10/2/90	Well Type:	2" PVC
Depth Drilled (ft):	240	Source of Data:	NDSWC
Screened Interval (ft):	216-236	Principal Aquifer :	Fort Union Group
L.S. Elevation (ft)	2240		

Lithologic Log

Unit	Description	Depth (ft)
CLAY	(Ft. Union) silty, sandy, very rigid and cohesive, almost indurated, light green	123-131
CLAY	(Ft. Union) silty, sandy, softer than above, light to dark gray, gets sandier at 135 and lenses of lignite also appear at 135	131-143
SAND	(Ft. Union) very fine to medium, predominately very fine to fine, clayey, lignitic, coarser material appears to be carbonates, fine material predominately quartz	143-168
SAND	(Ft. Union) silty, clayey, tight, light gray, very fine to fine sand	168-172
SAND	(Ft. Union) silty clayey, light to medium gray, very fine to fine sand	172-182
SAND	(Ft. Union) silty, very fine to medium, predominately very fine to fine, abundant clay, lignitic, coarser grains are predominately carbonates, finer grains are predominately quartz, grains range from angular to subround	182-203
SAND	(Ft. Union) silty, very fine to medium, predominately very fine to fine, lignitic	203-236
CLAY	(Ft. Union) silty, light to dark brown, soft, ribbons nicely, carbonaceous material abundant	236-240

156-091-28BAC1

Date Completed: 1953
Depth Drilled (ft): 350
L.S. Elevation (ft) 2229

Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-1
TILL	yellowish gray, sandy	1-72
SHALE	(Ft. Union) light gray	72-92
LIGNITE	(Ft. Union)	92-94
SHALE	(Ft. Union) light gray	94-117
SAND	(Ft. Union) clayey, light gray, with thin layers of hard sandstone	117-190
SAND	(Ft. Union) cleaner than from 117 to 190, but samples still contain much clay. Washed sample obtained from pits consisted mostly of medium grained, angular sand, about 75% or more quartz; remainder consisted mainly of basic igneous rock fragments	190-236
LIGNITE	(Ft. Union)	236-237
SHALE	(Ft. Union) light gray. Core obtained from 240 to 250 feet with about 60% recovery. Consisted mostly of light gray clayey siltstone and on foot of very fine, dirty sandstone.	237-274
LIGNITE	(Ft. Union)	274-275
SHALE	(Ft. Union) light gray, with hard layers	275-350

** Test Hole 156-091-28BAC1 was erroneously reported as 156-091-28BAC2 in the County groundwater study (Armstrong, 1969). Paulson originally reported this test hole at the location 156-091-28BAC1.

156-091-28BAC2

Date Completed:	1952	Well Type:	8" Steel
Depth Drilled (ft):	239	Source of Data:	Paulson, (1954)
Screened Interval (ft):	?-185	Principal Aquifer :	Fort Union Group
L.S. Elevation (ft)	2229		

Lithologic Log

Unit	Description	Depth (ft)
CLAY	yellow, sandy	0-76
CLAY	(Ft. Union) gray	76-108
SHALE	(Ft. Union) green	108-114
SHALE	(Ft. Union) gray	114-118
SHALE	(Ft. Union) gray, sandy	118-160
SANDSTONE	(Ft. Union) fine	160-162
SHALE	(Ft. Union) gray, sandy	162-170
SANDSTONE	(Ft. Union) fine, hard	170-171
SHALE	(Ft. Union) gray, sandy	171-185
SANDSTONE	(Ft. Union) fine, hard	185-188
SHALE	(Ft. Union) gray, sandy	188-205
SANDSTONE	(Ft. Union) hard	205-207
SHALE	(Ft. Union) gray, sandy	207-235
SHALE	(Ft. Union) brown, sandy	235-238
SHALE	(Ft. Union) gray	238-239

** Test Hole 156-091-28BAC2 was erroneously reported as 156-091-28BAC1 in the County groundwater study (Armstrong, 1969). Paulson originally reported this test hole at the location 156-091-28BAC2.

156-091-28CCC

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	350	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	0		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
SAND	medium to coarse	1-13
TILL	yellowish gray	13-45
SHALE	(Ft. Union), yellowish gray	45-140
SHALE	(Ft. Union), light gray	140-160
SAND	(Ft. Union), light gray, very fine to fine, much clay	160-212
LIGNITE	(Ft. Union)	212-214
CLAY	(Ft. Union), sandy, very fine, light gray	214-237
LIGNITE	(Ft. Union)	237-240
CLAY	(Ft. Union), sandy, gray. Indurated rock at 243 feet	240-248
SHALE	(Ft. Union), light gray, not sandy	248-264
LIGNITE	(Ft. Union)	264-267
SHALE	(Ft. Union), light gray, with hard layers at 293 feet and 298 feet	267-301
LIGNITE	(Ft. Union)	301-303
SHALE	(Ft. Union), light gray	303-315
LIGNITE	(Ft. Union)	315-317
SHALE	(Ft. Union), light gray	317-328
LIGNITE	(Ft. Union)	328-331
SHALE	(Ft. Union), light gray	331-350

156-091-29BBB

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	350	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2282		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-1
TILL	yellowish gray, sandy	1-46
TILL	grayer than above	46-56
TILL	yellowish gray, sandy	56-80
CLAY	(Ft. Union) yellowish gray	80-85
CLAY	(Ft. Union) very light purplish gray, sandy	85-90
CLAY	(Ft. Union) yellowish gray, sandy	90-103
SHALE	(Ft. Union) clayey, light gray, alternating with layers of sandy clay	103-195
CLAY	(Ft. Union) very sandy, light gray	195-224
SANDSTONE	(Ft. Union) very fine, light gray, dirty	224-228
SAND	(Ft. Union) very clayey, light gray	228-246
SANDSTONE	(Ft. Union) fine, dirty	246-249
SAND	(Ft. Union) very clayey (50% or more clay)	249-290
CLAY	(Ft. Union) light gray, sandy	290-295
CLAY	(Ft. Union) gray	295-316
LIGNITE	(Ft. Union)	316-318
CLAY	(Ft. Union) light gray	318-327
CLAY	(Ft. Union) brownish gray	327-335
LIGNITE	(Ft. Union)	335-338
CLAY	(Ft. Union) gray	338-350

