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Hydrogeology of the central and northwestern Missoula Valley

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THE HYDROGEOLOGY OF THE CENTRAL AND NORTHWESTERN MISSOULA VALLEY

by

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ABSTRACT

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The Hydrogeology of the Central and Northwestern Missoula Valley.

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This study begins meeting the need for detailed hydrogeologic information in the Missoula Valley northwest of the city of Missoula. Included are: a description of the Cenozoic geology of the valley floor; a quantification of hydrologic properties; an identification of the valley's ground water flow patterns; a characterization of recharge sources and their interaction with the aquifer; and an analysis of general inorganic water quality.

The geology and stratigraphy of the study area were deciphered using the observations of previous authors, geologic descriptions on well logs,and personal field observations. Ground water levels and flow patterns were interpreted from measurements in 34 private wells and nine piezometers. The measurements were used to create hydrographs and potentiometric surface plots. Hydrogeologic characteristics were calculated using well log pumping test data. Aquifer-Clark Fork River interactions were interpreted using data from the U.S.G.S. gauge and river measurements at Harper's and the Huson-railroad bridges. 37 water samples were analyzed for cation and anion concentrations and for total alkalinity. These data were used with flow data to characterize the aquifer.

The Missoula Valley is an intermontaine basin surrounded by Precambrian and Cambrian bedrock and Tertiary sediments, and floored with Tertiary and Quaternary sediments. The Quaternary sediments are fluvial, alluvial, colluvial, glacio-lacustrine and generally are sorted into three main strata. The Quaternary sediments form the framework for the principal aquifer of the valley.

Ground water is produced from all formations of the Missoula Valley. Ground water flow is generally to the northwest. Potentiometric surface and ground water flow maps indicate five sub-systems in the Missoula Aquifer, based on recharge and discharge areas and flow directions. Recharge to the aquifer is from the Clark Fork River, the creeks of the valley sides and the adjacent Tertiary sediments and bedrock highlands. Peak aquifer recharge is during the late spring and early summer. Aquifer response to recharge and discharge, as indicated by well water levels, depends upon the magnitude of the source of recharge, the well's proximity to the source, the hydrogeologic nature of the aquifer, and the effects of human consumption.

Missoula Valley ground water is calcium-bicarbonate type. The inorganic chemical analyses results corroborate a multiple system aquifer with different sources of recharge.

DEDICATION

This work is dedicated to James Allen Barnett,

whose love and support helped make it all possible.

ACKNOWLEDGEMENTS

I thank the following for their help with my work. The D.N.R.C. in Missoula and the M.B.M.G. in Butte, MT, for copies of well logs. Mel White at the U.S.G.S. in Helena, MT, for Clark Fork river stage data. Don Essic for the use of and help with the Geology Department's ion chromatograph. Dave Nimick for his help with the I.C.P. John Shannon and the Missoula County Health Department for advice and copies of county plat maps. Larry Weeks and Dick Kulawinski at Stone Container for the use of their piezometers. Montana Rail Link for the access to the railroad bridge at Huson, MT. Bill Woessner, Nancy Hinman and Jack Donahue for their help and advice during the project. Seth Makepeace, Ray Rogers, and Paul Mcleod for their help with gauging the Clark Fork and my field work. All my friends and relations who supported me and listened to and commented upon my cognitive rantings and ramblings.

And my special thanks to the residents of the Missoula Valley for the use of their wells, the free access to their property and the benefits of their knowledge. This project would have been impossible without them.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

INTRODUCTION

Since 1965, there have been five major investigations of Missoula Valley water resources. McMurtrey (1965) conducted the initial investigation of the valley's geology and water resources, including the Ninemile Creek valley. Grimestad (1977) characterized the aquifer in the area around the Stone Container Pulp Mill in conjunction with his examination of mill effluent infiltration through valley sediments. Geldon (1979) examined aquifer hydrogeology in the vicinity of the city of Missoula, MT, and described the aquifer's stratigraphic and hydrologic properties. Clark (1986) studied the interaction of the aquifer with the Clark Fork river and attempted to produce and calibrate a numerical model of the aquifer system. Morgan (1986) interpreted aquifer stratigraphy in the southeastern portion of the valley and suggested stratigraphic divisions in the Cenozoic sediments. Other hydrogeologic studies in the Missoula Valley include Meyer's (1985) investigation of the hydrogeology under the southern end of the city of Missoula, Ver Hey's (1987) study of contamination from septic systems, Peery's (1988) study of leaded gasoline migration in the sediments under the Missoula Champion Lumber Mill, Pottinger's (1988) study of pesticide fate in the unconfined sands and gravels at the mouth of Grant Creek, Wogsland's study of injection by Class V wells, and Miller's (1991) numerical model of the aquifer's southeastern portion.

Woessner (1988) prepared a detailed report on the southeastern portion of the aquifer, including the aquifer's chemical and physical properties and the results of a preliminary computerized numerical aquifer flow model. Woessner's study became part of the Missoula County Sole Source Aquifer Petition (Msla. Co. Hlth. Dept., 1989), a compilation of geologic, hydrologic, chemical, environmental, and sociological data on the aquifer and its use.

To date, only reconnaissance level work has been done on the central and northwestern portions of Missoula Valley Aquifer. This report attempts to meet the need for more detailed study in these areas. The westward expansion of the city of Missoula and the growth of its satellite communities necessitates a complete understanding of the hydrogeology of the Missoula Valley. An understanding vital to responsible urban planning and growth in the future.

Goals and Report Organization.

The goal of this study is to describe the hydrogeology of the Missoula Valley from the city of Missoula to the northwest end of the Missoula Valley.

This study attempts to:

1. Describe the geologic framework of the Cenozoic geology of the Missoula Valley floor;

2. Identify groundwater flow patterns in the study area;
3. Quantify the aquifer's hydrologic properties;
4. Characterize the interaction of the Clark Fork River with the aquifer;
5. Characterize the general water quality of the aquifer.

This report is organized into sections on geology, hydrogeology, chemistry, and conclusions. The geology, hydrogeology, and chemistry sections are divided into discussions of the different areas of the Missoula Valley; each section ends with a summary.

A Note on Locations.

I have used the United States Bureau of Land Management (U.S.B.L.M.) method of locating places. This method is well described by McMurtrey (1965) and is illustrated in Figure 1.

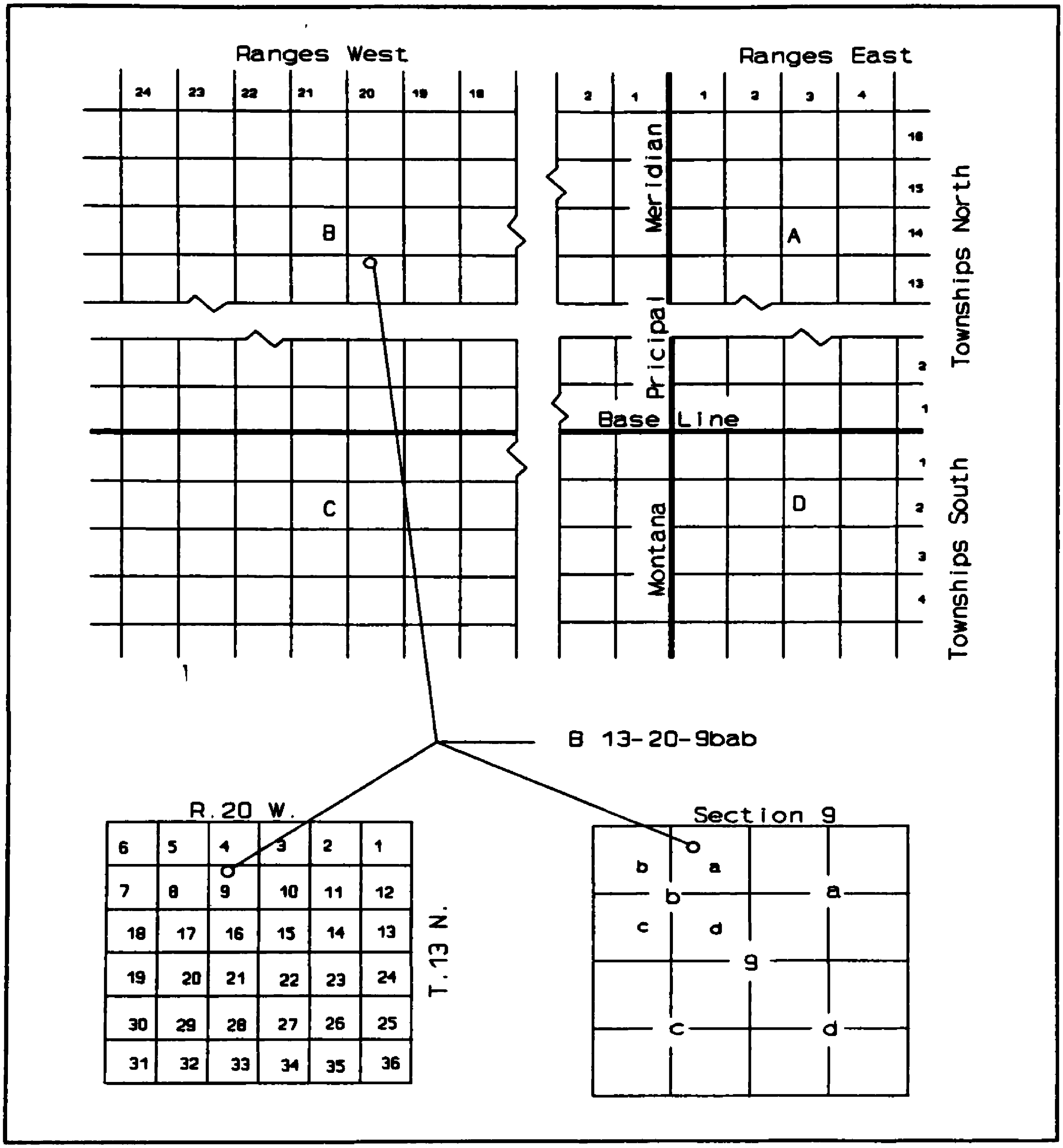

Figure 1: U.S.B.L.M Location Method.

Study Setting.

Physiography and Climate.

The Missoula Valley is a northwest-trending wedge-shaped intermontane basin located in the center of the western edge of Montana (Figure 2). The mountains surrounding the valley range from approximately 6,000 to 8,000 feet above sea level. The valley floor slopes northwest from 3,200 feet at Missoula to 3,000 feet at Huson. The valley floor is approximately 24 miles long, 8 miles wide at its southeast end, 3 miles wide at its northwestern end, and covers approximately 65 square miles. The valley is fed by two rivers and sixteen major creeks. The Clark Fork and Bitterroot rivers enter the valley and merge at the southeast end. Eight of the creeks are on the west side of the valley and flow into the Clark Fork. The eight creeks of the valley's east side either flow across the valley into the Clark Fork or are ephemeral on the valley floor gravels. The valley is drained solely by the Clark Fork river at the northwest end.

The climate of the area is semi-arid. The 1959 - 1988 annual precipitation average is 13.74 inches per year; February and March are the driest months and June the wettest. The thirty year average temperature is 44.6°F; January is the coldest month and July the warmest (Nat. Weath. Serv.,1989).

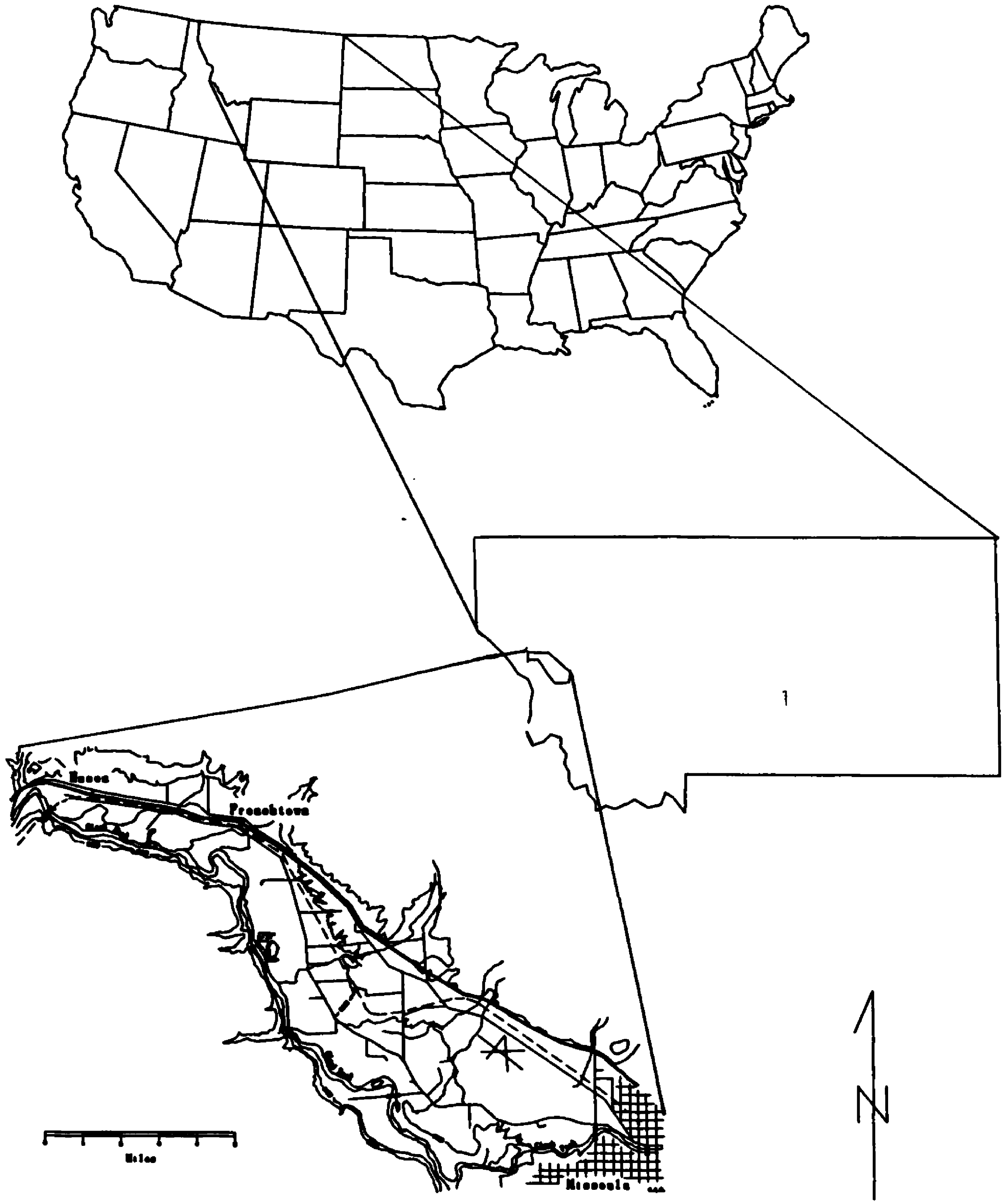

Figure 2: Location of the Missoula Valley.
Drawings not to same scale.

Study Area Location.

The area studied in this report lies between Reserve street on the west side of Missoula, MT, and the valley's northwest end at Huson, MT, and between the Clark Fork River and the northern edge of the valley floor which is generally marked by Interstate 90 (Figure 3).

Methods of Investigation.

This section describes techniques used to investigate the geology, hydrology, and chemistry of the study area. Each topic is dealt with separately.

Geology

I interpreted the geology of the valley and the stratigraphic continuity of the Missoula Aquifer using the observations of previous authors, geologic data from drillers' well logs, and my field observations. The drill logs came from the files of the Montana Department of Natural Resources and Conservation Water Rights office in Missoula, MT, the Montana Bureau of Mines and Geology in Butte, MT, and the residents of the study area. During my field work I inspected surficial deposits and outcrops, road and railroad cuts, and gravel pits throughout the area. I used these data to create cross sections of the valley geology to aid me with my interpretations.

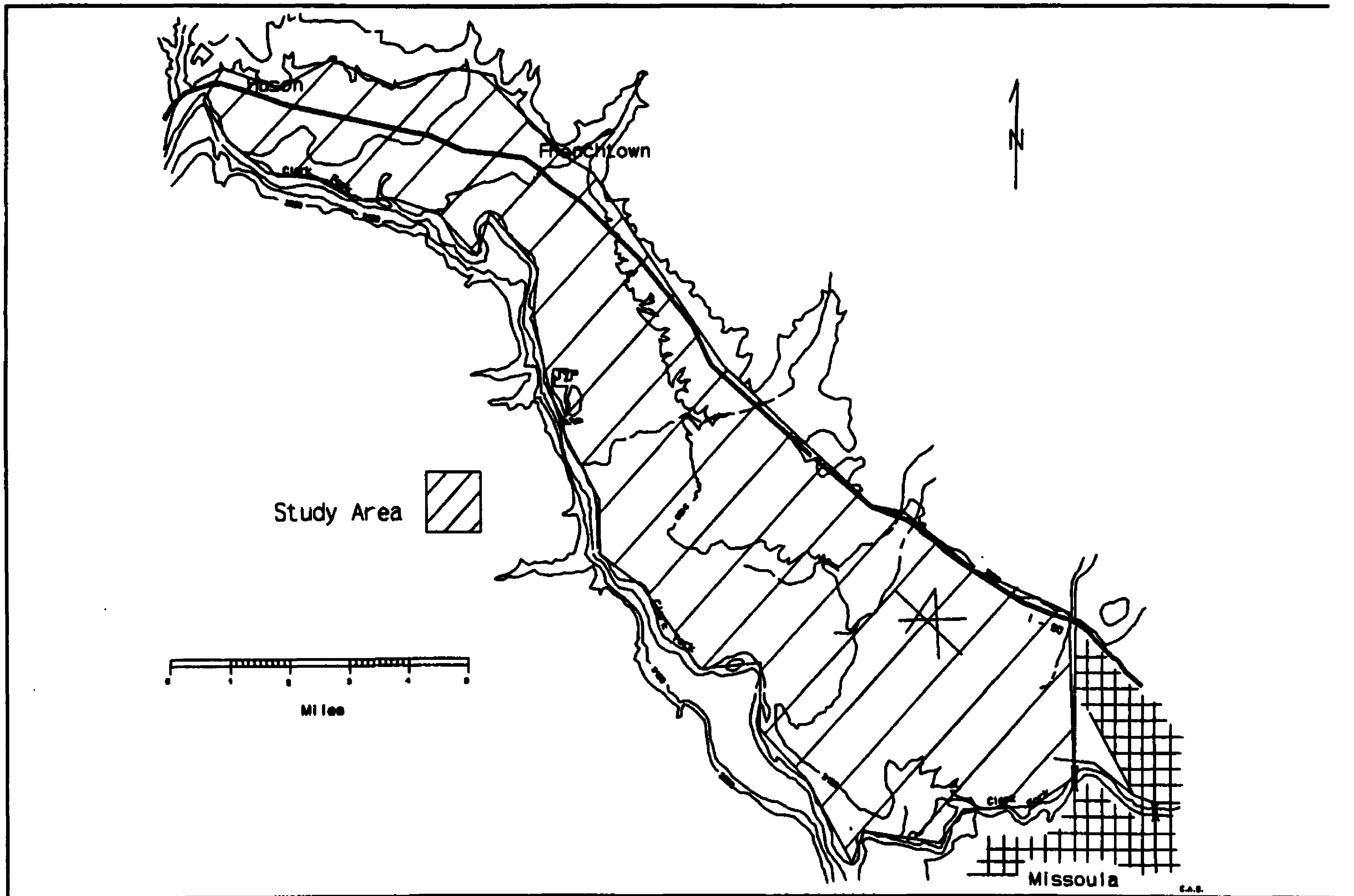

Figure 3: The Area of Study in the Missoula Valley.

Hydrology.

I determined the hydrologic behavior of the aquifer by measuring water levels in 34 wells and nine piezometers throughout the valley (Figure 4). I selected the wells based on their location, depth, and information provided in the well logs. I attempted to monitor one well in each one square mile section. This proved impossible as there were no wells in some of the sections. I chose wells around these areas to provide the closest coverage possible. I monitored the wells once a month except during the spring when I monitored them once every two weeks and I made my well measurements with a chalked three hundred feet long Lufkin steel tape. I installed Leopold Stevens Type F Continuous recorders on two wells. I plotted and contoured the water level measurements to determine the aquifer's potentiometric surface and ground water flow direction.

I determined the specific capacity of wells and the conductivity and transmissivity of the aquifer by analyzing pumping test data from drillers' well logs and from three pumping tests I conducted on house wells. I used the pumps already installed in the house wells for my tests. I pumped the wells for twenty five to thirty minutes. I calculated aquifer characteristics using KCALC, a computer program designed to calculate specific capacity and hydraulic conductivity from drillers' well log information (Appendix VI). KCALC is designed for a single screened interval and not for multiple screens or open ended casing. When there were multiple screened intervals

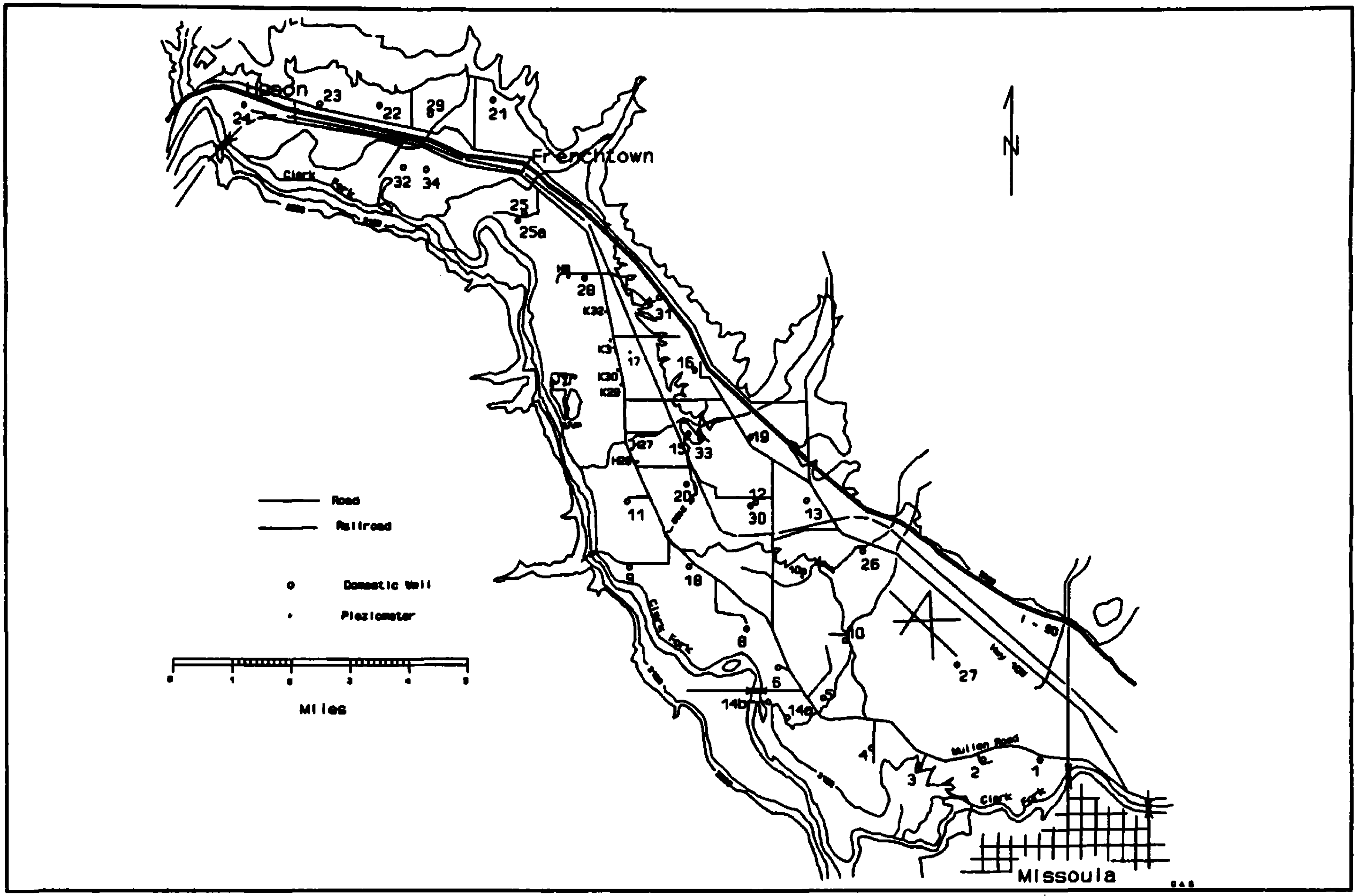

Figure 4: Location of wells and piezometers in the study area.

I combined them into one interval and one aquifer thickness. When the casing was open ended, I used a screened interval of one half foot.

I determined the degree of interaction between the Clark Fork River and the aquifer by comparing my well hydrographs with contemporaneous United States Geological Survey (U.S.G.S.) river stage data and by gauging river flow at two places in the study area. U.S.G.S. gauge station 12353000 is located in 13-20-21aac. I gauged the river at Harper's Bridge and at the railroad bridge at Huson, MT. I also gauged Mill Creek in Frenchtown, MT. Mill Creek was the only stream flowing from the valley's east side to the river at the time. I gauged the river and stream during a three day period in November, 1988, to measure the changes in river volume during low flow. Although November was not the month with the lowest flow volume, river stage was low and there was no interference by ice. I gauged the river with a Price type AA flow meter and Mill Creek with a Price Pygmy meter. I suspended the AA meter from the bridges by a bridge crane and mounted the Pygmy meter on a wading staff. I operated both meters according to U.S.G.S. instructions and recommendations (Buchanan & Somers, 1969). I used the flow data in a mass balance computation to determine the change in the river volume.

Chemistry.

I determined the aquifer's inorganic chemical characteristics by analyzing 37 sets of water samples taken during a single sampling round during early 1989. Each set consisted of three samples, two 140 millilitre (ml) and one 270ml, making a total of 111 samples. I collected 30 sets from wells, two sets from the Clark Fork River, and five sets containing deionized water which were used as controls. Three well sample sets were duplicates. A deionized water sample was taken at the beginning of each sampling day, was carried with me throughout the day, and then analyzed along with the other samples. The two 140ml samples in each sample set were for ion chromatographic (IC) analysis of anions and inductively coupled plasma spectroscopic (ICP) analysis of cations; the 270ml sample was analyzed by a potentiometric titration method for total alkalinity (Greenberg, 1985).

To take a sample set from a well, I ran water from an outside faucet through a plastic hose into a clean Rubbermaid bucket. Neither the hose nor the bucket had metal parts in contact with the water. I monitored the temperature and conductivity of the running water with a YSI model 33 S-C-T meter and the pH with an Orion Research Ionalyzer Specific Ion meter, model 407A. I standardized the S-C-T meter in the laboratory at the beginning and end of each sampling day, and the Orion pH meter before starting each sampling procedure. I standardized the S-C-T meter with a 0.01N potassium chloride solution and the pH meter with pH 7 and pH 8.8

buffer solutions. I waited until Ph, temperature, and conductivity stabilized, indicating that the water entering the bucket was water from the aquifer and not standing water from the well casing. I filtered the IC and ICP samples through a 0.45 µm filter to remove any particulate matter. Once Ph, temperature, and conductivity stabilized, I rinsed the three sample bottles, their caps, and the 60ml filter syringe three times with water from the hose and then flushed the filter with 60ml of water from the rinsed syringe. I filled the two 140ml bottles with filtered sample and preserved the ICP sample with 0.42ml of concentrated nitric acid. I collected the 270ml sample directly from the plastic hose. After tightly capping the samples I placed them in a cooler with an ice pack. At the day's end I stored all samples in a 3°C refrigerator. Before storing the 270ml alkalinity sample I added one drop of chloroform to prevent bacterial growth.

I calculated the conductivity at 25°C for each sample using the formulas shown on the last page of Appendix V.

I determined the total alkalinity of each sample by the potentiometric titration curve technique (Greenberg, 1985). I did forty titrations; the thirty-seven samples and three duplicates. Before running the titrations I pipetted 6ml of each sample into a 10ml beaker, sealed the beakers with Parafilm, and allowed them to come to room temperature. I titrated each sample with 0.01324N hydrochloric acid to Ph 4. I determined the volume of acid used from the inflection point and used that volume to calculate the total alkalinity using the formula shown on the last page of Appendix V.

I determined anion concentrations in the samples using the University of Montana Forestry Department's Dionex 2000i Ion Chromatograph operated according to manufacturer's instructions. I standardized the IC at beginning of each analysis session and then ran at least two deionized water blanks. I then ran my samples, analyzing each sample twice. I restandardized the machine after every three samples, or six runs.

I determined cation concentrations in the samples using the University of Montana Geology Department's Fisher Scientific Atom Comp Series 800 Inductively Coupled Plasma Spectrometer operated according to the manufacturer's instructions. I standardized the ICP with six appropriate solutions and USGS-97 and USGS-103 standard solutions. I then ran my samples and restandardized after every six samples. The ICP was programmed to analyze each sample twice and I ran three duplicates.

GEOLOGY

Introduction

This section is split up into three sections: surface geology, subsurface geology, and geologic interpretation. Appendix I contains a summary of the area's geologic history.

The purpose for describing the geology of the Missoula valley is to set the hydrogeologic framework for the valley's ground water system. I have subdivided the Missoula Basin into four major Areas based upon my field observations and geologic information from drillers' logs (Figure 5). The geologic descriptions will proceed from Area I to Area IV.

Surface Geology.

I deciphered the surface geology of the Missoula Valley using the maps and geologic descriptions of McMurtrey (1965), Hall (1969), Geldon (1979), and Clark (1986) and by field observations. Hall mapped the Precambrian red-green argillites that outcrop in the valley as the Miller Peak Formation, a designation now obsolete. I will refer to these rocks as the Missoula Group as they have not been remapped since the implementation of new designations (Winston, 1989).

Sand and gravel are the major components of most of the surface deposits. The gravels are representative of the geology of the Clark

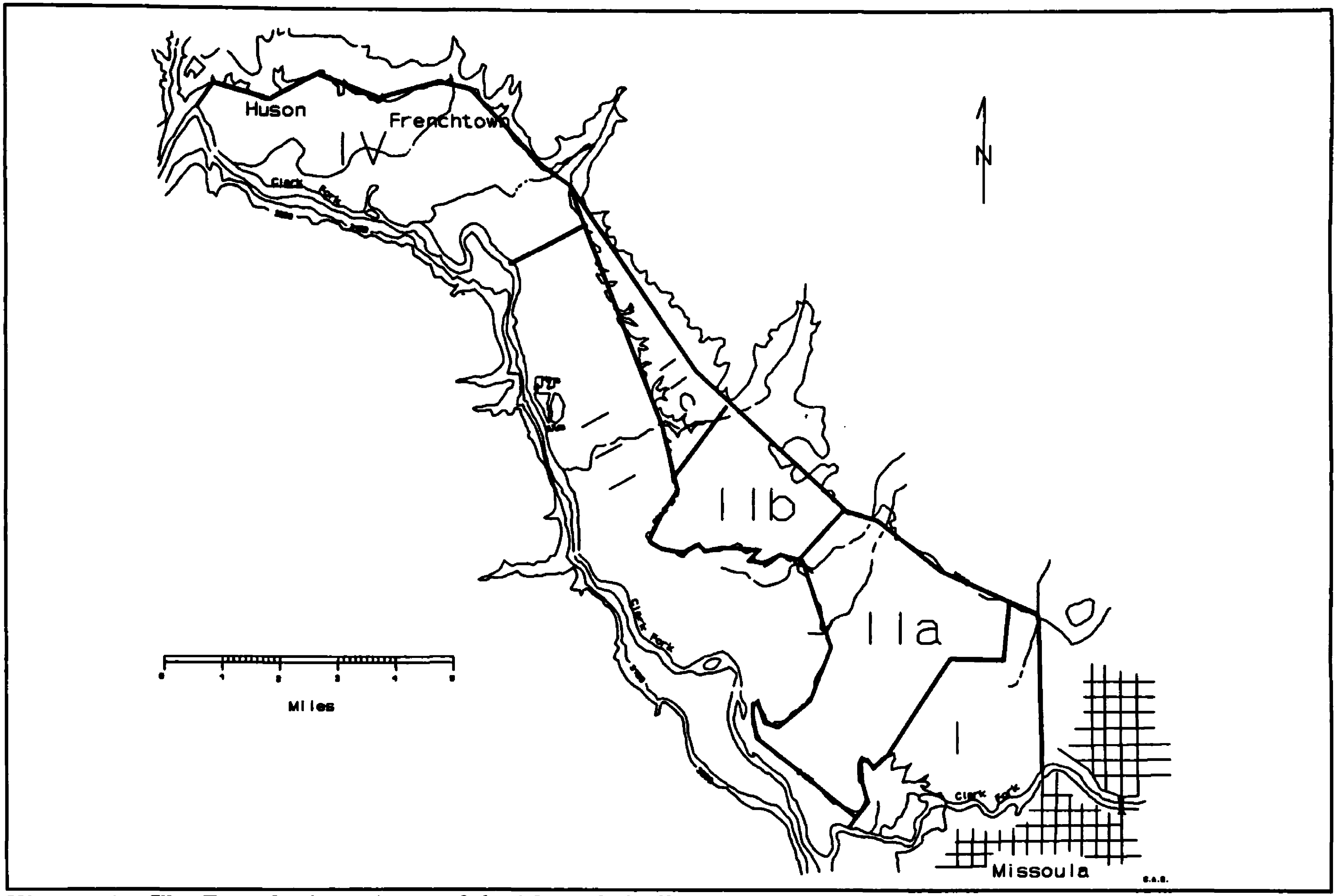

Figure 5: The Four Geologic Areas of the Missoula Valley.

Fork and Bitterroot drainage basins. The majority of the clasts are derived from Precambrian Belt Supergroup metasediments and Bitterroot valley granites. There are lesser amounts of the other rock types of the area, e.g. limestone. The surface geology of the Missoula Valley is shown in Figure 6.

Area I.

The surficial deposits of Area I are comprised of clay, sand, and gravel in Recent and Pleistocene deposits. Geldon (1979) placed these sediments into three units: Active Alluvium, Younger Terrace Alluvium, and Older Terrace Alluvium. Geldon estimated the ages of the second and third units range from the late to middle Pleistocene.

Active Alluvium is found in the modern flood plain of the Clark Fork River. This unit's surface is conspicuous for its inactive channels and oxbows. These river landforms may be reactivated due to the capricious nature of stream channel migration.

Younger Terrace Alluvium is found from the edge of the Active Alluvium to an approximately 12 foot high terrace scarp about half a mile north of the Clark Fork River. Relict river landforms, such as abandoned channels, are generally filled and appear as gentle undulations of the surface. These landforms are not readily discernable from the ground, though they may be distinguished on air photographs. The upper 10 to 15

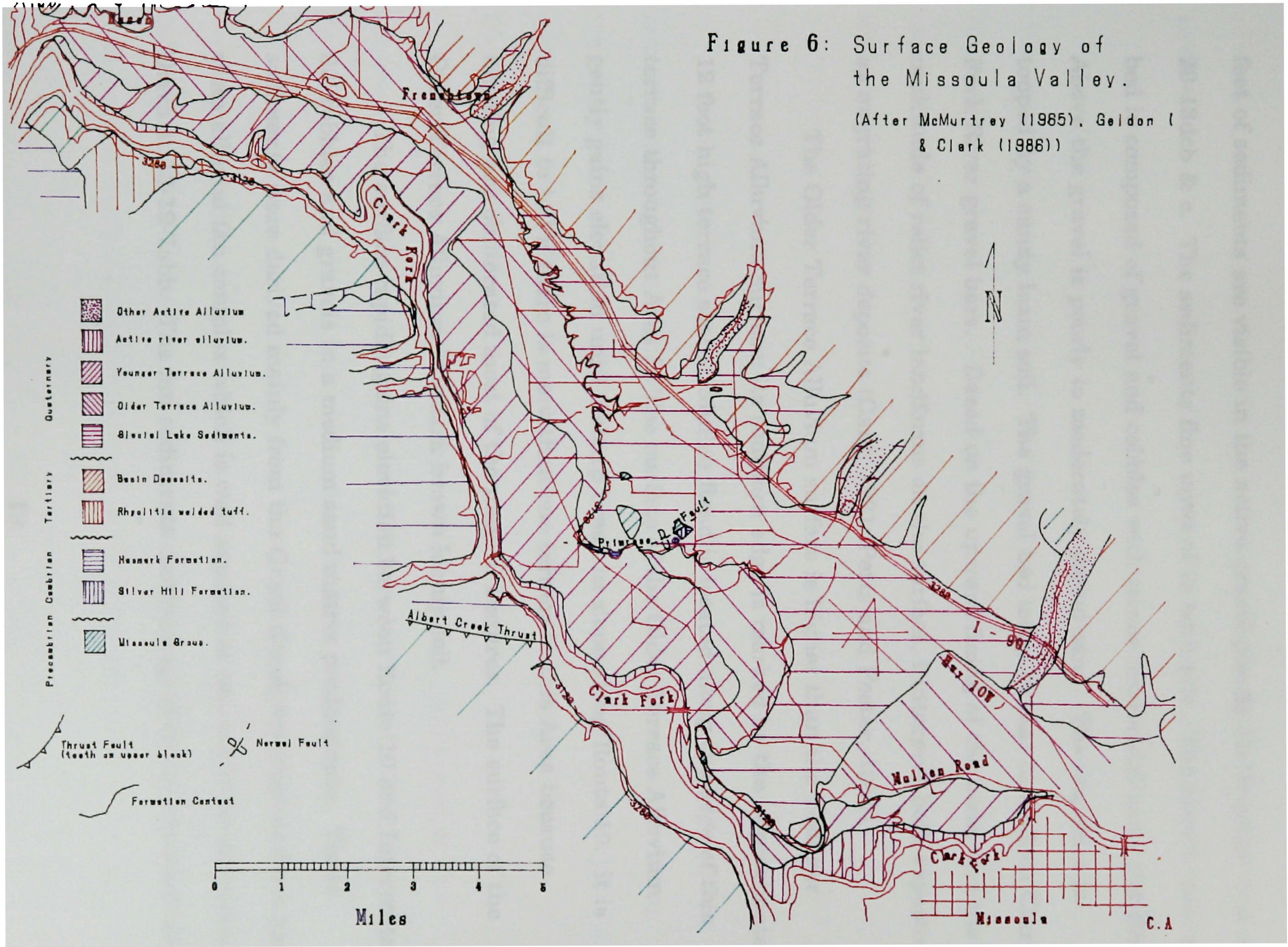

Figure 6: Surface Geology of the Missoula Valley.

(After McMurtrey (1965), Geldon (
& Clark (1986))

feet of sediments are visible in the active gravel pits at 13-19-18cba and 13-20-13dcb & c. The sediments fine upward in both pits. The lowest visible bed is composed of gravel and cobbles with minor interstitial sand and clay. Above the gravel is poorly to moderately sorted sand. The sequence is topped by a sandy loam soil. The gravel bed looks similar to modern Clark Fork River gravel bars. Based on the upward fining of the beds, and the multitude of relict river landforms on the surface, I interpret both exposures as migrating river deposits (Cant, 1981; Petts and Foster, 1985).

The Older Terrace Alluvium surface is higher than the Younger Terrace Alluvium surface; its southern edge is marked by the approximately 12 foot high terrace scarp. Mullen Road is located along the edge of this terrace throughout Area I. The surface of the Older Terrace Alluvium gently gains elevation until a sharp break in slope along Route 10. It is difficult to tell if there is more than one terrace in this Area because farming has obliterated most of the natural features. The surface of the Older Terrace Alluvium is a dark brown loamy soil.

The surface rapidly gains elevation between Route 10 and Interstate 90; cobbles and gravels in a medium sand matrix predominate. These sediments were derived mainly from the Grant Creek drainage and are part of an alluvial fan complex which is well exposed at the end of International Drive at 13-19-7abb. The fan sediments continue up slope to Interstate 90 where they give way to orange-yellow, predominantly fine grained Tertiary sediments.

Area II.

I have broken Area II into three subordinate areas, as shown in Figure 5. I grouped these three sub-areas together because of their geologic similarity and pervasive covering of Glacial Lake Missoula sediments. I will discuss each subordinate area separately.

Area IIa.

The surface deposits of Area IIa are almost entirely comprised of tan to reddish-pink Glacial Lake Missoula clays and silts. These sediments are well described by Chambers (1971) and are mostly varved silts and clays which settled out of the at least 60 fillings of Pleistocene Glacial Lake Missoula (Waite, 1985).

At the Area's southwest end is Council Hill ridge. Almost all of this ridge is formed of Tertiary sediments (McMurtrey, 1965; Hall, 1969) covered by a thin veneer of Glacial Lake Missoula sediments. The Tertiary sediments are exposed in a gravel pit at 13-20-15cccd. The sediments range from clay to approximately 14 inch boulders and are in rather poorly sorted beds. The cobbles and gravel are imbricated and sub- to well rounded. The beds range from clast to matrix supported; the matrix is poorly sorted clay to fine sand. The beds dip less than 10° to the north. The matrix is pale tan-brown and the entire exposure is light brown. Most of the cobbles and gravels are Belt metasediments; about 5% are granite. The south side of the pit exposes a broad channel. I believe the sediments were deposited in alluvial fan channels (Hanneman, 1989).

The northwest end of Council Hill ridge is a knob of Precambrian Missoula Group (McMurtrey, 1965; Hall, 1969; Winston, 1989). These Precambrian rocks are also covered with Glacial Lake Missoula sediments.

From Council Hill ridge northwest to the airport, the surface deposits are Glacial Lake Missoula sediments. The surface is hummocky and has a dendritic drainage pattern characteristic of these fine grained sediments. Glacial Lake Missoula sediments are visible in cross-section in old railroad cuts in 13-20-10 & 11 and on the north side of Route 10 in section 13-20-1.

On the northeast edge of Area IIa the Lake Missoula sediments interfinger with alluvium from LaValle and Butler Creeks and colluvium from the Tertiary deposits of the valley sides. The surficial deposits remain generally fine grained up to Interstate 90, though they change from tan-red silty clay to reddish brown and brown silty-sandy loam.

Area IIb.

Area IIb's surface is composed of rocks and sediments ranging from Precambrian to Holocene; the surface is generally loamy soil. The Primrose

Fault brings Precambrian and Cambrian bedrock to the surface at the Area's southwest end in the following locations: Missoula Group rocks from 14-20-30d to 14-20-29c, in 14-20-29dc, and in 14-20-30aa; the Silver Hill Formation in 14-20-32ab; and the Hasmark Formation at 14-20-32aaa and in 14-20-31a (Hall, 1969; Winston, 1989).

Much of the bedrock is unconformably covered with Tertiary (Hall, 1969) and/or Glacial Lake Missoula sediments. The interrelationship of these deposits is well exposed in the railroad cut that goes from Deschamps Lane (14-20-22aaa) to Moccasin Lane (14-20-30abb). For the first 1.1 miles west of Deschamps Lane the railroad cuts expose only varved Glacial Lake Missoula silts and clays. The lake sediments 1 mile west of Deschamps lane contain seven discontinuous horizontal sand lenses. The lenses range from 13 to 55 feet long parallel to the tracks. I could correlate only one lens across the tracks, a distance of approximately 110 feet. The lenses range from 1.5 to 6 inches thick and are located between varved sediment sets. The sand in the lenses is fine, moderately well sorted, and subangular to angular. The sand appears to be quartz with about 5% biotite and muscovite and about 15% pink clay. The clay is concentrated in interbedded sandy clay layers within the lenses.

At 1.1 miles west of Deschamps Lane (14-20-29cccb), the Missoula Group abruptly appears and the Lake Missoula clays unconformably lie on these rocks. The more resistant Missoula Group produces a topographic high and the height of the cuts goes from about 15 feet to about 35 feet. Approximately 40 feet farther west, a tan-gray bedded gravel layer, with a silt to clay matrix, appears between the Missoula Group and the Lake sediments. This gravel continues west and caps Tertiary (Hall, 1969) beds that begin approximately 60 feet west of the beginning of the cut. These beds contain bedded cobbles and gravels with grey-tan silty sand matrix. The Tertiary and overlying gravel beds are horizontal, continuous, and are about 23 to 28 feet thick for the entire railroad cut. The Missoula Group is faulted at 14-20-30daba and disappears from the railroad cut. The gravel beds thicken to about 30 feet and then disappear at 14-20-30acda. The last 0.25 miles of the railroad cut is entirely lake sediments.

The surface of the northwest side of Area IIb is composed almost entirely of pink lake sediments. The surface of the rest of the Area is a mixture of lake and other clays, silt, sand, gravel, and cobbles. These sediments are visible in two pits. The first is a borrow pit half a mile south of the Go West Drive-in Theater at 14-20-28bccb, with an 8 foot high exposure of 0.3 to 2 foot thick beds. These beds are generally poorly sorted, matrix supported, and have sharp contacts. The thinner beds have subrounded pea gravel supported by a matrix of approximately 70% sand and 30% silt and clay. The thicker beds are poorly sorted and consist of less than 7 inch gravels and cobbles supported by a medium to coarse sand matrix, usually with a light carbonate cement. About half of the beds are separated by 2 inch pinkish-tan clay layers. These clay layers look exactly like the varved sediments exposed in the railroad cuts in the southwest end of the Area. The clay has migrated down through the tops of some of the underlying sand and gravel beds and cements the sediments together.

The second pit is just north of the stockyards northeast of Route 10, at 14-20-21cbdc. The exposed sediments are very similar to those of the borrow pit except that the gravels are larger and there is more carbonate cement.

Based on the poor sorting, greater percentage of fine material and matrix support, I interpret these sediments as sheet floods and debris flows (Blatt et al., 1980). I measured the long axis trend of fifty elongate gravels and cobbles in each pit in order to determine the original flow direction (Blatt et al., 1980; Petts & Foster, 1985). In the first pit 72% of the trends are between N. 40 E. and N. 80 E. In the second pit 70% of the trends are between N. 50 E. and N. 84 E. These directions point up O'Keefe Creek canyon; thus the flows are from the O'Keefe Creek canyon. These flows form part of a large complex which was at times submerged, hence the thin beds of Lake Missoula clays. So, the deposits are part of an alluvial-deltaic fan complex which has been subsequently partially eroded.

Area IIc.

The surface deposits of Area IIc are Glacial Lake Missoula sediments up to Interstate 90 where they interfinger with Tertiary colluvium along the valley's edge. The Lake sediments range from pink-tan where undisturbed to reddish brown where disturbed by agriculture.

Area III

Area III's surface is composed of loamy brown soil with occasional gravels. The surface features are very similar to those of Area I except that the 12 foot high terrace is absent until the northern end of the Area. Gentle undulations caused by remnant river landforms, such as channels, oxbows, scroll bars, et cetera, are visible at ground level. These landforms are also manifest in air photographs of the Area.

The upper 8 to 12 feet of sediments of the Area's northern half are exposed in a gravel pit at 14-20-24ddb. The west side of the pit is made of two 2.5 to 3 foot thick sand and gravel beds. The two beds fine upward and are composed of clast-supported cobbles and gravels with medium sand to clay matrix. The gravel diameters are less than 11 inches. The silt and clay in the matrix is predominantly pale pink. The upper bed is topped by gray silty sand. I interpret these beds as river channels which migrated and filled (Petts & Foster, 1985).

The pit's north side exposes sand and gravel beds that are tabular and continuous over the 200 foot long side of the pit. The sand beds are under 3 feet thick and are medium to coarse clean sand, some with less than 4% gravel. The gravel beds are from 1.5 to 4 inches thick. The gravel is subrounded to rounded and moderately well sorted. The sequence is topped by silty soil with about 15% smaller than 2 inch gravel. I interpret these beds as either overbank flood or crevasse-splay deposits (Cant, 1981).

The entire pit exposes a fluvial channel system complete with associated inter-channel deposits. This interpretation concurs nicely with Area III's multitude of remnant fluvial landforms. The sediments and landforms exposed in the pit are probably representative of Area III's surficial deposits.

Area IV.

In Area IV the trend of the valley turns from northwest to west. The surface can be divided into three major terraces, the lowest on the valley's south side, beside the river, the highest on the valley's north side. The middle terrace is evident only in the middle of the Area. At the east and west ends of Area IV, the middle terrace is missing and the lowest terrace abuts against the highest forming a 12 to 16 foot high embankment.

