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Characterization of the lithostratigraphic factors controlling petroleum hydrocarbon migration in a portion of the Missoula Valley Aquifer Missoula Montana

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CHARACTERIZATION OF THE LITHOSTRATIGRAPHIC FACTORS CONTROLLING PETROLEUM HYDROCARBON MIGRATION IN A PORTION OF THE MISSOULA VALLEY AQUIFER, MISSOULA, MONTANA

By

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B.A., THE UNIVERSITY OF MONTANA, 1995

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Characterization of the Lithostratigraphic Factors Controlling Petroleum Hydrocarbon Migration In A Portion of the Missoula Valley Aquifer, Missoula, Montana (242 pp.)

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Petroleum hydrocarbon release sites have the potential to contaminate drinking water supplies and pose a threat to human health and the environment. Characterization of physical and chemical properties of petroleum hydrocarbons and the subsurface environment are critical for proper identification of the contaminant migration and fate, and for site remediation. Most commonly, processes of sorption, biodegradation, and natural attenuation, and the physical constraints that are a function of the lithostratigraphy are discussed in the literature. Studies that characterize the lithostratigraphic factors controlling petroleum hydrocarbon migration and fate in the coarse grained vadoze zone and groundwater setting are few.

The purpose of this study was to evaluate how lithologic and stratigraphic (lithostratigraphic) factors affect the distribution of petroleum hydrocarbon fuel (gasoline and diesel) in a coarse grained vadose zone and aquifer. Rotosonic drilling was used to complete five vertical borings and obtain relatively undisturbed continuous cores to depths ranging from 65 to 115 feet below ground surface. Detailed physical and geochemical logging of each core was performed and detailed boring logs, cross sections, and conceptual models of the lithostratigraphy were constructed. Subsurface soil samples were screened on site for the volatile petroleum hydrocarbons using a photoionization detector. Selected subsurface soil samples and all groundwater from site monitoring wells were analyzed for BTEX, MTBE, volatile petroleum hydrocarbons, and extractable petroleum hydrocarbons. Data were synthesized and the contaminant source and migration routes were determined.

Study results revealed that a main upper and lower unit are present. Clay and sand layers generally appear to have slowed the vertical migration of petroleum hydrocarbons beneath the source area while diffusion of the vapor phase within the main unsaturated coarse sandy gravel unit resulted in wide spread impacts to the groundwater system. In addition, water table fluctuations of up to 13 feet are believed to be responsible for the spread of residual petroleum hydrocarbons in the smear zone. These residual petroleum hydrocarbons continue to act as a source of petroleum hydrocarbon contamination to the subsurface soil and groundwater at the site.

ACKNOWLEDGEMENTS

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Special thanks to John LaFave and the Montana Bureau of Mines and Geology for providing funding to advance one borehole to a depth of 115 feet bgs. Thanks to Skip Rosquist and Jim Calcaterra for allowing me to use the USDA Forest Service laboratory for completing my grain size analyses. Thank you to TetraTech - MFG, Inc., Hi-Noon Petroleum, and the DEQ Petroleum Release Section for allowing me to use the data collected during the Burger King Phase III Remedial Investigation and previous investigations in this study. Also thanks to TetraTech - MFG, Inc., my employer, for working around my school schedule.

Thanks to all of my friends for their loyalty and support, and especially those that were always successful in convincing me to take the much needed breaks from work and school to play softball with them. Lastly, greatest thanks to my family for everything: parents, Gwen and Randy; sister, Stephanie; brother, Kevin; and dog, Kuge.

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1 INTRODUCTION

The following sections provide a brief introduction of: 1) the importance of studying petroleum hydrocarbon contamination in the subsurface; 2) the history of petroleum hydrocarbon contamination at the study site; and 3) the goals of this study.

In the United States, approximately 2.5 million underground storage tanks (USTs) are used to store fuel and oil (Fetter, 1999). Inadvertent releases of gasoline, diesel, and heating and fuel oils, and synthetic organic compounds are a common environmental problem (Lahavis, et. al., 1999; Thoma, et. al., 1999; Schwarzenbach, R.P, et. al, 1993). There are between 100,000 and 400,000 gasoline storage tanks leaking into soil and/or groundwater in the United States (Lahvis, et. al., 1999). Contamination from these sources are a significant environmental concern as more than half of the population of the United States relies upon groundwater for their drinking water source (Fetter, 1999) and private wells near gasoline stations are commonly contaminated by leaky USTs (Lince, et. al., 1998).

Additionally, risk-based corrective action procedures are beginning to replace fixed corrective action concentration limits during environmental investigations and remediation (Thoma et. al., 1999). These risk-based corrective action (RBCA) guidelines are used to evaluate the existing and potential risks to human health and the environment associated with a petroleum release (MDEQ, 2000) and soil and groundwater cleanup goals for a site may be based upon the results of the risk-based evaluation. Therefore, knowing the concentration of petroleum hydrocarbons in subsurface soil and groundwater, and evaluating the fate and transport of contaminants in natural systems is critical.

Characterization of key physical and chemical properties of the subsurface environment at a release site is important when evaluating the fate of contaminants in the subsurface. Physical factors influencing the movement of water and contaminants in an aquifer and vadose zone include structure, stratigraphy, and lithology of the aquifer and vadose zone materials (USGS, 1997). In addition, temperature, humidity, soil moisture, advection, diffusion, dispersion, and sorption onto aquifer materials affect contaminant mobility and water transport in the subsurface (Fetter, 1999 and Barker, et. al., 1987). In addition, Sawhney, et. al. (1988); Barker, et. al. (1987); Lince, et. al. (1998), and other workers have investigated how biodegradation in the aquifer and vadose zones also attenuates contaminant migration.

Sorption of petroleum hydrocarbons to/within soil organic matter has been examined by Pennell, et al. (1992); Hoff, et al. (1993); Steinberg and Kreamer (1993); Conklin et al. (1995); Herbert, et al. (1993) and Kohl, et al. (2000) and biodegradation of petroleum hydrocarbons in the subsurface has been studied by Lahvis and Baehr, (1996); Aelion, et al. (1997); and Lahvis et al., (1999). Details of how non-aqueous phase liquids (NAPLs) are transported in the vadose zone and saturated zones are described in Appendix A.

Unfortunately, almost no attention has been given to the importance of the lithostratigraphy affecting transport, especially at sites dominated by gravel and cobble sediment. This work will attempt to examine how the lithostratigraphy of the coarse-grained Missoula Valley Aquifer (MVA) influences the migration and fate of petroleum hydrocarbon contamination in the subsurface at a petroleum release site in Missoula, Montana.

GOALS

The goal of this study is to evaluate how lithologic and stratigraphic (lithostratigraphic) factors affect the distribution of petroleum hydrocarbon fuel (gasoline and diesel) in a coarse-grained vadose zone and aquifer in a portion of the MVA, Montana. Specific objectives include:

1. Construction of lithostratigraphic boring logs and cross sections using existing well logs and coring data.

2. Mapping of the position and extent of petroleum contamination in the vadose zone and aquifer.

3. Testing a groundwater particle tracking model to evaluate if the interpreted source area and migration pathways are appropriately designated.

4. Prediction of the fate of the spilled fuel.

Portions of this study were completed in conjunction with a Phase III Remedial Investigation performed by MFG, Inc., my employer. I was the primary field person for MFG during all aspects of the investigation, with the exception of groundwater sampling activites, and authored the Phase III Remedial Investigation report (MFG, 2001). The Phase II Remedial Investigation report was submitted to MDEQ Petroleum Release Section in October 2001. This thesis used some of the data and information collected during the Phase III Remedial Investigation report and incorporated additional data and evaluations performed as part of this thesis.

2 PHYSICAL SETTING AND SITE HISTORY

PHYSICAL SETTING

The Missoula Valley is located within the Rocky Mountains in west-central Montana. It is an intermountain valley approximately 35 square miles in size (Armstrong, 1991) (Figure 1). The valley is a fault-bounded basin and probably formed as a result of horizontal extension resulting from Laramide thrusting during the Cretaceous and middle Eocene time (Woessner, 1998). Horizontal extension caused normal faulting parallel to the faces of Mount Jumbo and Mount Sentinel and in the formation of the Clark Fork Fault (Woessner, 1988). The valley is bounded on the north by the Rattlesnake Hills; on the east by the Sapphire Range, on the south by the Bitterroot Range, and on the west by the Ninemile Divide (Armstrong, 1991).

The topography of the valley floor is relatively flat, sloping gently to the northwest from the hills toward where the Clark Fork River leaves the valley (Woessner, 1988). The elevation of the valley, generally following Brooks Street, ranges from approximately 3,200 feet above mean sea level (AMSL) near the Clark Fork River, north of the Site; approximately 3,180 feet AMSL at the Site; and approximately 3,155 feet AMSL near the Bitterroot River, south of the Site (Figure 1).

The climate of the area is semi-arid. Winter is dominated by Pacific maritime air (Woessner, 1988). The total annual average amount of precipitation for Missoula is approximately 13.6 inches per year and ranges from an average low of 0.78 inches in February to an average high of 1.89 inches in June (WRCC, 2001). The average annual minimum temperature in Missoula is 32.3 °F and the average annual maximum temperature is 56.4 °F (WRCC, 2001).

The Clark Fork and Bitterroot Rivers drain the Missoula Valley (Figure1). The Clark Fork River enters the valley from the east, through the Hellgate Canyon. The Bitterroot River enters the

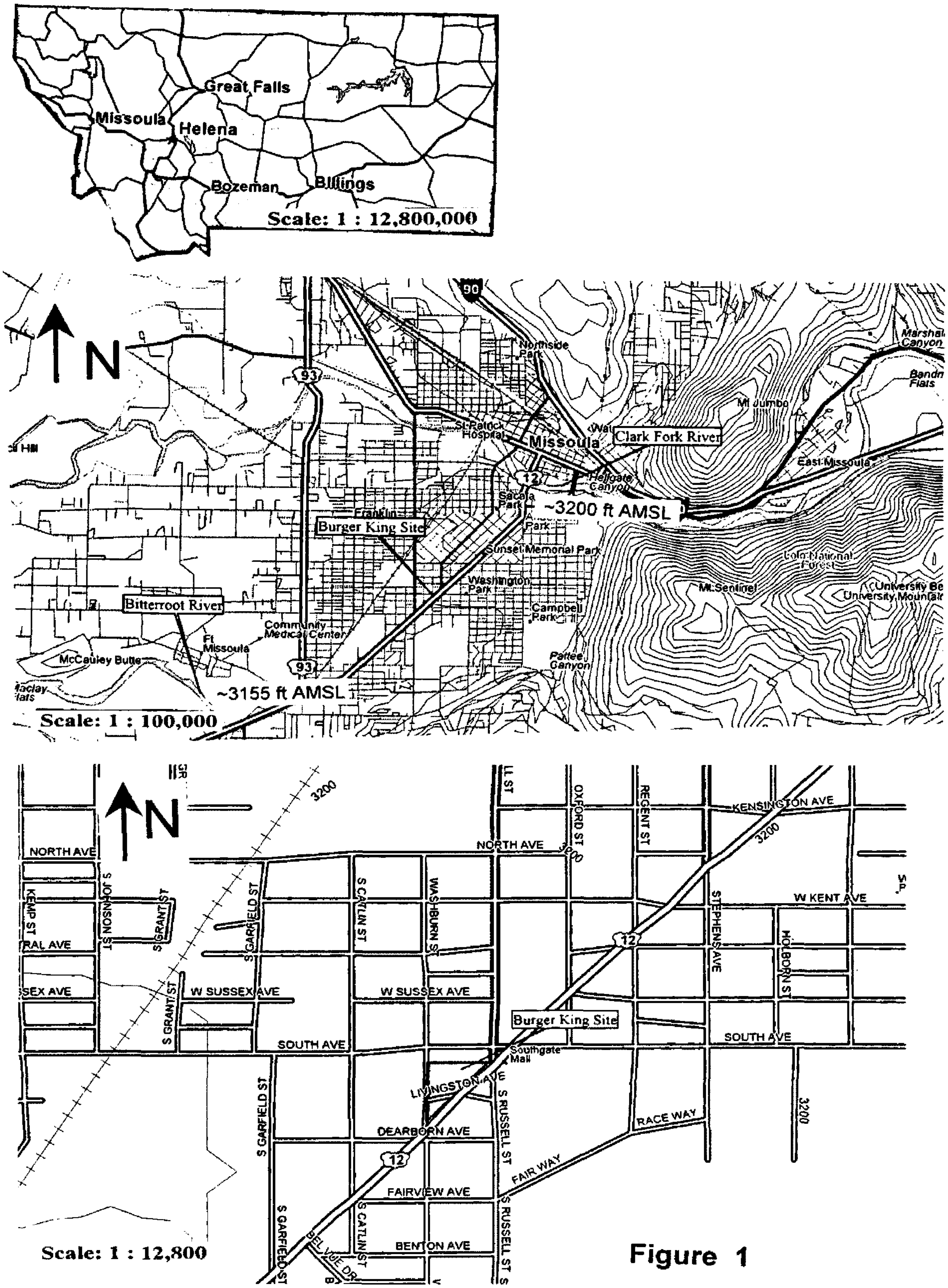


Figure 1

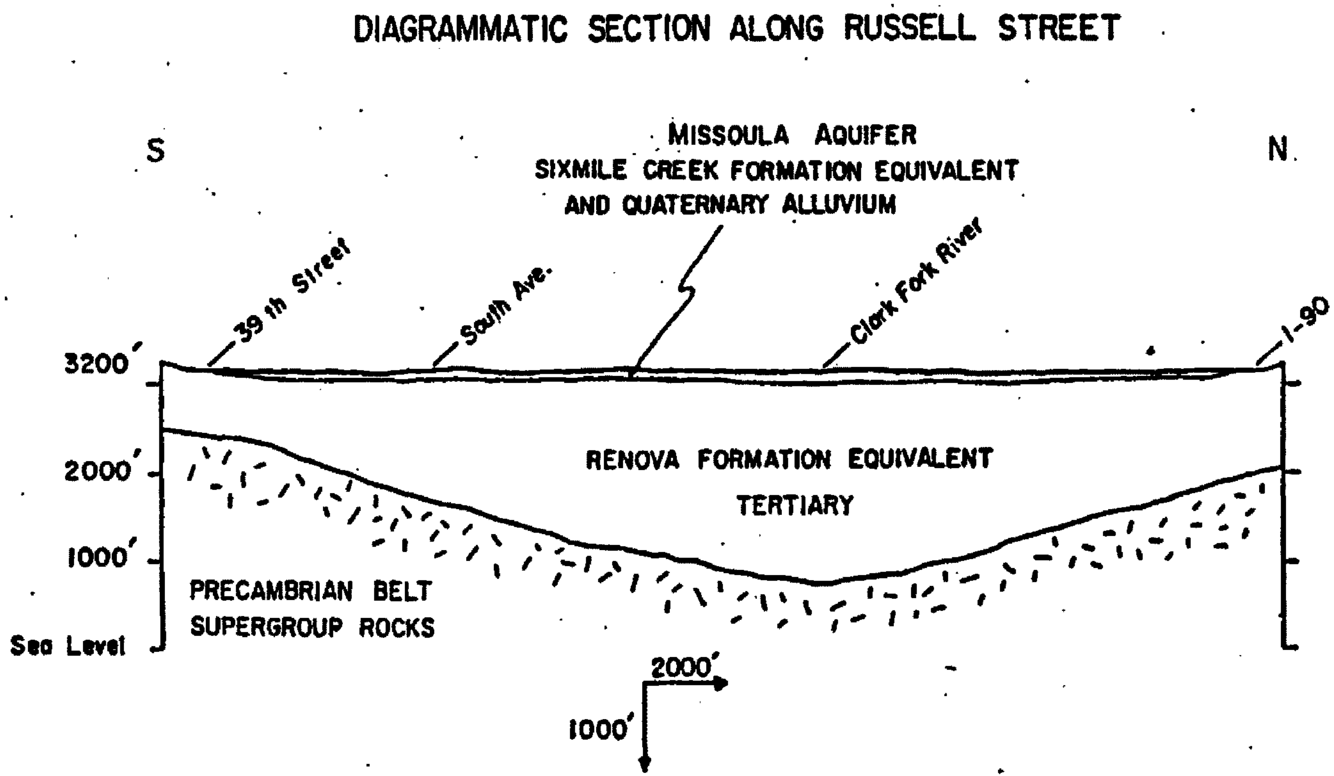
Site Location Map

valley in the southern portion of the Missoula Valley. Other streams entering the valley include Rattlesnake Creek, Grant Creek, and Pattee Creek.

Sediments comprising the Missoula Valley are continental clastic deposits (Figures 2 and 3; Clark, 1986 and Woessner, 1988). The valley floor is covered by alluvial and lacustrine sediments of Quaternary age. The foothills surrounding the valley floor and beneath the MVA are primarily composed of fine-grained sediments deposited during the Tertiary period, a time when the basin was internally drained. These Tertiary sediments (the Renova Formation), of Oligocene and early Miocene age, range in size from clay to coarse gravel and unconformably overlie Precambrian Belt Supergroup metasediments (Clark, 1986 and Woessner, 1988). Mountain ranges surrounding the Missoula Valley are composed of Precambrian Belt Supergroup metasediments (Woessner, 1988).

The Missoula Valley Aquifer (MVA) underlies the Site and valley floor. It is an unconfined highly productive aquifer and has been designated a Sole Source Aquifer by the Environmental Protection Agency (EPA; MCCHD, 1987). Mountain Water Company supplies a majority of Missoula's residents with water from more than 30 municipal wells (MSE, 1994b). Numerous studies have been performed to characterize the hydraulic properties of the MVA, and the interactions between the MVA and Clark Fork and Bitterroot Rivers (Woessner, 1988; Clark 1986; Smith, 1992; Morgan, 1986; Miller, 1991; and Pracht, 2001). The 1991 study by Armstrong evaluated the distribution and occurance of perchloroethylene in the MVA. Armstrong also created cross sections of the MVA in an attempt to evaluate how the stratigraphy of the MVA might affect the distribution of perchloroethylene.

Three main hydrostratigraphic units are present within the Missoula Valley. They include the Pleistocene – Holocene surface sand and gravel, Tertiary Sediments, and Precambrian Bedrock. The surface deposits of the Missoula Aquifer include sand, gravel, and boulders with some silt



Schematic north-south cross-section of the Missoula Valley. Location shown on Figure 2.6 (Clark, 1986).

FIGURE 2
Cross Section of Missoula Valley
Reference: Woessner, 1988

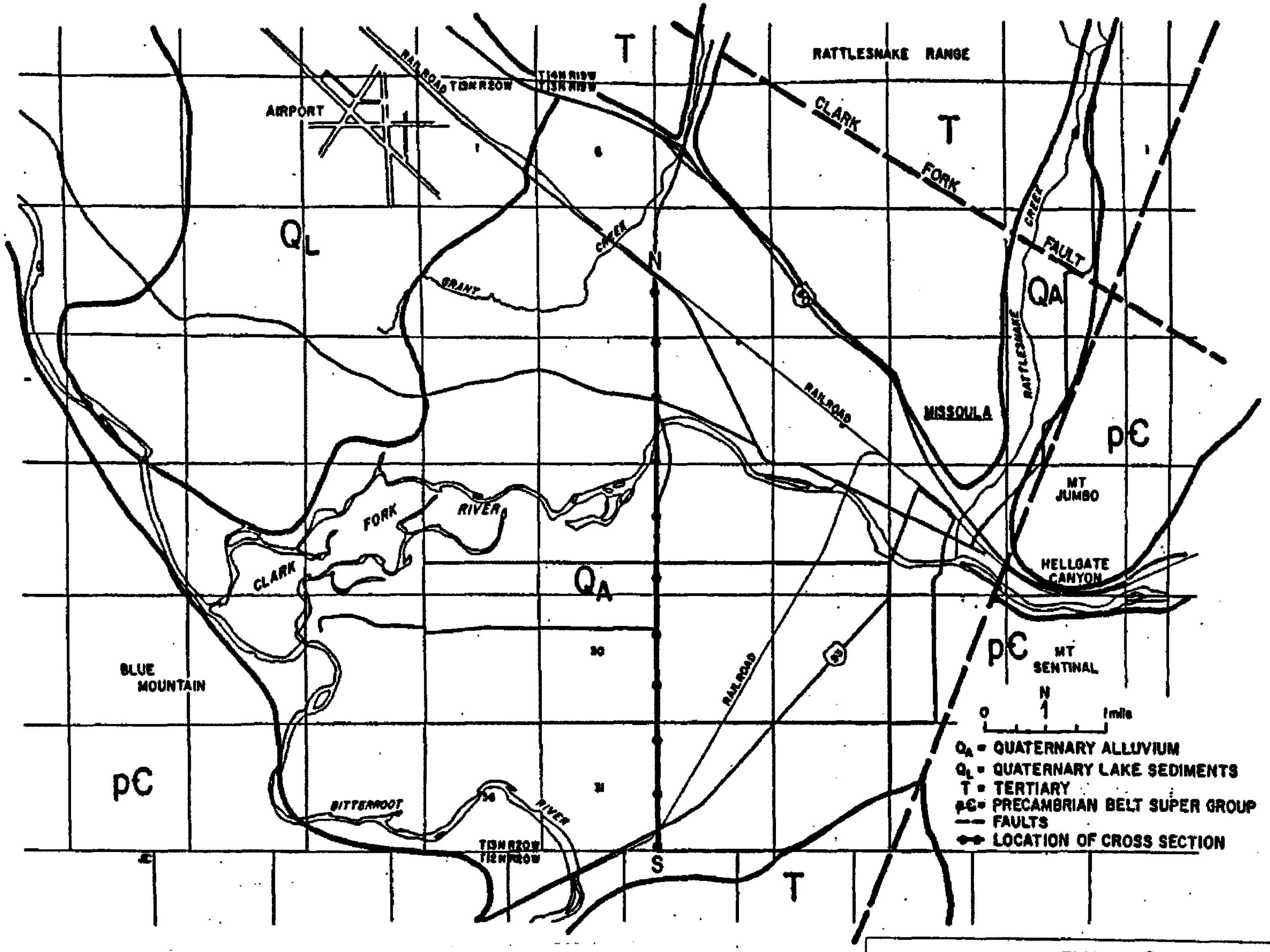


FIGURE 3

Geologic Map of Missoula

Reference: Woessner, 1988

and clay; Tertiary Sediments are composed of clay with interbedded and embedded sand and gravel; and the Precambrian rocks includes quartzite, red and green argillite, and carbonates (Woessner, 1988). Missoula Valley residents use all three of these hydrostratigraphic units as sources of groundwater (Woessner, 1988).

Using driller's logs, the MVA has been further divided into three main stratigraphic units, as follows (Woessner, 1988):

- Unit One includes interbedded boulders, cobbles, and gravel with sand, silt and some clay. Thickness ranges from 10 to 30 feet and is found at the land surface. Unit One typically is not saturated except beneath and adjacent to streams.

- Unit Two is a tan to yellow silty sandy clay with layers of coarse sand and gravel. The thickness of Unit Two averages 40 feet in the center of the basin and can be up to 130 feet. Unit Two may be absent in some portions of the valley.

- Unit Three consists of interbedded gravel, sand, silt, and clay and is coarser toward the bottom of the unit. The thickness of Unit Three varies from 50 feet to 100 feet. Development of wells in Unit Three can produce up to 3,000 gallons of water per minute.

Table 1 presents estimates of some of the aquifer properties developed by Clark (1986), Miller (1991), and Pracht (2001).

Table 1: Missoula Valley Aquifer Properties

Property	Unit One	Unit Two	Unit Three
Hydraulic Conductivity (gpd/ft^2)	---	---	Clark: 10,300 – 25,500 Miller: 1,550 – 18,000 Pracht: 141,791 – 268,657
Vertical Hydraulic Conductivity (gpd/ft^2)	---	---	Clark: 970 – 2,100
Transmissivity (gpd/ft)	310,000	8,000	750,000 – 1,710,000
Porosity	0.20	---	0.20
Specific Yield	0.12	---	0.10
Thickness (ft)	10 – 30	40	50 – 150

Morgan (1986) and Armstrong (1991) constructed several cross sections of the MVA using driller's well logs (e.g., Figures 4 and 5). The cross sections typically show two to three distinct hydrogeologic units, as described above. A further discussion of cross sections at the Site and the MVA is presented in Section 4.

Previous studies at the Site indicate the subsurface is predominantly composed of sandy gravel with layers of sand. A clay layer was logged at approximately 18 feet below ground surface (bgs) in boring/well MSE-1 (MSE, 1994b). MSE (1994a) estimated the total thickness of the coarse grained sediments to be approximately 125 feet.

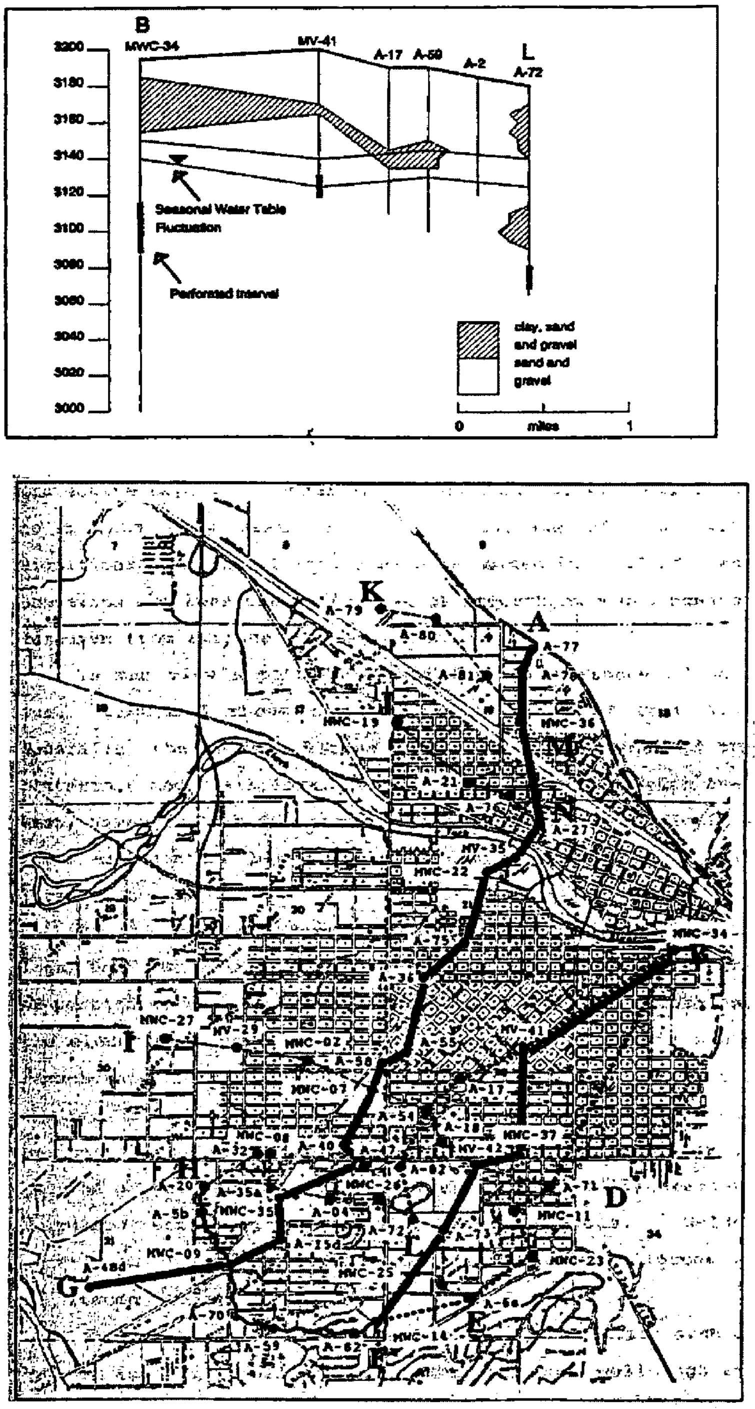


Figure 4 Example cross section of MVA completed using driller's logs (map shows location of cross section).
Source: Armstrong, 1991.

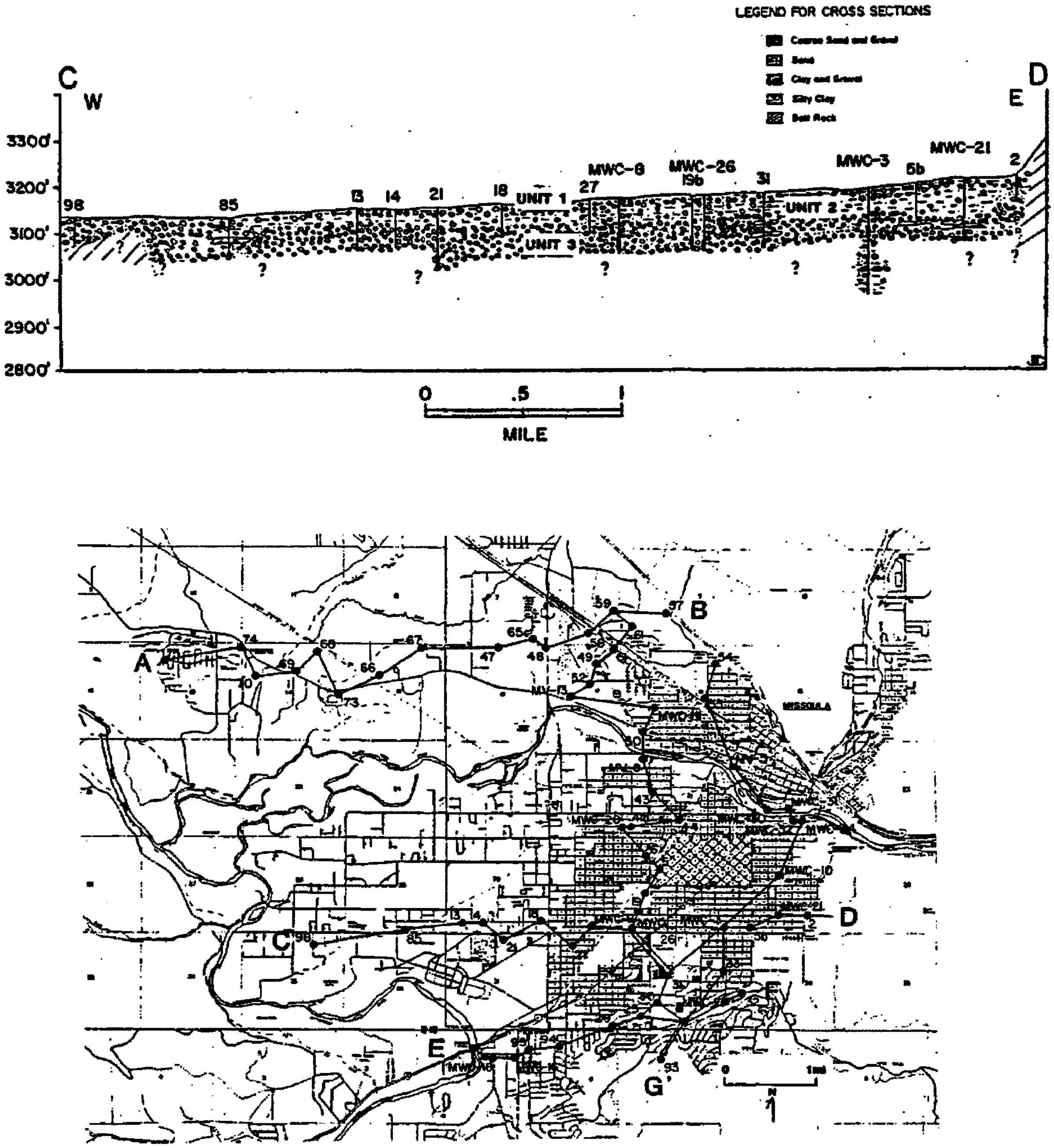


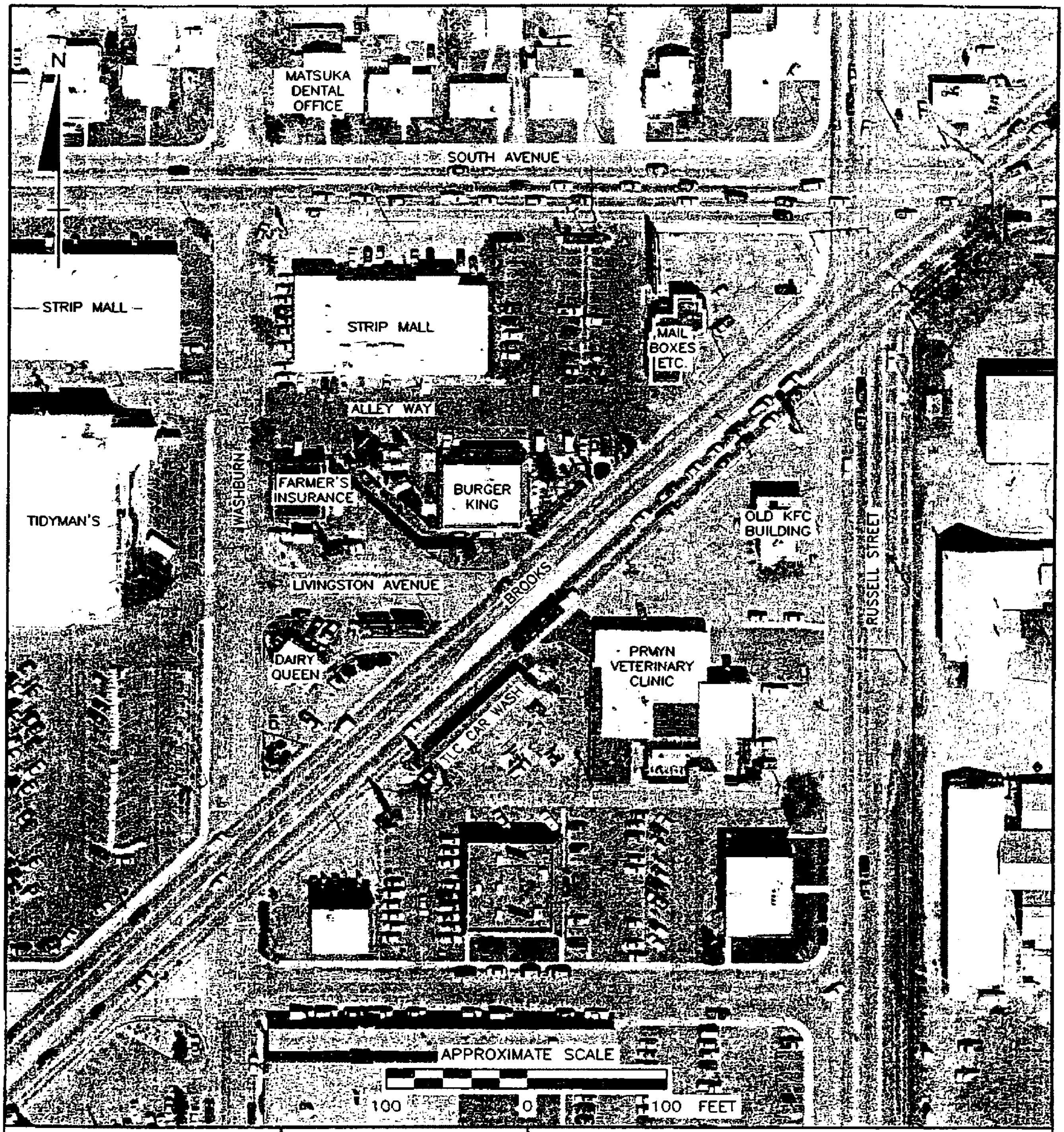
Figure 5 Example cross section of MVA completed using driller's logs (map shows location of cross section).
Source: Morgan, 1986 and Woessner, 1988.

SITE HISTORY

The Burger King Petroleum Release Site (the "Site") is located at 2405 Brooks Street, a primarily commercial/industrial area of Missoula, Montana. It is located in the central portion of the Missoula Valley near the intersections of Brooks Street (Highway 93), South Avenue, and Russell Street (Figure 6). The Site is located in Township 13 North, Range 19 West, Section 32.

Petroleum hydrocarbon odors at the Site were first reported in the Burger King restaurant to the Missoula City-County Health Department, prior to April 1990 (MSE, 1994a and MFG, 2001). Petroleum hydrocarbon contamination of the aquifer was discovered in April 1990, at a well serving the nearby Dairy Queen (MSE, 1994a).

One potential source of gasoline and diesel contamination at the Site was the former full service gasoline station located at the current location of the Burger King restaurant (SES, 1994). The former gasoline service station used above ground storage tanks (ASTs) to store both gasoline and diesel (SES, 1994). The pump islands (fuel dispensers) for the service station were located on the southeastern side of the property and were connected to the ASTs via underground pipes (SES, 1994). The locations of the former AST farm and fuel dispenser islands are shown in Figure 7. A 1967 aerial photograph reviewed by MSE, Inc. (MSE, 1994b) indicated the service station building was oriented as shown in Figure 7. At the time of operation, the service station contained an above ground storage tank (AST) farm. The pump islands for the service station



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BURGER KING PETROLEUM RELEASE SITE

FIGURE 6

AERIAL PHOTOGRAPH OF SITE

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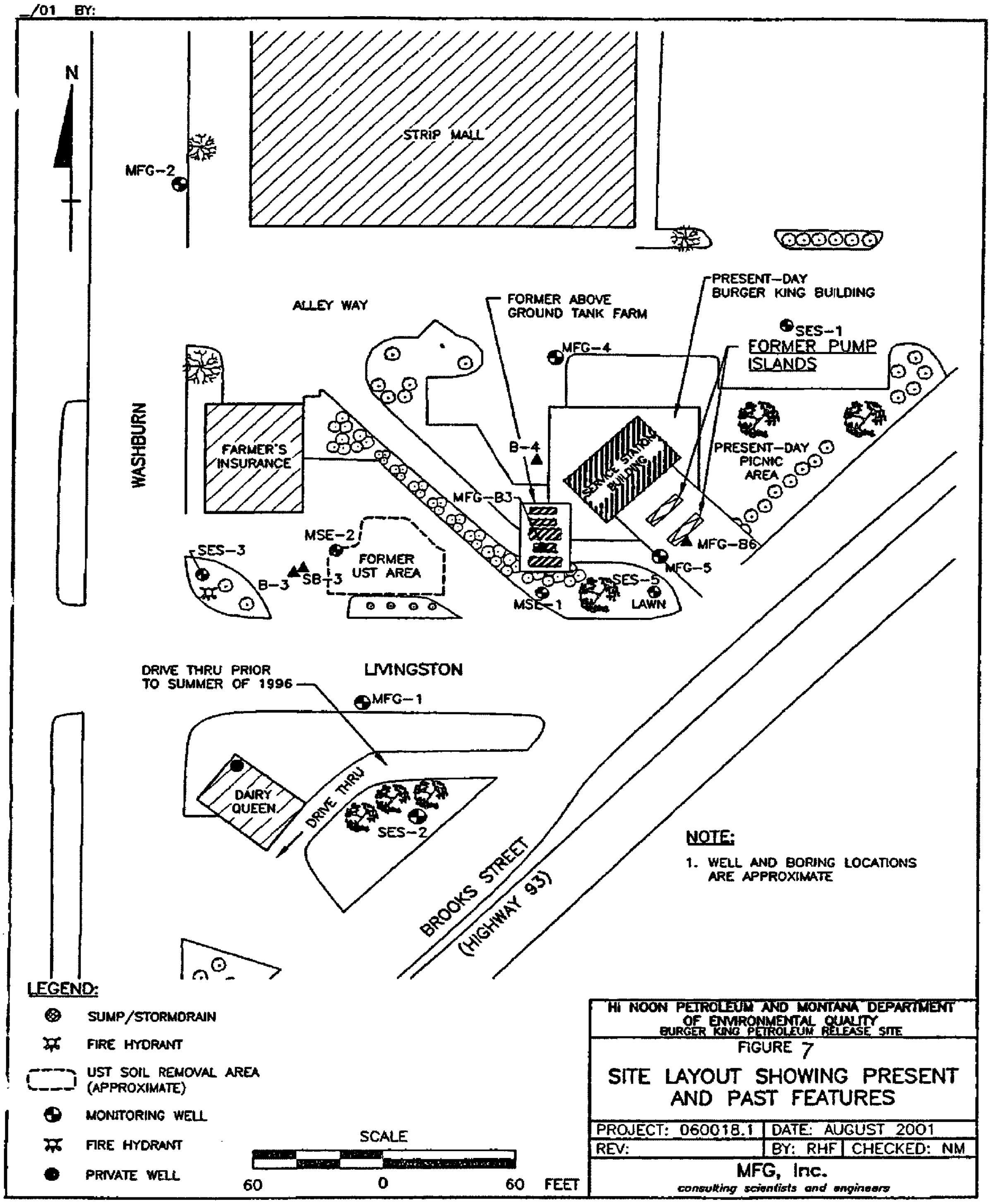

NOTE:

1. WELL AND BORING LOCATIONS ARE APPROXIMATE

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FIGURE 7

SITE LAYOUT SHOWING PRESENT AND PAST FEATURES

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were located on the east-southeast portion of the Site, adjacent to Brooks Street. In addition, the aerial photograph showed the AST farm was located at the west-southwest side of the service station and adjacent to the west side of the present-day Burger King restaurant (MSE, 1994b; Figure 7).

According to the initial investigation conducted in 1994 (MSE, 1994b), a total of five tanks comprised the AST farm. At the time of the initial investigation (MSE, 1994a), the type of fuel previously dispensed from the tanks was unknown. In addition, information regarding the type of storage tank used, when the tanks were removed or demolished, and the duration of operation of these tanks at the service station is unknown (MSE, 1994a). The exact location and orientation of underground piping used to transmit fuel from the ASTs to the pump island is also unknown. According to the Missoula County Fire Marshall, the tanks were probably removed prior to construction of the Burger King restaurant in 1976; however, there are no records documenting their removal (MSE, 1994a).

A second potential source of petroleum hydrocarbon contamination at the Site was identified as a convenience store located 1530 Livingston Avenue at what is now a Farmer's Insurance Agency (MSE, 1994a). The gasoline UST was located southeast of the building and the pump island was located south of the building and west of the UST (MSE, 1994b and Shannon, 1994; Figure 7). The fate of the UST system is unknown and no records of tanks were found at the Missoula County Fire Department (MSE, 1994a). A note and photograph of the convenience store was found while reviewing old files stating that the convenience store (Super Suds) opened in May 1977 and was in existence until November 1981. The photograph showed a crane in front of the store on Livingston Avenue, possibly dismantling the roof of the canopy over the pump island. Gasoline pricing signs were present in the photograph. It was unknown whether the UST was removed prior to or after November 1981. A soil boring SB-3 (Figure 7), in the area of the former UST and pump islands, encountered no petroleum hydrocarbon contamination between the ground surface and the bottom of the boring, 54 feet below ground surface (bgs; SES, 1994). There are no records indicating petroleum hydrocarbons were released at the convenience store.

One upgradient UST site with reported leaks was/is the Cenex gas station located at 1108 W. Central (Facility ID #32-08907), approximately 2,000 feet northeast of the Site on Brooks Street. The Cenex site had a total of three USTs (MSE, 1994a). Based on analytical data collected historically from the most northeastern on-Site monitoring well (SES-1; see Figure 7), it does not appear that the petroleum release at the Cenex gas station has impacted the groundwater beneath the Burger King Site (MFG, 2001).

According to the 1994 MSE report (1994a), there may have been three other USTs located across Brooks Street. These include the Kentucky Fried Chicken (currently a temporary loan business) location, the Missoula County Fairgrounds, and at Pruyn Veterinary Hospital (Figure 6). However, there were no reports of leaks originating from these USTs with the exception of the UST located at the fairgrounds. A small release occurred at this location and minor amounts of soil were removed. However, the fairgrounds release site has since been closed for no further action.

3 METHODS OF INVESTIGATION

The following section describes the methods used to accomplish the goals of this study, including data gathering and data review, drilling and sample collection, grain size analyses, completion of cross sections, delineation of soil contamination, monitoring well installation, groundwater sampling, and water table and vadose zone modeling.

The use of the terms subsurface soil or soil during subsurface investigations is common in the environmental consulting field and are general terms for referring to subsurface sediments and/or subsurface materials. The terms subsurface soil or soil may also be used in this thesis to refer to the subsurface sedimentary deposits of the MVA. The terms subsurface sediments, subsurface soil, and soil in this report are synonymous.

DOCUMENT REVIEW AND DATA GATHERING

Reports from previous investigations of the Site were reviewed prior to beginning this study. Data used in this evaluation were obtained from a 1994 site and field investigation (MSE, 1994a and MSE 1994b); 1994 and 1995 remedial investigations (SES, 1994 and SES, 1995), a soil vapory survey (Higgins, 1999), quarterly groundwater monitoring reports, and the Phase III Remedial Investigation Report (MFG, 2001). The data contained within these reports include boring and well log data, analytical results from subsurface materials and groundwater, and soil vapor survey results. Table 2 provides a summary of previous investigations and their results.

In addition, Mountain Water Company was contacted to collect additional information regarding an April 1990 water line rupture event at the Site. The purpose of obtaining these additional data was to evaluate the potential effect of a documented water line rupture event on contaminant migration at the Site. Information obtained from Mountain Water Company included: 1) the

TABLE 2
SUMMARY OF PREVIOUS INVESTIGATIONS
BURGER KING PETROLEUM RELEASE SITE

INVESTIGATION	REFERENCE	RESULTS
Investigation of a Possible Petroleum Release in the Vicinity of the Matuska Dentist Office and Brooks Avenue Dairy Queen	MSE, 1994a	The report identified the potential sources of petroleum hydrocarbons present in the Dairy Queen well. Possible sources included the former AST farm for a service station, located at the present-day Burger King restaurant, and USTs at the former convenience store, located at the Commnet 2000 (currently Farmer's Insurance) building. The report also noted that just prior to the first detection of petroleum hydrocarbons in the Dairy Queen Well water, the water line connecting the Burger King restaurant to the municipal water supply had ruptured, causing a large volume of water to be released to the subsurface. The location and size of water line that ruptured was not mentioned in the report. The Dairy Queen well was sampled in April 1990, just after the detection of petroleum hydrocarbons in the well. The well was sampled again in September 1990 and in 1992. The results of these studies indicated no detectable levels of petroleum hydrocarbon contamination in the well.
Installation of Soil borings and Monitoring Wells on the Commnet 2000 and Burger King Properties	MSE, 1994b	The report presented the location of the AST farm at the former service station and tanks associated with the convenience store (Figure 7). Three soil borings were installed and soil samples collected. Monitoring wells were installed in two of these borings (MSE-1 and MSE-2, see Figure 7). The purpose of the investigation was to confirm the presence or absence of contamination in subsurface soils and/or groundwater at the Site. Soil contaminated with petroleum hydrocarbons was encountered in both borings but groundwater contamination was only encountered in MSE-1.
Burger King Remedial Investigation	SES, 1994	The purpose of the investigation was to identify the source of petroleum hydrocarbon contamination and define the extent of the petroleum hydrocarbon release. Three monitoring wells (SES-1, SES-2, and SES-3) were installed at the Site (Figure 7). SES-3 showed evidence of petroleum

TABLE 2
SUMMARY OF PREVIOUS INVESTIGATIONS
BURGER KING PETROLEUM RELEASE SITE

INVESTIGATION	REFERENCE	RESULTS
		hydrocarbon contamination in subsurface soil and groundwater. Groundwater sampling was performed on all wells at the site, including the Dairy Queen well. Analytical results indicated detectable levels of gasoline and diesel components in MSE-1, SES-3, and the Dairy Queen well. Toluene was detected in well SES-1.
Burger King Phase II Remedial Investigation	SES, 1995	The purpose of the investigation was to further evaluate the extent and magnitude of petroleum hydrocarbons in subsurface materials and groundwater at the Site. Two soil borings were installed (SB-4 and SES-5; see Figure 7). SES-5 was completed as a groundwater monitoring well. Subsurface contamination was encountered at approximately 45 feet bgs. Groundwater sampling was performed. Dissolved phase petroleum hydrocarbon contamination was encountered in wells SES-3, SES-5, and MSE-1. No dissolved phase petroleum hydrocarbons were detected in SES-1, SES-2, MSE-2, and the Dairy Queen well.
Quarterly Groundwater Monitoring and Soil Gas (Vapor) Survey	Higgins, 1999	A soil vapor survey was performed in May 1999. The purpose of the investigation was to evaluate the distribution of gasoline and diesel range petroleum hydrocarbons in the subsurface. A total of 73 one-inch Gore-Sorbers® were installed at a depth of 3-feet into the subsurface at specific locations at the Site. Gore-Sorbers® remained in the ground for three weeks then were retrieved and sent to the Gore laboratory for analysis. According to the analytical results, several areas of the Site indicated there were "hot spots" located in and near the former AST area can be explained by the elevated concentrations of petroleum hydrocarbons in the vadose and saturated zones. PID screening values and subsurface and groundwater analytical results verify

TABLE 2
SUMMARY OF PREVIOUS INVESTIGATIONS
BURGER KING PETROLEUM RELEASE SITE

INVESTIGATION	REFERENCE	RESULTS
		petroleum hydrocarbons in this area. Some of the sorbers from the soil vapor survey confirmed that elevated petroleum hydrocarbon vapors existed in areas upgradient from the former AST farm area, and at other downgradient locations. The following details the locations of the "hot spot" areas. "Hot spot" gasoline range hydrocarbon vapors were present at soil vapor sorber locations as follows: 1) northeast of the Burger King building; 2) south of Burger King; 3) east of Burger King; 4) east of the insurance building; and 4) the east corner of the Dairy Queen building. "Hot spot" diesel range hydrocarbon vapors were present at soil vapor locations as follows: 1) northeast of the Burger King building; 2) southwest of the Burger King building; 3) south and west of the Burger King building; 4) at the east corner of Dairy Queen; and 5) east of the insurance building. *[Note: Gore-Sorbers® are one brand of soil vapor collection devices. The Gore-Sorbers® vapor collection module is constructed of GORE-TEX®. Each module contains various polymeric and carbonaceous adsorbents for the collection of volatile and semi-volatile organic compounds. For more information on this topic the reader is referred to the Gore web site at http://164.109.56.82/english/ipd/soilgas/index.html.]*

location of the water line; 2) the approximate location of three water line breaks along the line; 3) the diameter of the water line; 4) the carrying capacity of the 2-inch diameter water line; and 5) important details regarding the notification and service call dates. After evaluation of the data collected, a release volume was calculated (see Appendix E).

DRILLING AND SUBSURFACE SAMPLING

During the remedial investigation, the rotosonic drilling method was used to collect continuous cores of the MVA. Previous investigations at the Site used the hollow-stem auger drilling method. Hollow-stem auger drilling proved unsatisfactory due to the very coarse nature of the subsurface materials and poor sample recovery during split spoon sampling. Rotosonic drilling is quick, efficient, and produces less drill cuttings than other drilling methods (Barrow, 1994). The rotosonic drilling method employs the use of high frequency mechanical vibration to advance the drill stem into the subsurface and collect relatively undisturbed continuous cores of subsurface materials (Barrow, 1994). Boart Longyear, headquartered in Salt Lake City, Utah, was the drilling contractor for the Study. A photograph of the Boart Lonyear rotosonic drill rig used during the investigation is provided as Figure 8. Additional photographs of rotosonic drilling at the Site are provided in Appendix B (the compact disk).

Relatively undisturbed 4 ½-inch diameter continuous cores were obtained from each borehole drilled during this investigation. During drilling, the drill stem was extracted from the borehole at approximately 5 feet intervals. Subsurface sediment cores were extruded directly from the drill stem into clear plastic sleeves (Figure 9). Prior to extruding the core, the bottom of the plastic sleeve was tied in a knot by the driller. Cores were preserved in approximately 2-foot intervals. The end depth of each core interval was immediately written in indelible ink on each plastic core sleeve by the driller. The top end of each core was sealed with duct tape and additional sample identification was written on each sleeve, specifying the borehole name, date, and start and end

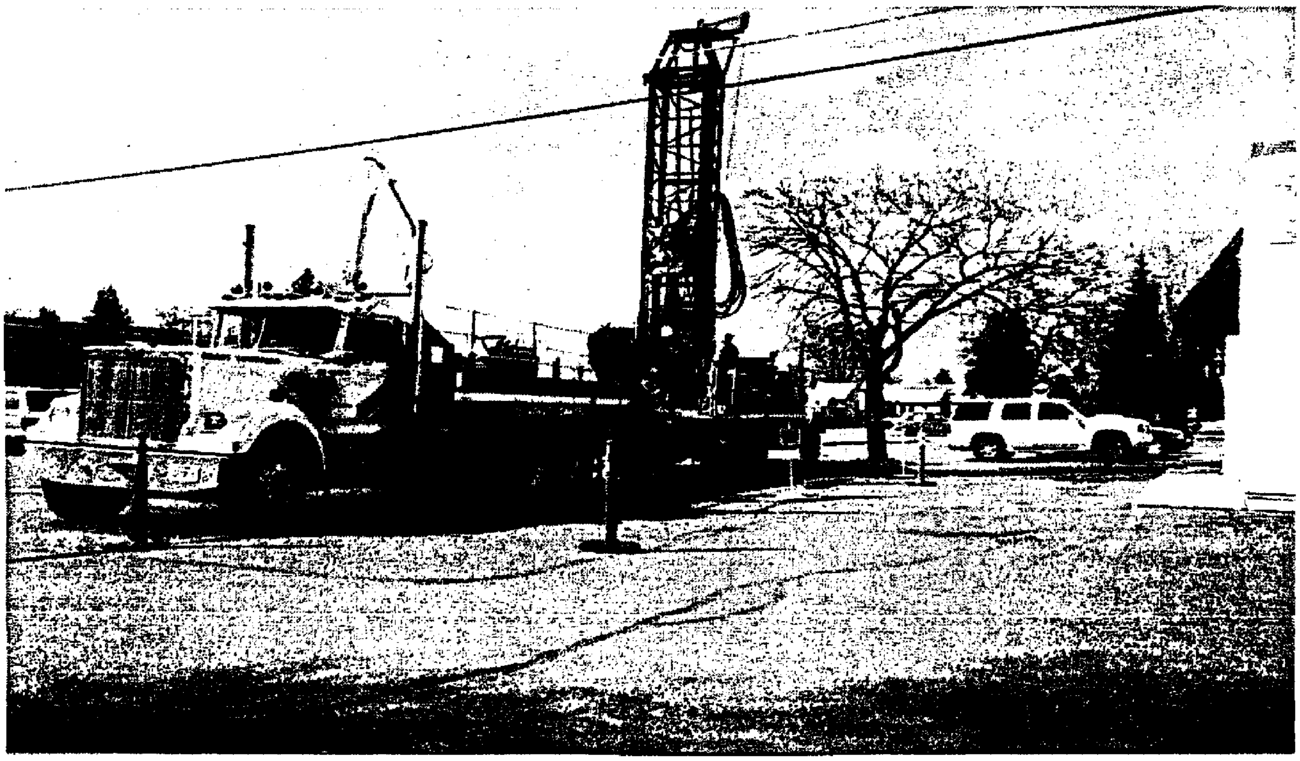

Figure 8 Boart-Longyear Rotosonic Drill Rig at MFG-2. Looking north.