156-091-32BAD

Date Completed: 1952
Depth Drilled (ft): 80
L.S. Elevation (ft) 2225
Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
SAND		0-5
SAND & GRAVEL		5-12
TILL	yellowish gray	12-38
TILL	gray	38-53
SHALE	(Ft. Union) light gray, sandy	53-80

156-091-32BDA1

Date Completed: 1952
Depth Drilled (ft): 70
L.S. Elevation (ft) 2200
Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
SAND		0-4
GRAVEL		4-14
TILL	yellowish gray	14-28
TILL	medium gray	28-56
SHALE	(Ft. Union) light gray	56-70

156-091-32BDA2

Date Completed: 1952
Depth Drilled (ft): 20
L.S. Elevation (ft) 2160
Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	slope wash, dark brown, clayey	0-3
TILL	yellowish gray	3-9
SHALE	(Ft. Union) light gray, clayey	9-12
SHALE	(Ft. Union) light gray, sandy	12-20

156-091-33AAA2

NDSWC 12446

Date Completed:	10/25/89	Purpose:	Test Hole
Depth Drilled (ft):	20	Source of Data:	NDSWC
L.S. Elevation (ft)	2173.98		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
SAND & GRAVEL	medium to very coarse sand and gravel, predominately very coarse sand and gravel, angular to well rounded, predominately subangular to subrounded, grain composition - predominately carbonates and lignites (60%), quartz, and shield silicates	1-5
CLAY	(Ft. Union) - light to medium gray, predominate mottled yellowish brown appearance near the top, very plastic, extremely carbonaceous	5-16
SILT	(Ft. Union) - medium to dark gray, almost black, fairly soft, somewhat cohesive, significant clay content with small amounts of sand, extremely carbonaceous	16-20

156-091-33ABD1

NDSWC 12437

Date Completed:	10/23/89	Purpose:	Test Hole
Depth Drilled (ft):	60	Source of Data:	NDSWC
L.S. Elevation (ft)	2176.19		

Lithologic Log

Unit	Description	Depth (ft)
SAND & GRAVEL	very fine to very coarse, predominately coarse sand and gravel, angular to subround, predominately angular, predominately carbonates, with some quartz and shield silicates	0-3
SAND	(Ft. Union), very fine to fine, silty sand, yellowish brown, with occasional pieces of lignite	3-7
CLAY	(Ft. Union) - oxidized, light yellowish brown, fairly cohesive, slightly silty	7-15
CLAY	(Ft. Union) light yellowish brown to light gray, fairly cohesive, slightly silty, exhibits some evidence of having been oxidized	15-28
CLAY	(Ft. Union) dark brown to black, soft, non-cohesive, very sticky	28-35
CLAY	(Ft. Union) light to medium gray, slightly silty, fairly soft, non-cohesive, greasy	35-45
CLAY	(Ft. Union) Light to medium gray, fairly rigid and cohesive, almost brittle, coal stringer at 50' and occasional lenses of dark gray to greenish sandy clays below 50'	45-60

156-091-33ABD2

NDSWC 12438

Date Completed:	10/23/89	Purpose:	Test Hole
Depth Drilled (ft):	20	Source of Data:	NDSWC
L.S. Elevation (ft)	2175.52		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-2
SAND & GRAVEL	very fine to coarse sand and gravel, predominately coarse sand and gravel, angular to subround, composition - quartz, shield silicates, and carbonates	2-3
CLAY	(TILL) silty, sandy, pebbly, yellowish brown, fairly soft, non-cohesive	3-13
GRAVEL	with rocks, predominately carbonates, some sand and gravel with quartz and shield silicates	13-14
CLAY	(Ft. Union) silty, light brown, mottled yellowish brown, soft, non-cohesive, oxidized	14-18
CLAY	(Ft. Union) light to medium gray, moderately cohesive to rigid, greasy	18-20

156-091-33ACA

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	20	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2158		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-2
CLAY	with sand and gravel	2-5
SAND	very coarse	5-9
SHALE	(Ft. Union) clayey, yellowish gray	9-20

156-091-33ACA2

NDSWC 12447

Date Completed:	10/25/89	Purpose:	Test Hole
Depth Drilled (ft):	40	Source of Data:	NDSWC
L.S. Elevation (ft)	2156.52		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
CLAY	(Till) - yellowish, orangish brown, silty, soft, non-cohesive, carbonaceous, abundant pebbles, slightly lignitic	1-4
CLAY	(Ft. Union), oxidized, sandy, silty, light yellowish brown, smooth and soft. Interbedded silts and clays with very fine sand.	4-17
SILT AND CLAY	(Ft. Union), Interbedded sequence of sandy silty clay and clayey silts, color ranges from light to dark bluish gray with some greenish grays. Silt sequence was fairly soft, non cohesive, and non plastic with abundant clay. Clay sequences were very cohesive almost rigid.	17-40

156-091-33ACB1

NDSWC 12448

Date Completed:	10/25/89	Well Type:	2" PVC
Depth Drilled (ft):	40	Source of Data:	NDSWC
Screened Interval (ft):	25-30	Principal Aquifer :	Fort Union Group
L.S. Elevation (ft)	2155.92		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
SAND & GRAVEL	very fine to very coarse, predominately coarse sand and gravel, angular to well rounded, predominately subrounded to subangular, grain composition - predominately carbonates (50%), quartz, and shield silicates, carbonates are predominately gravel size, quartz and shield silicates are predominately very coarse sand size	1-7
CLAY	(Ft. Union), oxidized, very silty, soft, non-cohesive, light yellowish brown to yellowish gray	7-14
CLAY	(Ft. Union), silty, light to medium gray, dark gray, and greenish gray, ranging from very soft to dense and brittle	14-23
SAND	(Ft. Union), very fine to fine, poor recovery, lignitic	23-31
CLAY	(Ft. Union), slightly silty, light to medium gray, fairly cohesive	31-40

