# HYDROGEOLOGY OF THE PINE LAKE RESEARCH BASIN <br> ALBERTA, CANADA 

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This thesis has been approved on the date shown below:


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#### Abstract

The Pine Lake research basin occupies a 90 -square-mile (230 $\mathrm{km}^{2}$ ) parkland environment in south-central Alberta. Various types of existing and field-generated geologic, geophysical and hydrologic data were employed to fully evaluate the hydrogeology of the research basin.

The study area is underlain by permeable sandstones, mudstones and coals of the thick Paskapoo Formation. Major sandstone aquifers are present at shallow depths where their hydraulic conductivity is estimated to average between 10 and $50 \mathrm{igpd} / \mathrm{ft}^{2}$ ( 0.5 to $2.5 \mathrm{~m} /$ day). Surficial geology is characterized by a thin mantle of glacial drift.

The water-table configuration is a subdued replica of the topography. Groundwater flow is from broad recharge areas on the main divides to discharge areas in the valley bottom. Sodium-bicarbonate groundwater dominates the basin and has evolved primarily via carbonate dissolution and cation exchange processes. Correlation between hydrochemical facies and groundwater flow patterns is poor. The groundwater regime in the research basin is most appropriately treated as a steadystate, regionally unconfined system in a heterogeneous and anisotropic rock media.

Recommendations for instrumentation and future hydrologic studies in the Pine Lake area include installation of a piezometer network, further aquifer testing and numerical modeling of the watershed.


## CHAPTER 1

## INTRODUCTION

The thesis is concerned with the evaluation of the general hydrogeology of the Pine Lake research basin. Basically, it represents the preliminary results of a continuing hydrological study in the basin. The establishment of the Pine Lake research basin project was undertaken by the Groundwater Division of the Alberta Research Council, Edmonton, Canada.

Location and Extent of Study Area
The Pine Lake area of Alberta (Figure l) is in the southcentral part of the province, approximately 78 miles ( 126 km ) northnortheast of the city of Calgary. The Pine Lake research basin described in this report comprises approximately a 90 -square-mile ( $230 \mathrm{~km}^{2}$ ) upper portion of the Ghostpine Creek drainage basin (Figure 2). It lies within the area of Townships 35 to 37 and Ranges 24 to 26, west of the Fourth Meridian. This area is between $113^{\circ} 17^{\prime}$ and $113^{\circ} 43^{\prime}$ West Longitude and between $51^{\circ} 58^{\prime}$ and $52^{\circ} 14^{\prime}$ North Latitude. The southern boundary of the research basin is in part arbitrary, so as to limit the size of the area for detailed investigation.


Figure 1. Location of Pine Lake, Alberta.


Figure 2. Map of central Alberta showing regional drainage and location of the Pine Lake research basin.

## Purpose and Scope of Present Study

Over the past few years, the need for the establishment of a permanent experimental and research basin in Alberta has been recognized by the Groundwater Division of the Alberta Research Council. Tóth (1977) described the main purposes of the establishment of the Pine Lake research basin as follows: (1) to investigate and determine quantitatively the various subsurface components for the hydrologic cycle in a parkland environment; (2) to develop standard or improved methods of evaluating subsurface hydrologic parameters (i.e., regional groundwater flow, recharge, discharge, natural basis yield, interaction with surface water, etc.) for similar groundwater studies in other parts of Alberta; and (3) to establish an experimental and training area where various tests, experiments and short-term studies can be performed and results accumulated over a substantial period of time. The Pine Lake basin was chosen because of the good access, varied and representative hydrogeologic conditions and possible practical usefulness of the study results in relation to local water supply and land development problems.

The objective of this thesis is to evaluate the hydrogeology of the proposed Pine Lake research basin. This evaluation is preliminary in nature, based solely on field reconnaissance observations and existing subsurface data. Hopefully, the results of the thesis study will provide a framework for instrumentation of the research basin and detailed analysis of the hydrogeologic environment and groundwater regime which are to follow in the near future.

Previous Work
To the writer's knowledge, there have been no previous detailed hydrogeological investigations in the Pine Lake area. However, a number of reconnaissance surveys have been made of the groundwater resources in south-central Alberta.

The first systematic evaluations of the regional hydrogeology and water resources, that in part included the Pine Lake basin, was those of Latour (1947) and Stalker (1950) of the Geological Survey of Canada. These reports were based on a well-inventory approach to describe geology and groundwater resources for each township in their respective map areas. Maps showing surficial geology, topography and location plus type of wells were published at a scale of 1 inch to 3 miles. Basic data recorded consisted of well records and yields, aquifer type, use and water quality. In general, the information presented on the regional availability of groundwater and its occurrence have been of great value to the present study.

The most recent analyses of the regional groundwater resources were made in reports generated by the Alberta Research Council. Le Breton (1971) and Borneuf (1972) completed studies on the reconnaissance hydrogeology of the Red Deer and Drumheller map sheets, respectively. Maps published by these authors are on a scale of $1: 250,000$ and cover an area of approximately 5000 square miles ( $13000 \mathrm{~km}^{2}$ ). These maps, along with a number of regional cross sections, illustrate the generalized geology to a depth of about 1000 feet ( 300 m ), directions of groundwater flow, subsurface hydrogeologic properties,
groundwater probability, hydrochemistry, locations of springs and flowing wells, and relevant meteorological data. The Pine Lake research basin comprises a small part of the total area investigated by Le Breton (1971). Only a very small portion of the research basin is in the area mapped by Borneuf (1972).

Although not directly related to the Pine Lake basin, a number of detailed groundwater studies have been completed in adjacent areas where similar hydrogeological conditions exist. Tóth (1966a) mapped and interpreted groundwater phenomena in a section of the Ghostpine Creek valley near Trochu (see Figure 2), southeast of the Pine Lake research basin. Tóth (1968) also made an extensive investigation of the Three Hills area, which included a portion of the Ghostpine Creek drainage basin south of Trochu. Gabert (1975) presented the results of an exhaustive study on the hydrogeology of the Red Deer area. The southeast corner of his map area partially overlaps the extreme northwestern region chosen to be included in the Pine Lake study. Interpretations made by these authors and their methods of analysis have been invaluable to the present evaluation of the Pine Lake research basin.

Finally, for the sake of completeness it would seem appropriate to also briefly mention some published studies which contain minor references of a hydrogeologic nature. For example, Allan and Sanderson (1945) made general observations regarding the relative porosities and permeabilities of major bedrock formations in a detailed report on the geology of the Red Deer-Rosebud map area. Bowser, Peters and Newton (1951) made an extensive soil survey of the Red Deer map sheet wherein
they briefly discuss "drainage" characteristics of various soil types. Stalker (1960) mapped the surficial geology of the Red Deer-Stettler map area and described the possibilities of obtaining groundwater supplies from various types of surficial deposits. Farvolden (1963a) presented a regional bedrock topography map, showing locations of major buried valleys in central Alberta which could be explored for aquifers. This included the Pine Lake basin. Although more recent geological studies have in part included the project area, their attention has been restricted to stratigraphy, coal geology or gravel resources and do not discuss hydrogeologic aspects.

## Type, Source and Treatment of Data

Points at which data were collected are shown in Figures 3, 4 and 5 (in pocket). The location map of general well data (Figure 3) represents all existing geologic and hydrologic information available in the files of the Groundwater Data Centre, Alberta Research Council, relevant to the Pine Lake research basin. A number of well records published by Latour (1947) have also been represented on this map. An envelope of data points outside the research basin boundary was included (to a sufficient distance) for purposes of regional interpretation.

The majority of well data shown (Figure 3) consists of well records submitted by water well drillers over the past 15 to 20 years. These reports contain basic information on well construction, details of completion, static water levels, lithologies and occasionally recovery measurements of water levels after a brief bail test.

Time-drawdown data from pump or bail tests are rare. Water chemistry analysis of samples submitted to rural health authorities by private well owners are quite numerous. Usually, the major anions and cations are reported, along with total dissolved solids, hardness, alkalinity, conductivity, fluorides and iron. Other information obtained from the Data Centre files included reports of water levels and well construction details from well inventory surveys, seismic shot hole reports from exploration companies and a few electric logs of oil or gas wells. Also available in the study area were records of three observation wells equipped with continuous water-level recorders. Groundwater hydrographs are available for the period 1963 to present. Considerable time and effort was devoted to interpreting all of the well records, the results of which are summarized as a schedule given in Appendix $A$.

A schedule listing water chemistry analyses is presented in Appendix B. Pertinent data for any given well location on the map can be found listed under its index number in either schedule.

A second major type of data used in the Pine Lake study consisted of observations and chemical analyses of water samples obtained by the writer during a field survey in the summer of 1978. Figure 4 illustrates the type and distribution of field observations. The actual descriptions of these features have been recorded in a set of field notes, Water samples from wells, springs and surface water were collected throughout the research basin. The results of the chemical analyses of these samples are listed with the pre-existing data in Appendix B.

The third major type of data consisted of logs (Figure 5) of relatively deep holes drilled usually for purposes other than obtaining a water supply. Electric logs of structure test holes comprise a large portion of the deep geologic-type information in the Pine Lake basin. As 1 understand, these test holes were drilled (early 1950's) for the purpose of obtaining shallow structural-stratigraphic data to delineate anomalous structures in potential oil or gas producing formations at much greater depths. They were also used to run vertical velocity surveys for seismic studies. Electric logs (self-potential and resistance) for these structure test holes were obtained from Chevron Standard Limited (Calgary) and the Energy Resources Conservation Board (Calgary). Also shown in Figure 5, are the locations of test holes drilled for a coal study by the Alberta Research Council. A lithological log and various types of geophysical logs were available for these holes. Points at which geophysical logs are available for oil or gas wildcat wells are also shown on this map. Unfortunately, these logs are of little value to the present groundwater study in that logging of the hole usually stopped at a depth of around 600-800 feet below land surface, depending on the length of the surface casing. A few radioactivity-type logs are available which can be used for shallow stratigraphic interpretation. Copies of these logs were obtained via the Well Information Service, Alberta Research Council. Appendix $C$ contains a schedule of basic information obtained from the three main types of deep well data, employing a separate numbering system to index each type.

All elevations listed in the above mentioned schedules (Appendices $A$ and C) are expressed in feet above mean sea level. Elevations of water wells were estimated from a topographic base map with 25-foot contours. Ground elevations of seismic shot holes, structure test holes, and oil or gas wildcat wells were reported on the logs and are presumed to have been surveyed.

## System and Terminology of Land Survey Units

The system and terminology of the land survey units in Alberta is shown in Figure 6. Townships are numbered northward from the fortyninth parallel (International Boundary). Ranges are numbered westward from each principal meridian. The Fourth Meridian is $110^{\circ} 00^{\prime}$ West Longitude, Fifth Meridian at $114^{\circ} 00^{\prime}$, and the sixth Meridian at $110^{\circ} 00^{\prime}$. A "Township" is an area of 6 square miles, containing 36 sections, each 1 square mile. A "Section" is divided into 16 "Legal Subdivisions". Most water wells are usually located in driller's reports only to the accuracy of a quarter section. However, using aerial photographs of a scale of 2 inches to 1 mile and field experience, locations of most of the wells and springs listed in Appendix $A$ and $B$ have accuracies to the legal subdivision. Seismic shot holes, structure test holes and wildcat wells have been surveyed and are often reported in terms of distances from section corners or to legal subdivisions. The system of numbering well locations as listed in the well schedules is best explained by example: the location number 3-26-36-25W4 denotes legal Subdivision 3, Section 26 , Township 36 and Range 25 West of the Fourth Meridian.


Figure 6. System and terminology of land survey units in Alberta.

## CHAPTER 2

## GEOGRAPHY

The purpose of this chapter is to describe the geographical features of the Pine Lake area, concentrating on those aspects most relevant to a groundwater study. In that the Pine Lake basin was chosen because of its representable environment, much of the physiographical generalities discussed below are applicable to a large portion of the surrounding region.

## Local History and Culture

The origin of the name Pine Lake (or Ghostpine Lake) comes from an Indian legend which has it that the area was haunted by the ghosts of a murdered band of Crees who had camped along the shores of the lake (Holmgren and Holmgren 1972). The first non-Indian to travel in the Pine Lake area was an explorer named Anthony Hendry (Bowser et al. 1951). He apparently spent part of the winter of 1754 along Pine Lake, which was referred to as Archithinue Lake in his diary. It wasn't until the 1890 's that real settlement of this region occurred, beginning with the construction of railways and surveying of the land. Today, a substantial rural population is well established in the study area. Mixed farming, specifically the production of forage and cereal crops as well as livestock, is the principal industry in the Pine Lake
basin. Although there are no settlements in the research basin, Pine Lake itself sustains several beach resorts, many private cabins and a provincial park which together attract large numbers of people from various towns and cities in central Alberta.

## Topography

The Pine Lake research basin is within a regional series of northwest-southeast trending elongate ridges and valleys in a portion of the Western Alberta Plains physiographic region (Figure 2). By far the most prominent regional topographic feature is the incised valley of the Red Deer River which is, in places, over 500 feet ( 150 metres) deep. Bedrock geology and differential erosion is responsible for the major topographic features in this region. The Pleistocene glaciations have created many of the small or local features and modified much of the original bedrock topography.

The topography and physiographic features of the Pine Lake basin are shown in Figure 7 (in pocket). For purposes of clarity, only the 50 foot elevations (above mean sea level) contours are shown on this map (a topographic map with 25 foot contours was used as a base). Elevations in the research basin range from over 3450 feet ( 1050 m ) in the rugged ridge area at the northwest end to less than 2850 feet ( 850 m ) along Ghostpine Creek, where it leaves the study area in the southeast. Maximum relief, therefore, is about 600 feet ( 180 m ) from the north to south end of the basin. Maximum relief in an east-west direction and between the valley bottom and adjacent ridges is typically much less, generally around 300 feet ( 90 m ) for the western
flank of the basin and about 200 feet ( 60 m ) for the eastern flank. Over most of the basin, the topography can be characterized as being gently rolling to rolling, with portions quite hilly as in the north, and parts gently level to undulating such as along some of the creek valley bottoms and on a few of the plateau-type areas which border parts of Pine Lake and the main ridges.

Drainage
Regional drainage in south central Alberta (Figure 2) is relatively well developed when compared to other parts of the Canadian prairies. The marked parallelism and regular spacing of the four main creeks -- Lonepine, Kneehills, Threehills and Ghostpine has been noted by a number of authors but the cause of this drainage trend remains to be determined. (l believe that the most probable explanation is some sort of structural control in the bedrock, perhaps gentle flexures in the underlying thick Cretaceous-Tertiary sequence of strata). Tóth (1962, 1968) summarized the general characteristics of the above mentioned creeks as being narrow, shallow, underfit, meandering streams of a barely perennial nature whose discharge is quite variable. Intermittent tributaries to these creeks effectively drain the surrounding areas. These tributaries trend east-west and commonly have smaller gullies branching off normal to them.

The type of drainage in the Pine Lake research basin is shown in Figure 7. Although the boundary is rather vague in places, the surface water drainage divide was used to delineate the areal extent of
the research basin. This was especially difficult to determine in those parts of the basin where hummocky terrain is prominent, such as in Township 37, Range 25 and along the western ridge in Township 36, Range 25 (Figure 7). The Pine Lake research basin is not hydrologically closed as might be misinterpreted from figure 7. The southern boundary is not a surface drainage divide in the true sense (although it was drawn partly along a topographic high) but was chosen in a convenient location so as to limit the size of the research basin. The Pine Lake basin is only approximately one-quarter the area of the true Ghostpine Creek drainage basin.

Drainage in the Pine Lake research basin is moderately developed over most of the study area. This is far from being true in those areas of hummocky topography where the lack of an integrated drainage system is quite apparent. Only a small portion of the basin contains areas where the drainage appears to be almost well developed. These areas would include the immediate flanks of the northern uplands (Township 37, Range 26) and possibly parts of the southern end of the basin along Ghostpine Creek and the adjacent ridges.

Two streams appear to drain the northern part of the basin above Pine Lake. They do not directly drain the highly elevated region, but rather their head waters are along the margin of extensive areas consisting of hummocky ground. A subdued ridge extending from the northern uplands to the confluence of the two streams near Pine Lake acts as a local drainage divide between these streams. Both of these streams flow intermittently south and into Pine Lake, commonly
interrupted by sections of the reach which are of a perennial nature. Depressions along the stream courses form small to large ponds when blocked naturally or dammed by beaver activity.

Pine Lake is the only major surface water body in the Ghostpine Creek drainage basin. An aerial view of the lake, looking south from the northern end, is shown in Figure 8. According to Stalker (1960), Pine Lake probably occupies a preglacial valley that was dammed by glacial drift and thereby created during the melting of a remnant ice block in the Pleistocene. Drainage into the lake is provided by a few intermittent, usually poorly defined, stream channels which appear to drain broad areas of boggy lowland on both sides of the lake. Pine Lake itself appears to serve as a head tank or reservoir that sustains stream flow in Ghostpine Creek. As shown in Figures 9 and 10, the outlet of Pine Lake is fairly well defined, forming the upper reach of Ghostpine Creek.

Ghostpine Creek has an interrupted nature in the Pine Lake basin. Part of its reach is perennial while other sections have an intermittent character. It is commonly only several feet wide and a few feet deep, meandering as an underfit stream with its bed incised into a wider preglacial flood plain valley. Tributaries to Ghostpine Creek have eroded significant drainage channels back into the main ridges. Several ponds and small lakes occur along the Ghostpine Creek valley and some of its tributaries. Many of these water bodies occupy natural closed depressions but some have been formed by dams constructed by man and beavers.


Figure 8. Aerial view of Pine Lake, looking south from north end of lake -- Courtesy W. Ceroici.


Figure 9. Aerial view of the south end of Pine Lake -- Courtesy W. Ceroici.


Figure 10. Infrared photograph showing outlet of Pine Lake -- Courtesy W. Ceroici.

Soils
The soil map for the Pine Lake research basin is shown in Figure 11 (in pocket). This map was abstracted from a comprehensive soil survey published by Bowser et al. (1951) on the Red Deer map area. The Pine Lake basin lies almost entirely within the Black Soil Zone of Alberta. Small portions of the basin at the southern end are classified as being in the Thin Black Soil Zone (Figure ll) and "islands" of soil types in the Degraded Black Soil Zone occur east of Pine Lake and at the extreme northern end of the basin. A soil zone is defined as a geographic area within which the majority of the soils have common characteristics such as color and depth of various horizons. These characteristics are the result of climatic conditions and vegetation existing in the zone area.

The Degraded Black Soils are usually tree covered, gray-black and moderately leached. The Falun loam (Figure ll) is fairly well to well drained, fertile and found on gently undulating to gently rolling topography. The Carvel loamy sand, east of Pine Lake, is only fair arable land.

The Black Soils are characterized as being organically rich and have greater than 6 inches ( 15 cm ) of black surface soil. The Beaverhills loam has a prismatic structure, occurs on undulating to hilly topography, is well drained, and supports a native parkland vegetation of grass, shrubs and trees. Angus Ridge loam is a fairly well to well drained soil found on gently undulating to rolling topography. The only other prominent soil types of the Black Soil Zone in the basin are
the Peace Hills loams and loamy sands. These are well to excessively drained and are found on level to undulating and dune-like topography respectively.

Thin Black Soils are found in the southern part of the basin, developing under conditions of noticeably less precipitation than the Black Soils. Bowser et al. (1951) noted that these soils typically consist of 3 to 6 inches ( $8-20 \mathrm{~cm}$ ) of black top soil and a deeper horizon of lime concentration. Elnora loam supports a native open parkland vegetation, is found on undulating to hilly topography, and is described as a well drained soil. Irma loams are usually of a sandy character and are well to excessively drained.

Most of the soils in the Pine Lake basin have developed from the underlying glacial drift, except in those areas where bedrock is partially exposed. Extreme weathering is not found in Alberta and, because soil mapping is based partly on texture which in turn depends on the parent material in moderate climates, soils often reflect surficial geology. This is the case in the Pine Lake area and Bowser et al. (1951) interpreted the parent materials for the various soil types mapped (see Figure 11).

From a hydrogeological view, soils can be an important indicator of underlying groundwater conditions. This aspect has not gone unnoticed in the Canadian prairies where soil conditions and associated vegetation have been used to interpret the groundwater regime (Meyboom 1966a, Tóth 1966a, Freeze 1969a, Tôth 1969). The application of this
interpretive technique to the present study will be discussed in a later chapter.

## Vegetation

Prior to settlement, the Pine Lake area was completely covered by a typical parkland vegetation (Government and University of Alberta 1969). Today, about 50 to 60 percent of the research basin has been cultivated and cleared. In spite of this, the native parkland environment is still quite apparent, especially in the rougher terrain and along parts of the drainage system where farming has not yet been feable. The principal tree growth is aspen poplar with willow most prominent in lowland areas. Although not as abundant, significant stands of spruce and jack pine occur along the drainage ways, around Pine Lake, on the sandy soils, and on some of the northern hill slopes. Varying amounts of natural open country is present, mostly covered by grasses but wild fruit trees, buck brush and rose bushes also flourish.

Part of the research basin south of Pine Lake is noticeably more open parkland country and in general appears to be a transitional zone from true parkland to the extensive prairie grassland cover south of the study area. This region is characterized by a vegetation cover of predominantly grasses on the southern slopes of hills and level plains. Tree growth of aspen poplar and/or willow is confined to northern slopes and low areas. Isolated groves of aspen poplar, willows and silver willow are present around local dry depressions.

An example of the typical vegetation in each of the major areas discussed above are shown in Figures 12 and 13. The nature of the


Figure 12. Parkland vegetation in northern part of research basin.


Figure 13. Open parkland country which is transitional to prairie grassland environment.
vegetation cover around Pine Lake can be discerned from the aerial photograph in Figure 8. As shown by these photographs, phreatophytes are abundant in most of the depressional areas and drainage ways. This feature has significant influence on the subsurface hydrology.

## Climate

The climate in the Pine Lake research basin is cold, humid continental and can be denoted by the climatological letter code Dbf, according to the Koeppen system of classification as modified by Trewartha (1957). The meaning of these letter symbols is as follows: "D" -- microthermal climate (rain-snow climate with cold winters) where the coldest month mean temperature is below $32^{\circ} \mathrm{F}\left(0^{\circ} \mathrm{C}\right)$ and the warmest month is above $50^{\circ} \mathrm{F}\left(10^{\circ} \mathrm{C}\right)$; "B" -- cool summer and the mean temperature of the warmest month is below $71.6{ }^{\circ} \mathrm{F}\left(22^{\circ} \mathrm{C}\right)$; "F" -- moist conditions exist through the year (no dry season).

Several meteorological stations in south-central Alberta provide a good network of observations on a large regional scale. Fortunately, a meteorological station does exist in the Pine Lake research basin and is in 4-10-37-25W4. Although observations of temperature and precipitation have only been made since 1960, these are the best data presently available and is probably representable of conditions in at least the northern half of the research basin. No meteorological station exists in the southern part of the Pine Lake basin. However, observations recorded at a station further south in the Ghostpine Creek valley near Trochu (Figure 2) are probably characteristic of the climatic conditions in the south end of the research basin. For that
reason, data from both the Pine Lake and Trochu Equity station are presented in Tables 1, 2 and 3 which contain mean monthly values of precipitation, temperature and potential evapotranspiration for the 30-year period 1941-1970.

## Precipitation

Based on the available information, mean annual precipitation in the Pine Lake research basin probably varies from about 17 inches ( 41 cm ) in the southern part of the study area to over 19 inches ( 48 cm ) in the northern uplands. This estimate agrees quite closely with climatic maps of Alberta prepared by Longley (1968) for the record from 1931-1960. Of the total mean annual precipitation shown for the Pine Lake station in Table $1,14.43$ inches ( 36.65 cm ) occurred as rainfall while mean snowfall was 49.8 inches ( 126.49 cm ) over the period recorded (Environment Canada 1973).

## Temperature

Mean annual temperatures for the Pine Lake and Trochu Equity station (Table 2) are 1 isted as $35.5^{\circ} \mathrm{F}\left(1.9^{\circ} \mathrm{C}\right)$ and $37.0^{\circ} \mathrm{F}\left(2.8^{\circ} \mathrm{C}\right)$ respectively. At the Pine Lake station, the warmest month is July with a mean extreme maximum temperature of $97^{\circ} \mathrm{F}\left(36^{\circ} \mathrm{C}\right)$ and the coldest month is January with a mean extreme minimum temperature of $-47^{\circ} \mathrm{F}\left(-44^{\circ} \mathrm{C}\right)$. There are usually between 100 and 110 frost free days from late May to early September (Longley 1968).
Table 1. Mean monthly precipitation, Pine Lake research basin

| Station | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Year |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Pine Lake |  |  |  |  |  |  |  |  |  |  |  |  |  |
| inches | 0.84 | 0.71 | 0.64 | 1.35 | 2.31 | 3.35 | 3.15 | 2.75 | 1.90 | 1.02 | 0.76 | 0.62 | 19.40 |
| cm | 2.13 | 1.80 | 1.63 | 3.43 | 5.87 | 8.51 | 8.00 | 6.99 | 4.83 | 2.59 | 1.93 | 1.56 | 49.28 |
| Trochu Equity |  |  |  |  |  |  |  |  |  |  |  |  |  |
| inches | 0.76 | 0.71 | 0.75 | 1.14 | 1.47 | 2.94 | 2.80 | 2.20 | 1.39 | 0.91 | 0.65 | 0.68 | 16.40 |
| cm | 1.93 | 1.80 | 1.91 | 2.90 | 3.73 | 7.47 | 7.11 | 5.59 | 3.53 | 2.31 | 1.65 | 1.73 | 41.66 |

Table 2. Mean monthly temperatures, Pine Lake research basin

| Station | Jan | Feb | Mar | Apr | May | June | July | Aug | Sept | Oct | Nov | Dec | Year |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Pine Lake |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }^{\circ} \mathrm{F}$ | 5.7 | 13.2 | 21.0 | 37.1 | 48.9 | 55.1 | 60.3 | 57.7 | 49.2 | 40.1 | 24.0 | 13.4 | 35.5 |
| ${ }^{\circ} \mathrm{C}$ | -14.6 | -10.4 | -6.1 | 2.8 | 9.4 | 12.8 | 15.7 | 14.3 | 9.6 | 4.5 | -4.4 | -10.3 | 1.9 |
| Trochu Equity |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }^{\circ} \mathrm{F}$ | 6.3 | 14.0 | 22.3 | 38.3 | 50.6 | 58.4 | 63.1 | 61.5 | 52.0 | 41.1 | 23.5 | 13.1 | 37.0 |
| ${ }^{\circ} \mathrm{C}$ | -14.3 | -10.0 | - 5.4 | 3.5 | 10.3 | 14.7 | 17.3 | 16.4 | 11.1 | 5.1 | -4.7 | -10.5 | 2.8 |

Table 3．Mean monthly potentlal evapotranspiration，Pine Lake research basin

| ¢ |  | －m |
| :---: | :---: | :---: |
| 足 | 1 | ＇ |
| ？ | ＇ | ＇ |
| 㟔 | $\underset{\sim}{\sim}$ | $=\underbrace{-}$ $-\sim$ |
| 号 | $\begin{array}{ll}\infty & \\ \sim \\ \sim\end{array}$ | N |
| $\stackrel{\square}{8}$ |  | $\infty$ $\sim$ $\sim$ $\sim$ $\sim$ 0 |
| $\frac{2}{3}$ | 式 | g $=\sim$ $=\sim$ |
| $\stackrel{\text { 2 }}{\sim}$ | $\infty$ $\infty$ $\dot{m}$ N | g <br>  <br> $=0$ <br> $\vdots$ |
| $\stackrel{\text { a }}{\text { ¢ }}$ | $\stackrel{n}{\sim}$ | $\infty$ $\sim$ $\sim$ $\sim$ |
| 京 | $\begin{array}{ll}\sim \\ \sim \\ 0 & \sim \\ 0\end{array}$ | $\begin{array}{cc}\infty \\ \stackrel{\infty}{\infty} & \infty \\ \vdots \\ \vdots \\ \sim\end{array}$ |
| 产 | 1 | ＇ |
| $\stackrel{8}{\text { ® }}$ | 1 ＇ | 1 |
| $\stackrel{\sim}{0}$ | 1 ＇ | ＇ |
| ¢ <br> $\vdots$ <br>  <br>  |  |  |

Potential Evapotranspiration
Potential evapotranspiration can be defined as the evapotranspiration which would occur from a soil surface covered with vegetation and never short of water (Linsley, Kohler and Paulhus 1975). If there is a shortage of water, actual evapotranspiration will be less than potential evapotranspiration.

The potential evapotranspiration values presented in Table 3 have been calculated by the writer, using the empirical method of Thornthwaite (1948). The mean annual potential evapotranspiration for the Pine Lake research basin is about 21 inches ( 53 cm ) in the south, to less than 20 inches in the northern region. The Government and University of Alberta (1969) estimated the average annual potential evapotranspiration as 20 to 22 inches ( 51 to 56 cm ) for the general region. Actual evapotranspiration is listed by the same source as being 16 to 18 inches ( 41 to 46 cm ).

Figures 14 and 15 summarize the relationship between precipitation and potential evapotranspiration for an average year in the Pine Lake area. These Thornthwaite diagrams show how precipitation only exceeds potential evapotranspiration from mid-October to mid-April. The importance of this feature in relation to groundwater recharge will be discussed in the following section.

## Physiographic Factors of Groundwater Recharge

Most of this chapter has been devoted to the physiographic description of the Pine Lake research basin; however it would seem a

THORNTHWAITE CLIMATE DIAGRAM
PINE LAKE STATION
AVERAGE YEAR


Figure 14. Graphical representation of climate at the Pine Lake meteorological station.

ThORiNTHWAITE CLIMATE DIAGRAM
TROCHU EQUITY STATION
average year


Figure 15. Graphical representation of climate at the TrochuEquity meteorological station.
brief consideration of those aspects of physiography which influence the groundwater regime is appropriate at this point.

One of the major physiographic factors of groundwater recharge on the Canadian plains is climate. This fact is illustrated in Figures 14 and 15 where, for an average year, potential evapotranspiration is seen to exceed precipitation from April to October, thereby posing a major constraint to groundwater recharge. During the rest of the year precipitation does exceed potential evapotranspiration, but the long cold winters effectively limit the period when surface water can actually infiltrate into the ground and recharge the groundwater system. In the Pine Lake area, these potential recharge conditions exist in the early part of October and late April when the ground is not frozen. Precipitation is low in the fall of the year and probably only sufficient to restore soil moisture. Precipitation over the winter months occurs as snow and a snow pack is formed. Therefore, only in late April to early May is the climate conducive to groundwater recharge. Furthermore, surface water is abundant (melting snow packs and high precipitation), evapotranspiration is low, and infiltration is not impeded by frozen ground. Even during periods of early thaw, there is information to suggest that the frozen or partially frozen ground is not impermeable and hence infiltration can take place (Stoeckeler and Weitzman 1960, Williams and Burt 1974), although relative to the major spring runoff event it is probably of minor importance.

A second major physiographic factor of groundwater recharge is topography. The topographic influence on groundwater flow in western Canada has been well documented in the literature. In general, the water table is a subdued replica of the topography. Under these conditions, regional topographic highs or uplands will behave as "recharge" areas, that is, groundwater is natrually at a higher hydraulic head and therefore motion is directed towards areas of lower potential energy (i.e., topographic lows are often discharge areas for groundwater flow). Another aspect of the effect of topography is that in upland regions the unsaturated zone is likely to be considerably thicker (due to the subdued nature of the water table) than in regional discharge areas where groundwater motion is largely upward. This will have significant implications when interpreting groundwater chemistry or the role of infiltration and unsaturated flow as a component of the subsurface hydrologic cycle.

Drainage of the land has great importance in determining the actual quantities of precipitation which will be available for groundwater recharge. In those parts of the basin where drainage is integrated, a considerable portion of the precipitation and snowmelt could be lost by runoff. However, large areas of hummocky upland exist where drainage is quite poor and surface water is detained in innumerable closed depressions where it has a much greater opportunity to infiltrate and recharge the saturated zone. The abundant growth of phreatophytic vegetation around these depressions and high summer evaporation will seriously limit this recharge process to early spring and perhaps
briefly during extended periods of thunderstorm rainfall in the summer months. In the intermediate and lowland areas, local depressions probably act as groundwater discharge points, at least over most of the summer, but intermittently may contribute to groundwater recharge (Meyboom 1966b).

The nature of the soils will also play a major role in influencing groundwater recharge. In areas where apparent lack of integrated drainage exists, recharge rates will largely be determined by infiltration rates of the soil which in turn depends mainly on sorptivity and hydraulic conductivity. Infiltration and percolation will be greatest in sandy textured soils, while in loams it will be considerably less and surface water therefore will be more vulnerable to runoff and evapotranspiration.

## CHAPTER 3

## SURFACE-WATER HYDROLOGY

Surface water is an integral part of the hydrologic cycle and in that respect has significant importance in a basin-wide evaluation of the subsurface hydrology. Although the availability of quantitative information on surface water in the Pine Lake research basin is limited, sufficient data are available to at least make some general observations and interpretations. Specifically, this chapter will discuss streamflow (runoff) as well as lake and slough hydrology. (Sloughs, pronounced sloठs, are small marshy ponds which occupy natural depressions on the land surface.) In addition, the possible significance of the data interpretation and surface water features in regard to local groundwater conditions will also be examined.

## Streamflow

Chow (1964) defines runoff as that portion of precipitation, plus any other flow contributions, which appears in surface streams and is the flow recorded at an outlet of the drainage basin. In the strictest sense of the meaning, streamflow represents the total runoff confined to stream channels. For the purpose of this study, streamflow and runoff will be considered as synonymous terms for the total of surface runoff and groundwater flow that eventually reach stream channels.

The drainage characteristics of the various streams and creeks in the Pine Lake research basin were previously described. Quantitative streamflow records in the Ghostpine Creek drainage basin are scanty and for that part of the drainage basin in the Pine Lake research basin, nonexisting.

Runoff observations have only been made for Ghostpine Creek. Measurements of creek stage were recorded for the period 1962 to 1966 but were not published. A discharge type gaging station was established on Ghostpine Creek near Huxley (Figure 2) where flows were recorded during 1967, 1968 and 1969. For reasons unknown to me, this gaging station was abandoned. In any event, these three years of record are all that exist in the drainage basin and, in the absence of other data, will have to be sufficient for the purpose of evaluating the streamflow characteristics of Ghostpine Creek.

The complete streamflow records for the three years of discharge measurements are given in Environment Canada (1974). A summary of the streamflow data for the Ghostpine Creek station near Huxley is presented in Table 4 which is self-explanatory. For purposes of illustration and discussion, the 1967 streamflow hydrograph with corresponding hyetograph have been plotted in Figure 16.

The drainage area of the Ghostpine Creek basin associated with the gaging station near Huxley is approximately 200 square miles ( 500 $\mathrm{km}^{2}$ ). Although a major portion of this area is fairly well drained by an integrated system of tributaries, significant tracts of land in the Pine Lake basin exist where the hummocky nature of the topography would
Table 4. Summary of streamflow data Ghostpine Creek near Huxley.


preclude major surface drainage. Surface runoff in these hummocky areas occurs largely as overland flow into local depressions called sloughs. However, in that the streamflow record is so short and only a crude estimate of mean annual runoff is being considered, no attempt was made to determine the area of the basin actually contributing to total runoff. (This would be desirable in future studies where instrumentation of the Pine Lake research basin would warrant more accurate water balances). Based on the streamflow records, total runoff for 1967 amounted to 5780 acre-feet $\left(7.13 \times 10^{6} \mathrm{~m}^{3}\right)$ whereas in 1969 annual runoff was 11000 acre-feet $\left(1.4 \times 10^{7} \mathrm{~m}^{3}\right)$. Converting these figures to a depth over the 200 square mile ( $500 \mathrm{~km}^{2}$ ) "drainage" area, annual runoff for 1967 and 1969 is 0.54 inches ( 1.37 cm ) and 1.03 inches ( 2.62 cm ) respectively. The 1968 record was incomplete and so no attempt has been made to calculate runoff. With such a short period of record, the runoff data is unlikely to be representative of mean basin runoff. Nevertheless, comparison of snowfall records indicates these years are near the annual mean snowfall and therefore may be adequate estimates.

A detailed hydrograph analysis of the available streamflow records of Ghostpine Creek is beyond the scope of this report. However, in the interest of discussing the general qualitative characterictics of the time distribution of runoff in the research basin, the 1967 Ghostpine Creek streamflow hydrograph and corresponding hyetograph characteristics (see Figure 16) will be discussed. Discharges in Ghostpine Creek are only measureable from the period of spring thaw
(usually April) to late fall (November). Because of the almost imperceptible flow, the creek is completely frozen during the winter months, except where it has formed ponds in local depressions. As illustrated by the 1967 hydrograph (Figure 16), streamflow in Ghostpine Creek is intermittent. The major runoff event in April to May is completely dependent on meltwater from the snowpacks formed during the winter months. Snowmelt runoff peaks in late April and by early May begins a major period of recession. Significant amounts of rainfall in May and especially June appear to briefly sustain streamflow through these months but by early July the low precipitation and high evapotranspiration rates clearly depletes streamflow through july until it is almost negligible. Streamflow is effectively zero until early October where evapotranspiration losses have decreased such that groundwater flow and minor amounts of rainfall are sufficient to sustain daily streamflows of less than 0.5 cubic feet per second (14 $1 / \mathrm{s}$ ).

As illustrated in Figure 16 , the baseflow component of runoff is almost negligible in the Ghostpine Creek drainage basin throughout most of the year. In other words, groundwater discharge into the streams of the basin is often only sufficient to meet the demands of evapotranspiration over most of the frost-free months. Although well illustrated by the 1967 streamflow hydrograph, this observation is equally valid for the other years of record. The actual amount of baseflow or groundwater discharge which contributes to streamflow in the spring period (April-June) is difficult to assess due to the large volumes of surface runoff. Freeze (1969a) used minimum monthly
discharges to estimate annual baseflow for several streams in a drainage basin in Saskatchewan. He pointed out that the baseflow in these intermittent streams may or may not represent total groundwater discharge but that such figures could be correlated with mean annual groundwater recharge. In any event, this procedure amounts to figures of 1780 acre-feet $\left(2.19 \times 10^{6} \mathrm{~m}^{3}\right)$ or 0.17 inches ( 0.43 cm ) over the drainage area associated with the Ghostpine Creek gaging station for the 1967 record. The figures for the 1969 record are 1120 acre-feet $\left(1.38 \times 10^{6} \mathrm{~m}^{3}\right)$ or 0.11 inches ( 0.27 cm ) respectively. Whether or not these figures are truly representable of groundwater discharge is debatable.

The interpretation of the magnitude of these baseflow or groundwater discharge estimates as indicating rocks of very low hydraulic conductivity would be wrong. Evapotranspiration is probably a significant factor in determining discharge and furthermore, as will be discussed in the chapter on hydrogeology, groundwater discharge is not entirely confined to the streams. In that regard, the techniques of estimating groundwater recharge from stream hydrographs (Meyboom 1961, Kunkle 1962) should be used with extreme caution in the Ghostpine Creek drainage basin.

## Lakes and Sloughs

As was discussed in the previous chapter, a number of small lakes are present in the Pine Lake research basin (Figure 7). Comparison of recent aerial photographs (1975) with older topographic maps (1970, 1959) has shown that all of these lakes are permanent bodies of
surface water, although a few have varied slightly in area over the past 25 years. Pine Lake is the largest reservoir of surface water in the research basin and the only one which will be further examined in detail.

The results of a hydrographic survey of Pine Lake (1967) by the Surveys Branch, Alberta Department of the Environment are shown in Figure 17. The water surface elevation is approximately 2917 feet above mean sea level ( 889.1 m ) and has remained fairly constant for the past 15 years of observations. The maximum depth of Pine Lake is about 40 feet ( 12 m ) along the center of the southern half of the lake, but decreases to about 25 feet ( 8 m ) at the northern end. Except for the north and south ends of the lake, depths drop off steeply around the shoreline. The surface area of Pine Lake was planimetered to be 1.55 square miles ( $4.02 \mathrm{~km}^{2}$ ). A storage capacity of 19606 acre-feet $\left(2.42 \times 10^{7} \mathrm{~m}^{3}\right.$ ) was determined by the Surveys Branch (Figure 17).

Measurements of lake levels have been recorded since 1965, but daily observations (based on a 5 foot $[1.5 \mathrm{~m}]$ fiberglass staff gage at the north end of Pine Lake) have only been available since 1973. The lake level hydrographs for the years 1973, 1975, 1976 and 1977 are shown in Figure 18. The 1974 record was incomplete and so it has not been plotted. Pine Lake is completely frozen over from about November to the end of April, thus these lake level records (Figure 18) are comprised entirely of observations in the May to October period.

A recession curve analysis of the lake level hydrographs was employed to estimate net evaporation from Pine Lake. These curves are


Figure 17. Hydrographic map of Pine Lake. -- After Surveys Branch, Alberta Department of the Environment, 1967. Contour numbers represent lake depth, in feet.

Figure 18. Lake level hydrographs, Pine Lake.
also shown in figure 18 and the results of the analysis are tabulated in Table 5. 'Net evaporation' from June 1 to October 1 was calculated by adding the lake level drop (based on the recession curves) and observed precipitation for that period. According to maps produced by Bruce and Weisman (1967), this four month period would account for about 80 percent of the annual evaporation, therefore the annual "evaporation" for each year of record was calculated by dividing the June 1 to October 1 figures by 0.80 . The mean value of annual "net evaporation" was determined to be about 19 inches ( 48 cm ). This is not the actual evaporation rate for Pine Lake. Without records of runoff in and out of the lake and estimates of seepage out of the lake bottom, groundwater discharge, and perhaps near shore transpiration, no meaningful evaporation rate can be calculated with existing data. Bruce and Weisman (1967) have constructed lake evaporation maps of Canada, using evaporation pan data and solar radiation measurements. Based on their map, mean annual lake evaporation for the Pine Lake area should be about 29 inches ( 74 cm ). However, their evaporation estimates apply only to water bodies with negligible heat storage (i.e., ponds and shallow lakes), an assumption which may not hold for Pine Lake.

The importance of sloughs (or potholes) in relation to the surface-water hydrology of the Pine Lake area has already been recognized in the earlier discussions of drainage. The great abundance of these features in parts of the Pine Lake research basin is attributed to the hummocky character of the surficial (glacial) material. The
Table 5. Results of ${ }_{a}$ recession curve analysis of lake level hydrographs, Pine Lake.

| Year | Lake Level Drop <br> June 1 - Oct 1 <br> (inches) | Precipitation <br> June 1 - Oct 1 <br> (inches) | Net Evaporation <br> June 1 - Oct 1 <br> (inches) | Net Annual <br> Evaporation |
| :---: | :---: | :---: | :---: | :---: |
| 1973 | 3.12 | 14.55 | 17.67 | 22.09 |
| 1974 | - | - | - | - |
| 1975 | 7.32 | 7.24 | 14.56 | 18.20 |
| 1976 | 2.40 | 10.95 | 13.35 | 16.69 |
| 1977 | 2.64 | 12.44 |  | 18.85 |

a. Mean Annual Net Evaporation $=18.96$ inches $=48.15 \mathrm{~cm}$
topographic map of the Pine Lake basin cannot adequately illustrate the detailed nature of this surface-water feature. The aerial photograph in Figure 19 is probably a better representation of the slough distribution and character in hummocky areas of the research basin.

The presence of sloughs in an area effectively limits surface runoff by acting as very small closed drainage basins, thereby precluding the development of an integrated drainage system. As a result, a significant amount of depressional storage is created whereby ponded water is either evaporated, transpired by hydrophytes and phreatophytes or infiltrates into the ground. Unfortunately, no quantitative information concerning the hydrology of sloughs (i.e., water budgets) is available in the Pine Lake area. Freeze (1969b) found that, for a water budget of a parkland region in Saskatchewan, the evaporation rate off sloughs could be assumed to take place at an annual rate of 80 percent of that for lakes. If this holds true for the Pine Lake area, then annual slough evaporation would be estimated at 23 inches ( 59 cm ).

A number of studies have conclusively shown that sloughs significantly affect both surface-water hydrology and the local groundwater regime (e.g., Meyboom 1966b, 1967b; Tóth 1966a; Lissey 1968; Freeze 1969a; Sloan 1972). Sloughs can behave strictly as focal points of groundwater recharge, act as groundwater discharge features, or possibly an intermediate combination of both in a throughflow manner. In fact, Meyboom (1966b) found an annual sequence of flow conditions in Saskatchewan, whereby the slough acts as a recharge feature in the spring and early summer and a groundwater discharge feature in late


Figure 19. Aerial view of hummocky terrain with sloughs, Pine Lake research basin.
summer and fall. In short, the surface-water hydrology and water budget of an individual slough can be complex. The interaction between groundwater flow and surface water greatly complicates this situation and is a subject which is further examined in a later chapter.

## CHAPTER 4

## GEOLOGY

The object of this chapter is to study those aspects of geology relevant to an analysis of the hydrogeologic environment of the Pine Lake research basin. In that regard, the discussion will be largely confined to a general description of the local bedrock strata (Tertiary) and surficial deposits (Quaternary). The main source of geologic information on south-central Alberta has been from published reports and papers which are numerous. Interpretation of the local geology is based entirely on geophysical logs of test holes and lithologs obtained from water well drillers' reports.

## Geological Setting and Regional Stratigraphy

In south-central Alberta, glacial deposits of the Pleistocene continental glaciation and Recent alluvium form a veneer over bedrock strata of Upper Cretaceous and Tertiary age. Excellent exposures of these bedrock formations occur along some of the more deeply incised drainage ways. Underlying these rocks are a thick succession of Lower Cretaceous and Paleozoic strata, many of which contain commercial quantities of oil and gas. Depth to the crystalline rocks of the Precambrian basement is in excess of 10,000 feet ( 3000 m ). Structurally, this thick sedimentary rock sequence exhibits a gentle westward dip,
comprising the eastern flank of the Alberta Syncline. The regional nature of the bedrock and deeper stratigraphy in central Alberta is summarized by the diagrammatic cross-section in Figure 20.

As is probably evident in Figure 20, most groundwater investigations in the south-central part of Alberta are directed to those stratigraphic units above the Lea Park Formation. West of Edmonton (Figure 21), groundwater supplies obtained from the bedrock strata are entirely derived from aquifers in either the Horseshoe Canyon or Paskapoo Formations. Practical economics and water quality limit aquifer exploration to the strata within several hundred feet (a few hundred meters) of the land surface. Domestic wells rarely need to exceed 300 feet ( 90 m ) to obtain a sufficient water supply. Although the deeper stratigraphic units do not represent feasible sources of groundwater for development, a number of researchers have shown that these deep formations play a significant role in the large regional groundwater flow patterns (Tóth 1962, Freeze and Witherspoon 1967, Hitchon 1969, Tóth 1978).

The Pine Lake research basin is characterized by a relatively thin mantle of surficial deposits that are usually less than 50 feet ( 15 m ) thick but can locally exceed 150 feet ( 45 m ). The entire area is underlain by semi-consolidated to consolidated sandstones, siltstones and shales of the thick Paskapoo Formation which constitutes the bedrock (Rutherford 1939, Allan and Sanderson 1945, Green 1970). Table 6 is a stratigraphic chart of the formations down to and including the Lea Park Formation in the Pine Lake basin. Information

Figure 20. Diagrammatic cross-section through central Alberta. -- After Geological Highway


Figure 21. Representative subsurface section of the Paskapoo Formation in the Pine Lake research basin.
Table 6. Stratigraphic chart of formations, PIne Lake area.

| Era | Period | Epoch |  | up or formation | Lithology | Thickness |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Cenozoic | Quaternary | Pleis tocene | "Glacial Drift" |  | till: lacustrine sand, shlt, end clay; outwash sand and gravel | $\begin{aligned} & 0-170 \text { feet } \\ & (0-50 \mathrm{~m}) \end{aligned}$ |
|  | Iertiary | Paleocene | Paskapoo Formation |  | gray, thick-bedded, calcareous cherty sandstone; gray and green siltstone and shale; minor coal and tuff beds | $\begin{aligned} & 250-1000 \mathrm{feet} \\ & (76-300 \mathrm{~m}) \end{aligned}$ |
| Hesozoic | Cretaceous | Upper Cretaceous | Scollard Member |  | Scollard Member: feldspathic sandstone and bentonitic shales; thick coal beds (nonmarine) | $\begin{aligned} & 100-250 \text { feet } \\ & (30-75 \mathrm{~m}) \end{aligned}$ |
|  |  |  |  | Battle Formation | purplish-black bentonitic mudstone; slliceous tuff beds | $\begin{aligned} & 15-\quad 30 \text { feet } \\ & (4-\quad 9 \mathrm{~m}) \end{aligned}$ |
|  |  |  |  | Whitemud Formation | pale gray-white bentonitic sandstone |  |
|  |  |  |  | Horseshoe Canyon formation | gray, feldspathic, clayey sandstones and mudstones; carbonaceous shale: coal and bentonitic beds; minor thin limestones (mainly nonmarine) | $\begin{aligned} & 1300-1400 \mathrm{feet} \\ & (400-425 \mathrm{~m}) \end{aligned}$ |
|  |  |  |  | rpaw Formation | dark gray shale and silty shale; <br> minor sandstones (marine) | $\begin{aligned} & 100-250 \text { feet } \\ & (30-75 \mathrm{~m}) \end{aligned}$ |
|  |  |  |  | y River formation | gray, thick-bedded, feldspathic <br> sandstones; gray clayey siltstone: <br> gray and green mudstone (nonmarine) | $\begin{aligned} & 650-950 \text { feet } \\ & (200-290 \mathrm{~m}) \end{aligned}$ |
|  |  |  |  | Park fornation | dark gray shale; pale gray silty shale (marine) | $\begin{aligned} & 450-600 \text { feet } \\ & (140-180 \mathrm{~m}) \end{aligned}$ |

regarding the units below the Paskapoo Formation is based upon interpretation of geophysical logs from oil and gas wildcat wells (figure 5) and on the compilation by Green (1970). Because the combined thickness of the Paskapoo Formation and glacial drift exceeds 1000 feet ( 300 m ) in many parts of the research basin, the rest of this chapter will be devoted to a discussion of the geology of these two units alone. In relation to groundwater hydrology, the Paskapoo Formation and drift undoubtedly contain all hydrostratigraphic units that would be of theoretical and practical importance. Furthermore, these shallow rock units are basically the only deposits for which detailed geologic, geophysical and hydrogeologic data are available.

## Paskapoo Formation

Definition and Nomenclature
The term 'Paskapoo" (an Indian word for blindman) was first used by Tyrrell (1887) for a series of massive sandstones, siltstones and shales above a 'big coal seam' which crop out along the Red Deer River valley. The first extensive study of the Paskapoo rocks in south-central Alberta was made by Allan and Sanderson (1945). A major contribution from their study was the identification of a widespread yolcanic ash unit in the upper part of the "Edmonton Series", later to be named the Kneehills tuff. Ower (1960) re-examined the bedrock geology of south-central Alberta and devised a more detailed stratigraphic division for these rocks. Campbell (1967) concentrated on correlating various coal beds in the Edmonton-Paskapoo Series, using the nomenclature of Ower (1960). He found, however, that this
classification was not easily applied to subsurface correlation with electric logs.

Carrigy (1970) proposed that the lower boundary of the Paskapoo Formation should be accepted as the top of the Kneehills tuff unit (Battle Formation) in central Alberta. Irish (1970) concurred with this boundary revision and completely modified the Upper CretaceousTertiary nomenclature of central Alberta. The Whitemud and Battle units were given formation status and the name Horseshoe Canyon was proposed for the beds lying between the Bearpaw and Whitemud Formations (Table 6). The term "Edmonton" was redefined as a Group consisting of the Horseshoe Canyon, Whitemud and Battle Formations. The Paskapoo Formation was redefined to include those strata above the Battle Formation previously included in the Edmonton Formation. Irish (1970) also proposed that the Upper Cretaceous strata between the Battle Formation and the uppermost coal seam of the Ardley coal zone be termed the Scollard Member of the Paskapoo Formation. Carrigy (1970, 1971) found that further subdivision of the Paskapoo Formation above the Scollard Member into regional mappable units was virtually impossible on the basis of lithology. However, Holter, Yurko and Chu (1975) have contributed further stratigraphic knowledge of the Paskapoo Formation in their study of the Ardley coal zone where they were able to map three main coal units: Lower Ardley 'A', Lower Ardley 'B' and the Upper Ardley.

Table 7 summarizes the relationships between the different nomenclature as presented in the paragraphs above. The terminology of
Table 7.


Irish (1970) is presently the most widely accepted and therefore will be adhered to in this report. As an example of the application of the nomenclature of 1 rish (1970), Figure 21 shows a representative subsurface section of the Paskapoo Formation in the Pine Lake research basin. The Upper Ardley coal zone appears to be absent or poorly developed over much of the Pine Lake area and therefore the Lower Ardley ' $B$ ' has been chosen as the marker bed for the top of the Scollard Member.

