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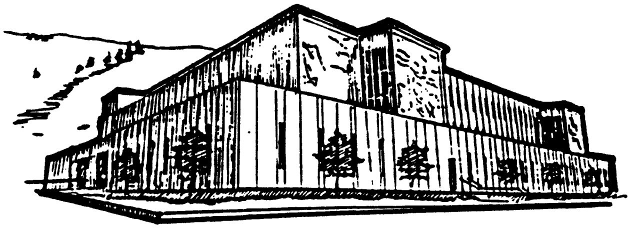

A Hydrogeologic Investigation of the Former Burlington Northern Fueling Site, Missoula, Montana

By

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B.A., University of Montana

Presented in partial fulfillment of requirements
for the degree of
Master of Science
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A. Campbell Stringer, M.S., June 1991
Geology

A Hydrogeological Investigation of the Former Burlington Northern Fueling Site, Missoula, Montana.

Director Dr. Nancy Hinman NWH

At the request of the Montana Water Quality Bureau (MWBQ) Burlington Northern Railroad (B. N.) initiated an environmental investigation at its fueling facility in Missoula. The subsurface was found to be contaminated with diesel fuel. The purpose of this study was to develop a conceptual model of the site and explain the behavior of diesel fuel in accordance with that model.

A conceptual model was developed based on geologic cross-sections, well hydrographs, potentiometric maps, aquifer test results and chemical analysis of ground water. An aquitard exists under the west end of the site and probably extends north to the bedrock of Waterworks hill. Outflow from Waterworks Hill is the most significant source of recharge to the perched aquifer. Ground water flow is to the southwest and west in the regional aquifer and to the southeast on the perched aquifer. Hydraulic conductivities are greater to the south and west than to the north and east. At least one hydrostratigraphic unit different from the regional aquifer exists, possibly Tertiary sediments. Significant quantities of recharge to the regional system are contributed by outflow from Waterworks hill, Rattlesnake Creek and the Clark Fork River.

Three zones of contamination are associated with three fueling areas. Mobility of diesel fuel was found to vary seasonally with water levels. Apparent product thicknesses fluctuated the most in wells having the most seasonal variability in water levels.

The conceptual model developed explains the observed behavior of diesel fuel.

ACKNOWLEDGEMENTS

This study was funded by Burlington Northern Railroad. Technical assistance and guidance were provided by Kennedy/ Jenks/ Chilton. I am grateful to these companies for their support. I would like to thank Dr. Nancy Hinman whose direction and wisdom helped this project reach fruition. I also thank Dr. William Woessner for his keen insight and counsel and Dr. Garon Smith who reviewed this manuscript. Finally, without the help of Matt Gibson and Jay Billings, I would still be collecting samples in the Iron Horse Brew Pub. Thank you.

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CHAPTER 1: INTRODUCTION

In 1985, at the request of the Montana Water Quality Bureau (MWQB), Burlington Northern Railroad (B.N.) initiated an environmental investigation at its former refueling site in Missoula, Montana. The MWQB had found that most older fueling sites in Montana and the United States had fuel contamination beneath them (personal communication, John Arrigo, MWQB). According to the Montana Water Quality Act, section 75-5-605:

> "It is unlawful to cause pollution . . . of any state waters or to place or cause to be placed any wastes in a location where they are likely to cause pollution of any state waters."

Also, according to MWQB, 1984:

> ". . . depending on the severity of the spill or accidental discharge, the department may require the owner or operator to: a) take immediate remedial measures; b) monitor the direction, depth and rate of movement of any contaminated groundwaters and anticipated future beneficial uses of the groundwater supply impacted. . . ".

Once contamination was detected beneath the B.N. site, the MWQB ordered that a monitoring program be established and some immediate remedial measures be taken. When this study began, three consulting firms had already investigated the site. Several monitoring wells had been installed and a moderate amount of diesel fuel had been recovered.

The theoretical physical behavior of petroleum fuels in porous media has been studied in detail. However, actual observed behavior in heterogenous environments is often unexplainable in terms of present knowledge. "Little is known about what happens (chemically) to diesel fuel that is spilled into the soil environment. Most research to date on the environmental fate of petroleum products has been done on gasoline and crude oil in the marine environment" (Burns, 1979).

Figure 1.1 shows the location of the study area within the Missoula Valley. Figure 2 is a map of the study area showing major features and well locations.

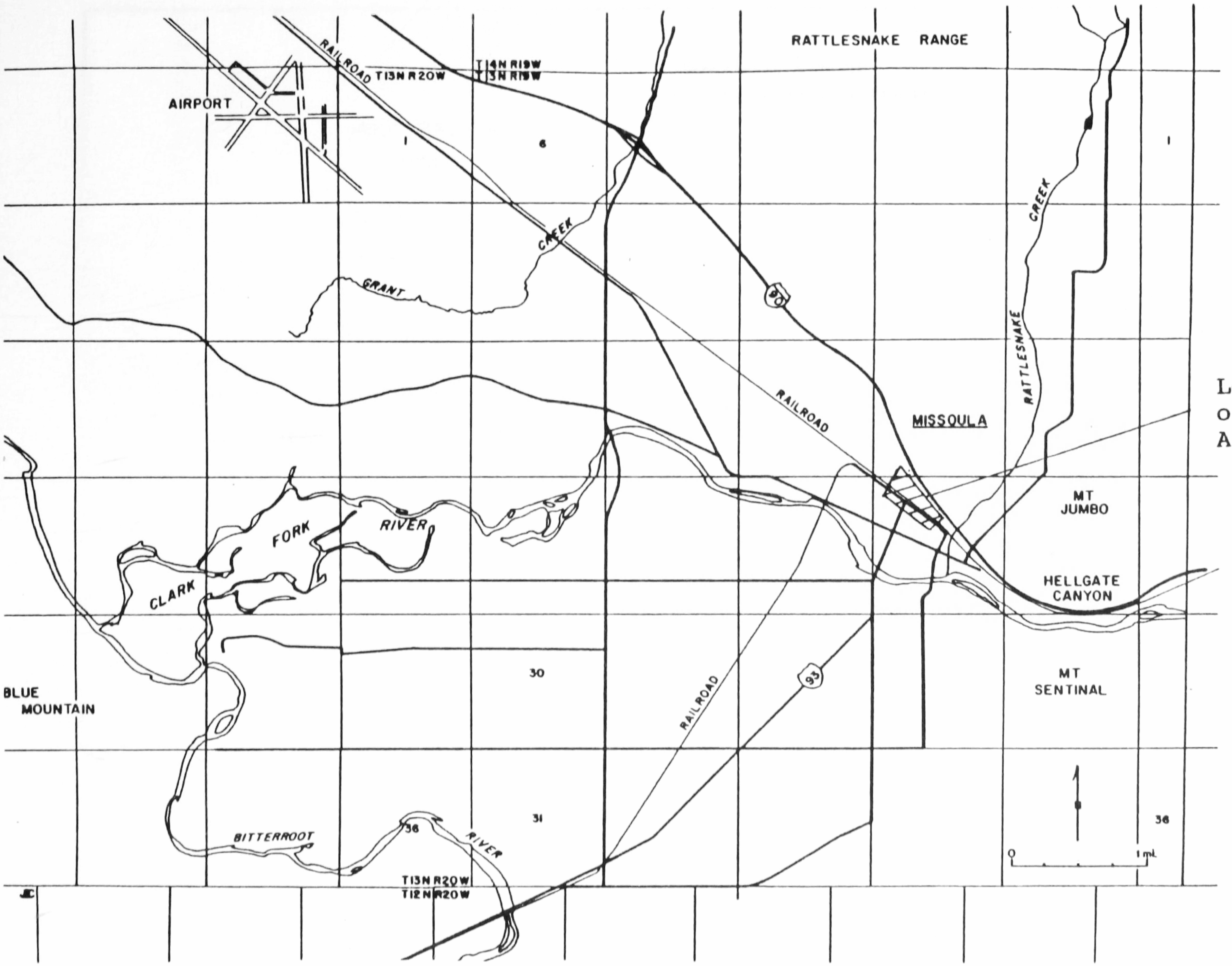
PROJECT GOALS

The first goal of this project was to develop a conceptual model of the physical system by:

A. Analyzing well logs and assessing the depositional environment;
B. Determining the gross ionic water chemistry;
C. Identifying distinct hydrostratigraphic units;
D. Ascertaining general direction of ground water flow;
E. Estimating aquifer properties.

The second goal of this project was to interpret the behavior of diesel fuel in accordance with the conceptual model by:

A. Evaluating the effect of seasonal changes in flow



Location of Study Area

Figure 1.1: Location of study area (drafted by J.E. Cuplin)

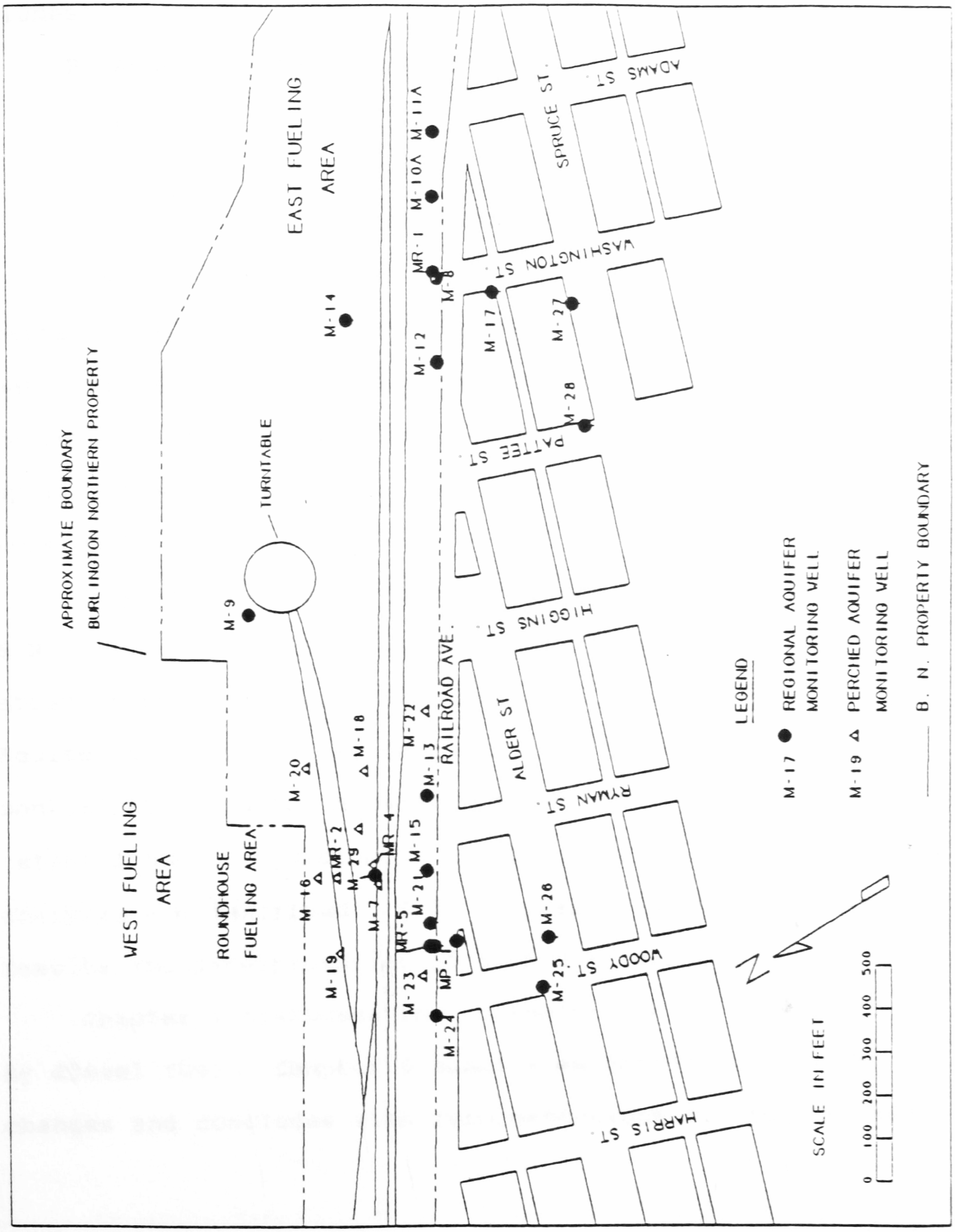


Figure 1.2: Site plan showing well locations

direction and water levels on the contaminant plumes;

B. Assessing any temporal changes in the contaminant plumes;

THESIS ORGANIZATION

The remainder of this thesis is organized into four parts. Chapter 2 discusses the theoretical and observed behavior of petroleum hydrocarbons such as diesel fuel, a review of pertinent previous investigations of diesel fuel spill sites, and a brief listing and description of previous work on the Missoula Aquifer.

Chapter 3 describes the physical flow system of the B.N. site. It presents background information on the stratigraphy, hydrology and chemistry of the Missoula Aquifer and cites other examples of groundwater contamination in the Missoula Valley. Methods used in stratigraphic, hydrologic, and chemical data collection and analysis are described. This chapter also presents the results and interpretation of such data analysis.

Chapter 4 discusses the contamination of the subsurface by diesel fuel. Chapter 5 summarizes anticipated future changes and concludes with recommendations for future work.

CHAPTER 2: BACKGROUND

This chapter is divided into three sections which provide background information on petroleum hydrocarbons in general and diesel fuel specifically. The first section presents an overview of the theory of multiphase flow in a porous medium. The second describes typical behavior of a liquid hydrocarbon spill. The third section lists some properties of diesel fuel.

Diesel fuel, is immiscible in water, as are all liquid hydrocarbon fuels. They are often referred to as non-aqueous phase liquids (NAPLs). NAPLs are immiscible with water because they are non-polar molecules and water is a polar molecule. Those NAPLs which are more dense than water are referred to as DNAPLs (for dense NAPL) and those which are less dense than water are referred to as LNAPLs (for light NAPL). In this discussion the terms LNAPL, hydrocarbon, product and oil will be used interchangeably.

I will first examine the theory of multi-phase fluid flow in order to provide a foundation for a discussion of the behavior of diesel fuel in porous aquifer material.

THEORY OF MULTIPHASE FLOW

An understanding of the pore-scale theory of multi-phase immiscible flow is critical in the consideration of the behavior of NAPLs in porous media. Much of this theory was developed by petroleum engineers.

Two types of flow are possible when two or more fluids occupy a porous medium domain: miscible displacement and immiscible displacement. Bear (1972) defines immiscible displacement as simultaneous flow of two immiscible fluids or phases in a porous medium domain. The interfacial tension is non-zero, and a distinct fluid-fluid interface separates the fluids in each pore. A capillary difference exists across the interface at each point on it. There is actually a zone between the two fluids but treating it as an abrupt interface is a simplifying approximation that aids in modeling immiscible flow.

When two or more immiscible fluids occupy the same void space, the **saturation** of a given fluid is the fraction of void volume of the porous medium occupied by the fluid within a relative elementary volume (REV) at a point.

When a liquid comes into contact with another substance (another immiscible liquid, a gas, or a solid) there is a free interfacial energy between them. Differences in surface tension result in interfacial tension.

At this point the concept of wettability must be introduced. Equation (1) is Young's equation for interfacial tension.

$$\sigma_{gl} \cos\theta = (\sigma_{sg} - \sigma_{sl}) \tag{1}$$

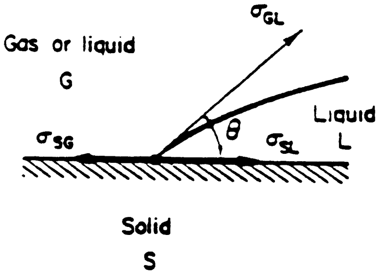


Figure 2.1: Interfacial tensions (Bear 1972)

In this equation σ_{ik} refers to the interfacial tension between two substances denoted by subscripts where s is solid, g is gas, and l is liquid. In equation (1) the angle θ is called the contact angle. The product σ_{gl} $\cos\theta$ is called the adhesion tension; it determines which fluid will wet the solid, i.e. adhere to it, and spread over it. When $\theta < 90°$ the fluid (L in Figure 2.1) is said to wet the solid and is called the **wetting fluid**. When $\theta > 90°$ the fluid (G in Figure 2.1) is called a nonwetting fluid.

When two immiscible fluids are in contact in the interstices of a porous medium a discontinuity in pressure exists across the interface separating them. Its magnitude is a function of the curvature of the interface separating them. This pressure is capillary pressure, P_c, which can be calculated as (Dracos, 1987):

$$P_c = P_{nw} - P_w = \sigma_{w,nw} \ (2/R_m) \qquad (2)$$

where P_{nw} is the pressure in the nonwetting fluid and P_w is the pressure in the wetting fluid at the interface. $\sigma_{w,nw}$ is the interfacial tension between the two fluids and Rm is an average radius of curvature of the interface.

Since it is not possible to know the shape of all the interfaces between fluids a more feasible formulation comes from averaging over a REV (Bear, 1979) which indicates:

$$P_c = f(S_w) \qquad (3)$$

at any point within the flow domain. S_w is the degree of water saturation of the void space. This relation can be determined experimentally, at least for two fluids. As shown in Figure 2.2, this relation is not unique. It shows a hysteresis. For the same degree of saturation of the wetting fluid, the absolute value of the wetting fluid is larger when the porous matrix is wetted. This Figure also shows that when the porous matrix is drained, the saturation at P_c = 0 is smaller than one.

Flow of water in the unsaturated zone is immiscible flow, where water is the wetting fluid and air the non-wetting fluid. When water, air and hydrocarbons all occupy the same pore space, water is a wetting fluid, air is

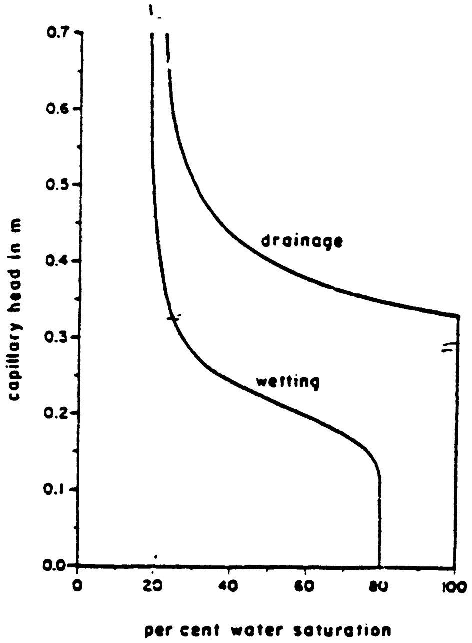


Figure 2.2: Capillary pressure-saturation relation for sand packing showing a hysteresis effect for drainage and wetting (Dracos, 1987)

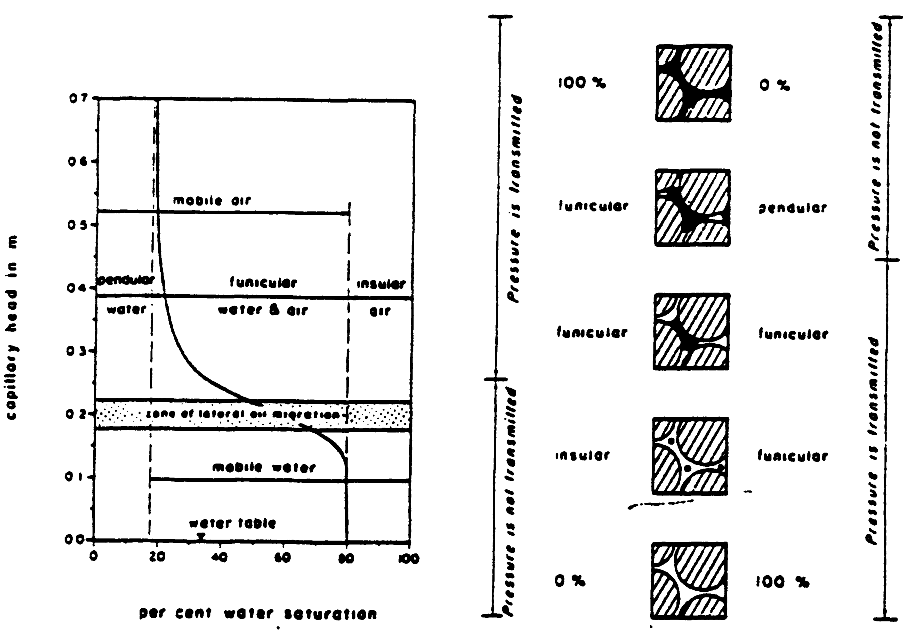


Figure 2.3: Distribution of a wetting (water) and a non wetting (air) in the fluid pore space of a solid matrix (Dracos, 1987).

a nonwetting fluid and a hydrocarbon is wetting with respect to air and nonwetting with respect to water.

In examining the theory of multi-phase fluid flow in porous media we must first consider the case of two-phase flow. Let us examine what happens when a wetting fluid infiltrates a porous medium which is totally saturated with a nonwetting fluid. Before the addition of the wetting fluid the saturation of the nonwetting fluid is 100 %. In the case of unsaturated flow of water, at this point the pores are dry and filled with air. When a small amount of water vapor is introduced into the pore spaces, water will be adsorbed on the surface of the solid particles because of the attractions between the molecules of the water and those of the solid (Stallman, 1964). This is known as the **adsorbed stage.**

As the saturation of wetting fluid increases, it forms **pendular rings** and occupies the angular grain contacts. This is known as the **pendular stage.** The wetting fluid is held by surface tension in discreet droplets. Pressure cannot be passed on from droplet to droplet. The wetting fluid is immobile. The wetting fluid remains pendular until it reaches a threshold saturation called the **pendular residual saturation.** This residular saturation of the wetting phase is close to 15 % for hydrocarbons of low viscosity, e.g. light crude oils, gasolines, kerosene, and diesel fuel (Dracos, 1987). At this residual saturation the relative permeability to the wetting phase is zero (Figure 2.4).

As the saturation of the wetting fluid continues to increase, the discreet pendular rings become interconnected, and pressure is transmitted. At this point flow of both the wetting and nonwetting fluid are possible. Both the wetting and nonwetting fluids are in the **funicular stage**. Flow of the nonwetting fluids takes place in conduits formed by the wetting fluid which is adhered to the grain surfaces.

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With increasing saturation of the wetting and decreasing saturation of the nonwetting fluid, the nonwetting fluid becomes isolated in discrete bubbles or droplets. The nonwetting fluid cannot flow when a pressure gradient is applied to the medium. The relative permeability to the nonwetting fluid is practically zero (Figure 2.4). The nonwetting fluid is in the **insular stage**. The upper threshold of saturation of the nonwetting fluid at which it is insular is called the **insular residual saturation** and is close to 20 % (Dracos, 1987). This explains why a porous medium cannot be completely saturated

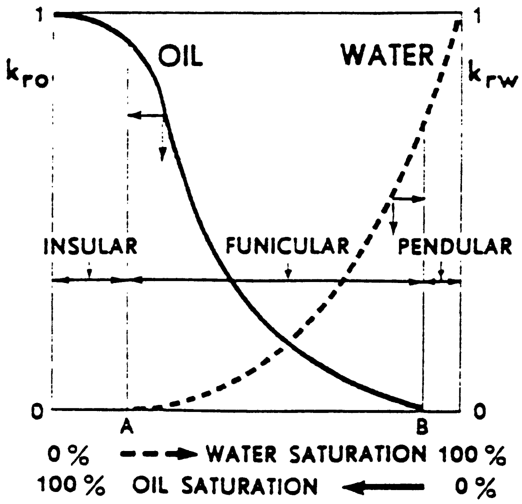

Figure 2.4: Relative Permeability

during a wetting cycle.

Unsaturated flow is a special case of two-phase flow where water is the wetting fluid and air is the nonwetting fluid. In the case of two phase flow where only water and hydrocarbons are present (as might occur in the saturated zone), the water completely surrounds the hydrocarbons and the hydrocarbons become immobile if their saturation falls below insular residual saturation (about 20 %).

If we add a third phase into the medium, flow changes some-what. Let us examine three phase flow of a hydrocarbon spill moving through the vadose zone in unsaturated flow. Water is held by capillary forces at pendular residual saturation. As the saturation of the hydrocarbon decreases, a quasi-pendular saturation is reached. Since most of the angular grain contacts are already occupied by water, the degree of saturation of the hydrocarbon at quasi-pendular saturation is less than 15 % and closer to 3 or 4 % (Dracos, 1987). A hydrocarbon can obviously flow mostly in the unsaturated zone as long as its own degree of saturation is large enough to allow for a funicular distribution in the available pore space. So, hydrocarbons can flow at saturations down to 20% (insular residual saturation) in the saturated zone and down to 3 or 4% (quasi-pendular residual saturation) in the unsaturated zone.

The model of three phase flow is some-what simplified for hydrocarbons infiltrating the vadose zone. In reality, there may be four or five phases as there are small amounts of dissolved components and a small amount of hydrocarbon vapor.

Averaging over a REV allows the derivation of flow equations for three phase flow. Equations for one dimensional flow presented here can be extended to three dimensions. The assumption is often made that during the infiltration of hydrocarbons, the air moves slowly and the pressure drop in the air is negligible, meaning the air is treated as being stagnant and at atmospheric pressure. This allows movement of NAPLs to be treated with only two equations (this assumption may or may not be valid).

If we start with Darcy's Law (including all its assumptions) in terms of intrinsic permeability (k) and fluid potential (Φ) we have:

$$Q = \frac{-kPA}{\mu}\frac{d\Phi}{dx} \tag{4}$$

where P = density, A = cross sectional area, μ = dynamic viscosity and $\Phi = p/P + gz$, where p = pressure, g = the acceleration due to gravity and z = depth. Modification of this form of Darcy's Law yields (van Dam, 1967)

$$Q_h = -\frac{k_{rh}\ k\ P_h\ A}{\mu_h}\frac{d\Phi_h}{dx} \tag{5}$$

and

$$Q_w = -\frac{k_{rw}\ k\ P_w\ A}{\mu_w}\ \frac{d\Phi_w}{dx} \tag{6}$$

where

$$\Phi_h = p/P_h + gz \tag{7}$$

and

$$\Phi_w = p/P_h + gz \tag{8}$$

The subscripts h and w refer to hydrocarbon and water respectively. As you can see, for a description of two phase flow it is necessary to define the individual fluid potential for each fluid. k_{rh} refers to the relative permeability for oil in the presence of water and k_{rw} refers to the relative permeability of water in the presence of oil. These relative permeabilities may be measured in the laboratory. They depend on the oil saturation.

The above equations adequately describe two-phase flow only if the potential forces described by eqns (7) and (8) are significantly larger than capillary forces. This is not generally true in the case of NAPL migration in water-bearing porous media. Equations (5) and (6) can be modified to take into account the influence of capillary forces by adding a capillary pressure term to eqns (7) and (8). van Dam (1967) did this and derived partial differential equations to describe the fluid potential for water, air and hydrocarbons. Dracos (1987), however, points out that these equations are highly non-linear and the functions that relate the degree of water saturation to k_w, k_h, and the different capillary pressures (for when water displaces air and hydrocarbons, and when hydrocarbons displace air) are very difficult to determine and are subject to hysteresis. Interested readers are referred to van Dam (1967) and Bear (1972) for further treatment of this topic.

TYPICAL LNAPL SPILL BEHAVIOR

At this point let us shift gears from the pore scale and look at the behavior of NAPLs at the aquifer scale. The following is a description of the behavior of a typical LNAPL spill from beginning to end.

There are three stages to an NAPL spill in porous media

(Figure 2.5). The first stage is seepage. After oil is introduced at ground surface it migrates downward. Often the oil will follow man-made conduits such as buried cables or building foundations which are usually back-filled with more highly permeable material than the matrix. Below this level two zones of spreading are observed. In the central **oil core**, oil is flowing due to gravitational forces and flow is described by Darcy's law. Surrounding the oil core is the **oil wetting zone**. It is analogous to the capillary fringe. In this zone oil is flowing due to capillary forces.

The shape of the spreading body is a function of hydraulic conductivity (K), capillarity, and the rate of infiltration. The rate of infiltration is a function of K and viscosity. As can be seen from Figure 2.6, in layered or highly heterogeneous systems, the shape of the spreading body can be highly irregular.

During seepage, if the vertically migrating oil body encounters a very fine-grained layer before it is immobilized, it may flow along this layer and be discharged where the layer intersects land surface (Figure 2.7). Obviously, low permeability layers can greatly influence the path of a spill.

If the amount of oil spilled is small it may reach residual saturation during seepage. The American Petroleum Institute (1972) developed equation (9) to estimate the amount of soil required to immobilize a given volume of oil.

$$\frac{0.20 \times V}{n \times Sr} = \text{cubic yards of soil required to reach immobile saturation} \quad (9)$$

n= porosity, V = the volume of oil,

Sr = residual saturation of oil

If the volume of water is large enough seepage continues until the front reaches the capillary fringe. Below this level, the degree of water saturation increases rapidly and the vertical migration of the front is drastically decelerated. This is the second stage: **lateral spreading**. Eventually, a pressure mound is built up which leads to lateral spreading of oil and slow penetration with depth. Lateral spreading is due to capillary forces. Hydrocarbon may penetrate temporarily below the water table. As the infiltrating volume is usually limited, the pressure mound which formed initially, flattens, and the lateral spreading slows down. The spreading body is often referred to as a "pancake". The thickness of the pancake is roughly that of the capillary fringe. Subsequent lateral movement of NAPLs underground is not generally well understood (Shepard, 1983).

In the final stage, **immobilization**, the hydraulic gradient existing in the aquifer begins influencing the movement of hydrocarbons. Hydrocarbons will then move in the direction of groundwater flow at a rate somewhat less than the underlying ground water. Gasoline moves at slightly less than half the ground water velocity; heavier hydrocarbons (e.g. diesel fuel), slightly less than half.

Initial spreading of the pancake on the water table can be approximated by ignoring ground water movement with the following formula (Shepard, 1983):

$$S = (1000/F)\ (V - (AD/Rv)) \tag{10}$$

where:

S = Maximum spread of product in sq. m
V = volume of product in cub. m
A = area of spill in sq. m
D = depth to ground water in m
(See Table 1 for values of F and Rv)

Dracos (1978) and Mull (1978) provide equations developed to estimate the rates of lateral and vertical migration of a hydrocarbon spill. They are complicated and may require data which are unobtainable in many cases. Hence they are not discussed here.

According to Shepard (1983) flow of laterally spreading hydrocarbons is maximized at a level about 2/3 the height of the capillary zone (this is generally well above the capillary fringe, see Figure 2.8). According to Dracos (1987) this maximum flow occurs at a height roughly corresponding to the average height of the capillary fringe. According to Schwille (1967) oil prefers to spread in that portion of the capillary zone that has a water saturation of about 75-80 %. Eventually oil reaches quasi-pendular

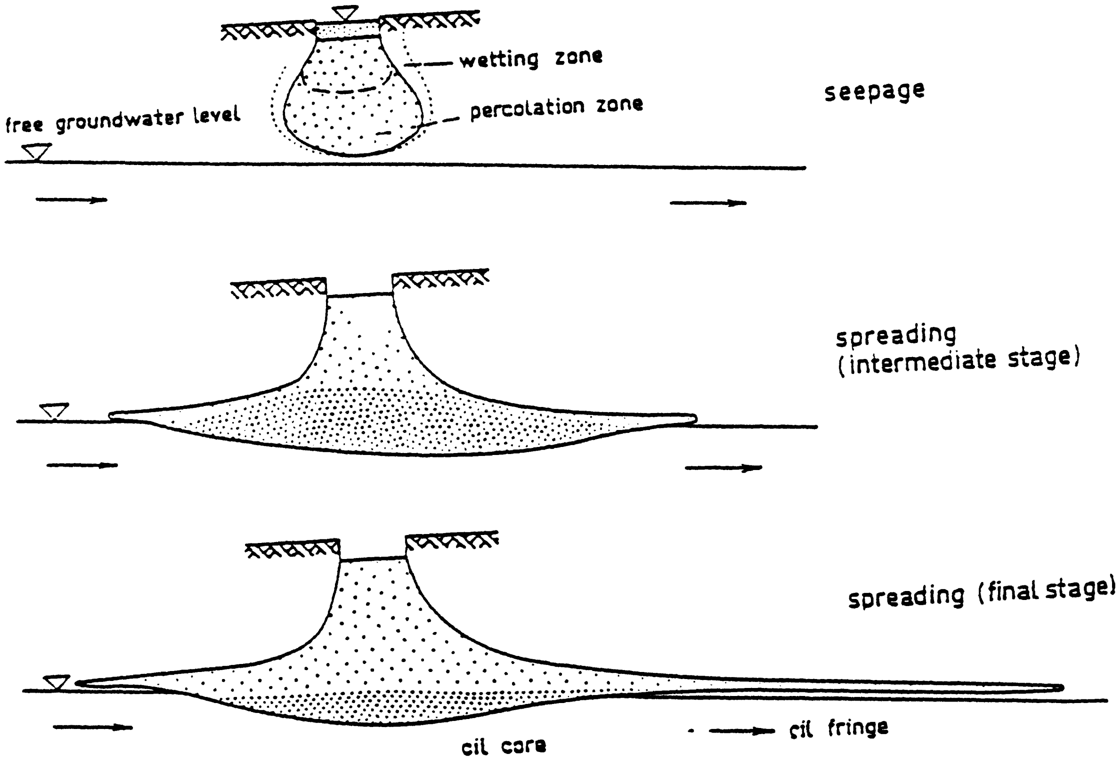

Figure 2.5: The spreading of a LNAPL in a porous medium (schematically) (Schwille, 1967).

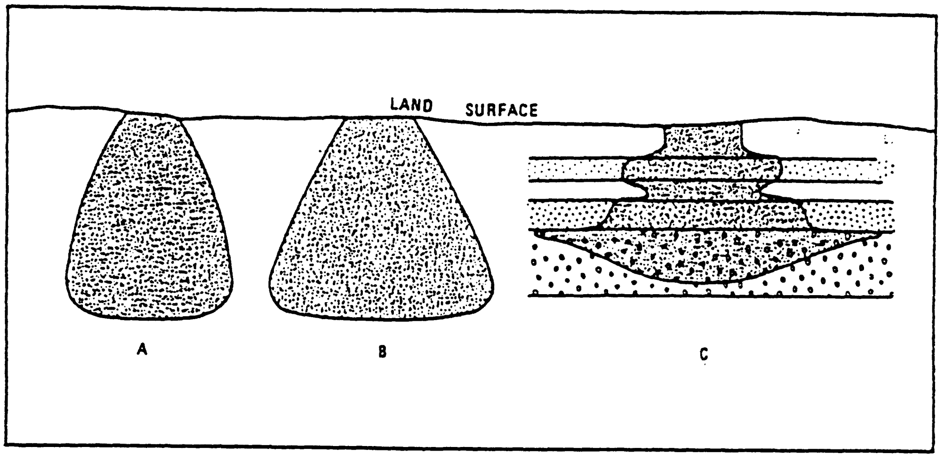

Figure 2.6: Generalized shapes of spreading cones at immobile saturation. A - highly permeable, homogeneous soil; B - less permeable, homogeneous soil; C - Stratified soil with varying permeability.

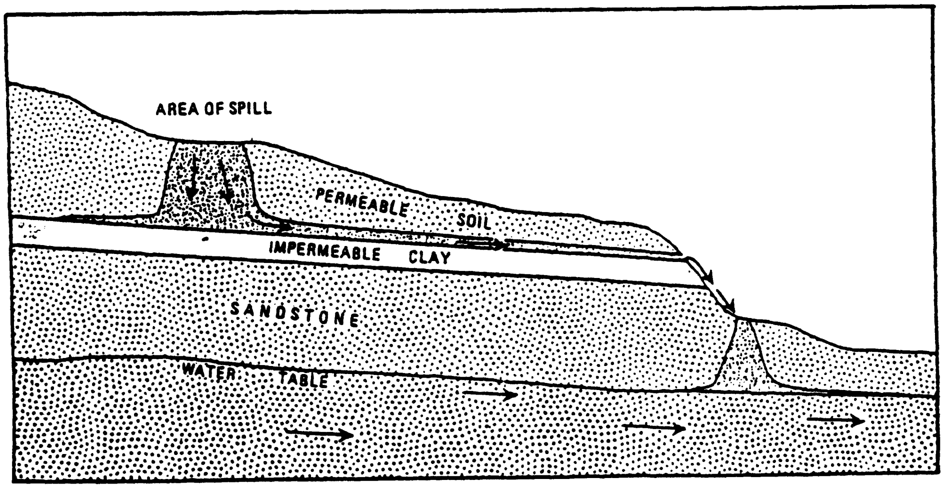

Figure 2.7: Influence of very low permeability layer on migration of a hydrocarbon spill.

Table 2.1
Typical values for Rv and F

Rv				
Soil	**Gasoline**	**Kerosine**	**Light fuel oil**	**F (mm)**
Coarse gravel	**400**	**200**	**100**	**4**
Gravel to coarse sand	**250**	**125**	**62**	**8**
Coarse to medium sand	**130**	**66**	**33**	**12**
Medium to fine sand	**80**	**40**	**20**	**20**
Fine sand to silt	**50**	**25**	**12**	**40**

Rv = A constant, depending on the retention capacity of the soil and viscosity of the product

F =Thickness of the mobile product layer in the capillary zone, as determined by in the laboratory

residual saturation and spreading ceases.

A mass of hydrocarbons, whether spreading or immobile, becomes a source of pollution. All hydrocarbons are soluble to some extent. Generally, the more refined the product the more soluble it is. In the vadose zone infiltrating water picks up these components as it comes into contact with immobilized hydrocarbons. At the water table soluble components are leached out of the oil core and carried down gradient by dispersion. Highly volatile components diffuse upward through the unsaturated zone in gas phase.

Factors Influencing the Spread of LNAPLS

In its final stages, the migration of a LNAPL is greatly influenced by interfacial and capillary forces. Water table fluctuations strongly influence the spread of NAPLs (figure 2.9). They tend to widen the pancake vertically. This increases the amount of NAPL retained in the unsaturated zone. NAPLs may be immobilized in the saturated zone by a rising water table. According to Dracos (1978, 1987), during a time of a rising water table, hydrocarbons rise much slower than the water table and are hence trapped below the water table at insular residual saturation. When the water table subsequently falls again below the level at which the trapped hydrocarbon is located, the water saturation is reduced and the hydrocarbon is remobilized. This is one explanation for the reappearance of hydrocarbons in observation wells after long absences.

Dracos assumes that oil at residual saturation is completely immobile. However, Shepard (1983) says:

> "Percolating gravitational water over a residual plume will leach droplets of product. Rising groundwater from seasonal recharge will cause water flow through the previously unsaturated area above the water table and the attendant breaking out of droplets of product. This accounts for changes in measured thickness of product on the water table in observation wells with fluctuating water levels. Product changes have also been observed in falling water table conditions after initial saturation of upper soils.
>
> Upon passage of gasoline through the interstices of the aquifer, shear action and

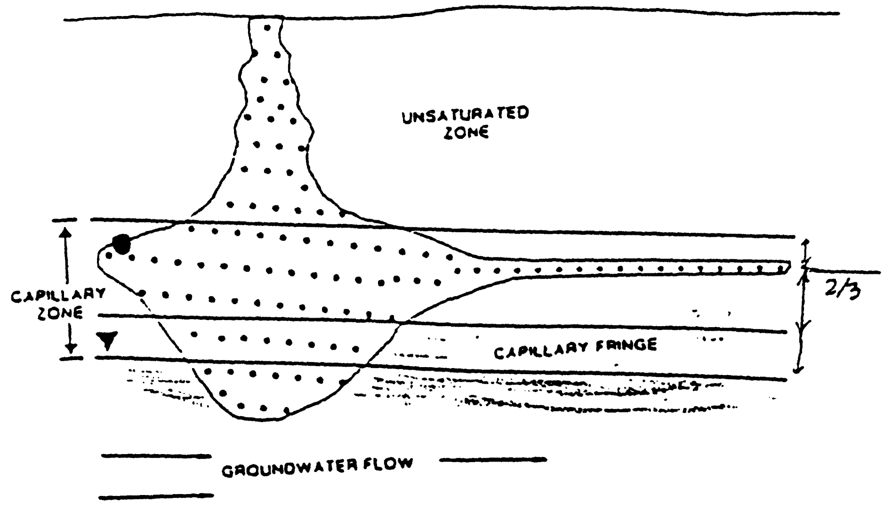

Figure 2.8: Hydrocarbon movement in the capillary zone (after Shepard, 1983)

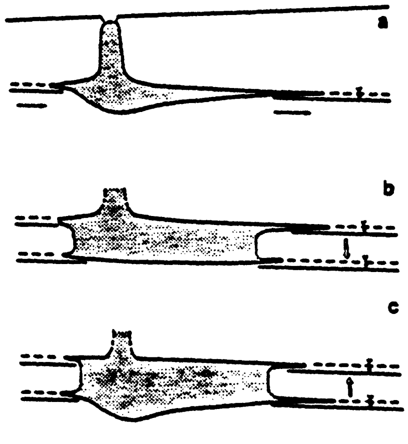

Figure 2.9: Redistribution of the hydrocarbon due to fluctuation of water table (Dracos, 1987)

> interfacial interaction with water disperse the hydrocarbon into droplets. These reach an equilibrium size distribution determined by the interfacial tension between gasoline and ground water and the capillary forces of the aquifer. Some components of the gasoline may absorb on the surfaces of the soil particles to escape later by partitioning equivalent to that found in liquid chromatography. This can cause low level introduction of gasoline components over a very long time through leaching by dynamic ground water.
>
> When soil grains are wetted by water and water flows in behind product to displace it, the water follows the wet surfaces of the soil, squeezing the product through the soil grain pores. For these droplets to move through the narrowest pores, they must be distorted from their spherical shape which affords the least surface area per unit volume. When hydraulic pressure forcing a droplet through a pore is not great enough to effect the required distortion, the droplet becomes immobile, or bound in the soil structure. Product bound in this manner can be moved only if (a) the hydraulic pressure is increased, (b) the interfacial energy between it and the surrounding water is lowered by, for example, a surfactant, or (c) the droplet is broken up by input of some other form of sonic energy, like sonic vibration."

Shepard implies that oil held at residual saturation (whether quasi-pendular or insular) is not necessarily immobile. Depending on the physicochemical properties of the NAPL and the size of the pores, imbibing water may displace some of the NAPL. This implies that the liquid mass may never become completely immobile.

Schwille (1967) performed a series of sand tank experiments designed to simulate an oil spill. In one experiment he raised then lowered the water table in the sand tank. From the results he concluded that: "A high water table is an effective means of preventing the penetration of oil into deeper subsoil. But oil which has penetrated to any level cannot be moved upwards or only so to a small extent." This implies that only a small amount of displacement of residual oil in an upward direction by water can take place.

Althari and others (1986) used a microwave dielectric measuring techniques to measure fluid residual saturations of model soils in the laboratory. Fluid residual saturations were measured after a series of displacements with various miscible and immiscible fluids. Crude oil and carbon tetrachloride were the immiscible fluids used. The ability of water to displace the immiscible fluid was found to be dependent on its immediate prior history of wetness. More immiscible fluid was retained if the medium was initially wetted with water than if it was dry or wetted with immiscible fluid. The retention of immiscible fluid was found to be less dependent upon grain size than upon the initial wetting of the grains. Flow rates were also found to be dependent on wetting of the grains. In general, flow rates decreased when grains were wet, but the magnitude of the decrease was greater for water wet media than for carbon tetrachloride wet media. This indicates that any estimation of the migration of a NAPL through a soil must take into account information about the soil wetness prior to the spill. They also found that the retention of crude oil was dependent on pore velocities of the displacing water.

Hochmuth and Sunada (1985) developed a two-dimensional, finite element, cross-sectional model which simulated two phase flow. In different runs of the model they varied four parameters: conductivity of the oil (Ko), air/oil entry capillary pressure , oil/water entry capillary pressure and the residual oil saturation. This variation produced a different result from one parameter to the next. They found, as might be expected, the value of Ko directly affects the rate at which the pancake spreads out and the shape of the pancake. They also found that the entry pressures affect the vertical location of the pancake relative to the original water table; specifically, the elevation of the pancake varies with the sum of the entry pressures input into the model. The effect of changing the residual oil saturation was relatively minor. A larger value for the residual oil saturation produced a slightly thinner pancake after seepage stopped and lateral spreading began. This occurs because more oil is immobilized at residual saturation.

PROPERTIES OF DIESEL FUEL

Diesel fuel is a complex mixture of hydrocarbons, consisting of over 1,000 individual components, that boils in the range 180 C to 345 C (350-650 F). This temperature range corresponds to the boiling points of straight chain hydrocarbons of 10-20 carbon atoms in length (C_{10} - C_{20}). Diesel fuel's major components are straight chain (normal or n-) and branched (iso- or i-) alkanes centered around C_{15}. A smaller but significant percentage of the fuel consists of aromatic constituents such as benzene, toluene and polycyclic aromatic hydrocarbons (PAHs).

The exact chemical composition of a fuel mixture varies depending on the source of the crude oil from which it was refined, the refining process used, and the time of the year it was produced. Both the variability and complexity of the fuel mixture make it difficult to predict its environmental fate or the risks to human health from exposure to it (Burns, 1987).

About one percent of diesel fuel's mass is water soluble. The water soluble components are known as the fuel's water soluble fraction (WSF). Burns (1987) found the average solubility of a number of unweathered fuel samples to be three milligrams/liter (mg/l) and the average of six weathered samples from different spill sites to be one mg/l. The decreased solubility of the weathered fuels is most likely due to evaporation and dissolution of their relatively volatile, water soluble, smaller aromatic components.

CHAPTER 3: AQUIFER PROPERTIES AND THE PHYSICAL FLOW SYSTEM

BACKGROUND

Missoula Valley Geology

The eastern Missoula Valley is approximately 35 square miles in size. It is surrounded by the Rattlesnake Hills to the North, the Sapphire Mountains to the East, the Bitterroot Mountains to the South. To the west the Clark Fork River serves as a discharge zone for the Missoula Aquifer.

The valley floor is relatively flat. However, it slopes generally toward the Northwest, away from the surrounding hills toward where the Clark Fork River leaves the valley. There are two major river terraces on the valley floor (Mc Murtrey and others, 1965).

The Missoula Valley is bounded by mountains consisting of Precambrian meta-sediments of the Belt Supergroup; 0.8 to 1.6 billion years in age.

The foothills surrounding the Missoula Valley are composed for the most part of fine-grained Tertiary sediments. Up to 2,500 feet of these sediments, ranging in size from clay to gravel, underlie the Missoula Valley (McMurtrey and others, 1965). Clark (1986) gives a thorough summary of Cenozoic geology of the valley. He lists three main units of Tertiary sediments:

> 1. Pre-Renova equivalent. Fanglomerates lying unconformably on Belt meta-sediments, and believed to be limited to valley margins.
>
> 2. Renova equivalent. These sediments are of similar lithology and stratigraphic position to the Renova Formation of the Jefferson basin in southwestern Montana and are sometimes referred to as "Renova" equivalent. They are late Eocene to early Miocene in age and partially to fully consolidated, fine-grained, volcanic ash rich sediments. These sediments crop out in the foot hills on the north and southeast sides of the valley (including the western portion of Waterworks Hill). These sediments unconformably overlie Belt meta-sediments at a variable and unknown depth. They were deposited in an internally drained basin with a semi-arid climate.
>
> 3. Sixmile Creek equivalent. This unit is separated from the Renova equivalent by an angular unconformity. It is probably Miocene to Pliocene in age. This unit is poorly exposed in the valley. It is generally more coarse grained than the Renova equivalent. Sediments were deposited in an arid environment and transported across desert plain surfaces. The South Hills probably represent a remnant pediment from Sixmile Creek time.

Pleistocene-Holocene flood plain and terrace alluvium deposits as well as Glacial Lake Missoula clays cover the surface of the Missoula Valley.

Sand and poorly sorted deltaic deposits of angular Belt detritus inter-finger with Glacial Lake Missoula clays in local areas marginal to the mouths of various tributary canyons (McMurtrey and others, 1965).

Figure 3.1 shows a simplified north to south cross-section of the Missoula Valley.

Quaternary alluvium and possibly Sixmile Creek gravels make up the Missoula Aquifer.

Woessner (1988) lists three stratigraphic zones within the Missoula Aquifer:

Unit 1: Interbedded boulders, cobbles and gravel with sand, silt, and some clay. Thickness from 10 to 30 feet. Found at land surface.

Unit 2: Tan to yellow, silty sandy clay with local layers of coarse sand and gravel. Thicknesses averages 40 feet. in the center of the basin to 130 feet in the northwest section of the valley.

Unit 3: Interbedded gravel, sand, silt and clay. Unit seems to be coarser at the bottom. Thickness varies from 50 to 100 feet. May include part of Sixmile Creek Formation.

Identification of these units is based on the stratigraphy of the central part of the aquifer. Along the valley margins, including the study site, the stratigraphy is considerably more complex, as is discussed in the results section of this chapter.