Area IV is similar to Area I in that the lowest terrace is the modern Clark Fork flood plain complete with active and dormant channels and interchannel landforms. The two older terraces contain relict fluvial landforms that are best viewed on aerial photographs.

Area IV's surface is silty soil. The underlying 8 to 10 feet of sediment are exposed in many gravel pits in the Area. One exposure is at 15-21-28dabcd. After removing some sloughed material, I viewed the top seven feet of sediment. At the bottom of the section are moderately sorted, sub- to well-rounded, clast-supported gravels and cobbles in a well-sorted medium sand matrix. The gravels fine upward in the next 1.5 feet and are topped by 1.5 feet of medium to coarse, well sorted sand. The sequence repeats in the next four feet and the entire set is topped by 0.5 feet of poorly sorted sandy loam soil with approximately 35% gravel. The sediments and structures of these beds correspond with the fining upward sequence deposited by migrating river channels (Petts & Foster, 1985) and are a cross-section through the remnant fluvial landforms visible on aerial photographs of the Area.

Area IV's north side slopes are made of Precambrian bedrock and Tertiary sediments. The lowest 100 feet of the slopes are covered by Glacial Lake Missoula sediments.

Surface Geology Summary.

The Missoula Valley surface is sandy-silty to clayey, loam soil. The valley's lower elevations, Areas I, III, and IV, are, for the most part, divided into two or three terraces and have an irregular, undulating surface caused by remnant river landforms. Many details of these landforms have been eradicated by farming. The upper 8 to 12 feet of sediment are visible in gravel pits throughout the valley. These sediments are migrating stream channel and interchannel deposits. There is a general fining of sediments from Missoula to the valley's northwest end. I viewed the upper 8 to 12 feet of sediments under the city of Missoula in various pits and trenches about the city. The major component of these sediments is boulders up to 18 inches in diameter. Thus the upper sediments of the valley floor continue to coarsen toward the valley's southeastern end.

The surface deposits of the valley floor's higher elevations, Areas IIa, b, and c, consist of Glacial Lake Missoula varved sediments interbedded and interfingered with alluvial sediments from the fans of the eastern edge of the valley. These fans were, at times, submerged in Glacial Lake Missoula and their deposits have alluvial and deltaic characteristics.

Subsurface Geology.

Information for the following section came from the often sketchy geologic descriptions on logs of wells drilled in the valley. I used the geologic descriptions to create cross-sections for each of the four Areas. Cross-section locations are show on Figure 7 and cross-sections A - H are Figures 8 - 15. As in the surface geology, I shall describe the subsurface geology of each of the Areas, from Area I to Area IV. The ages I state for certain strata are inferred only and are based on stratigraphic position and the formation descriptions given by McMurtrey (1965), Geldon (1979), Clark (1986), and Hanneman (1989).

Area I.

Area I's subsurface geology, shown in Figures 8, 9 and 10, is composed of interbedded clay, sand, and gravel. Figure 8 shows the sedimentary change from the floor to the edge of the valley. The sediments of the valley floor can be roughly divided into three types of beds: a mix of gravel, sand, and clay at the top; sand, silt, and clay interspersed with beds of gravel and sand-gravel in the middle; and sand and gravel at the bottom. The top layer consists of the fluvial deposits of the terraces described in the surface geology section. The north end of Figure 8 shows Grant Creek alluvial sediments interfingering with valley floor sediments. Grant Creek

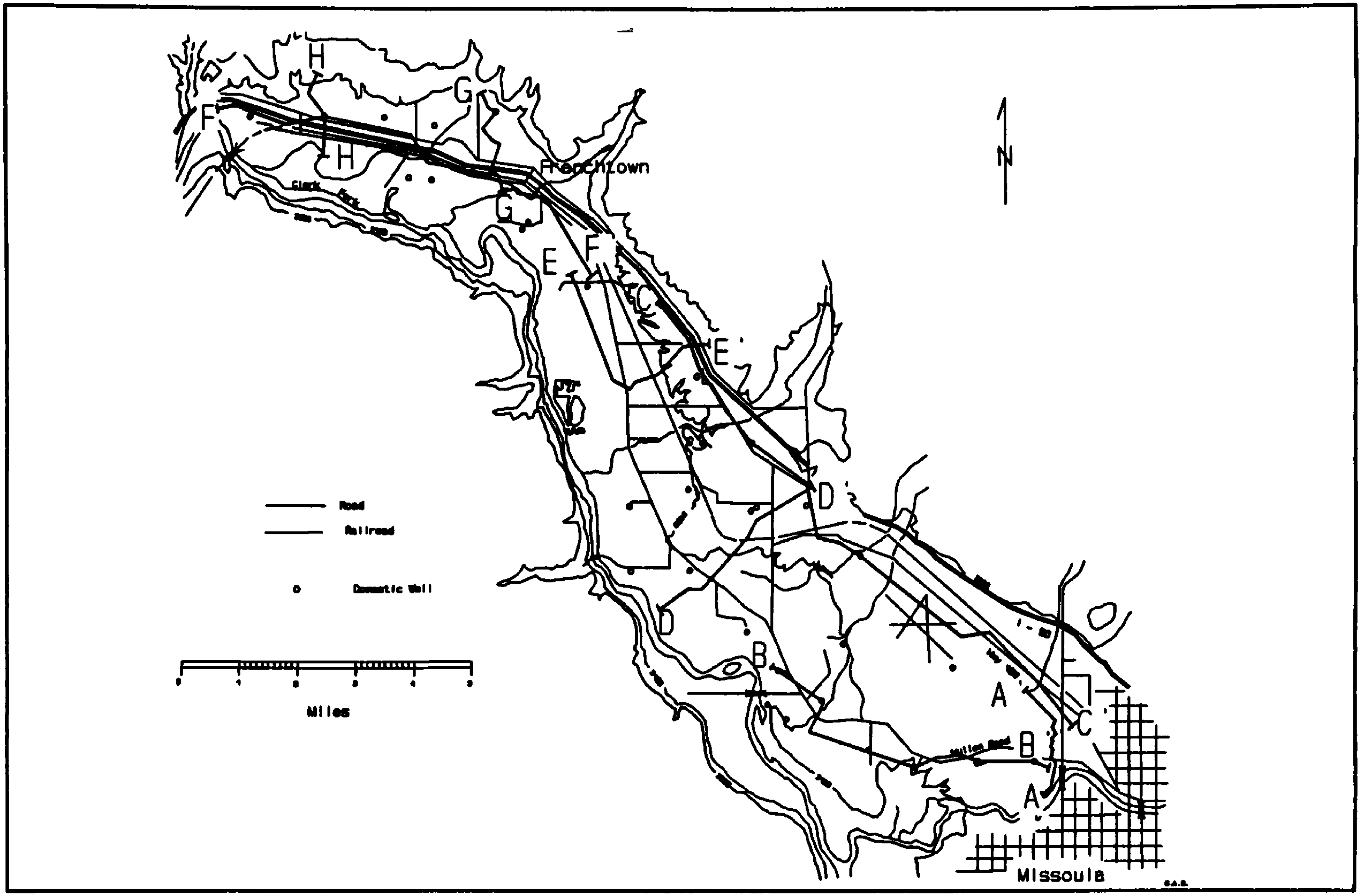

Figure 7: Geologic Cross-Section Locations.

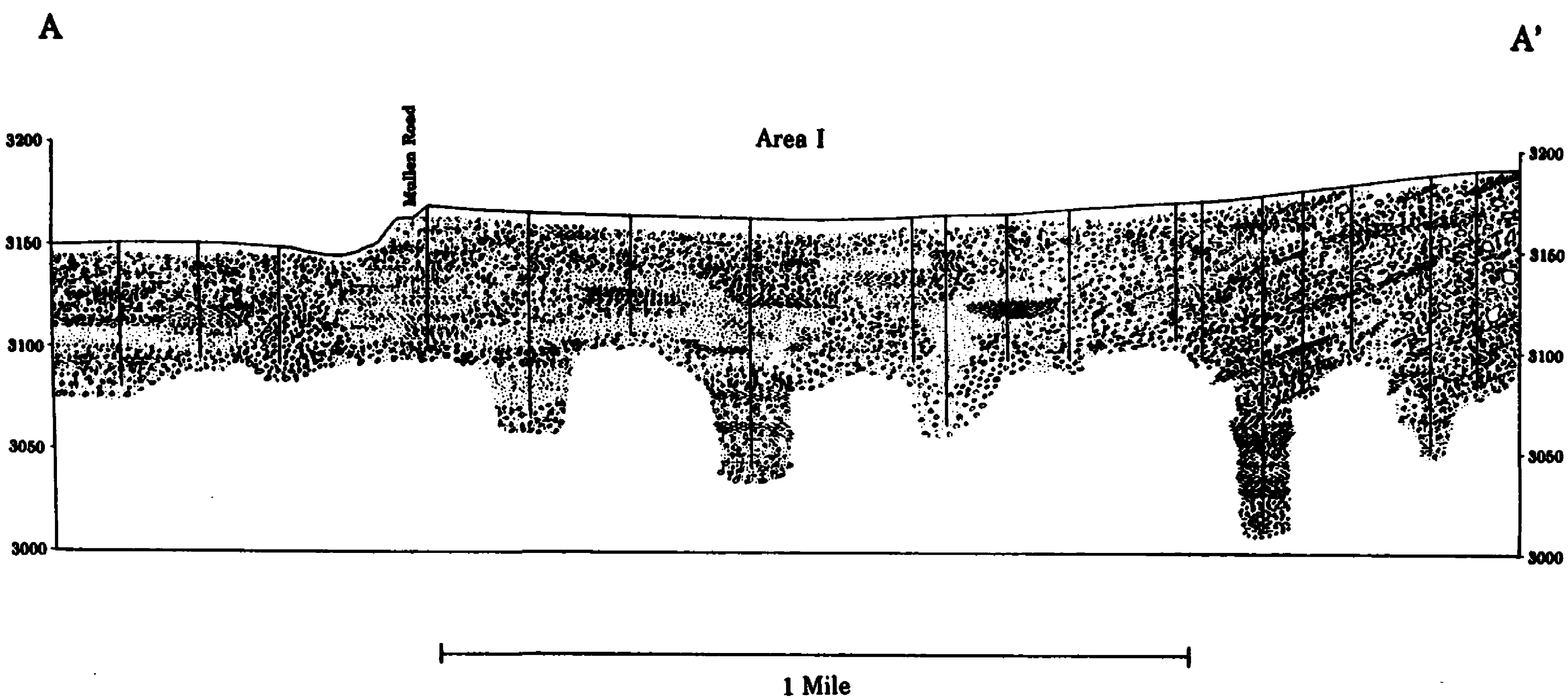

Figure 8: Geologic Cross-Section A - A'

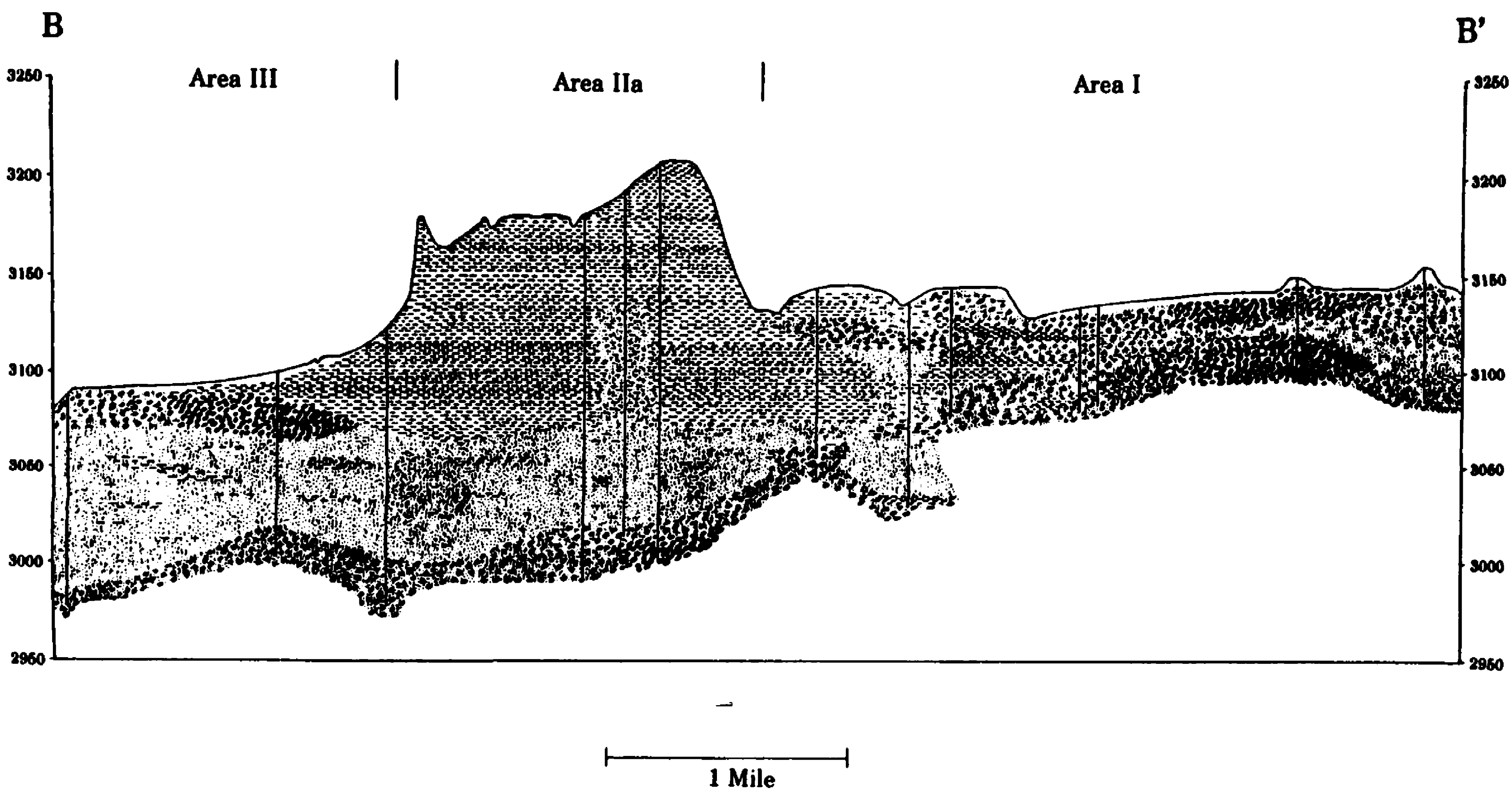

Figure 9: Geologic Cross-Section B - B'

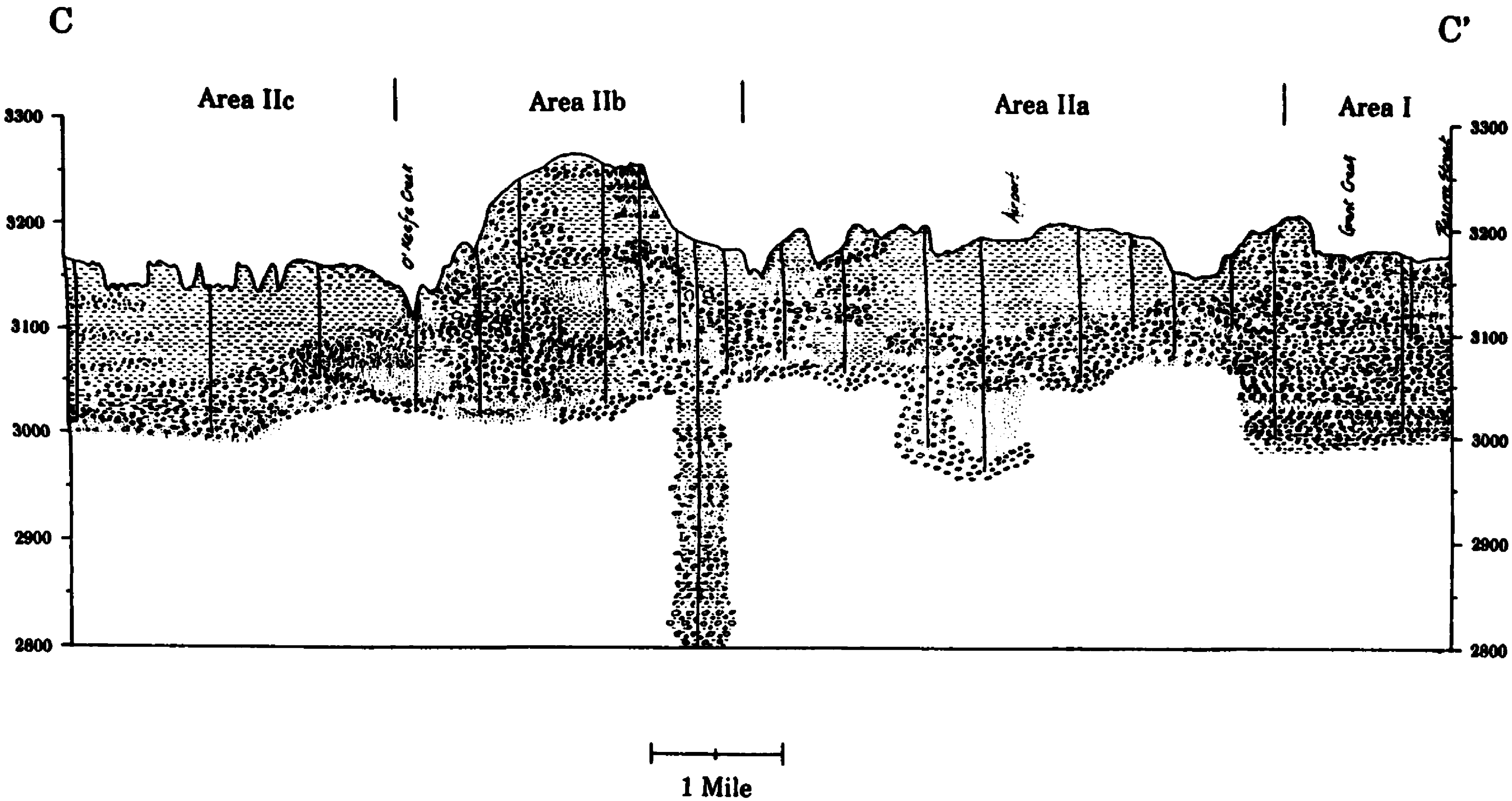

Figure 10: Geologic Cross-Section C - C'

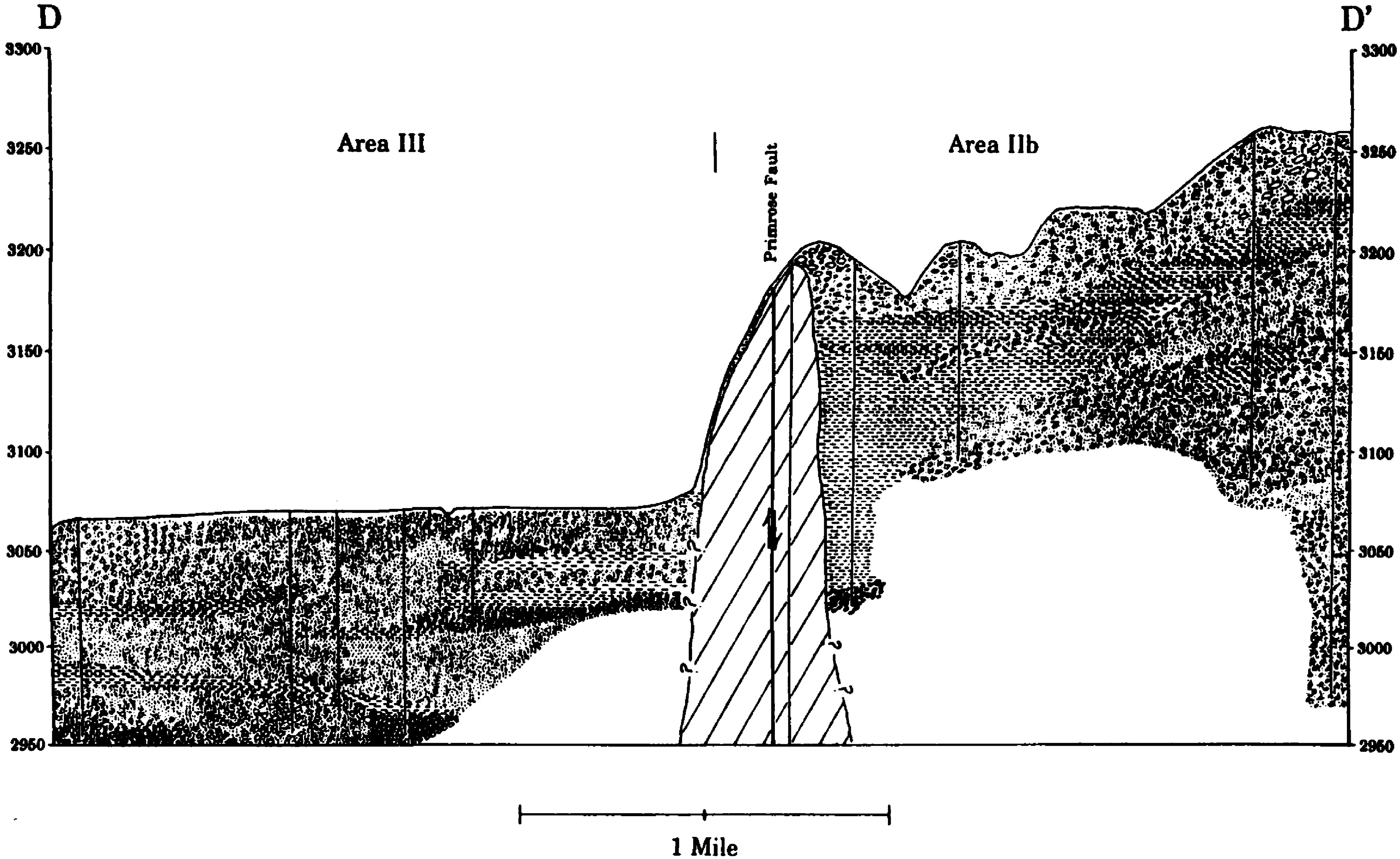

Figure 11: Geologic Cross-Section D - D'

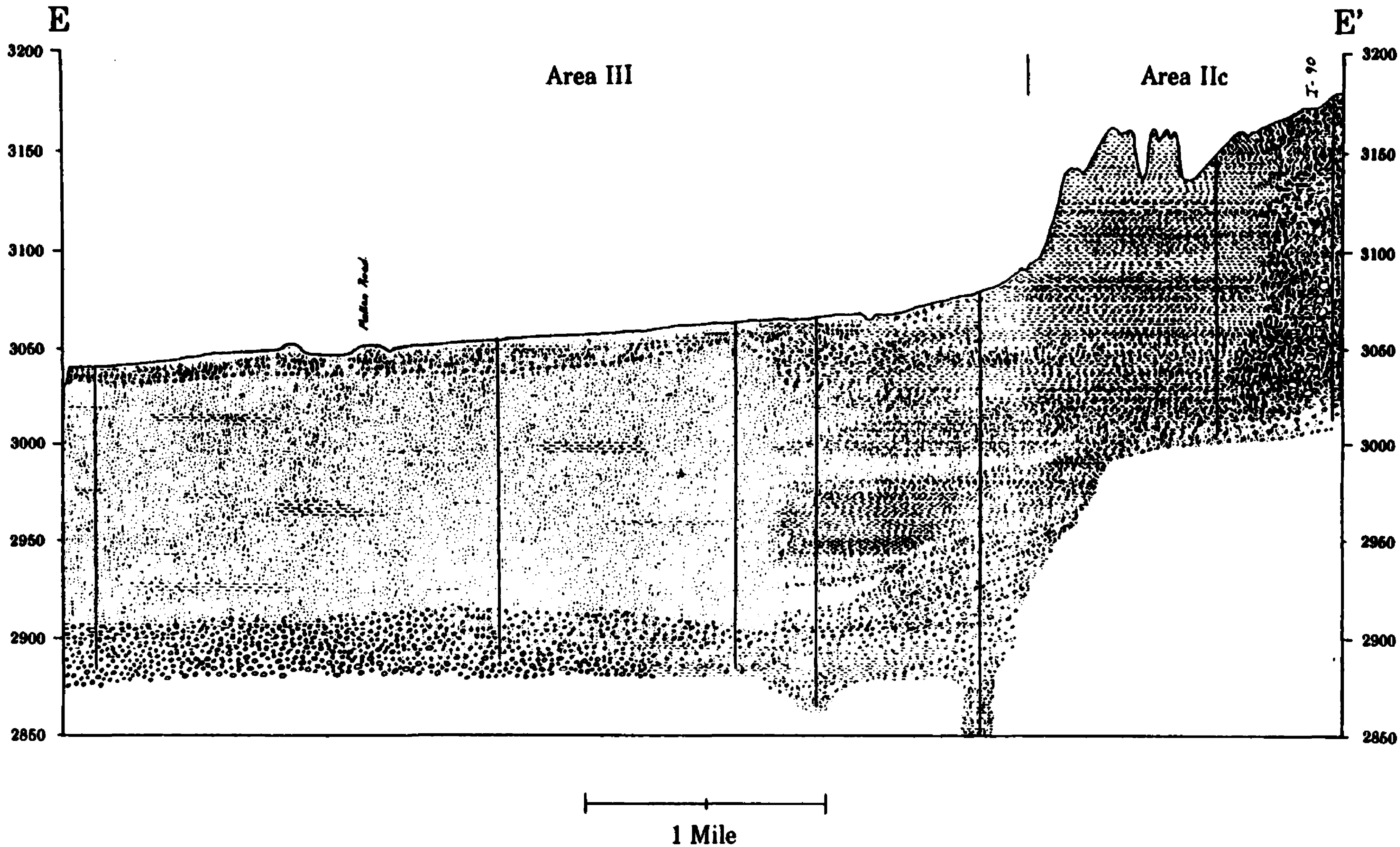

Figure 12: Geologic Cross-Section E - E'

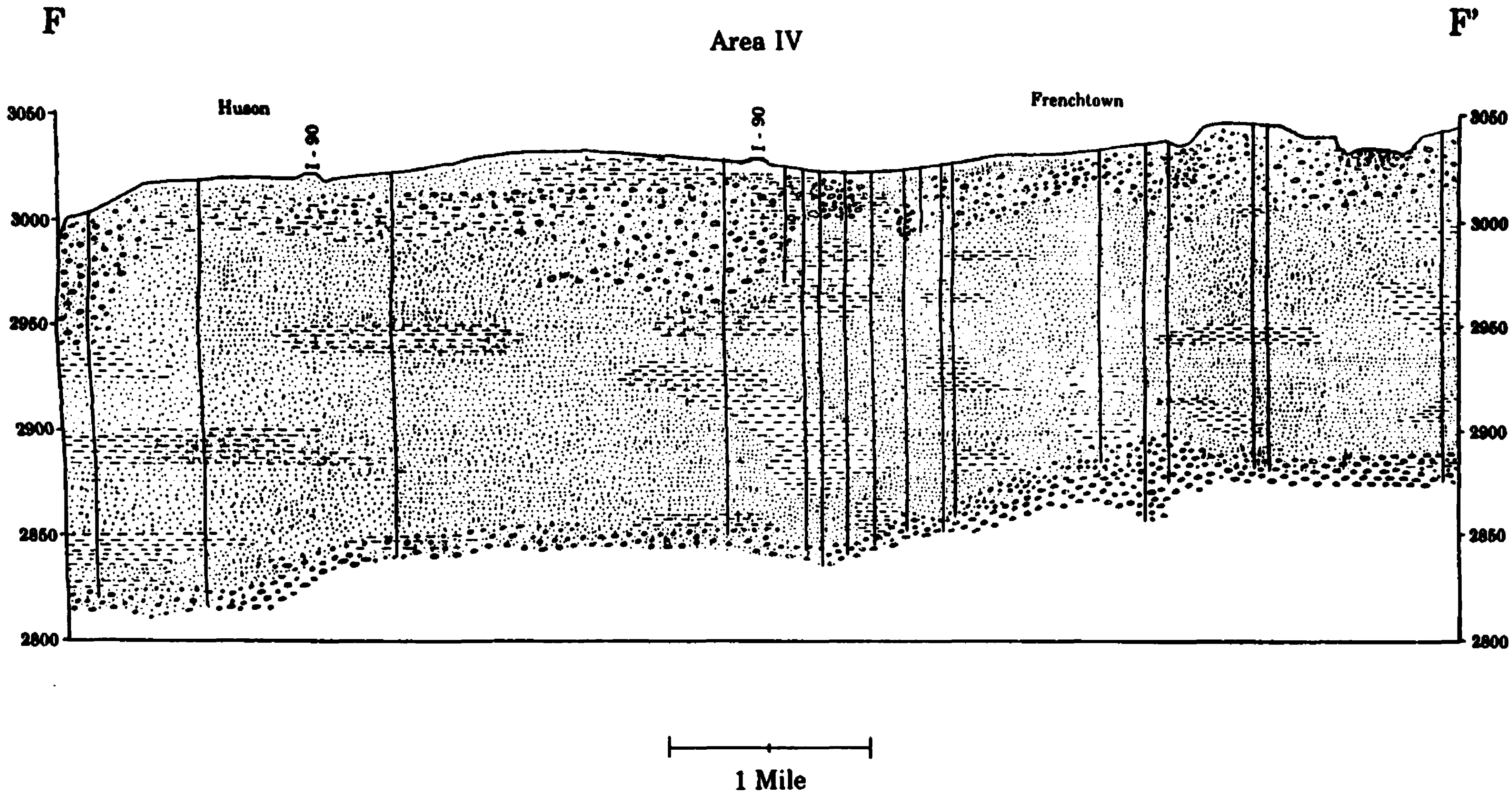

Figure 13: Geologic Cross-Section F - F'

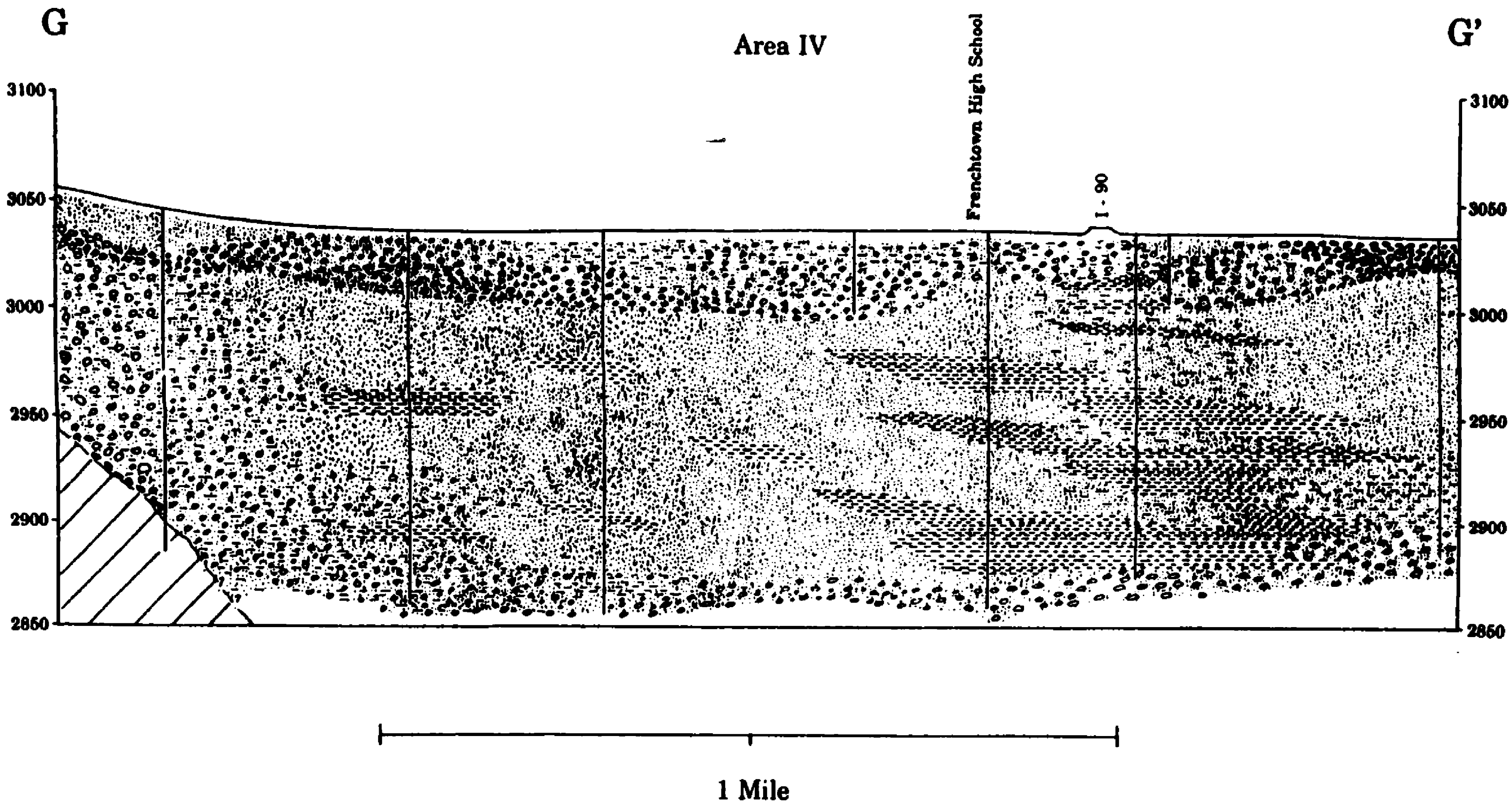

Figure 14: Geologic Cross-Section G - G'

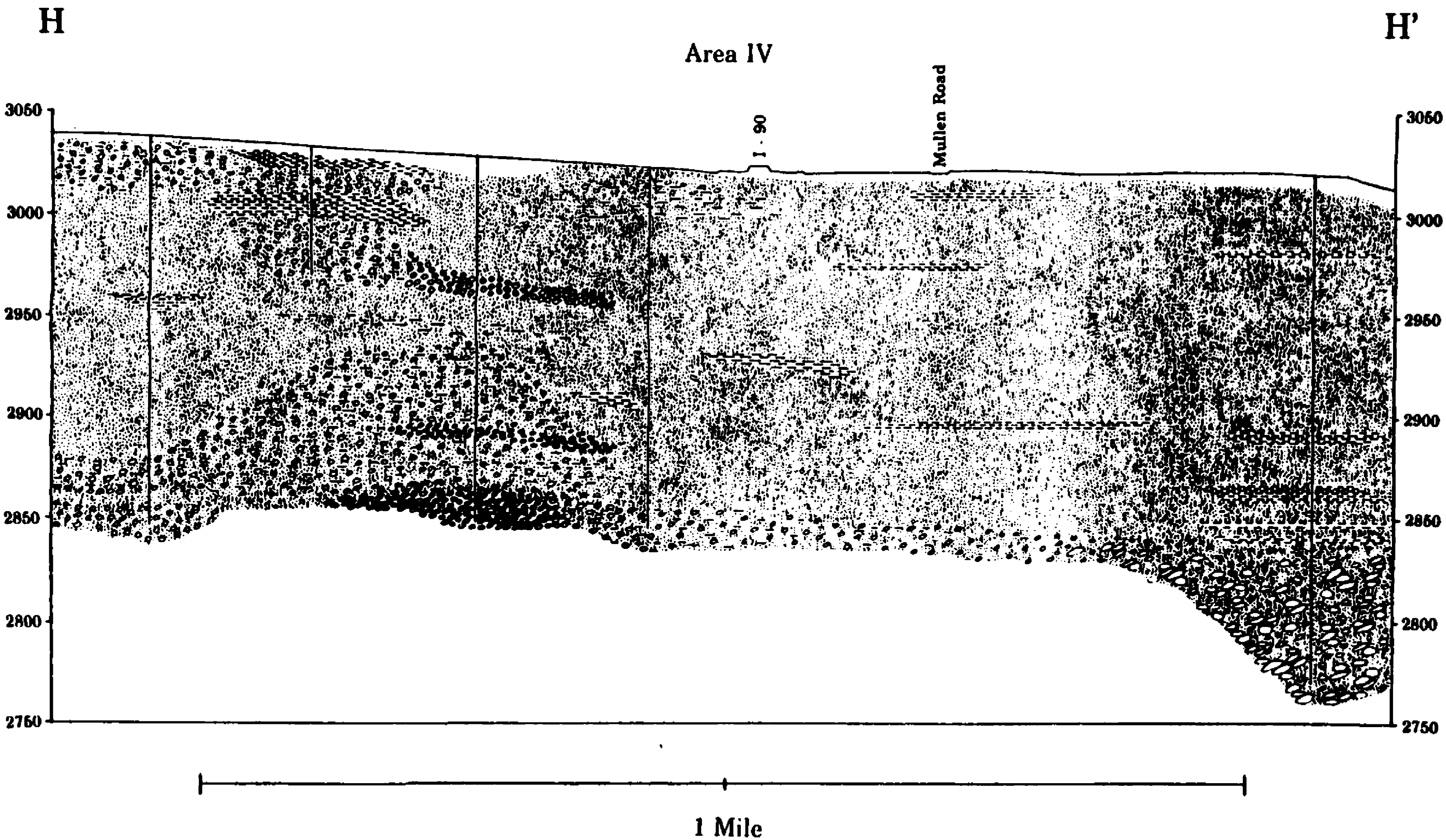

Figure 15: Geologic Cross-Section H - H'

alluvial sediments have more clay and contain boulders; boulders are absent in valley floor sediments.

Individual beds have relatively poor continuity across the valley (Figure 8) but are more continuous along the valley (Figure 9). The continuity of clay layers shown in the southeast end of Figure 9 may be due to the lack of detail on the drillers' logs since there is no differentiation between types of clay. Figure 9 shows the change from Area I to Area IIa. This cross-section shows the relationship between Area I's fluvial sediments and Area II's glacial lake sediments.

Area IIa.

Area IIa's subsurface geology is shown on Figures 9 and 10. The stratigraphy changes from Glacial Lake Missoula clays over sand and gravel in the southwest to lake sediments over and interfingering with clay, sand, and gravel from LaValle and Butler Creeks in the northeast. Figure 9 shows a mound of silty sand with some clay under the Lake Missoula clays. I plotted and contoured the top of the sand layer in the wells north and south of Figure 9; Figure 16 is a sketch of my contour interpretation. I believe the topography of the top of the sand reflects a drainage pattern created during one of the drainings of Glacial Lake Missoula.

At Area IIa's northeast end, Lake Missoula clays cover colluvium of the valley side slope and interfinger with LaValle-Butler Creek fan

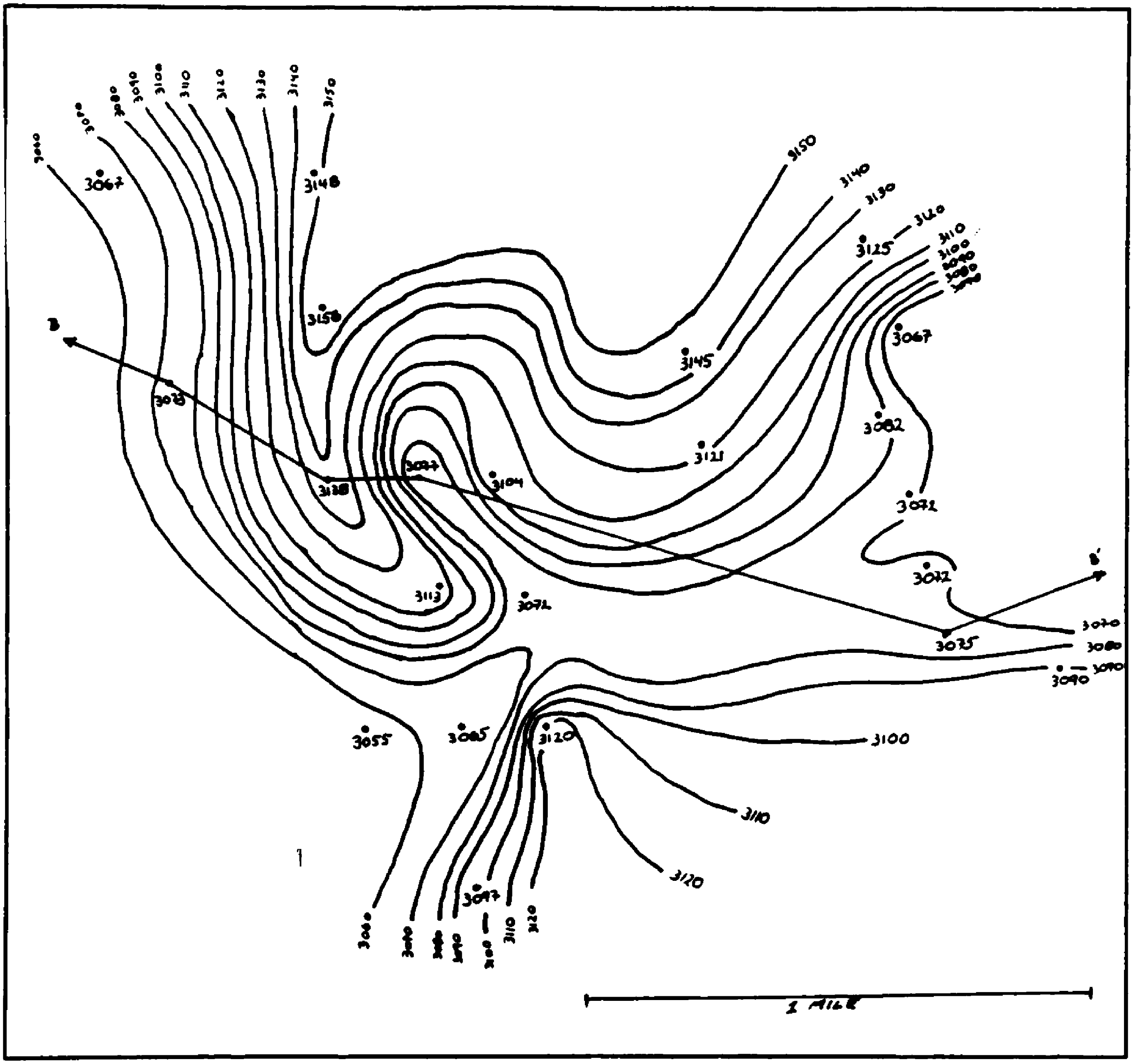

Figure 16: Upper Surface of Silty-Sand Layer in Areas I and IIa.

sediments (Figure 10). Glacial Lake Missoula filled to approximately 4,200 feet above mean sea level (Waite, 1985), so this fan was at times submerged, as were the other fans on the valley's north side. Thus these sediments are probably a mixture of fan and delta sediments.

The log of a well at 14-20-35baca indicates the Tertiary - Quaternary boundary (Geldon, 1979) 189 feet below the surface, or at approximately 3,046 feet above sea level.

Area IIb.

The intricacies of the surface geology continue in the subsurface of this Area, and are shown in Figures 10 and 11. At the Area's southwest end the Primrose Fault brings Precambrian and Cambrian bedrock to the surface. The bedrock dips to the north-northwest and is unconformably overlain by Tertiary sediments (Hall, 1969). Hall notes that the Tertiary sediments dip to the southeast as part of the north limb of an easterly trending syncline.

The Tertiary sediments are overlain by Quaternary interbedded clays, sands, gravels, and cobbles that are a mixture of Glacial Lake Missoula and O'Keefe Creek drainage sediments. The presence of Lake Missoula clays at the surface, and their interfingering with the fan deposits at depth, show that the O'Keefe Creek fan, like the LaValle-Butler Creek fan, was at times submerged by Glacial Lake Missoula. Thus the sediments are probably a mixture of alluvial fan and delta deposits.

Area IIc.

Area IIc's subsurface geology is shown in Figures 10 and 12. Area IIc lies between the valley floor and the Tertiary side slopes of the valley's northeast side. The sediments range from fluvial clays, sands, and gravels in the west that interfinger with Lake Missoula sediments; these in turn interfinger with colluvium on the eastern edge of the valley floor (Figure 12).

In the Area's western half the wells are finished in gravel or sandy gravel overlain by 100 to 150 feet of clay. The log of a well in this area (right side Figure 12) notes that the clays are red, gray, and brown and thus they may be a mixture of clays from Lake Missoula and the valley's sides. I believe most of this clay is Lake Missoula sediment, although I am not positive due to a lack of detail in the well logs. The gravel, or sandy gravel, to clay sequence is disrupted in the Area's eastern half. Here the sequence is complicated by interbedding with slope colluvium; often the clays are covered by up to 50 feet of colluvium. This change is indicated in the well logs by going from unadulterated clay in the west to clay with sands, gravels, cobbles, and boulders in the east.

Area III.

The subsurface geology of Area III is shown on Figures 9, 11 and 12. Although this is the largest Area, its stratigraphy is relatively consistent throughout. The top 10 to 40 feet is the fluvial gravel with interbedded sand and clay described in the surface geology section. These sediments interbed with Glacial Lake Missoula clays on the Area's eastern edge. The next 50 to 100 feet is sand interbedded with clay and gravel lenses. This sand layer is continuous with the sand layer that began under the western edge of Area I and is under Area IIa's Glacial Lake Missoula sediments. The amount of gravel in this layer decreases from southeast to northwest, i.e. along the valley's trend. The amount of silty clay and clay remains fairly constant. Towards the Area's northern end the upper fluvial gravel, sand, and clay layer thins and the sand layer is closer to the surface. Below the sand layer is 40 to 45 feet of gravel with fine to coarse sand. This layer is water-bearing and is where most domestic wells are finished. Under the gravel and sand is gravel with interbedded sand, grey, blue, and brown clay and clay-balls. This lowest layer is interpreted to be the Renova equivalent (Kuenzi, 1971; Geldon, 1979; Clark, 1986), at about 2,895 feet above sea level.

The exception to the three unit stratification occurs in section 14-21-25, approximately a half mile north of the constriction between the Cambrian outcrops along the Primrose Fault on the east and the valley's western side. The middle silty-sand layer becomes sand and clay interbedded with numerous gravel beds. The stratification in this section is similar to that of Area I. Grey-green and red argillites occur 141 to 152 feet below the section's western side.

The well located at 14-21-13daaa, at the boundary of Areas IIc and III (Figure 12), has a total depth of 410 feet. The cross-section shows the upper 231 feet. This well is notable because its log gives a description of the Quaternary and underlying Tertiary sediments. The top 24 feet are tan clay, followed by 11 feet of tan clay interbedded with sand and gravel. The next 26 feet are tan clay. Then follows 24 feet of grey-tan sandy clay and 35 feet of brown-gray interbedded sandy clay with sand. The next 50 feet coarsen downward and are fine to coarse sand and well rounded gravel. The well's final 240 feet is in interbedded grey, brown, orange, and blue clays and sands and gravels with possible pieces of wood and soil horizons. I believe the upper 85 feet are Glacial Lake Missoula sediments interbedded with sand and gravel of interlake periods. The next 85 feet are pre-glacial deposits. The bottom 240 feet are Tertiary sediments, probably the Renova equivalent, with a top boundary at approximately 2,900 feet above sea level (Kuenzi & Fields ,1971; Geldon, 1979; Clark, 1986).

Area IV.

Area IV's subsurface geology is shown in Figures 13, 14, and 15. This Area's stratigraphy closely resembles that of Area III. The top 10 to 60 feet is gravel with interbedded sand and clay. In places in the center of the Area there are up to 10 feet of silty sand over the gravel. This sand is not extensive. Under the gravel with sand and clay are 90 to 155 feet of silty, fine to medium sand with interbedded clay lenses. Below the sand is gravel with sand and clay (Figure 13). The Area's north side slope is composed of colluvium and Tertiary sediments over bedrock (Figure 14). The colluvium and Tertiary sediments interfinger with the upper gravel and middle sand layers. The well log descriptions of the Tertiary sediments and the valley gravels with sand and clay are similar enough that it is practically impossible to distinguish between them.

Subsurface Geology Summary.

In Areas I, III, and IV the geology can be broken down into four units. The top is 10 to 50 feet of fluvial gravel, sand, and clay beds. Below the fluvial sediments is a 100 to 150 foot thick layer that fines from southeast to northwest. In Area I this layer is interbedded gravel, sand, and clay. By Area IIa sand is the dominant component. By the middle of Area III the layer is sand with few clay and gravel beds. Below the sand layer is 30 to 50 feet of gravel with some sand and minor amounts of clay. At the bottom are Tertiary sediments, conspicuous for their multi-hued clays; these are probably the Renova Formation Equivalent.