156-091-33ACB2

NDSWC 12449

Date Completed: 10/25/89
Depth Drilled (ft): 20
Screened Interval (ft): 2-7
L.S. Elevation (ft) 2156.1
Well Type: 2" PVC
Source of Data: NDSWC
Principal Aquifer : Little Knife River Valley

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
SAND & GRAVEL	very fine to very coarse sand and gravel, predominately coarse sand and gravel, angular to well rounded, predominately subround, approximately 50% carbonates, with some quartz, and shield silicates	1-8
CLAY	(Ft. Union) oxidized, very silty, soft, slightly cohesive, light yellowish brown to yellowish gray	8-14
CLAY	(Ft. Union) slightly silty to very silty, light to medium gray and dark gray, ranges from soft and non-cohesive to smooth, greasy, and dense, almost brittle in places	14-20

156-091-33BAAA

NDSWC 12445

Date Completed: 10/25/89
Depth Drilled (ft): 40
L.S. Elevation (ft) 2194.24
Purpose: Test Hole
Source of Data: NDSWC

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
SAND & GRAVEL	very fine to very coarse, predominately coarse sand to gravel, subangular to well rounded, predominately subround, predominately carbonates, quartz, detrital shales, shield silicates	1-10
CLAY	(TILL) silty, yellowish, orangish, brown, soft, moderately cohesive, sand size grains of carbonates, detrital shales, quartz, lignites, and shield silicates	10-18
SANDSTONE	(Ft. Union) light gray to white, very fine to fine grained, well sorted, well lithified, slightly glauconitic	18-19
CLAY	(Ft. Union) oxidized, light to medium gray, yellowish and brownish mottled appearance, extremely carbonaceous, lignitic, soft and plastic	19-22
CLAY	(Ft. Union) light to dark gray, extremely carbonaceous, lignitic, slightly plastic, cohesive	22-28
SANDSTONE	(Ft. Union) light gray to yellowish gray, very fine to fine grained, well sorted, moderately lithified	28-29
CLAY	(Ft. Union) light gray to medium gray, moderately cohesive, slightly plastic, carbonaceous material not as common as above	29-40

156-091-33BACB

NDSWC 12444

Date Completed: 10/25/89
Depth Drilled (ft): 20
L.S. Elevation (ft) 2193.02
Purpose: Test Hole
Source of Data: NDSWC

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-2
SAND & GRAVEL	fine to very coarse sand and gravel, predominately coarse sand and gravel, angular to well rounded, predominately subround, oxidized, predominately carbonates, quartz, shield silicates	2-5
CLAY	(Ft. Union) mottled yellowish, orangish, brown, silty, extremely carbonaceous, soft, somewhat cohesive near top, moderately cohesive near base	5-20

156-091-33BAD

Date Completed: 1952
Depth Drilled (ft): 60
L.S. Elevation (ft) 2180
Purpose: Test Hole
Source of Data: Paulson, (1954)

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	brown, sandy	0-1
CLAY	light tan	1-2
SAND		2-7
TILL	yellowish gray	7-56
SHALE	(Ft. Union) light gray	56-60

156-091-33BADB

NDSWC 12441

Date Completed:	10/24/89	Purpose:	Test Hole
Depth Drilled (ft):	40	Source of Data:	NDSWC
L.S. Elevation (ft)	2177.02		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-2
SAND & GRAVEL	medium sand to gravel, predominately gravel, predominately carbonates with some quartz and shield silicates	2-3
CLAY	(TILL) mottled yellowish, brown, fairly cohesive, with some sand particles, consisting of predominately of carbonates and quartz	3-11
CLAY	(Ft. Union) light gray to mottled yellowish brown, dark reddish brown along fractures, shows evidence of significant fractures, cohesive to rigid	11-32
SILT	(Ft. Union) clayey, sandy, grayish green, fairly cohesive	32-40

156-091-33BADDC

NDSWC 12450

Date Completed:	10/25/89	Purpose:	Test Hole
Depth Drilled (ft):	40	Source of Data:	NDSWC
L.S. Elevation (ft)	2160.42		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-2
SAND & GRAVEL	very fine to very coarse sand and gravel, predominately medium to very coarse sand and gravel, predominately carbonates with smaller grains of quartz and shield silicates	2-4
CLAY	(Ft. Union) oxidized, light yellowish to dark orangish brown, very hard, almost brittle, slightly silty	4-7
SAND	(Ft. Union) silty, predominately very fine sand and silty, poor recovery, lignitic	7-12
CLAY	(Ft. Union) light yellowish brown to dark orangish brown, very hard, somewhat rigid, slightly silty	12-17
CLAY	(Ft. Union) sequence of interbedded clays and silts, some very fine to fine sands throughout. silts - ranged from medium gray to greenish gray; clays - ranged from light to medium gray, cohesive and plastic; silts - fairly soft, non cohesive, and greasy.	17-40

156-091-33BBBB

NDSWC 12443

Date Completed:	10/24/89	Purpose:	Test Hole
Depth Drilled (ft):	50	Source of Data:	NDSWC
L.S. Elevation (ft)	2223.94		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-3
SAND & GRAVEL	oxidized, fine to very coarse sand and gravel, predominately coarse to very coarse sand and gravel, angular to well rounded, predominately subround, coarsens near base, predominately carbonates, quartz, and shield silicates	3-10
CLAY	(TILL) sandy, silty, soft, non-cohesive, yellowish orangish brown, includes grains of carbonates, quartz, and shield silicates	10-22
CLAY	(Ft. Union) oxidized, light yellowish brown to light medium gray, extremely carbonaceous, shows evidence of fracturing with much brown stain along fractures, fairly plastic and sticky	22-42
SANDSTONE	(Ft. Union) very fine to fine grained, well sorted, light gray to white, slightly glauconitic, moderately to well lithified	42-44
SANDSTONE	(Ft. Union) very fine to medium grained, fair sorting, yellowish gray to yellow, glauconitic, very poorly lithified	44-46
CLAY	(Ft. Union) light to medium gray, rigid, cohesive, sticky, slightly silty	46-50