Ground Water Hydrology of the Missoula Valley

The sediments composing the Missoula Aquifer have extremely high hydraulic conductivities. Due to the aquifer's complex stratigraphy, aquifer properties take on a wide range of values; it is difficult to generalize about these characteristics. Woessner (1988) determined aquifer properties based on laboratory analysis, field aquifer tests, and driller's reports. Results are summarized in

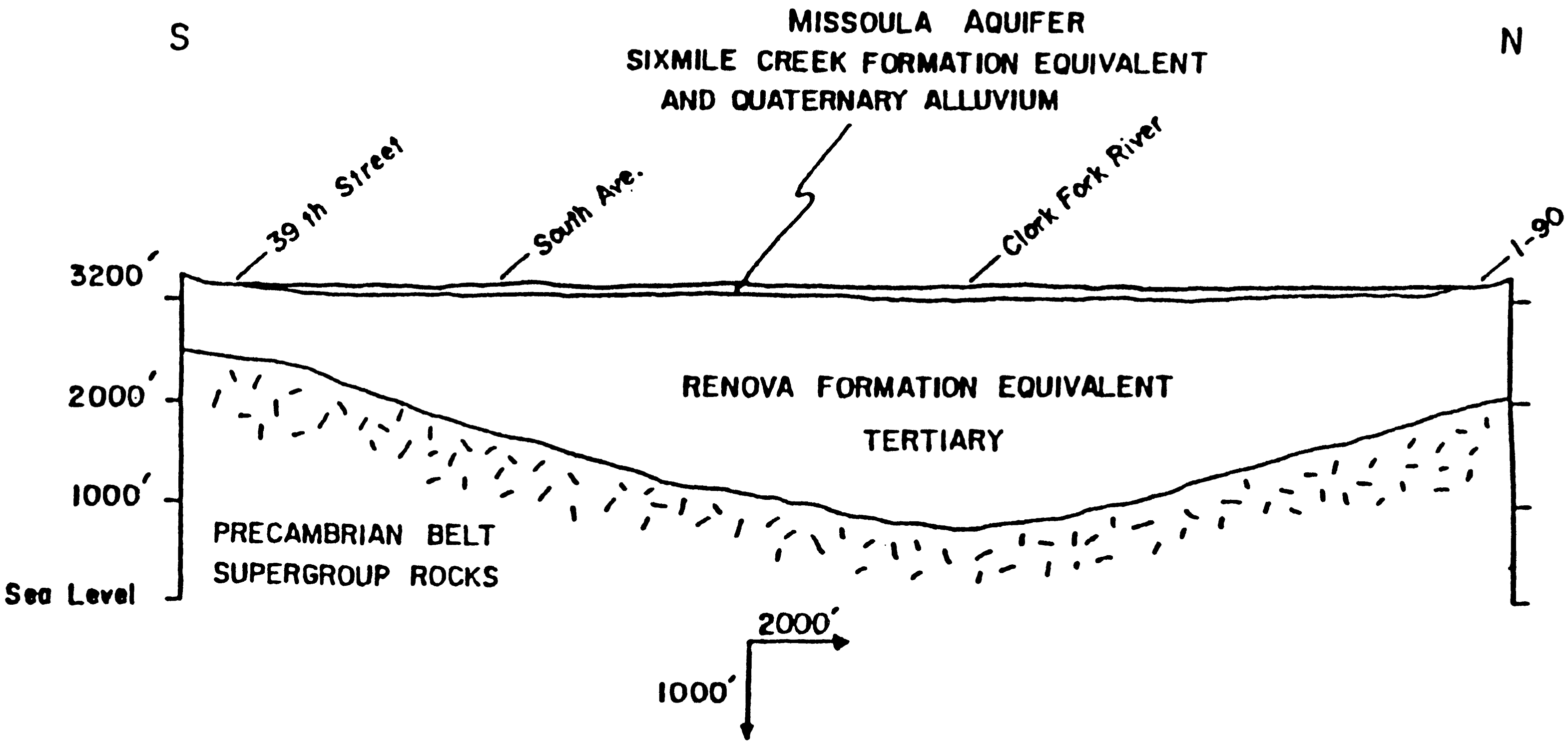

Figure 3.1: Schematic cross-section of the Missoula Valley (from Clark, 1986)

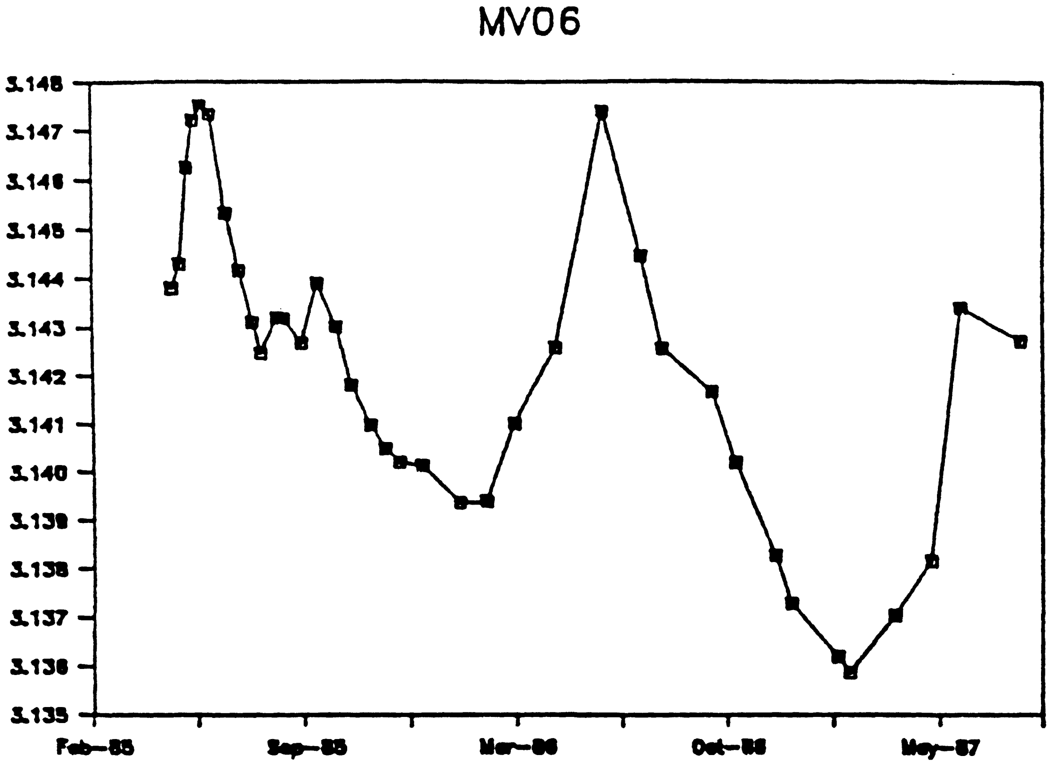

Figure 3.2: Typical central Missoula Aquifer Hydrograph (from Woessner, 1988)

Table 3.1
Estimates of Missoula Aquifer Properties (from Woessner,1988)

Property	Unit 1	Unit 2	Unit 3
Porosity	0.20	---	0.20
Specific Yield	0.1	---	0.10
Thickness (ft)	10-30	40	50-150
Hydraulic Conductivity (gpd/ft^2)	10,300	200	10,000-25,500
Vertical Hydraulic Conductivity (gpd/ft^2)	---	---	970-2,100
Transmissivity (gpd/ft)	103,000-310,000	8,000	750,000-1,710,000

Table 3.1.

The Missoula Aquifer generally has an annual rise in water levels between March and June, then a general decline until the following February or March. Figure 3.2 shows a typical hydrograph from the center of the Missoula Aquifer.

North of the Clark Fork River, ground water moves away from the channel and away from the northern aquifer boundary. Along this boundary, water from the Tertiary sediments of the northern foothills and from the alluvium in the Grant Creek and Butler Creek Valleys recharges the aquifer as is shown in (Figure 3.3). As a result, ground water flow north of the river is generally parallel to the river.

The Clark Fork River is the major source of recharge to the Missoula Aquifer (Clark, 1986 and Miller 1991). Spring precipitation and snow melt are the principal sources of

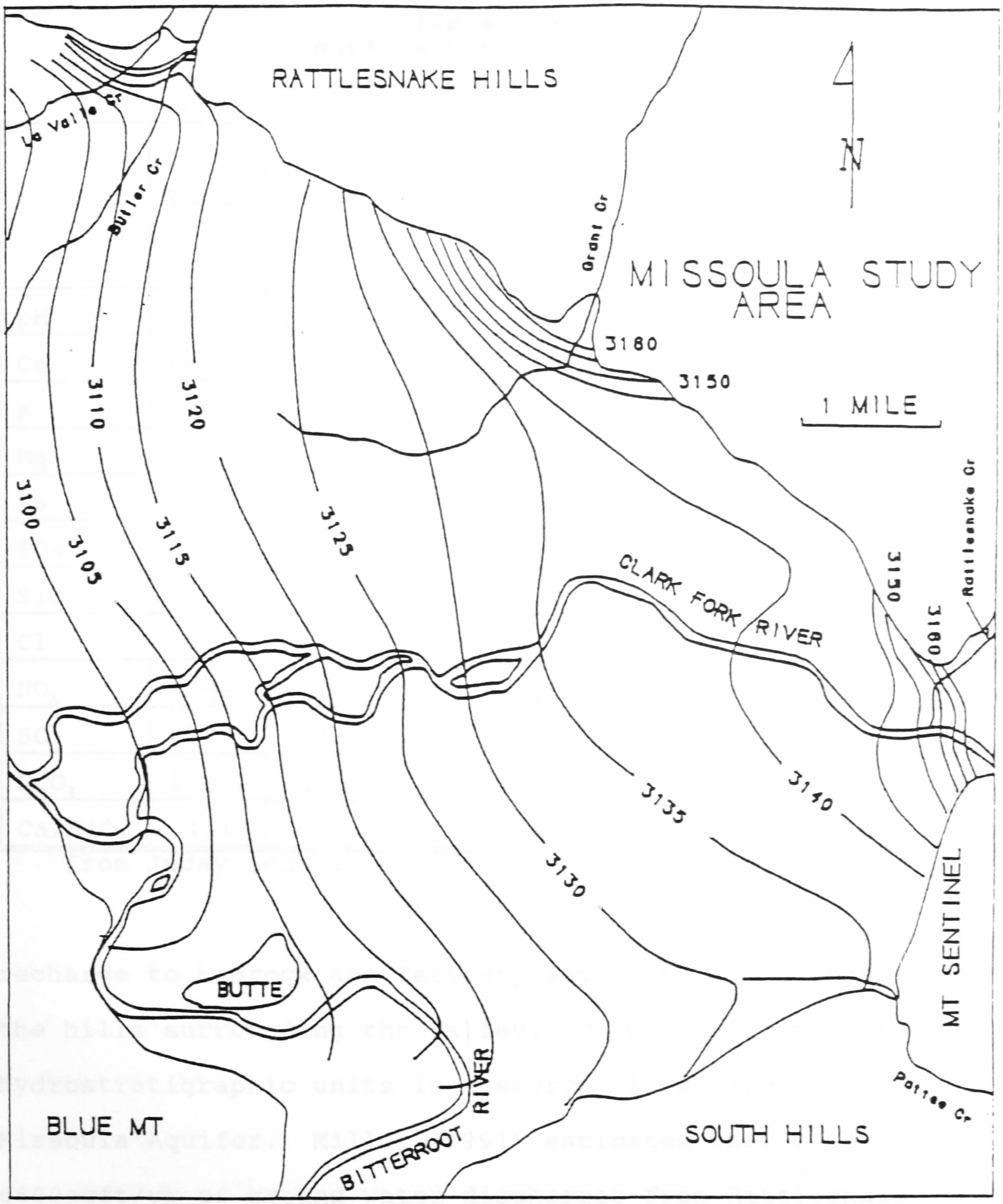

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Figure 3.3: Potetniometric surface map for Missoula Aquifer (Miller, 1991).

Table 3.2
Surface Water Analysis

	Clark Fork River			Rattlesnake Creek		
	Turah	Van Buren Street	Above Missoula Sewer Plant	Lolo Street Bridge	Vine Street Bridge	Front Street Bridge
pH	8.3	8.1	8.2	7.8	8.0	8.0
Ca	68.0	30.0	36.9	6.5	11.9	11.1
K	3.5	2.3	2.1	0.5	0.7	0.7
Mg	14.0	12.4	11.3	2.4	3.7	3.5
Na	12.6	7.4	5.8	1.8	2.5	2.5
PO4	0.089	0.038	0.036	0.023	0.014	0.014
SiO_2	16.6	14.8	14.2	7.3	7.0	7.2
Cl	3.9	2.1	1.9	0.4	1.3	1.3
NO_3	0.029	0.030	0.006	0.180	0.550	0.490
SO_4	68.5	40.0	38.0	1.5	4.2	3.2
HCO_3	128.2	115.7	141.9	26.5	55.0	52.9
Ca/SiO_2	4.10	2.03	2.60	0.89	1.7	1.54

from Juday and Keller, 1978 ; concentrations in mg/l

recharge to bedrock and Tertiary sediments which under-lie the hills surrounding the valley. Discharge from these hydrostratigraphic units is a source of recharge to the Missoula Aquifer. Miller (1991) estimates that 2900-6800acft/yr of ground water discharges from Rattlesnake Valley alluvium to the Missoula Aquifer.

Ground Water Quality of the Missoula Valley

In general water in the Missoula Aquifer is classified as calcium or calcium-magnesium bicarbonate with regard to major cations and anions (Geldon, 1979). From previous studies, calcium concentrations vary from 30 to 50 mg/l; sodium concentrations range from 4 to 8 mg/l; magnesium concentrations vary from about 10 to 35 mg/l; bicarbonate concentrations range from 150 to 200 mg/l; sulfate concentrations are generally less than 40 mg/l; chloride concentrations are generally less than 20 mg/l (Juday and Keller, 1978). Ground water in most of the Missoula Aquifer is very similar to Clark Fork River water in its chemical composition but with higher concentrations of most ions (Woessner, 1988; Clark, 1986, Juday and Keller, 1978). Rattlesnake Creek water differs from Clark Fork River water in that it has less calcium, magnesium, bicarbonate, sulfate, chloride and sodium (Juday and Keller, 1978).

Rattlesnake Creek pH values range from 7.6 to 8.0. Clark Fork River pH's in the Missoula Valley range from 8.0 to 8.1. Missoula Aquifer pH's north of the river and east of Reserve Street range from 7.3 to 8.3 with the lower end of this range occurring to the east.

Near the Clark Fork River, the mineral content of ground water fluctuates seasonally in response to changes in river water quality. At distances over one half mile from the river, ground water quality remains fairly constant in

Table 3.3
Average Concentrations of constituents of Missoula Basin aquifers (Geldon, 1979)

		Pliocene-Holocene Alluvium								Oligocene-Miocene		Precambrian Rock
		Missoula Basin										
	EPA Standards for Drinking Water	Clark Fork Basin	Hellgate Valley (6 wells)	Main Urban Area (19 wells)	Airport Area (3 wells)	Grant Creek Area (2 wells)	Target Range (10 wells)	Rattle-snake Creek (1 well)	Miller Creek (1 well)	Clark Fork Basin	Msla. Basin (5 wells)	Msla Basin
Calcium(Ca)	75	38	36.7	37.3	25.0	9.6	40.7	23.0	20.4	33	19.3	18.1
Magnesium (Mg)	30	14	15.6	20.3	11.4	7.3	16.7	10.8	8.5	11	13.3	22.8[9]
Sodium (Na)	--	8.5	8.2	7.6	7.3	2.8	8.2	3.6	4.5	56	13.8	8.5
Silica (SiO_2)	--	15	12.3	15.9	17.0	8.7	15.3	10.8	20.7	32	30.2	15.0
Nitrate (NO_3^-)	45	3.8	0.72	0.09	0.75	0.039	0.78	0.14	2.1	23	0.58	0.042
Phosphate (PO_4)	--	--	0.020	0.018	0.032	0.019	0.025	0.014	0.031	--	0.034	0.002
Sulfate(SO_4)	200	7.7	9.0[4]	28.5	8.0	3.5	27.7[6]	4.0	5.3	14	8.9[7]	16.1
Chloride (Cl)	200	2.5	5.8[5]	4.5	1.9	1.0	5.0	1.1	2.2	8.4	2.2	1.4
Bicarbonate(HCO_3)	--	140	181	198	140	59	195	131	102	210	144	171
Dissolved solids	500	165	274	314	219	91	306	186	187	292	241	255
Turbidity(NTU)	1		0.26	0.26	0.34	0.38	0.24	-	1.56	-	0.56[8]	0.72
pH	--	7.0	7.7	7.7	7.7	7.0	7.7	7.8	7.1	8.1	7.6	7.8
Iron(Fe)	0.3	0.33	--	--	--	--	--	--	--	2.3	--	--
Fluoride (F)	--	0.1	--	--	--	--	--	--	--	0.4	--	--
Potassium (K)	--	2.5	2.4	2.0	1.7	0.9	2.5	2.2	2.7	8.3	2.1	1.1
Manganese (Mn)	0.5	--	--	--	--	--	--	--	--	0.42	--	--

1. Data from Juday and Keller (this study) except as noted.
2. Data from U. S. Environmental Protection Agency (1976).
3. Data from Boettcher and Gosling (1977).
4. Average of 4 wells; 16 ppm if 2 wells near sewage plant with high sulfate are included
5. Average of 5 wells; 15.6 ppm Chloride in 6th well.
6. Average of 9 wells.
7. Average of 4 wells; 38.4 ppm in 5th well.
8. Average of 4 wells; 60.8 NTU in 5th well due to 5 ppm Fe.
9. Range 5.3 - 46.4 ppm.

any given well (Woessner, 1988).

Table 3.2 summarizes average concentrations of common constituents for wells in the Missoula Basin. The ratio of calcium to silica (SiO_2) can be used as indicator of the unconfined Missoula Aquifer alluvium to 0.64 in water inconfined Tertiary sediments (Geldon, 1979). The importance of the Clark Fork River in recharging the Missoula Aquifer is shown by decreasing Ca/Si ratios with increasing distance from the river.

Iron concentrations in water from Tertiary sediments are much higher than in Missoula Aquifer alluvium, ranging from about 5.0 to 7.0 mg/l. Iron concentrations in the Missoula Aquifer are generally less than 0.5 mg/l (Juday and Keller, 1979; McMurtrey and others, 1965).

Boettcher and Gosling (1977) summarize differences in water chemistry for valley-fill alluvium and Tertiary sediments for the entire Clark Fork River drainage upstream from St. Regis, Montana. Geldon (1979), however, states that many of these differences were not observed in the Missoula Valley. He does indicate that silica and sodium levels are higher in Tertiary sediments than in valley-fill sediments.

Within the Missoula Aquifer water quality is essentially constant, varying only as a function of contact time with aquifer materials.

Examples of Missoula Valley Ground Water Contamination

Diesel fuel at the B.N. site is but one of many sources of contamination in the Missoula Aquifer. Peery (1988) investigated a spill of approximately 600 gallons of leaded gasoline at the Champion Missoula Sawmill site. Within ten weeks of the spill domestic wells 1200 ft down gradient of the spill site had become contaminated with benzene, toluene, and xylene (BTX). BTX levels at the spill site decreased 65 % over two years. Eventually, BTX concentrations were reduced to below detection limits by the time contaminant plumes migrated 1200 feet down gradient. Peery attributed this attenuation to biodegradation and dispersion.

Pottinger (1988) investigated trace levels of herbicides in the supply well of the Missoula County Weed Control (MCWC) site. The MCWC facility sump was identified as the probable source from a list of possible sources. Ground water flow at this site was found to be complex and varied seasonally. A two-dimensional solute transport model was employed to predict the future behavior of contaminant plumes.

Hinman and others (1990) investigated the contamination of the Missoula Aquifer by perchloroethylene (PCE). An assessment of the extent of PCE contamination in the aquifer was made. After developing a stratigraphic framework, the authors determined that a portion of the aquifer was missing

Morgan's (1986) unit 2. Unit 2, being fine-grained, possibly provides a protective layer to much of the Missoula Aquifer (Woessner, 1988). The portion of the aquifer that was missing unit 2 tended to have more PCE contamination than other portions of the aquifer.

The Missoula County Health Department (1987) listed other events which have contaminated the Missoula Aquifer:

In 1982, a rupture in a high pressure gasoline pipeline spewed an undetermined amount of gasoline into Lavalle Creek located in the north central portion of the aquifer. This contaminated wells adjacent to the creek. This pipeline also leaked in the mid 1970's contaminated wells in the Grant Creek area just east Lavalle Creek and recently had a major leak in April 1992 at tank farm in Missoula.

The Browning-Ferris Landfill is located near the northeastern boundary of the Missoula Aquifer in Tertiary sediments. Since 1986, routine ground water samples have shown elevated levels for nearly every parameter sampled, including PCE, TCE, BTX, arsenic, and cadmium. So far, no contaminants have showed up in monitoring wells completed in the Missoula Aquifer just down gradient of the landfill.

METHODS

Geologic Environment

Well logs of about thirty wells located in the study area were analyzed to determine the presence and continuity of hydrostratigraphic units (Appendix A). These are monitoring and recovery wells installed by consulting firms under contract to Burlington Northern. Geologic cross-sections were produced based upon interpretation of these logs.

Water Level Data

Depth to the water table measurements were recorded on a monthly basis from January 1990 to November 1991. Measurements were recorded more frequently during periods of spring runoff to gain better definition of changes in the potentiometric surface during periods of greatest variability.

Depth to water measurements were made using different instruments in uncontaminated wells than in contaminated wells to avoid contaminating clean wells. In uncontaminated wells, measurements were made with a Solonist electric water probe. In contaminated wells, measurements were made with an Oil Recovery Systems interface probe, which also measured the depth to hydrocarbon. The two instruments were calibrated to a depth of 60 feet. Measurements of depth to water made with both instruments simultaneously varied by less than 0.02 feet.

During a water level monitoring event, measurements for all wells were made in the shortest length of time possible to avoid capturing short term water level changes within the data set. Monitoring events required six to eight hours to complete.

Water table elevations (above mean sea level) were calculated for uncontaminated wells by subtracting the depth to water measurement from the surveyed elevation of the well head. For contaminated wells, water table elevations were calculated by first subtracting the depth to water measurement from the surveyed elevation of the well head, as above. Then, to account for the isostasy of the diesel fuel floating on water in the well, the depth to hydrocarbon reading was subtracted from the depth to water reading yielding the thickness of hydrocarbon in the monitoring well. This is known as the apparent product thickness (APT). The APT is multiplied by the specific gravity of diesel fuel and added to the elevation of the water to produce the calculated water table elevation.

Potentiometric surface maps were plotted for various monitoring events within the study period. The resulting potentiometric maps are discussed in detail in the results section of this chapter.

Aquifer Properties

Prior to this study, values for aquifer properties at the B. N. site were not known. Much of the Missoula Aquifer has very high transmissivity values. Evidence implied that transmissivity values would be lower than those for the central portion of the Missoula Aquifer and that the alluvium at the west end of the site was more transmissive than for the east end of the site. Pumping in MR-5 (near the west end of the site) produces a very small cone of depression when pumped at approximately 40 gpm. By contrast, the influence of pumping in MR-1 is noticeable as a distinct cone of depression with a radius greater than 250 feet. With the recovery unit operating in MR-1 at four to five gpm, approximately 0.5 foot of drawdown has been observed in M-17, which is about 140 feet down gradient. At a pumping rate of approximately 8 gpm, drawdown of 0.2 foot was observed in M-12, which is over 200 feet to the west.

To gain a better understanding of the flow system, two aquifer tests were performed to produce estimates of aquifer properties for the east and west end of the site. A constant rate pumping test was performed in MR-5 in October 1990 by Kennedy/ Jenks/ Chilton with my assistance. During the test, MR-5 was pumped at 40 gpm for 24 hours. Time-drawdown and time-recovery data were collected and analyzed to yield estimates of transmissivity, specific yield and storativity in the immediate vicinity of the well. A constant rate pumping test was also performed in well MR-1 in July of 1991.

The aquifer tests were analyzed using standard curve matching techniques presented in Lohman (1979). Detailed description of the instrumentation and methodology used as well as the analyses of test data for MR-5 are presented in Kennedy/ Jenks/ Chilton (1990).

Hydraulic conductivity could not be estimate because the saturated thickness of the aquifer is not known.

Ground Water Discharge

Ground water leaving the B. N. site recharges the Missoula Aquifer. To estimate the amount of water discharging from the site on an annual basis, Darcy's law was used:

$$Q = K * A * I$$

where; Q = Discharge (L^3/t)
K = Hydraulic Conductivity (L/t)
A = Cross-sectional area (L^2)
I = hydraulic gradient (L/L)

The potentiometric map from December 10, 1990 (Figure 3.18) was used to estimate hydraulic gradients. Two cross-sections were used to calculate the flux out of the site: a 1400 foot line parallel to potentiometric lines running roughly southeast-northwest and a 600 foot line running roughly north-south. For the longer cross-section the higher transmissivity estimate from MR-5 was used as potentiometric lines along Spruce Street are relatively widely spaced on potentiometric maps (Figures 3.14 - 3.20).

The lower transmissivity estimate from MR-1 was used for the cross-section running north from M-21 as potentiometric lines are generally much closer together in the area. an aquifer thickness of 50 ft was assigned to the longer cross-section based on Miller's (1991) map of depth to the aquifer base. An aquifer thickness of 25 ft. was assigned to the shorter cross-section based on the assumption that the aquifer thins toward Waterworks Hill.

Water Quality

To determine the presence of distinct hydrostratigraphic units, the gross ionic chemistry was analyzed. Ground water samples were collected from all wells within the study site which had not ever been contaminated with free product. Contaminated wells were not sampled due to problems with purge water disposal and the probability that the hydrocarbons and associated biological activity have changed geochemical conditions in the formation waters surrounding those wells. The inability to assess the water quality from all wells hampered the effectiveness of this portion of the investigation.

Two inch wells were purged by hand with a teflon bailer until pH, temperature and conductance stabilized. Four inch wells were purged with a submersible pump until the same properties stabilized and samples were then collected with a bailer.

Samples were analyzed for metals (cations) by Inductively Coupled Argon Plasma Emission Spectrometry (ICAPES). Samples were analyzed for major anions by Ion Chromatography (IC). Samples were analyzed for alkalinity by the Gran titration method.

One uncontaminated well was not sampled. During sampling M-22 was bailed dry and failed to recover within 24 hours. A significant product sheen was observed in purge water from M-19 which had been assumed to be an uncontaminated well up to that time. Since the relative amount of hydrocarbon in M-19 was small, it was sampled and analyzed.

RESULTS AND DISCUSSION

Geologic Environment

Due to its location at the edge of the Missoula Valley, the B.N. fueling site is probably near the transition zone between three hydrostratigraphic units: The Missoula Aquifer, the Tertiary sediments, and the bedrock.

The B.N. fueling site is bounded on the north by Interstate 90 and Waterworks hill. The southeastern end of Waterworks Hill is mostly Precambrian Belt bedrock overlain in places by a veneer of Tertiary sediments. At the very southwestern tip is a fairly flat surface consisting of poorly sorted angular to sub-angular colluvium, sand, and silt. McMurtrey and others (1965) date this as being associated with Glacial Lake Missoula deposition.

Between this surface and Interstate 90 the sediments change to well rounded cobbles and gravel. This is probably the remains of an old Clark Fork River channel. Many Black cottonwood trees grow out of this zone. Recently, many of these trees began to die. Apparently, until 1988, the reservoir on Waterworks hill was leaking at approximately 300 gallons per minute (personal communication, Robert Ward, Mountain Water Company). This zone was acting as an artificial contact spring. When the leak was fixed, the source of water was cut off and after a couple of years the trees began to die. A wooden aqueduct leading to the reservoir is still operational. This may also be leaking significant amounts of water into the hill.

It is possible that the water leaking from Waterworks Hill was at one time a significant source of recharge to the B. N. site and may still be influencing ground water flow directions.

Figure 3.4 show the locations of geologic cross-sections shown in Figures 3.5, 3.6, and 3.7. They were constructed based on well logs for the various monitoring and recovery wells installed on the study site as no additional wells were available in this area. Special attention was paid while reviewing the well logs to identification of a lens of fine-grained material. This

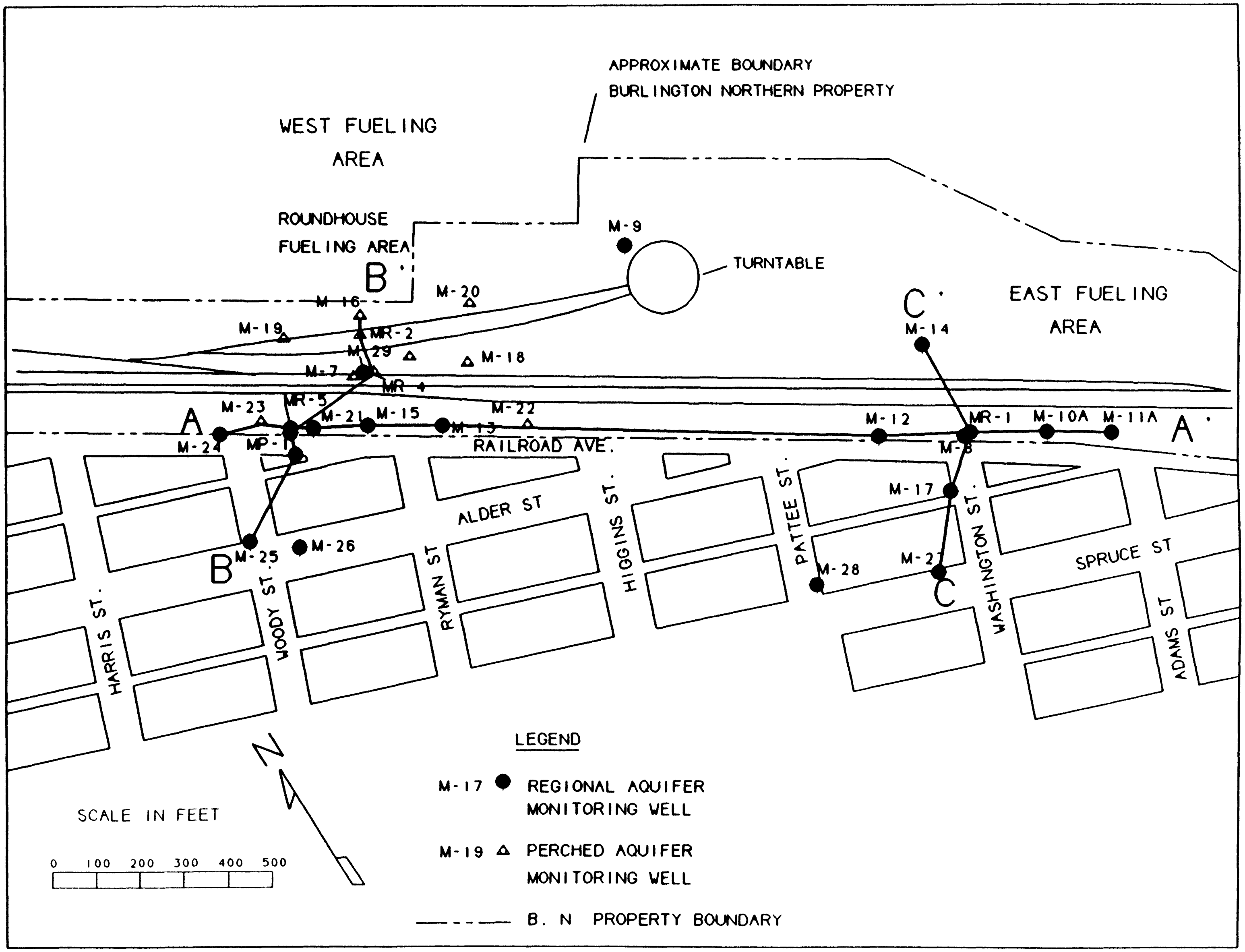

Figure 3.4: Location of cross-sections

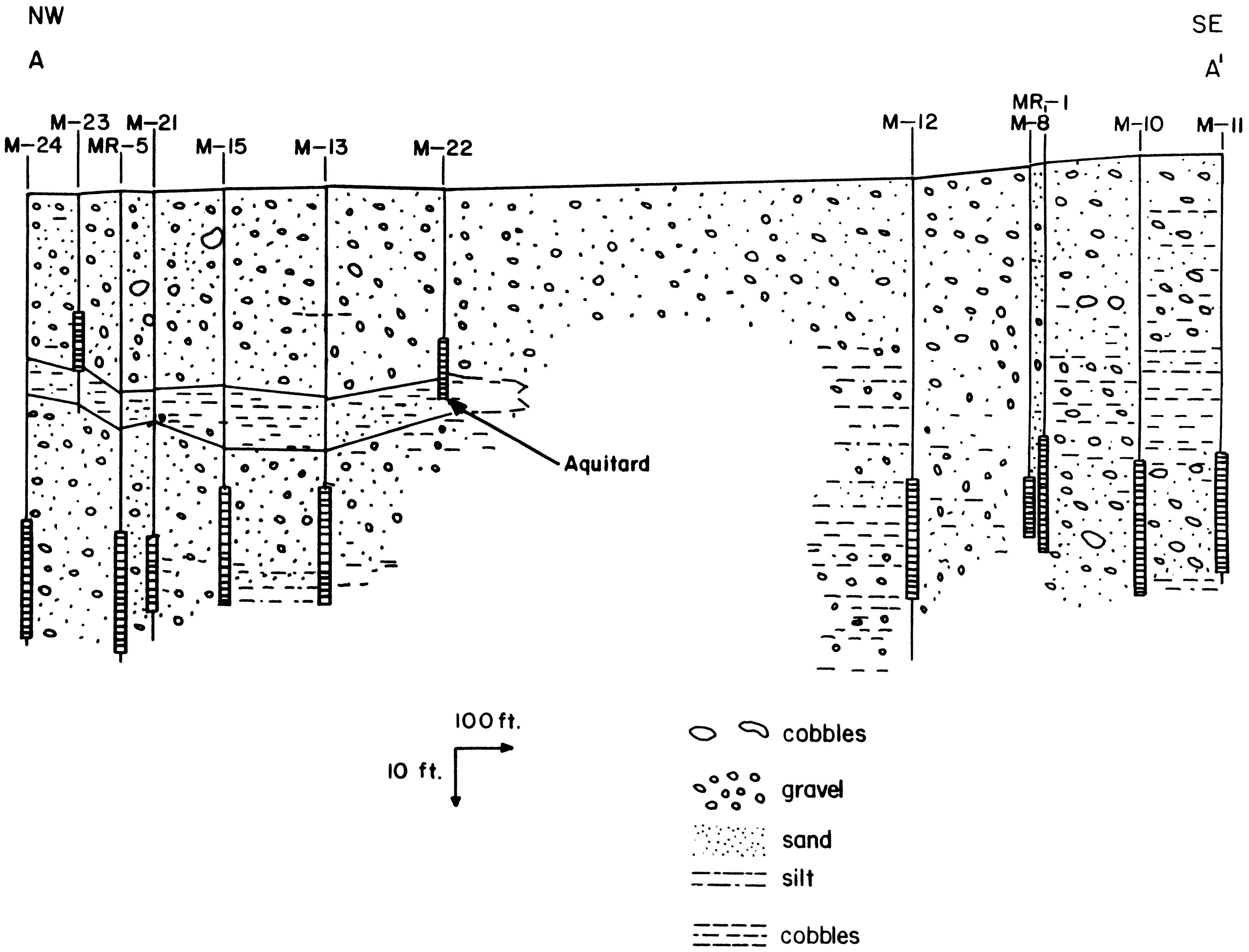

Figure 3.5: Cross-section A-A'

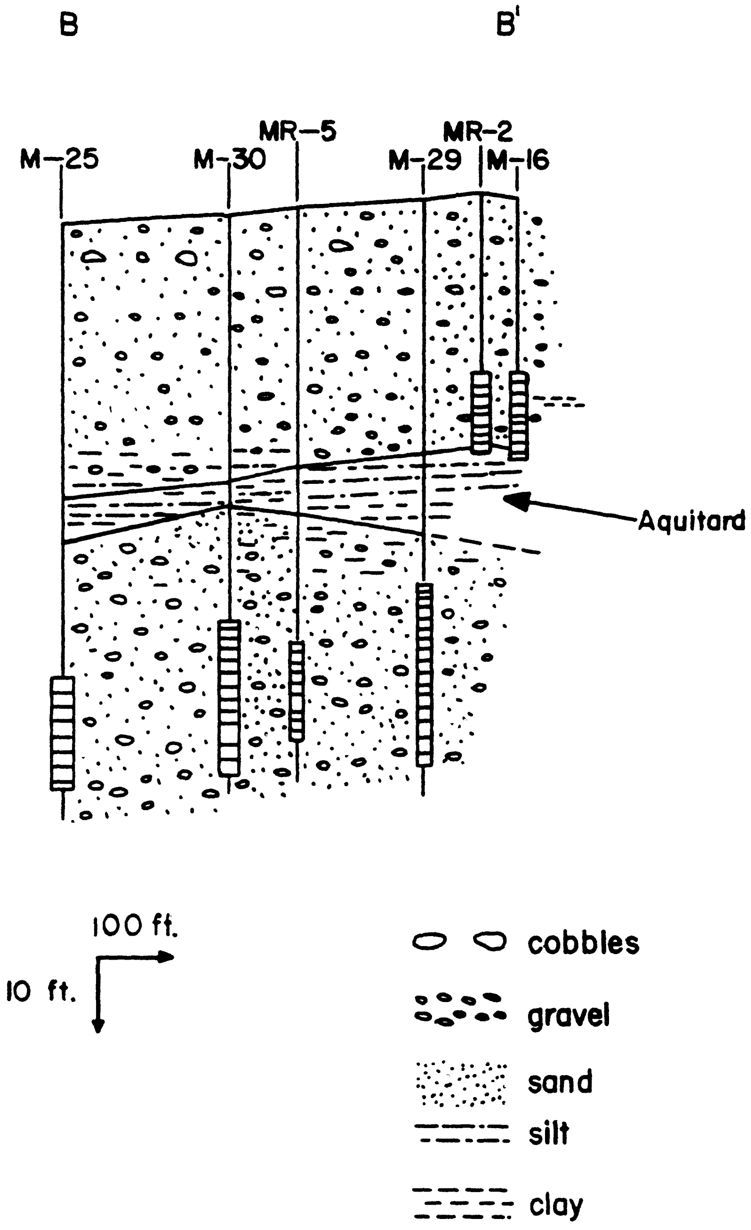

Figure 3.6: Cross-section B-B'

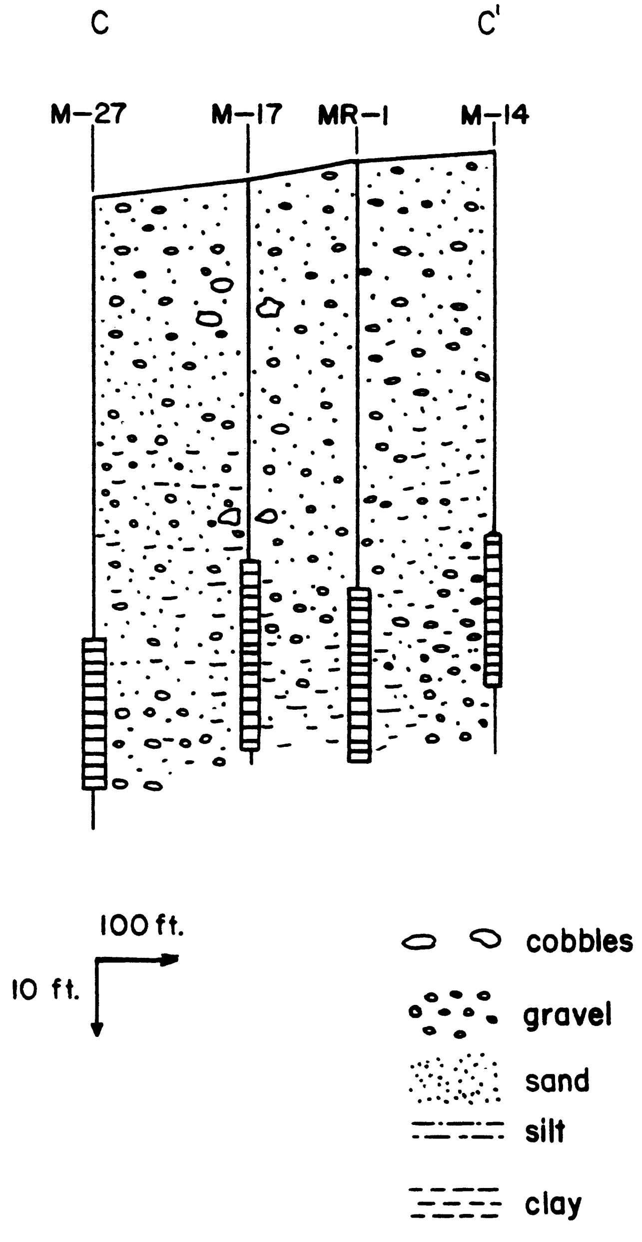

Figure 3.7: Cross section C-C'

fine-grained layer serves as an aquitard creating a perched aquifer in the vicinity of the Roundhouse fueling area.

Upon examination of these cross-sections three stratigraphic zones become apparent. The first zone is the upper 28 to 36 feet consisting of gravels with sand and some cobbles. The gravels are red and green, angular to rounded pieces of argilite and quartzite; the sand is light brown.

Below this is a fine-grained zone from 28 to 43 feet that serves as an aquitard (at least under the Roundhouse fueling area). It varies in consistency from competent lean pinkish brown to brown clay near the Roundhouse fueling area, to gravels with silt and some clay in the wells south of there. Much of this variability may be due to lack of consistency in description among different logging personnel. The aquitard ranges in thickness up to ten feet. In wells installed south of B. N. property the soils overlying the aquitard were moist to wet but did not appear to be water-bearing (Kennedy/Jenks/Chilton, 1989). The third zone, from 35 to 82 feet varies from gravel with sand (much like the upper zone) to clay with silt, and sand. In wells east of M-15 the lower portion of this zone has more fine-grained sediments. There appear to be numerous discontinuous fine-grained lenses at various depths below the aquitard. Some of these lenses are probably also smaller aquitards as they are often noted as areas of moisture or diesel odor on well logs.

Allen (1983) noted a poorly-sorted, fine-grained lens at the mouth of Pattee Creek. This lens serves as an aquitard and creates a perched aquifer at a depth of approximately 30 feet and may be similar in origin to the B.N. aquitard. He attributes this lens as the surface of a remnant alluvial fan.

The uppermost zone of the study site most certainly corresponds to Woessner's (1988) Unit 1. The lower two zones may correspond to Woessner's Unit 2 due to the presence of many fine-grained lenses. This appears consistent with Hinman and others' (1990) discussion of Unit 2. In any case the aquitard (at least in the zone underlying the roundhouse fueling area) is protecting the underlying regional aquifer. Fine-grained lenses underlying the aquitard also serve to slow the migration of pollutants toward the regional water table.

Figure 3.8 is a block diagram with the front panel cut out. It is a schematic three dimensional representation of my conceptual model.

Water Level Data

Figures 3.8 through 3.13 are hydrographs of well responses. 3.7 shows that regional wells on the west end of the study site had similar maximum and minimum water levels for both 1990 and 1991. Water levels peaked at a slightly