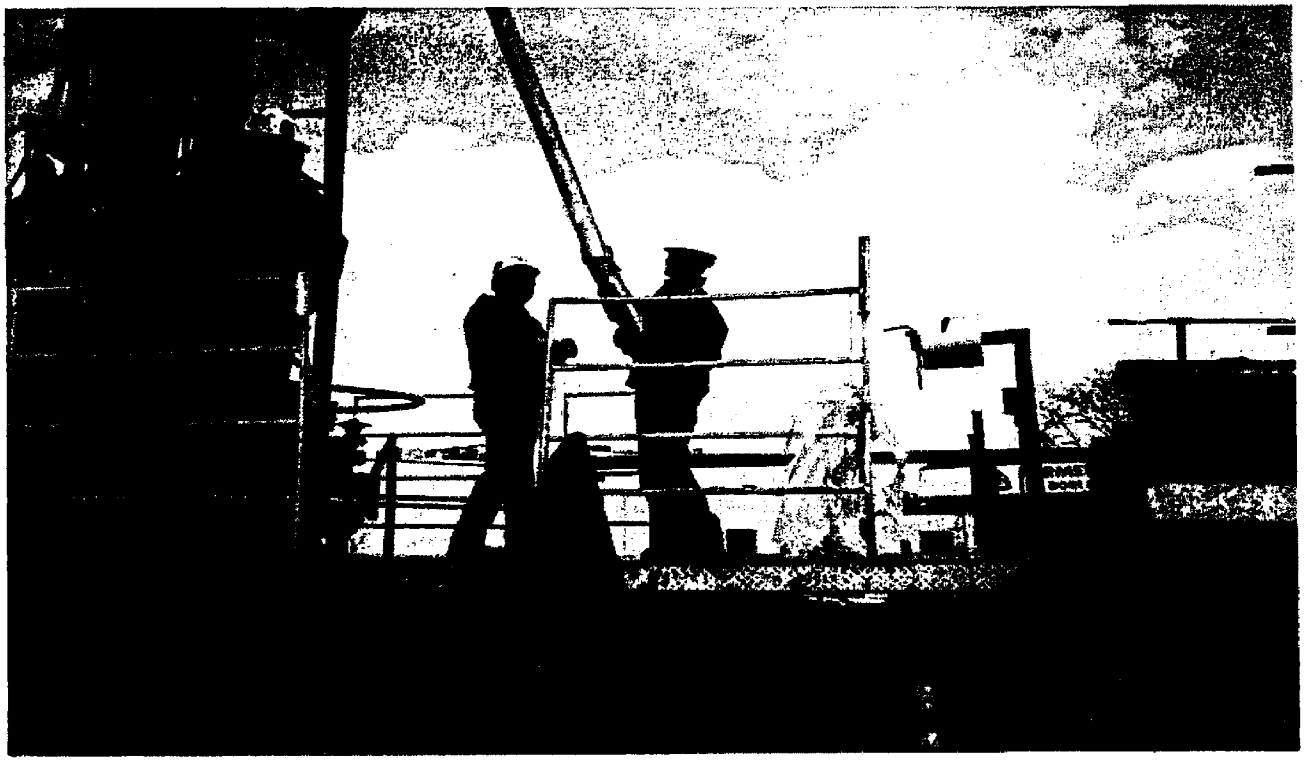

Figure 9 Extraction of core into plastic sleeve from drill stem.

depths of each core interval. All cores were preserved and stored in a secure location until detailed logging could be completed.

A total of five vertical boreholes and one angled borehole were drilled at the Site during the remedial investigation. The boreholes completed during this investigation include MFG-B1, MFG-B2, MFG-B3, MFG-B4, MFG-B5, and MFG-B6 (see Figure 7). Borehole locations were selected to: 1) evaluate the magnitude and vertical extent of petroleum hydrocarbons in the area of the former ASTs and service station pump islands, and 2) evaluate the potential migration of petroleum hydrocarbons onto or off of the Site. Three boreholes (MFG-B3, MFG-5 and MFG-B6) were located as close to the former ASTs and pump islands as possible; two boreholes (MFG-2 and MFG-4) were located upgradient of the former ASTs; and borehole MFG-1 was located downgradient of the former ASTs and pump islands. MFG-B6, the angled borehole, was used to obtain soil cores under the corner of the existing Burger King building; the former location of the pump islands. Total depths of the vertical boreholes ranged from 65 feet below ground surface (bgs) to 115 feet bgs. The total length of MFG-B6 was 28 feet, which corresponded to a final vertical depth of approximately 25 feet bgs. Groundwater was encountered in each vertical borehole at approximately 55 feet bgs; groundwater was not encountered in the angled borehole.

After completion of drilling activities, cores were logged in detail using standard procedures (see Appendix C). In addition, each core was photographed in its entirety. The entire suite of photographs taken during drilling and logging is contained on the enclosed compact disk (Appendix B).

GRAIN SIZE ANALYSES

Grain size analyses were performed to provide general information on the size and uniformity of the aquifer materials at the Site. In addition, the results were used to supplement the qualitative estimate of grain sizes performed on the cores in the field.

A total of 31 samples of cored material were analyzed for grain size from two of the five cores. Twenty grain size samples were analyzed from boring MFG-2 and 11 from boring MFG-B3. MFG-2 was selected because it was the deepest core and samples could be obtained from the greatest number of depth intervals. MFG-B3 was selected because it was one of the cores at the location of the former AST farm and petroleum hydrocarbons were detected through physical inspection and on-site PID screening.

Samples were collected at approximatly 10-foot intervals and from sections of the core with lithology or grain size contrasts. Intervals were skipped where an abundance of rock flour was present (due to the drilling action through large cobbles) or where the material appeared to be approximately the same as the sample interval directly above that location. Samples were collected from one-half foot to one-foot intervals. To collect the sample, subsurface material was scooped out of the core liner using a small bowl. The sample was then transferred to a quart-size Ziploc™ bag for storage. The boring number and depth interval of the sample were immediately recorded on each bag with indelible ink. All grain size analyses were performed using standard analytical methods at the Lolo National Forest Materials Testing Laboratory located at Fort Missoula in Missoula, Montana (details are presented in Appendix G).

CROSS SECTIONS

Geologic cross sections were constructed using QuickCross/Fence 2001 (M-Tech, 2001). Borehole information was entered into the QuickLog 2001 program and cross sections were generated using these logs. Some logs contained extensive detail and; therefore, a few thin non-continuous units were combined with larger units to reduce the complexity of the cross sections. Correlating some layers between new and previously described boreholes from auger drilling or water well driller's logs proved difficult simply due to the difference in the sample collection intervals and the lithologic logging detail provided in the logs. In cases where at least one major layer from a previously installed borehole could not be reasonably identified to correspond to a layer in one newly installed borehole, that borehole was excluded from the cross section (e.g., borehole SES-B4 was excluded from Cross Section B-B' [see Section 4]).

DETECTION OF SUBSURFACE SOIL CONTAMINATION

Volatile petroleum hydrocarbon detection in sediment samples was performed using a PE Photovac™ (model No. 2020) photoionization detector (PID). The PID was calibrated daily using 100 ppm isobutylene gas. PID readings were collected from the very bottom of each core interval. A small cut was made in the core's plastic core sleeve and the PID sampler tip was inserted. Each PID reading was recorded on the field log sheet after the reading stabilized. PID readings were discontinued once the water table was encountered or if soil moisture in the sample was too high, causing error readings on the PID.

Subsurface sediment samples were also collected from the depth interval with the highest PID reading and from the depth interval that crossed the approximate air/water interface (just above the water table). Boreholes where PID readings did not indicate a hydrocarbon presence were only sampled at the approximate air/water interface. Sample depths at the air/water interface ranged from 55 feet to 58 feet bgs. The Extractable Petroleum Hydrocarbon (EPH) Screen and volatile petroleum hydrocarbon (VPH) analyses were performed on these samples using standard procedures. VPH sample collection was performed according to EPA SW 846 Method 5035. For this sample collection procedure, a sample collection device, dedicated sample syringes, and pre-weighed VOA vials were obtained from the analytical laboratory (Energy Laboratories in Billings, Montana). EPA Method 5035 states the VOAs should be pre-preserved with methanol; however, Energy Laboratories recommended preserving the vials with methanol once they arrived at the laboratory due to a history of problems encountered with methanol leaking out of the vial during shipment. Therefore, the pre-weighed VOA vials obtained from the laboratory did not contain methanol preservative. VPH samples were collected using the dedicated syringes and sample collection device. The syringes were set up to collect approximately 10 grams of sample. Once the sample was collected in the syringe, it was immediately transferred to the VOA vial and capped.

One problem encountered while using the syringes was that some of the coarse-grained material would not become trapped in the syringe and could not be transfered easily to the VOA vial. When this occurred, approximately 10 grams of sample was transferred to the pre-weighed VOA vial using a disposable plastic spoon. The latter methodology does not compromise the analytical procedure because the appropriate volume of methanol preservative was added to the VOA vial at the laboratory.

Details about decontamination procedures used in the field are provided in the remedial investigation report prepared by MFG (MFG, 2001). Details about sample handling procedures are provided in the remedial investigation report prepared by MFG (2001). No field duplicates or field equipment rinsate blanks were collected during this study.

All samples were analyzed for VPH and EPH Screen using the Massachusetts Department of Environmental Protection procedures, as recommended in the Tier 1 Risk-Based Corrective Action (RBCA) Guidance document (MDEQ, 2000). The VPH method includes analysis for the following constituents: methyl t-butylether (MTBE), benzene, toluene, ethylbenzene, m+p-xylenes, o-xylene, total xylene, naphthalene, C9 to C10 aromatics, C5 to C8 aliphatics, C9 to C12 aliphatics, and Total Purgeable Hydrocarbons (TPH). EPH Screen analysis provides a total extractable hydrocarbon (TEH) value. If the EPH Screen result was above 50 ppm, the EPH fractionation analysis was requested. The full EPH test includes analysis of C9-C18 aliphatics, C19-C36 aliphatics, C11-C12 aromatics, TEH, and polynuclear aromatic hydrocarbons (PAH).

MONITORING WELLS

Monitoring wells were completed in four of the six boreholes drilled during this remedial investigation; boreholes MFG-B1, MFG-B2, MFG-B4, and MFG-B5 were completed as monitoring wells MFG-1, MFG-2, MFG-4, and MFG-5, respectively. Each monitoring well was completed at a total depth of approximately 65 feet bgs. Well construction information is presented in Table 3. Each well was completed as a flush-mount well. The location of each well is shown on Figure 7. Boring logs and well completion diagrams are provided in Appendix C.

HYDROGEOLOGY

The measuring point elevation (top of the polyvinylchloride casing) was surveyed by GMT Consultants. Water levels were collected using a Solinst electronic water level indicator. Additional water levels were collected from the Missoula Water Quality District wells at the corner of South and Bancroft and Blaine and Crosby using a steel tape. Water level information was also obtained directly from Mountain Water Company for the Southgate, Benton, and 200 South Avenue wells. The purpose of collecting water level data from the Water Quality District wells

TABLE 3
WELL COMPLETION INFORMATION
BURGER KING PETROLEUM RELEASE SITE

Well ID#	Completion Date	Measuring Point Elevation (feet AMSL)	Completion Depth (feet)	Well Diameter (inches)	Screen Length (feet)	Screened Interval (feet bgs)	Screened Interval (feet AMSL)
MSE-1	4/8/94	3182.8	60.1	2	15	45.1 - 60.1	3137.7 - 3122.7
MSE-2	4/9/94	3181.7	60.0	2	15	45.0 - 60.0	3136.7 - 3121.7
SES-1	9/26/94	3181.4	58.25	4	25	33.3 - 58.3	3148.1 - 3123.1
SES-2	9/21/94	3182.6	58.04	4	25	33.0 - 58.0	3149.5 - 3124.5
SES-3	9/28/94	3181.5	58.58	4	25	33.6 - 58.6	3148 - 3123
SES-5	8/25/95	3182.6	57.7	4	20	37.7 - 57.7	3144.9 - 3124.9
[1]MFG-1	4/5/01	3181.9	68.5	2	20	46.2 - 66.2	3135.7 - 3115.7
[1]MFG-2	4/6/01	3180	115	2	20	44.5 - 64.5	3135.5 - 3115.5
[1]MFG-4	4/8/01	3181.3	70	2	20	45.9 - 65.9	3135.4 - 3115.4
[1]MFG-5	4/9/01	3182.1	70	2	20	41.3 - 61.3	3139.8 - 3119.8

[1] Filter pack was completed using a 4" Pre-Pack SCH 40 0.020 Slot PVC Screen with 8x12 Sand Pack. See boring/well logs for well construction details.

and Mountain Water Company wells was to calculate a more regional gradient and evaluate groundwater flow direction for the area including and surrounding the Site. A water table map was prepared for the Site using water table elevation data collected on April 14, 2001.

No aquifer testing to evaluate hydraulic conductivity was performed during this remedial investigation. However, the use of two methods to estimate hydraulic conductivity from the grain size analysis results were evaluated. These methods include the Hazen Method (Driscoll, 1995) and the method developed by Shepard (Fetter, 1994). Further details discussing the use of these methods are provided in Appendix G.

Average linear velocity was calculated using the following equation using results obtained from the water table modeling effort.

$$V_x = \frac{K\Delta h}{n_e \Delta l} \qquad \text{(Fetter, 1994)}$$

Where:

V_x = average linear velocity/seepage velocity (ft/day)

K = hydraulic conductivity (ft/day)

n_e = effective porosity

$\Delta h/\Delta l$ = gradient (ft/ft)

GROUNDWATER SAMPLES

After all new wells were installed, the wells were developed prior to sampling. Water level measurements and groundwater sampling was performed at all previously installed wells and newly installed wells at the Site. Measurement of petroleum hydrocarbons product thickness was not performed as previous investigations and monitoring events at the Site had not indicated its presence. There was no measurable free product in the wells. Details of the groundwater sampling activities, and decontamination and sample handling procedures are provided in the remedial investigation report prepared by MFG (MFG, 2001).

All groundwater samples were analyzed for VPH and EPH Screen using the Massachusetts Department of Environmental Protection procedures, as recommended in the Tier 1 RBCA Guidance document (MDEQ, 2000). Groundwater samples were analyzed for the same analytical parameters as the subsurface soil samples.

MODELING

An attempt was made to simulate the potentiometric surface mapped at the Site using Visual MODFLOW 2.8.2, a 3-dimensional groundwater flow and contaminant transport computer model by Waterloo Hydrogeologic, Inc. (WHI, 2000). An attempt was also made to simulate the 1990 water line rupture to evaluate its potential to affect groundwater flow direction and rates, thus contaminant transport at the Site. Particle tracking was used in both simulations to evaluate possible contaminant transport routes at the Site. In addition, a vadose zone model was attempted to evaluate the fate of VOC within the zone of water table fluctuation using VLEACH (WHI, 2001). Models of groundwater flow and vadose zone transport at the Site were performed to assist in the interpretation and visualization of conditions at the Site. Models were not constructed or calibrated to act as prediction tools.

A water table model was attempted to simulate groundwater conditions on April 14, 2001. A two-layer steady state model was designed to simulate a potentiometric map of the Site and surrounding areas. Two layers were chosen after review of the lithostratigraphic logs, cross sections, and water table elevation data. Hydrogeologic conductivity values, previously estimated for the MVA in the vicinity of the Site, were initially used in the model. Appendix D provides a further discussion on setup and calibration of the model.

In addition to producing a simulated water table map for the Site, a steady state simulation of the water line rupture event was also attempted to evaluate the effect of the water line rupture event on the water table at the Site. Details of setup and calibration of the model are provided in Appendix D.

VLEACH, a one-dimensional finite difference model for predicting the vertical migration of volatile petroleum hydrocarbons and VOCs in the vadose zone (WHI, 2001), was used to evaluate vadose zone migration of ethylbenzene in the vadose zone over time. VLEACH partitions the total mass of contaminant, in each model cell, into three phases. These phases include: liquid (dissolved in water), sorbed (adsorbed to solid surfaces), and vapor (WHI, 2001). During model simulation, liquid phase contamination is subject to downward advection and contamination in the vapor phase is subject to gas diffusion. Ethylbenzene subsurface soil analytical results from MFG-B3 were used to evaluate the vadose zone modeling effort.

Modeling the Site using this or other models in the UnSat Suite is limited because:

- There are only a few select programmed soil types, none of which include gravel, as the dominant soil type.

- "Known" or "common" volatile petroleum hydrocarbons (i.e., benzene versus C9-C12 aliphatic volatile compounds) are pre-programmed. However, at this Site, the majority of the volatile compounds detected were general or "unknown" volatile aliphatics and aromatics.

Recognizing these limitations, an attempt was made to generally simulate LNAPL migration in the vadose zone. Additional details of model setup is provided in Appendix F.

4 RESULTS

The following presents the results of this study. The results are discussed in the following order: lithostratigraphy, hydrogeology, source area and contaminant distribution, mapping of soil and groundwater contamination, influence of a water line rupture on contaminant migration, and potentiometric surface and vadose zone model results.

LITHOSTRATIGRAPHY

Grain size analytical results including classification tables, a results summary table, and grain size distribution curves are presented in Appendix G. In addition, a qualitative estimation of the percent gravel versus percent sand and fines was made during logging of the cores. These results are presented on the detailed boring logs (Figure 10 and Appendix C). Because the samples collected from the cores may not have had a complete representation of all grain sizes present in the subsurface, particularly the larger cobble sized-grains, the results of the grain size analyses may not completely represent the full spectrum of grain sizes present in the subsurface.

Cross sections were constructed from boring logs completed during previous remedial investigations and during this study (Figures 11 through 15). The majority of subsurface soils beneath the Site are characterized as sandy gravel.

Each cross section shows several distinct interbedded layers of sand, clay, and caliche. Cross sections A-A' (Figure 12) and D-D' (Figure 15) also contain a silt layer at MFG-5. Cross sections B-B' (Figure 13) and D-D' (Figure 15) appear to contain fewer interbedded layers than cross sections A-A' and C-C' (Figure 16). However, only one borehole logged in lithostratigraphic detail was used in cross sections B-B' and D-D'. Therefore, more and continuous layers may exist in the subsurface than those shown on these two cross sections. Initially, an attempt was made to extended the Site cross sections to include water wells within one mile of the Site. However, this effort was abandoned after recognizing the lack of detail in the driller's logs.

Generally, sand and gravel clasts appear to be predominantly of Belt Super Group origin and include red and green argillite, various colors of quartzite, siltstone and sandstone, and chert. Sand and gravel of granitic composition were identified clearly in one small interval of MFG-4. Additionally, mica was identified at various depths in this borehole; however, it was present only in very minor amounts in the other boreholes and was not in notable abundance. Other clasts of granitic or other composition may have been present. Identification and logging of individual clast origin and/or composition were not performed as a part of this thesis study. Two characteristic lithostratigraphic units were identified.

Upper Unit

The Upper Unit is similar to the previously described Unit One described by others (see Section 2), with the exception of its thickness and total dept. During this evaluation, the Upper Unit was recognized as extending from the ground surface to a total depth of approximately 58 to 60 feet bgs. This was considered as the boundary between the Upper Unit and Lower Unit at the Site (see below). There appears to be a general coarsening of the sediments below the 58 to 60 foot depth interval. Previous descriptions of Unit One describe the unit as extending to a total depth of 30 feet bgs. There was no obvious change in lithology near this depth interval. However, interbedded sand, silt, clay, and caliche were present between approximately 20 feet and 60 feet bgs within the Upper Unit.

Figures 16 through 23 present representative photographs of subsurface materials encountered within the Upper Unit, including a caliche layers and a silt layer. The sandy gravel portions generally contain well-graded gravel and well to poorly graded sand. During field logging,

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University of Montana, Missoula
Spring 2002

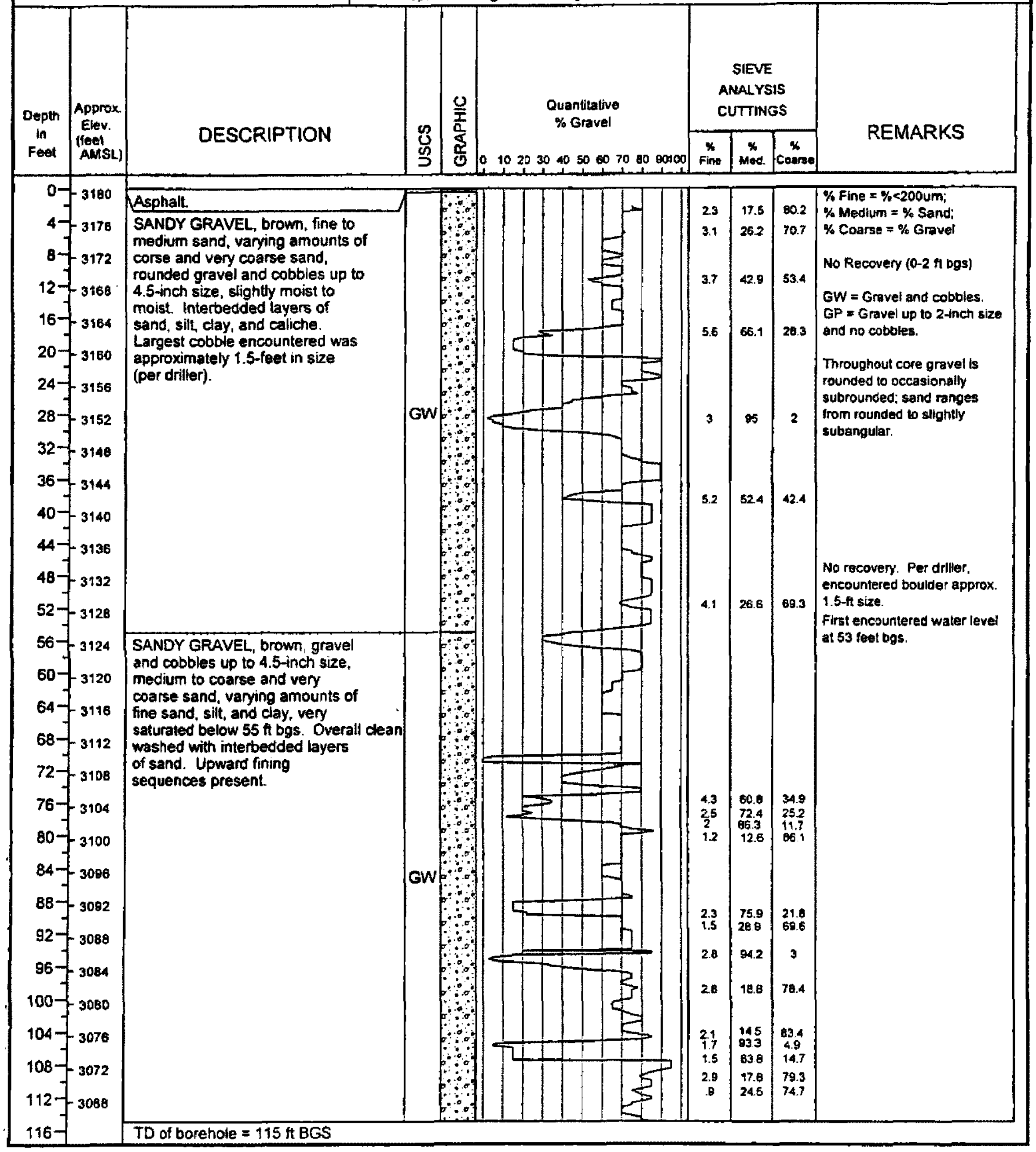
Figure 10

Qualitative Estimate of % Gravel for MFG-B2

Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Boring : 115 feet bgs

Start/Complete Date : 4-4-01 / 4-5-01
Boring/Well Location : Near 2404 Washburn
Approx. Surface Elev. : 3180.5 Feet AMSL
Measuring Point Elev. : 3180.01 Feet AMSL
Logged By : Natalie Morrow



DESCRIPTION

Asphalt.

SANDY GRAVEL, brown, fine to medium sand, varying amounts of corse and very coarse sand, rounded gravel and cobbles up to 4.5-inch size, slightly moist to moist. Interbedded layers of sand, silt, clay, and caliche. Largest cobble encountered was approximately 1.5-feet in size (per driller).

SANDY GRAVEL, brown, gravel and cobbles up to 4.5-inch size, medium to coarse and very coarse sand, varying amounts of fine sand, silt, and clay, very saturated below 55 ft bgs. Overall clean washed with interbedded layers of sand. Upward fining sequences present.

TD of borehole = 115 ft BGS

SIEVE ANALYSIS CUTTINGS

% Fine	% Med.	% Coarse
2.3	17.5	80.2
3.1	26.2	70.7
3.7	42.9	53.4
5.6	66.1	28.3
3	95	2
5.2	52.4	42.4
4.1	26.6	69.3
4.3	60.8	34.9
2.5	72.4	25.2
2	86.3	11.7
1.2	12.6	86.1
2.3	75.9	21.8
1.5	28.9	69.6
2.8	94.2	3
2.8	18.8	78.4
2.1	14.5	83.4
1.7	93.3	4.9
1.5	83.8	14.7
2.9	17.8	79.3
.8	24.5	74.7

REMARKS

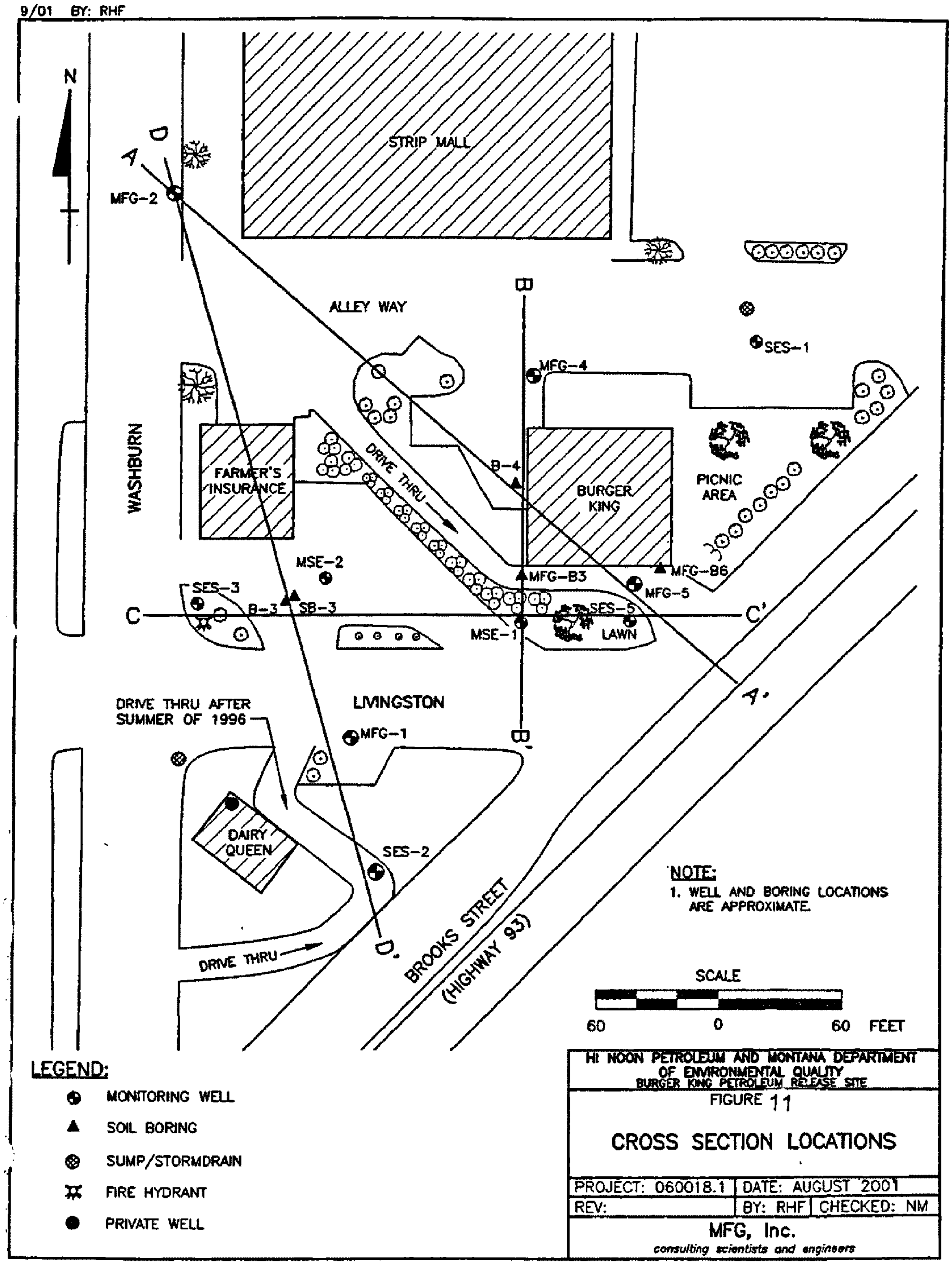
% Fine = %<200um;
% Medium = % Sand;
% Coarse = % Gravel

No Recovery (0-2 ft bgs)

GW = Gravel and cobbles.
GP = Gravel up to 2-inch size and no cobbles.

Throughout core gravel is rounded to occasionally subrounded; sand ranges from rounded to slightly subangular.

No recovery. Per driller, encountered boulder approx. 1.5-ft size.
First encountered water level at 53 feet bgs.



NOTE:
1. WELL AND BORING LOCATIONS ARE APPROXIMATE.

HI NOON PETROLEUM AND MONTANA DEPARTMENT OF ENVIRONMENTAL QUALITY
BURGER KING PETROLEUM RELEASE SITE

FIGURE 11

CROSS SECTION LOCATIONS

PROJECT: 060018.1	DATE: AUGUST 2001	
REV:	BY: RHF	CHECKED: NM

MFG, Inc.
consulting scientists and engineers

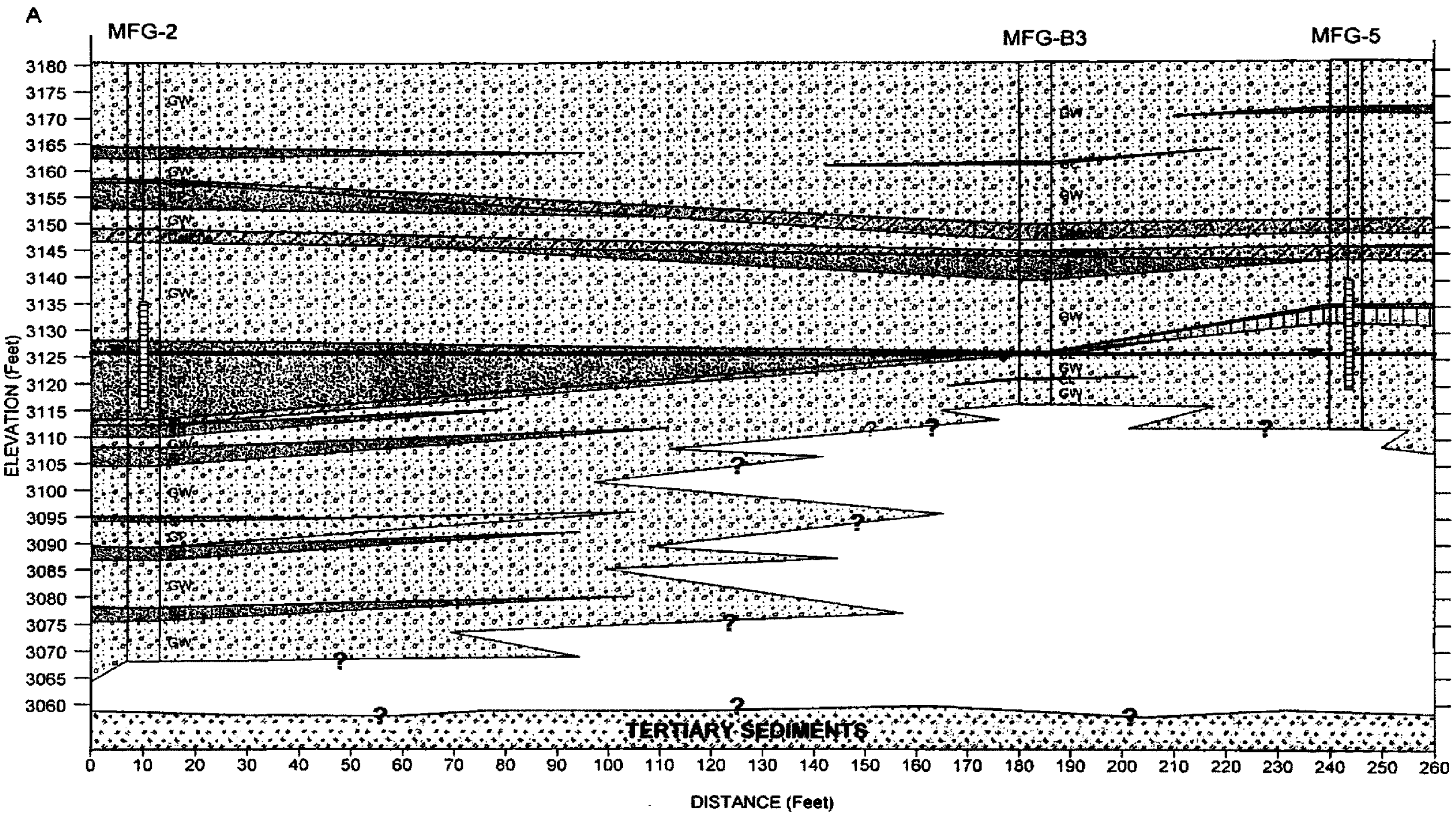


FIGURE 12

Lithostratigraphic Cross Section A-A'
Northwest to Southeast

Burger King Petroleum Release Site

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LEGEND

- GW: Well Graded Sandy Gravel
- GP: Poorly Graded Sandy Gravel
- SP: Poorly Graded Gravelly Sand
- SW: Well Graded Gravelly Sand
- Caliche: Caliche w/Sand, Gravel, and Clay
- CL: Clay with or without Gravel
- ML: Sandy Silt to Silty Sand w/Gravel
- ▼ Approx. water table at time of drilling

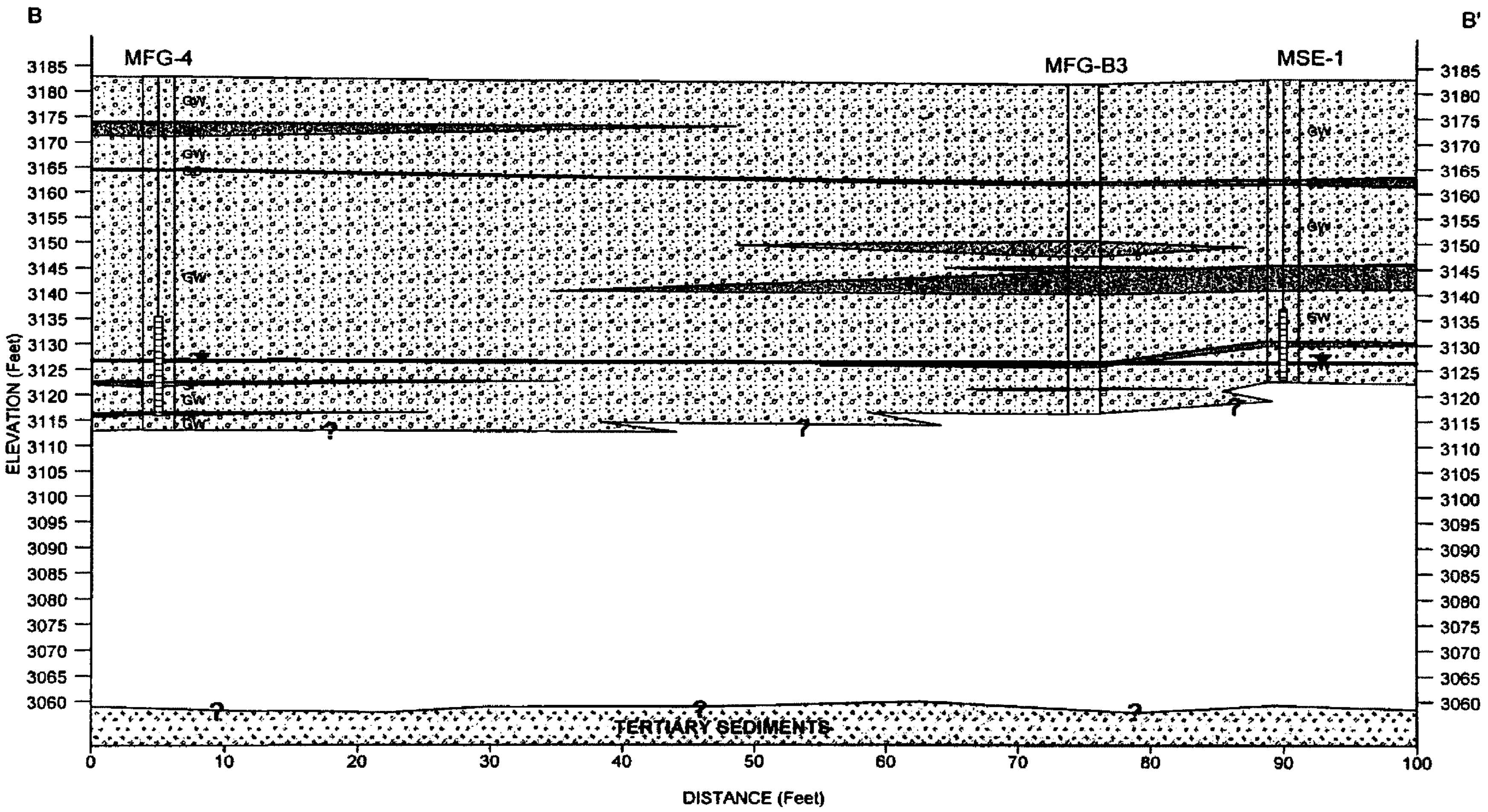

FIGURE 13

Lithostratigraphic Cross Section B-B'
North to South
Burger King Petroleum Release Site

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M.S. Thesis, University of Montana
Spring 2002

LEGEND

- ▨ GW: Well Graded Sandy Gravel
- ▨ GP: Poorly Graded Sandy Gravel
- ▨ SP: Poorly Graded Gravelly Sand
- ▨ SW: Well Graded Gravelly Sand
- ▨ Caliche: Caliche w/Sand, Gravel & Clay
- ▨ CL: Clay with or without Gravel
- ▥ ML: Silt
- ▼ Approx. water table at time of drilling

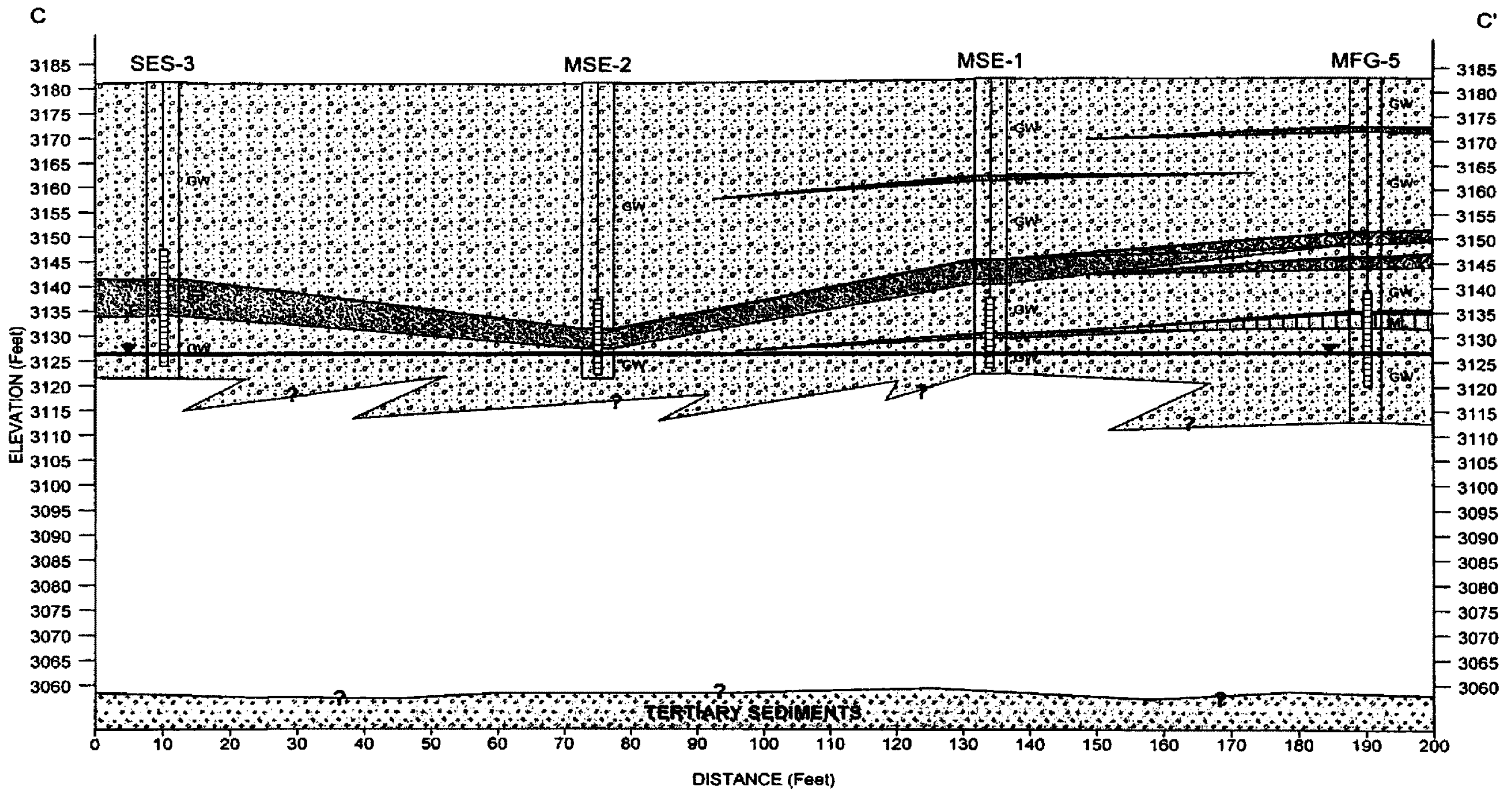

FIGURE 14

Lithostratigraphic Cross Section C-C'
West to East
Burger King Petroleum Release Site

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M.S. Thesis, University of Montana
Spring 2002

LEGEND

▨	GW: Well Graded Sandy Gravel	▨	Caliche: Caliche w/Sand, Gravel and Clay
▨	GP: Poorly Graded Sandy Gravel	▨	CL: Clay with or without Gravel
▨	SP: Poorly Graded Gravelly Sand	▥	ML: Silt
▨	SW: Well Graded Gravelly Sand	▼	Approx. Water table at time of drilling

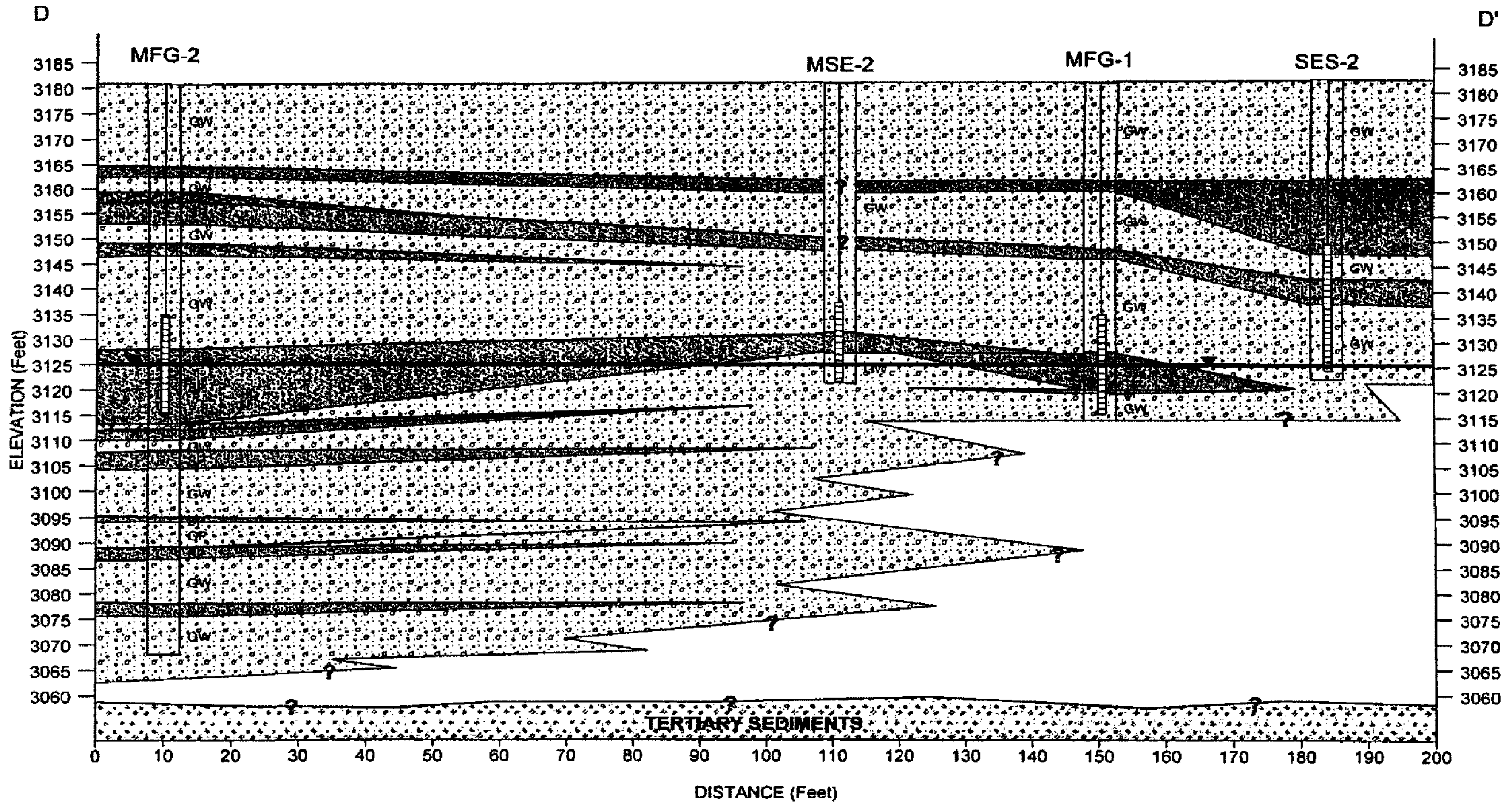


FIGURE 15

Lithostratigraphic Cross Section D-D'
West-Northwest to East-Southeast
Burger King Petroleum Release Site

Natalie J. Morrow
M.S. Thesis, University of Montana
Spring 2002

LEGEND

- ▨ GW: Well Graded Sandy Gravel
- ▨ GP: Poorly Graded Sandy Gravel
- ▨ SP: Poorly Graded Gravelly Sand
- ▨ SW: Well Graded Gravelly Sand
- ▨ Caliche: Caliche w/Sand, Gravel and Clay
- ▨ CL: Clay with or without Gravel
- ▨ ML: Silt
- ▼ Approx. Water table at time of drilling

well-graded gravel was defined as having variable sizes of gravel and contained cobbles. Poorly graded was defined as having variable sizes of gravel up to two inches in size but with no cobbles.

Grain size analysis revealed the content of gravel in the Upper Unit ranged from zero to 82.7 percent with an overall average of 55.2 percent; average sand content ranged from 15.5 percent to 97.3 percent with an overall average of 41.3 percent; and the average silt and clay content ranged from 1.5 percent to 6.8 percent with an overall average of 3.6 percent. The average median grain size in the Upper Unit was 0.22 inches.

Gravel in this unit ranges from granule to cobble size (according to the Wentworth Scale). Overall, the gravel was rounded but occasionally contained some slightly subrounded clasts. Cobbles and broken cobbles up to 5.5 inches in size were retained in the cores; however, the driller estimated that boulders up to approximately 1.5 feet in size may have been encountered during drilling in this unit.

Sand sizes ranged from very fine to very coarse and the size composition varied greatly throughout each borehole. In general, sand ranged from subrounded to subangular (see Figures 16,17,18,19,and 21). Sand layers were well to poorly graded, and generally contained some small gravel, silt, and minor clay. The sand layers contained in this unit ranged from approximately one to 4.5 feet thick. Many of these layers appear to be discontinuous across the Site. One sandy silt layer was encountered in MFG-5 between approximately 48 and 51 feet bgs. The sandy silt layer (Figure 23) contained small gravel and minor amounts of sand. This layer was light yellowish brown and may correspond sediment attributed to Unit Two described by others (see Section 2). However, this silt layer was not identified as a distinct unit because the Upper Unit is clearly present both above and below this layer in MFG-5.

Figure 16 MFG-B2 (9-13'): Representative sandy gravel within Upper Unit.

Figure 17 MFG-B2 (20-22.5'): Representative sandy gravel within Upper Unit with core of cobble (center).

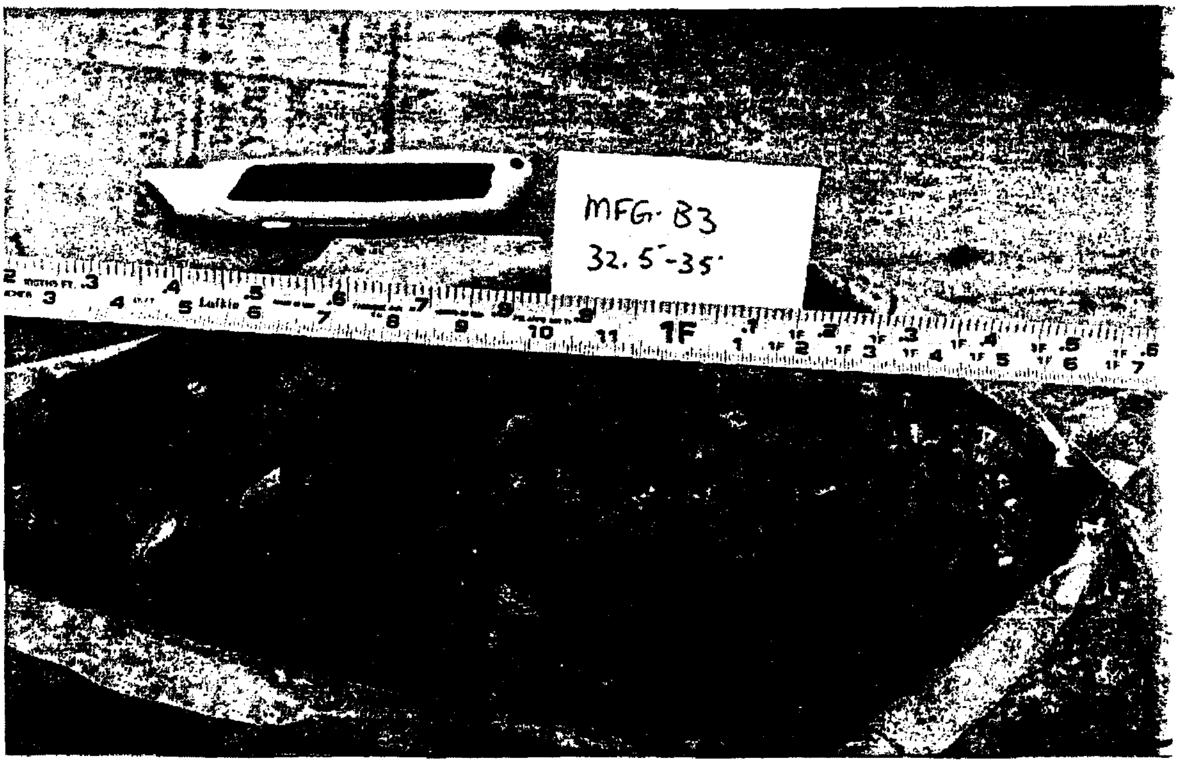


Figure 18 MFG-B3 (32.5-35'): Representative sandy gravel within Upper Unit.

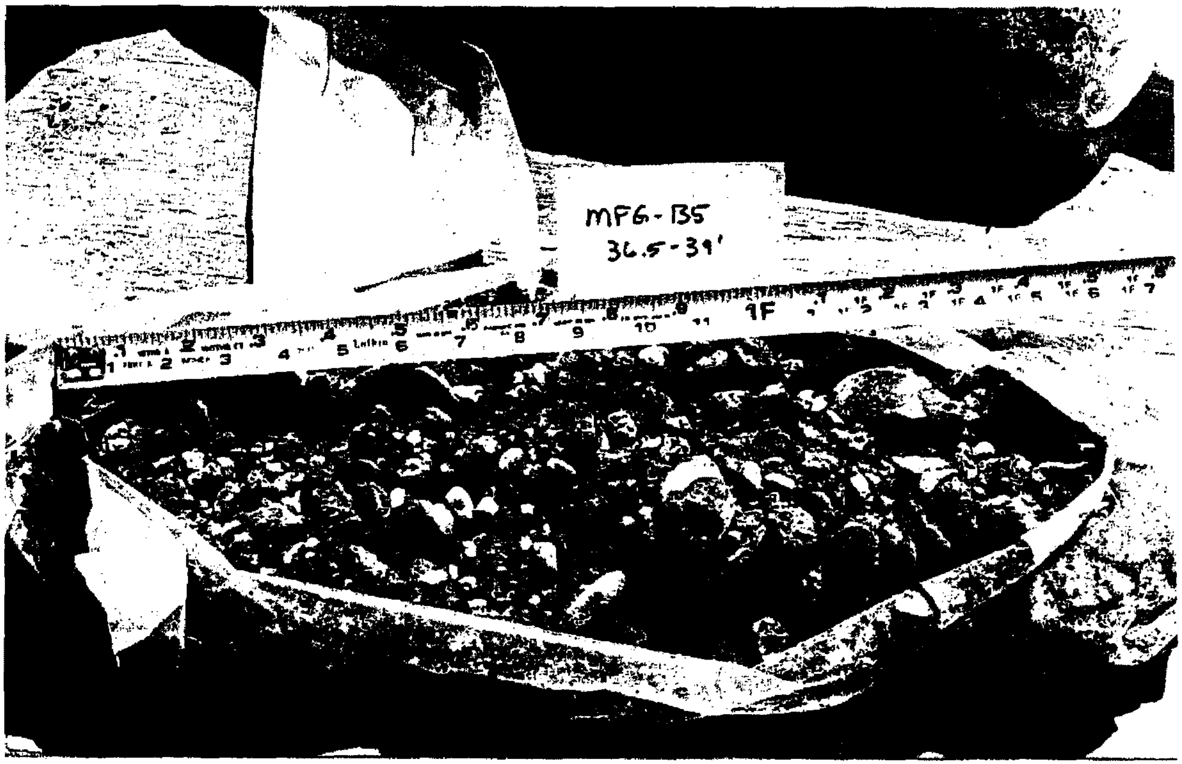


Figure 19 MFG-B5 (36.5-39'): Representative sandy gravel within Upper Unit.