Age and Correlation
According to Irish (1970) the correlation of the Scollard Member is based largely on the dinosaurian fauna. Sternberg (1947, 1949) showed that the presence of the dominant dinosaur genera Iriceratops and Tyrannascurus in the Scollard Member strata strongly suggests they are correlative with the Lance Formation of Wyoming, the Hell Creek Formation of Montana, and the Frenchman Formation of southeastern Alberta and southwestern Saskatchewan. This indicates that the Scollard Member is of Upper Cretaceous Lance age (irish 1970). Tozer (1956) has described the paleontology of that part of the Paskapoo Formation above the Scollard Member. His conclusion was that the molluscan fauna is of Paleocene age but is too long ranging for further refinement. Snead (1969) substantiated the age of these beds by microfloral studies on core samples. This Paleocene unit is therefore probably correlative with the Ravenscrag Formation of southeastern Alberta and southwestern Saskatchewan and the Fort Union Formation in adjacent Montana.

## Lithology

Irish (1970) described the general lithology of that part of the Paskapoo Formation above the Scollard Member as consisting of massive, in part cross-bedded, medium- to coarse-grained, buff-weathering, gray, calcareous sandstones; well indurated to soft, fine-grained sandstones and siltstones; and green to gray, friable, silty shales. Although the sandstones are dominant by quartz with minor amounts of feldspar, fragments of shale, carbonate, chert, quartzite and clay pellets comprise an important percentage which typically give these sands a "salt and pepper" textural appearance (Allan and Sanderson 1945). Also present in this section of the Paskapoo Formation are thin beds of argillaceous and siliceous, fossiliferous limestone, lenses of pebble conglomerate, minor thin beds of woody coal, carbonaceous shale, bentonitic clays and local bands of laminated lacustrine clays.

The Scollard Member is characterized by a lithological succession similar to that described above, except that beds exhibit a greater degree of interlensing and thick, extensive coal seams are prominent. As noted earlier, a maximum of three major coal units (Lower Ardley 'A', Lower Ardley 'B' and Upper Ardley) are discernable in the Scollard Member. Of the three, the Lower Ardley ' $B$ ' is the thickest and areally the most persistent (Holter et al. 1975). All of the coals are ranked as subbituminous grade (Allan and Sanderson 1945). Irish (1970) points out that in comparison to the Horseshoe Canyon Formation, the strata of the Scollard Member are more somber in color, contain much less bentonite and sandstones are noticeably more abundant.

Based on local bedrock exposures and available lithologic logs of water wells and coal test holes, the lithology of the Paskapoo Formation in the Pine Lake research basin is basically quite true to the descriptions given above.

Bedrock exposures (Paskapoo Formation) in the Pine Lake area are relatively scarce and all of those visited by the writer (see Figure 4) appear to have been created by road construction which managed to scrape through thin glacial drift. None of these exposures is of substantial size (i.e., sufficient stratigraphic section) to warrant a detailed section description. For the purposes of this study, only general lithologic and sedimentary features were recorded in the field and no petrographic analyses of the rocks has been performed. Figure 22 shows, as an example, the nature of one of the several observed bedrock exposures in the basin. Thickly bedded to massive sandstones dominate most of these exposures, although bentonitic grayish-brown clays and hard bluish-green, carbonaceous shale was also observed to occur at a road cut near the north end of Pine Lake. Medium-scale cross-stratification (Conybeare and Crook 1968) was observed in soft, brown sandstones along the base of a butte-like ridge located in 16-15-35-24W4. In general, the sandstones are typically yellowish-brown, medium- to coarse-grained, poorly consolidated and under close examination have a salt and pepper textural appearance. Also present in these exposures are thin resistant "ledges" of very hard, buff-gray, fine- to medium-grained sandstones and occasionally thin beds of dark brown, pebble conglomerate. Jointing, mainly


Figure 22. Bedrock (Paskapoo Formation) exposure in southern part of basin (9-15-35-24W4).
sub-horizontal but also sub-vertical, is fairly common throughout those parts of the exposures consisting of consolidated sandstone. This is especially true of the competent sandstone capping the plateau at 13-9-36-24W4. Attitudes of bedding planes measured at a few of the sandstone exposures to be striking nearly north-south with dips ranging from sub-horizontal to as much as 18 degrees to the west.

In the subsurface, lithologic logs from water well drillers' reports usually contain descriptions of the Paskapoo Formation as consisting of interbedded gray to green shale, gray sandy shales (siltstones?) and soft gray sandstone. Drillers frequently describe these rocks as bentonitic and when oxidized are commonly listed as yellow to brown shales or sandstones. Thin woody coal seams, highly fractured shales and very hard sandstone beds, are also quite commonly encountered by water well drilling in the Pine Lake area. The large number of water wells in most parts of the basin have therefore provided a good account of the lithology down to about 300 feet ( 90 m ) on the ridges and to about 100 feet ( 30 m ) near the valley bottom. Lithological descriptions of the Paskapoo Formation at greater depths is limited to four coal exploration test holes (C4-74, C11-74, Cl2-74 and C13-74; Figure 5). All of these drill holes penetrate the section of Paskapoo strata above the Lower Ardley ' $B$ ' but none were drilled through the entire Scollard Member. The beds sampled by these test holes were comprised of the following: dark gray, green and black shales; bentonitic shale, hard, buff shale; soft, bentonitic, sandy siltstone; soft, gray, fine- to medium-grained, salt and pepper
sandstone; very hard, gray, fine-grained sandstone; and thick seams of hard, black, dull to vitreous coal (Lower Ardley 'B').

## Lithostratigraphy

Perhaps one of the most important methods of ascertaining the geologic framework of an area underlain by a sedimentary rock sequence is a detailed stratigraphic analysis. In regard to a hydrogeologic investigation, the nature and distribution of lithostratigraphic units is of primary concern because of its significant influence on the distribution and occurrence of groundwater.

As explained earlier, the regional stratigraphy of the Upper Cretaceous-Tertiary strata is based almost entirely on lithologic criteria and areally persistent marker beds such as the Kneehills tuff (Battle Formation) and Ardley coal zone (Scollard Member). However, for hydrogeologic purposes, as in the Pine Lake research basin, a greater degree of refinement is needed. The application of a detailed lithostratigraphic approach to the heterogeneous strata of the Paskapoo Formation requires good geologic data control. Although abundant lithologic logs are available for the shallow bedrock over most of the Pine Lake basin, subsurface geologic information on deeper sections of the Paskapoo Formation is scarce. Fortunately, an excellent distribution of electric logs (Figure 5) from relatively deep (maximum 1250 feet $[380 \mathrm{~m}]$ ) structure test holes exist in the Pine Lake area. These logs consist of a spontaneous-potential and a single-electrode resistance curve, both of which appear to be quite responsive to various lithologies (i.e., sandstone, shale, coal and drift). An example of
an electric $\log$ of a structure test hole is given in Figure 21 where the typical log responses for various strata are also depicted. Reliable interpretation of the logs was greatly facilitated by comparing their responses to electric and geologic logs obtained from coal test holes.

A number of geological sections, based largely on the interpretation of electric logs, were constructed in order to determine the subsurface lithostratigraphy of the Pine Lake research basin. These sections are shown in Figures 23 to 29 (in pocket) and their locations are given on Figure 5. Because most of the structure test holes and coal test holes rarely penetrated the entire Scollard Member of the Paskapoo Formation, no attempt has been made to illustrate the lithostratigraphy below the Lower Ardley ' $B$ ' coal zone which constitutes an excellent marker bed. Examination of several electric logs of the Scollard Member indicate that it is essentially a shale-siltstone unit in the Pine Lake area, although it is not completely devoid of sandstone (e.g., figure 21). Information presented on the cross sections is also supplemented by geologic logs of water wells and a few radioactivity logs of cased oil and gas wells.

As shown by the geological sections, three major lithostratigraphic units have been differentiated in the subsurface. The units are glacial drift, sandstones, and mudstones (shales and siltstones). The stratigraphic detail of the glacial drift is not shown on these diagrams, all drift deposits therefore have been lumped as a single lithostratigraphic unit which will be discussed in further detail later
in this chapter. Only the major units of sandstone have been represented; that is to say that zones of predominately sandstone are shown as solid units enclosed in sections which are dominated by shales and siltstones. Because of the vertical scale exaggeration, this approach was necessary and therefore thin beds of sandstone may occur in those parts of the sections shown as shale and siltstone and vice versa.

Perhaps the most prominent stratigraphic feature documented by the geological sections (Figures 23-29) is the areally persistent nature of the Lower Ardley ' $B$ ' coal zone. This coal is easily detected on electric logs (Figure 21) and characteristically consists of two major coal beds, which are less than 6 feet ( 2 m ) in thickness separated by a shale and bounded at top and bottom by minor coals and shaly coals. The total thickness of the Lower Ardley ' $B$ ' coal zone, as distinguished on the distribution of electric logs, varies from about 15 feet ( 4.6 m ) in the eastern part of the basin to around 20 feet ( 6.1 m ) along the western boundary. A few minor coal seams exist above the Lower Ardley 'B', but their extent in the Pine Lake area is difficult to assess. No attempt was made to correlate these thin coals because the presence of the thick Ardley was more than sufficient for the purposes of this study.

The generalized cross sections illustrate several other important stratigraphic features. Although correlation of sandstone units in the Paskapoo Formation is difficult, with sufficient subsurface control, the task is not impossible. The Paskapoo Formation can be described as consisting of strata which are irregularly distributed and
of a lenticular nature. The geological sections through the research basin appear in part to support this general observation. Nevertheless, correlation of sandstone units over several miles is possible, although the complexity of this task may vary from being rather simple (section $A-A *$ ) to quite complicated (section $B-B \%$ ). Individual sandstone units, which are mappable over substantial distances, are usually greater than 20 feet ( 6 m ) in thickness and in some areas of the basin a number of sandstone beds appear to coalesce, forming units of sandstone which are over 300 feet ( 90 m ) in thickness. The shale-siltstone sequences which occur between these sandstones vary in thickness in the same manner as the sandstones but usually comprise over 60 percent of the strata above the Lower Ardley ' $B$ ' coal zone in the Pine Lake area.

The most northerly geological section (Figure 23) shows that this part of the Pine Lake research basin is characterized by a shalesiltstone unit that is about 100 feet ( 30 m ) thick and directly above the Lower Ardley 'B' coal zone. Only one minor sandstone bed is discernable on the electric logs and this is in the eastern part of the section. Above this 'basal" shale-siltstone unit lies a major sandstone sequence that averages 300 feet ( 90 m ) in thickness. Individual sandstone beds appear to exeed 30 feet ( 9 m ) in thickness in the western part of the basin but coalesce to the east, forming very thick beds of sandstone alone. More than 400 feet ( 120 m ) of predominantly shale and siltstone comprise the strata above the major sandstone unit, although a few thin but traceable beds of sandstone do occur as well.

Section $B-B *$ (Figure 24) also traverses the northern part of the research basin. The most noticeable feature of the lithostratigraphy in this area is that the massive sandstone sequence present in section $A-A *$ has transformed into a unit of sandstones interbedded with mudstones. Single beds of sandstone rarely exceed 50 feet ( 15 m ) in thickness and the unit as a whole is about 200 feet ( 60 m ) thick. Above the Lower Ardley ' $B$ ' coal zone is a sandstone unit which exceeds 50 feet ( 15 m ) in thickness and is continuous across the research basin in this area. The appearance of sandstone beds at shallower depths is significant in that these become important aquifers further south in the basin.

Section C-C\% (Figure 25) shows that two major sandstone units are present in this part of the basin. The deeper unit is characterized by a series of sandstones which in total are about 300 feet ( 90 m ) in the west and decrease to around 200 feet $(60 \mathrm{~m})$ in the east. The second major zone of sandstone occurs above the elevation 2900 feet ( 884 m ) and is dominated by a single bed that varies from 70 feet $(20 \mathrm{~m})$ thick in the west to less than 30 feet ( 9 m ) along the eastern divide. This unit likely subcrops below glacial drift near the north end of Pine Lake. The thickness of shale and siltstone between these two sandstone units is remarkably constant at around 150 feet ( 45 m ).

One of the most striking lithostratigraphic features of section D-D: (Figure 26) is a complete change in the occurrence of sandstones relative to the previous cross sections. In the central part of the research basin, thick sandstone beds only occur in the strata near
surface whereas lower parts of the Paskapoo Formation are predominantly shale and siltstone. Two continuous sandstone beds, less than 40 feet ( 12 m ) thick, are found in the deeper strata but they are minor compared to the sandstone units which comprise the bedrock and can exceed 100 feet ( 30 m ) in thickness. Towards the basin divides (Figure 26) sandstone beds become much more abundant throughout the stratigraphic section above the Scollard Member.

Section E-E* (Figure 27) traverses the research basin just south of Pine Lake and shows that thick, near-surface sandstone units are still present. Sandstone beds, which are quite areally persistent and in places exceed 50 feet ( 15 m ) in thickness, also are prominent in deeper parts of the section. The combined thickness of this deeper sequence of sandstones is about 300 feet ( 90 m ) but significant thicknesses of shale and siltstone occur between these sandy units.

As shown by section F-F\% (Figure 28), the eastern ridge in the southern part of the basin is dominated by a unit of sandstone which is over 300 feet ( 90 m ) thick. The lower 150 feet ( 45 m ) of this unit is relatively persistent towards the west but the upper half becomes a single sandstone bed about 50 feet ( 15 m ) thick. Mudstones also dominate the first 100 feet ( 30 m ) or so above the Lower Ardley ' $\mathrm{B}^{\prime}$ coal zone. Based upon the cross-sections presented, this feature must exist throughout most of the research basin.

The final geological section $G-G^{*}$ (Figure 29) illustrates the lithostratigraphy of the entire basin along its center. Locations of where the other sections traverse this longitudinal section are also
shown. This section essentially summarizes what has been discussed in the last few paragraphs.

I would like to close this discussion of the lithostratigraphy by briefly describing the areal lithofacies pattern. Figure 30 (in pocket) is a sandstone percentage map of that part of the Paskapoo Formation above the Lower Ardley 'B' coal zone. A more sophisticated facies map could have been constructed but hydrogeologically this simple map is sufficient to outline the areal variation in lithology. Much of what was discussed about the general vertical occurrence of sandstone relative to mudstone as illustrated by the cross sections is apparent on the lithofacies map. The Paskapoo Formation in the Pine Lake research basin is essentially a shale-siltstone sequence. This is especially true of a large area west of Pine Lake where over 80 percent of the strata are mudstones. A prominent northwest-trending, sandy lobe does extend into the western edge of the basin but is soon dissipated. Up to 70 percent of the section is comprised of sandstone in the area immediately southeast of the basin, of which a major sandy lobe extends northward forming part of the eastern ridge.

Structure and Thickness
Structural attitudes of sandstone ledges in a few of the bedrock exposures located in the research basin indicated that the strata strike nearly north-south and dip to the west. Unfortunately, the scarcity of bedrock exposures in the study area prohibits a detailed analysis of local structure by relying on surface data alone.

In the subsurface, the Lower Ardley ' $B$ ' coal zone is an excellent marker bed and therefore serves as a good datum for examining the structure of the Paskapoo Formation. Figure 31 (in pocket) shows the elevation on top of the Lower Ardley ' $B$ ' coal zone in the Pine Lake research basin. The structure contours largely trend north-south, although perturbations in the contour pattern are readily apparent. One of these structural trends almost appears to coincide with the western divide of the basin. Another major undulating trend in the contours sweeps across the basin in an east-west fashion near the north end of Pine Lake. A few isolated and closed structural highs and depressions also occur in the area. Spacing of the contours show that the Paskapoo strata dip westward at approximately 20 feet per mile ( 4 meters per kilometer) in the central and southern part of the basin to about 30 feet per mile ( 6 meters per kilometer) in the northwest. In general, the structure of the Paskapoo Formation can be described as gently undulating. Direct evidence of faulting and folding of Paskapoo strata in the Pine Lake area is not available. However, the undulating trends on the structure contour map (Figure 31) suggest that gentle flexures in the strata probably occur locally. In fact, the geological sections C-C\%, D-D* and E-E\% (Figures 25, 26 and 27) appear to illustrate a noticeable (but almost imperceptible) depression of the sandstone units towards the drainage way of the research basin and a gentle rise towards the ridges which form the drainage divides. The Ghostpine Creek drainage basin may, therefore, represent a broad gentle flexure of the bedrock strata.

The thickness of the Paskapoo Formation in the Pine Lake basin ranges from about 350 feet ( 110 m ) in the south to over 1200 feet $(360 \mathrm{~m})$ in the northern part of the basin. For that part of the stratigraphic sequence above the Lower Ardley ' $B$ ' coal, the thickness ranges from around 250 feet ( 76 m ) to 1000 feet ( 300 m ). The areal variation in thickness of this unit across the research basin is adequately illustrated by the geological sections (Figures 23 to 29) and therefore no isopach maps will be presented here.

## Bedrock Topography

The upper boundary of the Paskapoo Formation in the Pine Lake area is an erosional surface, unconformably overlain by glacial deposits of Pleistocene age. Figure 32 (in pocket) is a contour map showing the elevation of the bedrock surface which in turn represents the preglacial surface topography of the research basin. The main source of data used in constructing this map was the elevation of the glacial drift-bedrock contact in boreholes, supplemented by elevations of bedrock exposures, and interpretation of electric logs.

The most prominent feature of the bedrock topography in the research basin is that it closely reflects the general nature of the present topographic surface. The relief on the preglacial bedrock surface was quite pronounced, so much in fact that the present topography is highly dependent on the preglacial relief, despite the scouring effect of glaciations and local deposition of significant thicknesses of glacial drift.

The contour map (Figure 32) also shows that a northwesttrending, relatively deeply incised, southward flowing drainage system existed prior to the continental glaciations of the Pleistocene. This preglacial valley is here named the Archithinue Valley, as shown in Figure 32. Examination of the contours on the bedrock topography map demonstrates that the Archithinue Valley was a deeply incised feature with relief as much as 250 feet ( 75 m ). Ghostpine Creek is obviously an underfit stream, meandering in the location of a broad and deep valley bottom that was eroded prior to the advancement of Pleistocene glaciers and is now partly buried by unconsolidated deposits.

Delineation of the bedrock topography has always been an essential component of hydrogeologic investigations in the plains of western Canada. The reasons for this are simple, bedrock topography had a significant influence on controlling the nature and distribution of the glacial deposits and therefore the existing groundwater flow patterns. These aspects apply to the Pine Lake area and are the main reasons why a discussion of the bedrock topography has been included in this chapter.

Depositional History
As was indicated in Table 4, the strata of Paskapoo Formation are of nonmarine origin, specifically consisting of fluvial and lacustrine deposits. According to Irish (1970) the entire stratigraphic sequence above the Bearpaw Formation (Table 4) is of similar origin and can be attributed to major tectonic events taking place much farther to the west where Laramide mountain building and uplift was
quite active in this period. Erosion of the uplifted areas resulted in large volumes of sediment being transported by streams easterly into the Bearpaw Sea. Transportation of sediment from the uplifted areas continued throughout Horseshoe Canyon and Paskapoo time and its deposition as deltas and flood plains, along with regional uplift, resulted in the final withdrawal of the Bearpaw Sea from western Canada. Continued regional uplift brought an end to sedimentation in the Tertiary.

## Glacial Drift

Definition and Nomenclature
Unconsolidated surficial deposits in the Pine Lake area are almost entirely of glacial origin and collectively are termed "drift". "Glacial drift" or the short form "drift", as used in this report, specifically refers to the unconsolidated Pleistocene deposits of Boulders, till, gravel, sand, silt or clay which were formed as a result of continental glaciations. Although minor amounts of Recent alluvium exist, no deposits of the preglacial Saskatchewan Gravels and Sands (Stalker 1960), which occur in the preglacial valley of the Red Deer River, are present in the Pine Lake research basin.

Distribution and Lithology of Drift Deposits
The surficial geology of the research basin is documented by Figure 33 (in pocket). One of the most obvious features of this map is that ground moraine and hummocky moraine are the most extensive surface drift deposits in the Pine Lake research basin. Both of these deposits consist of till or boulder clay. The till is comprised largely of
sediments derived from the local bedrock (Paskapoo Formation and Edmonton Group) but rock fragments of igneous and metamorphic origin as well as hard sandstones and carbonates from distant areas are also present. Much of the till in the Pine Lake area is sandy relative to other regions, mainly because of the porminence of the Paskapoo Formation. Hummocky moraine is typically thicker than the ground moraine deposits and found in areas of high elevation. It is also characterized by knob-and-kettle topography and composed of till similar to that of ground moraine, although coarser because of the removal of finer material as outwash during deposition. In addition, the hummocky moraine includes numerous pockets of sand and gravel and is associated with short esker ridges, kames, wind gaps and dead ice plateaux (Figure 33), all of which form when ice movement has virtually ceased. Ground moraine was deposited mainly from the base of the glacier in relatively flat regions such that a consistent and even blanket of till was laid down. Stalker (1960) describes the nature of these till deposits as being compact, dense and very sticky when wet due to the abundance of bentonite which was derived from the local bedrock. The permeability of these tills is probably very low, although it may increase slightly where the material is quite sandy or jointing is common.

Outwash covers an extensive region around Pine Lake and in the northern part of the research basin. This deposit is comprised of gravel, sand, silt and clay transported from the ice-margin by meltwater streams. In the Pine Lake outwash, sand is by far the most abundant constituent but it is not completely devoid of gravel. The
thickest and coarsest part of this outwash occurs in the northern area of the deposit where stagnant ice overlay hummocky moraine (Stalker 1960). Figure 34 is a photograph of a sand and gravel pit which shows the nature of the outwash in this area. Note should be made of the lenticular character of the darker colored, very coarse, but poorly sorted gravel bed in the section exposed by the quarry operation. Southward in the outwash deposit, the material grades into lacustrine sands and silts. These deposits also occur along the existing Ghostpine Creek drainage way. Some of these glacial lake sands have been reworked by wind to form local dune deposits to the east and west of Pine Lake. Relative to the surrounding deposits of till and the bedrock strata, the permeability of the outwash material is likely to be very high.

Two minor drift deposits which have yet to be discussed are the esker ridges and stagnant ice deposits. The esker ridges as shown in Figure 33 are predominantly composed of poorly sorted silt, sand and gravel which were deposited by streams flowing near the base of the ice or in open air crevasses which were created during the retreat of the glacier. Stagnant ice deposits consist of moraine plateaux and iceblock depression features in the Pine Lake area. Moraine plateaux are described by Stalker (1960) as relatively flat-topped features that are comprised of water-deposited beds of mainly clay. lce-block depressions occur as flat areas of sediment enclosed by nearly circular ridges of drift and were constructed by the melting of exposed and isolated ice blocks.


Figure 34. Exposure of outwash deposit in sand and gravel pit north of Pine Lake (16-4-37-25W4).

## Thickness

The total undifferentiated thickness of the glacial drift in the Pine Lake research basin is shown in Figure 35 (in pocket). The most conspicuous feature delineated on this isopach map is the thickening of the drift deposits towards the thalweg of Archithinue Valley or the present Ghostpine Creek drainage way. Borehole data indicate that the thickness of the drift along this preglacial valley can exceed 140 feet ( 43 m ). Drift thickness also exceeds 100 feet ( 30 m ) in other parts of the research basin, especially areas where strongly developed hummocky moraine is dominant (compare Figures 33 and 35). The most outstanding example of this feature is found in an area just north of the research basin divide in Township 37, Range 25. More than 160 feet ( 49 m ) of drift was encountered in two test holes in this area and several others penetrated drift in excess of 130 feet ( 40 m ) thick. Contouring drift thickness in these regions is very difficult and probably misleading but for the completeness it has been done in Figure 35 . In reality, isopach patterns are unlikely.

On the average, drift thickness in the Pine Lake research Basin proper is less than 50 feet ( 15 m ). In fact, large areas of the Basin along and near both the east and west divides have depths to bedrock of less than 25 feet ( 8 m ). The most common range of thickness over the southern half of the basin is between 25 to 50 feet ( $8-15 \mathrm{~m}$ ). The dominance of hummocky moraine in the northern part of the basin makes it difficult to predict a representative thickness for this district.

## Stratigraphy

In order to delineate the stratigraphic succession of drift deposits in the Pine Lake area, subsurface data must also be examined. Figure 36 (in pocket) is a map showing the subsurface geology of the drift deposits as interpreted from drillers' logs of water wells. At the present, the detail of the analysis is limited due to the complexity of the geology and quality of data.

Stalker (1960) differentiated the till deposits of central Alberta into three members that represent separate glaciations. Distinction between these tills is based upon color, position, degree of compaction and weathering, and jointing characterisitcs. As shown in Figure 36, two major tills are discernable in the subsurface, a blue till and a gray till. The blue till is widespread in the northern part of the study area and is typically blue gray, dark blue or sometimes black, very sticky, and clay rich relative to the gray till. The dark color imparted to this till is possibly due to a high content of carbonaceous material and length of burial under saturated conditions. Gray till is the most abundant drift material in the research basin. Drillers often describe these deposits as gray sandy clay till, or if oxidized, as being various shades of yellow and brown. Compared to the blue till, the texture of the gray till appears to be less massive or dense and therefore possibly more permeable. Examination of the borehole geology map (Figure 36) indicates that the blue till is usually a basal unit overlain by gray till (e.g., well number 160) or by sands and silts (e.g., well number 291). However, at some
locations blue till is also underlain by gray till or sand (e.g., well numbers 338 and 354 ).

The abundance of outwash and glaciolacustrine sands and silts along the preglacial drainage way is as apparent on the borehole geology map as on the surficial geology map. Borings made along this thalweg penetrate thick deposits of interbedded gravel, sand and silt. Further away from the drainage way these sediments become integrated with the tills, in places forming an obvious intertill deposit. Significant amounts of stratified drift also occur near the ridge forming the divide in the southwest part of the research basin. The deposits in this area may in part be associated with ice-contact drift rather than outwash.

## Glacial History

The glacial history of south-central Alberta was treated in great detail by Stalker (1960). At least four major continental glaciations occurred during the Pleistocene but for the most part only the effects of the last glaciation (Wisconsin) can be documented in detail. The Wisconsin ice sheet advanced in a southerly direction and because of its relatively thin nature ( 1000 feet or 300 m ) pre-existing topography strongly influenced its erosional effects and direction of movement. Eventually, ice flow decreased and the ice sheet thinned, chiefly through downmelting. The environment envisaged for the Pine Lake area during Wisconsin deglaciation is one of large region of wasting ice to which the present moraine systems, extensive outwash, moraine plateaux, esker ridges and wind gaps owe their origins. The
bordering ridges were the first to be barren of ice and eventually stagnant ice only occupied Archithinue Valley. When the ice melted there, glacial Pine Lake was created by moraine blocking the valley.

## CHAPTER 5

## HYDROGEOLOGY

Hydrogeology can be defined as the science that deals with the occurrence, distribution and movement of groundwater, its relation to the subsurface and surface environment, and the nature of groundwater chemistry. Fundamental to this definition are two concepts, the hydrogeologic environment and the groundwater regime. Both of these terms have been casually used in the last few chapters but their explicit meanings have not yet been explained.

The hydrogeologic environment refers to those parameters of topography, geology and climate which generate and control various groundwater conditions. Specifically these parameters would include topographic relief, rock porosity and hydraulic conductivity, mineralogy, subsurface temperature, precipitation, air temperature and evapotranspiration. As suggested by the cause-and-effect relationship between the two concepts, knowledge of the hydrogeologic environment will define the groundwater conditions or regime.

The groundwater regime is described by Tóth (1970) as consisting of a number of parameters which for a given geographic region represent the physical and chemical conditions of the groundwater. In other words, a thorough study of the groundwater regime would involve investigating the amounts of water present in the saturated zone,
pattern of groundwater flow, volume discharge or flow velocity, chemical composition, water temperature and the spatial variance of these parameters with time. Theoretically, the relationship between the hydrogeologic environment and groundwater regime is genetic and quantitative. Therefore mathematical functions, if they exist, could be used to derive the physical and chemical conditions of groundwater from the environmental characteristics, provided boundary conditions or other constraints on the system are specified.

Based on the discussion above, the basic goals of a hydrogeologic investigation of a basin would be to determine:

1. The hydrogeologic environment;
2. The groundwater flow systems;
3. Its interaction with surface hydrology through recharge and discharge;
4. The chemistry of groundwater and its relation to other regime parameters;
5. The quantitative hydrologic properties of subsurface materials with special emphasis on aquifers and if possible the groundwater budget of the basin; and
6. The groundwater resources in regard to existing demands, potential development and environmental considerations.

Such a list of objectives is clearly applicable to this study of the Pine Lake research basin. The past few chapters have been devoted to an analysis of the hydrogeologic environment. Therefore, the remainder of this paper will concentrate on the evaluation of the groundwater
regime, specifically those aspects as listed above. Although they are an integral part of the hydrogeologic evaluation, the subjects of hydrogeochemistry and groundwater resources will be treated in separate chapters to follow.

## The Analysis of Groundwater Flow

Subsurface flow patterns can be deduced from either theoretical considerations or the interpretation field measurements. The theoretical approach relies upon the fact that groundwater flow obeys the laws of physics and therefore can be rigorously modeled mathematically, provided boundary conditions and the hydrogeologic environment are known. Field techniques also make use of the hydrogeologic environment in interpretation of flow patterns. These methods may consist of several types which commonly can be grouped as follows:

1. Piezometric or potentiometric analyses;
2. Interpretation of hydrogeochemistry;
3. Evaluation of groundwater field phenomena (surficial evidence);
4. Determination of groundwater temperature distribution; and
5. Use of environmental isotopes.

The first three methods in this list are often the most frequently used in regional groundwater flow studies and will be the only ones considered in this study.

The foundation of the theoretical approach to the steady-state analysis of regional groundwater flow was first established in the classic treatise on the theory of groundwater motion by Hubbert (1940).

He showed that groundwater flow is governed by a potential field which is represented by hydraulic head. An example of the type of flow pattern envisaged by his theory is shown in Figure 37.

Tóth (1962, 1963) expanded on Hubbert's work by using analytical methods to solve Laplace's equation for the potential distribution in two-dimensional model of a small, homogeneous drainage basin. In his mathematical model (Figure 38), theoretical vertical impermeable boundaries are placed at the drainage divides and along the drainage bottom. A horizontal impermeable boundary is placed at an arbitrary depth and the water table is assumed to slope linearly or follow the oscillations of a sine curve about a line which slopes toward the valley bottom. Figure 38 also displays Tóth's concept and definition of local, intermediate and regional flow systems.

While the analytical technique provided by Tóth (1962, 1963) aided in the investigation of the parameters involved in regional groundwater flow, the solutions were severely limited to specific field situations with simple basin geometry and geology. This situation was significantly improved with the advent of numerical methods in groundwater hydrology. A major contribution to the analysis of regional groundwater flow were the papers of Freeze and Witherspoon (1966, 1967, 1968). They employed two- and three-dimensional finite difference models to simulate groundwater flow in a wide variety of field conditions, including anisotropic, heterogeneous groundwater basins with complex water-table configurations. The results of their study demonstrated how the shape of the water table and underlying hydraulic


Figure 37. Approximate flow pattern in isotropic-homogeneous material between effluent streams. -- After Hubbert, 1940.


Figure 38. Theoretical flow pattern in a section through a composite drainage basin with homogeneous and isotropic geology. -After Tóth, 1963.
conductivity contrasts affected the groundwater flow pattern. An example of the flexibility of this numerical method is shown in figure 39. Freeze (1969a) also showed how the theoretical approach could be integrated with field techniques to form a powerful tool for delineating groundwater flow systems.

A recent application of numerical modeling that has particular relevance to the Pine Lake research basin are the studies made by Winter $(1976,1978)$. He employed a finite-difference model to simulate, in two- and three-dimensions, the steady-state pattern of groundwater flow systems near lakes in a glacial terrain (Figure 40). Based on the potential distributions derived for various hydrologic sections, Winter (1976, 1978) was able to document the nature of the interaction between lakes and groundwater. He concluded that it is the continuity of the boundary separating local from regional flow systems which determines whether the lake is a recharge, discharge or throughflow system. Factors that affect this flow-system divide include the height of the water table (relative to the lake level) on the downgradient side of the lake, lake depth, geometry and hydraulic conductivity of aquifers, and the degree of anisotropy.

An application of numerical modeling to the Pine Lake basin is beyond the scope of this study. The purpose of the above discussion on the theoretical approach was to help formulate an understanding of the type of groundwater flow patterns which might exist in the Pine Lake area. In fact, the mathematical model developed by Tóth (1962, 1963) was based on his field observations in an area of central

Figure 39. Hydrogeologic section showing theoretical flow patterns as determined by finite difference model. -- After Freeze, 1969c.

Figure 40. Hydrologic section showing groundwater flow pattern near lakes in a

Alberta which included the Ghostpine Creek watershed. Reference to the theoretical concepts will also be needed later in the chapter, once the field data have been analyzed and possible flow patterns conceptualized. Evaluation of the field data now follows.

## Water-table Configuration

The water table in the Pine Lake research basin is a subdued replica of the topography. This conclusion is based upon field observations and reported water levels in dug wells and shallow boreholes which indicate that the water table is usually less than 20 feet ( 6 m ) below the land surface in most parts of the research basin. Exceptions to this shallow depth occur along the drainage divides (Figure 7) where depth to the saturated zone may be twice as great. Although the water table is a subdued replica of the topography, it will not always conform to local topographic relief. Furthermore, subsurface permeabilities will in part be reflected by the depth and shape of the water table.

According to Freeze (1969c), the assumption that the water table in a groundwater basin is in steady state is only valid if the zone of water-table fluctuation is a yery small percentage of the total saturated depth of the basin and if the configuration of the water table remains in similar form throughout the period of fluctuation (i.e., locations of recharge and discharge remain the same). These two conditions appear to be met in most parts of the Pine Lake basin, at least on an annual baṣis. Records of water-table fluctuations over a 15 year period are available for three observation wells in the
southwestern part of the basin (Figure 3). These wells demonstrate the concept of dynamic equilibrium in that the maximum recorded annual water-level fluctuation was 2.10 feet ( 64 cm ) for a well completed in a surficial sand, 0.28 feet ( 8.5 cm ) in a well completed in till, and 0.74 feet $(22.6 \mathrm{~cm})$ for a bedrock observation well.

Whether or not steady conditions exist everywhere in the research basin is undetermined. For example, Meyboom (1966b) showed that in areas of hummocky topography, local groundwater flow patterns reversed over the year and as such demonstrated a transient rather than steady-state character. Until otherwise proved by field studies, caution should be exercised in invoking a steady-state configuration of the water table in those parts of the Pine Lake basin dominated by hummocky moraine.

## Distribution of Static Water Levels

A piezometric analysis is invaluable to a hydrogeologic study in that it is the most direct method of determining groundwater flow patterns. For a piezometer, which is only open over a very small interval, the static water level represents a discrete measurement of hydraulic head. Water wells may behave in a similar manner if they have been cased down to a specific aquifer where horizontal flow is prominent. However, when a well has a large open depth interval, the static water level is only a measure of the hydraulic head of the aquifer which possesses the greatest potential in that interval. In short, knowledge of the general groundwater flow regime and details
of well construction are essential to the use of water wells in piezometric analyses.

Unfortunately, no piezometer installations exist in the Pine Lake area from which meaningful hydraulic cross sections could be developed. In addition, the relatively complex stratigraphy and uneven depth distribution of domestic wells in the research basin restricts the use of piezometric surface maps to qualitative investigations. An attempt was made to illustrate the areal pattern of groundwater flow by contouring elevations of non-pumping water levels (Figure 41, in pocket). This map was constructed mainly from reported static water levels in wells but also supplemented from field data on known locations of springs and flowing seismic shot holes. Reference to these data can be found through Figure 3 and Appendix A.

Figure 41 is neither a piezometric surface map nor water-table map. Hydraulic heads of different aquifers are present and at a number of locations in the basin, where wells of different depths exist, hydraulic heads were noticed to change with depth. Along the topographic highs, hydraulic heads decrease with well depth. Near the drainage ways and around Pine Lake, static water levels appear to increase with well depth. Exceptions to these trends exist at a few isolated locations and whether this has physical significance or is a result of measurement error remains to be resolved by field studies. Away from the major ridges and valleys, the variation in head with depth tends to be less apparent, at least based on existing well data.

At best, the non-pumping water level map (Figure 41) describes the general direction of groundwater movement and any attempt to derive quantitative information would be pointless. It does delineate a groundwater basin where flow is directed from broad recharge areas on the drainage divides and valley flanks to presumably discharge areas near the valley bottom. The greatest proportion of groundwater flux appears to be normal to the drainage way trend, whereas the longitudinal component of flow is relatively small, especially in that part of the basin south of the north end of Pine Lake. Domestic wells rarely exceed a depth of 250 feet ( 75 m ) and therefore delineation of deeper flow systems is presently undetermined.

## Quantitative Evaluation of <br> Subsurface Hydrologic Properties

Both primary and secondary porosity occurs in the geologic materials of the Pine Lake research basin. Rocks of the Paskapoo Formation are typically soft, semi-consolidated lithologies and therefore porosity is largely of primary origin. The magnitude of effective porosity will obviously depend on the degree of cementation and abundance of clay. Secondary porosity exists in the bedrock strata in the form of fractures and joints which are the result of postdepositional tectonism and possibly glaciation effects. Fracturing is most conspicuous on examining exposures of the Paskapoo Formation and drillers commonly log aquifers as "fractured or broken sandstone" or "fractured shale". No clear relationship between stratigraphy and zones of fracturing and therefore its distribution is impossible to
predict in the subsurface. The surficial deposits have abundant joints (Stalker 1960) which undoubtedly have a significant influence in regard to the permeability of the tills. No measured specific yield or effective porosity data exist for either the bedrock or surficial deposits but a value of 0.10 is probably reasonable for the bedrock and most of the drift except for the surficial sands and gravels where the value is likely about 0.20 .

The prolific drilling of water wells over the past 20 years in the Pine Lake area has generated a significant amount of shallow, semiquantitative permeability data. After completion of a well, drilling contractors usually conduct a short bail test or pump test to determine well yield. For a domestic well the period of bailing or pumping is commonly about 30 minutes and then the total drawdown is noted. Timedrawdown measurements are rarely taken and observation wells are nonexistent. Occasionally, time-recovery data are recorded and this information has been of some value to the present study. In addition, a few pump tests of several hours duration have been performed in the basin.

Although the length of many of these bail or pump tests and accuracy in measurements are probably questionable as representing proper aquifer testing procedure, all available data have been analyzed in order to evaluate the local hydraulic characteristics of the subsurface strata. Measurements of total drawdown only (which essentially are specific capacity data) were used to obtain rough estimates of transmissivity through the calculation of "apparent transmissivity"
(Farvolden 1961). This method employs the modified nonequilibrium formula (Cooper and Jacob 1946) and assumes a straight line plot between 0.1 minute and the time of the single observation of total drawdown. The apparent transmissivity will either under or over estimate the actual transmissivity, depending whether the drawdown curve flattens or becomes steeper with time, respectively. Time-recovery data from bail and pump tests were plotted on semilogarithmic graph paper and transmissivity determined by the straight-line method using the Theis (1935) recovery formula. Time-drawdown data from the longer pump tests were also plotted on semilogarithmic graph paper and the modified nonequilibrium formula (Cooper and Jacob 1946) was used to calculate transmissivity. Logarithmic plots were made for a few drawdown test data where deviation from the Theis type curve was evident and in one case where there was data from an observation well. In total, there were twenty-eight recovery plots and five drawdown curves analyzed.

To present all of the bail or pump test data and discuss its response characteristics would be impractical. Only three cases will be considered here; completion in a sandstone aquifer; shale aquifer; and a deep well in an interbedded siltstone, shale, and sandstone sequence. The remaining graphs and analyses can be found in Appendix D which also illustrates the hydrogeology of each test location.

Figure 42 is an adequate example of the recovery data available in the Pine Lake area. At this particular location, the well was completed in a shallow sandstone unit which occurs along the bedrock


LITHOLOG AND COMPLETION DETAILS


Figure 42. Example of time-recovery curve analysis, sandstone aquifer.
ridge in the southwest part of the basin (see Figure 27). Most timerecovery plots (Appendix D) exhibit a change in slope during the observations and this may occur as either a decrease or increase with recovery. Because of the shortness of these tests, whether or not the changes represent true boundary effects or are actually a result of well-bore storage is uncertain. In any event, the latest trend of the data was used to determine transmissivity in all tests.

The hydrogeology and results of a 5-hour aquifer test at the north end of Pine Lake are given in Figure 43. This well was completed in a shale aquifer that is overlain by clays and sands. In general, the response of the shale is unusual in comparison to tests performed in shale intervals in other parts of the research basin. The reason for this could include: fracturing which has greatly enhanced the hydraulic conductivity; induced infiltration with the lake; leakage from the overlying saturated sand layer; or perhaps some sort of combination of the above.

An example of a pump test response for a deep well in the extreme northen end of the basin is given in Figure 44. This test was the only one on record where observation well data is also available. Unfortunately, details of well completion were never submitted and drawdown measurements are not of high quality. The drawdown analysis from the observation well are contradictory with the results of the pumping well. The cause of this is hard to determine without construction details of the observation well. Other nearby tests indicate that


$$
\text { (t) Time since pumping started or }(t / t) \frac{\text { Time since pumping started, in minutes }}{\text { Time since pumping stopped, in minutes }}
$$



Figure 43. Time-drawdown graphs and well completion details of a pump test in a shale aquifer.

(t) Time since pumping started, in minutes
inferred litholog


(t) Time since pumping started, in minutes

Figure 44. Results of a deep well aquifer test in a siltstone-shale-sandstone unit at northern end of research basin.
the transmissivity value determined from the pumping well data is probably representative of the strata in this area.

Figure 45 (in pocket) is a transmissivity map which summarizes the results of evaluating all drawdown and recovery data in the Pine Lake research basin. Only broad regions of similar transmissivity ranges for the shallow bedrock strata have been outlined on the map along with the distribution of the various types of data. Variation in well depth, stratigraptiy and distribution of aquifers is responsible for the complexity of the transmissivity pattern. The map does show that regions of high transmissivity (greater than 2000 igpd/ft) ${ }^{1}$ appear to dominate the entire eastern divide and a narrow part of the western ridge, probably because of the occurrence of major shallow sandstone units as delineated in Figures 24 to 28 . Further interpretation of the hydrogeologic properties of the various lithologies in the Paskapoo Formation requires a closer examination of individual pump test data and local hydrogeology. Hydraulic conductivities have been calculated from the transmissivity data shown in Figure 45 and estimated saturated thicknesses of aquifers encountered in the borehole. This information has also been tabulated in Appendix A.

Transmissivities derived from bail or pump tests of sandstone aquifers are commonly in the 2000 to 4000 igpd/ft ( 30 to $60 \mathrm{~m}^{2} /$ day ). range, although the preliminary data from the ridges in the southern part of the basin indicate that transmissivity can be less than 500
${ }^{1}$ Imperial gallons are used throughout this report.
igpd/ft ( $8 \mathrm{~m}^{2} /$ day). ${ }^{2}$ Hydraulic conductivities of sandstone units in the Pine Lake research basin were calculated to be around 10 to 500 igpd/ft ${ }^{2}$ ( 0.5 to $25 \mathrm{~m} /$ day). An average of representative hydraulic conductivity value of these sandstones is probably about $40 \mathrm{igpd} / \mathrm{ft}^{2}$ ( $2 \mathrm{~m} /$ day). Higher values may be expected where fracturing occurs. Almost all wells completed in shale formations are very low producers in the Pine Lake basin. Transmissivities are often less than 100 igpd/ft ( $1.5 \mathrm{~m}^{2} /$ day) but exceptions do occur where the shale is competent and fractured. Hydraulic conductivity is generally between 1 and 5 igpd/ft ${ }^{2}$ ( 0.05 and $0.25 \mathrm{~m} /$ day) where the shale is soft and therefore tight. Fracturing increases the permeability significantly such that its magnitude can locally exceed those of surrounding sandstones.

Where wells have been completed in series of strata dominated by siltstone, the yields are intermediate in nature. Transmissivities are generally lower than those for sandstones and higher than wells completed in shale alone. A representative value would have to be about 500 igpd/ft ( $25 \mathrm{~m}^{2} /$ day), although transmissivity could be greater or less depending on the sandstone-shale ratio. On the average, the hydraulic conductivity of siltstones in the research basin is estimated to be around $10 \mathrm{igpd} / \mathrm{ft}^{2}(0.5 \mathrm{~m} /$ day $)$.

The advent of modern drilling methods virtually eliminated the need to obtain shallow water supplies from the glacial drift in the

[^0]Pine Lake area and therefore permeability data is nearly absent for this material. However, two records of shallow wells near Pine Lake can be used to estimate transmissivity of the outwash deposit in which they are completed. Based upon the apparent transmissivity of 8100 igpd/ft ( $120 \mathrm{~m}^{2} /$ day) for a well completed in a 4 feet ( 1.2 m ) thick sand and gravel bed at the north end of Pine Lake, the hydraulic conductivity is estimated to be 2000 igpd $/ \mathrm{ft}^{2}$ ( $100 \mathrm{~m} / \mathrm{day}$ ). Similarly, for a shallow well bottomed in a 5 feet ( 1.5 m ) thick bed of sand and gravel outwash west of the lake the apparent transmissivity was found to be 860 igpd/ft ( $13 \mathrm{~m}^{2} /$ day ) and therefore the hydraulic conductivity is estimated to be about $170 \mathrm{igpd} / \mathrm{ft}^{2}(8 \mathrm{~m} / \mathrm{day})$. The paucity of better data precludes the appraisal of a representative hydraulic conductivity for these deposits. No data exist for the till deposits. Taking into account its sandy texture and published figures for tills in western Canada, the hydraulic conductivity of till in the Pine Lake area is estimated to be about $10^{-3}$ to 1 igpd/ft ${ }^{2}\left(10^{-5}\right.$ to $10^{-2} \mathrm{~m} /$ day $)$, depending on depth and clay content.

The above evaluation of subsurface hydraulic conductivities has not taken into account the possible anisotropy of the bedrock or surficial aquifers. Without suitable quantitative field data, the degree of anistropy must be estimated from purely geological considerations or published data from areas of a similar hydrogeologic environment. Freeze (1969a, 1969c) used numerical models of numerous field conditions to show that anisotropy is a dominant characteristic of bedrock strata in western Canada. He found that the anisotropy ratio
of horizontal to vertical hydraulic conductivity was usually in the order of magnitude of 10 to 100 for similar hydrogeologic conditions as found in the Pine Lake area. Gabert (1975) applied an anisotropy ratio of 64 in his electric analogue models of the Red Deer area, immediately north of the Pine Lake basin. Based on these considerations representative figures for the geologic deposits in the research basin would appear to be $K_{h} / K_{v}=50$ to 100:1 for the Paskapoo Formation; about 10:1 for till; and perhaps 1:1 for the glacial-lake sands and outwash.

Except for the single aquifer test shown in Figure 44, no other quantitative field data are available for evaluating the subsurface storage properties in the Pine Lake area. As shown on the logarithmic graph (Figure 44), a storage coefficient of $7.8 \times 10^{-3}$ was calculated from the data. Most aquifers in the Paskapoo Formation exhibit some degree of confining conditions in that water levels in wells rise under hydrostatic pressure above the water-bearing zone. The hydraulic conductivities of both the bedrock strata and glacial drift are such that the basin rock framework is a hydraulically interconnected unit. Tóth (1966b, 1968) and Gabert (1975) arrived at similar conclusions from their hydrogeological studies in south-central Alberta. Under these circumstances, aquifers will react in a semiconfined to confined manner when pump tested, depending on the relative hydraulic conductivites. In any event, the storage coefficients of the Paskapoo Formation can be expected to fall in the $10^{-4}$ to $10^{-2}$ range. As noted earlier,
specific yield of shallow bedrock or drift aquifers would likely vary between 0.05 to 0.20 .

Occurrence and Distribution of Aquifers
Domestic wells rarely have to be drilled deeper than 300 feet ( 90 m ) to obtain a suitable supply of groundwater in the Pine Lake area. The most common type of well construction in this region consists of a small diameter borehole (e.g., 6 inches -- 15 cm ) which is reamed out to the top of the first significant bedrock aquifer zone such that steel casing can be set with a driven seal. The aquifer interval is usually left as open hole if completed in a competent sandstone or a torch-slotted liner installed where caving conditions are encountered (see Appendix D for examples). The type and area distribution of bedrock lithologies which serve as "aquifers" to these domestic wells are shown in Figure 46 (in pocket). Use of the term "aquifer" for the strata in which these wells are completed may be misleading because the water-supply requirements for domestic and stock purposes is usually not great (200 igpd or $1 \mathrm{~m}^{3} / \mathrm{day}$ ). An obvious feature of the aquifer lithology map is the correlation it has with the distribution of transmissivities (Figure 46). The most productive wells occur in the thicker sandstone units and where bedrock shales are fractured.

The occurrence of potential sandstone aquifers are well illustrated by the geological sections (Figures 23 to 29 ) presented in the last chapter. The most extensive proven sandstone aquifer is a shallow unit which is overlain by siltstone and shale in the western part of
the basin but begins to subcrop below the drift toward the drainage ways. This aquifer is best depicted in section C-C* to F-F\% (Figures 25 to 28) where it ranges from about 30 feet ( 9 m ) to over 100 feet ( 30 m ) . in thickness. Unfortunately, no hydraulic conductivity measurements are available for many of the deeper, thick sandstones portrayed in the cross sections. An exception to this exists in the northern part of the research basin where a very thick sandstone unit is found at depth (Figure 29). Gabert (1975) bail tested a similar thick sandstone unit about 5 miles ( 8 km ) northwest of the research basin and evaluated its transmissivity to be around $400 \mathrm{igpd} / \mathrm{ft}\left(6 \mathrm{~m}^{2} /\right.$ day $)$ and the hydraulic conductivity of the water-bearing zones to be equal to 6 igpd/ft ${ }^{2}$ ( $0.3 \mathrm{~m} /$ day). Although this sandstone is stratigraphically equivalent to the unit in the research basin, its permeability may be different. ${ }^{3}$

On first appearance, the distribution of reported occurrences of fractured bedrock (see Figure 46) appears to have no definable pattern. Nevertheless, comparison of this map with the bedrock topography (Figure 32 ) demonstrates that a number of fractured strata locations occur along or near the preglacial drainage ways. Tóth (1966b) observed the same phenomena in the Olds area of south-central Alberta

[^1](Figure 2). He concluded that these fractured zones could be associated with landslides which were taking place along these bedrock channels in preglacial times. Fracturing which is present near the drainage divide of the research basin (figure 46) is rather sporadic but could be associated with broad, regional folding. Another type of potential fractured aquifer in the Paskapoo Formation are coal seams. According to Vogwill (1979), the hydraulic conductivity of these beds can be quite high, provided the seams are at depths less than 150 feet $(45 \mathrm{~m})$. A number of thin shaly coals are present in the shallow bedrock of the research basin, especially in the shaly sequence around Pine Lake, but these beds do not constitute significant water-bearing zones.

The majority of water wells in the Pine Lake area are completed in bedrock, in spite of the fact that aquifers exist in the glacial drift. The main reasons for this are preferences in water quality and ease of well construction. Wells that are completed in the drift are confined to those areas where hummocky moraine and outwash deposits are present. Adequate supplies of groundwater can be obtained from the till deposits, provided pockets of sand or gravel are present or a permeable avenue exists at the till-bedrock contact. The early dug wells almost always relied on these deposits for aquifers but prediction of where pockets of sand occurred in the till was virtually impossible.

## Hydrostratigraphic Units

Maxey (1964) defined hydrostratigraphic units as 'bodies of rock with considerable lateral extent that compose a geologic framework for a reasonably distinct hydrologic system." In order to quantitatively identify hydrostratigraphic units in a geologic environment such as that found in the Pine Lake basin, a substantial vertical distribution of piezometer and hydraulic conductivity data is required. Except for the "shallow" bedrock strata, little information is available for much of the deeper portions of the research basin's geologic framework. In view of this situation, a qualitative appraisal on hydrostratigraphy is the best which can be presently achieved. Based on the available hydrogeologic data and understanding of the lithostratigraphy (Chapter 4), four major hydrostratigraphic units can be delineated in the Pine Lake research basin.

Hydrostratigraphic Unit 1 is assigned to comprise all of the glacial drift deposits. The justification for this is straightforward in that this unit is comprised mainly of till deposits which have significantly different hydraulic properties from the underlying bedrock. This unit has a great control on the unsaturated flow regime and therefore rates of recharge to the saturated zone. Furthermore, groundwater commonly has a chemistry which is unique in this unit.

The second unit, Hydrostratigraphic Unit 2, is taken to include that part of the Paskapoo Formation in which completion of domestic water wells is still economical. The thickness of this unit is governed by the maximum likely depth of a domestic well in any
given area. On the main ridges this could range from 300 to 500 feet ( 90 to 150 cm ); whereas near the valley bottom it could be less than 200 feet ( 60 m ). Hydrostratigraphic Unit 2 is characterized by highly permeable, lenticular and extensive sandstones alternating with shales and siltstones. A major sandstone aquifer occurs in this unit over most of the research basin. In the longitudinal geological section G-G* (Figure 29), the base of Hydrostratigraphic Unit 2 could be placed near the top of the deep thick sandstone in the northern part of the basin and the boundary continued south in a manner which split the massive sandstone in the extreme south end of the basin. This division here would be at some arbitrary depth, perhaps 100 feet ( 30 m ) or so above the Lower Ardley ' $B$ ' coal zone (Figure 29).

The two deepest hydrostratigraphic units are for the most part of a conjectural nature. Unit 3 is here designated to include that portion of the stratigraphic sequence which occurs between the base of the Lower Ardley 'B' coal zone and lower boundary of Hydrostratigraphic Unit 2. This unit is characterized throughout the basin by its thick extensive sandstones which dominate the strata with the exception of the area around Pine Lake. The hydraulic conductivity of these sandstones may be high but their depth usually preclude domestic well development. The occurrence and relative depth of this unit is most favorable to the presence of intermediate to regional groundwater flow systems and therefore water quality may be poorer within Hydrostratigraphic Unit 3.