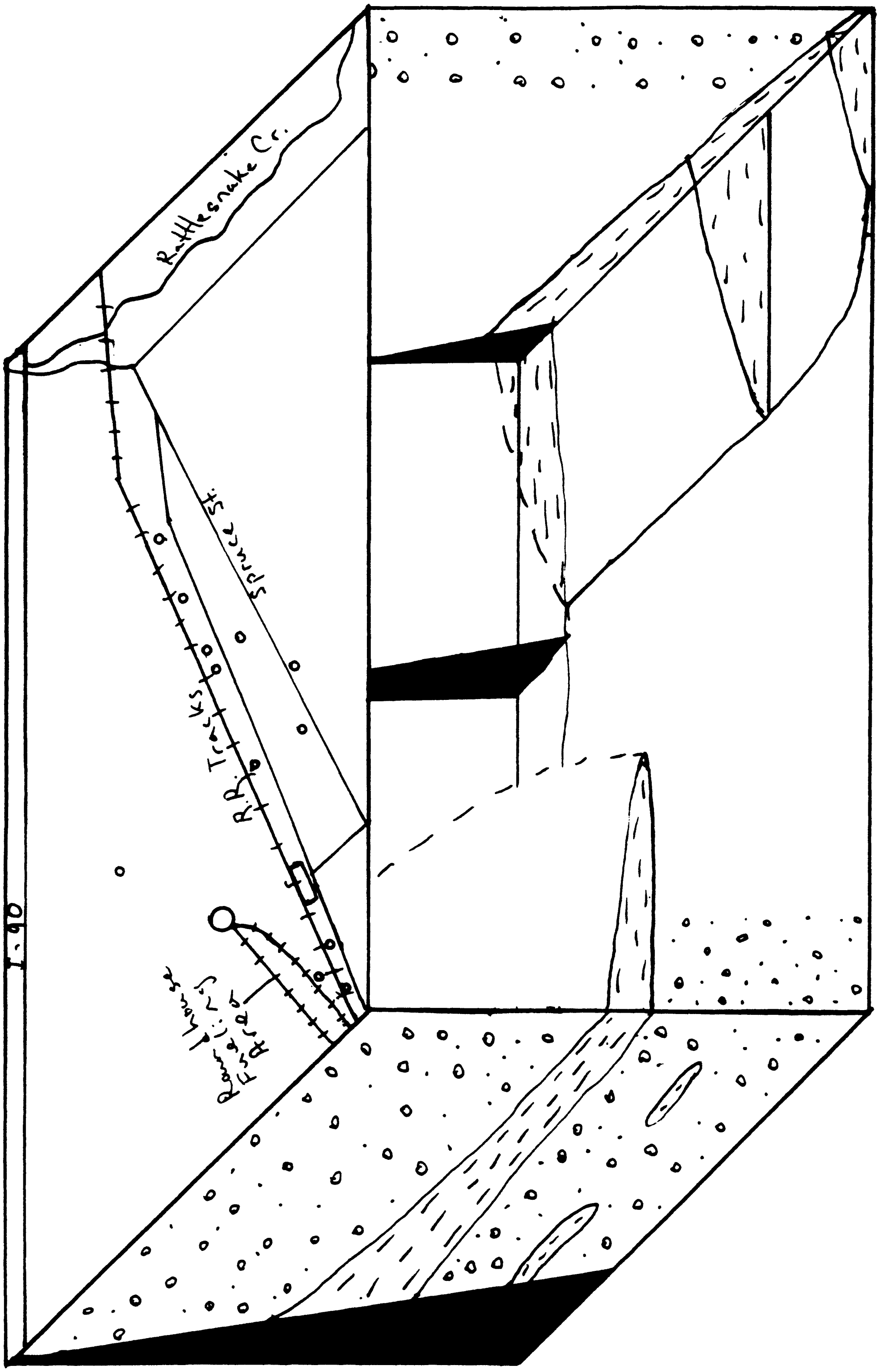

Figure 3.8: Schematic representation of conceptual model

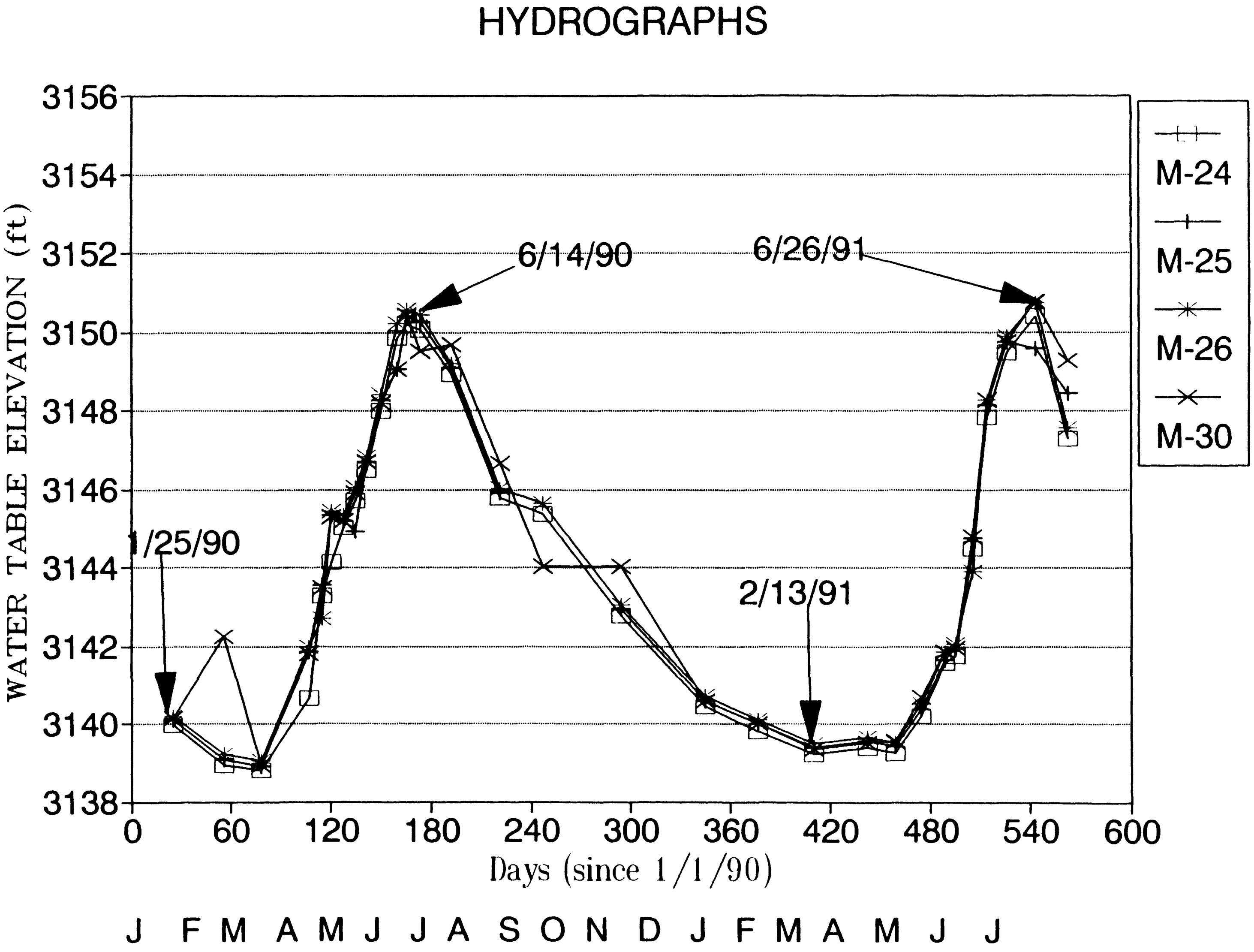

Figure 3.9: Hydrographs for west end regional wells

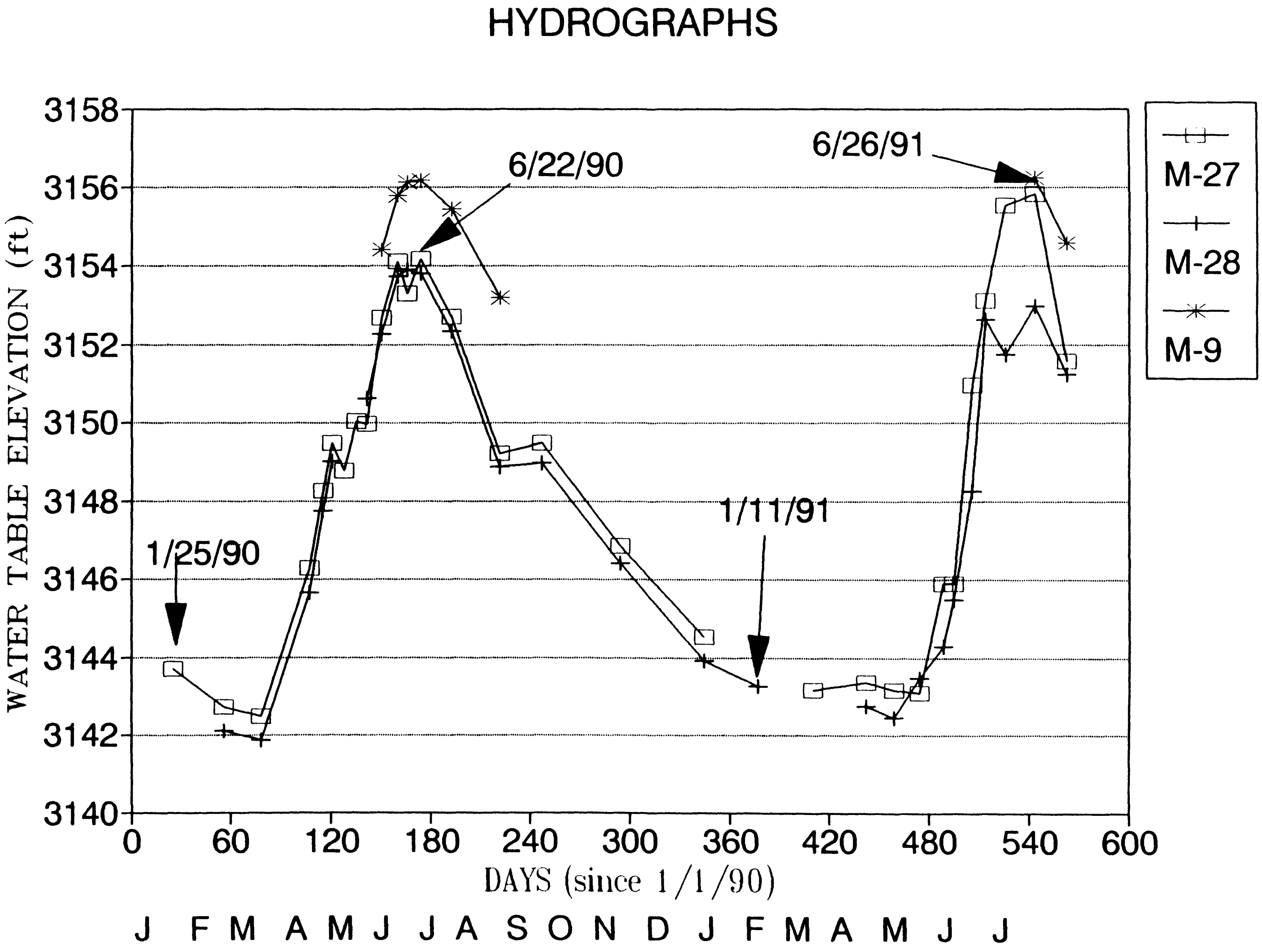

Figure 3.10: Hydrographs for M-9, M-27 and M-28

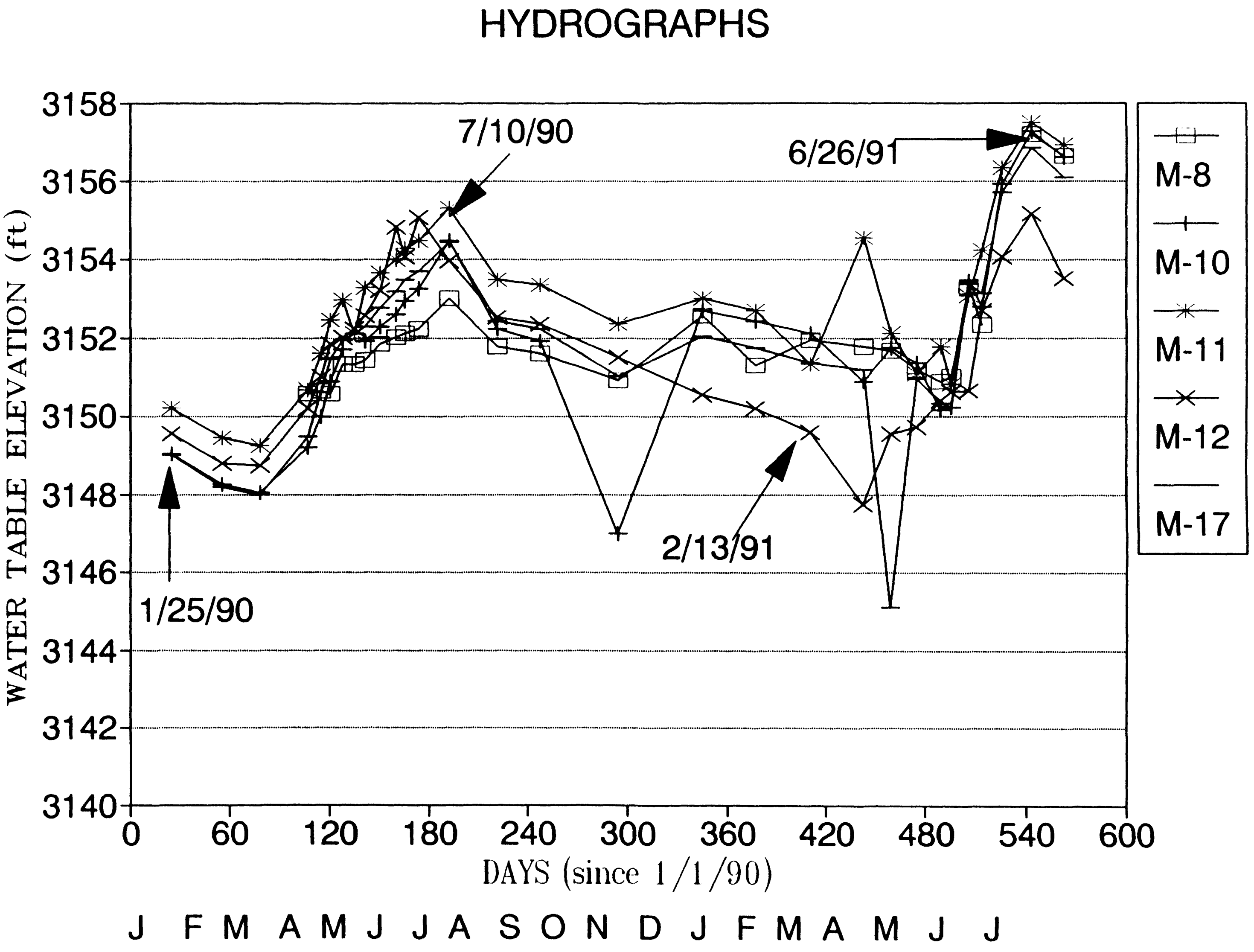

Figure 3.11: Hydrographs for east end regional wells

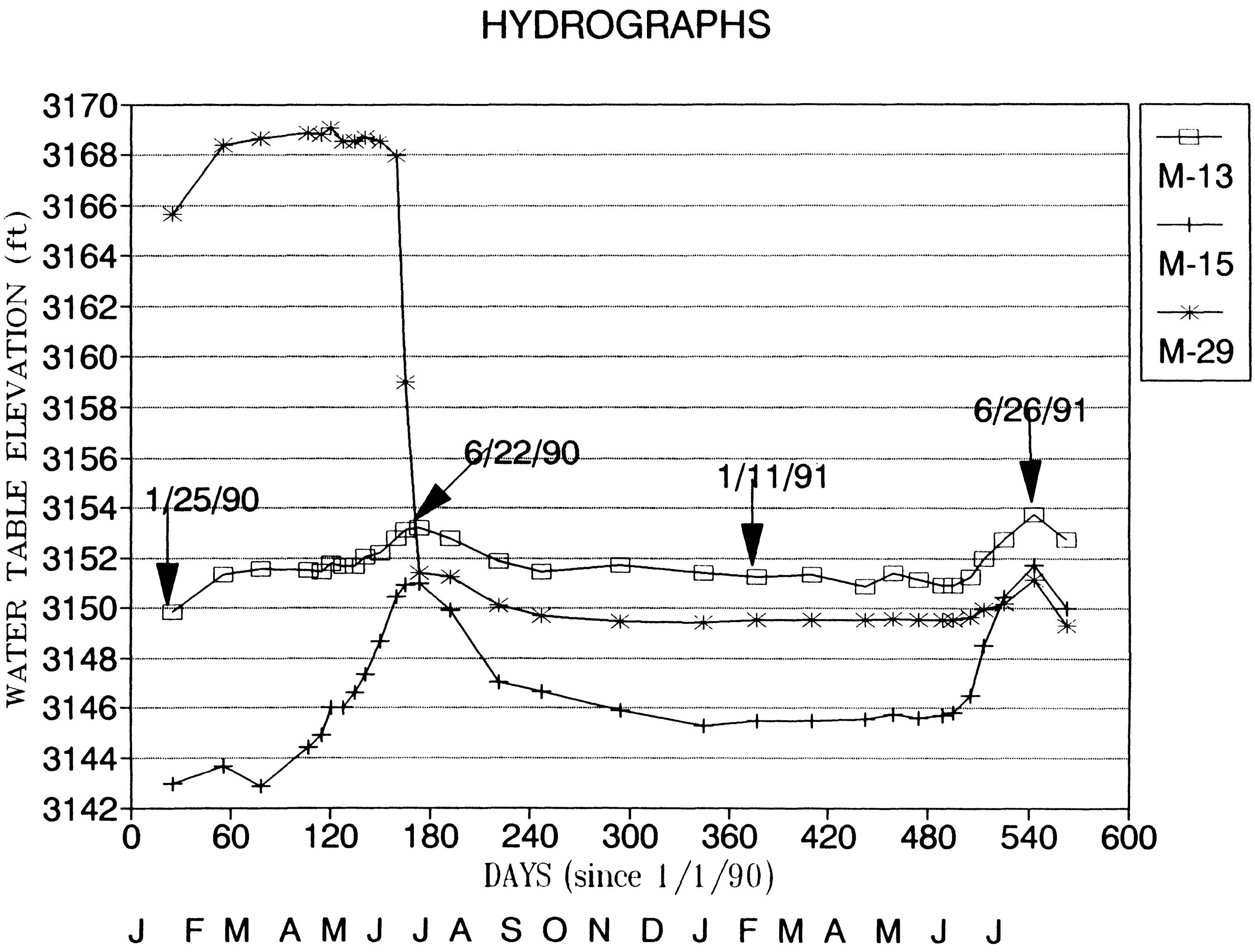

Figure 3.12: Hydrographs for M-13, M-15, and M-29

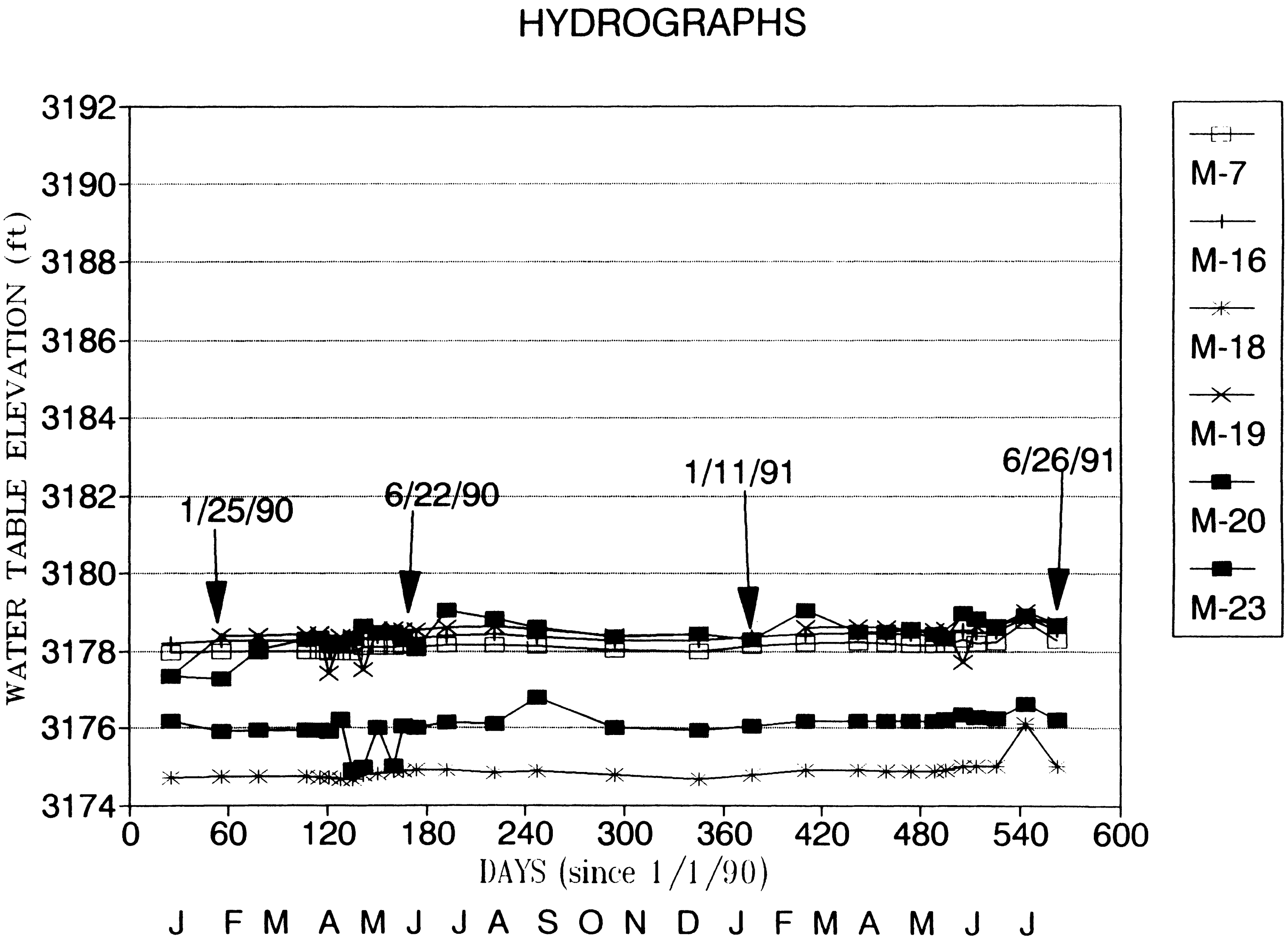

Figure 3.13: Perched well hydrographs

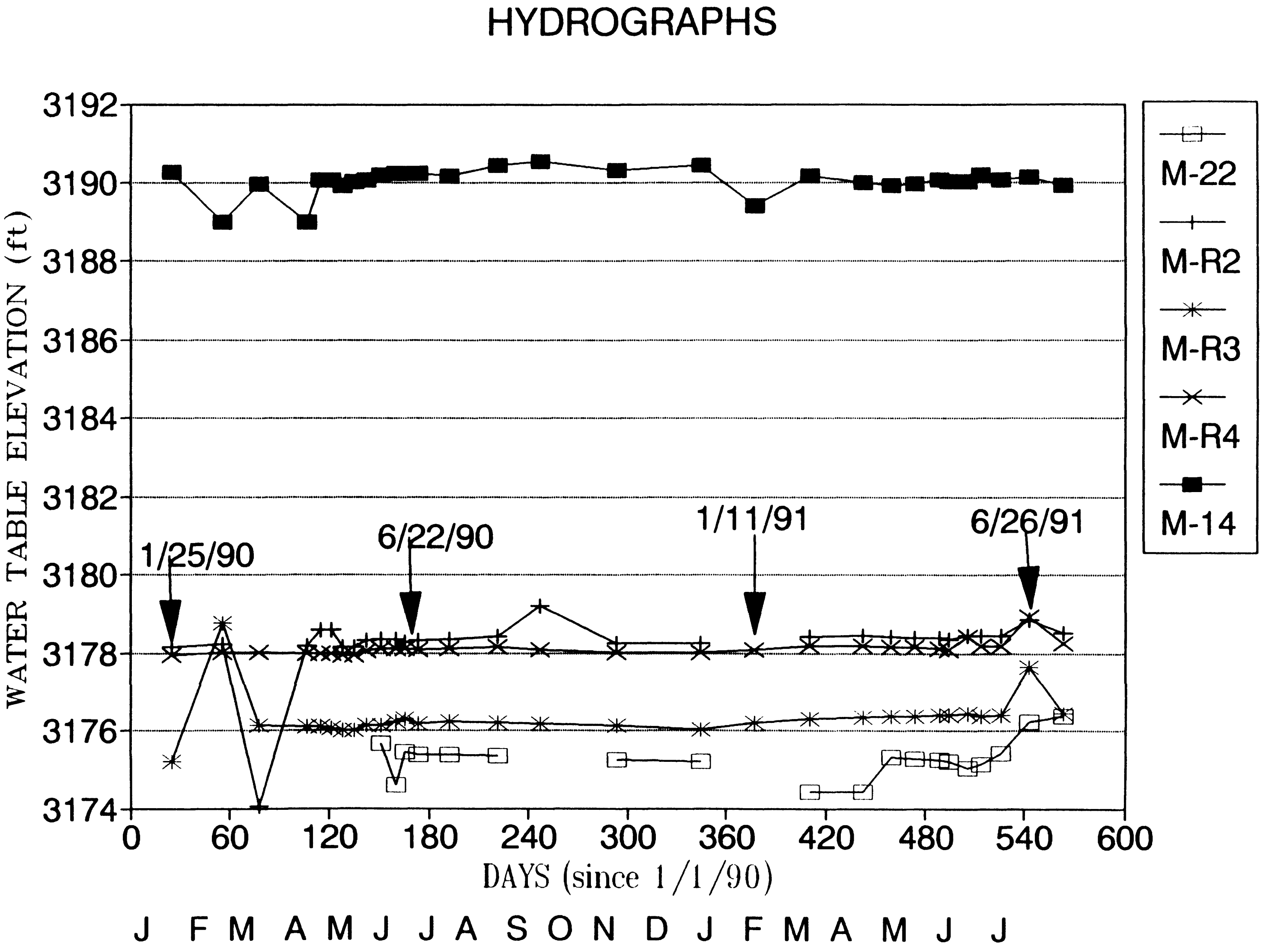

Figure 3.14: Perched well hydrographs

later date in 1991 than 1990, June 14 and June 26 respectively. The Clark Fork River 2.3 miles east of Missoula peaked on May 31 in 1990 and May 20 in 1991 (personnel communication, Mel White, U. S. G. S.).

Comparison of Figure 3.8 to Figure 3.9 shows the similarity between the hydrographs of M-27 and M-28 and those of west end regional wells. Peak high and low water levels occur at the same times. This evidence supports the idea that all these wells are completed in the regional aquifer. Figure 3.8 also shows that the small amount of data available suggests that M-9 is also completed in the same hydrostratigraphic unit as other regional wells.

Figure 3.10 shows that regional wells surrounding MR-1 had higher maximum and minimum water levels in 1991 than in 1990, except M-12. These wells are all in the zone of influence of MR-1. This is evident from the pumping test perfomed on MR-1 discussed below (M-12 was the least influenced by pumping in MR-1). Also, well responses appeared to be more erratic in 1991 than in 1990. This is due to the fact that the recovery system in MR-1 was not on-line during most of late 1990 and 1991 and was deployed intermittently for short periods during the spring of 1991. The lack of pumping in MR-1 was most likely responsible for higher peak levels observed in 1991, because little change was noticed in M-12. However, above normal precipitation in June of 1991 as well as higher Rattlesnake Creek levels may also be responsible.

M-29 was constructed in December of 1989. Figure 3.11 shows that M-29 had anomalously high levels for about the first six months of its operation. When M-29 was drilled it took hours for the well bore to fill up with water. When it did fill up, the static water level recorded on the drill log was approximately 3149 feet. One month later, in January, the water level recorded was approximately 19 feet higher. Water levels in M-29 remained high until a two week period in late June of 1990. During this period water levels in all other wells on site were rising, however water levels in M-29 dropped 17 feet. From September of 1990 until June of 1991 water levels in M-29 remained fairly static at about 3149.5 feet.

One possible explanation is the well's construction; M-29 was drilled through the aquitard, and the portion of the bore hole drilled through the fine-grained lens was grouted with bentonite to seal off the overlying perched water and product (Kennedy/Jenks/Chilton, 1989). If the bentonite was not completely hydrated initially, a significant amount of perched water may have been transmitted through the bore hole annulus, serving a source of recharge to the regional aquifer around M-29. This ground water would have eventually fully hydrated the bentonite, sealing off the perched water from the regional aquifer and allowed water levels to return to normal.

Another possible explanation is that M-29 is screened across the interface between an upper unconfined unit and a lower confined unit. When the well was first installed, fines may have clogged the portion of the well screen in the upper unit so that the well was only connected to the lower unit and static water levels reflected the potentiometric surface of the lower confined unit. Later, as the water table rose in the upper unit, if the fines were washed out, water would run out of the screen in the upper unit and the static water level would drop to that of the water table in the unconfined upper unit.

From July 1990 to July 1991, the hydrograph for M-29 bears some resemblance to that of M-13. It appears that the hydrograph for M-15 is very similar to those of regional wells on the west end of the study site except that its lowest 1991 level is higher than most of other west end regional wells. It may be that M-13 and M-29 are completed in a different hydrostratigraphic unit than M-15 and the other west end regional wells. This could also help explain why there is up to eight feet of difference in head between M-13 and M-15 during periods of low water. Another possible explanation is that there is a change in aquifer thickness between these wells. However, I attribute the difference to increase in hydraulic conductivity to the south and west of M-13 and M-29. All three wells have similar screened intervals (about 50 to 70 or 75 feet).

An interesting phenomenon takes place in M-15 and, to a lesser extent, in M-13 which cause data from at least M-15 to be less reliable during periods of low water; the interface probe gives intermittent readings (i.e. the signal sputters on and off) and wells produce a "bubbling" or "gurgling" sound. These bubbling noises and intermittent signals disappear during periods of peak water levels, only to reappear during periods of falling water levels. The cause of this is elusive. Possibly, water is pouring off a perched layer within the screened interval of these wells and it is this cascading that is heard. Support for this explanation is provided by the fact that when water levels rise high enough to cover this perched zone the noise would quit. Another possible explanation is that there may be a broken gas line or water pipe near by these wells and, the leakage is causing the noise.

Figures 3.12 and 3.13 show that over the period of the study, water levels in perched wells have remained fairly static, except for the period around June of 1991. This brief increase of up to a foot of head is due to infiltration from precipitation. June 1991 in Missoula was the wettest June in 22 years (The Missoulian, newspaper article).

Figure 3.13 also shows anomalous behavior in M-14. It is completed to a depth comparable to that of other regional wells, yet it has approximately 40 ft more head than regional wells. The well log for M-14 shows it was drilled to a depth of 80 feet with the interval from 50 to 70 feet screened. It also shows that there is a clay layer from 50 to 53 feet with cemented gravels from 53 to 80 feet. It seems most likely that this is a confined hydrostratigraphic unit. The anomalous chemistry of M-14 and the fact that water levels remain fairly static through time seem to indicate that it is not connected to the regional system.

Figures 3.14 through 3.20 depict the elevation contours for the potentiometric surface for the regional aquifer at different times during the study. Figure 3.18 shows how the water table looks without the recovery system pumping in MR-1. Figure 3.20 represents water table elevation on a larger scale. Ground water flow is generally to the southwest in the regional aquifer with a more westerly component under the west end of the B. N. site. This seems to indicate that recharge from either the bedrock aquifer and/or the Tertiary aquifer on Waterworks Hill is controlling the direction of flow in this portion of the regional aquifer. From Figure 3.20 we can also see that to the east of Rattlesnake Creek, flow is to the south east. This implies that Rattlesnake Creek is a hydrologic divide. So, Rattlesnake Creek may be an important source of recharge to the site but the Clark Fork River is probably less important, on the northern side of the site.

Figures 3.21 through 3.23 show that the direction of

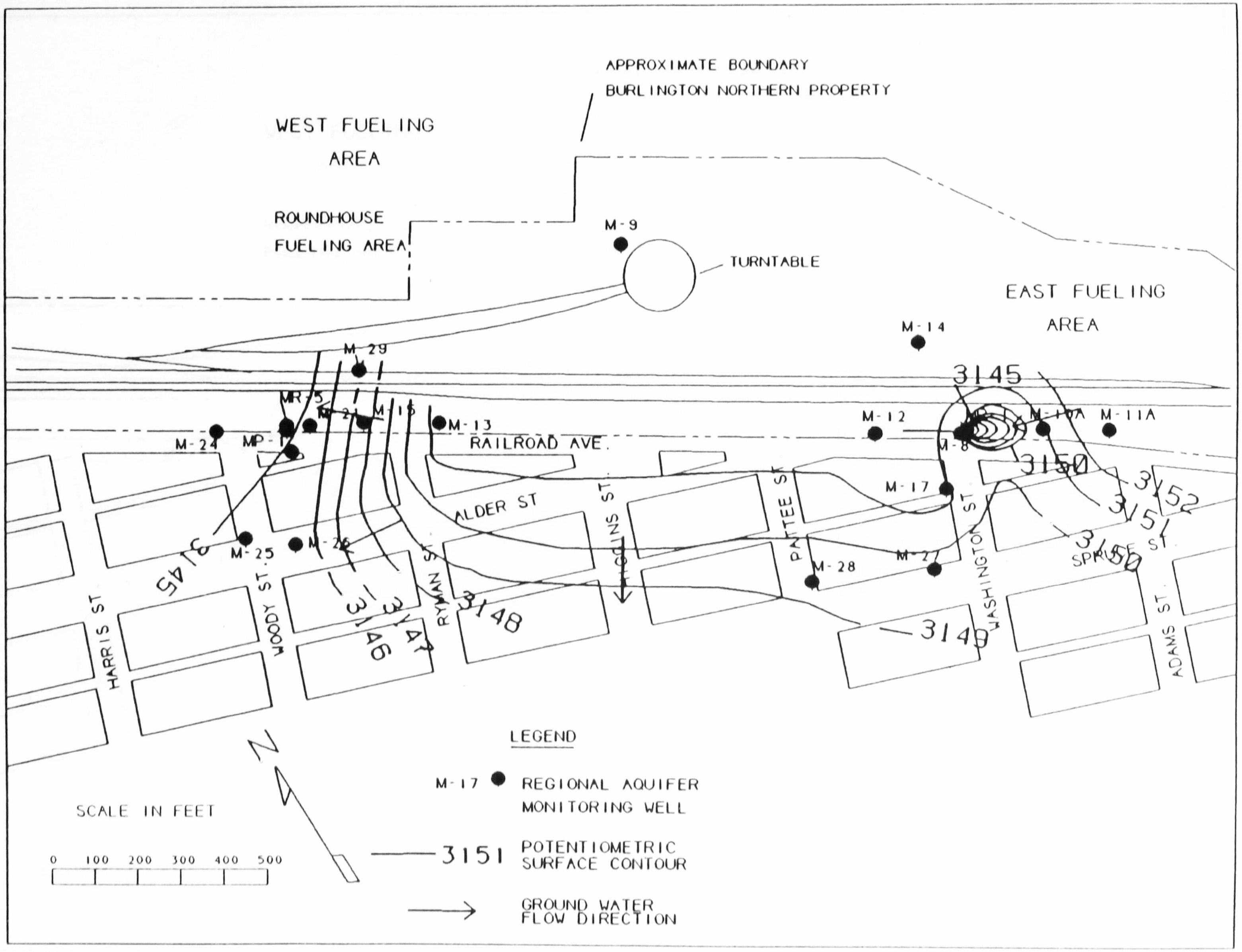

Figure 3.15: Regional aquifer potentiometric map for 5/1/90

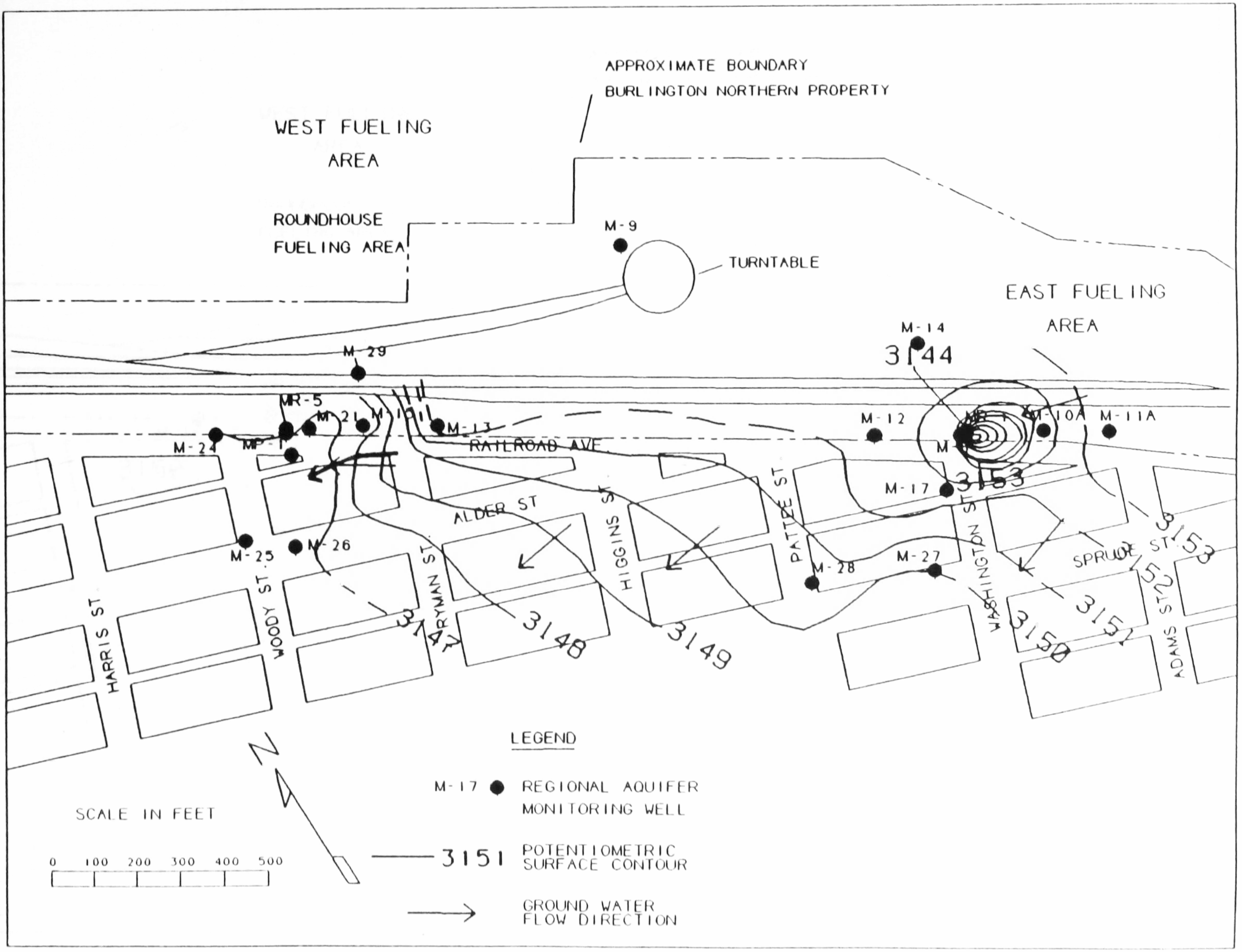

Figure 3.16: Regional aquifer potentiometric map for 5/22/90

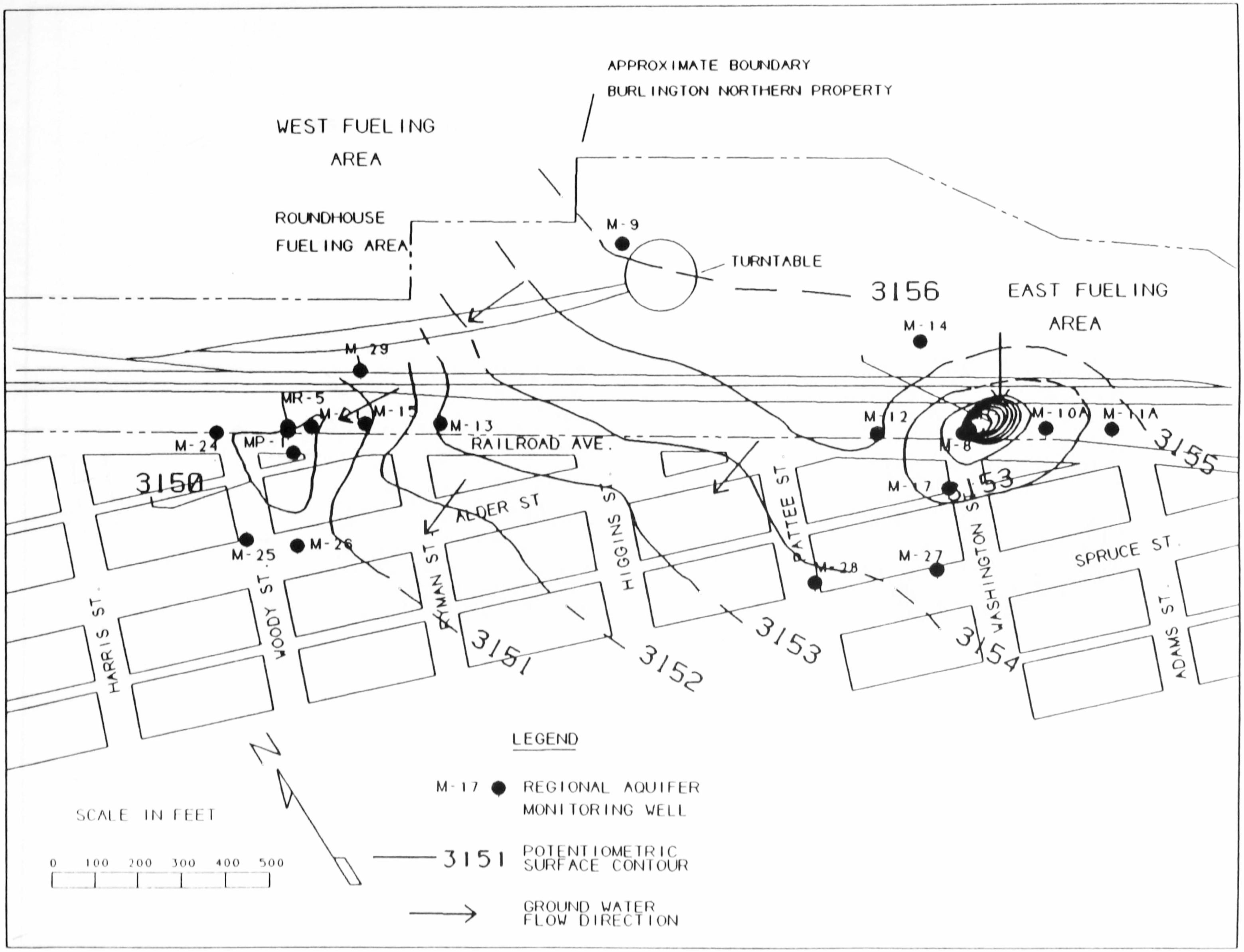

Figure 3.17: Regional aquifer potentiometric map for 6/21/90

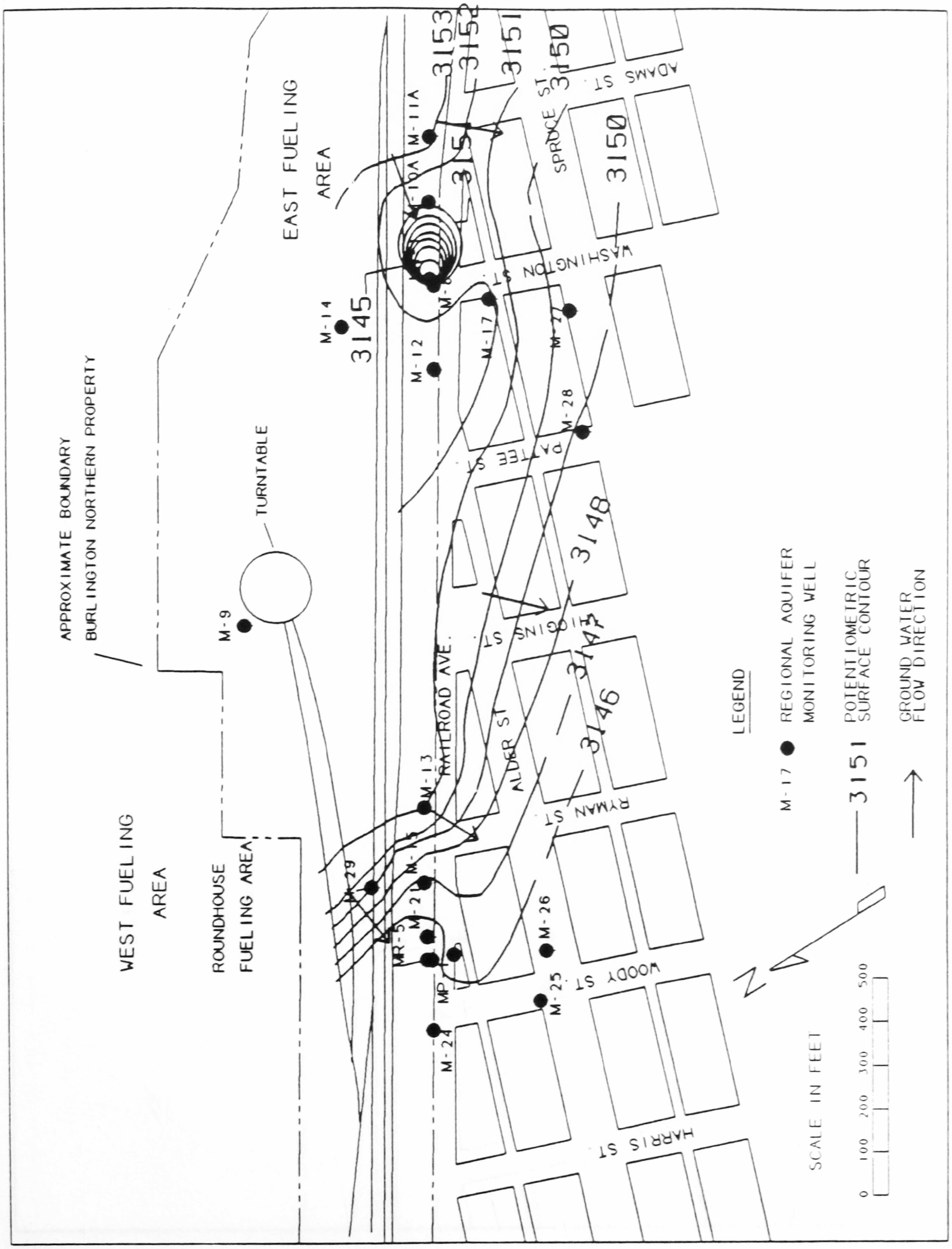

Figure 3.18 Regional aquifer potentiometric map for 9/3/90

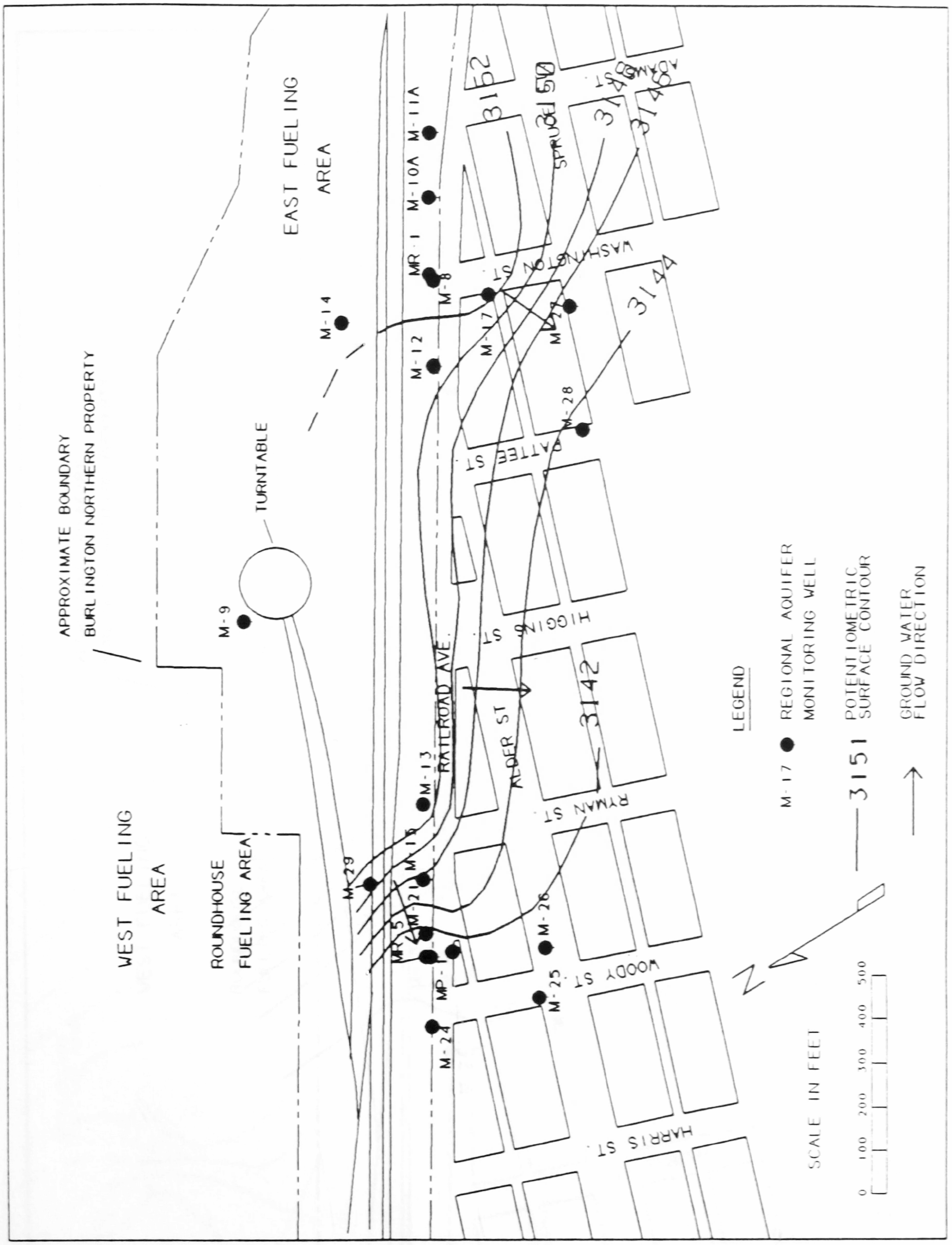

Figure 3.19 Regional aquifer potentiometric map for 12/10/90

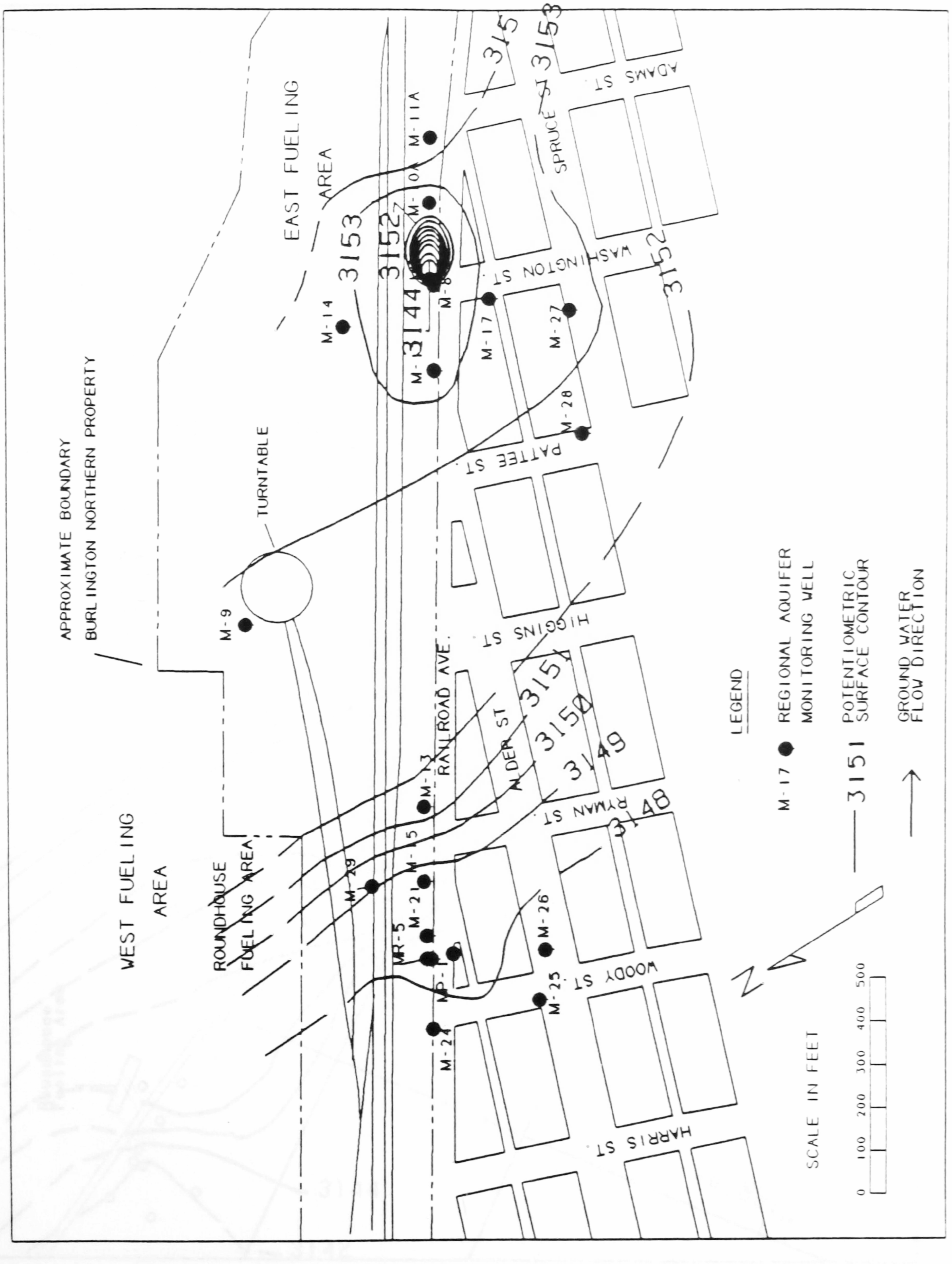

Figure 3.20 Regional aquifer potentiometric map for 5/28/91

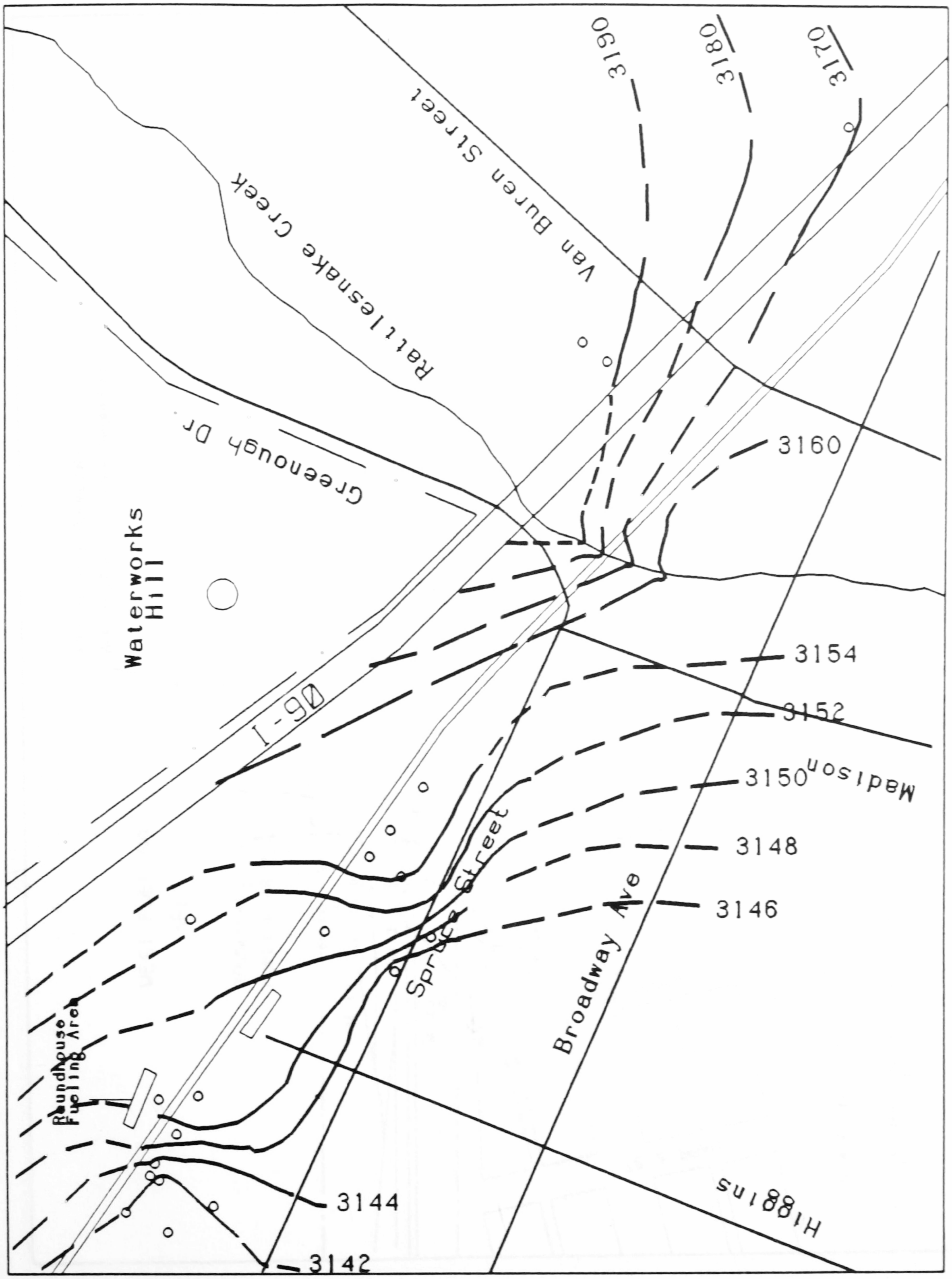

Figure 3.21 Large scale regional aquifer potentiometric map

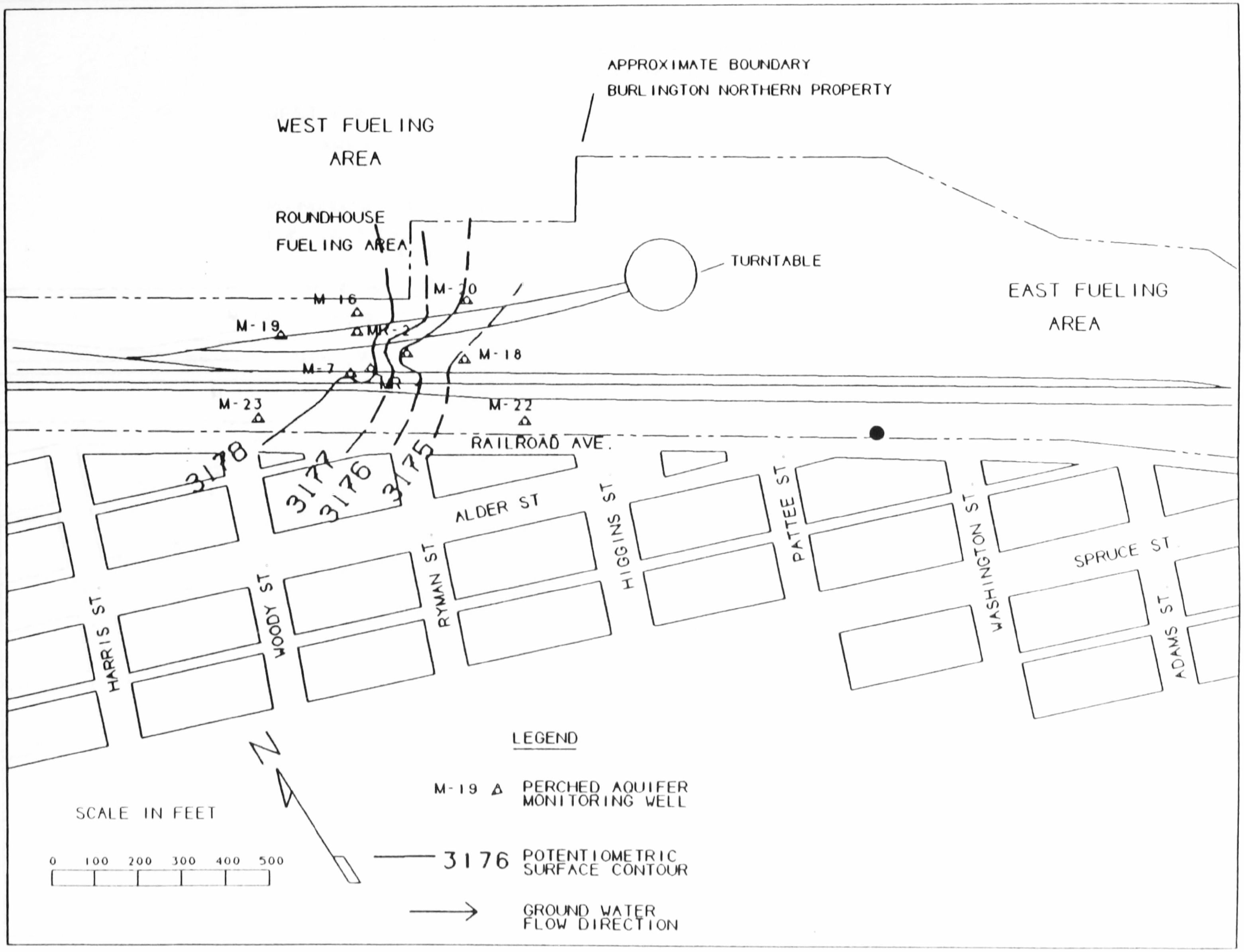

Figure 3.22 Perched aquifer potentiometric map for 3/19/90

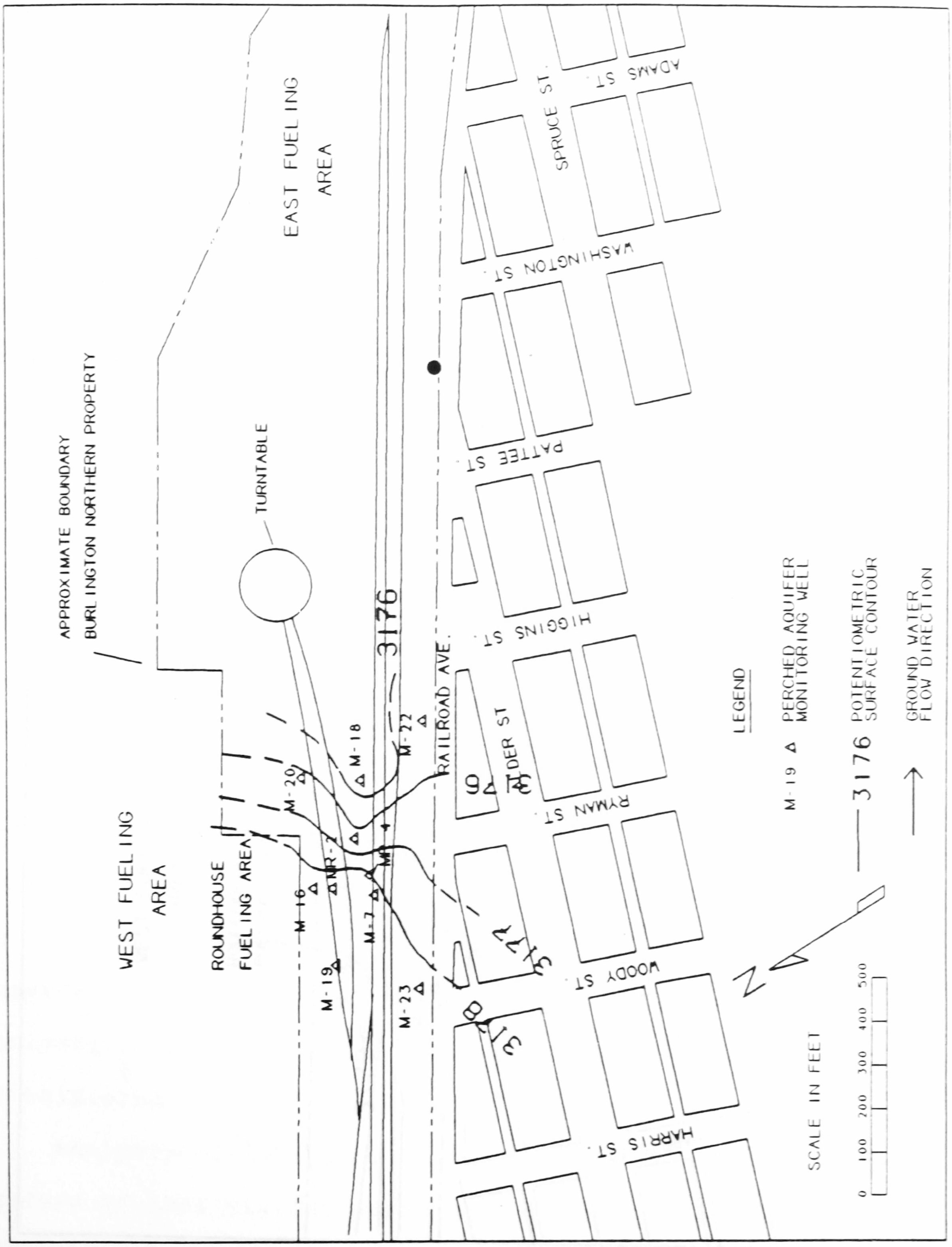

Figure 3.23 Perched aquifer potentiometric map for 10/20/90

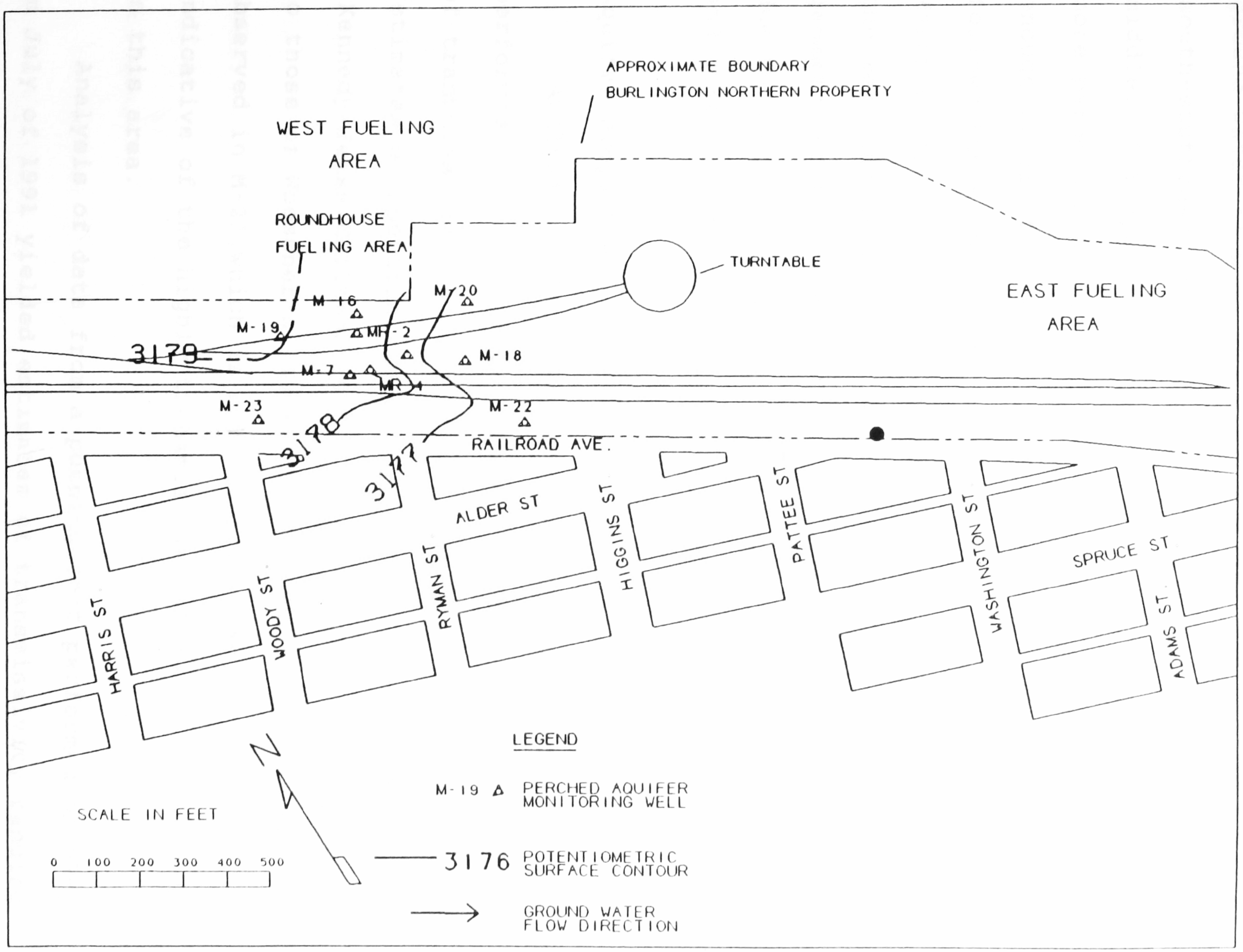

Figure 3.24 Perched aquifer potentiometric map for 6/26/91

ground water flow on the perched layer is generally to the south-southeast, with a recognizable trough running down the middle. Perhaps this trough is caused by leakage through a more permeable portion of the aquitard. There was not enough detail from well logs to know if flow direction follows the slope of the surface of the perched layer. In March of 1990, a seismic refraction survey was conducted on the west end of the site in an attempt to better define the geometry of the perched lens. This survey was unsuccessful due to excessive seismic noise from railroad yard operations and street traffic.