156-091-33BBC

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	30	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2160		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark gray, clayey	0-1
CLAY	moderate yellow, uniform. Probably lake deposits	1-15
SAND	medium to coarse	15-22
SHALE	(Ft. Union), light gray	22-30

156-091-33BBD

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	20	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2160		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown, clayey	0-1
CLAY	yellowish gray, with few pebbles	3-9
SAND	medium to coarse	9-18
SHALE	(Ft. Union), light gray, sandy	18-20

156-091-33BBD2

NDSWC 12452

Date Completed:	10/25/89	Well Type:	2" PVC
Depth Drilled (ft):	40	Source of Data:	NDSWC
Screened Interval (ft):	12-17	Principal Aquifer :	Little Knife River Valley
Casing size (in) & Type:		L.S. Elevation (ft)	2156.18

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-3
SAND & GRAVEL	fine to very coarse sand and gravel, predominately very coarse sand and gravel, angular to well rounded, predominately subangular, interbedded clay lenses throughout, grain composition - shield silicates (65%), carbonates (20%), quartz (15%)	3-17
CLAY	(Ft. Union), tan to yellowish brown, very silty, soft	17-18
CLAY	(Ft. Union), very silty, light to medium gray, soft, greasy	18-26
CLAY	(Ft. Union), slightly silty, medium to dark gray, moderately cohesive, slightly plastic, smooth and greasy	26-40

156-091-33BBDB

NDSWC 12442

Date Completed:	10/24/89	Purpose:	Test Hole
Depth Drilled (ft):	80	Source of Data:	NDSWC
L.S. Elevation (ft)	2175.55		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-2
CLAY	(TILL) oxidized, mottled yellowish brown, fairly soft, moderately cohesive, sticky, includes pebbles of carbonates and lignite, very silty	2-7
CLAY	(TILL) oxidized, mottled yellowish brown to light gray, moderately cohesive, and sticky	7-11
CLAY	(TILL) light to medium gray, fairly cohesive, sticky, very silty	11-22
CLAY	(Ft. Union) light gray, soft, plastic, becomes tighter near base	22-56
CLAY	(Ft. Union) medium gray, greenish gray, carbonaceous, moderately cohesive, almost rigid, very silty	56-74
SANDSTONE	(Ft. Union) very fine to fine sand, well sorted, light gray to white, glauconitic, moderately to well lithified	74-76
CLAY	(Ft. Union) silty, light to medium gray or greenish gray, some very fin to fine sand, moderately cohesive, sticky	76-80

156-091-33BDA2

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	50	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2160		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown, clayey	0-1
CLAY	with sand and gravel	1-3
GRAVEL	fine to coarse, average size about 3/8 inch. Consists of limestone (about 1/2), granite (1/4), basic igneous, concretions, and shale (1/4)	3-21
SHALE	(Ft. Union) light gray, sandy	21-50

156-091-33BDA3

Date Completed:	1964	Well Type:	64" Concrete Construction
Depth Drilled (ft):	26	Source of Data:	City of Stanley
Screened Interval (ft):	?-26	Principal Aquifer :	Little Knife River Valley
L.S. Elevation (ft)	2161.42		

Lithologic Log

Unit	Description	Depth (ft)
	No Log Available	

156-091-33BDA4

NDSWC 12439

Date Completed:	10/24/89	Well Type:	2" PVC
Depth Drilled (ft):	133	Source of Data:	NDSWC
Screened Interval (ft):	122-127	Principal Aquifer :	Fort Union Group
L.S. Elevation (ft)	2155.69		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-3
SAND & GRAVEL	very fine to very coarse sand and gravel, predominately very coarse sand and gravel, subangular to rounded, predominately subangular to subrounded, grain composition - predominately carbonates with some quartz and shield silicates, carbonates are typically coarser grained	3-22
CLAY	(Ft. Union), light gray, slightly silty, soft, sticky, ribbons easily	22-28
SILT	(Ft. Union), sandy, most in suspension, poor recovery	28-45
CLAY	(Ft. Union), light gray, slightly silty, soft, moderately cohesive, greasy, silt content increasing slightly at 55 feet	45-64
SILT	(Ft. Union), yellowish brown to greenish brown, slightly sandy, moderately cohesive, blocky	64-67
CLAY	(Ft. Union), light to dark gray, slightly silty and sandy, cohesive and blocky, sticky	67-102
SAND	(Ft. Union), very fine to medium, predominately very fine to fine, light grayish green, silty with occasional clay lenses, subangular to well rounded, predominately well rounded, predominately quartz with shield silicates	102-116
SAND	(Ft. Union), as above with prominent lignite lenses	116-129
SILT	(Ft. Union), sandy, light gray, fairly soft, non-cohesive	129-133

156-091-33BDA5

NDSWC 12440

Date Completed:	10/24/89	Well Type:	2" PVC
Depth Drilled (ft):	40	Source of Data:	NDSWC
Screened Interval (ft):	12-17	Principal Aquifer :	Little Knife River Valley
L.S. Elevation (ft)	2155.78		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-2
SAND & GRAVEL	very fine to very coarse sand and gravel, predominately very coarse sand and gravel, subangular to well rounded, predominately subround, grain composition: predominately carbonates, with some quartz, shield silicates	2-22
CLAY	(Ft. Union) very silty, light gray, soft, sticky	22-40