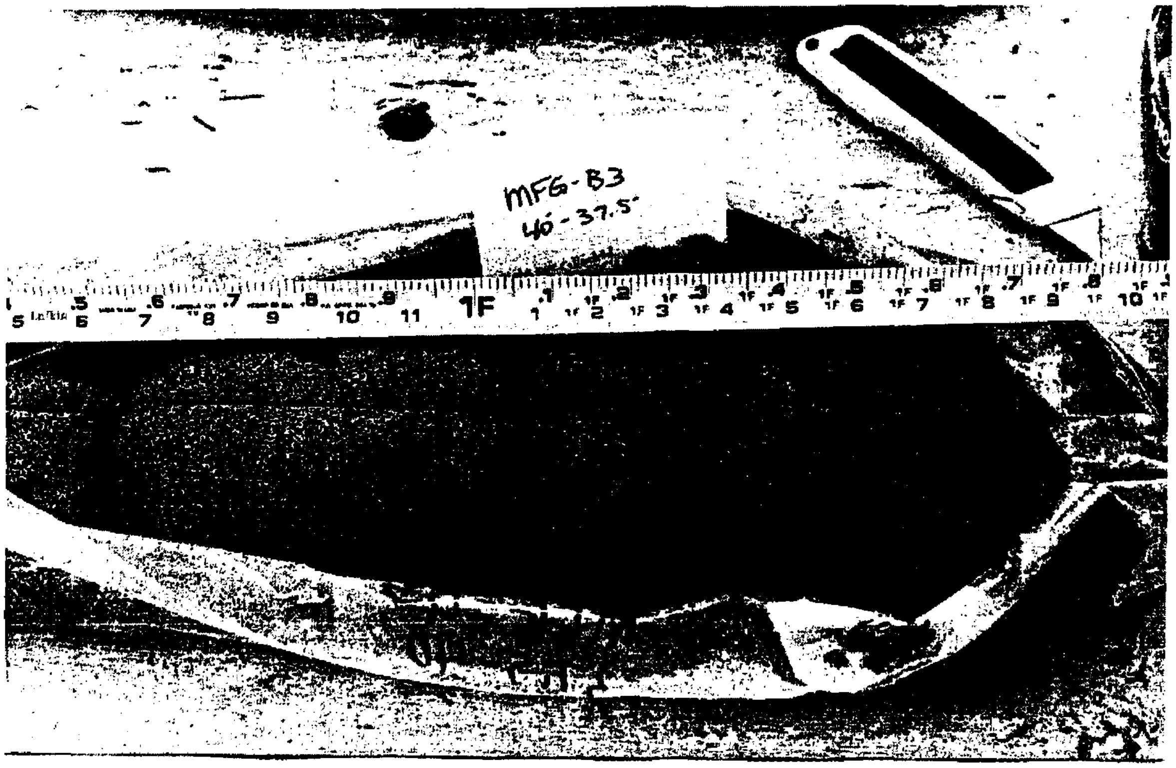


Figure 20 MFG-B3 (37.5-40'): Sand layer within Upper Unit, possibly part of Unit

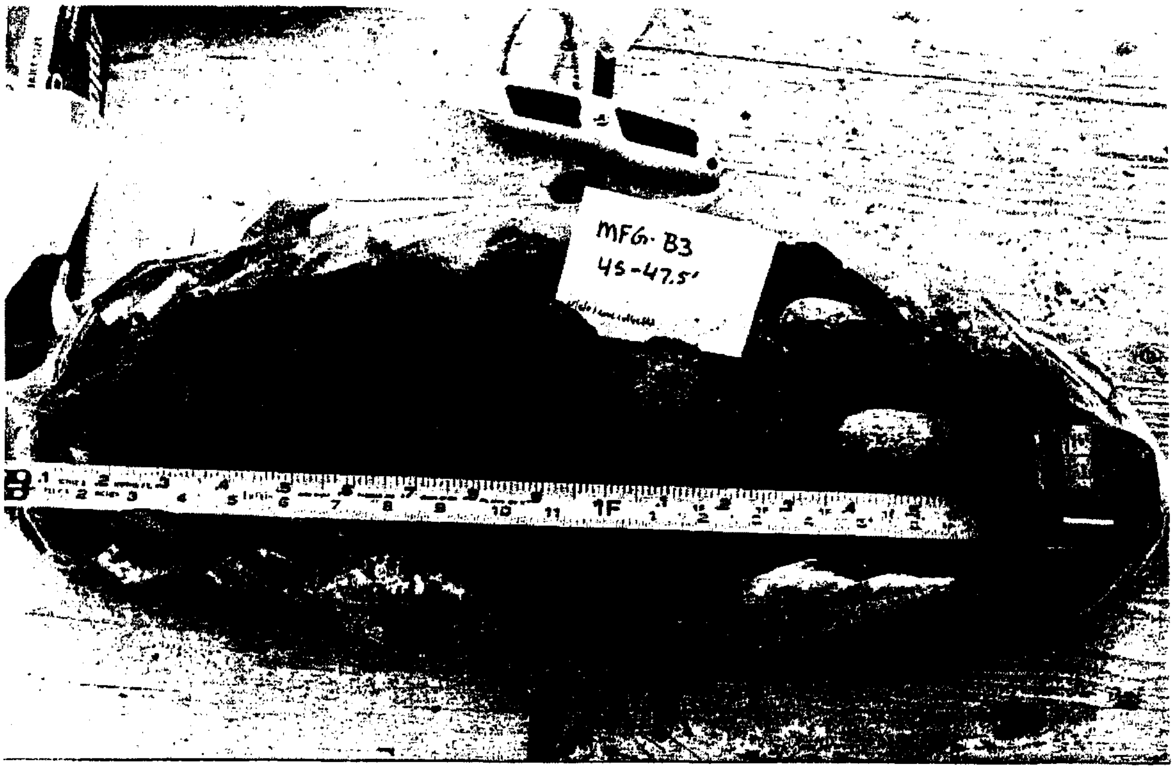


Figure 21 MFG-B3 (45-47.5'): Representative sandy gravel within Upper Unit.

Figure 22 MFG-B2 (25-27.5'): Caliche layer encountered in Upper Unit, possible part of Unit Two

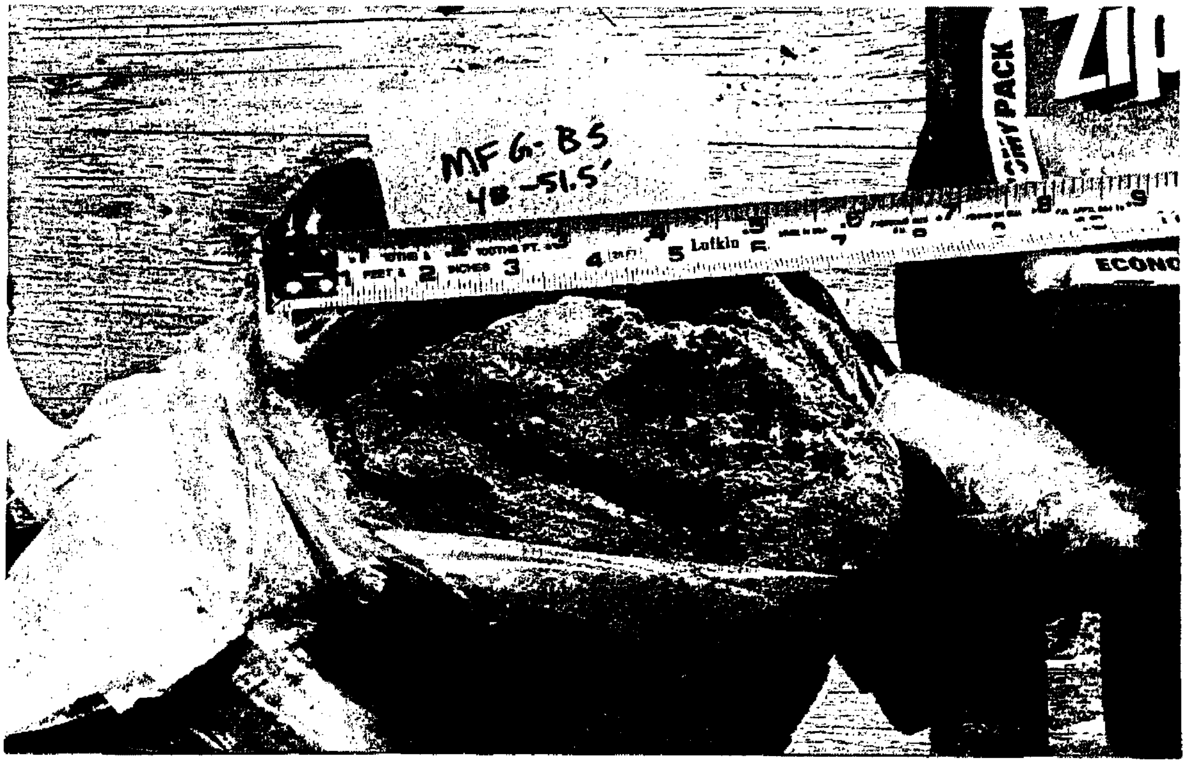


Figure 23 MFG-B5 (48-51.5'): Silt to sandy silt layer encountered in Upper Unit, possibly part of Unit Two.

Several clay/clayey layers were identified in the Upper Unit. The boreholes where clayey layers were encountered include MFG-B3, and MFG-4. In borehole MFG-B3, a clayey sandy gravel to sandy clay with gravel layer was encountered between approximately 19 and 20 feet bgs; a gravelly clay layer was encountered between approximately 55 and 55.75 feet bgs; and a clay layer between 60 to 60.25 feet bgs. One clayey gravel layer was encountered approximately between 18.5 to 19 feet bgs in MFG-4. The clay/clayey gravel layer located in these two borings between 18 to 20 feet bgs is consistent with a clay/clayey gravel layer noted in a similar interval by MSE, Inc. during the installation of well MSE-1 (MSE, 1994b).

Caliche was observed in all of the vertical boreholes (Figure 22). To verify the layers indentified were caliche, it was tested for the presence of calcium carbonate with dilute hydrochloric acid. The test confirmed a calcium carbonate cement was present. There appeared to be two to three layers containing broken fragments of caliche. It consisted of a whitish- to pinkish-cemented gravelly sand to sandy gravel. The gravel contained in the caliche was generally small but occasionally contained gravel up to 3 inches in size. Caliche layers were not logged in MFG-1; however, it was most likely present and may have been inadvertently dismissed as an artifact generated during drilling at the time of logging (MFG-1 was the first core logged).

Another unit (Unit Two) of the MVA has been described by others within the depth interval labeled as the Upper Unit. A sandy silt to silty sand layer, very similar to sediments attributed to Unit Two was encountered in MFG-5. It is assumed that this layer is the same as the tan to yellow silty sandy clay previously described as Unit Two. The sandy silt layer was not continuous across the Site. Unit Two has also been described as a silty sandy clay with layers of coarse sand and gravel. In addition, development of wells completed in this zone has also been known to produce pinkish colored water (Woessner, 2001).

The caliche layers are present between approximately 20 feet and 35 feet bgs at the Site and are off-white, to light to moderate pink in color. Sand layers are also present between approximately 30 feet and 40 feet bgs. This group of layers may represent what has been described as Unit Two by others (see Section 2).

Lower Unit

A second unit (the Lower Unit) was identified at the Site and extends to a depth of at least 115 feet bgs. This unit generally began between approximately 58 to 60 feet bgs. The Lower Unit consists mainly of sandy gravel with interbedded sand and clay layers, similar to the Upper Unit. This unit is similar to the previously described Unit Three (see Section 2). Consistent with previous observations, this Lower Unit is coarser than the Upper Unit. The median grain size of the lower unit is 0.36 inches (compared with a median grain size of 0.22 inches in the Upper Unit. Representative photographs of subsurface sediments encountered in the Lower Unit are included as Figures 24 through 39.

The main differences observed between the Upper Unit and Lower Unit are that the Lower Unit is mostly saturated and consisted of relatively clean washed sands and gravels with little silt and clay. As described during logging, gravel in the Lower unit is mainly well graded with few sections of poorly graded gravel. There were no known boulders encountered in the Lower Unit during drilling as cores of large clasts were not observed in the samples. In addition, the driller stated drilling conditions did not indicate boulders were encountered. Gravel content in the Lower Unit ranged from 3.0 percent to 86.1 percent with an overall average of 59.6 percent (Appendix G). Sand content ranged from 12.6 percent to 94.2 percent with an overall average of 38.5 percent. Silt and clay ranged from 0.9 percent to 4.3 percent with an overall average of 1.9 percent. Qualitative estimates of the percent gravel versus percent sand and fines were also made during logging of the cores (Appendix C).

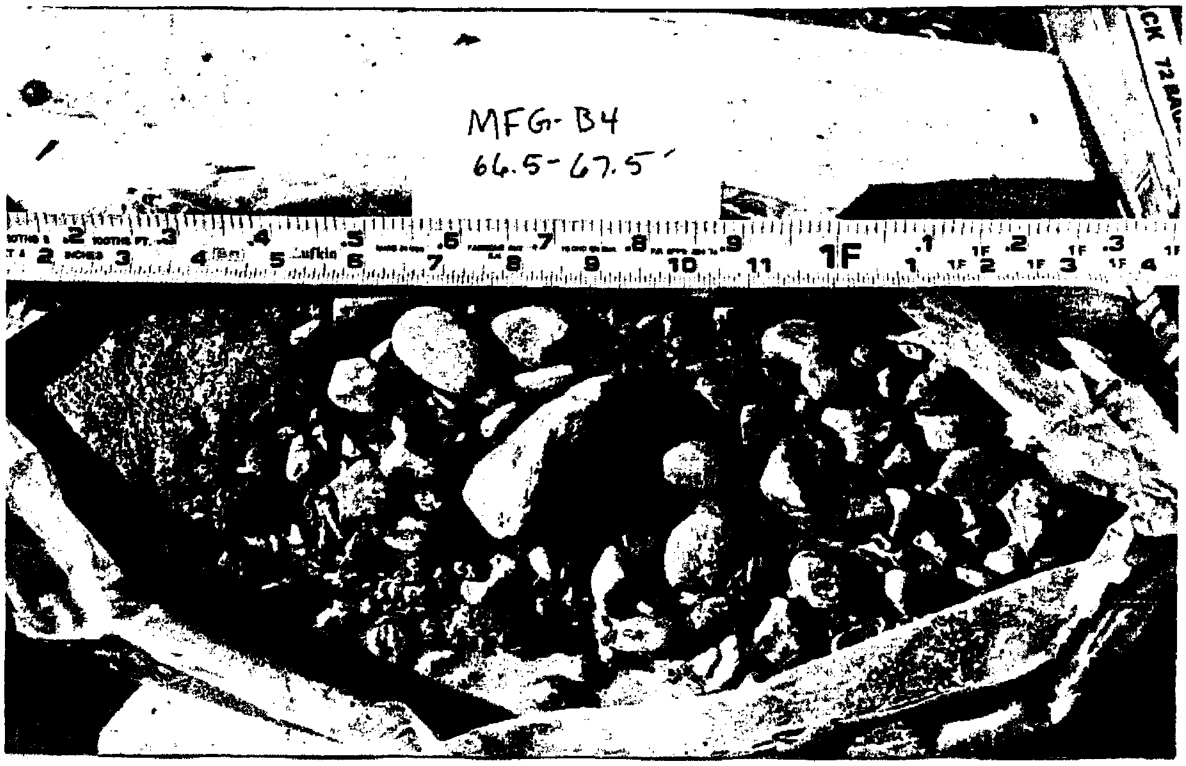


Figure 24 MFG-B4 (66.5-67.5'): Coarse gravel within Lower Unit.

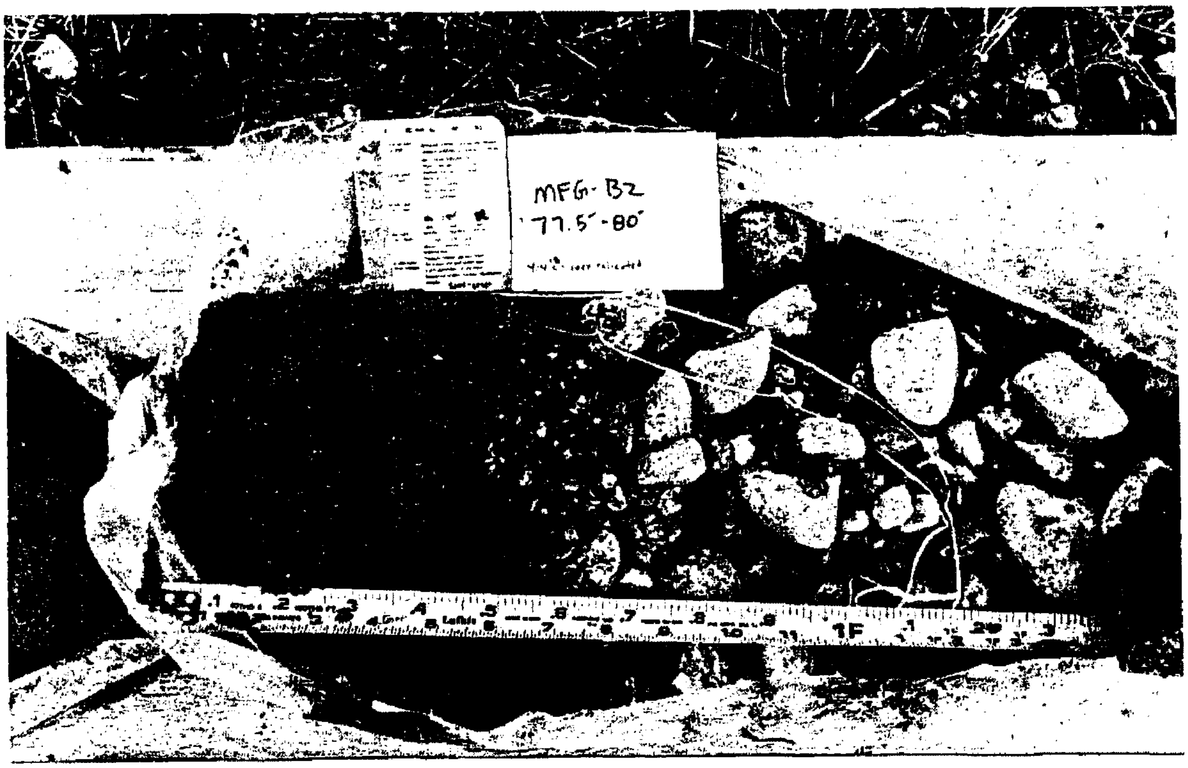


Figure 25 MFG-B2 (77.5-80'): A portion of an upward fining sequence in Lower Unit, ranges from coarse gravel to sand in photograph.

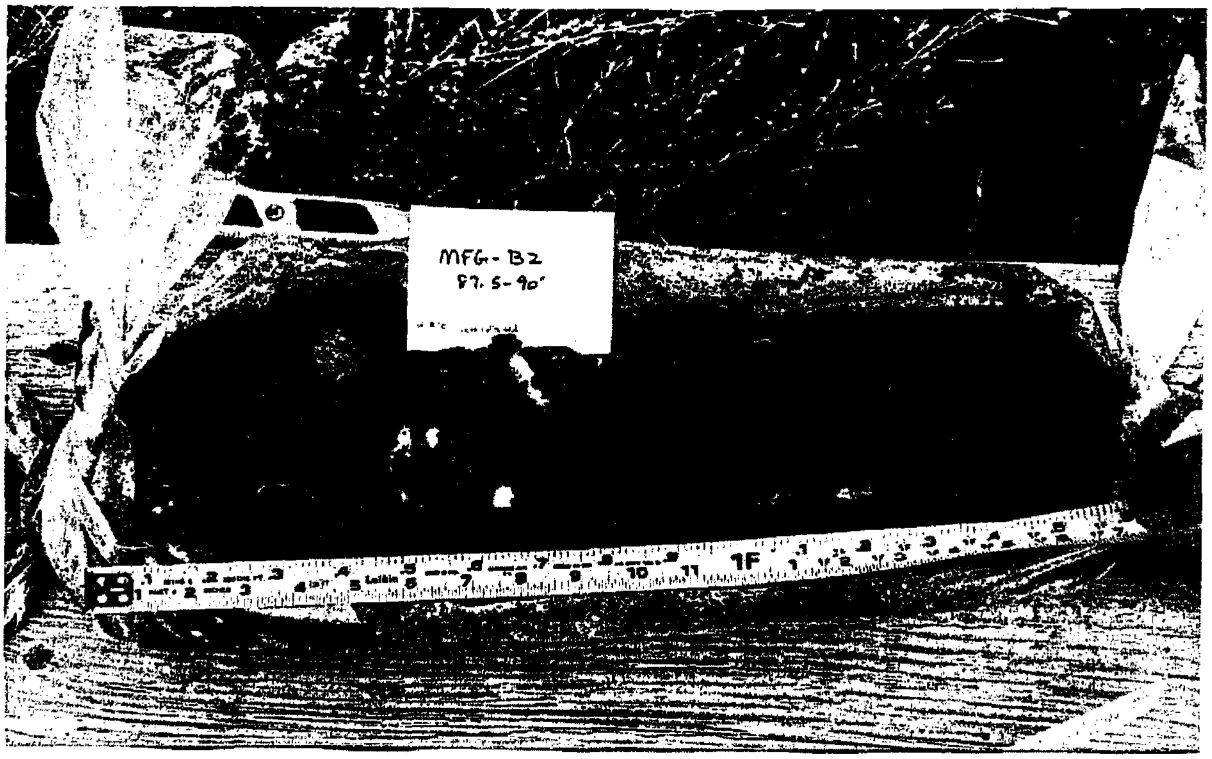


Figure 26 MFG-B2 (87.5-90'): Sand and gravel layers in Lower Unit.

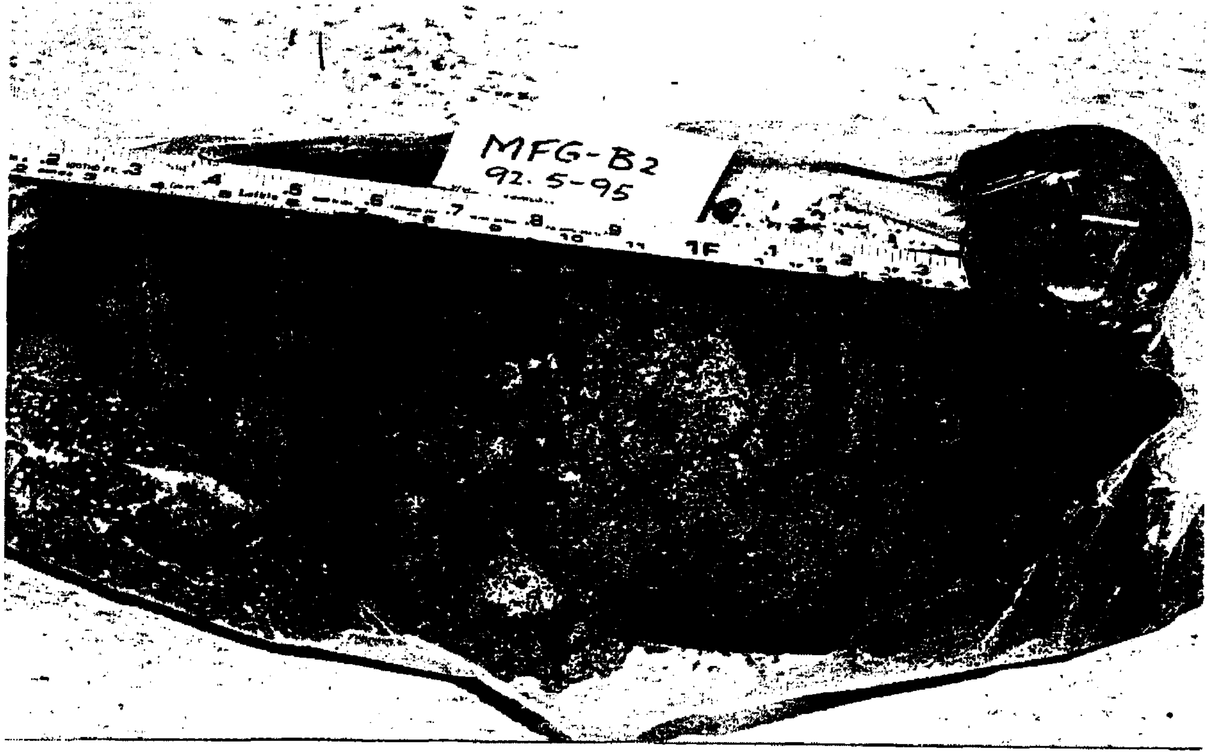


Figure 27 MFG-B2 (92.5-95): Shows 2-inch gravel layer (approx. center) with sand layer on right and sandy gravel on left. Lower Unit.

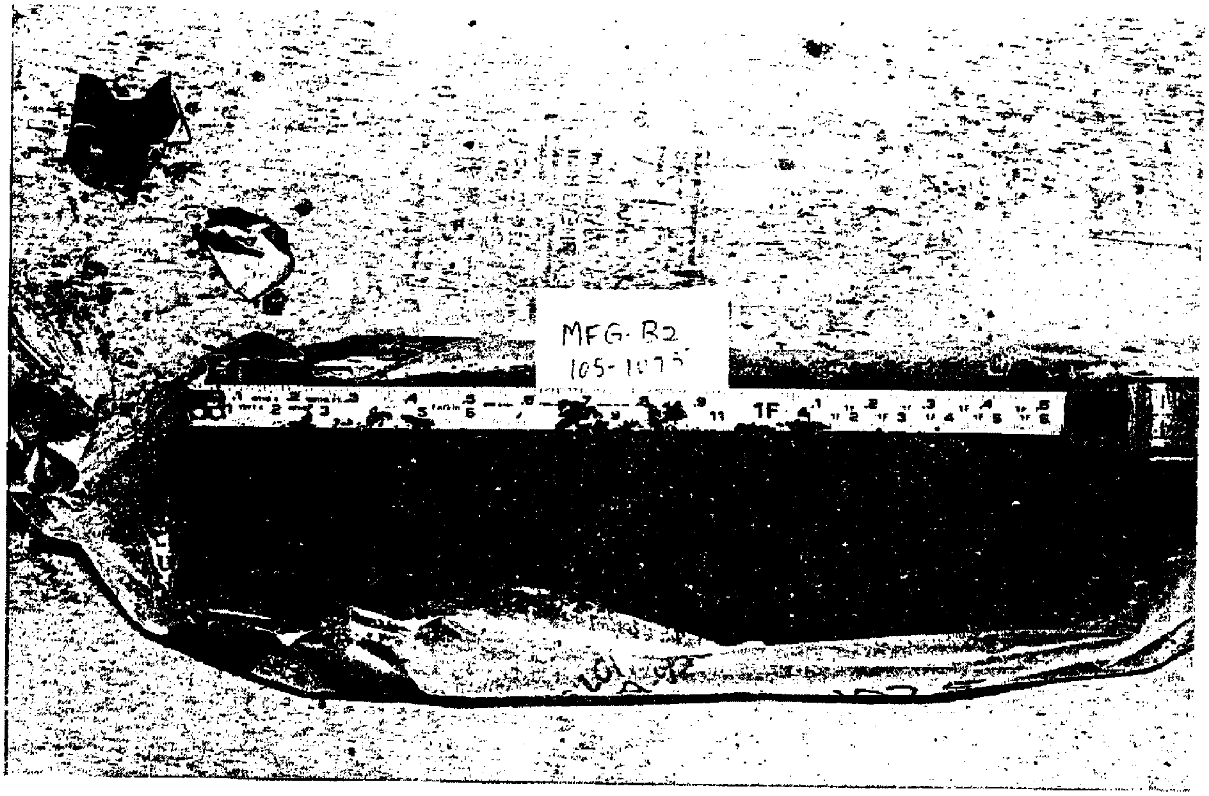


Figure 28 MFG-B2 (105-107.5'): Coarse sand layer in Lower Unit.

Figure 29 MFG-B2 (107.5-110'): Coarse gravel in Lower Unit.

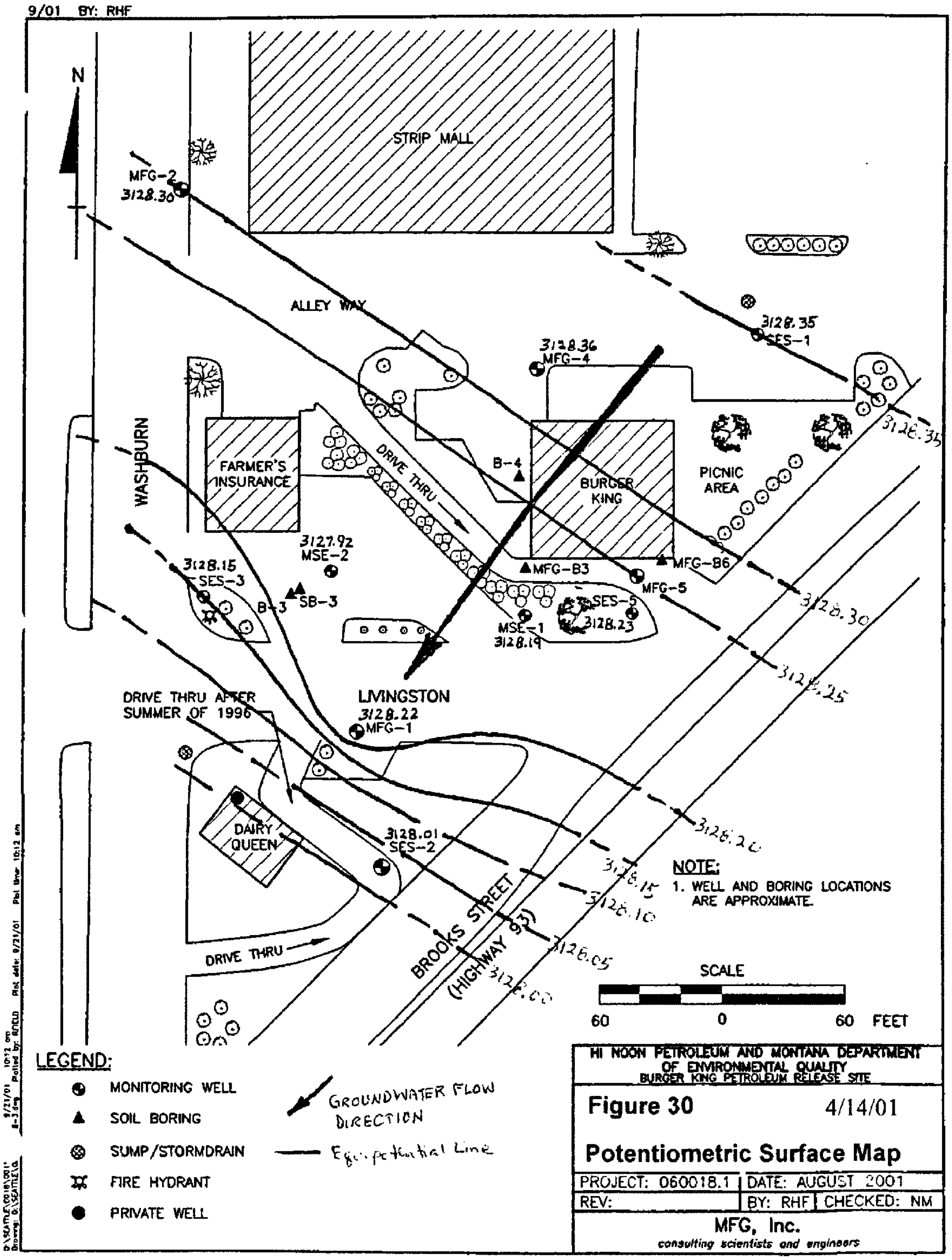
In addition, more defined gradational changes or sequences were observed within the sandy gravel and sand units. At least one distinct upward fining sequence was observed in MFG-2. One upward fining sequence began at approximately 75 feet bgs as sandy gravel, graded to sand at approximately 73 feet bgs and ended with a gravelly clay layer approximately 70 feet bgs.

Sand layers were poorly graded (or well sorted), usually contained some small gravel. the composition of some individual sand layers consisted of clean sand with other layers of clean coarse and very coarse sand. Interbedded sand layers ranged from 0.5 to four feet thick. One, 0.8 to 1-foot thick clay layer was observed in MFG-2 at approximately 70 feet bgs. This clay layer was the only clay layer observed in the Lower Unit. Silt and clay in the Lower Unit was typically less than five percent of the composition and was generally present mainly as muddy coatings on the gravel and sand.

HYDROGEOLOGY

Table 3 provides a summary of the borehole and well completion information, including those wells completed during previous investigations. The water table was mostly found in the Lower Unit. However, seasonally it would often rise into the lower portion of the Upper Unit . The saturated zone is estimated to be 60 to 70 feet thick. A water table map was prepared and the groundwater flow direction was estimated using water table elevation data collected on April 14, 2001 (Figure 30).

The Hazen Method and Shepard Method for estimating hydraulic conductivity from grain size analyses were reviewed; however, these methods were determined to be inappropriate (see Appendix G). Therefore, aquifer properties already established and used by others were selected to characterize the hydraulic properties of the subsurface material and for use in the groundwater modeling effort. Aquifer properties have been estimated for Unit Three



HI NOON PETROLEUM AND MONTANA DEPARTMENT OF ENVIRONMENTAL QUALITY
BURGER KING PETROLEUM RELEASE SITE

Figure 30 4/14/01

Potentiometric Surface Map

PROJECT: 060018.1 | DATE: AUGUST 2001
REV: | BY: RHF | CHECKED: NM

MFG, Inc.
consulting scientists and engineers

(Lower Unit) of the MVA by others and range from 6,000 ft/day (Miller, 1991) to 36,000 ft/day (Pracht, 2001).

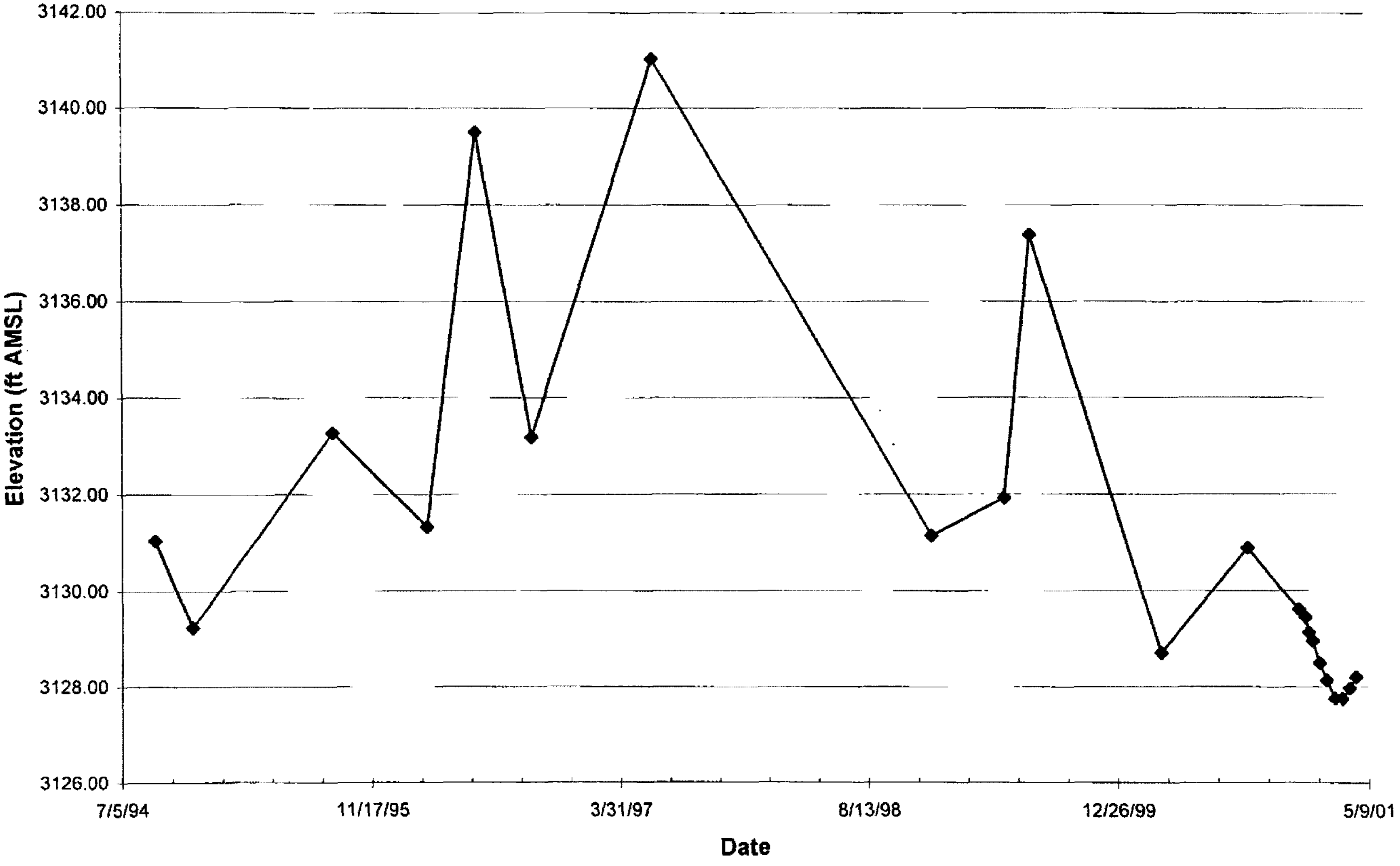
The groundwater gradient at the Site is approximately 0.0014 ft/ft. The porosity of the Upper and Lower Unit is estimated to be 0.20 (Clark, 1986). A hydraulic conductivity value of 19,000 ft/day was obtained during the water table modeling effort and is assumed to represent the aquifer at the Site. The average linear velocity is approximately 130 ft/day. For example, an average linear velocity of 133 ft/day indicates that groundwater from MFG-B3 will take at least 1.5 days to reach the Dairy Queen Well. Estimates made recently by Pracht (2001) for the portion of the MVA approximately paralleling Brooks street indicate average linear velocities ranging from 90 ft/day to 145 ft/day.

Water table elevation data and hydrographs show the water table fluctuates at least 13 feet at the Site. One representative hydrograph is presented as Figure 31. The lowest water table elevation recorded at the Site was approximately 3,128 feet AMSL in March 2001and the highest recorded water level was 3,141 feet AMSL in June 1997. The position of the water table is related to the Site stratigraphy in Figures 32 through 34.

SOURCE AREA AND CONTAMINANT DISTRIBUTION

While lithostratigraphy plays an important role in contaminant migration and fate at the Site and is the focus of this study, other factors such as water table fluctuations, the location of the source, and anthropogenic related events may also have influenced petroleum hydrocarbon migration at the Site.

Figure 31: Well MSE-1 Hydrograph



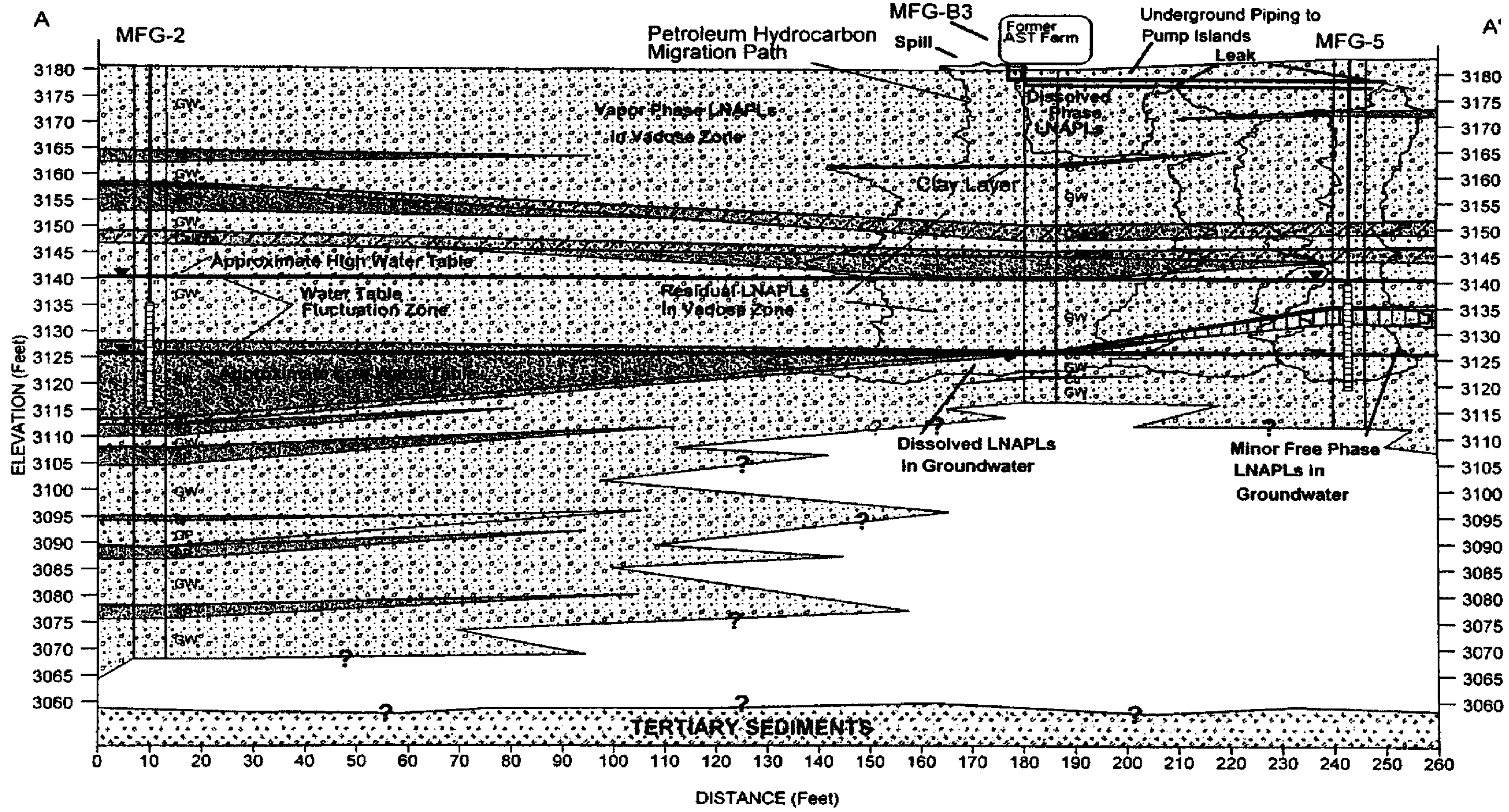


FIGURE 32

Conceptual Model of Lithostratigraphic Controls on Petroleum Hydrocarbon Migration in the Subsurface Beneath Underground Piping in Source Area

Cross Section A-A'
Northwest to Southeast
Burger King Petroleum Release Site

Natalie J. Morrow
M.S. Thesis, University of Montana
Spring 2002

LEGEND

▨	GW: Well Graded Sandy Gravel	▨	Caliche: Caliche w/Sand, Gravel, and Clay
▨	GP: Poorly Graded Sandy Gravel	▨	CL: Clay with or without Gravel
▨	SP: Poorly Graded Gravelly Sand	▨	ML: Sandy Silt to Silty Sand w/Gravel
▨	SW: Well Graded Gravelly Sand	▼	Approx. water table at time of drilling

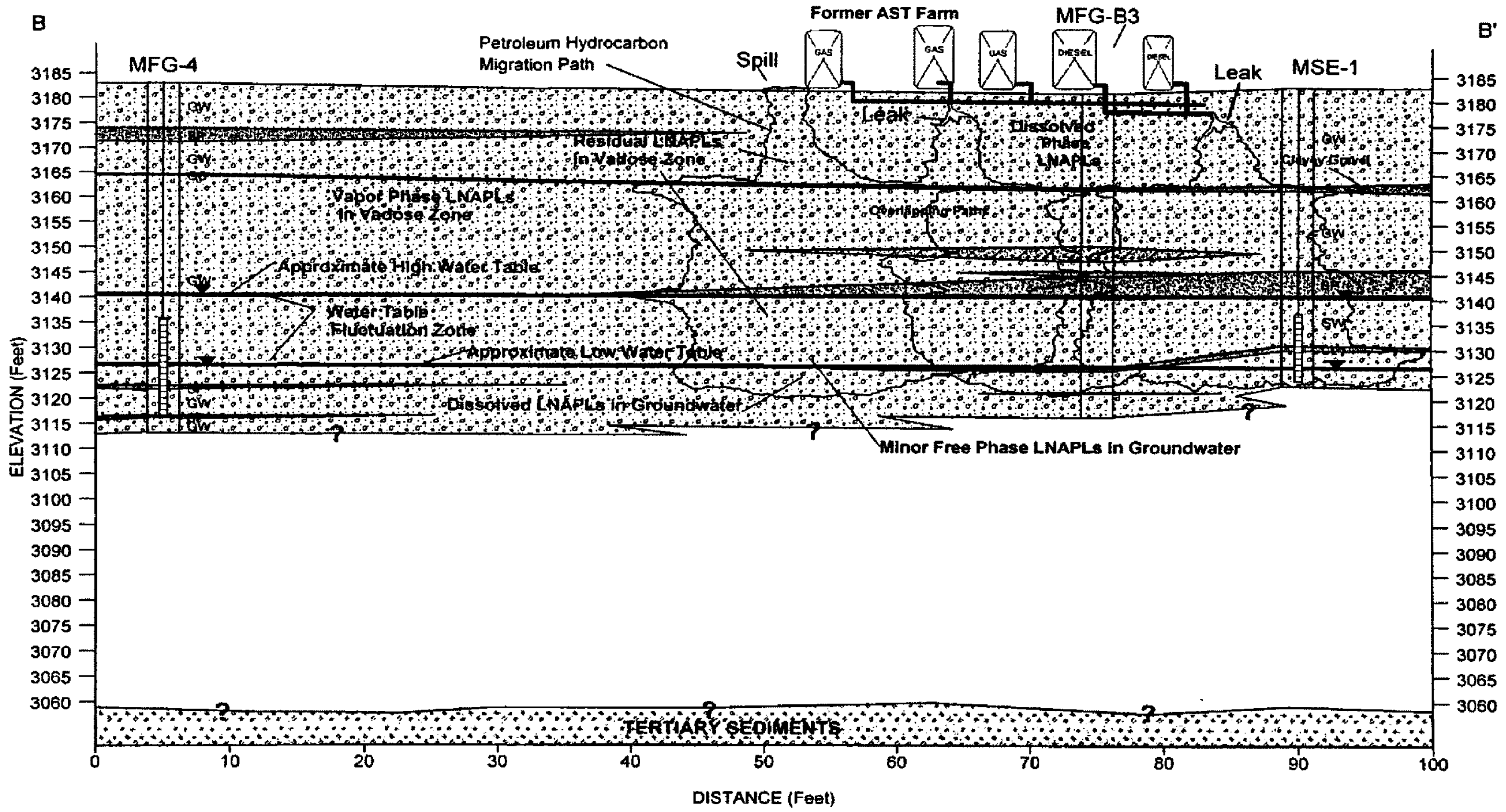


FIGURE 33

Conceptual Model of Lithostratigraphic Controls on Petroleum Hydrocarbon Migration in the Subsuface Beneath the Former Above Ground Storage Tank Farm

Cross Section B-B'
North to South
Burger King Petroleum Release Site

Natalie J. Morrow
M.S. Thesis, University of Montana
Spring 2002

LEGEND

▨ GW: Well Graded Sandy Gravel
▨ GP: Poorly Graded Sandy Gravel
▨ SP: Poorly Graded Gravelly Sand
▨ SW: Well Graded Gravelly Sand
▨ Caliche: Caliche w/Sand, Gravel & Clay
▨ CL: Clay with or without Gravel
▨ ML: Silt
▼ Approx. water table at time of drilling

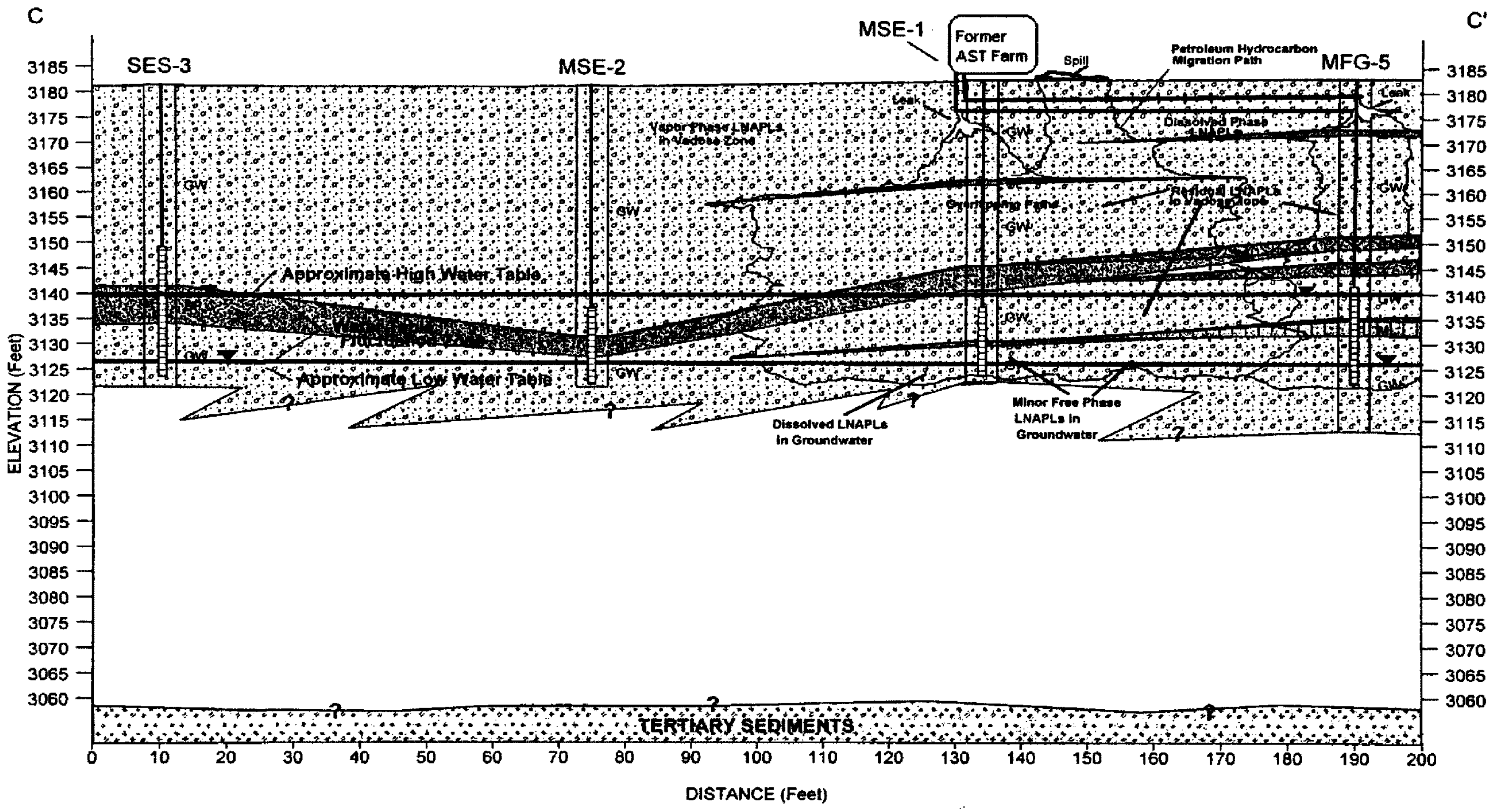


FIGURE 34

Conceptual Model of Lithostratigraphic Controls on Petroleum Hydrocarbon Migration in the Subsurface Beneath Underground Piping and AST Farm in Source Area

Cross Section C-C'
West to East
Burger King Petroleum Release Site

Natalie J. Morrow
M.S. Thesis, University of Montana
Spring 2002

LEGEND

- ▨ GW: Well Graded Sandy Gravel
- ▨ GP: Poorly Graded Sandy Gravel
- ▨ SP: Poorly Graded Gravelly Sand
- ▨ SW: Well Graded Gravelly Sand
- ▨ Caliche: Caliche w/Sand, Gravel and Clay
- ▨ CL: Clay with or without Gravel
- ▨ ML: Silt
- ▼ Approximate water level elevation at time of drilling

Subsurface Sediment PID and Analytical Results

The results of both past (MSE, 1994; SES, 1994; and SES, 1995) and present PID screening results were used in evaluating the extent, magnitude, and type of contamination present in subsurface sediments. During this study, VOCs were detected by the PID in two boreholes, MFG-B3 and MFG-5 (Table 4 and Figure 35). The PID did not record the presence of VOCs in MFG-1; however, groundwater analytical results revealed that MFG-1 also contained subsurface contamination at the smear zone (i.e., the approximate 13-foot aquifer interval in which the water table fluctuates). PID values and odor notations are shown on each boring log (Appendix C). PID readings were tabulated and are presented in Table 4. Figure 35 graphically presents PID readings versus depth for this investigation and previous investigations. Figure 7 shows the location of each borehole/well location.