The deepest unit, Hydrostratigraphic Unit 4 is taken to be comprised of all rocks below the Lower Ardley 'B' coal zone. The relative absence of sandstone bodies in the Scollard Member (Figure 21) and deeper formations implies that a major regional permeability contrast exists between Unit 4 and the shallower hydrostratigraphic units. This inference is supported by the field observations of Allan and Sanderson (1945) where they noted that numerous springs emerged near this contact at many points along the valley of the Red Deer River (Figure 2). Gabert (1975) and Ceroici (1979) differentiated a similar hydrostratigraphic boundary on the basis of quantitative hydrologic data.

## Surficial Evidence of Groundwater Flow Patterns

Mapping of groundwater generated field phenomena can be an important method of reconstructing groundwater flow patterns, either in conjunction with measured hydraulic head values or especially in regions where insufficient well data are available. In central AlBerta, recharge areas are found to be characterized by; a decrease of hydraulic head with depth; topographically elevated areas; dry appearance of the land; abundant dry depressions; relatively thick unsaturated zone; fluctuating water table; well drained soils; variable and lower groundwater temperature; and low total dissolved solids. Groundwater discharge areas are characterized by: an increase in hydraulic head with depth; topographically low; general net moisture excess, and abundant wet depressions; shallow water table with less
fluctuation; flowing wells; springs and seepages; "soap holes" (quick sand); 'burnt crops"; abundant growths of phreatophytes; saline soils and salt precipitates; generally warmer and less variable groundwater temperatures; and higher total dissolved solids.

The writer spent one month in the field, systemically traversing the Pine Lake basin in an east-west direction. Extenstive use was made of aerial photographs (scale of 2 inches $=1$ mile) and the historical knowledge of local residents. Lack of time and good weather limited the traverse grid detail and eventually only major groundwater features (i.e., water levels, springs, flowing wells, etc.) were mapped. Nevertheless, a sufficiently broad coverage of observation points were obtained as shown in Figure 4.

Flowing wells can occur under the natural conditions of increasing hydraulic head with depth in discharge areas of homogeneousisotropic media (Figure 37) or where a permeable horizon is confined by low permeability beds. The distribution of flowing domestic wells and reported seismic shot holes (Figures 3 and 4) are noticeably restricted to the valley bottoms in the Pine Lake basin. Most of these wells are of shallow depth, usually penetrating less than 50 feet ( 15 m ) into the bedrock where aquifers are locally confined by clayey tills. Such is the case for many of the flowing wells drilled near Pine Lake (Figure 4). Free-flowing yields of these wells are usually less than 3 igpm ( $14 \mathrm{l} / \mathrm{m}$ ) but it can exceed $50 \mathrm{igpm}(230 \mathrm{l} / \mathrm{m})$, as at the north end of Pine Lake where shallow sandstones and fractured shales are confined by clays in the glacial drift. Buried sand and
gravels in outwash deposits will also produce flowing wells along the drainage ways where they are locally confined by clays.

Springs and seepages are quite numerous in the Pine Lake research basin. Rarely does the flow of these springs exceed 10 to 15 igpm ( 4.5 to $701 / \mathrm{m}$ ). An exception to this was found in the narrow valley north of Pine Lake (location 11-3, Figure 4) where the flow rate was estimated around $35 \mathrm{igpm}(160 \mathrm{l} / \mathrm{m})$. The majority of springs in the basin discharge at rates between 1 to 5 igpm ( 5 to $25 \mathrm{l} / \mathrm{m}$ ). The geologic nature of these features is often difficult to ascertain, in that vegetation and the glacial drift obscure the situation. A large number of springs are used for watering cattle and hence have been dug out and cribbed off. The broad areas of seepage along drainage bottoms and small springs found along slopes of hills are probably indicative of upward rising groundwater flow and shallow water-table conditions in rather homogeneous, low permeability geologic materials. Some of the larger springs occur in valley bottoms near the base of a steep slope. An example of this type of occurrence near the north end of Pine Lake is shown by the photograph in Figure 47 . These springs are almost entirely of the contact type, either as a result of permeable sandstone overlying a shaley sequence (in areas of thin drift) or where coarse outwash deposits overlay clayey till. Many springs are further localized by slumping of surficial materials along steep valley walls.

The saline soil association shown along the Ghostpine Creek drainage system in Figure 11 was verified by the observations of salt


Figure 47. Typical spring environment in the Pine Lake area (16-22-36-25W4).
precipitates in this area. According to Tóth (1966a), these salt precipitates consist of sodium sulfate, calcium and magnesium sulfates and sodium bicarbonates in varying amounts. The existence of the salts in association with springs, flowing wells, saline sloughs and a shallow water table undoubtedly confirms they are the result of the evaporation of upward-rising groundwater. The micro-climate and abundance of surface water in the northern part of the research basin appears to preclude the development of salt precipitates in discharge areas of this region.

No attempt was made to correlate natural vegetation changes with groundwater conditions in a thorough manner. A description of the general vegetation in the basin was given in Chapter 2 and will not be repeated here. Profuse growths of phreatophytes (mainly willow) occur along drainage ways and closed depressions such that transpiration losses are substantial. Spotty occurrences of alkali-tolerant, brilliant red Salicomia mibra can be observed in areas of saline soils. "Burnt crops" are caused by local high water-table conditions where sodium sulfate in the groundwater retards crop growth. The occurrence of this feature was only noted in a few locations and is not restricted to valley bottoms.

Figure 48 (in pocket) summarizes the results of the field observations and their interpretation in the context of regional groundwater flow. This map shows beyond any doubt that Pine Lake, Ghostpine Creek, and their associated tributaries are major discharge areas for groundwater flow in the Pine Lake research basin.

## Conceptual Model of Groundwater Flow

Based on the available data and theoretical considerations, one can easily conceptualize the groundwater flow patterns in the research basin. First of all, the groundwater regime in the Pine Lake area is characterized by a three-dimensional, heterogeneous, anisotropic hydrologic unit called a "groundwater basin", as in the context defined by Freeze and Witherspoon (1967). A suitable two-dimensional section through a groundwater basin should be representative of the flow patterns, provided it is taken parallel to the direction of maximum hydraulic gradient. In the case of the Pine Lake area, a representative section could include any line transverse to the major drainage ways.

The type of flow pattern inferred for the research basin is portrayed by the hydrogeological cross-section in Figure 49 (in pocket). This particular section was traced from geological section C-C* (Figures 5 and 25) wherein the stratigraphy was simplified for clarity, the exaggerated scale retained for illustrative purposes, and hydrologic data added for interpretation. The choice of this section over another was based largely on the amount of geologic and hydrologic data, the well defined stratigraphy, and central location. A number of hydraulic head values from domestic wells are plotted in the cross section along with the approximate position of the water table such that shallow hydraulic head equipotentials could be qualitatively contoured. Application of the hydrostratigraphic unit concept to the subsurface geology is also clearly documented on the diagram.

The general pattern of groundwater flow (Figure 49) appears to be fairly simple. Groundwater recharge is most pronounced along the main ridges where the flow is essentially vertical through low permeability glacial drift and siltstone-shale strata. Relatively thin sandstones of greater hydraulic conductivity interrupt the vertical flow regime and serve to transmit the water horizontally to areas of local and intermediate groundwater discharge. A number of local flow systems occur, especially where the water table configuration is irregular as in the hummocky terrain on the west side of the basin. Flow lines are refracted substantially on encountering the extensive, shallow sandstone bed in Hydrostratigraphic Unit 2. This sandstone unit probably plays an important role in an intermediate-type flow system that together with the local flow systems are responsible for much of the groundwater discharge in the Pine Lake basin. Regional groundwater flow continues downward to the deep, thick sandstone sequence in Hydrostratigraphic Unit 3. From here, groundwater movement is lateral through the thick sandstones which transmit water from the regional recharge areas in the uplands to the major discharge areas around Pine Lake. Below Hydrostratigraphic Unit 3, groundwater flow is inferred to be dominated by a west to east motion that is part of a much larger regional flow system (in the thick Horseshoe Canyon Formation) discharging toward the Red Deer River.

Two features of the groundwater flow patterns cannot be adequately illustrated by the scale of Figure 49 . One of these is the local pattern of flow associated with Pine Lake. Regionally, the lake
appears to act as a major discharge feature but locally the situation may be more complex. Although the models of Winter $(1976,1978)$ do not seem to apply in the regional pattern, they may offer insight into local groundwater flow-lake interaction. A second feature which is not properly represented by the regional model (Figure 49) is groundwater flow in the areas of hummocky moraine. Again this is a feature which is likely to be complicated by local flow systems. The diagram of Winter (1976) shown in Figure 40 may be quite representative of the type of flow patterns existing in the knob-and-kettle topography of the northern and western parts of the research basin. Highly developed local systems occur between sloughs and are an integral part of an intermediate and regional system. Even this picture might be oversimplified by the fact that Meyboom (1966b) documented a sequence of transient flow conditions where directions of groundwater flow reversed on an annual basis.

## CHAPTER 6

## HYDROCHEMISTRY

The main purpose of this chapter is to describe the chemistry of groundwater in the Pine Lake research basin and assess its relationship to the hydrogeologic environment. An understanding of the hydrochemical patterns in the subsurface would not be possible without some knowledge of geology (i.e., mineralogy) and groundwater flow distributions. In turn, an understanding of the hydrogeochemistry is essential to a comprehensive evaluation of the groundwater regime.

## Type of Data and Method of Treatment

More than two hundred chemical analyses of well waters, springs and surface water in the Pine Lake area were examined by the writer. Approximately half of these were pre-existing records of water chemistry analyses of samples submitted to local health authorities by private well owners. The other half of the hydrochemistry data consists of detailed analyses of water samples taken by the author during the summer field survey. These samples were analyzed by the Alberta Research Council Geochemistry Laboratory. Both sets of analyses are presented in Appendix B. In general, caution should be taken in interpreting "groundwater" chemistry from many of the well samples tabulated in Appendix $B$ because construction details are commonly
unreported and the sampling procedures used by private well owners may be questionable. Nevertheless, for the purpose of this study, the volume of data and its consistency are sufficient to make general observations on the hydrochemical patterns inferred from the available data distribution (Figures 3 and 4).

The treatment of a large number of chemical analyses for interpretation logically requires the use of simple graphical methods for displaying the types of groundwater and its spatial variation. This is the approach which has been used to evaluate the data in the Pine Lake research basin. Because existing wells rarely exceed a depth of 300 feet ( 90 m ), the discussion below will be confined mainly to the areal hydrochemistry of Hydrostratigraphic Units 1 and 2. Some mention will be made of the chemistry of surface water.

## Chemical Types or Facies of Groundwater

The hydrochemistry of water from wells, springs and a few surface bodies in the Pine Lake area is shown diagrammatically in Figures 50 and 51 which are trilinear plots of the type proposed by Piper (1944). For clarity only water analyses from wells are shown in Figure 51 whereas spring and surface water analyses are illustrated in Figure 50. Because only a few wells in the entire basin are known to be completed in the glacial drift, a Piper diagram for drift wells has not been constructed. It is hoped that any unique chemistry of groundwater in the drift will be reflected by the analyses of spring waters.


Figure 50. Piper trilinear diagram of spring and surface water samples, Pine Lake research basin.


Figure 51. Piper trilinear diagram of groundwater samples from water wells, Pine Lake research basin.

The concept of hydrochemical facies or types as introduced by Back (1960, 1966) provides an efficient method of evaluation of the relationships between groundwater chemistry and those factors which control its character (i.e., geology, topography, climate and groundwater flow). The chemical facies of waters in the Pine Lake basin have been classified on the trilinear plots according to the dominant cations and anions in the waters. Boundaries have been arbitrarily chosen at the 60 percent value of equivalents per million for $\mathrm{Na}^{+}+\mathrm{K}^{+}$and $\mathrm{HCO}_{3}^{-}+$ $\mathrm{CO}_{3}{ }^{2-}$. Four types of groundwater have been delineated and are numbered on the diagrams in order of their apparent abundance of occurrence. Type 1 is defined as a sodium-bicarbonate facies; Type 2, a calcium-magnesium-bicarbonate water; Type 3, a sodium-sulfate-bicarbonate water; and Type 4 represents a calcium-magnesium-sulfate-bicarbonate facies.

## Distribution of Hydrochemical Facies

Figure 52 (in pocket) shows the areal distribution of hydrochemical facies in the research basin according to the classification presented above. Both spring and well data are plotted on this map and therefore it represents the composite chemistry of groundwater in the shallow bedrock and drift. No hydrochemical cross-sections have been constructed due to the insufficient vertical distribution of data.

As shown on the facies map (Figure 52), Type 1 (sodiumbicarbonate) groundwater is the most common hydrochemical facies encountered in the Pine Lake research basin. Its broad distribution does not appear to be topographically controlled nor is it unique to
springs or wells. One significant observation is that it is almost always the type of water encountered in deep aquifers.

Type 2 (calcium-magnesium-bicarbonate) waters are the next most abundant in the basin and are most conspicuous in a region enveloping the east side of Pine Lake and extending southeasterly along the flank of the eastern drainage divide. The type 2 facies is also prominent as discontinuous patches along both drainage divides. No correlation can be made with topography and the occurrence of this facies. However, it does appear that Type 2 groundwater is probably a shallow phenomena. This is deduced from the fact that calcium-magnesium-bicarbonate types are commonly found in springs. Wells producing this water are also less than 100 feet ( 30 m ) in depth.

Water dominated by sodium-sulfate-bicarbonate (Type 3) occurs in an area adjacent to the entire eastern drainage divide and in an irregular shaped region in the southwest part of the basin. A few isolated occurrences are found near Pine Lake and Ghostpine Creek. Only one spring in the basin contained a Type 3 facies. The majority of wells completed in this facies are between the depths of 100 to 215 feet ( 30 to 65 m ).

Type 4 (calcium-magnesium-sulfate-bicarbonate) is the least common hydrochemical facies and is restricted in occurrence to the major bedrock ridges in the extreme southern part of the research basin. Two isolated sample points are present on elevated ridges in the western part of the study area. Well depth in this facies is variable, in fact, one analyses of a spring near the edge of a steep bedrock ridge
also yielded a Type 4 water. A significant characteristic of Type 4 waters is that total dissolved solids is always greater than $1000 \mathrm{mg} / 1$ (Appendix B).

No systematic sampling of surface water was conducted in the Pine Lake basin. The chemistry of the few surface water samples was shown in Figure 50 where the appropriate hydrochemical facies was also indicated. Analyses of water from the lower reaches of Ghostpine Creek plot in the Type 1 facies group. In these analyses, total dissolved solids (TDS) range from 500 to $700 \mathrm{mg} / 1$. In comparison, values of $450 \mathrm{mg} / 1$ and $500 \mathrm{mg} / 1$ are estimated for the dissolved solids content of Pine Lake and the upper reach of Ghostpine Creek, respectively. Analyses of three sloughs in the southern area of the basin plotted in separate facies and TDS values varied from less than $500 \mathrm{mg} / 1$ to over $2500 \mathrm{mg} / 1$. Based on the present data, it would be improper to state any generalities concerning surface water chemistry in the research basin.

## Distribution of Chemical Constituents

In an attempt to further evaluate the hydrogeochemistry in the Pine Lake area, contour maps of various chemical constituents were prepared. Figures 53 to 60 (in pocket) show the areal distribution of some of the more important chemical constituents. Total dissolved solids, chloride, fluoride and iron are expressed on the maps in milligrams per liter ( $\mathrm{mg} / \mathrm{l}$ ) whereas the components sodium plus potassium ( $\mathrm{Na}^{+}+\mathrm{K}^{+}$), bicarbonate plus carbonate $\left(\mathrm{HCO}_{3}^{-}+\mathrm{CO}_{3}{ }^{2-}\right.$ ), and sulfate $\left(\mathrm{SO}_{4}{ }^{2-}\right)$ are expressed in percentage of the total cations or anions,

The calcium to magnesium ratios $\left(\mathrm{Ca}^{2+}: \mathrm{Mg}^{2+}\right)$ were calculated by using the equivalents per million concentration of each ion, respectively. Because of the apparent lack of hydrochemical facies contrast between springs and many of the well data, both sources of data have been used in the construction of the contour maps.

Total Dissolved Solids
The spatial variation in total dissolved solids is illustrated in Figure 53 by a contour interval equal to $500 \mathrm{mg} / 1$. Most groundwater in the Pine Lake basin has a dissolved solids value of $1000 \mathrm{mg} / 1$ or less and rarely does it exceed $2000 \mathrm{mg} / 1$, at least in the shallow hydrostratigraphic units. The most significant hydrochemical trend displayed by this map is that mineralization of groundwater is highest along the drainage divides and decreases toward lower elevations. The freshest subsurface water (less than $500 \mathrm{mg} / \mathrm{l}$ ) occurs in a region which surrounds Pine Lake. Waters with concentrations greater than $1000 \mathrm{mg} / 1$ dominate the entire eastern ridge, the highly elevated northern upland, and a broad mid-slope region that extends from the southwest shore of Pine Lake to the southern edge of the basin in Township 35, Range 24. Strangely enough, most of the western drainage ridge is relatively low in total dissolved solids in comparison to its eastern counterpart, Anomalously high TDS concentrations (greater than $2000 \mathrm{mg} / 1$ ) are found in an area of hummocky moraine in the northeastern part of the basin and on a bedrock ridge at the southern extremity.

Sodium and Potassium
The areal distribution of $\mathrm{Na}^{+}+\mathrm{K}^{+}$ions in the Pine Lake area is given in Figure 54. Some prominent features which can be observed in this distribution include: sodium and potassium are the dominant cations over much of the basin, with exception to those regions where Type 2 and 4 facies are present (Figure 52); the percentage of $\mathrm{Na}^{+}+\mathrm{K}^{+}$ decreases toward Pine Lake and its northern tributaries but increases toward Ghostpine Creek; and the highly elevated region in the extreme north appears to be characterized by a high $\mathrm{Na}^{+}+\mathrm{K}^{+}$content.

Calcium to Magnesium Ratio
Figure 55 shows the areal variation in the ratio $\mathrm{Ca}^{2+}: \mathrm{Mg}^{2+}$, expressed as a quotient of their respective equivalents per million concentration. The relative abundance of calcium and magnesium as compared to the sodium and potassium ions can be deduced from Figure 54. In most parts of the basin the ratio is between 1.0 and 2.0 , although it could be different in the north where data is sparse. An extensive area where the numerical value of $\mathrm{Ca}^{2+}: \mathrm{Mg}^{2+}$ exceeds 3.0 occurs along the western drainage divide and on part of the northeastern divide.

Bicarbonate and Carbonate
Bicarbonate and carbonate as a percentage of the total anions is greatest (greater than $80 \%$ ) along most of the major western ridge and on part of the basin divide directly east of Pine Lake (Figure 56). This percentage is also high around Pine Lake and Ghostpine Creek. In
areas of hummocky moraine (near the eastern and western divides), the bicarbonate and carbonate content can range between 60 and 80 percent but is commonly less. Lower concentrations of $\mathrm{HCO}_{3}^{-}$and $\mathrm{CO}_{3}{ }^{2-}$ are confined to the bedrock ridges at the southern end of the basin. Most of the wells producing in this area are completed in the 200 to 250 feet (60 to 75 m ) depth range.

Sulfate
The distribution of the percentage $\mathrm{SO}_{4}{ }^{2-}$ is given in Figure 57. Over most of the basin, the sulfate content is generally between 20 to 30 percent. This trend is interrupted by high sulfate concentrations in the south which extend in an arm up to Pine Lake. Sulfates are low around Pine Lake and along Ghostpine Creek. This feature is also quite extensive on the western divide and on part of the eastern ridge (Figure 57). Deep wells (greater than 300 feet or 90 m ) rarely encounter groundwater with a high sulfate content.

Chloride
A contour map showing the concentration of $\mathrm{Cl}^{-}$in $\mathrm{mg} / \mathrm{l}$ is presented in Figure 58 . This constituent is often less than $5 \mathrm{mg} / 1$ throughout the basin, with the exception of the elevated areas near the basin divides.

Fluoride
Figure 59 shows the natural distribution of fluoride in groundwaters of the Pine Lake basin using a contour interval of $0.5 \mathrm{mg} / 1$. Although values as much as $9.0 \mathrm{mg} / \mathrm{l}$ have been determined, fluoride
content probably averages around 0.5 to $1.0 \mathrm{mg} / 1$ or less for the research basin as a whole. A general trend which can be discerned from the map (Figure 59) is that fluoride tends to be highest on the major ridges and decreases toward the valley bottom. High fluoride waters (greater than $2.0 \mathrm{mg} / 1$ ) appear to be associated with deeper wells in permeable sandstone aquifers.

Iron
The distribution of iron illustrated in Figure 60 does not represent the natural ion content of groundwater in the research basin because of contamination from well casings and pumps. This is especially true of the locations where anomalous values can exceed $30 \mathrm{mg} / 1$. An average background range for the basin is somewhere around 0.5 to $1.0 \mathrm{mg} / 1$.

## Interpretation of Hydrochemistry

A great deal of research has been devoted to the use of the chemical composition of groundwater as an interpretive tool in hydrogeological studies. The foundation of this theory was laid by various authors who also sought to show how groundwater chemical types could be attributed to groundwater flow and the hydrogeologic environment. For example, according to the theory of Chebotarev (1955), one should see the following regional changes in dominant anions with distance and age:

$$
\begin{equation*}
\mathrm{HCO}_{3}^{-} \rightarrow\left(\mathrm{HCO}_{3}^{-}+\mathrm{SO}_{4}^{2-}\right) \rightarrow \mathrm{SO}_{4}^{2-} \rightarrow\left(\mathrm{SO}_{4}^{2-}+\mathrm{Cl}^{-}\right) \rightarrow \mathrm{Cl}^{-} \tag{1}
\end{equation*}
$$

The inference which can be made from this sequence is that groundwater should naturally evolve from a bicarbonate type in recharge areas to domination by sulfate or chloride ions in discharge areas, depending on the scale of the flow systems involved.

Based on the interpretation of the groundwater flow patterns in the last chapter and the hydrochemical facies map (Figure 52), an attempt can be made to link various facies type and therefore individwal chemical constituents with areas of recharge and discharge and particular flow systems. Unfortunately, the influence of flow patterns is not strongly developed in the hydrochemical facies of the Pine Lake research basin. Although the various maps (Figures 53 to 60) of the chemical constituents adequately show their distributions, the concentrations of chemical constituents in the research basin are probably more strongly modified from their principal concentrations by changing mineralogy, cation exchange processes, bacterial action and mixing phenomena than can be attributed to the classical Chebotarev sequence and the concept of flow systems.

Type 1 (sodium-bicarbonate) groundwaters are dominant throughout the Pine Lake area and undoubtedly represent the facies which characterizes the entire basin and upon which the other facies are superimposed. The apparent recharge areas in the hummocky moraine on the upland areas have diverse chemistries. Whether this is a result of actual areal variation in hydrochemical facies or more reflective of variable well depth is difficult to ascertain. In recharge areas, one should expect low total dissolved solids and high concentrations of
bicarbonate and carbonate. The reason for this is that groundwater acquires its principal chemical composition during infiltration into the soil and because of the $\mathrm{CO}_{2}$-rich environment $\mathrm{HCO}_{3}^{-}$is the most abundant species through dissolution of carbonates such as follows (Davis and De Wiest 1966):

$$
\begin{align*}
& \mathrm{CO}_{2}+\mathrm{H}_{2} \mathrm{O} \rightarrow \mathrm{H}_{2} \mathrm{CO}_{3} \rightarrow \mathrm{H}^{+}+\mathrm{HCO}_{3}^{-} \\
& \mathrm{HCO}_{3}^{-} \rightarrow \mathrm{H}^{+}+\mathrm{CO}_{3}^{2-}  \tag{2}\\
& \mathrm{CaCO}_{3}^{2}+\mathrm{H}^{+} \rightarrow \mathrm{Ca}^{2+}+\mathrm{HCO}_{3}^{-}
\end{align*}
$$

Discharge areas should be characterized by higher total dissolved solids and possibly domination of the anions by $\mathrm{SO}_{4}{ }^{2-}$, at least according to the Chebotarev sequence. The absence of sulfate or even sulfate-bicarbonate in the discharge areas is readily apparent on the hydrochemical facies map. Clearly, the hydrochemical patterns in the Pine Lake basin do not conform to the Chebotarev sequence. Type 1 and 2 waters appear to be prominent in the recharge areas but they also characterize the mapped discharge areas around Pine Lake and Ghostpine Creek. The noticeable decrease in total dissolved solids toward these drainage ways completely disagrees with the conceptualized flow patterns given in the last chapter. In that deeper wells are constructed along the ridges, the high TDS values in these areas are inevitably explainable for this reason alone. The distribution of Type 3 (sodium-sulfate-bicarbonate) and Type 4 (calcium-magnesium-sulfate-bicarbonate) groundwaters are largely restricted to mid-slope position of ridges and
along the southern boundary of the basin. Some of these occurrences may be associated with local or intermediate flow systems but more than likely they are controlled by local mineralogical and hydrochemical conditions. The presence of an extensive area of Type 4 waters on the southern sandstone ridge probably is a result of the highly permeable nature of the strata which reflects the chemical character of the glacial drift and shallow bedrock superimposed on the regional sodium-bicarbonate water at depth.

The limited amount of data makes it difficult to delineate unique hydrochemical facies for each hydrostratigraphic unit, especially from the maps presented earlier which contain data from wells of variable depth and even springs. Furthermore, very few wells produce groundwater from the drift deposits and therefore the areal chemistry of this unit is not represented on the hydrochemical maps. Most domestic wells are completed in the shallow bedrock for the simple reason that drift waters are very hard and therefore are typically dominated by $\mathrm{Ca}^{2+}$ and $\mathrm{Mg}^{2+}$ as major cations and $\mathrm{HCO}_{3}^{-}$as the major anion, although $\mathrm{SO}_{4}{ }^{2-}$ may be present if sufficient soluble sulfate minerals exist in the till. In any event, $\mathrm{Ca}-\mathrm{Mg}-\mathrm{HCO}_{3}$ or $\mathrm{Ca}-\mathrm{Mg}-\mathrm{SO}_{4}-\mathrm{HCO}_{3}$ waters characterize the glacial deposits whereas $\mathrm{Na}-\mathrm{HCO}_{3}$ waters dominate in the bedrock (especially at depth).

The complex mineralogical assemblages which occur in the glacial drift deposits in the Pine Lake area are easily accountable to generation of the prominent anions and cations. As noted above, the dissolution of carbonate minerals and soil zone $\mathrm{CO}_{2}$ is primarily
responsible for the abundance of $\mathrm{HCO}_{3}^{-}$in shallow groundwaters. The abundance of calcareous materials in the tills and other deposits of the area are sufficient to account for the prominence of $\mathrm{Ca}-\mathrm{Mg}-\mathrm{HCO}_{3}$ waters in the drift. Wallick (1977) also suggested that weathering of silicate minerals may contribute to the overall concentrations of these ions and others but recognized that carbonate equilibria is the most important control on the solubilities of $\mathrm{Ca}^{2+}, \mathrm{Mg}^{2+}, \mathrm{CO}_{2}$ and frequently $\mathrm{Fe}^{2+}$.

Gypsum and other sulfates also occur in drift materials and their disposition almost always is responsible for any significant concentrations of $\mathrm{SO}_{4}^{2-}$ in drift waters. The dissolution reaction for gypsum is represented by:

$$
\begin{equation*}
\mathrm{CaSO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O} \rightarrow \mathrm{Ca}^{2+}+\mathrm{SO}_{4}^{2-}+2 \mathrm{H}_{2} \mathrm{O} \tag{3}
\end{equation*}
$$

In many parts of the research basin, the presence of extensive outwash deposits in the drift have precluded the concentrations of $\mathrm{SO}_{4}{ }^{2-}$. A possible reason for this is that the strong flushing effect of local flow systems could have removed much of the soluble sulfate minerals from the flow regime. The prominence of sulfate in shallow groundwater along the southern boundary of the research basin may be a function of the effects of higher evaporation losses in this area. As the leaching depth is shallow, small amounts of gypsiferous or pyritic material in the drift or bedrock may be a significant source of $\mathrm{SO}_{4}{ }^{2-}$ and $\mathrm{Ca}^{2+}$. The relative abundance of $\mathrm{SO}_{4}{ }^{2-}$ in groundwaters along the eastern
divide is problematic but may be due to composition and thickness of tills.

Moderate concentrations of sodium in drift waters could be acquired through the processes of cation exchange on montmorillonitic clays but the majority of $\mathrm{Na}_{\mathrm{H}}-\mathrm{HCO}_{3}$ spring waters issuing from drift deposits around Pine Lake, Ghostpine Creek and their tributaries are probably the result of the strong influence of chemical processes dominant in the bedrock strata. These springs, therefore, are acting as "inliers" of bedrock hydrochemical facies rather than reflecting hydrochemical patterns in the drift.

The chemistry of groundwater encountered in the bedrock (Paskapoo Formation) of the Pine Lake area is highly dependent on the hydrogeochemistry of the glacial drift. Exceptions to this interpretation occur in the deep groundwater systems and some of the discharge areas; however, all have evolved from shallow calcium-magnesium-bicarbonate waters in the glacial drift to predominantly a sodium-bicarbonate facies in the bedrock. Dissolution of carbonates, sulfates and other minerals still influence the concentrations of the dominant anions and cations in bedrock groundwaters but more important now are the roles of other geochemical processes which greatly modify the primary chemical composition acquired in shallower zones. Freeze and Cherry (1979) have identified four major processes: cation exchange, $\mathrm{CO}_{2}$ generation at depths far below the water table, sulfate reduction and oxidation of sulfide minerals.

The most likely explanation for the dominance of sodiumbicarbonate waters in the bedrock of the Pine Lake research basin is the process of cation exchange coupled with carbonate dissolution. The abundance of bentonite (i.e., montmorillonite) in the rocks of the Paskapoo Formation provide ample opportunity for the replacement of $\mathrm{Na}^{+}$exchange sites by $\mathrm{Ca}^{2+}$ which is absorbed on the clays. This process also enhances further calcite dissolution which, if maintained at low concentrations, keeps equilibrium $\mathrm{HCO}_{3}^{-}$concentrations high (Freeze and Cherry 1979). High bicarbonate concentrations can also result from sulfate reduction by oxidation of organic matter thereby generating $\mathrm{CO}_{2}$ at depth as follows:

$$
\begin{equation*}
2 \mathrm{CH}_{2} \mathrm{O}+\mathrm{SO}_{4}^{2-} \rightarrow \mathrm{HCO}_{3}^{-}+\mathrm{HS}^{-}+\mathrm{CO}_{2}+\mathrm{H}_{2} \mathrm{O} \tag{4}
\end{equation*}
$$

This process requires an anaerobic bacteria (Hem 1970) and is often identifiable in wells by the odor of $\mathrm{H}_{2} \mathrm{~S}$ gas. Occurrences of this phenomenon in the research basin are known and therefore biochemical sulfate reduction is a likely process for explaining the absence or low concentrations of $\mathrm{SO}_{4}{ }^{2-}$ at depth and in many parts of the basin. Two minor geochemical processes which are associated with carbonaceous strata in the subsurface may occur in the Pine Lake area. First, increased concentrations of $\mathrm{HCO}_{3}^{-}$may also be expected in coalbearing strata due to greater amounts of $\mathrm{CO}_{2}$. A final geochemical process which should be mentioned is the possibility of the oxidation of sulfide minerals. The presence of pyrite in coals and carbonaceous shales in the Pine Lake area is documented by a number of detailed
coal exploration geologic logs (Figure 5). According to Freeze and Cherry (1979), hydrogen ions are released as a result of the reaction:

$$
\begin{equation*}
\mathrm{FeS}_{2}+\frac{15}{4} \mathrm{O}_{2}+\frac{7}{2} \mathrm{H}_{2} \mathrm{O} \rightarrow \mathrm{Fe}(\mathrm{OH})_{3}+4 \mathrm{H}^{+}+2 \mathrm{SO}_{4}^{2-} \tag{5}
\end{equation*}
$$

This oxidation must occur in the unsaturated zone and from the high production of $\mathrm{H}^{+}$a high $\mathrm{HCO}_{3}^{-}$content can be maintained in high pH groundwaters. Note should be made that significant amounts of $\mathrm{SO}_{4}{ }^{2-}$ is also generated and that this process can be active in drift materials derived from pyritic strata.

## Water Quality Considerations

The quality of water in the Pine Lake area can be selfinterpreted from the maps showing the hydrochemistry (Figures 52 to 60) of the basin and does not need to be repeated here. In short, all groundwaters sampled in the research basin appear to be suitable for human and livestock consumption, although some of the constituents exceed recommended drinking water standards set by the U.S. Environmental Protection Agency (1975). Quality of bedrock waters is generally superior to that of shallow drift wells because of its softer nature. The high sodium content and total dissolved solids of most of the groundwater in the basin limits its use in irrigation.

## CHAPTER 7

## GROUNDWATER RESOURCES

No hydrogeologic investigation would be complete without an evaluation of the groundwater resources. In the field of groundwater exploration and development, this usually involves the identification and mapping of major aquifers, determination of quantitative hydrologic properties through aquifer testing, and a prediction of sustainable well yields based on the hydraulic data. For the design of a particular groundwater development, this analysis would also include an assessment of the possible impact on the existing groundwater regime. More important, however, in the context of the original objective of establishing the Pine Lake research basin, is an evaluation of the subsurface components of the hydrologic cycle with emphasis on parameters such as recharge, discharge and natural basin yield. Ultimately, a final goal of any basin study is to build a better understanding of the complete hydrologic cycle which quantitatively requires an evaluation of the water balance.

## Groundwater Probability

The distribution, hydrologic properties and hydrochemistry of the major aquifers in the Pine Lake basin have been thoroughly discussed in previous chapters. What remains to be presented is a general
yield analysis of these aquifers. Figure 61 (in pocket) is a groundwater probability map of the research basin. The term "groundwater probability" may be misleading in that this map does not actually represent expected aquifer yields but rather the anticipated range of yields for wells completed in the shallow bedrock, according to standard well construction practices in the area.

Tóth (1966b) introduced the concept of the " 20 -year well yield" $\left(Q_{20}\right)$ through adaptation of the modified nonequilibrium formula (Cooper and Jacob 1946) to arrive at the following equation:

$$
\begin{equation*}
Q_{20}=\frac{T \cdot H}{c} \tag{6}
\end{equation*}
$$

where $T=$ transmissivity (igpd/ft), $H=$ total available drawdown ( ft ) between static water level and the top of the aquifer zone, $Q_{20}=$ maximum flow rate (igpm) which can be sustained over a period of 20 years without drawdown below the top of the main aquifer penetrated by the well; and $C=2110=$ conversion factor to account for $8 \log$ cycles of time and consistency of units. "This calculation's predictive accuracy depends greatly on how representative the transmissivity value is of regional conditions. Nevertheless, this concept has been employed in Alberta and for purposes of conformity Equation (6) has been used to produce the numerical values given in Figure 61. The type of transmissivity data from which the yield points have been calculated is also indicated on the map and values of 20 -year yield, transmissivity and available drawdown are tabulated in Appendix B. In places where a well penetrates an entire aquifer, the well yield predicted by

Equation (6) will be a good approximation to the local aquifer yield, provided a reasonably accurate transmissivity coefficient is available for the calculation. However, the complex stratigraphy and shortage of good aquifer tests precludes a detailed analysis of aquifer yield in the Pine Lake basin at the present time. For these reasons, only three yield ranges have been mapped: 1 to 5 igpm ( 5 to $25 \mathrm{l} / \mathrm{m}$ ); 5 to 25 igpm ( 25 to $115 \mathrm{l} / \mathrm{m}$ ); and greater than 25 igpm ( $115 \mathrm{l} / \mathrm{m}$ ). Although higher yields are widespread, no attempt has been made to differentiate them until further pump test data are available.

The well yield pattern in Figure 61 is a reflection of both transmissivity and water level parameters. In most parts of the basin, shallow bedrock wells can be expected to obtain sustained safe yields in the 5 to 25 igpm ( 25 to $115 \mathrm{l} / \mathrm{m}$ ) range. Areas of well yield less than 5 igpm ( $25 \mathrm{l} / \mathrm{m}$ ) are widespread on the western and southern ridges where poor well construction, deep static water levels and low transmissivities are probably responsible for the poor yields. Wells capable of sustaining yields of greater than 25 igpm ( $115 \mathrm{l} / \mathrm{m}$ ) occur along most of the eastern divide, near the north end of Pine Lake, and along a narrow band just east of the western ridge. Except for a few of these wells which are completed in fractured shale, the majority produce from major sandstone aquifers. Those points of anomalously high well yields are denoted on the map (Figure 61) by triangles and usually are the result of extremely high calculated transmissivities derived from short pump tests where drawdown was small. Based upon the available data, sustainable 20 -year well yields may exceed 100 igpm
( $450 \mathrm{l} / \mathrm{m}$ ) for parts of these shallow sandstone aquifers. Where they are sufficiently thick and the hydraulic conductivity enhanced by fracturing, $Q_{20}$ values could be even greater as suggested by some of the anomalously high values (Figure 61).

The purpose of showing the groundwater probability map is to present the general trend of existing groundwater resources in the Pine Lake research basin. The map should not be construed as representing the ultimate potential resources of the basin, in that the variability of well construction and sparcity of good aquifer tests make this picture far from being complete. Furthermore, extensive sandstone units are known to exist at depths which have yet to be explored for their possible groundwater resources.

## Estimates of Regional Groundwater Recharge

There have been several traditional methods used for estimating regional groundwater recharge in western Canada:

1. Field instrumentation at both the recharge and discharge areas of the flow system.
2. Analysis of baseflow components from streamflow hydrographs.
3. Application of soil moisture budgets based on precipitation and evapotranspiration data.
4. Flow net analysis of piezometric data.
5. The use of steady-state drainage equations.
6. Calculation of regional groundwater flow through the use of flow net analysis of numerical models.
7. Complete water budgets of instrumented drainage basins.

Some of the studies which have successfully applied these methods include: Freeze (1969a, 1969b), Freeze and Banner (1970), Meyboom (1960, 1961, 1964, 1967a, 1967b) and Tóth (1968). The lack of piezometric, meteorologic and hydrometric data (i.e., instrumentation) eliminates the present use of a number of these methods in the Pine Lake basin. No mathematical models have as of yet been constructed by the writer and therefore the method of numerical analysis through computer simulations (Freeze and Witherspoon 1968) cannot be presented. However, an attempt will be made to discuss the possibilities of applying methods (1), (2) and (5) to existing data in the research basin.

Analysis of Annual Water-table Fluctuations
Tóth (1962) noted that according to his theory of groundwater flow in small drainage basins, there should be a definite relationship between the saturated flow of groundwater and fluctuation of the water table. As groundwater flows from recharge areas to discharge areas, a corresponding drop and rise in the water table should be observed in each area respectively. In a steady-state groundwater system, theoretically the rise in water levels in discharge areas should equal the fall of levels in recharge areas for a homogeneous and isotropic media. However, fluctuations of water-table elevations are also caused by a number of natural and induced hydrologic phenomena, the most important of which include infiltration events, evapotranspiration and pumping of groundwater from wells.

The most convenient time of the year to measure the natural effect of groundwater flow on water-table fluctuations in western

Canada is during the winter months. In the Pine Lake area, the ground is usually frozen to a depth of several feet (a few meters), depending on the amont of snow cover, and remains so throughout the months of November to March. Freezing of the ground effectively eliminates the infiltration and evapotranspiration and if observation wells are not influenced by the pumping of wells, quantitative analysis of watertable hydrographs should be possible. A limiting factor to this type of analysis is the effect of the freezing process which according to the studies of Staple, Lehane and Wenhardt (1960) and Schneider (1961) causes moisture transfers in the unsaturated zone and thus a natural lowering of the water table. Freeze and Banner (1970) studied the relationships of soil moisture, frost and infiltration at an instrumented experimental plot in southern Alberta and found it difficult to attribute the lowering of water tables in recharge areas by the freezing mechanism as being significant relative to natural flow. Using the notation of Toth (1968), the natural yield of a flow system (i) for the time interval ( $t$ ) is given by the equation:

$$
\begin{equation*}
Q_{i, t}=\bar{s}_{y} \cdot \bar{f}_{d, t} \cdot A_{i, d}=\bar{s}_{y} \cdot f_{u, t} \cdot A_{i, u} \tag{7}
\end{equation*}
$$

where $\bar{s} y=$ average specific yield of the rocks, $\bar{f}_{d, t}=$ average drop of water levels in the area of downward flow ( $A_{i, d}$ ), and $\bar{f}_{u, t}=$ average rise of the water table in the area of upward flow ( $A_{i, u}$ ), provided the water-table fluctuations are only the result of groundwater flow from recharge to discharge areas. Equation (7) may also be expressed in terms of depth over the respective areas:

$$
\begin{equation*}
q_{i, t, d}=\frac{Q_{i, t}}{A_{i, u}}=\bar{s}_{y} \cdot \bar{f}_{d, t} \tag{8}
\end{equation*}
$$

and

$$
\begin{equation*}
q_{i, t, u}=\frac{Q_{i, t}}{A_{i, u}}=\bar{s}_{y} \cdot \bar{f}_{u, t} \tag{9}
\end{equation*}
$$

Tóth (1968) also showed that in cases where the seasonal changes of the hydraulic gradients in the flow system are small in comparison to the average gradient, then the total yield of the system ( $Q_{i, T}$ ) over a complete annual cycle is given by:

$$
\begin{equation*}
Q_{i, T}=Q_{i, t} \cdot \frac{T}{t} \tag{10}
\end{equation*}
$$

Of course, this equation will represent the natural basin yield if only a single flow system exists in a basin, otherwise the total natural yield would consist of a summation of the $Q_{i}, T$ for all flow systems in the basin.

Long term water-table hydrographs are available for three shallow observation wells in the Pine Lake research basin and are denoted here as Elnora \#2, Elnora \#3 and Elnora \#4. These wells are spaced almost equidistantly over the drainage divide in the southwestern corner of the basin. Their exact locations are shown in Figure 3. Elnora \#2 is 17 feet ( 5.2 m ) deep and is completed in a surficial sand deposit, presumably outwash. Elnora \#3 is on top of a ridge where it was drilled to a depth of 62 feet ( 18.9 m ) and completed in an interbedded sequence of shale, siltstone and sandstone. The thickness
of till at this location was found to be 16 feet $(4.9 \mathrm{~m})$. Elnora \#4 (Figure 3) is 45 feet ( 13.7 m ) and is completed in a clayey till overlain by outwash sand. All of these wells were constructed by the Alberta Research Council, and automatic water-level recorders have produced hydrographs since 1962.

To present the complete hydrograph records for all three observation wells would be unwieldly. An example of a hydrograph record from Elnora \#3 is given in Figure 62. The most apparent feature of all three hydrographs is the gradual rise in water levels beginning in late April and leveling off near the end of July. This feature is primarily a function of spring thaw and annual precipitation patterns and is well exhibited in Figure 62 (compare with Figure 16). Fluctuations in the hydrograph shown in Figure 62 for the period after May likely represents the effects of rainfall events and evapotranspiration, although this pattern continues into December. The decrease of evapotranspiration throughout the early fall sustains the water-table level achieved by high precipitation in August but eventually precipitation decreases (Figures 14 and 15) and levels drop slowly until the ground is completely frozen in early November. Because all three observation wells are in recharge areas, one should expect a drop in the water-table during the winter months (November to March) due to the natural gradient of groundwater flow and absence of recharge by precipitation. This was true in all three observation well records and the nature of the decline is typically as that shown in Figure 62.

Figure 62. Hydrograph of anservation well in the southwestern part of basin.

In order to quantify the effect of the groundwater flow system on the water-table fluctuations observed in the Pine Lake area, the technique used by Tóth (1968) was applied to the hydrograph of Elnora \#2, \#3 and \#4. Average changes in the water-table elevations over the period of November to March were determined graphically in the manner shown partially in Figure 62. Table 8 summarizes the results of this analysis for a 15 -year record (1962-1976) and the mean water-level change calculated for each observation well.

Based on the data given in Table 8, the following calculations of average depth of groundwater exchange $\left(q_{T}\right)$ can be made with Equations (8) and (10), along with estimates of specific yield for the local geologic deposits:

Elnora \#2;

$$
q_{t=5}=\bar{s}_{y} \cdot \bar{f}_{t}=(0.20)(1.34 \mathrm{ft})=3.216 \text { inches } / 5 \text { months }
$$

therefore

$$
q_{T}=(3.216) \frac{(12)}{5}=7.72 \text { inches } / \text { year }=19.6 \mathrm{~cm} / \text { year }
$$

Elnora \#3;

$$
q_{t=5}=\bar{s}_{y} \cdot \bar{f}_{t}=(0.10)(0.405 \mathrm{ft})=0.486 \text { inches } / 5 \text { months }
$$

therefore

$$
q_{T}=(0.486) \frac{(12)}{5}=1.17 \text { inches } / \text { year }=3.0 \mathrm{~cm} / \text { year }
$$

Table 8. Summary of hydrograph analyses, observation wells. -- Values represent water level changes during the period November to March. ${ }^{\text {a }}$

| Year | $\begin{gathered} \text { Elnora \#2 } \\ (\text { feet }) \end{gathered}$ | $\begin{gathered} \text { Elnora \#3 } \\ \text { (feet) } \end{gathered}$ | $\begin{gathered} \text { Elnora \#4 } \\ \text { (feet) } \end{gathered}$ |
| :---: | :---: | :---: | :---: |
| 1962 | -0.38 | +0.24 | +0.02 |
| 1963 | -1.56 | -0.19 | -0.11 |
| 1964 | -0.66 | 0.00 | -0.07 |
| 1965 | -2.10 | -0.32 | -0.28 |
| 1966 | -1.76 | -0.40 | -0.26 |
| 1967 | -0.60 | -0.44 | -0.19 |
| 1968 | -1.40 | -0.52 | 0.00 |
| 1969 | -1.64 | -0.74 | -0.15 |
| 1970 | -1.48 | -0.36 | -0.26 |
| 1971 | -1.34 | -0.52 | -0.26 |
| 1972 | -1.58 | -0.56 | -0.07 |
| 1973 | - | - | -0.14 |
| 1974 | -2.10 | - | -0.23 |
| 1975 | -1.40 | - | -0.20 |
| 1976 | -0.75 | -0.40 | -0.11 |
| Mean | -1.34 | -0.405 | -0.155 |

a, + = rise in level, - = drop in level.

Elnora \#4;

$$
q_{t=5}=\bar{s}_{y} \cdot \bar{f}_{t}=(0.20)(0.155 \mathrm{ft})=0.372 \text { inches } / 5 \text { months }
$$

therefore

$$
q_{T}=(0.372) \frac{(12)}{(5)}=0.89 \text { inches } / \text { year }=2.3 \mathrm{~cm} / \text { year }
$$

Assuming an average annual precipitation of about 18 inches ( 46 cm ) for this part of the basin, then the magnitudes of groundwater exchange (recharge) represent approximately $43 \%, 7 \%$ and $5 \%$ of annual precipitation for Elnora \#2, \#3 and \#4, respectively. Tóth (1968) arrived at a value of $9 \%$ of annual precipitation for recharge using the same method in the Threehills drainage basin (Figure 2). The values of $5 \%$ and $7 \%$ are probably more representative of areal recharge rates in the research basin than the value of $43 \%$ estimated for the surficial sand. Freeze (1969b) conducted a detailed hydrologic budget of a drainage basin in Saskatchewan and found that a large proportion of total groundwater recharge occurred in a central outwash deposit. Rates of recharge in this basin were calculated to dominate between $6 \%$ and $30 \%$ of annual precipitation. Considering the climatic conditions and surficial geology are similar to that encountered in the Pine Lake basin, the values of groundwater exchange calculated from the hydrograph analyses may indeed prove to be good preliminary estimates of areal recharge in the Pine Lake research basin. It should be noted however that these rates could vary dramatically, especially in the areas of
hummocky moraine where according to Meyboom (1967b) and Lissey (1968) groundwater recharge is concentrated or focused in sloughs.

Application of a Steady-state Drainage Equation
Meyboom (l966a) was the first to explore the possibility of using steady-state equations, originally developed for drainage of stratified soils, to calculate regional groundwater discharge in western Canada. He based his analogy on the fact that groundwater flow in a layered media may be schematized by nearly vertical flow through an upper less permeable layer, horizontal flow through a lower permeable horizon (so-called Dupuit flow), and essentially radial flow in the vicinity of an open drainage way. Meyboom (1967a) applied the steadystate equation of Ernst (1963) to calculate groundwater discharge in the Arm River drainage basin in Saskatchewan and arrived at a numerical value which was consistent with that derived from the summation of baseflow and evapotranspiration estimates. The similarity of Meyboom's (1967a, Figure 3) schematic representation of groundwater flow in the Arm River basin to that inferred for the Pine Lake research basin (Figure 49) inspired this writer to apply Meyboom's method of analysis.

A schematic representation of groundwater flow across the Pine Lake research basin is given in Figure 63. This diagram is based upon the conceptual model presented in Figure 49 but it may not hold for all parts of the Pine Lake basin. Nevertheless, the hydrogeologic model of a symmetric drainage basin consisting of a permeable layer overlain by a thicker less permeable unit will serve as a first approximation to the actual complex stratigraphy. The steady-state


Figure 63. Schematic representation of groundwater flow system across Pine Lake research basin near the north end of the lake. -h=hydraulic head, K=hydraulic conductivity, $D=$ thiokness of strata, L=distance between parallel drainage channels.
drainage equation for this particular hydrogeologic configuration as derived by Ernst (1963) and used by Meyboom (1967a) is:

$$
\begin{equation*}
h_{1}-h_{0}=N c_{1}+\frac{N L^{2}}{8\left(K_{1} D_{1}+K_{2} D_{2}\right)}+N L w \tag{11}
\end{equation*}
$$

where the coefficients are defined and evaluated for the Pine Lake basin as follows (Figure 63):
$L=$ distance between parallel drainage basins $=8$ miles ( 13 km )
$h_{1}=$ total hydraulic head of the water table at the drainage divide $=3100$ feet ( 945 m )
$h_{0}=$ water level in the drainage channel $=2917$ feet ( 890 m )
$D_{1}=$ thickness of the low permeability layer $=300$ feet ( 90 m )
$D_{2}=$ thickness of the deep permeable unit $=175$ feet ( 55 m )
$\mathrm{K}_{1}=$ hydraulic conductivity of the low permeability layer $=$ 2 igpd $/ \mathrm{ft}=0.3 \mathrm{ft} /$ day $(0.1 \mathrm{~m} /$ day $)$
$K_{2}=$ hydraulic conductivity of the permeable sandstone unit $=$ $40 \mathrm{igpd} / \mathrm{ft}^{2}=6.4 \mathrm{ft} /$ day $(2.0 \mathrm{~m} /$ day $)$
$D_{1}^{*}=$ thickness of the low permeability layer midway between drainage channels and to a depth equal to the bottom of the channel (Figure 63) $=200$ feet ( 60 m )
$c_{1}=\frac{D_{1}^{*}}{K_{1}}=$ vertical resistance $=667$ days
$D_{1}^{* *}=$ thickness of the low permeability layer at the drainage way $=$ 175 feet ( 55 m )
$r_{0}=$ radius of the wetted perimeter of the drainage channel $=20$ feet ( 6 m )
$w=\frac{1}{\pi K_{1}} \ln \frac{40_{1}^{* *}}{r_{0}}=$ vertical resistance $=3.8$ days $/$ feet ( 11 days $/ \mathrm{m}$ )
$N=$ total groundwater discharge confined to the drainage way.

Solving Equation (11) for the value of groundwater discharge results in $N \simeq 2$ inches/year ( $5 \mathrm{~cm} /$ year) or approximately 11 percent of the annual precipitation which is assumed to be about 18 inches ( 46 cm ). According to Meyboom (1967a), use of the steady-state drainage equation of Ernst (1963) requires the following assumptions: (1) the strata are of constant thickness, (2) each layer is homogeneous and isotropic, (3) $\left(D_{1}+D_{2}\right) / L<0.25$, (4) $K_{1} D_{1}<0.1 K_{2} D_{2}$, (5) the water table is nearly horizontal, (6) drainage takes place by parallel streams only, and (7) groundwater discharge is restricted entirely to the drainage channel. Although a number of these assumptions are met or closely approximated in the Pine Lake basin, whether or not it is realistic to assume restriction of groundwater discharge to the drainage channel in light of the field mapping (Figure 48) is questionable.

Interpretation of Streamflow Records
The method of baseflow separation as a means for estimating regional groundwater discharge has received considerable attention in western Canada (e.g., Meyboom 1961, Farvolden 1963b, Tóth 1968 and Freeze 1969a). This subject, in terms of its applicability to the Pine Lake research basin, has already been discussed in the section on
streamflow in Chapter 3. Based on two years of record, crude estimates of annual groundwater runoff over the drainage area amount to 0.17 inches ( 0.4 cm ) and 0.11 inches ( 0.3 cm ) for the years 1967 and 1969, respectively. According to these figures, groundwater discharge to the drainage ways amounts to only about 1 percent of annual precipitation. The conclusion that can be drawn from this data is that a large proportion of groundwater discharge in the Pine Lake basin occurs in the form of evapotranspiration.