156-091-33BDAB

NDSWC 12451

Date Completed:	10/25/89	Well Type:	2" PVC
Depth Drilled (ft):	40	Source of Data:	NDSWC
Screened Interval (ft):	15-20	Principal Aquifer :	Little Knife River Valley
L.S. Elevation (ft)	2155.7		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL		0-1
SAND & GRAVEL	fine to very coarse sand and gravel, predominately very coarse sand and gravel, angular to well rounded, predominately subrounded, grain composition - predominately carbonates (60%), quartz, and shield silicates, carbonates are generally coarser	1-8
SAND & GRAVEL	fine to very coarse sand and gravel, predominately medium to very coarse sand, angular to well rounded, predominately subround to round, grain composition - predominately quartz and shield silicates (65%) with carbonates, carbonates were generally coarser	8-21
CLAY	(Ft. Union), silty with some fine sand, light to medium gray, moderately cohesive, greasy	21-27
SAND	(Ft. Union), very fine to fine, silty, poor recovery	27-28
CLAY	(Ft. Union), slightly silty and sandy, medium to dark gray, plastic	28-40

156-091-33CAB

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	80	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2170		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown	0-1
TILL	yellowish gray	1-33
SAND	fine	33-40
SAND	sandy clay, yellowish gray, soft	40-55
SAND	coarser than from 40 to 55	55-60
SHALE	(Ft. Union) dark gray, clayey	60-80

156-091-33DAD

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	140	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2210		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	brown	0-1
TILL	yellowish gray	1-36
TILL	medium gray	36-39
SAND & GRAVEL		39-40
TILL	medium gray	40-78
SHALE	(Ft. Union), gray, sandy	78-110
SHALE	(Ft. Union), yellowish gray	110-129
SHALE	(Ft. Union), light gray, clayey	129-140

156-091-34BBB

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	20	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2160		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL AND SLOPE WASH		0-3
CLAY	tan	3-4
SAND & GRAVEL		4-8
SHALE	(Ft. Union), light gray	8-20

156-091-34CBB

Date Completed:	1952	Purpose:	Test Hole
Depth Drilled (ft):	50	Source of Data:	Paulson, (1954)
L.S. Elevation (ft)	2167		

Lithologic Log

Unit	Description	Depth (ft)
TOPSOIL	dark brown, sandy	0-1
CLAY	tan	1-3
SAND	coarse	3-13
TILL	light gray	13-22
SAND	(Ft. Union), mostly medium grained, relatively will sorted and clean	22-42
SHALE	(Ft. Union), light gray	42-50

APPENDIX B - Water Quality Analyses

Location	Screened Interval (ft)	Date Sampled	SiO_2	Fe	Mn	Ca	Mg	Na	K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	TDS	Hardness as $CaCO_3$	NCH	% Na	SAR	Spec Cond (µmho)	Temp (°C)	pH
			(milligrams per liter)																					
15609133ACBL		07-09-70	34	0.10	0.99	54	30	162	12	492	0	170	47	0.10	0	0.48	752	258		56.0	4.4	1190		8.2
15609133ACBL		10-31-74	18	0.08	0.08	69	80	350	15	680	21	390	190	0.60	1	0.31	1474	500		59.7	6.8	2300	7	8.5
15609133ACBL		11-13-89		0.14	0.01	45	102	629	23	719	44	567	602	0.25	0		2370	533		71.9	11.8	3820		8.6
15609133ACBL		04-26-90	11	0.04	0.07	53	98	610	32	649	36	530	490	0.20	1	0.40	2180	540		70.0	11.0	3420	11	8.7
15609133ACBL		06-27-90	13	0.05	0.08	55	100	610	22	681	21	550	510	0.30	3	0.53	2220	550		70.0	11.0	3510	22	8.5
15609133BDA3	?-26	05-27-66	22	0.14		111	89	500	10	942	0	795	90	0.10	1.0	0.27	2080	643		62.6	8.6	2820		7.8
15609133BDA3	?-26	06-12-68	23	0.20	0.06	110	71	487	9	924	0	687	119	0.20	1	0.39	1960	565		65.6	8.9	2620		7.9
15609133BDA3	?-26	10-25-78		0.40	2.34	106	89	352	16	771	0	381	187				1510	629				2200		7.3
15609133BDA3	?-26	09-08-83		0.26	2.88	74	65	325	15	755	0	239	248				1340	451		60.9	6.7	2153		7.5
15609133BDA3	?-26	08-13-85			0.27	70	69	433	16	771	0	726	13	0.20	0		1730	459			8.8	3020		7.7
15609133BDA3	?-26	10-16-86		0.38	2.97	80	87	484	16	795	12	315	440				1830	556		65.3	8.9	2490		7.6
15609133BDA3	?-26	10-07-88			2.37	77	99	600	17	915	0	416	434	0.20	0		2090	599		68.4	10.7	3270		7.4
15609133BDA3	?-26	04-26-90	20	0.43	2.20	100	120	620	18	880	0	560	530	0.20	1	0.32	2410	740		64.0	9.9	3740	5	7.3
15609133BDA3	?-26	09-06-27	22	0.37	1.90	100	120	640	17	845	0	620	560	0.20	3	0.36	2500	740		65.0	10.0	3840	9	7.6
15609133BDA4	122-127	11-14-89		0.00	0.01	101	98	751	8	1050	0	1330	17	0.12	0		2820	654		71.3	12.8	4240		7.3
15609133BDA5	12-17	11-14-89		0.29	2.86	68	101	553	15	865	0	444	556	0.24	0		2160	586		67.1	9.9	3540		7.4
15609133BDA5	12-17	04-26-90	20	0.85	3.60	110	140	710	18	862	0	670	690	0.20	1	0.26	2790	850		64.0	11.0	4340	5	8.1
15609133ACB1	25-30	11-13-89		0.01	0.02	75	57	115	8	672	0	97	33	0.36	0		716	422		37.1	2.4	1174		7.6
15609133ACB2	2-7	11-13-89		0.02	0.00	110	148	275	9	867	0	433	244	0.19	1.0		1650	884		40.2	4.0	2540		7.4
15609133BDAB	15-20	11-13-89		0.10	3.14	101	149	602	15	909	0	638	641	0.21	0		2590	866		60.1	8.9	4120		7.5
15609133BDAB	15-20	04-26-90	20	0.32	2.90	110	130	630	15	956	0	540	580	0.20	0	0.29	2500	810		62.0	9.6	3920	6	8.0
15609133BBD2	12-17	11-13-89		0.00	0.06	106	84	110	5	719	0	268	23	0.28	0		950	611		28.1	1.9	1470		7.4
15609133BBD2	12-17	04-26-90	16	0.07	0.46	100	68	50	4	590	0	180	6	0.30	1.0	0.10	717	530		17.0	0.9	1110	5	8.1
15609121CBA2		02-19-51		0.40		24	11	1020		1110		1370					2970	110		95.0				
15609122DDC		07-19-52		0.50		39	9	27		220		10			2		200	130						
15609125BCD		1952		4.90		9	4	1080		1080		1410	20				2950	39		98.0				
15609128ABA		1951		0.10		9	19	775		920	46	910	4		2		2170	100		94.0				
15609128BAC1		06-07-67	13	0.14		28	6	643	4	885	0	773	8	0.00	1	0.31	1860	94		93.0	29.0	2780		8.1
15609133BDA1		07-01-52				49	44	28		420		10			4		340	300		17.0				
15609133BDA1		07-01-52		0.30		95	62			500		45	2				450	490						
15609134CBB		07-30-52				97	53	210		370		580	8		2		1130	460		50.0				
15609620DCD		08-12-85		0.08	0.01	10	0	850	4	1290	70	4	530	3.50	1		2070	25		98.0	67.0	3300		8.8
15609128BADD		09-07-90		0.10	0.02	12	6	838	4	1025	0	1044	10	0.81	0		2940	55			49.1	3451		8.0
15609128BDDA		09-14-90		0.10	0.56	172	64	257	7	659	0	687	12	0.79	0		1858	695			4.2	1780		7.1