Aquifer Properties

Analysis of data from a constant rate pumping test performed on well MR-5 in October of 1990 yielded estimates of transmissivity ranging from 168,000 to 376,000 gpd/ft. Estimates of specific yield range from 0.04 to 0.22 (Kennedy/Jenks/Chilton, 1990). These values are comparable to those of Woessner's (1988) Unit 1. No drawdown was observed in M-21 which is only 50 feet away. This is indicative of the highly transmissive nature of the alluvium in this area.

Analysis of data from a pumping test performed on MR-1 in July of 1991 yielded estimates of transmissivity ranging from 7020 to 7300 gpd/ft. Estimates for storativity range from 0.070 to 0.0074 (see Appendix E). These values are comparable to Woessner's unit 2. During this test, measurable drawdown was observed in M-12 more than 200 feet away.

If the well logs (Appendix A) and cross-sections are examined (Figures 3.5 - 3.7), fine-grained sediments are noted within the screened interval of the bore holes for most wells within the cone of depression of MR-1. In contrast, gravels are noted within the screened interval of MR-5 and MP-1 (with the exception of a 2 foot thick lens of gravels with clay in MP-1). This would account for the two order of magnitude difference in transmissivity values for the two pumping tests.

Groundwater Discharge

Calculation of ground water flux leaving the site based on the the potentiometric map from December 10, 1990 (Figure 3.18) yielded estimates ranging from 2600 to 5600 acre-feet per year. These estimates of outflow are very similar to Miller's (1991) estimates for ground water discharge from the Rattlesnake and Grant Creek Valleys.

Water Quality

In general ground water within both the regional and perched aquifers is of a calcium bicarbonate type. usually, calcium and bicarbonate concentrations are some what higher and sulfate concentrations are slightly lower within the study site compared to the central Missoula Aquifer. Calcium concentrations vary from 23 to 91 mg/l; bicarbonate concentrations are fairly variable ranging from about 130 to 405 mg/l; sulfate concentrations vary from 5 to 25 mg/l (except for M-11). Silica (SiO_2) concentrations range from 3.56 to 20.26 mg/l. Higher calcium concentrations led to higher calcium to silica ratios as silica concentrations were comparable to those for the regional aquifer.

Stiff diagrams (Figure 3.24) for study site wells generally resemble those for the Missoula Aquifer. Stiff diagrams for M-11, M-12 and M-14 are anomalous. M-11 has elevated concentrations of sodium, magnesium, chloride and sulfate. M-12 has very high calcium, silica and bicarbonate concentrations. M-14 has elevated concentrations of sodium and reduced concentrations of calcium.

Ground water chemistry should to some extent reflect that of the source(s) of recharge to a system. It has been speculated that M-11, M-13, and M-14 and M-29 may be completed in different flow systems than wells completed in the regional aquifer (possibly Tertiary sediments). If some wells are completed in the Tertiary sediments, then the gross ionic chemistry of ground water from those wells should resemble that of other Tertiary wells rather than the Missoula Aquifer. Also, if Rattlesnake Creek is a significant source of recharge to the site, then the

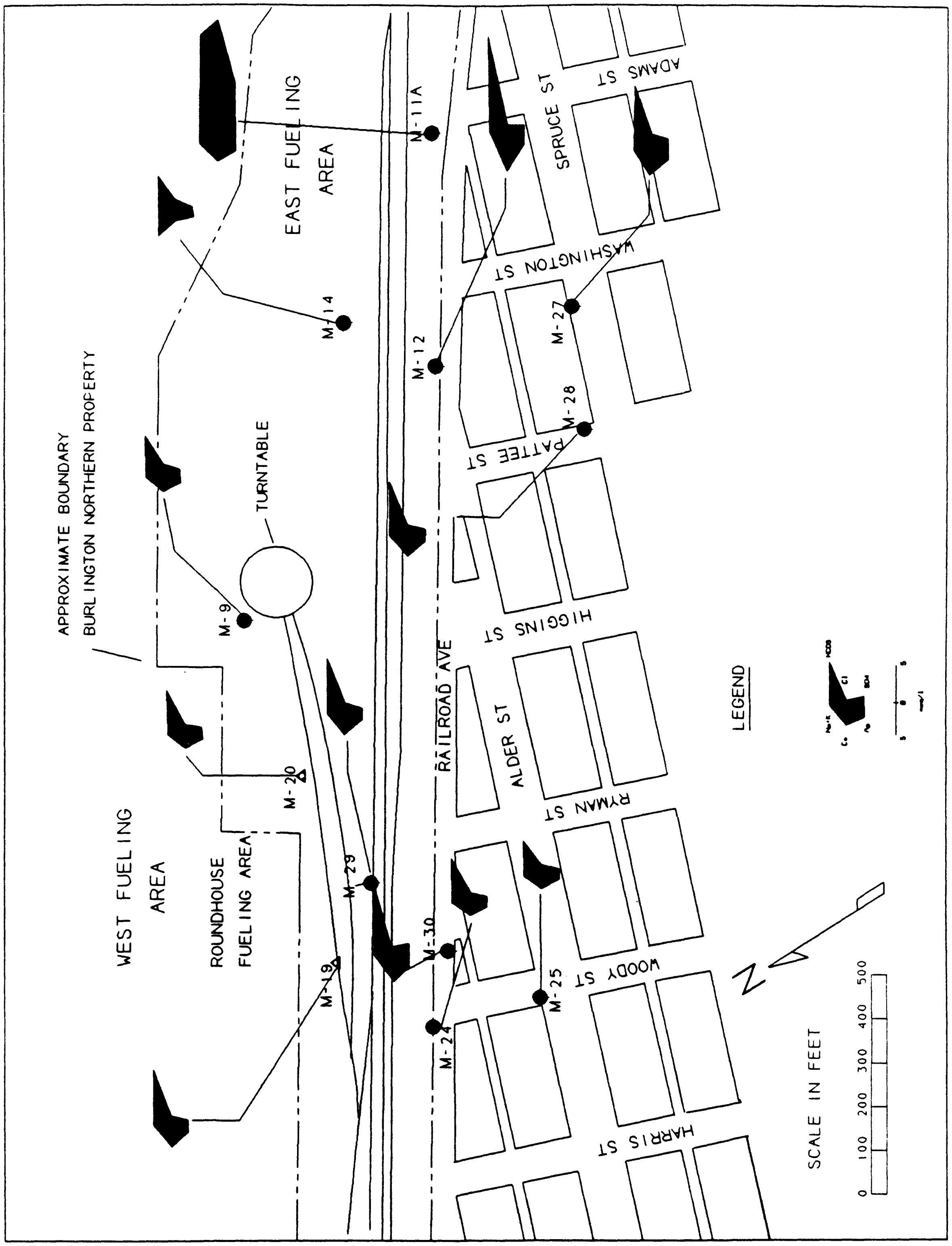

Figure 3.25 Stiff diagrams representing distribution of major ions

Table 3.4
Results of Chemical Analyses

Sample	**M-9**	**M-11**	**M-12**	**M-14**	**M-19**	**M-20**	**M-24**
pH	7.47	6.93	6.64	8.20	7.08	7.17	7.03
Ca	57.50	115.00	117.00	23.10	72.90	51.30	50.10
Fe	0.00	0.09	0.04	0.28	0.10	0.02	0.01
K	*	*	*	*	*	*	0.19
Mg	13.40	52.80	26.30	9.14	15.70	12.50	12.50
Na	4.14	41.80	5.15	41.30	5.26	3.79	4.52
P	0.07	0.22	0.14	0.08	0.09	0.05	0.08
SiO_2	12.02	12.28	22.89	7.62	12.54	11.87	9.71
Cl	5.91	26.31	6.70	2.13	7.40	4.93	6.55
NO_3	4.88	0.66	2.92	0.00	1.39	4.89	3.93
SO_4	21.68	251.10	5.25	30.17	14.30	15.82	16.60
HCO_3	194.01	371.25	404.50	156.19	231.85	170.83	174.7
Ca/SiO_2	4.46	9.37	5.11	3.03	5.82	4.32	5.16
	M-25	**M-26**	**M-27**	**M-28**	**M-29**	**M-30**	
Ph	7.17	6.89	7.27	6.75	6.87	7.12	
Ca	49.00	39.90	90.50	42.20	66.30	85.50	
Fe	0.01	0.04	0.40	0.15	8.17	0.04	
K	*	0.62	*	0.30	*	*	
Mg	13.30	11.40	27.80	12.70	13.80	7.10	
Na	4.50	4.59	11.30	4.00	4.36	5.36	
P	0.09	0.09	0.17	0.12	0.13	0.15	
SiO_2	11.35	9.01	11.00	8.79	20.26	15.3	
Cl	10.35	10.35	38.53	5.70	9.81	15.3	
NO_3	6.30	5.30	45.06	4.40	6.28	1.08	
SO_4	17.17	14.80	23.51	14.67	17.61	12.31	
HCO_3	141.24	129.65	253.19	133.61	229.40	259.29	
Ca/SiO_2	4.31	4.43	8.23	4.80	3.27	5.59	

* = Below limits of detection;

chemistry of at least some wells must resemble Rattlesnake Creek chemistry.

Silica (SiO_2) concentrations in the Clark Fork River and Rattlesnake Creek near the site are approximately 15 and 7 mg/l respectively (table 3.2). Rattlesnake Creek water silica concentrations are lower because it is "younger water", i.e. it has had less contact with siliceous rock and sediment and therefore, less time to dissolve silica.

Ground water from wells completed in Precambrian bedrock in the Missoula Valley has silica concentrations averaging 15 mg/l (table 3.3). Concentrations of silica in regional monitoring wells are generally between these values.

M-11 has the lowest silica concentration of regional wells at 5.74 mg/l. This is similar to Rattlesnake Creek silica concentrations. M-11 is the closest well to Rattlesnake Creek. This indicates that Rattlesnake Creek water is probably recharging the east end of the site.

M-29 has a silica concentration of 20.26 mg/l. It has the highest silica concentration of all wells sampled. M-29 was the only well with silica concentrations near those typical of other Tertiary ground water within the Missoula Valley. The average silica concentration of five Missoula Valley Tertiary wells is approximately 30 mg/l (Geldon, 1979).

M-29 is the only well with iron levels typical of

Tertiary sediments. M-30 is usually full of precipitated iron oxides. While purging the well for sample collection, purge water became very clear after five gallons was removed. Samples were collected after removal of 50 gallons. The last five gallons of ground water removed were allowed to sit in a bucket. After a short while, the water turned reddish-brown and became more so as more time passed. It was expected that this well would have high iron levels but it did not. In hindsight, metals samples should have been filtered with an in line system. Metals such as Iron II may begin to precipitate as Iron III hydroxide immediately upon contact with air due to oxidation.

Elevated chloride and sulfate concentrations in M-11 are difficult to explain. Perhaps these wells have been contaminated by some near surface source. It is also difficult to point to the exact cause of the anomalous stiff diagrams of M-11 and M-14; however, it could be that these wells are completed in the Tertiary due to their elevated sodium concentrations.

CONCLUSIONS

The aquifer materials underlying the B. N. fueling site are highly heterogeneous. It is difficult to determine the exact depositional environment. Perhaps sediments were laid down on an alluvial fan originating in the Rattlesnake

Valley.

Ground water flow is generally to the southwest in the regional aquifer at the B.N. site. From potentiometric maps, it appears that outflow from Waterworks Hill is probably a large source of recharge to the northern portion of the regional aquifer of the study site. This outflow is probably a combination of discharge from the bedrock and Tertiary aquifers as well as leakage from the reservoir. It would be difficult to estimate the quantity of this recharge. The quantities of recharge contributed by the fractured bedrock aquifer and by the Tertiary aquifer are unknown. Rattlesnake Creek is a hydrologic divide to the east of the study site. It is probably a smaller source of recharge. Ground water originating in the Clark Fork River probably flows through the southern portion of the B.N. site.

The aquitard underlying the site creates a perched aquifer under much of the west end. It is discontinuous elsewhere. Flow is generally to the south-southeast. The permeability of the aquitard appears to be highly variable. The aquitard protects the regional aquifer from infiltrating contaminants in some areas but not in others.

Ground water is generally of a calcium bicarbonate type. Silica concentration from M-11 is similar to that of Rattlesnake Creek. This supports the idea that Rattlesnake Creek is recharging the east end of the site. Silica concentrations in most regional wells is intermediate between those of the bedrock aquifer and the Clark Fork River and Rattlesnake Creek indicating a possible mixing of all three sources. Iron and silica concentrations from M-29 coupled with the well log indicate that its lower potion may be completed in the Tertiary aquifer; the water-level history of this well also supports this conclusion. The cause of anomalous chemical signatures in some wells is elusive. Monthly water sampling would give a clearer picture of the origin of groundwater in different wells.

CHAPTER 4: PROBLEM OF DIESEL FUEL CONTAMINATION

BACKGROUND

History of Diesel Fuel Use at the Missoula B.N. Site

Until World War II, steam locomotives passing through Missoula, Montana burned coal for fuel. With war came a great need for coal. Many locomotives were retro-fitted to burn bunker oil, which is similar to modern diesel fuel. With the invention of the diesel engine, steam locomotives were phased out and replaced by diesel locomotives.

The B.N. yards in Missoula at one time had three fueling areas: two on the main line tracks east and west of the depot, and one on the roundhouse tracks. Montana Rail Link (MRL) currently uses only the roundhouse fueling area. The east mainline fueling area is currently functional but is only used about once a month. The MRL dispenses approximately 2.6 million gallons of diesel fuel over a twelve month period (Kennedy/Jenks/Chilton, 1990).

Three zones of contamination exist (Kennedy/Jenks/Chilton, 1989). Each appears to be associated with a fueling area. One is on the perched aquifer beneath the Roundhouse fueling area, and two are on the regional aquifer associated roughly beneath the west mainline fueling area and the east mainline fueling area

These fueling areas, until recently, were serviced by two 25,000-gallon underground tanks located south of the roundhouse fueling tracks. In 1990 these tanks were removed and replaced by one above ground tank. During excavation of the western tank, much diesel stained soil was observed and the staining appeared to be of recent origin. Fiberglass track pans were installed at both fueling areas in about 1980 (Kennedy/Jenks/Chilton, 1989) in order to catch fuel spilled during normal locomotive fueling operations. These track pans drain to an oil/water separator.

The west main line fueling area was used to fuel Amtrak trains in the past but is now abandoned.

Local residents working for the railroad during the early diesel era remember cold winter nights when fuel hoses fell out while the crew was inside warming up. Fuel might run on the ground for several minutes. Until the early 1970's, diesel fuel was relatively cheap and fuel was not inventoried. It is difficult to estimate how much diesel fuel may have been spilled at the Missoula site over the last forty years.

Behavior of Diesel Fuel in Aquifer Material

The bulk of research concerning liquid hydrocarbon spills on land has dealt with either gasoline or crude oil. Few studies concerning the unique behavior of diesel fuel have been published (Burns, 1987; Dineen, 1990; Drangun, 1990; Hockensmith, 1990; Wang and others, 1990).

The behavior of LNAPLs in aquifers is a complex subject. Chapter 2 should be referred to for a detailed discussion of this topic. Two pertinent points from Chapter 2 should be recalled at this point:

1. Diesel cannot flow at saturations below 20 % in the saturated zone but may flow at saturations down to as low as 3 to 4 % in the unsaturated zone (Dracos, 1987).

2. Water table fluctuations greatly influence the spread of diesel fuel throughout an aquifer. The more water levels fluctuate seasonally or due to pumping, the greater the volume of diesel fuel which is held at residual saturation.

Kia and Abdul (1990) studied the retention of diesel fuel in aquifer material in a laboratory setting. They found that the level of residual saturation was highly variable in different types of soils. Retention varied with porosity. Retention was also found to be influenced by particle size and generally decreased with increasing particle size. The extent of the effect of particle size on the retention, however, was dependent on porosity, and therefore on the packing structure. The residual saturation of diesel fuel in aquifer material was found to be much greater than the residual saturation of water under similar packing conditions. The authors conclude that accurate estimates of residual retention under field conditions can only be obtained when laboratory measurements are carried out on undisturbed soil samples from the site in question.

Research on the environmental fate of fuels suggest that fuel weathering is a complex process involving three major processes: evaporation, dissolution and biodegradation. Burns (1987) compared the chemical compositions of fresh diesel fuel samples to weathered diesel fuel samples collected from various spill sites. He determined the relative effect of evaporation, dissolution and biodegradation on diesel fuel. All recovered samples showed evidence of weathering. The weathered samples showed an average loss of 75% of their straight chain (normal or n) alkane components. Because normal alkanes are relatively easily degraded by microorganisms, this suggests that considerable biodegradation took place. Burns found biodegradation to be the most significant natural weathering mechanism for these diesel fuel samples.

Monitoring Wells And Apparent Product Thickness

It is often assumed in estimating the volume of spilled hydrocarbons in the subsurface that there is a linear relationship between the apparent product thickness (APT) measured in a monitoring well and its actual thickness in the formation. This relationship is derived by assuming that the well and formation are in equilibrium, i.e., net flow of liquids between the well and the formation is zero. It is also assumed that the vertical component of flow is negligible. Using these two assumptions, one can then utilize the tension-saturation relationship for the formation to estimate the vertical hydrocarbon saturation distribution. This can be done for both the imbibation and drainage conditions. However, the field data quite frequently show hydrocarbon thickness changes that are not related to either withdrawal or release of hydrocarbons (Kemblowski and Chiang, 1990, and Abdul and others, 1989).

Lenhard and Parker (1990) studied fluctuating water levels and APTs in a low permeability aquifer and static subsurface hydrocarbon volumes. Their research showed generally, an inverse relationship between water table height and APT, i.e. as water levels rose APTs decreased. As was discussed in Chapter 2, there is a different residual saturation for hydrocarbons above and below the hydrocarbon-water interface. This fact and the idea that the well-bore acts as a higher permeability conduit were used to explain the inverse relationship between APTs and water levels (which is common at many sites).

Abdul and others (1989) performed theoretical analysis and laboratory column experiments to investigate the conditions required for hydrocarbons to flow into a well installed through a sandy aquifer material. Results indicated that hydrocarbons would only flow into a well after a layer of free product is formed in the adjacent porous medium. They conclude that although monitoring wells may be useful in delineating the extent of the free product plume and the plume of dissolved hydrocarbon constituents, they are not useful for delineating the extent of capillary-held hydrocarbon. However, residual hydrocarbons are often detected during the drilling process by smell or the appearance of stained soils.

Lenhard and Parker (1990) derive intricate equations for use in the estimation of hydrocarbon volume per surface area from APTs, but they require knowledge of many parameters that may be difficult to obtain.

Kemblowski and Chiang (1990), Abdul and others (1989), and Lenhard and Parker (1990) all conclude that no simple conversion scheme can be employed to relate the height of LNAPL in a monitoring well to a LNAPL volume in a porous media.

METHODS

During water level monitoring events, depth to water and depth to diesel fuel measurements were made in contaminated wells using an interface probe. Graphs of APTs over time for contaminated wells were generated. These graphs were analyzed to help assess any spatial and temporal variability within the zone of contamination.

A product recovery system was operating in well MR-1 (near the east mainline fueling area) during most of 1990. A graph of the quantity of fuel recovered over time was made to help assess the temporal variability of the free product plume in the vicinity of MR-1.

RESULTS AND DISCUSSION

Figures 4.1 - 4.3 show the change in APTs with time in contaminated regional and perched wells. In regional wells, as would be expected from the discussion above, APTs generally decrease during periods of rising water levels and increase during periods of falling water levels (compare to hydrographs in Chapter 3). Changes in APTs are most likely due to rising and falling water tables and do not necessarily reflect changes in the amount of hydrocarbon in the subsurface. However, sudden increases in APT during times of static water levels may signal new contamination events. In perched wells (Figures 4.2 and 4.3), APTs are fairly static except for M-23 and MR-3. Because water levels are fairly constant (see Figures 3.12 and 3.13) diesel fuel mobility is constant and APTs do not vary much.

In the spring of 1990, product recovery in MR-1 increased significantly as ground water levels rose in association with spring runoff (Figure 4.4). This would

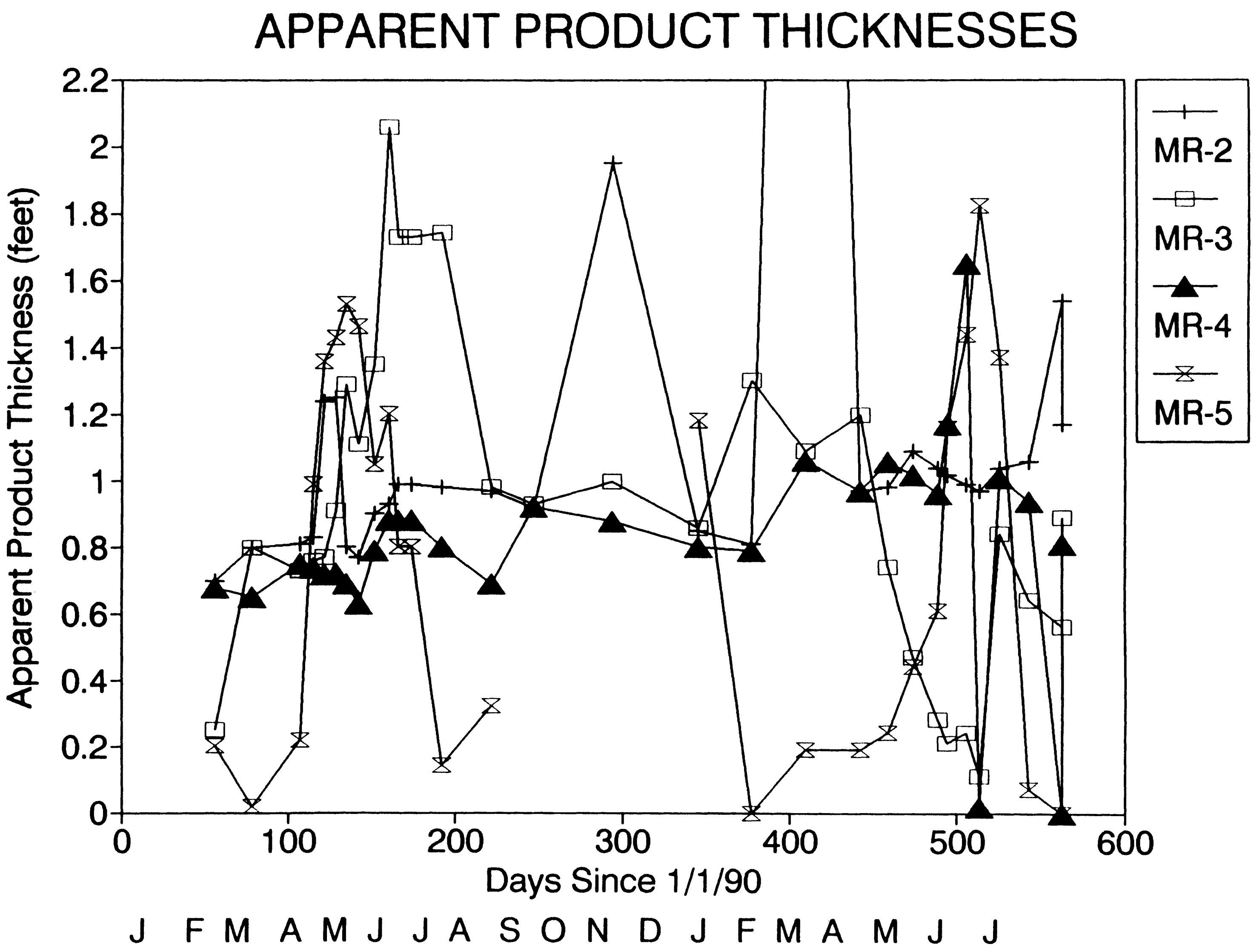

Figure 4.1: Apparent product thicknesses

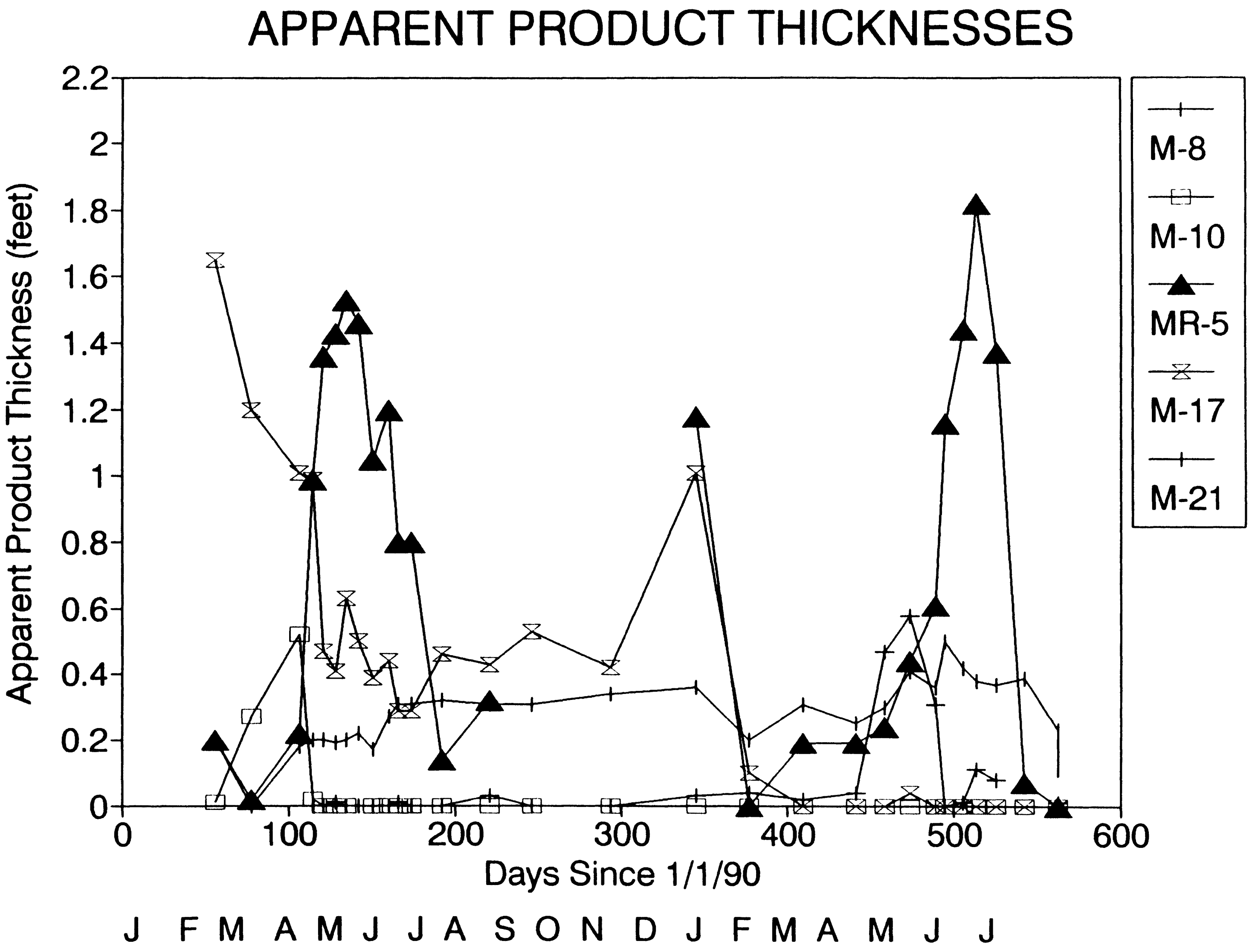

Figure 4.2: Apparent product thicknesses

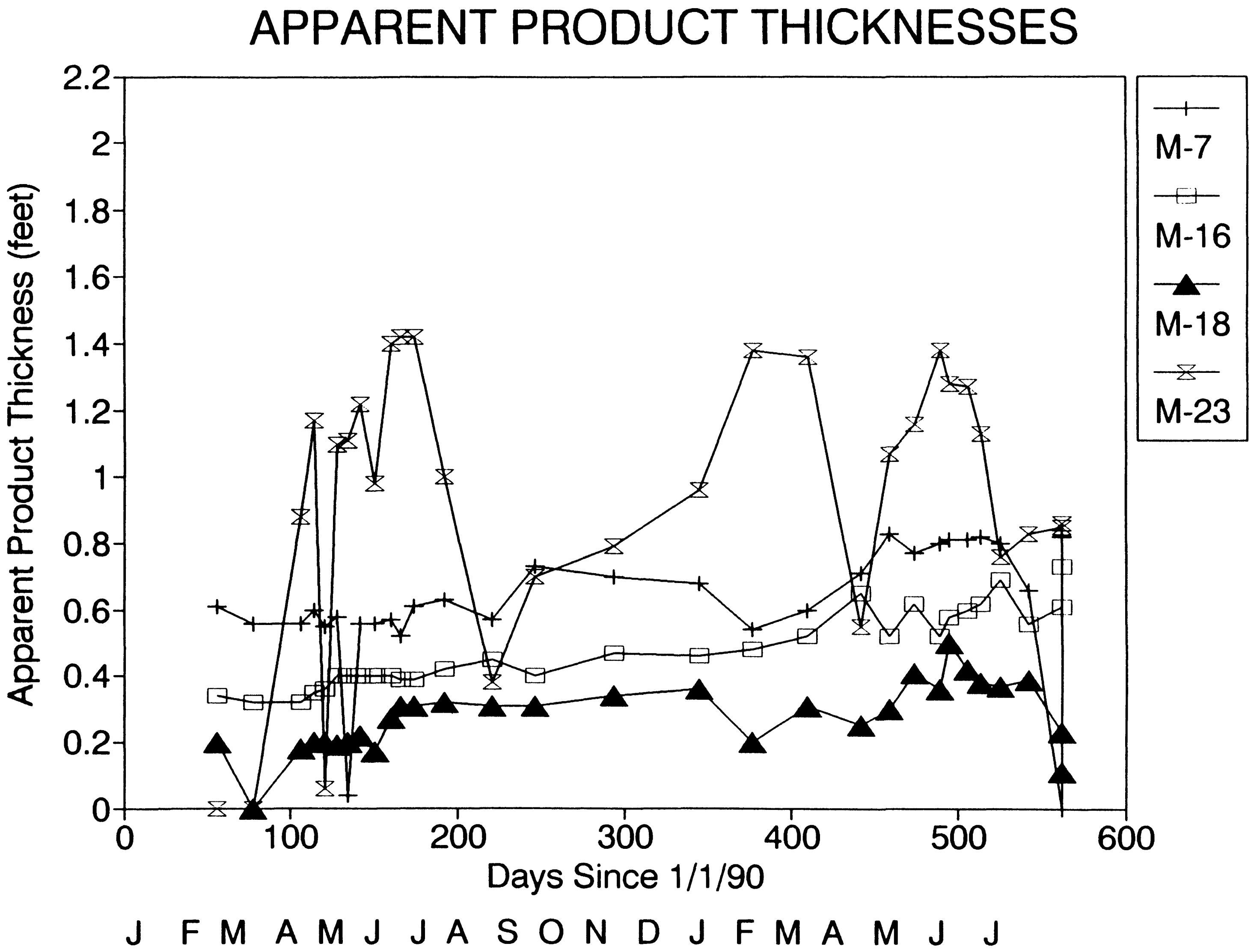

Figure 4.3: Apparent product thicknesses

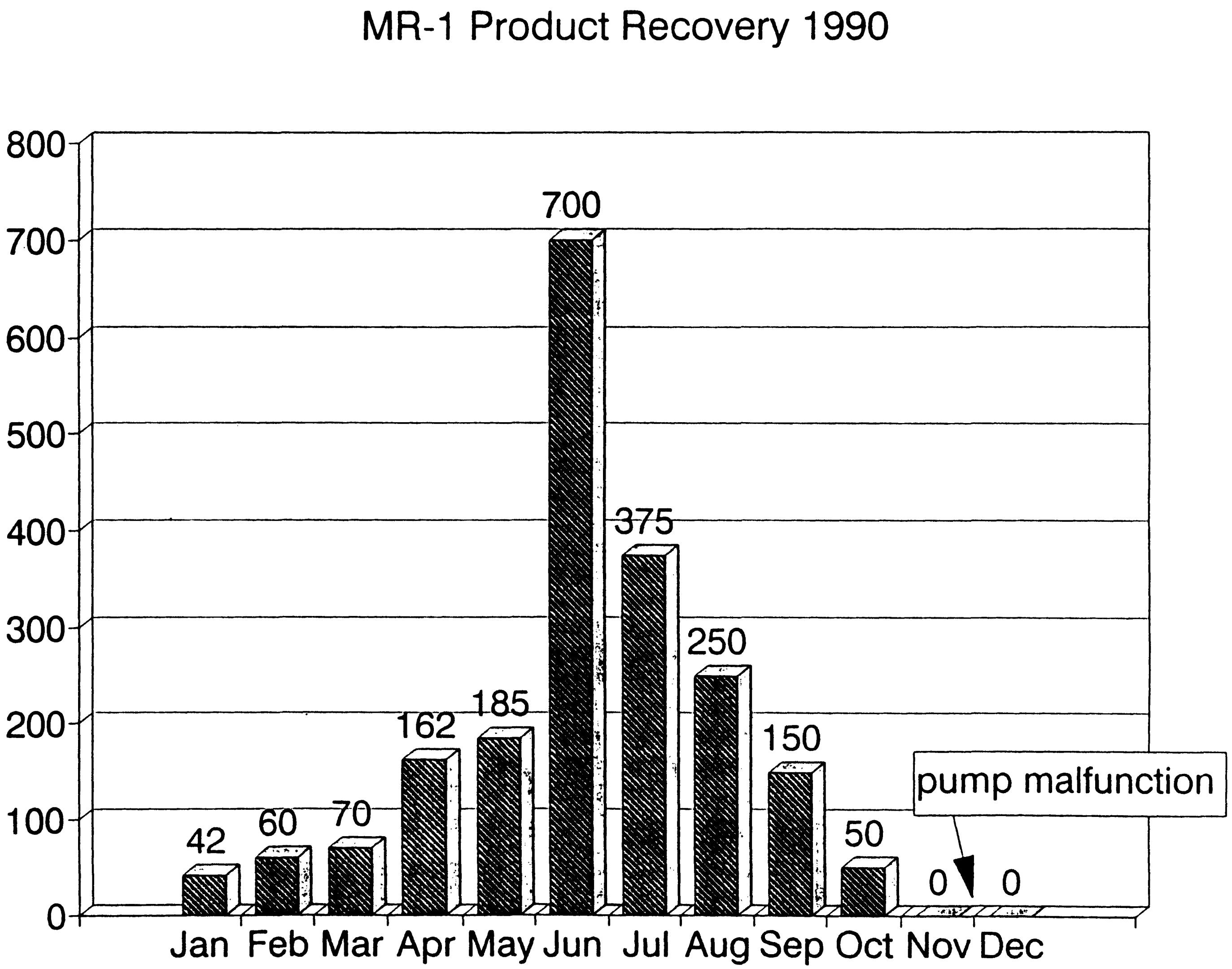

Figure 4.4: Diesel fuel recovery in MR-1 over time.

seem to run counter to the Dracos' arguments (see Chapter 2) concerning the behavior of LNAPLs in the presence of rising water levels. However, according to Shepard's discussion quoted in Chapter 2, if there was a large enough change in hydraulic pressure as the water table rose it could force immobile product out of pore spaces and re-mobilize it. A change in hydraulic pressure may have been provided by a steeper and slightly deeper cone of depression caused by a higher pumping rate in MR-1 during this period. No product was recovered in November and December of 1990 due to a malfunction in the recovery system.

A similar increase in product recovery was not observed in MR-1 during spring runoff of 1991. Very little product was recovered during this period. This could imply that all recoverable product had already been removed. Or, perhaps, with less product remaining in the pore spaces, too great a hydraulic pressure was required to displace the immobile product. However, there were many problems with the recovery system during this period. The system was taken off line when no recovery took place. By late June 1991, the water table surrounding MR-1 had recovered, and a cone of depression no longer existed. Only 0.01 foot of product was measured in MR-1. As the water table dropped, the APT increased to approximately 0.4 feet by September. Most likely product held at insular residual saturation was probably remobilized (see Chapter 2). No more product has been recovered from MR-1 to date due to continuing problems with the recovery system.

It is possible contamination events are still presently occurring. The Roundhouse fueling area is still in use. The tracks beneath the fueling area are equipped with fiberglass track pans, but they have never been tested for leakage.

Water and product level monitoring in November of 1991 revealed that M-29 contained over one foot of free product. Free product was removed from the well with a bailer. Free product recovered over a short period of time to about 0.5 feet of APT.

Up until that point, M-29 had been free of contamination (M-29 was completed in late 1989). These facts suggested possible recent spillage of fuels at or near the surface. It is important to note that M-29 is the only well which penetrates the perched aquifer. When it was completed, it was grouted through the aquitard with bentonite to prevent the advancement of contamination from the perched zone to the regional aquitard. Never the less, it is possible that the bore hole functions as a conduit through which the diesel fuel flowed. It seems unlikely it would take two years for this to occur. However, recall that the layer of mobile diesel fuel sits above the water table. Perhaps the water table prevented free product (due to immiscibility) from flowing down the borehole. If this area of the perched zone became dewatered and there were leaks in the grout, diesel fuel could at that time trickle down the sides of the well pipe.

In an attempt to determine whether the appearance of fuel in M-29 was the result of recent spillage, fuel samples were collected from M-29, M-23 and MR-5. A sample of fresh fuel was collected from Montana Rail Link's pump nozzle at the Roundhouse Fueling area as well. Kennedy/Jenks/Chilton had gas chromatogram (GC) analysis of the fuel samples performed. GC data for the sample from M-29 were compared to the weathered fuel samples and the fresh fuel sample according to the method of Burns (1987). Unfortunately, results were inconclusive. Kennedy/Jenks/Chilton had gas chromatogram (GC) analysis of the fuel samples performed. GC data for the sample from M-29 were compared to the weathered fuel samples and the fresh fuel sample according to the method of Burns (1987). Unfortunately, results were inconclusive.

CONCLUSIONS

Eventually, free product recovery systems will no longer be able to recover diesel fuel at the B. N. site. At that time there will still be a large quantity of product held in the ground by capillary forces. Only natural or enhanced biodegradation or flushing of the subsurface with surfactants will further reduce the quantity of diesel fuel. Also, with the contaminated area already containing diesel fuel at residual saturation, any future spillage will rapidly translate into more free product.

Past attempts to recover product in MR-5 have employed the use of a water table depression pump with a skimming system. The transmissivity of the regional aquifer is fairly high in the vicinity of MR-5. Pumping in MR-5 at 40 gpm produces a very small cone of depression. Recovery of free product in MR-5 using a single drawdown pump is unlikely to be successful.

The gradient of the potentiometric surface above the aquifer is to the east southeast. From well logs it appears that the aquitard is at best discontinuous. Flow of free product is generally in the direction of the hydraulic gradient. If enough fuel was spilled on the perched water table, it would continue to flow toward the eastern edge of the aquitard, spilling off the edge of the aquitard into the regional aquifer. There are no perched aquifer monitoring wells east of M-18 and no regional aquifer wells between M-13 and M-12. It is therefore quite possible there is another concentration of free product on the regional water table between M-13 and M-12.

Changes in APT in monitoring wells do not necessarily reflect actual changes in the amount of free product at the

B. N. site. Removing the free product from monitoring wells with a bailer and then allowing the free product to recover would more accurately reflect temporal changes in the thickness of fuel in the formation.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

A conceptual model of the physical system was developed. The aquifer consists of sand and gravel similar to Woessner's (1988) Unit 1. Further there is a fine grained layer above the water table at the west end of the site which is continuous enough to serve as an aquitard.

It was found that:

A. The aquitard extends to the base of Waterworks Hill;
B. Hydrostratigraphic units other than the regional aquifer are present;
C. Recharge to the regional system comes from a variety of sources;
D. Aquifer characteristics change from the north and east to the south and west;
E. The hydraulic gradient on the perched aquifer is roughly to the southwest. Spilled fuel reaching the aquitard will flow in this direction;

This study determined that without additional spillage the shape of the contaminant plumes is fairly static but is influenced by fluctuating water levels. The mobility of fuel is highly variable in the area south and west of MR-5 due to greatly fluctuating seasonal levels.

If the study site is ever to be remediated, all present and future sources of contamination must be eliminated. A short walk around the Roundhouse fueling area reveals numerous centers of soil with recent diesel fuel staining, especially immediately next to the track pans. As long as there is active locomotive refueling, the potential for additional contamination of the subsurface exists.

This investigation has shown that the hydrogeology of the Burlington Northern Former Fueling site is extremely complex. Lack of understanding of heterogeneities within the subsurface hinders effective remediation of the site.

Monthly monitoring of water and product depths should be continued. This will show long term trends in the flow regime of the area. Monitoring of apparent product thickness should be done after all free product has been bailed from monitoring wells and wells have been allowed to recover until APTs stop increasing.

Additional monitoring wells should be installed. One or more wells completed in the regional aquifer between the southeastern and northwestern well clusters and at least two wells completed between Waterworks Hill and the B.N. property boundary are needed. Such wells would greatly add to the knowledge of the flow system by filling in stratigraphic blanks in the geologic model as wells as giving better coverage of the area on potentiometric maps.

Before selecting a method to remediate the perched aquifer, a series of aquifer tests should be conducted to determine the transmissivity soils above the aquitard.

Leakage tests should be performed on all track pans and underground pipe lines to ensure that no new spillage is taking place.

Once all recoverable free product is removed, addition of nutrients such as nitrogen and phosphorous should might be added to the east end of the site to enhance natural bioremediation. Down gradient wells would have to be installed to capture nutrient plumes to keep them from contaminating the Missoula Aquifer. Such a technique would be unsuccessful due to the highly transmissive nature of the aquifer in that area.

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APPENDIX A: WELL LOGS

Project D 946 **Site** Missoula **BORING** M-7 **Sh 1 of** 1

Date Started 1/17/86 **Completed** 1/17/86 **Ground Elevation** _____

Total Depth 38 ft. **Location** S. of Fuel Tanks **Logged by** M.W. Zuber

Casing I.D. 2" **Contractor** Jerome's Drilling

Remarks Air Rotary w/ 6" Drive Casing

Screen set 28.0 – 38.0 ft.

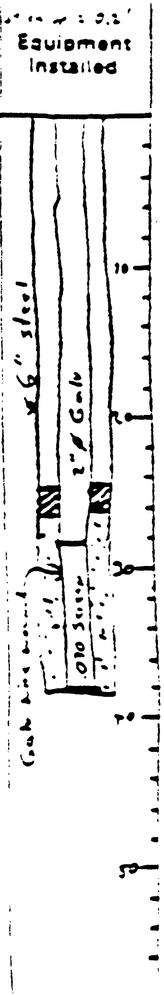
Elev. Feet	Depth Feet	Sample Type & Number	Sample Blows per 6 in.	Sample Depth Range	Sample Rec.	Graphic Log	Sample Description	Equipment Installed
							0-2 ft dk Brn-black silty medium GRAVEL, GM, moist, w/ dk oily stains	
	10						2-25 ft. Brown sandy medium GRAVEL, GW, dry, no evidence of contamination.	
	20						25-33 ft. GRAVEL, GW, as above with fuel odor, moist.	
							33-38 Tan CLAY, CL, wet, with high toughness & dry strength.	
	30							
	40							
	50							
	60							

water produced at ~32 ft. Fuel odor but not free product.

10
21
75
38.5

SWL = 30.2' G.S.
4/12/86

1/16 830 am 29.9
no fuel or oil on water table



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Project D 946 Site Missoula **BORING** M-8 Sh 1 of 1

Date Started 1/18/86 Completed 1/12/86 Ground Elevation

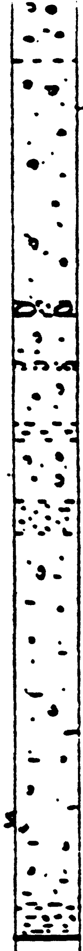
Total Depth 62 ft Location S of E. Mainline Siding Logged by M.W. Zoe

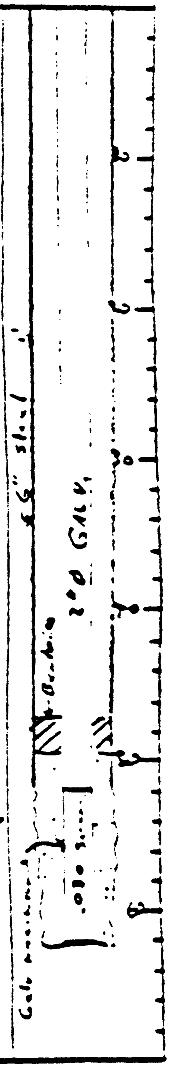
Casing I.D. 2" Galvanized Contractor Jerome's Drilling

Remarks Air Rotary w/ Driven 6" Casing

2" Ø .030 Screen set 52-62 ft.