## Natural Basin Yield

The "natural basin yield" was defined by Freeze and Witherspoon (1968) as the natural quantity of groundwater flow through an undeveloped drainage basin with a known water-table and geologic configuration. In terms of the basin safe yield, defined by Todd (1959) as the amount of water that can be abstracted annually without producing an undesirable result, natural basin yield probably represents a lower limit of available resources. The reasoning behind this follows from the comments of Theis (1940) who stated that discharge from wells must be balanced by an increase in recharge to the groundwater system or by a decrease in natural discharge if equilibrium conditions are to be maintained.

To get an idea of the possible magnitude of "safe yields" in the Pine Lake basin the average depths of groundwater exchange calculated by the steady-state drainage equation and hydrograph analyses can be converted to a discharge rate per unit area. As shown by Tóth (1968) these figures strictly represent the amount of water available in the
area of upward flow and therefore should be corrected to reflect the safe yield over the entire basin. The calculations below use the assumption of Tóth (1968) that the area of recharge is about equal to the area of discharge and therefore the estimates of natural basin recharge can be divided by a factor of 2 , although this is quite arbitrary. These calculations are presented below:

1. Elnora \#2

$$
\begin{aligned}
q_{T}=7.72 \text { inches/year } & \simeq 412 \text { acre-feet/square mile/year } \\
& \simeq 214 \mathrm{i} \mathrm{gpm} / \text { square mile } \\
& \simeq 376 \mathrm{i} / \mathrm{m} / \text { square kilometer }
\end{aligned}
$$

therefore

$$
q_{T}=107 \mathrm{igpm} / \text { square mile } \simeq 188 \mathrm{i} / \mathrm{m} / \text { square kilometer safe }
$$

2. Elnora \#3

$$
\begin{aligned}
\mathrm{q}_{\mathrm{T}}=1.17 \text { inches/year } & \simeq 62 \text { acre-feet/square mile/year } \\
& \simeq 32 \mathrm{igpm} / \text { square mile } \\
& \simeq 57 \mathrm{i} / \mathrm{m} / \text { square kilometer }
\end{aligned}
$$

therefore

$$
q_{T} \simeq 16 \mathrm{igpm} / \mathrm{square} \mathrm{mile} \simeq 29 \mathrm{I} / \mathrm{m} / \mathrm{square} \text { kilometer safe }
$$

3. Elnora \#4

$$
\begin{aligned}
q_{T}=0.89 \text { inches/year } & \simeq 47 \text { acre-feet/square mile/year } \\
& \simeq 25 \mathrm{igpm} / \text { square mile } \\
& \simeq 43 \mathrm{i} / \mathrm{m} / \text { square kilometer }
\end{aligned}
$$

therefore

$$
q_{T} \simeq 13 \mathrm{igpm} / \text { square } \mathrm{mile} \simeq 22 \mathrm{l} / \mathrm{m} / \mathrm{square} \text { kilometer safe }
$$

4. Steady-state drainage equation

$$
\begin{aligned}
q_{T}=N=2 \text { inches/year } & \simeq 107 \text { acre-feet/square mile/year } \\
& \simeq 55 \mathrm{igpm} / \text { square mile } \\
& \simeq 97 \mathrm{i} / \mathrm{m} / \text { square kilometer }
\end{aligned}
$$

therefore

$$
q_{T} \simeq 28 \mathrm{igpm} / \text { square mile } \simeq 49 \mathrm{l} / \mathrm{m} / \text { square kilometer safe }
$$

Tóth (1968) calculated a safe production rate of 19 igpm/square mile ( $33 \mathrm{l} / \mathrm{m} / \mathrm{square}$ kilometer) for the Threehills drainage basin, using the same method of analysis. In any event, these figures are presented here as only crude estimates and should be viewed upon in that context.

## Water Balance Considerations

In its simplest form the hydrologic budget equation or water balance is of the form:

$$
\begin{equation*}
1-0=\frac{d s}{d t} \tag{12}
\end{equation*}
$$

which states that the inflow into a hydrologic system during a given period minus the outflow into the system during a given period must equal the change in storage within the system. An extension of this simple water budget equation to the Pine Lake research basin would have to be considerably more detailed in order to properly quantify all of the hydrologic components. Such an equation could be written for an annual period as:

$$
\begin{equation*}
P+R_{i}-R_{0}+G_{i}-G_{0}-E T-Q_{p}=\Delta S_{S}+\Delta S_{g} \tag{13}
\end{equation*}
$$

where $P=$ precipitation, $R_{i}=$ surface runoff into the basin, $R_{0}=$ surface runoff out of the basin, $G_{\mathbf{i}}=$ groundwater flow into the basin, $G_{o}=$ groundwater flow out of the basin, $E T=$ evapotranspiration, $Q_{p}=$ total groundwater pumpage for domestic and livestock purposes, $\Delta S_{S}=$ change in storage of surface-water reservoirs, and $\Delta S_{g}=$ change in storage of groundwater system (saturated and unsaturated zone).

If the groundwater divide coincides with the surface divide (Figure 41 ), then $R_{i} \simeq 0$ and if groundwater pumpage is negligible, $Q_{p} \simeq 0$. Equation (13) can be further simplified by considering a long period of time (several years) such that $G_{i} \simeq G_{0}$ (underflow) and $\Delta S_{S}=\Delta S_{g} \simeq 0$, hence;

$$
\begin{equation*}
P-R_{0}-E T \simeq 0 \tag{14}
\end{equation*}
$$

where $P$ is now the average annual precipitation, $R_{0}=$ average annual surface runoff, and ET = average annual evapotranspiration. Given the values of precipitation and streamflow runoff, an estimate of the average annual evapotranspiration could be made with Equation (14), a parameter which is of ten difficult to spatially measure in the field. Assuming that the average annual precipitation for the Pine Lake research basin (Table 1) is approximately 18.0 inches ( 46 cm ) and that the average annual runoff is represented by 0.8 inches ( 2 cm ) over the basin (Chapter 3), then mean annual evaporation over the research basin can be estimated as:

$$
E T=P-R_{0}=18.0-0.8=17.2 \text { inches }(44 \mathrm{~cm}) .
$$

Comparison of this value can be made with the potential evapotranspiration of 20 to 21 inches ( 51 to 53 cm ) calculated in Table 1 and that of actual evapotranspiration estimated as 16 to 18 inches ( 41 to 46 cm ) by the Government and University of Alberta (1969).

Without more quantitative hydrologic data, a detailed analysis of the water budget in the Pine Lake basin would be unfounded. In fact, the conclusion reached by Freeze and Cherry (1979) is that application of steady-state water-budget equations are in reality inadequate to accurately evaluate the hydrologic regime of a drainage basin. They base this conclusion on the fact that the approach does not take into account the areal and temporal variations in precipitation, evapotranspiration, runoff, recharge or discharge which are known to exist. Nevertheless, studies have shown (e.g., Freeze 1969a, 1969b) that with a minimum amount of instrumentation and well-founded assumptions, a significant understanding of both the groundwater and surface-water regime can be achieved through the application of "lumped-parameter" water-budget equations.

## CHAPTER 8

## CONCLUSIONS AND RECOMMENDATIONS

In this thesis, an attempt has been made to present a comprehensive hydrogeologic analysis of a small research basin in southcentral Alberta. As outlined at the beginning of the text, the main purpose of this evaluation was to provide a preliminary framework for instrumentation and future hydrologic studies. Before examining some of these future research possibilities, a summary of the major findings of this investigation is presented.

## Summary and Conclusion

Geographical Aspects

1. The Pine Lake research basin comprises a 90 -square-mile (230 $\mathrm{km}^{2}$ ) portion of the much larger Ghostpine Creek drainage basin. Topography is rolling to hilly and maximum relief is approximately 600 feet ( 180 m ). The present topography is essentially a subdued replica of a buried bedrock topography.

2, Drainage is only moderately developed in the basin, except in extensive areas of knob-and-kettle terrain where no integrated surface drainage exists. Pine Lake and Ghostpine Creek are the major hydrographic features in the basin. Ghostpine Creek is an intermittent stream where streamflow is highly regulated by
surface runoff. Pine Lake is a permanent body of water that receives a significant amount of groundwater discharge.
3. The research basin is dominated by the Black Soil Group which basically reflect the surficial geology. Being fertile loams, these soils support a healthy phreatophytic vegetation and therefore transpiration losses of soil moisture is likely to be a major component of the local hydrologic cycle.
4. Mean annual precipitation is approximately 18 inches ( 46 cm ) and potential evapotranspiration was calculated by the Thornthwaite method on a monthly basis to be about 20 inches ( 51 cm ) annually. A crude water-budget calculation yielded an actual evapotranspiration of 17 inches ( 44 cm ) as an annual mean over the basin.
5. Physiography has a substantial influence on the groundwater regime in the Pine Lake area, Most important is its control on the rates and distribution of recharge and the pattern of groundwater flow. Unfortunately, no field data is available to quantify this observation.

Geology

1. The entire basin is underlain by the Paskapoo Formation which is of Upper Cretaceous to Tertiary age. This formation is characterized by a complex succession of sandstone, siltstone, shale and minor coals that exhibit a very gentle structural dip to the west. Thickness of the Paskapoo Formation ranges from
about 350 feet ( 110 m ) in the south to over 1200 feet ( 360 m ) in the northern part of the research basin.
2. Stratigraphically, the Lower Ardley 'B' coal zone is the most persistent marker bed in the Paskapoo Formation. It occurs at a depth of around 300 to 1000 feet ( 90 to 300 m ) and has a nearly constant thickness of 15 feet ( 5 m ). The absence of thick sandstone beds below the Lower Ardley ' $B$ ' coal zone makes this marker bed an adequate datum for the base of groundwater exploration. The strata above the coal zone contain two regionally extensive units dominated by sandstone beds: a deep basal unit that averages about 200 feet ( 60 m ) thick and a near-surface unit which is usually less than a 100 feet ( 30 m ) in thickness. The shallow sandstone unit is a major aquifer in the Pine Lake basin.
3. Bedrock exposures in the basin are sparse due to the presence of a surficial mantle of glacial drift. The drift is generally less than 50 feet ( 15 m ) thick but can exceed 140 feet ( 43 m ). in areas of hummocky moraine and along a buried bedrock drainage way (Archithinue Valley) that is presently occupied by Pine Lake and Ghostpine Creek. Till is the most abundant drift material. Deposits of sands and gravel occur in outwash deposits near Pine Lake, along Ghostpine Creek, and in a few esker ridges.

## Hydrologic Results

1. Based on two years of streamflow data, annual surface runoff may be in the magnitude of 0.80 inches ( 2 cm ) over the drainage basin. Estimating the baseflow component from such scanty runoff data is highly questionable. However, an "average" value of 0.14 inches ( 0.36 cm ) was calculated from minimum monthly discharges.
2. Pine Lake is a major groundwater discharge feature but without information regarding evaporation rates, surface water inflows and outflows, and the effective drainage area, calculation of an accurate water budget is impossible. Analyses of lake level hydrographs ( 4 years) yielded a mean annual "net evaporation'l equal to 19 inches ( 48 cm ).
3. The water table is a subdued replica of the topography, Regional groundwater flow is from broad recharge areas on the surrounding uplands and hummocky terrain toward wide discharge areas centered along the drainage ways. This is supported by the fact that hydraulic heads are observed to decrease with depth on the drainage ridges and increases with depth along the valley bottom. In addition, flowing wells and numerous springs are concentrated in the vicinity of major topographic lows.
4. Interpretation of short pump test data and geological considerations indicates the following ranges of hydraulic conductivity: sandstone, 10 to 500 igpd/ft ${ }^{2}$ ( 0.5 to $25 \mathrm{~m} /$ day); siltstone, 5 10 igpd $/ \mathrm{ft}^{2}$ ( 0.25 to $0.50 \mathrm{~m} /$ day ); shale, 1 to 5 igpd $/ \mathrm{ft}^{2}$
( 0.05 to $0.25 \mathrm{~m} /$ day); sand and gravel, 100 to $2000 \mathrm{igpd} / \mathrm{ft}^{2}$ ( 5 to $100 \mathrm{~m} /$ day) ; and till, $10^{-3}$ to $1 \mathrm{igpd} / \mathrm{ft}^{2}$ ( $10^{-5}$ to $10^{-2}$ $\mathrm{m} /$ day). Anisotropy ratio are estimated to be about 50 to 100 : 1 for the bedrock, $10: 1$ for the $t i l l$, and 1 : 1 for surficial sands and gravels. Field determined storage coefficients are rare but most bedrock aquifer tests can be expected to obtain storativities in the $10^{-4}$ to $10^{-2}$ range, depending on the degree of local confinement.
5. Based on their relative hydrologic properties, four major hydrostratigraphic units are delineated: Unit 1 is assigned to the glacial drift; Unit 2 includes those strata presently penetrated by domestic wells down to the top of the thick basal sandstone; Unit 3 is assigned to the strata of the thick basal sandstone down to the Lower Ardley ' $B$ ' coal zone; and Unit 4 to the rocks below the coal zone. Such a division is of course partly conjectural but it provides a starting point from which future studies can build upon and refine.
6. Groundwater flow in the research basin is most appropriately treated as a regionally unconfined system in a heterogeneous and anisotropic rock media, The absence of regional confining units and the hydraulically connected nature of the subsurface strata support this interpretation. As a first approximation, the groundwater regime can also be considered to be in steady state. This is supported by the fact that the configuration of the water table has not changed over the years, fluctuations
of water-table levels is small compared to the saturated thickness of the system, and pumping of groundwater in the basin is insignificant.

Hydrogeochemistry

1. The complex mineralogical assemblages in the glacial drift and operation of geochemical processes during infiltration are largely responsible for determining the existing hydrochemical facies pattern in the Pine Lake research basin. Sodiumbicarbonate is by far the most prominent hydrochemical facies in the bedrock but superimposed upon it are facies of: $\mathrm{Ca}-\mathrm{Mg}-\mathrm{HCO}_{3}, \mathrm{Na}-\mathrm{SO}_{4}-\mathrm{HCO}_{3}$ and $\mathrm{Ca}-\mathrm{Mg}-\mathrm{SO}_{4}-\mathrm{HCO}_{3}$. Total dissolved solids are commonly less than $1000 \mathrm{mg} / \mathrm{l}$ in the groundwater, at least within 300 feet ( 90 m ) of the surface.
2. Drift groundwaters are usually hard and characterized by the $\mathrm{Ca}-\mathrm{Mg}-\mathrm{HCO}_{3}$ facies. A Ca-Mg- $\mathrm{SO}_{4}-\mathrm{HCO}_{3}$ facies may develop where soluble sulfate minerals are present. Geochemical processes such as cation exchange and sulfate reduction are responsible for the transition of these shallow "recharge" facies to the dominant $\mathrm{Na}-\mathrm{HCO}_{3}$ water at depth.
3. In general, correlation of hydrochemical facies with groundwater flow patterns is presently untenable and should receive considerable more research before major conclusions are drawn.

Groundwater Resources

1. Nearly all wells in the Pine Lake basin are completed in bedrock aquifers, mainly because of ease in well construction, better water quality and higher probability of penetrating a dependable supply of water. In most parts of the basin, shallow bedrock wells should be able to obtain sustained 20-year safe yields in the 5 to 25 igpm ( 25 to $115 \mathrm{l} / \mathrm{m}$ ) range. Wells completed in the thick shallow sandstone unit may be capable of yielding more than 100 igpm ( $450 \mathrm{l} / \mathrm{m}$ ).
2. The ultimate purpose in evaluating the groundwater resources of a basin is to determine groundwater recharge. Through the analysis of water-table fluctuations recorded in three observation wells, the average depths of recharge amounted to 7.7 inches ( 20 cm ), 1.2 inches ( 3 cm ) and 0.9 inches ( 2 cm ), annually. Application of a steady-state drainage equation to a schematic representation of the Pine Lake basin resulted in an estimate of annual discharge of 2 inches ( 5 cm ) over the basin. Quantitative evaluation of the distribution of groundwater recharge is obviously going to require a more sophisticated approach than those above, if meaningful groundwater budgets are to be performed.

## Recommendations

Instrumentation
In terms of evaluating the quantitative aspects of the groundwater regime, some form of piezometer gridshould be established in the

Pine Lake basin. Based on the preliminary assessment of the hydrogeology and conceptualized groundwater flow pattern, the most functional design would consist of several piezometer nests arranged in a line and kept approximately parallel to the maximum topographic gradient. Ideally, three of these line networks would be useful; one across the northern, central and southern parts of the research basin. Because of the near symmetry of the basin, individual lines would only need to extend from one drainage divide to the valley bottom, although at least one should extend across the complete basin to investigate the symmetry assumption.

The number of nests along each piezometer line could be varied with the local conditions but a minimum of three would be required: one near the ridge, midway on the basin flank and at the drainage way. This initial instrumentation phase could later be expanded by installing piezometer nests between existing ones and so on.

Individual piezometer nests would have to be designed for the local site conditions. On the ridges this could entail locating the deepest piezometer at a depth of 500 feet ( 150 m ) or more. Toward the drainage divide this maximum piezometer depth would not need to exceed 400 feet ( 120 m ) in order to penetrate the main hydrostratigraphic units. Each nest should consist of at least three piezometer openings completed at some arbitrary depth interval, either in separate smalldiameter boreholes side by side or possibly in the same hole. Commercially available piezometer units are now available that offer a number of sophisticated designs. These units use a variety of pressure
transducers, packer assemblies and advanced electronics to take measurements of head or hydraulic conductivity and obtain samples for chemical analysis at several piezometer openings. In addition to a sufficient number of piezometers at a site, a water-table well should also be installed and equipped with a recorder. Good estimates of hydraulic conductivity can be obtained from the piezometers by applying the Hvorslev (1951) method to recovery data. An alternative would be to complete a few exploratory test holes of sufficient diameter throughout the basin for standard aquifer testing procedures.

Some sort of instrumentation of the unsaturated zone should also be considered. Experimental plots could be established at both a recharge and discharge area and the relationships between infiltration, evapotranspiration, soil moisture and groundwater recharge or discharge investigated. This type of site could include a precipitation gage, neutron probe access tubes, water-table observation well, tensiometers and perhaps a shallow piezometer nest.

At the present, only one meteorological station exists in the basin and that is in the northern part. Temporary precipitation gages should be established, prefereably to the west of Pine Lake and in the southern part of the basin. Runoff is one of the easiest components of the hydrologic cycle to measure in the field and such data would be desirable for the Pine Lake research basin. Establishing a permanent streamflow gaging station at the southern outlet of the research basin would be worthwhile. Temporary stations would have to be considered at the major inlets and outlets of Pine Lake if a serious analysis of
its water budget is attempted in the future. The actual interaction between Pine Lake and the groundwater regime would best be defined through piezometric analyses.

Future Study
A conclusion that is apparent from this investigation is that significant amounts of information can be derived from careful interpretation of basic data. However, in order to properly quantify the accuracy of these data, a certain amount of controlled testing is warranted. The stratigraphic relationships in the basin were constructed largely from geophysical data which should be verified by a few test holes. Aquifer testing could be conducted in these holes such that estimates of hydraulic conductivity are available for the deeper strata in the basin. Shallow test drilling is also needed in many parts of the basin to complete the hydrogeologic and hydrogeochemical picture. Areas where this is most needed can be discerned from the various maps presented earlier.

Perhaps the most important recommendation that can be made is the application of numerical modeling techniques. Now that the general aspects of the hydrogeologic environment and groundwater regime have been determined, numerical modeling of the basin could provide additional insight. This would be especially true in delineating possible groundwater flow patterns for the given water-table configuration and stratigraphic relationships. Preliminary flow net analysis could be used to identify the spatial distribution of recharge and discharge and quantitatively investigate their orders of magnitude for
various boundary conditions. Numerical modeling could also be integrated with future field programs whereby it may aid the researcher in deciding the most optimum locations of piezometers or other instrumentation. Furthermore, its role in understanding the interaction between Pine Lake and the groundwater flow systems would be invaluable.

## APPENDIX A

## SHALLOW WELL AND SPRING DATA

## Notes to Appendix A

1. Column 3: Elevation of land surface in the vicinity of the well as determined by extrapolation from topographic map having 25 ft contour interval.
2. Column 9: Type of well refers to the geology of the material in which the well is completed.
3. Column 11: Available drawdown ( $H$ ) is defined as the difference between static water level and the top of an aquifer.
4. Column 12: $T=$ transmissivity, $K=h y d r a u l i c ~ c o n d u c t i v i t y ~ a s ~$ determined from bail test.
5. Column 13: $Q_{20}=$ maximum discharge rate which can be sustained over a 20-year period without drawdown below the top of an aquifer (calculated via $Q_{20}=\frac{T \cdot H}{2110}$ ).

| $\begin{aligned} & \text { Index } \\ & \text { llumber } \end{aligned}$ | Loction | $\left\|\begin{array}{c} \text { Elevantion } \\ \text { cman } \\ \text { Impeet } \\ 0 . m . s .1 . \end{array}\right\|$ | $\left\|\begin{array}{c} \text { Depent } \\ 0 \\ \text { well } \\ \text { ret. } \end{array}\right\|$ | $\begin{gathered} \text { Construct lon, } \\ \text { Depth Interval } \\ \text { Open to } \\ \text { Aquifers } \\ \text { (feet) } \end{gathered}$ | use |  | $\begin{gathered} \text { Depth } \\ \text { to } \\ \text { Bedrock } \\ \text { Elev. } \\ \text { (feet) } \end{gathered}$ | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { Hell } \end{aligned}$ | $\begin{gathered} \text { Lithology } \\ \text { quoifer } \end{gathered}$ | $\begin{gathered} \text { Avar lable } \\ \text { Or audown } \\ \text { (feet) } \end{gathered}$ | $\begin{gathered} \mathrm{r}(\mathrm{lgpd} / \mathrm{ft}) \\ \mathrm{g}(\mathrm{gnd}) \\ \times\left(\mathrm{gpd} / \mathrm{ff}^{2}\right) \end{gathered}$ | $\begin{gathered} a_{20} \\ (\mathrm{igmm}) \end{gathered}$ | Other Remark |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 5-1-35-2464 | 2825 | 70 |  | Sthet mole | $\left\lvert\, \begin{gathered} \text { Fiowing } \\ 28254 \end{gathered}\right.$ |  |  |  |  |  |  |  |
| 2 | 9-2-35-24.44 | 2825 | 75 |  | Domestic | $\underset{\substack{\text { Flowing } \\ 2825 t}}{ }$ |  | Bedrock? |  |  |  |  | $\begin{aligned} & \text { Chem. sualvals } \\ & \text { Avaitable } \end{aligned}$ |
| 3 | 3-4-35-2464 | 2980 | 140 | 100-140 | $\begin{gathered} \text { Domestlc } \\ \text { stock } \end{gathered}$ | $\underset{2890}{90.2}$ | 27 2953 | pedrock | Sandstone | 40 | $\begin{gathered} 90 \\ (k=2) \end{gathered}$ | 2 | reco |
| 4 | 8-4,-35-24464 | 2970 | 108 |  | $\begin{gathered} \text { Domestlc } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 355 \\ 2935 \end{array}$ |  |  |  |  |  |  | $\begin{aligned} & \text { Chemi, enalysis } \\ & \text { Avail able } \end{aligned}$ |
| 5 | 10-1-35-2444 | 310 | 190 |  | Domestic |  |  |  |  |  |  |  | chem: anolysis Aval loble |
| 6 | 14-7-35-2444 | 3085 | 122 | 70-122 | $\begin{gathered} \text { Domestle } \\ \text { stock } \end{gathered}$ | - $\begin{gathered}69 \\ 3016\end{gathered}$ | 25 3060 | Bedrock | $\begin{aligned} & \text { Fractured } \\ & \text { Sandstone } \end{aligned}$ | 50 | $\begin{gathered} 400 \\ (k=16) \end{gathered}$ | 9 | ery da |
| 7 | 14-9-35-24.44 | 3050 | 150 |  | Ommestle | 131 <br> 2919 |  | Bedrock | Sandstone |  |  |  |  |
| - | 5-9-35-24046 | 3030 | 230 | 221-230 | Domestic | $\begin{array}{r} 130 \\ 2900 \end{array}$ | 30 3010 | medrock | Sandstone | 90 |  |  | Pumped al 5 gpm |
| 9 | 16-9-35-2444 | 3045 | 252 |  | $\begin{gathered} \text { Domest lc } \\ \text { stock } \end{gathered}$ | $\left\lvert\, \begin{gathered} 180 \\ 2765 \end{gathered}\right.$ |  | Redrock |  |  |  |  | them, analysis |
| 10 | 16-9-35-2444 | 3045 | 262 | $240-262$ | $\begin{gathered} \text { Domest ic } \\ \text { stock } \end{gathered}$ | $\|$170 <br> 2875 | 15 3030 | betrock | Sandstomes | 90 | ${ }_{\substack{5 \\(k \times 6)}}^{50}$ | 24 | Recovery data |


| Indem Number | Location | $\begin{gathered} \text { Elevation } \\ \text { (mad) } \\ \text { in feet } \\ 0 . m . s .1 . \end{gathered}$ | $\left\lvert\, \begin{gathered} \text { Depth } \\ \text { of } \\ \text { Wcil } \\ (\mathrm{rt} .) \end{gathered}\right.$ | Construction. Deoth Interval Open to Aquifers (reet) | Use | Depth to Wister Elev. (fect) | ```Depth to Bedrock Elev. (foct)``` | Type of Well | Lithology of Aquifer | Avallable Drawdown (feet) | $\begin{aligned} & T(i g p d / f t) \\ & \text { and } \\ & K\left(i_{\text {gpd }} / f^{2}\right) \end{aligned}$ | $\begin{gathered} Q_{20} \\ (i g \mathrm{pm}) \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 11 | $10-9-35-24.14$ | 3060 | 190 | 140-190 | Stock | $\begin{array}{r} 123 \\ 2937 \end{array}$ | $\begin{array}{r} 27 \\ 3033 \end{array}$ | Bedrock | Fractured Shale sillstones | 63 | $\begin{gathered} 940 \\ (K=14) \end{gathered}$ | 27 |  |
| 12 | 7-10-35-24/44 | 2910 | 300 |  |  | $\begin{array}{r} 30 \\ 2880 \end{array}$ |  | Aicdrock |  |  |  |  | Chem. Analysis Available |
| 13 | 15-12-35-2414 | 3055 | 230 |  | Ommestic | $\begin{array}{r} 60 \\ 2995 \end{array}$ |  | Bedrock |  |  |  |  | Chem. Analysis Avallable |
| 14 | 1-13-35-24.14 | 3035 | 215 |  | Onmestic |  |  |  |  |  |  |  | Chem. Analysis Availatle |
| 15 | 9-13-35-24W4 | 3035 | 210 |  |  | $\begin{array}{r} 170 \\ 2865 \end{array}$ |  |  |  |  |  |  |  |
| 16 | 16-14-35-2414 | 3075 | 266 | 200-266 | Domestic | $\begin{array}{r} 221 \\ 2854 \end{array}$ |  | Aedrock |  |  |  |  | Chem. Analysis Ausilable |
| 17 | 1-15-35-24.144 | 2875 | 85 |  |  | $\begin{array}{r} 15 \\ 2860 \end{array}$ |  | Redrock |  |  |  |  |  |
| 18 | 8-15-35-2444 | 2870 | 118 | - | Domestic | $\begin{array}{r} 10 \\ 2860 \end{array}$ |  | Bedrock |  |  |  |  | Chem. Anaitysis nuailable |
| 19 | 8-17-35-2414 | 3050 | 90 | 70-90 | stock | $\begin{array}{r} 30 \\ 3070 \end{array}$ | 35 3015 | Ardrack | fandstone (Coal?) | 55 | $\begin{gathered} 900 \\ (k-18) \end{gathered}$ | A | Chem. Aliolygis nuailathe |
| 20 | 1-18-35-24/44 | 3045 | 65 |  |  | 40 3005 |  |  |  |  |  |  |  |


| Index Number | Location | $\begin{gathered} \text { Elevation } \\ \text { (map) } \\ \text { in reet } \\ \text { a.m.s.l. } \end{gathered}$ | $\begin{gathered} \text { Depth } \\ \text { of } \\ \text { Well } \\ \text { (ft.) } \end{gathered}$ | Construction. Depth Interval Open to Aquifers (feet) | Use | Depth to Wnter Elev. (feet) | $\begin{gathered} \text { Depth } \\ \text { to } \\ \text { Hedrock } \\ \text { Elev. } \\ \text { (feet) } \end{gathered}$ | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { Well } \end{aligned}$ | Lithology of Aguifer | Available Orawdown (feet) | $\begin{aligned} & T(i g n d / f t) \\ & \text { and } \\ & K\left(i g p d / f t^{2}\right) \end{aligned}$ | $\begin{gathered} Q_{20} \\ \text { (igpm }) \end{gathered}$ | Other <br> Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 21 | 15-19-35-2444 | 2950 | 15 |  | Stock | $2947$ |  |  |  |  |  |  |  |
| 22 | 2-20-35-2464 | 3000 | 80 | 48-80 | Stock | $2958$ | $\begin{array}{r} 37 \\ 2963 \end{array}$ | Bedrock | Sandstone | 30 | $\begin{gathered} 20,610 \\ (1) \end{gathered}$ | 407 | Chem. Analysis Avallable |
| 23 | 16-20-35-2464 | 2920 | 96 | 71-96 | Domestic | $\begin{array}{r} 35 \\ 2885 \end{array}$ | $\begin{array}{r} 45 \\ 2875 \end{array}$ | Bedrock | Sindstone | 50* | $\begin{gathered} 1635 \\ (k=65) \end{gathered}$ | 39 |  |
| 24 | NW-20-35-24wh | 2890 | 30 |  |  | $\begin{array}{r} \text { Flowlng } \\ 2890+ \end{array}$ |  |  |  |  |  |  |  |
| 25 | 8-21-35-24W4 | 2875 | 58 |  | Domest la | $\begin{array}{r} 22 \\ 2853 \end{array}$ |  | Aetrock |  |  |  |  | Chem. Analysis Avallable |
| $\begin{aligned} & \text { R.C.A. } \\ & 77-6 \end{aligned}$ | 13-21-35-2464 | 2870 | 150 |  | Test Hole | Flows 28704 | $\begin{gathered} 1327 \\ 2738 \end{gathered}$ |  | Sand, Gravel Sandstone |  |  |  |  |
| 26 | 12-22-35-24 ${ }^{\text {W }}$ | 2910 | 132 | 112-132 | Stock | $\begin{array}{r} 40 \\ 2870 \end{array}$ | $\begin{array}{r} 28 \\ 2882 \end{array}$ | Bedrock | Sandstme. <br> silistone <br> (Practured) | 60 | $\begin{gathered} 7330 \\ (k=163) \end{gathered}$ | 208 | Chem. Analysis puallable |
| 21 | 4-23-35-24W4 | 2900 | 60 |  |  | 2891 |  |  |  |  |  |  |  |
| 28 | 15-24-35-24N4 | 3040 | 230 | 190-230 | Domestic | $\begin{array}{r} 160 \\ 2880 \end{array}$ | 43 2991 | Ardrock | Sandstome | 60 | $\begin{aligned} & 150 \\ & (k=2.8) \end{aligned}$ | 4 |  |
| 29 | 1-26-35-24W4 | 3060 | 286 |  | Onmestic | $\begin{array}{r} 50 \\ 3010 \end{array}$ | 19 3041 | Redrock | Shale no aquifers |  |  |  | $\left\lvert\, \begin{aligned} & \text { <l } \\ & \text { well } \\ & \text { anm abandened }\end{aligned}\right.$ |


| Index Humber | Location | $\left\|\begin{array}{c\|} \text { Elevation } \\ (\text { map }) \\ \text { in reet } \\ \text { a.m. } \end{array}\right\|$ | $\left\lvert\, \begin{gathered} \text { Depth } \\ \text { or } \\ \text { Well } \\ (12 .) \end{gathered}\right.$ | Construction, Depth Interval Onen to Aquifers (feet) | Use | Depth to Nater Elev. (feet) | $\begin{array}{\|c} \text { Depth } \\ \text { 1o } \\ \text { Oerirock } \\ \text { E1rv. } \\ \text { (Iect) } \end{array}$ | $\begin{aligned} & \text { Type } \\ & \text { nf } \\ & \text { hell } \end{aligned}$ | Lithology of Anuifer | Available <br> Drawriown <br> (feet) | $\begin{gathered} T(i \operatorname{god} / f t) \\ \text { and } \\ K\left(i g p d / \mathrm{ft}^{2}\right) \end{gathered}$ | $\begin{gathered} a_{20} \\ \left(i_{9 p m}\right) \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 30 | 5-26-35-24M4 | 3085 | 260 |  | Domestic stock | $\begin{array}{r} 120 \\ 2965 \end{array}$ | $3066$ | Bedrock | Shale <br> shistones | 120 | $\stackrel{20}{(k=2)}^{(20}$ | 1 | No toq avallable |
| 31 | 5-26-35-2414 | 3085 | 250 |  | Domestic | $\begin{array}{r} 191 \\ 2894 \end{array}$ | $\begin{array}{r} 25 \\ 3060 \end{array}$ | Fedrock | Sandstone | 50 |  |  |  |
| 32 | 13-26-35-2414 | 3115 | 240 | 186-240 | Domestic stock | $\begin{array}{r} 143 \\ 2972 \end{array}$ | $3060$ | Bedrock | Sandstone | 85 | $\begin{aligned} & 3960 \\ & (k=43) \end{aligned}$ | 160 |  |
| 33 | 13-26-35-24M4 | 3115 | 158 |  |  |  |  | Bedrock |  |  |  |  | Chem. Analysis Avallable |
| 33.5 | 11-28-35-2414 | 2915 | 160 | 145 | Domestic stock | $\begin{array}{r} 20 \\ 2895 \end{array}$ | $\begin{array}{r} 45 \\ 2870 \end{array}$ | Bedrock | Fractured <br> shate, coal | 130 | $\underset{(K=4)}{50}$ | 3 | Recovery data |
| 34 | 2-29-35-2444 | 2950 | 81 | 70-81 | Stock | $\begin{array}{r} 60 \\ 2890 \end{array}$ | 14 2936 | Bedrock | Sandstone | $15+$ | $\begin{aligned} & 1310 \\ & (\mathrm{~K}=66) \end{aligned}$ | 9 | Chem. Analysls Avallable |
| 35 | 8-29-35-2444 | 2885 | 140 | 120-140 | Domestic | $\begin{array}{r} 23 \\ 2862 \end{array}$ | 117 2768 | Bedrock | Sandstore | 110 | $\begin{aligned} & 13.080 \\ & (k=1 / 4) \end{aligned}$ | 680 |  |
| 36 | 2-30-35-24/4 | 2980 | 60 | 40-60 | Domestic | $\begin{array}{r} 399 \\ 2941 \end{array}$ | $\begin{array}{r} 36 \\ 2944 \end{array}$ | Bedrack | Sandsione shale | 15* | 29.930 | 190 |  |
| 37 | 4-30-35-2414 | 3010 | 110 |  | Domestic | $\begin{array}{r} 55 \\ 2955 \end{array}$ |  | Aedrock | ? |  |  |  | Chem. Analysis avallable |
| 38 | 4-31-35-2644 | 3020 | 50 |  | Domestle | 30 290 |  | Drirte |  |  |  |  | Chem. Analysis puallable |


| Index Number | Location | $\begin{array}{\|c\|} \hline \text { Elevation } \\ \text { (mpap) } \\ \text { ancet } \\ \text { a.m.s.l. } \end{array}$ | $\left\lvert\, \begin{gathered} \text { Depth } \\ \text { of } \\ \text { vell } \\ \left(\begin{array}{l} \text { fe. } \end{array}\right. \\ \hline \end{gathered}\right.$ | Construction, Depth Interval Open to Aquifers (feet) | Use | Depth to Hater Elev. (feet) | Depth to Bedrock Elev. (feet) | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { Well } \end{aligned}$ | $\begin{aligned} & \text { Withology } \\ & \text { of } \\ & \text { Aguifer } \end{aligned}$ | Avallatle <br> Orawdown (feet) | $\begin{gathered} 1(1 \mathrm{gpd} / \mathrm{ft}) \\ \substack{\text { and } \\ K\left(\text { igpd }^{2} / \mathrm{ft}^{2}\right)} \end{gathered}$ | $\begin{gathered} Q_{20} \\ (19 \mathrm{pm}) \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 39 | NE-31-35-24N4 | 2975 | 146 | 106-146 | Stock | $\begin{array}{r} 65 \\ 2910 \end{array}$ | $\begin{array}{r} 36 \\ 2939 \end{array}$ | Bedrock | Sandstone | 75 | $\begin{array}{r} 3120 \\ 1950 \end{array}$ | 110 | Recovery data |
| 40 | NW-31-35-24W4 | 3030 | 96 |  |  | 35 2995 |  |  |  |  |  |  | $\begin{aligned} & \text { Chem. Analysis } \\ & \text { Avaliable } \end{aligned}$ |
| 41 | 12-32-35-24/4 | 2930 | 80 |  |  | 20 2910 |  |  |  | - |  |  | Chem. Analysls Avallable |
| 42 | 9-33-35-2444 | 3025 | 60 |  | Shot thele | $\begin{aligned} & \text { Flowing } \\ & 3025+ \end{aligned}$ |  |  |  |  |  |  |  |
| 43 | 1-34-35-24.46 | 3095 | 160 | 130-160 | Domestic stock | $\begin{array}{r} 121 \\ 2974 \end{array}$ | 51 3044 | Bedrock | Sands tone | 35+ | $\begin{gathered} 23.880 \\ (k=220) \end{gathered}$ | 396 |  |
| 44 | 1-34-35-2464 | 3095 | 135 |  | $\begin{array}{\|c} \text { Domes lle } \\ \text { stock } \end{array}$ | $\begin{array}{r} 100 \\ 2995 \end{array}$ |  |  |  |  |  |  |  |
| 45 | 4-34-35-2444 | 3010 | 70 | 52-70 | $\begin{gathered} \text { momestic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 42 \\ 2968 \end{array}$ | $\begin{array}{r} 35 \\ 2975 \end{array}$ | Aedrock | Sandstone | $25+$ | 53.990 | 640 | Recovery data |
| 46 | 12-35-35-2444 | 3110 | 215 |  | pomestic |  |  | Redrock |  |  |  |  | them. Analysis Avallable |
| 47 | 1-36-35-24414 | 2957 |  |  | Shot tole | $\begin{gathered} \text { Flowing } \\ 2957+ \end{gathered}$ |  |  |  |  |  |  |  |
| 48 | SE-36-35-24.44 | 3025 | 3 |  | Spring | 3032 |  | Drifi |  |  |  |  | them. Analysls huailable |


| Index Number | Locstion | $\begin{gathered} \text { Elevation } \\ \text { (man) } \\ \text { in feet } \\ \text { a.m.s.l. } \end{gathered}$ | $\left\|\begin{array}{c} \text { Depth } \\ \text { of } \\ \text { Well } \\ \text { (ri.) } \end{array}\right\|$ | Construction, Depth interval Open to Aquifers ( Feet) | Use | Depth to Water Elev. (feet) | ```Depth to Acdrock Elev. (feet)``` | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { Hell } \end{aligned}$ | Lithology of Aquifer | Available Drawdown (feet) | $\begin{gathered} T(i g p d / f t) \\ \text { and } \\ K\left(i g p d / \mathrm{ft}^{2}\right) \end{gathered}$ | $\left\{\begin{array}{c} Q_{20} \\ (1 \mathrm{gpm}) \end{array}\right.$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 49 | 12-1-35-25wh | 3095 | 96 |  | Domestlc | $\begin{array}{r} 50 \\ 3045 \end{array}$ |  |  |  |  |  |  |  |
| 50 | 12-2-35-2544 | 3035 |  |  | Shot hole | $\begin{gathered} \text { Flowing } \\ 3035+ \end{gathered}$ |  |  |  |  |  |  |  |
| 51 | 9-3-35-25w4 | 3030 |  |  | Shot trole | $\begin{array}{r} \text { Flowing } \\ 3030^{+} \end{array}$ |  |  |  |  |  |  |  |
| 52 | 4-9-35-25044 | 3025 | 115 | 100-115 | Domestic | $\begin{array}{r} 30 \\ 2.995 \end{array}$ | $\begin{array}{r} 85 \\ 2940 \end{array}$ | Bedrock | Shale. <br> Sandstone | 704 |  | . | Chem. analysis avallable |
| 53 | 1-10-35-25W4 | 3030 | 98 | 84-98 | $\begin{gathered} \text { Oomestic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 35 \\ 2995 \end{array}$ | $\begin{gathered} 821 \\ 2948 \end{gathered}$ | Bedrock | Sands tome | 50 |  |  |  |
| 54 | 14-12-35-2514 | 3130 | 150 |  | Domestic | $\begin{array}{r} 20 \\ 3110 \end{array}$ |  | Bedrock |  |  |  |  | Chem. analysis avallable |
| 55 | 2-13-35-2514 | 3140 | 65 |  | Domestle stock | $\begin{array}{r} 45 \\ 3095 \end{array}$ |  |  |  |  |  |  |  |
| 56 | 13-13-35-2504 | 3120 | 220 | 180-220 | Domestic stock | $\begin{array}{r} 115 \\ 3005 \end{array}$ | $\begin{array}{r} 32 \\ 3088 \end{array}$ | Bedrock | Sandstones | 85 | $\begin{gathered} 240 \\ (K=3) \end{gathered}$ | 10 |  |
| 57 | 13-13-35-2564 | 3120 | 205 | 170-205 | Domes stic stock | $\begin{array}{r} 120 \\ 3000 \end{array}$ | $\begin{array}{r} 24 \\ 3096 \end{array}$ | Bedrock | Sandstones | 80 | 50 | 2 | Recovery data |
| 58 | 13-13-35-2514 | 3120 | 290 |  | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 140 \\ 2980 \end{array}$ |  | Hedrock |  |  |  |  | Chem. analys's avallable |


| Index Itumber | Location | $\begin{gathered} \text { Elevation } \\ \text { (map) } \\ \text { in feet } \\ \text { 0.m. } 5.1 . \end{gathered}$ | $\left\|\begin{array}{c} \text { Oepth } \\ \text { of } \\ \text { well } \\ \text { (Ft.) } \end{array}\right\|$ | Construction, Depth Interval Open to Aquifers (feet) | Use | Depth to Water Elev. (feet) | ```Depth to Bedrock Elev. (feet)``` | Type of Well | Lithology of Aquifer | Avallable Drawdown (feet) | $\begin{aligned} & T(i g o d / f t) \\ & \text { and } \\ & K\left(i g p d / f t^{2}\right) \end{aligned}$ |  | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 59 | 4-15-35-2544 | 3100 | 102 | 60-102 | Omestic stock | $\begin{array}{r} 42 \\ 3058 \end{array}$ | $\begin{array}{r} 38 \\ 3062 \end{array}$ | Bedrock | Sandstone. coals | 50+ |  |  | Chem. analysis avallable |
| 60 | 4-15-35-2544 | 3100 | 60 |  | Stock | $\begin{array}{r} 27 \\ 3073 \end{array}$ |  | Bedrock $7$ |  |  |  |  | Chem. analysis avallable |
| 61 | 1-17-35-2564 | 3075 | 125 | $87-125$ | Domestic stock | $\begin{array}{r} 72 \\ 3003 \end{array}$ | $\begin{array}{r} 84 \\ 2991 \end{array}$ | Bedrock | Fractured shale | 45 | $\begin{gathered} 370 \\ (k=10.6) \end{gathered}$ | 8 | Chem. analysis avallable <br> Recovery data |
| 62 | 15-20-35-2504 | 3150 | 158 | 98-158 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 104 \\ 3046 \end{array}$ | $\begin{array}{r} 80 \\ 3070 \end{array}$ | Pedrock | Sandstone | 50 | $\begin{gathered} 180 \\ (k=4.5) \end{gathered}$ | 4 |  |
| 63 | 15-21-35-2514 | 3150 | 90 | 65-90 | Domestla stock | $\begin{array}{r} 23 \\ 3127 \end{array}$ | $\begin{array}{r} 31 \\ 3119 \end{array}$ | Bedrock | Sandstone cnal | 50 | $\begin{gathered} 3060 \\ (k=50) \end{gathered}$ | 73 |  |
| 64 | 16-21-35-2514 | 3120 | 78 |  | Stock | $\begin{array}{r} 15 \\ 3105 \end{array}$ |  |  |  |  |  |  |  |
| 65 | 16-22-35-2514 | 3150 | 205 |  |  | $\begin{array}{r} 100 \\ 3050 \end{array}$ |  |  |  |  |  |  |  |
| 66 | 8-23-35-2514 | 3075 | 130 | 110-130 | Domestic stock | $\begin{array}{r} 85 \\ 2990 \end{array}$ | $\begin{array}{r} 25 \\ 3050 \end{array}$ | Bedrack | Sandstome | 40 | $\begin{gathered} 4670 \\ (k-40) \end{gathered}$ | 88 | Recovery data Chem. analysis available |
| 61 | SE-25-35-2514 | 3075 | 125 |  | Dormestic | $\begin{array}{r} 120 \\ 2905 \end{array}$ |  | Bedrock |  |  |  |  | chem. analysis Gvallable |


| Index Number | Location | $\begin{gathered} \text { Elevation } \\ \text { (man) } \\ \text { in feet } \\ \text { a.m. } 5.1 . \end{gathered}$ | $\left\lvert\, \begin{gathered} \text { Depth } \\ \text { of } \\ \text { ucll }^{\prime} \\ (\mathrm{ft} .) \end{gathered}\right.$ | Construction, Depth Interval Open to Aquifers (feet) | Use | Denth <br> In Hater flev. (fect) | Denth 10 Bedrock Elrv. (rcet) | Typr of Well | Lithology of Aquifer | Avallable Drawdown (feet) |  | $\begin{gathered} Q_{20} \\ (i \mathrm{gpm}) \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 68 | 4-25-35-25N4 | 3065 | 132 |  | Oomestic | $\begin{array}{r} 120 \\ 2945 \end{array}$ |  |  |  |  |  |  | Chem. Analysis avallable |
| 69 | 2-27-35-25N4 | 3190 | 183 | $118-183$ | Domestic stock | $\begin{array}{r} 87 \\ 3103 \end{array}$ | $\begin{array}{r} 95 \\ 3095 \end{array}$ | Hedrock | Sandstone coal | 90 | $\begin{gathered} 245 \\ (k=3) \end{gathered}$ | 10 | Chem. Analysis avaliable |
| 70 | 2-27-35-2514 | 3190 | 220 | 180-220 | Dommestic | $\begin{array}{r} 159 \\ 3031 \end{array}$ | $\begin{array}{r} 4 \\ 3186 \end{array}$ | Bedrock | $\begin{aligned} & \text { Sandstone } \\ & \text { conis } \end{aligned}$ | $55+$ |  | >20 |  |
| 71 | 9-27-35-2544 | 3125 | 164 | 144-164 | $\begin{gathered} \text { Onmest lic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 123 \\ 3002 \end{array}$ | $\begin{array}{r} 24 \\ 3101 \end{array}$ | Bedrock | Sandstone | 354 | $\begin{aligned} & 4670 \\ & (k=29) \end{aligned}$ | .278 | Recovery data |
| 72 | 2-28-35-2514 | 3180 | 115 | 90-115 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 52 \\ 3128 \end{array}$ | $\begin{array}{r} 28 \\ 3152 \end{array}$ | Bedrock | Fractured slltstone. shale | 45 | $\underset{(k=1.7)}{102}$ | >2 |  |
| 73 | 3-29-35-2514 | 1150 | 17 |  |  | $\begin{array}{r} 4 \\ 3146 \end{array}$ |  |  | - |  |  |  |  |
| 74 | 3-30-35-2514 | 3050 | 8002 |  | 011 well or gas |  |  |  |  |  |  |  | $\begin{aligned} & \text { E-Log Avallible } \\ & \text { f00' } \end{aligned}$ |
| 75 | 56-32-35-2504 | 3190 | Spring |  | Stock | 31904 |  |  |  |  |  |  |  |
| 76 | 6-34-35-2544 | 3089 | 3275 |  | $\begin{aligned} & 011 \text { or } \\ & \text { fas Well } \end{aligned}$ |  |  |  |  |  |  |  | $\begin{aligned} & -\log \text { Avallable } \\ & 300^{\prime}+ \end{aligned}$ |
| 77 | 12-34-35-2514 | 3175 | 200 |  | Domestic | $\begin{array}{r} 100 \\ 3075 \end{array}$ | 55 3170 | Bedrack | Sindsione. Shale | 80 | $\begin{gathered} 500 \\ (k-42) \end{gathered}$ | 20 |  |


| $\left\lvert\, \begin{aligned} & \text { Index } \\ & \text { number } \end{aligned}\right.$ | Location | Elevotion <br> impret <br> impet <br> a.m.s.1. | $\left\|\begin{array}{c} \text { Depth } \\ o \\ \text { well } \\ (f t .) \end{array}\right\|$ |  | use | $\begin{aligned} & \text { Depth } \\ & \text { poter } \\ & \text { Hoter } \\ & \text { (Iever } \\ & \text { (fect) } \end{aligned}$ |  | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { of } \end{aligned}$ | $\begin{aligned} & \text { Lithology } \\ & \text { nopifer } \end{aligned}$ | $\left.\begin{array}{\|c} \text { Availabte } \\ \text { Orawdown } \\ \text { (feet) } \end{array} \right\rvert\,$ |  | $\left\lvert\, \begin{gathered} a_{20} \\ (1 \text { gpm }) \end{gathered}\right.$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 78 | 12-35-35-2514 | 3075 | 220 | 160-220 | Domestic | $\begin{array}{r} 94 \\ 29811 \end{array}$ | 45 3080 | Bedrock | Fractured silistone. shate, coal | 115 | $\stackrel{\text { (kx } 25.5)}{ }$ | 1 |  |
| 79 | ne-36-35-25N4 | 3035 | 118 |  | Domestic | ${ }_{3015}^{20}$ |  |  |  |  |  |  |  |
| ${ }^{81}$ | 4-2-36-24.44 | 3150 | 100 | 80-100 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r}99 \\ 3071\end{array}$ | 24 3126 | Bedrock | Sandstone | 15* | $\begin{aligned} & \left.\begin{array}{c} 14,250 \\ (k=356) \end{array}\right) \end{aligned}$ | 100 |  |
| 82 | 13-2-36-2444 | 3100 | 300 | 240-300 | Ommestic | 204 2896 | 18 <br> 3082 | Bedrock | Sands towe | ${ }^{90+}$ | $(K=4.7)$ | 6 |  |
| ${ }^{83}$ | 13-2-36-24.44 | 3100 | 190 | 50-190 | $\begin{gathered} \text { Domest Ic } \\ \text { stock } \end{gathered}$ | 92 3008 | 315 | Pedrock | Sandstone shn stowe shate. coas | ${ }^{90+}$ | (k-3.5) | 3 | Recovery data |
| ${ }_{84}$ | SE-3-36-2444 | 3100 | 257 |  |  | 157 2943 |  | Redrock |  |  |  |  | $\begin{aligned} & \text { Chem, analysis } \\ & \text { avaliable } \end{aligned}$ |
| ${ }^{85}$ | SE-4.36-24.44 | 3035 | 70 | 67-70 | Stock | 50 2985 | 28 3007 | Bedrock | Sandstone | 15* | $\left(\begin{array}{c}730 \\ (k=12)\end{array}\right.$ | - |  |
| ${ }^{86}$ | 13-4-36-24,44 | 3010 | 50 |  |  | 40 290 |  |  |  |  |  |  |  |
| 87 | 16-4-36-2444 | 3030 | , |  | Sthot Mote | $\xrightarrow{0}$ |  |  |  |  |  |  |  |