In borehole MFG-B3, PID readings gradually increased as depth increased. The highest PID (1,089 ppm) was recorded at 50 feet bgs, which is close to the top of the smear zone. PID readings below 55 feet bgs gradually decreased to 8.5 ppm at 65 feet bgs. The highest PID reading in MFG-5 (1,265 ppm) was recorded at 57.5 feet bgs. Petroleum hydrocarbon odors were noted in each of these boreholes between 45 and 50 feet bgs, which corresponds to the approximate top of the smear zone.

VOCs may not have been detected in MFG-1 because PID readings were discontinued after 32.5 feet bgs because there was high soil moisture content in the cores that caused instrument errors. However, the color of the sand logged from 55 feet bgs through the total depth of the borehole (68.5 feet bgs) was noted during logging as dark grayish brown (possible hydrocarbon staining) but no odor was apparent.

TABLE 4
PID SCREENING RESULTS
BURGER KING PETROLEUM RELEASE SITE

MFG-1		MFG-2		MFG-B3		MFG-4		MFG-5		MSE-1		MSE-2		SB-3		SES-1		SES-2		SES-3		SES-B4		SES-5	
Depth	PID	Depth	PID	Depth	PID	Depth	PID	Depth	PID	Depth	PID	Depth	PID	Depth	PID	Depth	PID	Depth	PID	Depth	PID	Depth	PID	Depth	PID
1.5	1.2	2.0	0.0	1.5	1.5	4.0	0.1	0.5	0.0	4.5	1.4	4.5	16.2	4.5	2.7	5	3	5		5		11	6.3	6	7.1
4.0	7.3	4.0	3.2	6.5	6.5	6.5	0.5	6.5	4.0	9.5	1	9.5	0.7	9.5	0	10	3.9	10		10		13.5	2.4	11	8.2
6.5	2.2	6.5	3.1	9.0	9.0	7.5	0.5	9.0	1.0	14.5	226	14.5	1.5	14.5	0	15	4.8	15	2.2	15		16.25	1.4	16	2.4
8.5	2.0	9.0	5.0	11.5	11.5	10.0	0.2	11.5	0.0	19.5	368	19.5	1	19.5	0	20	3.8	20	2.5	20		21	0	21	3
11.0	2.5	11.0	4.3	14.0	14.0	12.5	0.2	13.0	0.8	25	50	25	1.2	25	0	25	4.1	25	0.2	25		25.75	27.4	26	2.6
13.0	3.8	13.0	5.6	16.5	16.5	15.0	0.1	15.5	1.1	29.5	0	29.5	0.9	29.5	0	30	3.8	30	2.6	30		31	14.7	31	3.3
15.0	4.5	15.0	4.2	18.0	18.0	16.5	0.2	16.5	5.0	34.5	0	34.5	0.8	34.5	0	35	4.3	35	2.5	35		33.5	16	36	2.5
17.0	5.9	17.5	4.2	20.0	20.0	18.0	2.5	17.5	8.8	40	0	40	2.2	40	0	40	10.3	40	0.3	40		36	10.8	41	2.4
19.0	4.0	20.0	5.0	22.5	22.5	20.0	1.3	20.0	5.4	44.5	0	44.5	20	44.5	0	45	10	45	0.3	45		38.25	11.8	46	6.8
21.5	4.0	22.5	5.5	25.0	25.0	21.5	3.0	22.5	9.2	49.5	1,100	49.5	1,385	49.5		50	20	50		50	33.8	45.5	1329	51	1,620
24.0	4.4	25.0	8.1	27.5	27.5	24.0	1.0	25.0	2.5	51.5	2,500	51.5		51.5	0	55	17.8	55		55	83.3			53.5	767
27.5	4.8	27.5	7.0	30.0	30.0	26.5	2.1	26.5	10.3	53	950	53	10	53	0									56	1,360
30.0	5.4	30.0	12.2	32.5	32.5	29.0	0.8	27.5	3.8															61	792
25.0	2.4	32.0	7.1	35.0	35.0	31.5	0.4	29.0	4.1																
32.0	14.4	34.0	7.8	37.5	37.5	34.0	10.7	31.5	3.5																
		36.5	8.0	40.0	40.0	36.5	4.8	34.0	5.8																
		39.0	5.9	42.5	42.5	39.0	27.5	36.5	4.0																
		41.5	5.0	45.0	91.4	41.5	10.1	39.0	7.2																
		44.0	7.5	47.5	723.0	44.0	16.0	41.5	6.5																
		46.5	5.5	50.0	1089.0	46.5	6.0	44.0	13.8																
		47.5	7.8	52.5	283.0	49.0	10.3	46.5	9.0																
		50.0	0.0	55.0	580.0	51.5	4.2	48.0	4.5																
		52.5	3.9	57.5	239.0	54.0	6.7	51.5	50.1																
		55.0	4.5	60.0	188.0	56.5	23.4	54.0	222.0																
				62.5	130.0	58.0	3.2	56.5	901.0																
				65.0	8.5	60.5	4.3	57.5	1265.0																
								60.0	776.0																
								62.5	45.4																
								65.0	49.9																
								67.5	48.0																
								70.0	24.0																

Blanks = No PID value recorded

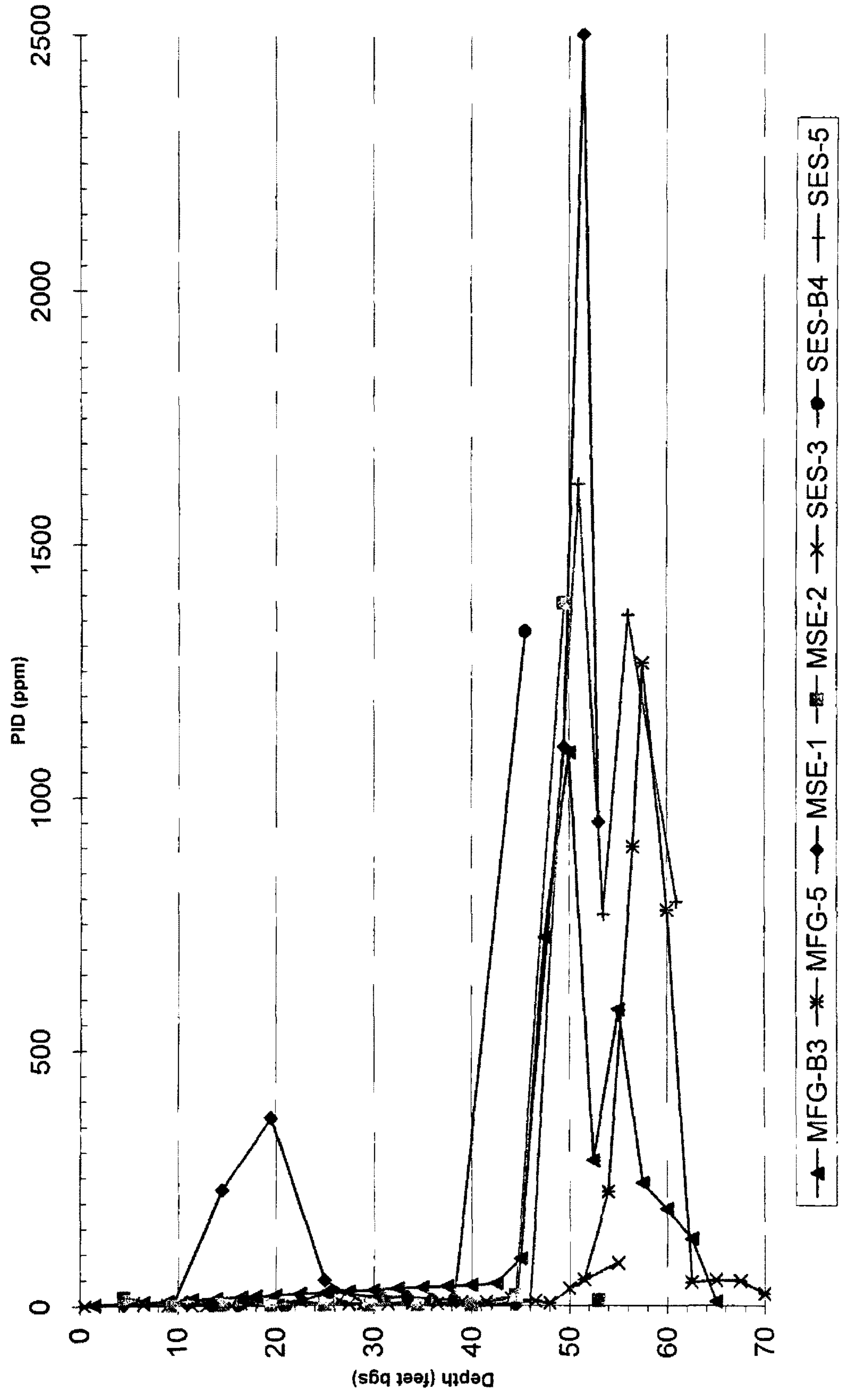
Depths for MSE and SES boreholes are averages, see the previous remedial investigation reports for actual depth ranges (MSE, 1994b; SES, 1994; and SES, 1995)

AIMS 2000 data was also collected for SES-3 (SES, 1994); however, this data appeared unreliable and was excluded from this table.

Depth = Feet below ground surface

PID measured in ppm-v

Figure 35
PID (ppm) vs. Depth



Notably absent in all PID screening results was substantial evidence of vadose zone contamination above the smear zone. This has been a consistent occurrence throughout all phases of investigation (MSE, 1994; SES, 1994; SES, 1995; and MFG, 2001) with the exception of PID results from one borehole, MSE-1. PID results from MSE-1 did indicate shallow subsurface petroleum hydrocarbon contamination between approximately 14 to 20 feet bgs. The results shown in Table 4 and Figure 35 indicate that petroleum hydrocarbon contamination was encountered in several boreholes (MSE-1, MSE-2, SES-3, SES-B4, SES-5, MFG-B3, and MFG-5) below a depth of approximately 45 feet bgs. The water table in each of these remedial investigations was encountered between 51 feet and 55 feet bgs.

The highest PID readings were obtained just below 50 feet bgs in boreholes MSE-1, MSE-2, SES-5, SES-B4, MFG-B3, and MFG-5. PID readings for SES-3 ranged from 33.8 to 83.3 ppm at 50 and 55 feet bgs, respectively. These values were lower than those recorded at the other boreholes at the same depth but still indicated petroleum hydrocarbon contamination at this location. In addition, an AIM 2000 instrument was used for field screening at SES-3 (SES, 1994); however, these values did not appear reliable and were not included in this evaluation.

Subsurface sediment analytical results obtained during this study and previous investigations are presented in Table 5. Analytical results were compared with the Tier 1 RBSLs for samples collected at a distance of less than 10 feet from/above groundwater (MDEQ, 2000) to evaluate the magnitude of contamination at the Site.

MFG-B3 and MFG-5 were the only boreholes where VOCs were detected by the PID. In each borehole, one sample was collected from the interval with the highest PID reading and from the approximate air/water interface (just at the water table) and one sample from just above the water table in each of these boreholes. The samples collected include MFG-B3(50 ft), MFG-B3(55 ft), MFG-B5(56.6 ft), MFG-B5(57.5 ft).

TABLE 5
SUBSURFACE SOIL BORING ANALYTICAL RESULTS

ANALYTE (ppm)	Tier 1 Subsurface Soil RBSLs <10 feet to Groundwater	MFG-B1 (55 ft)	MFG-B2 (58 ft)	MFG-B3 (50 ft)	MFG-B3 (55 ft)	MFG-B4 (58 ft)	MFG-B5 (56.5 ft)	MFG-B5 (57.5 ft)	MSE-1 (49 ft)	MSE-2 (49 ft)	SB-3 (53 ft)	SES-1 (50 ft)	SES-2 (55 ft)	SES-3 (50 ft)	SES-3 (65 ft)	SES-B4 (25 ft)	SES-B4 (45 ft)	SES-5 (50 ft)
Date Collected	—	4/4/01	4/4/01	4/6/01	4/6/01	4/8/01	4/10/01	4/10/01	4/94	4/94	4/94	9/94	9/94	9/94	9/94	8/95	8/95	8/95
Percent Moisture (% by weight)	NS	4	10	6	10	6	7	7	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
MTBE	0.1	< 0.10	< 0.10	< 0.10	< 0.10	<0.10	< 0.10	< 0.20[5]	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Benzene	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.10[5]	0.130	0.009	ND	<0.005	<0.005	<0.0001	<0.001	<0.005	<0.050	NM
Toluene	14	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.20[5]	< 1.0[5]	0.600	0.140	ND	<0.005	<0.005	0.023	<0.005	<0.005	0.244	NM
Ethylbenzene	13	< 0.05	< 0.05	0.18	0.060	< 0.05	< 0.05	< 0.10[5]	0.230	0.220	ND	<0.015	<0.015	0.044	<0.005	<0.05	0.414	NM
Total Xylene	220	< 0.05	< 0.05	1.1	0.37	< 0.05	0.19[5]	0.75[5]	0.260	2.0	ND	<0.026	<0.026	0.341	<0.015	<0.015	0.807	NM
Napthalene	3	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 2.0[5]	< 4.0[5]	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Volatile Petroleum Hydrocarbons[4]	NS	< 2.0	< 2.0	220	70	< 2.0	308	620	260	90	ND	<1.0	<1.0	560	<1.0	1,360	2,490	NM
Extractable Petroleum Hydrocarbons[4]	NS	< 10	< 10	275	154	< 10	142	485	NM	NM	NM	<1.0	<1.0	1620	<1.0	3,750	5,400	NM
C5-C8 Aliphatics	100	< 2.0[a]	< 2.0[a]	27[a]	7.9[a]	< 2.0[a]	45[a]	167[a]	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
C9-C12 Aliphatics	500	< 2.0[b]	< 2.0[b]	57[b]	21[b]	< 2.0[b]	103[b]	228[b]	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
C9-C10 Aromatics	15	< 2.0	< 2.0	64	16	< 2.0	68	157	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
C9-C18 Aliphatics	5,000	NM	NM	155	88	NM	86	311	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
C19-C36 Aliphatics	5,000	NM	NM	< 20	< 20	NM	< 20	< 20	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
C11-C22 Aromatics	400	NM	NM	86	28	NM	26	93	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Total Extractable Hydrocarbons	NS	NM	NM	239	127	NM	124	444	NM	NM	NM	<1.0	<1.0	1330	<1.0	3,230	4,350	NM

Notes:

1 RBSLs standards for C5-C8 Aliphatics, C9-10 Aromatics, and C11-C22 Aliphatics and Total Extractable Hydrocarbons were developed during creation of Tier 1 Risk Based Corrective Action standards (MDEQ, 2000) for impacted soil greater than 2 feet below ground surface and sample to groundwater depth less than 10 feet . The remaining compound standards were adopted from Circular WQB-7 Montana Numerica Water Quality Standards (MDEQ, 2000)

3 Results are presented in ppm (ppm: mg/kg), except where noted.

4 Volatile Petroleum Hydrocarbons (VPH) is equivalent to Total Purgeable Hydrocarbons (TPH) -Gasoline Range Organics); Extractable Petroleum Hydrocarbons (EPH) is equivalent to TPH-Diesel Range Organics

5 Reporting limit is elevated due to sample matrix interference.

[a] Aromatic constituents Benzene, Toluene, Ethylbenzene and m+p Xylenes were subtracted from this value.

[b] Aromatic constituents o-Xylene and C9 to C10 aromatics were subtracted from this value.

NM = Not Measured/Analyzed.

NS = No Standard

BOLD = Indicates result is at or above RBSL

No elevated PID readings were obtained from MFG-1, MFG-2, and MFG-4; therefore, only one sample was collected from the approximate air/water interface interface in each of these boreholes. The samples collected include MFG-B1 (55 ft), MFG-B2(58 ft), and MFG-B4(58 ft). Each sample was analyzed for VPH and EPH Screen. During this study boring MFG-B6, the angled boring that penetrated the zone below the former pump islands, did not reveal the presence of petroleum hydrocarbons during PID screening.

Of the seven subsurface sediment samples analyzed, four contained analytes exceeding Tier 1 Subsurface Soil RBSLs. These include MFG-B3(50 ft), MFG-B3(55 ft), MFG-B5(56.5 ft), MFG-B5 (57.5 ft). The results are summarized below.

C9-C10 aromatics RBSLs were exceeded in all four of the above samples and C5-C8 aliphatics were exceeded in MFG-B5(57.5 ft) only. C9-C10 aromatics results for MFG-B3(50 ft) and MFG-B3(55 ft) were 64 parts per million (ppm) and 16 ppm, respectively. C9-C10 aromatics results for MFG-B5(56.5 ft) and MFG-B5 (57.5 ft) were 68 ppm and 167 ppm, respectively. The C5-C8 aliphatics result for MFG-B5(57.5 ft) was 167 ppm. The remaining subsurface samples contained no analytes exceeding Tier 1 Subsurface Soil RBSLs.

Groundwater Analytical Results

All 10 monitoring wells at the Site were sampled between May 31 and June 1, 2001. Temperature, pH, and specific conductivity were monitored in the field during purging and sampling activities at two wells. The temperature range recorded was 17.5 to 21.2 degrees °C, specific conductivity ranged from 785 to 1,328 µmhos/cm at 25 °C, and pH was recorded in one well as 6.88 standard unit. Field parameter and analytical results are presented in Table 6.

TABLE 6
GROUNDWATER ANALYTICAL RESULTS
BURGER KING RELEASE SITE

																	EPH Fractionation				
Well Identification	Date	pH (Std. Units)	Specific Conductivity (umhos/cm @ 25°C)	Temp. (°C)	MTBE (ppb)	Benzene (ppb)	Toluene (ppb)	Ethylbenzene (ppb)	Total Xylene (ppb)	C5-C8 Aliphatics (ppb)	C9-C12 Aliphatics (ppb)	C9-C10 Aromatics (ppb)	VPH (ppb)	TPH-G (ppb)	EPH (ppb)	TPH-D (ppb)	C9-C18 Aliphatics (ppb)	C19-C36 Aliphatics (ppb)	C11-C22 Aromatics (ppb)	Total Extractable Hydrocarbons (ppb)	PAH (ppb)
RBSL		NS	NS	NS	30	5	1,000	700	10,000	350	1,000	100	NS	NS	NS	NS	1,000	1,000	1,000	1,000	
MSE-1	11/22/1994					<2.0	<2.0	3.2	25				625	2,130	54,000	59,000					
	8/30/1995					<1.0	4	1	<5.0				<1,000	1,000							
	3/8/1996					<0.5	<1.0 (1)	<1.0 (1)	5.8				203	906	660	700					
	6/13/1996					<0.5	1.4	2.3	8.7				86	241	<550	<550					
	10/3/1996				<2.0 (1)	<0.5	1.2	2.5	7.9				609	2,100	2,700	2,800					
	6/4/1997				<2.0	<0.5	<0.5	4.6	8.5				113	256	<500	<500					
	12/14/1998				<2.0	<0.6	<1.0 (1)	<2.0 (1)	<5.0 (1)				166	1,280	12,000	12,000					<10 (2)
	5/17/1999				<2.0	<0.5	<0.5	<0.5	<1.0				55	301	3,200	3,500					
	3/23/2000				<1.0	<0.5	<0.5	<0.5	<0.5	24	33	31	105		3,600		1,600	<600	530	3,100	
	9/15/2000				<1.0	<0.5	<0.5	<0.5	<0.5	<20	29	31	114		1,500		1,400	<670	<670	1,600	
	1/11/2001	6.74	383.2	9.3	<5.0	<2.5	5.4	<2.5	<2.5	677	348	550	1,820		25,000		16,000	<650	2,200	19,000	
	5/31/2001	NM	NM	NM	<1.0	<0.50	<0.50	<0.50	<0.50	<20	36	45	109		2,100		1,200	<640	<640		
MSE-2	11/22/1994					<0.5	<0.5	<0.5	<1.0				<20	<20	<500	<500					
	8/30/1995					<1.0	<1.0	<1.0	<5.0				<1,000	<1,000							
	3/8/1996					<0.5	<0.5	<0.5	<1.0				<20	<20	<570	<570					
	6/13/1996					<0.5	<0.5	<0.5	<1.0				<20	<20	<570	<570					
	10/3/1996				<2.0	<0.5	<0.5	<0.5	<1.0				<20	<20	<500	<500					
	6/4/1997				<2.0	<0.5	<0.5	<0.5	5.8				<20 (2)	23	<500	<500					
	12/14/1998				<2.0	<0.5	<0.5	<0.5	<1.0				<20	<20	<540	<540					<10 (2)
	5/17/1999				<2.0	<0.5	<0.5	<0.5	<1.0				<20	<20	<500	<500					
	3/23/2000				<1.0	<0.5	<0.5	<0.5	<0.5	<20	<20	<20	<20		<320						
	9/15/2000				<1.0	<0.5	<0.5	<0.5	<0.5	<20	<20	<20	<20		<330						
	1/11/2001	NM	NM	NM	<1.0	<0.5	<0.5	<0.5	<0.5	<20	<20	<20	<20		<340						
	5/31/2001	NM	NM	NM	<1.0	<0.50	<0.50	<0.50	<0.50	<20	<20	<20	<20		<300						
SES-1	11/22/1994					<0.5	0.81	<0.5	<2.0				<20	<20	<500	<500					
	8/30/1995					<1.0	<1.0	<1.0	<5.0				<1,000	<1,000							
	3/8/1996					<0.5	<0.5	<0.5	<1.0				<20	<20	<570	<570					
	6/13/1996					<0.5	<0.5	<0.5	<1.0				<20	<20	<570	<570					
	10/3/1996				<2.0	<0.5 (2)	0.63	<0.5 (2)	<1.0 (2)				<20	<20	<500	<500					
	6/4/1997				<2.0	<0.5	<0.5	<0.6	<1.0				<20	<20	<500	<500					
	12/14/1998				<2.0	<0.5	<0.5	<0.5	<1.0				<20	<20	<540	<540					<10 (2)
	5/17/1999				<2.0	<0.5	<0.5	<0.5	<1.0				<20	<20	<520	<520					
	3/23/2000			–	<1.0	<0.5	<0.5	<0.5	<0.5	<20	<20	<20	<20		<320						
	9/15/2000				<1.0	<0.5	<0.5	<0.5	<0.5	<20	<20	<20			<350						
	1/11/2001	6.29	864	9.8	<1.0	<0.5	<0.5	<0.5	<0.5	<20	<20	<20	<20		<310						
	6/1/2001	6.88	1,328	17.5	<1.0	<0.50	<0.50	<0.50	<0.50	<20	<20	<20	<20		650						
SES-2	11/22/1994					<0.5	<.5	<0.5	<1.0				<20	<20	<500	<500					
	8/30/1995					<1.0	<1.0	<1.0	<5.0				<1,000	<1,000							
	3/8/1996					<0.5	<0.5	<0.5	<1.0				<20	<20	<570	<570					
	6/13/1996					<0.5	<0.5	<0.5	<1.0				<20	<20	<560	<560					
	10/3/1996				<2.0	<0.5 (2)	0.86	<0.6 (2)	1.2				<20	<20	<500	<500					
	6/4/1997				<2.0	<0.5	<0.5	<0.5	<1.0				<20	<20	<500	<500					

TABLE 6
GROUNDWATER ANALYTICAL RESULTS
BURGER KING RELEASE SITE

Well Identification	Date	pH (Std. Units)	Specific Conductivity (umhos/cm @ 25°C)	Temp. (°C)	MTBE (ppb)	Benzene (ppb)	Toluene (ppb)	Ethylbenzene (ppb)	Total Xylene (ppb)	C5-C8 Aliphatics (ppb)	C9-C12 Aliphatics (ppb)	C9-C10 Aromatics (ppb)	VPH (ppb)	TPH-G (ppb)	EPH (ppb)	TPH-D (ppb)	EPH Fractionation				PAH (ppb)
																	C9-C18 Aliphatics (ppb)	C19-C36 Aliphatics (ppb)	C11-C22 Aromatics (ppb)	Total Extractable Hydrocarbons (ppb)	
RBSL		NS	NS	NS	30	5	1,000	700	10,000	350	1,000	100	NS	NS	NS	NS	1,000	1,000	1,000	1,000	
	12/14/1998				<2.0	<0.5	<0.5	<0.5	<1.0				<20	<20	<540	930					<10(2)
	5/17/1999				<2.0	<0.5	0.8	<0.5	<1.0				<20	<20	<590	1,600					
	3/23/2000				<1.0	<0.5	<0.5 (J)	<0.5	<0.5	<20	<20	<20	21		21,000		<1,200	13,000	4,400	20,000	
	9/15/2000				<1.0	<0.5	<0.5	<0.5	<0.5	<20	<20	<20	<20		<340						
	1/11/2001	NM	NM	NM	<1.0	<0.5	<0.5 (J)	<0.5	<0.5	<20	<20	<20	<20		2,200		<700 (3)	1,000 (3)	<700 (3)	1,100 (3)	
	5/31/2001	NM	NM	NM	<1.0	<0.50	1.2	<0.50	1.6	<20	<20	29	25		4,200		<650	700	<650	700	
SES-3	11/22/1994					<0.5	1.1	1.1	1.6				40	169	870	930					
	8/30/1995														95						
	3/8/1996					<0.5	<0.5	<1.0 (1)	<1.0				44	120	710	800					
	6/13/1996					<0.5	<0.5	<0.5	<1.0				<20	67	<560	<560					
	10/3/1996				<2.0	<0.5	<0.5 (J)	<0.5	1.2				21	<20	<500	<500					
	6/4/1997				<2.0	<0.5	<0.5	<0.5	<1.0 (J)				<20	82	<500	<500					
	12/14/1998				<2.0	<0.5	<0.5	<0.5	<1.0				<20	<20	1,800	1,800					<10(2)
	5/17/1999				<2.0	<0.5	<0.5	<0.5	<1.0				21	174	1,700	2,000					
	3/23/2000				<1.0	<0.5	<0.5	<0.5	<0.5	<20	29	<20	63		<320						
	9/15/2000				<1.0	<0.5	<0.5	<0.5	<0.5	<20	<20	<20	37		<300						
	1/11/2001	6.26	494.1	9.0	<1.0	<0.5	<0.5	<0.5	<0.5	<20	<20	<20	27		<310						
	5/31/2001	NM	NM	NM	<1.0	<0.50	<0.50	<0.50	<0.50	<20	45	69	135		3,600		<640	<640	<640	<640	
SES-6	9/5/1995														51,500	73,100					
	3/8/1996					<2.0 (1)	<2.0 (1)	3.2	60				915	1,960	9,100	9,600					
	6/13/1996					<0.5	<0.5	6.1	19				148	310	1,100	1,300					
	10/3/1996				<8.0 (1)	<2.0 (1)	<4.0 (1)	46	62				2,640	6,790	6,300	6,300					
	6/4/1997				<2.0	<0.5	<1.0 (1)	12	43				400	674	1,100	3,300					
	12/14/1998				<2.0	<1.0 (1)	<5.0 (1)	9.6	32				552	1,330	6,800	7,400					<10(2)
	5/17/1999				<2.0	<0.5	<2.0	14	106				598	1,260	2,300(3)	2,500(3)					
	3/23/2000				<10(1)	<10(1)	<10(1)	15	28	4,530	4,120	7,270	18,200		4,400		2,100	<600	<600	2,300	
	9/15/2000				<1.0	<0.5	<0.5	11	24	255	228	749	1,220		810						
	1/12/2001	6.27	771	9.0	<20	<25	96	84	118	13,800	16,200	23,200	58,100		7,300		3000	<650	850	4,900	
	6/1/2001	NM	785	21.2	<2.0(1)	3.4	4.6	17	55	179	309	467	928		3,700		<730	<730	<730	<730	
MFG-1	5/31/2001	NM	NM	NM	<1.0	<0.50	0.51	4.3	4.7	20	56	161	264		3,900		<630	<630	<630	<630	
MFG-2	5/31/2001	NM	NM	NM	<1.0	<0.50	<0.50	<0.50	<0.50	<20	<20	<20	<20		<370						
MFG-4	6/1/2001	NM	NM	NM	<1.0	<0.50	<0.50	<0.50	<0.50	<20	<20	<20	<20		<310						
MFG-5	6/1/2001	NM	NM	NM	<10	<5.0	<5.0	25	145	514	1,090	1,800	2,830		11,000		3,900	<610	1,100	6,830	
Dairy Queen Irrigation Well	11/22/1994					<0.50	<0.50	8.6	<5				151	253	13,000					16,000	
	8/30/1995					<1.0	<1.0	<1.0	<5.0					<1.0		<1,000					
	7/15/1999					<0.50	<0.50	<0.50	<0.50						<620						
	9/15/2000					<0.50	<0.50	<0.50	<0.50	<20	<20	<20			<320						

NOTES

J - Present but less than the limit of quantitation.

1 - Reporting limit increased due to sample matrix interference.

2 - See laboratory report for a complete list of PAH's.

3 - Surrogate recovery less than the lower QC advisory limit of 50%.

NM = Not measured

NS = No Standard

BOLD = Exceeds the regulatory standard or RBLS listed in the Tier 1 Risk Based Corrective Action guidance document (MDEQ, 2000).

TPH-G = Total Purgeable Hydrocarbons, Gasoline Range

TPH-D = Total Purgeable Hydrocarbons, Diesel Range

MTBE = methyl tert-butyl ether

VPH = Volatile Petroleum Hydrocarbons. Method is equivalent to TPH-G

EPH = Extractable Petroleum Hydrocarbons (EPH screen value). Method is equivalent to TPH-D

RBSL = Risk Based Corrective Action Risk Based Screening Levels (MDEQ, 2000)

Water table elevation data is presented in Appendix D.

Blanks = no analyses were performed

All samples were analyzed for VPH and EPH screen. Of the 10 monitoring wells sampled, four contained constituents with concentrations above the Tier 1 groundwater standard and/or RBSL (MDEQ, 2000). These wells include MSE-1, SES-5, MFG-1, and MFG-5. A total of 10 results exceeded the Tier 1 standard/RBSL.

The C5-C8 aliphatics standard/RBSL was exceeded in well MFG-5 with a result of 514 ppb. The MFG-5 result (1,090 ppb) also exceeded the C9-C12 aliphatics standard/RBSL. The C9-C18 aliphatics standard/RBSL was exceeded in wells MSE-1 and MFG-5. The C9-C18 aliphatics results for these two wells were 1,200 ppb and 3,900 ppb, respectively. C9-C10 aromatics standard or RBLS values were exceeding in wells SES-5, MFG-1, and MFG-5. The results for C9-C10 aromatics for these three wells were 467 ppb, 161 ppb, and 1,800 ppb, respectively. The C11-C22 aromatics standard/RBSL was exceeded in MFG-5 with a result of 1,100 ppb. Finally, wells MSE-1 and MFG-5 results for TEH exceeded the standard/RBSL. The results for TEH for these two wells were 1,200 ppb and 6,300 ppb, respectively.

MAPPING OF SOIL AND GROUNDWATER CONTAMINATION

Soil Impacts

Concentrations of VPH and EPH in subsurface sediments at each boring location are shown on Figure 37. One to two subsurface sediment samples were collected from each boring at the Site during this study and previous studies. The concentrations placed on the maps include the results from the sample interval with the highest concentrations. The Source Area of contamination is defined as the area where the former ASTs and underground piping resided (see Figure 36). The highest concentrations for both VPH and EPH were obtained within the Source Area. Soil contamination extent plumes for VPH and EPH were developed and are provided as Figures 38 and 39. The results show the extent of VPH in subsurface soil is slightly

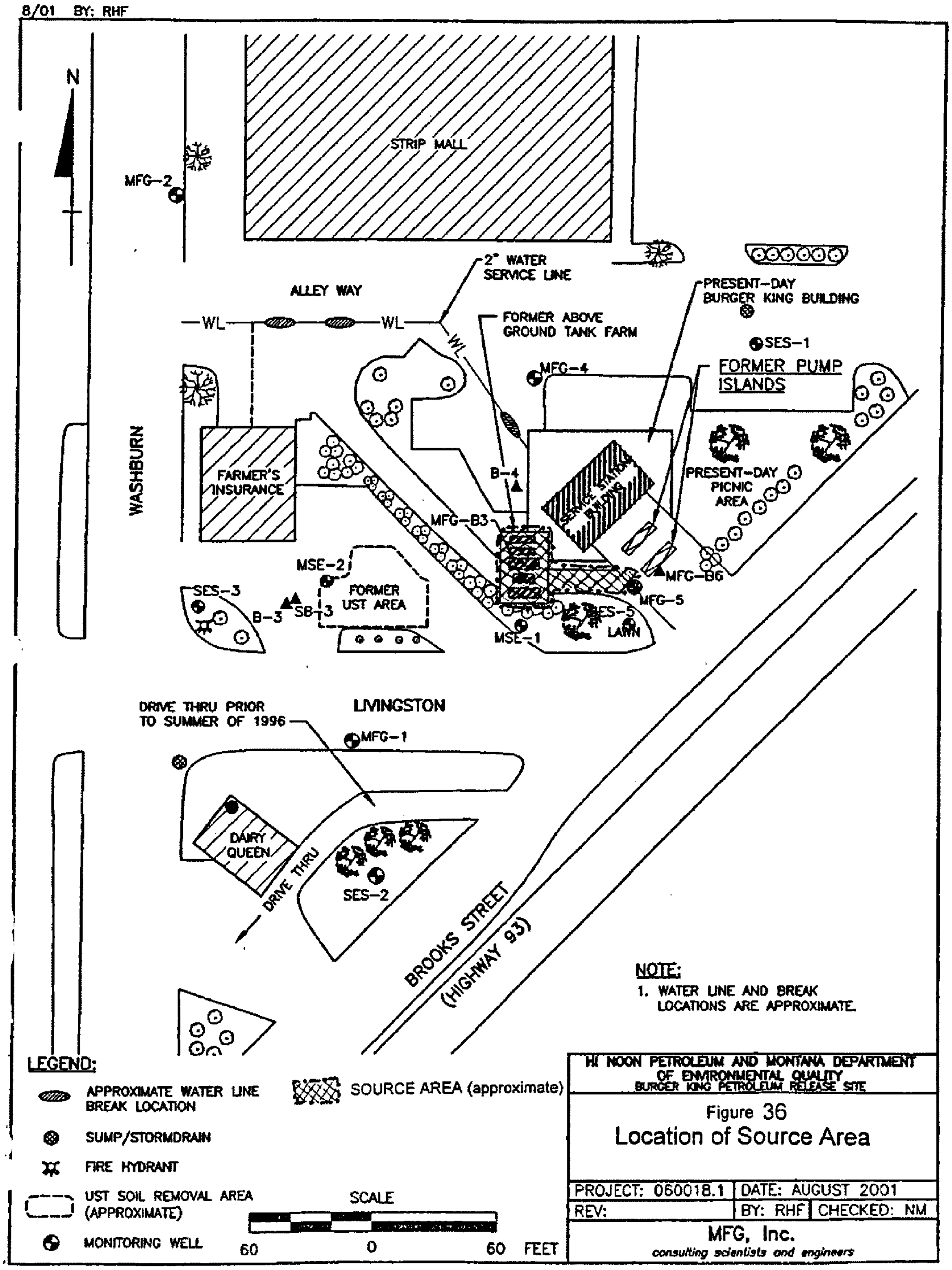


Figure 36
Location of Source Area

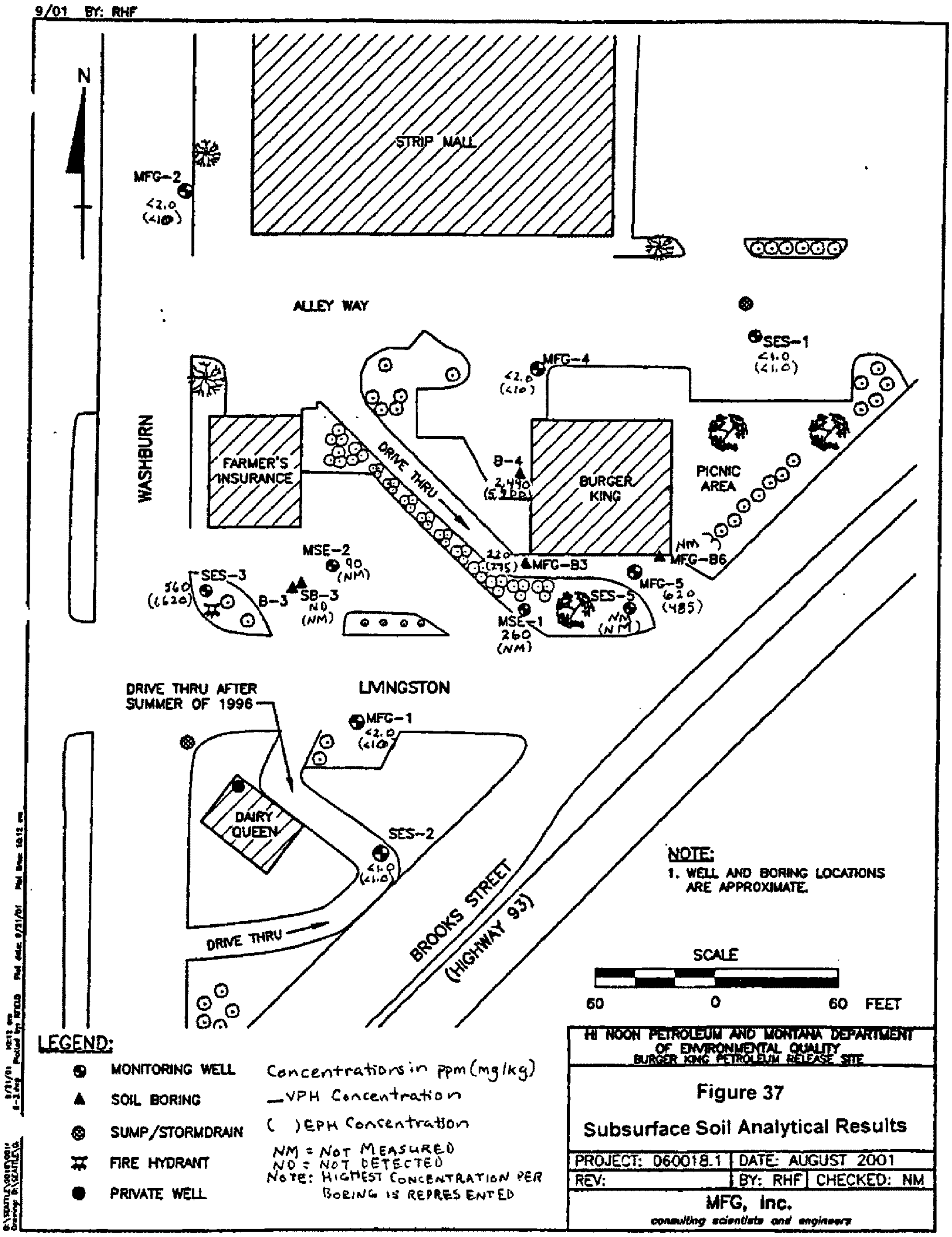


Figure 37

Subsurface Soil Analytical Results

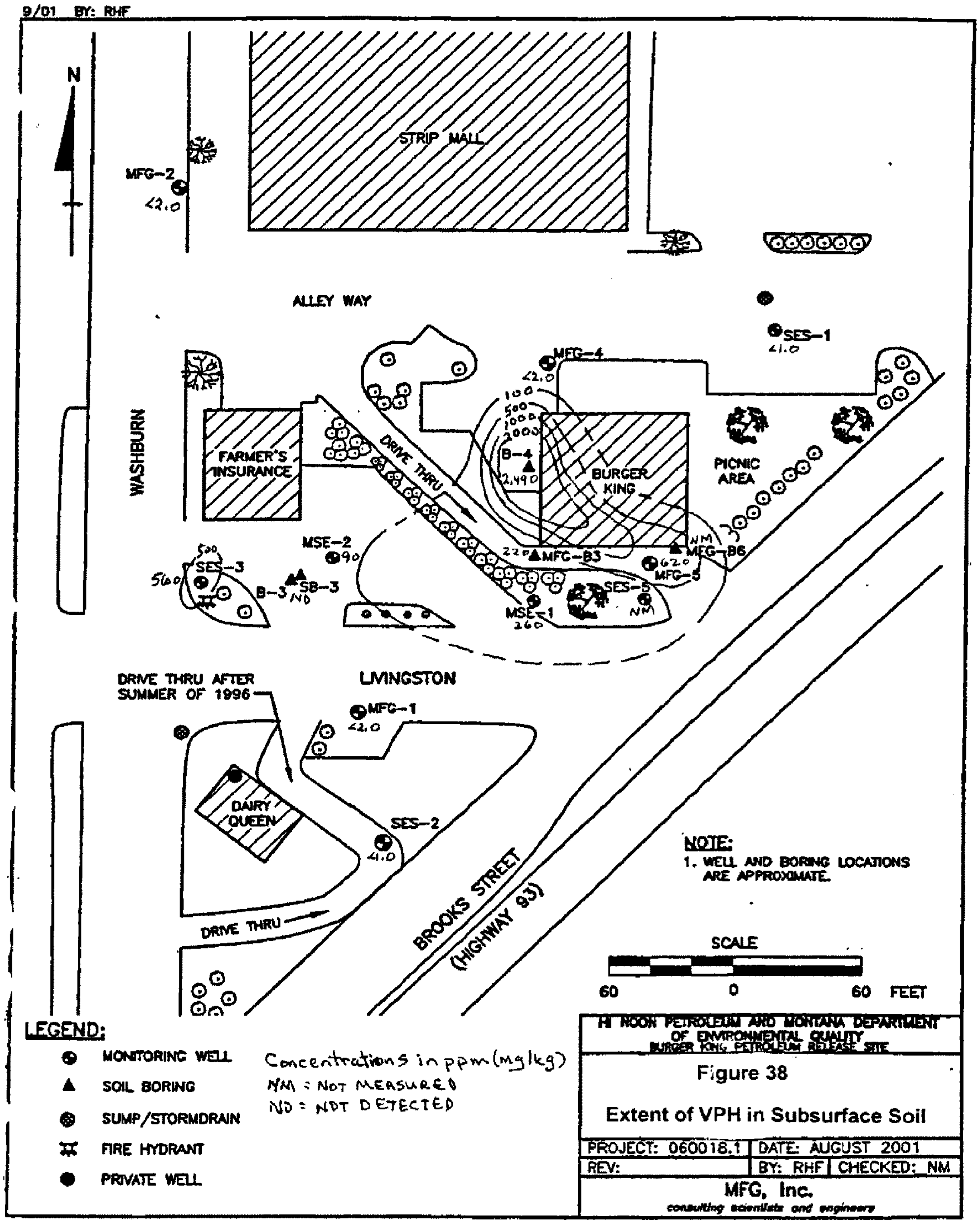
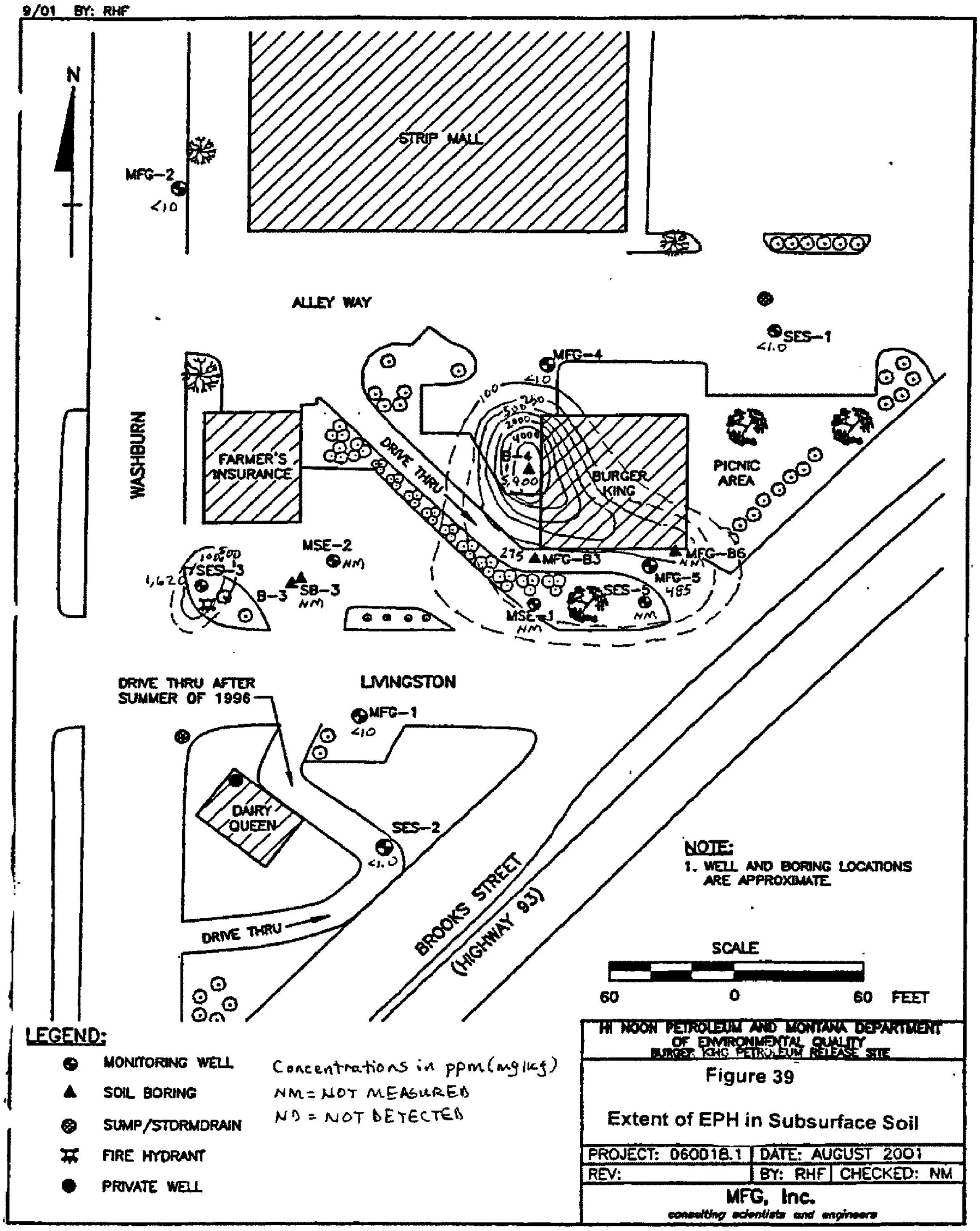


Figure 38

Extent of VPH in Subsurface Soil



Concentrations in ppm (mg/kg)
NM = NOT MEASURED
ND = NOT DETECTED

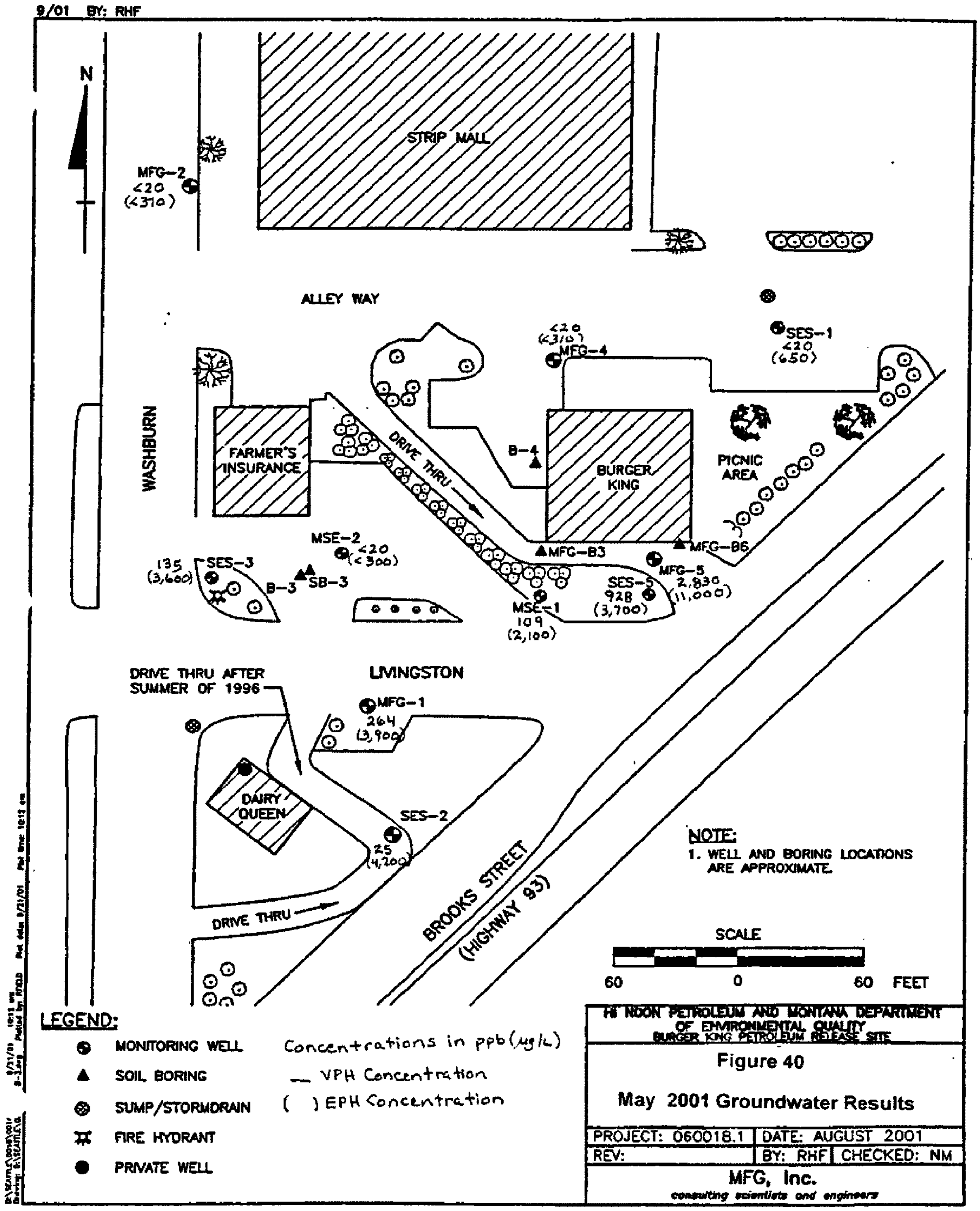
Figure 39

Extent of EPH in Subsurface Soil

greater than that for EPH.

Groundwater Impacts

Groundwater VPH and EPH concentrations from the May 2001 sampling event are shown on Figure 40. Groundwater concentration plume maps for VPH and EPH Screen results from the May/June 2001 groundwater analytical results are presented as Figures 41 and 42, respectively. The placement of concentration contours, and therefore, the plume boundaries are inferred, due to the limited amount of data available in some areas.