APPENDIX C - Stage Data for the Stanley Reservoir

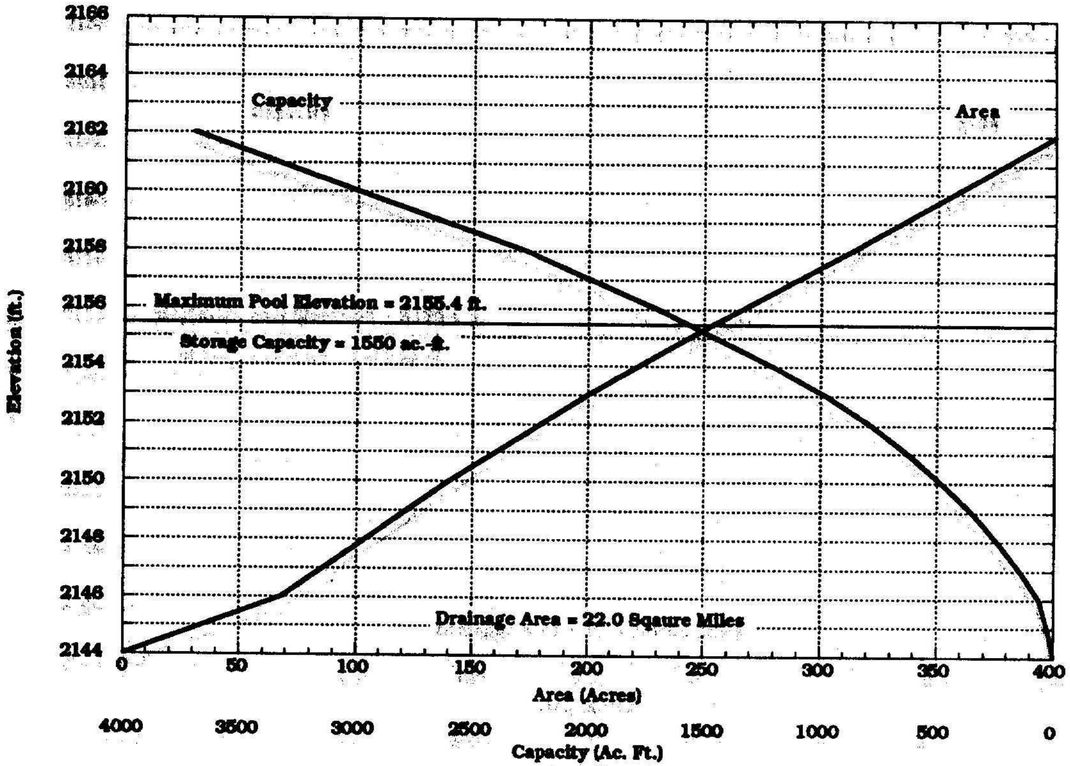

Figure 31 - Area-Capacity curve for the Stanley Reservoir.

156-091-33ACBL (Stanley Reservoir) Staff Gage Elev (msl,ft)=2147.99

Date	Depth to Water (ft)	WL Elev (msl, ft)
04/18/90	-2.11	2150.10
04/20/90	-2.20	2150.19
04/24/90	-2.11	2150.10
05/01/90	-2.20	2150.19
05/08/90	-2.20	2150.19
05/15/90	-2.11	2150.10
05/22/90	-2.00	2149.99
05/29/90	-3.10	2151.09
06/05/90	-3.25	2151.24
06/11/90	-3.28	2151.27
06/12/90	-3.00	2150.99
06/19/90	-3.25	2151.24
06/26/90	-3.18	2151.17
06/27/90	-3.18	2151.17
07/03/90	-3.00	2150.99
07/08/90	-2.95	2150.94
07/10/90	-3.00	2150.99
07/17/90	-2.80	2150.79
07/24/90	-2.60	2150.59
07/31/90	-2.60	2150.59
08/07/90	-2.40	2150.39
08/09/90	-2.34	2150.33
08/14/90	-2.30	2150.29
08/21/90	-2.20	2150.19
08/28/90	-2.15	2150.14
08/29/90	-2.15	2150.14
09/04/90	-2.00	2149.99
09/21/90	-1.68	2149.67