| Index Humber | Location | $\begin{gathered} \text { Elevation } \\ \text { (map) } \\ \text { in feet } \\ \text { a.m.s.l. } \end{gathered}$ | $\begin{gathered} \text { Depth } \\ \text { nf } \\ \text { Wcll } \\ \text { (ft.) } \end{gathered}$ | Consiruction. Onpth Interval Open to Aquifers (feet) | Use | Depth to Water Elev. (feet) | $\begin{gathered} \text { Depth } \\ \text { to } \\ \text { Bedrock } \\ \text { Elev. } \\ \text { (feet) } \end{gathered}$ | Type of <br> Hell | Lithotogy of Aquifer | Avallable Drawdown (feet) | $\begin{aligned} & T(i g p d / f t) \\ & \text { and } \\ & K\left(i \operatorname{gpd} / f t^{2}\right) \end{aligned}$ |  | Other nemarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 88 | 13-5-36-2464 | 2925 | 65 | 60-65 | Domestic | $\begin{gathered} 0 \\ 2925+ \end{gathered}$ | $\begin{array}{r} 59 \\ 2866 \end{array}$ | Bedrock ? | Fractured shate | $60+$ | 3660 | 104 | Chem. analysls avallable |
| 89 | 13-5-36-24W4 | 2920 | 60 |  | Shot hole | $\begin{gathered} 0 \\ 2920+ \end{gathered}$ |  |  |  |  |  |  |  |
| $\left\|\begin{array}{cc} \text { A.C.A. } \\ 71-3 \end{array}\right\|$ | 8-6-36-24 W4 | 2920 | 110 |  | Test hole |  | $\begin{array}{r} 54 \\ 2866 \end{array}$ |  | Sandstone |  |  |  |  |
| 90 | 11-6-36-2 ${ }^{\text {W/4 }}$ | 2925 | 62 | 42-62 | $\left\{\begin{array}{c} \text { Domes tic } \\ \text { stock } \end{array}\right.$ | $\begin{array}{r} 24 \\ 2901 \end{array}$ | $\begin{array}{r} 21 \\ 2904 \end{array}$ | Bedrock | Sandstone fractured | 30 | $\begin{aligned} & 1190 \\ & (k=2 h) \end{aligned}$ | 17 |  |
| 91 | 14-6-36-24M4 | 2950 | 93 | 70-93 | Domestic | $\begin{array}{r} 70 \\ 2880 \end{array}$ | $\begin{array}{r} 17 \\ 2933 \end{array}$ | Aedrock | Sandstone shale | 15 | $\begin{aligned} & 1560 \\ & (k=30) \end{aligned}$ | 11 |  |
| 92 | 16-6-36-24W4 | 2925 | 90 | 76-90 | Domestic | $\begin{array}{r} 17 \\ 2908 \end{array}$ | $\begin{array}{r} 59 \\ 2866 \end{array}$ | Bedrock | Sandstone | 65 | $\begin{aligned} & 1220 \\ & (k=80) \end{aligned}$ | 38 | Chem, analysis avallable |
| 93 | 16-5-36-24N4 | 3010 | 130 | 120-130 | Industria | $\begin{array}{r} 60 \\ 2950 \end{array}$ | $\begin{array}{r} 60 \\ 3050 \end{array}$ | Bedrock | 7 | 1 | $\begin{gathered} 625 \\ (k=63) \end{gathered}$ |  |  |
| 94 | 16-6-36-24W4 | 2925 | 71 | 60-71 | Domestic | $\begin{array}{r} 30 \\ 2895 \end{array}$ | $\begin{array}{r} 60 \\ 2865 \end{array}$ | Bedrock | Sands tone | 35+ | $\begin{aligned} & 1220 \\ & (k=49) \end{aligned}$ | 20 | chem. analysis javallable |
| 95 | 16-6-36-2464 | 2925 | 81 | 61-81 | pomestic | $\begin{array}{r} 17 \\ 2908 \end{array}$ | $\begin{array}{r} 58 \\ 2867 \end{array}$ | Bedrock | siltstone | $55+$ | >36.620 | 256 |  |
| 96 | 16-6-36-2444 | 2925 | 50 | 40-50 | Pranestic | $\begin{array}{r} 5 \\ 2920 \end{array}$ | $\begin{array}{r} 30 \\ 2895 \end{array}$ | Bedrock | Sandstorie | $40+$ | $\begin{gathered} 150 \\ (x=15) \end{gathered}$ | 3 | Recovery data |


| Index Humber | Location | $\begin{gathered} \text { Elevation } \\ \text { (mara) } \\ \text { in feet } \\ \text { a.m.s.l. } \end{gathered}$ | $\left\|\begin{array}{c} \text { Deplh } \\ \text { of } \\ \text { well } \\ (1 \mathrm{I} .) \end{array}\right\|$ | Construclion. <br> Depth Interval <br> Open to Aquirers (feet) | Use | Depth 10 Water Elev. (feet) | Depth 10 Bedrock flev. (feet) | $\begin{aligned} & \text { type } \\ & \text { oI } \\ & \text { Hell } \end{aligned}$ | Lithologr or Aquifer | Available <br> Drawdown <br> (feet) | $\begin{gathered} T(i g p d / f t) \\ k(i g d) \\ k\left(i_{j p d}{ }^{2}\right) \end{gathered}$ | $\left\{\begin{array}{l} Q_{20} \\ \text { (igpm) } \end{array}\right.$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 97 | 16-6-36-24.14 | 2925 | 87 | 80-87 | Domestic | $\begin{array}{r} 20 \\ 2905 \end{array}$ | $\begin{array}{r} 56 \\ 2869 \end{array}$ | Bedrock | Sands tone | $60+$ | 1470 | 42 |  |
| 98 | 16-6-36-2484 | 2925 | 75 | 55-75 | Domestic | $\begin{array}{r} 21 \\ 2901 \end{array}$ | $\begin{array}{r} 57 \\ 2868 \end{array}$ | Bedrock | Sandstone | $50+$ | $\begin{gathered} 5707 \\ (k=260) \end{gathered}$ | 135 |  |
| 99 | 1-7-36-24/44 | 2965 |  |  | Domestic |  |  |  |  |  |  |  | Chem. analysis avallable |
| 100 | 5-9-36-24W4 | 2985 | 60 | 48-60 | Domestic | $\begin{array}{r} 30 \\ 2955 \end{array}$ | $2976$ | Bedrock | Sandstone | $25+$ | $\begin{gathered} 320 \\ (k=27) \end{gathered}$ | . 237 | Chem. analysis avallable |
| 101 | 5-9-36-24W4 | 2985 | 74 | 44-74 | Domestic stock | $\begin{array}{r} 32 \\ 2953 \end{array}$ | $\begin{array}{r} 14 \\ 2971 \end{array}$ | Bedrock | Sandstone | 35* | $\begin{gathered} 3800 \\ (k-35) \end{gathered}$ | >63 |  |
| 102 | 8-10-36-24.44 | 3090 | 100 |  | Domestic | $\begin{array}{r} 90 \\ 3000 \end{array}$ |  |  |  |  |  |  |  |
| 103 | 13-11-36-24/4 | 3060 | 140 | 103-140 | $\begin{gathered} \text { Pomestic } \\ \text { stock } \end{gathered}$ | $\begin{aligned} & 34 \\ & 3026 \end{aligned}$ | $\begin{array}{r} 18 \\ 3042 \end{array}$ | Bedrock | Sandstone shale. coals | 857 | $\begin{gathered} 60 \\ (k=12.4) \end{gathered}$ | 2 | Chem. analysis avallable |
| 104 | 5-12-36-24/44 | 3040 | 80 |  | poxmestic stock | 50 2990 |  |  |  |  |  |  |  |
| 105 | NE-12-36-24,4 | 3100 | 61 | 34-61 | $\begin{gathered} \text { Domesilic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 18 \\ 3082 \end{array}$ | $\begin{array}{r} 30 \\ 3070 \end{array}$ | Bedrock | S.andstone | 35 | $\begin{aligned} & 910 \\ & (k=21) \end{aligned}$ | 15 |  |
| 106 | 5-14-36-2414 | 3060 | 100 |  |  |  |  |  |  |  |  |  | Chem. analysis available |


| Index Humber | tocation |  | $\left\|\begin{array}{c} \text { Depth } \\ \text { of } \\ \text { well } \\ (\mathrm{ref} \end{array}\right\|$ | Construction. Depth Interval Open to Aquifers (feet) | Use | Depth to Water Elev. (reet) | $\begin{array}{\|c\|} \hline \text { Depth } \\ \text { of } \\ \text { oreck } \\ \text { Bevev. } \\ \text { (feet) } \end{array}$ | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { Well } \end{aligned}$ | $\begin{aligned} & \text { Lithology } \\ & \text { of } \\ & \text { Aquifer } \end{aligned}$ | $\left\lvert\, \begin{gathered} \text { Available } \\ \text { Orawdom } \\ \text { (feet) } \end{gathered}\right.$ | $\begin{gathered} T(i \operatorname{igd} / f \mathrm{ft}) \\ \mathrm{and} \\ \mathrm{~K}\left(\mathrm{igpd} / \mathrm{ft}^{2}\right) \end{gathered}$ | $\left\lvert\, \begin{gathered} Q_{20} \\ (i g \mathrm{gm}) \end{gathered}\right.$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 107 | 3-15-36-24104 | 3085 | 255 | 120-255 | Domest ic stock | $\begin{array}{r} 78 \\ 3007 \end{array}$ | $\begin{array}{r} 24 \\ 3061 \end{array}$ | Bedrock | Sands tone | $65+$ | $\stackrel{2980}{(\mathbf{k}=32.4)}$ | 92 |  |
| 108 | NW-16-36-24W4 | 3080 | 127 | 100-121 | Domestic stock | $\begin{array}{r} 999 \\ 29 \mathrm{Bl} \end{array}$ | $\begin{array}{r} 15 \\ 3065 \end{array}$ | Bedrack | Sandstone | $20+$ | $\begin{aligned} & 87.195 \\ & (k=1744) \end{aligned}$ | 8.27 |  |
| 109 | 4-18-36-24w4 | 2965 | 108 |  | Domestic | $\begin{array}{r} 60 \\ 2905 \end{array}$ |  |  |  |  |  |  | Chem: onalysis avallable |
| 110 | 4-18-36-24w4 | 2965 | 80 | 60-80 | Domestic | 42 2923 | 28 2937 | Bedrock | Shale, <br> siltstone | 30 | $\begin{gathered} 6810 \\ (\mathrm{k}=577 \end{gathered}$ | . 97 | Recovery data |
| 111 | 12-18-36-24w4 | 2980 | 80 |  | $\begin{array}{\|c} \text { pomestic } \\ \text { stock } \end{array}$ | $\begin{array}{r} 50 \\ 2930 \end{array}$ |  |  |  |  |  |  |  |
| 112 | 12-18-36-24 ${ }^{\text {M }}$ | 2980 | 145 | 117 - 145 | pomestic | $\begin{array}{r} 84 \\ 2896 \end{array}$ | $\begin{array}{r} 11 \\ 2969 \end{array}$ | Bedrock | Shale | 55 | $\begin{array}{r} 2280 \\ \quad 19 \end{array}$ | 59 | Recovery data |
| 113 | NE-18-36-24W4 | 3030 | 47 |  |  | 40 2990 |  |  |  |  |  |  | Chem. analysls available |
| 114 | 14-19-36-24/14 | 2983 | 60 |  | Shot hole. | $\stackrel{0}{2983+}$ |  |  |  |  |  |  |  |
| 115 | 14-19-36-24W4 | 2984 | 60 |  | Shot hole | $\underset{2984+}{0}$ |  |  |  |  |  |  |  |
| 116 | 14-19-36-24w4 | 2983 | 40 |  | Sthot hole | $\stackrel{0}{09}{ }^{0}$ |  |  |  |  |  |  |  |


| Index Humber | Location | Elevation (map) in feet a.m.s.i. | $\left\lvert\, \begin{gathered} \text { Depth } \\ \text { of } \\ \text { well } \\ \text { (ft. } \end{gathered}\right.$ | Construction. Depth Interval Open to Aquifers (feet) | Use | $\begin{aligned} & \text { Denth } \\ & \text { to } \\ & \text { Water } \\ & \text { Elev. } \\ & \text { (feet) } \end{aligned}$ | $\begin{array}{\|c\|} \text { Oepth } \\ \text { to } \\ \text { Hedrock } \\ \text { Elev. } \\ \text { (fert) } \end{array}$ | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { Well } \end{aligned}$ | Lithology or Aquifer | Available <br> Drawdown <br> (feet) | $\begin{gathered} T(i g \mathrm{pd} / \mathrm{ft}) \\ \mathrm{and} \\ \mathrm{~K}\left(\mathrm{igpd} / \mathrm{ft}^{2}\right) \end{gathered}$ | $\begin{gathered} \mathrm{Q}_{20} \\ (i \mathrm{igpm}) \end{gathered}$ | $\begin{aligned} & \text { Other } \\ & \text { Remarks } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (1) | 14-19-36-2444 | 2994 | 45 |  | Strot hole | $\begin{gathered} 0 \\ 2994+ \end{gathered}$ |  |  |  |  |  |  |  |
| 118 | 15-19-36-2414 | 2990 | 60 |  | Shot hole | $\stackrel{0}{2990+}$ |  |  |  |  |  |  |  |
| 119 | 16-19-36-24.14 | 2991 | 40 |  | Shot hole | $2991+$ |  |  |  |  |  |  |  |
| 120 | 16-19-36-24 ${ }^{\text {W }}$ | 2997 | 40 |  | Sthot hole | $\begin{gathered} 0 \\ 2997+ \end{gathered}$ |  |  |  |  |  |  |  |
| 121 | 16-19-36-24w4 | 2997 |  |  | stot trole | $\stackrel{0}{2997}$ |  |  |  |  |  |  |  |
| 122 | 4-20-36-24144 | 3035 | 90 |  | Domestic | 35 3000 |  |  |  |  |  |  | Chem. analysis available |
| 123 | 12-20-36-24N4 | 3025 | 165 |  | Oomestic | $\begin{array}{r} 60 \\ 2965 \end{array}$ |  |  |  |  |  |  | Chem. analysis avaitable |
| 124 | 13-20-36-24.44 | 3013 | 47 |  | Shot hole | $\begin{array}{r} 0 \\ 3013 * \end{array}$ |  |  |  |  |  |  |  |
| 125 | NW-20-36-24W4 | 3025 | 90 |  | Test mole | $\begin{array}{r} 60 \\ 2965 \end{array}$ |  |  |  |  |  |  | $\begin{aligned} & \text { Chem. analvsis } \\ & \text { available } \end{aligned}$ |
| 126 | 5-21-36-24.14 | 3145 | IBo | 157-180 | Domestic | 135 3010 | $\begin{array}{r} 12 \\ 313 \end{array}$ | Ardrack | Saudstone | $40+$ | $\underset{(k=48.6)}{2190}$ | 42 |  |


| $\begin{aligned} & \text { Index } \\ & \text { liumber } \end{aligned}$ | Location |  |  |  | use |  |  | $\begin{aligned} & \text { Type } \\ & \text { yel } \\ & \text { Hell } \end{aligned}$ | $\begin{aligned} & \text { Litholog } \\ & \text { nquífer } \end{aligned}$ | $\left\|\begin{array}{c} \text { Avai intule } \\ \text { Ori.isoun } \\ \text { (feet) } \end{array}\right\|$ | $\begin{gathered} r(i \operatorname{igd} / f \mathrm{f}) \\ \text { and } \\ \mathrm{K}\left(\mathrm{igpd} / \mathrm{ff}^{2}\right) \end{gathered}$ | $\begin{gathered} 0_{20} \\ (\text { (igpm) } \end{gathered}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 121 | 14-21-36-24,4 | 3165 | 200 | 130-200 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{aligned} & 190 \\ & 3195 \end{aligned}$ | 3150 | Bedrock | $\begin{aligned} & \text { Sandstone } \\ & \text { shale } \end{aligned}$ | 65 | ${ }_{(k=9.7)}^{290}$ | 9 |  |
| 128 | 4-22-36-2444 | 3133 | 5867 |  | $\left\lvert\, \begin{array}{ll} 011 \text { or } \\ \text { gas well } \end{array}\right.$ |  |  |  |  |  |  |  | $\left\lvert\, \begin{array}{\|c\|c\|} \mathrm{BnO} 0_{+} \text {Loq aval lable } \end{array}\right.$ |
| 129 | 9-22-36-2444 | 3120 | 130 |  | Domestic | 90 3030 |  |  |  |  |  |  | $\begin{aligned} & \text { chem, analuyis } \\ & \text { avaliable } \end{aligned}$ |
| 130 | 14-22-36-24.44 | 3120 | 60 |  |  | $\begin{gathered} 22 \\ 3098 \end{gathered}$ |  |  |  |  |  |  |  |
| 131 | 4-23-36-24.44 | 3085 | 131 | 106-131 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | ${ }_{3013}$ | 35 3050 | Aedrack | Sandstone | 50 | $\begin{gathered} 1230 \\ (k=23.7) \end{gathered}$ | 29 | Recovery data |
| 132 | 14-23-36-24.44 | 3065 | 62 |  |  | 30 3035 |  |  |  |  |  |  |  |
| 133 | 12-26-36-24/4 | 3060 | 110 | 79-110 | Domestic stock | 62 2998 | 3015 | Aedrock | Sandstone silistone | 40 | $\begin{gathered} 28,670 \\ (\times 956) \end{gathered}$ | 544 |  |
| 134 | 4-27-36-24.44 | 3150 | 70 | 50-70 | $\begin{gathered} \text { Oomestic } \\ \text { stock } \end{gathered}$ | 46 3 3104 | 3113 | Bedrock | Sandstone | 15 | $\begin{aligned} & 94900 \\ & (k=431) \end{aligned}$ | ${ }_{68}$ |  |
| 135 | 4-27-36-21.44 | 3120 | 62 |  | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{aligned} & 19 \\ & 3100 \end{aligned}$ | 50 3070 | Redrock | Sands tone | 30 | $\begin{aligned} & 2440 \\ & (k=477) \end{aligned}$ | 35 |  |
| 136 | 4-27-36-24.44 | 3125 | 165 |  | Abandoned |  | 60 3005 | Bedrock | Sthale |  |  |  |  |


| $\left\lvert\, \begin{aligned} & \text { ndex } \\ & \text { number } \end{aligned}\right.$ | Location | Elevation (map) in feet a.m.s. | $\left\|\begin{array}{cc} \text { Depeth } \\ \text { of } \\ \text { well } \\ (f t .1 \end{array}\right\|$ |  | use | $\begin{aligned} & \text { Denth } \\ & \text { Water } \\ & \text { Water } \\ & \text { (Ieve } \\ & \text { (fect } \end{aligned}$ |  | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { of li } \end{aligned}$ | $\begin{aligned} & \text { Lithology } \\ & \text { Aquifer } \end{aligned}$ | $\left.\begin{gathered} \text { Avai lable le } \\ \text { oramdown } \\ \text { (feet) } \end{gathered} \right\rvert\,$ | $\begin{gathered} T(i g p d / f l) \\ k\left(1 \mathrm{god} / \mathrm{ff}^{2}\right) \end{gathered}$ | $\left\|\begin{array}{c} a_{20} \\ (\mathrm{igpm}) \end{array}\right\|$ | $\underset{\substack{\text { Ocher } \\ \text { Remarks }}}{ }$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 136 | 4-27-36-2444 | 3125 | 165 |  | Abandoned |  | 60 3065 | Bedroch | Shale |  |  |  |  |
| 131 | 9-27-36-2444 | 3050 | 140 |  | Domest ic |  |  |  |  |  |  |  | Chem. analysts avallable |
| 138 | 2-28-36-2444 | 3180 | 300 | 270-300 | $\begin{gathered} \text { Oomestic } \\ \text { stock } \end{gathered}$ |  | 15 3165 | Bedrock | Sandstone | 115 | ${ }_{\substack{2300 \\(k=66)}}$ | 125 | Recovery data |
| 139 | 2-28-36-24.44 | 3180 | 200 |  | $\begin{gathered} \text { Domestic } \\ \text { slock } \end{gathered}$ | 168 <br> 3012 |  |  |  |  |  |  | $\begin{array}{\|l\|l} \text { chem analysis } \\ \text { aval lable } \end{array}$ |
| 140 | 15-28-36-2444 | 3090 | 118 |  | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | [ $\begin{array}{r}83 \\ 3007\end{array}$ |  |  |  |  |  |  |  |
| 141 | 4-29-36-2444 | 3025 | 80 |  | Domestic | 29 <br> 2996 | - ${ }^{468}$ |  |  |  |  |  |  |
| 142 | 4-29-36-2444 | 3030 | 43 |  | Domestic | 2997 |  |  |  |  |  |  |  |
| 143 | 3-30-36-2444 | 2990 | 50 |  | Stock | $\underset{\text { 290\% }}{\text { 0 }}$ | 40 2950 | Bedrock | $\begin{aligned} & \text { Fractured } \\ & \text { shale } \end{aligned}$ |  |  |  |  |
| 144 | 8-30-36-24.44 | 3050 | 125 |  | pomestic stock | 2995 | 45 3005 | Bedrock | Sands tone | 60 | $\left(\begin{array}{l}370 \\ (k=14.9)\end{array}\right.$ | 11 |  |
| 145 | A-30-36-2444 | 3050 | 62 |  | Pomestic | ${ }_{3012}^{38}$ |  |  |  |  |  |  |  |


| Indes <br> Humber | Locelion | $\begin{gathered} \text { Elevation } \\ \text { (map) } \\ \text { in fret } \\ \text { a.m.s.l. } \end{gathered}$ | $\begin{gathered} \text { Droth } \\ \text { of } \\ \text { Well } \\ (f, .) \end{gathered}$ | Construction, Depth Interval Open to Aquifers (feet) | Use | $\begin{gathered} \text { Denth } \\ \text { to } \\ \text { Water } \\ \text { (Ifev, } \\ \text { (fert) } \end{gathered}$ | $\begin{aligned} & \text { Drpith } \\ & \text { in } \\ & \text { Brdirnck } \\ & \text { Flev. } \\ & \text { (frent) } \end{aligned}$ |  | $\begin{gathered} \text { Lithologr } \\ \text { of } \\ \text { Aquifer } \end{gathered}$ | Available Drawdown (feet) | $\begin{aligned} & T(i g p d / f t) \\ & \text { ond } \\ & K\left(i g p d / f t^{2}\right) \end{aligned}$ | $\begin{gathered} Q_{20} \\ \left(i_{\mathrm{gpm}}\right) \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 146 | 1-31-36-2464 | 3135 | 198 | 178-198 | Domestic | $\begin{array}{r} 151 \\ 2984 \end{array}$ | $\begin{array}{r} 19 \\ 3116 \end{array}$ | Bedrach | Sandsione | $40+$ | $\begin{aligned} & 13,080 \\ & (\mathrm{~K}=248) \end{aligned}$ | 248 |  |
| 167 | 1-31-36-24W4 | 3135 | 206 | 180-206 | Domestic | $\begin{array}{r} 154 \\ 2981 \end{array}$ | $\begin{array}{r} 20 \\ 3115 \end{array}$ | Brdrock | Sandstone | $40+$ | $\begin{aligned} & 19.620 \\ & (k=392) \end{aligned}$ | 372 |  |
| 148 | 6-32-36-2 $\mathrm{NW}^{\text {6 }}$ | 3110 | 200 | $130-200$ | Stock | $\begin{array}{r} 120 \\ 2990 \end{array}$ | $\begin{array}{r} 59 \\ 3051 \end{array}$ | Fedrock | Sandstone <br> shale | 70 | $\begin{gathered} 200 \\ (k=2.9) \end{gathered}$ | 7 | Recovery data Chem. Analysis avallable |
| 149 | 9-32-36-24W4 | 3100 | 145 |  |  | $\begin{array}{r} 125 \\ 2975 \end{array}$ |  |  |  |  |  |  |  |
| 150 | $\begin{aligned} & 7-33-36-24 \\ & 7 \end{aligned}$ | 3060 | 122 |  |  | $\begin{array}{r} 90 \\ 2970 \end{array}$ |  |  |  |  |  |  |  |
| 151 | 12-33-36-2464 | 3075 | 130 | 90-130 | Domes 1 Ic | $\begin{array}{r} 91 \\ 2984 \end{array}$ | $\begin{array}{r} 45 \\ 3030 \end{array}$ | Brdrock | Sandstone | 35 | $\begin{gathered} 5810 \\ (k=194) \end{gathered}$ | 96 | Recovery data |
| 152 | 12-33-36-2414 | 3075 | 126 |  |  | $\begin{array}{r} 30 \\ 3045 \end{array}$ |  |  |  |  |  |  |  |
| 153 | 16-33-36-2414 | 3040 | 105 | 91-105 | stock | $\begin{array}{r} 70 \\ 2970 \end{array}$ | $\begin{array}{r} 50 \\ 2990 \end{array}$ | Bedrock | Sandstone shale | 30 | $\begin{gathered} 730 \\ (k=12) \end{gathered}$ | 10 |  |
| 154 | 13-34-36-2464 | 3025 | 80 |  |  | $\begin{array}{r} 64 \\ 2961 \end{array}$ |  |  |  |  |  |  |  |
| 154.5 | 4-2-36-2544 | 3100 | 43 | 24-43 | Stock | $\begin{array}{r} 18 \\ 3087 \end{array}$ | $\begin{array}{r} 19 \\ 3081 \end{array}$ | Hedrock | Saudelone shoule | 20 | $\underset{\left(K-1, f_{1}, 8\right)}{190}$ | 2 |  |


| $\begin{array}{\|l\|l\|} \hline \text { nduex } \\ \text { number } \end{array}$ | tocation |  | $\left[\left.\begin{array}{c} \text { Oenth } \\ \text { or } \\ \text { (fell } \\ (f .1 \end{array} \right\rvert\,\right.$ | Construct ion, <br> oepth nt terval <br> open to <br> Aquifers <br> (fcet) | use | $\begin{aligned} & \text { oenth } \\ & \text { Hater } \\ & \text { Hater } \\ & \text { (fecv } \\ & \text { (fect } \end{aligned}$ | $\begin{array}{\|c} \text { Depth } \\ \text { to } \\ \text { tercrock } \\ \text { Elve. } \\ \text { (fret) } \end{array}$ | $\begin{array}{\|c\|c\|} \hline \text { Type } \\ \text { orf } \end{array}$ | $\begin{aligned} & \text { Lithology } \\ & \text { of of } \\ & \text { aquer } \end{aligned}$ | $\left.\begin{array}{\|c} \text { Avariable } \\ \text { Drawdoum } \\ (\text { feet }) \end{array} \right\rvert\,$ | $\begin{gathered} T(\mathrm{igd} / \mathrm{ft}) \\ \mathrm{and}) \\ \mathrm{K}\left(\mathrm{igpd} / \mathrm{ft}^{2}\right) \end{gathered}$ | $\begin{gathered} \mathrm{C}_{20} \\ (\mathrm{igpm}) \end{gathered}$ | $\begin{aligned} & \text { Other } \\ & \text { Remarks } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 155 | 2-3-36-24/44 | 3085 | 123 | 32-123 | stock | 30 3055 | 28 3057 | Bedroch | Sands tone | 20 | $\begin{aligned} & 12,150 \\ & (k+347) \end{aligned}$ | 115 | $\begin{aligned} & \text { Chem. analysils } \\ & \text { svaliable } \end{aligned}$ |
| 156 | 2-3-36-25N4 | 3100 | 74 |  |  | ${ }_{3}^{22}$ |  |  |  |  |  |  | $\begin{aligned} & \text { Chem; analysls } \\ & \text { avai inate } \end{aligned}$ |
| 157 | ne-4-36-25wh | 3160 | 120 | 103-120 | Stock | 63 <br> 3097 | 76 3084 | Bedrock | Sandstone | 50 | $\begin{gathered} 950 \\ (x=36.4) \end{gathered}$ | ${ }^{23}$ |  |
| 158 | 12-5-36-2504 | 3165 | 200 | 160-200 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | 126 3039 | 100 3065 | Bedrock | Sandstone coal, shale | 60 | $(k-15)^{300}$ | 9 |  |
| 159 | 12-6-36-2544 | 3080 | 80 |  |  | 66 3014 |  |  |  |  |  |  |  |
| 160 | 8-7-36-25144 | 3175 | 118 | 103-118 | $\begin{gathered} \text { Domest lt } \\ \text { stock } \end{gathered}$ | 55 3120 | 94, 309 | Bedrock | $\begin{aligned} & \text { Sandstone } \\ & \text { shale } \end{aligned}$ | 55 | $\begin{gathered} 5890 \\ (k=131) \end{gathered}$ | 154 |  |
| 161 | 5u-8-36-25u4 | 3185 | 99 |  |  | 400 3145 |  |  |  |  |  |  |  |
| 162 | 16-8-36-2514 | 3275 | 155 | 133-155 | $\begin{gathered} \text { Domest Ic } \\ \text { stock } \end{gathered}$ | $\begin{aligned} & 110 \\ & 3165 \end{aligned}$ | ${ }_{320}^{68}$ | Bedrock | $\begin{aligned} & \text { Shale } \\ & \text { Siltstone } \end{aligned}$ | 40 | $\left(\begin{array}{c} 130 \\ 136.5) \end{array}\right.$ | 3 | Recovery data |
| 163 | 16-8-36-2544 |  | 115 |  |  |  |  |  |  |  |  |  | $\begin{aligned} & \text { Chem. analysis } \\ & \text { ovallable } \end{aligned}$ |
| 164 | 16-8-36-2544 | 3275 | 109 |  |  | 100 3175 |  |  |  |  |  |  | $\begin{aligned} & \text { chem, anlays } 1, \\ & \text { available } \end{aligned}$ |


| Index Humber | Location | $\left.\begin{gathered} \text { Elevation } \\ \text { (man) } \\ \text { in fert } \\ \text { a.m.s.l. } \end{gathered} \right\rvert\,$ | $\begin{gathered} \text { Depth } \\ \text { of } \\ y_{c} \\ \text { (rit } \\ \hline \end{gathered}$ | Construction, Depth Intervil Open to Aquifers (reet) | Use | Depith to W.iter Elev. (feet) |  | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { Well } \end{aligned}$ | Lithology of Aquifer | Avioilable Dr.twritown (reet) | $\begin{aligned} & T(i g p d / f i) \\ & \text { and } \\ & K\left(i g p d / f t^{2}\right) \end{aligned}$ | $\begin{gathered} Q_{20} \\ (i g \mathrm{pm}) \end{gathered}$ | Other <br> Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 165 | 5-9-36-25w4 | 3225 | 180 | 120-180 | Domestic stock | $\begin{array}{r} 91 \\ 3134 \end{array}$ | $\begin{array}{r} 26 \\ 3199 \end{array}$ | Bedrock | Shale silistone | 80 | $\begin{gathered} 80 \\ (k=1.4) \end{gathered}$ | 3 | Recovery data |
| 166 | 8-9-36-2514 | 3175 | 54 |  | Stock | $\begin{array}{r} 8 \\ 3167 \end{array}$ | $\begin{array}{r} 25 \\ 3150 \end{array}$ | Bedrock | Shale <br> Fractured ? | 40 | $\begin{aligned} & 1470 \\ & (k=59) \end{aligned}$ | 28 |  |
| 167 | 9-9-36-25w4 | 3135 | 145 | 138-145 | Stock | $\begin{array}{r} <93 \\ 3042 \end{array}$ | $\begin{array}{r} 70 \\ 3065 \end{array}$ | Bedrock | Sandstone | 1 | $\begin{aligned} & 2680 \\ & (K=72) \end{aligned}$ | $>38$ |  |
| 168 | 12-9-36-2514 | 3225 | 111 |  |  | $\begin{array}{r} 35 \\ 3190 \end{array}$ |  |  |  |  |  |  |  |
| 169 | 15-10-36-25w4 | 3023 | 60 |  | Shot hole | $\begin{gathered} 0 \\ 3023+ \end{gathered}$ |  |  |  |  |  |  |  |
| 170 | 1-12-36-25M4 | 2950 | 92 |  | Domestic |  |  |  |  |  |  |  | Chem, analysis available |
| 171 | 1-12-36-2514 | 2950 | 110 |  | Domestic | $\begin{array}{r} 43 \\ 2907 \end{array}$ |  |  |  |  |  |  | Chem, analysis available |
| 172 | 1-12-36-2614 | 2950 | 71 | 63-71 | pomestic | $\begin{array}{r} 34 \\ 2916 \end{array}$ | $\begin{array}{r} 20 \\ 2930 \end{array}$ | Bedrock | Sandstore | 30 | $\begin{gathered} 930 \\ (k=23) \end{gathered}$ | 13 | Chem. analysls available |
| 173 | 3-12-36-2514 | 2970 | 50 | 38-50 | Stock | $\begin{array}{r} 0 \\ 2970 \end{array}$ | $\begin{array}{r} 30 \\ 2940 \end{array}$ | Dedrock | Sandstone | $45+$ |  |  | Chem. analysts avallable |
| 174 | 8-12-36-25w4 | 2960 | 107 | $80-107$ | pomestic | $\begin{array}{r} 43 \\ 2917 \end{array}$ | 38 2972 | Bedrock | Sands tome | 55* | $\stackrel{290}{(k=4.8)}$ | 8 |  |


| $\left\{\begin{array}{l} \text { Index } \\ \text { Number } \end{array}\right.$ | Location |  | $\left\|\begin{array}{c} \text { Depent } \\ n_{n} \\ w_{1}(1) \\ (f, 1) \end{array}\right\|$ |  | Use |  | Depth o Bedrock EInv. (feet) | $\begin{gathered} \text { Type } \\ \text { wof } \end{gathered}$ | $\begin{aligned} & \text { Lithology } \\ & \text { Aquifer } \end{aligned}$ | $\begin{gathered} \text { Available } \\ \text { Orawdown } \\ \text { (feet) } \end{gathered}$ | $\begin{gathered} T(i g o d / f t) \\ \text { and }\left(i g d / f^{2}\right) \end{gathered}$ | $\left\lvert\, \begin{gathered} 0_{20} \\ \left(i_{i g n}\right) \end{gathered}\right.$ | $\underset{\substack{\text { Other } \\ \text { Remarks }}}{ }$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 175 | 14-12-36-2544 | 2965 | 107 | 95-107 | Domest ic | $\begin{array}{r} 45 \\ 2920 \end{array}$ | 26 2939 | Bedrock | Sandstane | $55+$ | $\underset{(k=32)}{3180}$ | -33 |  |
| 176 | 14-12-36-2544 | 2945 | 155 | 93-155 | Domest ic | 59 2886 | (378 | Bedrock | Sandstione | ${ }^{90+}$ | $\begin{gathered} 1820 \\ (\mathrm{~K}=30) \end{gathered}$ | 78 | Chem. analysis avallable Recovery dala |
| 171 | 14-12-36-2544 | 2945 | 102 | 98-102 | Domest ic | 55 2890 | 45 2900 | Bedrock | Shale | 40 | 3180 | 60 |  |
| 178 | 1-13-36-2544 | 2925 | 100 |  | Domest ic | $\begin{array}{r} 644 \\ 2861 \end{array}$ |  |  |  |  |  |  | $\begin{aligned} & \text { chem. analys is } \\ & \text { available } \end{aligned}$ |
| 179 | 1-13-36-2544 | 2925 | 80 | 59-80 | Domestic | $\begin{array}{r} 366 \\ 2889 \end{array}$ | ${ }_{\substack{388 \\ 288}}$ | Aedrock | Sandstone | 35 | $\begin{gathered} 53,860 \\ (k=1077) \\ (0) \end{gathered}$ | ${ }^{89}$ |  |
| 180 | 1-13-36-2544 | 2925 | 93 |  | Domest ic | 295 |  |  |  |  |  |  |  |
| 181 | 1-13-36-2544 | 2925 | 98 | 8日 - 98 | Domest ic | 2858 | 25 2900 | Bedrock | $\begin{array}{\|l\|} \text { Shale } \\ \text { (fractured) } \end{array}$ | 35 | $\stackrel{2930}{(k \times 58.7)}$ | 49 |  |
| 182 | 6-13-36-2544 | 2925 | 180 | 172-180 | Oomest ic | $\begin{array}{r} 366 \\ 28969 \end{array}$ | 15 2850 | nedrock | $\begin{aligned} & \text { Shale } \\ & \text { (fracturrd) } \end{aligned}$ | 135 | $\begin{gathered} (\mathrm{K}=6.8) \end{gathered}$ | 22 |  |
| 183 | 6-13-36-2544 | 2920 | 80 | 60-80 | Onmest ic | 13 2907 | 54 2868 | Pedrock |  | $50+$ | $? \quad \begin{aligned} & 11750 \\ & (k=1175) \end{aligned}$ | 278 |  |
| 184 | 13-14-36-2544 | 3025 | 15 |  | Oomestic | 12 3013 |  |  |  |  |  |  |  |


| Index llumber | Location | $\begin{gathered} \text { Elcu-tion } \\ \text { (mag) } \\ \text { in feet } \\ \text { a.m.s.i. } \end{gathered}$ | $\begin{gathered} \text { Depth } \\ \text { of } \\ \text { well } \\ (\mathrm{ft} .)^{2} \end{gathered}$ | Construction. Depth Interval Open 10 Aquifers (feet) | Vis | Depth tn Water Elev. (fect) | ```Depth to Bedrock tlev. (feet)``` | $\begin{gathered} \text { Type } \\ \text { of } \\ \text { Hell } \end{gathered}$ | Lithology of Aquirer | Available Orawdown (feet) | $\begin{aligned} & 1(\mathrm{igpd} / \mathrm{ft}) \\ & \text { and } \\ & K\left(\mathrm{igpd} / \mathrm{ft}^{2}\right) \end{aligned}$ | $\begin{gathered} Q_{20} \\ (\mathrm{igpm}) \end{gathered}$ | Other <br> Aemarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 185 | 5-15-36-2514 | 3095 | 100 | 80-100 | Stock | $\begin{array}{r} 50 \\ 3045 \end{array}$ | $\begin{array}{r} 39 \\ 3056 \end{array}$ | Bedrock | siltstone. shale | $45+$ |  | $>11$ | Chem. analysis avallable |
| 186 | 3-16-36-2544 | 3190 | 63 | 49-63 | Domest ic stock | $\begin{array}{r} 28 \\ 3162 \end{array}$ | $\begin{array}{r} 16 \\ 3174 \end{array}$ | Bedrock | Sandstone | 254 | $\underset{(k \times 23)}{1720}$ | 20 |  |
| 187 | 16-17-36-2564 | 3160 | 85 | 35-85 | Stock | $\begin{array}{r} 59 \\ 3101 \end{array}$ | $\begin{array}{r} 23 \\ 3137 \end{array}$ | Bedrock | Sandstoue <br> shate | 10 | $\begin{gathered} 210 \\ (k=13) \end{gathered}$ | 2 | Recovery data |
| 188 | 12-19-36-2514 | 3200 | 180 |  |  | $?$ |  |  |  |  |  |  | Chem. analysis available |
| 189 | 12-19-36-2544 | 3200 | 185 |  |  | 90 3110 |  | 0.lft |  |  |  |  | Chem. analysis available |
| 190 | 12-19-36-25w4 | 3200 | 126 |  | Domestic | $\begin{array}{r} 81 \\ 3119 \end{array}$ |  |  |  |  |  |  |  |
| 191 | 11-21-36-2544 | 3090 |  |  | Shot trole | $\underset{3090+}{0}$ |  |  |  |  |  |  |  |
| 192 | 12-21-36-25w4 | 3100 |  |  | Sthet hole | $\stackrel{0}{3100+}$ |  |  |  |  |  |  |  |
| 193 | 12-21-36-2514 | 3100 | 75 |  | Shot hole | $\begin{gathered} 0 \\ 3100+ \end{gathered}$ |  |  |  |  |  |  |  |
| 194 | 8-22-36-2514 | 3035 | 105 | $90-105$ | Domestic sleck | $\begin{array}{r} 62 \\ 29 / 3 \end{array}$ | 53 2982 | Bedrock | siltstone (ryoctured) | 35 | $\begin{gathered} 160 \\ (k=11.4) \end{gathered}$ | 1 | Recovery data Chem. analy<is available |


| lindex | Location | Elevation impap infet a.m.s. |  | Const ruct ion, Oepth Interval poen ot nquifers (fect) | Use |  | Depth Do Bedrock Elfev. (feet) | $\begin{aligned} & \text { Type } \\ & \text { Hefll } \end{aligned}$ | $\begin{aligned} & \text { Litholoqu } \\ & \text { aquifer } \end{aligned}$ | $\left\|\begin{array}{c} \text { Ava i iable } \\ \text { or aumoun } \\ \text { (feet) } \end{array}\right\|$ |  | $\left\|\begin{array}{c} a_{20} \\ (i, ~ i g m) \end{array}\right\|$ | ¢ $\begin{gathered}\text { Other } \\ \text { Remarks }\end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 195 | 8-22-36-2544 | 3000 | 122 |  | $\begin{gathered} \text { Domestlc } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 30 \\ 2970 \end{array}$ |  |  |  |  |  |  | Chem. analys Is avallable |
| 196 | 11-22-36-2544 | 3025 | 190 | 153-190 | $\begin{gathered} \text { Domest lc } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 79 \\ 2946 \end{array}$ | $3005$ | Bedrock | $\begin{aligned} & \text { silitstone } \\ & \text { sandstone } \end{aligned}$ | 105 | $(k-1.1)$ | 2 | Chem, analysis avaliable |
| 197 | 16-22-36-2544 | 3025 | 95 | 75-95 | Domestic | $\begin{array}{r} 40 \\ 2985 \end{array}$ | 323 | Bedrock | shale <br> (fractured) |  |  |  | $\begin{aligned} & \text { Chem. analysis } \\ & \text { avaliable } \end{aligned}$ |
| 198 | 16-22-36-2544 | 3015 | 94 |  | Domest ic | 2986 |  |  |  |  |  |  | Chem. analys is avaliable |
| R.C.A:A | 16-22-36-2544 | 2920 | 120 |  | Test hole | 2920 | ${ }_{2808}^{18}$ | Bedrock |  | 115 |  |  |  |
| 199 | 16-22-36-2544 | 2935 | 190 | 145-190 | Domest lic | 15 2920 | ${ }^{142} 2793$ | Bedrock | Stiale (fractured) | 150 | $\left(\begin{array}{c}50 \\ (x-1)\end{array}\right.$ | 4 | Recovery data Chem. analysis available |
| 200 | 4-23-36-2544 | 3000 | 165 | $80-165$ | Domestic | ${ }_{2960}^{40}$ | <75 | Bedrock | ${ }_{\text {cosal }}^{\text {cosie }}$ | 120 | 1470 | ${ }^{83}$ | Chem. analysis available |
| 201 | 14-23-36-2544 | 2930 | ${ }^{83}$ | 65-83 | Domestic | $2900$ | ${ }_{2868}$ | Pedrock | $\left\lvert\, \begin{aligned} & \text { Shale } \\ & \text { siltstone } ? \end{aligned}\right.$ | 15* | $\underset{(k-42)}{840}$ | 30 | Recovery data <br> Chem. analysis <br> avallable |
| 202 | 14-23-36-2544 | 2930 | BS | 78-85 | Domestic | $\xrightarrow{09}$ | 285s | $p^{\text {Pedrock }}$ | $\begin{aligned} & \text { Fractured } \\ & \text { sh.ile } \end{aligned}$ | $80 *$ |  | 30 |  |


| Index Number | Location | $\begin{gathered} \text { Elevation } \\ (\text { ming } \\ \text { in rect } \\ \text { a.m.s.l. } \end{gathered}$ | $\left\lvert\, \begin{gathered} \text { Depth } \\ \text { of } \\ \text { Well } \\ \text { (ft.) } \end{gathered}\right.$ | Construction. Depth Interval Open to Aquifers (feet) | Use | Depth to Hater Elev. (feet) | Depth to Bedrock Elev. (fect) | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { Hell } \end{aligned}$ | Lithology of Aguifer | Available <br> Orawdown <br> (reet) | $\begin{aligned} & T\left(\mathrm{igpd} / \mathrm{g} t^{\text {and }}\right. \\ & K\left(\mathrm{igpd} / \mathrm{ft}^{2}\right) \end{aligned}$ | $\left\|\begin{array}{c} a_{20} \\ (i \mathrm{gmm}) \end{array}\right\|$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 203 | 2-24-36-2514 | 2925 | 60 | 46-60 | Domestic | $2923^{27}$ | $\begin{array}{r} 40 \\ 2885 \end{array}$ | Bedrock | Sandstone | $50+$ | $\begin{gathered} 3270 \\ (k=109) \end{gathered}$ | 71 | Chem, analysis avallable |
| 204 | 2-24-36-2544 | 2960 | 100 |  | Domestic | $\begin{array}{r} 607 \\ 2900 \end{array}$ |  |  |  |  |  |  | Chem. analysis avaliable |
| 205 | 2-24-36-25w4 | 2945 | 90 | 70-90 | Domestic | $\begin{array}{r} 21 \\ 2924 \end{array}$ | $\begin{array}{r} 25 \\ 2920 \end{array}$ | Aedrock | Sandstone | 70 |  | 20 | Chem. analysis avallable |
| 206 | NW-26-36-25N4 | 2970 | 95 | 65-95 | Domestic stock | $\begin{array}{r} 38 \\ 2932 \end{array}$ | $\begin{array}{r} 41 \\ 2929 \end{array}$ | Bedrock | Sandstone | 45 | $\begin{gathered} 3970 \\ (k=120) \end{gathered}$ | 85 |  |
| 207 | 3-25-36-2514 | 2970 | 85 | 75-85 | Domestic stock | $\begin{array}{r} 26 \\ 2944 \end{array}$ | $\begin{array}{r} 35 \\ 2935 \end{array}$ | Bedrock | Sandstore slltstone | 50 | $\begin{gathered} 3924 \\ (k=98) \end{gathered}$ | 93 | Recovery data |
| 208 | 3-25-36-2504 | 2975 | 105 | 40-105 | Stock | $\begin{array}{r} 30 \\ 2945 \end{array}$ | $\begin{array}{r} 60 ? \\ 2915 \end{array}$ | Bedrock | Sands tone |  |  |  |  |
| 209 | 2-26-36-25w4 | 2950 | 105 |  | Drmestic | $\begin{array}{r} 20 \\ 2930 \end{array}$ |  |  |  |  |  |  | Chem. analysis avallable |
| 210 | 2-26-36-25 M | 2960 | 60 | 59-60 | Domestic | $\begin{array}{r} 30 \\ 2930 \end{array}$ | $\begin{array}{r} 60 \\ 2900 \end{array}$ | orift | Gravel | 25 | $\begin{aligned} & 8130 \\ & (k=1626) \end{aligned}$ | 96 |  |
| 211 | 3-26-36-2464 | 2940 | 80 | 60-80 | Domestic | $\begin{array}{r} 13 \\ 2927 \end{array}$ | $\begin{array}{r} 53 \\ 2887 \end{array}$ | Bedrock | Shile <br> Siltstone | 60 | $\begin{gathered} 690 \\ (k=23) \end{gathered}$ | 20 | Pump test data Chem. allalysis available |
| 212 | 3-26-36-25,44 | 2930 | 55 | 40-55 | Domestic | $\begin{array}{r} 0 \\ 7930 \end{array}$ | 37 2893 | Brdrack | Shile silistone | 504 | $\begin{gathered} 1300 \\ (k-81) \end{gathered}$ | 28 |  |


| $\left\lvert\, \begin{aligned} & \text { Index } \\ & \text { IIumber } \end{aligned}\right.$ | Location |  | $\left[\left.\begin{array}{c} \text { Denth } \\ \text { or } \\ \text { well } \\ \text { (fi. } \end{array} \right\rvert\,\right.$ |  | Use | Drpet to Woter flevi (feet |  | $\begin{gathered} \text { Trbe } \\ \text { of } \\ \text { Well } \end{gathered}$ | $\begin{aligned} & \text { Lithology } \\ & \text { of } \\ & \text { nquifer } \end{aligned}$ | Avoilable Orawdoum (feet) |  | $\begin{gathered} Q_{20} \\ (\mathrm{igpm}) \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 213 | 10-26-36-2544 | 3015 | 90 |  | $\begin{gathered} \text { Domest ic } \\ \text { slock } \end{gathered}$ | $\begin{gathered} 46 \\ 2969 \end{gathered}$ | 48 2967 | Bedrock | $\begin{aligned} & \text { silistone } \\ & \text { (shale) } \end{aligned}$ | 40 | $\begin{gathered} 1150 \\ (\mathrm{k}=29) \end{gathered}$ | 22 |  |
| 214 | 10-26-36-2544 | 3015 | 75 |  | $\begin{gathered} \text { Domestlc } \\ \text { stock } \end{gathered}$ | 55 <br> 2960 | 55 2960 | Aedrock | shale | 15 | $\begin{aligned} & 44000 \\ & (\mathrm{~K}=220) \end{aligned}$ | 31 |  |
| 215 | 10-26-36-2544 | 3015 | 15 |  | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 10 \\ 3005 \end{array}$ |  |  |  |  |  |  |  |
| 216 | 1-27-36-2546 | 3030 | 122 |  | Domest Ic |  |  |  |  |  |  |  | Chem. onalysis available |
| 217 | 4-28-36-2544 | 3093 | 100 |  | Shot hole. | $\begin{gathered} 0 \\ 3093+ \end{gathered}$ |  |  |  |  |  |  |  |
| 218 | 4-28-36-2546 | 3107 | 100 |  | Shot hole | $3107+$ |  |  |  |  |  |  |  |
| 219 | 13-28-36-2544 | 3085 | 80 |  | $\left\lvert\, \begin{gathered} \text { Donmestict } \\ \text { stock } \end{gathered}\right.$ | $3035$ | 90 2995 | Drife |  |  |  |  |  |
| 220 | 8-29-36-2544 | 3067 | 80 |  | Shot mole | $30674$ |  |  |  |  |  |  |  |
| 221 | 8-29-36-2544 | 3070 | 100 |  | Shot mole | $3070+$ |  |  |  |  |  |  |  |
| 222 | 13-29-36-2544 | 3093 | 45 |  | Shat hole | 3093* |  |  |  |  |  |  |  |


| index Humber | Location | $\begin{gathered} \text { Elevation } \\ \text { (map) } \\ \text { in feet } \\ \text { a.m.s.l. } \end{gathered}$ | $\left\lvert\, \begin{gathered} \text { Depth } \\ \text { of } \\ \text { Ueli } \\ (f t .) \end{gathered}\right.$ | Construction, Depth Interval Open to Aquifers (feet) | Use | Depth to Water Elev. (Iect) | $\begin{gathered} \text { Depth } \\ \text { to } \\ \text { Bedrock } \\ \text { Elev. } \\ \text { (feet) } \end{gathered}$ | Type of Well | Lithology of Aquifer | Avallable Drawdown (reet) | $\begin{aligned} & 1(i g p d / f t) \\ & \text { and } \\ & K\left(i g p d / f t^{2}\right) \end{aligned}$ | $Q_{20}$ $(1 \mathrm{gpm})$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 223 | 14-29-36-2514 | 3100 | 150 |  | Shot hole | $\begin{gathered} 0 \\ 31004 \end{gathered}$ |  |  |  |  |  |  |  |
| 224 | 15-29-36-2514 | 3100 | 60 |  | Strot hole | $\begin{gathered} 0 \\ 3100+ \end{gathered}$ |  |  |  |  |  |  |  |
| 225 | 15-29-36-2504 | 3100 | 100 |  | Shot hole | $\begin{gathered} 0 \\ 1100+ \end{gathered}$ |  |  |  |  |  |  |  |
| 226 | 15-30-36-2514 | 3125 | 37 | 23-37 | $\begin{gathered} \text { Oomestic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 19 \\ 3106 \end{array}$ | $\begin{array}{r} 10 \\ 3115 \end{array}$ | Bedrock | Sandstone <br> sllistone | 10 | $\begin{gathered} 380 \\ (k=26) \end{gathered}$ | 2 |  |
| 227 | 1-31-36-2514 | 3160 | 120 | 110-120 | Domestic stack | $\begin{array}{r} 61 \\ 3099 \end{array}$ | $\begin{array}{r} 58 \\ 3102 \end{array}$ | Bedrock | silistone shale | 50 | $\begin{aligned} & 1870 \\ & (k=31) \end{aligned}$ | 44 |  |
| 228 | 5-31-36-25w4 | 3240 | 175 |  | Domestic | $\begin{array}{r} 110 \\ 3130 \end{array}$ | $\begin{array}{r} 20 \\ 3220 \end{array}$ | Bedrock | Sandstone | 60 | $\begin{gathered} 160 \\ (k=33) \end{gathered}$ | 5 |  |
| 229 | 11-31-36-25w4 | 3123 | 50 |  | Shot hoie | $\begin{gathered} 0 \\ 3123+ \end{gathered}$ |  |  |  |  |  |  | 0 - 50 clay |
| 230 | 11-31-36-25w4 | 3124 | 50 |  | Sthot hole | $\stackrel{0}{3124+}$ |  |  |  |  |  |  | 0-50 clay |
| 231 | 14-31-36-25w4 | 3127 | 45 |  | Shot hole | $\begin{gathered} 0 \\ 3127+ \end{gathered}$ |  |  |  |  |  |  |  |
| 232 | 14-31-36-25w4 | 3106 | 100 |  | Shot hole | $\begin{gathered} 0 \\ 3106+ \end{gathered}$ |  |  |  |  |  |  |  |


| Index Humber | Location | $\begin{gathered} \text { Elevation } \\ \text { (man) } \\ \text { infeet } \\ \text { a.m.s.l. } \end{gathered}$ | $\begin{gathered} \text { Depth } \\ \text { or } \\ \text { well } \\ (f i .) \\ \text { (fin } \end{gathered}$ | Construction. Depth Interval Open 10 Anpifers (fcet) | Use | Deoth to Water Elev. (feet) | ```Depth to Bedrock Elev. (rret)``` | Type of Well | Litholngy of Aquifer | Available Drawdown (feet) | $\begin{aligned} & T(i \operatorname{gpd} / f t) \\ & \text { and } \\ & K\left(i g p d / f t^{2}\right) \end{aligned}$ | $\begin{gathered} Q_{20} \\ (\mathrm{igpm}) \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 233 | 14-31-36-2514 | 3115 | 1 |  | Shot hole | $\stackrel{0}{3115+}$ |  |  |  |  |  |  |  |
| 234 | 15-31-36-25w4 | 3112 | 50 |  | Shot hole | $\stackrel{0}{3112+}$ |  |  |  |  |  |  | $0 \text { - } 50 \text { clay }$ <br> and rocks |
| 235 | 15-31-36-2544 | 3116 | 50 |  | Shot hoile | $\begin{gathered} 0 \\ 31164 \end{gathered}$ |  |  |  |  |  |  | 0 - 50 clay |
| 236 | 9-31-36-2564 | 3081 | 100 |  | Shot hole | $\begin{array}{r} 0 \\ 3081 \end{array}$ |  |  |  |  |  |  |  |
| 237 | 16-31-36-2514 | 3077 | 100 |  | Shot hole | $\begin{gathered} 0 \\ 3077+ \end{gathered}$ |  |  |  |  |  |  |  |
| 238 | 16-31-36-2544 | 3074 | 50 |  | Shot hole | $\stackrel{0}{30714+}$ |  |  |  |  |  |  |  |
| 239 | 4-32-36-2544 | 3145 | 135 | 110-135 | Domestic stock | $\begin{array}{r} 58 \\ 3087 \end{array}$ | $\begin{array}{r} 24 \\ 3121 \end{array}$ | Bedrock | Sandstone shale | 70 | $\begin{gathered} 523 \\ (\mathrm{k}=32.7) \end{gathered}$ | 17 | Recovery data |
| 240 | 13-32-36-2504 | 3077 | 50 |  | Shot trole | $\stackrel{0}{3071+}$ |  |  |  |  |  |  | 0-50 clay |
| 241 | 13-32-36-2564 | 3067 | 50 |  | Shot hole | $\begin{gathered} 0 \\ 3067+ \end{gathered}$ |  |  |  |  |  |  | 0 - 50 clay |
| 242 | 13-32-36-2564 | 3066 | 40 |  | Strot trole | $\begin{gathered} 0 \\ 3066+ \end{gathered}$ |  |  |  |  |  |  | 0-40 clay |