HI NOON PETROLEUM AND MONTANA DEPARTMENT OF ENVIRONMENTAL QUALITY
BURGER KING PETROLEUM RELEASE SITE

Figure 40

May 2001 Groundwater Results

PROJECT: 060018.1	DATE: AUGUST 2001	
REV:	BY: RHF	CHECKED: NM

MFG, Inc.
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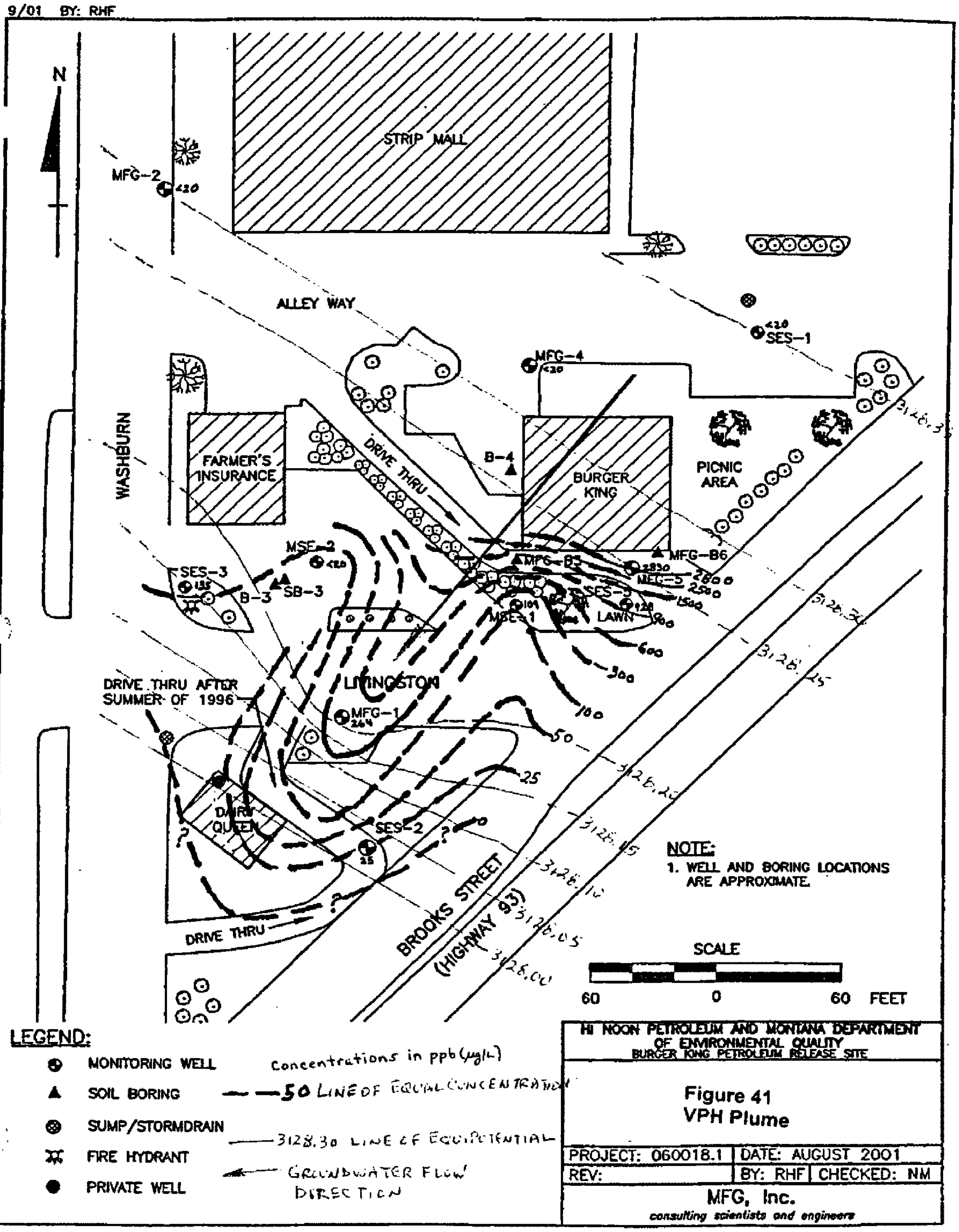
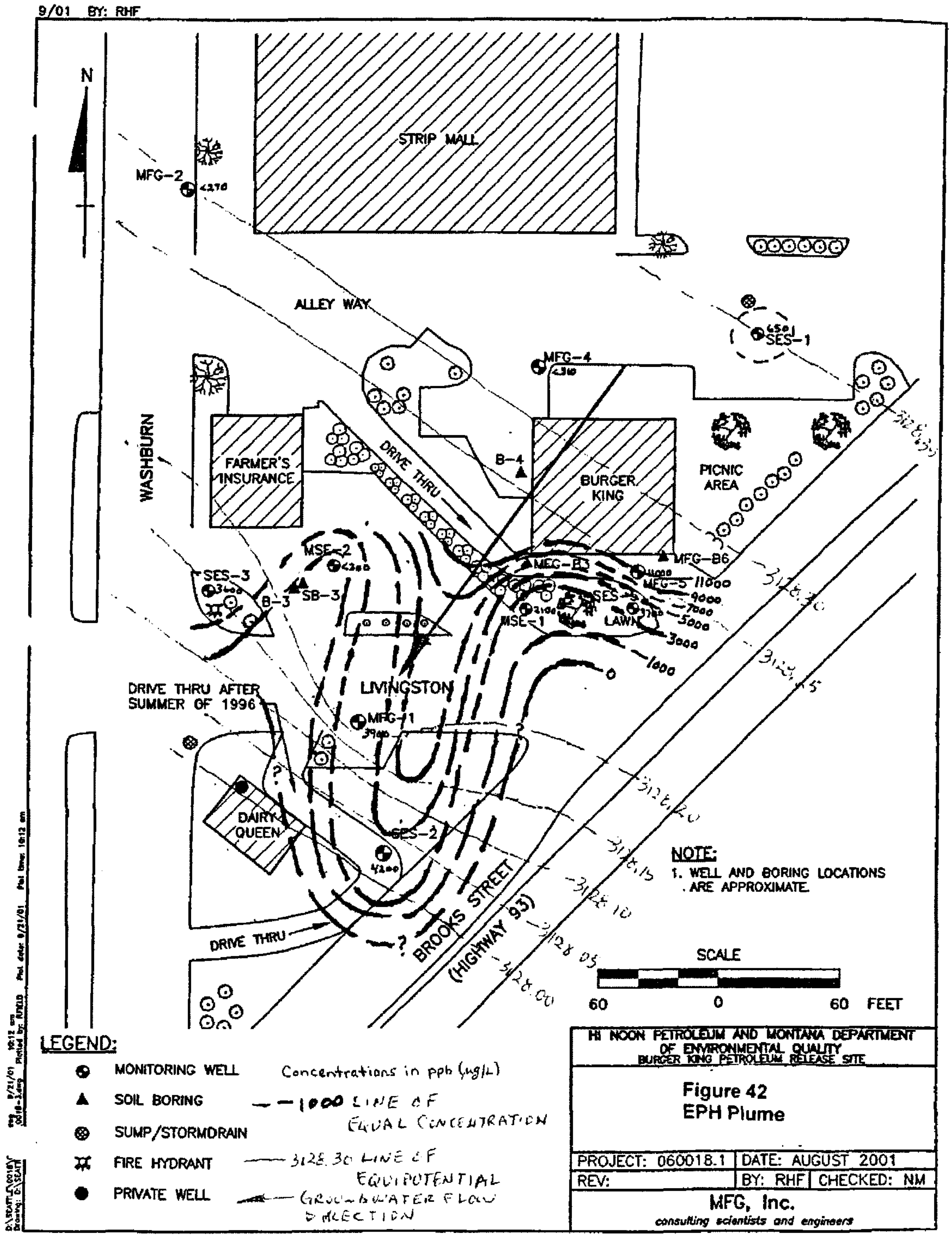


HI NOON PETROLEUM AND MONTANA DEPARTMENT OF ENVIRONMENTAL QUALITY
BURGER KING PETROLEUM RELEASE SITE

Figure 41
VPH Plume

PROJECT: 060018.1 | DATE: AUGUST 2001
REV: | BY: RHF | CHECKED: NM

MFG, Inc.
consulting scientists and engineers



HI NOON PETROLEUM AND MONTANA DEPARTMENT OF ENVIRONMENTAL QUALITY
BURGER KING PETROLEUM RELEASE SITE

Figure 42
EPH Plume

PROJECT: 060018.1 DATE: AUGUST 2001
REV: BY: RHF CHECKED: NM

MFG, Inc.
consulting scientists and engineers

The dimensions of the VPH plume are approximately 170 feet long by 130 feet wide (Figure 41); the dimensions of the EPH plume are approximately 210 feet long by 130 feet wide (Figure 42). The EPH plume may be longer than what it would be if well SES-2 were not contaminated with asphalt sealants from the drive-thru. The EPH plume (Figure 42) was redeveloped excluding well SES-2, since the contamination in that well is believed to be from asphalt sealants applied to the drive-thru. The revised EPH plume is shown on Figure 43. The shape of the plume narrows is closer in shape to the VPH plume map, and trends in a similar direction as the VPH plume map (Figure 41). A further discussion of factors affecting contaminant migration and plume shape is included in Section 5.

Since groundwater monitoring began in 1994 and 1995, wells in and closest to the Source Area (MSE-1, SES-5, and MFG-5) have consistently shown elevated petroleum hydrocarbons in the groundwater for both the gasoline range (VPH) and diesel range (EPH) constituents. VPH results have ranged from 55 to 58,100 ppb and EPH Screen results have ranged from not detected (less than 550) to 51,500 ppb.

Downgradient wells (MSE-2, SES-2, SES-3, MFG-1, and the Dairy Queen well) have shown variable levels of petroleum hydrocarbon contamination. The Dairy Queen well was sampled in 1990 after hydrocarbon odors were reported in the groundwater. The results indicated volatile petroleum hydrocarbon contamination in the well at detectable levels. The MDHES sampled this well two subsequent times, once in 1990 and once in 1992. Results indicated there were no detectable petroleum hydrocarbons in the well. Detectable levels of petroleum hydrocarbons were again detected in a sample collected in 1994. Samples collected in 1995 and since that time have indicated no detectable petroleum hydrocarbons present in the well.

Only recently, since December 1998, has well SES-2 (a downgradient well) shown detectable levels of diesel range organics, total extractable hydrocarbons and EPH. The EPH fractionation

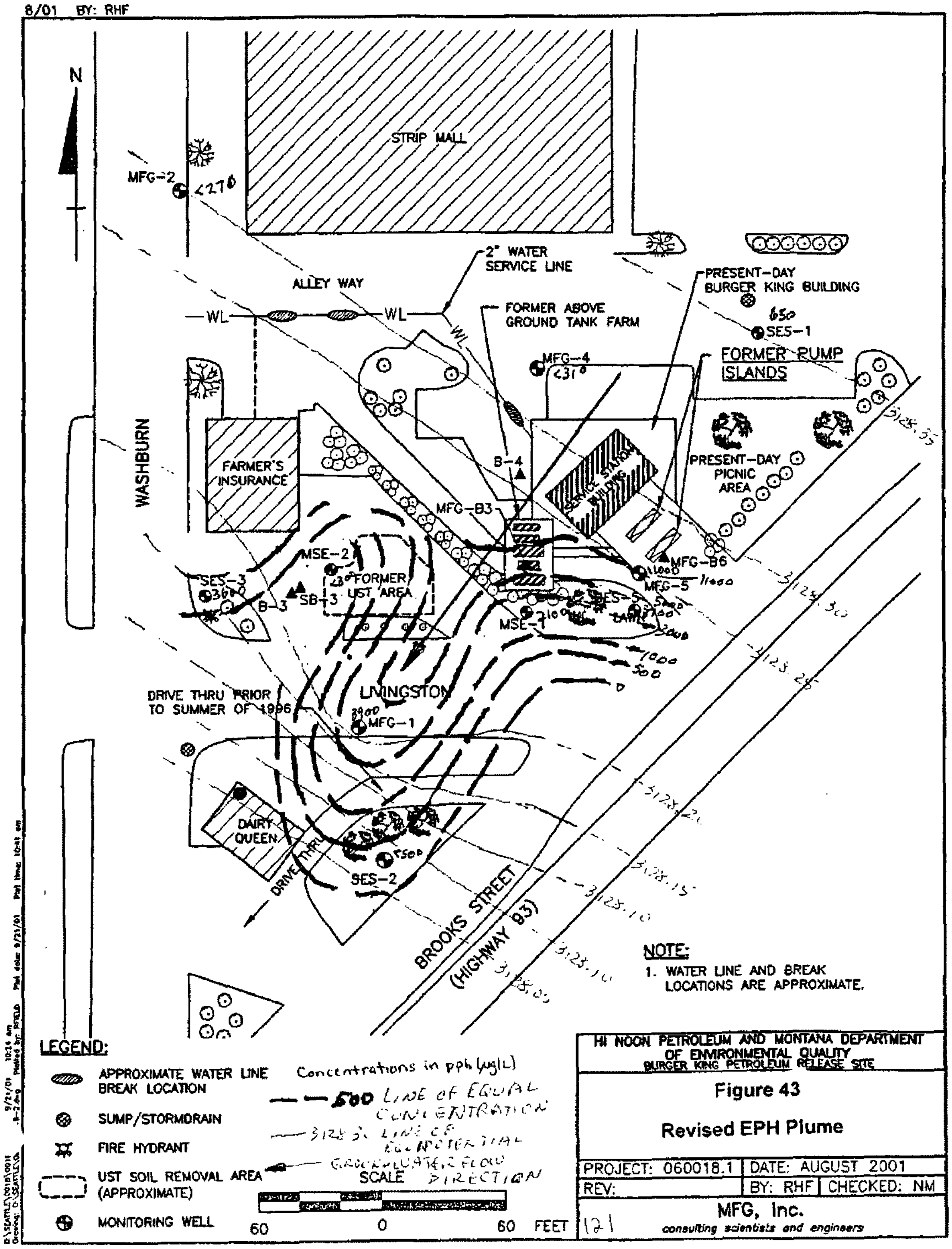


Figure 43

Revised EPH Plume

results, from March 2000 and January 2001, indicated some values above WQB-7 standards or Tier 1 RBSLs (MDEQ, 2000). EPH Screen results ranged from 2,200 to 21,000 ppb. The remaining EPH results from this well were all below detection (at least less than 590 ppb). SES-3 groundwater analytical results have indicated variable detections of both VPH and EPH Screen results. VPH results range from "not detected" (less than 20ppb) to 135 ppb; EPH Screen results range from "not detected" (less than 560) to 3,600 ppb. The first sample obtained from MFG-1 was May 31, 2001. The VPH result was 264 ppb and the EPH Screen result 3,900 ppb. These results appear to confirm the existence of a groundwater connection between the former AST farm at Burger King and Dairy Queen. Wells upgradient of the Source Area include SES-1, MFG-2, and MFG-4. All VPH and EPH Screen results for these wells have not shown a presence of petroleum hydrocarbon contamination, with the exception of the June 1, 2001 EPH Screen result for SES-1. This result was 650 ppb, below the 1,000 ppb action level for performing EPH fractionation analyses. At this point in time, this result June 1, 2001 result is considered to be an aberration and not indicative of any migration of petroleum hydrocarbons into this area from the Source Area. This well is located in the Burger King parking lot, between the alley way and picnic area. It is possible that petroleum hydrocarbons enter the well during runoff due to a poor seal on the surface cap. However, further groundwater sampling is necessary to confirm or invalidate this assumption. A further discussion of groundwater contamination in wells SES-2 is provided in Section 5.

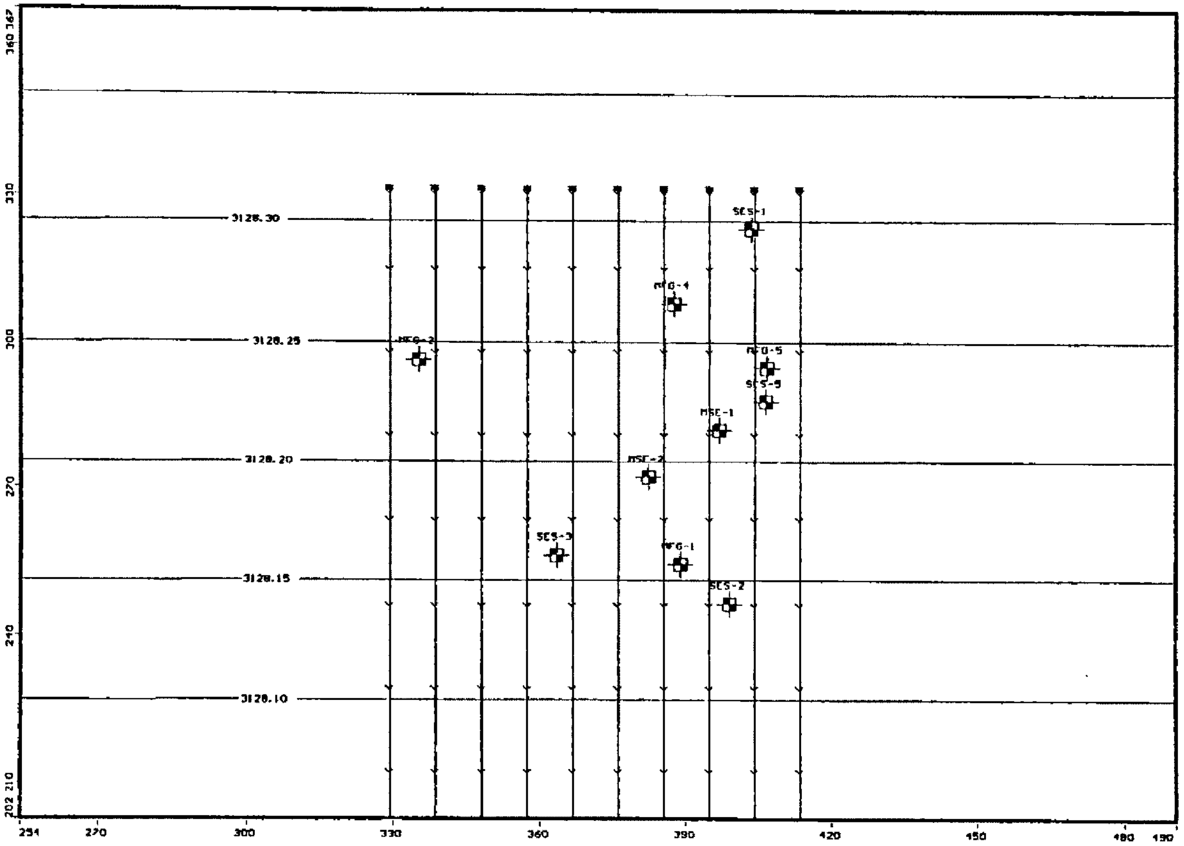
INFLUENCE OF A WATER LINE RUPTURE ON CONTAMINANT MIGRATION

The results of research into the water line rupture event in April 1990 indicated that it could be a mechanism of contaminant distribution to other areas of the Site. During the water line rupture event, up to 1.2 million gallons of water ("worst case" scenario) may have been discharged to the subsurface over a minimum of five days. The main rupture location was located no more than 20 to 30 feet north (upgradient) of the Source Area. The other two noted rupture locations were located near the entrance to the drive through. Appendix E provides additional details regarding the water line rupture.

MODEL RESULTS

To obtain a 0.0014 ft/ft gradient across the modeled area and the Site, constant head boundaries were placed at the upgradient and downgradient boundaries of the modeled area (Figure 45). No flow boundaries were placed on each side representing flow lines (southwest and northwest sides) of the modeled area. For the model, the subsurface at the Site was divided into two layers as shown on Figure 46.

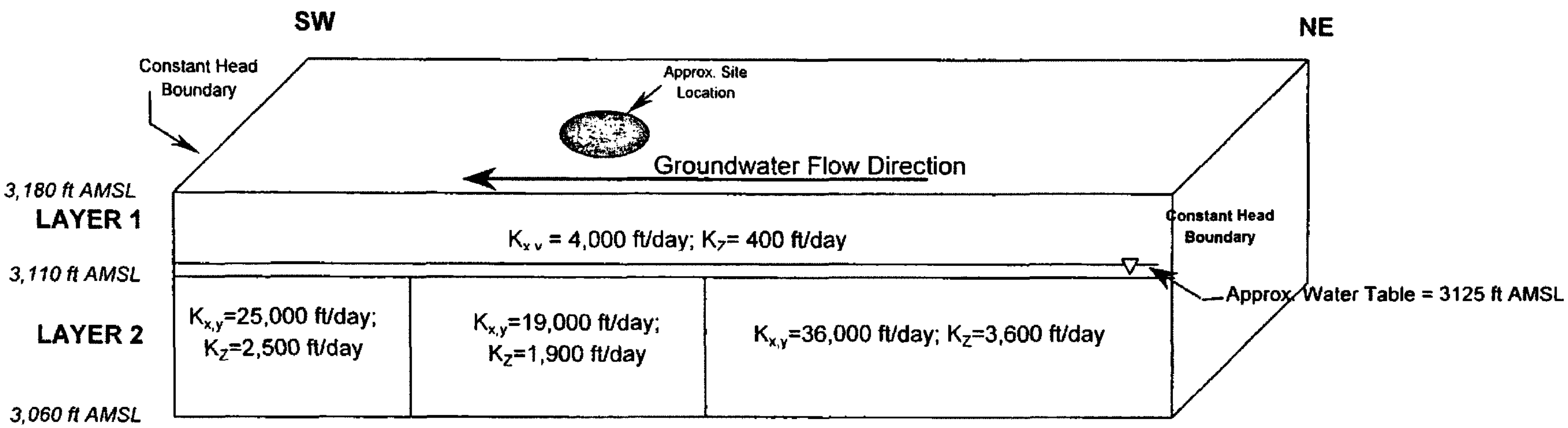
An average estimated hydraulic conductivity of 4,000 ft/day for Layer 1 was used in the modeling effort. Three hydraulic conductivity zones were applied to Layer 2. Initially, these include values tested by Practht (2001) for simulations along Brooks street in the vicinity of the Site and within the modeled area. These values include 36,000 ft/day, 21,500 ft/day, and 25,000 ft/day. Hydraulic conductivity within the three zones of Layer 2 were adjusted until the calculated versus observed heads of each well fell within the 95 percent confidence interval of the 1:1 line, with the exception of two wells (MSE-2 and MFG-5; see Figure 45). In addition, adjustments were continued until a reasonable mean calibration error value was reached. The mean absolute error calibration between calculated and observed heads was 0.1 feet. Calculated versus observed head graph and statistics are presented in Figure 47.



MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: Buger King Site
Modeller: Natalie Morrow
9 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1

FIGURE 44
Particle Tracking Results



Not To Scale

K = Hydraulic Conductivity

ft AMSL = Feet Above Mean Sea Level

Elevations are approximate

FIGURE 45
WATER TABLE MODEL RESULTS

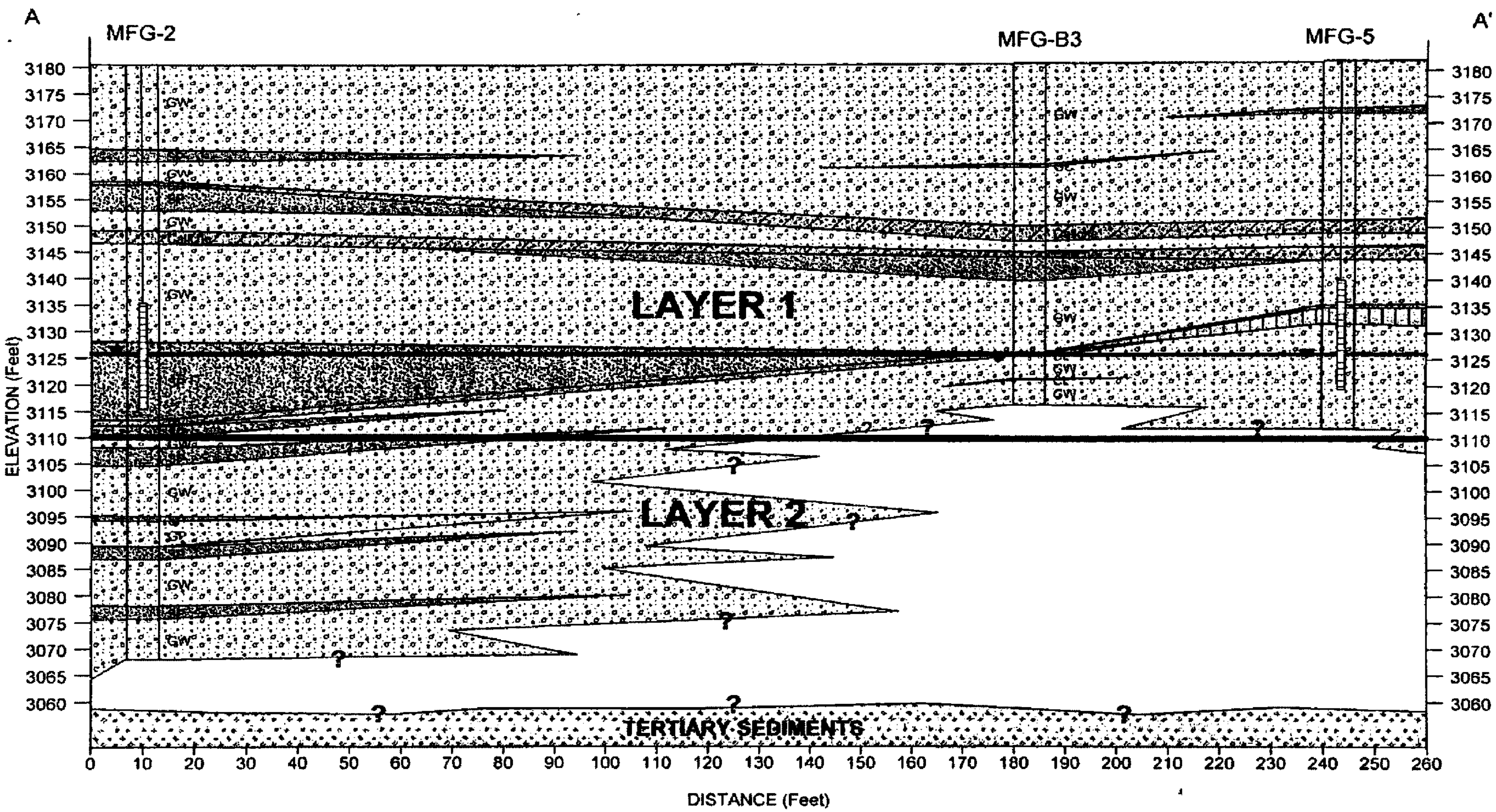


FIGURE 46

Groundwater Modeling Layers
Cross Section A-A' (NW to SE)
Burger King Petroleum Release Site

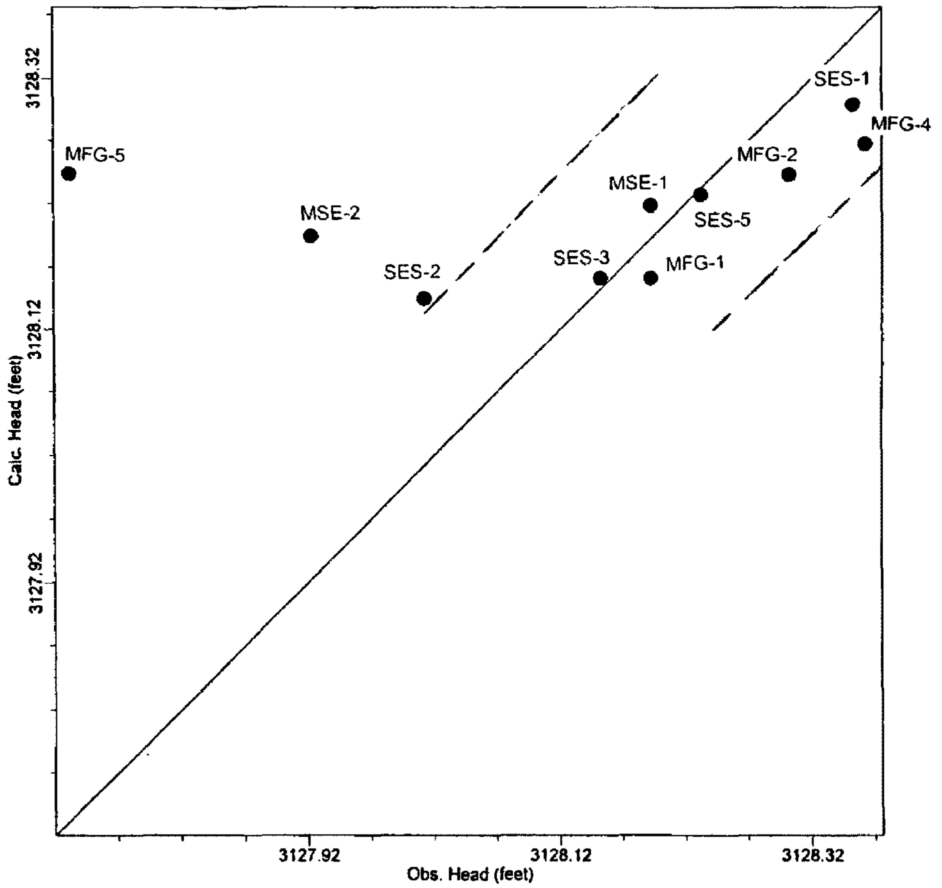
Natalie J. Morrow
M.S. Thesis, University of Montana
Spring 2002

After calibration of the model was complete, the final calibrated hydraulic conductivity of the three zones included 36,000 ft/day north-northeast of the Site, consistent with that estimated by Pracht (2001); 25,000 ft/day hydraulic conductivity zone south-southwest of the Site, also consistent with that estimated by Pracht (2001); and the hydraulic conductivity at the Site was 19,000 ft/day. (Figure 45).

A hydraulic conductivity value of 19,000 ft/day is a reasonable estimate considering the very coarse grained nature of much of the aquifer at the Site. The decrease in the hydraulic conductivity from 36,000 ft/day in the north-northeastern zone to 19,000 ft/day may be justified due to the increased occurrence of sand and sand with gravel layers observed within the aquifer (see Figure 12 and the boring log for MFG-2 in Appendix C). These layers would tend to lower the hydraulic conductivity. Driller's logs reviewed in the vicinity of the Site generally do not identify these individual sand or sand with gravel layers; therefore, it is unclear as to the extent and thickness of these layers in upgradient and downgradient areas. These layers, identified during logging, are typically several inches to a few feet thick; it is possible that they are localized and non-continuous, restricting them to the Site and local site area.

Steady state groundwater model simulations were performed to assess the potential effect of the 1990 water line break on the subsurface at the Site. The actual amount of water released to the subsurface is unknown. However, the total "worst case" scenario of water released to the subsurface due to a full rupture of the water line would have been approximately 1.2 million gallons over five days time (Appendix E).

Calculated vs. Observed Head : Steady state



Well #	Observed (ft AMSL)	Calculated (ft AMSL)
MSE-1	3128.19	3128.22
MSE-2	3127.92	3128.19
SES-1	3128.35	3128.30
SES-2	3128.01	3128.14
SES-3	3128.15	3128.16
SES-5	3128.23	3128.22
MFG-1	3128.19	3128.16
MFG-2	3128.30	3128.24
MFG-4	3128.36	3128.26
MFG-5	3127.73	3128.24

Num.Points : 10
Mean Error : 0.07042773 (feet)
Mean Absolute : 0.119416 (feet)
Standard Error of the Estimate : 0.05958162 (feet)
Root mean squared : 0.1921192 (feet)
Normalized RMS : 30.49511 (%)

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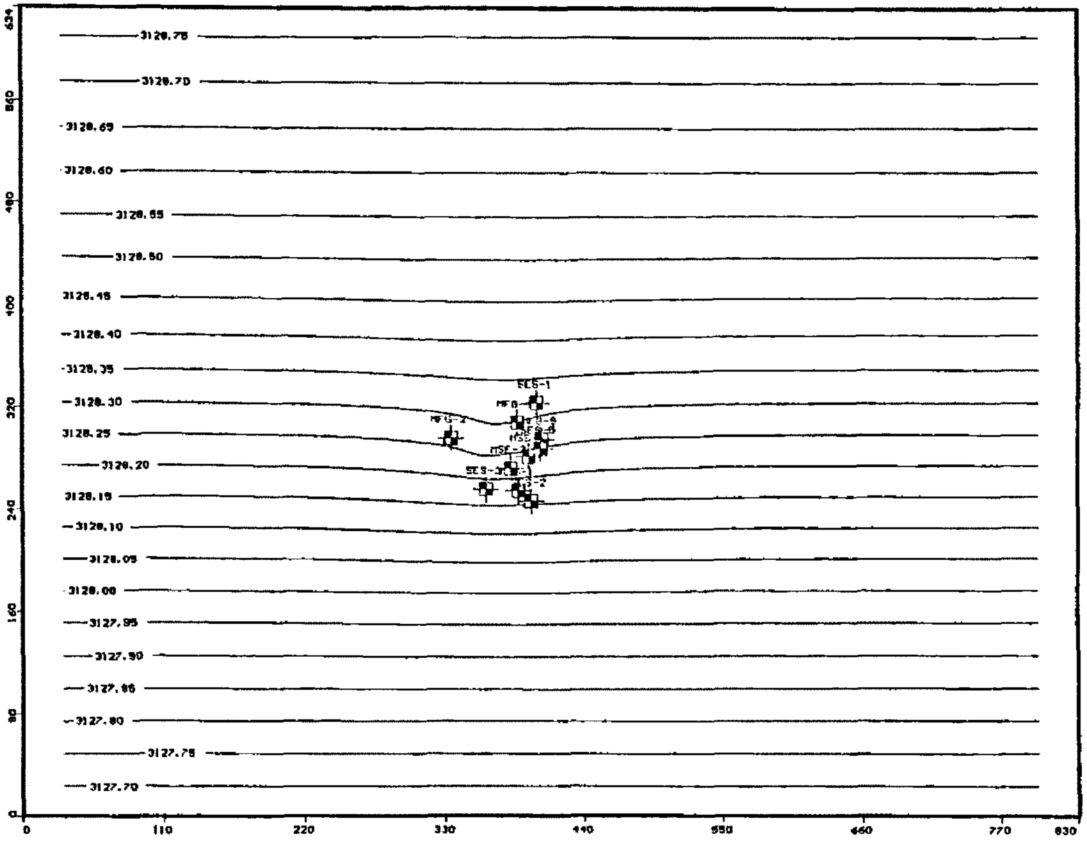
M.S. Thesis - U of Montana, Missoula
Burger King Site

FIGURE 47

The water table map and parameters, described above, were used for the water line rupture simulations and was simulated using various water discharge values. In addition, various release volumes were assigned to the three water line rupture locations to for transmission to the water table in the model. The water table and particle tracking results for the "worst case" scenario are presented as Figures 48 and 49, respectively. All water line rupture results are included in Appendix E.

In general, the results of each steady state simulation suggested that the volume of water potentially discharged during the water line break might have caused a temporary and slight increase in the gradient of the water table (see Figure 48 and Appendix E). Only direct recharge of water to the saturated zone is represented in the model (i.e., the influence on the vadose zone is ignored). Hence, lithostratigraphic effects, within the vadose zone, that effect the distribution and rate of recharge of water reaching the water table are not represented. Therefore, the results of the water line rupture model are only suggestive of what may have occurred at the water table.

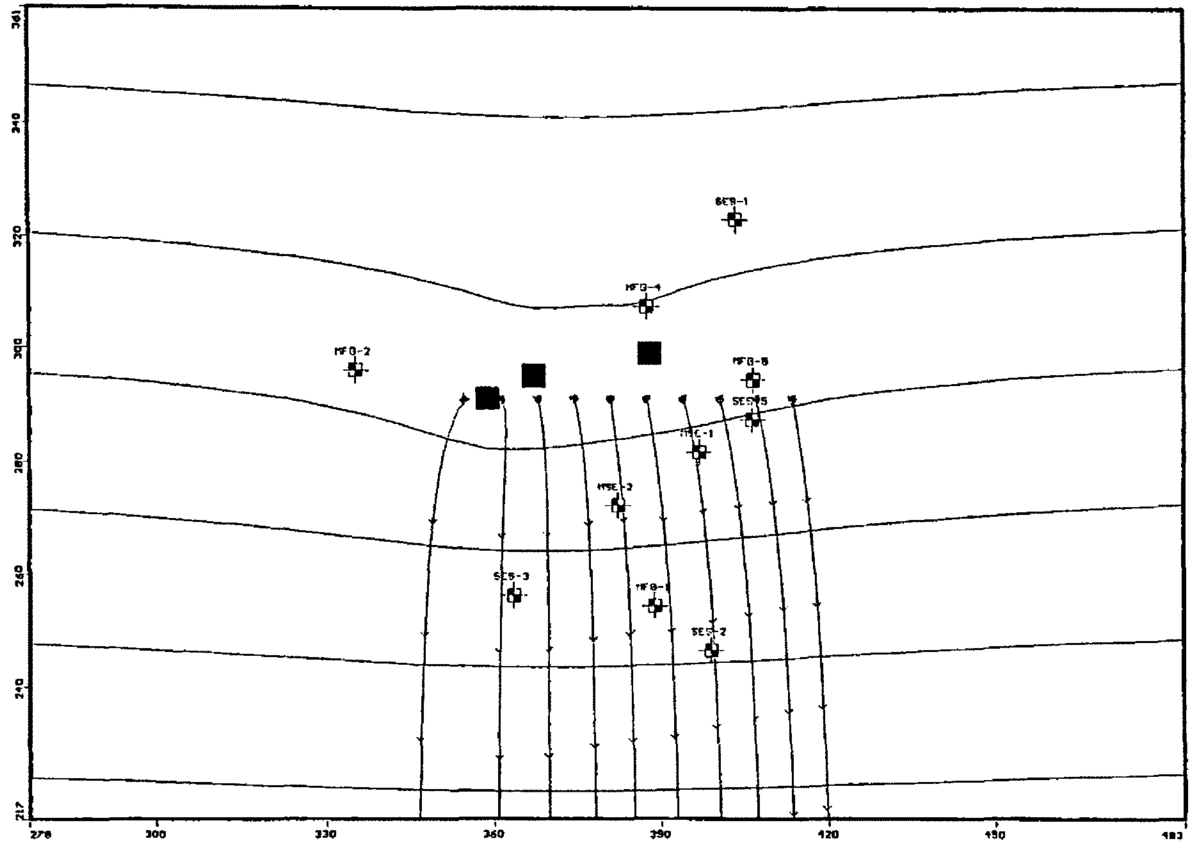
A conceptual model of the water line rupture event adjacent to the Source Area depicts how lithostratigraphic controls may have affected downward percolating water (Figure 50). The water may not have flowed directly to the water table but along various vertical and horizontal flow paths prior to reaching the water table. An urban storm water study was perfomed by Wogsland (1988) in the vicinity of the Site. During the study, five runoff events were monitored and the runoff volumes entering the storm drains were calculated. During these events, Wogsland (1988) reported runoff volumes ranging between 2,000 gallons to 46,600 gallons. The results of the study indicated that small changes in the water table were evident due to these precipitation runoff events (Wogsland, 1988). Under the



MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: WL Rupture – Worst Case
Modeller: Natalie Morrow
10 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1

FIGURE 48
Water Line Rupture Results



MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: WL Rupture – Worst Case
Modeller: Natalie Morrow
10 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1

FIGURE 49
Water Line Rupture Particle Tracking

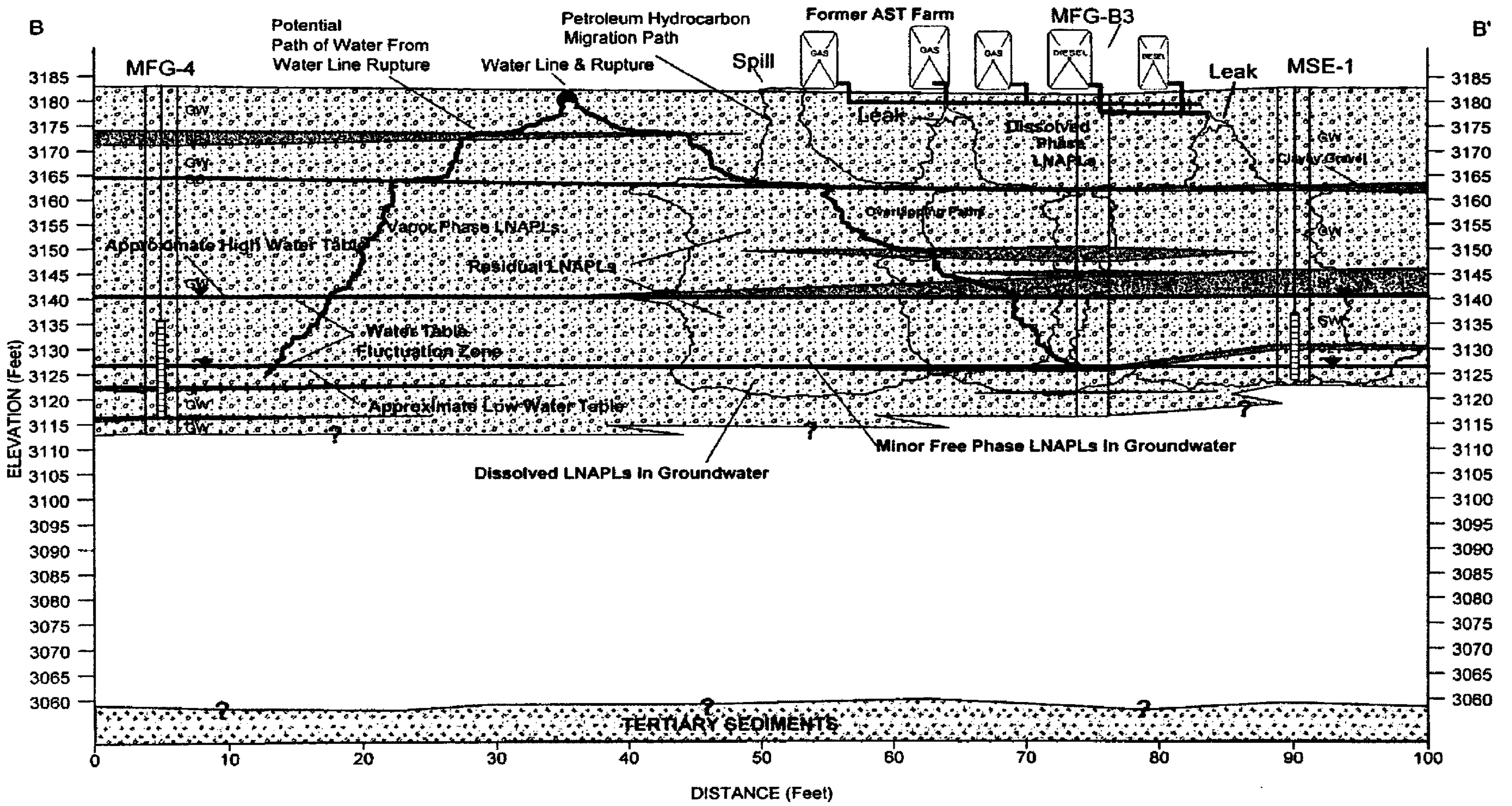


FIGURE 50

Conceptual Model of Lithostratigraphic Controls on Water From the Water Line Rupture in the Subsuface Adjacent to and Beneath the Source Area

Cross Section B-B'
North to South
Burger King Petroleum Release Site

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Spring 2002

LEGEND

- ░ GW: Well Graded Sandy Gravel
- ░ GP: Poorly Graded Sandy Gravel
- ▓ SP: Poorly Graded Gravelly Sand
- ▓ SW: Well Graded Gravelly Sand
- ▨ Caliche: Caliche w/Sand, Gravel & Clay
- ▨ CL: Clay with or without Gravel
- ▥ ML: Silt
- ▼ Approx. water table at time of drilling

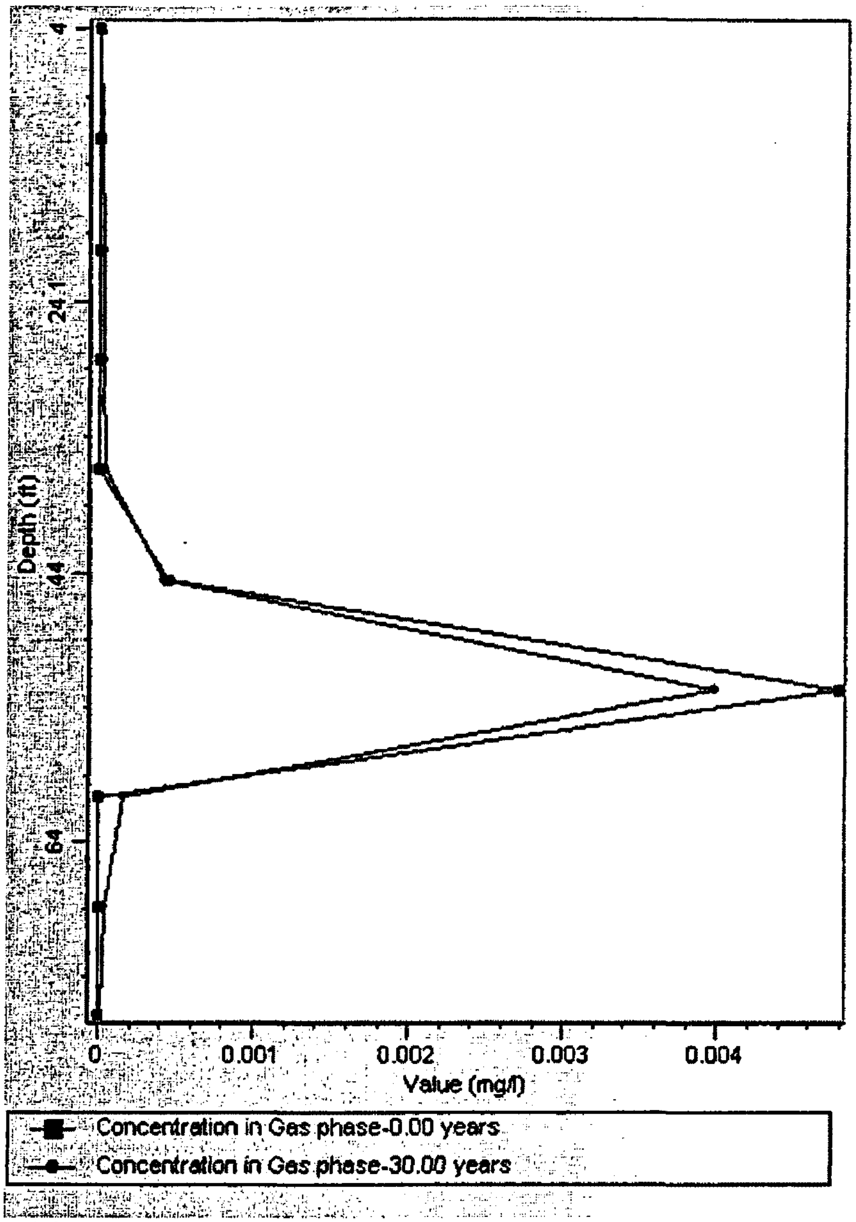
"worst case" senario for the Site approximately 1.2 million total gallons or 240,000 gallons per day would have discharged to the subsurface. Under a "minor case" scenario with a water line rupture discharge volume of 20 gallons per minute, approximately 28,800 gallons per day would have discharged to the subsurface. Under both of these scenarios, the volume of water per day is within or exceeds the volume range in which Wogsland (1988) noted rises in the water table due to storm water runoff events. Therefore, it is possible that the water line rupture event would have transmitted enough water to the subsurface to produce a noticeable change in the water table at the Site.

Vadose zone modeling was performed to determine if flow processes could be simulated in the vadose zone near the groundwater-vadose zone interface. Ethylbenzene concentrations in MFG-B3 were used in the simulation. The following table summarizes the input parameters. The purpose of the model was to evaluate the concentration of ethylbenzene in the subsurface after 30 years. Because subsurface samples were only collected from the smear zone, the model only represents contaminants in this area. There may be low levels of petroleum hydrocarbon contamination above the smear zone, however this was not verified through analytical sampling.

PARAMETER	VALUE
Ethylbenzene Soil Concentration	0.18 mg/kg at 50 feet bgs 0.06 mg/kg at 55 feet bgs
Percent Moisture	6% at 50 feet bgs
Organic Carbon	0.1
Soil Matrix/Profile	Sand Profile
Model Run Time	30 Years
Remaining Parameter	Model Defaults

Concentration results for gas, soil water (pore water), and solid (adsorbed) phases for zero (0) to 30 years results indicate only a minor decrease in ethylbenzene concentration would have occurred in each of these phases over the 30-year model simulation. One representative graph showing the change in the ethylbenzene concentration in the gas (vapor) phase within the vadose zone is provided as Figure 51. The remaining vadose zone modeling results are included in Appendix F.

As mentioned in Section 3, the vadose zone model may not appropriately represent the Site. Therefore, it may not accurately reflect the fate of ethylbenzene, or other VOCs if modeled, in the subsurface at the Site. However, while the results may not be accurate for much of the subsurface materials encountered within the Source Area, it may be representative of sand layers and higher sand content zones within the sandy gravel units. Subsurface soil samples collected within the Source Area have continued to exhibit detectable levels of ethylbenzene. Soil samples collected from the vadose zone in from MSE-1 in 1994 had an ethylbenzene concentration of 0.230 mg/kg and the soil sample collected in 1995 from SES-B4 contained an ethylbenzene concentration of 0.414 mg/kg. A sample collected six to seven years later within the Source Area from MFG-B3 contained ethylbenzene concentrations of 0.18. While the samples were collected from different boreholes and slightly different depths within the vadose zone, the analytical results tend to support the model results by indicating only a slight, if any, decline in the ethylbenzene concentration over seven years within the Source Area. However, additional soil analyses in subsequent years would be needed to fully support the results of the modeling effort. Section 5 presents a further discussion of these results.



MFG-B3 Ethylbenzene concentration change in gas phase from 0 to 30 years

FIGURE 51

5 DISCUSSION

CONCEPTUAL MODELS

Conceptual models were constructed to help visualize petroleum hydrocarbon migration from the subsurface to groundwater (Figures 32 through 34). Included in each conceptual model is the former AST farm, and sources of petroleum hydrocarbon to the subsurface include spills and leaks. Vertical migration of contaminants will be quickest in the coarse sandy gravel areas of the subsurface while the presence of clay, sand, silt, and caliche layers beneath the former AST farm will slow vertical migration and increase horizontal or lateral spreading of petroleum hydrocarbons in the subsurface. Overall, the limited surface source of contaminants will relate to a large foot print of degradation because lower permeable layers are present.

SOURCE AREA

It does not appear that an off site source is responsible for petroleum hydrocarbon contamination at the Site. Even though a specific point or mechanism of release (i.e., fittings, overfills, piping, etc.) has not been confirmed, enough circumstantial evidence has been obtained in order to identify the likely Source Area. It appears to be the service station located at the Burger King Site and includes the former AST farm, the area beneath and adjacent to the underground piping pathway to the pump islands (along the south side of the Burger King building), and the area near the pump islands, but not directly below the pump islands (see Figure 36).

After reviewing previously collected data and data collected during this study the highest concentrations of petroleum hydrocarbons in both subsurface sediments and groundwater exist at the fringe of and within the Source Area (at MFG-B3, MFG-5, and SES-B4) (Tables 5 and 6 and Figures 39 and 40). It appears reasonable to conclude that contamination of the subsurface environment occurred due to: 1) spills and overflow events at the ASTs; 2) leaks from pipes and fittings; and 3) leaking underground piping between the ASTs and the pump islands. The following provides some supporting discussion for defining the Source Area.

Elevated subsurface PID readings were obtained during the drilling of MSE-1 between 14 to 20 feet bgs (Figure 35 and Table 4). Drilling at this location also noted a clay layer with perched water at this depth. A shallow subsurface sample was collected from approximately 25 feet bgs at SES-B4 (B-4 on the map). The VPH and EPH analytical results from this sample were contained elevated constituents. A clay layer was also encountered during drilling of MFG-B3. A clay layer located approximately 18 feet bgs has most likely trapped, spread, and released petroleum hydrocarbons within the Source Area.

The soil vapor survey conducted results (Higgins, 1999) support the proposed source area and role of the clay layer in impacting contaminant migration (see Table 2). The soil vapor survey indicated several areas containing elevated levels (or "hot spots") of volatile and semi-volatile petroleum hydrocarbons. Gasoline range hydrocarbon "hot spots" include: 1) north of the northeast corner of the Burger King building and west of SES-1; 2) just south of the Burger King restaurant near SES-5; 3) just east of the insurance building; 4) and the east corner of the Dairy Queen building. Diesel range hydrocarbon "hot spot" include: 1) north-northeast of the Burger King building and west of SES-1; 2) southwest of the Burger King building, southwest of the Source Area and west of MSE-1; 3) south and west of the Burger King building within the Source Area; 4) at the east corner of Dairy Queen; 5) and just east of the insurance building (see Figure 7).

Each of the "hot spots" identified above appear to be associated with identifiable man-made features or the Source Area. The gasoline and diesel "hot spot" located north-northeast of the Burger King building and west of SES-1 is located near where the Burger King restaurant sewer line connects with the main Missoula City sewer line. Vapors at this location may be collecting around this feature(s). Gasoline and diesel range vapors were also present adjacent to two buildings, the Dairy Queen and insurance building. The vapors may be collecting around the foundations on these buildings. The remaining "hot spots" are within or adjacent to the Source Area. Hence, the petroleum hydrocarbon contamination from the Source Area is probably responsible for the vapors collected in these areas. The remaining lower concentrations around the Site are most likely present due to diffusion and/or sorption of gas phase petroleum hydrocarbons in the coarse grained and finer grained layers within the vadose zone. The subsurface soil analytical results, soil vapor survey results, and the results of the plume maps (see Section 4) suggest the defined Source Area is the source of subsurface soil contamination at the Site.

PETROLEUM HYDROCARBON PHASES PRESENT AT THE SITE

Petroleum hydrocarbon contamination is probably present in several forms. In general, it appears that most of the petroleum hydrocarbons present in the subsurface sediments are in the form of residual hydrocarbons in the vapor and liquid phases. These residuals probably exist due to the following: 1) vapors and liquid phase petroleum hydrocarbons trapped during the initial vertical and horizontal migration from the source toward the water table; 2) as vapors and liquids trapped in the pore spaces as a result of water table fluctuations: 3) emplacement of residual hydrocarbons as a result of the water line rupture; 4) continued spreading due to water table fluctuations and diffusion and sorption of vapors; and 5) dissolved phase hydrocarbons in the groundwater.

Dissolved phase petroleum hydrocarbons in groundwater and some free phase petroleum hydrocarbons, present as sheen and globules, have been observed during purging of wells in the Source Area. However, attempts to measure free product thickness with an interface probe has failed to identify a measurable thickness in the wells at the Site. This is likely due to the very coarse-grained nature of the subsurface materials. Petroleum hydrocarbon contamination in the Source area is likely present in the vadose zone as residual petroleum hydrocarbons in the vapor and dissolved phase within water films, and in the liquid phase as ganglia (blobs of petroleum hydrocarbons) trapped in pore spaces as the hydrocarbons migrated downward and as a result of water table fluctuations. The Source Area contains petroleum hydrocarbons in subsurface soil with concentrations above the MDEQ Tier 1 standards and RBSLs. Vapor phase contamination has been confirmed through the results of the soil vapor survey and other residual hydrocarbons have been confirmed through field screening and analytical results.

Petroleum hydrocarbons downgradient of the Source Area are probably present as vapors residing in the pore spaces in the vadose zone and in vapor and dissolved phases in the smear zone. As mentioned above, the soil vapor survey results indicated Site-wide vapor phase contamination which supports this observation. In addition, downgradient petroleum hydrocarbon contamination was observed in groundwater in MFG-1 even though subsurface soil analytical results showed no detectable levels of hydrocarbon contamination. It is expected that some residual hydrocarbons are present within the "smear zone" at this location.

The extent of contamination was estimated using all data and analytical results collected from to date. Because there have been no data collected from subsurface soils and groundwater beyond the Dairy Queen, southwest of the Site, nor in areas east and west of the Site, the exact extent of contamination is unknown. Results show subsurface soil and groundwater within the Source Area have been the most affected by petroleum hydrocarbon contamination (see Figures 39 and 40). Downgradient wells contain variable levels of dissolved phase petroleum hydrocarbons contamination while upgradient wells have not indicated the existence of such contamination.

LITHOSTRATIGRAPHIC CONTROLS ON CONTAMINANT MIGRATION

The lithostratigraphy present at the Site has shown to play an important role in contaminant migration. The lithostratigraphic factors and other features or factors believed to have influenced or may still be influencing contaminant migration at the Site include the following:

- Sandy gravel within the vadose zone: The main component of the vadose zone is sandy gravel. This component is believed to contribute greatly to the migration of contamination through the diffusion of VOCs both horizontally and vertically. This conclusion is supported by the results of the soil vapor survey performed by Higgins (1999). Overall, the results of the soil vapor survey showed a fairly wide distribution of VOC vapors throughout the Site. Sorption within the sandy gravel units probably also occurs within water films and on subsurface materials. This may be more evident within the Source Area and vicinity of the Source Area due to the higher concentrations of VOCs found in this area (see Section 4). However, few VOCs have been detected in the upper regions of the vadose zone during PID screening within the Source Area and have not been detected outside the Source Area (Table 4 and Figure 35).

- Sand layers within the vadose zone: Sand layers within the vadose zone at the Site are believed to contribute to contaminant migration within the Source Area by slowing the vertical migration of petroleum hydrocarbons and; therefore, also contributing to the horizontal spreading of petroleum hydrocarbons (see Figures 32, 33, and 34). Diffusion and sorption are also expected to play key roles in the contaminant migration within the Source Area. As the petroleum hydrocarbons migrate downward, some components are volatilized and become diffused. The soil vapor survey (Higgins, 1999) indicated wide spread contamination of volatile petroleum hydrocarbons across the Site. Other petroleum hydrocarbons may become in dissolved within water films on soil particles, and others may become sorbed to the subsurface materials. Sand layers would have a greater ability to trap residual hydrocarbons due to the high interstitial tension on the particles.