Elev. Feet	Depth Feet	Sample Type & Number	Blows per 6 in.	Depth Range	Rec.	Graphic Log	Sample Description	Stick-up 1.8' Equipment Installed
							0-4 ft Dk brn sandy GRAVEL GW, w/ coal fines & asphalt, moist.	
	10						4-62 ft Md Brown sandy GRAVEL GW, to 1"+ size, dry.	
	20						20-21 ft w/ boulders 24-24.2 ft layer of brn fine uniform SAND, SP, moist. 28-29, Red Brn, SILT, ML, moist with slight fuel odor.	
	30						33-35 Brown fine uniform SAND SP, moist, w/ slight fuel odor.	
	40						35-62 increasing sand and silt content. 55-60 w/ fuel odor	
	50						60 ft. water produced. 60-62 w/ some red-brn silty clay in cuttings. TD = 62 Ft.	
WL		1:00 SWL = 57 Ft GS						
	60							
		2:30 SWL = 58.13' TOC no free product, slight oil sheen						





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Project D 946 Site Missoula **BORING** M-2 Sh 1 of 2

Date Started 1/16/86 Completed 1/17/86 Ground Elevation

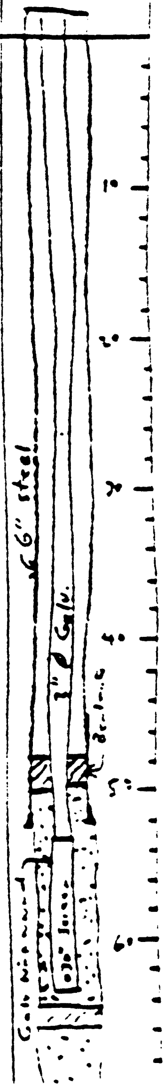
Total Depth Location N. of Twin Tank Logged by M W Zuber

Casing I.D. 2" Contractor Jerome Well Drilling

Remarks Air Rotary Drilled, driving 6" steel casing.

Drilltech D40K Rig

2" Ø Galv. .030 Screen set 53-63 ft.

Elev. Feet	Depth Feet	Sample: Type & Number	Sample: Blows per 6 In.	Sample: Depth Range	Sample: Rec.	Graphic Log	Sample Description	Equipment Installed
9:10 AM 1/17	10 20 30 40 50 60 70						0-5 ft. fine-medium GRAVEL, GW, dry. Composed of quartzite and varicolored metamorphic rock, up to ~1.5 inches. 0-2 ft with asphalt. 7-9 ft red-brown medium SAND, SW, moist, silty and gravelly. 16-18 Interbedded with red-brown silty sand, moist. 29-44 becomes moist, gravel cuttings mixed with brn, moist, silty sand. Gravel grading finer, more sandy. 44-49 larger gravel, rig chatter, fresh rock cuttings. 49-54 Gravel is interbedded with md red-brown, silty SAND, SM, moist	Stick up = 2.3 ft 

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Project D 946 Site Missoula **BORING** M-9 Sh 2 of 2
Date Started ______ Completed ______ Ground Elevation ______
Total Depth ______ Location ______ Logged by ______
Casing I.D. ______ Contractor ______
Remarks ______

Elev. Feet	Depth Feet	Sample: Type & Number	Sample: Blows per 6 in.	Sample: Depth Range	Sample: Rec.	Graphic Log	Sample Description	Equipment Installed
	70						54-67 Md brn, clayey silt, ML, Moist-wet, very little sand and gravel, med. plasticity	
	80						67-80 Md brn silty clayey Gravel, GM	
		24 21 21 10 73 -8 65 (2" casing & screen) -2 63						

1:30 1st wl Reached.
2:25 Trip out
3:10 SWL ~ 60 ([illegible])
3:34 SWL = 61
1/4 9:10 AM SWL = 57
1/5 57.6' TOC

TEST HOLE LOG

PAGE ______ OF ______

HYDRO [illegible]

HELENA MONTANA

PROJECT [illegible] JOB NUMBER ______ HOLE NUMBER H-10

STATE MT COUNTY [illegible] LOCATION: T ______ R ______ SEC. ______ TRACT ______

SITE DESCRIPTION [illegible] of [illegible] ELEVATION G.S. ______ DATE [illegible]

RECORDED BY [illegible] DRILL METHOD [illegible] DRILLER [illegible] DRILLING COMPANY [illegible]

TOTAL DEPTH 70' CASING TYPE AND DESCRIPTION 4" steel, 0.250

TOTAL DEPTH CASED 70' WELL COMPLETION DESCRIPTION screen 57-68' [illegible] slot screen [illegible]

REMARKS locking cap 6" below ground [illegible]

DEPTH	GRAPHICAL LOG & WELL COMPLETION	ELEVATION	SAMPLE	HAMMER BLOWS	PERCENT CORE RECOVERY	NOTES ON: WATER LEVELS, DRILLING FLUID, DRILLING RATE, WELL COMPLETION.	DESCRIPTION AND CLASSIFICATION
			0-5 5-10 10-15 15-20 25-30			0-31	Gravel, silt + fine sand well-graded, angular to subrounded, 1-3cm gravel; ~23% silt+sand
			30-35 35-40 -45			31-47	gravel, as above with ~40-50% silt + minor sand - strong fuel odor.
			45-50 50-55 55-60			47-61	sand, gravel + silt - slightly moist @ 51' - thin zones of 1-2' at 5[illegible], 55. Material is [illegible] at [illegible] [illegible]. Fuel odor strong [illegible]
			60-65 65-70			61-70	Saturated sand + gravel - tr. of silt, strong fuel odor. Material was wet @ 61' and saturated to 64'
						SWL: 59.5' 11/11/86 - bailed approx.	1/4" free product from well
						11/[illegible]/86 [illegible] 59.[illegible]'	bailed approx 1" free product

color, odor, moisture, (lithology) etc

15555 NE 33rd

PROJECT NUMBER: 86109

PROJECT NAME: [illegible]

BORING NUMBER: MW-8

COORDINATES:

DATE: [illegible]

ELEVATION:

GWL: Depth 65' Date/Time [illegible]

DATE STARTED: [illegible]

ENGINEER/GEOLOGIST: R Hamlet

Depth Date/Time

DATE COMPLETED: [illegible]

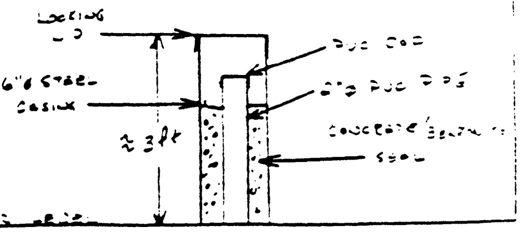
DRILLING METHODS: Air Rotary

PAGE 1 OF 2

DEPTH ( )	SAMPLE TYPE & NO	BLOWS ON SAMPLER PER ( )	RECOVERY ( )	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	WELL CONSTRUCTION	REMARKS
				Soft Dk. Brown stained black, low plastic Clay fill w/fine sands & gravel	Fill			2" Ø PVC Pipe
10				Dense, Red/Green, Round to Angular Poorly Sorted Gravels w/some fine grained sands 50% Gravel 40% Sand 10% Silt/clay fines	GP/GC			Concrete/Bentonite Seal 6" Ø Steel Casing
20				Boulders Encountered				
30				Soft, Reddish Brown, Highly Plastic, Sl. Silty, Very Sandy Clay lenses. Alternating layers of Gravels & very sandy clays, 30ft to 60ft. Thicknesses of lenses unknown	GP/GC CL GP/GC CL GP/GC			Vapor fumes present in cuttings & air Cuttings from clay zones have diesel smell. Bentonite Seal #16 Sand Pack
50								Very strong diesel fumes
60	GRAB			Dense, Red/Green, Round to Angular Poorly Sorted Gravels w/App. 50% fine grained sands & traces of clay fines.				2" Ø PVC Slotted Screen

NOTES.

Top of Well - Above Ground Completion

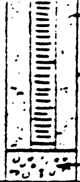


243A-3 86

[illegible]
15555 NE 33rd
Redmond, WA 98052
1-206-882-4364
ECOVA

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER [illegible]
PROJECT NAME [illegible]
BORING NUMBER [illegible]
COORDINATES:
DATE [illegible]
ELEVATION:
GWL: Depth 65' Date/Time [illegible]
DATE STARTED [illegible]
ENGINEER/GEOLOGIST [illegible]
Depth Date/Time
DATE COMPLETED [illegible]
DRILLING METHODS AIR ROTARY
PAGE 2 OF 2

DEPTH (ft)	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER ( )	RECOVERY ( )	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	WELL CONSTRUCTION	REMARKS
60				DENSE RED/GREEN, ROUND TO ANGULAR POORLY SORTED GRAVELS W/20% FINE GRAINED SANDS, 10% FINES & TRACES OF BLACK GLOSSY MATERIAL (COAL OR VOLCANIC GLASS)	GP/GC			▼ 5 — 61.05 ft ▼ WATER LEVEL AND DIESEL IN WATER & CUTTINGS GRAVEL BACKFILL
70								
				T.D. of BORING 72 ft				
80								

NOTES.

TEST HOLE LOG

PAGE ______ OF ______

HYDROMETRICS

HELENA MONTANA

PROJECT [illegible] JOB NUMBER ______ HOLE NUMBER M-1

STATE MT COUNTY M[illegible]a LOCATION: T ______ R ______ SEC. ______ TRACT ______

SITE DESCRIPTION [illegible] ELEVATION G.S. ______ DATE 11/11/86

RECORDED BY [illegible] DRILL METHOD [illegible] DRILLER [illegible] DRILLING COMPANY [illegible]

TOTAL DEPTH 72 CASING TYPE AND DESCRIPTION 6" .25 steel

TOTAL DEPTH CASED 72' WELL COMPLETION DESCRIPTION [illegible] 55-70' [illegible] 6 pressure [illegible]

REMARKS [illegible]

DEPTH	GRAPHICAL LOG & WELL COMPLETION	ELEVATION	SAMPLE	HAMMER BLOWS	PERCENT CORE RECOVERY	NOTES ON: WATER LEVELS, DRILLING FLUID, DRILLING RATE, WELL COMPLETION.	DESCRIPTION AND CLASSIFICATION
						0-30	GW gravel [illegible] red brown sandy matrix. (10-20% sand)
						30-46	GW gravel as above with slight fuel odor
						46	- Hard drilling through boulder
						46-60	GW gravel in [illegible] matrix as above, [illegible] in fines 25% [illegible] strong fuel odor
						60-63	- material [illegible] as [illegible] gray-green Strong water at 63'
						63-72	- GW gravel in sand. TD [illegible] brown [illegible] fuel odor
						SWL = 57.4' 11/12/86 - Bailed	no free product, oily sheen on water + odor

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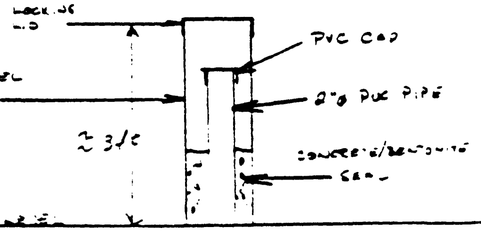
VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER [illegible]	PROJECT NAME Burlington Northern - Missoula	
BORING NUMBER [illegible]	COORDINATES	DATE 1-28-87
ELEVATION	GWL Depth 65' Date/Time [illegible]	DATE STARTED: 1-28-87
ENGINEER/GEOLOGIST [illegible]	Depth Date/Time	DATE COMPLETED: 1-29-87
DRILLING METHODS Air Rotary		PAGE 1 OF 2

DEPTH (ft)	SAMPLE TYPE & NO	BLOWS ON SAMPLER PER ( )	RECOVERY ( )	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	WELL CONSTRUCTION	REMARKS
				Soft Dk Brown stained black low plastic Clay fill w/ Gravels	Fill			
				Dense Red/Green Round to Angular, Poorly Sorted Gravels w/med. Brown clay matrix.	GP/GC			2"ø PVC Pipe
10				Dense, Red/Green Round to Angular, Poorly Sorted Gravels w/fine grained sands & some silts.				Concrete/Bentonite Seal
20				Increasing Red clay matrix. 30% to 50% clay fines				6"ø Steel Casing
				Decreasing clay matrix ~ 15% - 20%				
30								
				Soft, Reddish-Brown, Highly Plastic Silty Clay thickness unknown.	CL			
40					GC			Bentonite Seal
				Boulders Encountered	GP/GC			
50								Old Diesel fumes in cuttings at a Depth of 54 ft.
								#6 Sand Pack
60	Grab			Dense Red/Green Round to Angular Poorly Sorted Gravels w/traces of fine sands				Fumes Decreasing

NOTES.

Top of Well - Above Ground Completion



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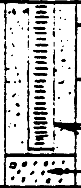
VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER [illegible]	PROJECT NAME [illegible]	
BORING NUMBER [illegible]	COORDINATES:	DATE [illegible]
ELEVATION.	GWL Depth Date/Time	DATE STARTED: [illegible]
ENGINEER/GEOLOGIST: R. HAMLET	Depth Date/Time	DATE COMPLETED: [illegible]
DRILLING METHODS: AIR ROTARY		PAGE 2 OF 2

DEPTH ( )	SAMPLE TYPE & NO.	BLOWS ON SAMPLER PER ( )	RECOVERY ( )	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	WELL CONSTRUCTION	REMARKS
60				Dense, Red/Green Round to Angular, Poorly Sorted Gravels w/Traces of fine Sands.	GP/GC			S.W.L. 61.33 ft. Water Level A.T.D. 65' 2"Ø Slotted PVC Screen Gravel Pack
70				Stiff, med Reddish Brown, med. Plastic, sl. Silty sl. Sandy, Micaceous Clay	[illegible]			
				T.D. of Boring 72'				
80								

NOTES.

TEST HOLE LOG

PAGE ______ OF ______

HYDROMETRICS

HELENA MONTANA

PROJECT [illegible] JOB NUMBER ______ HOLE NUMBER 11-12

STATE [illegible] COUNTY [illegible] LOCATION: T ______ R ______ SEC. ______ TRACT [illegible]

SITE DESCRIPTION [illegible] ELEVATION G.S. ______ DATE [illegible]

RECORDED BY ______ DRILL METHOD [illegible] DRILLER [illegible] DRILLING COMPANY [illegible]

TOTAL DEPTH 82 CASING TYPE AND DESCRIPTION [illegible] 3.25 steel

TOTAL DEPTH CASED 62 WELL COMPLETION DESCRIPTION [illegible] 60-70'

REMARKS [illegible] decided [illegible] at 65'

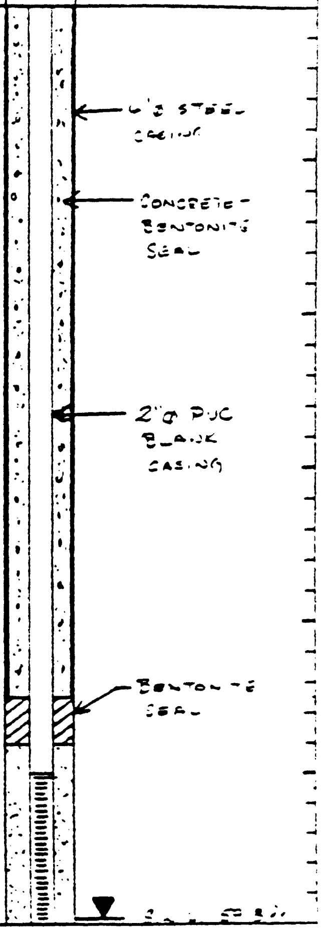
DEPTH	GRAPHICAL LOG & WELL COMPLETION	ELEVATION	SAMPLE	HAMMER BLOWS	PERCENT CORE RECOVERY	NOTES ON: WATER LEVELS, DRILLING FLUID, DRILLING RATE, WELL COMPLETION.	DESCRIPTION AND CLASSIFICATION
						0-1	[illegible]
						1-19	GW subrounded-[illegible] gravel [illegible] brown [illegible] sandy matrix
						19-20	SP Sand-well [illegible]
						20-25	[illegible]
						25-50	[illegible] brown-gray Sandy silt [illegible] Slightly moist no odor
						50-51	SM silty med [illegible] with minor sand [illegible] gravel - Moist no odor
						51-55	GW gravel, subrounded, 90% [illegible] 10% med brown [illegible] moist no odor
			55-56	split spoon		55-59	SM Silt, v. fine med brown with [illegible] no odor
						59-65	[illegible] (CL) [illegible] no odor
						65-66	[illegible] saturated
						66-82	[illegible]

ECOVA

VISUAL CLASSIFICATION OF SOILS

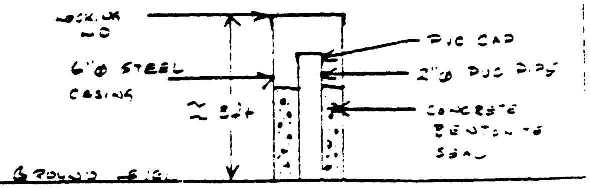
PROJECT NUMBER: 5	PROJECT NAME: BN - MISSOULA	
BORING NUMBER: M-3	COORDINATES:	DATE: 1/2/86
ELEVATION:	GWL: Depth Date/Time	DATE STARTED:
ENGINEER/GEOLOGIST [illegible] BRICE	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: AIR ROTARY		PAGE OF 2

DEPTH (ft)	SAMPLE TYPE & NO	BLOWS ON SAMPLER PER ( )	RECOVERY ( )	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	WELL CONSTRUCTION	REMARKS
	GRAB SAMPLES			COAL / CLINKER	FILL			
10				SUBROUNDED - ROUNDED GRAVEL IN A MED. BROWN SANDY MATRIX	GW			
20				SAND - WELL SORTED IN <1' LENSE MED. BROWN	SP			
30 40				GRAVEL IN SANDY MATRIX, MED BROWN GRAVEL IN RED BROWN-GRAY CLAYEY SILT MATRIX; SLIGHTLY MOIST, NO ODOR	GW			
50				SILT, MED BROWN W/ MINOR SAND <10% GRAVEL, MOIST NO ODOR	SM			
				GRAVEL, SUBROUNDED 90% W/ 10% MED BROWN SILT MATRIX, NO ODOR, MOIST.	GW			
60	S.S.			SILT, V. FINE, MED BROWN, W/ MINOR INTERBEDDED FINE SANDS (1-2mm THICK) WET, NO ODOR	SM			



NOTES:
JEROME DRILLING
LOGGED BY HYDROMETRICS

RECOMPLETION DIAGRAM of M...



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Redmond, WA 98052
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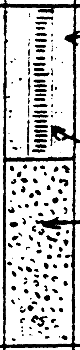
ECOVA

VISUAL CLASSIFICATION OF SOILS

PROJECT NUMBER: 2	PROJECT NAME: BN - Missoula	
BORING NUMBER: M - 2	COORDINATES:	DATE: 2/86
ELEVATION:	GWL Depth Date/Time	DATE STARTED:
ENGINEER/GEOLOGIST: CHRIS BROCK	Depth Date/Time	DATE COMPLETED:
DRILLING METHODS: AIR ROTARY		PAGE 2 OF 2

DEPTH (ft)	SAMPLE TYPE & NO	BLOWS ON SAMPLER PER ( )	RECOVERY ( )	DESCRIPTION	USCS SYMBOL	MEASURED CONSISTENCY (TSF)	WELL CONSTRUCTION	REMARKS
60	GRAB SAMPLES			CLAY MED. BROWNISH GRAY NO ODOR	CL			← SAND PACK
				GRAVEL - LITTLE/NO FINES SATURATED	GW			2"Ø PVC SLOTTED SCREEN
70				CLAY & GRAVEL, BROWNISH-GRAY TO BROWN, <10% SAND & 10-20% GRAVELS	CL			← PEA GRAVEL BACKFILL
80								

NOTES.

Figure **Kennedy/Jenks Engineers**

PROJECT BURLINGTON NORTHERAN RAILROAD
MISSOULA
JOB NO 866709.06

DATE 3/23/87
BY OL

BORING M-13

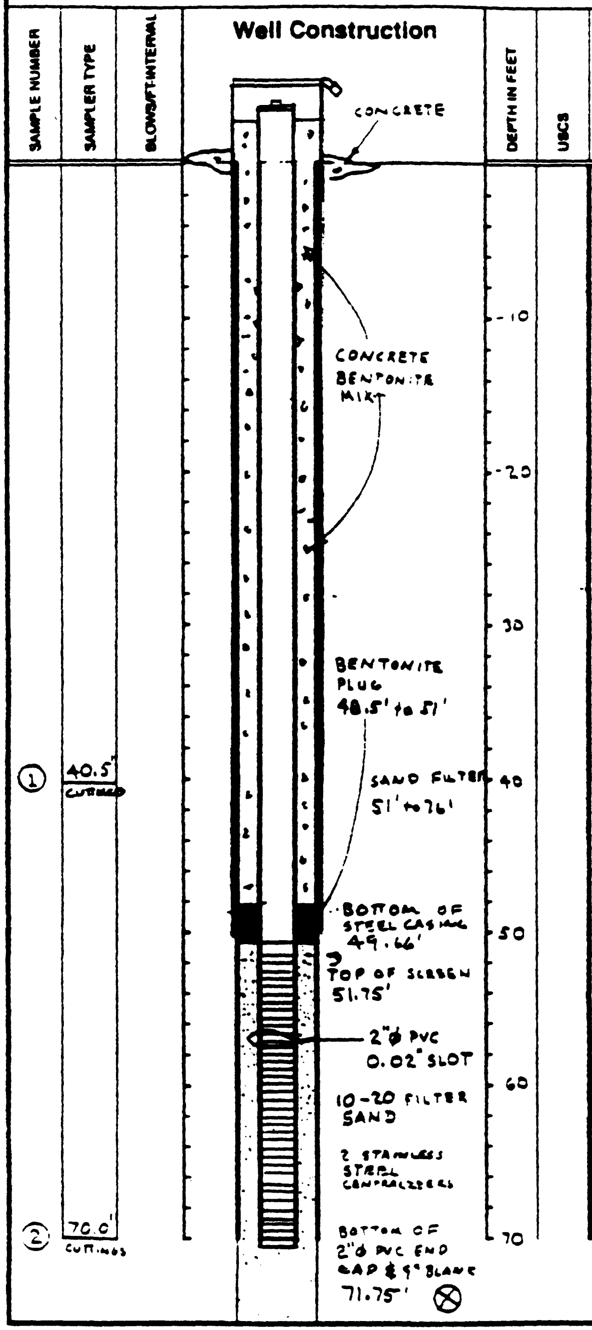
Details of Boring and Well Construction

SURFACE ELEVATION:

DRILLING METHODS: AIR ROTARY

SAMPLING METHODS: CONTINUOUS MONITORING OF CUTTINGS, COLLECTION OF CUTTINGS AT SELECTED DEPTHS

DRILLER: HILLMAN DRILLING



SYMBOLS	
GM	0 to 4' DARK STAINED SANDY GRAVELS
GM	4' to 14' CLEAN GRAVELS W/FINE SAND WELL SORTED, GRAVELS < 1" ROUNDED & ANGULAR PRESENT
GM & SM	14' to 17 GRAVELY SAND, FINE SAND LIGHT BROWN COLOR
~~SM~~ GW	@ 17' GRADING TO SANDY GRAVEL, GRAVELS < 1¼", MOST ANGULAR AND LESS THAN ⅜"
GC & SC	@ 24 GRADING TO CLAYEY-SANDY GRAVEL, MOIST, NO PRODUCT ODOR. LAYER ≃ 2' THICK
	26' to 35' SANDY GRAVEL
SC	@ 35 to 36' SANDY CLAYEY LAYER WITH GRAVEL STAINED WITH PRODUCT MOIST PRODUCT-WATER
SC	@ 38' CLAYEY SAND WITH FINE GRAVEL
SP	@ 40½ COARSE ANGULAR SAND SATURATED WITH PRODUCT NO GRAVEL
GC	@ 44 to 59 ANGULAR GRAVEL GRAVEL < ⅜", CLAYEY MATRIX PRODUCT PRESENT
SP	@ 59 GRADING BACK TO ANGULAR SANDS
SM	@ 61 GRADING TO FINE SAND
SM & SC	61 to 72 SILTY SAND, SOMEWHAT CLAYEY.

BOTTOM OF BORING 76' DRILL BIT RUN PAST END OF CASING

F 37
(9/85)

SHEET 1 OF 1

Figure **Kennedy/Jenks Engineers**

PROJECT BURLINGTON NORTHERN RAILROAD
MISSOULA
JOB NO 866709.06
DATE 3/23/87
BY CL

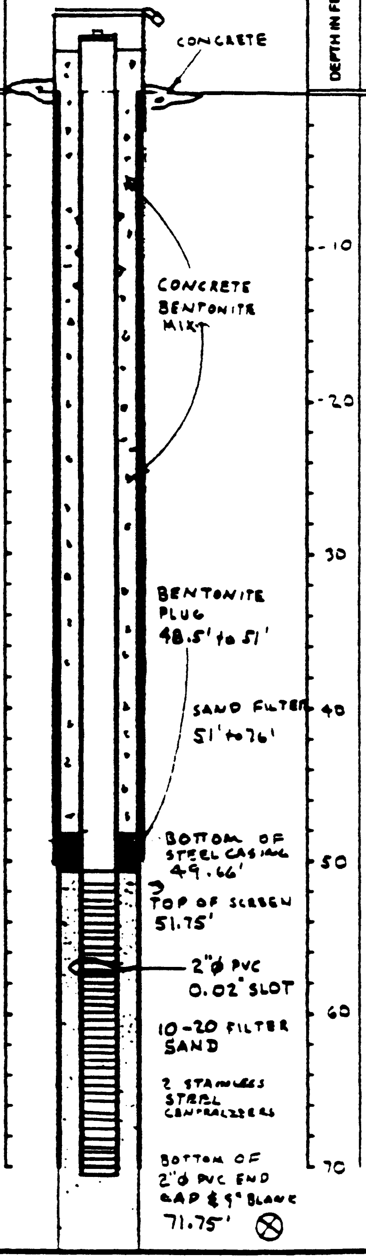
BORING M-13

Details of Boring and Well Construction

SURFACE ELEVATION:
DRILLING METHODS: AIR ROTARY
SAMPLING METHODS: CONTINUOUS MONITORING OF CUTTINGS, COLLECTION OF CUTTINGS AT SELECTED DEPTHS
DRILLER: HILLMAN DRILLING

SAMPLE NUMBER	SAMPLER TYPE	BLOWS/FT INTERVAL
①	40.5' cuttings	
②	70.0' cuttings	

Well Construction



SYMBOLS	
GM	0 to 4' DARK STAINED SANDY GRAVELS
GM	4' to 14' CLEAN GRAVELS W/FINE SAND WELL SORTED, GRAVELS < 1" ROUNDED & ANGULAR PRESENT
GM & SM	14' to 17 GRAVELY SAND, FINE SAND LIGHT BROWN COLOR
SM GW	@ 17' GRADING TO SANDY GRAVEL, GRAVELS < 1¼", MOST ANGULAR AND LESS THAN 3/8"
GC & SC	@ 24 GRADING TO CLAYEY-SANDY GRAVEL, MOIST, NO PRODUCT ODOR LAYER ≈ 2' THICK
	26' to 35' SANDY GRAVEL
SC	@ 35 to 36' SANDY CLAYEY LAYER WITH GRAVEL STAINED WITH PRODUCT MOIST PRODUCT-WATER
SC	@ 38' CLAYEY SAND WITH FINE GRAVEL
SP	@ 40½ COARSE ANGULAR SAND SATURATED WITH PRODUCT NO GRAVEL
GC	@44 to 59 ANGULAR GRAVEL GRAVEL < 3/8", CLAYEY MATRIX PRODUCT PRESENT
SP	@59 GRADING BACK TO ANGULAR SANDS
SM	@ 61 GRADING TO FINE SAND
SM & SC	61 to 72 SILTY SAND, SOMEWHAT CLAYEY.
	BOTTOM OF BORING 76' DRILL BIT RUN PAST END OF CASING

Figure **Kennedy/Jenks Engineers**

PROJECT BURLINGTON NORTHERN RAILROAD
MISSOULA
JOB NO 866709.06

DATE 3/25/87
BY OL

BORING M-14

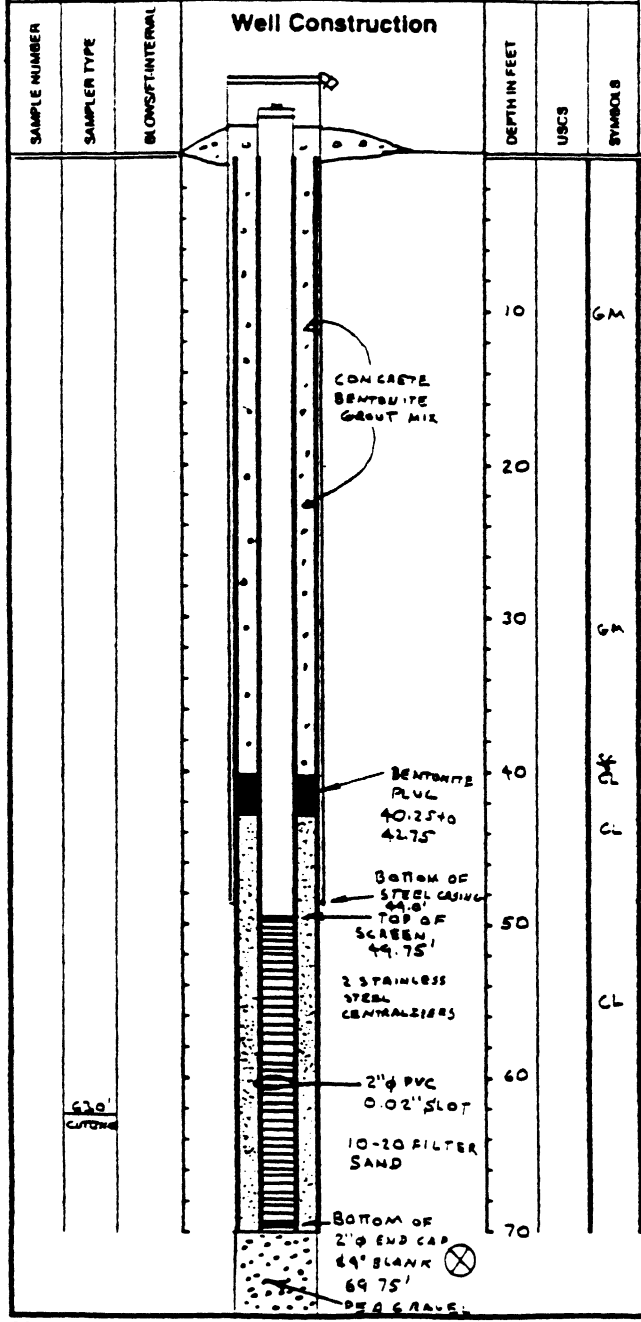
Details of Boring and Well Construction

SURFACE ELEVATION:

DRILLING METHODS: AIR ROTARY

SAMPLING METHODS: CONTINUOUS MONITORING OF CUTTINGS COLLECTION OF CUTTINGS AT SELECTED DEPTHS

DRILLER: HILLMAN DRILLING



0-2	SANDY GRAVEL
2-12	SANDY GRAVEL, GRAVELS <2" DIA SUBANGULAR to ROUNDED SOME COBBLES' & BOULDERS' SAND LT. BROWN
@15'	SANDY GRAVEL, w/COBBLES 65% GRAVEL 35% SAND MOST GRAVELS < 1" DIA
@18'	SLIGHT PRODUCT ODOR CUTTINGS STAINED GRADING TO COARSE SAND w/GRAVEL, GRAVELS ROUNDED
21½	BOULDER ?, HARD CEMENTED GRAVELS LAYER ≈ 8" THICK GRAVELS < ½" DIA GRAVELS MOIST DIESEL ODOR
@26	SANDY GRAVEL, MOIST 65% GRAVEL, 35% SAND, PRODUCT ODOR.
@29	HARD LAYER, SLIGHT PRODUCT ODOR
30 to 40	SANDY GRAVEL w CLAY BECOMING FINER
40 to 41½	CLAYEY LAYER w/SANDY GRAVEL MOIST
41½ to 50	SILTY SAND w/GRAVEL GRAVELS SUBANGULAR SAND BROWN, 75% SAND 25% GRAVEL
@50	SILTY CLAY, TIGHTLY PACKED
@53	BOULDER
53 to 80	CEMENTED GRAVELS HARD GRAY GREEN MOIST

BOTTOM OF HOLE 80 Ft

F 37
(6/85)

SHEET 1 OF 1

Figure **Kennedy/Jenks Engineers**

PROJECT BURLINGTON NORTHERN RAILROAD
MISSOULA
JOB NO 366709.06

DATE 3/25/87
BY DL

BORING M-15

Details of Boring and Well Construction

SURFACE ELEVATION:

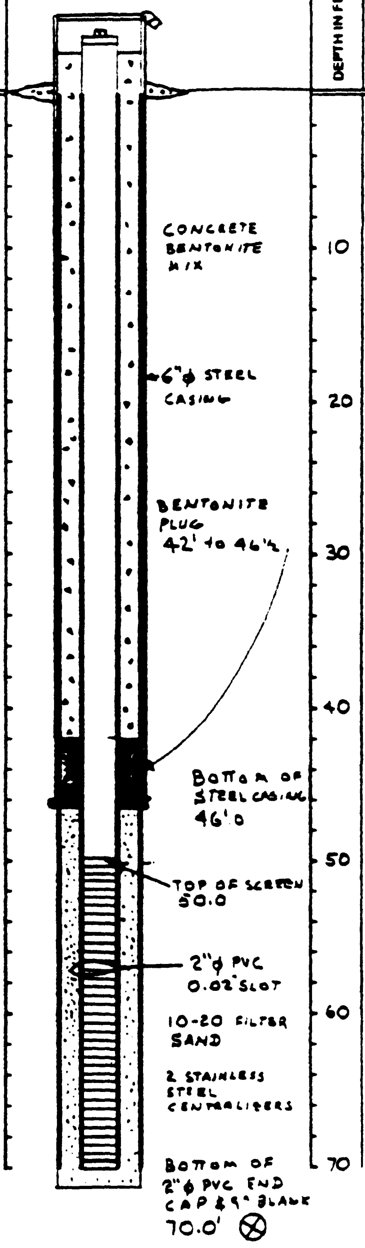
DRILLING METHODS: AIR ROTARY

SAMPLING METHODS: CONTINUOUS MONITORING OF CUTTINGS; COLLECTION OF CUTTINGS AT SELECTED DEPTHS

DRILLER: HILLMAN DRILLING

SAMPLE NUMBER	SAMPLER TYPE	BLOWS/FT INTERVAL
○	32' CUTTINGS	
○	60' CUTTINGS	

Well Construction



USCS

SYMBOLS

0 to 1½' DARK STAINED SANDY GRAVEL

1½' to 20' SANDY GRAVEL, Lt BROWN SAND
MOST GRAVELS < 1¼", rounded
FEW COBBLES UP TO 3"
THIN LAYERS OF SAND INTERBEDDED

@ 25 to 32 SANDY GRAVEL
70 to 80% GRAVEL
20 to 30% SAND
SUBANGULAR TO ROUND
DARKER COLOR SANDY MATRIX
STICKING TO GRAVELS
NO PRODUCT ODOR

@ 32' CLAY LAYER
ODOR OF PRODUCT

@ 36' CLAY w/GRAVEL, BROWN CLAY
GRADING TO GRAVEL
GRADING TO SAND
ODOR OF PRODUCT

@ 43' COARSE SAND w/GRAVEL
≈ 85% GRAVEL, 15% SAND
PRODUCT ODOR

@ 45' SANDY GRAVEL BROWN SAND
GRAVELS ROUNDED, GRAVELS < 1"
MOIST, NO PRODUCT ODOR

@ 49 GRAVELY SAND, GRAVELS < ⅛"
GRAVELS SUBANGULAR, MOIST

@ 53' HARD LAYER, BOULDER
(RED CHIPS)

54' to 60 SAME AS AT 44' – NO ODOR

60' GRAVELY SAND
PRODUCT ODOR WET

@ 70 SILTY SAND w/GRAVEL

BOTTOM OF HOLE 70½'

F 37
(8/85)

SHEET 1 OF 1

Figure **Kennedy/Jenks Engineers**

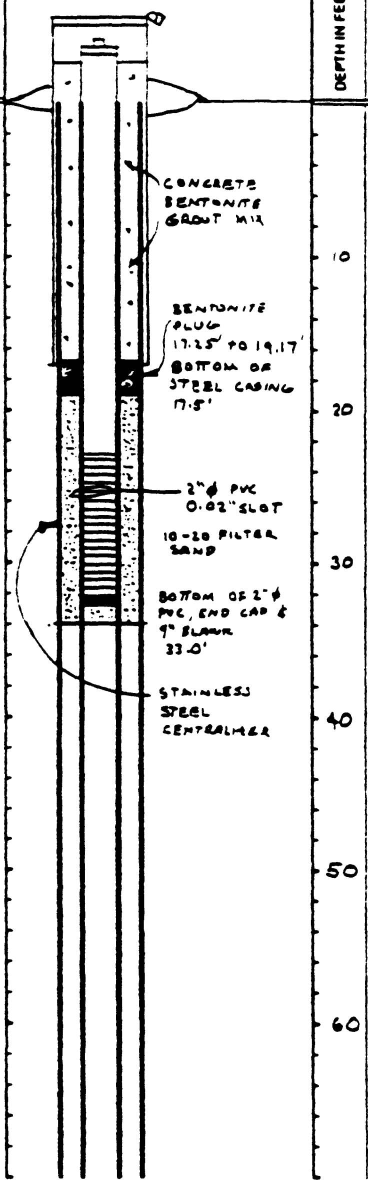
PROJECT BURLINGTON NORTHERN RAILROAD
MISSOULA
JOB NO 966709.06
DATE 3/26/87
BY OL
BORING M-16

Details of Boring and Well Construction

SURFACE ELEVATION:
DRILLING METHODS: AIR ROTARY
SAMPLING METHODS: CONTINUOUS MONITORING OF CUTTINGS' COLLECTION OF CUTTINGS AT SELECTED DEPTHS
DRILLER: HILLMAN DRILLING

SAMPLE NUMBER | SAMPLER TYPE | BLOWS/FT INTERVAL

Well Construction



USCS	SYMBOLS		
	GM	0 to 2	SANDY GRAVEL, STAINED DARK
	GM	2 to 14	SANDY GRAVEL LT BROWN SAND 65% GRAVEL, 35% SAND GRAVELS <2" DIA, MOST < ½" DIA. SUBANGULAR TO ROUNDED SAND INTERBED
		14 to 16	GRAVEL, w/ SAND, w/ SOME COBBLES 90% GRAVEL 10% SAND ROUNDED GRAVELS, GRAVELS UP TO 3" DIA
		@16	GRADING BACK TO SANDY GRAVEL GREEN GRAY CHIPS UP TO 6" DIA RL
	SM	@17	SAND - MEDIUM TO FINE LAYER ≈ 6" THICK
		18 to 24	SANDY GRAVEL w/ COBBLES
		24 to 26	COARSE SAND w/ GRAVEL MOIST
	CH	@ [illegible]	CLAY LAYER
		@3	GRAVEL - SAND
		@34	CLAY - BROWN - SILTY CLAY BOTTOM OF BORING 34

SHEET ______ OF ______

Figure **Kennedy/Jenks Engineers**

PROJECT BURLINGTON NORTHERN RAILROAD
MISSOULA
JOB NO 366709.06

DATE 4/14/87
BY OL

BORING M-17

Details of Boring and Well Construction

SURFACE ELEVATION:

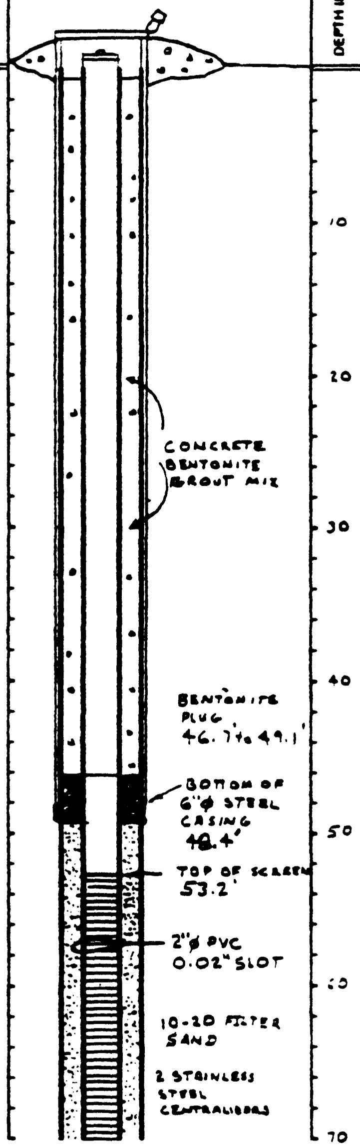
DRILLING METHODS AIR ROTARY

SAMPLING METHODS: CONTINUOUS MONITORING OF CUTTINGS : COLLECTION OF CUTTINGS AT SELECTED DEPTHS

DRILLER: HILLMAN DRILLING

SAMPLE NUMBER	SAMPLER TYPE	BLOWS/FT-INTERVAL
53.0	CUTTINGS	
64.0	CUTTINGS	

Well Construction



USCS / SYMBOLS		
GM	0 to 10	SANDY GRAVEL 70% SAND, 30% GRAVEL
	@10'	SAND LAYER ≈ 6" THICK FINE SAND LT BROWN
GM	10½ to 13	SANDY GRAVEL w/COBBLES COBBLES 4" to 8" DIA. GRAVELS ROUNDED MOST < 2" 65% GRAVEL 35% SAND LOOSE, LAYERS OF FINE SAND INTERBEDDED, MOIST
	13 to 19	COBBLES w/SAND COBBLES ROUNDED, FINE SAND BROWN to TAN SAND COBBLES 4" to 6"
GM	19 to 25	SANDY GRAVEL, UP TO 3" DIA MOIST, ROUNDED GRAVEL
	25 to 26½	FINE SAND, LT BROWN MOIST
	26½ to 30	SANDY GRAVEL w/COBBLES HARD LAYER AT TOP, SOMEWHAT SAND CEMENTED LT BROWN to TAN
SW	@30	SANDY GRAVEL, GRAVELS < ⅜" DIA 50% SAND 50% GRAVEL
	@31	GRADING TO GRAVEL w/SOME SAND SIZE INCREASING TO ½" DIA
	@33	COARSE SAND LAYER, BROWN ANGULAR
SM GW	34 to 40	GRAVELLY SAND, GRAVELS < 3/8" DIA 80% SAND, 20 GRAVEL, MOIST
	@40	SANDY GRAVEL GRAVELS UP to 2" DIA MOST < ½" DIA, ROUNDED
	@44	SAME AS AT 40' EXCEPT GRAVELS SUBANGULAR UP TO 3" DIA.
	@47	GRAVEL, UP TO 3" DIA, 90% GRAVEL 10% SAND
CL	48 to 49	SANDY CLAY LT BROWN, MOIST NO PRODUCT ODOR
GW	49 to 52	GRAVEL
CL	52 to 56	SANDY, CLAYEY, GRAVEL MOIST, PRODUCT ODOR
CL	56 to 68	SILTY SANDY CLAY WITH SOME GRAVEL, SOME STAINING OF CLAY CAUSED BY DIESEL @56', LT BROWN to TAN

F D
(8/85)

SHEET ______ OF 2

Figure

Kennedy/Jenks Engineers

PROJECT BURLINGTON NORTHERN RAIL-ROAD
MISSOULA

JOB NO 366709.06

DATE 4/14/87

BY OL

BORING M-17

Details of Boring and Well Construction

SURFACE ELEVATION:

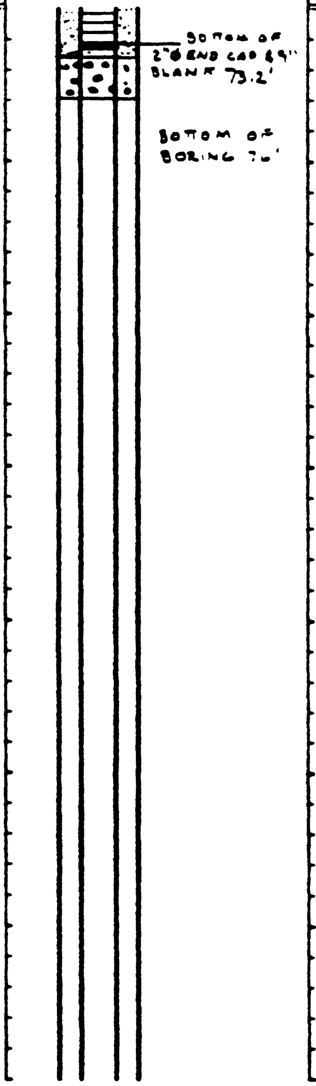
DRILLING METHODS:

SAMPLING METHODS:

DRILLER:

SAMPLE NUMBER	SAMPLER TYPE	BLOWS/FT INTERVAL	DEPTH IN FEET	USCS	SYMBOLS
				CL	
			80		
				GW	

Well Construction



BOTTOM OF
2"Ø END CAP 69"
BLANK 73.2'

BOTTOM OF
BORING 76'

@69 GRAVELY CLAY, GRADING TO GRAVEL

@70 GRADING TO GRAVEL W/SAND GRAVELS SUBANGULAR, < 2" DIA, MOST < 1/2 DIA., SAND LT BROWN
60% GRAVEL 40% SAND

@75 SANDY GRAVEL, GRAVELS UP TO 3" DIA 70% GRAVEL, 30% SAND/SILT

@75 1/2 HARD LAYER
BOTTOM OF HOLE @76'

F J7
10/85.

SHEET 2 OF 2

Figure **Kennedy/Jenks Engineers**

PROJECT: BURLINGTON NORTHERN RAILROAD MISSOULA

JOB NO: [illegible]

DATE: 7/17/87

BY: DL

BORING M-12

Details of Boring and Well Construction

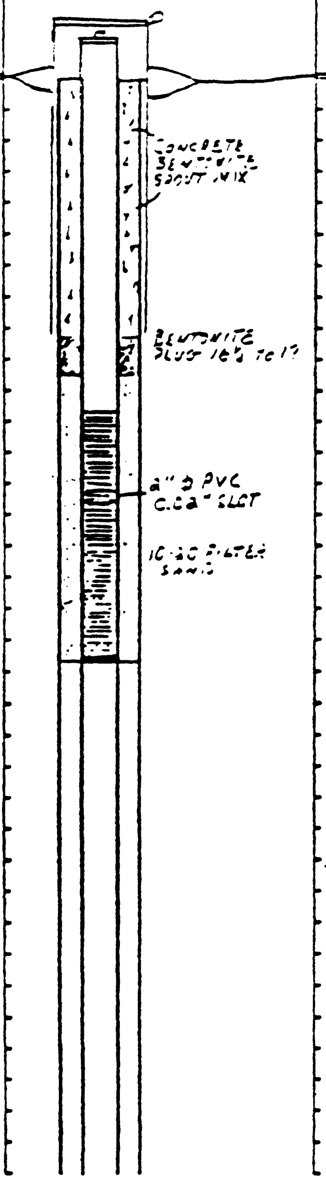
SURFACE ELEVATION:

DRILLING METHODS: AIR ROTARY

SAMPLING METHODS: CONTINUOUS MONITORING OF CUTTINGS

DRILLER: HILLMAN DRILLING

SAMPLE NUMBER | SAMPLER TYPE | BLOWS/FT INTERVAL | Well Construction | DEPTH IN FEET | USCS | SYMBOLS



	0 to 4 SANDY GRAVEL, STAINED BLACK
GM	4 to 12 GRAVELLY SAND TO SANDY GRAVEL, BROWN
	12 to 15 GRAVEL AND COBBLES
GM	15 to 23 SANDY GRAVEL
	23 to 25 HARD DRILLING, MOIST
GM	25 to 39½ SANDY GRAVEL BROWN GRAVEL UP TO 2½"
	@ 32 DIESEL ODOR
CL	@ 39½ CLAY LAYER

Figure **Kennedy/Jenks Engineers**

PROJECT BURLINGTON NORTHERN RAILROAD MISSOULA
JOB NO 864709.00
DATE 11/19/87
BY OL

BORING M-19

Details of Boring and Well Construction

SURFACE ELEVATION:
DRILLING METHODS: AIR ROTARY
SAMPLING METHODS: CONTINUOUS MONITORING OF CUTTINGS
DRILLER: HILLMAN DRILLING

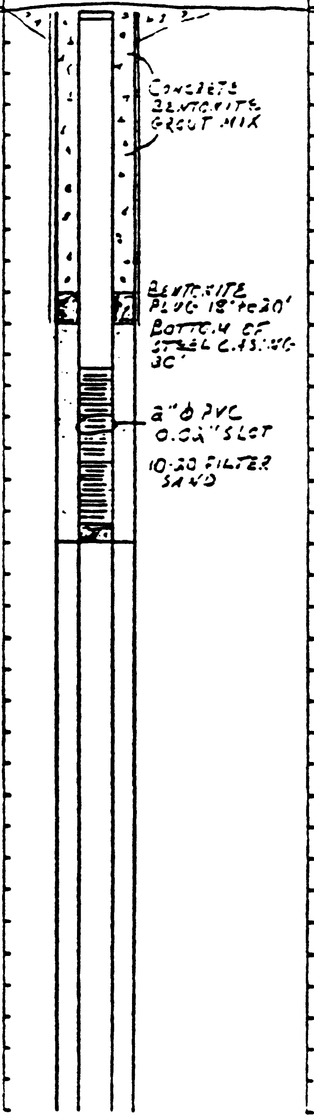
SAMPLE NUMBER	SAMPLER TYPE	BLOWS/FT INTERVAL	Well Construction	DEPTH IN FEET	USCS	SYMBOLS	
							0 TO 3 GRAVELLY SAND, STAINED, DARK
						GM	3 to 10 GRAVEL WITH SILTY SAND, BROWN
				10			10 to 24 SANDY GRAVEL, UP TO 2"
				20			
							@ 24 CLAY LAYER ≃ 6"
						GM	24 to 33 GRAVEL WITH SAND, UP TO 3"
				30			
							@ 32 DIESEL ODOR
						CL	@ 33 CLAY LAYER
				40			
				50			
				60			

Figure **Kennedy/Jenks Engineers**

PROJECT: BURLINGTON NORTHERN RAILROAD
MISSOULA
JOB NO. 3L-779 [illegible]

DATE 11/21/87
BY OL

BORING M-20

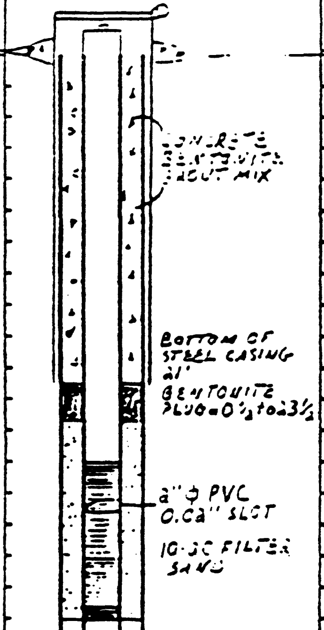
Details of Boring and Well Construction

SURFACE ELEVATION:

DRILLING METHODS: AIR ROTARY

SAMPLING METHODS: CONTINUOUS MONITORING OF CUTTINGS

DRILLER: [illegible] DRILLING



SAMPLE NUMBER	SAMPLER TYPE	BLOWS/FT INTERVAL	DEPTH IN FEET	USCS	SYMBOLS	
						0 TO 1 SAND AND GRAVEL, STAINED BLACK
					GM	1 to 36 SANDY GRAVEL, BROWN TO TAN, UP TO 3"
			10			
						@15 GRAVEL UP TO 3"
			20			
						@24 GRAVEL AND COBBLES UP TO 6"
			30			
					CL	@36 SILTY CLAY, BROWN, PLASTIC, NO ODOR OR DISCOLORATION
			40			
			50			
			60			

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA

DRILLING COMPANY ESD, INC. DRILLER E.H.