The subsurface geology of Area II is complex. Under most of Area IIa, and the western edges of Areas IIb and c, the top layer is Glacial Lake Missoula varved silts and clays. The Glacial Lake Missoula sediments lie directly atop the thick sand layer. The lake sediments's edges interfinger with the sand layer and overlying fluvial sediments. At the southwest end of Areas IIa and b, the lake sediments cover Tertiary sediments and Cambrian and Precambrian bedrock. Area IIb is composed of interbedded layers of Tertiary sediment, O'Keefe Creek alluvium, and Glacial Lake Missoula sediments. On the eastern side of Areas IIa, b, and c, lake sediments overlie and interfinger with fan/delta alluvium and slope colluvium.

Interpretation.

In this section I offer an interpretation of sedimentary depositional history in the valley and possible reasons for the presence of the modern deposits. The interpretation is based on the previous authors' works and my cross-sections and field observations.

The Missoula Basin began opening during the early Tertiary Laramide Orogeny (Dott & Batten, 1981). The basin might have been an embayment of the Late Cretaceous Sea although no Cretaceous sediments are known at the surface of the Missoula Valley (McMurtrey, 1965). Detritus from surrounding mountains was deposited in the basin as it opened. Incoming debris filled the basin during the late Oligocene, was partially removed during the early Miocene, and again filled the basin during the late-middle to late Miocene. The final external drainage developed during early Pliocene.

The remaining topographic highs of Tertiary and older deposits on the valley floor are very important to the topography and remaining sediments of the modern valley. These sediments provide an elevated base for the post-Tertiary deposits and have protected them from erosion by the Clark Fork River. The two topographic highs in the study area are the Council Hill ridge and the southwest end of the O'Keefe Creek fan complex. Tertiary beds at both locations are mapped as part of the Renova Formation

Equivalent of the Missoula Valley. Kuenzi and Fields (1971) defined the Renova Formation as characterized by finer than sand sediments and the younger Six Mile Creek Formation as characterized by coarser than sand deposits. I spoke with Dave Alt (1989) about differentiating between the Renova and Sixmile Creek Formations in the Missoula Valley. From his experience, the Renova is mostly fine grained, contains ash layers and is grey, blue, and red to yellow. The Sixmile Creek Formation is mostly coarse grained, characterized by gravels and cobbles, contains no ash layers, and is grey-brown to light tan-brown. Based on this information and my field observations, I am tempted to suggest that the Tertiary beds in the gravel pit on Council Hill ridge and in the railroad cuts at the southwest end of the O'Keefe fan are actually Sixmile Creek equivalents and not Renova as previously thought. The Tertiary beds at both locations appear to be alluvial fan channel and debris flow deposits. Hanneman (1989) mapped alluvial fan channel and debris flow deposits in pre-Renova, Renova, Six Mile Creek, and post-Six Mile Creek strata. Thus the deposits' ages can not be discerned from sediment size alone and the actual age of the Missoula Valley Tertiary deposits is still in question.

McMurtrey (1965) suggests that, during Renova time, the Clark Fork River was forced to the valley's west side by alluvial fans on the east side. If the Missoula basin was internally drained during this time (Clark, 1986; Alt, 1989), then there was no through-flowing Clark Fork, and alluvial fans built up on all sides of the valley, thereby keeping the inflowing river toward the valley's center. A through-flowing river developed during the wetter climate at the end of Renova time, approximately 20 mya, and the beginning of Sixmile Creek time, approximately 16 mya. This river probably removed much of the Renova Equivalent sediments from the valley. Extension and movement along the Clark Fork Fault continued to raise the mountains to the east and north of the valley. Faster erosion of the higher mountains on the valley's northeast side introduced more sediment to that side of the valley. The Bitterroot possibly joined the Clark fork east of where it does now, as the Bitterroot valley opens to the north. Continued growth of the fans on the valley's northeast side eventually started pushing the Clark Fork toward the valley's western side. Although there was still deposition on the fans, the wet climate allowed a net sediment loss from the valley.

The climate became arid again sometime before 16 mya and Sixmile Creek Equivalent deposition began. During Sixmile Creek time, approximately 16 mya to 7 mya, the valley drained internally and sediments accumulated. The lack of volcanic ash produced coarser deposits than those of the Renova Equivalent. I am unsure of the thickness of possible Sixmile Creek Equivalent deposits in the Missoula Valley. Without proper dating of Missoula Valley sediments it is impossible to assign the valley's Tertiary beds to either Equivalent.

The climate became wet again around 7 mya and between then and the end of the Tertiary, around 1.8 mya, the streams again became through-flowing and removed sediments from the valley (Clark, 1986). Continued regional extension raised the mountains north and east of the valley and lowered the valley floor. Possible listric normal faulting caused the western side of the valley to drop more than the eastern side (Sears, 1989). This, coupled with continued growth of the alluvial fans of the valley's east side, eventually forced the Clark Fork toward the western side. As the Clark Fork moved laterally across the valley it continued to remove the Tertiary sediments.

The Bitterroot river may have meandered across the entire four miles of its valley's mouth until McCauley Butte was uncovered. McCauley Butte is a knob of Missoula Group metasediments at 13-20-35. Once exposed, McCauley Butte began to direct the course of the Bitterroot. When the river was east of the Butte it flowed toward the north. When the river was west of the Butte, it was forced to flow alongside Blue Mountain, directed toward the area that is now Council Ridge. Eventually a channel formed between Blue Mountain and Council Ridge. At times the Clark Fork shifted south of the valley's center and used the channels previously created by the Bitterroot. The joined Clark Fork and Bitterroot rivers eventually created the only egress from the southeast end of the valley. Continued deposition on the alluvial fans on the valley's northeast side ensured that the Clark

Fork stayed toward the southern and western sides of the valley. Barriers like the Precambrian and Cambrian bedrock at the southwest end of Area IIb protected the unconsolidated sediments behind them from river erosion. Although there is no record of Tertiary sediments younger than 7 mya, the end of Six Mile Creek time, there is no reason to suppose that deposition, and erosion, did not continue in the Missoula Valley through to the end of the Tertiary (Hanneman, 1989).

The majority of the Quaternary sediments resulted from the actions of Pleistocene glaciers. The lowest of these sediments is the 30 to 50 feet of gravel overlying the Tertiary beds. Although this layer is a minor part of the valley's stratigraphic column, it is important because it is the main aquifer in the valley. All the wells of the southwest end of Area IIa, Area III, and IV, except the few that exploit the shallow Quaternary or deeper Tertiary aquifers, end in the gravel layer; so the layer is extensive. The drillers' descriptions of the layer are similar to those given for the surficial layer of gravel, sand, and clay; thus I believe that the gravel layer above the Tertiary sediments is fluvial. The abrupt change from the clay-rich Tertiary beds to relatively clean gravel suggests an unconformity between the two layers. Unfortunately the length of time represented by this inferred unconformity is unknown. Hanneman (1989) mapped the Cenozoic sediments of the Divide, Melrose, Beaverhead, and Jefferson valleys. She found that fluvial gravels with low clay matrices were common only in deposits younger than 17 mya.

The glacially derived sediments that remain on the Missoula Valley's surface are from the Pinedale Glaciation, 25,000 to 10,000 years ago; a part of the Wisconsin Glacial Period (Chambers, 1971). There were three major Pleistocene glacial periods before the Wisconsin (Dott & Batten, 1981). I believe that the 30 to 50 feet of gravel above the Tertiary sediments is all that remains of these earlier glacial and interglacial periods. The gravel was deposited by river processes similar to those functioning today.

Chambers (1971) notes that there were at least two Glacial Lake Missoulas prior to the Pinedale Glacial Lake which deposited the valley's remaining glacially derived sediments. The middle silty sand layer is the remains of these pre-Pinedale glacial lakes and the early stages of Pinedale Glacial Lake Missoula. As one goes from Area IIa southwest toward Hellgate Canyon, the sand layer coarsens from sand, to sand and gravel, to sand, gravel, cobbles, and boulders. This coarsening is an artifact of increased current energy toward the valley's entrance. As a glacial lake emptied, water rushed into the valley through Hellgate Canyon. Apparently the lakes did not drain completely and shallower lakes remained between fillings. I inspected the sand and gravel deposits between Sherman Gulch and Deep Creek and at the mouths of Dry Gulch and Deep Creek on the valley's west side (around 13-21-1). These deposits consist of beds of pink clay, sand, and small gravels; approximately 1% of the gravel has a diameter greater than five inches. Bedding and cross-bedding is evident. The lack of alluvial fan sedimentary structures implies that these deposits are deltaic (Donahue, 1992). The deposits are 200 to 400 feet above the valley's floor and indicate that shallow lakes remained in the valley between lake fillings. Upon entering the valley, the current's energy dissipated in the shallow lake and could entrain only finer sediments. The weaker current deposited the coarser sediments near the canyon's mouth, while it transported sand and finer sediments further down the valley, depositing them in the lower two-thirds of the valley. The channel in the top of the sand under Area IIa may be a drainage pattern from when the sand was subaerially exposed or it may have been created by currents in the lake. Absence of the distinct sand layer under section 14-21-25 (southern Area III) shows that constriction of the valley floor by bed-rock outcrops produced higher energy flows. The stronger flows hampered deposition of finer sediments and winnowed out those deposited during the lake and interlake periods.

During Pinedale time, Glacial Lake Missoula deposited at least 140 feet of varved lake sediments. Chambers (1971) suggests that the entire Missoula Valley was covered with a complex braided river system during the interlake periods. I suggest this is only partially true. The lack of gravel and ripples in the sand beds suggests that there were again shallow lakes remaining in the valley between lake fillings. A shallow lake would have caused the coarser sediments to drop out near the mouth of Hellgate Canyon and would have protected the ripples from the effects of subaerial exposure. Chambers (1971) noted the presence of gravel beds between sets of varved lake sediments so it is possible that some of the lakes did drain completely, although no evidence of this is recorded in the railroad cuts. The pink-tan varved sediments were deposited on the pre-existing topography, including the surface of the silty sand layer. When the ice damming the lake gave way, the lake emptied, and the flow entrained sediments. The sand lenses between varve sets, exposed in the railroad cuts at the end of the O'Keefe Creek fan complex, show that sand and finer sediments were carried over the top of the varved sediments. This indicates that sand and finer sediments were deposited in the valley's lower end throughout the Pinedale Glaciation. When the lake had completely emptied, the Clark Fork was a braided stream that reoccupied the channels created before the lake, i.e. in approximately the same areas as today. The river deposited interbedded clay, sand, and gravel on its flood plain. The lateral migration of the braided stream system eventually covered the valley's lower elevations with fluvial gravel, sand, and clay. This layer interfingered with the varved clays. Lake sediments in the vicinity of the stream were removed, during the following interlake period, while lake sediments on the topographic highs were preserved.

The varved clays interfinger with alluvial/deltaic sediments at the mouths of the drainages around the valley. They also interfinger with colluvial sediments from the sides of the valley. Both these situations produce complex stratigraphic sequences.

The last Pinedale Glacial Lake Missoula was about 13,000 years ago (Atwater, 1986). During the past 13,000 years the Clark Fork river has meandered across the full breadth of the modern flood plain and produced the terraces of Areas I, III, and IV. The interlake braided stream gravel layer protected the underlying silty-sand layer from erosion by the post glacial Clark Fork. The majority of the sediments deposited during this final period are reworked glacial sediments. The creeks entering the valley initially carried postglacial sediments and deposited them on their fans. Recently, the creeks have cut down through and eroded their alluvial fans; this is especially evident on the O'Keefe Creek fan. The final river migration direction was toward the south and west, leaving the river and its deposits where they are today.

HYDROLOGY

Introduction.

This chapter will describe the hydrology of the Missoula Valley. The chapter is broken down into sections on surface water and ground water.

Surface Water.

The Missoula Valley is fed by the Clark Fork and Bitterroot Rivers and 16 major creeks from the sides of the valley. The eight creeks from the valley's west side flow directly into the Clark Fork, which is located against the west side of the valley. Of the eight creeks of the valley's east side, only O'Keefe and Mill Creeks actually cross the valley, the others seep in and recharge the aquifer before crossing the valley. I used U.S.G.S. Clark Fork River gauge data and my gauged river data to determine losses and gains in the river's volume. Figure 17 is the hydrograph of Clark Fork River discharge from October, 1987, to December, 1988. The data are from U.S.G.S. gauge station 12353000 at 13-20-21aac and are included in Appendix IV. Appendix IV also contains the river stage measurements. Not surprisingly, the hydrographs of discharge and stage are identical except for scale differences. The discharge hydrograph shall be used in the following discussions.

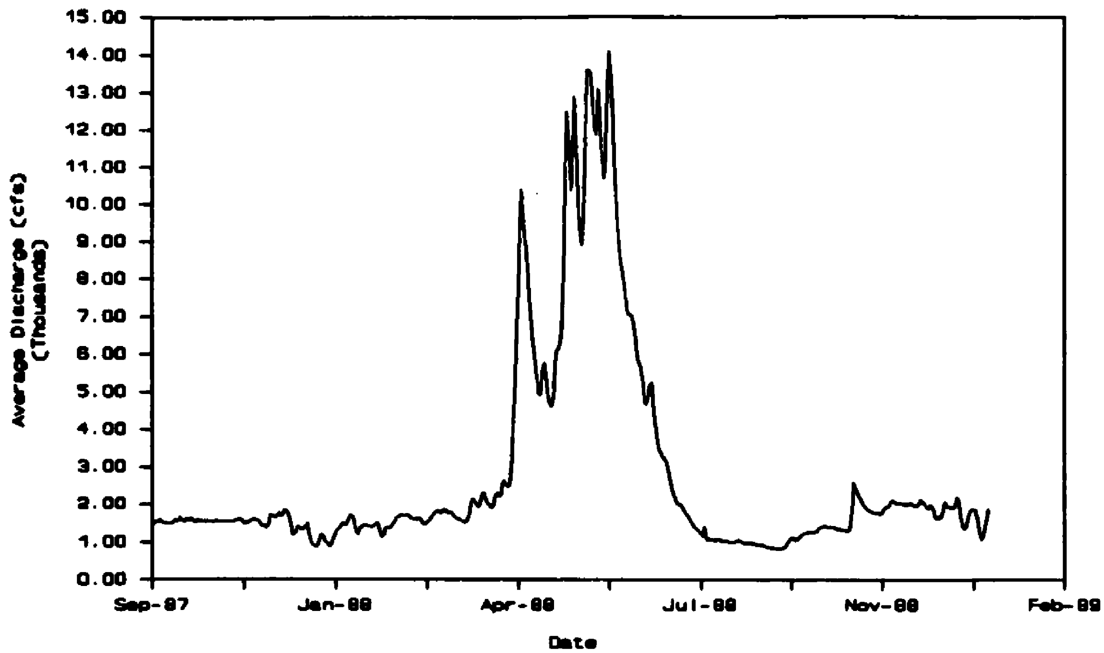

Figure 17: Clark Fork River discharge 1987-1988, USGS gauge station 12353000.

1988 was a year of drought. The 1987 - 1988 snow pack was abnormally low as was the amount of precipitation during the spring and summer, 1988. The river began rising in early January, 1988, in response to a mid-winter warm-spell and rain. The slow net rise in river stage from January to early April is due to spring precipitation and melt water from the snow pack. The sharp rise and fall of stage in April is due to heavy rains followed by an approximately two week long heat wave when temperatures reached the 80's with no precipitation. In a year of normal snow pack, the increased temperatures would have increased the amount of melt water in the river. By April, 1988, most of the snow pack was already melted and so the lack of rain produced a drop in the river stage. The return of spring rains in early May again raised the river stage until the first week of June. The summer of 1988 was abnormally dry. The occasional thunder showers did little but wet the ground surface and river stage dropped until early September. September 10th was the first day of rain and snow in the region since June. Fall precipitation and the end of the irrigation ditch season caused a rise in river stage until early November after which the river again dropped.

The Clark Fork River is the major source of recharge to the southern part of the Missoula Aquifer and the sole hydrologic egress from the valley (Woessner, 1988). Woessner states that the Clark Fork is influent from four miles downstream of Hellgate Canyon, during June and July, to over six miles, during winter and spring. I gauged the river in November, 1988, at Harpers Bridge and the Huson Railroad Bridge to attempt to quantify river gain and loss from the U.S.G.S. gauge station to Huson. The results of these gaugings are shown in Table 1.

Based on conclusions from the potentiometric surface maps (Figures 18 & 19), I did not expect to find lower flow at the end of the valley than in the middle. I did error calculation based on a minimum of 5% error. The results of these calculations are also shown in Table 1. Even using the greatest adjusted flow for the Huson Railroad bridge and the least adjusted

Table 1: Clark Fork River Flow Data, November, 1988.

Site	Location	Flow Rate[1] (cfs)	Flow +5% Error	Flow -5% Error	> Change[2]	
U.S.G.S. Gauge	13-20-21daac	2,030	2132	1929		
Harper's Bridge	14-21-35ada	2,588	2717	2459		
	Change in Flow[4]	558	585	530	788	
Stone Container Discharge	14-20-14bc	22	23	21		
Mill Creek	15-21-34dada	10	11	9.5		
Huson Railroad Bridge	15-22-26dac	2,355	2473	2237		
	Change in Flow[5]	-265	-278	-253	-17	-514

[1] Assuming the river has a constant grade throughout the valley's length, flow rate is indicative of the volume of water in the river.

[2] (Flow at Harper's Bridge + 5%) - (Flow at U.S.G.S. Gauge - 5%) & (Flow at railroad Bridge + 5%) - ((Flow at Harper's Bridge + Flow at Mill Creek + Stone Container Discharge) - 5%)

[3] (Flow at Harper's Bridge - 5%) - (Flow at U.S.G.S. Gauge + 5%) & (Flow at railroad Bridge - 5%) - ((Flow at Harper's Bridge + Flow at Mill Creek + Stone Container Discharge) + 5%)

[4] Flow at Harper's Bridge - Flow at U.S.G.S. Gauge.

[5] Flow at railroad Bridge - (Flow at Harper's Bridge + Flow at Mill Creek + Stone Container Discharge).

flows for Harper's bridge, Stone Container discharge, and Mill Creek, the change in flow is still negative. I.e. there is apparently less flow at the Huson Railroad bridge than at Harper's bridge.

The gauging conditions at the Huson Railroad Bridge were acceptable, but the conditions at Harper's Bridge were abysmal due to logs and brush against the upstream side and deep pools at the downstream side of the bridge. I have very little confidence in the accuracy of the Harper's Bridge gauging results and speculate that better field measurements would show that the Clark Fork is gaining flow over most of its reach.

Ground Water.

This section is broken down into: a description of the valley's aquifers, including: a discussion of their hydrologic characteristics; a discussion of ground water flow based on potentiometric surface plots; a discussion of recharge to the valley; and a discussion of aquifer response to recharge and discharge based well water levels.

Missoula Valley Aquifers.

I will describe the aquifers of the valley by chronological order and by their Area location when appropriate. The descriptions will include the depth to the aquifer, the composition of the aquifer, and an average value for hydraulic conductivity, transmissivity, and specific capacity. The well and aquifer information is from drillers' well logs. The logs span about thirty years of drilling, so the depth to the water table or potentiometric surface may be different than it is today.

The ground water of the Missoula Valley is stored in three types of aquifers: Precambrian and Cambrian bedrock, Tertiary sediments, and Quaternary sediments. Precambrian and Cambrian bedrock aquifers are important in the middle of Area IIb. Tertiary aquifers are important in Area IIa and b and along the valley's eastern and northern side slopes. The Quaternary aquifer provides the major source of water on the valley's floor. In general my calculated hydraulic conductivity values (Appendix VI) are close to those recorded in the Missoula Sole Source Aquifer Study (Woessner, 1988). Appendix VII is a list of all my aquifer characteristic calculations and Table 2 summarizes the values by geology and Area.

Precambrian and Cambrian Bedrock Aquifers.

Wells that draw water from Precambrian and Cambrian bedrock are located in the southern part of the middle of Area IIb. Well logs indicate that bedrock is covered by 4 to 240 feet of clay-rich Tertiary and Quaternary sediments. The bedrock aquifers are confined. Wells are 120 to 300 feet deep and depth to first water is from 71 to 284 feet. Porosity in these metasedimentary bedrocks is limited to micro-fractures from rock cleavage

Table 2: Hydrologic Characteristics of the Missoula Valley.

		TERTIARY						VALLEY FLOOR ALLUVIUM				
		BR	IIa	IIb	G	BL	OK	I	IIa	IIc	III	IV
	avg.	4.6	1.2	1.4	20	150	9.5	150	70	13	290	45
SC	min.	0.29	0.13	0.05	5.7	3.6	3	3.3	2.1	1.2	1.3	0.97
	max.	17	2.7	5.7	49	500	25	1,300	270	35	11,000	570
	avg.	48	15	110	4,000	18,000	890	8,900	3,500	2,000	8,300	4,800
K	min.	2	1	2	760	400	120	200	150	170	410	21
	max.	77	36	360	7,600	55,000	2,000	39,000	12,000	11,000	209,000	20,000
	avg.	9,500	2,200	3,200	48,000	2,6000	22,000	290,000	180,000	31,000	590,000	81,000
T	min.	400	200	96	15,000	130	3,300	6,900	5,300	2,700	3,200	1,100
	max.	35,000	5,000	13,000	115,000	97,000	58,000	2 E+6	711,000	90,000	2 E+7	450,000

SC in gpm/ft
K in gpd/ft^2
T in gpd/ft

BR Pre-Cambrian and Cambrian Bedrock
G Grant Creek Alluvium
BL Butler - LaValle Creek Alluvium

OK O'Keefe Creek Alluvium

and major joints and fractures (Lazuk,1988).

In my KCALC calculations I used a general aquifer thickness of 200 feet. Hydraulic conductivity and transmissivity average 48 gpd/ft^2 and 9,500 gpd/ft. The average well specific capacity is 4.6 gpm/ft. Drawdown is between 10 to 150 feet for pumping rates from 6 to 30 gpm. Although these values are some of the lowest in the valley, I believe they may be an order of magnitude too high. Lazuk (1988) reported hydraulic conductivity values for the Missoula Group rocks of the Jocko Valley from 0.48 to 1.29 gpd/ft^2. My elevated values are probably an artifact of KCALC which is designed for porous sediments, not fractured bedrock.

Tertiary Sediment Aquifers.

Wells that draw water from Tertiary sediments are found at the southwest end of Area IIa and in the middle of Area IIb. Wells finished in Tertiary sediments in Area III are either screened in the basal Quaternary gravel or are unproductive. Tertiary sediment aquifers are confined and consist of clay-rich beds of up to cobble sized sediments. The cleaner gravel beds may yield water in exploitable volumes.

Tertiary sediments at the southwest end of Area IIa are covered with up to three feet of Glacial Lake Missoula sediments. McMurtrey's (1965) gravimetric survey places bedrock at 1,800 to 2,600 feet above mean sea level. Based on these values, and a surface elevation of 3,200 feet, there are approximately 1,400 to 600 feet of Tertiary sediments in this Area. The well logs indicate depth to water is 160 to 300 feet. None of the wells is finished in bedrock. Hydraulic conductivity and transmissivity average 15 gpd/ft^2 and 2,200 gpd/ft. The specific capacity for wells in these sediments averages 1.2 gpm/ft. The low specific capacity of these wells reflects the low hydraulic conductivity of the aquifer. This Area has the lowest calculated hydraulic conductivity values in the valley.

I found logs of five wells in Area IIb that definitely end in Tertiary sediments, based on the change from solely tan-red clays characteristic of the Lake Missoula sediments to multihued clays characteristic of the Tertiary sediments. Depth to Tertiary sediments is from 26 to 76 feet and depth to exploitable water is from 98 to 245 feet. None of the wells is finished in bedrock. Hydraulic conductivity and transmissivity average 110 gpd/ft^2 and 3,200 gpd/ft and the specific capacity of these wells averages 1.4 gpm/ft. The highest hydraulic conductivity value, 370 gpd/ft^2, is from a well screened in a 6 feet thick bed of gravel and coarse sand. The bed is surrounded by clay beds and all water in the well comes from this gravel layer. The specific capacity for this well is 0.94, one of the lowest in the Area. The presence of wells with low specific capacity that exploit comparably high hydraulic conductivity beds suggests that these wells are in relatively conductive beds surrounded by aquitards which restrict recharge into the exploited bed thereby limiting yield. As can be seen in the cross sections, water bearing beds tend to be inextensive and thus would rapidly lose their available stored water.

Quaternary Sediment Aquifers.

Quaternary sediments in the Missoula Valley can be divided into two groups: alluvia from creeks on the eastern side of the southern end of the valley and sediments of the valley floor.

Creek Alluvium.

Wells in Grant Creek alluvium (Area I) have a total depth between 185 and 245 feet and are finished in 160 to 200 feet of sand-gravel and gravel. Well logs indicate that first water is between 80 and 110 feet below the surface. Hydraulic conductivity and transmissivity values average 4,000 gpd/ft^2 and 48,000 gpd/ft and specific capacity averages 20 gpm/ft

Water bearing sediments in Butler - LaValle Creek alluvium (Area IIa) are confined by 85 to 140 feet of clay with minor gravel beds. The wells exploit gravel beds between 95 and 215 feet deep and total well depth ranges from 100 to 220 feet. Average hydraulic conductivity and transmissivity values are 18,000 gpd/ft^2 and 26,000 gpd/ft, and average specific capacity is 150 gpm/ft. The hydraulic conductivity value is indicative of a clean sand or gravel (Freeze & Cherry, 1979) and is the highest average value in the study area. The high specific capacity and hydraulic conductivity values are probably due to two factors. Firstly, the water bearing gravel beds are stream sediments and are fairly well sorted. Secondly, these wells are located in two sections: 14-20-34 and 35. The highest values are from wells in section 35 (Appendix VII), which were drilled in the late 1950's and early 1960's. The wells in section 34 were drilled in the mid 1970's to late 1980's. Drawdown during pump tests is between 1 to 2 feet in section 35 and 11 to 40 feet in section 34. When the section 35 wells were drilled there were fewer wells in the Area thus more exploitable water in storage in the aquifer. This lack of stress on the aquifer might have allowed a better recharge response and given the lower drawdown value.

Water bearing sediments in O'Keefe Creek alluvium (Area IIb) are confined by 39 to 175 feet of clay-rich sediments. Wells are 96 to 299 feet deep and exploit gravel and sand-gravel beds between 81 to 295 feet deep. Average hydraulic conductivity and transmissivity are 890 gpd/ft^2 and 22,000 gpd/ft, and average specific capacity is 9.5 gpm/ft. These are the lowest values of all Creek alluvium aquifers and reflect not only the higher amount of clay in O'Keefe Creek sediments but also the lower amount of recharge to the system. Unlike Grant, Butler, and LaValle Creeks, O'Keefe Creek does not flow over and recharge the area where the wells are located. O'Keefe Creek flows north of the area and apparently has little affect, if any, on recharge to this aquifer.

Valley Floor Sediments.

As discussed in the geology section, the Quaternary sediments of the valley floor were deposited by fluvial and glacio-lacustrine processes. These sediments form the valley's primary aquifer and are collectively referred to as the Missoula Aquifer (Woessner, 1988). In my study area, these valley floor sediments can be broken down into three relatively distinct strata: a basal gravel, a middle silty sand, and an upper gravel. These sediments interfinger with creek alluvia and slope colluvium on the valley's eastern and northern sides. The basal gravel is the main source of ground water for the entire valley. These strata are described in the geology section. The base of the aquifer is the contact between the basal gravel and the underlying Tertiary sediments. The aquifer varies in thickness from 168 feet near Missoula (Woessner, 1988) to about 230 feet in Area IV. The thickness in Area IV is inferred from McMurtrey's (1965) gravimetric survey as I could find no well that reached Tertiary sediments. Shallow wells indicate that the upper gravel is generally unconfined. The silty sand and basal gravel are generally confined to semi-confined, though logs of wells near the Clark Fork River in the southern part of Area III suggest that these strata may act in an unconfined manner.

The depth to water bearing sediments in Area I is from 6 to 75 feet. The three layer stratification is generally obscure and the deeper sources are on the north side of the Area covered by clay to gravel sediments. The water bearing sediments change from unconfined on the south side of the Area, near the Clark Fork River, to confined at the north side. The first water generally appears confined one half to three quarters of a mile north of the river. Wells exploit sand-gravel and gravel beds from 30 to 106 feet deep. These beds are part of a larger confined to semi-confined system as the silt to clay aquitards and aquicludes are apparently inextensive, as shown on cross-sections A and B. Average hydraulic conductivity and transmissivity are 9,000 gpd/ft^2 and 290,000 gpd/ft, and average specific capacity is 150 gpm/ft. The highest specific capacity and hydraulic conductivity values are from wells closest to the river.

In Area IIa the aquifer is confined by Glacial Lake Missoula sediments. Under the Lake sediments, the other Quaternary sediments begin to have the distinctive three layer stratigraphy and the main source of water is the basal gravel. Depth to first water is between 52 to 112 feet below the surface. The shallower contacts are on the sides of the Lake sediments where the clay cover is thinnest. The wells exploit sand, sand-gravel, and gravel beds from 80 to 105 feet deep on the edge of the Lake sediments to 152 to 190 feet deep under the middle of the Lake sediments. Average hydraulic conductivity and transmissivity are 3,500 gpd/ft^2 and 180,000 gpd/ft, and average specific capacity is 70 gpm/ft.

Water bearing sediments in Area IIc are covered by 80 to 150 feet of clay with sand and gravel. The overburden is a mixture of Glacial Lake

Missoula sediments and colluvium from the valley's eastern slope. The aquifer in this Area is 90 to 150 feet deep, confined sand-gravel beds. Average hydraulic conductivity and transmissivity of the aquifer are 2,000 gpd/ft^2 and 31,000 gpd/ft, and the average well specific capacity is 13 gpm/ft. The hydraulic conductivity and specific capacity values are more characteristic of alluvial sediments from the creeks on the valley's sides. The elevation of the aquifer gravel in Area IIc averages 110 feet higher than the basal gravel of the valley floor, though well logs from Areas IIc and III indicate that the gravel of Area IIc connect with the basal gravel (Figure 12). The elevation of aquifer gravel beds in Area IIc and the proximity to the side slope suggest that the lower aquifer-characteristic values are due to the influence of poorer sorted slope sediments.

The water table in Area III is from 2 to 38 feet deep. The deeper levels are on the Area's east side, farthest from the river. Most of the Area's wells exploit the basal gravel aquifer though there are some older wells which use the upper gravel aquifer. Depth to the top of the basal gravel is from 80 to 168 feet. Well depth ranges from 95 to 224 feet; some of the deeper wells penetrate Tertiary sediments but are screened in the basal gravel aquifer. Hydraulic conductivity and transmissivity values are high and average 8,300 gpd/ft^2 and 590,000 gpd/ft. Average specific capacity for the wells is 290 gpm/ft, the highest value in the valley. Wells nearer the river tend to have the highest values (see Appendix VII); this is probably an artifact of KCALC. The program calculates hydraulic conductivity and specific capacity based on aquifer thickness and drawdown during pumping. As the wells nearer the river have a ready source of recharge, the drawdown is minimal. A good example of this effect is the Montana Fish and Game well at 13-20-5caaad. This well has a hydraulic conductivity of 209,167 gpd/ft^2 and a specific capacity 10,772 gpm/ft. Drawdown in this well was 1 inch after 4 hours of pumping at 28 gpm. The well is about 200 feet from Warm Slough on one side and about 500 feet from the Clark Fork, on the other, and is in sand and gravel for almost its entire depth. So not only does the well have a ready source of recharge but also it is in highly conductive sediments.

The water table in Area IV is from 2 to 35 feet deep. As in Area III, the water table slopes down the trend of the valley with a gradient approximately the same as that of the surface. Most of the wells in the Area exploit the basal gravel aquifer. Depth to the basal gravel is from 155 to 180 feet deep. None of the Area's wells contacts Tertiary sediments. Extrapolating from the thickness of the gravel in Area III, the bottom of the gravel in Area IV is between 205 and 230 feet deep. Wells in the basal gravel are from 158 to 202 feet deep. There are a few wells which end in the middle silty-sand. The well logs indicate that all the deep wells are confined and have an average hydraulic conductivity and transmissivity of

4,800 gpd/ft^2 and 81,000 gpd/ft, and an average specific capacity of 45 gpm/ft.

Ground Water Flow.

I constructed potentiometric surface contour maps from my monthly monitored well data. Figures 18 and 19 are the generalized potentiometric surfaces during May and November, 1988, and show the valley's characteristic ground water flow patterns; Table 3 is a list of the well water elevations. These plots were drawn for data from wells which end in the basal gravel aquifer. The piezometers around the Stone Container plant, including shallow Well 17, were not used for these plots. The water levels in these piezometers were strongly influenced by the voluminous ground water withdrawal by Stone Container's wells and are not representative of natural water levels. The data from Wells 14b, 22, and 25a were also not used. These are shallow water table wells. The measurements and hydrographs for these piezometers and shallow wells are included in Appendices II and III.

The May, 1988, potentiometric surface plot (Figure 18) shows that the valley may be broken down into four major flow regimes. At the valley's southern end, ground water flows away from the river and to the west, re-entering the river at the south end of Area III, between Wells 6 and 9. I expected flow to the northwest on the north side of Area I, under the

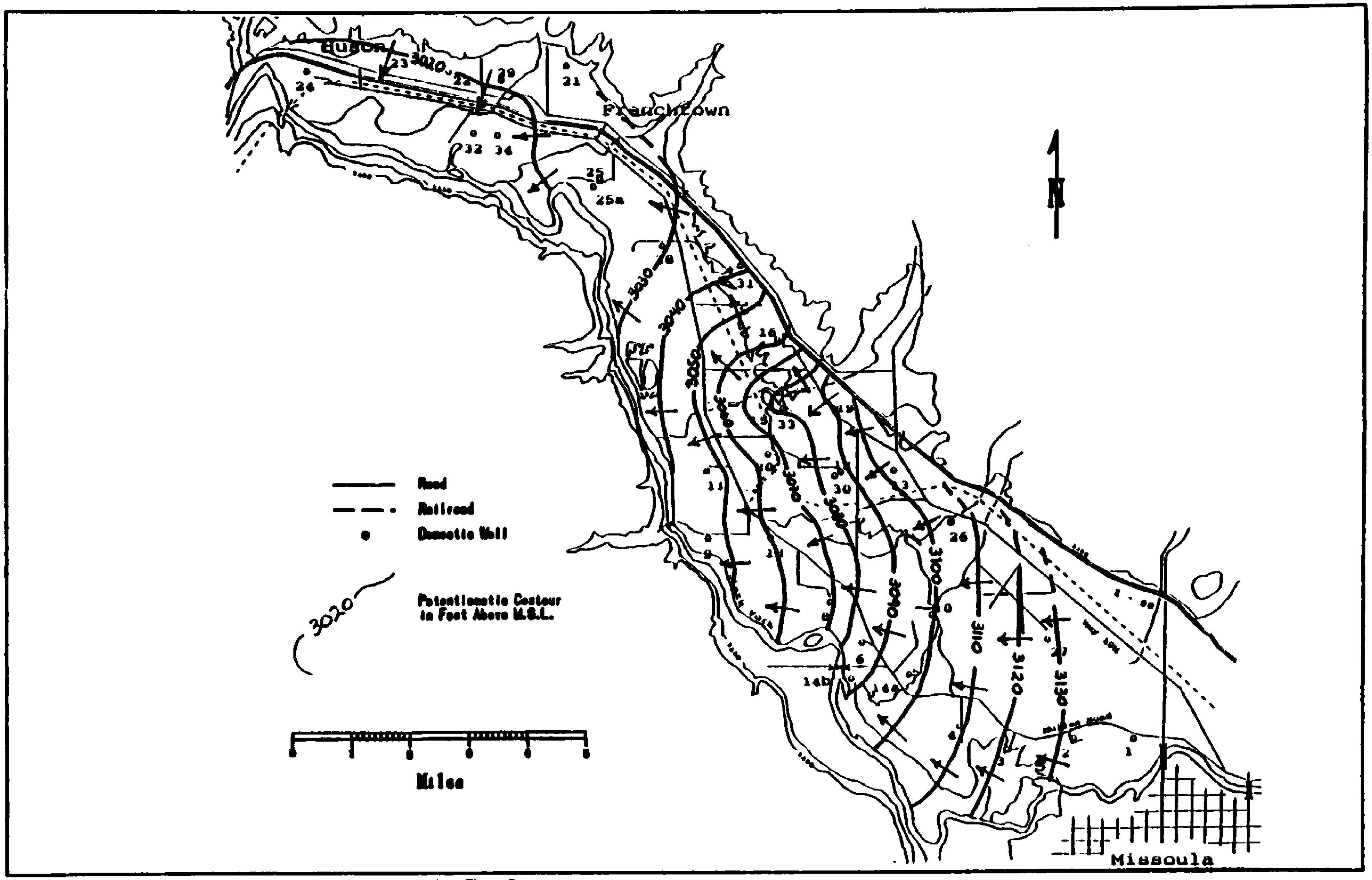

Figure 18: May, 1988, Potentiometric Surface.

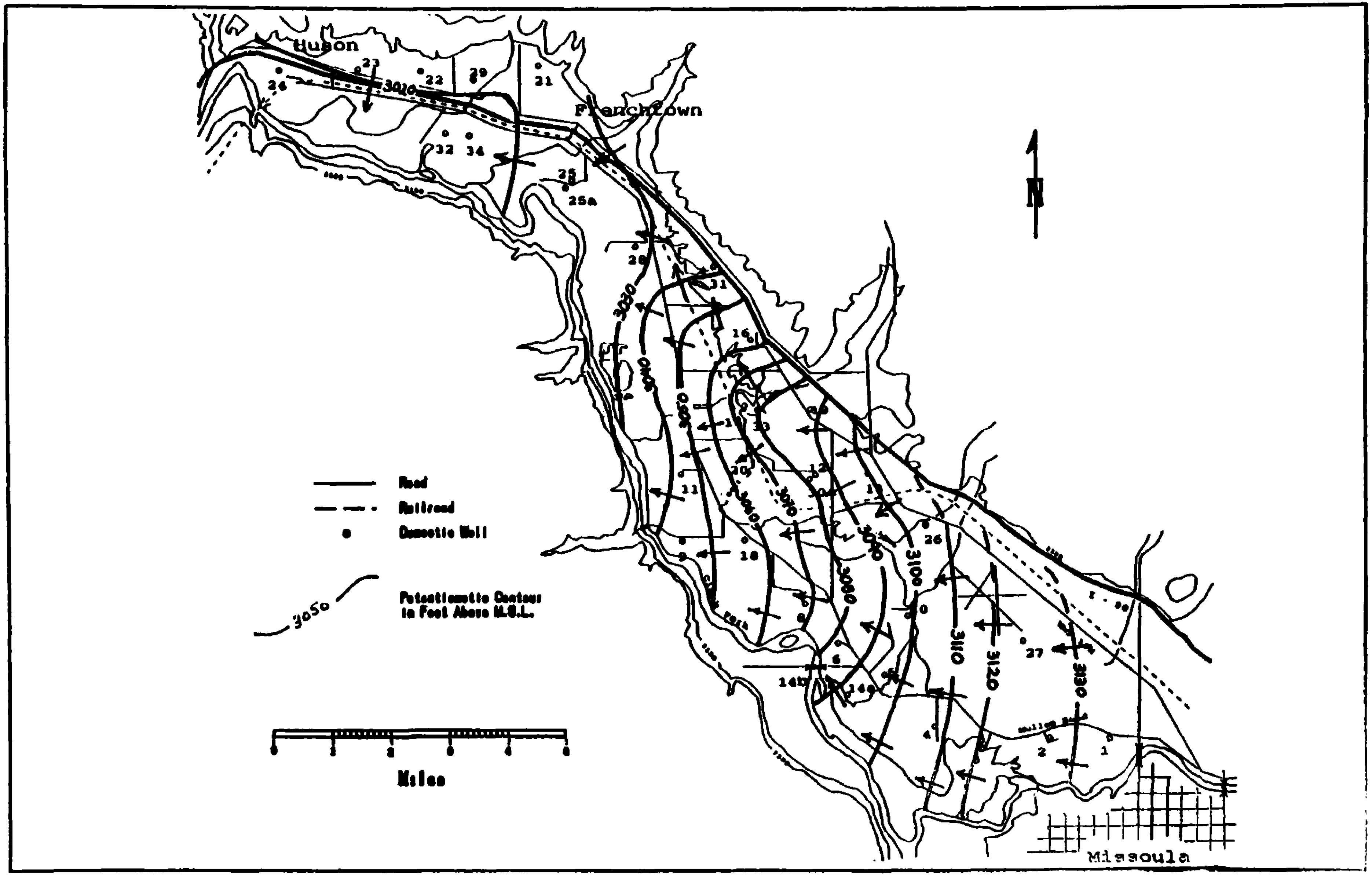

Figure 19: November, 1988, Potentiometric Surface.

Table 3: Well Water Elevations for May and November, 1988.

Well Number	May	November
1	3,137	3,132
2	3,132	3,129
3	3,122	3,121
4	3,109	3,108
5	3,098	3,097
6	3,085	3,083
8	3,069	3,067
9	3,046	3,045
10	3,100	3,098
11	3,044	3,042
13	3,103	3,100
14a	3,094	3,092
15	3,080	-
16	3,059	3,105
18	3,060	3,056
19	3,090	3,089
20	3,066	3,066
21	3,022	3,023
23	3,019	3,021
24	3,013	3,013
25	3,028	3,027
26	3,104	3,105
27	3,129	3,127
28	3,029	3,028
29	3,021	3,022
31	3,038	3,038
33	-	3,080
34	-	3,015

All Elevations in Feet Above Sea Level

influence of recharge from Grant Creek (Pottinger, 1988), though this is not apparent from my measurements. The apparent ground water recharge to the river at the south end of Area III is in part due to a hydraulic boundary caused by Area IIb's bedrock and low hydraulic conductivity sediments. This boundary deflects ground water flow from northwest to west and to the river.

The influence of the low hydraulic conductivity rocks and sediments and of recharge from the O'Keefe Creek drainage form a separate flow regime in Area IIb and the south end of Area IIc. Flow from the east side of Area IIb is away from the center of the low conductivity rocks and sediments. On the north side the flow is joined recharge from O'Keefe Creek drainage and produces the recharge bulge in the potentiometric contours near Wells 15 and 33.

The ground water flow across Area III northwest of O'Keefe Creek diverges from along the valley on the east side to toward the river on the west. This flow divergence is undoubtedly assisted by the removal of 25 million gallons of ground water per day by the Stone Container Corporation pulp mill from the west side of the middle of Area III (Stone, 1989).

May ground water flow in Area IV is toward the river. The attitude of the 3,020' contour indicates that there is flow from the north valley sides and into the valley. All the ground water in the Missoula Valley exits the valley at the west end of Area IV.

The November, 1988, potentiometric surface plot (Figure 19) shows that the flow patterns are the same as in May. These patterns are characteristic of ground water flow directions in the Missoula Valley. In general, the contours are shifted to the east, some as much as a mile (e.g. 3,130' contour). This shift is due to seasonally lower ground water levels. The main exception to this shift is in Area IV where well water levels were higher in November than in May. This may be due to a rebound effect of recharge to the basal aquifer from the overlying strata and the Tertiary sediments of the north valley side in response to withdrawal for human consumption during the summer. This is discussed in a later section.

Recharge.

The main apparent sources of recharge to the Missoula Aquifer are the Clark Fork River (Woessner, 1988), the creeks of the west and north valley sides, and the adjacent Tertiary sediments and Precambrian and Cambrian bedrock highlands. This observation is indicated by the two potentiometric surface plots.

Based on Figure 18, spring recharge from the Clark Fork River apparently ends by Area I's southwestern end or Area III's south end. Based on a comparison of the rise in river stage and the rise in well water levels throughout the valley (see Figure 17 and Appendix III) the river locally recharges the adjacent flood plain for a brief time during the spring.

The timing of the spring rise in river stage is contemporaneous with a rise in stage in the valley side creeks and increased flow from the Tertiary sediments and Precambrian and Cambrian bedrock highlands. Although the well hydrographs (see the following section and Appendix III) show a rise in water levels at the same time as the rise in river stage, only the wells adjacent to the river respond directly to the rise in river stage and subsequent recharge. The spring rise of the potentiometric surface throughout the valley is in response to recharge from all sources and the subsequent change in the river boundary condition.

It is important to realize that the well hydrographs show a composite response to all forms of recharge and discharge. Thus the spring rise in well water levels across the valley is indicative of total, multiple source, recharge to the system and not of the effects of a single recharge source.

The dog-leg in the contours (Figures 18 and 19) in Area IIb's north side indicates that though O'Keefe creek itself is ephemeral, the drainage is a major recharge source for the middle of the valley.

A quantification of recharge from the Tertiary valley sides was not included in the scope of this project and thus was not investigated. The potentiometric surface plots indicate that flow from the Tertiary sediments into the valley may be an important source of recharge to the Missoula Aquifer, especially north of the O'Keefe Creek drainage. Using the data in Appendix VII and the hydraulic gradient used by Miller (1991) for his finitedifference flow model, I applied Darcy's Law[1] to calculate the amount of flow from the Tertiary. The area along the 12.5 miles from the O'Keefe Creek drainage to Huson, based on an average thickness of 86 feet, is 5,676,000 feet[2]. The average hydraulic conductivity is 121 feet per day and the hydraulic gradient is 0.05 (Miller,1991). The calculated flow is 288,000 acre feet per year, or an average of 23,000 acre feet per year per mile. Miller calculated 3,340 acre feet per year, an average of 402 acre feet per year per mile. I have already discussed the problems in the KCALC calculations and Miller discusses the problems in his calculations, so the order of magnitude difference in our values is not surprising. I assume that a realistic value for flow from the Tertiary lies somewhere between our two values.

Aquifer Response to Recharge and Discharge.

In the following section I shall discuss aquifer response to recharge and discharge, as indicated by well water levels. I shall use exemplary well hydrographs in my discussion. The monitored well data and hydrographs are found in Appendices II and III. Figure 4 shows the location of the monitored wells and piezometers.

Well water elevations fluctuated from three to nine feet during the study period; the greatest changes were in Area I, near the river. Aquifer

[1]Darcy's Law: Q=-A*K*I. Q=flow; A=cross-sectional area; K=hydraulic conductivity; I=hydraulic gradient.

response to recharge and discharge, as evinced by well water levels, depends upon five factors:

- The source of the recharge,
- The proximity of a well to the recharge source,
- The position of the influent reach of the Clark Fork,
- The effects of human consumption, and
- The hydrogeology of the aquifer.

Wells 1 - 6 and 14a and b nicely demonstrate the first three factors; Figure 20 is the hydrograph of Well 1. The similarity of the timing of the water elevation change in this well to the rise and fall of river stage, and its proximity to the river, indicates that the major source of recharge to the aquifer around the wells is the Clark Fork. As discussed in the section on recharge, the spring rise in Well 1's water level is also due to a change in the river's boundary condition. So, although the major source in recharge to the aquifer around this well is apparently the Clark Fork River, the aquifer is also responding to other recharge sources, e.g. Grant Creek and the adjacent Tertiary sediments and Precambrian bedrock. This observation is supported by the potentiometric surface contour plots.