- Clay layers within the vadose zone: Previous investigations at the Site have indicated the clay layer located beneath and within the Source Area has had an affect on petroleum hydrocarbon migration. Shallow contamination was observed at MSE-1 during drilling and sampling. Shallow subsurface soil contamination at this location may be due to the presence of this clay layer and its proximity to a main leak source or spill from the former AST farm. This clay layer may have been initially responsible for reducing the rate of downward migration of petroleum hydrocarbons at this point and still retaining some petroleum hydrocarbons at this shallow depth. As a lower permeability zone, the clay layer reduces the ability of the petroleum hydrocarbons to migrate vertically and increases the migration of petroleum hydrocarbons horizontally within the vadose zone. Once the petroleum hydrocarbons reach a higher permeability zone, they will again migrate vertically. Sorption, and to a lesser extent diffusion, probably also play roles in the petroleum hydrocarbon migration within the clay layer.

- Caliche layers within the vadose zone: Caliche layers within the vadose zone probably contribute to petroleum hydrocarbon contamination at the Site in a similar manner to the sand and clay layers, depending on the permeability and composition of the layer at the point of contact. No petroleum hydrocarbon contamination was evident within these layers.

The presence of caliche zones in the Missoula basin sediments has not been previously described. Caliche forms in arid to semiarid climates. The soil in these environments tend to accumulate calcium carbonate, typically in the form of calcite (Blatt, et al., 1980). Caliche forms as a result of the combined factors of changes in the partial pressure of carbon dioxide in the soil zone and evaporation (Blatt, et al., 1980). In arid environments, the quantity of organic matter in soil is less and there is an increase in evaporation of water from the vadose zone (Blatt, et al., 1980). More water is drawn to the surface through capillary action, the water and carbon dioxide in the soil are lost to the atmosphere, causing the precipitation of calcium carbonate in the soil (Blatt, et al., 1980). Therefore, in areas with low rain fall, the caliche zone is relatively close to the surface. Figure 52 presents a visualization of the factors involved in caliche formation, as discussed above. The caliche detected in the cores is most likely indicative of one or more periods of climatic dry spells where there was little precipitation and little or no vegetation present. Thus far, the sediments of the MVA are believed to be Quaternary age. However, a documented dry spell occurred in the late Pleistocene. Therefore, the identification of the caliche layers may suggest the MVA sediments were deposited earlier, during the Pleistocene, than what is now commonly believed. Further age dating studies are needed to evaluate their true time of deposition.

CONTROLS ON PETROLEUM HYDROCARBON MIGRATION IN GROUNDWATER

Water table fluctuations probably have contributed to the spread of petroleum hydrocarbon contamination at the Site. For the most part, the zone of water table fluctuation appears to be mostly within sandy gravel. However, a portion of this interface area does contain some layers of

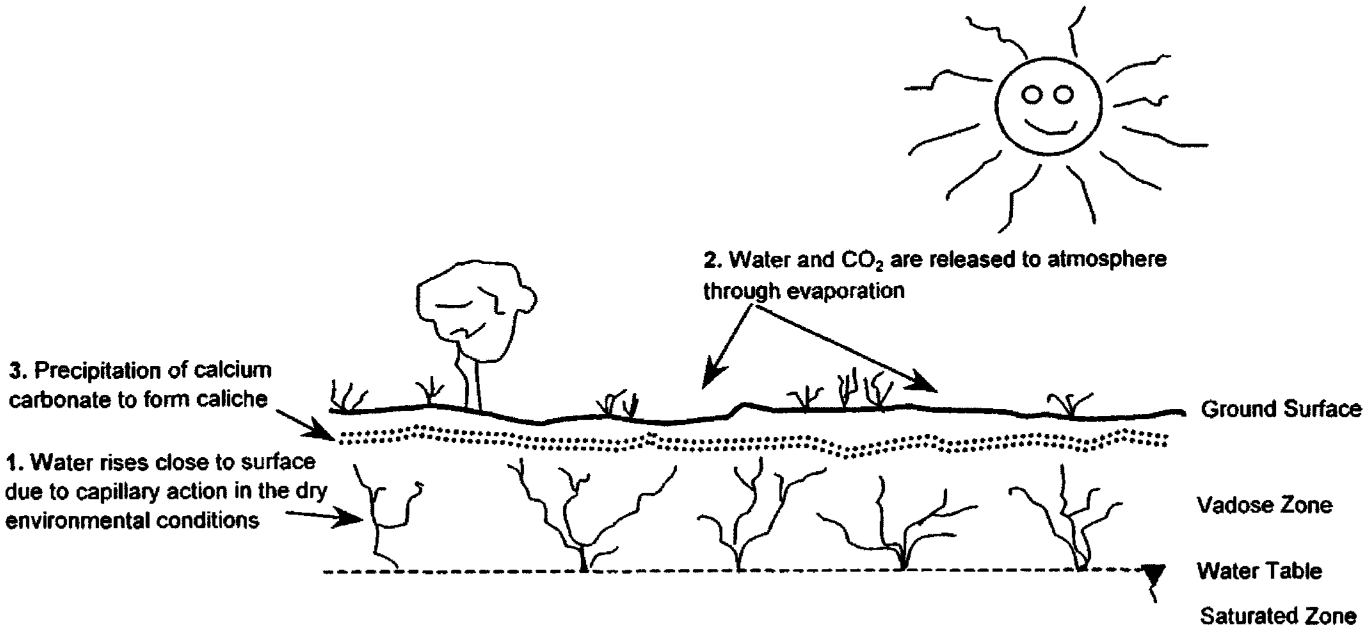


FIGURE 52

Caliche Formation

(Arid to Semi-arid Environment)

sand, silt, and clay. The sand layers within this zone probably retain more sorbed hydrocarbons than the sandy gravel where diffusion may be more dominant. PID results and subsurface material sampling suggest that petroleum hydrocarbon contamination beneath the Source Area is at least 10 to 13 feet thick. This zone contained the highest PID readings and subsurface soil analytical results were consistently obtained between approximately 45 and 60 feet bgs at the Site. The subsurface interval of 45 to 60 feet bgs is within the water table fluctuation zone ("smear zone") at the Site. The petroleum hydrocarbons trapped in these areas are probably in the form of residual petroleum hydrocarbons and trapped ganglia in pore spaces in the smear zone and aquifer.

Horizontal spreading of petroleum hydrocarbons at the water table further contribute to the distribution of petroleum hydrocarbons in the subsurface. At the time of drilling, the aquifer was contained mostly within the Lower Unit at the Site. For the most part, the upper portion of the aquifer within the Source Area consists of coarse sandy gravel. The hydraulic conductivity is expected to be quite high in this zone and; therefore, dissolved petroleum hydrocarbons in groundwater would also be expected to move quite rapidly. The shape of the plume is also a factor of the hydraulic properties of the aquifer which are controlled by the lithostratigraphy.

Recall the Burger King restaurant was completed in 1976. Therefore, the service station has probably been inactive for at least 25 years and new sources of petroleum hydrocarbons at the Burger King Site have not occurred for at least 25 years. The results of this study have shown that elevated concentrations remain within the Source Area in both subsurface soil and groundwater.

Additionally, the slow migration and remaining high concentrations in groundwater in the Source Area may be due to residual petroleum hydrocarbons trapped in the "smear zone" that are slowly dissolving and entering the groundwater flow system. These residual petroleum hydrocarbons often constitute the majority of the volume of petroleum hydrocarbon contamination at sites (Conrad, et al., 1992) and can form a relatively immobile source (Baehr and Corapcioglu, 1987 and Lahvis and Baehr, 1996). In addition, sorption of colloidal particles at the gas-water interface is irreversible due to the capillary forces (Wan and Wilson, 1994). However, fluctuating water tables and recharge may assist in colloid mobility (Wan and Wilson, 1994). This immobile gas-water interface in porous media can retard the transport of particulate contaminants (Wan and Wilson, 1994). This relationship help support the observation that the highest levels of petroleum hydrocarbons are concentrated within the relatively small Source Area and appear to quickly decrease away from the source area.

While passing groundwater may dissolve portions of these residual hydrocarbons, they still act as continuing sources of petroleum hydrocarbon contamination (Conrad, et al., 1992). In cases where a local equilibrium has been reached, only residual hydrocarbons at the extreme upstream end of the zone are dissolved into the passing groundwater (Conrad, et al., 1992). The elevated concentrations of petroleum hydrocarbons within the Source Area may suggest that there is an abundance of residual petroleum hydrocarbons (as supported by the analytical results) within the smear zone and the system may be in or close to equilibrium. Conrad et al., (1992) also found that water tends to flow preferentially around residual hydrocarbon blobs (or ganglia) with greater flow through water-filled pores and much less flow through pores containing sorbed hydrocarbon films. This effect reduces dissolution of residual petroleum hydrocarbons into the flowing groundwater (Conrad et al., 1992).

In addition, the vadose zone model results indicated only a minor decline in ethylbenzene concentrations would likely occur within the smear zone after 30 years. The minor decline in ethylbenzene may support the fact that residual petroleum hydrocarbons present within this area have been and will continue to be a significant source of petroleum hydrocarbon contamination at the Site; that the petroleum hydrocarbons are not being dissolved into groundwater at a fast rate;

that little is being volatilized and escaping into the atmosphere; and it may also suggest that the system may be in equilibrium or close to equilibrium.

After groundwater has passed through this area and the saturation limit has been reached (e.g., no more hydrocarbons are dissolved), a dispersion zone is created. The size of the dispersed zone is dependent on the velocity of groundwater flow and the interphase mass transfer rate (Conrad, et al., 1992). In addition, the ratio of longitudinal dispersivity (α_L; mixing in directions along the flow path) and transverse dispersivity (α_T; mixing in directions normal to the flow path) also plays a major role in the shape of a contaminant plume (Fetter, 1999). The lower the ratio (α_L/α_T), the broader the shape of the plume (Fetter, 1999). Therefore, because the shape of the VPH and EPH plumes are fairly wide, the α_L/α_T ratio is expected to be relatively small and/or the vadose zone spreading has enlarged the source area. The higher the velocity and the lower the interphase mass transfer rate, the larger the dispersed zone (Conrad, et al., 1992). These interactions may explain the high concentrations still found in the Source Area and the size of the plume. Other factors strongly affecting the shape and size of the contaminant plumes include: the petroleum hydrocarbon release rate and volume, the porosity of the subsurface materials, hydraulic conductivity of the subsurface materials, the hydraulic gradient (API, 1996). In addition, the extent of the petroleum hydrocarbon plume is also dependent on the chemical and physical properties of the petroleum hydrocarbon (API, 1996). A steep hydraulic gradient will produce a narrower plume and faster migration of hydrocarbons in the subsurface (API, 1996). Plumes in shallow hydraulic gradients are generally fairly wide, almost as wide as they are long (API, 1996). At the Site, VPH constituents are generally more soluble and volatile than EPH constituents and have an overall slightly greater overall extent than EPH. For example, benzene is more soluble in water than diesel range petroleum hydrocarbons; therefore, benzene would have a greater overall distribution than diesel range petroleum hydrocarbons.

Water Line Rupture Event

The contamination detected in the Dairy Queen well in April 1990, just after the water line rupture event, may have been due to the mobilization of petroleum hydrocarbons from the Source Area into the groundwater. It is unknown to what extent petroleum hydrocarbons existed in the groundwater beneath the Dairy Queen prior to this event; however, there were no previous reports of detections in this well water prior to this event. In addition, the Dairy Queen well was sampled again in September 1990 and in 1992 by regulatory agencies. Each of these subsequent events showed no detectable petroleum hydrocarbons in the groundwater at the Dairy Queen well. The subsequent sampling events indicate the April 1990 detection of petroleum hydrocarbons in the well water were most likely due to a slug of petroleum hydrocarbons released during the water line rupture event or reactivation of petroleum contamination present at the water table or in the smear zone.

Given the proximity of the main rupture location to the Source Area, the water line rupture event may have redistributed petroleum hydrocarbons from the Source Area into other areas of the vadose zone and/or groundwater. The conceptual model showing the approximate location of the water line ruptured is provided as Figure 33. As discussed previously, when the water line ruptured, a large volume of water was released into the subsurface over a minimum of five days. The conceptual model shows the lithostratigraphic controls of the water released from the water line rupture. As shown in the conceptual model, several lithostratigraphic layers were present in the subsurface beneath the water line rupture location and Source Area. These include two sand layers, a clay layer, and a caliche layer.

The conceptual model indicates the water from the water line rupture probably encountered at least some of the petroleum hydrocarbon contamination present within and adjacent to the Source Area. At a minimum, the water traveling through the vadose zone probably encountered vapor phase, dissolved phase, and residual phase LNAPLs in the vadose zone. Once the water encountered the LNAPLs, they were probably either redistributed in the vadose zone and/or were flushed to the saturated zone where they were further mobilized and redistributed downgradient. These LNAPLs probably traveled in the dissolved and possibly free phases with some eventually becoming trapped as residual LNAPLs.

Detected Impacts at Well SES-2

There are two possible on-site sources of petroleum hydrocarbons to well SES-2. The first source is petroleum hydrocarbons originating from the AST farm and associated piping at Burger King and a second possible source is petroleum hydrocarbons originating from asphalt sealants applied to the roadway in the Dairy Queen drive-thru.

The well casing for SES-2 is damaged, and the damage may have occurred during remodeling construction at the Dairy Queen drive thru (see below). The top of the well casing is broken and the surface cap does not seal properly. Therefore, it is possible that asphalt sealants may enter the well during asphalt maintenance activities or gasoline, diesel, and vehicle oil may enter the well in runoff during precipitation events. Additionally, the Dairy Queen drive thru was originally oriented so that vehicles would enter from Brooks Street (Figure 7), and at that time, well SES-2 was not in the drive thru. Sometime during the summer of 1996 (Harvey, 2001), the drive thru was changed to allow entrance from Washburn. As a result of the drive-thru modification, well SES-2 is now located in the drive-thru. The present orientation of the drive-thru is shown on Figure 40 and the drive thru orientation prior to 1996 is shown on Figure 7. The approximate carbon range for asphalt sealants is C18 through C26. These carbon ranges have been detected at concentrations exceeding Tier 1 Groundwater RBSLs in SES-2. It is believed that the main source of contamination in this well is from the drive-thru and not from the former AST farm.

Repairing the well casing and ensuring surface components seal properly should reduce the potential for asphalt sealants and other petroleum hydrocarbons to enter the well.

6 CONCLUSIONS

1. Overall, two main lithostratigraphic units were identified at the Site. These include the Upper Unit and Lower Unit. The Upper Unit extends from ground surface to approximately 58 to 62 feet bgs and is composed of sandy gravel with layers of sand, silt, clay, and caliche. The Lower Unit consists of sandy gravel with layers of sand and clay, appears to be overall coarser than the Upper Unit, and extends from approximately 58 to 62 feet bgs to a total depth of at least 115 feet bgs. The total depth of the Lower Unit and aquifer is believed to be approximately 125 feet at the Site. Unit Two, described by others, was not clearly identifiable.

2. The lithostratigraphy played a role in contaminant migration (e.g., the clay layer present at MSE-1 caused reduction in vertical migration and some perching of petroleum hydrocarbons and water on top of the clay layer). Residual petroleum hydrocarbons trapped within pore spaces in the smear zone (or water table fluctuation zone) are believed to be a continuing source of petroleum hydrocarbon contamination to groundwater. Various other sand and clay layers within the vadose zone probably contributed to horizontal spreading of petroleum hydrocarbon contamination in the subsurface. Vapor phase migration of petroleum hydrocarbons was most likely significant in the vadose zone.

3. Groundwater flow is to the southwest, approximately paralleling Brooks Street. A water table model, water line rupture model, and vadose zone model were used to assist in interpretation of possible controls on petroleum hydrocarbon migration and fate. The results of the water table model suggest that the hydraulic conductivity of the MVA at the Site is 19,000 ft/day with an average linear velocity of 130 ft/day. The simulation of a water line rupture indicated a temporary rise in the water table would occur (under steady state conditions) and re-mobilization of petroleum hydrocarbons in the subsurface would have been likely.

4. The vadose zone appears to remain a significant source of contamination to the subsurface soil and groundwater. It is likely that little change in the ethylbenzene concentrations found in the smear zone would occur over a 30-year simulation period. This is supported by observations that elevated levels of petroleum hydrocarbons are still present within the Source Area after the 25 years. Thus, the smear zone appears to remain a significant source of contamination to the groundwater.

5. Rotosonic drilling proved to be a very efficient and effective tool for examining the subsurface lithostratigraphy at the Site in great detail. The data it provided was invaluable to this study.

The results of this study have provided detailed information about the lithostratigraphy present in one portion of the MVA. This study has also given support to the value and importance of characterizing the lithostratigraphy and lithostratigraphic controls on petroleum hydrocarbon migration. Lithostratigraphy together with identifying and evaluating other natural and anthropogenic factors influencing in the fate and migration of petroleum hydrocarbons are important and can be valuable tools in assessing the fate and migration of petroleum hydrocarbons in the subsurface and will provide a better understanding of the complex system for remediation purposes.

7 RECOMMENDATIONS

Some of the methods presented in this study may be of benefit during future studies at contaminant release sites including: 1) the use of rotosonic drilling and detailed logging to better characterize the lithostratigraphy at the site; 2) detailed logging of the cores to understand the lithology and stratigraphy present that may play a role in contaminant fate and migration; 3) grain size analyses to support observations made during logging and for use in remediation alternatives; 4) a thorough review of data collected from previous studies and integration of this data during additional site characterizations; 5) a thorough review of other relevant factors that may have a role in contaminant fate and migration (e.g., the water line rupture event); and 6) construction of cross sections and conceptual models to assist in visualizing lithostratigrapic and/or other natural and anthropogenic controls of contaminant fate and migration.

Additional investigative methods that are recommended in future studies of petroleum contaminated sites include: 1) collection of several depth integrated subsurface soil samples from the vadose zone to better characterize the petroleum hydrocarbon concentration changes with depth; 2) collection of subsurface soil samples for additional vadose zone characterization for use in vadose zone modeling efforts, such as total organic carbon content, moisture content, density, and porosity; 3) use rotosonic drilling at complex sites or as needed to assist in better characterization of the lithostratigraphy present at a site; 4) thoroughly review data collected during previous studies and integrate this data to help solve contaminant fate and migration issues at the site; and 5) use visual aids such as cross sections and conceptual models to assist with understanding contaminant fate and migration.

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APPENDIX A

NAPL PAPER

Non Aqueous Phase Liquid Transport and Migration in the Vadose and Saturated Zones

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1.0 INTRODUCTION

This paper provides an overview of the migration of organic compounds, particularly light non-aqueous phase phase liquids (LNAPLs), and their migration in the vadose zone and at the water table. In general, organic compounds in this paper refer to LNAPLs; however, some of the information presented will also apply to dense nonaqueous phase liquids (DNAPLs). The vadose zone section not only discusses topics relevant to the vadose zone but also provides a brief background about the physical and chemical properties of organic compounds that are important for their migration in both the vadose and saturated zones. The saturated zone section provides a brief overview of contaminant transport and migration of organic compounds at the water table.

1.1 Preview

Petroleum hydrocarbons and other organic compounds spilled or released at or near land surface migrate through the vadose (or unsaturated) zone and eventually may reach the water table. In the vadose zone, there are three zones of saturation. They include the pedular zone, the funicular zone, and the capillary zone. Water saturation and the nature of contaminant migration varies within each of these zones. Along the path through the vadose zone, a variety of mechanisms will either transport or retard the migration of the contaminant to the water table. Some of these include volatilization of the compound; sorption to mineral or soil particle surfaces; sorption to soil organic matter; volatilization and/or dissolution into water films or air bubbles; and biodegradation. Finally, the transporation of the organic compound will depend on the physical and chemical characteristics of the compound. Some of these include the solubility of the compound in water and air, the volatility of the compound, and the viscocity of the compound.

Movement of organic compounds at the water table and in the saturated zone depend on the physical and chemical properties of the compound, water table fluctuations, groundwater flow, and sorption processes, similar to those described for the vadose zone.

1.2 Paper Organization

This paper is organized into four sections. Section 1 provides an introduction and preview into the paper topic. Vadose zone characteristics and processes of contaminant transport and migration are presented in Section 2. Section 3 discusess the saturated zone. A summary is provided in Section 4 and References in Section 5. Figures and tables referenced in the text are attached at the end of the paper.

2.0 VADOSE ZONE

This section is organized as follows. Section 2.1 provides a brief introduction. Pressure, tension, and saturation properties are discussed in Section 2.2. Section 2.3 discusses the three water saturation zones within the vadose zone. An overview of sorption and diffusion processes is presented in Sction 2.4. Section 2.5 discusses the physical properties of organic compounds. Section 2.6 provides a detailed discussion of the gas-water and solid-water interfaces in the vadose zone. Miscellaneous other important vadose zone mechanisms such as vapor migration and biodegredation are discussed in Section 2.7.

2.1 Introduction

Non aqueous phase liquids (NAPLs) are transported, distributed and retarded in the vadose zone by various factors. VOCs are non-aqueous phase liquids (NAPLs). Some common VOCs include benzene, toluene, p-xylene, ethylbenezene, tetrachloroethylene (PCE), and trichlorethylene (TCE). Mobility of volatile organic compounds (VOCs) in the vadose zone is very dependent on the diffusion and sorption of the organic compound within the soil matrix (Steinberg and Kreamer, 1993). These are non-steady-state processes (Thoma, et al., 1999). There are four retention mechanisms that occur in the vadose zone. These include sorption to mineral surfaces, sorption to organic matter, volitilization into the gas phase, and dissolution into bulk water.

2.2 Tension, Pressure, and Saturation

The effects of interfacial tension, pressure, and saturation of the wetting and non-wetting phases are presented in the following sections.

2.2.1 Interfacial Tension

Interfacial energy exists when a liquid is in contact with another substance (Fetter, 1999). This other substance may be a solid, an immiscible liquid, or a gas. Interfacial energy is created as a result of the difference in the degree of attraction one substance has for the molecules comprising the other substance (Fetter, 1999). In a system with two immiscible liquids, the interfacial tension is an important component in determining what fluid will be the wetting liquid in the vadose zone and which will be the non-wetting fluid.

When two liquids are present in the vadose zone, one liquid will preferentially spread over, or wet, the entire solid surface (the wetting liquid), the other will remain as the non-wetting fluid and reside in the pore spaces of the porous media (Fetter, 1999). If a system is dry when the oil (NAPL) is introduced to the system, the porous media will become oil-wet; with the wetting fluid being the oil and water becoming the non-wetting fluid (Fetter, 1999). Systems are rarely oil-wet due to water that is held as pendular rings, even in soil that appears dry (Fetter, 1999).

2.2.2 Pressure

Air pressures measured above the water table will be equal to atmospheric pressure (Fetter, 1994). Fluid pressures above the water table are negative with respect to atmospheric pressure, creating tension (Fetter, 1994). This capillary pressure (or surface tension) at the air-water interface and the molecular attraction of the solid and liquid phases in the vadose zone cause an upward attraction of water molecules and other molecules at the water table (Fetter, 1994). The height of the capillary rise will depend on the pore size. Smaller pores will draw a higher capillary rise due to the increased surface tension. Larger pores will have a lower capillary rise because there is less surface tension.

2.2.3 Saturation

The fraction of the total pore space filled by a fluid is called the saturation ratio (Fetter, 1999). The total of all fluids present, including air, will add up to a total saturation of 1.0. In the vadose zone, a wetting fluid may become replaced by the non-wetting fluid. Displacement of the wetting fluid by non-wetting fluid is called drainage (Fetter, 1999). Displacement of the non-wetting fluid by the wetting fluid is called imbibition (Fetter, 1999). Residual wetting saturation, or irreducible wetting-fluid saturation, is the saturation point at which no more wetting fluid will be displaced by the nonwetting fluid (Fetter, 1999). At the point where a zero capillary pressure is reached, some of the non-wetting fluid will still remain in the pore spaces. This is called irreducible non-wetting fluid saturation, or residual non-wetting fluid saturation (Fetter, 1999). Residual saturation depends on surface tension of the oil (or non-wetting fluid) and pore size distribution (Kemblowski and Chiang, 1988). As the pore radius distribution becomes more narrow, the less the residual oil saturation (Kemblowski and Chiang, 1988).

The irreducible wetting fluid (water) is greatest close to the water table, where the most negative capillary pressures exist; the irreducible non-wetting fluid is shown to be in greater abundance in the higher zones of the vadose zone, where there is less capillary pressure and where it has displaced more of the wetting fluid. During drainage of the wetting fluid and advancement of the non-wetting fluid, there is an increase in the capillary pressure (Gvirtzman and Roberts, 1991).

Figure 1 shows the percent water saturation distribution for various zones from the land surface to the saturated zone. According to Cole (1994), the vadose zone contains 20 to 60 percent water saturation, the capillary zone contains 60 to 80 percent water saturation, the water table fluctuation zone contains 60 to 100 percent water saturation and the saturated zone is 100 percent saturated.

2.3 Water Saturation Zones within the Vadose Zone

The vadose zone is comprised of three zones of varying water saturation. Figure 1 provides an overview of percent water saturation for the vadose zone and capillary zone. Cole (1994) indicates the upper vadose zone contains 20 to 60 percent saturation and the lower portion of the vadose zone (capillary zone) is 60 to 80 percent saturated.

The three zones within the vadose zone include the pendular zone, funicular zone, and insular or capillary zone (Gvirtzman and Roberts, 1991 and Hoag and Marley, 1986). The position of the free liquid surface (saturated zone) will determine the vapor pressures in the porous media and also the types of saturation zones present in the vadose zone. The capillary zone is the portion of the capillary fringe that is saturated (Gvirtzman and Roberts, 1991). In some systems, the funicular zone may be absent (Hoag and Marley, 1986).

2.3.1 Pendular Zone

The pedular zone is the driest and upper most zone within the vadose zone. This zone is characterized by very low water content. Thin films of water coat the grains of the porous media due to the hydrophilic properties of the solid (Gvirtzman and Roberts, 1991). Therefore, this zone is still considered water wet (Fetter, 1999). Because of the low water content and high surface tension on the grains, water does not flow in the pendular zone. The wetting liquid in this zone is retained as isolated masses (Gvirtzman and Roberts, 1991 and Hoag and Marley, 1986) and the remaining void space is filled either by air or the non-wetting liquid (NAPL or organic compound).

Each mass is in the form of pendular rings (figure 2) around the tangent points of spheres (Gvirtzman and Roberts, 1991), at the grain contact points in the porous media (Fetter, 1999). The wetting fluid accumulates in this fashion, under equilibrium conditions, because it is the form that requires minimum surface energy (Gvirtzman and Roberts, 1991). The shapes of the air-liquid interfaces are convex, toward the contact points (Hoag and Marley, 1986). The curvature of the ring will depend upon the equilibrium vapor pressure with the surrounding vapor pressure of the system (Hoag and Marley, 1986). In addition, pendular rings that become isolated are still connected to the bulk water phase by mass transfer through the vapor phase (Gvirtzman and Roberts, 1991). This may occur when the pendular rings around grain contact points are spatially uneven at some equal height above the free liquid (capillary zone). The system will then come into equilibrium through mass transfer between the vapor phase and liquid phase (Gvirtzman and Roberts, 1991). The size of the pendular rings varies from zero to a maximum size where they meet each other. A zero case scenario is where only the non-wetting fluid fills the pores (Gvirtzman and Roberts, 1991). In addition, the curvature of the pendular ring air-liquid interface is proportional to the height above the free liquid zone (Hoag and Marley, 1986). Therefore, the curvature of the pendular ring will increase (sharpen) as the amount of liquid in the pendular ring decreases which is proportional to the distance of the pendular ring above the free liquid surface (Hoag and Marley, 1986). In other words, the pendular rings will be sharper higher in the system (close to land surface) than those at depth in the system.

Finally, the residual saturation (the amount of the compound remaining in the system) of the organic compound in the pendular zone of the vadose zone will dictate if the organic compound will reach the water table and the amount that reaches the water table (Hoag and Marley, 1986).

2.3.2 Funicular Zone

The funicular zone is characterized by a gradual increase in the size of the pendular rings. The pendular rings increase in size until they unite and fuse into more complicated masses or ganglia (Gvirtzman and Roberts, 1991 and Hoag and Marley, 1986). Ganglia (or ganglion) are described as nodular blobs of a non-wetting phase that occupies at least one void space and generally several adjoining chambers of the void space (Gvirtzman and Roberts, 1991). Figure 3 shows some examples of ganglia produced during a study performed by Conrad, et al. (1992). Spherical ganglia may form in cases where the non-wetting phase loses its continuity between adjacent chambers (Gvirtzman and Roberts, 1991). This may occur as pendular rings of the wetting fluid merge and cut off the ganglia "arms." Ganglia trapped by the wetting phase in this manner are spherical and immobile (Gvirtzman and Roberts, 1991). The funicular zone may not always be present in the vadose zone. The system may move directly from the pendular zone to the capillary zone.

2.3.3 Capillary (Insular) Zone

The ganglia of the funicular zone continue to merge until a capillary surface is formed (Hoag and Marley, 1986). These coalesced ganglia form the capillary surface. The capillary zone, the lowest portion of the capillary fringe, is the portion of the capillary fringe that is water saturated (Gvirtzman and Roberts, 1991). The capillary fringe is not a regular surface and the capillary rise will be different across the surface depending on the interconnectedness and size of the pore spaces (Fetter, 1999). LNAPLs may migrate through the vadose zone and accumulate on top of the capillary zone, creating an "oil table" (Fetter, 1999), where the pores are saturated with NAPL. If a sufficient amount of LNAPL accumulates, the water capillary zone may disappear and the "oil table" will rest on top of the water table (Fetter, 1999).

2.4 Sorption and Diffusion Processes

The following sections provide an overview of sorption and diffustion processes that occur in the vadose zone. Section 2.7 provides a more detailed discussion focusing on the air-water (gas-water) and solid-water interfaces.

2.4.1 Sorption

Sorption includes the processes of adsorption, absorption, chemisorption, and ion exchange (Fetter, 1999). Adsorption is the process by which a solute sticks to or clings to the surface of a solid particle. Absorption occurs when a solute can diffuse onto or into a particle (Fetter, 1999), such as, into the structure of soil organic matter or into the structure of a clay mineral. Chemisorption is the process by which a solute is incorporated onto the surface of soil particles, sediment or rock through chemical reactions (Fetter, 1999). Ion exchange is the process by which ions are attracted to a positively or negatively charged surface and held there by electrostatic forces (Fetter, 1999). For example, a cation may be attracted to the negative charge of a clay mineral surface.

One of the most important factors controlling the mobility and distribution of VOCs in the unsaturated zone is vapor-phase sorption (Pennell, et al., 1992 and Steinberg and Kreamer, 1993) and diffusion of the VOCs within the porous media (Steinberg and Kreamer, 1993). Vapor-phase sorption is the process by which VOC vapors sorb to soil organic matter, adsorbed water films, mineral surfaces and soil particles, and at the air-water interface (Conklin, et al, 1995; Pennell, et al, 1992; and Thoma, et al, 1999). The degree to which these mechanisms will be important in a system depends primarily upon the soil moisture content (relative soil humidity), the vapor pressure and solubility of the organic compound, and the surface area and organic carbon content of the porous media (Pennell, et al, 1992). In addition, the hydrophobicity (see Section 2.5.5) of the organic compound controls the amount of that compound that may accumulate in the vadose zone by the various sorption processes (Conklin, et al, 1995 and Kohl, et al, 2000).

2.4.2 Diffusion

Diffusion is also an important transport mechanism in the vadose zone. Diffusion is the process by which a solute will migrate from an area of greater concentration toward an area of lower concentration (Fetter, 1999). It is controlled by chemical interactions between the organic compound and the porous media, physical properties of the chemical and porous media, and the environmental conditions in the vadose zone (Thoma, et al., 1999). Vapor phase migration of volatilized organic compounds may occur in the vadose zone due to atmospheric pressure gradients (Fetter, 1999).

2.5 Physical Properties of Organic Compounds

The most important physical properties of petroleum hydrocarbons (organic compounds) include volatility, solubility in water, specific gravity and viscosity (Cole, 1994). An evaluation of these properties will aid in determining how the compound will be found and migrate in the environment. In addition, the octanol-water partition coefficient, Henry's Law constant, and/or the water-air partition coefficient may be used to evaluate the nature of the compound in the environment.

2.5.1 Volatility

The volatility of a substance is defined as the tendency of a substance to transfer to or from a solid or liquid phase to and from the gaseous phase (Fetter, 1999, Cole, 1994 and

Schwarzenbach, et al., 1993). The higher the vapor pressure is of the compound, the more volatile the compound (Fetter, 1999). A compound described as highly volatile is one that vaporizes or transfers easily to or from the gas phase (Cole, 1994). At a given vapor pressure, the lower molecular weight compounds will show much less interfacial adsorption, more volatility, than the higher molecular weight compounds (Costanza and Brusseau, 2000). An example of a highly volatile compound is gasoline. Diesel fuel and oil have low vapor pressure values and are; therefore, less volatile.

Vapor density is related to the equilibrium vapor pressure of a compound (Fetter, 1999). Vapor density indicates whether a gas will rise or sink in the atmosphere (Fetter, 1999). If the vapor density is lighter than air it will rise and vice versa.

The boiling point of a compound is related to vapor pressure. A compound with a high vapor pressure will have a low boiling point and vice versa (Cole, 1994). Figure 4 shows the relationship between vapor pressure and boiling point for selected alkane group of organic compounds. Figure 5 shows the boiling point distribution of common petroleum hydrocarbon products. In addition, the melting point of the compound is useful to determine if a compound will be solid or liquid. If the temperature in the system is below the melting point of the compound, the compound will be in the solid phase (Fetter, 1999). Table 1 provides volatility values for some common petroleum hydrocarbons.

2.5.2 Solubility

The aqueous solubility of a compound is a measure of how much an organic compound prefers to be present as a solute in water (Schwarzenbach, et al., 1993). The higher the aqueous solubility number or value of the compound, the more likely the compound is to dissolve in water. Figure 6 shows some common organic compounds and their ranges of solubility in water. The solubility of a gas must be measured at a given vapor pressure (Fetter, 1999). The solubility of a liquid is a function of the temperature of the water and nature of the compound (Fetter, 1999). Lighter molecular weight compounds are more soluble in water than heavier molecular weight compounds (Cole, 1994).

2.5.3 Viscosity

Viscosity is the measure of the resistance of a substance to flow due to gravity (Cole, 1994). The viscosity will indicate the speed of movement of a compound through the porous media (Cole, 1994). The higher the viscosity, the slower it will move; the lower the viscosity, the faster it will move. Figure 7 provides a summary of different groups of petroleum hydrocarbon and their relative viscosity and volatility to one another. The figure indicates that compounds that are more volatile have lower viscosity. In general, the more volatile a component, the faster it will move.

2.5.4 Henry's Law Constant and Water-Air Partition Coefficients

Henry's Law constant (K_H) is the ratio of the amount of a compound in the gas phase to the amount of the compound in the water phase (Schwarzenbach, et al., 1993). High K_H values indicate that a compound would move more easily from the water phase into the gas phase (Schwarzenbach, et al., 1993). Figure 8 shows the ranges in Henry's Law constant for some common organic compounds.

Water-air partition coefficients are also used to express the amount of a compound partitioned between the water phase versus the gas phase. It is the ratio of the aqueous solubility of a substance to the saturated vapor concentration of the substance (Fetter, 1999). In this case, a compound with a high water-air partition coefficient will partition or dissolve into the water phase more readily than it will partition into the gas phase (Fetter, 1999). For example, gasoline compounds (i.e., benzene, a component of gasoline) may infiltrate via dissolution and collect at the water table even though no gasoline reaches the water table (Fetter, 1999).

2.5.5 Octanol-Water Partition Coefficient

The octanol-water partition coefficient is a measure of the degree to which an organic compound will dissolve between two immiscible liquids (Fetter, 1999 and Schwarzenbach, et al., 1993). The organic compound is mixed with equal amounts of water and an organic solvent (octanol). The higher the octanol-water partition coefficient (K_{ow}), the less mobile the compound tends to be in the environment (Fetter, 1999). Figure 9 shows the K_{ow} range of values for some common organic compounds.

2.5.6 Hydrophobic versus Hydrophillic

A hydrophilic compound is one that has an affinity for or likes water (Bates and Jackson, 1987). Organic compounds may be adsorbed onto solid surfaces due to hydrophobiciy (Fetter, 1999). A hydrophobic compound is one that lacks an affinity for water or is "water hating" (Bates and Jackson, 1984 and Schwarzenbach, et al., 1993). Hydrophobic compounds vary in polarity and are electrically neutral (Fetter, 1999). As chain lengths of the organic compound increases, surface tension decreases due to the increased hydrophobic surface area in contact with the water (Costanza and Brusseau, 2000). The solubility of an organic molecule is affected by the degree to which the organic compound is attracted by polar water molecules which is also dependent on the polarity of the organic compound (Fetter, 1999). While some hydrophobic compounds dissolve in water, they have low solubilities. Hydrophobic compounds generally adsorb to organic material, if present, in the porous media and to a lesser extent to mineral surfaces (Fetter, 1999).

2.6 Gas-Water and Solid-Water Interfaces

The following sections describe the interactions that occur between organic compounds and the air, water, and solids present in the vadose zone.

2.6.1 Gas-Water (Air-Water) Interface

Petroleum hydrocarbon compounds may adsorb not only at the air-water interface but may also dissolve into adsorbed water films coating the soil particles of the porous media (Pennell, et al, 1992). The determining factor controlling how much of a compound is in each phase (air/gas or water) is dependent on the physical and chemical characteristics of the compound. These physical and chemical characteristics are measured using the octanol-water partition coefficient, Henry's Law constant or water-air partition coefficient, and/or the organic compounds solubility in water (Section 2.5).

Weakly polar solutes may become simultaneously adsorbed at the air-water interface and dissolved into the liquid phase of water films coating the porous media (Pennell, et al., 1992). The dissolution of organic vapors into adsorbed water films increases as the solubility and volatility of the VOC increases (Hoff, et al., 1993). That is, the more likely the VOC is to dissolve in water, the more likely it will sorb onto and into water coatings on the porous media. Lower molecular weight compounds are more volatile (Costanza and Brusseau, 2000). Because the lower molecular weight compounds are more volatile, they will be more saturated in the system. Therefore, more gas molecule collisions will occur and there will a greater probability these molecules will be come adsorbed in water.

Adsorbed water films comprise a large surface area to volume ratio; therefore, adsorption at the air-water interface may be a significant contributor to the sorption of organic compound vapors in the vadose zone (Pennell, et al., 1992). Hence, water films may compose a larger portion of the total sorbed VOCs, especially in soils with a low organic matter content (Pennell, 1993, Costanza and Brusseau, 2000). Volitilization and dissolution are strongly controlled by the gas-water interfacial area (Costanza and Brusseau, 2000). Vapor diffusion rates are typically much faster than aqueous diffusion rates; consequently, the larger the air interfacial area to water ratio, the greater the mass transfer rates between the air-water interface (Costanza and Brusseau, 2000).

Gas phase organic compounds, as well as, colloidal particles participate in air-water mass transfer in the vadose zone. Colloids are particles 1 nm to 10 µm in size (Wan and Wilson, 1994). Contaminant mobility may be enhanced by the adsorption or organic and inorganic molecules to mobile colloids in the vadose zone (Wan and Wilson, 1994). In a study conducted by Wan and Wilson (1994), colloids were found to be sorbed at the air-water interface on air bubbles. Wan and Wilson (1994), suggest the preferential sorption of colloid particles at the gas-water inferface as a mechanism for vadose zone transport of organic compounds.

2.6.2 Solid-Water Interface

Water has been shown to drastically inhibit the sorption of VOCs by the porous media (Steinberg and Kreamer, 1993). In porous media lacking water, the sorption of organic compounds by soil is mainly by adsorption of the compound onto the surfaces of the porous media. Organic compounds may sorb onto mineral surfaces or partition into soil organic matter (Pennell, et al, 1992). Colloid particles (less than 2 µm in size) are also important solid surfaces and may include clay minerals and organic matter (Fetter, 1999).

Hydrated soils act as sorbents for organic compounds in which soil organic matter functions as a partition medium and other soil surfaces function as absorbents (Pennell, et al., 1992). In soils where the water content is sufficiently low or absent, partially hydrated mineral surfaces are primarily responsible for sorption (Hoff, et al., 1993a and Smith, et al., 1990). Therefore, adsorption of organic compounds by mineral surfaces in water-saturated soils in close proximity to the water table will be insignificant (Smith, et al., 1990). In general, soil organic matter is the primary sorption mechanism in systems with high water content; sorption to mineral surfaces dominates in very low water content soils (Costanza and Brusseau, 2000). A combination of these two mechanisms will be present in systems with intermediate water content (Costanza and Brusseau, 2000).

Soil Organic Matter

According to Kohl, et al. (2000), soil organic matter is a critical control in the fate and transport of nonpolar organic compounds (i.e., polynuclear aromatic hydrocarbons (PAHs) and polychlorinated biphenyls(PCBs)) in the environment. Soil organic matter may be present as dissolved macromolecules, coatings on inorganic colloids, or organic particulates (Herbert, et al, 1993). Herbert, et al (1993) states that soil organic matter is the most important material to facilitate the transport of organic compounds. The effectiveness of soil organic matter to transport organic compounds depends on the concentration of soil organic matter in the soil solution, their stability as mobile particulates in the soil solution, their mobility through the vadose zone, and the degree to which they interact with the organic compound (Herbert, et al, 1993). In some instances, the organic compounds may become permanently bound to soil organic matter, even after a very brief contact period, creating bound organic compound residuals (Kohl, et al, 2000). In addition, organic compounds may not only adsorb to the surfaces of the soil organic matter but also dissolve and become distributed within the structure of the soil organic matter (absorption) which is controlled by the compounds solubility in water (Kohl, et al, 2000).

In a study performed on Woodburn soil for 12 aromatic hydrocarbons, the extent of the organic compounds insolubility in water was shown to be the primary factor controlling the partitioning of the compound into soil organic matter (Chiou, et al, 1983). In addition, soil organic matter in high humidity/hydrated soils has been suggested as the dominant mechanism for vapor-phase adsorption for some compounds (Pennell, et al, 1992 and Steinberg and Kreamer, 1993). Studies have shown that, a strong inverse relationship between relative humidity and the sorption of organic compounds on soil and organic matter exist in the vadose zone (Pennell, et al., 1993; Steinberg and Kreamer, 1993; and Thoma, et al., 1999). That is, as relative humidity in the porous media increases, sorption of organic compounds to the porous media and other soil constituents decreases. In general, as the relative humidity in soil increases, water strongly competes with organic compounds and vapors for the soil mineral adsorption sites. This results in a decrease or suppression of VOC sorption on these surfaces (Pennell, et al, 1993; Steinberg and Kreamer, 1993; and Chiou, et al, 1983). Therefore, soil organic matter may be the more dominant adsorption site for organic vapors and compounds in higher humidity soils (Chiou, et al, 1983; Steinberg and Kreamer, 1993; and Pennell, et al, 1993). However, the relationship between humidity and increases in sorbed organic compounds into soil organic matter may not always be the case, especially in low orgainic matter soils (Pennell, et al, 1993). In this case, sorption to other solid surfaces or interaction at the air-water interface may play the more important role.

Other Solid Surfaces

Other solid surfaces such as sand grains and clay minerals will also sorb organic compounds. When the water films become too thin solid surfaces may become exposed to the air. This will increase the sorptive capacity of the soil (Hoff, et al., 1993b). This will expose highly sorptive clay mineral sites and other soil surfaces (Hoff, et al., 1993b).

2.7 Other Important Vadose Zone Mechanisms

The following sections discuss volitilization and biodegradation of organic compounds in the vadose zone.

2.7.1 Volitilization

Volitilization is a diffusion-driven process (Lahvis, et al., 1999). Vapor or gas phase movement of volatilized organic compounds that do not sorb to the gas-water or solid-water interface may also occur in the vadose zone. In this case, the volatilized organic compound is in the gas phase and may be transported by diffusion through the porous media of the vadose zone under air pressure gradients as atmospheric pressure fluctuates (Fetter, 1999). Organic compounds with high vapor pressure are likely to volatilize and be transported in this manner (Kostecki and Calabrese, 1989). These vapors may migrate vertically and/or laterally and collect in sewer lines, basements, utility corridors (Kostecki and Calabrese, 1989). Potential fire or explosion hazards may be created in these instances. Not only do these vapors present a problem in physical structures, they vapors may also migrate to the surface and affect surface water and agricultural crops in the immediate vicinity of the soil containing the organic compound (Kostecki and Calabrese, 1989).

2.7.2 Biodegradation

Degradation is the process of an organic compound becoming smaller or broken down by chemical or biological means (Fetter, 1999). Organic compounds are substrates for microbial growth (Fetter, 1999). The substrate is an energy source for the microbes. The microbes adhere to solid surfaces in the porous media and form a biofilm (Fetter, 1999). Aerobic degradation is the process of biodegradation in which microbes need oxygen in their metabolism (Fetter, 1999). Anaerobic biodegradation occurs where little or no oxygen is needed for microbial metabolism.

Aerobic biodegradation and volatilization of organic compounds near the water table are mechanisms for mass removal of organic compounds from groundwater (Lahvis, et al., 1999). As aerobic biodegradation proceeds in the vadose zone, a concentration gradient is created. The concentration gradient, in turn, increases the volatilization (a diffusion driven process) of organic compounds (Lahvis, et al., 1999). In addition, aerobic biodegradation rates near the water table have been shown to exceed biodegradation rates higher in the unsaturated zone by an order of magnitude (Lahvis, et al., 1999). Biodegradation can also prevent vertical diffusion of organic compounds into the unsaturated zone (Lahvis, et al., 1999).

The rate of biodegradation is site specific. The rate of biodegradation may be affected by the hydrocarbon substrate, electron acceptor, nutrient availability, hydrogeology, biomass concentration, temperature, and pH (Lahvis and Baehr, 1996). In the field, biodegradation is typically monitored by measuring the changes in the concentrations of oxygen and carbon dioxide in the subsurface (Lahvis and Baehr, 1996; Lahvis, et al., 1999; and Suchomel, et al., 1990). Figure 10 provides an example of the chemical and biological processes occurring in the vadose zone and saturated zone. The vadose zone shows a decrease in oxygen content moving from land surface to the saturated zone. In Figure 10 Above the capillary zone, there is an increase in carbon dioxide content. In this study, biodegradation activity was reported as occurring in the capillary fringe, just above the water table (Lahvis and Baehr, 1996).

3.0 SATURATED ZONE

This section discusses the migration of organic contaminants at and near the water table. Section 3.1 provides a brief introduction. Section 3.2 discusses the important physical properties of organic compounds at the water table. Sorption, diffusion, and dispersion mechanisms are presented in Section 3.3. Section 3.4 and 3.5 briefly discus biodegradation and colloid transport in a saturated system, respectively. Finally, Section 3.6 discusses the migration of organic compounds near the water table.

3.1 Introduction

Organic compounds, such as gasoline, spilled at or near the land surface migrate through the vadose zone and may eventually encounter the water table. Compounds that are less dense than water (LNAPLs) will float on the top of the water table, those that are more dense (dense NAPLs or DNAPLs) will sink to the bottom of the aquifer (Gvirtzman and Roberts, 1991).

3.2 Physical Properties of Organic Compounds

As discussed above in Section 2.5, physical properties and ways to evaluate a compounds migration in the environment will also be important for their movement in the saturated zone. The most important physical properties of petroleum hydrocarbons (organic compounds) include volatility, solubility in water, specific gravity and viscosity (Cole, 1994). In addition, mechanisms to evaluate how the compound will migrate in the environment must also consider the octano-water partition coefficient, Henry's Law constant, or the water-air partition coefficients. In example, the gasoline compound of BTEX (benzene-toluene-ethylbenzene-xylene) contains four organic compounds that will migrate at different velocities in groundwater (Alvarez, et al., 1998). Benzene is more soluble in water than xylene; therefore, benzene will migrate faster in groundwater than xylene.

3.3 Sorption, Diffusion, and Dispersion

Section 2.5 discusses sorption and diffusion processes in the vadose zone. These processes, along with advection and mechanical dispersion, are also important in the saturated zone.

3.3.1 Advection

Advection is the process in which dissolved solids (solutes) are carried along with flowing groundwater (Fetter, 1999 and Mackay, et al., 1985). It is the dominant factor of the migration of dissolved contaminants in sand and gravel aquifers (Mackay, et al., 1985). The amount of solute carried in the flowing groundwater is a function of the quantity of groundwater flowing and the concentration of the solute in the groundwater (Fetter, 1999).

3.3.2 Diffusion and Dispersion

The spreading of solutes from an area of high concentration to low concentration is called diffusion (see Section 2.5). Mechanical dispersion is the process by which mixing or spreading of the solute with groundwater occurs along flow paths in the porous media (Fetter, 1999 and Mackay, et al., 1985). There are two types of mechanical dispersion, longitudinal dispersion and transverse dispersion. Longitudinal dispersion is the mixing that occurs along the direction of the flow path (Fetter, 1999). Transverse dispersion is the mixing that occurs in a direction normal to the flow path (Fetter, 1999). Spreading of solutes in groundwater is believed to be proportional to the rate of groundwater flow and is also dependent on the structure of the porous medium of the aquifer (Mackay, et al., 1985). Dispersion in the longitudinal direction is greater than dispersion in the transverse directions (Mackay, et al., 1985). Hydrodynamic dispersion considers the mixing that occurs due to both diffusion and dispersion in the flowing groundwater (Fetter, 1999).

3.3.3 Sorption

Sorption in the saturated zone occurs by the same processes as the vadose zone (see Section 2.5). Solutes flowing along groundwater paths may interact with the aquifer materials. These interactions include adsorption, absorption, chemisorption, and ion exchange (Fetter, 1999 and Mackay, et al., 1985). Solute migration may be retarded and concentrations of the solute may be evident as more solute interactions take place (Mackay, et al., 1985). Interactions of the solute with the aquifer materials depend on the characteristics of the solute (solubility, hydrophobicity, etc.), the solute concentration, the pH of the groundwater, and the presence of other dissolved components (Mackay, et al., 1985).

3.3.4 Air-water Interface

The air-water interface in the saturated zone is limited to gas bubbles in the system. Sorption of organic compounds at this air-water interface may occur in the saturated zone. Gas bubbles in the saturated zone may be produced by: 1) the entrapment of air during water table fluctuations, 2) generation of gas bubbles due to aqueous phase pressure decreases, and 3) organic and biogenic activities (Wan and Wilson, 1994). Organic compounds may sorb to the the air bubbles in the saturated zone (Wan and Wilson, 1994 and Hoff, et al, 1993).

3.3.5 Solid-Water Interface

Solid-water sorption interfaces are present in the saturated zone as solid soil and mineral surfaces and soil organic matter. Like the vadose zone (see Section 2.6.2), soil organic matter is the dominant sink for organic compounds in saturated systems (Fetter, 1999). In systems, where soil organic matter is less than one percent of the soil or aquifer on a weight basis, then soil or mineral surfaces will be the dominant sorption site (Fetter, 1999).

3.4 Biodegradation

Biodegradation will also take place in the saturated zone. As discussed in Section 2.7.2, biodegradation includes aerobic and anaerobic forms of biodegradation. Aerobic biodegradation takes place with microbes that require oxygen in their metabolism. In both aerobic and anerobic biodegradation, hydrocarbons or other organic compounds are consumed and used as energy sources by the microbes (Fetter, 1999). Biodegradation may retard the migration of organic compounds in the vadose zone.

3.5 Collids

Colloids are particles with diameters less than 1 μm in size. These include dissolved organic macromolecules (i.e., humic substances or microorganisms – viruses and bacteria), and mineral matter (Fetter, 1999). Dissolved solutes may sorb to the surfaces of colloids. As mentioned previously, some colloids are small enough to sorb to air or gas bubbles and be transported in the vadose and saturated zones. Colloids may also be transported by groundwater flow through the porous media (Fetter, 1999). Transport of colloids in groundwater may be affected by groundwater flow velocity, the size and nature of the colloid, the geometry of the pores of the porous media, and the quantity of colloids (Fetter, 1999). Colloids may enhance the transport capability of an organic compounds. For example, a hydrophobic compound may sorb to the colloid and the colloid transported through the aquifer. Therefore, some compounds may migrate farther or along different paths due to sorption to colloids.

3.6 Organic Compound Migration Near the Water Table

The following sections provide a brief introduction to contaminant migration in Section 3.6.1. hydrocarbon behavior in groundwater is discussed in Section 3.6.2, and a more detailed discussion of hydrocarbon migration from the vadose zone to the water table in Section 3.6.3.

3.6.1 Introduction

Once an organic compound, such as gasoline, is released to the land surface, it begins to migrate through the vadose zone. A release of organic liquid at the land surface will eventually reach the capillary zone (Conrad, et al., 1992). This organic liquid will reach the water table if the water table is shallow or the volume of the liquid released is great enough. During this migration, the mass of hydrocarbon penetrates as a distinct phase through the vadose zone, it will partially dissolve or sorb to the solid-water and air-water interfaces (Gvirtzman and Roberts, 1991). Section 2.2 discusses the three zones of the vadose zone (or unsaturated zone). These include the Pendular Zone, the Funicular Zone, and Capillary Zone. Section 2 provides a detailed discussion of the processes occurring in the vadose zone during contaminant migration. Eventually, the capacity of the vadose zone to retain the hydrocarbon will be exceeded; thus, the hydrocarbon will reach the water table (Gvirtzman and Roberts, 1991). Figure 11 is a diagram showing the migration of an organic compound to the water table.

3.6.2 Forces Controlling Hydrocarbon Behavior

The three major forces controlling organic liquid behavior in groundwater include: capillary forces, viscous forces, and gravity or buoyancy forces (Conrad, et al., 1992). The interaction between cohesive forces between each compound and the adhesive forces between the solid phase and each compound is the capillary force (Conrad, et al., 1992). The capillary force is proportional to the strength of the fluid wetting the solid surface and to the interfacial tension (see Section 2.2) at the fluid-fluid interface (Conrad, et al., 1992). The capillary force is inversely proportional to the pore size of the porous media (Conrad, et al., 1992). Viscosity forces are proportional to the pressure gradient and permeability within the porous media. Buoyancy, a gravitational force, is proportional to the density difference between the fluids in the groundwater (Conrad, et al., 1992). Capillary forces are typically the dominant of the three forces (Conrad, et al., 1992). The effects of these forces are further discussed in Section 3.6.3.