DRILLING METHOD AIR ROTARY DRILL BIT(S) SIZE: 5-7/8"

ISOLATION CASING	N/A	FROM		TO		FT.
BLANK CASING	2-INCH SCH. 40 PVC	FROM	0	TO	55	FT.
PERFORATED CASING	2-INCH 0.020 SLOT PVC	FROM	55	TO	70	FT.
SIZE AND TYPE OF FILTER PACK	10-20 SILICA SAND	FROM	51.8	TO	70	FT.
SEAL	BENTONITE CHIPS	FROM	49.3	TO	51.8	FT.
GROUT	CONCRETE	FROM	0	TO	49.3	FT.

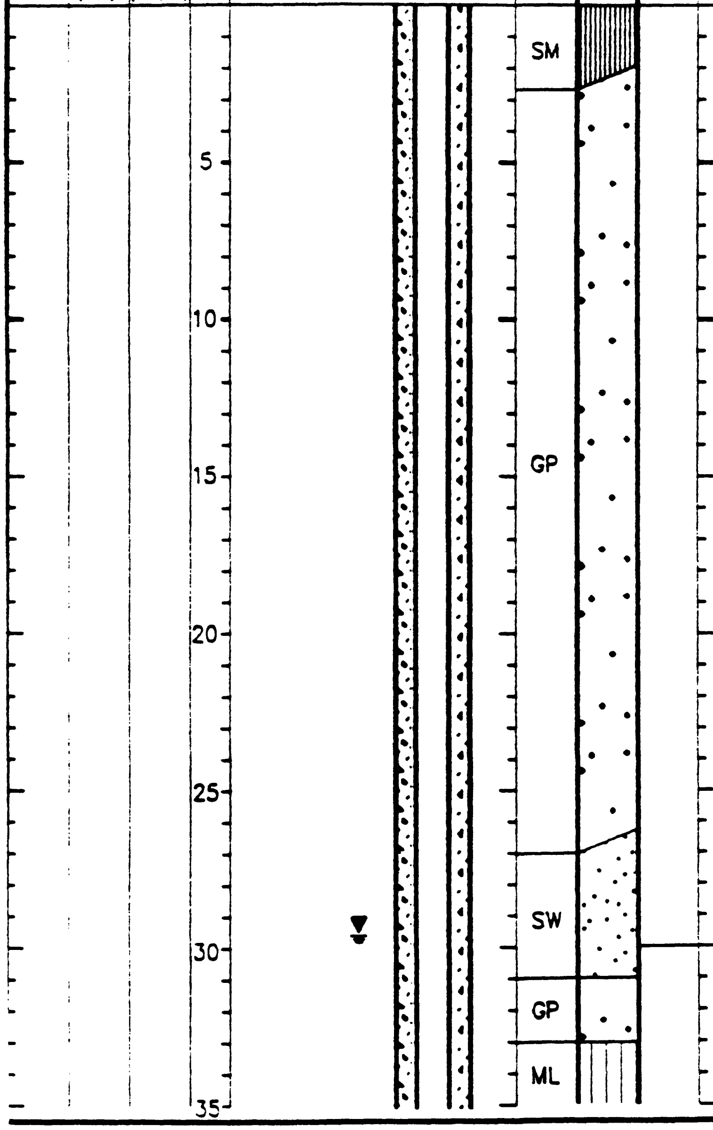
Boring/Well Name M-21

Project Name BN-MISSOULA

Project Number 896004.09

ELEVATION AND DATUM 3208.83	TOTAL DEPTH 75
DATE STARTED 8/7/89	DATE COMPLETED 8/7/89
STATIC WATER ELEVATION	
LOGGED BY M.L.G.	
SAMPLING METHODS LOGGED FROM CUTTINGS	WELL COMPLETION ☐ SURFACE HOUSING ☒ STAND PIPE 2 FT.

SAMPLES: TYPE NO. | RECOVERY (FEET) | PENETRATION RESIST (BLOWS/6 IN.) | DEPTH (FEET) | WELL CONSTRUCTION | USCS LOG | LITHOLOGY | OVM/ppm | SAMPLE DESCRIPTION AND DRILLING REMARKS



SILTY SAND WITH GRAVEL:

Brown to light brown, gravels up to 1.5".

POORLY GRADED GRAVEL WITH SAND:

Reddish brown, medium grained, sub-rounded, red and green quartzite, damp, slight diesel odor.

Less sand

Gravels and Cobbles

@ 15' to 17'

Increasing sand with silt

Moist @ 25'

Boulder 25'to 26'

WELL GRADED SAND:

Reddish brown, medium to very coarse, little fine sub-rounded gravel, moist to saturated, strong odor.

Less moisture @ 30'

POORLY GRADED GRAVELS :

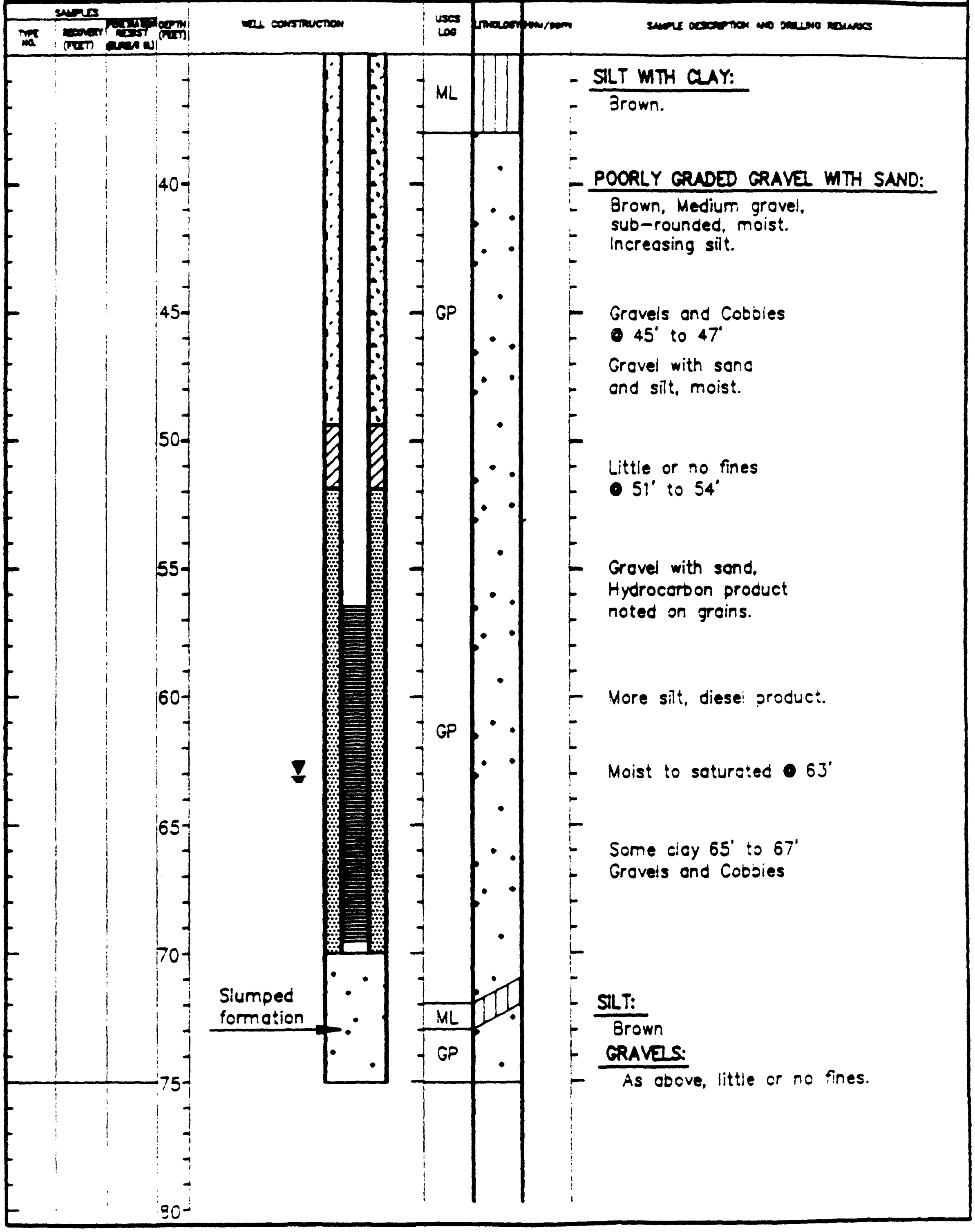
SILT AND SAND:

Brown, coarse grained, wet.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name BN-MISSOULA **Project Number** 896004.09 **Boring/Well Name** M-2



SILT WITH CLAY:

Brown.

POORLY GRADED GRAVEL WITH SAND:

Brown, Medium gravel, sub-rounded, moist. Increasing silt.

Gravels and Cobbles @ 45' to 47'

Gravel with sand and silt, moist.

Little or no fines @ 51' to 54'

Gravel with sand, Hydrocarbon product noted on grains.

More silt, diesel product.

Moist to saturated @ 63'

Some clay 65' to 67' Gravels and Cobbles

SILT:

Brown

GRAVELS:

As above, little or no fines.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA

DRILLING COMPANY ESD, INC.

DRILLER E.H.

DRILLING METHOD AIR ROTARY

DRILL BIT(S) SIZE: 5-7/8"

ISOLATION CASING N/A FROM TO FT.

BLANK CASING 4-INCH SCH. 40 PVC FROM 0 TO 25 FT.

PERFORATED CASING 4-INCH 0.020 SLOT PVC FROM 25 TO 35 FT.

SIZE AND TYPE OF FILTER PACK 10/20 SILICA SAND FROM 23 TO 35 FT.

SEAL BENTONITE CHIPS FROM 21 TO 23 FT.

GROUT CONCRETE FROM 0 TO 21 FT.

Boring/Well Name M-22

Project Name BN-MISSOULA

Project Number 896004.09

ELEVATION AND DATUM 3209.35

TOTAL DEPTH 37

DATE STARTED 8/8/89

DATE COMPLETED 8/8/89

STATIC WATER ELEVATION

LOGGED BY M.L.G.

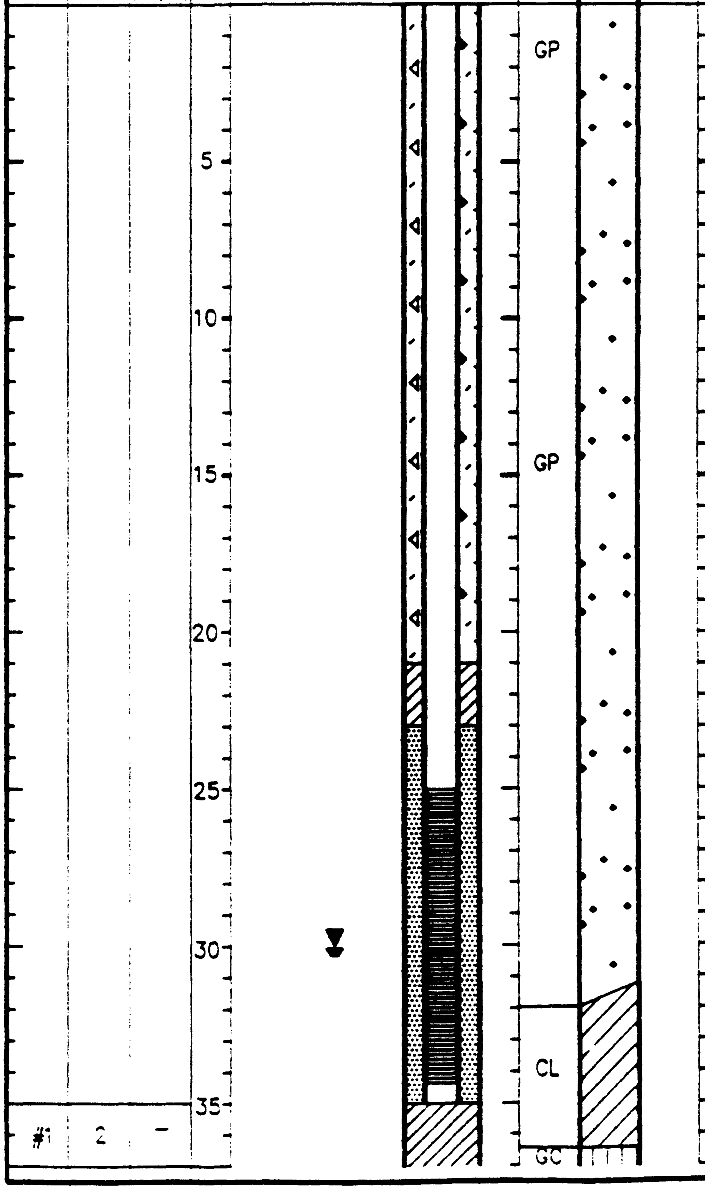
SAMPLING METHODS SPLIT-SPOON SAMPLER

WELL COMPLETION

⌧ SURFACE HOUSING

▭ STAND PIPE 2 FT.

SAMPLES								
TYPE NO.	RECOVERY (FEET)	PENETRATION RESIST (BLOWS/6 IN)	DEPTH (FEET)	WELL CONSTRUCTION	USCS LOG	LITHOLOGY	OVM/PPM	SAMPLE DESCRIPTION AND DRILLING REMARKS
#1	2	-	35					



POORLY GRADED GRAVEL:

Brownish Grey, Subrounded
Red and Green Quartzite
up to 2", with Sand

As Above-Reddish
Brown, Finer Gravel
with Sand and Silt

Incressing Silt, Moist
From 20'-25'

Cobbles 29' to 30'
Readisn Brown Sandy
Fine Gravels, No Odor, Wet

CLAY:

Brown, Moderately
Stiff, Low plastisity, some Silt,
Gravel

POORLY GRADED GRAVEL WITH CLAY:

Readisn Brown, some Sand

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA

DRILLING COMPANY ESD, INC.　DRILLER E.H.

DRILLING METHOD AIR ROTARY　DRILL BIT(S) SIZE: 5-7/8"

ISOLATION CASING 6-INCH STEEL　FROM 0 TO 12 FT.

BLANK CASING 4-INCH SCH. 40 PVC　FROM 0 TO 20 FT.

PERFORATED CASING 4-INCH 0.020 SLOT PVC　FROM 20 TO 30 FT.

SIZE AND TYPE OF FILTER PACK 10/20 SILICA SAND　FROM 18.7 TO 30.2 FT.

SEAL BENTONITE CHIPS　FROM 14.8 TO 18.7 FT.

GROUT CONCRETE　FROM 0 TO 14.8 FT.

Boring/Well Name M-23

Project Name BN-MISSOULA

Project Number 896004.09

ELEVATION AND DATUM 3209.07　TOTAL DEPTH 35.7

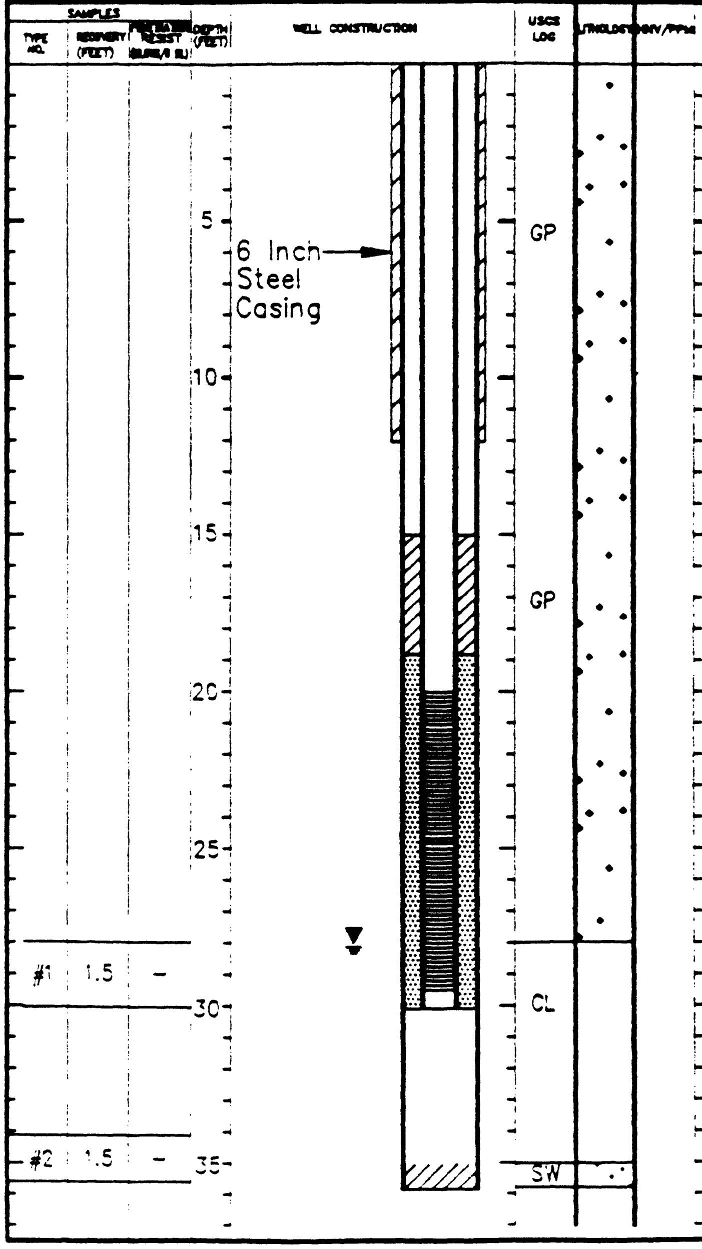
DATE STARTED 8/8/89　DATE COMPLETED 8/9/89

STATIC WATER ELEVATION 3209.07

LOGGED BY M.L.G.

SAMPLING METHODS SPLIT-SPOON SAMPLER

WELL COMPLETION ☐ SURFACE HOUSING ☒ STAND PIPE 3 FT.



SAMPLE DESCRIPTION AND DRILLING REMARKS

POORLY GRADED GRAVEL WITH SAND:
Brownish Grey to Reddish Brown, Subrounded Red and Green Quartzite up to 2", Fine to Medium Grained some Silt, Damp.

Soils Stained, Diesel Odor 9'-11'
As Above -Reddish Brown.

Diesel Odor

Cobbles from 19'-21'

Moist @ 23', Diesel Odor

Increasing Silt, Moist

Strong Odor, Stained Soils

CLAY:
Brown, Medium Stiffness, Low Plasticity, Some Gravels up to 1" and Sand
More Gravel

WELL GRADED SAND WITH GRAVEL:
Reddish Brown, Fine to Coarse Grained, Fine Subrounded Gravel, Moist.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA

DRILLING COMPANY ESD, INC. DRILLER E.H.

DRILLING METHOD AIR ROTARY DRILL BIT(S) SIZE 5-7/8"

ISOLATION CASING N/A FROM TO FT.

BLANK CASING 4-INCH SCH. 40 PVC FROM 0 TO 55 FT.

PERFORATED CASING 4-INCH 0.020 SLOT PVC FROM 55 TO 75 FT.

SIZE AND TYPE OF FILTER PACK 10-20 SILICA SAND FROM 51.4 TO 75 FT.

SEAL BENTONITE CHIPS FROM 1 TO 51.4 FT.

GROUT CONCRETE FROM 0 TO 1 FT.

Boring/Well Name M-24

Project Name BN-MISSOULA

Project Number 896004.09

ELEVATION AND DATUM 3206.07

TOTAL DEPTH 80

DATE STARTED 10/16/89

DATE COMPLETED 10/17/89

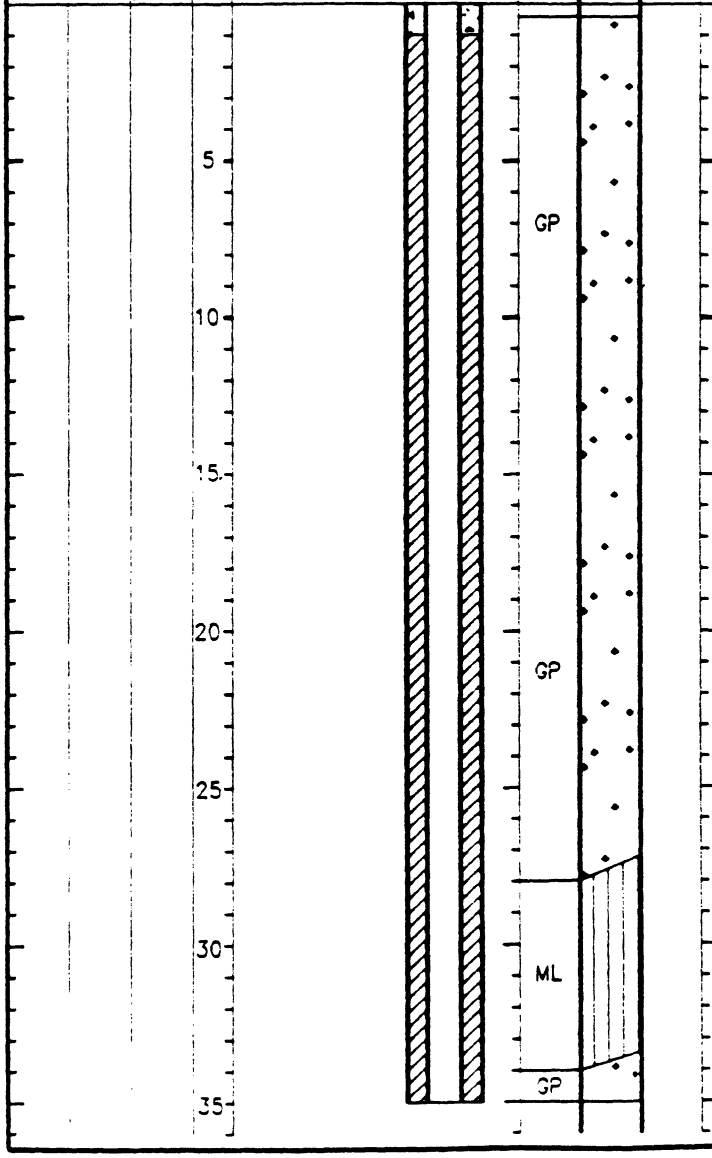
STATIC WATER ELEVATION

LOGGED BY M.L.G.

SAMPLING METHODS LOGGED FROM CUTTINGS

WELL COMPLETION ☒ SURFACE HOUSING ☐ STAND PIPE _____ FT.

SAMPLES								
TYPE NO.	RECOVERY (FEET)	PENETRATION RESIST (BLOWS/6 IN.)	DEPTH (FEET)	WELL CONSTRUCTION	USCS LOG	LITHOLOGY	ppm/ppm	SAMPLE DESCRIPTION AND DRILLING REMARKS



POORLY GRADED GRAVELS WITH SAND:

Brown to Reddish Brown, Subrounded Red and Green Quartzite up to 2", Very fine to medium grained, Damp

Moist to wet @ 27'

SILT AND SAND:

Brown, Fine to Medium Grained with Fine Gravel, Moist to Wet.

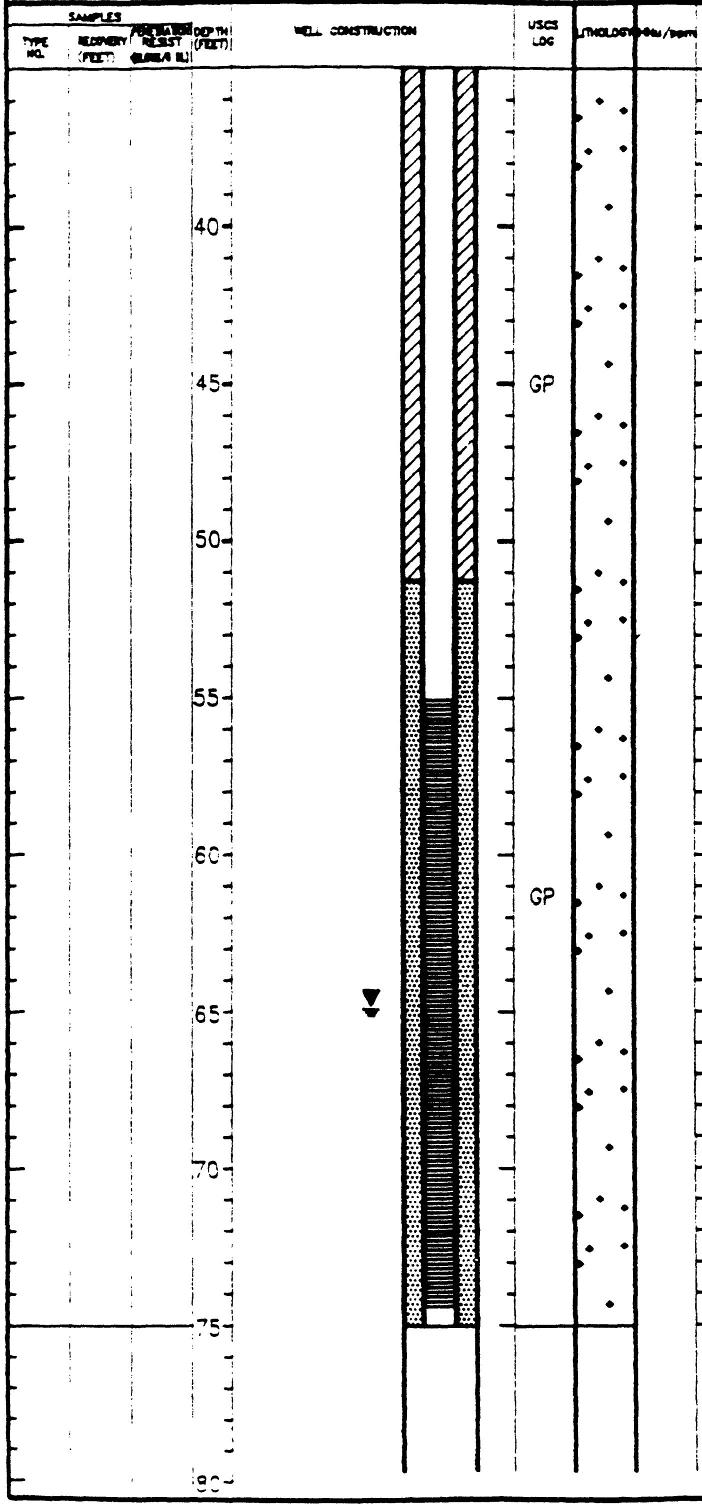
POORLY GRADED GRAVELS:

Reddish Brown, Sand present

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name BN–MISSOULA **Project Number** 896004.09 **Boring/Well Name** M–24



SAMPLE DESCRIPTION AND DRILLING REMARKS

POORLY GRADED GRAVEL WITH SAND:

Brown to Reddish brown, Fine to Medium Grained, Interbedded Clay present, Moist.

Increasing Clay.

As above: little Clay, Damp.

More Sand.

As above–little or no fines, Coarse Sand and Gravels.

As above.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA

DRILLING COMPANY ESD, INC. DRILLER E.H.

DRILLING METHOD AIR ROTARY DRILL BIT(S) SIZE: 5-7/8"

ISOLATION CASING N/A FROM TO FT.

BLANK CASING 4-INCH SCH. 40 PVC FROM 0 TO 60 FT.

PERFORATED CASING 4-INCH 0.020 SLOT PVC FROM 60 TO 75 FT.

SIZE AND TYPE OF FILTER PACK 10-20 SILICA SAND FROM 56 TO 75 FT.

SEAL BENTONITE CHIPS FROM 1 TO 56 FT.

GROUT CONCRETE FROM 0 TO 1 FT.

Boring/Well Name M-25

Project Name BN-MISSOULA

Project Number 896004.09

ELEVATION AND DATUM 3204.79 TOTAL DEPTH 83

DATE STARTED 10/18/89 DATE COMPLETED 10/20/89

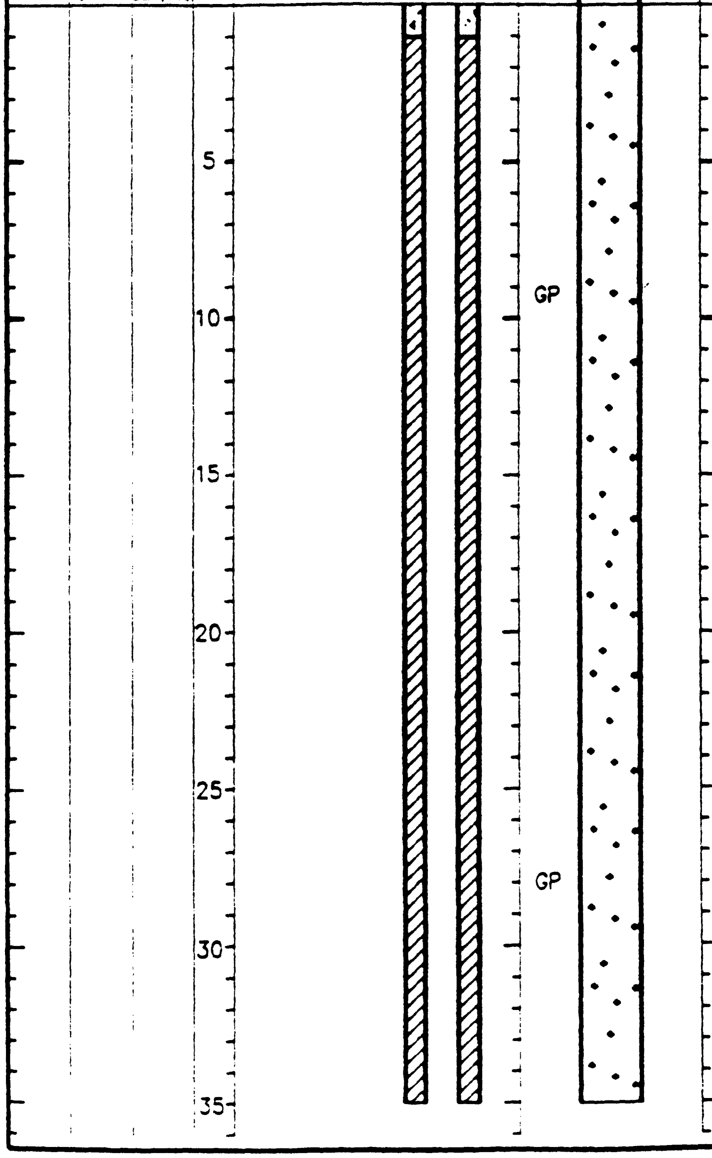
STATIC WATER ELEVATION

LOGGED BY M.L.G.

SAMPLING METHODS LOGGED FROM CUTTINGS

WELL COMPLETION
☒ SURFACE HOUSING
☐ STAND PIPE ____ FT.

SAMPLES			DEPTH (FEET)	WELL CONSTRUCTION	USCS LOG	LITHOLOGY	ppm/ppm	SAMPLE DESCRIPTION AND DRILLING REMARKS
TYPE NO.	RECOVERY (FEET)	PENETRATION RESIST (BLOWS/6 IN.)						



Asphalt

POORLY GRADED GRAVELS WITH SAND:

Greyish Brown, Fine Grained with some Silt, Subrounded Red and Green Quartzite, 1"-2" Damp.

As above-Reddish Brown.

As above-Sand Coarsening, Greyish Brown.

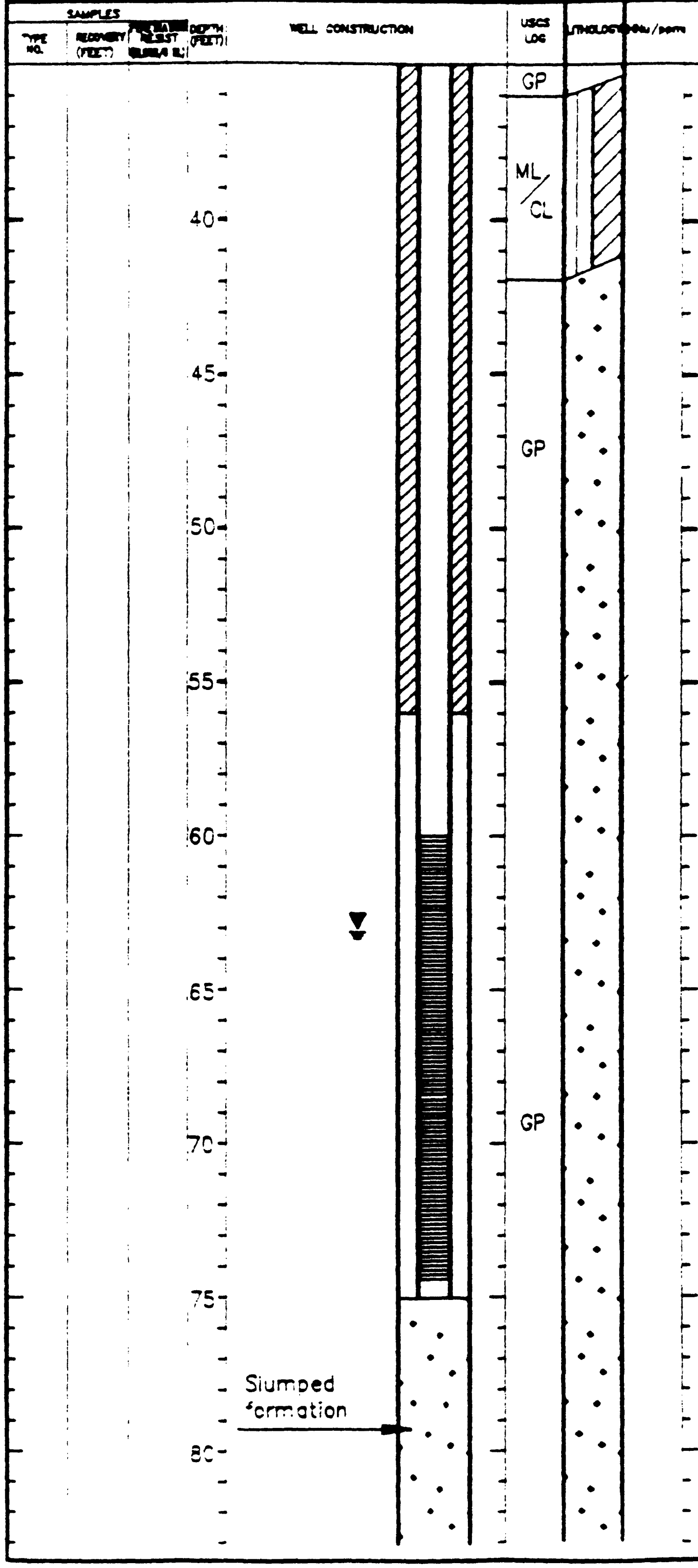
Moist to Wet, Increasing Fine Sand and Silt, No Odor

Softer Drilling, Moist to wet.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name BN-MISSOULA **Project Number** 89600409 **Boring/Well Name** V-25



SAMPLE DESCRIPTION AND DRILLING REMARKS

SILT AND CLAY:

Brown, with some Medium to Coarse Sand, Soft Drilling, Moist to Wet.

POORLY GRADED GRAVELS WITH SAND:

Brown, Cobbles present @ 46', Damp.

As above—with Silts possibly interbedded, Moist.

POORLY GRADED GRAVELS:

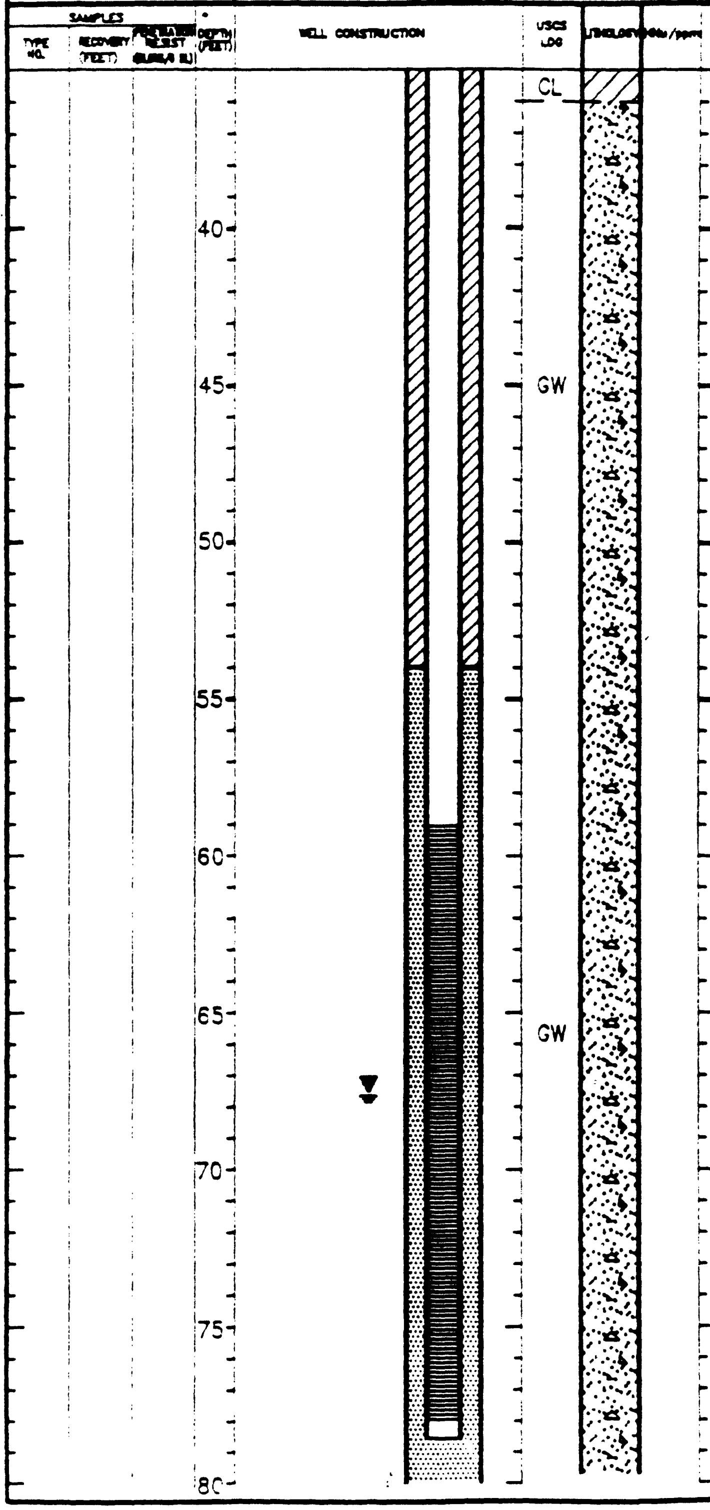
Brown, Subrounded Red and Green Quartzite, with some coarse to very coarse Sand, Saturated.

As above—poor returns.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name BN-MISSOULA **Project Number** 896004.09 **Boring/Well Name** M-26



SAMPLE DESCRIPTION AND DRILLING REMARKS

SANDY LEAN CLAY:
Pinkish brown, soft to very soft and 1-5% gravel. Wet.(~ " thick)

WELL GRADED GRAVEL:
Pinkish brown,<5% fine sand,fines trace to absent,Moist,Subangular to Subrounded gravel to ", some flat to elongate, Moist.

Smaller gravel (<1/2")

Drier; still moist.

WELL GRADED GRAVEL WITH SAND:
Medium brown, 25-50% coarse to fine sand, <5% fines, gravel is subangular to subrounded grey quartzite, Moist.

WELL GRADED GRAVEL:
Pinkish brown,5-10% fine sand,<5% fines; gravel subangular to subrounded, mostly <1/4", dark grey quartzite. Moist.

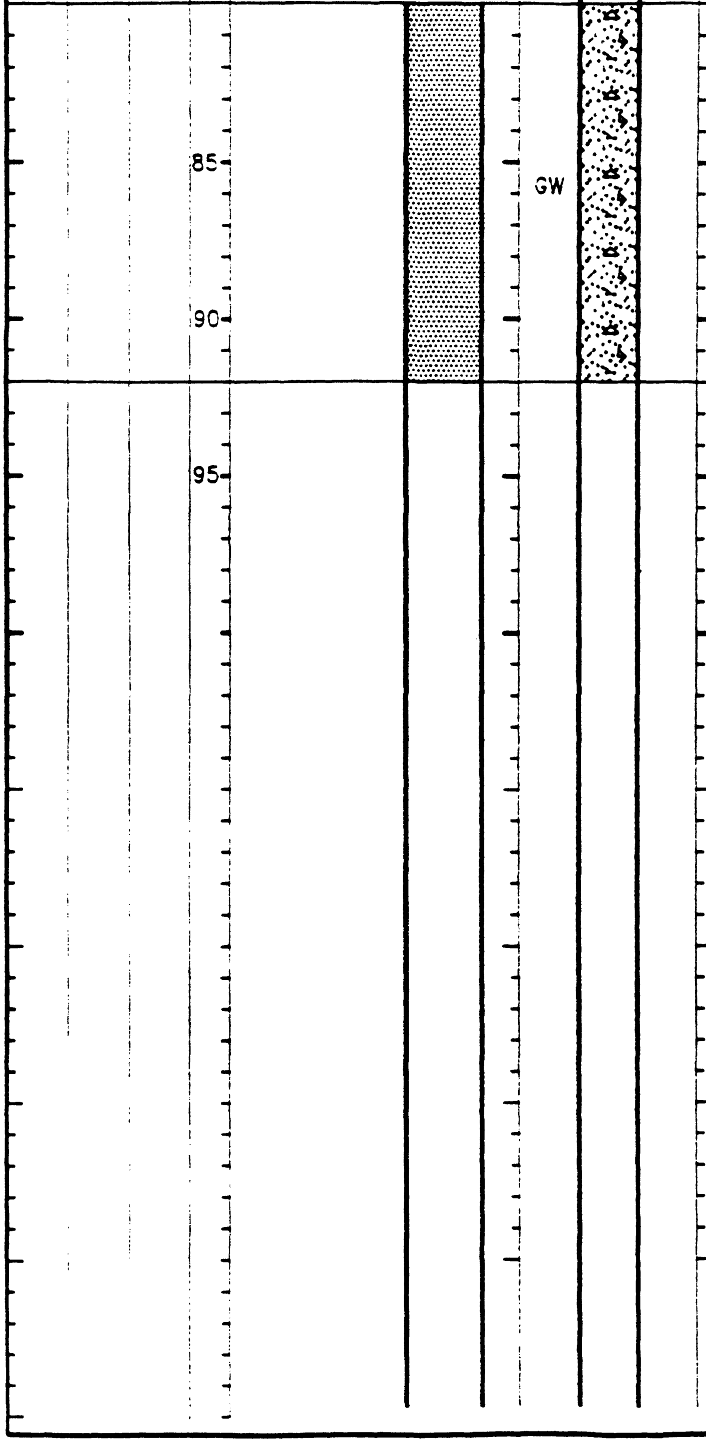
Gravel to 1"; includes –. green & pale pink quartzite. Saturated.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name BN-MISSOULA **Project Number** 896004 09 **Boring/Well Name** M-26

SAMPLES								
TYPE NO.	RECOVERY (FEET)	PENETRATION RESIST (BLOWS/6 IN.)	DEPTH (FEET)	WELL CONSTRUCTION	USCS LOG	LITHOLOGY	HNU/ppm	SAMPLE DESCRIPTION AND DRILLING REMARKS



WELL GRADED GRAVEL:

As above and in washed sample chips of porphyritic aphanitic igneous rock gravel (minor) as well as quartzite gravels.

Water/silt/fine sand slurry and rounded gravel of green argillite and red quatzite.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA

DRILLING COMPANY ESD, INC. DRILLER E.H.

DRILLING METHOD AIR ROTARY DRILL BIT(S) SIZE 6"

ISOLATION CASING N/A FROM TO FT.

BLANK CASING 4-INCH SCH. 40 PVC FROM 0 TO 59 FT.

PERFORATED CASING 4-INCH 0.020 SLOT PVC FROM 59 TO 79 FT.

SIZE AND TYPE OF FILTER PACK 10-20 SILICA SAND FROM 56 TO 79 FT.

SEAL BENTONITE CHIPS FROM 1 TO 56 FT.

GROUT CONCRETE FROM 0 TO 1 FT.

Boring/Well Name M-27

Project Name BN-MISSOULA

Project Number 896004.09

ELEVATION AND DATUM 3209.80

TOTAL DEPTH 83

DATE STARTED 10/29/89

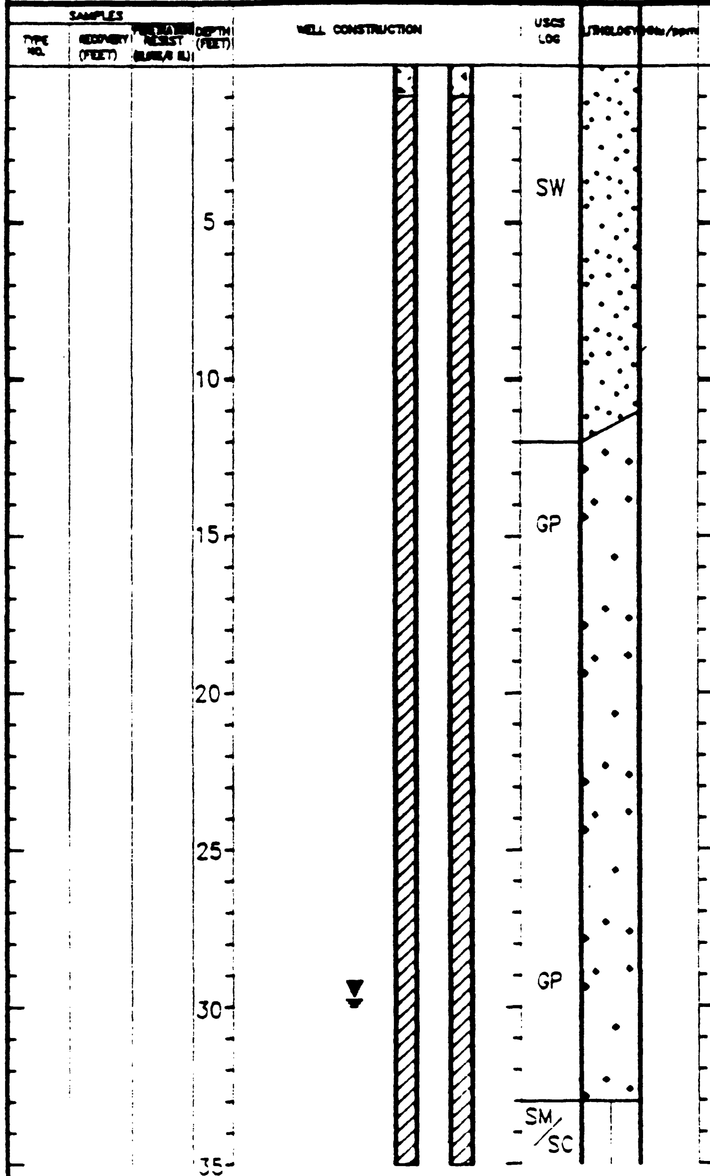
DATE COMPLETED 10/30/89

STATIC WATER ELEVATION

LOGGED BY M.L.G.

SAMPLING METHODS LOGGED FROM CUTTINGS

WELL COMPLETION ☒ SURFACE HOUSING ☐ STAND PIPE ____ FT.



SAMPLE DESCRIPTION AND DRILLING REMARKS

Asphalt

WELL GRADED GRAVELLY SAND:

Light Brown, Fine to coarse Grained, Subrounded Quartzite, Gravels up to 1", Damp

POORLY GRADED GRAVEL WITH SAND:

Reddish Brown, Subrounded, up up to 1", Fine to Coarse Grained Sand, Damp.

As above-Brownish Grey. Moist @ 21', with Some Silt.

Increasing Silt and Sand.

Moist to wet.

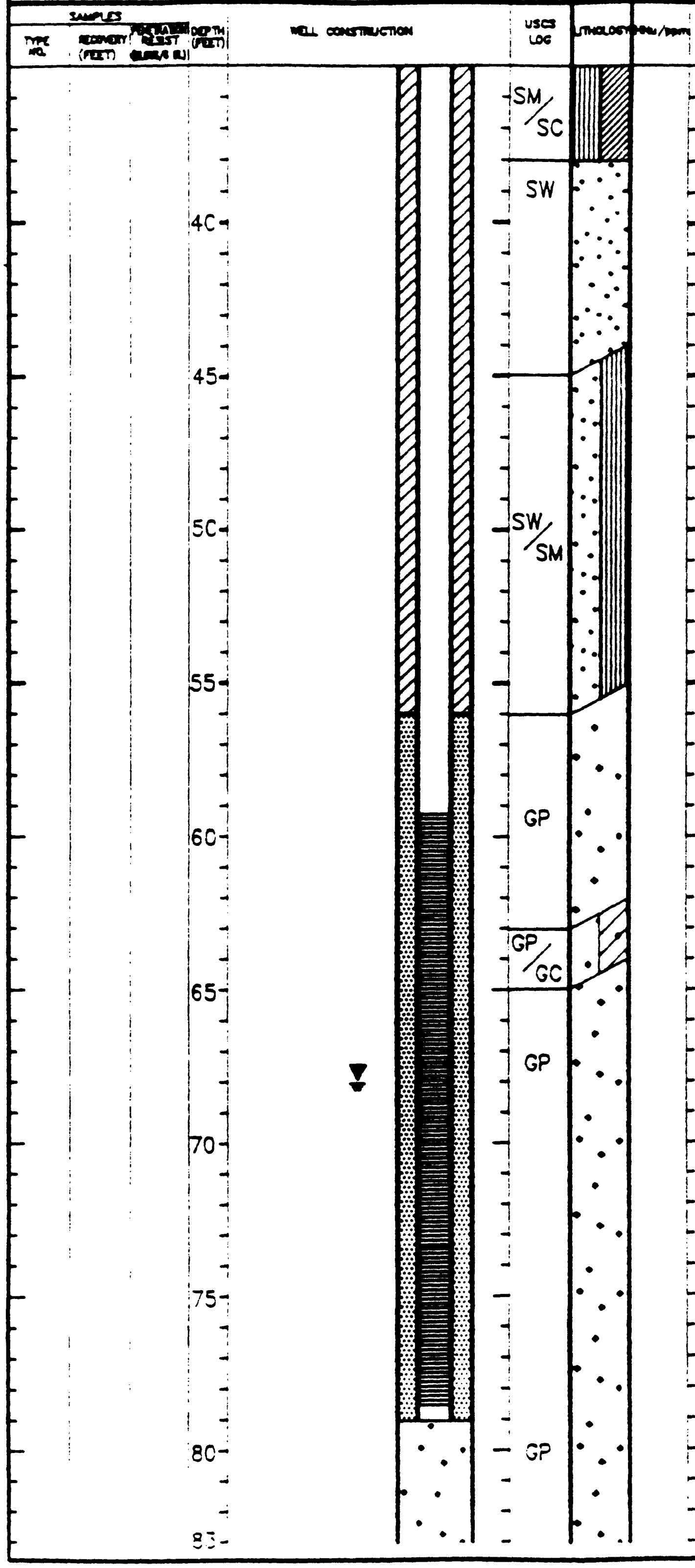
Gravelly Sand, Wet. No odor

SILTY SAND AND GRAVEL:

Brown, very fine to fine grained with some Clay.

Boring & Well Construction Log **Kennedy/Jenks/Chilton**

Project Name BN-MISSOULA **Project Number** 896004.09 **Boring/Well Name** M-27



SAMPLE DESCRIPTION AND DRILLING REMARKS

Increasing Clay, Low Plasticity.

WELL GRADED SAND WITH GRAVEL:

Reddish Brown, Fine to Coarse Grained, Gravel up to 1/2", Damp.

As above with Silt and little Clay, Possibly Interbedded.

Moist to Wet.