The decrease in the amplitude of seasonal variation of the well water levels as one moves away from a recharge source indicates a damping of aquifer response as the recharge volume is spread over a larger volume and as ground water is removed from the aquifer by pumping. The effect of the

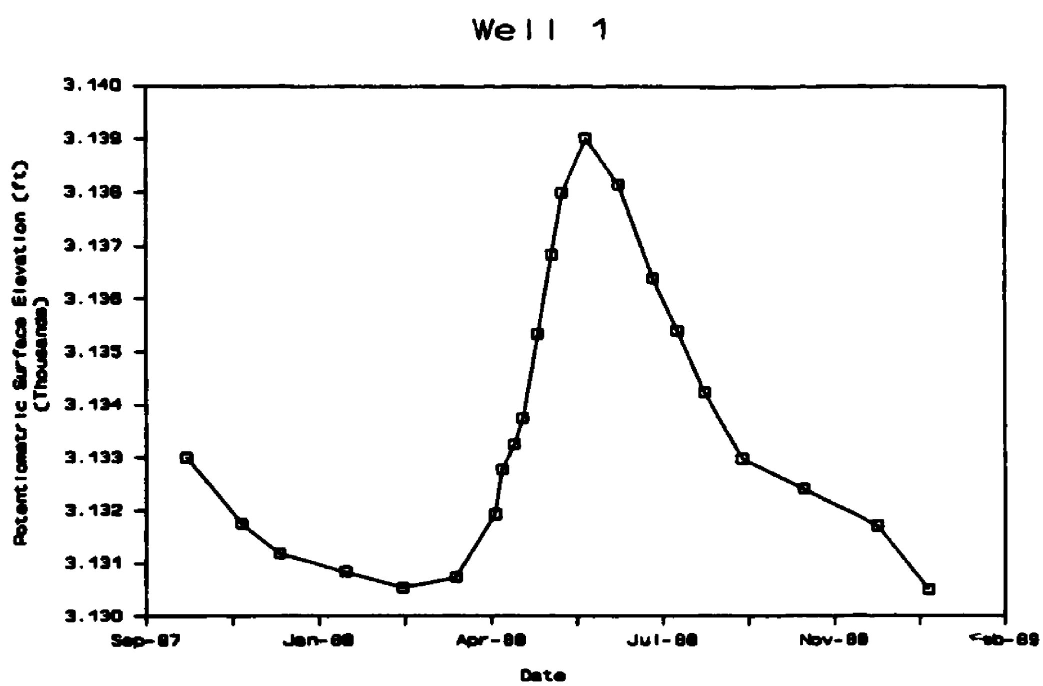

Figure 20: Hydrograph of Well 1.

distance from the recharge source is evident in the response of Wells 1, 3, and 6 (Figures 21 and 22). Well 1 shows very little response to the April drop in river stage; this well is affected mostly by the influent portion of the river. The aquifer responds more severely to the drop in stage as one goes from Well 3 to Well 6. These wells are in a region where the river changes from influent to effluent during the April dry spell and then influent again with the rise in river stage. The rapidity of the aquifer response indicates that the aquifer is responding not only to changes in the stage of the river but also to changes in the amount of water entering the system from other sources.

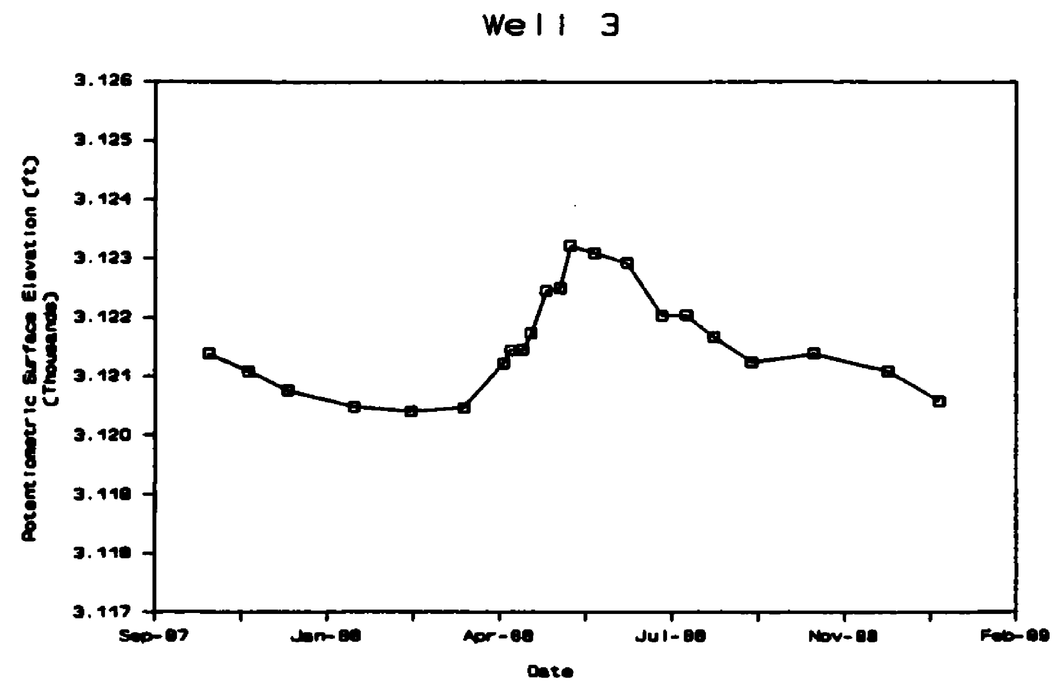

Figure 21: Hydrograph of Well 3.

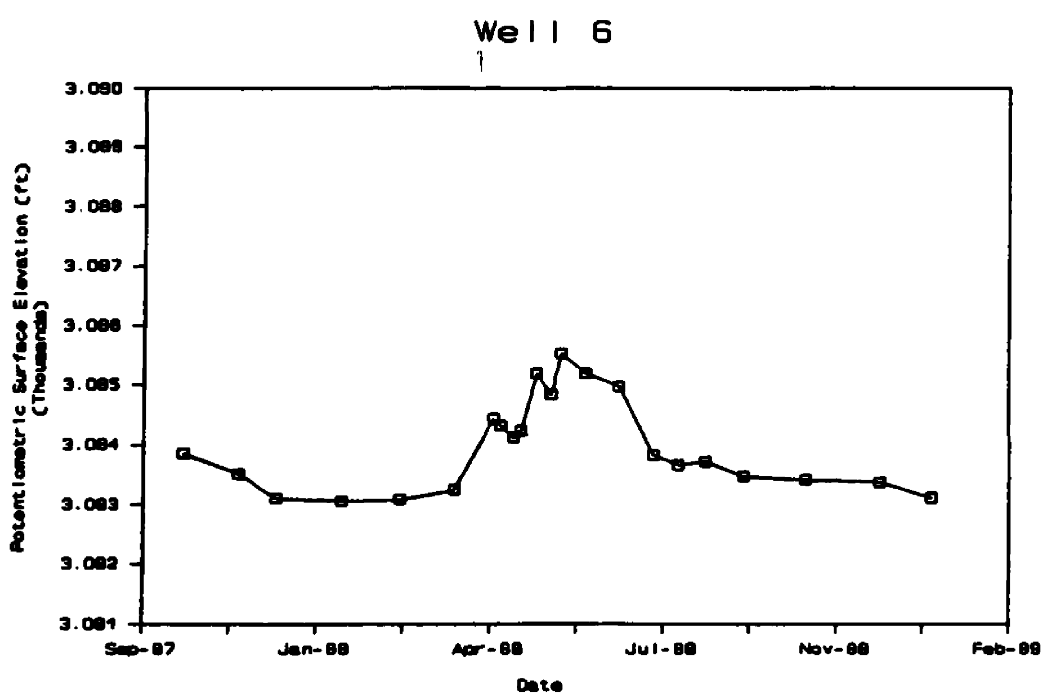

Figure 22: Hydrograph of Well 6.

Water levels in Wells 27 and 26 indicate the importance of the proximity of the recharge source and the hydrogeology of the aquifer (Figures 23 & 24). The potentiometric surface plots indicate that the majority of the recharge to the aquifer around these wells is from Grant, Butler, and LaValle Creeks and from flow from Tertiary aquifers of the valley sides (Pottinger,1988). Well 27 is about one mile down-gradient of Grant Creek. The well's acute response to spring recharge is indicative of its proximity to its recharge source and the high hydraulic conductivity of the aquifer.

The different response to recharge in Wells 27 and 26 is indicative of a change in the geologic nature of the aquifer. Well 26 is approximately 60 feet from LaValle Creek and is in the low hydraulic conductivity sediments of Area IIb. These sediments effectively suppress recharge from the creek to the aquifer around the well. Thus, although the well is in the middle of the Butler - LaValle Creek drainage, the low hydraulic conductivity aquifer restricts recharge from the creeks so the hydrograph of the well shows a dampened response to recharge.

The comparison of the hydrographs of Wells 26, 27, and 13 (Figure 25) indicates that Well 13 is also removed from the influence of Butler and LaValle Creeks even though it is directly down-gradient from their recharge area. The major source of recharge to Well 13 appears to be the Tertiary aquifers of the valley sides (Pottinger, 1988). The hydrograph of Well 13

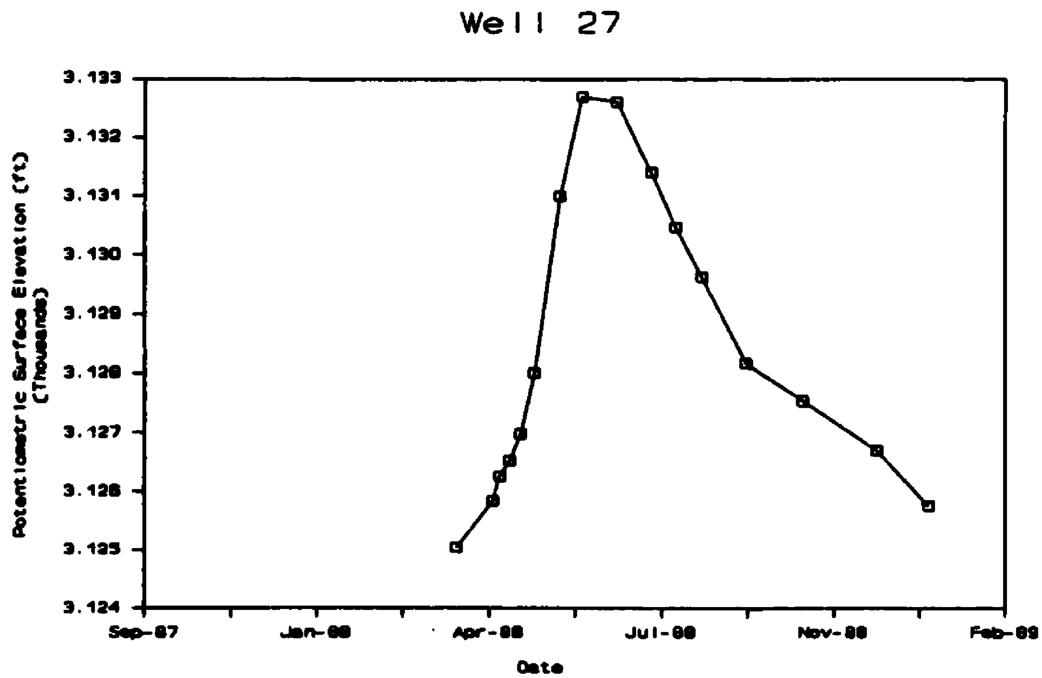

Figure 23: Hydrograph of Well 27.

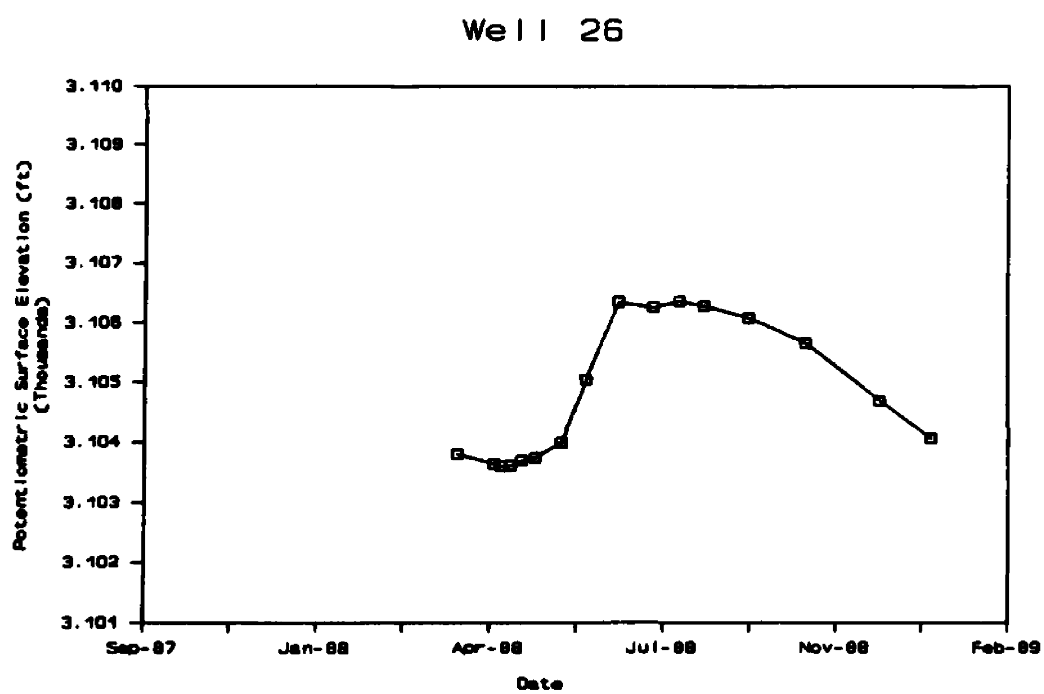

Figure 24: Hydrograph of Well 26.

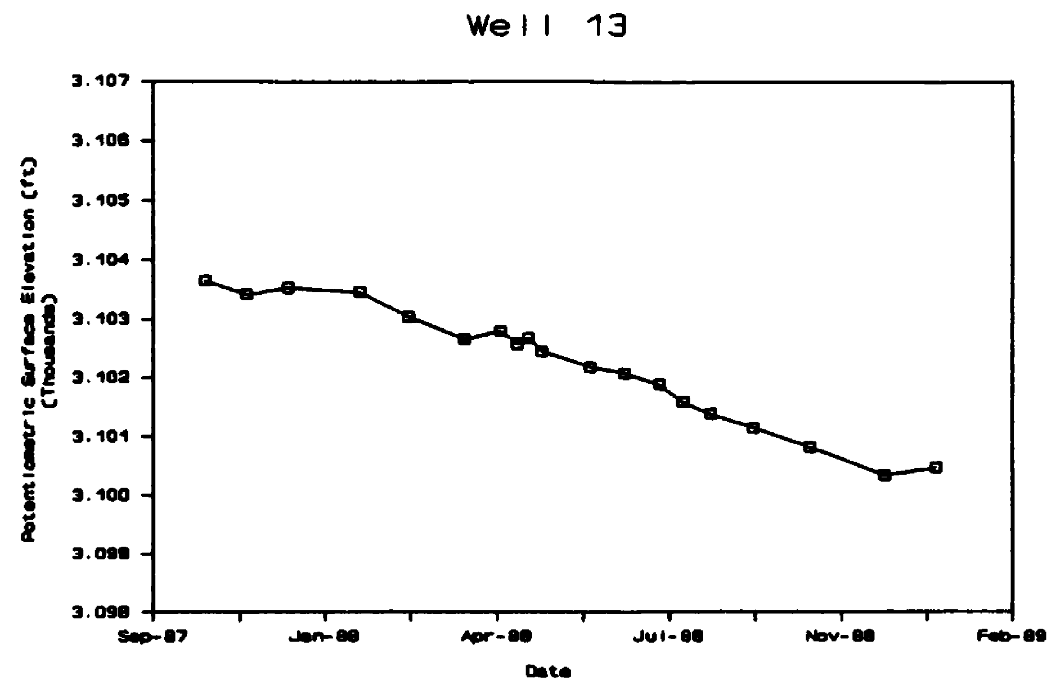

Figure 25: Hydrograph of Well 13.

shows that total discharge from the aquifer, through ground water flow and human consumption, exceeded recharge. The almost linear decrease of Well 13's water level is characteristic of wells on the northeast edge of Area IIb. These wells are practically isolated from recharge sources by the low hydraulic conductivity of the Area's sediments. The main sources of recharge for this Area are the valley side Tertiary sediments and O'Keefe Creek.

The influence of O'Keefe Creek can be seen in a comparison of the hydrograph of Well 13 with those of Wells 16 and 19 (Figure 26 and 27). The water level in all three wells drops throughout the year but the effect of

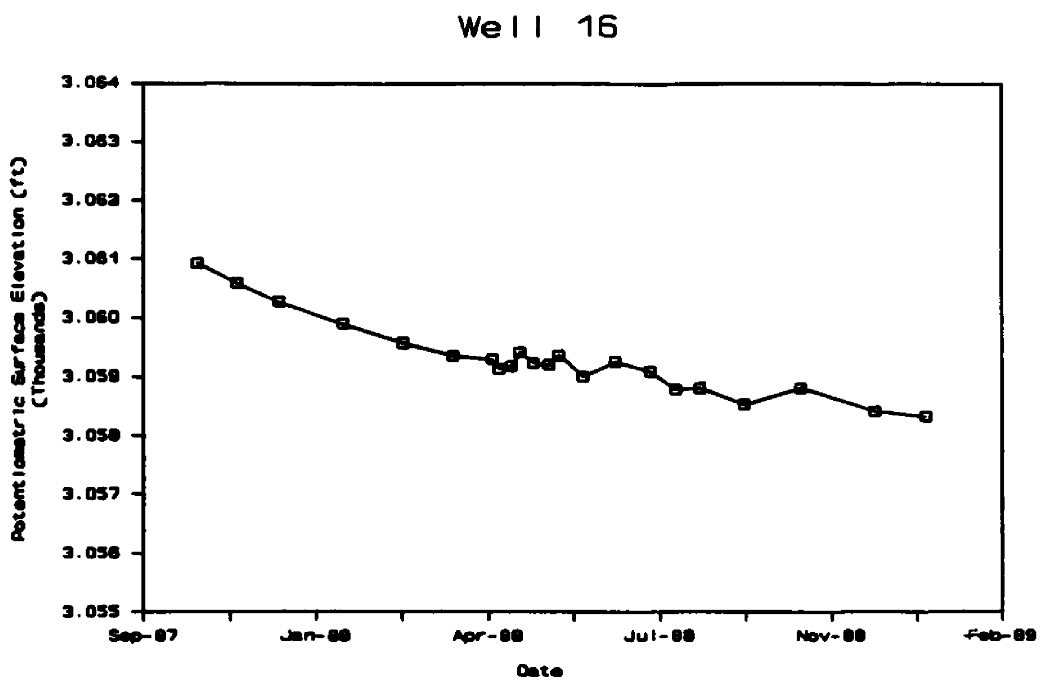

Figure 26: Hydrograph of Well 16

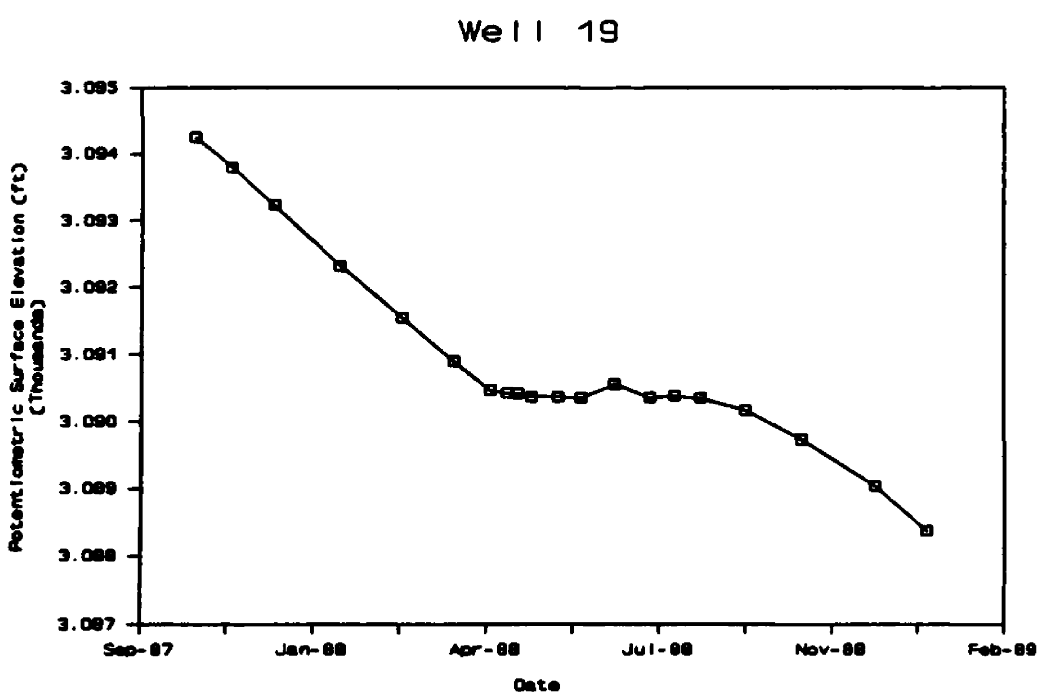

Figure 27: Hydrograph of Well 19

the spring recharge is more evident in Well 19. The nature of the bed of O'Keefe Creek changes as the creek enters the Missoula Valley. At the bottom of Evaro Hill, the creek lies in sands and gravels. As the creek enters The Missoula Valley it flows over Glacial Lake Missoula sediments which greatly reduce the rate of infiltration from the creek. So, although Well 16 is directly down-gradient from O'Keefe Creek, its hydrograph shows only minor effects of the spring recharge.

The effects of human consumption on the aquifer are highly evident in the hydrographs of Wells 9, 10, and 29 (Figures 28, 29 & 30). Each of these wells was unpumped during the study and Wells 9 and 29 had continuous recorders. Well 9 is shallow and near the river (Area III), wells 10 and 29 are deep wells in the middle of the aquifer (Areas III & IV). Both wells 9 and 10 react quickly to river recharge, though their distance from the recharge region of the river gives them the characteristic damped response. Well 29 shows a sharp drop in water elevation beginning with the June measurement and lasting until early September. Neither of the other two wells shows a response of the same magnitude. This response is characteristic of basal gravel wells in Area IV. The potentiometric surface maps (Figures 18 & 19) indicate that Area IV receives its ground water from the rest of the valley and the north side slopes, except during the spring river rise, as indicated by Well 29's hydrograph. The substantial drop in the potentiometric surface was undoubtedly due to the quantity of

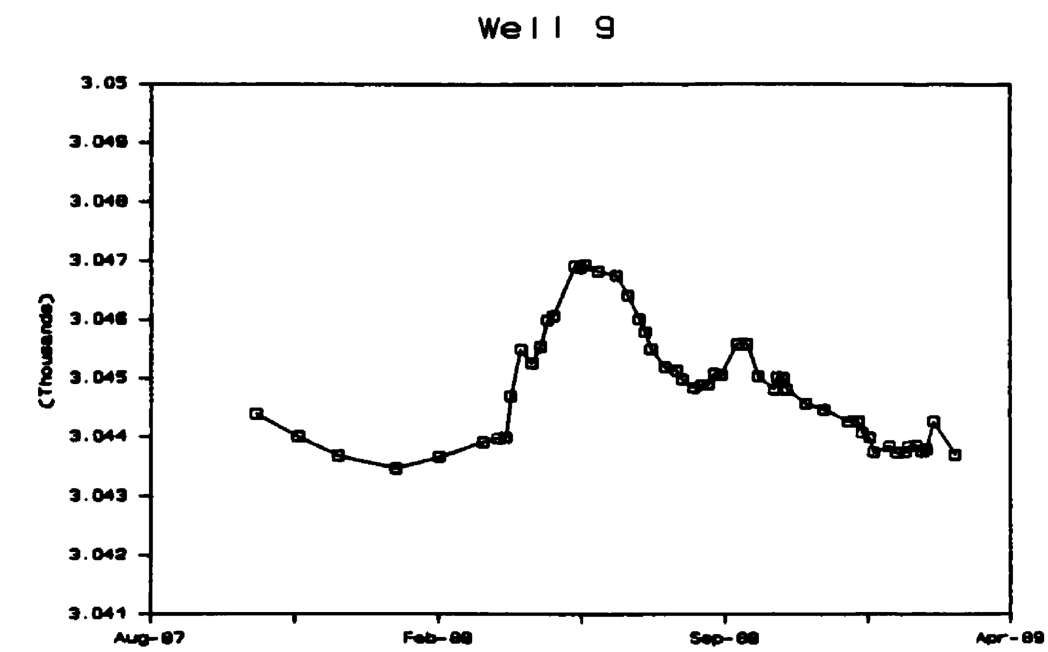

Figure 28: Hydrograph of Well 9

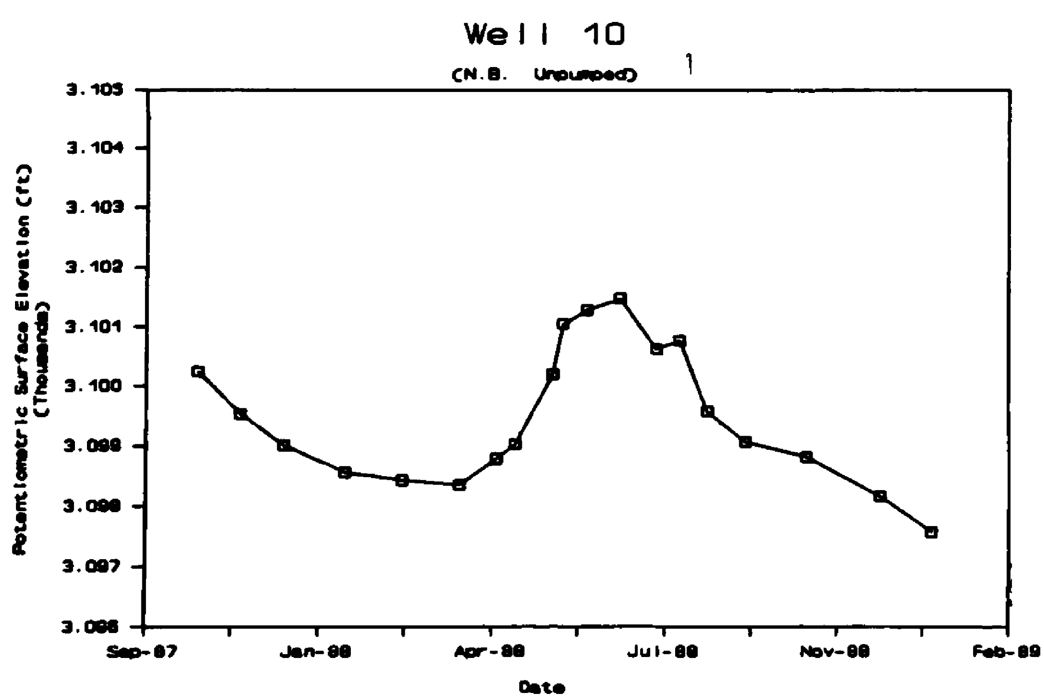

Figure 29: Hydrograph of Well 10

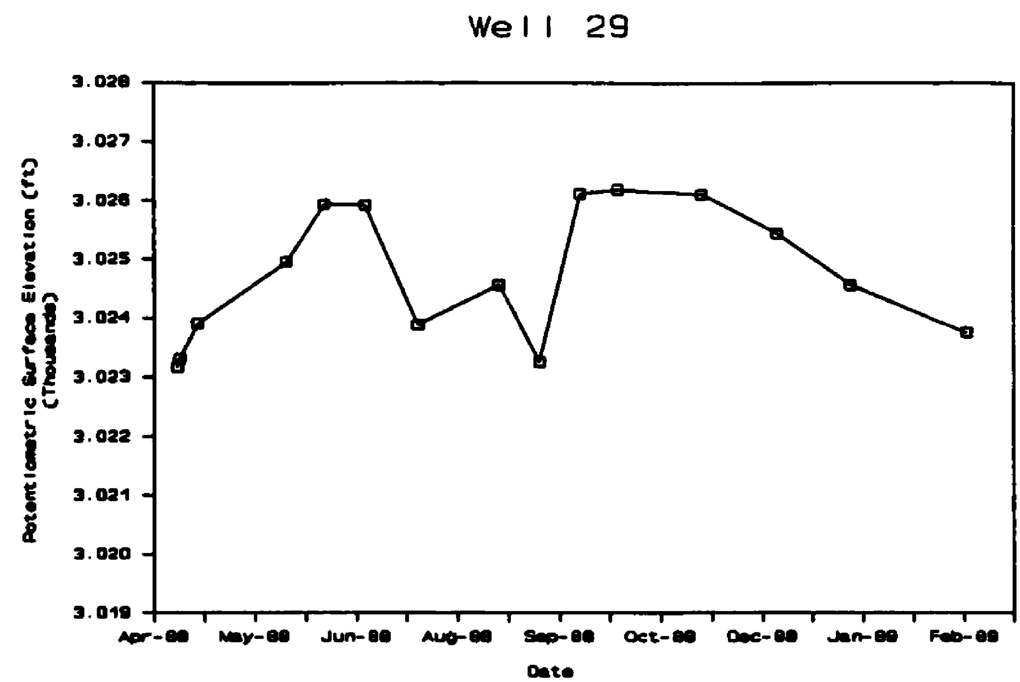

Figure 30: Hydrograph of Well 29

water consumed throughout the valley during the long dry summer. Once the summer ended (early September), ground water consumption diminished and the aquifer returned to a level indicative of lesser removal rates and stress. The volume of water withdrawn was probably greater than in a non-drought year. All hydrographs of wells in the lower elevations of the valley (Areas I, III, and IV) show an increase in slope after the September reading, indicating that the effects of decreased ground water consumption can be seen over the entire valley floor.

Aquifer stress produced by heavy consumption is visible intra-Area as well as inter-Area. Well 29 and 21 (Figure 31) exploit the basal gravel

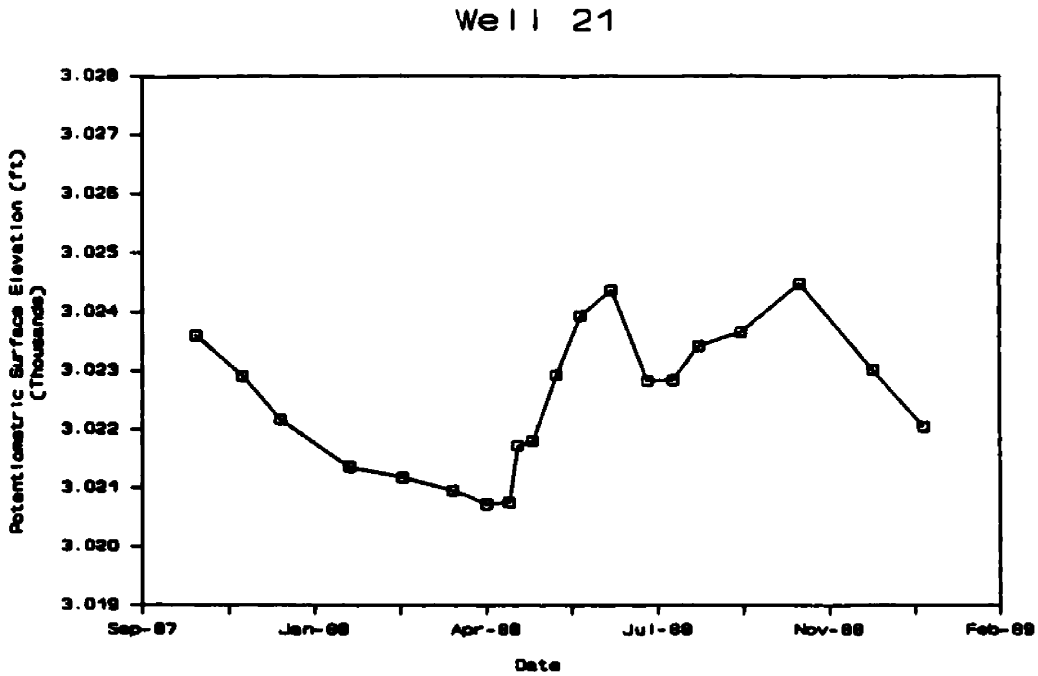

Figure 31: Hydrograph of Well 21

aquifer. Well 22 (Figure 32) exploits the shallow gravel, water table, aquifer. All wells are in Area IV. Wells 29 and 21 show the characteristic substantial drop in summer well water elevations caused by withdrawal from the basal gravel aquifer. Well 22 shows only a small drop. This drop may signify summer withdrawal for agricultural needs (this is trivial as field irrigation is done off the river and irrigation ditches and most gardens are watered from a house well), recharge from the upper gravel to the middle silty-sand layer which in turn is recharging the basal gravel, or a combination of the two.

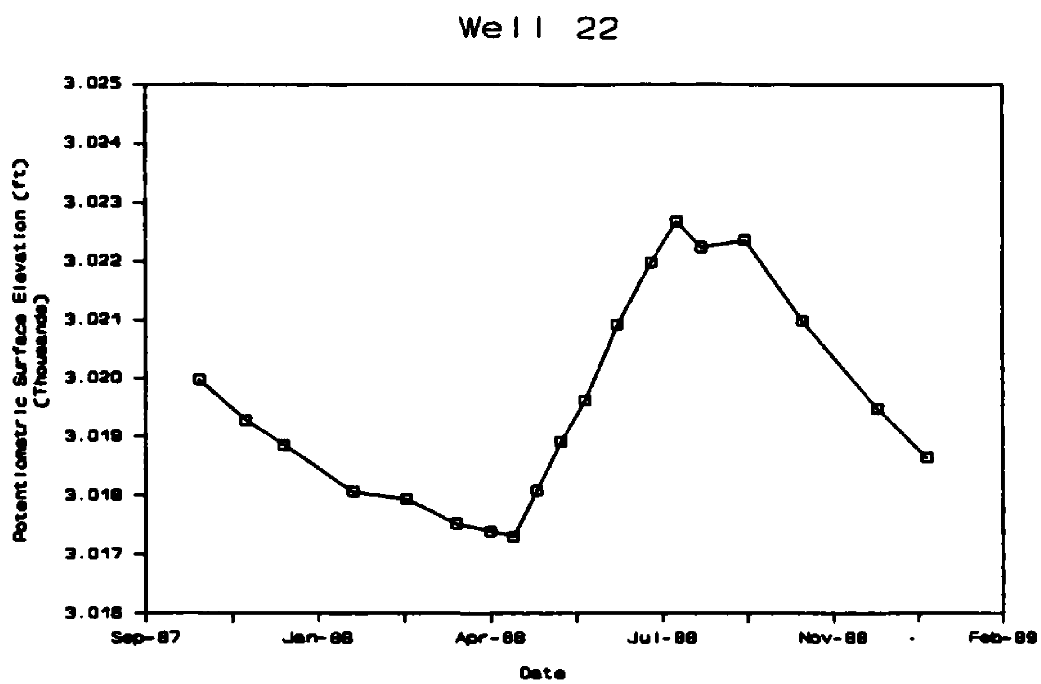

Figure 32: Hydrograph of Well 22

Summary.

The Missoula Valley aquifers can be separated into four main groups: Precambrian and Cambrian Bedrock; Tertiary Sediments; Quaternary Creek Alluvia; and Quaternary Valley Floor Alluvia. The bedrock and Tertiary sediments have very low hydraulic conductivity, less than 400 gpd/ft^2. KCALC calculations indicate that the creek and valley floor alluvia have a wide hydraulic conductivity range up to 210,000 gpd/ft^2. The Valley Floor Alluvia forms the valley's major aquifer. This aquifer has three stratigraphic units: an upper gravel; a middle silty-sand; and a basal gravel. Tertiary sediments below the basal gravel form the bottom of the aquifer. The water table is in the upper gravel and the three layers are saturated. The basal gravel is the valley's main domestic, and industrial aquifer. The silty-sand layer does not produce at high enough rates for domestic use and the upper gravel water table aquifer is used for mainly minor agricultural needs.

The aquifer system is recharged by the Clark Fork River, the side creeks and the Tertiary sediments and Precambrian and Cambrian bedrock highlands of the east and north valley sides. Spring recharge via infiltration from the river and valley side creeks apparently is the major recharge event.

The valley has a characteristic flow pattern which holds for the year. Flow patterns delineate four major flow regimes: general westerly flow from Area I to Area III's south end; flow from the east side of Area IIb which splits to north and south over Area IIb's low hydraulic conductivity bedrock and sediments, the north side flow joins up with recharge from O'Keefe Creek Drainage; northwest to westward flow in Area III's northern third; and westward flow along and across Area IV to the river. Ground water exits the valley at Huson and via discharge to the Clark Fork River.

Magnitude of aquifer response to recharge depends upon proximity to the source of recharge and the hydrogeologic characteristics of the aquifer.

Wells close to their recharge source and in a moderate to high hydraulic conductivity aquifer show acute response to recharge. Wells farther away from their recharge source and/or in low hydraulic conductivity aquifers show dampened response to recharge. Hydrographs of wells in Area IIb's low hydraulic conductivity, finer sediments show less than a quarter of a foot response to spring recharge from any source. The water elevation in these wells dropped throughout the project.

Wells throughout the valley had lowered water elevations during the summer of 1988 in response to heavy withdrawal. This response was amplified in Area IV. Comparison of hydrographs from the upper and basal gravels indicate some recharge to the basal gravel from the water table aquifer.

CHEMISTRY

The ground water inorganic chemical analyses results were used to characterize the aquifers and delineate any sources of recharge based upon the chemistry of the groundwater. This is possible because groundwater will acquire the chemical characteristics of its aquifer. The details of the analysis procedures are in the Methods section. A complete listing of analysis results is in Appendix V and the calculated results are in Table 4.

My analysis show that the groundwater in the Missoula Valley is calcium-bicarbonate water. The exception to this is Well 12 which is sodium-bicarbonate water. This well is in Area IIb in the complex sedimentary pile at the bottom of the O'Keefe Creek drainage. I checked with the well's owners; there is no water softener. I also learned that the water chemistry in that area may change from house to house. Many of the wells around Well 12 were reported to have hard water, while the water from Well 12 is soft.

Total Dissolved Solids (TDS) ranges from 171 to 375 parts per million (ppm). The majority of the samples were in the mid to upper 200 ppm range. The lowest TDS value was from Well 27, which had a value closer to river values. This well is the closest to the Grant Creek drainage. Pottinger (1988) noted that TDS values increase away from Grant Creek.

Hardness, expressed as the sum of magnesium and calcium

Table 4: Calculated Chemical Characteristics of the Missoula Valley Groundwater.

Area	Well No.	Ca/Si	Mg+Ca*	TDS*
I	1	8.44	66.89	302.47
I	2	8.96	71.87	319.72
I	3	7.90	72.35	308.12
I	27	4.91	41.35	171.00
IIa	4	7.64	66.50	280.62
IIa	26	5.99	62.26	278.12
IIb	12	0.56	21.62	221.31
IIb	13	3.18	49.73	289.98
IIb	13	3.15	48.02	284.88
IIb	19	2.24	38.47	221.99
IIc	15	2.74	40.84	210.66
IIc	16	3.18	55.30	295.28
III	5	7.80	65.57	267.10
III	6	7.70	63.76	264.11
III	8	5.89	51.05	219.08
III	9	6.38	62.62	282.62
III	10	6.55	51.24	205.63
III	10	6.67	49.82	204.83
III	11	6.29	79.91	367.04
III	14	7.41	63.55	272.63
III	18	4.53	61.87	356.84
III	20	1.82	32.62	196.05
III	28	5.78	74.01	353.31
III	28	5.84	74.50	348.50
IV	21	4.61	52.41	253.97
IV	21	4.63	52.89	254.41
IV	22	7.86	85.80	374.61
IV	23	3.62	44.12	211.15
IV	24	3.70	46.20	223.90
IV	25	5.06	61.77	279.33
Clark Fork River				
Harper's Bridge.		5.40	41.29	183.21
Kona Ranch Bridge.		5.64	43.81	196.81

* All values in ppm.

concentrations, in the valley ranges from 22 to 80 ppm. These values showthat the water is moderately hard (Hem, 1985). The hardest water is from the floor of the valley, except for Wells 27, 23 and 24, which have uncharacteristically low hardness.

The ratio of calcium to silica can be used as an indicator of the freedom of circulation in the aquifer (Geldon, 1979), as silica will accumulate in groundwater with restricted circulation. The ratio values range from 0.56 to 8.96 ppm. The lowest values are along the east side of the valley and at the end of the valley.

Figure 33 shows stiff diagrams of the valley's water chemistry. The relative size of the diagram denotes TDS. In general there is an increase in TDS along the valley's trend and also from east to west across the valley. The chemical difference between the valley's eastern side and the valley floor is generally evident. The sodium-bicarbonate water of Well 12 is striking in its different signature. The low TDS water of Area IV is notable in comparison with the other Areas of the valley floor. Well 22 is finished in the upper aquifer of Area IV. Its marked difference from the deeper water may be due to the chemistry of the upper strata or to domestic and agricultural pollution.

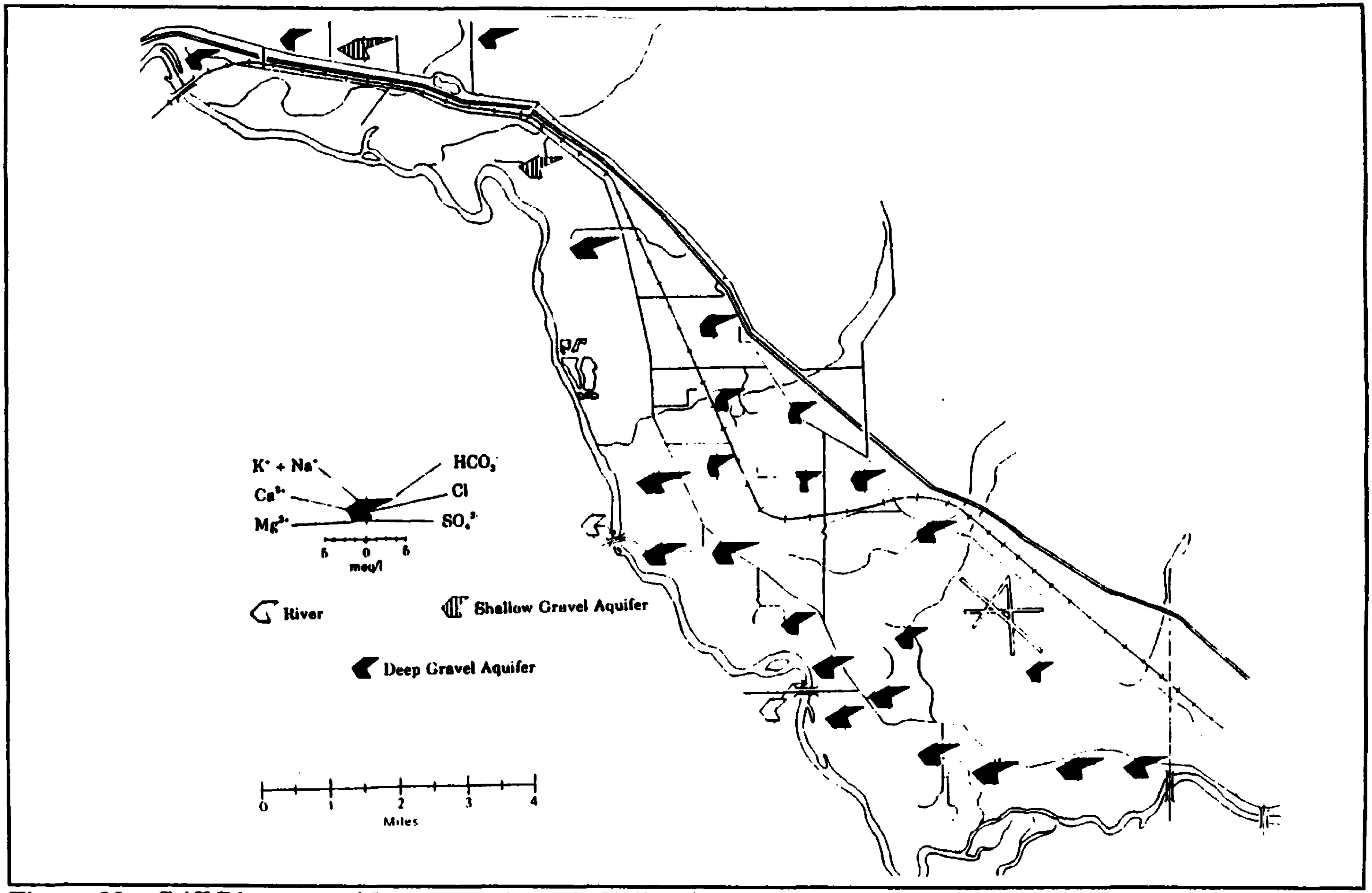

Figure 33: : Stiff Diagrams of Inorganic Missoula Valley Groundwater Chemistry.

CONCLUSION AND RECOMMENDATIONS

Summary and Conclusions.

The Missoula Valley is a northwest trending inter-montaine basin in the center of the west edge of Montana. The valley is fed by the Clark Fork and Bitterroot Rivers and 16 major creeks. The Valley is drained by solely the Clark Fork River.

The Valley basement and surrounding mountains are Precambrian and Cambrian meta-sedimentary rocks. The valley floor is covered with Tertiary to Holocene sediments. The valley's eastern side is composed of a complex, intermixed pile of Tertiary colluvium and Quaternary creek alluvia. The bottom of the valley is comprised of up to 3,000 feet of basal Tertiary sediments topped by up to 350 feet of Pleistocene to Holocene glacial and fluvial sediments. The Pleistocene to Holocene sediments were deposited either from Glacial Lake Missoula or by the Clark Fork River and generally increase in sorting and decrease in size away from Hellgate Canyon. These sediments have a characteristic three layer stratigraphy which becomes more prominent farther from Hellgate Canyon and contain the principal aquifer of the valley. The geology of the valley is graphically summarized in Figure 34, a schematic geologic cross-section through the valley's center from Reserve street to the Huson end of the valley.

The geologic units of the valley floor form the frame work for the

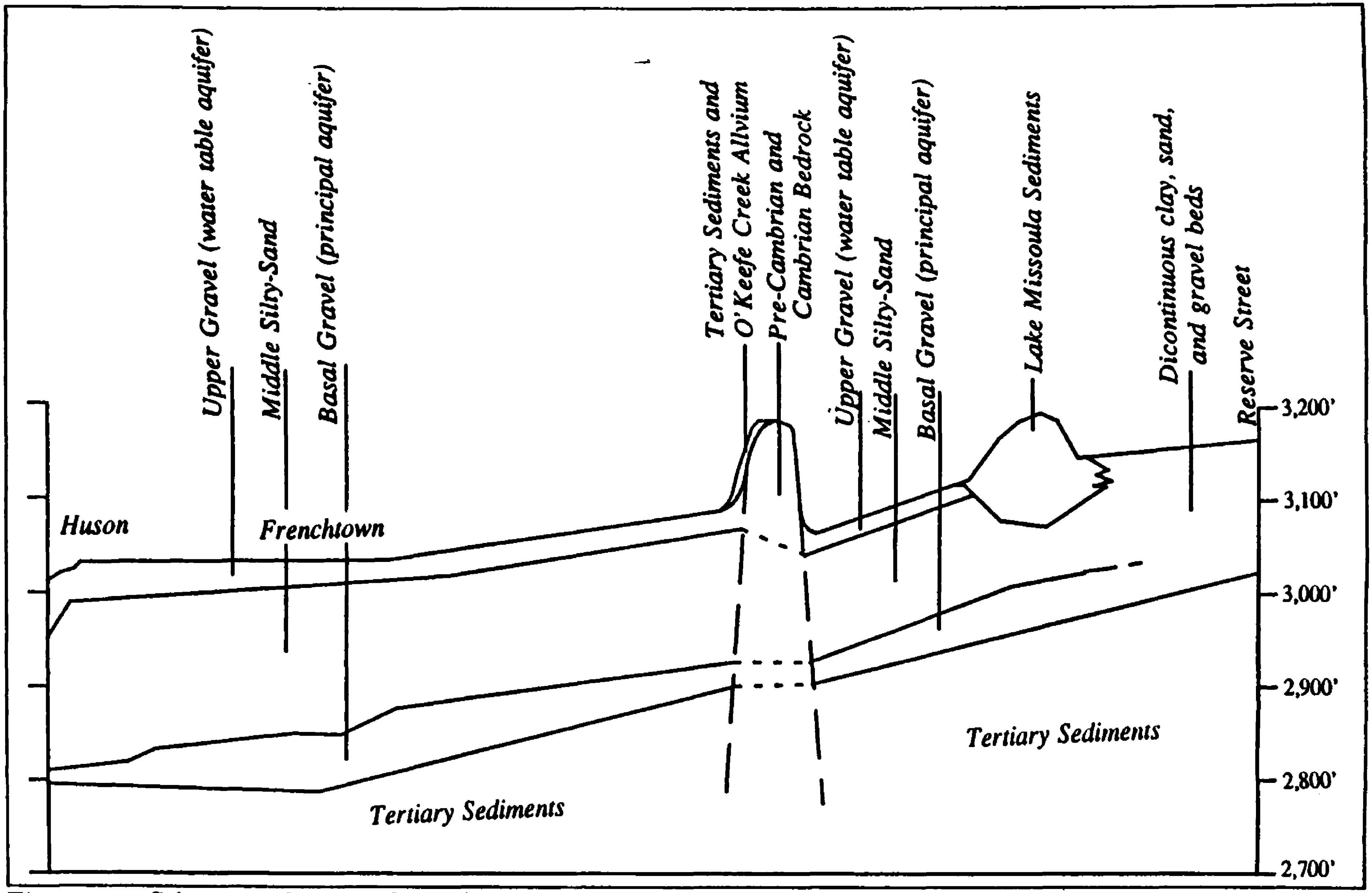

Figure 34: Schematic Geologic Cross-Section though center of Missoula Valley.

aquifers of the valley. The three layered valley floor sediments are the Missoula Aquifer, even thought the three layer stratigraphy is absent under the city of Missoula. The high hydraulic conductivity gravel stratum at the base of the of the valley floor Quaternary sediments is the principal aquifer.