APPENDIX D - Water Level Data

156-091-33ACB1
Fort Union Group

LS Elev (msl,ft)=2155.92
SI (ft.)=25-30

Date	Depth to Water (ft)	WL Elev (msl, ft)
11/06/89	4.37	2151.55
11/14/89	4.37	2151.55
11/21/89	4.37	2151.55
11/28/89	4.47	2151.45
12/07/89	4.47	2151.45
12/12/89	4.47	2151.45
12/19/89	4.57	2151.35
12/29/89	4.62	2151.30
01/02/90	4.63	2151.29
01/08/90	4.72	2151.20
01/16/90	4.76	2151.16
01/22/90	4.83	2151.09
01/23/90	4.79	2151.13
02/06/90	4.91	2151.01
02/13/90	4.89	2151.03
02/20/90	5.06	2150.86
02/27/90	5.10	2150.82
03/29/90	4.93	2150.99
04/03/90	4.87	2151.05
04/10/90	4.86	2151.06
04/17/90	4.88	2151.04
04/18/90	4.86	2151.06
04/24/90	4.87	2151.05
04/26/90	4.73	2151.19
05/01/90	4.70	2151.22
05/08/90	4.72	2151.20
05/15/90	4.82	2151.10
05/22/90	4.83	2151.09
05/29/90	3.65	2152.27
06/05/90	3.47	2152.45
06/12/90	3.72	2152.20
06/19/90	3.87	2152.05
06/26/90	3.87	2152.05
06/27/90	3.91	2152.01
07/03/90	3.91	2152.01
07/08/90	4.13	2151.79
07/09/90	4.13	2151.79
07/10/90	4.12	2151.80
07/17/90	4.32	2151.60
07/24/90	4.45	2151.47
07/31/90	4.54	2151.38
08/07/90	4.70	2151.22
08/09/90	4.81	2151.11
08/14/90	4.75	2151.17
08/21/90	4.87	2151.05
08/28/90	4.88	2151.04
08/29/90	4.95	2150.97
09/04/90	5.09	2150.83
09/21/90	5.35	2150.57

156-091-33ACB2
Little Knife River Valley Aquifer

LS Elev (msl,ft)=2156.1
SI (ft.)=2-7

Date	Depth to Water (ft)	WL Elev (msl, ft)
11/06/89	5.79	2150.31
11/14/89	5.97	2150.13
11/21/89	5.97	2150.13
11/28/89	6.08	2150.02
12/07/89	6.12	2149.98
12/12/89	6.15	2149.95
12/19/89	6.00	2150.10
12/29/89	5.89	2150.21
01/02/90	6.44	2149.66
01/08/90	6.49	2149.61
01/16/90	6.50	2149.60
01/22/90	6.56	2149.54
01/23/90	6.54	2149.56
02/06/90	6.68	2149.42
02/13/90	6.76	2149.34
02/20/90	6.87	2149.23
02/27/90	6.96	2149.14
03/06/90	6.98	2149.12
03/13/90	6.98	2149.12
03/20/90	6.90	2149.20
03/27/90	6.69	2149.41
03/29/90	6.71	2149.39
04/03/90	6.59	2149.51
04/10/90	6.56	2149.54
04/17/90	6.45	2149.65
04/18/90	6.42	2149.68
04/24/90	6.44	2149.66
04/26/90	6.25	2149.85
05/01/90	6.15	2149.95
05/08/90	6.13	2149.97
05/15/90	6.27	2149.83
05/22/90	6.21	2149.89
05/29/90	4.43	2151.67
06/05/90	4.57	2151.53
06/12/90	4.77	2151.33
06/19/90	4.70	2151.40
06/26/90	4.96	2151.14
06/27/90	4.84	2151.26
07/03/90	4.74	2151.36
07/08/90	5.09	2151.01
07/09/90	5.09	2151.01
07/10/90	5.28	2150.82
07/17/90	5.48	2150.62
07/24/90	5.77	2150.33
07/31/90	5.88	2150.22
08/07/90	6.10	2150.00
08/09/90	6.15	2149.95
08/14/90	6.13	2149.97
08/21/90	6.16	2149.94
08/28/90	6.15	2149.95
08/29/90	6.20	2149.90
09/04/90	6.29	2149.81
09/21/90	6.78	2149.32

156-091-33BBD2
Little Knife River Valley Aquifer

LS Elev (msl,ft)=2156.18
SI (ft.)=12-17

Date	Depth to Water (ft)	WL Elev (msl, ft)
11/06/89	5.45	2150.73
11/14/89	5.25	2150.93
11/21/89	5.57	2150.61
11/28/89	5.57	2150.61
12/07/89	5.65	2150.53
12/12/89	5.71	2150.47
12/19/89	5.75	2150.43
12/29/89	5.75	2150.43
01/02/90	6.05	2150.13
01/08/90	5.92	2150.26
01/16/90	5.96	2150.22
01/22/90	6.04	2150.14
01/23/90	6.03	2150.15
02/06/90	6.22	2149.96
02/13/90	6.31	2149.87
02/20/90	6.43	2149.75
02/27/90	6.51	2149.67
03/06/90	6.53	2149.65
03/13/90	6.20	2149.98
03/20/90	6.10	2150.08
03/27/90	6.05	2150.13
03/29/90	6.08	2150.10
04/03/90	5.99	2150.19
04/10/90	6.02	2150.16
04/17/90	6.04	2150.14
04/18/90	5.99	2150.19
04/24/90	6.04	2150.14
04/26/90	5.89	2150.29
05/01/90	6.00	2150.18
05/08/90	5.97	2150.21
05/15/90	6.05	2150.13
05/22/90	6.04	2150.14
05/29/90	4.75	2151.43
06/05/90	4.85	2151.33
06/12/90	4.95	2151.23
06/19/90	4.89	2151.29
06/26/90	5.08	2151.10
06/27/90	5.06	2151.12
07/03/90	5.03	2151.15
07/09/90	5.37	2150.81
07/10/90	5.33	2150.85
07/17/90	5.57	2150.61
07/24/90	5.72	2150.46
07/31/90	5.72	2150.46
08/07/90	5.93	2150.25
08/09/90	6.08	2150.10
08/14/90	5.93	2150.25
08/21/90	6.07	2150.11
08/28/90	6.10	2150.08
08/29/90	6.19	2149.99
09/04/90	6.35	2149.83
09/21/90	6.63	2149.55