| Index thumber | tocation | $\begin{gathered} \text { Elevation } \\ \text { (mars) } \\ \text { in feet } \\ \text { a.m.s.l. } \end{gathered}$ | $\left\|\begin{array}{c} \text { Depth } \\ \text { of } \\ \text { Hell } \\ (\mathrm{ft} .) \end{array}\right\|$ | Construction. Oepth Interval Open to Aquifers (reet) | Use | Depth to Hater Elev. (rect) | 0epth to Bedrock Elev. (fect) | $\begin{aligned} & \text { Type } \\ & \text { of } \\ & \text { Hell } \end{aligned}$ | Lithology of Anuifer | Available Orawdown (fcet) | $\begin{aligned} & 1(i g p d / f t) \\ & \text { and } \\ & K\left(i g p d / f_{t}{ }^{2}\right) \end{aligned}$ | $\left\|\begin{array}{c} 0_{20} \\ (\mathrm{ig} \mathrm{gm}) \end{array}\right\|$ | Other <br> Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 243 | 13-32-36-2514 | 3067 | 150 |  | Shot hole | $\begin{gathered} 0 \\ 3067+ \end{gathered}$ |  |  |  |  |  |  |  |
| $\text { R.C.A. } 1$ $17-2$ | 15-33-36-2514 | 3125 | 80 | 50-80 | Test hole | $\begin{array}{r} 18 \\ 3107 \end{array}$ | $\begin{gathered} 54 \\ 3071 \end{gathered}$ | Bedrock | Sandstone | 45 |  |  |  |
| 244 | 15-36-36-25W4 | 2969 | 60 |  | Shot hole | $\begin{gathered} 0 \\ 2969+ \end{gathered}$ |  |  |  |  |  |  | $\begin{aligned} & 0-60 \\ & \text { sand E gravel } \end{aligned}$ |
| 245 | 13-35-36-25w4 | 3021 | 52 |  | Shot hole | $\begin{gathered} 0 \\ 3021+ \end{gathered}$ |  |  |  |  |  |  |  |
| 246 | 15-35-36-25wh | 3060 | 109 | 75-109 | Stock | $\begin{array}{r} 70 \\ 2990 \end{array}$ | $\begin{array}{r} 63 \\ 2997 \end{array}$ | Bedrock | Sandstone siltstone coal | 30 | $\begin{aligned} & 19.620 \\ & (k=654) \end{aligned}$ | 279 |  |
| 247 | 15-35-36-25w4 | 3060 | 230 |  | stock | $\begin{array}{r} 110 \\ 2950 \end{array}$ | $\begin{array}{r} 38 \\ 3022 \end{array}$ | Bedrock | Sandstone | 115 | $\begin{array}{r} 575 \\ (k=23) \end{array}$ | 31 |  |
| 248 | 15-35-36-2504 | 3055 | 265 |  | Domestic | $\begin{array}{r} 105 \\ 2950 \end{array}$ | $\begin{array}{r} 35 \\ 3020 \end{array}$ | Bedrock | Sandstone |  |  |  |  |
| 249 | 13-11-36-2646 | 3125 | 121 |  | Stock | $\begin{array}{r} 45 \\ 3080 \end{array}$ | $\begin{array}{r} 35 \\ 3090 \end{array}$ | Bedrock | Sandstone | 65 | $\begin{aligned} & 13.080 \\ & (\mathrm{k}=4.09) \end{aligned}$ | 403 | Chem. ansiysis avallable |
| 250 | 1-14-36-26.14 | 3070 | 60 |  | Domestic | $\begin{array}{r} 25 \\ 3045 \end{array}$ | >60 | Drift | Sand gravel | 30 | $\begin{array}{r} 860 \\ (k=86) \end{array}$ | 12 |  |
| 251 | 12-14-36-2604 | 3150 | 80 | 70-80 | Oomestic | 28 3122 | 18 3132 | Fedrock | Sandstone | 45 | $\begin{array}{r} 410 \\ (k=23) \end{array}$ | 9 |  |


| $=$ | ，inter | 过 | 5 |  |  | \％ | 20 |  | amo | 0 | 边 | ｜riol | $\cdots$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| ${ }^{32}$ | 12. |  |  |  |  | \％ |  |  |  |  |  |  |  |
| 23 | 边 | \％ |  |  | ＂ | $\ldots$ |  |  |  |  |  |  |  |
| 208 | ， | ，195 |  |  |  | \％ |  |  |  |  |  |  |  |
| 28 | 23， 2, ama | \％＂s ${ }^{\text {s }}$ |  |  | $\cdots$ |  |  |  |  |  |  |  |  |
| 28 |  | ＂＂ |  |  |  | \％ |  |  |  |  |  |  |  |
| 280 | $0\|:\|$ | n＂\％ |  |  |  | $\cdots$ |  |  |  |  |  |  |  |
| 40 |  | mp |  |  | n2 | mon |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |


| Index Humber | Location | $\begin{gathered} \text { Elevation } \\ \text { (man) } \\ \text { in reet } \\ \text { a.m.s.l. } \end{gathered}$ | $\begin{gathered} \text { Depen } \\ \text { of } \\ \text { Well } \\ \text { (rt.) } \end{gathered}$ | Construction, Oepth Interval Open to Aquifers ( Feet) | Use | Depth to Water Elev. (feet) | Oepth to Bedrock Elev. (feet) | Type of Well | Lithology of Aquifer | Avallable Orawdown (feet) | $\begin{aligned} & T(i g \mathrm{gd} / \mathrm{ft}) \\ & \text { and } \\ & \mathrm{K}\left(\mathrm{igpd} / \mathrm{ft}^{2}\right) \end{aligned}$ | $\left\lvert\, \begin{gathered} a_{20} \\ (i \mathrm{~g} \mathrm{pm}) \end{gathered}\right.$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 261 | 2-25-36-2644 | 3115 |  |  | Shot trole | $\begin{gathered} 0 \\ 3115+ \end{gathered}$ |  |  |  |  |  |  |  |
| 262 | 3-25-36-26,4 | 3110 | 60 |  | Strot hole | $\stackrel{0}{3110+}$ |  |  |  |  |  |  |  |
| 263 | 13-25-36-26w4 | 3115 | 30 |  | Shot hole | $\begin{gathered} 0 \\ 3115+ \end{gathered}$ |  |  |  |  |  |  |  |
| 264 | 13-25-36-2614 | 3115 | 60 |  | Shot mole | $\stackrel{0}{3115+}$ |  |  |  |  |  |  |  |
| 265 | 13-25-36-26w4 | 3120 | 75 |  | Shot hole | $\stackrel{0}{3120+}$ | $\begin{array}{r} 35 \\ 3085 \end{array}$ | Bedrock | Sands tone shale |  |  |  |  |
| 266 | 15-25-36-26W4 | 3135 | 45 |  | Shot hole | $\begin{gathered} 0 \\ 3135+ \end{gathered}$ |  |  |  |  |  |  |  |
| 267 | 15-25-36-2614 | 3135 | 75 |  | strot trole | $\begin{gathered} 0 \\ 3135+ \end{gathered}$ | $\begin{array}{r} 35 \\ 3100 \end{array}$ | Bedrock | Sands tone shale |  |  |  |  |
| 268 | 16-25-36-26w4 | 3160 | 140 |  | pomestic stock | $\begin{array}{r} 40 \\ 3120 \end{array}$ |  |  |  |  |  |  |  |
| 269 | 16-25-36-26V4 | 3160 | 130 |  | Domestic stock | $\begin{array}{r} 50 \\ 3110 \end{array}$ |  |  |  |  |  |  | Chem. analysis avallable |
| 270 | 16-25-36-26w4 | 3160 | 230 | 177-230 | pomestic stock | $\begin{array}{r} 130 \\ 3030 \end{array}$ | 48 3112 | Oedrock | shlistone coals | 95 | $\begin{gathered} 350 \\ (k=27) \end{gathered}$ | 16 | Recovery data |


| Index | tocation | $\begin{gathered} \text { Elevation } \\ \text { (monf) } \\ \text { infeet } \\ \text { a.m.s.i. } \end{gathered}$ |  | Construction. <br> DepthDiterval <br> Open tor <br> anuifers <br> (feet) | use | $\begin{gathered} \text { Oepth } \\ \text { oed } \\ \text { Water } \\ \text { flev } \\ \text { (feec) } \end{gathered}$ |  | $\begin{aligned} & \text { Type } \\ & \text { yof } \\ & \text { Hell } \end{aligned}$ | $\begin{aligned} & \text { Lithology } \\ & \text { Aquifer } \end{aligned}$ | $\left\lvert\, \begin{array}{\|c\|} \text { Avallable } \\ \text { Drawdown } \\ \text { (feet) } \end{array}\right.$ |  | $\begin{gathered} a_{20} \\ (1 \text { Igpm }) \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 271 | 8-26-36-2644 | 3093 | 60 |  | Shot mole | $\begin{gathered} 0 \\ 3093 \end{gathered}$ |  |  |  |  |  |  |  |
| 272 | 13-26-36-2644 | 319 | 80 |  | shot mote | $\stackrel{0}{3119+}$ |  |  |  |  |  |  |  |
| 273 | 13-26-36-2644 | 3122 | 30 |  | Shot mote | $\begin{gathered} 0 \\ 3122+ \end{gathered}$ |  |  |  |  |  |  |  |
| 274 | 16-26-36-2644 | 3115 | 150 |  | shot trole | Mis+ |  |  |  |  |  |  |  |
| 275 | 1-27-36-2664 | 3120 | 180 |  | shot tole | $3120+$ |  |  |  |  |  |  |  |
| 276 | 9-27-36-2664 | 3110 | 80 |  | shot hole | $\stackrel{1110+}{0}$ |  |  |  |  |  |  |  |
| 271 | 10-35-36-2644 | 3160 | 280 |  | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{aligned} & 30 \\ & 3100 \end{aligned}$ |  |  |  |  |  |  |  |
| 278 | 14-35-36-2644 | 3130 | 94 | $82-94$ | stock | $\begin{gathered} 68(7) \\ 3062 \end{gathered}$ | $\begin{gathered} 82 \\ 3048 \end{gathered}$ | Bedrock | $\left\lvert\, \begin{aligned} & \text { shale } \\ & \text { (fractured) } \end{aligned}\right.$ | 20 | 630 | 6 |  |
| 279 | $\begin{aligned} & \text { su- } 36-36-26 W 4 \\ & (6) \end{aligned}$ | 3190 | 75 |  |  | 30 3160 |  |  |  |  |  |  |  |
| 280 | 15-36-36-2644 | 3215 | 125 |  | Domest lic | 175 |  |  |  |  |  |  | Chem. analysis aval lable |


| Index | Location |  |  |  | use | $\begin{aligned} & \text { Denth } \\ & \text { Lo } \\ & \text { Water } \\ & \text { (Ierev. } \\ & \text { (feet) } \end{aligned}$ | Depth Bedrock Elock (feet) | $\begin{aligned} & \text { Type } \\ & \text { Hefll } \end{aligned}$ | $\begin{aligned} & \text { Lit tholooq } \\ & \text { Aquifer } \end{aligned}$ | $\left.\begin{array}{\|c} \text { Availlable } \\ \text { orawdown } \\ \text { (feet) } \end{array} \right\rvert\,$ |  | $\begin{gathered} 0_{20} \\ (\text { (igpm) } \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 281 | 1-4-37-2444 | 3025 | 90 | 65 -90 | Domestic | 60 2965 | $2960$ | Bedrock | Sandstone | 25 | $\left.\begin{array}{c} 19.690 \\ (\mathrm{k}=4929 \end{array}\right)$ | 233 |  |
| 282 | SE-6-37-24W4 | 3060 | 135 |  | stock | 75 2985 |  |  |  |  |  |  |  |
| 283 | 16-7-37-24.44 | 2975 | 320 | 297-320 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{gathered} 150 \\ 2825 \end{gathered}$ | ${ }_{2923}^{52}$ | Bedrock | Silestone shale. coal | 200 | $\begin{gathered} 1170 \\ (\mathrm{~K}=20) \end{gathered}$ | II' |  |
| 284 | 1-18-37-24.44 | 2930 | 240 | 200-240 | $\begin{gathered} \text { Oomestle } \\ \text { stock } \end{gathered}$ | 190 2740 | 108 2822 | 9edrock | Sandstone | 35 | $\begin{gathered} 130 \\ (k=18.3) \end{gathered}$ | 12 |  |
| 285 | 1-1-37-2514 | 3165 | 242 | 200-242 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 140 \\ 3025 \end{array}$ | 320 3145 | pedrock | $\begin{aligned} & \text { Sandstone } \\ & \text { sitistone } \end{aligned}$ | 23 | $\begin{gathered} 2950 \\ (K=42) \end{gathered}$ | 32 |  |
| 286 | 4-1-37-2504 | 3030 | 70 |  | Oomest ic | 148 3016 |  |  |  |  |  |  | $\begin{aligned} & \text { Chem. analysts } \\ & \text { avallable } \end{aligned}$ |
| 281 | 16-2-37-2544 | 3140 | 180 |  | Oomest ic | 120 3020 |  |  |  |  |  |  | Chem, analysis avallable |
| 288 | 2-3-37-2514 | 3000 | 80 |  | stock | $3000+$ |  |  |  |  |  |  |  |
| 289 | 9-3-37-2544 | 3080 | 125 | 102-125 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | 105 2975 | 90 2990 | Bedrock | Shale <br> fractured | 15 | ${ }_{(12066)}^{2625}$ | 19 |  |
| 290 | 12-3-37-2544 | 3040 | 110 | 80-110 | Industrial | 70 2970 | 295 | Redrock | stlistone | 40 | 13.080 | 248 | no drawdown |


| Index Humber | Location | $\begin{gathered} \text { Elevation } \\ \text { (man) } \\ \text { in feet } \\ \text { a.m.s.l. } \end{gathered}$ | $\left.\begin{gathered} \text { Depth } \\ \text { of } \\ v_{c} \\ \text { (fti } \\ \text { fit } \end{gathered} \right\rvert\,$ | Construction, Depth Interval Open to Aquifers (feet) | Use | Depth to Hater Elev. (feet) | Depth to Bedrock Elev. (feet) | Type of <br> Hell | Lithology of Aquifer | Avallable Drawdown (feet) | $\begin{aligned} & T(i g p d / f t) \\ & \text { and } \\ & K\left(i g p d / f t^{2}\right) \end{aligned}$ |  | Other Acmarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 291 | 9-6-37-2514 | 3075 | 165 | 104-165 | Domestic | $\begin{array}{r} 95 \\ 2980 \end{array}$ | $\begin{array}{r} 88 \\ 2987 \end{array}$ | Bedrock | slitstone sands tone coal | 65 | 13.080 |  | Ho draudown |
| 292 | 5-5-37-2514 | 3070 | 50 |  | Shot hole | $\begin{gathered} 0 \\ 3070+ \end{gathered}$ |  |  |  |  |  |  | $0-50$ +111 |
| 293 | 5-5-37-25w4 | 3090 | 50 |  | Shot hole | $\begin{gathered} 0 \\ 3090+ \end{gathered}$ |  |  |  |  |  |  | $0-50$-111 |
| 294 | 1-6-37-2544 | 3074 | 50 |  | Shot hole | $\begin{gathered} 007 \mathrm{~h}+ \end{gathered}$ |  |  |  |  |  |  | 0-50 1111 |
| 295 | 1-6-37-2564 | 3075 | 50 |  | Shot trole | $\begin{gathered} 0 \\ 3075+ \end{gathered}$ |  |  |  |  |  |  | 0-50 111 |
| 296 | 1-6-37-2514 | 3082 | 50 |  | Shrot hole | $\stackrel{0}{3082+}$ |  |  |  |  |  |  | 0-50 1111 |
| 297 | 1-6-37-25w4 | 3076 | 80 |  | Shot thole | $\underset{3076+}{0}$ |  |  |  |  |  |  |  |
| 298 | 1-6-37-2514 | 3067 | 50 |  | Shot hole | $\begin{gathered} 0 \\ 3067+ \end{gathered}$ |  |  |  |  |  |  | 0-50 111 |
| 299 | 1-6-37-25w4 | 3082 | 50 |  | shot hole | $\underset{3082+}{0}$ |  |  |  |  |  |  | 0-50 1111 |
| 300 | 1-6-37-25w4 | 3086 | 50 |  | shot trole | $\begin{gathered} 0 \\ 3086+ \end{gathered}$ |  |  |  |  |  |  | 0-50 1ill |


| Index Number | Location | $\begin{gathered} \text { Elevation } \\ \text { (mos) } \\ \text { in feet } \\ \text { a.m.s.l. } \end{gathered}$ | $\left\|\begin{array}{c} \text { Depth } \\ \text { of } \\ \mathrm{Well}_{\mathrm{c}} \\ (\mathrm{ft} .) \end{array}\right\|$ | Construction. Depth Interval Open to Aquifers (feet) | Use | Depth to Water Elev. (feet) | ```Depth to Bedrock Elev. (feet)``` | Type of Well | Uthology of nnuifer | Avaliable Drawdown (feet) | $\begin{gathered} T(i g p d / f t) \\ \text { end } \\ K\left(i g p d / \mathrm{ft}^{2}\right) \end{gathered}$ | $\begin{gathered} Q_{20} \\ (i g \mathrm{pm}) \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 301 | 2-6-31-25w4 | 3078 | 50 |  | Shot hole | $\stackrel{0}{3078+}$ |  |  |  |  |  |  | 0-50 t111 |
| 302 | 3-6-37-2514 | 3100 |  |  | Sthot hole | $\stackrel{0}{3100+}$ |  |  |  |  |  |  |  |
| 303 | 4-6-37-25w4 | 3113 | 50 |  | Shot hole | $\stackrel{0}{3113+}$ |  |  |  |  |  |  | 0-50 tlll |
| 304 | 7-6-37-25W4 | 3081 | 50 |  | Shot hole | $\stackrel{0}{3081+}$ |  |  |  |  |  |  | 0-50 (11) |
| 305 | 8-6-31-25144 | 3080 | 55 |  | Shot hole | $\begin{gathered} 0 \\ 3080+ \end{gathered}$ |  |  |  |  |  |  |  |
| 306 | 13-7-37-25w4 | 3166 | 60 |  | Shot hole | $\underset{3166+}{0}$ |  |  |  |  |  |  |  |
| 307 | 16-8-37-25w4 | 3105 | 150 |  | Sthot hole | $\begin{gathered} 0 \\ 3105+ \end{gathered}$ |  |  |  |  |  |  |  |
| 308 | 16-8-37-2514 | 3104 | 62 |  | Shot hole | $\stackrel{0}{0}$ |  |  |  |  |  |  |  |
| 309 | 5-9-37-25W4 | 3134 | 50 |  | Shot hole | $\begin{gathered} 0 \\ 3134+ \end{gathered}$ |  |  |  |  | . |  | 0-20 aravel 20-50 clay $\varepsilon$ rock |
| 310 | 5-9-37-2544 | 3127 | 50 |  | Stot hole | $\begin{gathered} 0 \\ 3127+ \end{gathered}$ |  |  |  |  |  |  | $\begin{aligned} & 0-50 \\ & \text { clay E rock } \end{aligned}$ |


| Index Number | Location | $\begin{gathered} \text { Elevation } \\ \text { (map) } \\ \text { in feet } \\ \text { a.m.s.l. } \end{gathered}$ | $\left\|\begin{array}{c} \text { Depth } \\ \text { of } \\ \text { Well } \\ (\mathrm{fe} .)^{2} \end{array}\right\|$ | Construction. Depth Interval Open to Aquifers (reet) | Use | Depth to Hater Elev. (feet) | ```Denth to Bedrock Elev. (feet)``` | Type of Hell | Lithology of Anuifer | Avallable Orawdown (reet) | $\begin{aligned} & \mathrm{T}(\mathrm{igpd} / \mathrm{ft}) \\ & \mathrm{and} \\ & K\left(\mathrm{igpd} / \mathrm{ft}^{2}\right) \end{aligned}$ | $\left\|\begin{array}{c} Q_{20} \\ (1 \mathrm{gmm}) \end{array}\right\|$ | Other Aemarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 311 | 4-10-37-25wh | 3065 | 100 |  | Domestic | $\begin{array}{r} 83 \\ 2982 \end{array}$ | $\begin{array}{r} 100 \\ 2965 \end{array}$ | Drift | Drift/Dedrock Contact |  |  |  | Chem. snalysls avallable |
| 312 | 12-14-37-2564 | 3060 | 120 | 104-120 | Stock | $\begin{array}{r} 90 \\ 2970 \end{array}$ | $\begin{array}{r} 92 \\ 2968 \end{array}$ | Bedrock | Fractured shale. silestone | 25 | $\begin{gathered} 3755 \\ (k \rightarrow 94) \end{gathered}$ | 45 | Recovery data |
| 313 | 12-14-37-2504 | 3060 | 110 |  | $\left\lvert\, \begin{gathered} \text { Domes tic } \\ \text { stock } \end{gathered}\right.$ | $\begin{array}{r} 90 \\ 2970 \end{array}$ |  | Bedrock | Shale, silistone |  |  |  | Chem. analysls avallable |
| 314 | 3-16-37-2514 | 3135 | 200 | 145-200 | Oomestic | $\begin{array}{r} 121 \\ 3014 \end{array}$ | $\begin{array}{r} 136 \\ 2999 \end{array}$ | Bedrock | Shale sandstone | 70 | $\begin{gathered} 140 \\ (k=7.2) \end{gathered}$ | 5 |  |
| 315 | 1-17-37-2564 | 3105 | 59 |  | Shot hole | $\begin{gathered} 0 \\ 3105+ \end{gathered}$ |  |  |  |  |  |  |  |
| 316 | 8-21-37-2544 | 3110 | 212 | 180-212 | $\left\lvert\, \begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}\right.$ | $\begin{array}{r} 172 \\ 2938 \end{array}$ | $\begin{array}{r} 164 \\ 2946 \end{array}$ | Bedrock | Sandstone siltstone | 30 | $\begin{aligned} & 26,158 \\ & (k=581) \end{aligned}$ | 372 |  |
| 317 | 6-2h-31-25wh | 2950 | 130 | 100-130 | Domestic stock | $\begin{array}{r} 20 \\ 2930 \end{array}$ | $\begin{array}{r} 97 \\ 2853 \end{array}$ | Bedrack | Shale siltstone | 100* | $\begin{gathered} 190 \\ (k=14.6) \end{gathered}$ | 9 | Recovery data |
| 318 | 8-28-37-25044 | 3025 | 100 |  | Domestic | $\begin{array}{r} 90 \\ 2935 \end{array}$ | 91 2934 |  |  |  |  |  | Chem. analysis avaliable |
| 319 | 4-31-37-2564 | 3109 | 60 |  | Strot hole | $\begin{gathered} 0 \\ 3109+ \end{gathered}$ |  |  |  |  |  |  |  |
| 320 | 14-31-31-25w4 | 3025 | 120 |  | Stock | 37 2988 | 35 2990 | Bedrock | Sandstone | 75 | $\begin{gathered} 1010 \\ (k=25) \end{gathered}$ | 36 |  |


| $\begin{aligned} & \text { Index } \\ & \text { Humber } \end{aligned}$ | tocation |  |  | Construct ion. Oepth niterval open to nquifers (feet) | use | $\begin{aligned} & \text { oesth } \\ & \text { Hater } \\ & \text { Hater } \\ & \text { (feck) } \\ & \text { (fect) } \end{aligned}$ |  | $\begin{aligned} & \text { Type } \\ & \text { Hef } \end{aligned}$ | $\begin{aligned} & \text { Litllologr } \\ & \text { Anuifer } \end{aligned}$ | $\left\|\begin{array}{c} \text { Available } \\ \text { Orawdown } \\ (\text { feet } \end{array}\right\|$ |  | $\left\|\begin{array}{c} a_{20} \\ (i g p m) \end{array}\right\|$ | ¢ Other |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 321 | 14-31-37-2544 | 3025 | 90 |  |  | 50 290 | $3009$ | Bedrock | $\begin{aligned} & \text { Sandstone } \\ & \text { shate } \end{aligned}$ | 7 |  |  |  |
| 322 | 16-31-37-254b | 3000 | 150 |  | stock | 115 2885 | 40 2960 | nedrock | Sands tone | $30+$ | $\begin{gathered} 370 \\ (k=1) \end{gathered}$ | 5 | $\begin{aligned} & \text { Chem. analysis } \\ & \text { avallable } \end{aligned}$ |
| 323 | 13-32-37-2544 | 2950 | 130 | 34-130 | mestic | 53 2897 | 30 2920 | Redrock | Sandstone | 60 | ${ }_{(k \times 21.8)}^{650}$ | 19 |  |
| 324 | 15-32-27-2544 | 2910 | 90 | 70-90 | mestic | 30 2880 | 2902 | Bedrock | Sands tone | 55+ | ${ }_{(k-13.3)}^{290}$ | - |  |
| 325 | 1-1-37-2544 | 3139 | 180 |  | Shot hale | $3139+$ |  |  |  |  |  |  |  |
| 326 | 4-3-37-2644 | 3160 | $\because 0$ | 36-110 | $\begin{gathered} \text { Domestlc } \\ \text { stock } \end{gathered}$ | ${ }_{3123}^{37}$ | 12 3148 | Bedrock | $\begin{array}{\|l\|l\|} \hline \text { siltstone } \\ \text { shale } \\ \text { sandstone } \end{array}$ | 65 | $(k=3.4)$ | 1 |  |
| 327 | 4-3-37-2644 | 3160 | 50 |  | - Donestic | 3113 |  | Bedrock | sititstone shalle sandstone |  |  |  | $\begin{aligned} & \text { Chem, matuy is } \\ & \text { avai lable } \end{aligned}$ |
| 328 | 8-3-37-2664 | 3135 | 15 |  | stock | ${ }_{3135+}^{0}$ |  |  |  |  |  |  |  |
| 329 | 13-3-37-2644 | 3205 | 140 |  | $\begin{gathered} \text { Domest ic } \\ \text { Iock } \end{gathered}$ | 3115 | 90 3115 | pedrock | $\begin{aligned} & \text { sitistone } \\ & \text { shale } \end{aligned}$ | 45 | 280 |  | $\begin{aligned} & \begin{array}{l} \text { Chem. onalysis } \\ \text { available } \end{array} \end{aligned}$ |


| Index Humber | Location | $\begin{gathered} \text { Elevation } \\ \text { (mop) } \\ \text { in feel } \\ \text { a.m.s.1. } \end{gathered}$ | $\left(\left.\begin{array}{c} \text { Depeth } \\ \text { or } \\ \text { wetil } \\ \text { (ft. } \end{array} \right\rvert\,\right.$ | Construction. Depth Interval Open to (foet) | Use | $\begin{aligned} & \text { Depth } \\ & \text { to } \\ & \text { Water } \\ & \text { cotev } \\ & \text { (feet) } \end{aligned}$ | $\begin{gathered} \text { Depth } \\ \text { to } \\ \text { Bedrock } \\ \text { Elev. } \\ \text { (feet) } \end{gathered}$ | $\begin{gathered} \text { Trpe } \\ \text { Hell } \end{gathered}$ | $\begin{aligned} & \text { Lit hology } \\ & \text { Aquifer } \end{aligned}$ | $\left.\begin{array}{\|c} \text { Available } \\ \text { orawdowr } \\ \text { (feet) } \end{array} \right\rvert\,$ |  | $\begin{gathered} a_{20} \\ (1 \mathrm{gmom}) \end{gathered}$ | ( $\begin{gathered}\text { Other } \\ \text { Remarks }\end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 330 | 16-4-37-2644 | 3185 | 231 | 147-231 | Domestic | $\begin{aligned} & 124 \\ & 3061 \end{aligned}$ | $\begin{aligned} & 100 \\ & 3175 \end{aligned}$ | Bedroch | Sands tone siltstone | 45 | $\begin{gathered} 660 \\ (x-20) \end{gathered}$ | 14 | Pump lest dato |
| 331 | 8-9-37-2664 | 3185 | 270 | 250-270 | stock | 224 2961 | 23 3162 | Bedrock | $\begin{aligned} & \text { shlestone } \\ & \text { shale } \\ & \text { sand tione } \end{aligned}$ | 40 | $\begin{aligned} & 1330 \\ & (k-16.3) \end{aligned}$ | 25 |  |
| 332 | 8-9-37-2664 | 3170 | 382 | 282-382 | stock | 185 2985 | 42 3128 | Bedrock | $\begin{aligned} & \text { Sandstone } \\ & \text { coals } \end{aligned}$ | 190 | $\begin{gathered} 80 \\ (k=2) \end{gathered}$ | 7 |  |
| 333 | 8-9-37-26w4 | 3180 | 240 | 215-240 | stock | 179 3001 | 3153 | Bedrock | Sands tone | 55 | $\begin{gathered} 820 \\ (x-+1) \end{gathered}$ | 21 |  |
| 334 | 5-10-37-26 W/ | 3185 | 185 | 138-185 | stock | 137 3048 | 3173 | Bedrock | $\begin{aligned} & \text { Fractured } \\ & \text { shale } \\ & \text { sandstone } \end{aligned}$ | 40 | $\begin{gathered} 160 \\ (k=15) \end{gathered}$ | 14 | Recovery data |
| 335 | $\underset{7}{13-10-37-26 \mathrm{W4}}$ | 3150 | 140 | 100-140 | Domestic | 100 3050 | ${ }_{3138}^{22}$ | Bedrock | $\begin{aligned} & \text { siltstone } \\ & \text { sandstone } \end{aligned}$ | 35 | ${ }_{(100}^{100}$ | 12 |  |
| 335.5 | NE-10-37-26W4 | 3180 | 90 | 70-90 | stock | $\begin{array}{r} 41 \\ 3139 \end{array}$ | 70 3120 | Dedrock | $\begin{array}{\|l\|l} \hline \text { Shale } \\ \text { siltstone } \end{array}$ | 40 | $\begin{gathered} 3860 \\ (k=97) \end{gathered}$ | 33 | Pump lest data |
| 336 | Nw-12-37-2644 | 3240 | ${ }^{82}$ |  |  |  |  |  |  |  |  |  | $\begin{aligned} & \text { Chem anolysis } \\ & \text { ovailatle } \end{aligned}$ |
| 337 | Sw-13-37-2644 | 3200 | 125 |  |  |  |  |  |  |  |  |  | Chem. analysis Avallable |
| 338 | 1-15-37-26.4 | 3165 | 105 | 90-105 | $\underset{\substack{\text { Oumestic } \\ \text { strock }}}{\text { ctic }}$ | 3133 | ${ }_{\substack{85 \\ 3080}}$ | Restrock | $\begin{array}{\|l} \text { shale } \\ \text { siltstone } \end{array}$ | 65 | $\underset{\substack{560 \\(x=16)}}{\text { ¢ }}$ | 11 |  |


| $\begin{aligned} & \text { Index } \\ & \text { Ilumber } \end{aligned}$ | Location | $\left\|\begin{array}{c} \text { Elevation } \\ (\text { mnn } \\ \text { in } \\ \text { a.m.et } \\ \text { a.m. } \end{array}\right\|$ |  | $\left\{\begin{array}{c} \text { construct ion. } \\ \text { ocpth noterval } \\ \text { opent to } \\ \text { Aufics } \\ \text { (feet) } \end{array}\right.$ | Use | $\begin{aligned} & \text { Depth } \\ & \text { Hator } \\ & \text { Hater } \\ & \text { (Ieve } \\ & \text { (feet } \end{aligned}$ | $\begin{gathered} \text { ocpth } \\ \text { oceto } \\ \text { Bectrock } \\ \text { EIFver } \\ \text { (feet) } \end{gathered}$ | $\begin{aligned} & \text { Type } \\ & \text { vef } \\ & \text { wefl } \end{aligned}$ | $\begin{aligned} & \text { Litholony } \\ & \text { of } \\ & \text { ancifer } \end{aligned}$ | $\left\|\begin{array}{c} \text { Available } \\ \text { Orawdown } \\ \text { (feret) } \end{array}\right\|$ | $\begin{gathered} T(\text { igod } / f 0) \\ \text { sind } \\ K\left(i g d / f_{t}{ }^{2}\right) \end{gathered}$ | $\left.\begin{gathered} a_{20} \\ (19 p m) \end{gathered} \right\rvert\,$ | Oether Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 339 | 3-15-37-2694 | 3140 | 130 | 60-130 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{array}{r} 9595 \\ 3045 \end{array}$ | $\begin{gathered} 222 \\ 318 \end{gathered}$ | 日edrock | Sandstone | 30 | $\begin{gathered} 13.080 \\ (654) \end{gathered}$ | 186 |  |
| 340 | 2-21-37-2644 | 3060 | 84 |  | $\left\lvert\, \begin{gathered} \text { Domest ic ic } \\ \text { Stock } \end{gathered}\right.$ | $3020$ | $2900$ | Bedrock | sandstone | $40+$ |  |  |  |
| 341 | 4-22-37-2644 | 3057 | 45 |  | shot hole | $3051+$ |  |  |  |  |  |  | 0-45 clay |
| 342 | 15-22-37-2644 | 3160 | 64 | 57-64 | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ | $\begin{aligned} & 1145 \\ & 3145 \end{aligned}$ |  |  |  |  |  |  | $\begin{aligned} & \text { Chem, Analysis } \\ & \text { avaliable } \end{aligned}$ |
| 343 | 1-23-37-2644 | 3435 | 262 | 183-262 | Domestic | $\begin{aligned} & 231 \\ & 3204 \end{aligned}$ | 40 3395 | Bedrock | $\begin{aligned} & \text { Shale } \\ & \text { Sandstone } \end{aligned}$ | 30 | $\left(\begin{array}{c} 98=38) \end{array}\right.$ | 2 | Pump test data |
| 344 | 1-24-37-2644 | 3440 | 500 |  | Abandoried | 187 325 | $\begin{aligned} & 339 \\ & \hline 639 \end{aligned}$ | Aedrock | $\begin{aligned} & \text { silitstone } \\ & \text { shane } \\ & \text { shandtone } \end{aligned}$ | 13 | $\begin{gathered} 290 \\ (\mathrm{~K}=38) \end{gathered}$ | 2 |  |
| 345 | 1-24-37-2644 | 3440 | 210 | 200-210 | Domest le | 185 <br> 3255 | 43 339 | Bectrock | Sands tone | 9 | $\begin{gathered} 8890 \\ (k-444) \end{gathered}$ | 38 |  |
| 346 | 1-24-37-2644 | 3440 | 400 |  | Domest ic | 179 |  | Pedrock | $\begin{aligned} & \text { Sandstone } \\ & \text { siltstone } \end{aligned}$ | 20 | $\left(\begin{array}{c} 500 \\ (\mathrm{~S}=23) \end{array}\right.$ | 5 | Pump test data |
| 347 | 12-24-37-2644 | 3300 | 96 |  | Stock | $\begin{array}{r} 466 \\ 3254 \end{array}$ |  |  |  |  |  |  |  |
| 348 | 13-25-37-2644 | 3150 | $8_{0}$ | 50-80 | Domestic | 3138 | - ${ }^{18}$ | ${ }^{\text {Pedrock }}$ | $\begin{aligned} & \text { Fractured } \\ & \text { shate } \\ & \text { sillstone } \end{aligned}$ | 25 | $\begin{gathered} 24,30 \\ (k=122) \end{gathered}$ | 29 |  |


| $\begin{aligned} & \text { Index } \\ & \text { number } \end{aligned}$ | Location |  |  | Construction. Depth Interval Open to (fect) (fect) | Use | $\begin{aligned} & \text { Depth } \\ & \text { (o } \\ & \text { Hater } \\ & \text { (Ifev. } \\ & \text { (fect) } \end{aligned}$ | $\begin{array}{\|c} \text { Depth } \\ \text { to } \\ \text { Bedrock } \\ \text { Elcv. } \\ \text { (fect) } \end{array}$ | $\begin{array}{\|c\|c} \text { Type } \\ \text { of } \\ \text { hell } \end{array}$ | $\begin{gathered} \text { Ulthology } \\ \text { Aquifer } \end{gathered}$ | $\left.\begin{gathered} \text { Aval lable } \\ \text { orandoum } \\ \text { (feet) } \end{gathered} \right\rvert\,$ |  | $\begin{gathered} 0_{20} \\ (11 \mathrm{Igpm}) \end{gathered}$ | other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 349 | NE-25-37-2644 | 3190 | 98 |  | Oomestic | ${ }_{3184}{ }^{6}$ |  |  |  |  |  |  | $\begin{aligned} & \text { Chem, anslysis } \\ & \text { avaliable } \end{aligned}$ |
| 350 | 3-27-37-2604 | 3125 | 33 |  |  | 3113 |  | orife |  |  |  |  |  |
| 351 | 1-34-37-2644 | 3079 | 60 |  | Shot trole | $3079+$ |  |  |  |  |  |  |  |
| 352 | 8-34-37-2644 | 3085 | 90 |  | stock | ${ }_{3053}$ | 65 3020 | Bedrock | $\begin{aligned} & \text { Sands tone } \\ & \text { shale } \end{aligned}$ | 50 | $\underset{(k=122)}{3667}$ | B7 |  |
| 353 | 1-35-37-2644 | 3105 | 150 |  | shot hole | $310{ }^{0}+$ |  |  |  |  |  |  |  |
| 354 | ne-35-37-2644 | 2985 | 151 | 118 - 151 | stock | 989 2886 | 63 2922 | Bedrock | Sandstone | 45 | $\begin{gathered} 500 \\ (K=39) \end{gathered}$ | 11 |  |
| 355 | 8-36-37-26 W4 | 3100 | 76 | $61-76$ | stock | 3273 | 359 | Dedrock | $\begin{aligned} & \text { Fractured } \\ & \text { shale } \end{aligned}$ | 40 | $\begin{gathered} 13,1,30 \\ (k=549) \end{gathered}$ | 260 |  |
| 356 | 8-36-37-26 W4 | 3100 | 120 | 90-120 | Stock | 50 3050 | $\begin{array}{r} 87 \\ 3013 \end{array}$ | Bedrock | $\begin{aligned} & \text { Sandstone } \\ & \text { silistone } \end{aligned}$ | 60 | $\begin{gathered} 1635 \\ (x=41) \end{gathered}$ | 47 | $\begin{aligned} & \text { chem analysis } \\ & \text { avosilable } \end{aligned}$ |
| 357 | 8-36-37-2644 | 3100 | 85 |  |  | $3100+$ |  |  |  |  |  |  |  |


| Index Humber | Location | $\left\|\begin{array}{c} \text { Elevetlon } \\ \text { (map) } \\ \ln \text { reet } \\ \text { a.m.s.l. } \end{array}\right\|$ | $\left\|\begin{array}{c} \text { Depth } \\ \text { of } \\ \text { Well } \\ (F \mathrm{ft} .) \end{array}\right\|$ | Construction. Depth interval Open to Aquifers (feet) | Use | Depth to Water Elev. (fcet) | ```Depth to Bedrock Elev. (rcet)``` | Type of Hell | Lithology of Aquifer | Avallable Drawdown (rect) | $\begin{aligned} & T(i g p d / f t) \\ & \text { and } \\ & K\left(i \operatorname{god} / \mathrm{ft}^{2}\right) \end{aligned}$ | $\begin{gathered} Q_{20} \\ (i g p m) \end{gathered}$ | Other Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 358 | 14-36-37-2614 | 3030 | 140 | 58-140 | Domestlc slock | $\begin{array}{r} 67 \\ 2963 \end{array}$ | $\begin{array}{r} 43 \\ 2987 \end{array}$ | Bedrock | siltstone sthale sands tone | 40 | $\begin{gathered} 1510 \\ (k-28) \end{gathered}$ | 29 |  |
| 359 | 14-36-37-26W4 | 3030 | 130 | 60-130 | $\begin{aligned} & \text { Domest Ic } \\ & \text { stock } \end{aligned}$ | $\begin{array}{r} 75 \\ 2955 \end{array}$ | $\begin{array}{r} 42 \\ 2988 \end{array}$ | Bedrock | Shale <br> sandstone <br> coal | 15 | $\begin{gathered} 4670 \\ (k=104) \end{gathered}$ | 33 |  |
| L-1 | SE-16-35-25W4 | 3142 | 120 |  | Domestic stock |  | 60 3082 | Bedrock |  |  |  |  |  |
| L-2 | NE-20-35-25w4 | 3145 | 145 |  | $\begin{gathered} \text { Domestle } \\ \text { stock } \end{gathered}$ |  | $\begin{array}{r} 95 \\ 3050 \end{array}$ | Bedrock |  |  |  |  |  |
| 1-3 | 5W-28-35-25w4 | 3125 | 22 | Dug | Domestic stock | $\begin{array}{r} 18 \\ 3107 \end{array}$ |  | Drift |  |  |  |  |  |
| L-4 | SE-30-35-25W4 | 3080 | 111 |  | Domestle stock | $\begin{array}{r} 90 \\ 2990 \end{array}$ | $\begin{array}{r} 85 \\ 2995 \end{array}$ | Bedrock |  |  |  |  |  |
| L-S | SE-34-35-25w4 | 3090 | 136 |  | $\begin{gathered} \text { Domestic } \\ \text { stock } \end{gathered}$ |  |  | Bedrock |  |  |  |  |  |
| L-6 | NN-34-35-25w4 | 3175 | 101 |  | Domestic stock | $\begin{array}{r} 40 \\ 3135 \end{array}$ |  | Aedrock |  |  |  |  |  |


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## APPENDIX B

## HYDROCHEMICAL ANALYSES

## Notes to Appendix B

1. Column 3: TDS = total dissolved solids as determined by weighing the residue on drying.
2. Columns 3 to 12: epm = equivalents per million, and the symbol \% $=$ percentage epm of the ion to the total respective cations or anions.
3. Columns 3 and 4: When the entry $\mathrm{Ca}+\mathrm{Mg}=$ is present, this indicates that these constituents were estimated from the reported "hardness" and not determined individually.
4. Columns 14 and 15: ppm $=$ parts per million concentration.
5. Column 16: Facies type refers to the classification (Figures 50 and 51) given in the text (Chapter 6).


| Index | $\begin{gathered} \text { vell } \\ \text { oepth } \\ \text { Dase } \\ \text { Sampled } \\ \text { (Theet } \end{gathered}$ | ios | eoma | $\cdots$ | ${ }_{\text {epm }} \mathrm{ca}$ | $\mathrm{comm}^{\mathrm{Ma}}$ | $\mathrm{ram}_{\mathrm{n}+\mathrm{K}}$ | $\mathrm{Ca}_{\text {ca/ }} \mathrm{Hg}$ | ${ }_{\text {epm }} \mathrm{ll}$ | ${ }_{\text {epm }}{ }^{50}$ | ${ }_{\text {HCO }}^{3}+\mathrm{CO}_{3}$ | $\mathrm{epm}^{\mathrm{NO}} \mathrm{z}$ | $\begin{gathered} \mathrm{Fe} \\ \mathrm{pDm} \end{gathered}$ | $\underset{p p m}{\text { fon }}$ | $\begin{gathered} \text { Focies } \\ \text { trpe } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 26 | $\left.\right\|_{30-8788} ^{132}$ | 886 | 12.181 | $\square$ | 3.57 cot | $\mathrm{H}_{9}=2.75$ |  |  | .06 10.41 | $4.13128 .1$ | $\text { 10.55in. } 1$ |  | 52 |  | 1 |
| 3 |  | 1130 |  | 1 | ${ }^{5.21}{ }^{\text {cat }}$ | $\mathrm{Ha}_{9}-67$ | 1.53: ${ }^{33}$ |  | (110.5 | $\left.7.85\right\|_{1} ^{134.5}$ | $13.47159 .2$ |  | . 5 |  | 4 |
| 34 | $\begin{gathered} 18-81 \\ 18-82 \end{gathered}$ | 1380 |  | 1 | $\left.{ }_{1.35}\right\|_{6.74}$ | 2.14: 10.7 | 16.531, ${ }^{13}$ | 0.63 | . 09 | $9.271^{166.3}$ | $\left.{ }^{10.66}\right\|_{53.2} ^{1}$ | tr. | 0.2 |  | 3 |
| 37 | ${ }_{3110}^{110} \mathbf{3 - 6 1}$ | 1178 |  | 1 | c | $\mathrm{Ma}_{9}=24$ | 14.60, 76 |  | 06 10.3 <br> 0.  | 8.06, $1^{\prime} 42.1$ | 11.07157.9 |  | 2.23 |  | 3 |
| 38 | ${ }_{15-9-71}{ }^{50}$ | 544 | $1.131111 .6 .$ | . $10: 1.0$ | $\text { 4. } 39 \text { : }$ | $4.11{ }_{4}^{42.2}$ | 1.231 12.6 | 1.0 | [ $31 \begin{array}{c:c}13.1 \\ & 1\end{array}$ | $2.481$ | 6.11161 .5 | 1.04 110.5 | 0.16 | 0.11 | 2 |
| 40 | 1-1-68 | 1332 | 114.531 ${ }^{1} 89.5$ | , | 1.7 | $\mathrm{m}_{9}$ - | 1 |  | . $06{ }_{0}^{0.3}$ | 9.02147 .1 | 10.031 52.4 | ${ }^{.01}: 0.2$ | 0.03 | 0.76 | 3 |
| 41 | ${ }_{\substack{80 \\ 1-1-68}}^{\text {cos }}$ |  | 18.5 | 1 | . 28 Cat | $\mathrm{M}_{9}$ |  |  | 11 0.75 | $3.58_{1}^{\prime 24.5}$ | (10.92 ${ }^{1} 174.7$ |  | 2. 21 | 1.21 | 1 |
| 46 | 21 | 702 | 1 1 | 1 | 1.37 ca | 65.2 | 3.93! 34.80 |  |  | 2.98126 .4 | 8. 26 [73.1 |  | 0.40 | 0.2 | 2 |
| 48 |  | 1280 | 1 | 1 | 11.88 cat | $\mathrm{m}_{7}=63$ | 6.88131 |  |  |  | 10.42155.5 | Tr. | 0.80 |  |  |
| 52 |  | 1743 | 25.8 | . 2510.9 | 1.1514 .2 | . 31 | 6.05 | 3.49 | . 1410 | 15.57 , 56.2 | 11.98143.3 | ir. | 0.12 | 0.47 | 3 |
| 54 | 26 | 63 | 7.74 ${ }^{67.8}$ | 1.0110 .6 | 1.3111.4 |  | 7.81 $1_{1}^{168.5}$ | 0.57 | (11) $\begin{gathered}1 \\ 10.97\end{gathered}$ | 2.94125 .9 | 8.31! ${ }^{1} 17.2$ | r. | tr. | 0.19 | , |
| 58 |  | 748 |  | 1 |  |  | I |  | 1 | 1.58 $1_{22}$ | 9.44, 78 |  | 0. 30 |  |  |


| Inden Number | $\begin{gathered} \text { vell } \\ \text { Depth } \\ \text { onte } \\ \text { Sompled } \\ \text { (epet) } \end{gathered}$ | $\begin{aligned} & \text { Tos } \\ & \text { pom } \end{aligned}$ | $\mathrm{epm}^{\mathrm{Ha}}$ | eom ${ }^{\text {k }}$ | epm ${ }^{\text {ca }}$ | $\mathrm{comm}^{\text {Hg }}$ | $\int_{\text {epm }}^{\substack{\mathrm{Na}+\mathrm{K} \\ \\ \text { a }}}$ | $\mathrm{Co} / \mathrm{Mg}$ ratio | ${ }_{\text {epm }} \mathrm{l}$ | ${ }_{\text {epm }} \mathrm{SO}_{4}$ | $\mathrm{HCO}_{3}+\mathrm{CO}_{3}$ | ${ }_{\text {epm }}{ }^{\mathrm{NO}}$ | $\begin{aligned} & \mathrm{Fe} \\ & \mathrm{Fpm} \end{aligned}$ | ppm | Facies Trpe |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 59 | ${ }_{16-8-72}^{102}$ | 428 | 1 | I | $1.601_{25.9}$ | $\begin{aligned} & 1 \\ & 1 \\ & 1 \\ & 1 \end{aligned}$ | $\begin{gathered} 1 \\ 4.091 \\ 92.9 \\ \hline \end{gathered}$ | 3.27 | $\begin{array}{l:l} 0.03 & 0.5 \\ & 1 \end{array}$ | (1.06:17.2 | [ 5.0818 | 0.01 ! | 0.1 |  | ' |
| 60 | 边 $\begin{gathered}60 \\ 5-4-77\end{gathered}$ | 204 | 1.61135 .1 |  | 1.15:25.1 | ${ }^{1.73} 137.7$ | 1.713 1 | 0.67 |   <br> 0.11 2.9 | 0.2 5.2 <br>   <br> 0.85  | 3.51, ${ }_{1} 9.9$ | Tr. | 3.46 | 0.12 | 2 |
| 61 |  | 710 | $\left\|\begin{array}{c} 16.14 \\ 1 \end{array}\right\|$ | $064: 0.5$ | ${ }^{0.05}$ | $0.081$ | $\left[\begin{array}{cl} 4.2 & 100.0 \\ 1 \end{array}\right.$ |  | $1$ | $\left[\begin{array}{cc} 0.81 & 7.0 \\ & 10 \\ & 10 \end{array}\right.$ | $\mid 10.719$ | Tr. | 80 | 0.47 | , |
| 66 | $\left\lvert\, \begin{gathered}130 \\ 21-9-75\end{gathered}\right.$ | ${ }^{893}$ | $12.44,95.8$ | (008 10.06 | $0.45$ | $0.08: 0.62$ | $\begin{gathered} 22.451 \\ 1 \\ 1 \end{gathered}$ |  | $\begin{array}{cc} 0.40 & 1 \\ \hline & 1.5 \\ & 1 \end{array}$ | $\begin{array}{c\|c} 6.20 & 38.4 \\ 1 \end{array},$ | $4.9 .51158 .90$ | 0.02 0.10 | 0.10 | 0.91 | 3 |
| 67 | (18-11-75 | 1585 | $21.49{ }^{92.4}$ | 05 0.2 | 1.30 <br> 5.6 | 0.41 \| 1.8 | 1.54192.7 | 3.17 | . 0310.1 |  | 11.54, 43.8 | Tr. | 0.10 | 0.93 | 3 |
| 68 | (1882-60 | 1356 | $1$ | 1 | $3.0 \quad \mathrm{ca}+$ | 4.0 | 88. 32186 |  | 17 10.8 | 9.91'46.5 | (1.24152.7 |  | 0.12 |  | 3 |
| 69 | 183 <br> $-7-70$ | 804 | 1 | 1 | 1.76 ca + | . 0 | ${ }^{1.003} 1^{86.0}$ |  | .06 0.5 <br>   | 4.621 36.1 | 8.06163 .0 1 | Tr. | 0.40 |  | , |
| 84 | ${ }_{-5-68}^{258}$ | 792 | i | 1 | ${ }^{0.28} \mathrm{I}^{\mathrm{Ca}+}$ | 2.1 | R2.91, 97.0 |  | .06: ${ }^{0 .} 10.5$ | ${ }^{3.03122 .91}$ | $91013176.2$ |  | 18 | 1.23 | , |
| ${ }^{88}$ | ${ }_{\text {23-8-76 }}$65 <br> 68 | 366 | $0.87 \mathrm{l}_{13.0}$ 1 | [108 | $\left.\right\|_{1} ^{14.89} 173.3$ | $\begin{array}{\|c\|c\|} \hline 0.82 & 12.3 \\ & \end{array}$ | ${ }^{.95} 1_{1}^{11.2}$ | 5.96 | r. | $\left[\left.\begin{array}{cc} 0.67 & 9.0 \\ 1 & \end{array} \right\rvert\,\right.$ | ¢ 5.75190 .9 |  | 0.40 | 13 | 2 |
| 90 | 68 $-8-71$ | 920 | 1 | [1 | 0.35: ${ }^{2} \mathbf{2 . 2}$ | 1.65, 10.6 | ${ }^{3.64}{ }^{1}{ }^{17.0}$ | 0.21 | .09:0.6 | $\begin{gathered} 5.21133 .310 \\ 1 \end{gathered}$ | 1033,66.1 | $.008$ |  |  | , |
| 92 | 20-9-76 ${ }^{90}$ | 373 | 1.39 $1^{18.8}$ | -09:1.2 | ( ${ }^{3.09} 141.8$ |  | 1.48120.0 | 1.10 | .03 0.37 <br>   | $\begin{array}{cc} 21 & 2.6 \\ 1 & \end{array}$ | 7.98, ${ }^{\text {, } 97.1}$ | tr. | 0.60 | 0.13 | 2 |
| 94 | $\underset{\text { 2-6-74 }}{\substack{76}}$ | 306 | ${ }^{48} 8_{1}^{18}$ | .06711.1 | 2.5: $\begin{gathered} \\ \\ \\ \\ \end{gathered}$ | $\left\lvert\, \begin{gathered}3.21 \\ 1 \\ 151.3 \\ \end{gathered}\right.$ | .55: 08 | 0.78 | ${ }^{23}:{ }^{1}$ | .58  <br>  9.3 <br>   <br>   | $\left\lvert\, \begin{gathered}5.43 \\ \vdots\end{gathered}\right.$ | Tr. | 20 | 20 | 2 |