3.6.3 Hydrocarbon Migration

The following sections describe the downward and lateral migration of LNAPLs in the capillary zone and at the water table.

Downward Migration

Seepage of the hydrocarbon comprises the first stage in contaminant migration. After the hydrocarbon is introduced to the ground surface, it will migrate downward. Man-made conduits (i.e., utility or foundation) may affect the migration of the contaminant (Cole, 1989 and Stringer, 1992). Two zones of spreading occur during seepage of the hydrocarbon. In the center of the hydrocarbon plume in the vadose zone is the oil core (Figure 11). The oil core consists of oil flowing due to gravitational forces and flow is described by Darcy's Law (Stringer, 1992). The oil core is surrounded by the oil wetting zone (or oil capillary zone) (Stringer, 1992). The spreading shape of the oil depends on the hydraulic conductivity, the rate of infiltration, and capillary forces (Stringer, 1992). The spreading shape will be different as it encounters different hydraulic conductivity zones. For example, the vertical migration of hydrocarbons will be faster in gravel and slower through sand, silt, and clay units. The lateral migration of hydrocarbons is also affected by the lithology.

Lateral Migration

Lateral spreading of the hydrocarbon in the vadose zone and saturated zone will occur as different lithologies are encountered. As mentioned above, hydrocarbons will travel faster through gravel where the interstitial forces are less and slower through finer grained zones where interstitial forces are greater. For example, hydrocarbon migration in gravel may have straighter path than if sand or clay layers are encountered as it migrates downward. The sand and clay layers may cause lateral spreading due to the decreased hydraulic conductivity and permeability of the unit.

If there is a sufficient volume of hydrocarbon, it will continue to migrate downward until it reaches the capillary fringe. At the capillary fringe, there is sufficient water saturation to decrease the flow of the hydrocarbon at the leading edge (Stringer, 1992). At this point, a pressure mound builds (Conrad, et al., 1992 and Stringer, 1992). Eventually, the mound will build to the point at which lateral spreading will occur due to capillary forces (Figure 11; Conrad, et al., 1992 and Stringer, 1992). At this point, only slow vertical penetration will continue and the hydrocarbon may temporarily infiltrate below the water table (Stringer, 1992). Eventually, the pressure mound will flatten and lateral spreading and distribution continue, but more slowly, as the volume of hydrocarbon flowing to the area decreases (Conrad, et al., 1992 and Stringer, 1992). The spreading portion of the hydrocarbon is referred to as a "pancake." The thickness of the pancake is approximately the same thickness as the capillary fringe (Stringer, 1992). Spreading stops when the oil reaches residual saturation. LNAPL migration, is influenced by interfacial and capillary forces in the later stages (Stringer, 1992).

Finally, the hydraulic gradient of the aquifer will influence the movement of hydrocarbons. This stage is referred to as the immobilization stage (Stringer, 1992). At this stage, hydrocarbons will move in the direction of groundwater flow. The movement is at a rate that is slightly less than the flow of the underlying groundwater (Stringer, 1992). The rate of movement is dependent on the density of the hydrocarbon.

Water Table Fluctuation Effects

Water table fluctuations will continue to spread the LNAPLs. At the water table and capillary zone, natural fluctuations in the water table cause "smearing" and redistribution of the organic compound (Figure 11 and 12;Lahvis, et al., 1999). In the "smear zone" organic compounds may dissolve in groundwater, volatilize and diffuse through the vadose zone, sorb to aquifer sediments and soil organic matter, or undergo chemical and biological reactions (Lahvis, et al., 1999). These water fluctuations will widen the pancake vertically and; therefore, increases the amount that will be retained in the unsaturated zone (Stringer, 1992). Water table fluctuations through the "smear zone" creates a situation where the porous media is sometimes saturated during rises in water level to a situation where the porous media becomes water wet during lowering in water level (see Section 2.2). Residual hydrocarbons (residual hydrocarbon fluid saturation) will also remain in the capillary fringe due to water table fluctuations (Conrad, et al., 1992). Residual hydrocarbon may be dissolved by the passing groundwater even though the compound may be immiscible in water (Conrad, et al., 1992). The residual hydrocarbons trapped in the "smear zone" and capillary zone often contribute the major volume of the hydrocarbon pollution in a system (Conrad, et al., 1992).

Hydrocarbons will rise with a rising water table but at a slower rate than the water table. Therefore, these hydrocarbons become trapped below the water table at insular residual saturation (Stringer, 1992). As the water table falls below the level of the trapped hydrocarbon, the water saturation decreases and the hydrocarbons remobilized (Stringer, 1992). The above is an explanation for the reappearance of hydrocarbons in a well after long absences of them (Stringer, 1992). The trapping of hydrocarbons in water wet porous media, which had been previously saturated media (i.e., the "smear zone"), is explained by the effects of capillary forces (see Section 3.6.2). These trapped hydrocarbons, residual, are typically in the form of immobilized ganglia and become separated from the main body of hydrocarbon (Conrad, et al., 1992). These residual hydrocarbons are also referred to as the residual non-wetting fluid saturation (Conrad, et al., 1992).

Figure 12 presents a diagram of hydrocarbon contaminant distribution in the various zones. According to the figure, residual hydrocarbons are present in the vadose zone. In the capillary zone, free liquid hydrocarbon and adsorbed hydrocarbons are present. In the water table fluctuation zone, hydrocarbons may be sorbed to soil material or are present as ganglia. In the saturated zone, dissolved hydrocarbons are present along with some trapped hydrocarbons (probably small ganglia).

4.0 SUMMARY

This paper provided an overview of some of the major components of NAPL transport and migration in the vadose zone and at the water table. Tension, pressure and the degree of saturation in the vadose zone play an important role in the retention and transport of NAPLs. The amount of tension, pressure, and saturation in the system will affect how water and NAPLs will be found in the system, either as wetting or non-wetting fluids and the abundance of these substances within the vadose zone at various distances below surface in the system. There are three saturation zones in the vadose zone. Each zone is characterized by the moisture content and configuration of the wetting and non-wetting fluids in the porous media. Within these zones, a variety of processes occur that enhance or inhibit NAPL migration. These include sorption and diffusion processes. Sorption is one of the most important factors controlling the mobility and distribution of VOCs in the vadose zone. Diffusion also plays a role NAPL migration in the vadose zone and may occur due to atmospheric pressure gradients. However, the degree to which these processes will control migration will depend on the physical and chemical properties of both the contaminant and the porous media. The physical and chemical properties include volatility, solubility, hydrophobicity, and viscosity of the NAPL. Some physical and chemical properties of the vadose zone that may affect contaminant transport include sorption of the compound into air bubbles or pendular rings at the air-water interface and to mineral surfaces and soil organic matter at the solid-water interface. Volatilization and biodegredation are also important factors in the migration and retardation of NAPLs in the vadose zone. These two may work together to degrade and retard NAPLs in the vadose zone.

In the saturated zone, the same physical and chemical properties of the NAPLs along with sorption, diffusion, dispersion (including advection) will help determine their fate in the system. Interactions with air bubbles at the air-water interface and colloidal material may enhance contaminant transport in the system. Sorption at the solid-water interface and biodegradation may help to retard the migration of the NAPL in the system. Once an LNAPL is introduced at the surface, it will migrate downward. Spreading will occur due to gravitational forces and may spread unevenly depending on the rate of infiltration, capillary forces, and as the LNAPL encounters porous media of differing hydraulic conductivities. If the volume of LNAPL is sufficient enough, it will continue to migrate vertically until it reaches the capillary fringe. The LNAPL will begin to slow due to an increase in water saturation. A mound will begin to build, vertical migration will slow, and eventually lateral spreading will occur and form a "pancake," and the LNAPL may temporarily infiltrate below the water table. LNAPL will then become transported at a rate dependent on groundwater flow velocity and hydraulic conductivity of the porous media.

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TABLE I

Product	Volatility (at 70°F in psia)	Flashpoint		Flammability Limits % by vol.	
		in °C	in °F	LFL[5]	UFL
Gasoline[1]	4 – 8	-30 – -43	-36 – -45	1.4	7.6
Benzene	1.6	-11	12	1.3	7.9
Toluene	1.9	4	40	1.2	7.1
Ethylbenzene	2.2	18	68	—	—
Xylenes[2]	2	27	81	1.1	7.0
n-Hexane	1.5	-40	-40	1.2	7.1
JP–4 Jet Fuel	1.6	-10 – +35	-22 – +95	—[3]	—[3]
Diesel	0.009	40 – 65	100 – 130	1.3[4]	6.0[4]
Kerosene	0.011	40 – 75	100 – 160	1.4	6.0
Light Fuel Oil #1 and #2	$<10^{-3}$	40 – 100	100 – 200	—[4]	—[4]
Heavy Fuel Oil #4, #5, and #6	$<10^{-3}$	65 – 130	140 – 270	1.0	5.0
Lubricating Oil	$<10^{-3}$	150 – 225	300 – 450	—[4]	—[4]
Used Oil	$<10^{-3}$	>100	>200	—[4]	—[4]

[1] Values vary slightly depending on grade.

[2] Value is for m–xylene.

[3] Similar to gasoline.

[4] Relatively nonflammable, NFPA = 2.

[5] LFL is Lower Flammability Limit; UFL is Upper Flammability Limit.

(Cole, 1994)

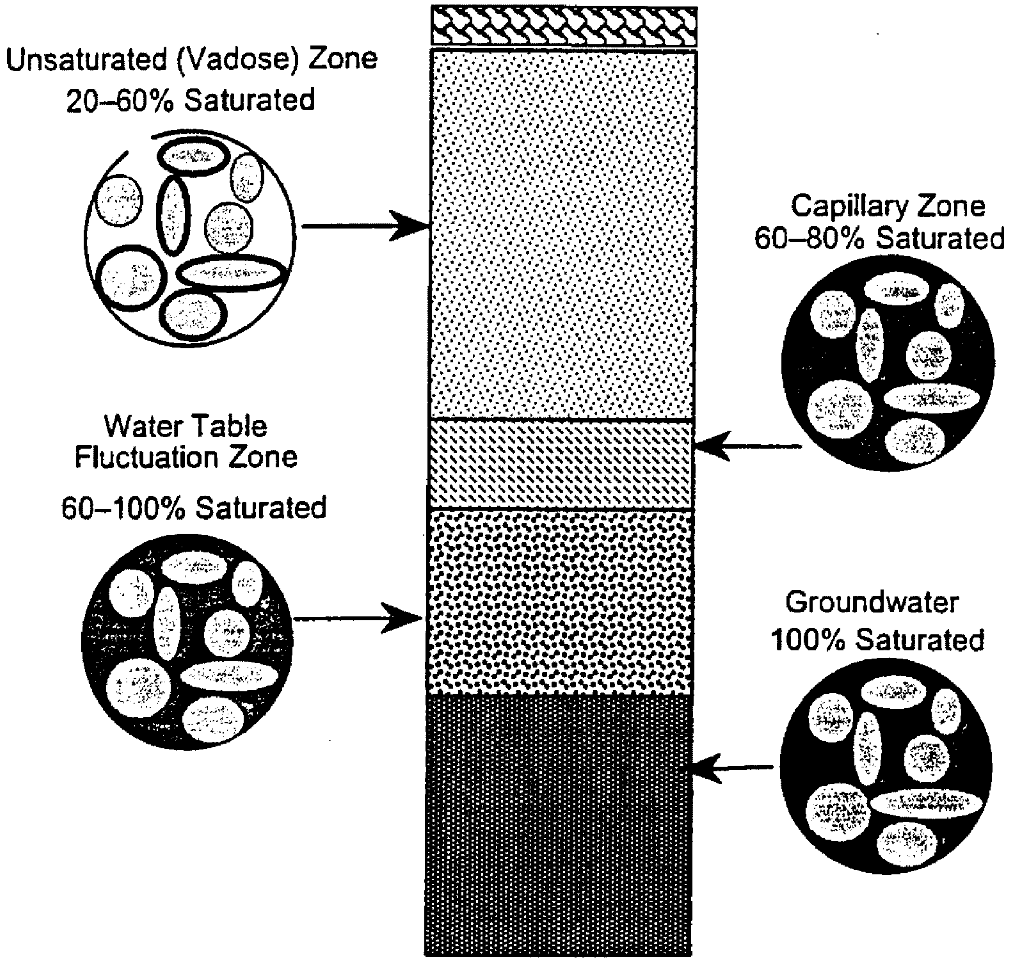


Figure 1 Generalized Soil Column in Microview. A microscopic view of soil particles and phases indicates that soil moisture in the vadose zone is largely confined to an aqueous layer surrounding the particles. The interstitial pore spaces in this zone are filled with air. The aqueous layer and the vapor spaces are important since the majority of microbial action is carried out in the region. The capillary zone is partially saturated with bulk water mostly on the surface of soil particles. The fluctuation zone is mostly saturated with bulk liquid phase interstitial water. There are no interstitial vapor spaces left in the saturated zone. Consequently this region is largely anaerobic.

(Cole, 1994)

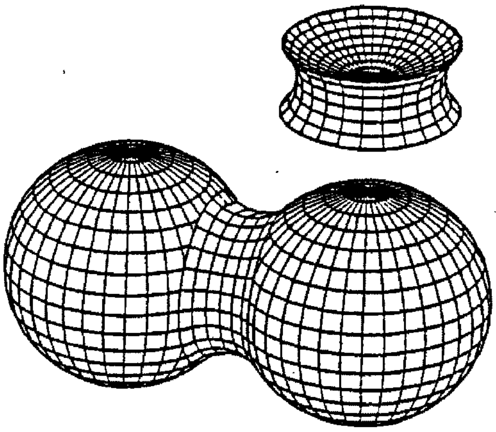


Fig. 2 A pendular ring between two spheres and another one isolated from the bounding solids.

(Gvirtzman and Roberts, 1991)

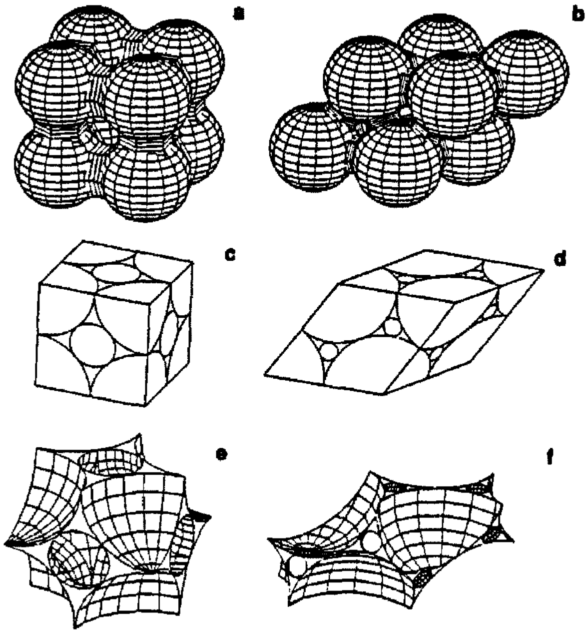


Fig. 2 (*a*) Cubic and (*b*) rhombohedral packings of identical spheres with wetting and nonwetting fluids filling the void space. (*c*) and (*d*) Unit cells and (*e*) and (*f*) unit voids for both packing arrangements are also shown. The pendular rings are drawn at their maximum size for a contact angle of zero.

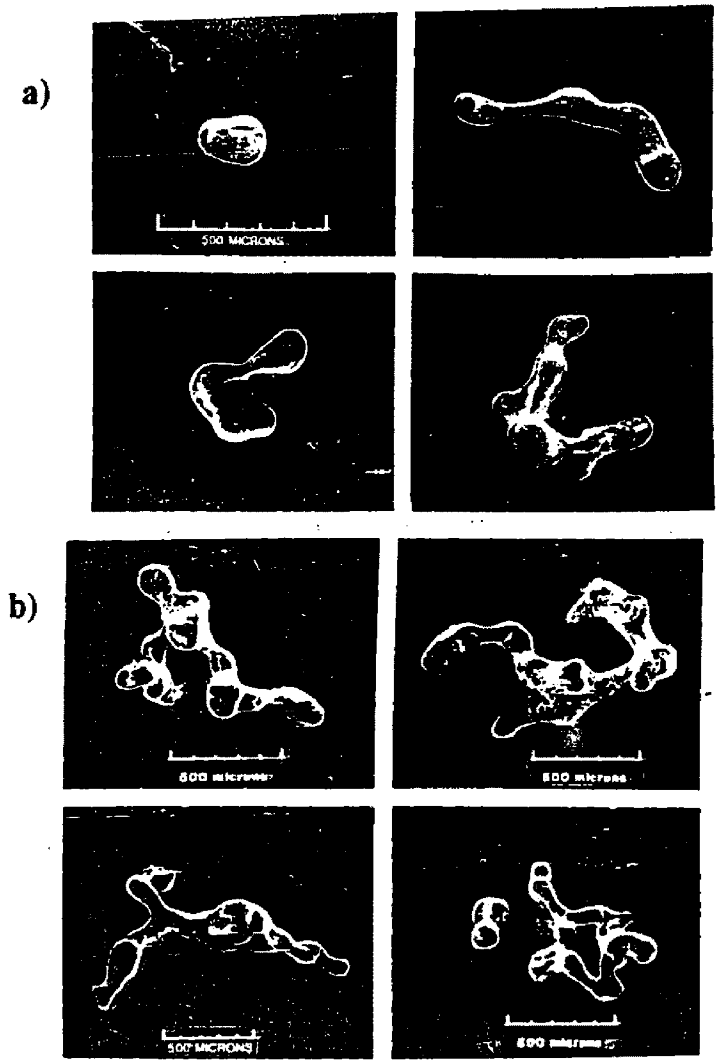


Fig. 3 SEM photomicrographs of blob casts from Sevilleta sand column. (*a*) Some relatively simple blob shapes. (*b*) Larger, more complex, branching blobs.

(Conrad, et al., 1992)

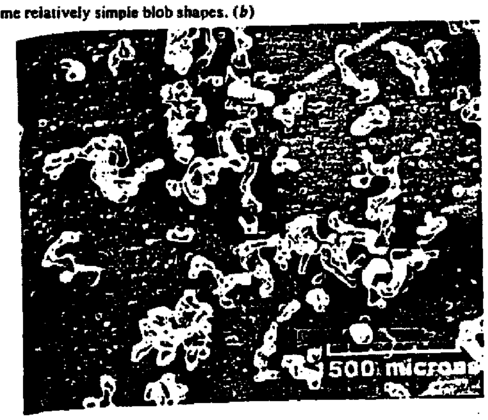


Fig. 3 SEM photomicrograph of many blob casts from the Sevilleta sand.

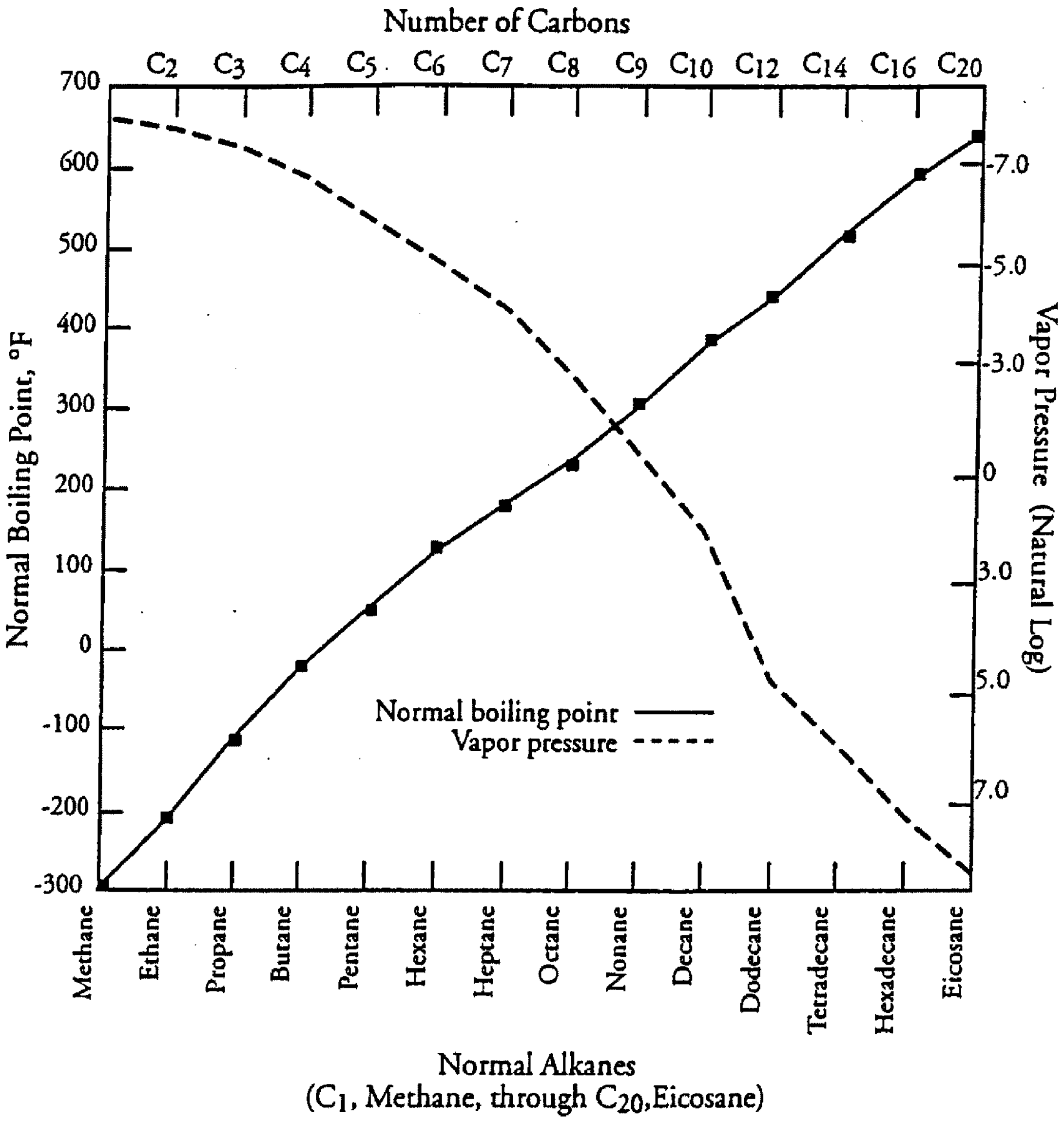


Figure 4 *. Volatility of Selected Alkanes. The normal (at 1 atmosphere) boiling point (solid line) and vapor pressure (at 20°C, dotted line) for several representative hydrocarbons are shown. Boiling points increase as the vapor pressure decreases. A higher vapor pressure corresponds to higher volatility and indicates an increased tendency to exist in the vapor phase in porous soils. For compounds having molecular weights greater than decane, C_{10}, the vapor pressure is too low for significant vapors to exist at ambient temperatures.*

(Cole, 1994)

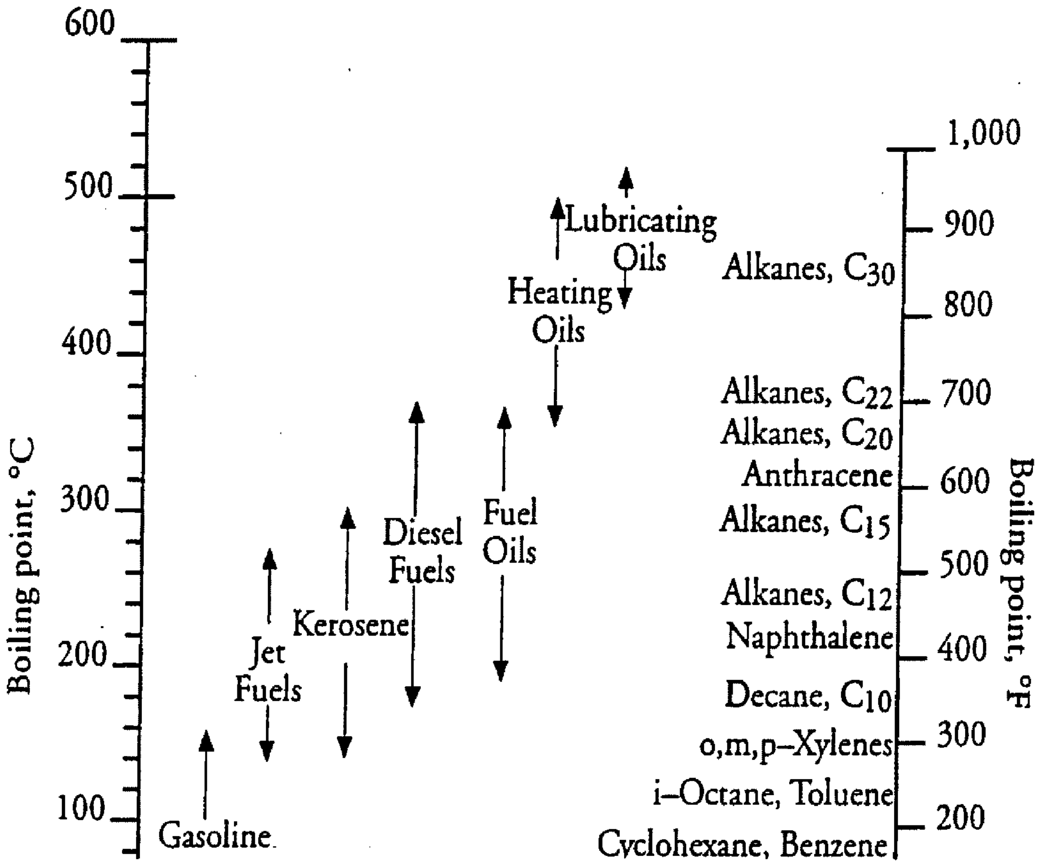


Figure 5 . Boiling Point Distribution of Petroleum Products. Boiling point ranges for representative petroleum products are shown. Since boiling points are inversely proportional to vapor pressures (volatility), the ranges also reflect relative volatilities. Gasoline is in a class by itself. Jet fuel, diesel, and other kerosene derivatives form a group; similarly lubricating and fuel oils have extremely low vapor pressures.

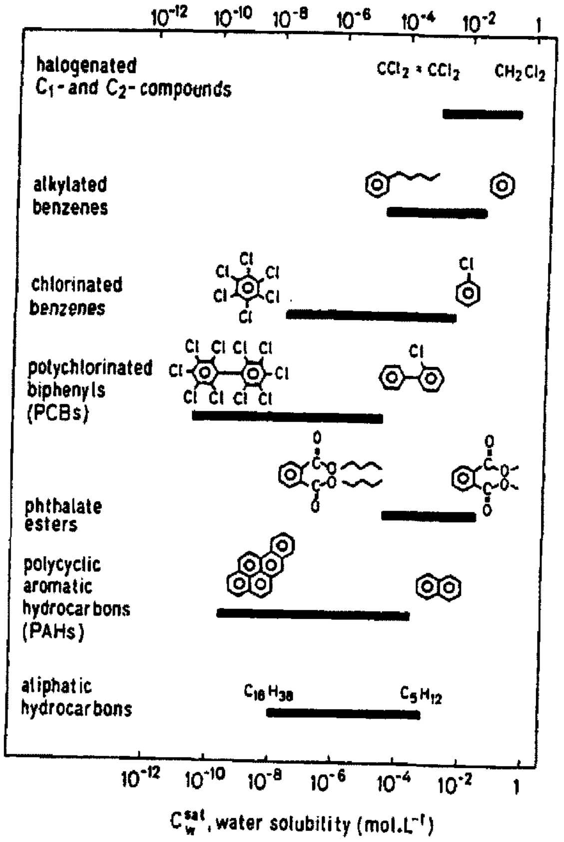


Figure 6 Ranges in water solubilities (C_w^{sat}) of some important classes of organic compounds.

(Schwartenbach, et. al., 1993)

Group I	Group II	Group III	Group IV
Gasoline Aviation Gasoline Naphthas (All types) Gas Turbine Fuel Oil, #0-GT	Jet Fuel A, A-1, B Kerosene Fuel Oil #1 Diesel Fuel #1D Gas Turbine Fuel Oil, #1-GT	Fuel Oil #2, #4 Diesel Fuel #2D, #4D Gas Turbine Fuel Oil, #2-GT	Fuel Oil #5, #6 Gas Turbine Fuel Oil, #2-GT Lubricating Oils

Low Kinematic Viscosity (Fastest movers) → High Kinematic Viscosity (Slowest movers)

Highest Vapor Pressure (Most volatile) → Lowest Vapor Pressure (Least volatile)

Figure 7 *Kinematic Viscosity. Schematic representation of the relative kinematic viscosity of representative petroleum products. The higher the kinematic viscosity, the faster the product can be expected to move through soils. Only the products of Groups I and II migrate rapidly enough to be considered "free flowing." Group I products can migrate rapidly enough to warrant aggressive response. The products of Groups III and IV are essentially immobile in all soil types.*

(Cole, 1994)

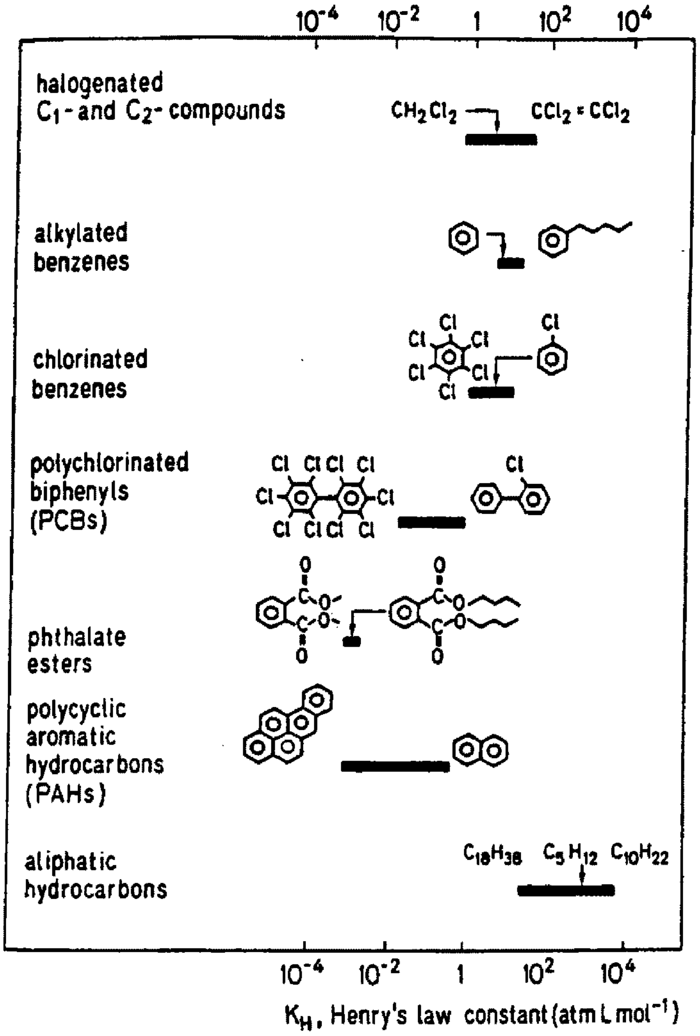


Figure 8 Ranges in Henry's Law constants (K_H) for some important classes of organic compounds.

(Schwarzenbach, et al, 1993)

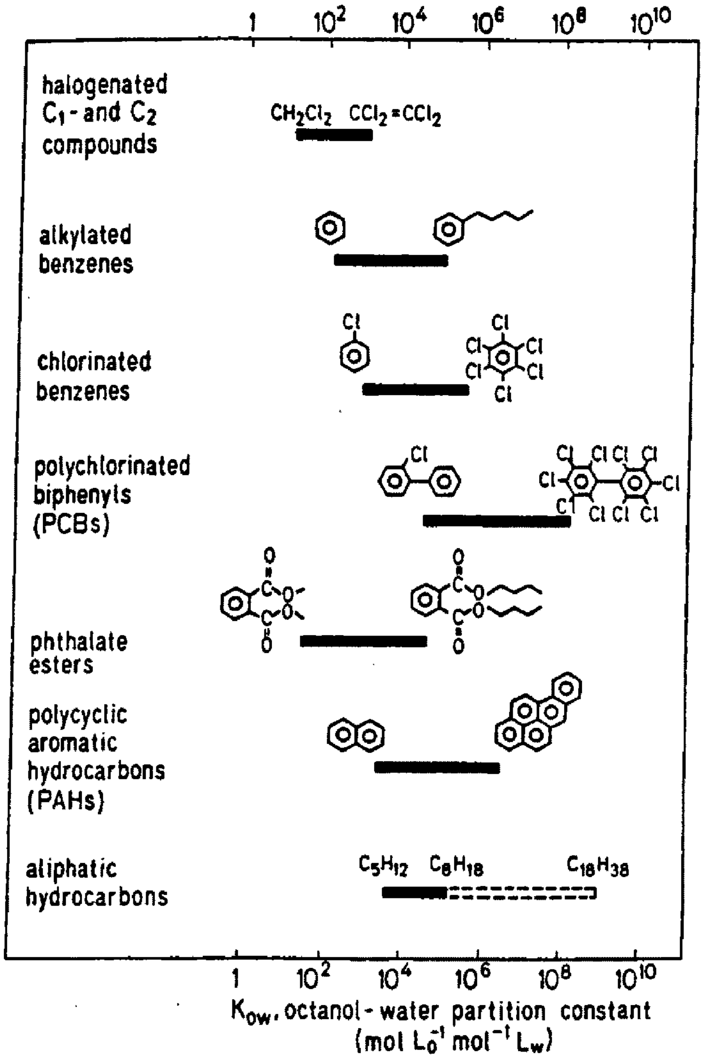


Figure 9 Ranges in octanol–water partition constants (K_{ow}) for some important classes of organic compounds (Schwarzenbach, et al, 1993)

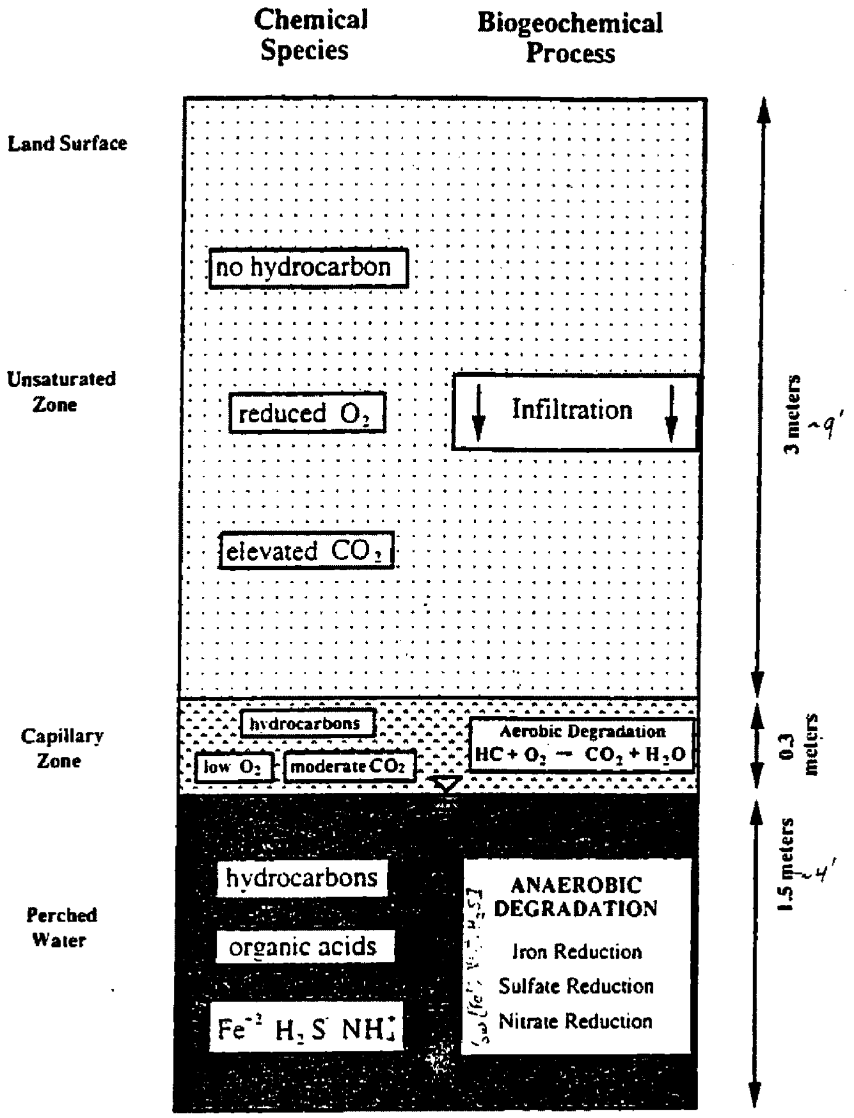


Figure 10 Conceptualization of biogeochemical processes and their distribution in the subsurface at Galloway Township, New Jersey, December 1990. (Lahavis and Baehr, 1996)

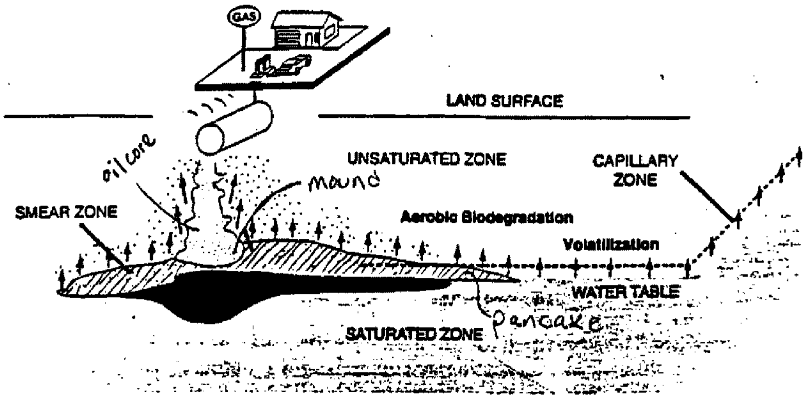


Figure 11 Conceptualization of natural attenuation remediation at a petroleum product spill site.

(Lahvis, et al., 1999)

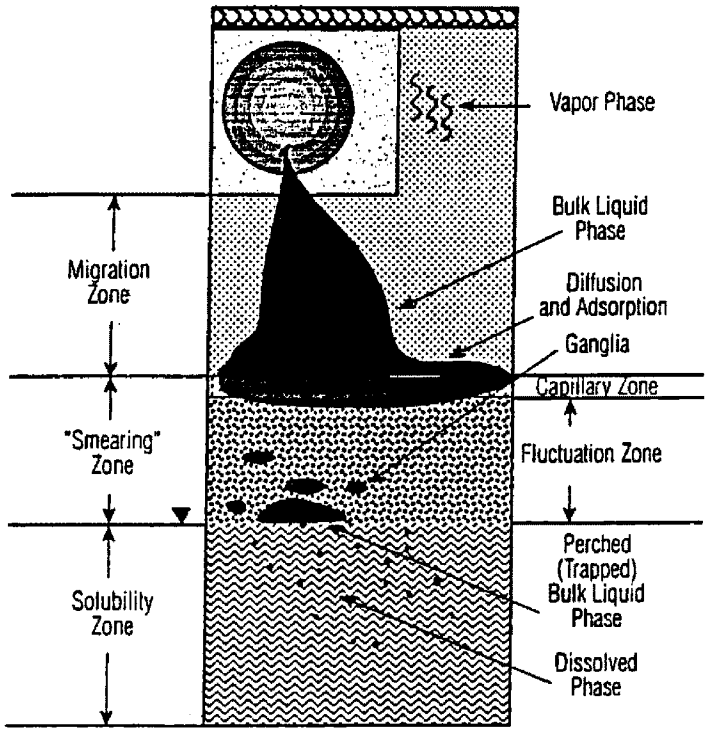


Figure 12 Distribution of Hydrocarbon Phases in Soils. Petroleum hydrocarbons tend to partition among soil particles, vapor, the aqueous phase, and a bulk hydrocarbon phase. In the unsaturated or vadose zone the open pore spaces among soil particles allow volatile contaminants to vaporize. Vapors will migrate through a loose, porous soil, but remain trapped in a tighter, more dense soil. In the saturated zone water is the primary bulk phase and contamination is normally limited to dissolved hydrocarbons or to trapped, dispersed bulk hydrocarbons. In the intermediate zones hydrocarbons can migrate during dryer periods when the zone is drained and less than 100% saturated. During periods when the water table rises hydrocarbons become trapped since water migrates much faster than bulk liquid phase hydrocarbons.

(Cole, 1994)

APPENDIX B

PHOTOGRAPHS

(See Compact Disk)

APPENDIX C

BORING AND WELL LOGS

Rotosonic Drilling Method

Difficulty drilling included auger refusal and auger abandonment in one hole at the Site. In addition, split spoon sampling was performed at 5-foot intervals during previous investigations. This sampling method may not have provided good sample recovery for geologic logging or analytical sampling due to the coarse subsurface materials. The air rotary drilling method was not chosen for use during the remedial investigation due to the disturbed nature of cuttings returned to the surface for logging purposes. In addition, subsurface sampling during air rotary drilling using a split spoon encounters the same limitations as with split spoon sampling during hollow-stem auger drilling. These and other methods may not always yield the best data and/or may not be the most effective methods for subsurface investigations (Barrow, 1994).

Detailed Core Logging

Each core was logged in detail as follows: 1) the Unified Soil Classification System (USCS) was used for consistency to record physical features of the subsurface sediments encountered; 2) a sand gauge was used to provide consistency while logging sand sized material; 3) a Munsel® Soil Colors Chart was used to record the general color of the subsurface sediments encountered; 4) the relative moisture content of the subsurface sediments was noted; and 5) a qualitative estimate description of the percent gravel versus the percent of sand and fines was made throughout each core. The USCS is a logging system commonly used in the environmental consulting and engineering fields to describe subsurface materials (and soil) encountered during drilling or excavation. It is used to provide consistency while logging characteristics of subsurface samples.

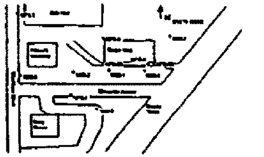
LOG OF BORING MFG-B1

(Page 1 of 4)

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198



LOG OF BORING MFG-B1

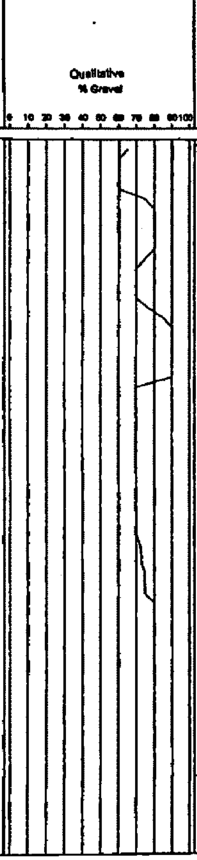
(Page 1 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotasonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotasonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 68.5 feet bgs

Start/Complete Date : 4-4-01 / 4-4-01
Boring/Well Location : Livingston Ave, adj. to BQ
Approx. Surface Elev. : 3182.2 Feet AMSL
Measuring Point Elev. : 3181.86 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3182.2	DESCRIPTION	USCS	Samples	PID (ppm)
0	3182	Asphalt			
1	3181	SANDY GRAVEL, brown (10YR 4/3), gravel up to 3/4- inch size,fine to coarse sand, dry to slightly moist. Fill.		1	1.2
2	3180	SANDY GRAVEL, very dark brown (7.5YR 2.5/3), rounded to subrounded gravel up to 2-inch size, fine to medium sand, few coarse sand, some silt, slightly moist. Grades to brown (7.5YR 5/3), gravel and cobbles up to 4-inch size, decrease in sand content, fine to medium sand, some coarse sand.			
3	3179			2	
4	3178	As above. Lots of broken cobbles, medium to coarse sand, few very coarse sand, few to some fine sand.			7.3
5	3177			3	
6	3176	As above.			2.2
7	3175			4	
8	3174	As above. Gravel size decreasing, two cobbles up to 3.5-inch size, gravel up to 2-inch size, sand as above.			2.0
9	3173		GW		
10	3172			5	
11	3171	As above. One cobble 4-inch size, gravel up to 2.5-inch size, sand as above.			2.5
12	3170			6	
13	3169	SANDY GRAVEL, brown (7.5YR 4/4), one cobble 4-inch size, remainder of gravel up to 2-inch size, increase in gravel up to 3/4-inch size, slightly moist.			2.5
14	3168			7	
15	3167	As above. Gravel up to 2.5-inch size, fine to medium sand, few coarse and very coarse sand.			3.8
16	3166			8	
17	3165	As above. Some gravel up to 3-inch size, one broken cobble 4-inch size.			4.5
18				9	

Qualitative % Gravel



REMARKS

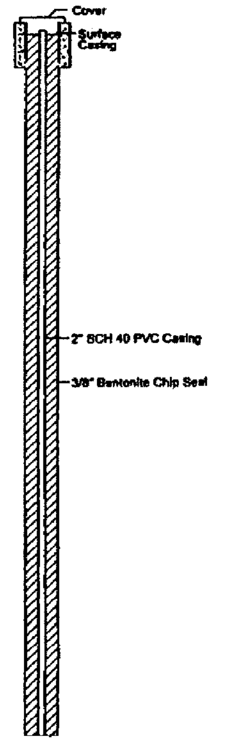
PID readings were collected with a Photovac Photoionization Detector calibrated with 100 ppm isobutylene gas.

PID readings were collected at the bottom of each core interval.

GW = Gravel and cobbles.
GP = Gravel up to 2-inch size and no cobbles.

Throughout core gravel is rounded to occasionally subrounded; sand ranges from rounded to slightly subangular.

Well: MFG-1
Elev.: 3181.86 Ft AMSL



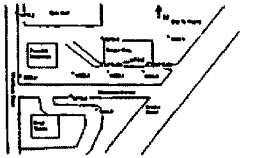
LOG OF BORING MFG-B1

(Page 2 of 4)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis   University of Montana, Missoula   Spring 2002

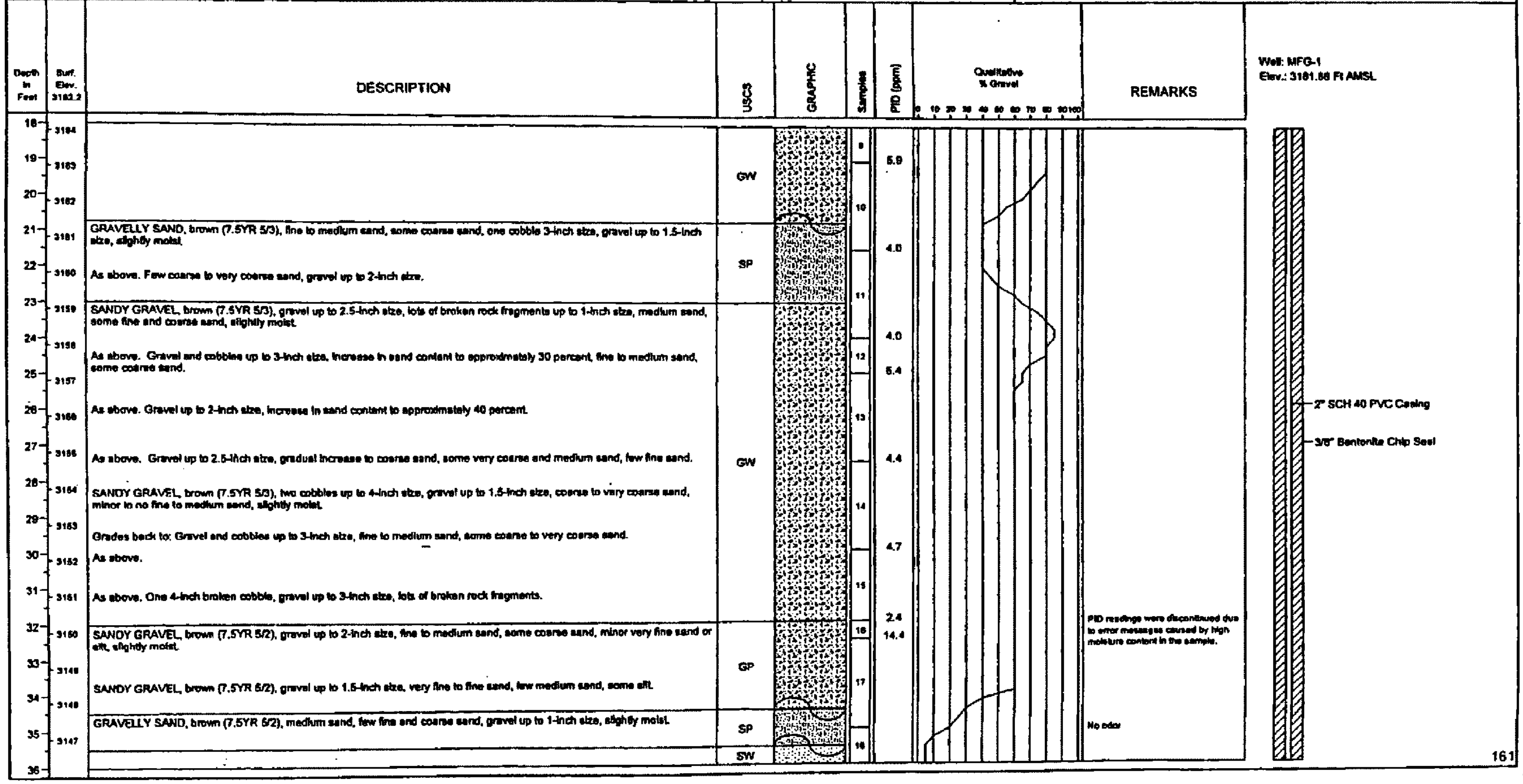


LOG OF BORING MFG-B1

(Page 2 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotasonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotasonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 64.5 feet bgs

Start/Complete Date : 4-4-01 / 4-4-01
Boring/Well Location : Livingston Ave. adj. to DQ
Approx. Surface Elev. : 3162.2 Feet AMSL
Measuring Point Elev. : 3161.88 Feet AMSL
Logged By : Natalie Morrow



Depth in Feet	Surf. Elev. 3162.2	DESCRIPTION	USCS	Samples	PID (ppm)	REMARKS
18	3164		GW	9		
19	3163				5.9	
20	3162			10		
21	3161	GRAVELLY SAND, brown (7.5YR 5/3), fine to medium sand, some coarse sand, one cobble 3-inch size, gravel up to 1.5-inch size, slightly moist.	SP		4.0	
22	3160	As above. Few coarse to very coarse sand, gravel up to 2-inch size.				
23	3159	SANDY GRAVEL, brown (7.5YR 5/3), gravel up to 2.5-inch size, lots of broken rock fragments up to 1-inch size, medium sand, some fine and coarse sand, slightly moist.	GW	11		
24	3158	As above. Gravel and cobbles up to 3-inch size, increase in sand content to approximately 30 percent, fine to medium sand, some coarse sand.			4.0	
25	3157			12	5.4	
26	3156	As above. Gravel up to 2-inch size, increase in sand content to approximately 40 percent.		13		
27	3155	As above. Gravel up to 2.5-inch size, gradual increase to coarse sand, some very coarse and medium sand, few fine sand.			4.4	
28	3154	SANDY GRAVEL, brown (7.5YR 5/3), two cobbles up to 4-inch size, gravel up to 1.5-inch size, coarse to very coarse sand, minor to no fine to medium sand, slightly moist.		14		
29	3153	Grades back to: Gravel and cobbles up to 3-inch size, fine to medium sand, some coarse to very coarse sand.			4.7	
30	3152	As above.		15		
31	3151	As above. One 4-inch broken cobble, gravel up to 3-inch size, lots of broken rock fragments.				
32	3150	SANDY GRAVEL, brown (7.5YR 5/2), gravel up to 2-inch size, fine to medium sand, some coarse sand, minor very fine sand or silt, slightly moist.	GP	16	2.4 14.4	PID readings were discontinued due to error messages caused by high moisture content in the sample.
33	3149	SANDY GRAVEL, brown (7.5YR 6/2), gravel up to 1.5-inch size, very fine to fine sand, few medium sand, some silt.		17		
34	3148	GRAVELLY SAND, brown (7.5YR 6/2), medium sand, few fine and coarse sand, gravel up to 1-inch size, slightly moist.	SP			
35	3147		SW	18		No odor
36						

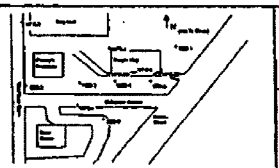
LOG OF BORING MFG-B1

(Page 3 of 4)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2196

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002



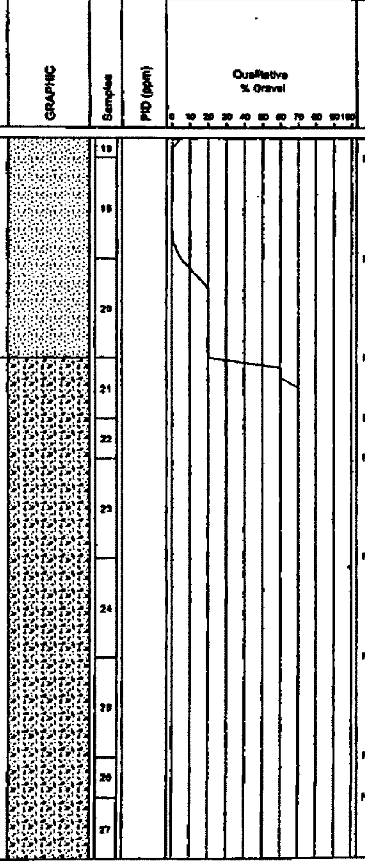
LOG OF BORING MFG-B1

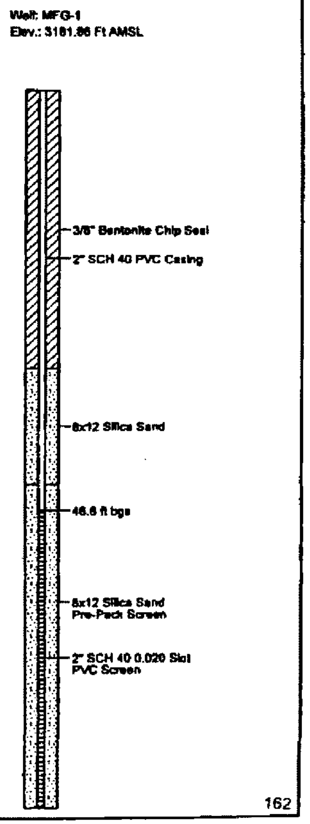
(Page 3 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 68.5 feet bgs