POORLY GRADED GRAVELS WITH SAND:

POORLY GRADED GRAVELS WITH CLAY AND SAND:

Brown, Saturated, No Odor.

POORLY GRADED GRAVEL:

Subrounded Red and Green,
Quartzite up to 1",
Very Coarse Sand,
Little or No Fines.

As above.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA

DRILLING COMPANY ESD INC. DRILLER J.C.

DRILLING METHOD AIR ROTARY DRILL BIT(S) SIZE: 6"

Boring/Well Name M-28

Project Name BN-MISSOULA

Project Number 896004.09

		FROM	TO	FT.
ISOLATION CASING				
BLANK CASING	4-INCH SCH. 40 PVC	0	57.5	
PERFORATED CASING	4-INCH 0.020 SLOT PVC	57.5	77.5	
SIZE AND TYPE OF FILTER PACK	10-20 SILICA SAND	53	83	
SEAL	BENTONITE CHIPS	1	53	
GROUT	CONCRETE	0	1	

ELEVATION AND DATUM 3208.20 TOTAL DEPTH 83

DATE STARTED 11/2/89* DATE COMPLETED 11/28/89

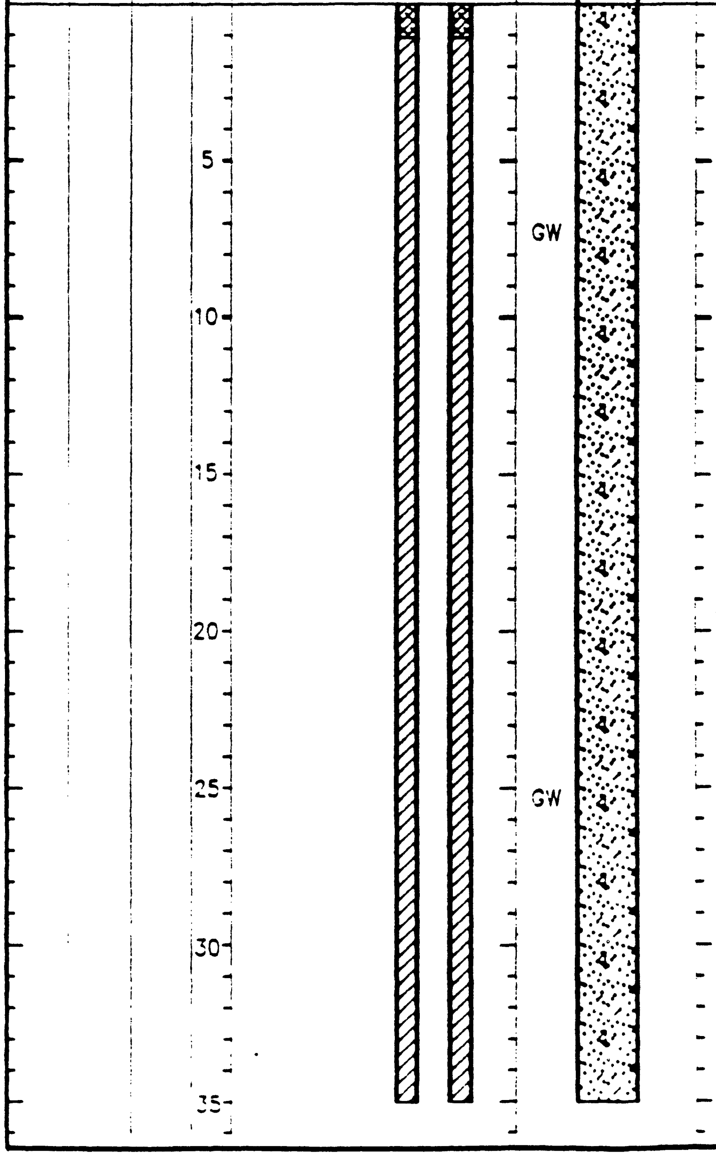
STATIC WATER ELEVATION

LOGGED BY S.J.R.

SAMPLING METHODS LOGGED FROM CUTTINGS

WELL COMPLETION
- SURFACE HOUSING
- STAND PIPE ____ FT.

SAMPLES: TYPE NO. | RECOVERY (FEET) | PENETRATION RESIST (BLWS/6 IN) | DEPTH (FEET) | WELL CONSTRUCTION | USCS LOG | LITHOLOGY | ppm/ppm | SAMPLE DESCRIPTION AND DRILLING REMARKS



Top few ft. moist, casing drives easily without drilling.

WELL GRADED GRAVEL

Reddish brown, subangular to subrounded gravels of red-purple and green quartzite; trace sand. dry.

Increasing sand, smaller gravels.

Lighter color (pale pink)—trace clay.

WELL GRADED GRAVEL WITH SAND:

(Some fine to coarse sand); red-brown, trace clay, dry.

Moist

WELL GRADED GRAVEL:

Red-brown, mostly larger gravels (to 1.5") that are subangular to subrounded dk gray and red-purple quartzite, dry.

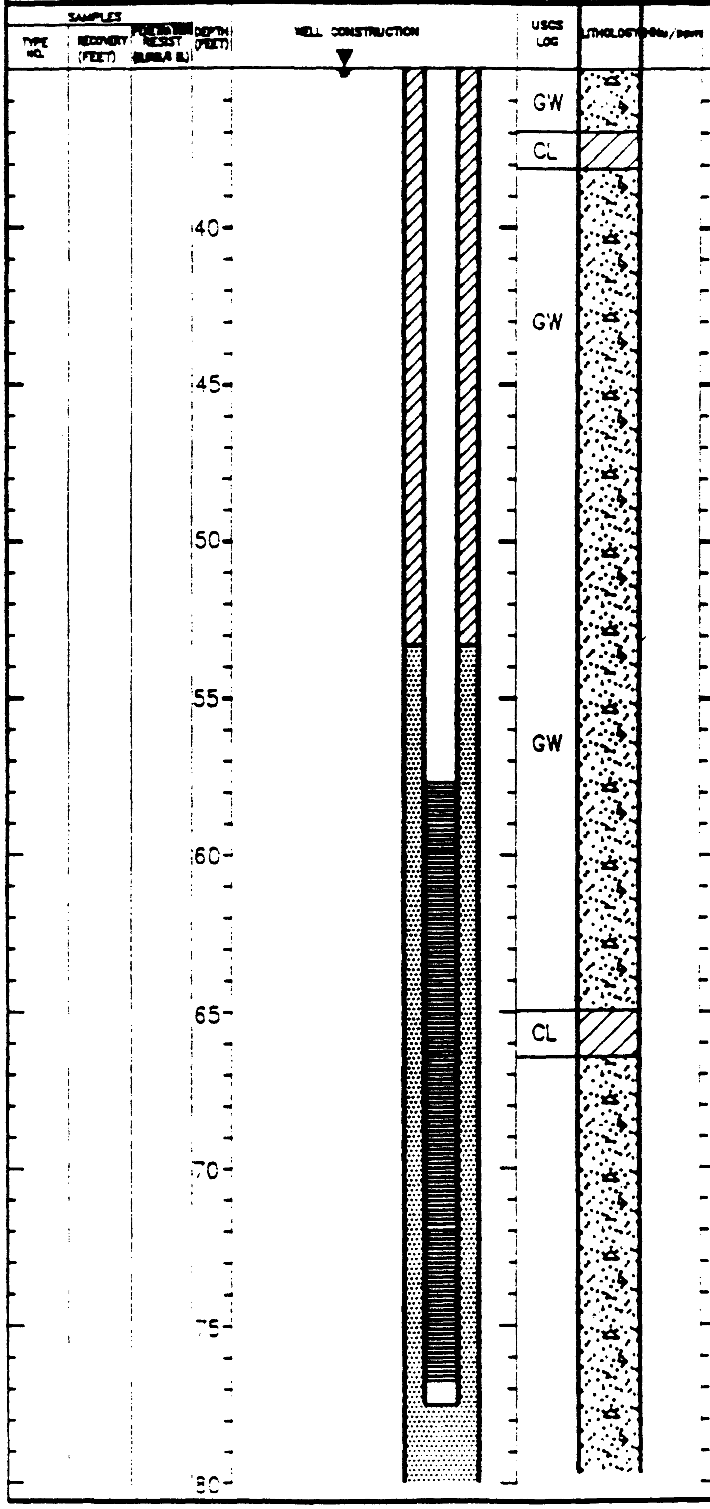
Increasing sand.

*drilling mechanical problems; quit 11 3 89; resumed 11 27 89

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name 3N–MISSOULA **Project Number** 896C04.09 **Boring/Well Name** M–28



SAMPLE DESCRIPTION AND DRILLING REMARKS

Top of poorly developed perched aquifier, Moist.

GRAVELLY LEAN CLAY WITH SAND:

Pinkish brown, some fine gravel and sand; difficult to estimate thickness. Moist

WELL GRADED GRAVEL:

Medium brown, trace sand, trace fines. Gravel up to 1/4" Moist.

Gravel decreasing in size; increasing amounts of coarse sand.

Dry to moist depending upon clay content; probably interbedded layers of gravel and sand and clay; clay holds water.

Moist; gravels increasing in size to 1" (mostly green and red quartzite)

Increasing clay content (still <5%), trace orange-brown quartz-eye ▼ rhyolite gravel.

GRAVELLY LEAN CLAY WITH SAND:

Medium brown, fine gravel
No returns until ~70 ft.(clay plugging casing)

WELL GRADED GRAVEL:

Medium brown, angular to rounded fine to coarse gravel in slurry of brown clay, silt fine sand and groundwater. Gravel to 1" in length

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name BN-MISSOULA **Project Number** 896004.09 **Boring/Well Name** W-28

SAMPLES								
TYPE NO.	RECOVERY (FEET)	PENETRATION RESIST (BLOWS/6 IN)	DEPTH (FEET)	WELL CONSTRUCTION	USCS LOG	LITHOLOGY	PID/ppm	SAMPLE DESCRIPTION AND DRILLING REMARKS
					GW			**WELL GRADED GRAVELS:** (As above)
			85					
			90					

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA

DRILLING COMPANY ESD INC. DRILLER J.C./E.H.

DRILLING METHOD AIR ROTARY DRILL BIT(S) SIZE 8"/6"

ISOLATION CASING 8-INCH STEEL CASING	FROM 0	TO 35	FT.
BLANK CASING 4-INCH SCH. 40 PVC	FROM -0.9	TO 49.5	FT.
PERFORATED CASING 4-INCH 0.020 SLOT PVC	FROM 49.5	TO 74.5	FT.
SIZE AND TYPE OF FILTER PACK 10-20 SILICA SAND	FROM 45	TO 75	FT.
SEAL BENTONITE CHIPS	FROM 1	TO 45	FT.
GROUT CEMENT	FROM 0	TO 1	FT.

Boring/Well Name M-29

Project Name BN-MISSOULA

Project Number 896004.09

ELEVATION AND DATUM 3208.95 TOTAL DEPTH 85

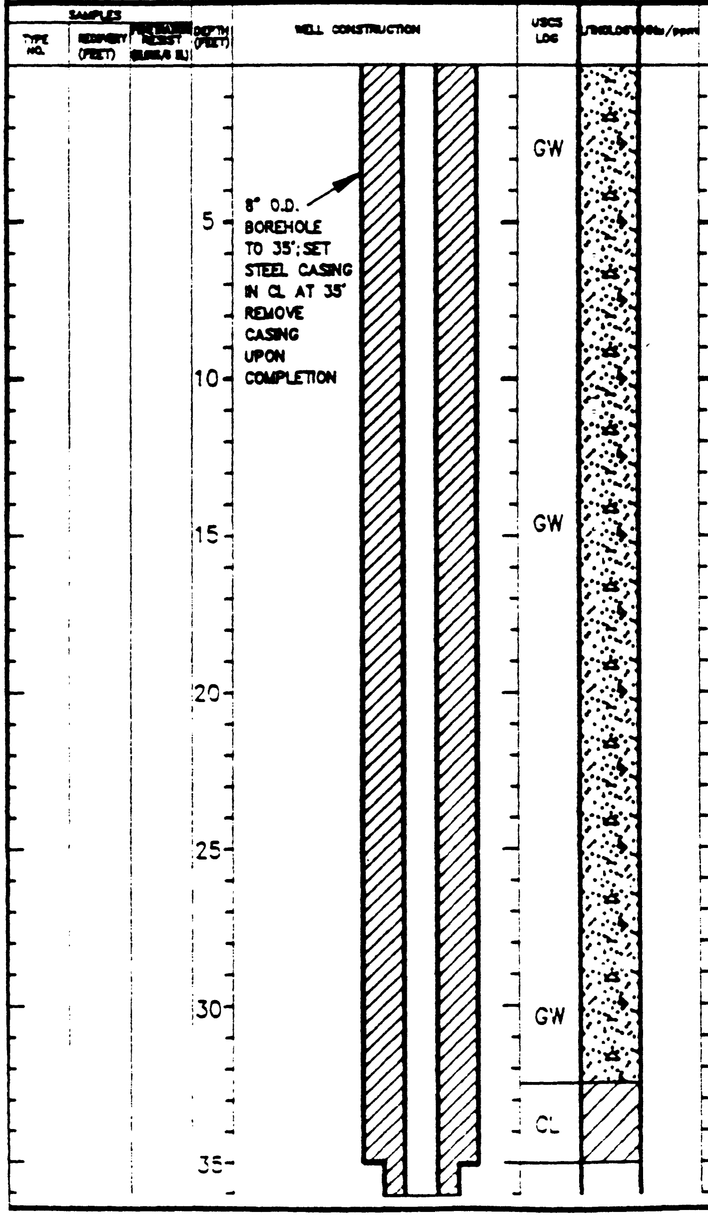
DATE STARTED 11/29/89 DATE COMPLETED 12/4/89

STATIC WATER ELEVATION

LOGGED BY S.J.R.

SAMPLING METHODS LOGGED FROM CUTTINGS

WELL COMPLETION ☐ SURFACE HOUSING ☒ STAND PIPE 1.9 FT.



SAMPLE DESCRIPTION AND DRILLING REMARKS

Gravels are being ground to sand-sized particles by 8-inch carbide-button rock bit.

WELL GRADED GRAVEL WITH SAND:

Tan to medium brown (dry color) coarse gravels ground by bit (according to EH) fine gravels are subrounded green and red siltite to quartzite; fine to coarse sand, dry.

Dark grey-brown, strong deisel odor

Dark grey, dry, less odor.

Wet, more odor.

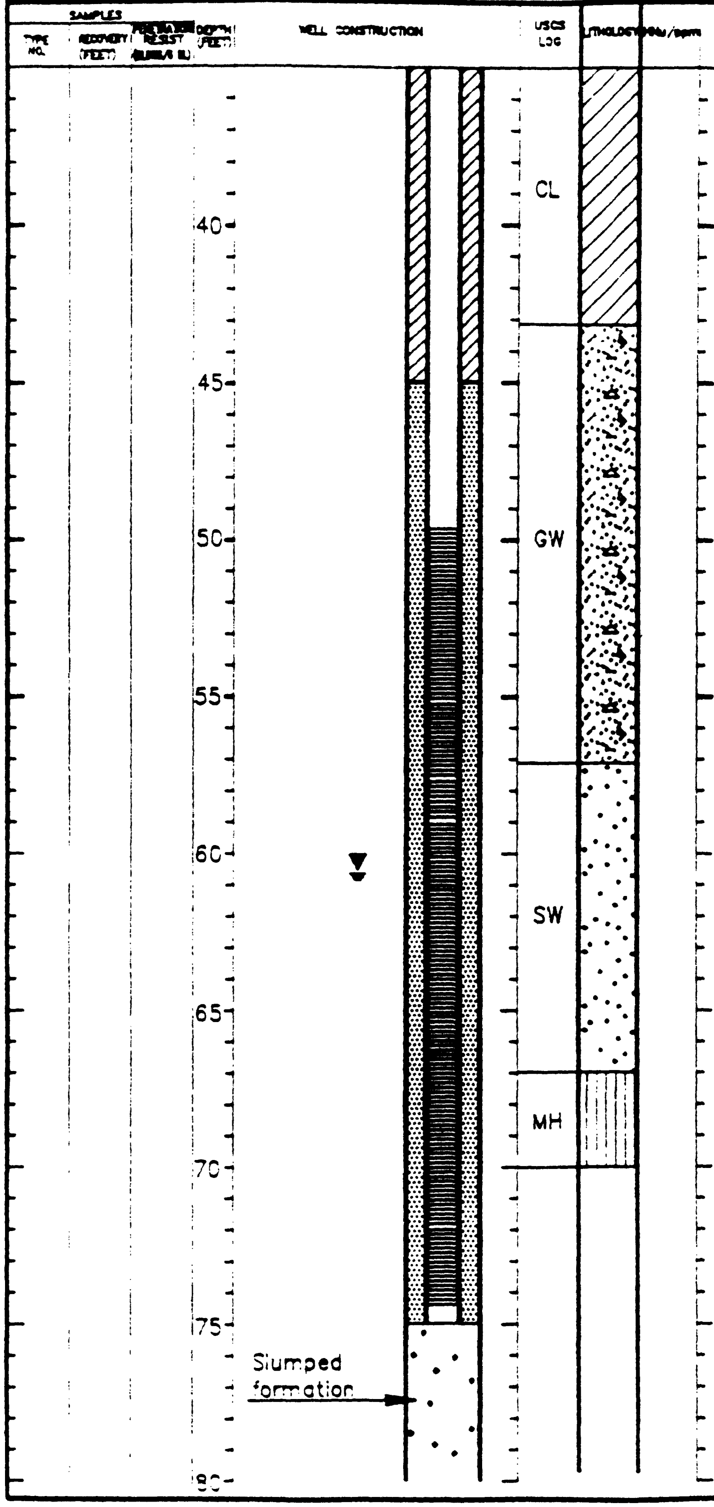
SANDY LEAN CLAY:

Medium pinkisn brown, some very fine to fine sand, faint odor, Wet, dark gray at top.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name BN-MISSOULA **Project Number** 896004.09 **Boring/Well Name** M-29



SAMPLE DESCRIPTION AND DRILLING REMARKS

SANDY LEAN CLAY:

As above.

No returNs, clay attachiNg to iNside of casing. Bit chatter, drilling gravels.

WELL GRADED GRAVEL WITH SAND:

Dark gray-brown, fine gravel up to 3/4" is angular to subrounded, mostly dk grey quartzite; minor green phyllite, pink quartzite; little very fine to coarse sand; trace silt, trace clay, dry.

WELL GRADED GRAVEL WITH SAND:

Dk grey-brown, very fine to medium subangular to angular quartzite and quartz grains; trace silt, moderate to strong diesel odor, moist.

SANDY ELASTIC SILT:

Medium brown, some very fine to fine sand, trace gravel, moderate to strong diesel odor, moist.

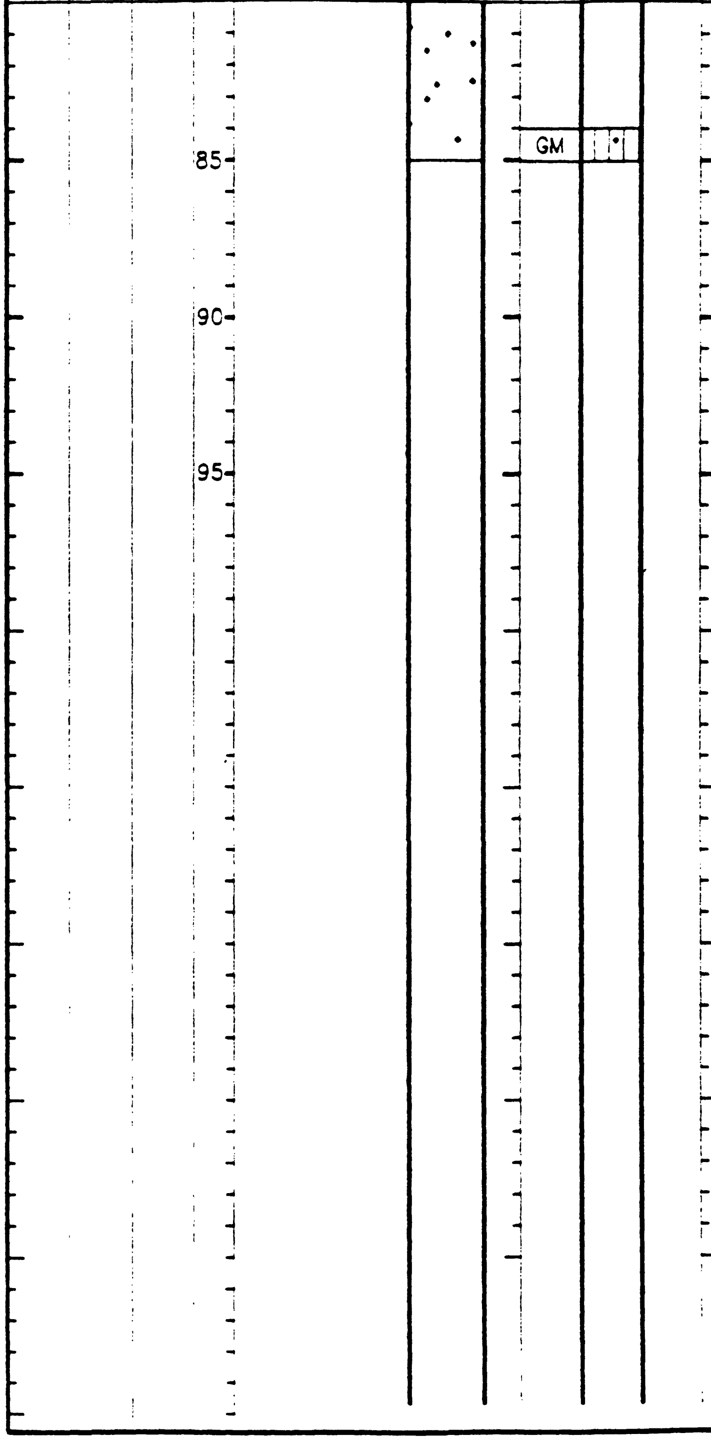
No returns 70'-84'
clays/silts plugging casing;
soft easy drilling; probably a mix of silt, clay, sand + fine gravel.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name BN-MISSCULA **Project Number** 896004.09 **Boring/Well Name** W-29

SAMPLES								
TYPE NO.	RECOVERY (FEET)	PENETRATION RESIST (BLOWS/6 IN)	DEPTH (FEET)	WELL CONSTRUCTION	USCS LOG	LITHOLOGY	[illegible]/ppm	SAMPLE DESCRIPTION AND DRILLING REMARKS



81'--bit chatter, larger gravels.

82'-84', soft again.

SILTY GRAVEL WITH SAND:

Medium brown, some very fine to medium coarse sand, fine angular to subrounded gravels, wet, faint odor.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA

DRILLING COMPANY ESD INC.

DRILLER J.C./E.H.

DRILLING METHOD AIR ROTARY

DRILL BIT(S) SIZE: 6"

Boring/Well Name M-3C

Project Name BN-MISSOULA

Project Number 896004.09

		FROM	TO	FT.
ISOLATION CASING				FT.
BLANK CASING	4-INCH SCH. 40 PVC	0	54	FT.
PERFORATED CASING	4-INCH 0.020 SLOT PVC	54	74	FT.
SIZE AND TYPE OF FILTER PACK	10-20 SILICA SAND	50	74	FT.
SEAL	3/8-inch BENTONITE CHIPS	1	50	FT.
GROUT	CONCRETE	0	1	FT.

ELEVATION AND DATUM 3206.41

TOTAL DEPTH 77'

DATE STARTED 12/5/89

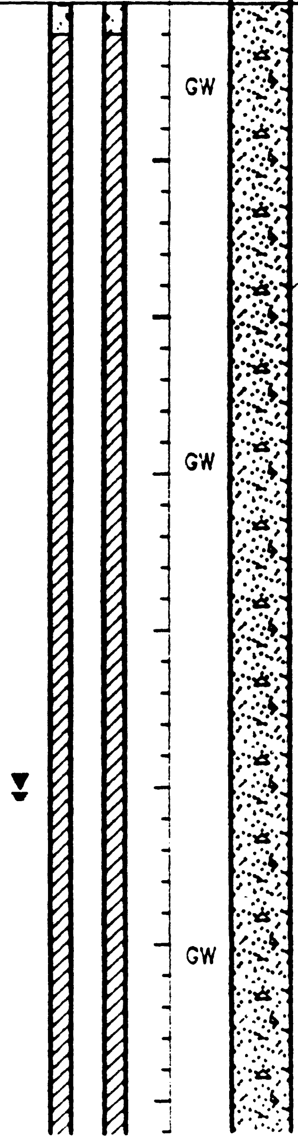
DATE COMPLETED 12/8/89

STATIC WATER ELEVATION

LOGGED BY S.J.R.

SAMPLING METHODS LOGGED FROM CUTTINGS

WELL COMPLETION
☒ SURFACE HOUSING
☐ STAND PIPE _____ FT.

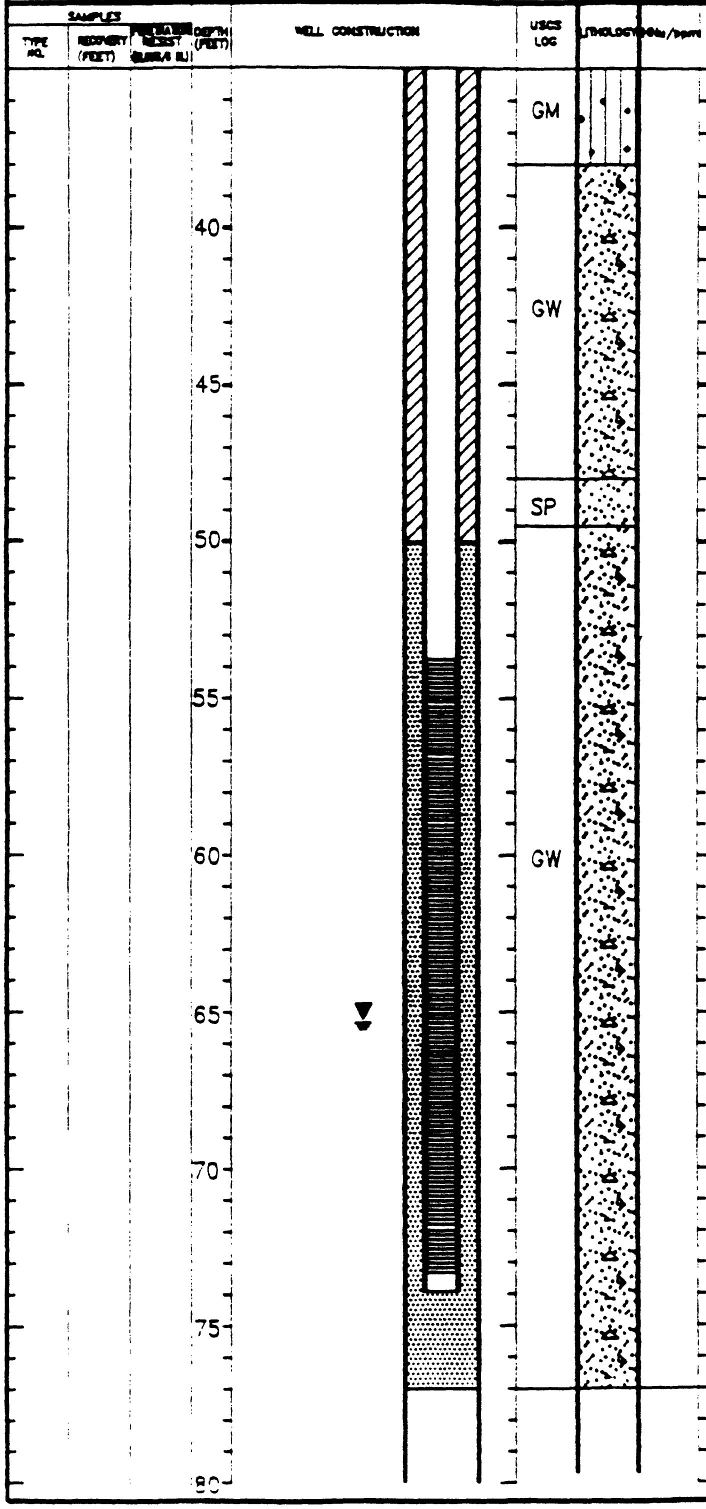


SAMPLES TYPE NO.	RECOVERY (FEET)	PENETRATION RESIST (BLOWS/6 IN)	DEPTH (FEET)	WELL CONSTRUCTION	USCS LOG	LITHOLOGY	OVM/ppm	SAMPLE DESCRIPTION AND DRILLING REMARKS
								(0"-6"-red paving bricks) **WELL GRADED GRAVEL:**
					GW			Medium brown, mostly subrounded to rounded, fine to coarse gravel of green and red quartzite; trace sand, moist, gravels to 1.5".
			5					
			10					
			15		GW			
								Reddish-brown, dry.
			20					
								Moist, faint odor, trace clay.
			25					Slight increase in sand; wet; strong fuel odor.
								Gravels slightly larger (to 2") slight increase in pink clay (as coating on gravels). Gravels flattened to elongate. wet, fuel odor.
			30		GW			
			35					

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name BN-MISSOULA **Project Number** 896004.09 **Boring/Well Name** M-3C



SAMPLE DESCRIPTION AND DRILLING REMARKS

SILTY GRAVEL WITH SAND:

Medium brown, mostly angular to subrounded fine gravels, little to some very fine to coarse sand, little to some silt, trace clay. wet, diesel odor

WELL GRADED GRAVEL:

Medium brown, mostly angular to rounded, some flattened and elongate, fine to coarse gravel, trace, sand/fines,moist,no odor.

40'—drier, still moist.

45'—mostly fine gravels.

POORLY GRADED SAND:

Dark brownish—grey, mostly medium angular to rounded sand of quartzite,quartz,grains,moist. fuel odor.

WELL GRADED GRAVEL:

Dark brownish—grey, mostly fine, subrounded to rounded gravel, few sand, moist, strong fuel odor.

51'—gravels coarsening, less sand, moist, strong odor.

Fine to coarse gravels, trace fines, wet, fuel odor.

Mostly coarse gravel to 1.5"
some fine gravel, trace fines
wet, fuel odor.
mostly fine gravel, some coarse
gravel, trace fines, wet, fuel odor

Figure **Kennedy/Jenks Engineers**

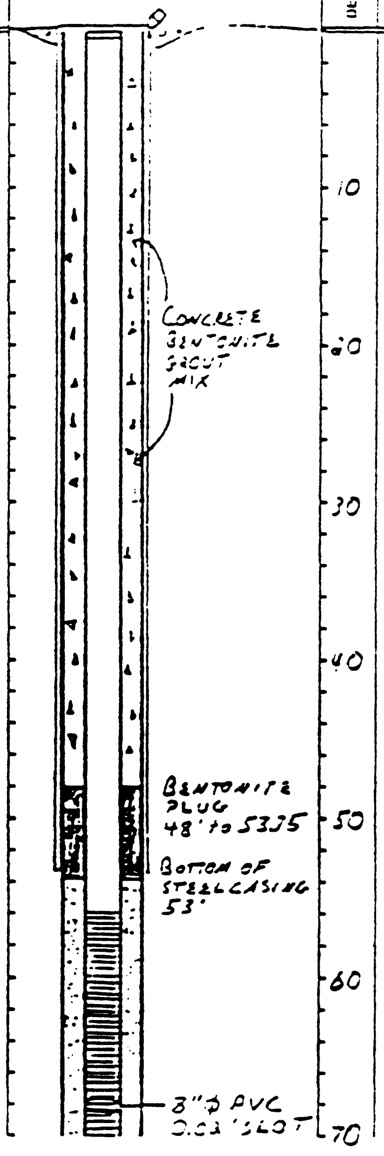
PROJECT BURLINGTON NORTHERN RAILROAD, MISSOULA
JOB NO. 866709 06
DATE 1/18/87
BY OL

BORING MR-1

Details of Boring and Well Construction

SURFACE ELEVATION:
DRILLING METHODS. AIR ROTARY
SAMPLING METHODS. CONTINUOUS MONITORING OF CUTTINGS; COLLECTION OF CUTTINGS AT SELECTED DEPTHS
DRILLER: HILLMAN DRILL CO

SAMPLE NUMBER	SAMPLER TYPE	BLOWS/FT INTERVAL	Well Construction	DEPTH IN FEET	USCS	SYMBOLS



SYMBOLS	
GM	0 to 6 SAND AND GRAVEL STAINED BLACK, 50% SAND 50% GRAVEL
	6 to 11 SANDY GRAVEL, TAN TO LIGHT BROWN
	@ 9 COBBLES
GP	11 to 30 GRAVELS WITH SOME SAND, UP TO 3" Φ HARD DRILLING
GM	30 to 45 SANDY GRAVEL UP TO 3" Φ, ROUNDED
GM	45 to 56 SANDY GRAVEL AND COBBLES HARD DRILLING
GP	56 to 68 GRAVELS AND COBBLES WITH SOME SAND ANGULAR, HARD DRILLING
	@ 68 SOFT DRILLING NO ROCK

Figure **Kennedy/Jenks Engineers**

PROJECT BURLINGTON NORTHERN RAILROAD
MISSOULA
JOB NO 2467C [illegible]

DATE 11/18/87
BY DL

BORING MR-1

Details of Boring and Well Construction

SURFACE ELEVATION:
DRILLING METHODS:
SAMPLING METHODS.
DRILLER:

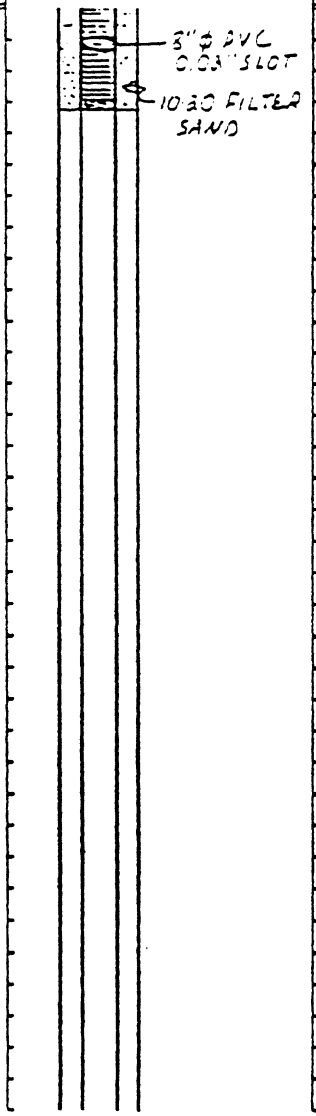
SAMPLE NUMBER	SAMPLER TYPE	BLOWS/FT INTERVAL	Well Construction	DEPTH IN FEET	USCS	SYMBOLS	
				80			SOFT DRILLING NO CUTTINGS

Figure **Kennedy/Jenks Engineers**

PROJECT BURLINGTON NORTHERN RAILROAD
MISSOULA
JOB NO 2-67029.06

DATE 11/20/87
BY OL

BORING MC-2

Details of Boring and Well Construction

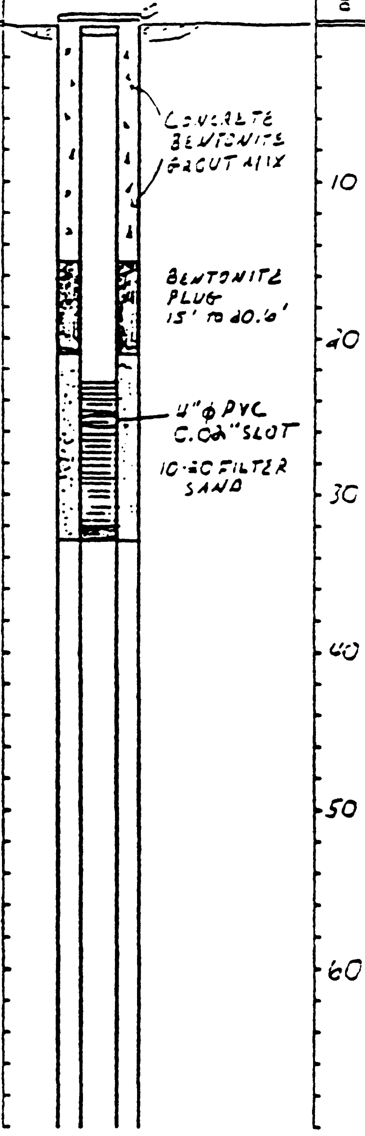
SURFACE ELEVATION:

DRILLING METHODS: AIR ROTARY

SAMPLING METHODS. CONTINUOUS MONITORING OF CUTTINGS; COLLECTION OF CUTTING AT SELECTED DEPTHS

DRILLER: HILLMAN DRILLING

Well Construction



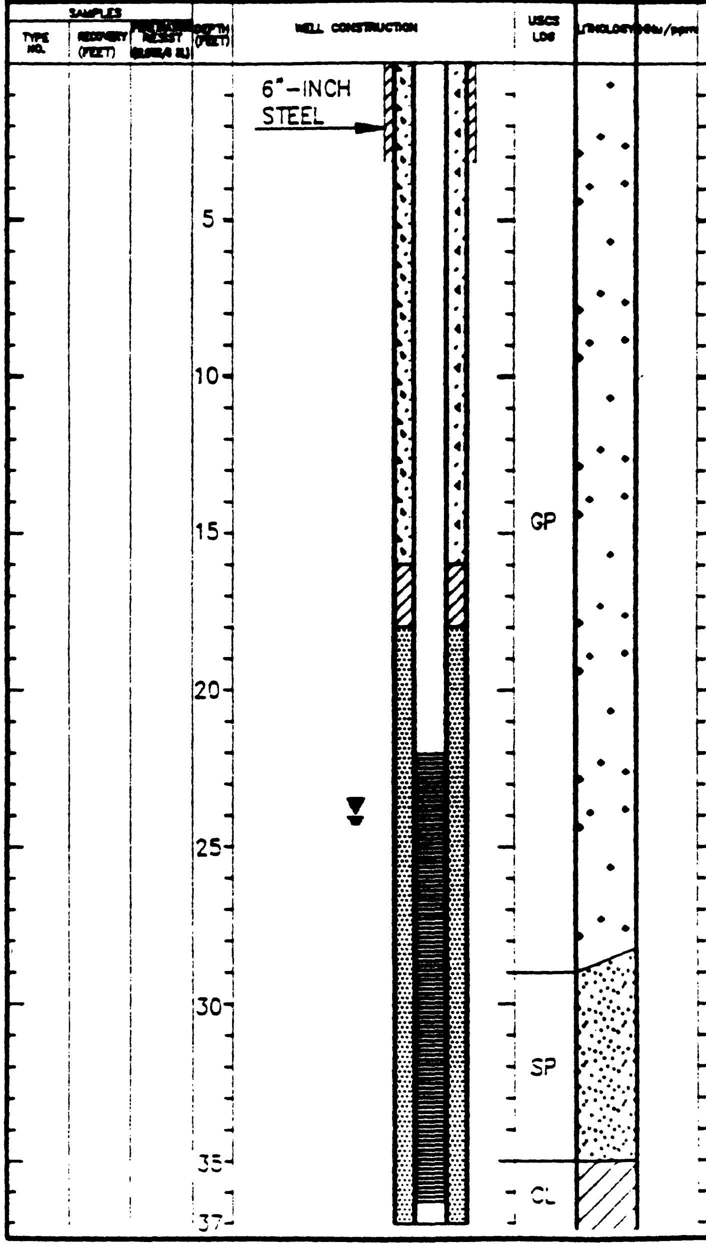
SAMPLE NUMBER	SAMPLER TYPE	BLOWS/FT INTERVAL	USCS	SYMBOLS	
				GM	0 to 5 SANDY GRAVEL, STAINED DARK
				SM	6 to 10 SILTY SAND, STRONG DIESEL ODOR
				GP	10 to 15 GRAVEL W/SAND UP TO 3" DIA., ROUNDED
				GM	15 to 23 SANDY GRAVEL, STAINED SILTY, MOIST
					23 to 33½ SILTY GRAVEL, LIGHT BROWN
				CL	@ 33½ CLAY LAYER

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA
DRILLING COMPANY ESD, INC. DRILLER E.H.
DRILLING METHOD AIR ROTARY DRILL BIT(S) SIZE: 5-7/8"
ISOLATION CASING 6" INCH STEEL FROM 0 TO 3 FT.
BLANK CASING 4-INCH SCH. 40 PVC FROM 0 TO 22 FT.
PERFORATED CASING 4-INCH 0.020 SLOT PVC FROM 22 TO 37 FT.
SIZE AND TYPE OF FILTER PACK 10-20 SILICA SAND FROM 18 TO 37 FT.
SEAL BENTONITE CHIPS FROM 15 TO 18 FT.
GROUT CONCRETE FROM 0 TO 15 FT.

Boring/Well Name MR-3
Project Name BN-MISSOULA
Project Number 896004.09
ELEVATION AND DATUM 3210.41 TOTAL DEPTH 37
DATE STARTED 8/5/89 DATE COMPLETED 8/6/89
STATIC WATER ELEVATION
LOGGED BY M.L.G.
SAMPLING METHODS LOGGED FROM CUTTINGS
WELL COMPLETION
☐ SURFACE HOUSING
☐ STAND PIPE 3 FT.



SAMPLE DESCRIPTION AND DRILLING REMARKS

POORLY GRADED GRAVELS WITH SAND:

Greyish Brown, Subrounded Red and Green Quartzite up to 1.5", Fine to Medium Grained, Stained with Diesel @ 0'-7', Moist.

Less odor.

As above-Reddish Brown. Increasing Sand with some Silt.

Moist to Saturated @ 23'. Smaller Gravel.

Diesel odor.

POORLY GRADED SAND:

Reddish Brown, Fine to Medium Grained, with Little Coarse Sand and Fine Gravel, Strong odor, Strained.

LEAN CLAY:

Brown with Fine to Medium Sand.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA

DRILLING COMPANY ESD, INC.

DRILLER E.H.

DRILLING METHOD AIR ROTARY

DRILL BIT(S) SIZE: 6"

ISOLATION CASING 6-INCH STEEL FROM 0 TO 5 FT.

BLANK CASING 4-INCH SCH.40 PVC FROM 0 TO 21 FT.

PERFORATED CASING 4-INCH 0.020 SLOT PVC FROM 21 TO 36 FT.

SIZE AND TYPE OF FILTER PACK 10-20 SILICA SAND FROM 17.8 TO 36 FT.

SEAL BENTONITE CHIPS FROM 14.5 TO 17.8 FT.

GROUT CONCRETE FROM 0 TO 14.5 FT.

Boring/Well Name MR-4

Project Name BN-MISSOULA

Project Number 896004.09

ELEVATION AND DATUM 3209.27

TOTAL DEPTH 36

DATE STARTED 8/6/89

DATE COMPLETED 8/6/89

STATIC WATER ELEVATION

LOGGED BY M.L.G.

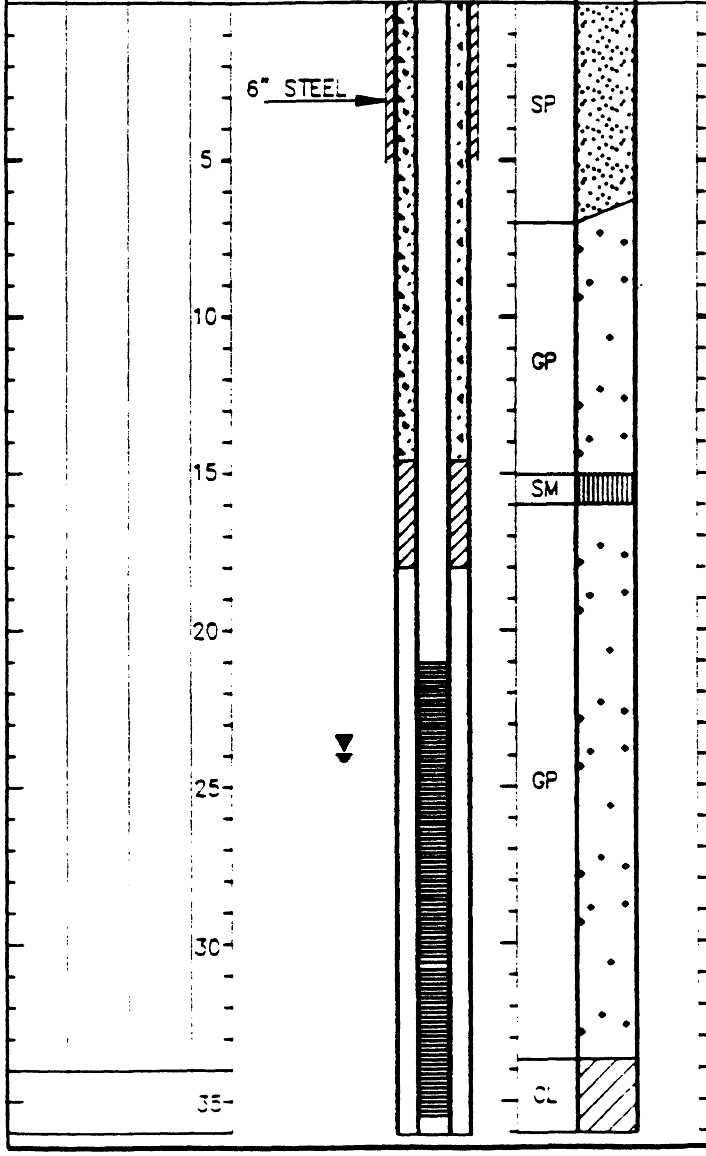
SAMPLING METHODS SPLIT SPOON SAMPLER

WELL COMPLETION

☐ SURFACE HOUSING

☐ STAND PIPE 2 FT.

SAMPLES								
TYPE NO.	RECOVERY (FEET)	PENETRATION RESIST (BLOWS/6 IN)	DEPTH (FEET)	WELL CONSTRUCTION	USCS LOG	LITHOLOGY	PPM/ppm	SAMPLE DESCRIPTION AND DRILLING REMARKS



POORLY GRADED SAND:

Reddish Brown, Fine to Medium Grained, with Some Fine Gravel, Damp.

POORLY GRADED GRAVEL:

Subrounded, up to 2".

Increasing Sand and Silt.

Diesel Odor @ 14'.

SILTY SAND:

Reddish Brown, Moist.

POORLY GRADED GRAVEL:

Subrounded Red and Green Quartzite, with Fine Sand, Dry to Damp.

With Increasing Sand and Silt, Damp.

Moist @ 23'.

Strong Diesel Odor.

As above-more Fine Sand and Silt, Strained.

Diesel odor

LEAN CLAY:

Brown, with Sand.

Boring & Well Construction Log

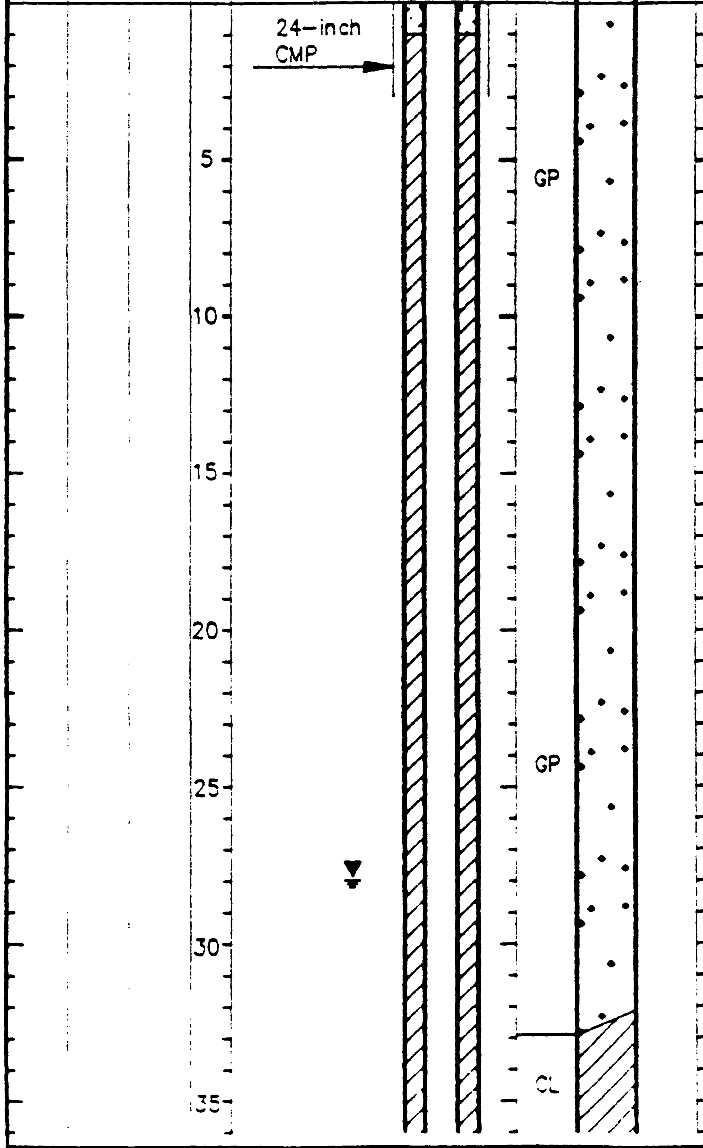
Kennedy/Jenks/Chilton

BORING LOCATION BN, MISSOULA, MONTANA
DRILLING COMPANY ESD, INC. DRILLER E.H.
DRILLING METHOD AIR ROTARY DRILL BIT(S) SIZE: 10"
ISOLATION CASING 24-INCH CMP FROM 0 TO 3 FT.
BLANK CASING 6-INCH SCH.40 PVC FROM 0 TO 57 FT.
PERFORATED CASING 6-INCH 0.020 SLOT PVC FROM 57 TO 77 FT.
SIZE AND TYPE OF FILTER PACK 10-20 SILICA SAND FROM 49 TO 70 FT.
SEAL BENTONITE CHIPS FROM 1 TO 49 FT.
GROUT CONCRETE FROM 0 TO 1 FT.

Boring/Well Name MR-5
Project Name BN-MISSOULA
Project Number 896004.09

ELEVATION AND DATUM 3207.20
TOTAL DEPTH 80
DATE STARTED 8/24/89
DATE COMPLETED 8/28/89
STATIC WATER ELEVATION
LOGGED BY M.L.G.
SAMPLING METHODS LOGGED FROM CUTTINGS
WELL COMPLETION
☐ SURFACE HOUSING
☒ STAND PIPE 0.5 FT.

SAMPLES: TYPE NO. | RECOVERY (FEET) | PENETRATION RESIST (BLOWS/6 IN.) | DEPTH (FEET) | WELL CONSTRUCTION | USCS LOG | LITHOLOGY | PPM/ppm | SAMPLE DESCRIPTION AND DRILLING REMARKS



POORLY GRADED GRAVEL WITH SAND:

Reddish Brown, Fine Grained, Damp.

As above-with Increasing Fine to Medium Sand.

Moist to Saturated @ 27'

Mostly Sand with some Fine Gravel.