156-091-33BDA4
Fort Union Group

LS Elev (msl,ft)=2155.69
SI (ft.)=122-127

Date	Depth to Water (ft)	WL Elev (msl, ft)
11/06/89	-2.06	2157.75
11/14/89	-2.16	2157.85
11/21/89	-2.16	2157.85
04/17/90	-1.65	2157.34
04/26/90	-1.98	2157.67
05/15/90	-1.95	2157.64
05/22/90	-2.17	2157.86
05/29/90	-2.17	2157.86
06/19/90	-2.07	2157.76
06/26/90	-2.07	2157.76
06/27/90	-2.07	2157.76
07/09/90	-2.07	2157.76
07/24/90	-1.92	2157.61
07/31/90	-1.89	2157.58
08/07/90	-1.82	2157.51
08/09/90	-1.77	2157.46
08/09/90	-1.77	2157.46
08/29/90	-1.75	2157.44
08/29/90	-1.75	2157.44
09/21/90	-1.45	2157.14

156-091-33BDA5

Little Knife River Valley Aquifer

LS Elev (msl,ft)=2155.78
SI (ft.)=12-17

Date	Depth to Water (ft)	WL Elev (msl, ft)
11/06/89	7.47	2148.31
11/14/89	7.41	2148.37
11/21/89	7.41	2148.37
11/28/89	7.67	2148.11
12/07/89	7.60	2148.18
12/12/89	7.60	2148.18
12/19/89	7.80	2147.98
12/29/89	7.90	2147.88
01/02/90	7.82	2147.96
01/08/90	8.20	2147.58
01/16/90	8.24	2147.54
01/22/90	8.26	2147.52
01/23/90	8.20	2147.58
02/06/90	8.37	2147.41
02/13/90	8.57	2147.21
02/20/90	8.84	2146.94
02/27/90	8.56	2147.22
03/06/90	8.94	2146.84
03/13/90	8.88	2146.90
03/20/90	8.69	2147.09
03/27/90	8.54	2147.24
03/29/90	8.76	2147.02
04/03/90	8.73	2147.05
04/10/90	8.43	2147.35
04/17/90	8.49	2147.29
04/18/90	8.44	2147.34
04/24/90	8.83	2146.95
04/26/90	8.45	2147.33
05/01/90	8.25	2147.53
05/08/90	8.24	2147.54
05/15/90	8.48	2147.30
05/22/90	8.45	2147.33
05/29/90	5.95	2149.83
06/05/90	6.42	2149.36
06/12/90	6.47	2149.31
06/19/90	6.58	2149.20
06/26/90	6.83	2148.95
06/27/90	6.87	2148.91
07/03/90	6.92	2148.86
07/09/90	7.38	2148.40
07/10/90	7.21	2148.57
07/17/90	7.58	2148.20
07/24/90	7.87	2147.91
07/31/90	7.77	2148.01
08/07/90	8.23	2147.55
08/09/90	8.46	2147.32
08/14/90	8.04	2147.74
08/21/90	8.35	2147.43
08/28/90	8.52	2147.26
08/29/90	8.53	2147.25
09/04/90	8.48	2147.30
09/21/90	8.86	2146.92

156-091-33BDAB

Little Knife River Valley Aquifer

LS Elev (msl,ft)=2155.7
SI (ft.)=15-20

Date	Depth to Water (ft)	WL Elev (msl, ft)
11/06/89	6.99	2148.71
11/14/89	7.04	2148.66
11/21/89	7.04	2148.66
11/28/89	7.16	2148.54
12/07/89	7.22	2148.48
12/12/89	7.28	2148.42
12/19/89	7.44	2148.26
12/29/89	7.59	2148.11
01/02/90	7.97	2147.73
01/08/90	7.78	2147.92
01/16/90	7.77	2147.93
01/22/90	7.69	2148.01
01/23/90	7.81	2147.89
02/06/90	7.98	2147.72
02/13/90	8.07	2147.63
02/20/90	8.37	2147.33
02/27/90	8.40	2147.30
03/06/90	8.49	2147.21
03/13/90	8.35	2147.35
03/20/90	8.29	2147.41
03/27/90	8.17	2147.53
03/29/90	8.26	2147.44
04/03/90	8.21	2147.49
04/10/90	7.98	2147.72
04/17/90	7.99	2147.71
04/18/90	7.95	2147.75
04/24/90	8.29	2147.41
04/26/90	7.98	2147.72
05/01/90	7.79	2147.91
05/08/90	7.79	2147.91
05/15/90	7.95	2147.75
05/22/90	7.94	2147.76
05/29/90	5.73	2149.97
06/05/90	5.44	2150.26
06/12/90	6.09	2149.61
06/19/90	6.04	2149.66
06/26/90	6.30	2149.40
06/27/90	6.36	2149.34
07/03/90	6.38	2149.32
07/08/90	6.78	2148.92
07/09/90	6.78	2148.92
07/10/90	6.71	2148.99
07/17/90	7.09	2148.61
07/24/90	7.33	2148.37
07/31/90	7.33	2148.37
08/07/90	7.75	2147.95
08/09/90	7.93	2147.77
08/14/90	7.67	2148.03
08/21/90	7.38	2148.32
08/28/90	8.05	2147.65
08/29/90	8.08	2147.62
09/04/90	8.09	2147.61
09/21/90	8.37	2147.33