| $\begin{aligned} & \text { Index } \\ & \text { Humber } \end{aligned}$ | $\begin{gathered} \text { Hell } \\ \text { oeoth } \\ \text { otate } \\ \text { Sampled } \\ \text { Saleel) } \end{gathered}$ | $\begin{aligned} & \text { ppm } \\ & \text { ppo } \end{aligned}$ | epm ${ }^{\text {No }}$ | epm $\quad$ \% | epm $\quad$ co | $\mathrm{copm}^{\mathrm{Mg}}$ | $\mathrm{com}^{\mathrm{Na}+\mathrm{K}}$ |  | ${ }_{\text {epm }}{ }^{\text {c }}$ | ${ }_{\text {epm }} \mathrm{SO}_{4}$ | $\mathrm{HCO}_{3}+\mathrm{CO}_{3}$ | $\mathrm{epm}^{\mathrm{NO}_{3}}$ | Fe ppm | ¢ p m | Facies Type |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 99 | -6-68 | 526 | $i$ |  | $2.36 \mathrm{Ca}+$ | $\mathrm{Mg}=25.0$ | 1.0115.0 |  | 0.11 1.2 | 2.12: 22.7 | (7.12:176.2 |  | 0.6 |  | ' |
| 100 | ${ }_{-60}^{60}$ | 344 | 1 |  | $8^{81}$ Ca + |  | ${ }_{1.73} 131.0$ |  | $\begin{array}{ccll}0.11 & 12.0 \\ & 1\end{array}$ | 0.42:7.6 | . 5.00090 .3 |  | 1.01 | . 16 | 2 |
| 103 | ( $\begin{gathered}140 \\ 28-5-76\end{gathered}$ | 867 | 13.311 96.4 | $40.02: 15$ |  |  | 13.33196.6 |  | $0.03: 0.2$ | 5.81! 38.9 | $9\|9.10: 60.9\|$ | tr. | 0.30 | 1.30 | 1 |
| 106 | ${ }_{-5-68}^{100}$ | 874 | $\begin{aligned} & i \\ & i \\ & i \end{aligned}$ | I | 3.11 ca | Mg-' 22.0 | (0.761 19.0 |  | 0.06 0.4 <br> 0.4  | 4.96 '35.8 | $8\left(8.85: \begin{array}{l} 1 \\ 163.8 \\ : \end{array}\right.$ |  | 0.71 | 0.16 | , |
| 109 | ${ }_{8-6-71}^{108}$ | 360 | $2.83 ; 41.0$ | $0 \begin{array}{l:l} 0.08 & 1.2 \end{array}$ | $1.70 \text { i } 24.6$ | ${ }^{2.30}{ }^{23}$ | 2.91 \| 42.2 | 0.74 | $\begin{array}{c:c} 0.14 & 2.0 \\ & \\ \hline \end{array}$ | $0.6719 .3$ | $3.38188 .7$ | Tr. | 0.28 | 0.08 | 2 |
| 113 | 47 $-5-61$ | 1224 | 13.31181 .71 1 |  |  | $\mathrm{Hg}_{\mathrm{g}}=18.3$ |  |  | $\begin{array}{l:l} \hline 0.11 & 0.6 \end{array}$ | $7.5 \text { 110.7 }$ | $1 a_{62} \text { ! } 57.7$ |  |  |  | 3 |
| 122 | -90-59 | 396 | 1 |  | $5.79 \quad \mathbf{C a}+$ | Mg - 90.0 | ${ }^{0.67} 1^{10.0}$ |  |  |  | $6.466^{1} 99.0$ | . 221 | 0.40 |  | 1 |
| 123 | ${ }_{-5-68}^{165}$ | 840 |  |  | $0.08 \quad \mathrm{ca}{ }^{\text {+ }}$ | $\mathrm{Mq}_{9}=0.5$ | (1) $\begin{gathered}0.17 \\ 0\end{gathered} 1.3$ |  | p. $17 \begin{array}{ll}17 & 1.3 \\ & 1\end{array}$ | ${ }^{4.64}: 35.2 \mid 8$ | 2.36 163.5 |  |  | 1.00 | , |
| 125 | ${ }_{-5-68}$ | 546 | ! |  | $2.58 \quad c_{3}+$ | Ma $=29.0$ | 6.39 171.0 1 |  | $\begin{array}{\|l\|l} \hline & 4.5 \\ \hline \end{array}$ | $\begin{array}{cc} 2.146127 .4 \\ \vdots \end{array}$ | $4 \begin{gathered} 6.10 \\ 1 \\ \\ \hline \end{gathered}$ | 01 0.1 | 0.06 | 0.16 | ' |
| 129 | 130 $.9-68$ | 828 | i |  | $8.60 \quad c a+$ | Mg - 53.0 |  |  | $\begin{array}{c:c} 0.17 & 1.0 \\ & 1 \end{array}$ | $\begin{array}{cc} 5.21 & 1 \\ & 30.0 \\ 1 \end{array}$ | $01042: 63.9$ |  | 14.0 |  | 2 |
| 137 | ${ }_{-5-68}^{140}$ | 1528 | $22.75198 .0$ |  |  | 1.1 |  |  |  | ${ }^{10.56 ' 1410.0 ~}$ |  |  | 0.06 | 0.66 | 3 |
| 139 | 200 | 816 | \|14.72: 97.4 |  | O. 10 Ca C | $n_{9}=2.6$ |  |  | [0606 ${ }^{0.0 .9}$ | 3.91:56.5 | \| 52.95142 .6 |  | 0.60 |  | 3 |


| $\begin{aligned} & \text { Index } \\ & \text { Number } \end{aligned}$ |  | pos | eom Na | eom $\%$ | epm ${ }^{\text {ca }}$ | $\mathrm{eom}^{\mathrm{Mg}}$ ! | $\mathrm{comm}^{\mathrm{Na}+\mathrm{K}}$ | ca/ $/ \mathrm{Hg}$ rat 10 | cpm | ${ }_{\text {epm }}^{50}$ | $\mathrm{HCO}_{3}+\mathrm{CO}_{3}$ | $\mathrm{epm}^{\mathrm{NO}_{3}}$ | fe pom | f FPm | Facles Trpe |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 148 | ${ }_{-5-68}^{20}$ | 1784 |  |  | $0.62 \quad 18+$ | $\mathrm{Ma}_{9}=2.4$ | 25.64\|97.6 |  | $0^{0.06: 0.2}$ | [14.10,53.1 | 12.10, $1^{46.1}$ |  | 0.02 | 0.90 | 3 |
| 155 | -8.62 | 986 |  |  | $3.71 \quad \mathrm{ca}+$ | Hg - 23.3 | 12.22176 |  | $0.11,0.7$ | 6.06138 .0 | 9.74'61.1 |  | 1.15 | 0.45 | 1 |
| 156 | $\begin{aligned} & 260-4-60 \\ & 20 \end{aligned}$ | 874 |  |  | 5. | 0.1 | 8.58159.5 |  |  | 3.911 | 10.521 |  | 1.7 |  | 2 |
| 170 | $29-5-27$ | 884 | [4.66'97.6 | $6 \left\lvert\, \begin{array}{c:c} 0.03 & 0.2 \\ & 1 \end{array}\right.$ |  | 0.08 ${ }^{0} 0^{0.05}$ | $\left\lvert\, \begin{gathered} 1 \\ 14.69 \\ \hline 97.8 \end{gathered}\right.$ | 3.13 | $0.03!$ | $\begin{gathered} 4.56 \\ 1 \\ 1 \end{gathered}$ | $8 \left\lvert\, \begin{gathered} 10.72170 .0 \\ ! \end{gathered}\right.$ | ${ }^{\text {r }}$. | 0.08 | 0.68 | 1 |
| 17 | (1210 ${ }_{210}$ | 1088 | 9.79176.8 | 0.069: 0.54 | $42.30: 18.1$ |  | 9.86, 71.4 | 4.69 | (0.0910.6 | $\begin{array}{\|c:c} 3.75 & 26.7 \\ & \end{array}$ | $\text { , 10.18: } 12.6$ | $\stackrel{ }{ } \mathrm{r}$. | 2.4 | 23 | 1 |
| 172 | $23-7-70$ | 1020 |  |  | $2.30 \quad$ cat | Mg - 13.9 | (14.17185.8 |  | 0.0610.4 | $5.50,33.3$ | 10.96166.3 |  | 1.36 |  | 1 |
| 173 | ${ }_{6-6-74}^{50}$ | 1046 | 13.75 178.2 | $2 \left\lvert\, \begin{array}{ll} 0.09 & 0.5 \\ \hline \end{array}\right.$ | $\left\lvert\, \begin{array}{c:c} 1.75 & 9.95 \\ & 1 \end{array}\right.$ | ${ }^{1.97} 1^{11.2}$ | ${ }^{13.84} 1^{1} 18.7$ | 0.89 | $.11_{0.6}$ | 6.25134 .2 | 11.90165.1 | tr. | . 70 | 0.52 | 1 |
| 176 |  | 687 | 14.831997.3 | 0.03 0.2 <br>  0.05 <br> 0.0  |  | 0.08 0.5 <br> 3.35  | [14.86, 97.5 | 3.75 | 0.09: 0.8 | 0.21! 1.9 | 10.80196.7 | Tr. | ir. | 15 | 1 |
| 178 | ${ }_{15-5-71}^{100}$ | 315 | ${ }^{1.001} 12$ |  | $3.64 \mathrm{I}_{44.9}$ | ${ }^{3.37} 1_{4}^{1 / 6}$ | $1.071_{1}^{13.2}$ | 1.08 | (1) $\begin{gathered}0.14 \\ 1 \\ 1 \\ 1\end{gathered}$ | $0.65: 8.7$ | $\mathbf{c}_{6.69,189.4}^{1}$ | rr. | 0.58 | 0.08 | 2 |
| 180 | ${ }_{27-7-75}$ | 540 | 1.92181.4 | $40.05: 0.5$ | 1.25 112.9 <br> 1  |  | [1.97'81.9 | 2.55 | ${ }^{0.06}: 0.6$ | 0.29 ${ }^{1} 2.8$ | $8 \text { 10.08, } 96.2$ | rr. | 0.6 | 1.01 | , |
| 181 | 10-9-73 | 513 | 8.7 '94.7 | $0.21: 2.3$ | $\begin{array}{\|l\|l\|} \hline 0.20 & 2.2 \\ \hline \end{array}$ | 0.08 0.9 | 8.91197.0. | 2.5 | ${ }^{0.028,} 0$ | $\left\lvert\, \begin{array}{c:c} 1.21 & 13.4 \\ 1 \end{array}\right.$ | 7.75, 186.0 | tr. | 0.10 | 0.50 | , |
| 145 | 18-12-61 | 916 | ! |  | 3.29 cat | 26.1 | 9.29, 13.9 |  | $0.0288_{1}^{1} 0.2$ | 8. 20165.2 | 4.33134.4 $1^{1}$ | ir. | 0.20 | 0.34 | 3 |
| 188 | ${ }_{8-1-68}^{180}$ | ${ }^{89}$ | 18.17198.9 |  | 0.20 Cat | 1.1 | :98.9 |  | 0.06:0.4 | h.02: 27.2 | \| 10.64172 .0 |  | 0.08 | 1.11 |  |


| $\begin{gathered} \text { Index } \\ \text { Number } \end{gathered}$ | $\begin{gathered} \text { vell } \\ \text { Depth } \\ \text { Date } \\ \text { Sompled } \\ \text { ITelel } \end{gathered}$ | Tos | epm No | epm $\quad$ \% | epm ca | ${ }_{\text {epm }}{ }^{\text {Mg }}$ |  | $\begin{aligned} & \mathrm{Co} / \mathrm{Mg} \\ & \text { rat } 10 \end{aligned}$ | $\mathrm{cpm}^{\text {cl }}$ | ${ }_{\text {epm }} \mathrm{SO}_{4}$ | ( ${ }_{\text {HCO }}^{3}+\mathrm{CO}_{3}$ | $\mathrm{epm}^{\mathrm{No}} 3$ | Fe pom | $\stackrel{\mathrm{F}}{\mathrm{p} 0 \mathrm{~m}}$ | Facies |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 189 | $\begin{gathered} 185 \\ -4-64 \end{gathered}$ | 1802 |  |  | 15.77 cat | $\mathrm{Mg}^{-68.5}$ | 7.09, 3 30.8 |  |  | 13.391 | 9.641 |  | 4.80 |  | 4 |
| 194 | ${ }^{105}$ | 790 | 7.07' 97.5 |  | 0.42 cat |  | 97.5 |  | $\begin{array}{l:l} 0.06 & 0.5 \end{array}$ | $2.466^{19} 19$ | ${ }^{10.231} 1^{80.2}$ |  | 0.24 |  | 1 |
| 195 | ${ }_{-2-61}^{122}$ | 666 | $\|4.66: 96.7\|$ |  | 0.50 cat | Ma |  |  | Ir. | 1.9417 .8 | 8.951' 82.2 |  | 0.20 |  | , |
| 196 | ${ }_{-8-75}^{190}$ | 611 | 10.75 , 98.4 | 0.01510 .14 | 0.05:0.5 | 0.7 | 10.77'98.5 |  | 0.20:1.7 | 1.0018 .4 | 10.25: 86.1 | rr. | 0.90 | 8.75 | 1 |
| 197 | ${ }_{11-85-71}$ | 510 |  |  | $1.35{ }^{1} 18.2$ |  | 3.2 $4^{43.1}$ | 0.47 | 11.2 | $0.631^{1} 8.5$ | $6.69!90.0$ | 0.2 |  |  | 2 |
| 198 | ${ }_{30-6-65}^{94}$ | 494 |  |  | 6.49 cat | $\mathrm{Ha}_{\mathrm{G}}=8 \mathrm{BI} .8$ | 1.44, $1_{18.2}$ |  |  | 0. 98112.4 | 6.88' 86.8 | $0.07: 0.9$ | tr. |  | 2 |
| 199 | ciso | 818 | ${ }^{13.40} 1_{1}^{188.9}$ | 0.07710 .5 | 1.0 6.6 | 0.58 3.9 | ${ }^{13.48)^{\prime} 89.4}$ | 1.72 | 8.86 ${ }^{124.8}$ | 0.211 .4 | 11.43: 73.6 | Tr. | 0.76 | 0.68 | 1 |
| 200 | ${ }_{\text {c-2-61 }}^{165}$ | 520 |  |  | $4.99 \mathrm{Ca+}$ | Mg-55.0 | 4.10, $1^{1} 5.0$ |  | 0.06 0.1 | 0.9019 .9 | $8.161^{189.5}$ |  | 0.80 |  | 2 |
| 201 | ${ }^{83}$ | 915 |  |  | 0.30: 2.1 | 12.9 | 13.31!94.7 | 0.73 | 0.06: 0.4 | 4.16'129.6 | 9.83: 70.0 | Tr. | 0.90 |  | 1 |
| 203 | ${ }_{-9-75}^{60}$ | 539 | 9.05196 .5 | (10.02 ${ }_{0}^{1}$ | 0.20 2.1 | (10.9 08 | 9.07'96.7 | 2.5 | 0.14 1.5 | $2.351_{1}^{125.2}$ | 6.68: 71.6 | Tr. | 0.90 | 3.00 | 1 |
| 204 | ${ }_{14-2-75}^{100}$ | 528 | 9.09 193.1 | $0.0{ }_{0}^{0.03} \mathbf{1 0 . 3 1}$ | 0.55:5.6 | p.082: 0.8 | 9.12193 .4 1 | 6.71 | p. 028 : 0.3 | 1.58, 17.5 | $7.4111^{81.9}$ | tr | 0.30 | 0.51 | ' |
| 205 | $\xrightarrow{\text { 27-7-76 }}$ | 619 | $8.188^{80.8}$ | 0.06 0.6 | 0.65 6.1 | . 23 12.1 | 8.24181.3 | 0.53 | p.06: 0.5 | 2.50, 21.1 | 9.271: $\mathbf{1}_{18.1}$ | Tr | 0.40 | 0.74 | 1 |
| 209 | $\|$$27-70$ <br> 10 <br> -6.75 | 856 | 14.40! 97.5 | $50.0{ }^{0.02} 10.14$ | 0.25 11.7 | p. 08210 | \| $4 . \begin{gathered}1 \\ 14.42197 .6 \\ \vdots\end{gathered}$ | 3.05 | 0.14:1.0 | $5.95 \square^{1 / 43.9}$ | 7.39: 54.5 | rr. | 0.40 | 1.23 | 3 |


| Index number | $\begin{gathered} \text { vell } \\ \text { Depth } \\ \text { oate } \\ \text { Sompled } \\ \text { Sopled } \end{gathered}$ | $\begin{aligned} & \text { ros } \\ & \text { ppm } \end{aligned}$ | epm ${ }^{\mathrm{Na}}$ | eom ${ }^{\text {k }}$ | $\mathrm{epm}^{\text {ca }}$ | $\mathrm{com}^{\mathrm{Mg}}$ : | $\mathrm{com}^{\mathrm{Na}+\mathrm{K}}$ | $\mathrm{Ca}_{2} / \mathrm{Mg}_{9}$ ratio | epm ${ }^{\text {c }}$ | ${ }_{\text {epm }}^{\mathrm{SO}_{4}}$ | $\mathrm{HCO}_{3}+\mathrm{CO}_{3}$ | $\mathrm{epm}^{\mathrm{no}}$, | $\mathrm{Fe}$ | $\underset{\text { ppm }}{\text { F }}$ | $\begin{array}{\|c} \hline \text { Fasies } \\ \text { Type } \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 211 | ${ }_{28-7-75}^{80}$ | 910 | 16.01:97.7 | 0.03 [0.18 | 1.5 | 0.082: 0.5 | 16.04i97.9 | 3.05 | 0.028; 0.2 | 4.621 $1^{30.8}$ | $10.3{ }^{168.6}$ | tr. | 0.60 | 1.22 | 1 |
| 216 | ${ }_{\substack{122 \\-8-65}}$ | 750 |  |  | 2.79 Cat | 22.4 | 9.499, 76.2 |  |  | 1.62, ${ }^{13}$ | ${ }^{10.82,86.8}$ | 0.01: 0.13 | 5.0 |  | 1 |
| 249 | ${ }_{\substack{121 \\-5-68}}^{\text {20, }}$ | 432 |  |  | 2.93 Ca+ | $\mathrm{Ha}_{9}=4.8$ | 3.11147.6 |  | 0.1111.7 | $2.67 i^{\prime 40.8}$ | $\begin{aligned} & 3.74157 .2 \\ & 1 \end{aligned}$ | $0.00 ; 0.09$ | 13.95 | 0.20 | 4 |
| 269 | ${ }_{3}^{130}$ | 894 |  |  | 4.71 Cat | $\mathrm{Hg}_{9}=33.8$ | 9.24, $\mathbf{i}^{96.2}$ |  | $0.11: 0.8$ | $\left.4.71\right\|^{34.2}$ | $8.93^{\prime} 64.0$ |  |  | 2.70 | ' |
| 280 | ${ }_{\substack{125 \\-3-59}}^{\text {d }}$ | 1692 |  |  | 11.88 Cat | 3 | 12.70, 51.7 |  | 0.09:0.4 | 13.26, ${ }^{1}$, ${ }^{\text {a }}$, 9 | 11.21/45.6 | 0.01: 0.06 | 0.20 | 0.20 | 4 |
| 286 | ${ }_{-12}^{70}$ | 1534 | $23.45 ; 93.5$ | $50.05{ }^{1}$ | . 05 | [0.41 <br>  <br>  <br> 1.6 |  | 2.56 | 0.028 | $11.45!$ | 34 | $0.01$ | 3.60 | 0.31 | 3 |
| 287 | ${ }^{180}{ }_{-68}$ | 1906 |  |  | ${ }^{0.50}{ }^{\text {c }}$ cat | $\mathrm{Hg}=1.7$ | 29.23;98.3 |  | 0.06: ${ }_{0}$ | 7 | $14.26 .48 .0$ |  | 0.18 | 0.78 | 3 |
| 31 | ${ }_{7}^{100}$ | 959 | ${ }^{13.621 / 76.8}$ | $0.05{ }^{0} 0.28$ | 3.29 $1^{18.6}$ | 0.74 4.2 | 13.67! 17.1 | 4.45 | ${ }^{0.02681} 0.2$ | 546; $3^{4.7}$ | $1{ }^{10.26!65.1}$ | r. | 0.90 | 0.15 | , |
| 313 | ${ }^{110} 68$ | 90 |  |  | 0.92 cat | - 3.0 | 7!97.0 |  | $0.11,0.36$ | 16.45553 .7 | $14.055_{1}^{14}$ |  | 0.38 | 0.55 | 3 |
| 318 | 100 | 560 |  |  | 35 6.3 <br> 0  | 1.23 ! | ${ }^{18.93187 .8}$ | 1.10 | 0.17io.79 | 9.89 ${ }^{\prime} 45.9$ | 51,53.4 |  | . 60 |  | 3 |
| 322 | ${ }^{150}{ }_{-74}$ | 1544 | $24.45596 .0$ | $\begin{array}{l:l:l} 0.0 .23 \\ \hline 0.9 \end{array}$ | 0.70 2.8 |  | 24.68!96.9 | 8.50 | 0.25: 1.0 | 12.03148.9 | 12.15149.4 | 0.001 | 50 | 0.96 | 3 |
| 321 | ${ }_{7-6-65}^{50}$ | 704 |  |  | 0.30 2.5 <br> 0.45  | (\%.171.4 | 11.64196.1 | 1.71 | $0.23!1.9$ | $1.98 i_{16.4}^{i}$ | 9.83181.2 |  | 0.10 | 1.30 | , |
| 329 | 160 $15-4-77$ | 766 | $\|13.57!195.4\|$ | $\left\lvert\, \begin{gathered} 0.036 i 0.25 \\ 1 \end{gathered}\right.$ | 0.45 3.2 <br>   | 㖪.17: 1.2 | $2\|3.61!95.6\|$ | 2.65 | 0.09! 0.7 | $2.12: 15.8$ | $11.12 ; 83.0$ | $0.02: 0.15$ | 0.30 | 1.00 | ' |


| Inder <br> Number | Vell <br> Depth Date Sampled (leet) | TOS <br> ppm | epm | epm | $\text { epm } \quad \mathrm{Ca}$ | $\begin{aligned} & \mathrm{Mq} \\ & \\ \text { epm } & \% \end{aligned}$ | $\begin{aligned} & \mathrm{Na}+\mathrm{K} \\ & \mathrm{epm} \end{aligned}$ | $\mathrm{Ca} / \mathrm{Hg}$ <br> ratio | $\begin{array}{cl} \mathrm{Cl} \\ \text { epm } & 8 \end{array}$ | $\begin{gathered} \mathrm{SO}_{4} \\ \text { epm } \end{gathered}$ | $\begin{aligned} & \mathrm{HCO}_{3}+\mathrm{CO}_{3} \\ & \mathrm{epm} \end{aligned}$ | $\mathrm{NO}_{3}$ | $\begin{gathered} \mathrm{Fe} \\ \mathrm{ppm} \end{gathered}$ | $\begin{gathered} F \\ \text { ppm } \end{gathered}$ | $\begin{gathered} \text { Facies } \\ \text { Type } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 336 | $\begin{gathered} 82 \\ 21-4-78 \end{gathered}$ | 729 | $12.18!98.3$ | 0.02310 .19 | 0.1010 .81 | 0.08210 .66 | 12.20198.5 | 1.22 | 0.056 0.4 | $2.79: 21.2$ | 10.29178 .1 | Tr. | Tr. | 0.63 | 1 |
| 337 | $\begin{aligned} & 125 \\ & -6-70 \end{aligned}$ | 1010 |  |  | 0.60 Ca | $\mathrm{Hg}=3.7$ I | $15.5 \text { is6.3 }$ |  | $0.11: 0.7$ | $4.31{ }^{4} 126.8$ | 11.6817 72.6 |  | 0.06 |  | I |
| 342 | $\begin{gathered} 64 \\ 12-10-65 \end{gathered}$ | 440 |  |  | 1.0514 .1 | 3.54;47.6 | 2.75137.1 | 0.30 | $0.45: 6.1$ | 1.12:15.1 | 5.82 78.3 |  | 2.40 | 0.80 | 2 |
| 349 | $\begin{gathered} 98 \\ 3-6-68 \end{gathered}$ | 1026 | $19.64: 98.1$ |  | $0.36: \mathrm{Ca}^{+}$ | $\mathrm{Mg}=1.8$ | $\begin{aligned} & 198.1 \\ & 1 \end{aligned}$ |  | $0.056_{1}^{1} 0.33$ | 5.04130 .0 | 11.67169 .4 |  | 0.55 | 0.93 | 1 |
| 356 | 120 $-5-74$ | 922 | 12.53175.9 ${ }_{1}^{1}$ | $0.02: 0.12$ | 3.89:23.6 | 0.08210 .5 | 12.55176 .0 |  | $0.03: 0.2$ | 3.75:23.3 | 12.29176.2 | Tr. | Tr. | 0.88 | 1 |
| 1-2 | 27-7-78 | 419 | $1.14113 .8$ | $0.13 ; 1.5$ | 4.29 ; 51.8 | $2.72: 37.8$ | 1.27!'15.3 | 1.58 | $0.11: 1.4$ | $0.67: 8.1$ | $7.44: 90.3$ | $0.02{ }^{1} 0.3$ | 0.10 |  | 2 |
| 2-10 | $\begin{gathered} 150 \\ 28-7-78 \end{gathered}$ | 1355 | 3.18! 13.0 | $0.10: 0.4$ | $6.09 \mathrm{i}^{1} 24.9$ | \$5.06 61.7 | 3.28113.4 | 0.40 | $0.34: 1.4$ | $13.33 i 55.5$ | 10.24:42.7 | 0.0910 .4 | 0.30 | 0.20 | 4 |
| 2-11 | $\begin{aligned} & \text { POND } \\ & 28-7-78 \end{aligned}$ | 453 | 1.52118.2 | $0.66: 7.9$ | $3.04: 36.4$ | $3.13: 37.4$ | 2.18126.1 | 0.97 | $\begin{array}{cc:c}0.11 & 1.5 \\ & \end{array}$ | 3.12141 .1 1 | $4.28: 56.3$ | 0.0911 .2 | 0.70 | 0.40 | 4 |
| 3-1A | SPRIING $29-7-78$ | 967 | 12.22169.6 | $0.05: 0.3$ | 2.4113 .6 | $2.88: 16.4$ | 12.27,69.9 ${ }^{1}$ | 0.83 | $0.11: 0.7$ | 5.27131.5 | $11.19: 67.7$ | 0.02 0.1 <br>  1 | 0.70 | 0.40 | I |
| 3-18 | CREEK $29-7-78$ | 494 | 5.48:60.7 | $0.18,2.0$ | 1.15112 .7 1 1 | 2.22124 .6 | 5.66162 .7 | 0.52 | 0.17:1.9 | $1.25: 14.2$ | $7.33: 83.4$ | $0.04: 0.4$ | 0.20 | 0.40 | 1 |
| 3-7 | CREEK $29-7-78$ | 476 | 5.57160 .7 | $0.18: 2.0$ | $1.20: 13.1$ | $\left.2.22\right\|^{24.2}$ | 5.75162.7 | 0.54 | 0.11:1.3 | 1.25114.4 | 7.27183.7 | 0.05:0.6 | 0.30 | 0.40 | 1 |
| 4-1 | $\begin{gathered} 266 \\ 1-8-78 \end{gathered}$ | 1357 | 10.79145.2 | $0.20: 0.9$ | $\begin{gathered} 5.74 \\ i \\ 1 \end{gathered}$ | 7.16130 .0 | (0.99,46.1 ${ }_{1}^{1}$ | 0.80 | 0.23 it.0 | $11.76: 52.2$ | (10.52:46.7 | 0.01 0.0 <br>  1 | 0.40 |  | 4 |
| 4-3 | SPRING $1-8-78$ | 852 | 14.57!84.1 |  | $1.2 \left\lvert\, \begin{array}{lll}1.9 \\ & 1 \\ & & \end{array}\right.$ | $1.55: 8.9$ | $\mid 14.57184 .1$ | 0.78 | Tr. | 4.37127.1 | $\left\lvert\, \begin{array}{cc:c}11.72: 72.6 \\ & \\ & \end{array}\right.$ | 0.061 | 0.60 | 0.20 | 2 |


| Index | Vell Depth Date Sampled (fleet) | $\begin{aligned} & \text { Tos } \\ & \text { pom } \end{aligned}$ | eom ${ }^{\text {No }}$ | $\cdots$ | ${ }^{\text {ca }}$ | $\mathrm{Om}^{\mathrm{Hg}}$ | $\underset{\mathrm{emm}}{\mathrm{Na}+\mathrm{K}}$ | $\mathrm{Ca} / \mathrm{Hg}$ ratio | epm 3 | ${ }_{\text {epm }} \mathrm{SO}_{4}$ | $\left\lvert\, \begin{array}{cc} \mathrm{HCO}_{3}+\mathrm{CO}_{3} \\ \mathrm{epm} & 2 \end{array}\right.$ | $\mathrm{ClO}_{3}$ | $\begin{array}{\|l\|} \mathrm{Fe} \\ \mathrm{ppm} \end{array}$ | Fpm | Facles Trpe |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5-1A | ${ }_{2-8}^{250}$ | 586 | $4.61135 .4$ | $0.10{ }^{1} 0.8$ | 3.29 ${ }^{25.3}$ | 5.021,38.6 | $4.71,36.2$ | 0.66 | $0.11{ }^{0} 0.9$ | 2.69 21.1 | ${ }^{9.93}{ }^{1} 17.9$ | $0.01: 0.08$ | 1.40 |  | 2 |
| 5-18 | $\underset{\substack{\text { S-A }-78}}{\text { spang }}$ | 490 | $.410$ |  | $\left.3.39\right\|_{27.8} ^{1}$ | 3.54, ${ }^{129.0}$ | $5.28,1^{\prime} 4.2$ | 0.96 | $0.111_{0} 0.9$ | 1.75 14.5 | 10.16:84.5 | 0.00:0.0 | 0.10 | 0.90 | 2 |
| 5-2 | $\begin{array}{\|l\|l\|} \text { SPRING } \\ 2-8-78 \end{array}$ | 4.54 | 2.83123 .8 | (0.10 0.0 .9 | $3.69$ | $5.271^{144.3}$ | $2.93{ }^{24.7}$ 1 | 0.70 | $0.111 .0$ | 1.71 16.9 <br> 1  | 9.64184 .0 | 0.02: 0.2 | 0.10 | 0.20 | 2 |
| 5-3A | $\left\lvert\, \begin{gathered} 160 \\ 2-8-78 \end{gathered}\right.$ | 644 | 11.79197.7 | 0.20 1.7 <br> 0.0  | $\begin{array}{l:l\|} \hline 0.07 & 0.6 \\ \hline \end{array}$ |  | 11.90199 .4 1 |  | $0.23: 1.9$ | 0.07\|0.6 | 11.52197 .5 | 0.00:000 | 0.30 | 0.10 | 1 |
| $5-38$ | $\begin{gathered} \text { pono } \\ 2-8-78 \end{gathered}$ | 6 | 28.27, ${ }^{1} 70.8$ | 0.87 2.2 <br>  0.5 | 0.521.3 <br> 2.5 | 10.29125.7 | $\begin{gathered} 29.14173 .0 \\ 1 \end{gathered}$ |  | $0.96!2.4$ | 22.74,56.4 | $62!41.22$ | 0.01:0.0 |  | 3.20 | 3 |
| 5-5 | ${ }_{\substack{58 \\ 2-8-78}}$ | 769 | 9.83 $1^{169.3}$ | (0.15: 1.1 | $2.15!15.1$ | $061 / 4.5$ | 9.98'70.4 | 1.04 | $0.171_{1.2}$ | $2.855^{\prime} 11.0$ | ${ }^{10.52}!^{71.6}$ | 0.01!0.1 | 0.70 | 0.20 | ' |
| 5-6 | $\begin{gathered} \substack{\text { sping } \\ 2-8-76} \end{gathered}$ | 876 | 11.051711 | 0.40 0.7 | 1.85:11.9 | 2.55116 .4 | 11.15! 11.8 | 0.73 | $0.110_{0}^{\prime} 0.8$ | 5.43136 .2 | 9.44'163.0 | 0.01; 0.0 | 0.10 | 0.30 | , |
| 6-1 | ${ }_{3-8-78}^{70}$ | ${ }^{811}$ | 2.78117 .6 | 0.61 |  | 6.67 $1^{1 / 42.2}$ | 3.39121.5 | 0.86 | 0.6814 .4 1 | 3.62 ${ }^{2} 23.8$ | ${ }^{10.67}$ '70.0 | ${ }_{0}^{0.27} 1.7$ | 0.40 | 0.90 | 2 |
| 6-2 | $\substack{\text { spring } \\ 3-8-78}$ | 642 | 4.48134 .9 | 0.06; 0.5 | 4.19132.6 | 4.12'132.0 | $\begin{gathered} 4.53135 .4 \\ 1 \end{gathered}$ | 1.02 | 0.0610.5 | $3.299^{1} 29.0$ | $\begin{array}{cc}7.8 & 168.7 \\ \\ 1\end{array}$ | 0.2111.8 | 0.60 | 0.10 | 2 |
| 6-3 | $\begin{aligned} & \text { SLOUGH } \\ & 3-8-78 \end{aligned}$ | 830 | $\begin{gathered} 6.66142 .2 \\ 1 \end{gathered}$ | 2. 1.46 ! 9.2 | $1.90 i_{12}$ | 5.76136.5 | 8.12:51.4 | 0.33 | $\begin{array}{\|l\|l\|l\|} \hline 0.28 \end{array}$ | 2.62117 .7 | 11.81: 79.9 | $0.07!0.5$ | 50 | 0.40 | 2 |
| 6-4 | ${ }_{3-8,78}{ }^{15}$ | 1030 | $13.271,74.1$ | $\begin{array}{l:l:l}  & 0.05 & 0.3 \end{array}$ | ${ }^{2.20}{ }^{12.3}$ | $2.39113 .3$ | $13.321^{1} 19.4$ | . 92 | 0.1110.6 |  | $\left\|\begin{array}{cc} 11.24 & 163.9 \end{array}\right\|$ | $0.03: 0.2$ | 0. | 0.10 | 1 |
| 6-5 | $\begin{gathered} 132 \\ 3-8-88 \end{gathered}$ | 117 | $17.799_{1}^{186.2}$ | $2 \left\lvert\, \begin{array}{lll} 0.03 & 0.15 \\ & 1 \end{array}\right.$ | $1.39 i^{1} 6.7$ | 1.42\% 6.9 | 17.82:86. ${ }^{\text {a }}$ | 0.98 | ${ }_{0}^{0.11: 0.56}$ | $8.061^{10.8}$ | $11.56: 58.6$ | 0.01:0.05 | 0.10 | 0.40 | 3 |


| Index <br> Mumber | Well <br> Depth Date <br> Sempled (leet) | $\begin{aligned} & \text { TOS } \\ & \text { opm } \end{aligned}$ | ermm | epm 3 | epm | ¢ $\begin{aligned} & \text { Mg } \\ & \text { epm }\end{aligned}$ | epm ${ }^{\text {Na+K }}$ | $\mathrm{Ca} / \mathrm{Hg}$ <br> rato | $\qquad$ | epm | $\mathrm{HCO}_{3}+\mathrm{CO}_{3}$ | $\operatorname{enm}_{3}^{\mathrm{NO}_{3}}$ | fe | $\begin{gathered} \text { F } \\ \text { ppm } \end{gathered}$ | Facies Type |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 6-6 | $\begin{gathered} 220 \\ 3-8-78 \end{gathered}$ | 716 | 12.79199.4 | 10.0 | $0.07: 0.5$ |  | 12.86:99.4 | 2.44 | 0.11 0.90 <br>  1 | 2.27 18.3 | 10.00:80.7 | $0.02 ; 0.10$ | 0.10 | 1.10 | 1 |
| 6-7 | SPRING $3-8-78$ | 1080 | $15.92 ; 86.7$ | $0.05: 0.3$ | 1.0315 .6 | $1.36,7.40$ | 15.97187.0 | 0.76 | 0.0610 .3 | 5.85133.5 | $11.56: 66.1$ | $0.0210 .10$ | 0.30 | 0.60 | 1 |
| 6-8 | SPRING $3-8-78$ | 1241 | 15.35, ${ }^{\prime}$ | 0.08100 .4 | $2.54 i^{12.1}$ | 3.05114.5 | 15.43173.4 | 0.83 | 0.0610 .3 | 9.47 1145 | 11.19154.0 | $0.00: 0.0$ | 1.20 | 0.20 | 3 |
| 6-9 | $\begin{gathered} 140 \\ 3-8-78 \end{gathered}$ | 740 | 13.44 ${ }^{\prime} 98.8$ | $0.021 \begin{array}{lll}0.0 .2 \\ & 1 & \end{array}$ | $0.12{ }^{1} 0.9$ | $0.02: 0.1$ | 13.46!99.0 | 6.00 | 0.1711.3 | 1.0618 | 12.07)90.6 | $0.02: 0.2$ | 0.80 | 2.60 | I |
| 1-1 | SPRING $4-8-78$ | 768 | 10.92177.6 | $0.05: 0.35$ | 1.5511 .0 | 1.55i11.0 | 10.97!78.0 | 1.00 | $0.11{ }^{1} 0.80$ | 3.27 23.6 <br> 1  | $10.45: 75.4$ | 0.0310 .21 | 0.20 | 0.70 | 1 |
| 7-3 | SPRING $4-8-78$ | 862 | 14.27,95.2 | 0.00:0.0 | 0.5013 .4 | $0.21: 1.4$ | 14.27195 .2 | 2.38 | 0.0610 .40  <br>   <br>   | 2.96 ${ }^{2} \mathbf{2 0 . 2}$ | 11.64179.4 | $0.00: 0.0$ | 0.40 | 0.40 | 1 |
| 7-5 | SPRING $4-8-78$ | 402 | $2.17{ }^{1} \mathbf{1}$ | 0.07 $\begin{array}{r}1.0 \\ 1 \\ i\end{array}$ | 3.27 \| 45.1 | 1.74!24.0 | $2.24,30.9$ | 1.88 | ${ }_{0.171}^{1} 2.20$ | 1.01:13.0 | ${ }^{6.57}{ }_{1}^{1} 84.8$ | $\begin{gathered} 0.003: 0.1 \\ i \end{gathered}$ | 0.50 | 0.30 | 2 |
| 7-6 | $\begin{gathered} 78 \\ 4-8-78 \end{gathered}$ | 446 | 2.87! ${ }^{16.2}$ | 0.1011.2 | 3.39142 .8 | 1.56119 .7 1 | $2.97!37.4$ | 2.17 | $0_{0.171}^{1} 2.0$ | ${ }_{1.09}^{1} 12.7$ | 7.24184 .4 | $0.08: 1.0$ | 1.10 | 0.20 | 2 |
| 7-7 | $\begin{gathered} 140 \\ 4-8-78 \end{gathered}$ | 520 | 0.98i8.7 | 0.0510 .4 | $5.59{ }_{1}^{1} 49.6$ | 3.56131.6 | 1.0319 .1 | 1.57 | 0.1111 .0 | 3.37 130.3 | 7.64 68.6 | $0.00: 0.0$ | 30.5 | 0.10 | 2 |
| 7-8 | $\stackrel{205}{4-8-78}$ | 876 | $\begin{gathered} 13.88 i 83.7 \\ \vdots \end{gathered}$ | 0.0110.06 | $\begin{array}{rr}1.22 & 7.4 \\ & \\ \\ 1\end{array}$ | 0.7614.6 | 13.89183.8 | 1.61 | 0.17 1.1 | 3.27121 .5 1 | 11.52 175.8 | 0.13: 0.9 | 0.20 | 1.70 | 1 |
| 8-1 | 70 $7-8-78$ | 1236 | 14.96:68.1 | $0.04: 0.18$ | $3.32: 15.1$ | $3.6{\underset{1}{1}}_{16.6}^{i}$ | 15.00:68.3 | 0.91 | $0.17: 0.8$ | $\begin{gathered} 9.54145 .3 \\ 1 \end{gathered}$ | 11.28:53.5 | $\begin{gathered} 0.0710 .3 \\ 1 \end{gathered}$ | 0.10 | 0.30 | 3 |
| 8-4 | $\begin{gathered} 120 \\ 7-8-78 \end{gathered}$ | 839 | 5.65139 .3 | $0.08: 0.60$ | $5.34: 37.2$ | 3.29122 .9 1 | 5.73139 .9 | 1.62 | 0.2811 .8 | 4.75131 .1 | 10.24167 .1 | $0.00: 0.0$ | 3.7 | 0.10 | 2 |


| Index Number | Well <br> Depth Date <br> Sampled (feet) | TOS <br> ppm | $\text { epm } \%$ | $\begin{array}{ll} & K \\ & \\ \text { epm } & \\ 2\end{array}$ | $\text { epm } \quad \text { Ca }$ | ¢epm | Nom | $\mathrm{Ca} / \mathrm{Mg}$ <br> ratio | cl | $\%$ | $\begin{gathered} \mathrm{SO}_{4} \\ \mathrm{epm} \end{gathered}$ | $\mathrm{HCO}_{3}+\mathrm{CO}_{3}$ | $\mathrm{Hepm}_{3}$ | $\begin{gathered} \mathrm{Fe} \\ \mathrm{ppm} \end{gathered}$ | $\begin{gathered} F \\ p \mathrm{pm} \end{gathered}$ | Facies Type |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 8-5 | $\begin{aligned} & \text { SPRING } \\ & 7-8-78 \end{aligned}$ | 566 | 2.52il 23.2 | $0.08: 0.7$ | 4.88 45.0 <br>  1 <br>   | 3.29130 .3 | 2.60:23.9 | 1.48 | 0.17 | 1.5 | $1.71: 14.6$ | 9.83183.8 |  | 0.40 | 0.20 | 2 |
| 8-6 | $\begin{gathered} 125 \\ 7-8-78 \end{gathered}$ | 1328 | 18.05 177.6 | 0.0100 .04 | $2.65: 11.4$ | 2.55 111.0 | 18.06178 .0 1 | 1.04 | 0.68 | 2.9 | ${ }_{9.93142 .8}^{1}$ | 12.12152.2 | $0.48: 2.1$ | 0.40 | 0.80 | 3 |
| 8-7 | $\begin{gathered} 200 \\ 7-8-78 \end{gathered}$ | 654 | 5.35:47.3 | 0.1311 .1 | 4.69 : 24.7 | 3.13126.9 | 5.48148.4 | 1.50 | 0.56 | 4.9 | $3.08{ }^{\prime} 27.0$ | 9.38164 .7 1 | $0.38: 3.4$ | 1.50 | 0.20 | 2 |
| 9-1 | $\begin{gathered} 123 \\ 8-8-78 \end{gathered}$ | 1020 | 18.09198.9 | $0.00: 0.0$ | 0.15100 .8 | $0.06 \begin{array}{ll} 1 & 0.3 \\ 1 & \end{array}$ | 18.09198.9 | 2.50 | 0.11 | 0.6 | 4.06:23.4 | 13. | 0.0410 .2 |  | 0.40 | 1 |
| 9-18 | $\begin{gathered} 74 \\ 8-8-78 \end{gathered}$ | 770 | 9.96 $\begin{gathered}183.1 \\ 1\end{gathered}$ | 0.03\|0.3 | 0.10 0.8 <br>   <br>   | 1.89i15.8 | 9.99183 .4 1 | 0.05 | $0.17$ | 1.2 | $3.91{ }^{1} 28.8$ | 9.47169.7 | $\left\{\begin{array}{r} 0.041 \\ 1 \\ 1 \end{array}\right.$ |  | 0.40 | 1 |
| 9-3 | $\begin{aligned} & \text { SPRING } \\ & \mathrm{B}-8-78 \end{aligned}$ | 1039 | 14.27 ${ }^{76.0}$ | 0.00;0.0 | $\left(\begin{array}{ccc}2.20 & 11.7 \\ & 1 & \end{array}\right.$ | 2.3112 .3 | 14.27176.0 | 0.96 | $0.06$ | 0.3 | 5.95135 .4 | 11.4165.5 | $\begin{gathered} 0.0010 .0 \\ 1 \end{gathered}$ | 0.50 | 0.20 | I |
| 9-4 | $\begin{gathered} 60 \\ 8-8-78 \end{gathered}$ | 964 | 2.74 $\mathrm{rl}^{2} 16.7$ | $0.05: 0.3$ | $\begin{array}{rll}5.69 & 1 & 34.7 \\ & 1\end{array}$ | 7.9148 .2 | 2.79117.0 | 0.72 | 0.39 | 2.4 | 4.48127 .5 | 10.83!66.7 | 6.54:3.3 |  | 0.20 | 2 |
| 9-6 | $\begin{gathered} 180 \\ 8-8-78 \end{gathered}$ | 768 | 14.05198 .0 | 0.0010.0 ${ }^{1}$ | $0.20 \begin{array}{lll}0.20 & 1.4 \\ & 1 & \\ & 1 & \end{array}$ | 0.0810 .6 | 14.05198.0 | 2.50 | 0.11 | 0.80 | 1.77112 .8 1 | 11.95186 .2 | $0.03_{1}^{1} 0.2$ |  | 1.60 | 1 |
| 9-10 | $\begin{gathered} 120 \\ 8-8-78 \end{gathered}$ | 1140 | 18.18: 96.2 | $0.00: 0.0$ | 10.47 12.5 | 0.25:1.3 | 18.18196 .2 | 1.88 | 0.17 | 0.9 | 5.60131 .1 | $12.19,67.7$ | $0.05^{1} 0.3$ |  | 0.50 | 1 |
| 9-12 | $\begin{gathered} 63 \\ 8-8-78 \end{gathered}$ | 646 | $2.35: 20.2$ | $0.15: 1.3$ | ${ }_{4.94}{ }^{1} 42.5$ | 4.20136 .1 1 1 | 2.50, 21.5 | 1.18 | 0.11 | 1.0 | $\begin{array}{cc} 2.83 & 1 \\ 1 \\ 1 \end{array}$ | 8.75174 .8 1 1 | $0.00 ; 0.0$ |  | 0.10 | 2 |
| 9-13 | $\begin{gathered} 100 \\ 8-8-78 \end{gathered}$ | 590 | 6.96:69.1 | 0.0410 .4 | 1.651 | 1.42114 .1 1 1 | $7.00,69.5$ | 1.16 | $0.11$ | 1.1 | 2.02 119.5 | 8.16178.8 | $0.06: 0.6$ |  | 0.20 | 1 |
| 9-14 | $\begin{gathered} 130 \\ 8-8-78 \end{gathered}$ | 822 | $14.96: 98.5$ | 0.0010 .0 | $0.19: 1.2$ | 0.03 $\begin{gathered}1 \\ 1\end{gathered}$ | 14.96:98.5 | 6.33 | 0.11 | 0.8 | 2.48:16.9 | 12.08:82.2 | 0.03:0.2 |  | 0.60 | 1 |


| $\begin{array}{\|l\|l\|} \hline \\ \text { number } \end{array}$ |  | $\begin{array}{\|l\|l\|} \hline 0 \mathrm{~s} \\ \mathrm{ppm} \end{array}$ | eom Na | \% ${ }^{\text {k }}$ \% | $\mathrm{epma}^{\mathrm{ca}}$ | $\mathrm{epm}^{\mathrm{Mg}} \mathrm{m}$ | $\mathrm{comm}^{\mathrm{Na}+\mathrm{K}}$ | $\mathrm{Ca}_{\text {c/ } / \mathrm{Hg}}^{\text {ratio }}$ | ${ }_{\text {epm }} 1$ | $\mathrm{epm}^{5 \mathrm{~S}_{4}}$ |  | $\mathrm{epm}^{\mathrm{NO}_{3}}$ | $\mathrm{Fe}^{\text {pom }}$ | $\stackrel{F}{\text { ppm }}$ | $\begin{gathered} \text { Facies } \\ \text { Type } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 9-15 | $\begin{gathered} \substack{\text { SpRIMG } \\ 8-8-78} \end{gathered}$ | 526 | 1.7418 .6 1 | (1) 0.05 | 4.59149.1 | 2.96131 .7 <br> 10 | 1.79,19.2 | 1.47 | 0.11:1.1 | 1.37114 .0 | 8.36184 .98 |  |  | 0.20 | 2 |
| 10-1 | $\begin{aligned} & \text { SPRING } \\ & 9-8-78 \end{aligned}$ | 850 | 12.88,98.2 |  | 1.55110 .3 | 0.67 <br> 1.4 <br> 18 | 12.89, ${ }^{\text {, 85, } 3}$ | 2.31 |  | 7 |  | 0.21:1.4 | 1.10 | 0.50 | , |
| 10-2 | $\begin{gathered} \text { spRILG } \\ 9-8-78 \end{gathered}$ | 953 | $\left\lvert\, \begin{gathered} 15.1890 .0 \\ 1 \end{gathered} 0^{0}\right.$ |  | $0.711^{1.6}$ | 0.91: 5.4 |  | 0.85 | 0.06 0.4 | $4.681^{28.7}$ | $9$ | 0.0310.2 |  | 0.30 |  |
| 10-3 | 9-8 | 982 | $\left\lvert\, \begin{array}{c:c} 14.7 & 18.3 \\ & 1 \end{array}\right.$ | (0.00 ${ }^{0.0}$ | ${ }^{0.54} 1_{1}^{1} 3.3$ | 1.22: 1.4 | 14.7 ${ }^{89.3}$ | 0.44 | 0.06 ${ }^{0.0 .4}$ | $45.10 i^{31.7}$ |  | 0.0010 .1 |  | 0.40 | 1 |
| $10-4$ | $\begin{aligned} & \text { SPAING } \\ & 9-8-78 \end{aligned}$ | 928 | $9.79 \mid 64.7]_{0}$ | 0.00 10.0 | ${ }_{2.79}^{1} 1_{18.5}^{1.5}$ | ${ }_{2.55}^{1}$ 16.9 | $\left.9.799_{1}^{1} 64.7\right]$ | 1.02 | $\begin{array}{\|l:l} 0.11 & 0.8 \\ \hline \end{array}$ | $8\left[\left.3.39\right\|^{\prime} 23.1 \mid\right.$ | $\mid 11.191$ |  | 0.00 | 0.20 |  |
| 10-5 | $\begin{gathered} \text { SpR1MG } \\ 9-8-78 \end{gathered}$ | 832 | ${ }^{12.66185 .5}$ | 5 | 1.45 19.8 | 0.7014 .7 | $12.66\}^{\prime} 85.5$ | 2.07 |  | (3.04 121.1 | 7 | $\begin{array}{ll:l}0.04 & 0.3\end{array}$ | . 30 | 0.90 |  |
| 10 | 9-80 | 894 | $\begin{gathered} 9.18 l_{62.1} \\ 1 \end{gathered}$ | $10 .$ | ' | $\left[\begin{array}{c} 2.55 \\ 1 \\ 1 \\ 1 \end{array}\right] .3$ | $\begin{aligned} & 9.1966 \\ & \hline \end{aligned}$ | 1.19 | $\left[\begin{array}{c:c} 0.11 & 0.7 \\ & 1 \end{array}\right]^{3}$ | $\begin{array}{llll}3.83 & 25.4\end{array}$ | $0^{80}$ | $\begin{array}{l:l\|l\|} \hline 0.00 & 0.0 \\ \hline \end{array}$ |  | 0.3 |  |
| 10-7 | $\begin{aligned} & \text { SPRING } \\ & 9-8-78 \end{aligned}$ | 690 | $83163.3$ | $3\left[\begin{array}{c} 0.00 \\ \\ \\ 1 \end{array} 0.0{ }^{0.0}\right.$ | $\begin{array}{ll} 2.64 & 1 \\ \hline & 21.4 \end{array}$ | 1.89! 15.3 | $7.83,63.3$ | 1.40 | $\left\|\begin{array}{ll} 0.06 & 1 \\ & 0.5 \end{array}\right\|=2$ | 0.52.17, 17.6 | $\|10.11182 .0\|$ | $\left\|\begin{array}{l:l} 0.00 & 0.0 \end{array}\right\|$ | 0.00 | 0.20 | , |
| 10-8 | $\begin{aligned} & \text { SPRING } \\ & 9-8-78 \end{aligned}$ | 642 | $\begin{gathered} 3.96133 .1 \\ 1 \end{gathered}$ | $\begin{array}{llll}0.01 & 0.1\end{array}$ | (1) 3.641 | 4.361 | 3.97133 | 0.84 | $\left\lvert\, \begin{array}{c:c} 0.06 & 0.5 \\ & 1 \end{array}\right.$ | ( $0.51 .64,14.3$ | 9.75184.9 | $\left\|\begin{array}{ll} 0.04 & 0.3 \end{array}\right\|$ |  | 0.10 | 2 |
| 10.9 | $\xrightarrow{\substack{180 \\ 9-8-78}}$ | 828 | $14.62 i_{98.9}$ | 0.00 0.0 <br>  1 |  | $0.0{ }_{0} 0.0 .2$ | 14.62, 9 98.9 | 4.00 | $\left[\begin{array}{l:l} 0.11 & 0.8 \\ & \end{array}\right.$ | 0.82.96 121.4 | $4 \left\lvert\, \begin{gathered} 1 \\ 10.717 .6 \\ 1 \end{gathered}\right.$ | [0.0210.2 |  | 1.6 |  |
| 10-10 |  |  | $11.92 \mathrm{e}_{1}^{\mathrm{i}} \mathrm{e}_{3} .9$ | $\left\|\begin{array}{c:c} 0.00 & 0.0 \\ & \end{array}\right\|$ | 0.56 1.0 <br> 0  | 1.73112 | 11.92183 .9 | 0.33 | $\begin{array}{\|c:c} 0.06 & 0.4 \\ & 1 \\ & \end{array}$ | (4.4.96129.0 | ${ }^{9.6} 1^{70.4}$ | ${ }^{0.02} 1^{0.2}$ |  | 0.20 | , |
| 11.1 | $\begin{gathered} 1070-78 \\ 10-8-7 \end{gathered}$ | 695 | $\begin{gathered} 12.01199 .2 \\ 1 \end{gathered}$ | $\left.2 \begin{array}{lll} 0.00 & 1 & 0.0 \\ & 1 \end{array} \right\rvert\,$ | $\begin{array}{l:l} 0.07 & 0.6 \\ \hline \end{array}$ | $0.02: 0.10$ | 12.01\|99.2 | 3.50 | $\begin{array}{\|l\|l\|l\|} \hline 0.34 & 1 & 2.6 \\ & & \\ \hline \end{array}$ | (1.06:8.2 | $2$ | 0.02: 0.2 |  | 1.20 | , |