The valley is recharged by the Clark Fork River, the creeks of the hills and mountains surrounding the valley, and flow from the Tertiary sediments of the east and north valley sides. Potentiometric surface plots indicate that for most of the year only the first four to five miles of the river is influent. Hydrographs from wells on the valley's west side indicate that the river is influent for the length of the valley during the spring rise in river level. The valley's east and north sides are recharged by the creeks and Tertiary sediments; the creeks of the west side of the valley flow directly to the river. Potentiometric surface plots indicate that the O'Keefe creek drainage is an important source of recharge to the valley's northern half throughout the year. This is important as Area IIb's low hydraulic conductivity bedrock and sediments effectively dam the influence of the river.

Hydraulic conductivity in the valley is lowest in the fractured Precambrian and Cambrian bedrock and clay-rich Tertiary sediments and averages around 7,000 gpd/ft^2 in the creek alluvium and glacio-fluvial sediments. Flow in the valley is generally along the trend of the valley. The notable exception to this is in the middle of the valley where bedrock and Tertiary sediments deflect groundwater flow toward the Clark Fork River.

Groundwater elevations seasonally fluctuate three to nine feet, as evinced by domestic well water levels. Lowest well water levels are in March and April while the highest are between March and July. The timing and magnitude of groundwater fluctuations depends on the distance from the recharge source, the aquifer's geology and hydrologic parameters, and the effects of human exploitation.

Inorganic chemical analyses indicate that the valley's ground water is good quality. The analyses indicate that the aquifer along the valley's east side, especially in Area IIb, has a different chemical nature than the valley floor aquifer. This may be due to the influence of Tertiary sediments, which have a markedly different chemistry.

In light of geologic, flow direction and chemical information, the interaction of the Clark Fork River and the aquifer are most important on the valley floor. Interaction with the eastern and northern valley side creeks is important along the eastern edge of the valley and in the Frenchtown-Huson end of the valley.

Recommendations.

During the past few years, the importance and fragility of the Missoula Valley Aquifer has been impressed on the residents of the valley. There has been a drought which limited our use of aquifer water. There have been numerous reported cases of chemical, especially organic chemical, and biological pollution. The continued increase in the valley's population will increase the exploitation of the aquifer for consumable water and will increase the possibility of aquifer degradation. Obviously there is a need for sensible, responsible urban planning in the future. Area IIb is a good example of this need. The Area is practically isolated from its source of recharge due to the low hydraulic conductivity of its aquifers and does not receive adequate recharge for the human needs of the area. Proper planning will site wells in areas where the aquifer has a ready source of recharge; the obvious place for wells is in the higher hydraulic conductivity sediments of the valley's floor.

Further studies need be done on the aquifers of the Missoula Valley to ensure their optimum and responsible use. Studies such as:

- A study of the vertical flow patterns in the valley, which would aide in determining the importance of recharge from the underlying Tertiary sediments and of flow between the different Quaternary alluvia.

- A study of flow through and out of the Tertiary sediments of the valley's east and north sides; possibly in conjunction with chemical analysis.

- A study of the chemistry of the aquifer, especially in the complex sedimentary pile of the valley's east side.

- A detailed study of the connection between the Clark Fork river and the Aquifer, including the effects of recharge by the irrigation ditches of the valley.

- A study of the effects of domestic, agricultural, and industrial consumption on the aquifer.

The people of the Missoula Valley are fortunate to have a quality water resource. But, they need to realize that it is a limited and sensitive resource that must be protected.

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APPENDIX I

A Summary of the Geologic History of the Missoula Valley

Introduction.

The following is a review of local geologic history from previous works on the Missoula Basin and Western Montana geology.

The Missoula Valley began opening due to listric normal faulting during the early Tertiary Laramide Orogeny (Dott & Batten,1981). Though the Laramide Orogeny ended during the early Eocene, extension and subsidence continued at least until the late Pliocene when the final lowering of the Alberton Narrows occurred. Early Miocene extension is evinced by tilting of Oligocene beds. The tilting is not present in middle to late Miocene beds (Clark, 1986). Hall (1969) notes that the Primrose Fault places Tertiary sediments against Precambrian rocks and that there are pieces of Tertiary sediments in the fault gouge, so the fault last moved during or after the Tertiary.

Pre-Tertiary.

The mountains that surround the Missoula Valley and the comprise basement of the valley are composed of Precambrian and Cambrian formations. The Precambrian rocks belong to the Belt Supergroup. The mountains on the west side of the valley are composed of the Precambrian Miller Peak Formation, Bonner Quartzite, Garnet Range Formation and Pilcher Quartzite and also the Cambrian Hasmark and Silver Hill Formations. At the southern end of the ridge (13-20-20 to 13-21-1) the

Albert Creek Thrust places the Precambrian Miller Peak over the Cambrian Hasmark (Hall, 1969).

On the floor of the valley there are two out-crops of basement rocks. The north end of the Council Hill ridge, at 13-20-9ccc, is made of Miller Peak Formation (Hall, 1969). About a mile north of Primrose, MT, at 14-20-29,30,31 and 32, the Primrose thrust causes an exposure of Miller Peak, Bonner Quartzite, Silver Hill and Hasmark. The Hasmark is visible from east of Mullen Road in the rail road cut in 14-20-31. The Precambrian formations are on the down-dropped north side of the fault. Hall (1969) theorizes that the Precambrian formations are down-dropped approximately 4,000 feet from the once overlying Albert Creek Thrust.

McMurtrey (1965) notes that the Missoula Basin began opening as a result of Laramide Orogeny extension and the basin might have been an embayment of the Late Cretaceous Sea. There are pre-Eocene deposits in neighboring valleys, but none in the Missoula Valley. Based on this, McMurtrey conjectures that there may be Paleocene and possibly Cretaceous formations at depth in the Missoula Basin. Clark (1986) notes that R.W. Fields logged a pre-Renova conglomerate in U.S. Department of Energy well MB-2 near Alberton, MT. This conglomerate is interpreted as mud-flows and fanglomerates, and is supposed to be located only on the margins of the basin. The actual age of this conglomerate is unknown.

Tertiary.

The Missoula Valley basin is filled with a thick sequence of Tertiary erosional debris which unconformably lie upon the Precambrian and Cambrian basement and pre-Renova conglomerates. These sediments are 2,500 (Geldon, 1979) to 3,000 (McMurtrey, 1965) feet thick at the deepest part of the basin and are mostly Tertiary Renova and Sixmile Creek formation equivalents. The Renova and Sixmile Creek Formations are definitively described by Kuenzi and Fields (1971).

The Renova Formation is predominantly fine grained with less than 30% coarse sediments. At the type section of the formation the fine material consists of sequences of clays, muds, ash, and very fine sand. The coarse material ranges in size from coarse sand to cobbles and small boulders. The formation was deposited in flood plain, pond, stream channel and eolian environments in an arid, internally drained desert basin during the latest Eocene to late middle Oligocene (Clark, 1986; Kuenzi, 1971). During Renova time, the Missoula Valley was an internally drained desert valley. The basin was subsiding and eventually filled with volcanoclastic and erosional debris. The Missoula Valley Renova Equivalent outcrops all along the eastern and northern slopes of the valley (McMurtrey, 1965) and is exposed at 13-20-15cccd in a gravel pit and in 14-20-30 and 31 in the rail road cut visible from Mullen road (Hall, 1969). In the southern two thirds of the valley the Tertiary deposits are well marked by Interstate 90 which roughly follows the lower edge of the outcrops. The outcrops consist of poorly sorted clay to medium sand matrix and minor bedded layers of cobbles and gravels in a fine sand to clay matrix. The matrix is generally a rusty yellow but may be blue, grey, tan and brown.

The Renova Formation is unconformably overlain by the Sixmile Creek Formation. This early-middle to latest Miocene formation is mostly erosional sand and gravel and is characterized by gravels and cobbles. At the type section the formation consists of coarse sand, pebbles, gravels and cobbles of sandstones, siltstones and mudstones. The Sixmile Creek Formation sediments are derived from fast eroding, newly uplifted mountains. The sediments were deposited on alluvial fans in complex systems of ephemeral and perennial stream channel and overbank deposits (Kuenzi & Fields, 1971). McMurtrey (1965) propounds that there are no Sixmile Creek deposits in the Missoula Valley. Clark (1986) notes the Sixmile Creek Equivalent exposed in a road cut on Upper Miller Creek Road, 2.6 miles south of Highway 93. In this exposure the formation consists of poorly sorted and consolidated cobbles and gravels in a medium to coarse, clean sand matrix. These sediments are interbedded with clean, well sorted, weakly iron-stained medium sand and poorly sorted silty medium sand.

Between the end of Renova deposition and the beginning of Sixmile Creek deposition the climate changed from arid to wet (Clark, 1986) and a laterite soil developed on the top of the Renova (Alt, 1989). The Missoula basin finally became externally drained and through-going streams eroded much of the Renova deposits. By the beginning of Sixmile Creek time the climate changed and was again arid, the basin drained internally and eventually filled with detritus from the surrounding highlands (Clark, 1986).

During the Pliocene extensional faulting continued. This raised the surrounding mountains and lowered the Alberton Narrows, west of Huson, MT, to their modern positions. The climate again became wet and the valley developed external drainage. Streams and rivers removed much of the valley sediments, thereby creating the hanging valleys surrounding the modern basin, e.g. on Mount Sentinel (Clark, 1986).

Quaternary.

Quaternary sediments comprise most of the upper strata of the Missoula Valley and unconformably lie on Tertiary deposits. The Quaternary deposits are comprised of interbedded cobbles, gravel, sand, and clays which represent a complex mixture of colluvial, alluvial, fluvial and lacustrine sediments (Morgan, 1986; Geldon, 1979; and Clark, 1986). Probably the most striking and well studied of these sediments are the tan-pink Glacial Lake Missoula varved silts and clays. Chambers (1971) studied the varves in and around the Missoula valley and did a detailed description of a portion of the sequence. Chambers notes that the sediments are varved silts and clays interbedded with occasional beds of cross-bedded sand and imbricated gravel. The varved silts and clays are yearly lacustrine deposits from the at least 60 fillings of the lake (Waitt, 1985) and the sand and gravel are flood deposits from the catastrophic release of the lake.

Recent.

Recent sediments are interbedded cobbles, gravels, sands and clays at the surface of the valley. These sediments are active in the modern channels of the Clark Fork River and in the channels of the streams entering the valley (McMurtrey, 1965). The sediments form poorly to moderately sorted fluvial deposits that interfinger with older, glacial and post glacial sediments. It is usually difficult to positively differentiate between late and post Glacial and Recent sediments because most are in fluvial deposits of reworked glacial sediments.

APPENDIX II

Domestic Well & Piezometer Measurements
October 1987 - December 1988

A note on captions:

Loc. : Township, Range, and Section location of the well
M.P. : The elvation, in feet (unless otherwise noted), above the ground of the measurement point on the casing.
Elev. : The ground elevation, in feet above mean sea level, at the base of the exposed casing.
Cas. : The diameter of the well casing.
T.D. : The Total Depth of the well, in feet.

Well No. 1
Loc.: 13-19-18acccc
Owner: Oscar Koepplin
Address: 4155 Mullen Road.

M.P.: 2.6 Elev.: 3161
Cas.: 5.5" T.D.: 50

Date	Water Elev.	Change Water Elev.
23-Oct-87	3133.00	
24-Nov-87	3131.75	-1.25
16-Dec-87	3131.18	-0.57
23-Jan-88	3130.84	-0.34
25-Feb-88	3130.54	-0.30
27-Mar-88	3130.74	0.20
19-Apr-88	3131.92	1.18
23-Apr-88	3132.78	0.86
30-Apr-88	3133.26	0.48
05-May-88	3133.75	0.49
14-May-88	3135.34	1.59
22-May-88	3136.85	1.51
28-May-88	3138.01	1.16
11-Jun-88	3139.02	1.01
30-Jun-88	3138.16	-0.86
20-Jul-88	3136.41	-1.75
03-Aug-88	3135.42	-0.99
19-Aug-88	3134.25	-1.17
10-Sep-88	3132.98	-1.27
16-Oct-88	3132.40	-0.58
28-Nov-88	3131.70	-0.70
28-Dec-88	3130.50	-1.20

Well No. 2
Loc.: 13-20-13accdd
Owner: Mike Schwenk
Address: 1600 Marie Drive.

M.P.: 1.58 Elev.: 3139.24
Cas.: 5.5" T.D.: 39.3

Date	Water Elev.	Change Water Elev.
23-Oct-87	3130.12	
24-Nov-87	3129.22	-0.90
16-Dec-87	3128.77	-0.45
23-Jan-88	3128.37	-0.40
25-Feb-88	3128.18	-0.19
27-Mar-88	3128.33	0.15
19-Apr-88	3129.14	0.81
14-May-88	3131.44	2.30
28-May-88	3133.16	1.72
11-Jun-88	3133.74	0.58
30-Jun-88	3133.31	-0.43
21-Jul-88	3132.29	-1.02
03-Aug-88	3131.81	-0.48
19-Aug-88	3131.04	-0.77
10-Sep-88	3130.17	-0.87
16-Oct-88	3129.80	-0.37
28-Nov-88	3129.21	-0.59
28-Dec-88	3128.31	-0.90

Well Elevation surveyed off county spike in telephone pole at north end of Marie Drive.

Spike: 3150.77' above sea level
Theodolite: +0.97' above spike
Well: -12.5' below theodolite

Well No. 3
Loc.: 13-20-14caaa
Owner: Larry Pettijohn
Address: 1505 Topaz Lane

M.P.: 1.12 Elev.: 3144
Cas.: 5.5" T.D.: 96

Date	Water Elev.	Change Water Elev.
31-Oct-87	3121.39	
23-Nov-87	3121.09	-0.30
16-Dec-87	3120.76	-0.33
23-Jan-88	3120.49	-0.27
25-Feb-88	3120.41	-0.08
27-Mar-88	3120.48	0.07
19-Apr-88	3121.24	0.76
23-Apr-88	3121.46	0.22
30-Apr-88	3121.47	0.01
05-May-88	3121.75	0.28
14-May-88	3122.47	0.72
22-May-88	3122.51	0.04
28-May-88	3123.23	0.72
11-Jun-88	3123.11	-0.12
30-Jun-88	3122.94	-0.17
20-Jul-88	3122.05	-0.89
03-Aug-88	3122.06	0.01
19-Aug-88	3121.69	-0.37
10-Sep-88	3121.26	-0.43
16-Oct-88	3121.41	0.15
28-Nov-88	3121.10	-0.31
28-Dec-88	3120.59	-0.51

Well No. 4
Loc.: 13-20-15acadbd
Owner: Sam & Peggy Wagner
Address: 8025 Lazy H Trail

M.P.: 0.54 Elev.: 3191
Cas.: 5.5" T.D.: 180

Date	Water Elev.	Change Water Elev.
23-Oct-87	3107.93	
27-Nov-87	3107.64	-0.29
91-Dec-87	3107.25	-0.39
30-Jan-88	3106.99	-0.26
27-Feb-88	3106.81	-0.18

Due to measuring problems, moved across road.

Loc.: 13-20-15acadcd
Owner: William Goodrich
Address: 8050 Lazy H Trail

M.P. 1.71 Elev.: 3196
Cas.: 5.5" T.D.: 178

Date	Water Elev.	Change Water Elev.
29-Mar-88	3107.25	0.44
19-Apr-88	3107.90	0.65
30-Apr-88	3108.11	0.21
14-May-88	3108.98	0.87
28-May-88	3109.84	0.86
11-Jun-88	3109.62	-0.22
30-Jun-88	3109.55	-0.07
20-Jul-88	3108.35	-1.20
03-Aug-88	3108.66	0.31
19-Aug-88	3108.38	-0.28
10-Sep-88	3107.89	-0.49
16-Oct-88	3108.18	0.29
28-Nov-88	3107.86	-0.32
28-Dec-88	3107.34	-0.52

Well No. 5
Loc.: 13-20-9dabb
Owner: John & Pam Bukovatz
Address: 9350 Mullen Road

M.P.: 1.08 Elev.: 3097
Cas.: 6" T.D.: 95

Date	Water Elev.	Change Water Elev.
27-Mar-88	3096.72	
19-Apr-88	3097.32	0.60
23-Apr-88	3097.31	-0.01
30-Apr-88	3097.35	0.04
05-May-88	3097.54	0.19
14-May-88	3098.49	0.95
22-May-88	3098.32	-0.17
28-May-88	3099.05	0.73
11-Jun-88	3098.92	-0.13
30-Jun-88	3099.12	0.20
20-Jul-88	3098.01	-1.11
03-Aug-88	3098.03	0.02
19-Aug-88	3097.98	-0.05
10-Sep-88	3097.57	-0.41
16-Oct-88	3097.57	0.00
28-Nov-88	3097.24	-0.33
28-Dec-88	3096.78	-0.46

Well No. 6
Loc.: 13-20-9bbbcd
Owner: Karl & Donna Tyler
Address: 13100 Mullen Road

M.P.: 1.19 Elev.: 3089
Cas.: 5.5" T.D.: 109.5

Date	Water Elev.	Change Water Elev.
23-Oct-87	3083.85	
24-Nov-87	3083.51	-0.34
16-Dec-87	3083.10	-0.41
23-Jan-88	3083.06	-0.04
25-Feb-88	3083.09	0.03
27-Mar-88	3083.25	0.16
19-Apr-88	3084.43	1.18
23-Apr-88	3084.32	-0.11
30-Apr-88	3084.12	-0.20
05-May-88	3084.24	0.12
14-May-88	3085.19	0.95
22-May-88	3084.84	-0.35
28-May-88	3085.52	0.68
11-Jun-88	3085.19	-0.33
30-Jun-88	3084.97	-0.22
20-Jul-88	3083.82	-1.15
03-Aug-88	3083.66	-0.16
19-Aug-88	3083.72	0.06
10-Sep-88	3083.47	-0.25
16-Oct-88	3083.41	-0.06
28-Nov-88	3083.37	-0.04
28-Dec-88	3083.11	-0.26

Well No. 8
Loc.: 13-20-5bdddd
Mallard Court Lot 15
Owner: Charley Campfield
Address: Evaro.
Well
Address: 11555 Mallard Court

M.P.: 2.2 Elev.: 3073
Cas.: 4" T.D.: 30

Date	Water Elev.	Change Water Elev.
23-Oct-87	3067.12	
30-Nov-87	3066.78	-0.34
30-Jan-88	3066.50	-0.28
28-Feb-88	3066.59	0.09
29-Mar-88	3066.71	0.12
19-Apr-88	3068.04	1.33
30-Apr-88	3067.99	-0.05
14-May-88	3069.15	1.16
28-May-88	3069.72	0.57
21-Jul-88	3067.71	-2.01
04-Aug-88	3067.52	-0.19
19-Aug-88	3067.53	0.01
10-Sep-88	3067.37	-0.16
17-Oct-88	3067.40	0.03
28-Nov-88	3067.05	-0.35
29-Dec-88	3066.68	-0.37

Well No. 9
Loc.: 14-21-36dbbb
Owner: Gene & Joice Starlin
Address: 14125 Harper's Bridge Rd.

M.P.: 0.7 Elev.: 3056
Cas.: 4" T.D.: 31

Date	Water Elev.	Change Water Elev.
10/23/87	3044.40	
11/21/87	3044.01	-0.39
12/19/87	3043.68	-0.33
01/28/88	3043.48	-0.20
02/27/88	3043.67	0.19
03/29/88	3043.92	0.25
04/08/88	3043.98	0.06
04/14/88	3044.00	0.02
04/17/88	3044.70	0.70
04/24/88	3045.50	0.80
05/02/88	3045.27	-0.23
05/08/88	3045.55	0.28
05/13/88	3046.00	0.45
05/17/88	3046.07	0.07
06/01/88	3046.93	0.86
06/05/88	3046.90	-0.03
06/08/88	3046.95	0.05
06/17/88	3046.84	-0.11
06/30/88	3046.77	-0.07
07/08/88	3046.43	-0.34
07/16/88	3046.03	-0.40
07/20/88	3045.81	-0.22
07/24/88	3045.52	-0.29
08/03/88	3045.20	-0.32
08/11/88	3045.15	-0.05
08/15/88	3045.00	-0.15
08/23/88	3044.86	-0.14
08/28/88	3044.90	0.04
09/02/88	3044.90	0.00
09/06/88	3045.09	0.19
09/11/88	3045.06	-0.03
09/22/88	3045.60	0.54
09/29/88	3045.60	0.00
10/07/88	3045.04	-0.56
10/18/88	3044.82	-0.22
10/20/88	3045.03	0.21
10/24/88	3045.02	-0.01
10/27/88	3044.82	-0.20
11/09/88	3044.58	-0.24
11/22/88	3044.48	-0.10
12/09/88	3044.28	-0.20
12/16/88	3044.28	0.00
12/19/88	3044.08	-0.20

Date	Water Elev.	Change Water Elev.
12/24/88	3044.00	-0.08
12/27/88	3043.75	-0.25
01/07/89	3043.85	0.10
01/12/89	3043.74	-0.11
01/18/89	3043.75	0.01
01/20/89	3043.85	0.10
01/26/89	3043.86	0.01
01/30/89	3043.76	-0.10
02/02/89	3043.80	0.04
02/07/89	3044.27	0.47
02/22/89	3043.71	-0.56

* Data from Stevens ontinuous Recorder chart.

Well No. 10
Loc.: 13-20-3ccab
Owner: Charles Deschamps
Address: 8150 Mullen Rd.

M.P.: 1.05 Elev.: 3099
Cas.: 5.5" T.D.: 116

Date	Water Elev.	Change Water Elev.
30-Oct-87	3099.24	
24-Nov-87	3098.54	-0.70
19-Dec-87	3098.02	-0.52
23-Jan-88	3097.57	-0.45
25-Feb-88	3097.43	-0.14
29-Mar-88	3097.36	-0.07
19-Apr-88	3097.79	0.43
30-Apr-88	3098.04	0.25
22-May-88	3099.21	1.17
28-May-88	3100.05	0.84

New M.P.: 3.53

Date	Water Elev.	Change Water Elev.
11-Jun-88	3100.29	0.24
30-Jun-88	3100.48	0.19
21-Jul-88	3099.63	-0.85
03-Aug-88	3099.77	0.14
19-Aug-88	3099.58	-0.19
10-Sep-88	3099.08	-0.50
16-Oct-88	3098.82	-0.26
28-Nov-88	3097.57	-0.60

Well No. 11
Loc.: 14-21-25caaada
Owner: C.W. Fairbanks.
Address: Fairbanks Lane., off Mullen Rd., south of Schilling Siding.

M.P.: -2.18 Elev.: 3059
Cas.: 5.5" T.D.: 115

Date	Water Elev.	Change Water Elev.
30-Oct-87	3041.38	
21-Nov-87	3040.68	-0.70
17-Dec-87	3039.77	-0.91
23-Jan-88	3039.39	-0.38
27-Feb-88	3040.81	1.42
29-Mar-88	3040.64	-0.17
19-Apr-88	3043.07	2.43
30-Apr-88	3041.68	-1.39
14-May-88	3042.79	1.11
28-May-88	3044.39	1.60
11-Jun-88	3044.51	0.12
30-Jun-88	3045.19	0.68
20-Jul-88	3044.23	-0.96
03-Aug-88	3043.96	-0.27
19-Aug-88	3043.39	-0.57
13-Sep-88	3043.65	0.26
16-Oct-88	3042.62	-1.03
28-Nov-88	3041.80	-0.82
28-Dec-88	3040.02	-1.78

Well No. 12
Loc.: 14-20-19dbbabc
Owner: Arnold Harrison
Address: 11205 Moccasin Lane.

M.P.: 0.85 Elev.: 3220
Cas.: 5.5 T.D.: 200

Date	Water Elev.	Change Water Elev.
30-Oct-87	3109.23	
21-Nov-87	3109.26	0.03
16-Dec-87	3113.61	4.35
23-Jan-88	3116.23	2.62
27-Feb-88	3120.16	3.93
29-Mar-88	3117.36	-2.80

Well abandoned after a finding leak in system.
N.B. These values are suspect. See Well 30.

Well No. 13
Loc.: 14-20-28dbbabc
Owner: Robert Beale.
Address: Arrow Factors Corp., 9775 E. Summit Dr.

M.P.: -4.75 Elev.: 3224
Cas.: 5.5" T.D.: 158

Date	Water Elev.	Change Water Elev.
30-Oct-87	3103.65	
23-Nov-87	3103.42	-0.23
17-Dec-87	3103.53	0.11
28-Jan-88	3103.45	-0.08
25-Feb-88	3103.04	-0.41
29-Mar-88	3102.65	-0.39
19-Apr-88	3102.80	0.15
29-Apr-88	3102.58	-0.22
05-May-88	3102.68	0.10
13-May-88	3102.45	-0.23
10-Jun-88	3102.18	-0.27
30-Jun-88	3102.08	-0.10
20-Jul-88	3101.89	-0.19
03-Aug-88	3101.60	-0.29
19-Aug-88	3101.39	-0.21
13-Sep-88	3101.15	-0.24
16-Oct-88	3100.82	-0.33
28-Nov-88	3100.34	-0.48
28-Dec-88	3100.47	0.13

Well No. 14a
Loc.: 13-20-9ccacd
Owner: Marguerite Miller
Address: Kona Ranch,
Kona Ranch Rd.

M.P.: 0.45 Elev.: 3105
Cas.: 5.5" T.D.: 111'

Date	Water Elev.	Change Water Elev.
31-Oct-87	3092.73	
27-Nov-87	3092.51	-0.22
19-Dec-87	3092.18	-0.33
28-Jan-88	3092.02	-0.16
25-Feb-88	3092.03	0.01
29-Mar-88	3092.08	0.05
19-Apr-88	3092.96	0.88
30-Apr-88	3092.91	-0.05
14-May-88	3093.82	0.91
28-May-88	3094.43	0.61
11-Jun-88	3094.37	-0.06
30-Jun-88	3094.21	-0.16
20-Jul-88	3093.00	-1.21
03-Aug-88	3093.06	0.06
19-Aug-88	3092.97	-0.09
12-Sep-88	3092.83	-0.14
16-Oct-88	3092.67	-0.16
28-Nov-88	3092.43	-0.24
28-Dec-88	3092.02	-0.41

Well No. 14b.
Loc.: 13-20-8daabc
In stock pen.
Owner: Marguerite Miller
Address: Kona Ranch,
Kona Ranch Rd.

M.P.: 1.21 Elev.: 3085
Cas.: 5.5" T.D.:97

Date	Water Elev.	Change Water Elev.
31-Oct-87	3080.79	
27-Nov-87	3080.96	0.17
19-Dec-87	3080.74	-0.22
28-Jan-88	3080.67	-0.07
25-Feb-88	3080.70	0.03
29-Mar-88	3080.93	0.23
19-Apr-88	3083.00	2.07
30-Apr-88	3082.11	-0.89
14-May-88	3083.62	1.51
28-May-88	3084.02	0.40
11-Jun-88	3083.13	-0.89
30-Jun-88	3082.34	-0.79
20-Jul-88	3081.27	-1.07
03-Aug-88	3080.88	-0.39
19-Aug-88	3080.86	-0.02
12-Sep-88	3080.78	-0.08
16-Oct-88	3080.79	0.01
28-Nov-88	3080.80	0.01
28-Dec-88	3080.58	-0.22

Well No. 15
Loc.: 14-20-19accd
Owner: Clark & Terry Gea
Address:9195 Western Farms
Rd

M.P.: 2.5 Elev.: 3140
Cas.: 5.5" T.D.: 142

Date	Water Elev.	Change Water Elev.
31-Oct-87	3079.28	
27-Nov-87	3081.30	2.02
16-Dec-87	3082.36	1.06
23-Jan-88	3080.24	-2.12
27-Feb-88	3079.69	-0.55
27-Mar-88	3079.55	-0.14
19-Apr-88	3080.45	0.90
30-Apr-88	3080.25	-0.20
14-May-88	3079.87	-0.38
28-May-88	3080.78	0.91
11-Jun-88	3081.08	0.30
30-Jun-88	3081.15	0.07

The data for this area continues in Well 33.

Well No. 33
Loc.: 14-20-19accd
Owner: Frank Wilton
Address: #24 Harvey Mobile
Home Court, Bonner.
Well
Address: 9355 Western Farms
Road. Lot 12c.

M.P.: 4.46 Elev.: 3135
Cas.: 5.5" T.D.: 124

Date	Water Elev.	Change Water Elev.
18-Aug-88	3081.44	
13-Sep-88	3081.21	-0.23
16-Oct-88	3081.17	-0.04
28-Nov-88	3080.29	-0.88
28-Dec-88	3078.93	-1.36

Well No. 16
Loc.: 14-20-18dabbba
Owner: John Handford
Address: Moccasin Meadows

M.P.: 0 Elev.: 3160
Cas.: 5.5" T.D.: 131

Date	Water Elev.	Change Water Elev.
31-Oct-87	3060.92	
23-Nov-87	3060.58	-0.34
17-Dec-87	3060.27	-0.31
23-Jan-88	3059.91	-0.36
27-Feb-88	3059.58	-0.33
27-Mar-88	3059.37	-0.21
19-Apr-88	3059.31	-0.06
23-Apr-88	3059.15	-0.16
30-Apr-88	3059.19	0.04
05-May-88	3059.43	0.24
13-May-88	3059.24	-0.19
22-May-88	3059.21	-0.03
28-May-88	3059.38	0.17
11-Jun-88	3059.02	-0.36
30-Jun-88	3059.27	0.25
20-Jul-88	3059.10	-0.17
04-Aug-88	3058.80	-0.30
18-Aug-88	3058.83	0.03
13-Sep-88	3058.54	-0.29
16-Oct-88	3058.82	0.28
28-Nov-88	3058.43	-0.39
28-Dec-88	3058.33	-0.10

Well No. 18
Loc.: 14-20-31acdbc
Owner: Kris & Kim Kahle
Address: 12795 Mullen Road.

M.P.: 1.57 Elev.: 3067
Cas.: 5.5" T.D.: 66

Date	Water Elev.	Change Water Elev.
31-Oct-87	3056.98	
21-Nov-87	3055.92	-1.06
16-Dec-87	3055.52	-0.40
23-Jan-88	3054.51	-1.01
27-Feb-88	3054.51	0.00
27-Mar-88	3054.63	0.12
19-Apr-88	3054.54	-0.09
23-Apr-88	3055.33	0.79
29-Apr-88	3055.66	0.33
14-May-88	3059.51	3.85
22-May-88	3059.96	0.45
28-May-88	3060.74	0.78
11-Jun-88	3060.38	-0.36
30-Jun-88	3060.47	0.09
20-Jul-88	3059.68	-0.79
03-Aug-88	3059.70	0.02
19-Aug-88	3059.74	0.04
12-Sep-88	3059.79	0.05
16-Oct-88	3058.13	-1.66
28-Nov-88	3056.37	-1.76
28-Dec-88	3055.62	-0.75

Well No. 19
Loc.: 14-20-20dbbab
Owner: Milo Bensen
Address:9050 Highway 10 West

M.P.: 0.7 Elev.: 3160
Cas.: 5.5" T.D.: 87

Date	Water Elev.	Change Water Elev.
31-Oct-87	3094.25	
21-Nov-87	3093.80	-0.45
16-Dec-87	3093.23	-0.57
23-Jan-88	3092.32	-0.91
28-Feb-88	3091.55	-0.77
29-Mar-88	3090.89	-0.66
19-Apr-88	3090.46	-0.43
29-Apr-88	3090.42	-0.04
05-May-88	3090.41	-0.01
13-May-88	3090.36	-0.05
28-May-88	3090.36	0.00
10-Jun-88	3090.35	-0.01
30-Jun-88	3090.55	0.20
20-Jul-88	3090.35	-0.20
03-Aug-88	3090.38	0.03
18-Aug-88	3090.35	-0.03
13-Sep-88	3090.17	-0.18
16-Oct-88	3089.73	-0.44
28-Nov-88	3089.03	-0.70
28-Dec-88	3088.37	-0.66

Well No. 20
Loc.: 14-20-30abccd
Owner: Don Brinkerhoff
Address: 12911 Moccasin Lane, Frenchtown.

M.P.: 1.6 Elev.: 3090
Cas.: 5.5" T.D.: 86.5

Date	Water Elev.	Change Water Elev.
31-Oct-87	3067.30	
21-Nov-87	3066.95	-0.35
16-Dec-87	3066.36	-0.59
23-Jan-88	3065.65	-0.71
27-Feb-88	3065.36	-0.29
27-Mar-88	3065.13	-0.23
19-Apr-88	3065.00	-0.13
23-Apr-88	3065.06	0.06
30-Apr-88	3065.25	0.19
05-May-88	3065.47	0.22
14-May-88	3065.74	0.27
22-May-88	3066.27	0.53
28-May-88	3066.61	0.34
11-Jun-88	3066.95	0.34
30-Jun-88	3067.49	0.54
20-Jul-88	3067.10	-0.39
03-Aug-88	3067.20	0.10
19-Aug-88	3067.40	0.20
12-Sep-88	3067.48	0.08
16-Oct-88	3066.67	-0.81
28-Nov-88	3065.55	-1.12
28-Dec-88	3064.70	-0.85

Well No. 21
Loc.: 15-21-27bdcdc
Owner: Ed Helm
Address: 17775 Hoedown Lane

M.P.: 1.14 Elev.: 3038
Cas.: 5.5" T.D.: 175

Date	Water Elev.	Change Water Elev.
31-Oct-87	3023.61	
27-Nov-87	3022.92	-0.69
19-Dec-87	3022.18	-0.74
28-Jan-88	3021.37	-0.81
28-Feb-88	3021.19	-0.18
28-Mar-88	3020.97	-0.22
17-Apr-88	3020.73	-0.24
30-Apr-88	3020.76	0.03
05-May-88	3021.74	0.98
14-May-88	3021.82	1.06
28-May-88	3022.95	1.13
11-Jun-88	3023.96	1.01
29-Jun-88	3024.39	0.43
20-Jul-88	3022.85	-1.54
04-Aug-88	3022.86	0.01
19-Aug-88	3023.44	0.58
13-Sep-88	3023.67	0.23
17-Oct-88	3024.49	0.82
29-Nov-88	3023.03	-1.46
28-Dec-88	3022.06	-0.97

Well No. 22
Loc.: 15-21-29accbd
Owner: Calvin Touchette
Address: Frenchtown

M.P.: 0 Elev.: 3033
Cas.: 5.5" T.D.: 50

Date	Water Elev.	Change Water Elev.
31-Oct-87	3019.98	
27-Nov-87	3019.28	-0.70
19-Dec-87	3018.86	-0.42
28-Jan-88	3018.07	-0.79
28-Feb-88	3017.94	-0.13
28-Mar-88	3017.53	-0.41
17-Apr-88	3017.40	-0.13
30-Apr-88	3017.31	-0.09
14-May-88	3018.10	0.79
28-May-88	3018.93	0.83
11-Jun-88	3019.64	0.71
30-Jun-88	3020.93	1.29
20-Jul-88	3022.00	1.07
04-Aug-88	3022.70	0.70
18-Aug-88	3022.25	-0.45
13-Sep-88	3022.37	0.12
16-Oct-88	3020.99	-1.38
29-Nov-88	3019.49	-1.50
28-Dec-88	3018.65	-0.84

Well No. 23
Loc.: 15-21-30bdcdd
Owner: Ernest Johnson

M.P.: 1.57 Elev.: 3028
Cas.: 5.5" T.D.: 178.3

Date	Water Elev.	Change Water Elev.
31-Oct-87	3020.86	
27-Nov-87	3020.27	-0.59
19-Dec-87	3019.39	-0.88
28-Jan-88	3019.24	-0.15
28-Feb-88	3019.08	-0.16
28-Mar-88	3019.15	0.07
17-Apr-88	3018.76	-0.39
29-Apr-88	3019.10	0.34
05-May-88	3019.56	0.46
14-May-88	3019.20	0.10
28-May-88	3019.30	0.10
11-Jun-88	3020.51	1.21
30-Jun-88	3019.90	-0.61
20-Jul-88	3018.27	-1.63
04-Aug-88	3017.89	-0.38
18-Aug-88	3019.03	1.14
13-Sep-88	3019.62	0.59
16-Oct-88	3020.92	1.30
29-Nov-88	3020.50	-0.42
29-Dec-88	3019.84	-0.66

Well No. 24
Loc.: 15-22-25bccdd

Owner: Robert Yorton
Address:Old Mullen Rd, Huson

M.P.: 1.4 Elev.: 3015
Cas.: 5.5" T.D.: 163

Date	Water Elev.	Change Water Elev.
19-Dec-87	3013.22	
28-Jan-88	3012.89	-0.33
28-Feb-88	3012.79	-0.10
28-Mar-88	3013.05	0.26
17-Apr-88	3012.85	-0.20
24-Apr-88	3013.12	0.27
30-Apr-88	3013.36	0.51
14-May-88	3013.24	-0.12
28-May-88	3013.17	-0.07
11-Jun-88	3014.27	1.10
29-Jun-88	3013.23	-1.04
20-Jul-88	3011.47	-1.76
04-Aug-88	3009.76	-1.71
10-Sep-88	3010.75	0.99
17-Oct-88	3012.82	2.07
29-Nov-88	3012.68	-0.14
28-Dec-88	3012.18	-0.50

Well No. 25
Loc.:14-21-3aaba
House Well
Owner:Chuck & Joice Sheppard
Address:Hamel Lane,
Frenchtown

M.P.: 1.35 Elev.: 3035
Cas.: 4" T.D.: 35.4

Date	Water Elev.	Change Water Elev.
27-Nov-87	3026.36	
19-Dec-87	3026.06	-0.30
28-Jan-88	3025.87	-0.19
28-Feb-88	3026.05	0.18
28-Mar-88	3026.20	0.15
17-Apr-88	3026.86	0.66
30-Apr-88	3027.45	0.59
14-May-88	3028.23	0.78
28-May-88	3028.75	0.52
11-Jun-88	3028.81	0.06
29-Jun-88	3027.92	-0.89
20-Jul-88	3026.89	-1.03
04-Aug-88	3026.26	-0.63
19-Aug-88	3026.15	-0.11
13-Sep-88	3026.06	-0.09
16-Oct-88	3026.87	0.81
29-Nov-88	3026.56	-0.31
29-Dec-88	3026.14	-0.42

Well No. 25a
Loc.:14-21-3aabcb
Barn Well
Owner:Chuck & Joice Sheppard
Address:Hamel Lane,
Frenchtown

M.P.: 0.6 Elev.:3033
Cas.: 4" T.D.: 20

Date	Water Elev.	Change Water Elev.
27-Nov-87	3025.88	
19-Dec-87	3025.70	-0.18
28-Jan-88	3025.41	-0.29
28-Feb-88	3025.60	0.19
28-Mar-88	3025.76	0.16
17-Apr-88	3026.71	0.95
30-Apr-88	3027.07	0.36
14-May-88	3028.07	1.00
28-May-88	3028.73	0.66
11-Jun-88	3028.57	-0.16
29-Jun-88	3027.44	-1.13
20-Jul-88	3026.21	-1.23
04-Aug-88	3025.65	-0.56
19-Aug-88	3025.53	-0.12
13-Sep-88	3025.48	-0.05
16-Oct-88	3026.23	0.75
29-Nov-88	3026.10	-0.13
29-Dec-88	3025.61	-0.49

Well No. 26
Loc. 14-20-34acbabb
Owner:Hazel Boscarino,
Stevensville.

M.P.: 1.7 Elev.: 3186
Cas.: 5.5" T.D.: 121.7

Date	Water Elev.	Change Water Elev.
29-Mar-88	3103.80	
19-Apr-88	3103.64	-0.16
23-Apr-88	3103.60	-0.04
29-Apr-88	3103.61	0.01
05-May-88	3103.69	0.08
13-May-88	3103.74	0.05
28-May-88	3104.00	0.26
11-Jun-88	3105.05	1.05
30-Jun-88	3106.34	1.29
20-Jul-88	3106.25	-0.09
04-Aug-88	3106.35	0.10
18-Aug-88	3106.27	-0.08
13-Sep-88	3106.07	-0.20
16-Oct-88	3105.65	-0.42
28-Nov-88	3104.69	-0.96
28-Dec-88	3104.06	-0.63

Well No. 27
Loc.:13-20-12bbbdb
Owner:Dr. Pruyn
Address:4395 W. US Hwy. 10

M.P.: -1.54 Elev.: 3173
Cas.: 4" T.D.: 104.8

Date	Water Elev.	Change Water Elev.
29-Mar-88	3125.05	
19-Apr-88	3125.85	0.80
23-Apr-88	3126.27	0.42
29-Apr-88	3126.54	0.27
05-May-88	3126.99	0.45
13-May-88	3128.01	1.02
28-May-88	3131.01	3.00
10-Jun-88	3132.70	1.69
30-Jun-88	3132.61	-0.09
20-Jul-88	3131.43	-1.18
03-Aug-88	3130.49	-0.94
18-Aug-88	3129.66	-0.83
13-Sep-88	3128.19	-1.47
16-Oct-88	3127.55	-0.64
28-Nov-88	3126.71	-0.84
28-Dec-88	3125.76	-0.95

1

Well No. 28
Loc.:14-21-11aabba

Owner:Dale Ragan, 9 Mile Rd, Huson.
Address: W. Marcure Lane

M.P.: 0.9 Elev.: 3045
Cas.: 5.5" T.D.: 160

Date	Water Elev.	Change Water Elev.
06-Apr-88	3027.08	
17-Apr-88	3027.56	0.48
23-Apr-88	3027.82	0.26
30-Apr-88	3027.55	-0.27
05-May-88	3027.94	0.39
14-May-88	3028.69	0.75
22-May-88	3028.89	0.20
28-May-88	3029.55	0.66
11-Jun-88	3029.67	0.12
29-Jun-88	3029.70	0.03
20-Jul-88	3028.88	-0.82
03-Aug-88	3028.90	0.02
19-Aug-88	3029.05	0.15
13-Sep-88	3028.77	-0.28
16-Oct-88	3028.90	0.13
28-Nov-88	3028.06	-0.84
28-Dec-88	3027.04	-1.02

Well No. 30
Loc.:14-20-29dbbabc
Owner: Jim Tribble
Address: 11225 Moccasin Lane

M.P.: 2.05 Elev.: 3220
Cas.: 5.5" T.D.: 144

Date	Water Elev.	Change Water Elev.
29-Mar-88	3136.45	
19-Apr-88	3134.39	-2.06
29-Apr-88	3136.68	2.29
10-Jun-88	3135.55	-1.13
29-Jun-88	3135.49	-0.06
20-Jul-88	3131.97	-3.52

This well is in the same area as well 12.
This well also leaked;these measurements are suspect.

Well No. 31
Loc.:14-21-12aaddd
Owner: Edward Marcure
Address: Marcure Ln & Mullen Rd.

M.P.: 1.42 Elev.: 3163
Cas.: 5.5" T.D.: 160

Date	Water Elev.	Change Water Elev.
14-May-88	3038.05	
22-May-88	3038.27	0.22
29-May-88	3038.62	0.35
29-Jun-88	3038.92	0.30
20-Jul-88	3039.03	0.11
03-Aug-88	3038.92	-0.11
19-Aug-88	3039.04	0.12
13-Sep-88	3038.99	-0.05
16-Oct-88	3038.83	-0.16
28-Nov-88	3038.25	-0.58
28-Dec-88	3037.73	-0.52

Well No. 32
Loc.: 15-21-32adadb
Owner: Jeff Malo
Address: Frenchtown

M.P.: 2.96 Elev.: 3012
Cas.: 5.5" T.D.: 178

Date	Water Elev.	Change Water Elev.
03-Aug-88	3014.41	
18-Aug-88	3014.64	0.23

This well was imperviously sealed at the end of August Measurements for the area continue in well 34

Well No. 34
Loc.:15-21-33bcca
Owner:Mike Woodworth
Address: Frenchtown

M.P.: 1.8 Elev.: 3019
Cas.: 5.5" T.D.: 170

Date	Water Elev.	Change Water Elev.
19-Aug-88	3014.48	
13-Sep-88	3015.03	0.55
16-Oct-88	3016.30	1.27
29-Nov-88	3015.46	-0.84
28-Dec-88	3014.56	-0.90

******PIEZOMETERS*******

Well No. 10a
Loc.:14-20-33ddcb

Owner: Charles Deschamps
Address: 8150 Mullen Rd.