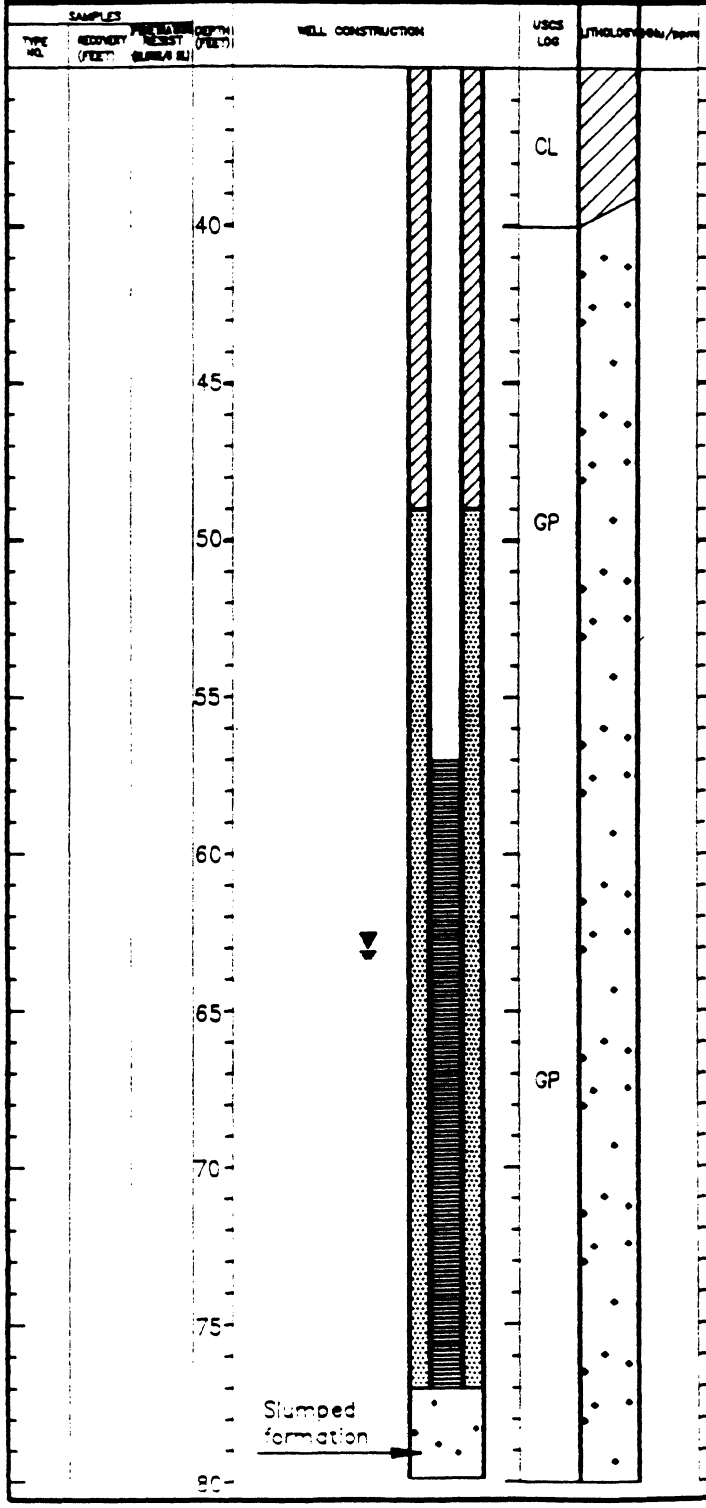
SILTY CLAY:

Brown, Poor Returns, with some Cobbles.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

Project Name BN-MISSOULA **Project Number** 896004.09 **Boring/Well Name** MR-5



SAMPLE DESCRIPTION AND DRILLING REMARKS

Drilling soft, Little returns.

POORLY GRADED GRAVELS WITH SAND:

Brown, Subrounded up to 2", Fine Grained, Moist.

Hard Drilling, Gravels and Cobbles.

Wet to Saturated.

Poor Returns, Drill with Water and Air.

Gravels.

Boring & Well Construction Log

Kennedy/Jenks/Chilton

BORING LOCATION BN MISSOULA MONTANA

DRILLING COMPANY ESD, INC. DRILLER J.C.

DRILLING METHOD AIR ROTARY DRILL BIT(S) SIZE 7" O.D.

ISOLATION CASING N/A FROM TO FT

BLANK CASING 2-INCH SCH 40 PVC FROM 0 TO 54.5 FT

PERFORATED CASING 2-INCH 0.020 SLOT PVC FROM 54.5 TO 74.5 FT.

SIZE AND TYPE OF FILTER PACK 10/20 SILICA SAND FROM 51 TO 75 FT.

SEAL BENTONITE CHIPS FROM 1 TO 51 FT

GROUT CONCRETE FROM 0 TO 1 FT

Boring/Well Name MP-1

Project Name BN-MISSOULA

Project Number 896004.09

ELEVATION AND DATUM 3209.60 TOTAL DEPTH 75 FEET

DATE STARTED 10/10/90 DATE COMPLETED 10/11/90

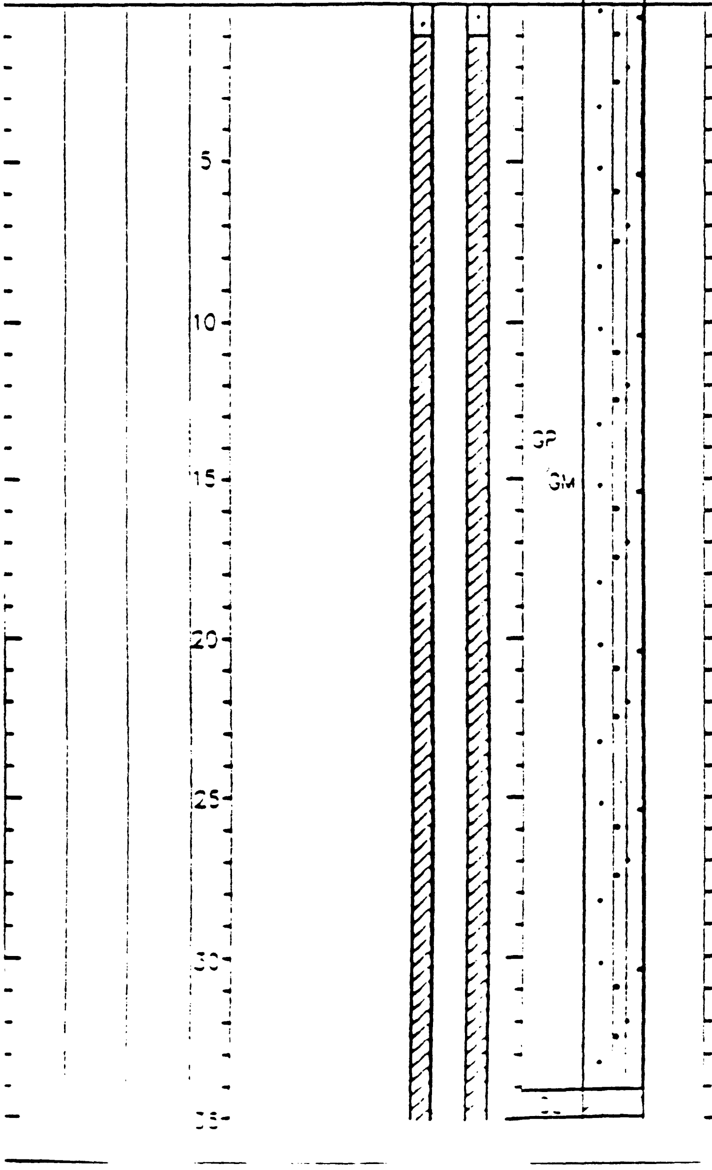
STATIC WATER ELEVATION

LOGGED BY M.L.G.

SAMPLING METHODS SPLIT-SPOON

WELL COMPLETION
☰ SURFACE HOUSING
☰ STAND PIPE ___ FT

SAMPLES								
TYPE NO	RECOVERY (FEET)	PENETRATION RESIST. (BLOWS/6 IN)	DEPTH (FEET)	WELL CONSTRUCTION	USCS LOG	LITHOLOGY	HNU	SAMPLE DESCRIPTION AND DRILLING REMARKS



Poorly Graded GRAVEL with Silt
Light brown, subrounded fine to coarse gravels with silt and sand, damp

Mostly silt 7-8 feet.

Gravel with less silt moist, diesel odor

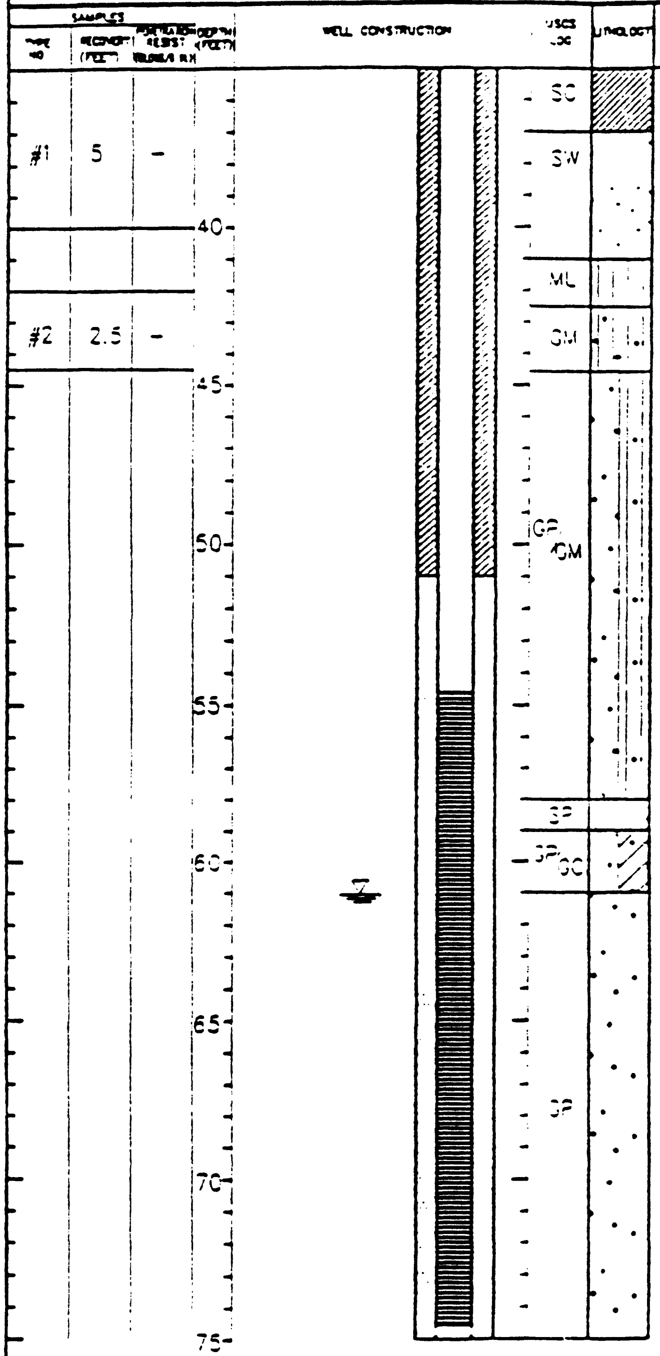
Sample refused

CLAY
Soft drilling, brown cuttings stained with diesel, wet to saturated

Boring & Well Construction Log

Kennedy/Jenks/Chilto

Project Name BN-MISSOULA **Project Number** 396004.09 **Boring/Well Name** MP-



SAMPLE DESCRIPTION AND DRILLING REMARKS

Clayey SAND
Reddish brown medium to coarse san
few gravels up to 1", wet, diesel odor

Well Graded SAND
Reddish brown, fine to coarse increasing
gravels, little silt, wet.

SILT with Sand
Brown increasing sand and fine grave
wet, fuel odor at 41 feet.

Silty GRAVEL
Brown, fine gravel moist.

Poorly Graded GRAVEL with Silt
Brown, subrounded fine gravels, with
silt and sand, moist, fuel odor

As Above.

Gravels 53-54 feet. Some clay presen

Poorly Graded SAND with Gravel
Brown to dark gray, fine to medium
sand with fine gravel, wet, stained
with diesel.

Poorly Graded GRAVEL with Clay
Brown to dark gray silty gravel. 6" [illegible]
at 60 feet (Drillers call), wet to
saturated stained with diesel.

Poorly Graded GRAVEL
Subrounded Red and Green Quartzite
1/2" to 1", very coarse sand, little
fines, saturated.

As Above.

APPENDIX B: WATER LEVEL DATA

WATER LEVEL MESUREMENTS

Well Number	Surveyed Well Elevation	1/25/90	2/25/90	3/25/90	4/17/90	4/25/90
M-7	3208.01	3177.94	3178.00	3178.00	3178.00	3177.98
M-8	3214.19				3150.59	3150.66
M-9	3214.59	DRY	DRY	DRY	DRY	DRY
M-10	3216.62	3149.04	3148.27	3148.06	3149.22	3150.01
M-11	3217.54	3150.21	3149.46	3149.27	3150.68	3151.61
M-12	3213.06	3149.57	3148.80	3148.75	3150.22	3151.04
M-13	3211.08	3149.83	3151.36	3151.54	3151.52	3151.44
M-14	3217.92	3190.28	3189.00	3189.96	3189.02	3190.08
M-15	3210.78	3142.96	3143.69	3142.85	3144.41	3144.90
M-16	3210.60	3178.20	3178.27	3178.27	3178.25	3178.23
M-17	3211.19	3149.03	3148.19	3147.99	3149.49	3150.63
M-18	3211.09	3174.71	3174.74	3174.74	3174.72	3174.70
M-19	3207.31	3177.35	3178.41	3178.41	3178.42	3178.42
M-20	3210.83	3176.16	3175.91	3175.95	3175.95	3175.95
M-21	3208.83	3148.09	3138.99	3143.89	3141.78	3143.43
M-22	3209.35	DRY	DRY	DRY	DRY	DRY
M-23	3209.07	3177.33	3177.26	3178.04	3178.29	3178.31
M-24	3206.07	3139.97	3138.95	3138.80	3140.65	3143.30
M-25	3204.79	3140.11	3139.09	3138.92	3141.86	3143.57
M-26	3205.54	3140.22	3139.21	3139.04	3141.99	3142.70
M-27	3209.80	3143.72	3142.71	3142.49	3146.28	3148.26
M-28	3208.20		3142.09	3141.87	3145.68	3147.76
M-29	3208.95	3165.64	3168.38	3168.63	3168.85	3168.82
M-30	3206.41	3140.15	3142.25	3138.94	3141.81	3143.49
M-R1	3213.32				3144.54	3145.23
M-R2	3208.27	3178.17	3178.23	3174.05	3178.20	3178.61
M-R3	3210.41	3175.21	3178.78	3176.13	3176.11	3176.09
M-R4	3209.27	3177.95	3178.01	3178.02	3178.00	3177.99
M-R5	3207.20	3140.93	3140.19	3140.09	3142.46	3142.85
MP-1	3209.60					

Well Number	Surveyed Well Elevation	5/1/90	5/8/90	5/15/90	5/22/90	5/31/90
M-7	3208.01	3177.96	3177.94	3177.94	3178.08	3178.11
M-8	3214.19	3150.59	3151.33	3151.33	3151.45	3151.86
M-9	3214.59	DRY	DRY	DRY	DRY	3154.42
M-10	3216.62	3150.91	3151.72		3151.93	3152.30
M-11	3217.54	3152.48	3152.98	3152.14	3153.31	3153.66
M-12	3213.06	3151.86	3152.03	3152.24	3152.59	3153.23
M-13	3211.08	3151.75	3151.67	3151.68	3152.03	3152.22
M-14	3217.92	3190.05	3189.94	3190.02	3190.08	3190.20
M-15	3210.78	3146.04	3146.02	3146.63	3147.33	3148.67
M-16	3210.60	3178.20	3178.19	3178.19	3178.34	3178.38
M-17	3211.19	3151.48	3151.97	3152.12	3152.32	3152.79
M-18	3211.09	3174.71	3174.68	3174.67	3174.76	3174.81
M-19	3207.31	3177.39	3178.37	3178.37	3177.52	3178.56
M-20	3210.83	3175.90	3176.21	3174.91	3174.98	3176.01
M-21	3208.83	3145.26	3145.16	3145.89	3146.65	3148.19
M-22	3209.35	DRY	DRY	DRY	DRY	3175.66
M-23	3209.07	3178.22	3178.18	3178.33	3178.62	3178.47
M-24	3206.07	3144.13	3145.03	3145.71	3146.49	3148.02
M-25	3204.79	3145.34	3145.21	3144.92	3146.70	3148.27
M-26	3205.54	3145.46	3145.33	3146.05	3146.84	3148.41
M-27	3209.80	3149.48	3148.79	3150.03	3149.97	3152.69
M-28	3208.20	3149.03			3150.61	3152.28
M-29	3208.95	3169.08	3168.54	3168.55	3168.67	3168.56
M-30	3206.41	3145.31	3145.20	3145.91	3146.70	3148.23
M-R1	3213.32	3144.61	3143.70	3143.77	3143.92	3143.91
M-R2	3208.27	3178.62	3178.17	3178.17	3178.32	3178.35
M-R3	3210.41	3176.06	3175.99	3175.99	3176.13	3176.12
M-R4	3209.27	3177.98	3177.94	3177.94	3178.07	3178.12
M-R5	3207.20	3145.67	3145.63	3146.32	3147.06	3148.40

Well Number	Surveyed Well Elevation	6/8/90	6/14/90	6/22/90	7/10/90	8/8/90
M-7	3208.01	3178.07	3178.11	3178.09	3178.15	3178.17
M-8	3214.19	3152.04	3152.14	3152.22	3153.02	3151.79
M-9	3214.59	3155.78	3156.15	3156.16	3155.45	3153.19
M-10	3216.62	3152.61	3152.96	3153.27	3154.49	3152.24
M-11	3217.54	3154.01	3154.28	3154.48	3155.32	3153.51
M-12	3213.06	3154.84	3154.08	3155.09	3153.98	3152.53
M-13	3211.08	3152.79	3153.09	3153.22	3152.80	3151.85
M-14	3217.92	3190.24	3190.25	3190.23	3190.18	3190.43
M-15	3210.78	3150.46	3150.91	3150.95	3149.91	3147.02
M-16	3210.60	3178.38	3178.36	3178.35	3178.39	3178.45
M-17	3211.19	3153.19	3153.49	3153.70	3154.46	3152.45
M-18	3211.09	3174.88	3174.87	3174.92	3174.91	3174.85
M-19	3207.31	3178.56	3178.55	3178.54	3178.59	3178.62
M-20	3210.83	3175.02	3176.03	3176.01	3176.14	3176.12
M-21	3208.83	3150.02	3150.40	3149.91	3148.87	3145.95
M-22	3209.35	3174.59	3175.47	3175.38	3175.37	3175.35
M-23	3209.07	3178.47	3178.33	3178.07	3179.06	3178.83
M-24	3206.07	3149.85	3150.20	3150.07	3148.94	3145.77
M-25	3204.79	3149.08	3150.42	3150.28	3149.09	3145.91
M-26	3205.54	3150.23	3150.56	3150.43	3149.22	3146.02
M-27	3209.80	3154.12	3153.28	3154.17	3152.71	3149.22
M-28	3208.20	3153.73	3153.92	3153.82	3152.34	3148.88
M-29	3208.95	3167.93	3159.03	3151.42	3151.22	3150.14
M-30	3206.41	3149.06	3150.44	3149.53	3149.70	3146.66
M-R1	3213.32	3144.00	3145.10	3144.51	3143.42	3143.94
M-R2	3208.27	3178.36	3178.30	3178.31	3178.36	3178.44
M-R3	3210.41	3176.23	3176.30	3176.17	3176.23	3176.20
M-R4	3209.27	3178.12	3178.12	3178.09	3178.13	3178.15
M-R5	3207.20	3150.09		3150.09	3149.74	

Well Number	Surveyed Well Elevation	9/3/90	10/20/90	12/10/90	1/11/91	2/13/91
M-7	3208.01	3178.12	3178.01	3177.98	3178.11	3178.20
M-8	3214.19	3151.62	3150.94	3152.56	3151.32	3151.97
M-9	3214.59	DRY	DRY			
M-10	3216.62	3151.94	3146.99	3152.72	3152.45	3152.12
M-11	3217.54	3153.36	3152.36	3153.01	3152.71	3151.36
M-12	3213.06	3152.37	3151.50	3150.54	3150.20	3149.59
M-13	3211.08	3151.43	3151.72	3151.40	3151.26	3151.34
M-14	3217.92	3190.54	3190.32	3190.45	3189.41	3190.17
M-15	3210.78	3146.67	3145.91	3145.28	3145.48	3145.48
M-16	3210.60	3178.37	3178.26	3178.27	3178.37	3178.45
M-17	3211.19	3152.24	3151.04	3152.07	3151.74	3151.39
M-18	3211.09	3174.86	3174.76	3174.67	3174.78	3174.92
M-19	3207.31	3178.56	3178.41	3178.44		3178.61
M-20	3210.83	3176.78	3176.01	3175.95	3176.05	3176.16
M-21	3208.83	3145.52	3142.96	3140.57	3139.95	3139.27
M-22	3209.35	DRY	3175.24	3175.20		3174.44
M-23	3209.07	3178.61	3178.36	3178.42	3178.29	3179.05
M-24	3206.07	3145.36	3142.76	3140.43	3139.78	3139.20
M-25	3204.79		3142.95	3140.59	3139.99	3139.37
M-26	3205.54	3145.65	3143.06	3140.72	3140.11	3139.48
M-27	3209.80	3149.48	3146.86	3144.53		3143.17
M-28	3208.20	3148.99	3146.40	3143.92	3143.27	
M-29	3208.95	3149.69	3149.48	3149.43	3149.51	3149.53
M-30	3206.41	3144.03	3144.03	3140.59	3140.01	3139.35
M-R1	3213.32	3143.50	3143.40	3151.92	3152.34	3152.00
M-R2	3208.27	3179.23	3178.26	3178.27		3178.44
M-R3	3210.41	3176.17	3176.13	3176.02	3176.22	3176.30
M-R4	3209.27	3178.09	3178.02	3178.02	3178.10	3178.19
M-R5	3207.20		3143.61		3140.58	3140.01
MP-1	3209.60					

Well Number	Surveyed Well Elevation	3/17/91	4/3/91	4/18/91	5/3/91	5/9/91
M-7	3208.01	3178.21	3178.20	3178.17	3178.15	3178.16
M-8	3214.19	3151.78	3151.68	3151.22	3150.89	3151.04
M-9	3214.59					
M-10	3216.62	3150.90	3151.75	3151.39	3150.19	3150.25
M-11	3217.54	3154.56	3152.13	3151.11	3151.80	3150.83
M-12	3213.06	3147.76	3149.56	3149.74	3150.42	3150.62
M-13	3211.08	3150.87	3151.40	3151.11	3150.91	3150.94
M-14	3217.92	3190.00	3189.93	3189.98	3190.06	3190.04
M-15	3210.78	3145.56	3145.76	3145.60	3145.70	3145.79
M-16	3210.60	3178.46	3178.43	3178.43	3178.40	3178.42
M-17	3211.19	3151.21	3145.11	3150.96	3150.34	3150.26
M-18	3211.09	3174.90	3174.86	3174.86	3174.87	3174.91
M-19	3207.31	3178.63	3178.60	3178.58	3178.55	3178.57
M-20	3210.83	3176.16	3176.19	3176.19	3176.19	3176.22
M-21	3208.83	3139.48	3139.35	3140.32	3141.66	3141.88
M-22	3209.35	3174.44	3175.33	3175.29	3175.25	3175.22
M-23	3209.07	3178.50	3178.51	3178.57	3178.42	3178.32
M-24	3206.07	3139.37	3139.24	3140.20	3141.57	3141.75
M-25	3204.79	3139.56	3139.41	3140.38	3141.66	3141.94
M-26	3205.54	3139.67	3139.52	3140.50	3141.85	3142.07
M-27	3209.80	3143.38	3143.15	3143.09	3145.92	3145.92
M-28	3208.20	3142.76	3142.46	3143.48	3144.31	3145.48
M-29	3208.95	3149.52	3149.57	3149.53	3149.51	3149.55
M-30	3206.41	3139.53	3139.57	3140.69	3141.84	3141.96
M-R1	3213.32	3151.74	3151.65		3145.93	3143.92
M-R2	3208.27	3178.45	3178.44	3178.40	3178.39	3178.36
M-R3	3210.41	3176.35	3176.38	3176.37	3176.41	3176.40
M-R4	3209.27	3178.20	3178.15	3178.16	3178.12	3178.08
M-R5	3207.20	3140.32	3140.43	3141.10	3142.58	3142.81
MP-1	3209.60					

Well Number	Surveyed Well Elevation	5/20/91	5/28/91	6/9/91	6/26/91	7/16/91
M-7	3208.01	3178.28	3178.21	3178.22	3178.77	3178.27
M-8	3214.19	3153.33	3152.33		3157.18	3156.65
M-9	3214.59				3156.23	3154.60
M-10	3216.62	3153.46	3152.81	3155.94	3157.27	3156.63
M-11	3217.54	3153.10	3154.24	3156.33	3157.50	3156.93
M-12	3213.06	3150.65	3152.70	3154.08	3155.16	3153.54
M-13	3211.08	3151.21	3151.96	3152.70	3153.74	3152.70
M-14	3217.92	3190.02	3190.21	3190.08	3190.12	3189.94
M-15	3210.78	3146.49	3148.53	3150.45	3151.69	3150.00
M-16	3210.60	3178.54	3178.46	3178.49	3178.88	3178.54
M-17	3211.19	3153.41	3153.17	3155.72	3156.84	3156.11
M-18	3211.09	3175.02	3175.00	3175.00	3176.10	3175.01
M-19	3207.31	3177.70	3178.63	3178.63	3179.03	3178.72
M-20	3210.83	3176.34	3176.26	3176.25	3176.63	3176.22
M-21	3208.83	3144.56	3148.03	3149.71	3150.54	3148.51
M-22	3209.35	3175.06	3175.13	3175.41	3176.23	3176.37
M-23	3209.07	3178.99	3178.83	3178.64	3178.91	3178.69
M-24	3206.07	3144.47	3147.85	3149.47	3150.39	3147.29
M-25	3204.79	3144.76	3148.13	3149.74	3149.60	3148.47
M-26	3205.54	3143.91	3148.29	3149.89	3150.76	3147.58
M-27	3209.80	3150.98	3153.14	3155.55	3155.82	3151.58
M-28	3208.20	3148.25	3152.64	3151.77	3153.00	3151.25
M-29	3208.95	3149.64	3149.97	3150.16	3151.15	3149.31
M-30	3206.41	3144.80	3148.27	3149.76	3150.78	3149.28
M-R1	3213.32				3157.20	3156.57
M-R2	3208.27	3178.47	3178.46	3178.46	3178.89	3178.54
M-R3	3210.41	3176.45	3176.39	3176.40	3177.65	3176.45
M-R4	3209.27	3178.45	3178.19	3178.21	3178.95	3178.27
M-R5	3207.20	3144.61	3148.07	3149.54	3150.51	3149.14

Well Numbe	Surveyed Well Elevation	11/14/91	12/10/91
M-7	3208.01	3154.12	3184.123
M-8	3214.19	3214.59	3153.075
M-9	3214.59	3154.26	3214.59
M-10	3216.62	3154.5	3153.337
M-11	3217.54	3150.86	3154.19
M-12	3213.06	3149.9	3150.45
M-13	3211.08	3217.92	3151.51
M-14	3217.92	3148.28	3190.26
M-15	3210.78	3210.6	3147.961
M-16	3210.60	3153.55	3178.164
M-17	3211.19	3211.09	3152.709
M-18	3211.09	3207.31	3174.858
M-19	3207.31	3210.83	3178.29
M-20	3210.83	3141.68	3176.1
M-21	3208.83	3209.35	3140.997
M-22	3209.35	3209.07	3209.35
M-23	3209.07	3141.66	3178.023
M-24	3206.07	3141.85	3140.87
M-25	3204.79	3141.99	3140.05
M-26	3205.54	3146.02	3141.19
M-27	3209.80	3145.45	3145.27
M-28	3208.20	3147.37	3144.62
M-29	3208.95	3141.89	3148.927
M-30	3206.41	3153.78	3141.13
M-R1	3213.32	3208.27	3213.32
M-R2	3208.27	3210.41	3178.137
M-R3	3210.41	3209.27	3176.328
M-R4	3209.27	3141.65	3177.946
M-R5	3207.20	3142.3	
MP-1	3209.60		3141.168

APPENDIX C: APPARENT PRODUCT THICKNESS DATA

APPARENT PRODUCT THICKNESSES

Well	25	56	78	107	115	121	128	135	142	151
No.	1/25/90	2/25/90	3/25/90	4/17/90	4/25/90	5/1/90	5/8/90	5/15/90	5/22/90	5/31/90
M-7	0.61	0.56	0.56	0.60	0.55	0.58	0.04	0.56	0.56	0.57
M-8	NA			0.00	0.00	0.01	0.00	0.00	0.00	0.00
M-9	0.00	0.00			0.00	0.00	0.00	0.00	0.00	
M-10	0.01	0.27	0.52	0.02	0.00	0.00	0.00		0.00	0.00
M-11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-13	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-15	0.00		0.04	0.05					0.00	0.00
M-16	0.34	0.32	0.32	0.35	0.36	0.40	0.40	0.40	0.40	0.40
M-17	1.65	1.20	1.01	0.99	0.47	0.41	0.63	0.50	0.39	0.44
M-18	0.20	0.00	0.18	0.20	0.20	0.19	0.20	0.22	0.17	0.27
M-19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-21	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-22	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00
M-23	0.00	0.00	0.88	1.17	0.06	1.10	1.11	1.22	0.98	1.40
M-24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-28		0.00	0.00	0.00	0.00	0.00			0.00	0.00
M-29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-R1									0.00	0.00
M-R2	0.70	0.80	0.81	0.83	1.24	1.25	0.80	0.77	0.90	0.93
M-R3	0.25	0.80	0.73	0.76	0.77	0.91	1.29	1.11	1.35	2.06
M-R4	0.68	0.65	0.75	0.74	0.72	0.72	0.69	0.63	0.79	0.88
M-R5	0.20	0.02	0.22	0.99	1.36	1.43	1.53	1.46	1.05	1.20

Well	160	166	174	192	221	247	294	345	377	410
No.	6/8/90	6/14/90	6/22/90	7/10/90	8/8/90	9/3/90	10/20/90	12/10/90	1/11/91	2/13/91
M-7	0.52	0.61	0.63	0.57	0.73	0.70	0.68	0.54	0.60	0.71
M-8	0.01	0.00	0.00	0.03	0.00	0.00	0.03	0.04	0.02	0.04
M-9	0.00	0.00	0.00	0.00	0.00	0.00				
M-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-15	0.02	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
M-16	0.39	0.39	0.42	0.45	0.40	0.47	0.46	0.48	0.52	0.65
M-17	0.29	0.29	0.46	0.43	0.53	0.42	1.01	0.10	0.00	0.00
M-18	0.31	0.31	0.32	0.31	0.31	0.34	0.36	0.20	0.31	0.25
M-19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
M-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-21	0.00	0.02	4.60	2.37	0.59	0.05	0.04	0.05	0.04	0.01
M-22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
M-23	1.42	1.42	1.00	0.38	0.70	0.79	0.96	1.38	1.36	0.55
M-24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
M-28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-R1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.66
M-R2	0.99	0.99	0.98	0.97	0.92	1.95	0.85	0.81	7.00	0.97
M-R3	1.73	1.73	1.74	0.98	0.93	1.00	0.86	1.30	1.09	1.20
M-R4	0.88	0.88	0.80	0.69	0.92	0.88	0.80	0.79	1.06	0.97
M-R5	0.80	0.80	0.14	0.32			1.18	0.00	0.19	0.19
MP-1							2.88	0.00	0.07	0.25

Well	442	459	474	489	495	506	514	526	543	563
No.	3/17/91	4/3/91	4/18/91	5/3/91	5/9/91	5/20/91	5/28/91	6/9/91	6/26/91	7/16/91
M-7	0.83	0.77	0.80	0.81	0.81	0.82	0.80	0.66	0.00	0.82
M-8	0.47	0.58	0.31	0.00	0.01	0.11	0.08		0.00	0.01
M-9										
M-10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-15	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.02	0.01
M-16	0.52	0.62	0.52	0.58	0.60	0.62	0.69	0.56	0.61	0.73
M-17	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-18	0.30	0.41	0.36	0.50	0.42	0.38	0.37	0.39	0.23	0.11
M-19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-21	0.06	0.01	0.05	0.01	0.01	0.00	0.00	0.00	0.00	0.64
M-22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-23	1.07	1.16	1.38	1.28	1.27	1.13	0.76	0.83	0.85	0.86
M-24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-R1	0.63	0.68		0.00	0.00	0.00	0.00	0.00	0.01	0.03
M-R2	0.98	1.09	1.04	1.02	0.99	0.97	1.04	1.06	1.54	1.17
M-R3	0.74	0.47	0.28	0.21	0.24	0.11	0.84	0.64	0.56	0.89
M-R4	1.06	1.02	0.96	1.17	1.65	0.02	1.01	0.94	0.00	0.81
M-R5	0.24	0.44	0.61	1.16	1.44	1.82	1.37	0.07	0.00	0.00
MP-1	0.02	0.01	0.04	0.02	0.16	0.00	0.40	0.01	0.00	0.36

APPENDIX D: WATER QUALITY DATA

#	Sample	Al2373	As1936	Ca3179	Cd2288	Cu3247	Fe2599	K 7665	Mn2576	Mg2576
1	m-9	-0.019	0.03	57.5	0.0018	0.0223	0.001	-0.93	13.4	0.02
2	m-11	-0.004	0.049	115	0.0001	0.0127	0.0948	-30	52.8	4.346
3	m-11 duplicate	-0.01	0.006	109	0.0003	0.0096	0.0925	-2.5	50.8	4.129
4	m-12	-0.018	0.049	117	0.001	0.0317	0.0364	-29	26.3	1.591
5	m-14	0.136	0.008	23.1	0.0012	0.0107	0.2773	-0.27	9.14	0.0721
6	m-14 duplicate	0.13	0.015	22.6	0.0003	0.0082	0.2769	0.93	8.87	0.0695
7	m-19	-0.035	0.021	72.9	0.0003	0.0008	0.1012	-1.1	15.7	0.3357
8	m-20	0.016	0.008	51.3	0.0015	0.0071	0.0181	-0.78	12.5	0.0153
9	m-24	-0.005	0.011	50.1	0.0007	0.0342	0.0098	0.19	12.5	0.012
10	m-25	0.004	0.011	49	0.0019	0.0274	0.0072	-1.7	13.3	0.0036
11	m-26	0.021	0	39.9	0.0034	0.0353	0.036	0.62	11.4	0.0184
12	m-27	-0.022	0.006	90.5	0.0025	0.0192	0.401	-0.08	27.8	0.0433
13	m-28	-0.009	0.001	42.2	0.0003	0.0184	0.1501	0.3	12.7	0.0125
14	m-29	0.268	0.058	66.3	0.0013	0.0249	8.165	-1.4	13.8	1.077
15	m-30	-0.028	-0.001	85.5	0	0.0054	0.0443	-0.33	27.1	1.391
16	std 1 blank	-0.018	0.01	0.21	0	-0.0028	-0.0005	-0.78	0.003	0.0001
17	std 2	0.002	-0.02	100	9.978	9.94	0.166	-1.7	99.2	9.9
18	std 2	-0.008	-0.004	101	10.08	10.16	0.1684	-2.3	98.4	9.832
19	std 2	0.011	-0.015	100	9.962	9.927	0.1682	-20	100	10.01
20	std1-blank	-0.011	0.002	0.199	-0.0021	-0.0037	-0.0005	-0.38	-0.017	0.0001
21	water blank	-0.022	-0.002	-0.005	-0.0003	-0.0034	-0.0022	7.2	1.45	0.1426
22	water blank	-0.019	-0.008	0.021	0.0027	0.0054	-0.0046	-0.36	-0.025	-0.0004
23	water blank	-0.036	0.004	0.019	0.0024	0.0048	-0.0036	-0.66	-0.015	0.0015
24	water blank	0.009	0.004	1.52	0.1543	0.1366	0.0098	0.31	-0.011	0.0019

Averages Thu 08-15

#	Sample	Na5890	Ni2316	P 2149	Pb2204	Sb2068	Si2881	Ti3349	Zn2138
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1	m-9	4.14	0.005	0.071	-0.009	0.027	6.03	-0.0065	0.3929
2	m-11	41.8	0.009	0.218	-0.007	0.202	5.74	-0.0094	0.0339
3	m-11 duplicate	34.3	0.007	0.174	-0.009	0.158	5.52	-0.0093	0.0326
4	m-12	5.15	0.003	0.136	0.006	0.081	10.7	-0.0103	0.0396
5	m-14	41.3	0.001	0.075	-0.005	0.024	3.56	-0.0002	0.013
6	m-14 duplicate	34.3	0.001	0.101	0.001	0.002	3.43	-0.0014	0.0133
7	m-19	5.26	0.001	0.094	-0.013	0.031	5.86	-0.0072	0.0171
8	m-20	3.79	0.003	0.048	0.003	0.031	5.55	-0.005	0.052
9	m-24	4.52	0.004	0.079	0	0.031	4.54	-0.0054	0.1724
10	m-25	4.5	0.001	0.09	0	0.011	5.32	-0.0052	0.0783
11	m-26	4.59	0.005	0.088	0.006	0.03	4.21	-0.0033	0.0929
12	m-27	11.3	0.004	0.167	-0.006	0.104	5.14	-0.0081	0.0427
13	m-28	4	0.004	0.116	-0.017	0.012	4.11	-0.0051	0.0397
14	m-29	4.36	0.018	0.131	0.007	0.035	9.47	0.0018	0.187
15	m-30	5.36	0.002	0.148	-0.007	0.106	7.15	-0.0081	0.0489
16	std 1 blank	0	0.001	0.016	-0.007	-0.019	-0.026	-0.0002	0.0107
17	std 2	0.666	0.015	0.665	10	0.3	-0.055	-0.0085	10.01
18	std 2	0.703	0.014	0.697	10.2	0.328	-0.055	-0.0089	10.15
19	std 2	0.666	0.016	0.692	10.1	0.319	-0.051	-0.0082	10.05
20	std1-blank	-0.027	0.001	0.031	-0.017	-0.025	-0.041	-0.0016	0.0105
21	water blank	0.078	0.006	0.07	-0.006	-0.031	-0.034	-0.0014	-0.0004
22	water blank	-0.041	-0.002	-0.014	0.004	-0.015	-0.035	-0.001	0.0049
23	water blank	-0.051	0	0.029	-0.004	-0.03	-0.032	-0.0016	0.0035
24	water blank	-0.01	0.002	-0.003	0.163	-0.031	-0.028	0.0008	0.1516

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Burlington Northern Site
Missoula, Montana

Results of Chemical Analyses of Groundwater Samples

Well M-9 7/17/9

	RUN #1	RUN #2
F	0.149	ND
Cl	5.785	6.04
NO3	4.919	4.836
HPO	ND	ND
SO4	21.167	22.185

Well M-12 7/16/91

	RUN #1	RUN #2
F	0.457	0.451
Cl	6.745	6.644
NO3	2.936	2.905
HPO	ND	ND
SO4	5.325	5.156

Well M-26 7/17/91

	RUN #1	RUN #2
F	ND	ND
Cl	10.424	10.288
NO3	5.321	5.255
HPO	ND	ND
SO4	14.887	14.683

Well M-27 7/17/91

	RUN #1
F	0.344
Cl	38.531
NO3	45.058
HPO	ND
SO4	23.505

Well M-11 7/17/91

	RUN #1	RUN #2	RUN #3 (dillution)
F	0.969	1.083	
Cl	25.927	26.684	
NO3	0.842	0.484	
HPO	ND	ND	
SO4	146.89	153.062	251.1

Well M-20 7/17/91

	RUN #1
F	0.15
Cl	4.925
NO3	4.894
HPO	ND
SO4	15.819

Well M-24 7/17/91

	RUN #1	RUN #2	RUN #3
F	ND	ND	ND
Cl	6.245	6.846	6.682
NO3	3.68	4.181	4.194
HPO	ND	ND	ND
SO4	17.406	15.8	15.785

Well M-19 7/16/91

	RUN #1
F	0.15
Cl	7.4
NO3	1.387

Well M-25 6/4/91

F	0.931
Cl	10.346
NO3	6.297
HPO	0.956
SO4	17.17

Well M-29 6/4/91

F	0.537
Cl	9.809
NO3	6.278
HPO	0.3
SO4	17.61

Alkalinity Titrations
Aqueous Geochem Lab
Thursday 8/8/91

Sample M-11(a) BN Missoula Second run

V added	EMF	F
0.00	-20.50	1.32E+00
0.10	-3.30	2.73E+00
0.15	21.50	7.43E+00
0.18	49.50	2.27E+01
0.20	76.30	6.57E+01
0.21	90.30	1.15E+02
0.23	106.30	2.17E+02
0.25	116.50	3.27E+02
0.28	126.50	4.91E+02
0.32	135.50	7.12E+02
0.36	142.30	9.47E+02
0.42	149.70	1.30E+03
0.50	157.00	1.79E+03
0.60	163.70	2.42E+03
0.76	171.70	3.52E+03

Sample M-12 BN Missoula

V added	EMF	F
0.18	63.00	3.86E+01
0.21	105.50	2.08E+02
0.24	123.50	4.29E+02
0.26	129.70	5.52E+02
0.28	135.50	7.00E+02
0.30	140.30	8.53E+02
0.32	144.50	1.02E+03
0.35	149.50	1.25E+03
0.39	154.70	1.56E+03
0.44	160.30	1.99E+03
0.50	165.50	2.50E+03
0.58	171.00	3.20E+03
0.68	176.70	4.16E+03
0.80	182.00	5.36E+03

Sample M-24 BN Missoula

V added	EMF	F
0.00	-18.70	1.42E+00
0.03	-9.70	2.05E+00
0.06	24.30	7.95E+00
0.08	69.00	4.66E+01
0.09	85.70	9.04E+01
0.11	105.50	1.99E+02
0.14	120.50	3.64E+02
0.17	128.70	5.10E+02
0.21	138.00	7.49E+02
0.30	150.30	1.26E+03
0.40	159.70	1.91E+03
0.55	169.30	2.96E+03
1.70	176.00	5.59E+03

Sample M-30 BN Missoula

V added	EMF	F
0.00		
0.03	-24.00	1.17E+00
0.07	-1.00	2.95E+00
0.10	24.30	8.10E+00
0.12	60.70	3.43E+01
0.13	77.50	6.67E+01
0.14	90.50	1.12E+02
0.16	105.70	2.05E+02
0.19	119.00	3.51E+02
0.22	128.00	5.07E+02
0.26	136.50	7.22E+02
0.31	143.70	9.79E+02
0.37	151.00	1.34E+03
0.45	158.00	1.82E+03
0.55	164.00	2.40E+03
0.70	171.70	3.45E+03
0.85	177.50	4.57E+03

Sample M-12b BN Missoula

V added	EMF	F
0.00	-58.30	2.99E-01
0.10	-9.50	2.14E+00
0.15	24.70	8.43E+00
0.18	63.00	3.86E+01
0.19	82.50	8.35E+01
0.20	96.50	1.46E+02
0.22	112.30	2.73E+02
0.24	122.00	4.04E+02
0.27	131.00	5.84E+02
0.32	143.00	9.57E+02
0.38	151.70	1.38E+03
0.44	158.00	1.82E+03
0.54	166.30	2.62E+03
0.65	172.70	3.52E+03
0.75	177.50	4.41E+03

Sample M-11(b) BN Missoula

V added	EMF	F
0.00	-30.30	9.00E-01
0.17	75.00	6.16E+01
0.19	110.60	2.52E+02
0.22	128.30	5.13E+02
0.25	139.30	8.02E+02
0.28	146.50	1.08E+03
0.31	152.70	1.40E+03
0.35	158.70	1.80E+03
0.40	164.70	2.33E+03
0.47	171.30	3.10E+03
0.57	178.30	4.25E+03

Sample M-19 BN Missoula

V added	EMF	F
0.00	-24.50	1.13E+00
0.10	41.50	1.59E+01

Sample M-14 BN Missoula

V added	EMF	F
0.00	-26.00	1.07E+00
0.03	-9.70	2.05E+00
0.05	19.70	6.60E+00
0.06	43.70	1.71E+01
0.07	71.50	5.12E+01
0.08	88.00	9.85E+01
0.09	97.30	1.43E+02
0.11	111.50	2.52E+02
0.13	120.50	3.62E+02
0.18	133.70	6.24E+02
0.22	141.30	8.56E+02
0.30	152.00	1.35E+03
0.45	164.00	2.31E+03
0.60	172.00	3.36E+03

Sample M-29 BN Missoula

V added	EMF	F
0.00	-30.00	9.10E-01
0.03	-23.70	1.18E+00
0.08	23.30	7.71E+00
0.10	63.50	3.79E+01
0.11	79.70	7.20E+01
0.12	95.00	1.32E+02
0.13	104.30	1.92E+02
0.15	116.00	3.06E+02
0.17	123.50	4.15E+02
0.21	134.00	6.40E+02
0.30	148.30	1.17E+03
0.45	163.50	2.26E+03
0.60	171.50	3.29E+03

Sample M-9 BN Missoula

V added	EMF	F

0.12	80.30	7.41E+01
0.14	102.00	1.76E+02
0.17	117.00	3.22E+02
0.22	132.30	6.01E+02
0.25	138.30	7.71E+02
0.30	145.30	1.04E+03
0.40	155.30	1.61E+03
0.55	165.70	2.57E+03
1.70	172.70	4.91E+03
1.85	178.30	6.37E+03

Sample M-26 BN Missoula

V added	EMF	F
0.00	-10.00	
0.07	86.30	9.16E+01
0.08	97.50	1.43E+02
0.09	105.00	1.93E+02
0.11	117.30	3.16E+02
0.13	125.30	4.38E+02
0.15	131.30	5.60E+02
0.18	138.00	7.39E+02
0.22	144.70	9.79E+02
0.27	151.30	1.30E+03
0.33	157.30	1.69E+03
0.40	162.70	2.15E+03
0.48	167.70	2.70E+03
0.58	172.70	3.43E+03
0.70	177.70	4.36E+03

Sample M-20 BN Missoula

V added	EMF	F
0.00	-11.70	1.87E+00
0.10	101.70	1.70E+02
0.12	115.30	2.94E+02
0.14	124.00	4.18E+02
0.16	130.50	5.45E+02
0.18	135.00	6.56E+02
0.21	141.50	8.59E+02
0.24	146.30	1.05E+03

0.00	-27.30	1.01E+00
0.05	2.00	3.29E+00
0.09	75.00	5.93E+01
0.10	90.30	1.09E+02
0.11	98.30	1.50E+02
0.13	111.50	2.54E+02
0.15	119.70	3.54E+02
0.19	130.70	5.57E+02
0.22	136.70	7.15E+02
0.30	148.50	1.18E+03
0.45	161.70	2.11E+03
0.60	170.50	3.17E+03

Sample M-25 BN Missoula

V added	EMF	F
0.00	-18.70	1.42E+00
0.05	24.00	7.82E+00
0.07	74.00	5.65E+01
0.08	89.30	1.04E+02
0.09	99.50	1.56E+02
0.11	113.30	2.70E+02
0.14	123.50	4.10E+02
0.18	133.70	6.24E+02
0.28	148.70	1.18E+03
0.42	161.00	2.03E+03
0.57	169.70	3.03E+03

Sample M-28 BN Missoula

V added	EMF	F
0.00	-23.30	1.18E+00
0.05	29.70	9.78E+00
0.07	76.30	6.18E+01
0.08	92.30	1.17E+02
0.09	102.50	1.75E+02
0.10	109.00	2.27E+02
0.12	118.70	3.36E+02
0.14	126.50	4.61E+02
0.17	134.30	6.36E+02

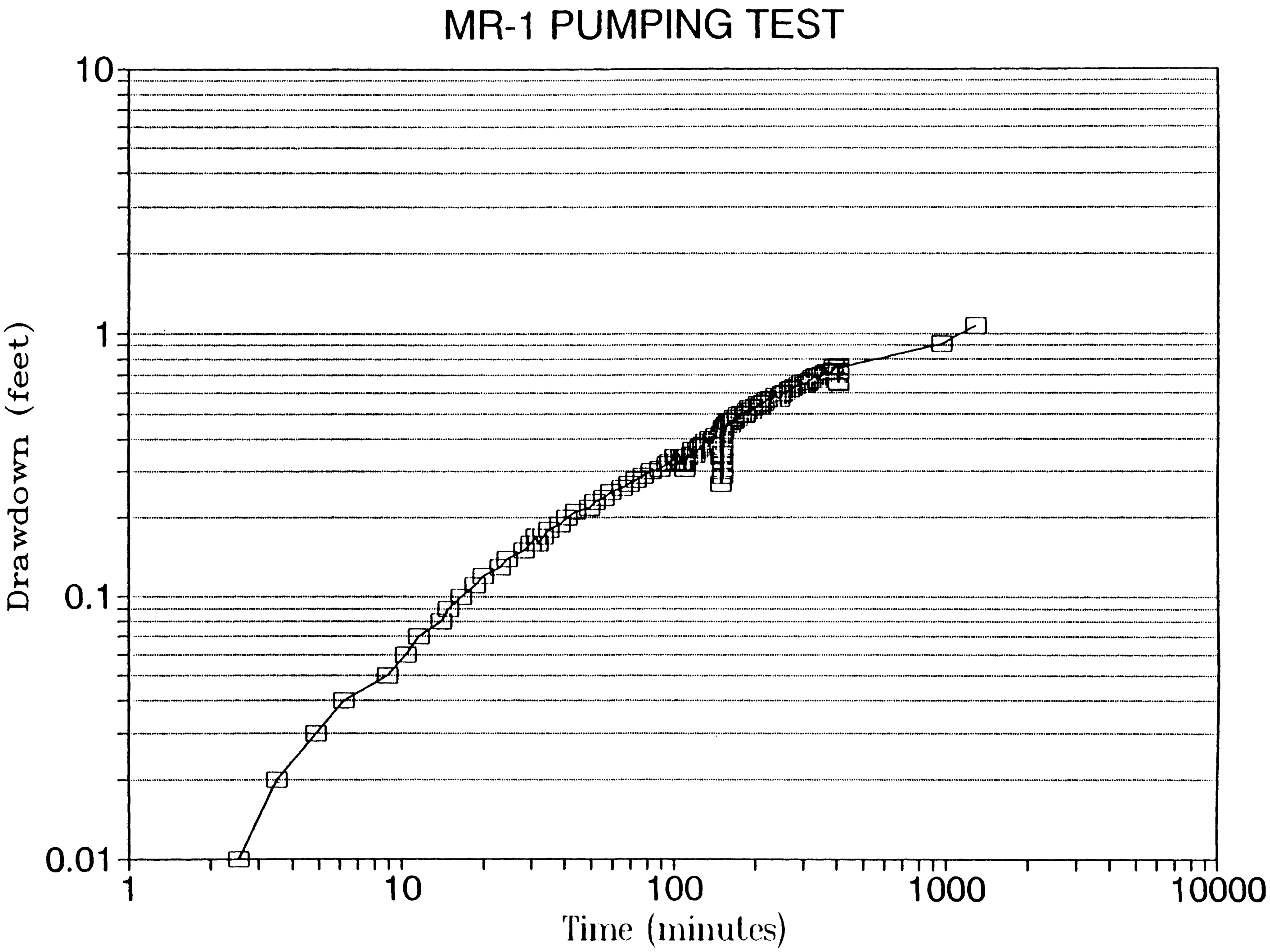
0.28	151.50	1.31E+03
0.33	156.70	1.65E+03
0.39	161.50	2.04E+03
0.47	167.00	2.62E+03
0.57	172.50	3.39E+03
0.70	178.30	4.47E+03

0.25	147.50	1.11E+03
0.40	161.50	2.05E+03
0.55	170.50	3.10E+03

Sample M-27 BN Missoula

V added	EMF	F
0.00	-23.00	1.20E+00
0.03	-17.30	1.52E+00
0.10	37.00	1.34E+01
0.12	75.30	6.09E+01
0.13	89.30	1.06E+02
0.14	99.30	1.58E+02
0.16	111.70	2.60E+02
0.18	119.30	3.54E+02
0.22	130.70	5.64E+02
0.29	142.00	9.08E+02
0.37	151.50	1.37E+03
0.50	161.30	2.12E+03
0.65	169.00	3.04E+03
0.85	176.50	4.39E+03

APPENDIX E: MR-1 PUMPING TEST DATA


MR-1 PUMPING TEST
10
1
0.1
0.01
Drawdown (feet)
1
10
100
1000
10000
Time (minutes)