| Index Number | Well <br> Depth Date <br> Sampled (fect) | $\begin{aligned} & \text { TOS } \\ & \text { ppm } \end{aligned}$ | $\mathrm{Cl}_{\text {eprn }} \mathrm{Na}$ | epm | epm |  |  | $\mathrm{Ca} / \mathrm{Hg}$ retio | Cl | $\left\lvert\, \begin{aligned} & \mathrm{SO}_{4} \\ & \text { epm } \end{aligned}\right.$ | $\left\lvert\, \begin{aligned} & \mathrm{HCO}_{3}+\mathrm{CO}_{3} \\ & \mathrm{epm} \end{aligned}\right.$ |  | Fe | $\begin{gathered} F \\ p p m \end{gathered}$ | $\begin{gathered} \text { Facies } \\ \text { Type } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 11-2 | $\begin{aligned} & \text { SPRING } \\ & 10-8-76 \end{aligned}$ | 678 | 11.53197.0 | 0.00 $\begin{aligned} & 0.0 \\ & 0.0\end{aligned}$ | 0.23 112.0 | $0.12{ }^{0.1} 1.0$ | 11.53197 .0 | 1.92 | 0.06 $\begin{aligned} & 0.0 .5 \\ & \\ & \\ & \\ & \end{aligned}$ | 1.60:13.7 | 10.07'85.8 | 0.00: 0.0 |  | 0.50 | I |
| 11-3 | $\begin{aligned} & \text { SPRING } \\ & \text { 10-8-78 } \end{aligned}$ | 808 | 12.66!92.0 | 0.03 00.2 | 0.43 113.1 | 0.63 114.6 | $12.699^{1} 92.2$ | 0.68 | $\begin{array}{l\|l\|} 0.06 & 0.4 \\ & \end{array}$ | 3.33124 .8 1 | 10.24 1 | $\begin{array}{rrr}0.021 & 0.2 \\ & \\ & \end{array}$ |  | 0.70 | I |
| 11-6 | $\begin{gathered} 170 \\ 10-8-78 \end{gathered}$ | 732 | $12.44 \mathrm{i} 97.4$ | 0.0210 .2 | $\left(\begin{array}{lll}0.21 & 1.6\end{array}\right.$ | 0.10100 .8 | $12.46,97.6$ | 2.10 | 0.061 0.5 | 2.19\|17.8 | 10.00181.4 | $0.04: 0.3$ |  | 0.80 | I |
| 11-7 | $\begin{aligned} & \text { SPRING } \\ & 10-8-78 \end{aligned}$ | 388 | 1.85izi.6 | $0.06 \begin{array}{cll}0.0 .7\end{array}$ | 3.72 43.5 | 2.92134 .2 | 1.91122.3 | 1.27 | ${ }_{0}^{0.0610 .65}$ | 0.8319 .0 | 8.29189.7 | $0.06: 0.65$ | 0.10 | 0.20 | 2 |
| 11-8 | $\begin{aligned} & 105 \\ & 10-8-78 \end{aligned}$ | 770 | 13.61 98.1 | 0.0110 .1 | 0.19 191.4 | $0.06: 0.4$ | $13.62 ; 98.2$ | 3.17 | 0.2311 .7 | $1.85{ }^{1} 13.6$ | $11.48{ }^{1} 84.5$ | 0.021 1 1 |  | 1.10 | 1 |
| 11-9 | $\begin{aligned} & \text { SPRING } \\ & 10-8-78 \end{aligned}$ | 396 | 1.69121.5 | 0.0610 .8 | 2.30129 .3 | $\left.3.79\right\|^{48.3}$ | ${ }^{1.75 i^{22.3}}$ | 0.61 | 0.1712 .1 | $0.92: 11.4$ | 6.92,86.2 | 0.02: 0.20 |  | 0.10 | 2 |
| 11-10 | $\begin{aligned} & \text { SPRING } \\ & 10-8-78 \end{aligned}$ | 814 | 9.96168 .8 1 | 0.04 0.3 <br>  1 | 2.25115 .5 | $2.22 \mid 15.4$ | 10.00!68.9 | 1.01 | 0.11 1 0.8 <br>  1  | $\begin{gathered} 2.96121 .4 \\ ! \end{gathered}$ | $10.72177 .5$ | $0.0410 .3$ |  | 0.20 | 1 |
| 12-1 | $\begin{aligned} & \text { SPRING } \\ & \text { 11-8-78 } \end{aligned}$ | 734 | 7.87158 .1 1 | 0.06110 .5 | $2.74{ }^{2} 120.2$ | $2.88{ }_{1}^{1} 21.2$ | 7.93:58.6 | 0.95 | $0.06: 0.4$ | $2.67{ }_{1}^{1} 20.4$ | 10.31179.1 | $0.01: 0.1$ |  | 0.10 | 2 |
| 12-2 | $\begin{aligned} & \text { SPRING } \\ & \text { II-B-78 } \end{aligned}$ | B44 | 10.40169.6 | $\left(\begin{array}{ccc}0.04 & 1 & 0.3 \\ & 1 & \end{array}\right.$ | 1.95113 .0 | 2.55117 .1 | $\begin{gathered} 10.44!69.9 \\ ! \end{gathered}$ | 0.77 | $\begin{array}{llll}0.17 & 1 & 1.1 \\ & 1 & \end{array}$ | 3.44i23.2 | $\begin{gathered} 11.08!74.9 \\ ! \end{gathered}$ | $0.11: 0.8$ |  | 0.10 | 1 |
| 12-3 | $\begin{gathered} 255 \\ 11-8-78 \end{gathered}$ | 846 | $14.75,96.5$ | 0.001000 | 0.30012 .0 | 0.24 1  <br> 1 1.6  <br>  1  | $\begin{gathered} 14.75!96.5 \\ ! \end{gathered}$ | 1.25 | $\left\lvert\, \begin{array}{cl} 0.06 & 1 \\ & 1 \end{array}\right.$ | $2.81: 19.1$ | 11.80:80.2 | $\begin{gathered} 0.05: 0.3 \\ 1 \end{gathered}$ |  | 0.20 | 1 |
| 12-4 | $\begin{aligned} & 100 \\ & 11-8-78 \end{aligned}$ | 460 | 3.61141.9 | 0.04100 .5 | $1.10{ }^{1} 12.7$ | 3.87, 44.9 | 3.65:42.4 | 0.20 | $\begin{array}{l:l:l} 0.11 & 1.3 \\ & 1 & \end{array}$ | $1.31: 14.6$ | 7.56:84.1 | 0.00:0.1 |  | 0.10 | 2 |
| 12-5 | $\begin{aligned} & \text { SPRING } \\ & 11-8-78 \end{aligned}$ | 722 | 9.26175 .7 | $0.05: 0.4$ | 0.121 .0 | 2.8122 .9 | 9.31i76.1 | 0.04 | $\begin{array}{llll}0.11 & 1 & 0.9 \\ & 1 & \end{array}$ | 2.56 ' 20.1 | 10.00:78.5 | $0.06: 0.5$ |  | 0.10 | 1 |


| Index Humber | Well <br> Depth Date Sampled (leet) | $\begin{aligned} & \text { TOS } \\ & \text { pom } \end{aligned}$ | Comm | epm | Comm $\begin{array}{ll} & \\ & \\ & \\ \end{array}$ | epm $\quad$ Mg |  | $\mathrm{Ca} / \mathrm{Mg}$ <br> ratio | $\qquad$ | ${ }^{50}$ | $\begin{gathered} \mathrm{HCO}_{3}+\mathrm{CO}_{3} \\ \text { eom } \end{gathered}$ | $\mathrm{eom}_{3}^{\mathrm{NO}_{3}}$ | Fe | $\begin{gathered} \text { F } \\ \text { ppm } \end{gathered}$ | $\left\lvert\, \begin{gathered} \text { Facies } \\ \text { Type } \end{gathered}\right.$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 12-7 | $\begin{gathered} 180 \\ 11-8-78 \end{gathered}$ | 1008 | 16.79:98.6 | $0.00{ }^{0.00}$ | 0.1711 .0 | 0.0710 .4 | $16.791^{98.6}$ | 2.43 | $0.06: 0.3$ | 4.06124 .9 | 12.16174 .6 1 | 0.0310 .2 |  | 0.40 | 1 |
| 12-8 | $\begin{gathered} 72 \\ 11-8-78 \end{gathered}$ | 296 | 2.39148 .7 | 0.0210 .4 | $0.921^{18.8}$ | 1. 58 \| 32.1 | 2.41149 .1 | 0.58 | $0.17{ }^{3.2}$ | 0.51 9.5 | $4.63{ }^{1} 86.3$ | $0.05 / 1.0$ |  | 0.30 | 2 |
| 13-1 | $\begin{gathered} 80 \\ 15-8-78 \end{gathered}$ | 430 | 1.06, 12.5 | 0.07 : 0.9 | 3.64 $/ 41.7$ | $\begin{array}{cc}3.7 & 1^{44.9} \\ 1\end{array}$ | 1.11/13.4 | 0.94 | 0.2813 .3 | 0.67 18.0 | $\left.7.11\right\|^{83.8}$ | $0.41 \mid 4.9$ | 0.70 | 0.10 | 2 |
| 13-2 | SPRING $15-8-78$ | 370 | 2.35134 .5 | 0.0610 .9 | 2.35134 .4 | 2.06130 .2 | 2.41135.4 | 1.21 | 0.1712.3 | 0.51 17.0 | 6.67190.6 | $0.001^{0.1}$ | 0.30 | 0.10 | 2 |
| 13-4 | SPRING $15-8-78$ | 356 | $1.36: 18.4$ | $0.05 \mid 0.7$ | $3.091^{41.9}$ | 2.88139.0 | 1.4119.1 | 1.14 | $0.11,1.5$ | 0.51 6.7 <br>  1 | $6.97 \mid 91.4$ | 0.0310 .4 | 0.60 | 0.10 | 2 |
| 13-5 | SPRING $15-8-78$ | 660 | $6.26,50.4$ | $0.03: 0.3$ | $2.99 \mathrm{i}^{24.1}$ | 3.13\|25.2 | 6.2950 .7 | 1.08 | 0.1100 .9 | 3.41127.0 | $9.11 \mid 72.1$ 1 | $0.011^{0.1}$ | 0.30 | 0.10 | 2 |
| 14-1 | $\begin{gathered} 175 \\ 17-8-78 \end{gathered}$ | 902 | $11.53{ }^{170.0}$ | 0.00 100.0 | 3.44120 .9 | $1.49,9.1$ | 11.5370 .0 | 2.39 | 0.3412.2 | $3.33 \mid 21.3$ | [11.92\|76.3 | $0.04: 0.2$ | 0.20 | 0.60 | 1 |
| 14-2 | $\stackrel{90}{17-8-78}$ | 750 | 12.61:89.4 | $0.00{ }^{0.0} 0$ | 1.1017 .8 | $0.40{ }^{2} \mid$ | ${ }_{12.611_{89.4}}$ | 2.75 | $0.11 \mid 0.8$ | $1.96,13.8$ | 12.03185 .1 | 0.0410 .3 | 0.10 | 0.40 | 1 |
| 14-3 | $\begin{gathered} 37 \\ 17-8-78 \end{gathered}$ | 358 | 2.78131 .8 | 0.02 0.2 <br>   | 3.93145 .0 | $2.00 \mid 22.3$ | 2.00132 .0 | 1.97 | $0.34 \mathrm{f}^{3.7}$ | 1.04111 .3 | 2.83 ¢ 84.9 | 0.0110 .1 | 0.90 | 0.20 | 2 |
| 14-4 | $\begin{aligned} & \text { SPRING } \\ & 17-8-78 \end{aligned}$ | 578 | 6.92161.4 | 0.0510 .5 | 2.94126 .1 | 1.35112 .0 1 | 6.37161 .9 | 2.13 | 0.06 0.5 | $1.52 \mid 13.6$ <br> 1 | 9.52 185.5 | 0.0410 .4 | 2.70 | 0.30 | 1 |
| 14-5 | $\begin{gathered} 98 \\ 17-8-79 \end{gathered}$ | 616 | 8. 39167.4 | $\left(\begin{array}{c:c}0.04 & 0.3 \\ & 1\end{array}\right.$ | $2.611^{21.0}$ | $1.40{ }_{1}^{111.3}$ | 8.43167 .7 1 | 1.86, | $0.06,0.49$ | 1.79114.5 | 10.47184.7 | 0.01 10.08 1 | 0.40 | 0.40 | 1 |
| 14-6 | $\begin{gathered} 80 \\ 17-8-78 \end{gathered}$ | 664 | 5.92146 .5 | $0.06: 0.47$ | $4.65 \mathrm{I}^{16.5}$ | $2.10,16.5$ | $5.981 / 16.97$ | 2.21 | $0.11 \mid 0.90$ | $3.291^{1} 26.9$ | 8.80171 .8 | $0.05,0.41$ | 5.70 | 0.20 | 7 |



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| ※ E | $\stackrel{\%}{\circ}$ | $\stackrel{\square}{\circ}$ | $\stackrel{\square}{\circ}$ | $\stackrel{8}{\circ}$ | $\stackrel{\square}{\circ}$ | $\stackrel{?}{-}$ | $\stackrel{0}{0}$ | 号 |  |  |
|  | \％ | $\circ$ <br> $\vdots$ <br> $\vdots$ <br> $\vdots$ <br> 0 | $\begin{array}{r} \tilde{\sim} \\ -\frac{1}{0} \\ \dot{0} \end{array}$ |  | $\begin{gathered} \text { ö } \\ -\dot{0} \\ \hline \stackrel{0}{0} \\ 0 . \end{gathered}$ | $\begin{array}{r} \stackrel{\circ}{0} \\ -\stackrel{0}{\circ} \\ \hline \stackrel{0}{0} \end{array}$ |  | $\begin{aligned} & \text { N } \\ & \hdashline \begin{array}{c} 0 \\ 0 \\ 0 \end{array} \end{aligned}$ | 0 <br> 0 <br> 0 |  |
| $\begin{aligned} & \mathrm{e}^{m} \\ & + \\ & \mathbf{o}^{m} \\ & \hline \end{aligned}$ |  |  |  |  |  |  |  |  |  |  |
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## APPENDIX C

## DEEP WELL DATA

## Notes to Appendix C

1. Column 1: The letter in the index indicates the following type of well: $S=$ structure test hole, $C=$ coal test hole and $H=$ gas or oil test hole.
2. Column 3: Datum elevation refers to the elevation from which the geophysical well logs are measured as zero depth. In most cases this is a surveyed land or ground elevation. The letters G.L. beside the number indicate ground level while the letter K.B. indicate a Kelly Bushing elevation.
3. Columns 6 to 8: The abbreviation L. Ardiey 'B' stands for Lower Ardley ' $B$ ' coal zone.
4. Columns 9 and 10: These columns refer to the amount of sandstone (cumulative) in the strata above the Lower Ardley ' $B$ ' coal zone.

| Index Number | Location | $\begin{gathered} \text { Datum } \\ \text { Elevation } \\ \text { (feet) } \end{gathered}$ | $\begin{aligned} & \text { Depth } \\ & \text { Logged } \\ & \text { (feet) } \end{aligned}$ | $\begin{gathered} \text { Company } \\ \text { Date } \end{gathered}$ | Depth to top of <br> L. Ardley '0' (fect) | $\begin{aligned} & \text { Elevation } \\ & \text { of } \\ & \text { L. Ardley 'B' } \\ & \text { (feet) } \end{aligned}$ | Thickness <br> of <br> L. Ardley ' $B$ ' (fcet) | $\begin{gathered} \text { Thickness } \\ \text { of } \\ \text { Santstone } \\ \text { (feet) } \end{gathered}$ | Percent <br> Sandstone | Depth to Bedrack (feet) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| s-1 | 13-36-34-2444 | 3003 | 855 | July 19, 1953 | 391 | 2612 | 16 | 270 | 79 |  |
| 5-2 | 15-34-34-24.14 | 2850 | 650 | Juty 14. 1953 | 257 | 2593 | 17 | 100 | 48 |  |
| 5-3 | 3-3-35-2444 | 3000 | 155 | July 17, 1953 | 415 | 2583 | 18 | 136 | 37 |  |
| 5-4 | 2-4-35-24/4 | 2960 | 758 | June 9. 1953 | 376 | 2584 | 20 | 200 | 61 | 107 |
| 5-5 | 13-6-35-2464 | 3055 | 905 | $\begin{aligned} & \text { Gulf oll } \\ & \text { Nov. 3. } 1952 \end{aligned}$ | 526 | 2529 | 17 | 213 | 45 |  |
| 5-6 | 9-10-35-24144 | 2842 | 770 | June 9. 1953 | 241 | 2601 | 18 | 128 | 67 | 48 |
| 5-7 | 9-13-35-24/44 | 3020 | 862 | Juty 13. 1953 | 411 | 2609 | 16 | 160 | 44 |  |
| 5-8 | 1-14-35-2444 | 3045 | 843 | June 8, 1953 | 446 | 2599 | 11 | 262 | 66 | 20 |
| 5-9 | 13-2-35-25N4 | 3042 | 919 | $\begin{array}{c:c} \text { Gulf } 011 \\ \text { Nov. 8, } 1952 \end{array}$ | 535 | 2507 | 19 | 262 | 54 |  |
| 5-10 | 13-12-35-2544 | 3109 | 960 | $\begin{aligned} & \text { Gulf oil } \\ & \text { oct. 31. 1952 } \end{aligned}$ | 601 | 250B | 18 | 160 | 29 |  |
| 5-11 | 16-12-35-2544 | 3104 | 906 | $\begin{aligned} & \text { Gulf } 011 \\ & \text { Hov. 2. } 1952 \end{aligned}$ | 596 | 250 | 17 | 200 | 37 |  |
| $5-12$ | 4-23-35-25w4 | 3152 | 1059 | $\begin{gathered} \text { Guff of } \\ \text { Oct. 25. } 1992 \end{gathered}$ | 684 | 2468 | 21 | 130 | 21 |  |
| 5-13 | 4-24-35-2544 | 3106 | 1006 | $\begin{aligned} & \text { Guff o11 } \\ & \text { Oc1. 22. } 1957 \end{aligned}$ | 622 | 24.84 | 17 | 150 | 26 |  |
| 5-14 | 16-24-35-25w4 | 3057 | 967 | $\begin{aligned} & \text { Gulf } 011 \\ & \text { Oct. 29, } 1952 \end{aligned}$ | 570 | 2187 | 17 | 224 | 43 |  |


| $\begin{array}{r} \text { Index } \\ \text { Number } \end{array}$ | Location | Datum <br> Elevation (feet) | Depth Logged (feet) | $\begin{gathered} \text { Company } \\ \text { Date } \end{gathered}$ | Depth to top of <br> L. Ardley 'B' (feet) | Elevation of <br> L. Ardley ' $\theta$ ' (feet) | Thickness of <br> t. Ardley 'B' (feet) | Thickness of Sandstone (feet) | Percent Sandstone | Depth to Bedrock (feet) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5-15 | 4-26-35-2504 | 3152 | 804 | $\begin{aligned} & \text { Chevron } \\ & \text { Aug. 27, } 1951 \end{aligned}$ | 699 | 2453 | 17 | 324 | 50 |  |
| 5-16 | 4-27-35-2504 | 3116 | 774 | Chevron Sept. 14. 1951 | 654 | 2462 | 21 | 335 | 56 |  |
| 5-17 | 4-28-35-2504 | 3109 | 803 | Chevron $\text { Aug. 23. } 1951$ | 666 | 2443 | 21 | 228 | 37 | 83 |
| 5-18 | 13-32-35-25w4 | 3167 | 909 | $\begin{gathered} \text { Chevron } \\ \text { Aug. } 21,1951 \end{gathered}$ | 719 | 2448 | 19 | 260 | 39 | 89 |
| 5-19 | 4-33-35-25 W4 | 3183 | 814 | Chevron $\text { Oct. } 30,1951$ | 756 | 2427 | 21 | 320 | 45 |  |
| 5-20 | 4-34-35-2564 | 3191 | 800 | Chevron Oct. 17, 1953 | 725 | 2466 | 20 | 285 | 42 | 36 |
| 5-21 | 1-4-36-264/4 | 3025 | 627 | Chevron <br> Aug. 21. 1951 | 480 | 2545 | 17 | 185 | 43 |  |
| 5-22 | 13-32-35-24/4 | 2928 | 569 | Chevron Aug. 17. 1951 | 413 | 2515 | 17 | 170 | 47 | 60 |
| 5-23 | 13-7-36-24144 | 2970 | 556 | Chevron $\text { Hov. 13. } 1951$ | 484 | 2486 | 15 | 120 | 28 |  |
| 5-26 | 13-11-36-2444 | 3050 | 553 | Chevron $\text { Dec. 2, } 1951$ | 479 | 2571 | 15 | 215 | 50 |  |
| 5-25 | 4-16-36-24/4 | 3057 | 600 | Chevron Dec. 2. 1951 | 528 | 2529 | 15 | 182 | 38 |  |
| 5-26 | 12-24-36-2414 | 2710 | 416 | Royallte 011 Auq. 23, 1952 |  |  |  |  |  |  |


| Index Number | Location | $\begin{aligned} & \text { Datum } \\ & \text { Elevation } \\ & \text { (feet) } \end{aligned}$ | $\begin{aligned} & \text { Depth } \\ & \text { Logged } \\ & \text { (raet) } \end{aligned}$ | $\begin{gathered} \text { Company } \\ \text { Date } \end{gathered}$ | Denth to top of <br> L. Ardley 'D' (rect) | Elevation of <br> L. Ardley 'B' (fect) | Thickness of <br> L. Ardley ' $\theta$ ' (feet) | Thickness of Sandstone (feet) | Percent <br> Sandstone | Depth to Bedrock (feet) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| s-27 | 13-24-36-2444 | 3052 | 526 | Royalite oll <br> June 19. 1952 | 503 | 2549 | 14 | 276 | 50 | 42 |
| 5-28 | 4-26-36-2444 | 3053 | 606 | Chevron <br> Mov. 7. 195 | 489 | 2564 | 14 | 162 | 37 |  |
| 5-29 | 4-27-36-2444 | 3122 | 636 | $\begin{aligned} & \text { Royalite oll } \\ & \text { Scpt. 11. Igs? } \end{aligned}$ | 591 | 2531 | 14 | 248 | 46 |  |
| 5-30 | 1-30-36-24,14 | 3000 | 557 | Popalite oll Sepl. 16, 1952 | 503 | 2497 | 14 | 175 | 39 | 55 |
| 5-31 | 13-35-36-24.44 | 2981 | 490 | Royalite oll <br> July 3. 1952 | 477 | 255\% | 14 | 150 | 40 | 50 |
| 5-32 | 4-1-36-2544 | 3022 | 201 | Chevron <br> Auq. 16. 195 | 557 | 2465 | 16 | 208 | 41 |  |
| 5-33 | 4-2-36-2544 | 3088 | 111 | Chevron Sept. 21, 1951 | 619 | 2469 | 17 | 220 | 39 |  |
| 5-34 | 4-3-36-2544 | 3136 | 850 | Chevron Aug. 14, 1951 | 709 | 2471 | 23 | 246 | 37 |  |
| 5-35 | 4-4-36-2544 | 3211 | 851 | Chrevron Sent. 14. 1951 | 775 | 2436 | 70 | 406 | 56 |  |
| 5-36 | 4-6-36-2544 | 3046 | 676 | Chevron $\text { 0ct. 28. } 1951$ | 609 | 2435 | 21 | 270 | 48 | 86 |
| 5-37 | 4-7-36-2544 | 3030 | 155 | Chevron Sert. 18, 195 | 657 | 2413 | 19 | 328 | 54 |  |
| 5-38 | 13-7-36-2544 | 3143 | 804 | Cheuron Sept. 18, 1953 | 179 | 2414 | 19 | 296 | 44 | 70 |


| $\begin{aligned} & \text { Index } \\ & \text { Number } \end{aligned}$ | Location | $\begin{gathered} \text { Datum } \\ \text { Elevat ion } \\ \text { (feet) } \end{gathered}$ | $\begin{aligned} & \text { Depth } \\ & \text { Logged } \\ & \text { (rceet) } \end{aligned}$ | $\begin{aligned} & \text { Company } \\ & \text { Date } \end{aligned}$ | Depth to top of <br> L. Ardley ' B ' (fect) | Elevation of <br> 1. Ardley ' 0 ' (feet) | Thickness <br> of <br> L. Ardler ' $\theta$ ' <br> (reet) | $\begin{gathered} \text { Thickness } \\ \text { of } \\ \text { Sands } \\ \text { (feel) } \end{gathered}$ | Percent Sands tone | Depth to Bedrock (feet) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5-39 | 4-8-36-2544 | 3148 | 786 | Chevron <br> Sept. 25. 1951 | 731 | 2417 | 19 | 330 | 49 | 71 |
| 5-40 | 16-8-36-25W4 | 3239 | 901 | $\begin{aligned} & \text { Chevron } \\ & \text { Aug. 29. } 1951 \end{aligned}$ | 198 | 2441 | 16 | 290 | 39 |  |
| 5-41 | 4-11-36-25w4 | 3068 | 1018 | $\begin{aligned} & \text { Chevron } \\ & \text { Nov. 28, 1951 } \end{aligned}$ | 599 | 2469 | 17 | 100 | 18 |  |
| 5-42 | 4-14-36-25N4 | 3012 | 607 | cheuron Nov. B. 1951 | 560 | 2452 | 15 | 102 | 20 | 60 |
| 5-43 | 13-15-36-2504 | 3113 | 1042 | Cheuron $\text { Nov. 24. } 1951$ | 661 | 2452 | 18 | 182 | 30 |  |
| s-44 | 4-17-36-2514 | 3220 | 849 | Chevron Sept. 21, 1951 | 797 | 2423 | 17 | 330 | 44 |  |
| 5-45 | 4-18-36-2514 | 3148 | 850 | Chevron $\text { Sept. 6, } 1951$ | 790 | 2358 | 26 | 282 | 38 | 70 |
| s-46 | 4-18-36-2514 | 3148 | 1253 | $\begin{aligned} & \text { Chevron } \\ & \text { Mov. 20. } 1951 \end{aligned}$ | 791 | 2357 | 25 | 290 | 39 | 66 |
| 5-47 | 13-19-36-2514 | 3171 | 1248 | $\begin{gathered} \text { Chevron } \\ \text { Oce. } 16,1951 \end{gathered}$ | 174 | 2397 | 17 | 182 | 25 | 70 |
| 5-48 | 13-20-36-25144 | 3193 | 852 | Chevron Sept. 11. 1951 | 174 | 2419 | 18 | 162 | 22 |  |
| 5-49 | 13-22-36-2514 | 3038 | 682 | Chevron Nov. 1. 1951 | 559 | 2479 | 18 | 124 | 24 |  |
| 5-50 | 13-23-36-2514 | 2925 | 550 | Cherron <br> Mov. 4. 1951 | 443 | 2482 | 19 | 178 | 33 | 137 |


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| Index Number | Location | $\begin{array}{\|c} \text { Datum } \\ \text { Elevation } \\ \text { (Ieet) } \end{array}$ | Depth Logged ('ret) | $\begin{aligned} & \text { Company } \\ & \text { Oate } \end{aligned}$ | Depth to ton of <br> L. Ariley 'b' (feet) | Elevation <br> of <br> 2. Ardley ' $B$ ' <br> (fret) | Thickness of <br> L. Ardley 'B' (reet) | 'Thlckness of Sands tone (feet) | Percent <br> Sandstone | Depth to Aedrock (feet) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5-63 | 4-6-37-24.44 | 3187 | 801 | $\begin{gathered} \text { Royalite } 011 \\ \text { Srpt. 16, } 1952 \end{gathered}$ | 689 | 2498 | 14 | 286 | 45 |  |
| 5-64 | 4-6-37-24.14 | 3187 | 739 | $\begin{gathered} \text { Chevron } \\ \text { Nov. } 12,1951 \end{gathered}$ | 690 | 2497 | 17 | 245 | 38 |  |
| 5-65 | 13-7-37-24W4 | 3020 | 564 | $\begin{gathered} \text { Chevron } \\ \text { Oct. 18, 195) } \end{gathered}$ | 498 | 252.2 | 13 | 130 | 29 | 150 |
| 5-66 | 4-17-37-2464 | 2960 | 554 | Royalite ofl June 7. 1952 | 419 | 2541 | 14 | 146 | 40 | 108 |
| s-67 | 4-18-37-24.144 | 2973 | 634 | $\begin{gathered} \text { Chevron } \\ \text { Jan. 3. } 1952 \end{gathered}$ | 468 | 2505 | 14 | 140 | 34 | 98 |
| 5-68 | 13-1-37-25w4 | 3144 | 700 | $\begin{gathered} \text { Chevron } \\ \text { oct. } 11,1953 \end{gathered}$ | 658 | 2486 | 15 | 214 | 35 | 68 |
| s-69 | 13-2-37-2514 | 3115 | 689 | $\begin{aligned} & \text { Chevron } \\ & \text { sept. 16, } 1953 \end{aligned}$ | 642 | 2473 | 16 | 264 | 45 |  |
| S-70 | 1-3-37-2544 | 3027 | 630 | $\begin{gathered} \text { Chevron } \\ \text { Nov. } 10,1951 \end{gathered}$ | 571 | 2456 | 17 | 240 | 46 | 57 |
| 5-71 | 13-4-37-2544 | 3150 | 743 | $\begin{gathered} \text { Cheyran } \\ \text { 0ct. 11, } 1953 \end{gathered}$ | 696 | 2454 | 14 | 248 | 38 | 36 |
| 5-72 | 2-5-37-2544 | 3111 | 745 | $\begin{gathered} \text { Chevron } \\ \text { Oce. } 7,1951 \end{gathered}$ | 649 | 2162 | 15 | 168 | 28 | 63 |
| 5-73 | 16-5-37-25w4 | 3169 | 808 | $\begin{gathered} \text { Chevron } \\ \text { Dec. } 72,1951 \end{gathered}$ | 71 | 2458 | 15 | 236 | 36 | 52 |
| 5-74 | 4-6-37-2544 | 3168 | 847 | $\begin{aligned} & \text { Chevrn" } \\ & \text { Nriv. } 29,1951 \end{aligned}$ | 786 | 7382 | 17 | 170 | 23 | 66 |


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| 言 |  |  |  |  |  |  |  |  |  |  |  |  |
|  | $\bar{\sim}$ | \％ |  | \％ | $\cdots$ | $\stackrel{N}{6}$ | N | İ | \％ | E | \％ | $\widehat{6}$ |
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| 比㐌 | $\stackrel{n}{i}$ | $\stackrel{\circ}{5}$ | $\underset{i}{i}$ | $\stackrel{\infty}{i}$ | $\stackrel{\sim}{i}$ | ： | $\overline{\text { in }}$ | ※̈ | $\stackrel{\text { in }}{\text { in }}$ | $\stackrel{\text { a }}{\sim}$ | $\stackrel{\sim}{\dot{\sim}}$ | ¢ |


| Index Number | Location | $\begin{gathered} \text { Datum } \\ \text { Elevation } \\ \text { (fect) } \end{gathered}$ | Depth Logged (feet) | $\begin{gathered} \text { Company } \\ \text { Date } \end{gathered}$ | Denth to top of <br> L. Ardley '0' (rect) | $\begin{aligned} & \text { Elevation } \\ & \text { of } \\ & \text { 1. Ardicy ' } \\ & \text { (fect) } \end{aligned}$ | Thickness <br> of <br> L. Ardley 'B' <br> (feet) | $\begin{array}{\|c} \text { Thickness } \\ \text { of } \\ \text { Sandstone } \\ \text { (feet) } \end{array}$ | Percent <br> Sandstone | Depth to Bedrock (feet) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5-87 | 4-16-37-2514 | 3122 | 721 | Chevron <br> Sept. 13. 1953 | 650 | 2472 | 13 | 284 | 47 | 112 |
| 5-88 | 16-17-31-25w4 | 3194 | 813 | Chevron <br> Dec. 23, 1951 | 727 | 2467 | 15 | 248 | 31 | 85 |
| 5-89 | 1-19-37-2514 | 3250 | 879 | $\begin{gathered} \text { Chevron } \\ \text { Oct. } 10,1953 \end{gathered}$ | 830 | 2420 | 13 | 264 | 34 | 81 |
| 5-90 | 16-19-37-25W4 | 3190 | 827 | Chevron $\text { Dec. 9, } 1951$ | 767 | 2423 | 15 | 240 | 34 | 111 |
| 5-91 | 13-21-37-2564 | 3171 | 732 | Royalite 011 May 28, 1952 | 701 | 2470 | 15 | 270 | 42 | 120 |
| 5-92 | 4-22-37-25w4 | 3099 | 743 | Chevron $\text { Sept. 8, } 1953$ | 631 | 2468 | 15 | 170 | 29 | 166 |
| 5-93 | 4-26-37-2514 | 2985 | 547 | Rovalite oll <br> May 27. 1952 | 491 | 2494 | 15 | 138 | 31 | 156 |
| 5-94 | 4-28-37-25w4 | 3146 | 916 | $\begin{aligned} & \text { Chevron } \\ & \text { Sept. } 11,1953 \end{aligned}$ | 695 | 2451 | 14 | 312 | 48 | 132 |
| 5-95 | 4-29-37-25w4 | 3168 | 810 | Chevron <br> Sept. 13, 1953 | 730 | 2438 | 14 | 232 | 34 | 110 |
| 5-96 | 4-30-37-2514 | 3385 | 1010 | Royalite 011 June 3. 1952 | 955 | 2430 | 15 | 286 | 32 |  |
| 5-97 | 13-33-37-2544 | 2876 | 492 | Royallte 011 <br> May 22, 1952 | 469 | 2607 | 15 | 178 | 43 |  |
| 5-98 | 4-2-37-2664 | 3116 | 831 | Chevron <br> Sept. 7. 1951 | 786 | 2330 | 22 | 284 | 39 |  |


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|  | N | $\underset{\sim}{\sim}$ | $\cdots$ | $\underset{\sim}{\sim}$ | $\stackrel{\sim}{\sim}$ | 会 | $\underset{\sim}{8}$ | $\stackrel{\sim}{\sim}$ | $\stackrel{8}{i}$ | $\stackrel{\circ}{\sim}$ | $\underset{\sim}{\sim}$ |  |
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| 言 |  | $\begin{aligned} & 5 \\ & \frac{0}{2} \\ & \hline \end{aligned}$ |  | 品 | C |  | ن |  | $\stackrel{\dot{\alpha}}{\dot{\alpha}}$ | $\stackrel{\dot{C}}{\dot{C}}$ |  |  |
|  | $\underset{\sim}{\sim}$ | $\stackrel{\text { ® }}{\text { d }}$ | 区 | Кू | \％ | $\stackrel{8}{1}$ | \％ | ${ }_{6}$ | \％ | ${ }_{8}^{\circ}$ | ® | $\stackrel{\text { \％}}{ }$ |
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| （1） | in | $\frac{8}{4}$ | $\bar{\square}$ | $\stackrel{N}{\square}$ | $\stackrel{\varrho-}{\square}$ | － | $\stackrel{\infty}{i}$ | $\stackrel{\pi}{3}$ | $\frac{\pi}{i}$ | $\stackrel{\text { İ }}{\text { i }}$ | $\stackrel{\text { N }}{\text { in }}$ | $\bar{i}$ |


| Index Number | Location | Datum Elevation (feet) | Depth Logged (Ieet) | $\begin{gathered} \text { Company } \\ \text { Date } \end{gathered}$ | $\begin{aligned} & \text { Depth to } \\ & \text { ton of } \\ & \text { L. Ardley 'B, } \\ & \text { (feet) } \end{aligned}$ | $\begin{aligned} & \text { Elevation } \\ & \text { Lof } \\ & \text { Arder 'B' } \\ & \text { (reet) } \end{aligned}$ | Thickness of <br> L. Ardley ' $\theta^{\prime}$ (feet) | Thickness of Sands tone (feet) | Percent <br> Sands tone | Depth to Bedrock (feet) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H-2 | 10-8-35-24/14 | $\begin{array}{ll} 3031 & (6 . t .) \\ 3042 & (\text { K.B. }) \end{array}$ | 5700 | Kerr-HiGee 1975 |  |  |  |  |  |  |
| H-3 | 10-9-35-24.144 | $\begin{aligned} & 3071 \text { (G.L.) } \\ & 3089 \text { (K.B.) } \end{aligned}$ | 5814 | Kerr-Hcice $1976$ |  |  |  |  |  |  |
| H-4 | 7-10-35-2444 | $\begin{array}{ll} 2911 & \text { (G.L.) } \\ 2925 & \text { (k.B.) } \end{array}$ | 4916 | Camac Expl. |  |  |  |  |  |  |
| H-5 | 6-19-35-24W4 | $\begin{aligned} & 3024 \text { (6.L.) } \\ & 3047 \text { (K.B.) } \end{aligned}$ | 7803 | $\begin{gathered} \text { Phillips Pet. } \\ 1955 \end{gathered}$ |  |  |  |  |  |  |
| H-6 | 14-21-35-24/4 | $\left\lvert\, \begin{array}{ll} 2890 & (6 . L .) \\ 2902 & \text { (K.B.) } \end{array}\right.$ | 7512 | Husky 011 1955 | 347 | 2555 | 17 | 110 | 39 | 115 |
| H-7 | 6-1-35-2544 | $\begin{aligned} & 3072 \\ & 3085 \\ & \text { (6.L. .). } \end{aligned}$ | 8006 | $\begin{gathered} \text { B.A. }{ }^{\text {I956 }} \end{gathered}$ | 565 | 2520 | 17 |  |  |  |
| H-10 | 10-14-35-2564 | $\left\lvert\, \begin{array}{ll} 3177 & \text { (G.L.L.) } \\ 3189 & \text { (K.B.) } \end{array}\right.$ | 7065 | Zapata Pet. <br> 1962 |  |  |  |  |  |  |
| H-11 | 13-14-35-24u4 | 3209 (K.8.) | 6295 | Husky 011 1955 | 124 | 2485 | 20 |  |  |  |
| H-12 | 6-17-35-2514 | 3033 <br> 1044 <br> (G.L.) <br> (K.8.) | 5813 | $\begin{gathered} \text { Amoco } 011 \\ 1970 \end{gathered}$ | 610 | 2434 |  |  |  |  |
| H-13 | 6-21-35-25u4 | $\left\lvert\, \begin{array}{ll} 3098 & \text { (6.L. }) \\ 3112 & \text { (K.B.) } \end{array}\right.$ | 3493 | Czar Resources 1977 | 642 | 2470 | 19 |  |  |  |
| H-14 | 16-22-35-2514 | $\begin{array}{ll} 3150 & (\mathrm{G.L.}) \\ 3162 & (\mathrm{K.B.)} \end{array}$ | 7850 | $\begin{gathered} \text { Perto 0.11 } \\ 1972 \end{gathered}$ |  |  |  |  |  |  |
| H-15 | 6-23-35-24144 | $\left\lvert\, \begin{array}{ll} 3160 & (6 . L .) \\ 3173 & \text { (K.B.) } \end{array}\right.$ | 7178 | Republic Resource $1974$ |  |  |  | $>$ |  |  |


| $\begin{aligned} & \text { Index } \\ & \text { Number } \end{aligned}$ | tocatlon | $\begin{array}{\|c} \text { Datum } \\ \text { Elevation } \\ \text { (feec) } \end{array}$ | $\begin{aligned} & \text { Depth } \\ & \text { Logged } \\ & \text { (feee) } \end{aligned}$ | $\begin{gathered} \text { Company } \\ \text { Date } \end{gathered}$ | $\begin{aligned} & \text { Depth to } \\ & \text { top of } \\ & \text { L. Ardey } \\ & \text { (feet) } \end{aligned}$ |  | Thicknes <br> of L. Ardley ' B (feet) | $\begin{array}{\|c} \text { Thickness } \\ \text { of } \\ \text { Sandstone } \\ \text { (reet) } \end{array}$ | $\begin{gathered} \text { Percent } \\ \text { Sandstone } \end{gathered}$ | $\begin{gathered} \text { Depth to } \\ \text { Bedrock } \\ \text { (feet) } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H-16 | 4-27-35-2544 | 3163 (к.6.) | 1998 | 1953 <br> Federated Pet. 1955 | 698 | 21.65 | ${ }^{11}$ |  |  |  |
| H-17 | 3-30-35-2544 |  | 8002 | $\begin{gathered} \text { Amurex } 0011 \\ 1953 \end{gathered}$ | 609 | 24,48 | 20 |  |  |  |
| H-18 | 6-33-35-2544 | $\left.\begin{array}{\|ll} 3188 & (G . L .) \\ 3203 & (\mathrm{~K} . \mathrm{B} .) \end{array} \right\rvert\,$ | 5957 | $\left\lvert\, \begin{gathered} \text { Can. Pacific } 011 \\ 1964 \end{gathered}\right.$ | 769 | 2434 | 23 |  |  |  |
| H-19 | 6-34-35-2544 | $\begin{array}{\|ll} 3089 & (G . L .) \\ 3101 & (K . B .) \end{array}$ | 3247 | Phil!1ps pet. | 624 | 2477 | 16 |  |  |  |
| $\mathrm{H}-2 \mathrm{O}$ | 1-35-35-25w4 | $\left(\begin{array}{ll} 3050 & (G . L .) \\ 3063 & (\mathrm{K.B.} \end{array}\right)$ | 7067 | $\begin{aligned} & \text { Seafore pet. } \\ & \text { 1966 } \end{aligned}$ |  |  |  |  |  |  |
| H-23 | 15-2-36-2444 |  | 7608 | $\begin{gathered} \text { Phililips pet. } \\ \hline 955 \end{gathered}$ | 482 | 2599 | 15 | 200 | 48 |  |
| H-24 | 16-5-36-24.4 | $\begin{array}{\|l\|l\|} 3015 & \text { (G.L.) } \\ 3027 & \text { (K. B.) } \end{array}$ | 6834 | $\left.\right\|_{\substack{\text { Skelly } \\ 1972 \\ 1972}}$ |  |  |  |  |  |  |
| H-25 | 4-22-36-2444 | $\begin{array}{lll} 3133 & (6.2 .) \\ 3146 & (x .8 .) \end{array}$ | 5867 | $\begin{gathered} \text { Great Plains Dev. } \\ \text { 1961 } \end{gathered}$ |  |  |  |  |  |  |
| H-27 | 6-32-36-2444 | $\begin{aligned} & 3088 \text { (G.L.) } \\ & 3100(\text { K. B. }) \end{aligned}$ | 5590 | $\begin{aligned} & \text { Sealori Peel. } \\ & 19666 \end{aligned}$ |  |  |  |  |  |  |
| H-28 | 11-5-36-2544 | $\begin{array}{cc} \left.\begin{array}{c} 3218 \\ 3231 \\ 320.2 .) \\ (k .8 .) \end{array}\right) \end{array}$ | 5998 | $\begin{gathered} \text { Cibraltar } 1972 \\ 1972 \end{gathered}$ | ноо | 24.31 | 19 |  |  |  |
| H-29 | 6-12-36-25w4 | $\begin{aligned} & 2966(\mathrm{G} . \mathrm{L} .) \\ & \mathrm{k} 979(\mathrm{k} . \mathrm{B} .) \end{aligned}$ | 1120 |  |  |  |  |  |  |  |
| H-30 | 6-17-36-2504 | $\begin{array}{ll}3253 & \text { (G. L.) } \\ 17265 & \text { (K. . })\end{array}$ | 6105 | $\begin{gathered} \text { Resman } \\ 1901 \text { Hings } \\ 1975 \end{gathered}$ | ${ }^{831}$ | 24,34 | 18 |  |  |  |


| Index <br> Number | Location | Datum Elevation (feet) | Depth Logged (feet) | Company Date | Depth to top of <br> L. Ardley ' 0 ' (fect) | Elevation of <br> L. Ardiey ' $\theta$ ' (feet) | Thickness of <br> L. Ardley ' $B$ ' (feet) | Thickness of Sandstone (feet) | Percent Sandstone | Depth to Bedrock (feet) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H-31 | 6-18-36-25w4 | $\begin{array}{ll} 3200 & \text { (G.L.) } \\ 3212 & \text { (K.B.) } \end{array}$ | 5366 | Resman Holdings 1975 | 780 | 2437 | 19 |  |  |  |
| H-32 | 6-20-36-2514 | $\begin{array}{ll} 3223 & \text { (G.L.) } \\ 3236 & \text { (K.B.) } \end{array}$ | 5964 | Resman Holdings 1975 | B05 | 2431 | 17 |  |  |  |
| H-33 | 6-26-36-25w4 | 3039 (G.2.) 3050 (k.b.) | 7075 | $\begin{gathered} \text { Imperial } 011 \\ 1959 \end{gathered}$ | 560 | 2490 | 15 | 150 | 30 |  |
| H-34 | 11-32-36-25N4 | 3092 (G.l.) <br> 3105 <br> (k. B.) | 7137 | Wainoco 011 1973 |  |  |  |  |  |  |
| H-35 | 7-11-36-26w4 | 3066 (G.L.) 3080 (K.B.) | 5885 | Anoco Petroleum 1972 | 665 | 2415 | 19 |  |  |  |
| H-36 | 6-12-36-26.46 | $\begin{array}{ll} 3030 & \text { (G.L.) } \\ 3044 & \text { (K.B.) } \end{array}$ | 5870 | Anoco Peltroleum 1972 |  |  |  |  |  |  |
| H-37 | 7-13-36-26w4 | 3084 (G.L.) | 5919 | Resman Holdings 1975 | 678 | 2419 | 20 |  |  |  |
| H-38 | 6-14-36-26w4 | $\begin{array}{ll} 3115 & \text { (G.L.) } \\ 3128 & \text { (K.B.) } \end{array}$ | 7710 | Dlamond Shamrock 1970 |  |  |  |  |  |  |
| H-39 | 2-23-36-26wh | $\begin{array}{ll} 3093 & \text { (G.L.) } \\ 3105 & \text { (K.B.) } \end{array}$ | 7522 | Shell ofl 1966 |  |  |  |  |  |  |
| H-40 | 16-25-36-2614 | $\begin{aligned} & 3167 \text { (G.L.) } \\ & 3180 \text { (K.B.) } \end{aligned}$ | 1162 | Sohlo Petroleum 1957 | 782 | 2398 | 17 |  |  |  |
| H-41 | 7-36-36-26w4 | $\begin{array}{ll} 3165 & \text { (G.l. }) \\ 3177 & \text { (k.b.) } \end{array}$ | 7188 | $\begin{gathered} \text { Mertand Expl. } \\ 1974 \end{gathered}$ | 786 | 2391 | 17 |  |  |  |
| H-45 | 10-11-37-2564 | 3069 (G.L.) <br> 085 <br> (k.B.) | 7017 | $\begin{gathered} \text { Uno-Tex. Pet. } \\ 1962 \end{gathered}$ |  |  |  |  |  |  |



APPENDIX D

SELECTED AQUIFER TEST ANALYSES

| SYMBOLS USED IN GEOLOGIC STRIP LOGS |  |
| :---: | :---: |
|  | Till |
| 三身 | Clay |
| 9 | Silty Clay |
| O | Sand |
| \% | Sands tone |
| \%x | Sandstone, bentonitic |
|  | Siltstone |
| - | Shale |
|  | Coal |



LITHOLOG AND COMPLETION DETAILS


Well No. 33.5
11-28-35-24W4



Well No. 57
13-13-35-25W4


LHTHOLOG AND COMPLETION DETAILS


Well No. 61
1-17-35-25W4


LITHOLOG AND COMPLETION DETAILS


Well No. 71
9-27-35-25W4



Well No. 83
13-2-36-24W4


LITHOLOG AND COMPLETION DETAILS


Well No. 96
16-6-36-24W4


LITHOLOG AND COMPLETION DETAILS


Well No. 110
4-18-36-24W4


LITHOLOG AND COMPLETION DETAILS


Well No. 138
2-28-36-24W4


LITHOLOG AND COMPLETION DETAILS


Well No. 151
12-33-36-24W4


LITHOLOG AND COMPLETION DETAILS


Well No. 162
16-8-36-25W4


LITHOLOG AND COMPLETION DETAILS


Well No. 165
5-9-36-25W4



Well No. 317
6-24-37-25W4


LITHOLOG AND COMPLETION DETAILS


Well No. 330
16-4-37-26W4

(t) Time since pumping started, in minutes.

LITHOLOG AIN COMPLETION DETAILS


Well No. 335.5
16-10-37-26W4



Well No. 335.5
16-10-37-26W4


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$\phi$
figure 3
location map of well data pine lake research basin

## LEGEND

- Complete driller's report, including water chemistry
o. analisis.
- Onservation. well, eqipped with automatic water
- Water chemistrv, analysis only
- Well inventory data only
$\delta$ Spring reported
- Flowing seismic shot hole report.
- oil or gà well electric log on tilie.
-Outtine-ot-basin
Data Sources: $\begin{gathered}\text { Groundwater Data Centre } \\ \text { Alberta Research Council }\end{gathered}$
${ }^{\text {and }}$ Latour (9948)
$\theta$




```
LEGEND
-30% Topographic elevation contour (in teet above mean sea, Ievel)
FBoundary of Pine Lake Research Basin
(Contour interval \(=50\) teet)
```



$\phi$
FIGURE 11













(

©

| NON-PUMPING | WATER |
| :--- | :--- |
| PINE LEVEL | MAP |

## LEGEND

Control Poin
Assumed Contiour
Detined

CONTOUR INTERVAL $=50 \mathrm{H}$



## TRANSMISSIVITY MAP

PINE LAKE RESEARCH BASIN.

## LEGEND

all transmissivity values are expressed THE UNITS OF IGPD/FT)

- value defived from drawdown data-short pump
value derived Irom recovery data - bail test

${ }^{-}$value estimated from total drawdown reported | (apoparent transmiss |
| :---: |

$\triangle$ anome lous valuu edruw

$\theta$






$\phi$
FIGURE 54
DISTRIBUTION OF Na+K IONS, IN PERCENTAGE OF TOTAL CATIONS.

PINE LAKE RESEARCH BASIN

LEGEND
Control Point: well,spring ..............,
contóur interval $=20 \%$




$\phi$

Distribution of so ions, in PERCENTAGE OF TOTAL ANIONS
PINE LAKE RESEARCH BASIN

LEGEND
CONTROL POINT: wellspring
contour interval: $20 \%$



$\phi$

Distribution of fluoride (MG/L) pine lake research basin

LEGEND
CONTROL POINT; well. spring..............o.,
FLOURIDE CONTENT,
GREATER THAN 2 2om

SCALE 1:50,000




[^0]:    ${ }^{2}$ While the report was being prepared, a 12 -hour aquifer test in this sandstone ridge indicated a transmissivity of 4000 igpd/ft ( 60 $\mathrm{m}^{2} /$ day).

[^1]:    ${ }^{3}$ A 12-hour aquifer test performed by the writer during the preparation of this report confirmed the low permeability of this sandstone in the northern part of the basin. Transmissivity was calculated to be $330 \mathrm{igpd} / \mathrm{ft}\left(5 \mathrm{~m}^{2} /\right.$ day $)$ for a test hole which penetrated about 70 percent of the unit. However, a 24 -hour aquifer test conducted in the same deep sandstone unit at the north end of Pine Lake yielded a transmissivity value of 4200 igpd/ft ( $62 \mathrm{~m}^{2} /$ day $)$ and a hydraulic conductivity equal to $42 \mathrm{igpd} / \mathrm{ft}^{2}(2 \mathrm{~m} /$ day $)$.