M.P.: 1.33 Elev.: 3078
Cas.: 2" pvc T.D.: 7.46

Date	Water Elev.	Change Water Elev.
30-Oct-87	3076.64	
24-Nov-87	3076.75	0.11
24-Dec-87	Frozen	
24-Jan-88	Frozen	
25-Feb-88	3076.76	
29-Mar-88	3076.38	-0.38
19-Apr-88	3076.37	-0.01
30-Jun-88	3076.55	0.18
21-Jul-88	3076.54	-0.01
03-Aug-88	3076.60	0.06
19-Aug-88	3076.66	0.06
10-Sep-88	3076.68	0.02
16-Oct-88	3076.71	0.03
28-Nov-88	3076.90	0.19
28-Dec-88	3076.82	-0.08

Well No. 17
Loc.:14-21-13abccc
Located in field 3/4 miles north of the Schilling Siding and Mullen Road intersection.
Owner: Marguerite Miller
Address: Kona Ranch, Kona Ranch Road

M.P.: 1.2 Elev.: 3068
Cas.: 2' T.D.: 27.6

Date	Water Elev.	Change Water Elev.
30-Nov-87	3050.09	
17-Dec-87	3049.75	-0.34
23-Jan-88	3049.65	-0.10
27-Feb-88	3049.39	-0.26
27-Mar-88	3048.41	-0.98
18-Apr-88	3047.99	-0.42
02-May-88	3048.09	0.10
03-May-88	3048.12	0.03
04-May-88	3048.19	0.07
05-May-88	3048.30	0.10
06-May-88	3048.38	0.09
07-May-88	3048.47	0.09
08-May-88	3048.56	0.09
09-May-88	3048.65	0.09
10-May-88	3048.73	0.08
11-May-88	3048.83	0.10
12-May-88	3048.93	0.10
13-May-88	3049.04	0.11
14-May-88	3049.14	0.10
15-May-88	3049.19	0.05
16-May-88	3049.27	0.34
18-May-88	3049.35	0.08
20-May-88	3049.44	0.09
23-May-88	3049.64	0.20
31-May-88	3050.36	0.72
13-Jun-88	3051.19	0.83
20-Jun-88	3051.68	0.49
27-Jun-88	3052.24	0.56
05-Jul-88	3052.64	0.40
01-Aug-88	3053.54	0.90
08-Aug-88	3053.68	0.14
15-Aug-88	3053.90	0.22
02-Sep-88	3053.95	0.05
22-Sep-88	3054.14	0.19

Well No. H26
Loc.:14-21-24dcdba
Owner: Stone Container
Address:Plant on Mullen Road

M.P.:2.35 Elev.: 3065
Cas.: 2" T.D.: 25.15

Date	Water Elev.	Change Water Elev.
31-Oct-87	3049.45	
27-Nov-87	3048.34	-1.11
17-Dec-87	3047.75	-0.59
23-Jan-88	3046.91	-0.84
27-Feb-88	3046.67	-0.24
27-Mar-88	3046.85	0.18
19-Apr-88	3046.80	-0.05
30-Apr-88	3047.11	0.31
14-May-88	3048.63	1.52
28-May-88	3050.40	1.77
30-Jun-88	3053.02	2.62
21-Jul-88	3052.78	-0.24
03-Aug-88	3052.53	-0.25
19-Aug-88	3052.31	-0.22
14-Sep-88	3051.49	-0.82
17-Oct-88	3049.85	-1.64
28-Nov-88	3047.85	-2.00
28-Dec-88	3047.00	-0.85

Well No. H27
Loc.:14-21-dbdbdc

Owner: Stone Container
Address:Plant on Mullen Road

M.P.:1.17 Elev.: 3063
Cas.: 2" T.D.: 24.93

Date	Water Elev.	Change Water Elev.
31-Oct-87	3048.55	
27-Nov-87	3047.35	-1.20
17-Dec-87	3046.22	-1.13
23-Jan-88	3044.06	-2.16
27-Feb-88	3042.82	-1.24
27-Mar-88	3042.78	-0.04
19-Apr-88	3043.36	0.58
30-Apr-88	3042.82	-0.54
14-May-88	3043.84	1.02
28-May-88	3043.44	-0.40
30-Jun-88	3043.65	0.21
21-Jul-88	3043.34	-0.31
03-Aug-88	3042.00	-1.34
19-Aug-88	3042.81	0.81
14-Sep-88	3042.47	-0.34
17-Oct-88	3042.17	-0.30
28-Nov-88	3042.17	0.00
28-Dec-88	3041.81	-0.36

Well No. K29
Loc.:14-21-13cacaa
Owner: Stone Container
Address: Plant on Mullen Road

M.P.: 4.1 Elev.: 3062
Cas.: 2" T.D.: 25.97

Date	Water Elev.	Change Water Elev.
31-Oct-87	3044.73	
27-Nov-87	3044.48	-0.25
17-Dec-87	3044.96	0.48
23-Jan-88	3045.27	0.31
27-Feb-88	3044.85	-0.42
27-Mar-88	3042.84	-2.01
19-Apr-88	3042.76	-0.08
30-Apr-88	3042.63	-0.13
14-May-88	3043.15	0.52
28-May-88	3043.96	0.81
30-Jun-88	3045.33	1.37
21-Jul-88	3045.73	0.40
03-Aug-88	3046.21	0.48
19-Aug-88	3046.37	0.16
14-Sep-88	3046.08	-0.29
17-Oct-88	3045.38	-0.70
28-Nov-88	3043.92	-1.46
28-Dec-88	3042.75	-1.17

Well No. K30
Loc.:14-21-13bdbcd
Owner: Stone Container
Address: Plant on Mullen Road

M.P.: 4.16 Elev.: 3061
Cas.: 2" T.D.: 24.37

Date	Water Elev.	Change Water Elev.
31-Oct-87	3047.95	
27-Nov-87	3047.46	-0.49
17-Dec-87	3047.56	0.10
23-Jan-88	3048.00	0.44
27-Feb-88	3047.82	-0.18
27-Mar-88	3046.10	-1.72
29-Apr-88	3045.91	-0.19
30-Apr-88	3045.80	-0.11
14-May-88	3046.19	0.39
28-May-88	3046.90	0.71
30-Jun-88	3048.84	1.94
21-Jul-88	3049.34	0.50
03-Aug-88	3049.87	0.53
19-Aug-88	3049.98	0.11
14-Sep-88	3049.71	-0.27
17-Oct-88	3048.76	-0.95
28-Nov-88	3047.16	-1.60
28-Dec-88	3046.11	-1.05

Well No. K31
Loc.:14-21-13bbaab
Owner: Stone Container
Address: Plant on Mullen Road

M.P.: 4.27 Elev.: 3056
Cas.: 2" T.D.: 18.29

Date	Water Elev.	Change Water Elev.
31-Oct-87	3046.64	
27-Nov-87	3046.63	-0.01
17-Dec-87	3045.91	-0.72
23-Jan-88	3045.84	-0.07
27-Feb-88	3046.15	0.31
27-Mar-88	3044.66	-1.49
19-Apr-88	3044.43	-0.23
30-Apr-88	3044.13	-0.30
14-May-88	3045.15	1.02
28-May-88	3046.11	0.96
30-Jun-88	3048.23	2.12
21-Jul-88	3048.52	0.29
03-Aug-88	3049.19	0.67
19-Aug-88	3049.17	-0.02
14-Sep-88	3049.26	0.09
17-Oct-88	3048.07	-1.19
28-Nov-88	3046.15	-1.92
28-Dec-88	3044.89	-1.26

Well No. K32
Loc.:14-21-12ccaba
Owner: Stone Container
Address: Plant on Mullen Road

M.P.: 4.1 Elev.: 3055
Cas.: 2" T.D.: 22.39

Date	Water Elev.	Change Water Elev.
31-Oct-87	3045.67	
27-Nov-87	3045.90	0.23
17-Dec-87	3044.92	-0.98
23-Jan-88	3044.19	-0.73
27-Feb-88	3044.92	0.73
27-Mar-88	3043.55	-1.37
29-Apr-88	3043.25	-0.30
30-Apr-88	3042.91	-0.34
14-May-88	3044.06	1.15
28-May-88	3045.16	1.10
30-Jun-88	3047.06	1.90
21-Jul-88	3047.18	0.12
03-Aug-88	3047.41	0.23
19-Aug-88	3047.77	0.36
14-Sep-88	3047.78	0.01
17-Oct-88	3046.84	-0.94
28-Nov-88	3045.19	-1.65
28-Dec-88	3043.91	-1.28

Well No. H9
Loc.:14-21-11abbaa

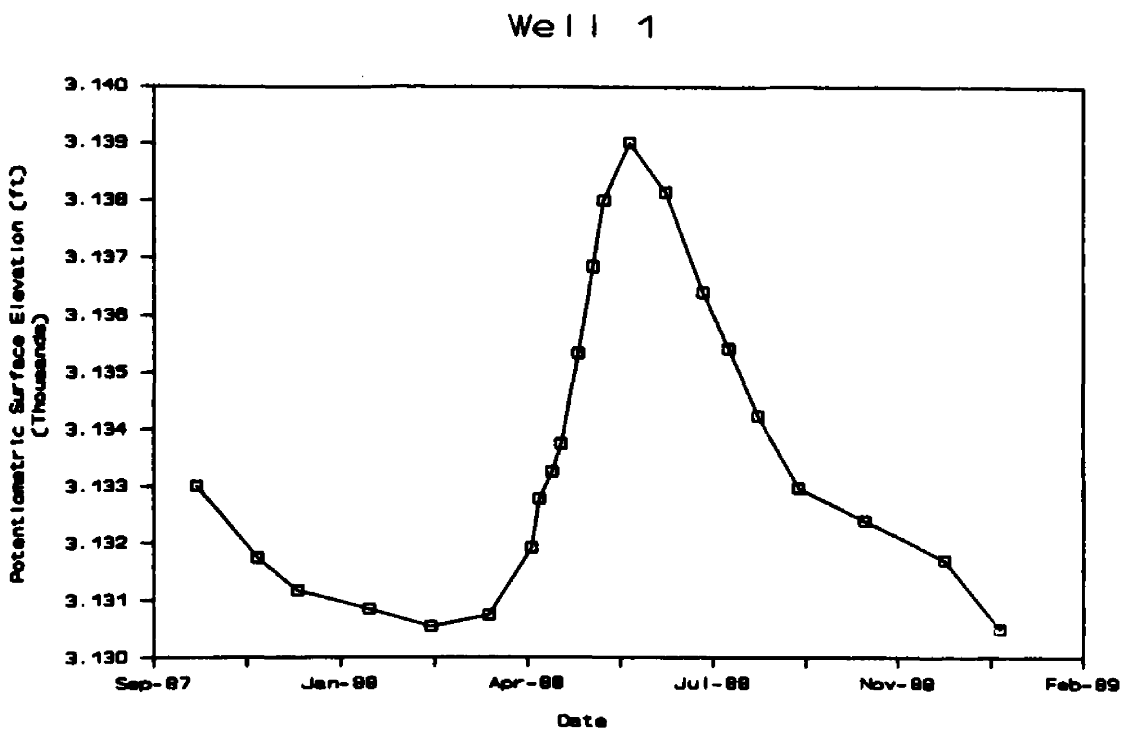
Owner: Stone Container
Address: Plant on Mullen Road

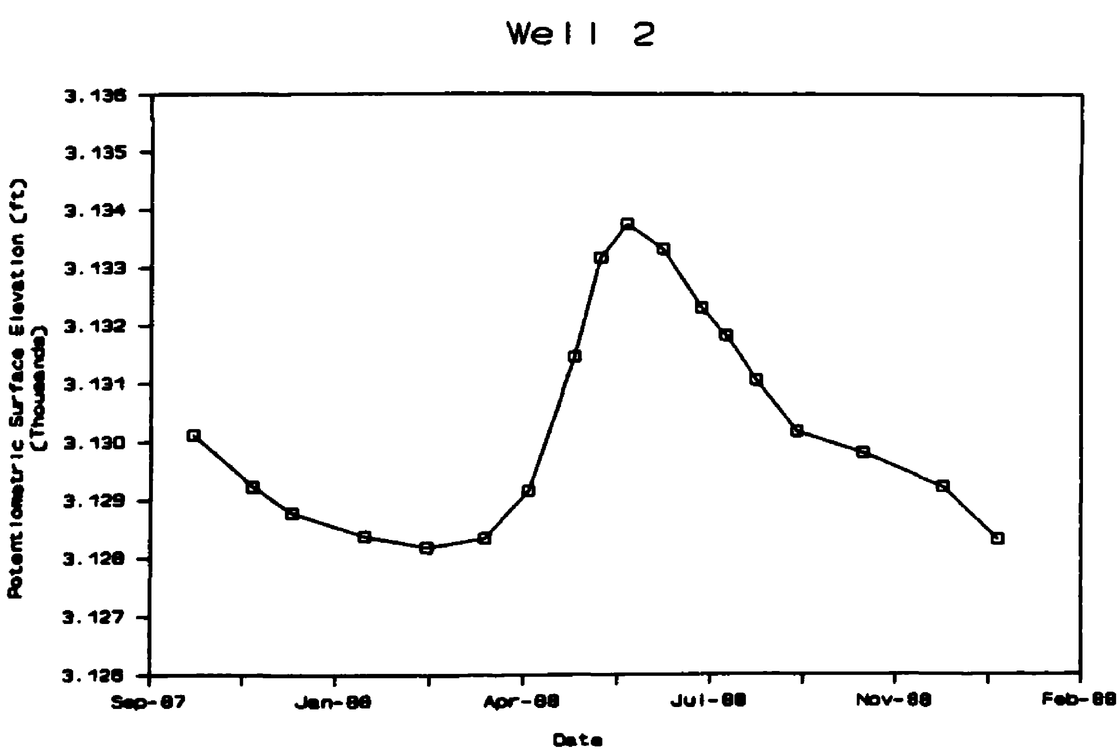
M.P.: 4.1 Elev.: 3045
Cas.: 2" T.D.: 23.77

Date	Water Elev.	Change Water Elev.
31-Oct-87	3029.83	
27-Nov-87	3030.06	0.23
17-Dec-87	3029.42	-0.64
23-Jan-88	3028.27	-1.15
27-Feb-88	3029.50	1.23
27-Mar-88	3028.83	-0.67
29-Apr-88	3028.63	-0.20
30-Apr-88	3028.56	-0.07
14-May-88	3029.37	0.81
28-May-88	3029.90	0.53
30-Jun-88	3030.36	0.46
21-Jul-88	3030.46	0.10
03-Aug-88	3030.73	0.27
19-Aug-88	3031.05	0.32
14-Sep-88	3030.80	-0.25
17-Oct-88	3030.00	-0.80
28-Nov-88	3029.35	-0.65
28-Dec-88	3028.86	-0.49

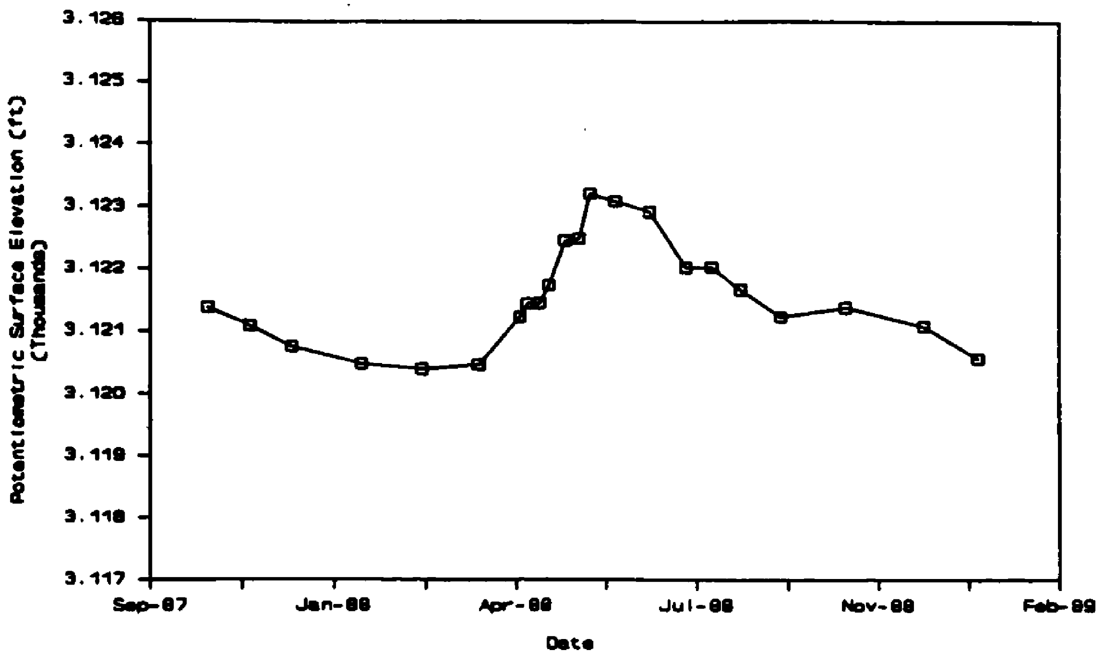
APPENDIX III

Well & Piezometer Hydrographs
October 1987 - December 1988


Well 1
Potentiometric Surface Elevation (ft)
(Thousands)
3.130
3.131
3.132
3.133
3.134
3.135
3.136
3.137
3.138
3.139
3.140
Sep-87
Jan-88
Apr-88
Jul-88
Nov-88
Feb-89
Date

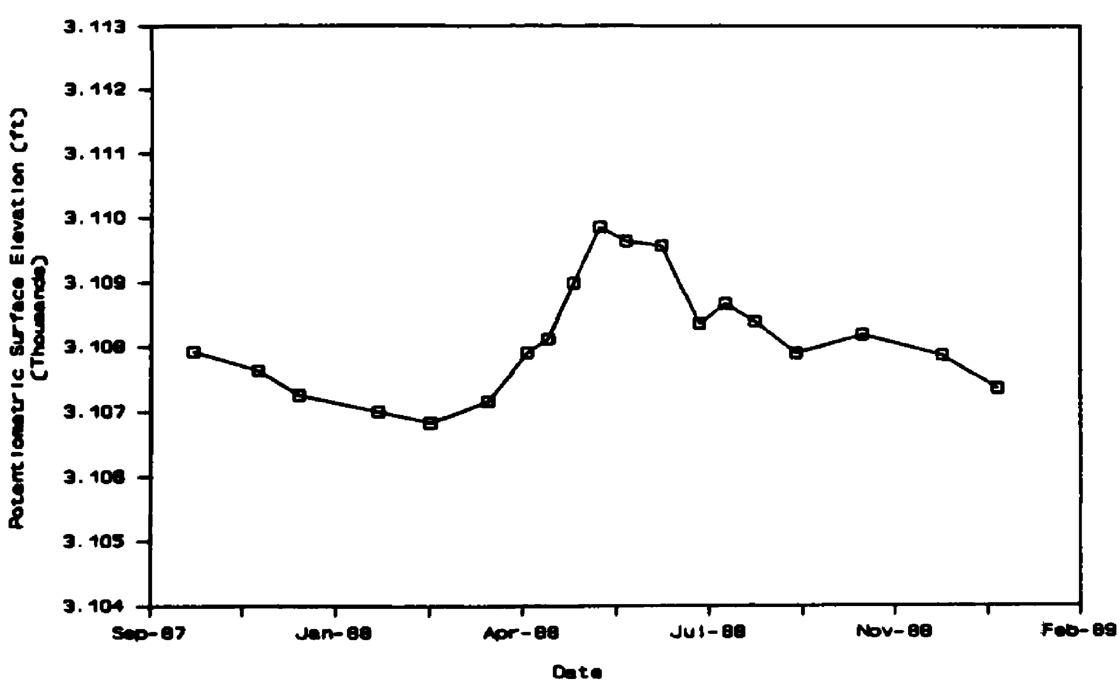

Well 2
Potentiometric Surface Elevation (ft)
(Thousands)
3.126
3.127
3.128
3.129
3.130
3.131
3.132
3.133
3.134
3.135
3.136
Sep-87
Jan-88
Apr-88
Jul-88
Nov-88
Feb-88
Date

Well 3



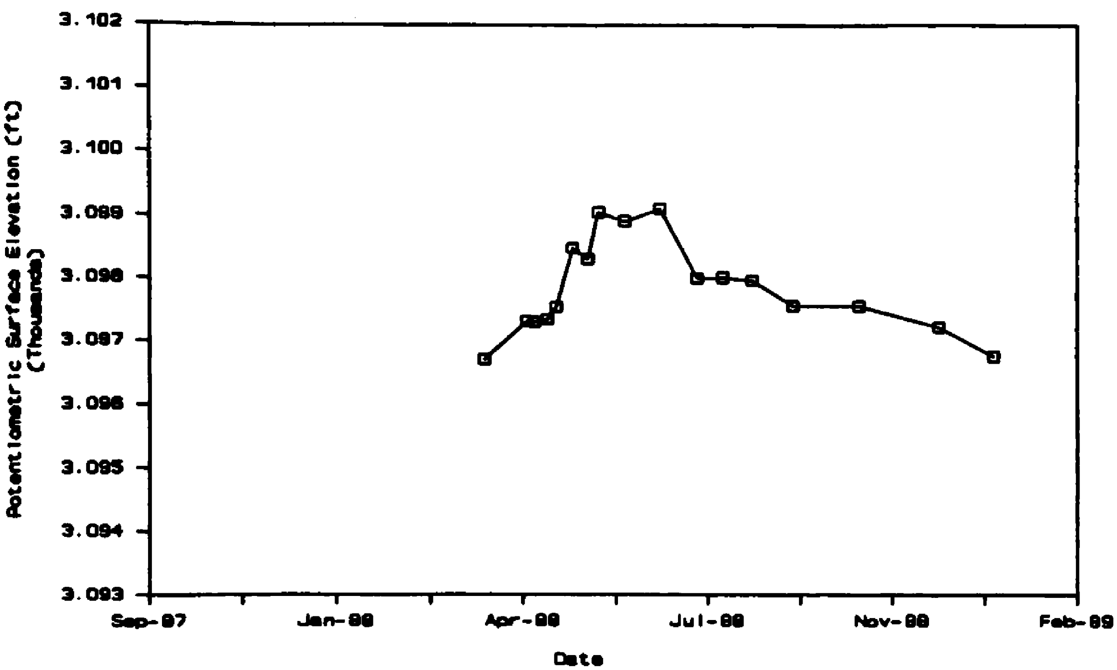
3.126
3.125
3.124
3.123
3.122
3.121
3.120
3.119
3.118
3.117
Potentiometric Surface Elevation (ft) (Thousands)
Sep-87
Jan-88
Apr-88
Jul-88
Nov-88
Feb-89
Date

Well 4

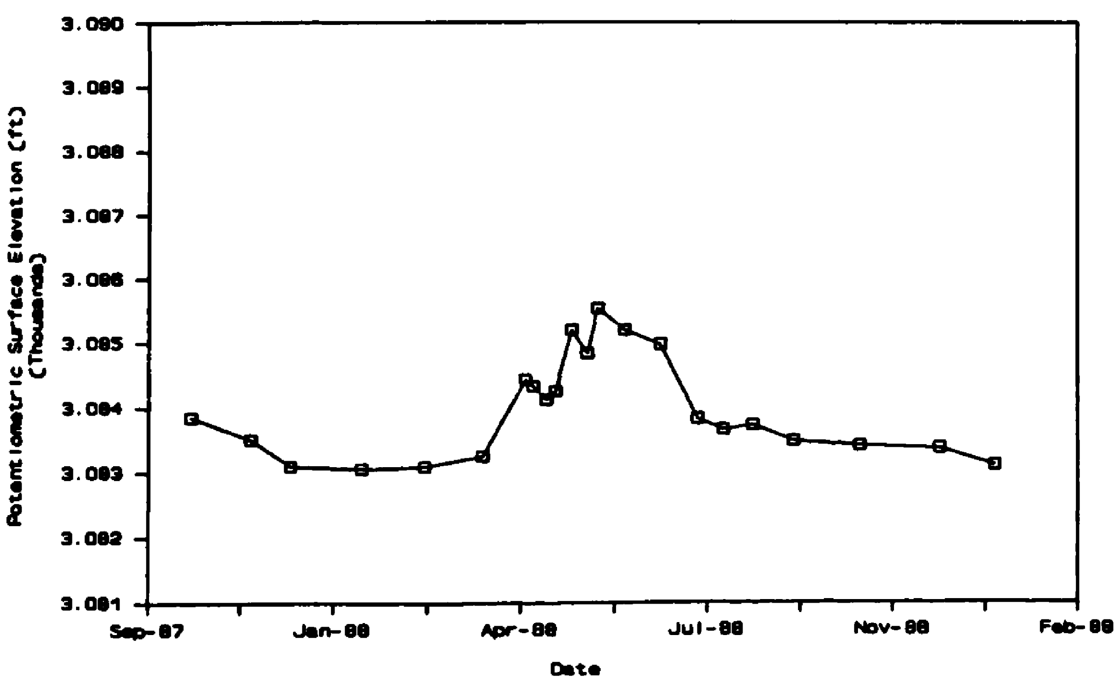


3.113
3.112
3.111
3.110
3.109
3.108
3.107
3.106
3.105
3.104
Potentiometric Surface Elevation (ft) (Thousands)
Sep-87
Jan-88
Apr-88
Jul-88
Nov-88
Feb-89
Date

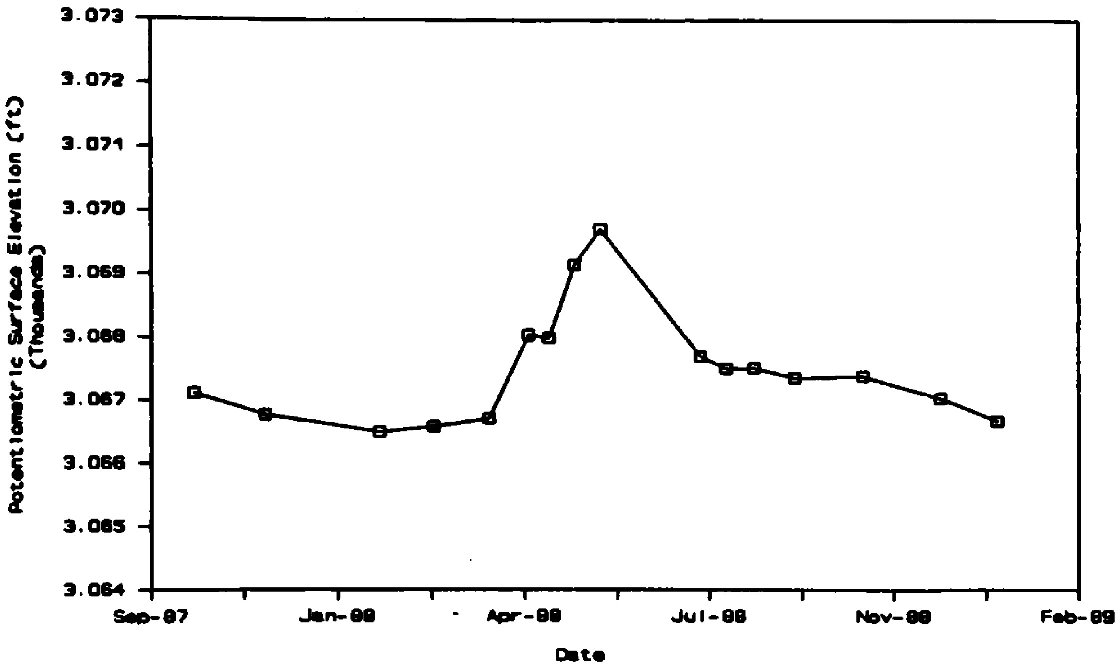
Well 5


3.102
3.101
3.100
3.099
3.098
3.097
3.096
3.095
3.094
3.093
Potentiometric Surface Elevation (ft)
(Thousands)
Sep-87
Jan-88
Apr-88
Jul-88
Nov-88
Feb-89
Date

Well 6

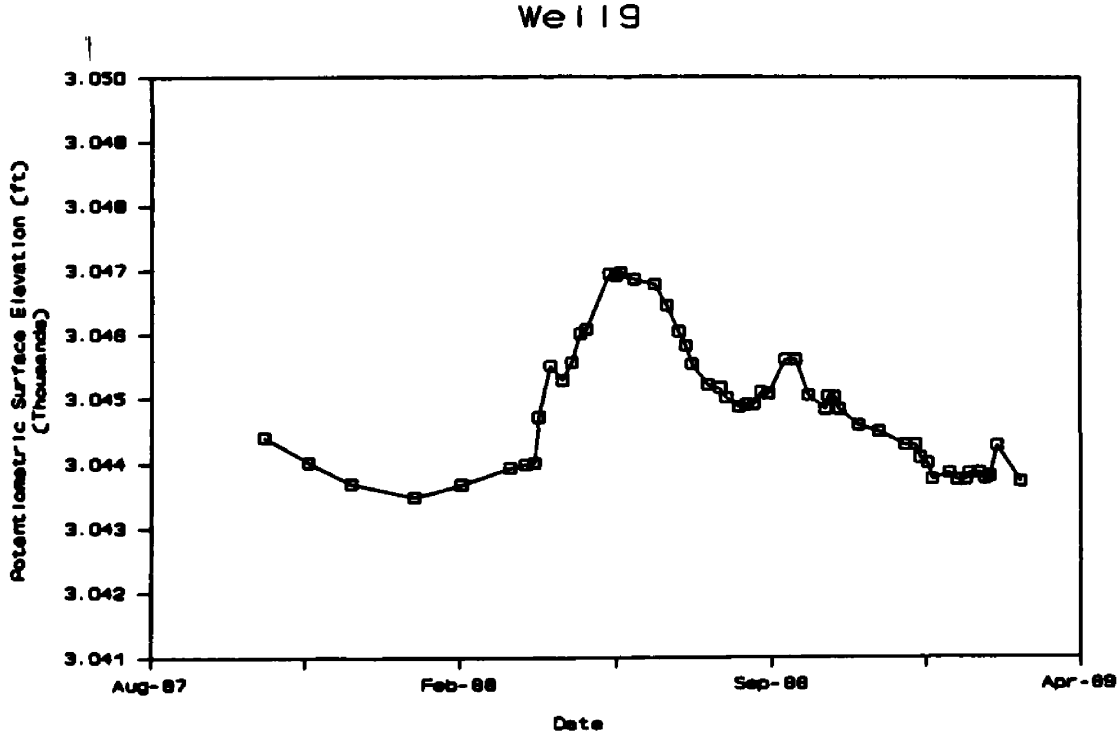

3.090
3.089
3.088
3.087
3.086
3.085
3.084
3.083
3.082
3.081
Potentiometric Surface Elevation (ft)
(Thousands)
Sep-87
Jan-88
Apr-88
Jul-88
Nov-88
Feb-89
Date

Well 8



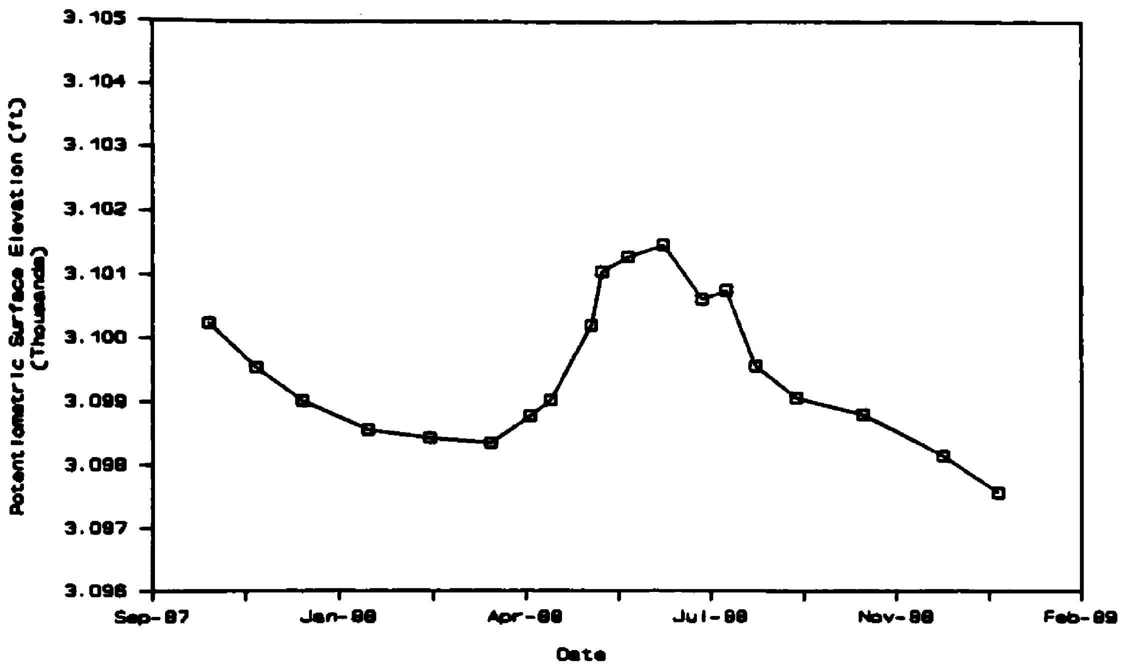
Potentiometric Surface Elevation (ft)
(Thousands)
3.073
3.072
3.071
3.070
3.069
3.068
3.067
3.066
3.065
3.064
Sep-87
Jan-88
Apr-88
Jul-88
Nov-88
Feb-89
Date

Well 9

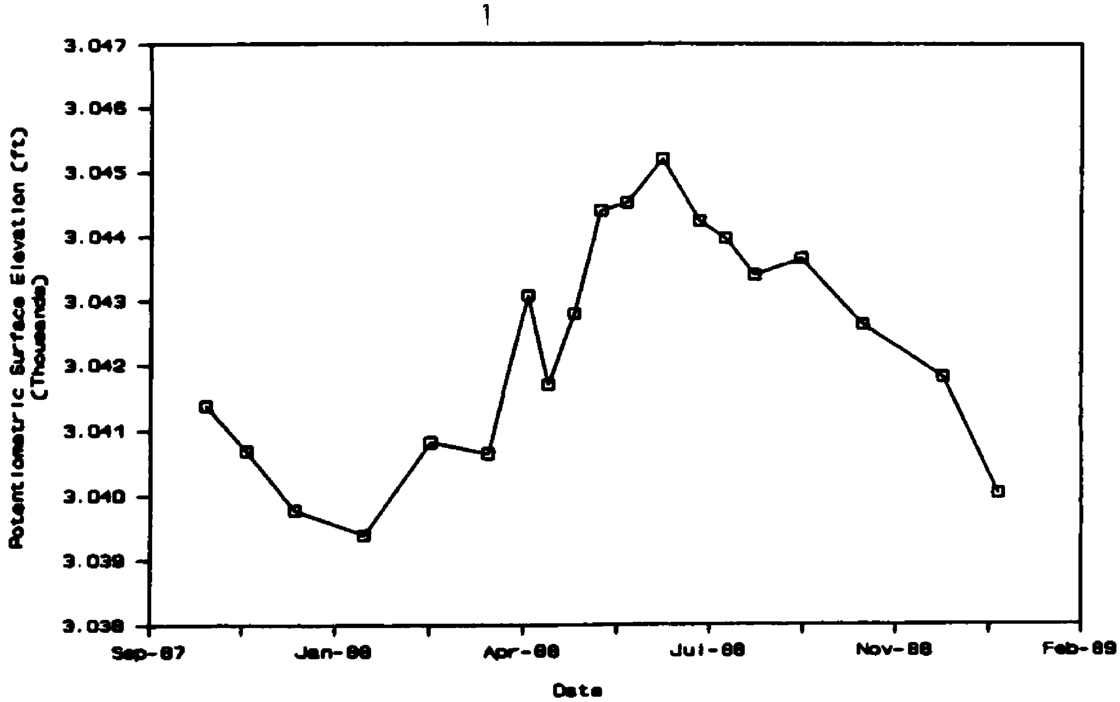


Potentiometric Surface Elevation (ft)
(Thousands)
3.050
3.049
3.048
3.047
3.046
3.045
3.044
3.043
3.042
3.041
Aug-87
Feb-88
Sep-88
Apr-89
Date

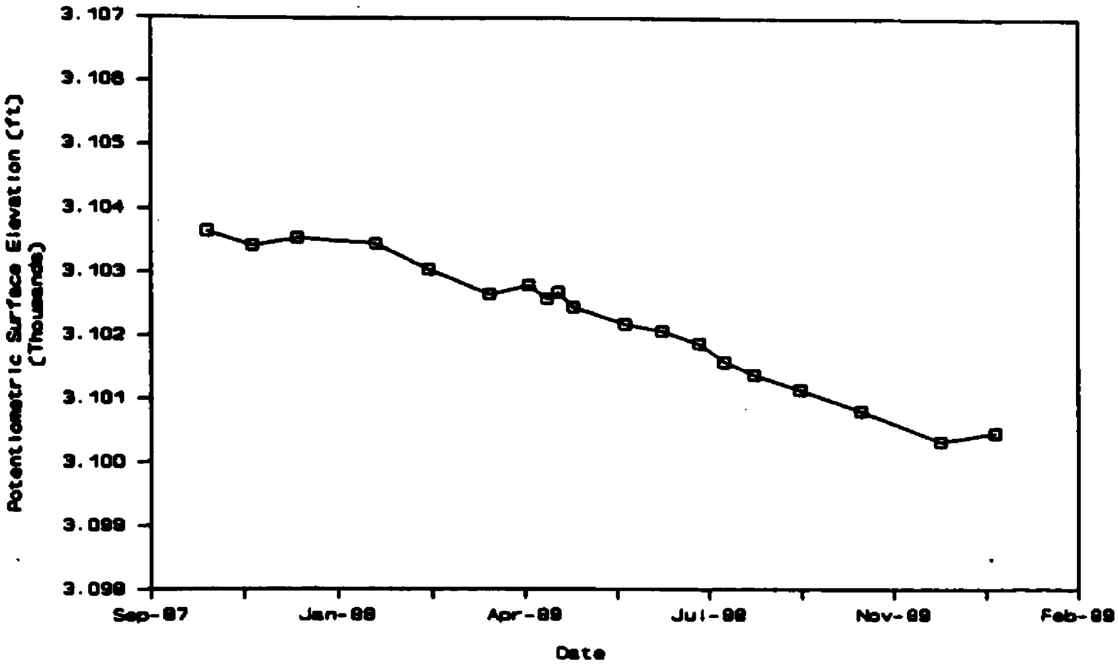
Well 10



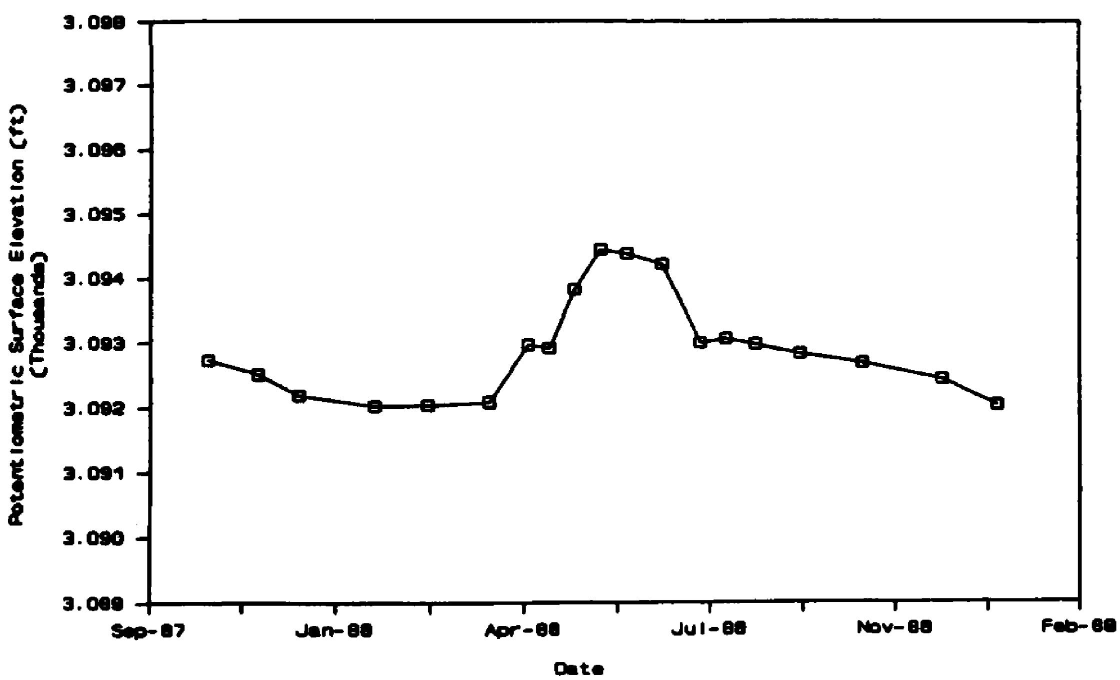
Well 11



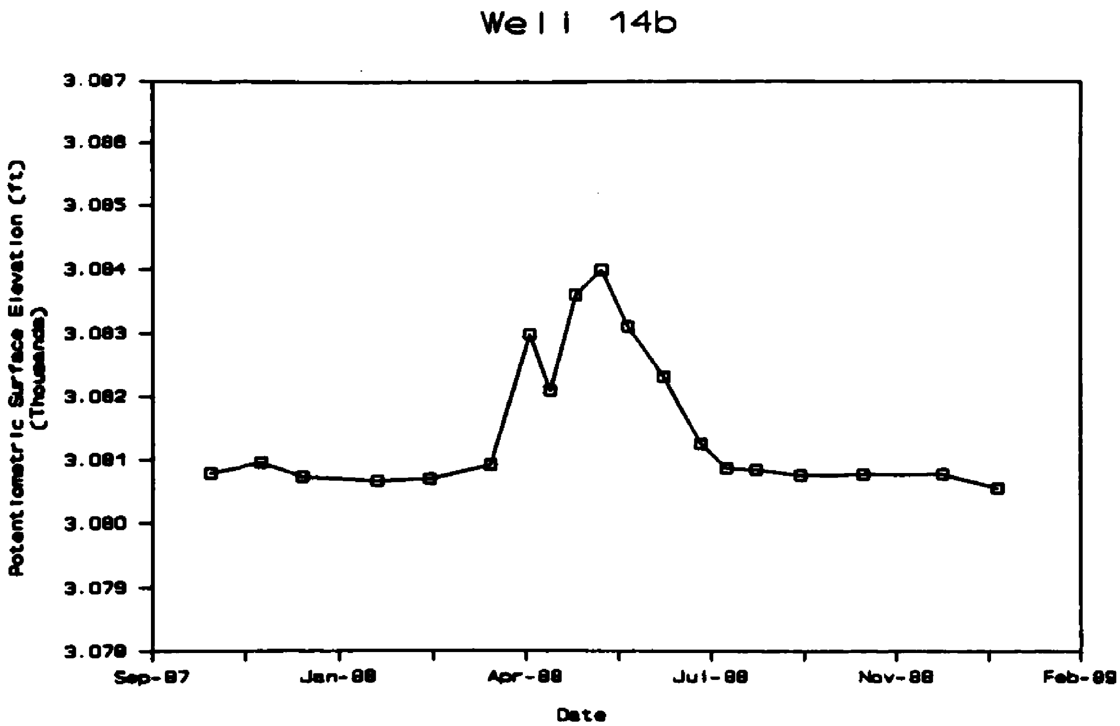
Well 13



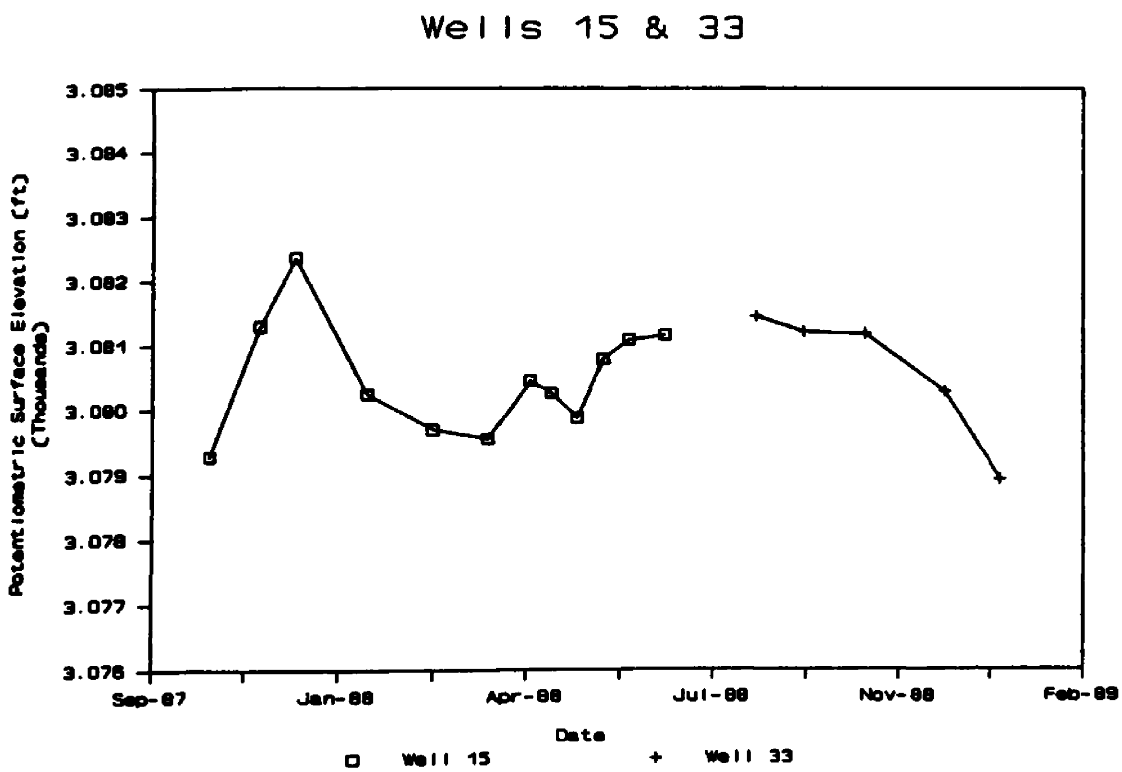
Well 14a



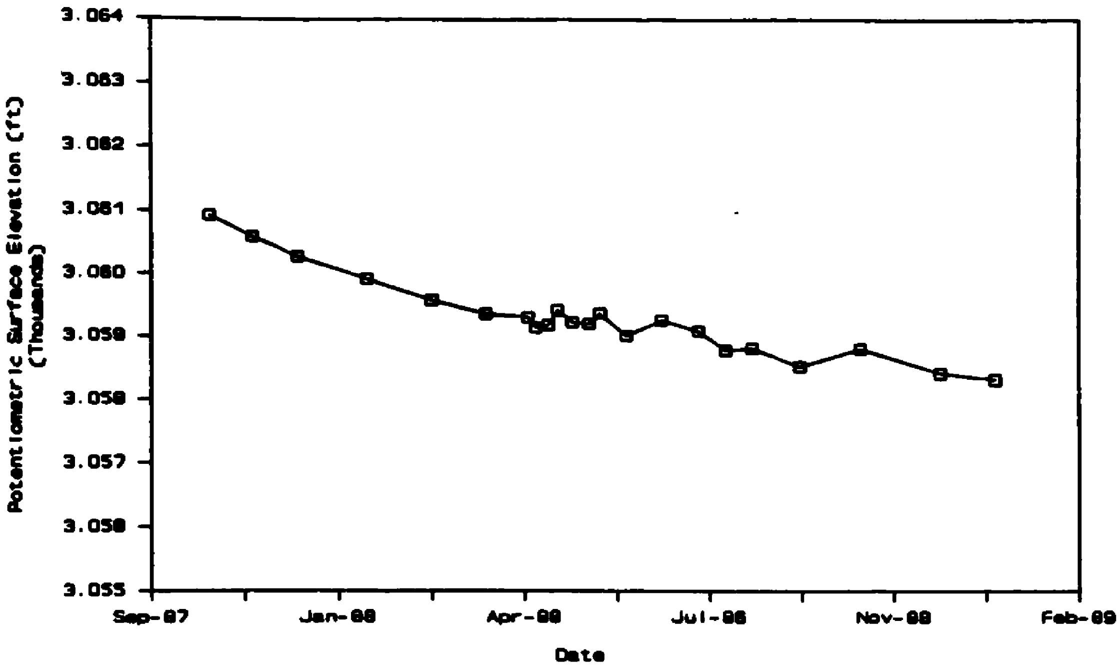
Well 14b



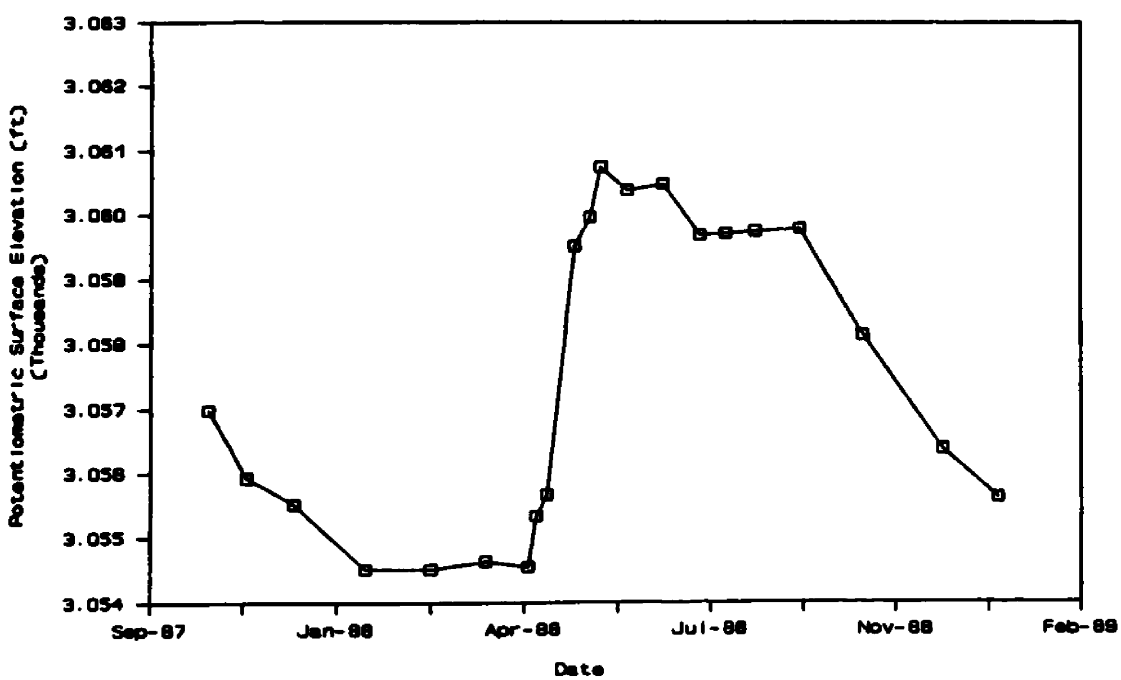
Wells 15 & 33



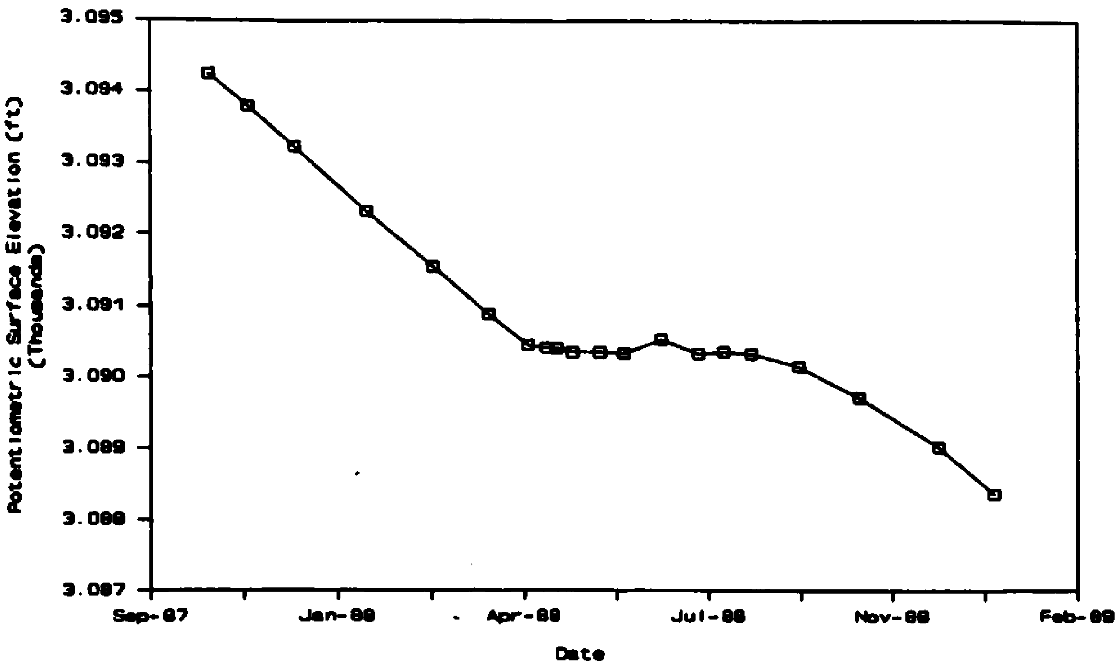
Well 16



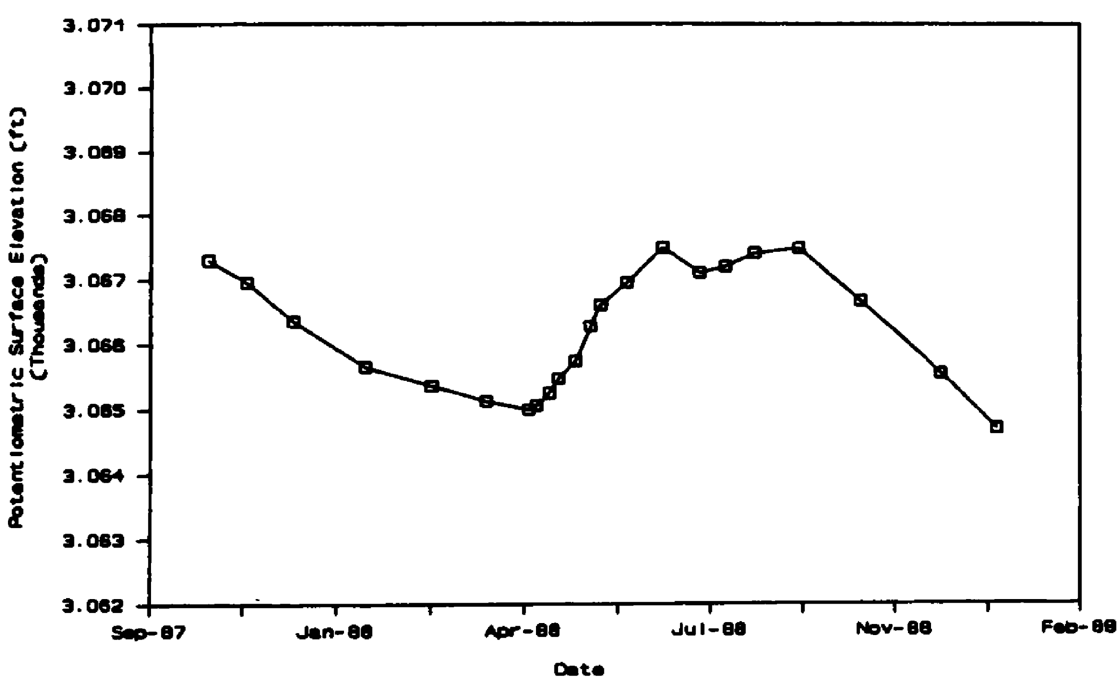
Well 18



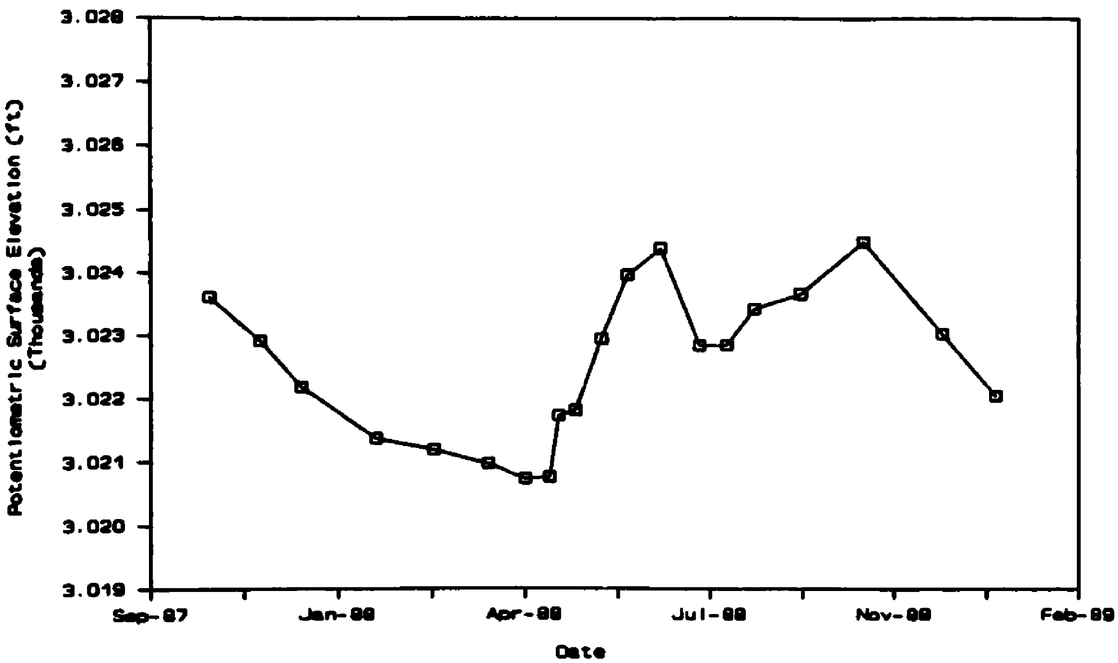
Well 19



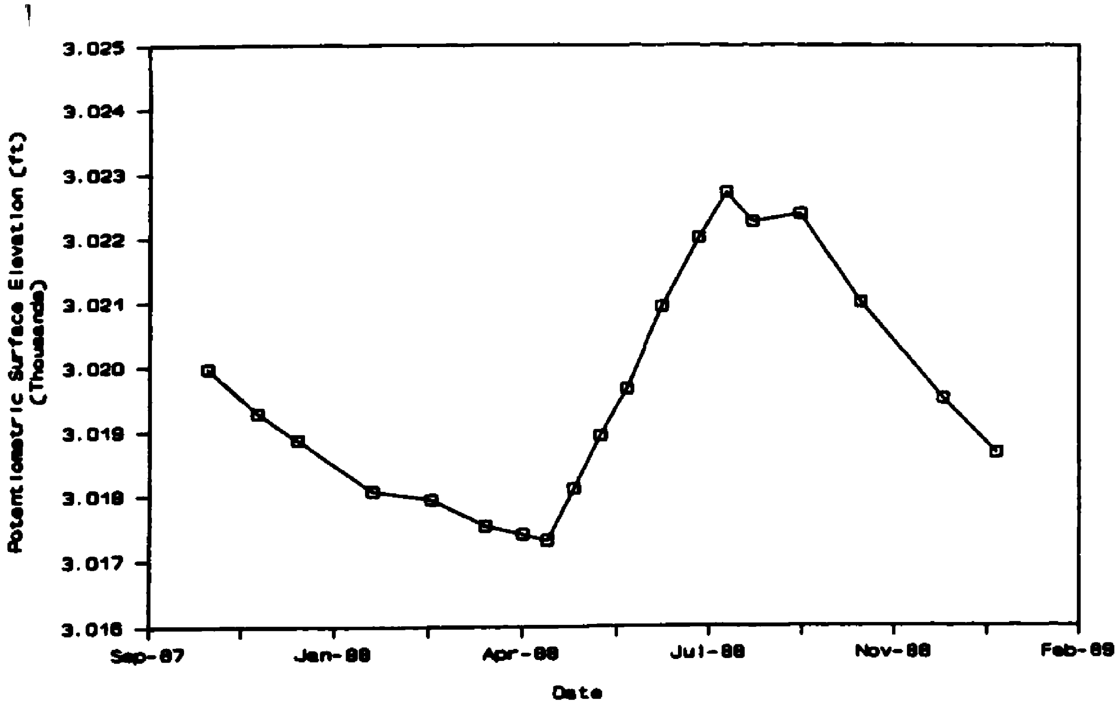
Well 20



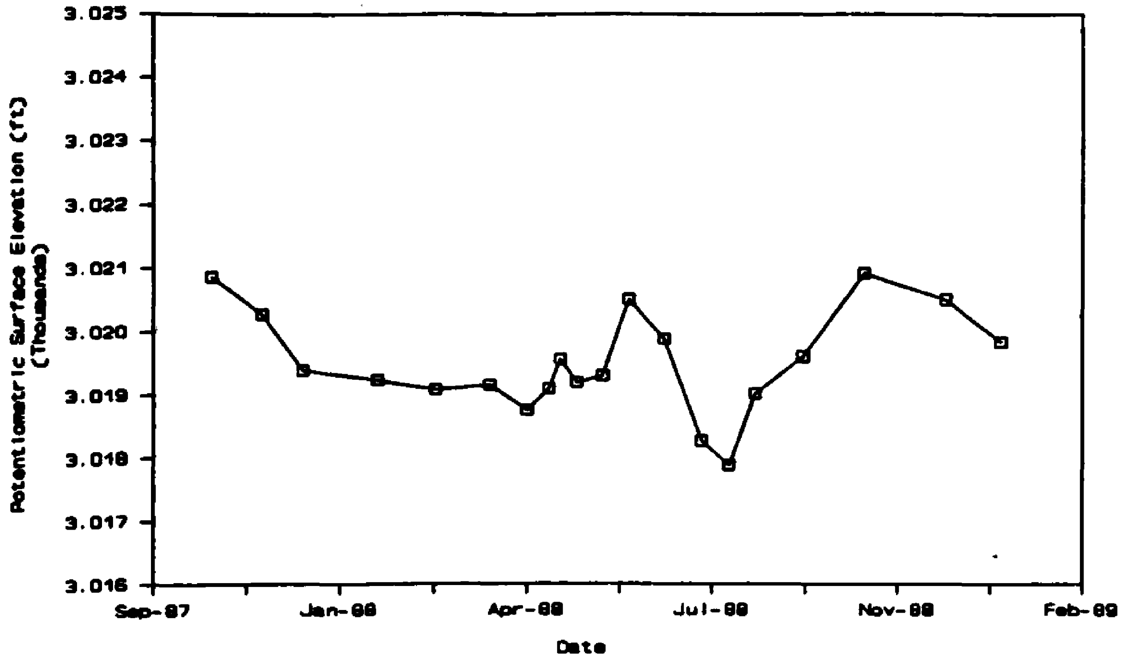
Well 21



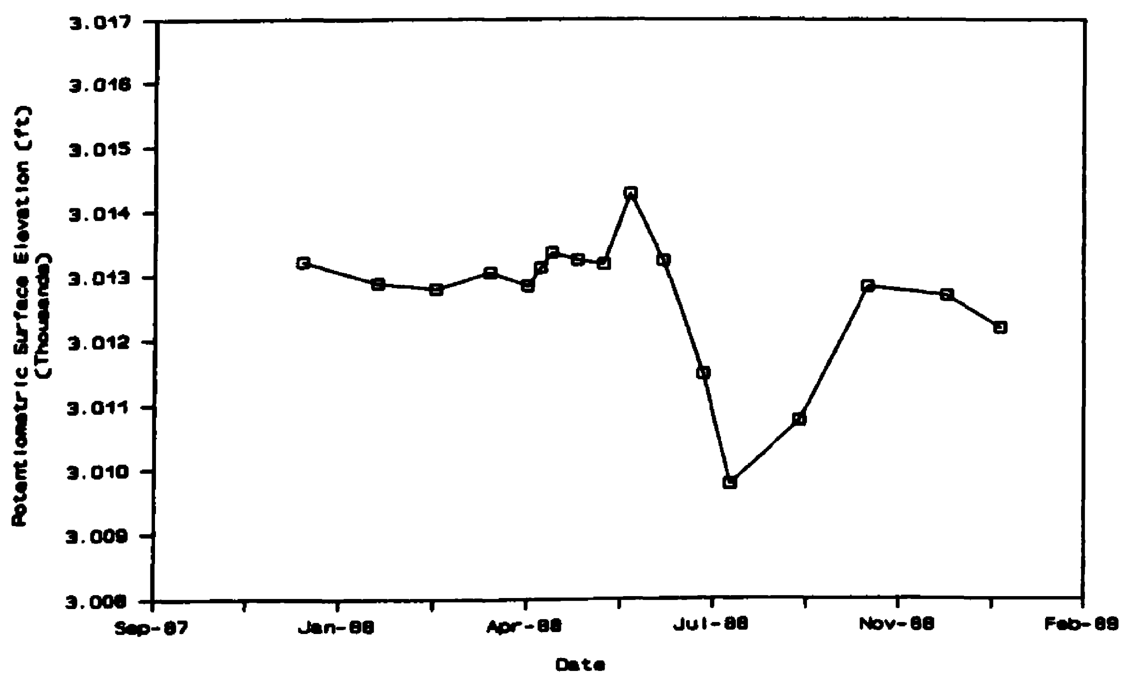
Well 22

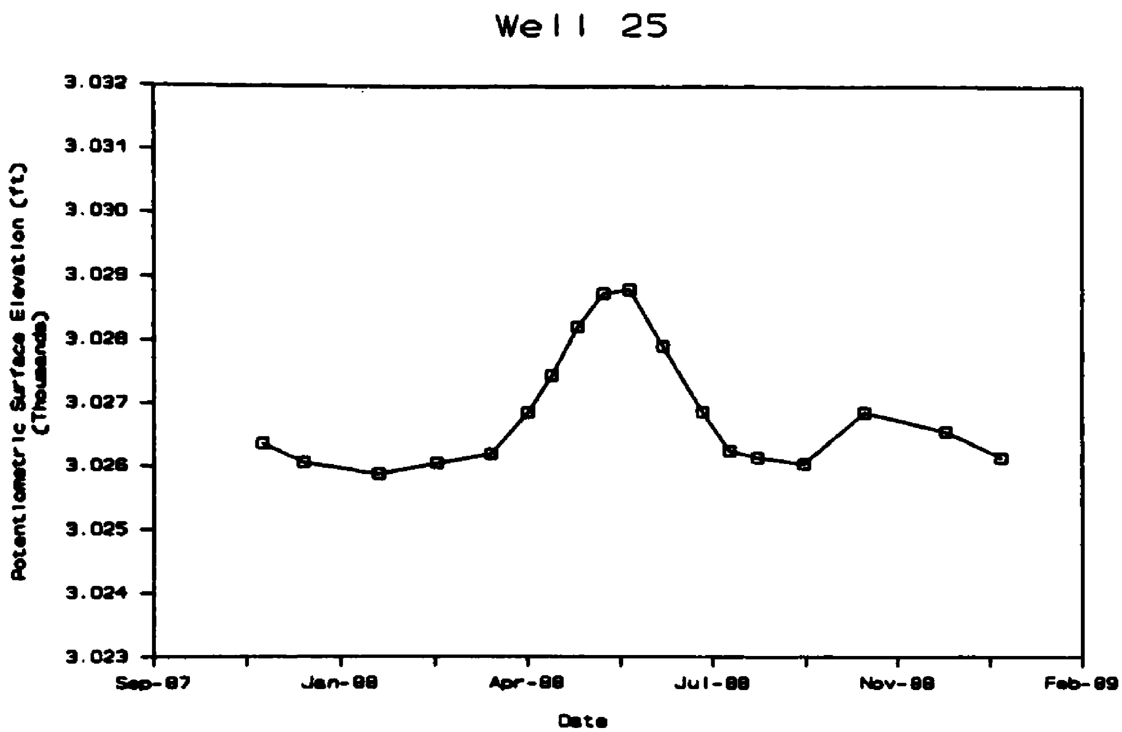


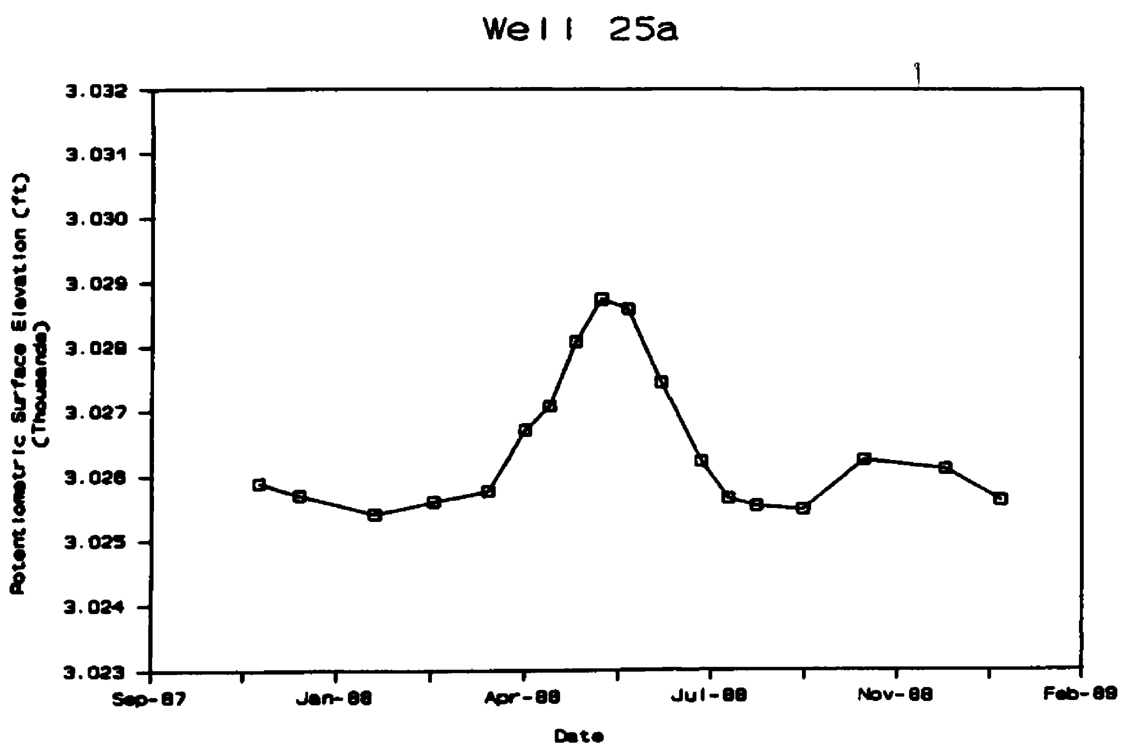
Well 23



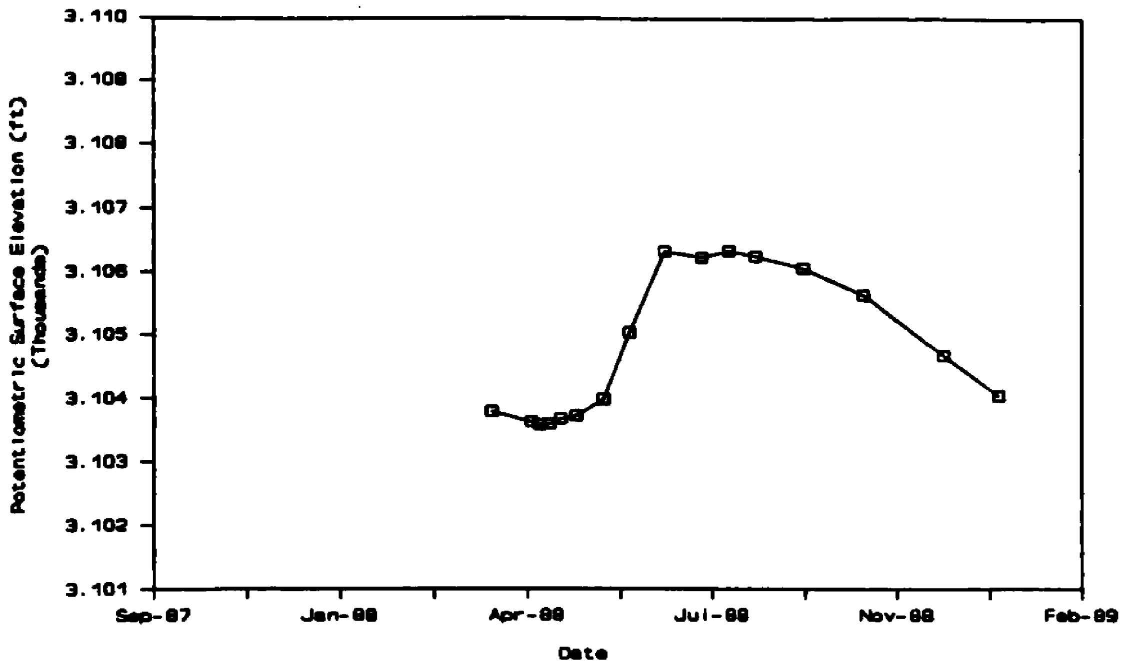
Well 24



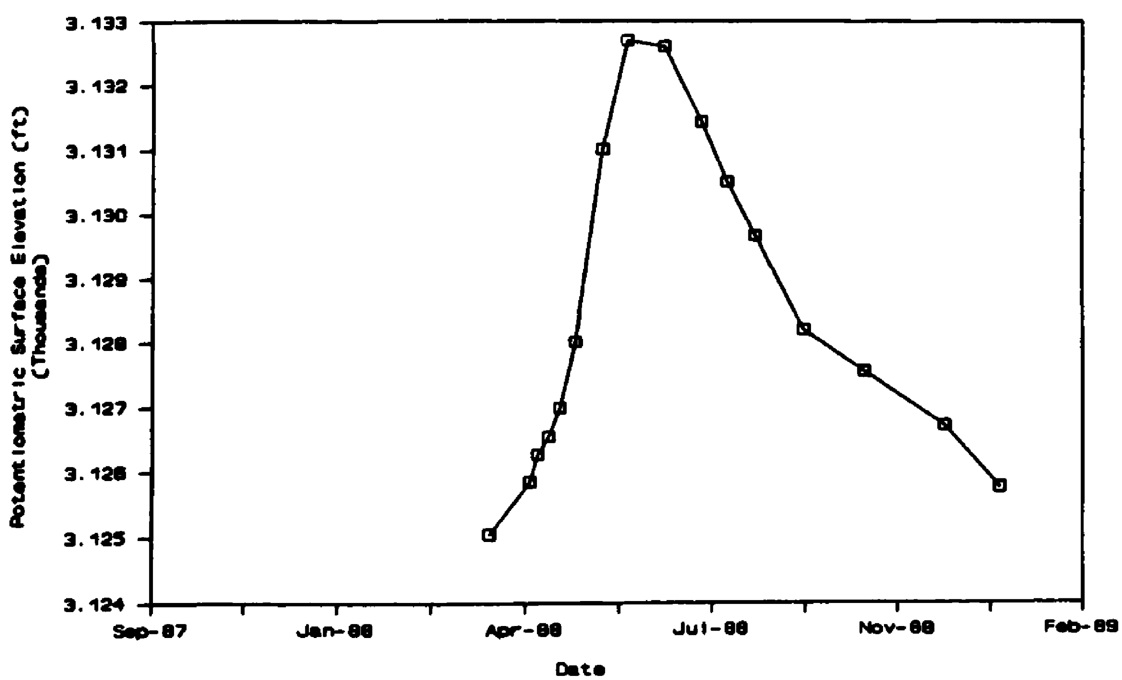

Well 25
Potentiometric Surface Elevation (ft)
(Thousands)
3.032
3.031
3.030
3.029
3.028
3.027
3.026
3.025
3.024
3.023
Sep-87
Jan-88
Apr-88
Jul-88
Nov-88
Feb-89
Date


Well 25a
Potentiometric Surface Elevation (ft)
(Thousands)
3.032
3.031
3.030
3.029
3.028
3.027
3.026
3.025
3.024
3.023
Sep-87
Jan-88
Apr-88
Jul-88
Nov-88
Feb-89
Date

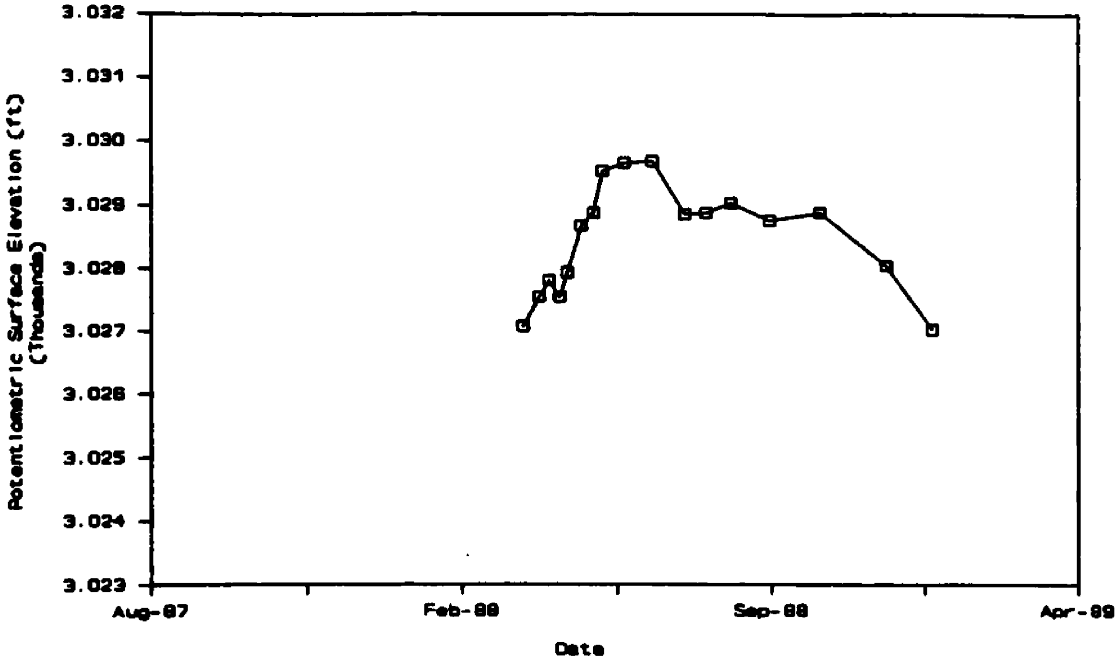
Well 26



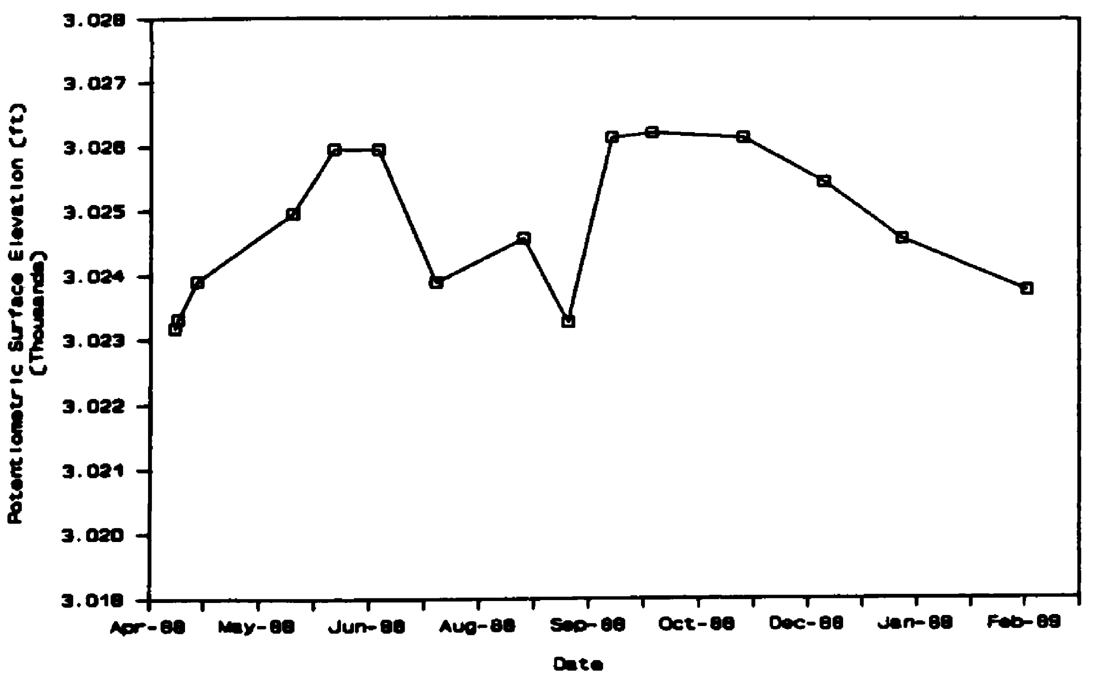
Well 27



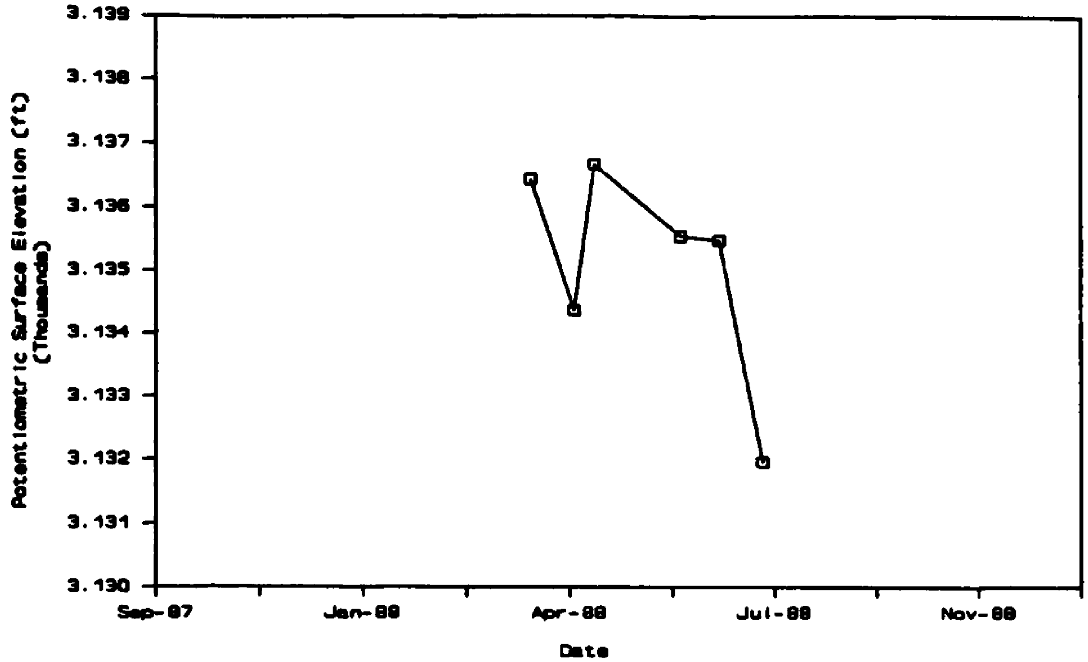
Well 28



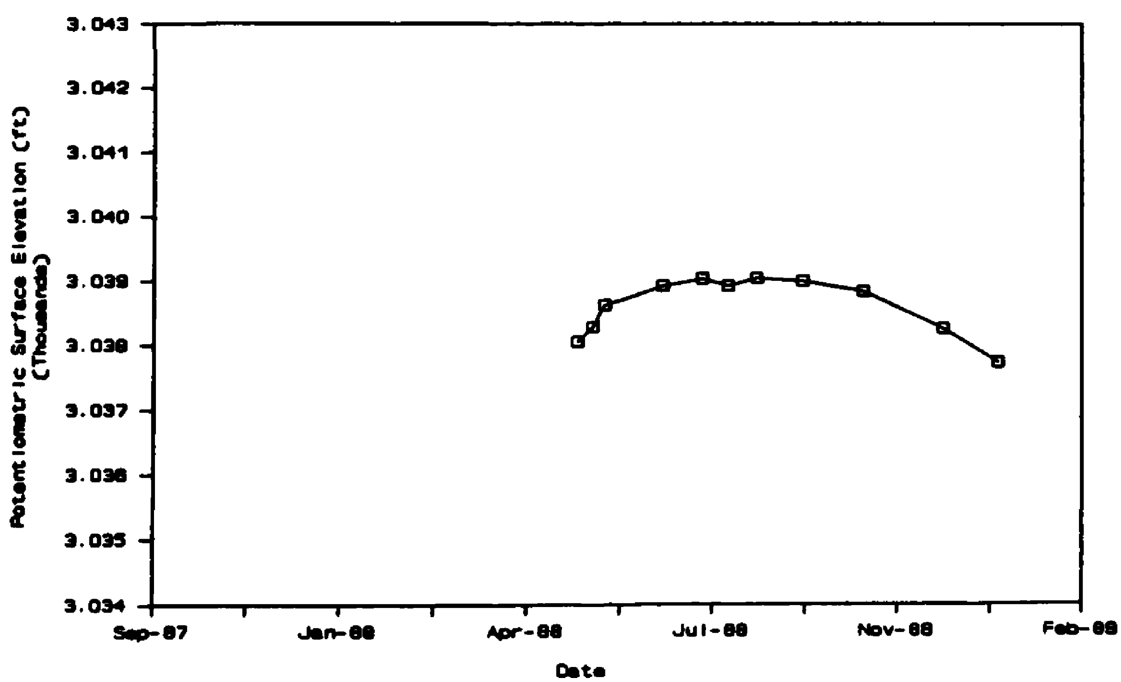
Well 29



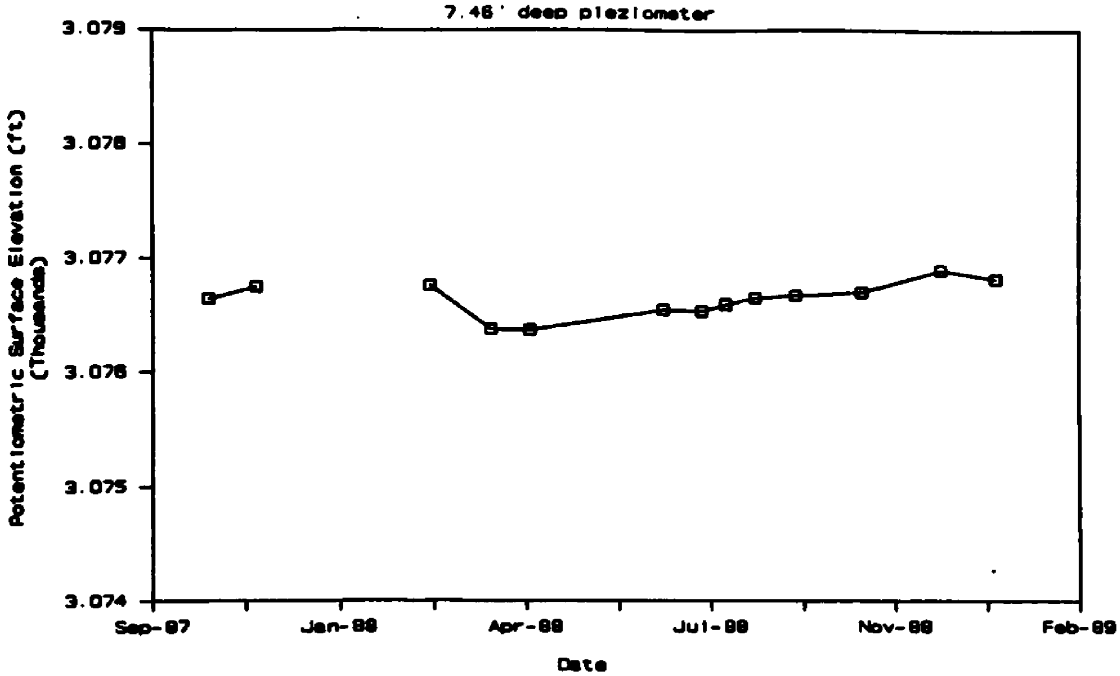
Well 30



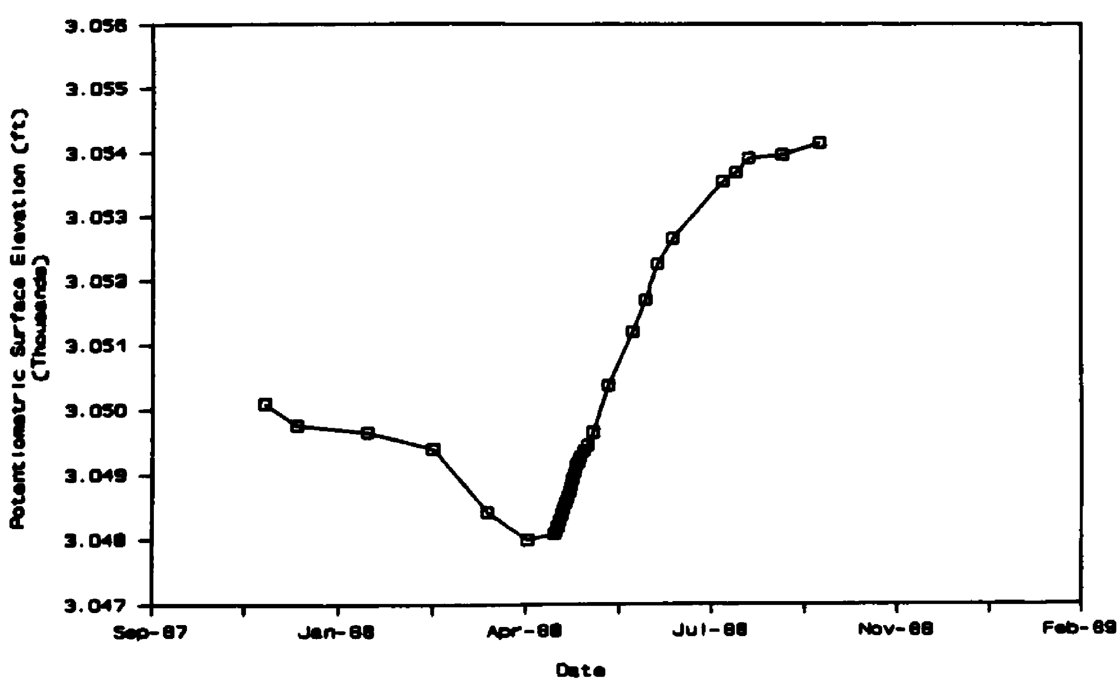
Well 31



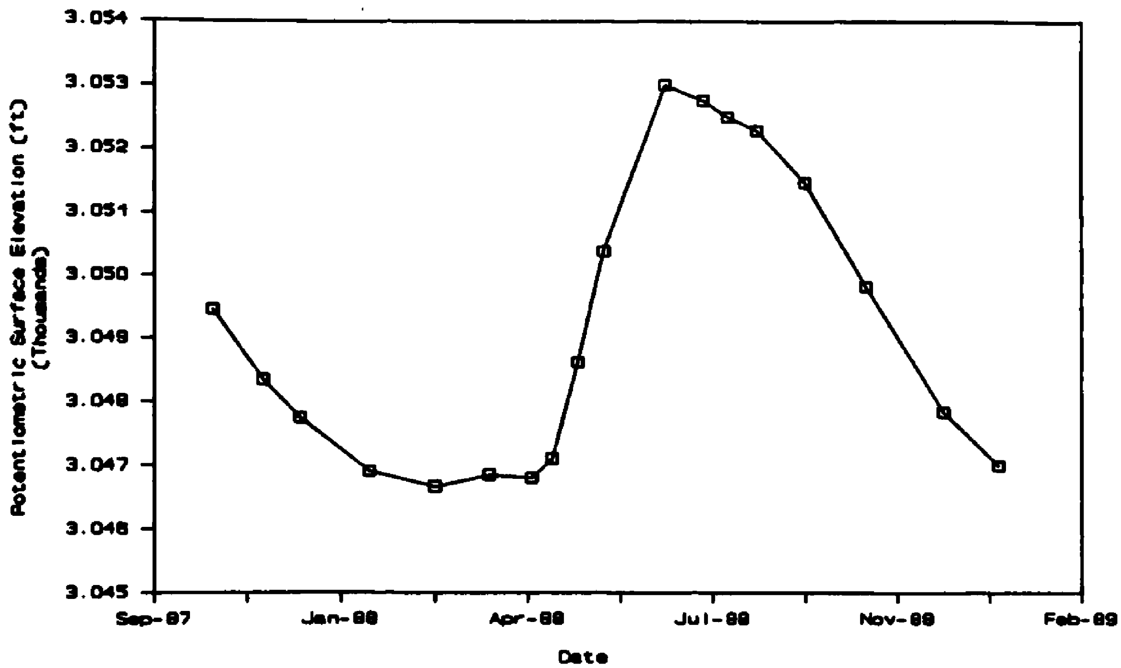
Well 10a



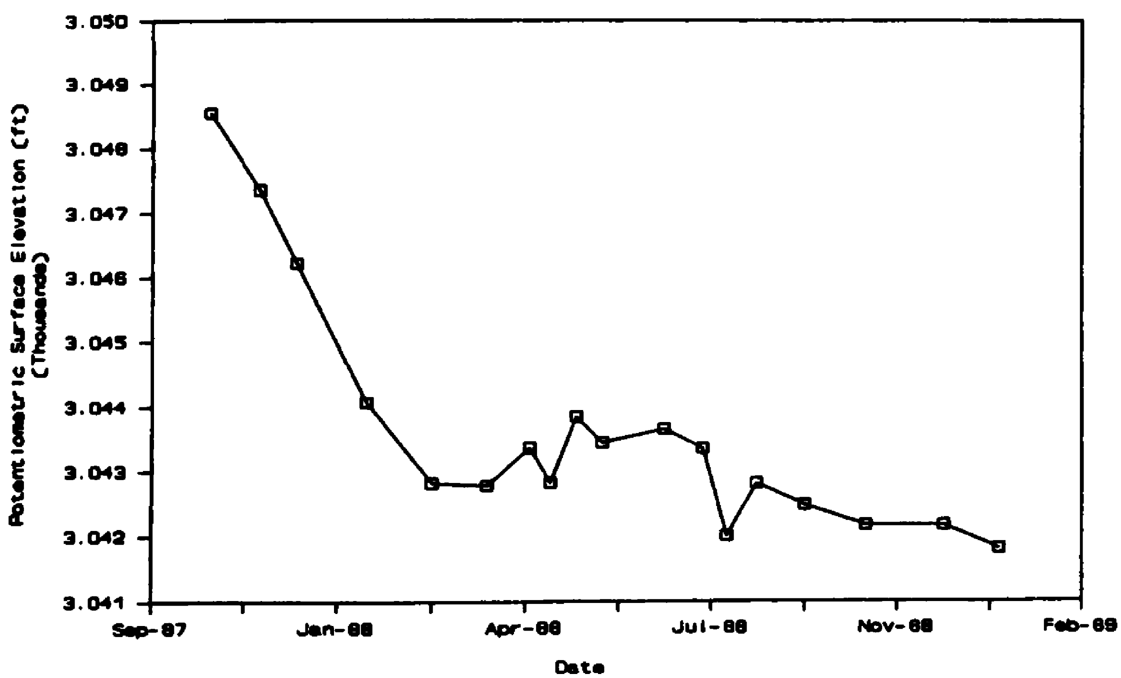
Well 17



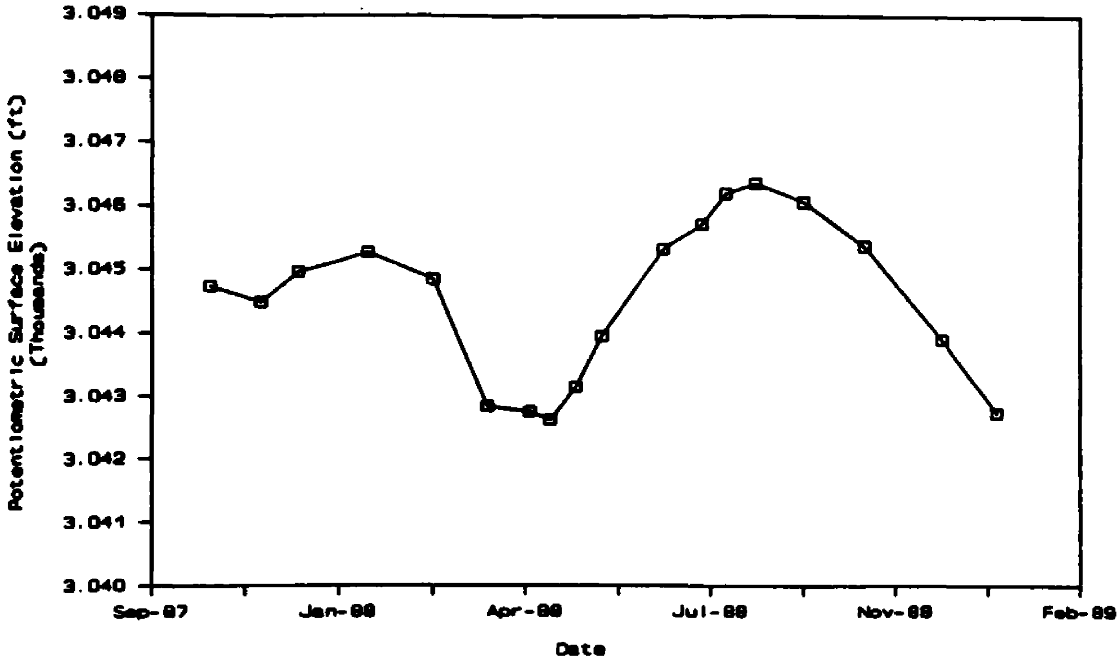
Pieziometer H26



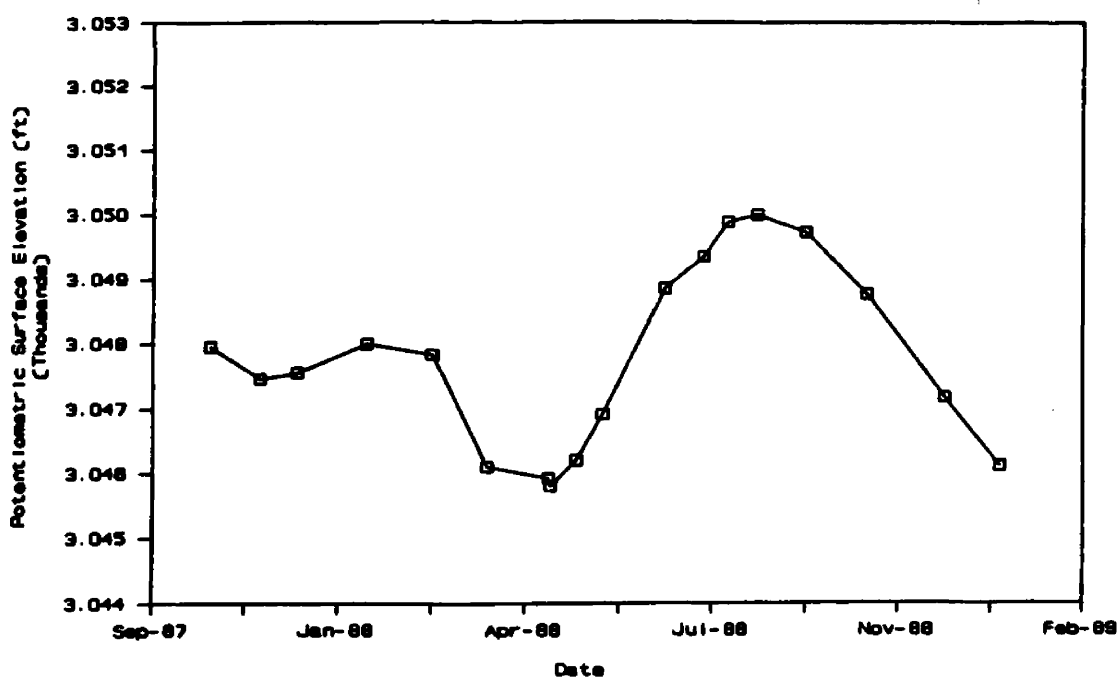
Pieziometer H27



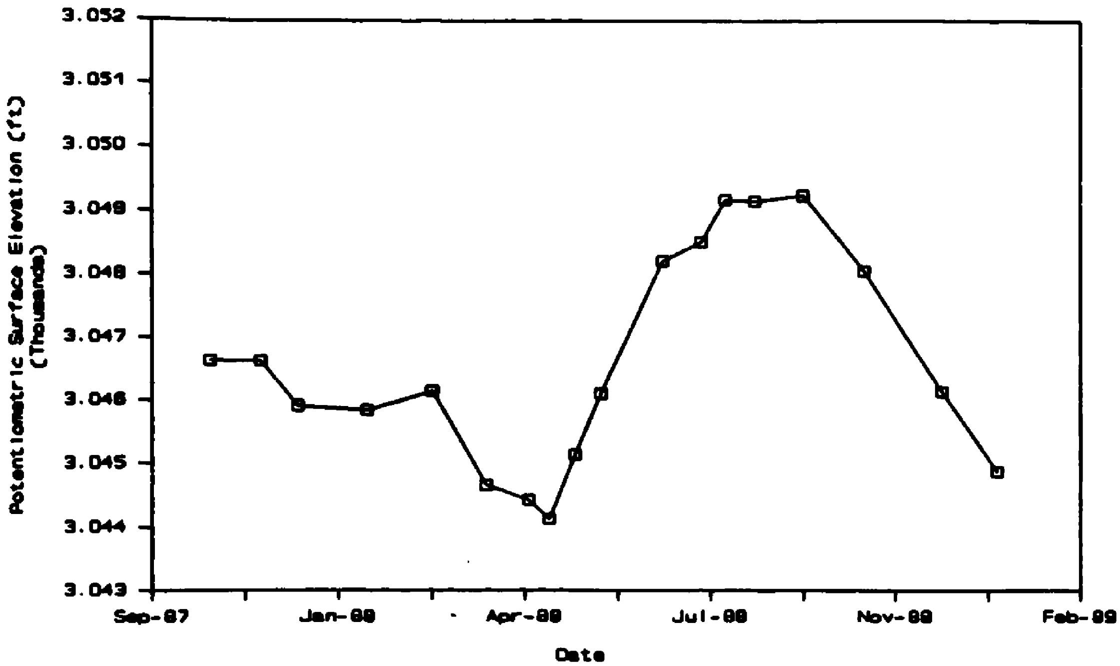
Piezometer K29



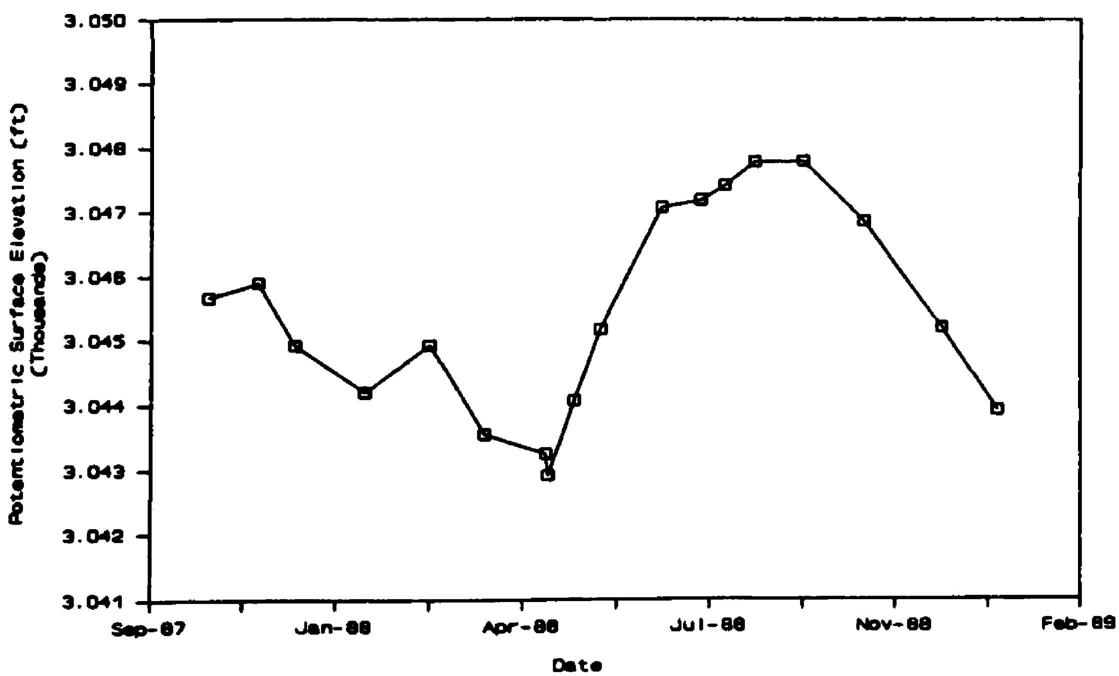
Piezometer K30

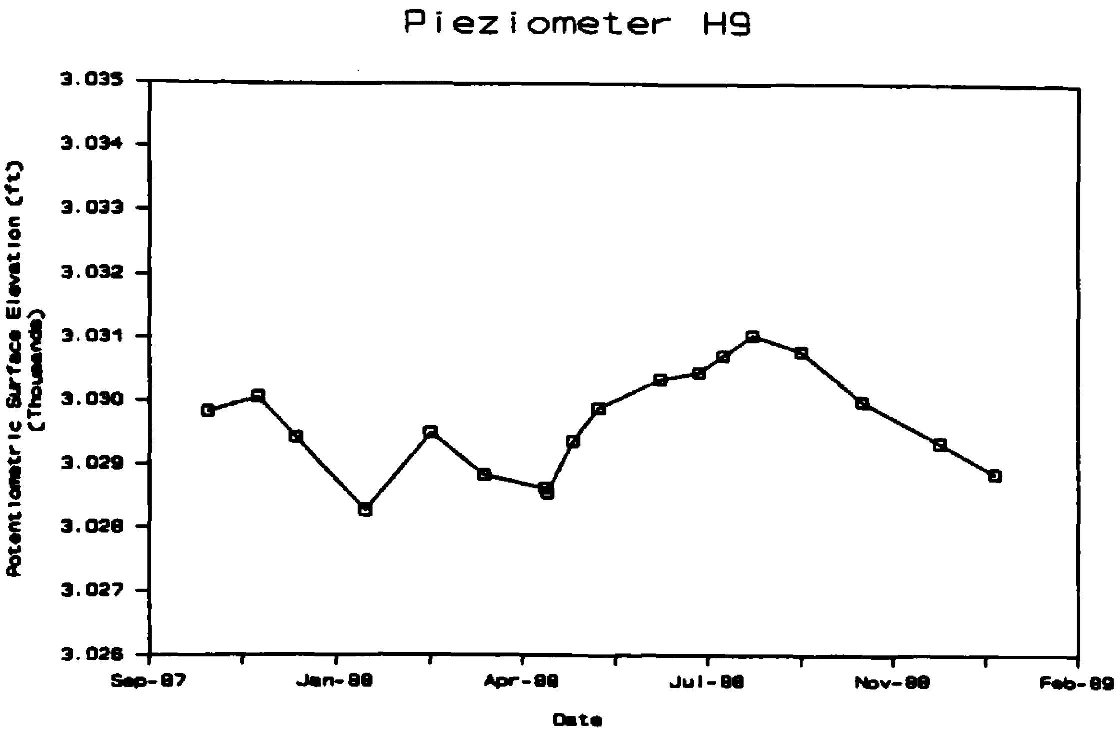


Piezjometer K31



Piezjometer H32




Piezlometer H9
3.035
3.034
3.033
3.032
3.031
3.030
3.029
3.028
3.027
3.026
Potentiometric Surface Elevation (ft)
(Thousands)
Sep-87
Jan-88
Apr-88
Jul-88
Nov-88
Feb-89
Date

APPENDIX IV

U.S.G.S. Clark Fork River Discharge and Stage Data
October 1987 - December 1988

Clark Fork River Discharge 1987 - 1988
U.S.G.S. Gauge Station 12353000
Discharge in cfs

Day	Oct-87	Nov-87	Dec-87	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
1	1500	1530	1380	1190	1270	1730	1960	5790	12400	4180	1060	865	1420	1760	1870
2	1530	1540	1460	1040	1150	1780	1900	5380	11500	3800	1060	857	1450	1760	1660
3	1530	1560	1730	994	1200	1810	1960	4960	10700	3470	1070	851	1410	1800	1650
4	1590	1560	1700	923	1370	1830	2170	4710	11000	3350	1060	841	1400	1910	1690
5	1550	1530	1690	884	1390	1790	2300	4610	13300	3270	1080	837	1400	1950	1640
6	1510	1540	1660	1030	1380	1800	2230	4900	14100	3220	1060	833	1390	1940	1800
7	1520	1550	1730	1160	1390	1860	2240	5780	13600	3170	1020	829	1390	2040	2090
8	1490	1550	1770	1280	1470	1850	2560	6130	12600	2940	1030	824	1370	2130	2000
9	1490	1540	1690	1340	1540	1780	2630	6150	11100	2650	1040	850	1350	2100	1940
10	1500	1540	1740	1400	1650	1770	2520	6350	9730	2430	1020	865	1360	2070	1950
11	1510	1540	1850	1470	1670	1770	2470	6810	9100	2250	1000	940	1350	2040	1920
12	1590	1540	1820	1500	1710	1710	2560	8310	8580	2130	994	1020	1320	2030	1930
13	1560	1550	1720	1450	1730	1650	3000	11000	8220	2040	993	1090	1320	2030	2040
14	1580	1580	1550	1500	1710	1630	3910	12500	7820	2000	1020	1130	1310	2040	2200
15	1640	1590	1240	1610	1700	1610	5000	11500	7340	1990	1050	1120	1310	2020	2110
16	1590	1590	1180	1730	1720	1600	6260	10400	7100	1930	1050	1060	1360	1990	1650
17	1540	1600	1290	1680	1700	1560	7930	11700	7070	1820	1030	1090	1870	2010	1440
18	1610	1540	1420	1540	1630	1520	9570	12900	7070	1740	993	1140	2590	2050	1360
19	1600	1490	1360	1260	1610	1550	10400	11500	6840	1680	970	1160	2480	2030	1450
20	1570	1510	1340	1220	1610	1600	9410	10000	6550	1590	976	1220	2320	1980	1710
21	1630	1530	1340	1370	1600	1770	8820	9110	6130	1520	975	1240	2240	1970	1840
22	1570	1550	1420	1420	1630	2050	8310	8930	5840	1420	975	1250	2130	1970	1890
23	1520	1590	1480	1450	1630	2140	7500	9860	5700	1370	981	1260	2030	2060	1870
24	1560	1590	1240	1460	1530	2070	6770	12000	5330	1320	973	1270	1960	2150	1850
25	1590	1590	1070	1450	1470	1980	6250	13600	4780	1280	947	1270	1910	2090	1600
26	1570	1580	949	1420	1480	1940	5750	13600	4670	1220	941	1260	1870	2030	1290
27	1550	1550	905	1410	1540	2080	5300	13500	4890	1140	924	1260	1840	1960	1070
28	1560	1460	872	1410	1580	2310	4940	13000	5190	1390	921	1300	1820	1890	1180
29	1550	1430	943	1430	1640	2300	4940	12100	5240	1070	917	1380	1790	1970	1300
30	1560	1440	1080	1500		2130	5580	11900	4680	1060	903	1400	1780	1970	1630
31	1550		1200	1500		2020		13100		1090	878		1780		1880

Clark Fork River Stage 1987 - 1988
U.S.G.S. Gauge Station 12353000
Stage in feet above Datum (3083.88 above M.S.L.)

Day	Oct-87	Nov-87	Dec-87	Jan-88	Feb-88	Mar-88	Apr-88	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Nov-88	Dec-88
1	1.06	1.08	0.95	0.78	0.86	1.25	1.42	3.37	5.46	2.68	0.65	0.44	1.00	1.27	1.35
2	1.09	1.09	1.02	0.63	0.74	1.29	1.37	3.20	5.21	2.50	0.65	0.43	1.02	1.27	1.19
3	1.09	1.11	1.25	0.58	0.79	1.30	1.42	3.03	5.00	2.34	0.66	0.42	0.98	1.30	1.19
4	1.13	1.11	1.22	0.50	0.94	1.32	1.56	2.92	5.10	2.27	0.65	0.41	0.97	1.38	1.21
5	1.10	1.09	1.22	0.46	0.96	1.30	1.65	2.88	5.69	2.23	0.67	0.40	0.97	1.41	1.17
6	1.07	1.09	1.19	0.62	0.96	1.30	1.61	3.00	5.89	2.20	0.65	0.40	0.97	1.40	1.30
7	1.08	1.10	1.24	0.75	0.96	1.35	1.61	3.37	5.76	2.18	0.61	0.39	0.96	1.48	1.51
8	1.06	1.10	1.28	0.86	1.03	1.34	1.82	3.51	5.52	2.04	0.62	0.39	0.95	1.54	1.45
9	1.05	1.10	1.22	0.92	1.09	1.29	1.86	3.51	5.12	1.88	0.62	0.42	0.93	1.52	1.41
10	1.06	1.09	1.25	0.97	1.18	1.28	1.79	3.59	4.72	1.74	0.61	0.44	0.94	1.50	1.41
11	1.07	1.09	1.34	1.04	1.20	1.28	1.76	3.76	4.53	1.62	0.59	0.52	0.93	1.47	1.39
12	1.13	1.10	1.32	1.06	1.23	1.23	1.82	4.27	4.36	1.54	0.58	0.61	0.90	1.47	1.40
13	1.11	1.12	1.23	1.02	1.24	1.18	2.08	5.06	4.25	1.48	0.58	0.68	0.90	1.47	1.48
14	1.13	1.13	1.10	1.06	1.23	1.17	2.55	5.48	4.12	1.45	0.61	0.72	0.90	1.48	1.59
15	1.17	1.14	0.83	1.15	1.22	1.15	3.04	5.22	3.95	1.44	0.64	0.71	0.90	1.46	1.52
16	1.13	1.14	0.77	1.24	1.24	1.14	3.55	4.91	3.87	1.40	0.64	0.65	0.94	1.44	1.18
17	1.09	1.09	0.87	1.20	1.23	1.11	4.15	5.26	3.86	1.31	0.62	0.69	1.34	1.46	1.01
18	1.15	1.05	0.99	1.09	1.16	1.07	4.67	5.59	3.86	1.25	0.58	0.73	1.83	1.48	0.93
19	1.14	1.07	0.94	0.84	1.15	1.10	4.93	5.21	3.77	1.21	0.55	0.75	1.77	1.47	1.01
20	1.12	1.08	0.92	0.81	1.15	1.14	4.62	4.80	3.66	1.14	0.56	0.80	1.66	1.43	1.23
21	1.17	1.11	0.92	0.95	1.14	1.28	4.44	4.53	3.51	1.08	0.56	0.83	1.62	1.42	1.33
22	1.12	1.13	0.99	0.99	1.17	1.48	4.28	4.47	3.39	0.99	0.56	0.84	1.54	1.42	1.37
23	1.08	1.13	1.04	1.02	1.17	1.54	4.01	4.76	3.34	0.94	0.57	0.85	1.47	1.49	1.35
24	1.11	1.13	0.82	1.03	1.09	1.49	3.75	5.36	3.19	0.91	0.56	0.86	1.42	1.55	1.34
25	1.13	1.13	0.66	1.01	1.04	1.44	3.55	5.76	2.95	0.86	0.53	0.85	1.38	1.51	1.14
26	1.12	1.13	0.53	0.99	1.04	1.41	3.36	5.75	2.90	0.80	0.52	0.84	1.35	1.47	0.87
27	1.10	1.10	0.48	0.99	1.09	1.50	3.17	5.73	3.00	0.73	0.50	0.85	1.33	1.42	0.66
28	1.11	1.03	0.44	0.98	1.13	1.66	3.02	5.62	3.13	0.68	0.50	0.89	1.32	1.37	0.77
29	1.11	1.00	0.52	1.00	1.17	1.65	3.02	5.39	3.15	0.66	0.50	0.95	1.29	1.43	0.88
30	1.11	1.00	0.67	1.06		1.54	3.29	5.32	2.91	0.65	0.48	0.97	1.29	1.43	1.17
31	1.10		0.79	1.06		1.46		5.63		0.68	0.45		1.29		1.36

APPENDIX V

Results of Missoula Valley Ground Water Chemical Analyses

MISSOULA VALLEY GROUND WATER CHEMISTRY.

Sample Area	Loc.	Field Data: Temp. (C)	Field Cond.	Cond. at 25 C	pH	Tot Alk	I.C.P. Cation Analysis: Al	As	Ca	Cd	Cu	Fe	K	Mg
1	3	10.1	260	355	8.70	182.05	0.04	*	54.334	*	0.002	0.011	2.0	18.02
1	27	9.2	148	207	7.72	109.78	0.02	*	31.426	*	0.002	0.006	*	9.93
1	2	9.9	278	398	8.08	194.74	0.04	*	53.374	*	0.016	0.018	2.1	18.50
1	1	11.1	263	365	8.10	184.26	0.03	*	51.474	*	*	0.031	1.9	15.42
2a	4	10.6	254	355	8.02	171.02	*	*	49.372	*	0.003	0.010	*	17.13
2a	26	9.8	242	340	7.49	191.43	0.02	0.04	41.845	0.003	*	0.004	*	20.42
2b	13	11.8	280	360	7.01	161.64	0.02	*	34.695	*	*	0.004	*	13.33
2b	19	10.0	192	268	6.50	135.16	0.02	*	24.445	0.002	0.007	0.005	*	14.03
2b	13	11.9	175	228	7.01	161.64	0.03	*	36.456	*	0.002	0.008	*	13.28
2b	12	11.2	181	245	6.12	119.99	*	0.03	12.925	0.003	0.002	0.023	5.2	8.70
2c	16	11.0	259	338	6.60	178.88	0.02	0.04	36.845	0.003	0.004	0.017	*	18.46
2c	15	10.1	188	251	6.53	129.64	*	*	26.965	0.002	*	0.007	*	13.88
3	28	10.9	331	436	7.23	206.05	0.03	0.03	54.725	*	*	0.010	*	19.78
3	10	9.5	187	269	8.40	129.09	*	*	39.182	*	*	*	*	12.06
3	28	10.9	316	413	7.40	207.15	0.02	*	54.025	*	*	0.029	*	19.99
3	10	9.2	187	286	7.61	126.06	0.02	*	37.925	*	*	0.007	*	11.90
3	9	10.8	257	338	6.50	160.54	*	*	47.860	*	*	0.011	1.0	14.76
3	14	9.2	230	322	8.40	149.5	0.02	*	48.159	*	*	0.004	1.1	15.39
3	6	10.0	250	336	7.82	160.54	*	*	47.642	*	0.002	*	*	16.12
3	20	11.4	179	231	6.61	118.06	*	0.03	22.875	0.002	*	0.013	*	9.74
3	11	12.0	341	435	6.78	235.56	0.03	0.03	58.028	0.002	0.001	0.016	1.8	21.89
3	5	10.1	250	354	8.24	162.19	0.02	*	48.992	*	0.041	0.009	*	16.58
3	18	10.1	313	419	7.21	221.22	*	*	44.490	*	0.002	*	1.5	17.38
3	8	10.0	195	267	8.30	131.03	0.03	*	38.877	*	*	0.010	1.1	12.17
4	22	11.0	335	456	6.90	234.46	0.03	*	68.076	*	0.003	0.010	3.8	17.73
4	21	10.9	233	318	7.18	169.36	0.02	*	39.486	*	*	0.179	1.7	13.41
4	23	11.5	190	244	7.46	140.68	0.02	0.03	32.940	*	0.002	0.007	1.9	11.18
4	24	11.9	202	257	7.63	148.12	0.02	*	34.200	0.002	*	0.040	2.4	12.00
4	25	9.1	254	363	6.54	183.71	*	*	48.616	*	*	0.306	*	13.16
4	21	10.9	233	318	7.18	169.64	*	*	39.036	*	*	0.178	1.6	13.38
5	CF Harp	4.4	146	230	7.35	97.65	0.02	*	32.115	*	0.003	0.020	1.3	9.17
5	CF Kona	4.3	151	238	7.45	103.05	0.02	*	34.035	*	0.003	0.020	1.2	9.78
6	D.W.	22.8	1	1	5.70	*	*	*	*	*	*	*	*	*
6	D.W.	23.9	0	0	*	*	*	*	*	*	*	*	*	
6	D.W.	23.0	1	1	4.5	*	*	*	*	*	*	*	*	0.01
6	D.W.	22.5	1	1	6.5	*	*	*	*	*	*	*	*	*
6	D.W.	21.9	3	3	6.8	*	*	*	*	*	*	*	*	*

Sample Area	Sample Loc.	I.C.P. Cation Analysis (cont.) Mn	Na	Ni	Sb	P	Si	Zn	I.C. Anion Analysis F	Cl	NO3	HPO4	SO4
1	3	*	8.50	*	0.06	*	6.88	0.062	0.074	9.182	6.509	*	20.436
1	27	0.001	2.70	0.01	*	*	6.41	0.029	*	1.842	4.323	*	4.536
1	2	0.001	9.71	*	0.06	*	5.95	0.089	0.153	8.728	6.830	*	19.407
1	1	0.001	9.18	*	*	*	6.10	0.011	0.209	4.449	1.622	*	27.725
2a	4	0.009	7.60	*	*	*	6.46	0.009	0.095	7.689	2.591	*	18.629
2a	26	*	6.34	*	0.06	0.24	6.99	0.061	0.061	1.789	1.985	*	6.822
2b	13	*	28.28	*	*	*	11.00	0.086	0.345	8.304	17.977	0.132	9.074
2b	19	*	17.05	*	*	0.11	10.90	0.084	0.152	13.051	3.454	*	13.473
2b	13	0.001	26.64	*	*	*	11.47	0.073	0.391	9.995	20.035	0.130	9.838
2b	12	0.010	28.76	*	*	*	23.03	0.568	1.143	4.021	2.878	0.067	13.918
2c	16	0.002	18.05	*	0.07	0.24	11.58	0.527	0.183	3.951	4.051	0.087	22.279
2c	15	*	11.74	*	*	*	9.84	0.053	0.167	3.677	2.862	*	11.786
3	28	0.002	15.90	*	*	*	9.37	0.023	0.037	2.939	1.620	0.062	37.932
3	10	*	4.89	*	*	*	5.99	0.006	0.108	3.917	1.966	*	8.424
3	28	0.002	16.44	*	*	*	9.35	0.032	0.041	3.322	1.707	*	41.162
3	10	*	4.98	0.02	*	*	5.69	0.017	*	5.114	3.776	*	9.332
3	9	0.001	8.91	0.01	*	*	7.50	0.004	0.149	12.815	1.159	*	27.906
3	14	*	6.11	0.01	*	*	6.50	0.081	0.093	3.991	2.304	*	39.356
3	6	*	6.87	0.01	*	*	6.19	0.010	0.044	8.395	2.825	*	15.471
3	20	0.002	16.67	*	*	*	12.57	0.201	0.233	2.289	4.616	*	8.684
3	11	0.002	13.23	0.01	0.06	0.16	9.22	0.037	0.188	3.147	0.278	*	23.370
3	5	0.001	7.09	*	*	*	6.28	0.062	0.079	8.945	2.710	*	14.101
3	18	*	33.20	0.01	*	*	9.82	0.016	0.320	3.984	1.298	0.065	23.556
3	8	*	8.27	*	*	*	6.60	0.015	0.085	8.098	4.595	*	8.189
4	22	0.028	9.52	*	*	*	8.66	0.033	0.069	3.045	3.268	0.138	25.769
4	21	0.686	11.61	*	*	*	8.52	0.056	0.135	1.448	0.093	*	7.664
4	23	0.016	8.91	0.01	*	*	9.09	0.003	0.227	1.126	0.187	0.273	4.587
4	24	0.104	9.67	0.01	*	*	9.24	0.013	0.235	1.373	0.056	0.172	6.301
4	25	0.996	8.21	*	*	*	9.60	0.025	0.087	2.271	*	*	12.355
4	21	0.678	11.74	*	*	*	8.46	0.053	0.132	1.354	0.056	*	7.694
5	CF Harp	0.011	6.93	*	*	*	5.95	0.020	0.208	2.952	0.792	0.083	26.032
5	CF Kona	0.015	7.01	*	*	*	6.04	0.011	0.222	2.794	0.804	*	31.773
6	D.W.	*	*	0.01	*	*	*	0.002	*	0.813	0.164	*	*
6	D.W.	*	*	*	*	*	*	*	*	0.574	*	*	*
6	D.W.	*	0.14	*	*	*	*	0.007	*	1.245	*	*	*
6	D.W.	*	*	*	*	*	*	0.004	*	1.229	*	*	*
6	D.W.	*	*	*	*	*	*	0.005	*	1.312	0.494	*	*

Explanation of Missoula Valley Ground Water Chemistry Table.

Area:

Areas I - IV first introduced in the Geology section.

Sample Loc. :

A number - domestic well.
CF - Clark Fork River at either Harpers or Kona Ranch bridge.
D.W. - Deionized water

Field Data:

pH, conductivity and temperature readings taken in the field.
Conductivity at 25°C calculated from the following formulas:

Cell constant (CC) =
(1408.1/avg. Cond)(1+0.00191(Avg Temp - 25)).

Conductivity at 25°C =
(Measured Cond. x CC.)/(1 + 0.0191(Meas. Temp - 25))
(Greenberg,1985)

CC formula is a combination of formulas from Greenberg (1985) and the YSI S-C-T model 33 instruction booklet. The Original formulas are:

CC = Resistivity x 1408.1μmhos (YSI)

CC = (Resistivity x 1413μmhos)(1+0.00191(temp - 25°))
(Greenberg)
Resistivity = 1/conductivity

All conductivity readings in μmhos. All temperature readings in °C. Each is an average of 2 readings taken at the start and end of each day used to deal with daily drift in the instrument.

Tot. Alk.:

Total alkalinity. Calculated by titrating with 0.1347708 N HCl to end point and then using:

Alkalinity, mg $CaCO_2$,/L = (A x N x 50,000)/ml sample
A = ml acid used
N = normality of acid.
(Greenberg,1985)

I.C.P. Cation Analysis:

Ion chromatograph analysis for anions. All values are an average of two analyses except for samples 4, 15 & 27 which were duplicated and are averages of 4 analyses. All values in ppm.
* = concentration below detection limit.

I.C. Anion Analysis:

Inductively coupled plasma spectroscopic analysis for cations. All values are an average of two analyses and are in ppm.
* = concentration below detection limit.

APPENDIX VI

KCALC
A program by Alan Wylie for calculating S.P. and K values from pump test data

```
REM     KCALC calculates hydraulic conductivity using information in
REM driller's logs. This information then is corrected for partial
REM penetration using an equation developed by Kozeny and corrected
REM to equivalent drawdown in a confined aquifer using Jacob's drawdown
REM correction. The corrected drawdown and discharge then are used to
REM solve for hydraulic conductivity using a method developed by Walton.
REM     The partial penetration correction assumes steady state conditions,
REM and is not valid when the aquifer thickness is small, the percent of
REM penetration is large, and the well radius is large. For this reason
REM KCALC does not make the Kozeny correction if 90% of the aquifer is
REM screened.
REM     The Jacob equations are designed for transient conditions. The less
REM correct the steady state assumption is the more in error the corrected
REM discharge will be.
REM     More information on these equations can be found in GROUNDWATER
REM AND WELLS by F. G. Driscoll, published by Johnson Division, St. Paul, Mn.
REM     KCALC can save your data to a disk file called KCOND.DAT. This
REM file can be reaccused at a later time by KCALC without erasing data
REM already in the file.
        CLS
        PI=4*ATN(1)
5       INPUT "Do you want to save the data to a disk file (Y-yes, N-no)";DISK$
        IF DISK$<>"Y" AND DISK$<>"y" AND DISK$<>"N" AND DISK$<>"n" GOTO 5
        IF DISK$="N" OR DISK$="n" GOTO 10
        OPEN "A", #1, "KCOND.DAT"
10      CLS
REM INPUT DATA FROM THE AQUIFER TEST
        INPUT "Is the aquifer confined or unconfined? (C-conf, U-unconf)";AQT$
        IF AQT$<>"C" AND AQT$<>"c" AND AQT$<>"U" AND AQT$<>"u" GOTO 10
        IF AQT$="U" OR AQT$="u" THEN AQT$="U"
        INPUT "What is the well name";WELLNAME$
        INPUT "What is the discharge in gal/min";Q
        INPUT "What is the depth to the top of the screened interval";TSCREEN
        INPUT "What is the depth to the bottom of the screened interval";BSCREEN
        INPUT "What is the diameter of the well in inches";RW
        INPUT "What is the depth to the top of the aquifer in feet";AQUIFERT
        INPUT "What is the depth to the bottom of the aquifer in feet";AQUIFERB
        INPUT "What was the static water level";H2
        INPUT "What was the water level after pumping";H1
        INPUT "What was the length of the test in minutes";TM
        INPUT "For a water table aquifer estimate specific yield",SY
20      INPUT "Do you want to change any input data (Y-yes, N-no)";ANS$
        IF ANS$<>"Y" AND ANS$<>"y" AND ANS$<>"N" AND ANS$<>"n" GOTO 20
        IF ANS$="Y" OR ANS$="y" GOTO 10
        PRINT:PRINT
        RW=RW/24
        S=H1-H2
```

```
        B=AQUIFERB-AQUIFERT
        IF SY=0 THEN SY=B*EXP10(-6)
        LS=BSCREEN-TSCREEN
        IF LS<1 THEN LS=1
REM IF THE WELL IS NOT FULLY PENETRATING, CORRECT FOR PARTIAL
PENETRATION
        IF LS>.9*B THEN CALL NPPC
        IF LS<=.9*B THEN CALL PPC(LS,B,RW,PI,Q)
        H1=AQUIFERB-H1
        H2=AQUIFERB-H2
REM IF 80% OR MORE OF A WATER TABLE AQUIFER IS DEWATERED DO JACOB'S
DRAWDOWN
REM CORRECTION
        IF H1<.8*H2 AND AQT$="U" THEN CALL SCORR(S,B)
        SC=(Q/S)/7.48052
        PRINT "the corrected specific capacity is";SC;"ft^3/min ft


REM CALCULATE HYDRAULIC CONDUCTIVITY USING THE JACOB EQUATION
        T=100
        CALL JACOB(PI,T,TM,SY,RW,SC2)
        SC1=SC2
        T=1000
        CALL JACOB(PI,T,TM,SY,RW,SC2)
        M=1/(LOG10(SC2)-LOG10(SC1))
        I=2-(M*LOG10(SC1))
        A=(M*LOG10(SC))+I
        K=EXP10(A)/B
REM CONVERT K TO GAL/DAY/FT^2 THEN PRINT RESULTS
        K=K*10771.9488
        PRINT "The hydraulic conductivity for ";WELLNAME$;" is";K;"gal/day/ft^2"
REM WRITE DATA TO DISK IF DISK OPTION IS ON
        IF DISK$="N" OR DISK$="n" GOTO 35
        PRINT#1, WELLNAME$;",";K
35      INPUT "Do you need to run the program again (Y-yes, N-no)";ANS$
        IF ANS$<>"Y" AND ANS$<>"y" AND ANS$<>"N" AND ANS$<>"n" GOTO 35
        IF ANS$="Y" OR ANS$="y" GOTO 10
        CLOSE #1
        END


SUB NPPC
        PRINT "No partial penetration correction necessary."
        END SUB
```

```
SUB PPC(LS,B,RW,PI,Q)
REM THE KOZENY PARTIAL PENETRATION CORRECTION
        P=LS/B
        F1=7*SQR(RW/(2*P*B))
        F2=COS((P*PI)/2)
        Q=Q/(P*(1+(F1*F2)))
        PRINT "the corrected discharge is";Q
        END SUB
SUB SCORR(S,B)
REM JACOB DRAWDOWN CORRECTION
        S=S-(S^2/(2*B))
        PRINT "the corrected drawdown is";S
        END SUB


SUB JACOB(PI,T,TM,SY,RW,SC2)
        N=4*PI*T
        LD=(4*T*TM)/(SY*RW^2)
        LD=LOG(LD)
        SC2=N/(LD-.5772)
        END SUB
```

APPENDIX VII

Conductivity and Transmissivity Values for the Missoula Valley

Explanation

Location: T, R - Township and Range.
Sect. - Section, done to the smallest quarter possible.

Comment: PC - Fractured Precambrian Missoula Group bedrock.
T - Tertiary colluvium.
BLV - Butler-LaValle Creek Fan alluvium.
BLVd - Distal Butler-LaValle Creek Fan alluvium.
G - Grant Creek Fan alluvium.
OK - O'Keefe Creek Fan alluvium.
CAS - Pump test done by author.
Nothing - Quaternary fluvial and glacio-fluvial sediments.

u\c: Unconfined or confined.

S.C.: Specific Capacity of the well; in gpm/ft. I.e. the volume yeild (gpm) of the well per unit (ft) of drawdown of the water in the well.

K: Hydraulic Conductivity of the aquifer; in gpd/ft^2. Calculated by KCALC.

Elev.: Elevation of the top of the aquifer; in feet. Calculated from the well log depth to the water bearing strata and the elevation of the well from a U.S.G.S. 7.5min quadrangle map.

Thick: Thickness of the aquifer; in feet. Values from well logs.

T: Transmissivity of the aquifer; in gpd/ft. Calculated by multiplying hydraulic conductivity by thickness.

The capitalized abbreviations in the average calculations at the bottom of each Area are the same as those used in the Comments column. VALSED refers to the fluvial and glacio-fluvial beds of the valley floor that are above the Tertiary multicolored clays.

Area I

Location T,R	Sect.	Comment	u\c	SC	K	Elev.	Thick	T
13-19	6cdbd	G	c	5.78	757	3,042	18	13,626
	7daab	G	c	48.7	3,714	3,128	31	115,134
	7dabd	G\T?	c	5.81	7,571	3,021	2	15,142
	7ddbd		c	179.6	12,427	3,135	39	484,653
	7dadb		c	16.23	2,280	3,103	18	41,040
	7ccbaa		c	24.01	2,272	3,112	25	56,800
	7ddbbb		c	92.09	9,875	3,118	23	227,125
	18bddd		u	24.46	1,284	3,120	25	32,100
	18adbab		c	21.02	1,248	3,124	38	47,424
	18adda		c	157.09	13,927	3,118	30	417,810
	18dadcd		c	95.34	16,024	3,140	15	240,360
	18bbadc		u	48.62	1,507	3,140	42	63,294
13-20	1dbcbc		c	155.97	22,660	3,124	18	407,850
	1dadbd		c	38.45	1,832	3,139	49	89,768
	11dcca		c	14.81	1,361	3,045	25	34,025
	13dbab		c	31.04	3,372	3,090	24	80,928
	13dbba		c	5.24	1,214	3,064	11	13,354
	13aabac		c	121.03	11,398	3,127	28	319,144
	13aac		c	92.16	7,229	3,127	32	231,328
	13bdbda		c	181.48	16,091	3,105	28	450,548
	14caaab		c	268.7	16,600	3,079	42	697,200
	14caaab	CAS	c	1264.21	20,824	3,079	42	874,608
	14caaa		c	225.09	13,463	3,075	43	578,909
	14bdda		c	575.85	38,685	3,073	40	1,547,400
	14bdada		c	46.08	2,681	3,074	40	107,240
	14bddd		c	57.6	3,385	3,072	40	135,400
	14abad		c	8.15	1,187	3,068	17	20,179
	14baad		c	3.29	197	3,062		356,895

Averages:		S.C.	K	T
G		20.1	4,014	47,967
	min	5.7	757	15,142
	max	48.7	3,714	115,134
VALSED		149.9	8,921	288,215
	min	3.3	197	6,895
	max	1264.2	38,685	1,547,400

Area IIa

Location T,R	Sect.	Comment	u\c	SC	K	Elev.	Thick	T
13-20	1caad		c	14.66	1,181	3,108	28	33,068
	1cabb		c	32.76	1,671	3,103	47	78,537
	9ddcc		c	48.25	2,745	3,004	42	115,290
	10cddca		c	203.99	11,363	3,015	48	545,424
	10dcdcb		c	223.67	9,165	3,030	64	586,560
	12bbdd		c	21.17	2,308	3,092	22	50,776
	14bbdda		c	5.98	598	3,093	23	13,754
	15adaca		c	3.58	165	3,058	48	7,920
	15dadca		c	121.03	11,606	3,037	28	324,968
	15ddcdb		c	2.07	146	3,055	36	5,256
	15acadc		c	121.03	11,606	3,106	130	1,508,780
	15daccb		c	6.34	512	3,029	27	13,824
	15dacda		c	9.8	746	3,040	33	24,618
	15dacda		c	9.72	903	3,024	24	21,672
14-20	22b	T	c	0.74	9	2,990	160	1,440
	22b	T	c	2.65	36	3,130	140	5,040
	22bb	T	c	0.13	0.97	3,115	215	209
	34aaaa	BLV	c	3.59	398	3,090	20	7,960
	34abbd	BLVd	c	39.27	3,242	3,086	30	97,260
	34ada	BLVd	c	24.98	3,096	3,070	20	61,920
	34aacb	BLVd	c	8.92	1,117	3,080	30	33,510
	35badca	BLV	c	506.51	68	3,108	43	2,924
	35bbdbd	BLV	c	64.78	9	3,131	14	126
	35cbccd	BLV	c	319.79	43	3,004	16	688
	35dcbc	BLV	c	238.63	32	2,983	18	576

Averages:		S.C.	K	T
T		1.17	15	2,230
	min	0.13	1	209
	max	2.65	36	5,040
BLV		151	1,000	25,621
	min	3.6	10	126
	max	507	3,242	97,260
VALSED		60	3,908	237,889
	min	2	146	5,256
	max	224	11,606	1,508,780

Area IIb

Location T,R	Sect.	Comment	u\c	SC	K	Elev.	Thick	T
14-20	21dcaca	OK	c	8.3	358	3,041	51	18,258
	21ccbbc	OK	c	1.57	124	3,078	27	3,348
	27cbabc	T	c	0.94	363	3,035	6	2,178
	27cbcca	T	c	0.39	37	2,973	22	814
	28ddbbb	T	c	0.13	2	2,698	115	230
	28cddcd		c	24.98	1,986	3,051	29	57,594
	28acddd		c	9.72	953	3,047	25	23,825
	28dbdba		c	10.47	968	3,100	25	24,200
	28aacca		c	13.46	807	3,140	40	32,280
	28dadca		c	2.99	1,422	3,104	5	7,110
	29dbaa	T	c	0.05	6	2,928	16	96
	29dbdbd	T	c	5.69	125	3,055	100	12,500
	29dbdac	PC	c	3.37	35	2,961	200	7,000
	29dcbab	PC	c	0.29	2	3,080	200	400
	29dbbbc		c	4.64	504	3,090	20	10,080
	29dcbad	PC	c	16.68	177	3,109	200	35,400
	32abbb	PC	c	0.34	4	3,003	200	800
	33bb	PC	c	2.17	20	3,086	200	4,000

Averages:		S.C.	K	T
PC		4.57	48	9,520
	min	0.29	2	400
	max	17.0	77	35,400
T		1.44	107	3,179
	min	0.05	2	96
	max	5.69	363	12,536
OK		4.90	241	10,803
	min	1.60	124	3,344
	max	8.30	358	18,261
VALSED		11.00	1,107	28,846
	min	4.60	504	7,109
	max	25.00	1,986	57,594

Area IIc

Location T,R	Sect.	Comment	u\c	SC	K	Elev.	Thick	T
14-20	7bcbbd		c	13.39	2,207	3,029	15	33,105
	17cbcaa		c	5.16	587	3,054	21	12,327
	17ccbsb		c	8.08	618	3,023	50	30,900
	17cbcdc		c	2.32	165	3,045	30	4,950
	18dadbd		c	7.63	580	3,060	30	17,400
	18baaa		c	8.68	632	3,022	30	18,960
	18dddcb		c	12.94	1,001	3,050	30	30,030
	19accd		c	4.49	509	3,030	20	10,180
	19dbba		c	1.2	269	3,020	10	2,690
	19accdc		c	15.19	1,744	2,990	20	34,880
	20dbdab		c	24.91	1,687	3,063	36	60,732
	20abcca		c	19.45	1,242	3,066	36	44,712
14-21	1cddbd		c	19.15	6,011	3,028	8	48,088
	12aadda		c	35.01	11,258	3,018	8	90,064

Averages:		S.C.	K	T
VALSED		12.69	2,036	31,358
	min	1.20	165	2,690
	max	35.00	11,258	90,064

Area III

T,R	Location Sect.	Comment	u\c	SC	K	Elev.	Thick	T
13-20	3cbcda		c	39.95	8,884	2,992	12	106,608
	4dbdc		c	96.12	12,355	3,003	20	247,100
	5bbccc		c	4.71	867	2,974	13	11,271
	5bacab		c	4.26	551	2,974	17	9,367
	5aaaca		c	15.93	530	3,045	65	34,450
	5caaad		u	10771.9	209,167	3,062	108	22,590,036
	5bdcdd		c	3.96	430	2,974	22	9,460
	5bcaab		c	19.9	2,053	2,986	24	49,272
	6bbbdb		u	875.22	14,536	3,051	101	1,468,136
	6bbcd		u	27.53	407	3,050	87	35,409
	9dabba		c	29.77	3,709	3,019	20	74,180
	same	CAS	c	20.72	2,336	3,019	20	46,720
	9bacb		c	4.64	1,064	2,990	10	10,640
	9bbbcd		c	3.22	598	2,992	12	7,176
	9addbc		u	33.66	912	3,090	50	45,600
	9adbbc		c	187.01	16,544	3,025	29	479,776
	10babca		c	17.28	2,041	3,015	20	40,820
14-20	19bbdd		c	1.27	529	2,952	6	3,174
	30bbca		c	5.16	1,376	2,966	112	154,112
	30baab		c	26.26	2,695	2,978	23	61,985
	30abccc		c	4.64	1,186	3,011	9	10,674
	31dccac		c	5.61	692	2,994	20	13,840
	31dabcb		c	5.24	957	2,979	14	13,398
	31bcaab		c	18.7	4,806	2,964	10	48,060
	31ddbac		c	44.66	7,579	2,968	15	113,685
	32cdcda		c	32.91	7,895	2,958	10	78,950
	32ddbab		c	4.11	760	2,983	13	9,880
	32dabba		c	32.02	2,052	3,009	35	71,820
14-21	2daabb		c	14.51	2,938	2,884	12	35,256
	13cadcc		u	34.86	2,521	3,045	20	50,420
	13ddcca		c	68.67	4,056	2,938	42	170,352
	13ddcdb		c	13.17	680	2,938	46	31,280
	13bbbbd		u	114.98	1,113	3,036	145	161,385
	13ccad	T	c	51.40	5,685	2,862	22	125,070
	13cacbd		c	2.24	641	2,898	10	6,410

Area III continued.

T,R	Location Sect.	Comment	u\c	SC	K	Elev.	Thick	T
14-21	24abcbd		c	1.94	474	2,925	10	4,740
	24caa		c	74.36	12,567	2,901	15	188,505
	24daabb		c	10.25	8,737	2,920	3	26,211
	24abbca		c	34.71	7,446	2,916	18	134,028
	24bd	T	c	68.56	7,673	2,861	22	168,806
	25ccbbd		c	32.17	2,719	2,938	29	78,851
	25cccc		c	96.12	6,938	2,945	36	249,768
	25cbbbd		c	81.16	4,271	2,947	48	205,008
	25addbb		c	8.3	1,263	2,968	15	18,945
	36babbd		u	27.98	1,464	3,037	24	35,136
	36abbca		c	17.35	3,739	2,953	12	44,868
	36ac/d		c	4.19	515	3,037	19	9,785

Averages:		S.C.	K	T
T		60	6,679	146,938
	min	52	5,685	125,070
	max	69	7,673	168,806
VALSED		279	8,148	587,030
	min	1.27	407	3,174
	max	11,000	209,167	22,590,036

Area IV

T,R	Location Sect. Comment	u\c	SC	K	Elev.	Thick	T
15-21	27cdcca	c	73.61	11,445	3,011	17	194,565
	27bdccd	c	58.15	3,935	2,927	33	129,855
	27cbcaa	c	25.96	3,114	2,874	20	62,280
	27ccbcc	u	34.41	1,736	3,014	27	46,872
	28cabcd	c	23.04	1,463	2,867	34	49,742
	28dccba	c	117.37	10,351	2,864	28	289,828
	28ccbac	c	34.71	7,544	2,851	12	90,528
	28daaca	c	172.05	14,897	2,872	30	446,910
	28cbacc	c	30.89	5,059	2,860	15	75,885
	28bcc	c	4.26	2,031	2,943	5	10,155
	29ddaad	c	25.43	3,118	2,848	20	62,360
	29ddaaa	c	6.43	579	2,853	25	14,475
	29addab	c	4.86	441	2,881	24	10,584
	30bbddb	c	0.97	68	2,993	30	2,040
	30bbcca	c	4.34	248	3,018	37	9,176
	30acaac	c	1.2	275	3,001	10	2,750
	30bdcdb	c	4.4	994	2,855	10	9,940
	30ddbda	c	12.12	2,950	2,845	10	29,500
	30babcb	c	8.9	1,363	2,860	15	20,445
	30dc	c	21.69	1,420	2,867	35	49,700
	31abbcc	c	44.28	21	2,821	51	1,071
	32adadc	c	114.00	2,695	2,943	98	264,110
	33aacdd	c	29.02	7,237	2,855	10	72,370
	33abbcc	c	568.52	15,090	2,850	10	150,900
	33abcca	c	32.24	8,186	2,853	10	81,860
	33bbcac	c	15.41	2,284	2,869	16	36,544
	33bbabb	c	86.77	20,430	2,852	12	245,160
	34baacc	c	12.72	1,479	2,871	20	29,580
	34aaacb	c	13.46	1,572	2,874	20	31,440
	34bdbbd	c	1.27	311	2,877	10	3,110
	34daccd	c	5.83	1,374	2,877	10	13,740
	34bdbca	c	6.28	1,906	3,006	8	15,248
	35cbcbd	u	5.09	353	3,022	16	5,648
	35bcddn	c	45.63	8,871	2,892	13	115,323
	35cdbbb	c	29.02	7,475	2,884	10	74,750
	35cadbd	c	4.26	338	2,897	37	12,506

Area IV continued.

T,R	Location Sect.	Comment	u\c	SC	K	Elev.	Thick	T
15-22	25bcc		c	36.28	9,130	2,940	10	91,300
	25bddca		c	77.8	7,136	2,832	27	192,672
	25bdbbc		c	64.33	16,619	2,838	10	166,190
	25cbaaa		c	24.69	6,487	2,831	10	64,870
	25bdccc	CAS	c	21.47	1,447	2,858	33	47,751
	26abdaa		c	2.92	658	2,929	10	6,580
	26adcaa		c	60.29	15,198	2,834	10	151,980
	26aadbd		c	56.85	4,201	2,865	33	138,633
	26aaacc		c	15.71	2,998	2,850	13	38,974

Averages:		S.C.	K	T
VALSED		45.31	4,812	81,331
	min	0.97	21	1,071
	max	568	20,430	446,910