Start/Complete Date : 4-4-01 / 4-4-01
Boring/Well Location : Livingston Ave. adj. to DQ
Approx. Surface Elev. : 3182.2 Feet AMSL
Measuring Point Elev. : 3181.86 Feet AMSL
Logged By : Natalie Morrow

Depth In Feet	Surf. Elev. 3182.2	DESCRIPTION	USCS	Samples	REMARKS
36	3146	SAND, brown (7.5YR 5/2), medium sand, slightly moist.		18	No odor.
37	3145				
38	3144	As above with some coarse sand and very few gravel up to 1/4-inch size.		19	
39	3143		SW		No odor.
40	3142	As above, medium to coarse sand, gravel up to 2-inch size.		20	
41	3141				No odor.
42	3140	SANDY GRAVEL, brown (7.5YR 5/2), gravel up to 1.5-inch size, grades to gravel and cobbles up to 3-inch size, one cobble core 4-inch size, lots of broken rock fragments, medium to coarse sand, slightly moist. As above. Cobbles up to 4-inch size.		21	
43	3139	As above. Gravel up to 3.5-inch size, most gravel up to 2-inch size. Lots of pea gravel.		22	No odor.
44	3138	As above. Gravel up to 2.5-inch size, medium to very coarse sand.			No odor.
45	3137			23	
46	3136				No odor.
47	3135	As above.			
48	3134		GW	24	
49	3133	As above. Broken rock fragments up to 1.5-inch size.			No odor.
50	3132			25	
51	3131	As above. Very moist to wet.			No odor.
52	3130			26	No odor.
53	3129	As above. Slightly moist to moist.		27	
54					





LOG OF BORING MFG-B1

(Page 4 of 4)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
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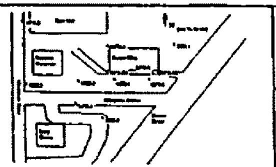
Natalie J. Morrow
Geology, M.S. Thesis   University of Montana, Missoula   Spring 2002



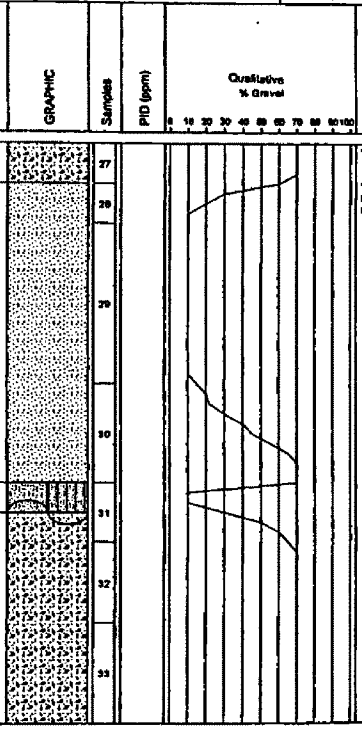
LOG OF BORING MFG-B1

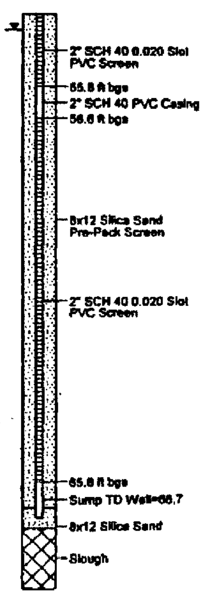
(Page 4 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 68.5 feet bgs

Start/Complete Date : 4-4-01 / 4-4-01
Boring/Well Location : Livingston Ave, adj. to DO
Approx. Surface Elev. : 3182.2 Feet AMSL
Measuring Point Elev. : 3181.86 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3182.2	DESCRIPTION	USCS	Samples	REMARKS
54	3128	SANDY GRAVEL, brown (7.5YR 6/2), gravel up to 1.5-inch size, grades to gravel and cobbles up to 3-inch size, one cobble core 4-inch size, lots of broken rock fragments, medium to coarse sand, slightly moist.	GW	27	Water first encountered between 54.2 feet bgs. Capillary fringe/ water table Sample: MFG-B1(55') No odor.
55	3127	GRAVELLY SAND, dark grayish brown (10YR 4/2), fine to coarse sand, minor silt, one cobble up to 5.5-inch size, few gravel up to 1.5-inch size, saturated.	SW	28	
56	3126				
57	3125				
58	3124	As above.		29	
59	3123				
60	3122	As above. Increase in size and abundance of gravel up to 2.5-inch size, on cobble 4.5-inch size.			
61	3121	Gravel as above, medium to coarse sand, fairly clean sand and gravel.		30	
62	3120				
63	3119	GRAVELLY SILTY SAND, fine to very fine sand, few very coarse sand, some silt, few gravel up to 3/4-inch size, saturated, fairly clean sand. Gradual decrease in sand content.	SP-SM	31	
64	3118	SANDY GRAVEL, dark grayish brown (10YR 4/2), gravel up to 2.5-inch size, fine to very fine sand, few medium and coarse sand, some silt, saturated.	GW		
65	3117	As above. Gravel up to 3-inch size, medium to very coarse sand, fairly clean sand and gravel.		32	
66	3116	As above. Cobbles up to 4-inch size, most gravel up to 1-inch size, medium to coarse sand.			
67	3115	As above.		33	
68	3114				
69	3113	Total depth of borehole = 68.5 feet below ground surface.			
70	3112				
71	3111				
72					





LOG OF BORING MFG-B2

(Page 1 of 7)

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Release# 2196

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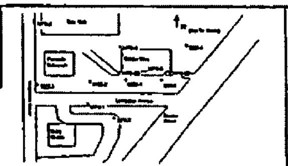
Geology, M.S. Thesis University of Montana, Missoula Spring 2002



LOG OF BORING MFG-B2

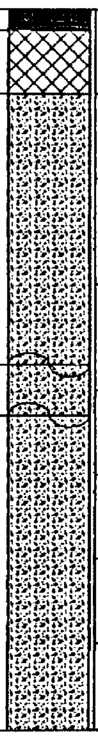
(Page 1 of 7)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Core
Total Depth of Borehole 115 feet bgs

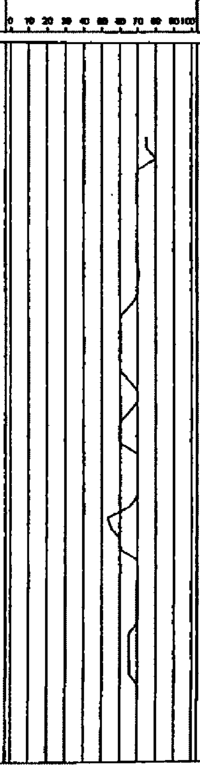
Start/Complete Date : 4-4-01 / 4-6-01
Boring/Well Location : Near 2404 Washburn
Approx. Surface Elev. : 3180.5 Feet AMSL
Measuring Point Elev. : 3180.01 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3180.5	DESCRIPTION	USCS	Samples	PID (ppm)	SIEVE ANALYSIS CUTTINGS % Fine	% Med.	% Coarse
0		Asphalt.						
	3180	Fill. No recovery		1				
1								
	3179							
2		SANDY GRAVEL, dark brown (7.5YR 3/4), gravel up to 2-inch size, fine to medium sand, some coarse sand, minor organics (roots), slightly moist to moist.						
	3178							
3				2		2.3	17.5	80.2
	3177							
4		As above. Gravel and cobbles up to 3.5-inch size, few coarse sand, slightly moist.			3.2			
	3176							
5			GW					
	3175			3		3.1	26.2	70.7
6								
	3174	As above. Two cobbles 4.5-inch and 4-inch size, gravel up to 2.5 inch size, slightly moist.			3.1			
7								
	3173							
8				4				
	3172	SANDY GRAVEL, red (2.5YR 5/4), gravel up to 2-inch size, one cobble 3.5-inch size, fine sand, some medium sand, few coarse sand, slightly moist.						
9			GW		5.0			
	3171							
10		SANDY GRAVEL, dark brown (7.5YR 3/4), gravel up to 2-inch size, cobbles up to 3-inch size, fine to medium sand, few coarse sand, slightly moist.		5				
	3170							
11					4.3	3.7	42.9	53.4
	3169							
12		As above. Brown (7.5YR 5/4), medium sand, few fine sand.		6				
	3168	As above. Cobbles up to 3.5-inch size, gravel up to 1.5-inch size, fine to medium sand, few coarse sand.						
13			GW		5.6			
	3167	As above. Gravel up to 2.5-inch size.						
14				7				
	3166							
15		As above. Gravel up to 2-inch size.			4.2			
	3165							
16				8				
	3164							
17								

GRAPHIC



Qualitative % Gravel



REMARKS

% Fine = % <200um;
% Medium = % Sand;
% Coarse = % Gravel

No Recovery (0-2 ft bgs)

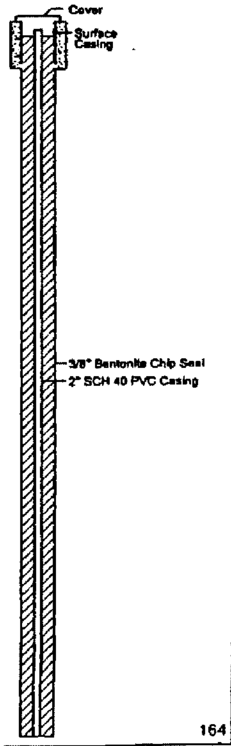
PID readings were collected with a Photovac Photoionization Detector calibrated with 100 ppm isobutylene gas.

PID readings were collected at the bottom of each core interval.

GW = Gravel and cobbles.
GP = Gravel up to 2-inch size and no cobbles.

Throughout core gravel is rounded to occasionally subrounded; sand ranges from rounded to slightly subangular.

Well: MFG-2
Elev.: 3180.01 Feet AMSL



LOG OF BORING MFG-B2

(Page 2 of 7)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

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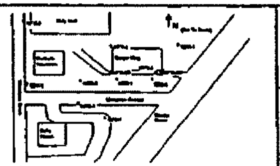
Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002

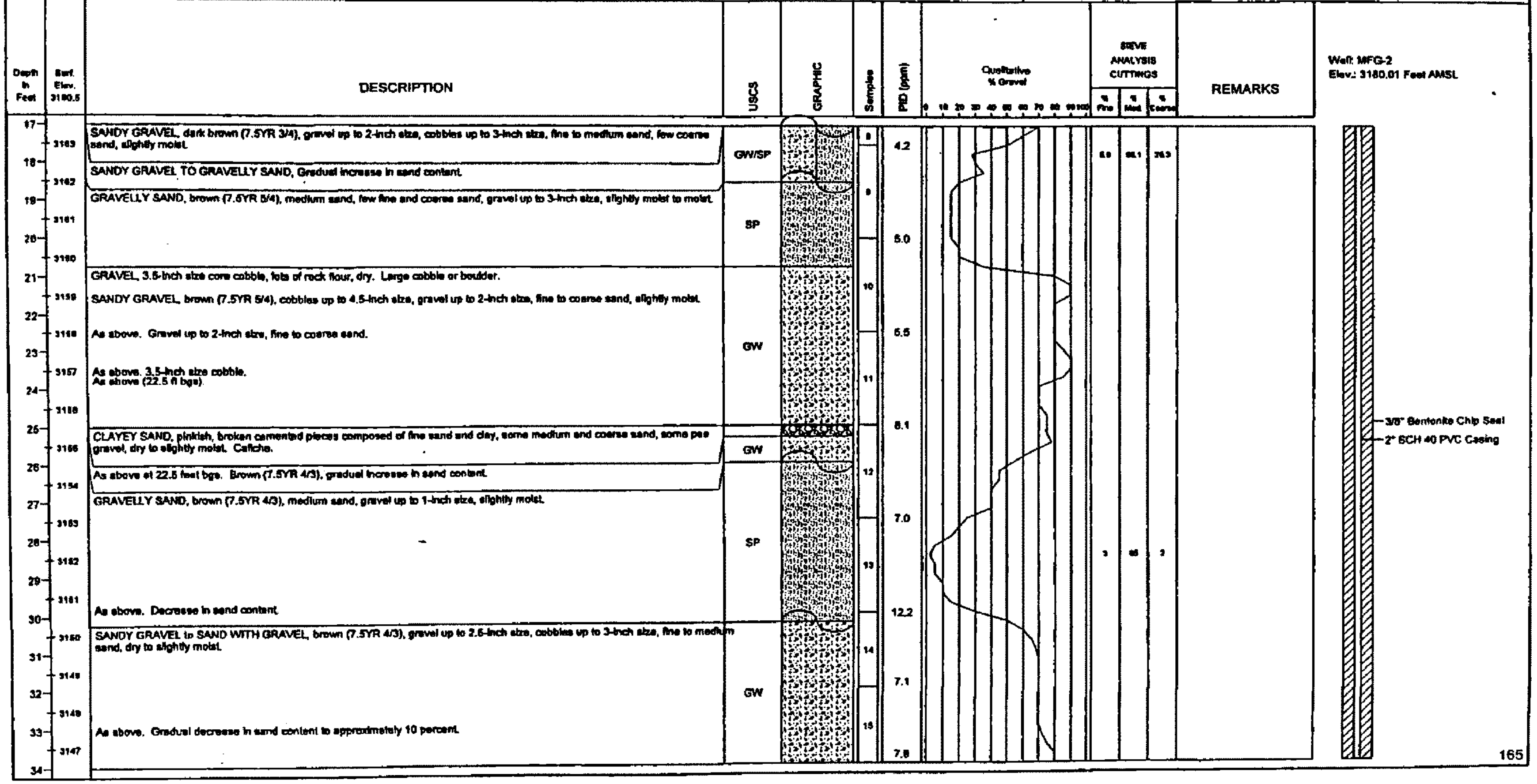


LOG OF BORING MFG-B2

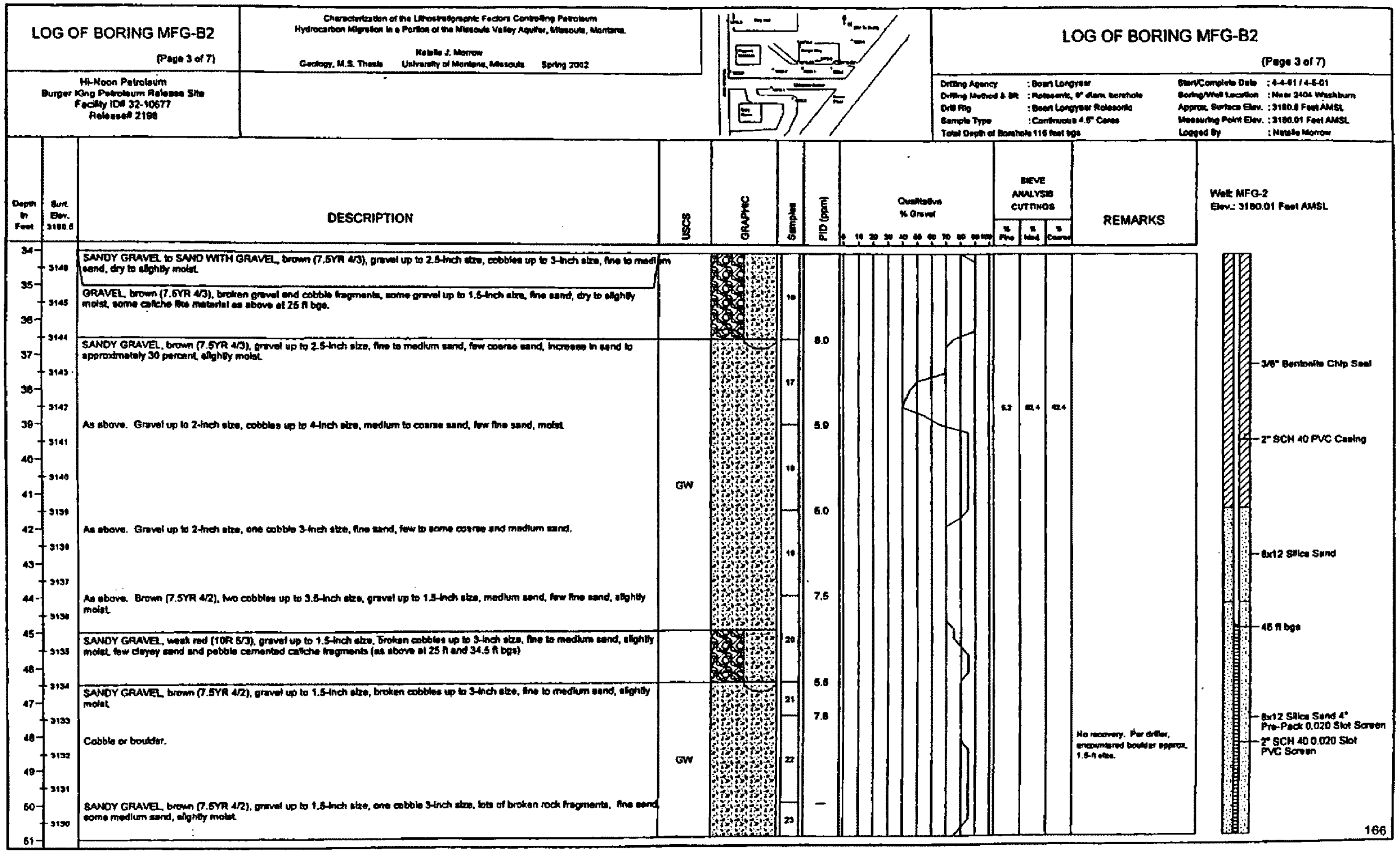
(Page 2 of 7)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 118 feet bgs

Start/Complete Date : 4-4-01 / 4-5-01
Boring/Well Location : Near 2404 Washburn
Approx. Surface Elev. : 3180.5 Feet AMSL
Measuring Point Elev. : 3180.01 Feet AMSL
Logged By : Natalie Morrow



Depth in Feet	Surf. Elev. 3180.5	DESCRIPTION	USCS	Samples	PID (ppm)	SIEVE ANALYSIS CUTTINGS % Fine	% Med	% Coarse	REMARKS
17	3163	SANDY GRAVEL, dark brown (7.5YR 3/4), gravel up to 2-inch size, cobbles up to 3-inch size, fine to medium sand, few coarse sand, slightly moist.	GW/SP	8	4.2	5.6	68.1	26.3	
18	3162	SANDY GRAVEL TO GRAVELLY SAND, Gradual increase in sand content.							
19	3161	GRAVELLY SAND, brown (7.5YR 5/4), medium sand, few fine and coarse sand, gravel up to 3-inch size, slightly moist to moist.	SP	9					
20	3160				5.0				
21	3159	GRAVEL, 3.5-inch size core cobble, lots of rock flour, dry. Large cobble or boulder. SANDY GRAVEL, brown (7.5YR 5/4), cobbles up to 4.5-inch size, gravel up to 2-inch size, fine to coarse sand, slightly moist.	GW	10					
22	3158	As above. Gravel up to 2-inch size, fine to coarse sand.			5.5				
23	3157	As above. 3.5-inch size cobble. As above (22.5 ft bgs).		11					
24	3156								
25	3155	CLAYEY SAND, pinkish, broken cemented pieces composed of fine sand and clay, some medium and coarse sand, some pea gravel, dry to slightly moist. Caliche.	GW		8.1				
26	3154	As above at 22.5 feet bgs. Brown (7.5YR 4/3), gradual increase in sand content.		12					
27	3153	GRAVELLY SAND, brown (7.5YR 4/3), medium sand, gravel up to 1-inch size, slightly moist.	SP		7.0				
28	3152			13		3	95	2	
29	3151	As above. Decrease in sand content.			12.2				
30	3150	SANDY GRAVEL to SAND WITH GRAVEL, brown (7.5YR 4/3), gravel up to 2.5-inch size, cobbles up to 3-inch size, fine to medium sand, dry to slightly moist.	GW	14					
31	3149				7.1				
32	3148			15					
33	3147	As above. Gradual decrease in sand content to approximately 10 percent.			7.8				
34									



LOG OF BORING MFG-B2

(Page 3 of 7)

Hi-Noon Petroleum
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Geology, M.S. Thesis University of Montana, Missoula Spring 2002

LOG OF BORING MFG-B2

(Page 3 of 7)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotasonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotasonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 116 feet bgs

Start/Complete Date : 4-4-01 / 4-5-01
Boring/Well Location : Near 2404 Washburn
Approx. Surface Elev. : 3180.5 Feet AMSL
Measuring Point Elev. : 3180.01 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	DESCRIPTION	USCS	Samples	PID (ppm)	REMARKS
34	SANDY GRAVEL to SAND WITH GRAVEL, brown (7.5YR 4/3), gravel up to 2.5-inch size, cobbles up to 3-inch size, fine to medium sand, dry to slightly moist.		16		
35	GRAVEL, brown (7.5YR 4/3), broken gravel and cobble fragments, some gravel up to 1.5-inch size, fine sand, dry to slightly moist, some caliche like material as above at 25 ft bgs.				
36.5	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 2.5-inch size, fine to medium sand, few coarse sand, increase in sand to approximately 30 percent, slightly moist.	GW		8.0	
38			17		
39	As above. Gravel up to 2-inch size, cobbles up to 4-inch size, medium to coarse sand, few fine sand, moist.			5.9	
40			18		
41				6.0	
42	As above. Gravel up to 2-inch size, one cobble 3-inch size, fine sand, few to some coarse and medium sand.		19		
44	As above. Brown (7.5YR 4/2), two cobbles up to 3.5-inch size, gravel up to 1.5-inch size, medium sand, few fine sand, slightly moist.			7.5	
45	SANDY GRAVEL, weak red (10R 5/3), gravel up to 1.5-inch size. Broken cobbles up to 3-inch size, fine to medium sand, slightly moist, few clayey sand and pebble cemented caliche fragments (as above at 25 ft and 34.5 ft bgs)		20	5.5	
46.5	SANDY GRAVEL, brown (7.5YR 4/2), gravel up to 1.5-inch size, broken cobbles up to 3-inch size, fine to medium sand, slightly moist.	GW	21	7.8	
48	Cobble or boulder.		22		No recovery. Per driller, encountered boulder approx. 1.5-ft size.
50	SANDY GRAVEL, brown (7.5YR 4/2), gravel up to 1.5-inch size, one cobble 3-inch size, lots of broken rock fragments, fine sand, some medium sand, slightly moist.		23	—	

SIEVE ANALYSIS CUTTINGS

% Fine	% Med	% Coarse
5.2	52.4	42.4

Well: MFG-2
Elev.: 3180.01 Feet AMSL

LOG OF BORING MFG-B2

(Page 4 of 7)

Hi-Noon Petroleum
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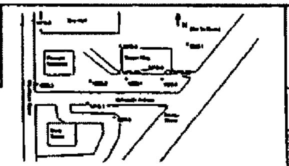


LOG OF BORING MFG-B2

(Page 4 of 7)

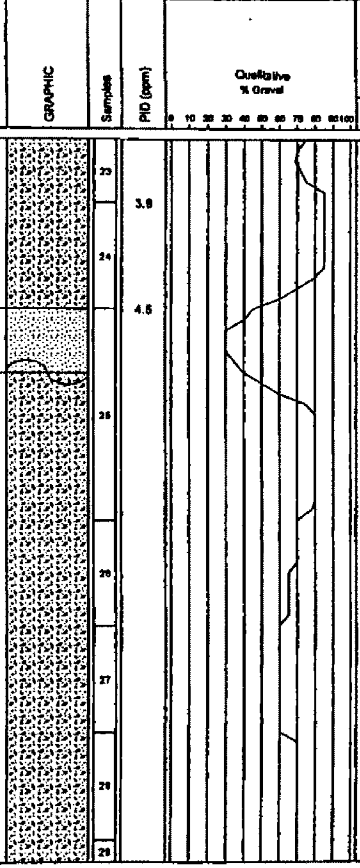
Drilling Agency : Boart Longyear
Drilling Method & ID : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 115 feet bgs

Start/Complete Date : 4-4-01 / 4-8-01
Boring/Well Location : Near 2404 Washburn
Approx. Surface Elev. : 3180.5 Feet AMSL
Measuring Point Elev. : 3180.01 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet: 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68

Surf. Elev. 3180.5: 3129, 3128, 3127, 3126, 3125, 3124, 3123, 3122, 3121, 3120, 3119, 3118, 3117, 3116, 3115, 3114, 3113

DESCRIPTION	USCS
SANDY GRAVEL, brown (7.5YR 4/2), gravel up to 1.5-inch size, broken cobbles up to 3-inch size, fine to medium sand, slightly moist. As above. Gravel up to 2.5-inch size, fine to medium sand, slightly moist to moist.	GW
GRAVELLY SAND, dark yellowish brown (10YR 4/3), fine to coarse sand grades to fine to very coarse, gravel and cobbles up to 3-inch size, few cobbles to 4-inch size, some silt and clay, saturated.	SW
SANDY GRAVEL, dark yellowish brown (10YR 4/3), gravel up to 1.5-inch size, two cobbles up to 4.5-inch size, medium to very coarse sand, few fine sand, saturated. As above. Coarse to very coarse sand, some fine to medium sand, some silt. As above. Gravel up to 2-inch size, some pea gravel, cobbles to 4-inch size, very coarse sand, some fine to medium sand. As above. As above.	GW



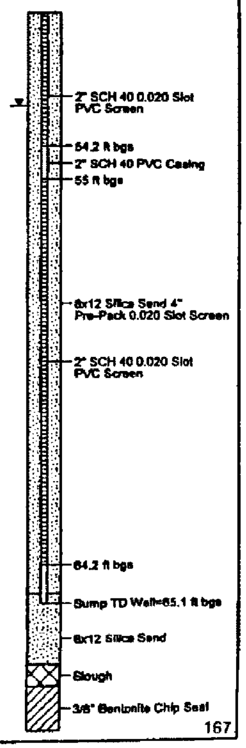
SIEVE ANALYSIS CUTTINGS % Fine	% Med.	% Coarse
4.1	36.6	59.3

REMARKS

First encountered water level at 53 feet bgs.

Collected subsurface sample MFG-B2(58')

Well: MFG-2
Elev.: 3180.01 Feet AMSL



LOG OF BORING MFG-B2

(Page 5 of 7)

Hi-Noon Petroleum
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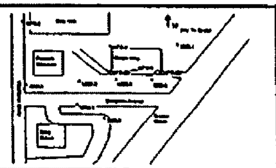


LOG OF BORING MFG-B2

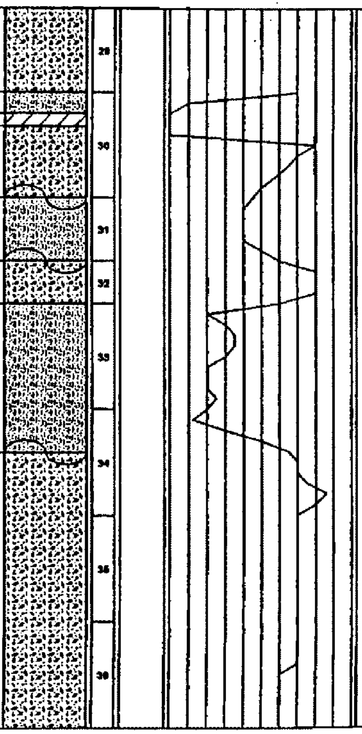
(Page 5 of 7)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 8" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 115 feet bgs
Start/Complete Date : 4-4-01 / 4-5-01
Boring/Well Location : Near 2404 Washburn
Approx. Surface Elev. : 3180.5 Feet AMSL
Measuring Point Elev. : 3180.91 Feet AMSL
Logged By : Natalie Morrow

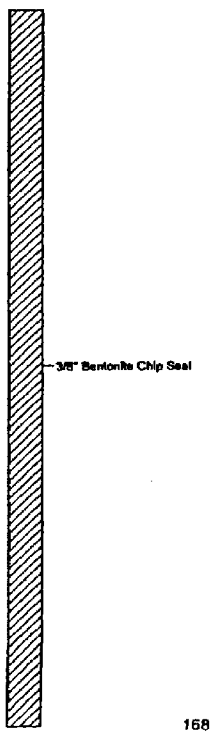
Depth in Feet: 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85

Surf. Elev. 3180.5: 3112, 3111, 3110, 3109, 3108, 3107, 3106, 3105, 3104, 3103, 3102, 3101, 3100, 3099, 3098, 3097, 3096

DESCRIPTION	USCS	Samples	PID (ppm)	SIEVE ANALYSIS CUTTINGS % Fine	% Med	% Coarse	REMARKS
SANDY GRAVEL, dark yellowish brown (10YR 4/3), gravel up to 1.5-inch size, two cobbles up to 4.5-inch size, medium to very coarse sand, few fine sand, saturated.	GW	29					
SAND, brown (7.5YR 4/3), medium sand, few coarse sand, few pea gravel, saturated.	SP						
GRAVELLY CLAY, brown (7.5YR 5/4), 5-10 percent gravel, gravel up to 1-inch size, minor silt, wet.	CL						
SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, pea gravel, cobbles up to 3.5-inch size, fine to medium sand, some coarse sand and silt, saturated.	GW	30					
GRAVELLY SAND, brown (7.5YR 4/3), fine sand with silt, some medium sand and pea gravel. Grades to fine to medium sand with few coarse sand, some silt, and pea gravel. Saturated.	SP	31					
SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, broken cobbles up to 4-inch size, medium to coarse sand, some fine sand, saturated.	GW	32					
GRAVELLY SAND, brown (7.5YR 4/3) medium to coarse sand, very few very coarse and fine sand, minor silt, gravel up to 1-inch size, one cobble 3-inch size, saturated.	SP	33		4.3	60.8	34.9	
As above. Coarse to very coarse sand, few medium sand, gravel up to 1.5-inch size, some pea gravel.				2.6	72.4	25.2	
As above. Grading to very coarse sand and gravel up to 1/2-inch size.				2	86.3	11.7	
SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 2-inch size, cobbles up to 3.5-inch size, very coarse sand, some fine to coarse sand, minor silt, saturated.	GW	34		1.3	12.6	86.1	
As above. Fine to medium sand, few coarse sand, some silt and clay.		35					
As above. Grades to gravel up to 1.5-inch size, cobbles 3-inch size, very coarse sand, some medium to coarse sand, minor fine sand and silt.							
Gradual increase in sand to approximately 40 percent, increase in pea-size gravel, minor silt.		36					
As above.							



Well: MFG-2
Elev.: 3180.01 Feet AMSL



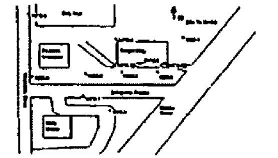
LOG OF BORING MFG-B2

(Page 6 of 7)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis   University of Montana, Missoula   Spring 2002

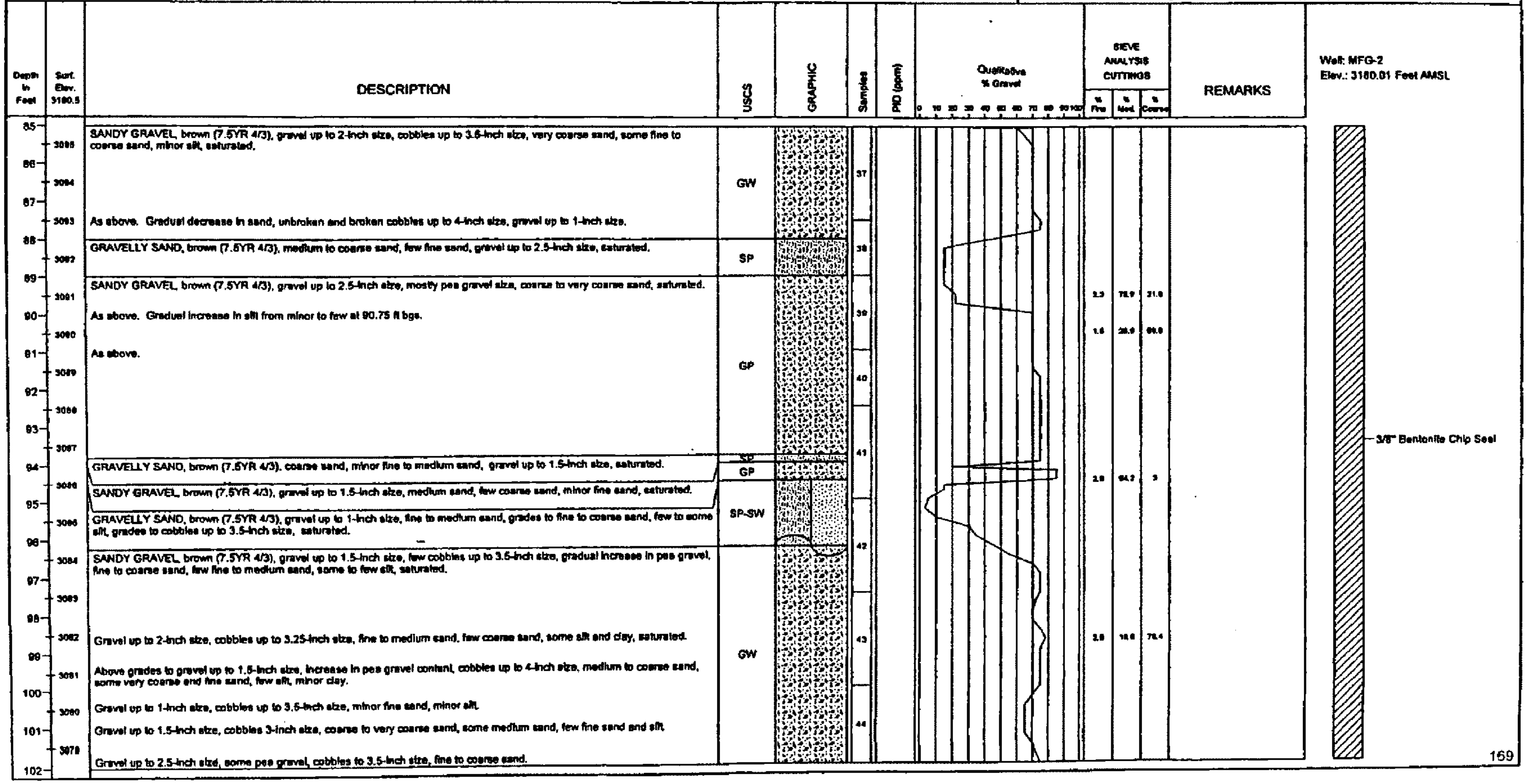


LOG OF BORING MFG-B2

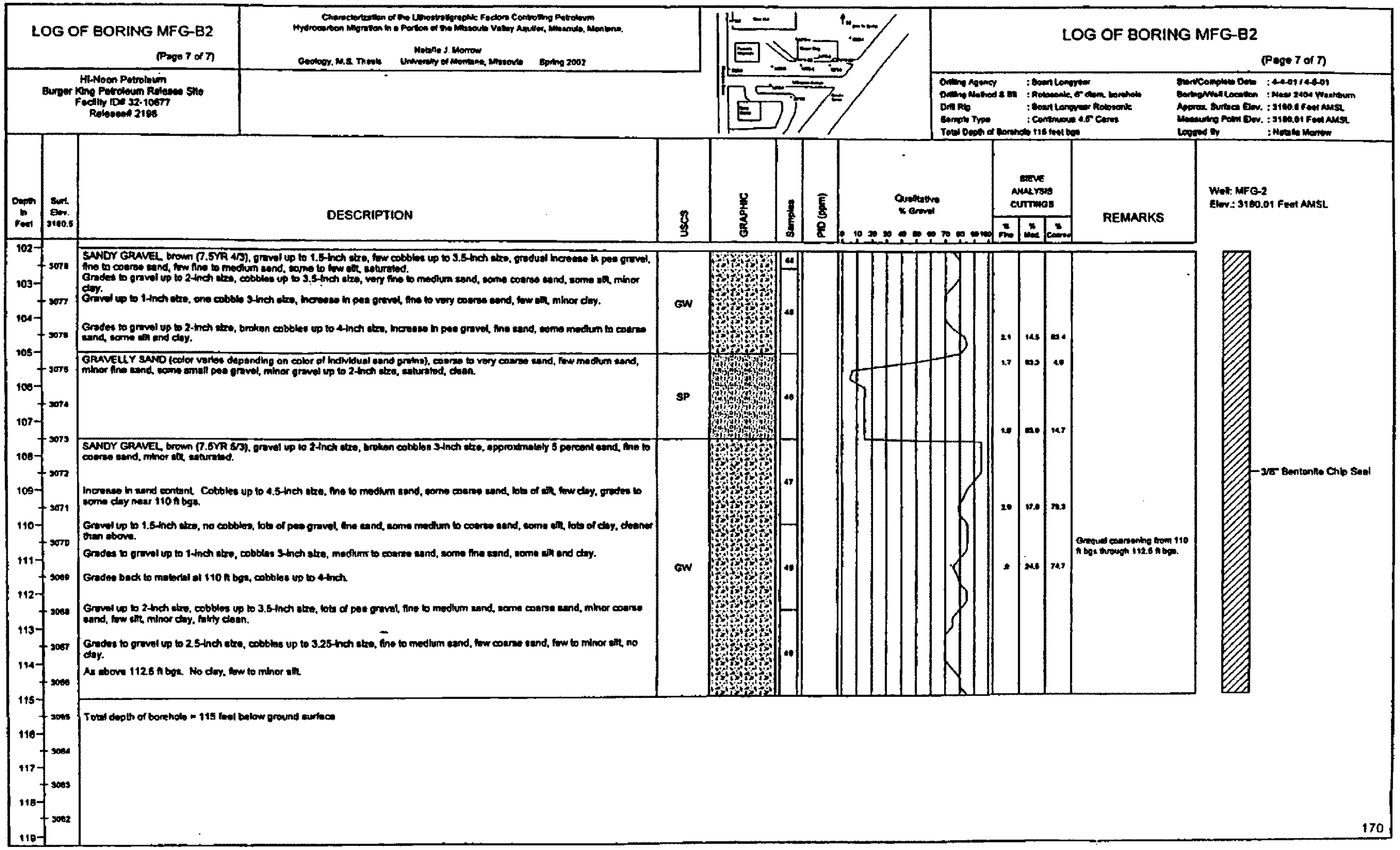
(Page 6 of 7)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 115 feet bgs

Start/Complete Date : 4-4-01 / 4-5-01
Boring/Well Location : Near 2404 Washburn
Approx. Surface Elev. : 3180.5 Feet AMSL
Measuring Point Elev. : 3180.01 Feet AMSL
Logged By : Natalie Morrow



DESCRIPTION	USCS	Samples	SIEVE ANALYSIS CUTTINGS % Fine	% Med.	% Coarse	REMARKS
SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 2-inch size, cobbles up to 3.5-inch size, very coarse sand, some fine to coarse sand, minor silt, saturated. As above. Gradual decrease in sand, unbroken and broken cobbles up to 4-inch size, gravel up to 1-inch size.	GW	37				
GRAVELLY SAND, brown (7.5YR 4/3), medium to coarse sand, few fine sand, gravel up to 2.5-inch size, saturated.	SP	38				
SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 2.5-inch size, mostly pea gravel size, coarse to very coarse sand, saturated. As above. Gradual increase in silt from minor to few at 90.75 ft bgs. As above.	GP	39 40	2.3 1.6	75.9 28.9	21.8 69.5	
GRAVELLY SAND, brown (7.5YR 4/3), coarse sand, minor fine to medium sand, gravel up to 1.5-inch size, saturated.	SP	41	2.8	94.2	3	
SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, medium sand, few coarse sand, minor fine sand, saturated.	GP					
GRAVELLY SAND, brown (7.5YR 4/3), gravel up to 1-inch size, fine to medium sand, grades to fine to coarse sand, few to some silt, grades to cobbles up to 3.5-inch size, saturated.	SP-SW	42				
SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, few cobbles up to 3.5-inch size, gradual increase in pea gravel, fine to coarse sand, few fine to medium sand, some to few silt, saturated. Gravel up to 2-inch size, cobbles up to 3.25-inch size, fine to medium sand, few coarse sand, some silt and clay, saturated. Above grades to gravel up to 1.5-inch size, increase in pea gravel content, cobbles up to 4-inch size, medium to coarse sand, some very coarse and fine sand, few silt, minor clay. Gravel up to 1-inch size, cobbles up to 3.5-inch size, minor fine sand, minor silt. Gravel up to 1.5-inch size, cobbles 3-inch size, coarse to very coarse sand, some medium sand, few fine sand and silt. Gravel up to 2.5-inch size, some pea gravel, cobbles to 3.5-inch size, fine to coarse sand.	GW	43 44	2.8	18.8	78.4	



LOG OF BORING MFG-B2

(Page 7 of 7)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2196

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002

LOG OF BORING MFG-B2

(Page 7 of 7)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 115 feet bgs
Start/Complete Date : 4-4-01 / 4-6-01
Boring/Well Location : Near 2404 Washburn
Approx. Surface Elev. : 3180.6 Feet AMSL
Measuring Point Elev. : 3180.01 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3180.5	DESCRIPTION	USCS	Samples
102	3078	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, few cobbles up to 3.5-inch size, gradual increase in pea gravel, fine to coarse sand, few fine to medium sand, some to few silt, saturated.	GW	44
103	3077	Grades to gravel up to 2-inch size, cobbles up to 3.5-inch size, very fine to medium sand, some coarse sand, some silt, minor clay. Gravel up to 1-inch size, one cobble 3-inch size, increase in pea gravel, fine to very coarse sand, few silt, minor clay.		45
104	3076	Grades to gravel up to 2-inch size, broken cobbles up to 4-inch size, increase in pea gravel, fine sand, some medium to coarse sand, some silt and clay.		
105	3075	GRAVELLY SAND (color varies depending on color of individual sand grains), coarse to very coarse sand, few medium sand, minor fine sand, some small pea gravel, minor gravel up to 2-inch size, saturated, clean.	SP	46
106	3074			
107	3073	SANDY GRAVEL, brown (7.5YR 5/3), gravel up to 2-inch size, broken cobbles 3-inch size, approximately 5 percent sand, fine to coarse sand, minor silt, saturated.	GW	
108	3072	Increase in sand content. Cobbles up to 4.5-inch size, fine to medium sand, some coarse sand, lots of silt, few clay, grades to some clay near 110 ft bgs.		47
109	3071	Gravel up to 1.5-inch size, no cobbles, lots of pea gravel, fine sand, some medium to coarse sand, some silt, lots of clay, cleaner than above.		
110	3070	Grades to gravel up to 1-inch size, cobbles 3-inch size, medium to coarse sand, some fine sand, some silt and clay.		48
111	3069	Grades back to material at 110 ft bgs, cobbles up to 4-inch.		
112	3068	Gravel up to 2-inch size, cobbles up to 3.5-inch size, lots of pea gravel, fine to medium sand, some coarse sand, minor coarse sand, few silt, minor clay, fairly clean.		
113	3067	Grades to gravel up to 2.5-inch size, cobbles up to 3.25-inch size, fine to medium sand, few coarse sand, few to minor silt, no clay. As above 112.5 ft bgs. No clay, few to minor silt.		49
114	3066			
115	3065	Total depth of borehole = 115 feet below ground surface		
116	3064			
117	3063			
118	3062			
119				

SIEVE ANALYSIS CUTTINGS

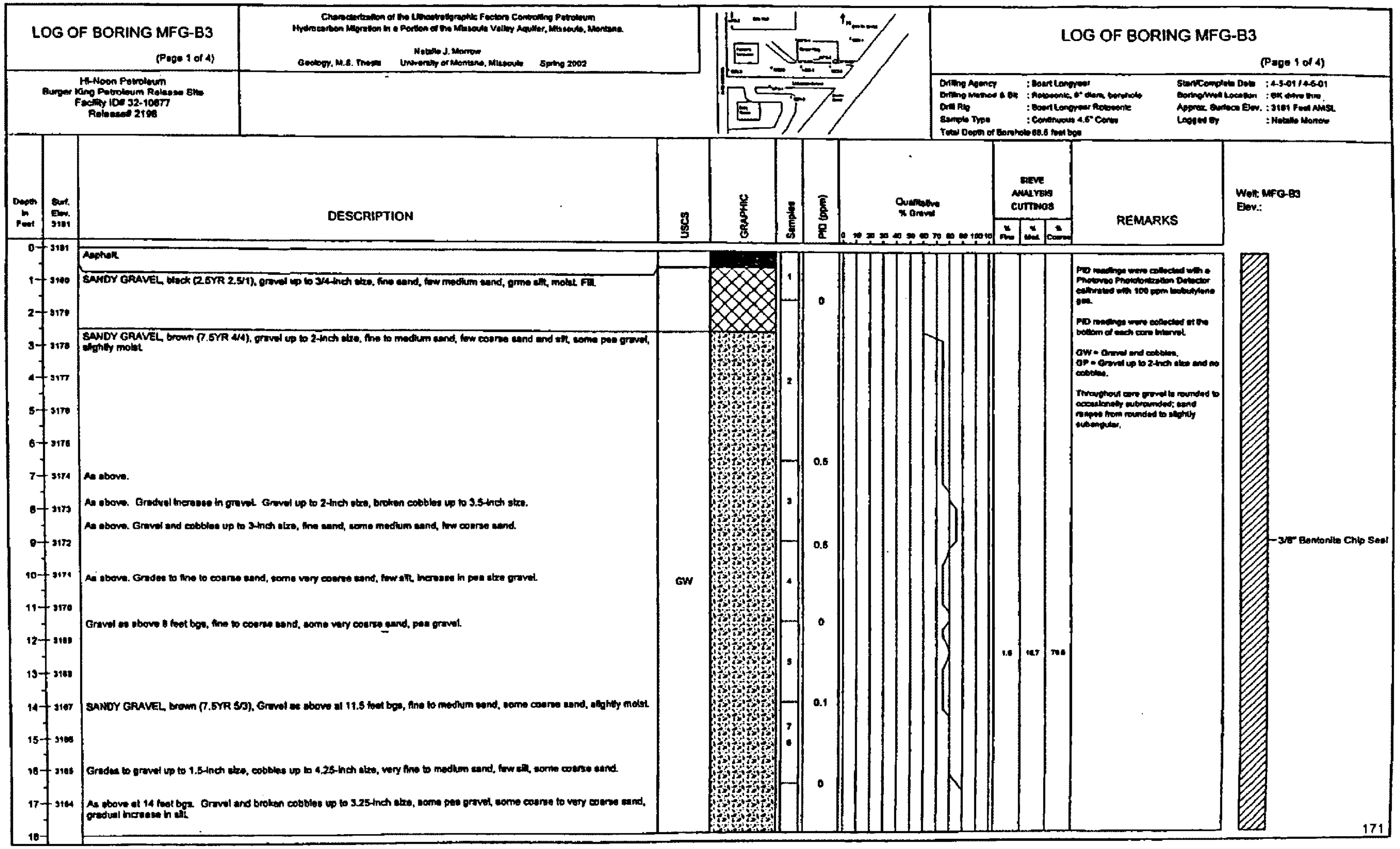
% Fine	% Med.	% Coarse
2.1	14.5	83.4
1.7	93.3	4.9
1.8	83.5	14.7
2.9	17.8	79.3
.8	24.5	74.7

REMARKS

Gradual coarsening from 110 ft bgs through 112.5 ft bgs.

Well: MFG-2
Elev.: 3180.01 Feet AMSL

3/8" Bentonite Chip Seal



LOG OF BORING MFG-B3

(Page 1 of 4)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002

LOG OF BORING MFG-B3

(Page 1 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 68.5 feet bgs
Start/Complete Date : 4-5-01 / 4-6-01
Boring/Well Location : BK drive thru
Approx. Surface Elev. : 3181 Feet AMSL
Logged By : Natalie Morrow

DESCRIPTION

Asphalt.

SANDY GRAVEL, black (2.5YR 2.5/1), gravel up to 3/4-inch size, fine sand, few medium sand, grme silt, moist. Fill.

SANDY GRAVEL, brown (7.5YR 4/4), gravel up to 2-inch size, fine to medium sand, few coarse sand and silt, some pea gravel, slightly moist.

As above.

As above. Gradual increase in gravel. Gravel up to 2-inch size, broken cobbles up to 3.5-inch size.

As above. Gravel and cobbles up to 3-inch size, fine sand, some medium sand, few coarse sand.

As above. Grades to fine to coarse sand, some very coarse sand, few silt, increase in pea size gravel.

Gravel as above 8 feet bgs, fine to coarse sand, some very coarse sand, pea gravel.

SANDY GRAVEL, brown (7.5YR 5/3), Gravel as above at 11.5 feet bgs, fine to medium sand, some coarse sand, slightly moist.

Grades to gravel up to 1.5-inch size, cobbles up to 4.25-inch size, very fine to medium sand, few silt, some coarse sand.

As above at 14 feet bgs. Gravel and broken cobbles up to 3.25-inch size, some pea gravel, some coarse to very coarse sand, gradual increase in silt.

REMARKS

PID readings were collected with a Photovac Photoionization Detector calibrated with 100 ppm isobutylene gas.

PID readings were collected at the bottom of each core interval.

GW = Gravel and cobbles.
GP = Gravel up to 2-inch size and no cobbles.

Throughout core gravel is rounded to occasionally subrounded; sand ranges from rounded to slightly subangular.

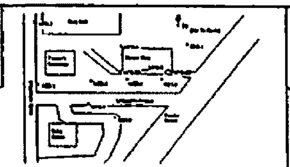
LOG OF BORING MFG-B3

(Page 2 of 4)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis   University of Montana, Missoula   Spring 2002



LOG OF BORING MFG-B3

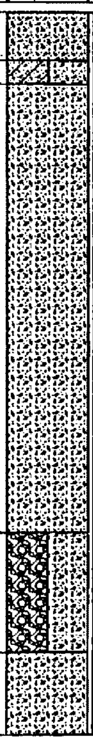
(Page 2 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 68.5 feet bgs

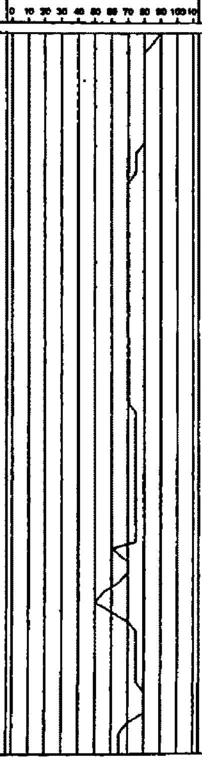
Start/Complete Date : 4-5-01 / 4-5-01
Boring/Well Location : BK drive thru
Approx. Surface Elev. : 3161 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3161	DESCRIPTION	USCS	Samples	PID (ppm)	SIEVE ANALYSIS CUTTINGS % Fine	% Med.	% Coarse	REMARKS
18	3163	SANDY GRAVEL, brown (7.5YR 4/4), gravel up to 2-inch size, fine to medium sand, few coarse sand and silt, some pea gravel, slightly moist.	GP		0.2	2.1	17.9	80.1	
19	3162	SANDY GRAVEL, brown (7.5YR 5/3), gravel up to 1.5-inch size, fine to coarse sand, slightly moist.	GC-GW	8					
20	3161	CLAYEY SANDY GRAVEL, reddish brown (5YR 4/3), gravel up to 1-inch size, fine to medium sand, some coarse sand, moist to very moist.	GW		0.2				
21	3160	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, cobbles up to 4-inch size, fine to medium sand, few to some clay and silt, moist.		9					
22	3159	Above grades to gravel up to 1/2-inch size, few gravel 1.5-inch size, one cobble 4-inch size. As above. Fine to medium sand, some coarse sand, minor fine sand or silt.			4.0				
23	3158	Gravel up to 3/4-inch size, sand and silt as above at 22 feet bgs.							
24	3157	Grades to gravel up to 2.5-inch size, cobbles up to 3.5-inch size, medium sand, some coarse sand, and few fine sand, slightly moist.		10					
25	3156	As above at 24 feet bgs, increase in amount of pea gravel, increase in broken cobble fragments (3/4-inch size).			0				
26	3155			11					
27	3154				1.0				
28	3153	SANDY GRAVEL, brown (7.5YR 5/4), gravel up to 1.5-inch size, increase in pea gravel, increase in cobbles from above (up to 4.5-inch size), fine to medium sand, some very fine and coarse sand, few silt, slightly moist.							
29	3152			12					
30	3151	As above at 28 feet bgs.			0.4				
31	3150	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, fine to medium sand, some coarse sand, "caliche" fragments consisting of gravel in fine to medium sand matrix.		13					
32	3149				3.6	6.8	42.9	50.3	
33	3148	As above.		14					
34	3147	SANDY GRAVEL, light reddish brown (2.5YR 6/3), gravel up to 2.5-inch size, increase in pea gravel, very fine to medium sand, some coarse sand, minor coarse sand, no "caliche" fragments, dry to slightly moist.	GW						
35	3146	SANDY GRAVEL, brown (7.5YR 5/3), gravel up to 1.5-inch size, very fine to medium sand, some silt, few coarse sand, slightly moist.		15	0.8				
36									

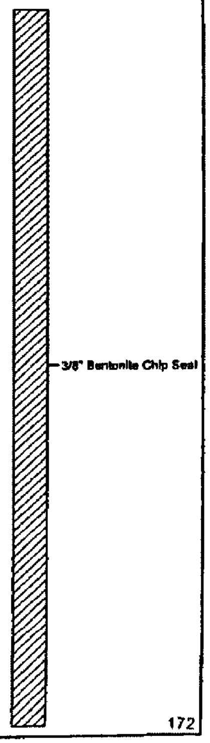
GRAPHIC



Qualitative % Gravel



Well: MFG-B3
Elev.:



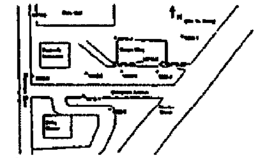
LOG OF BORING MFG-B3

(Page 3 of 4)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002



LOG OF BORING MFG-B3

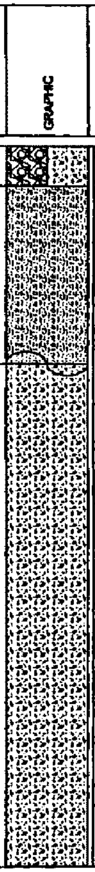
(Page 3 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 68.5 feet bgs

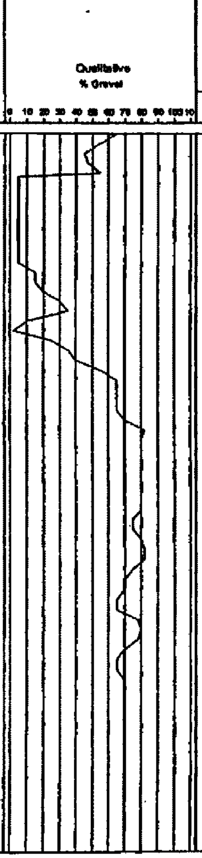
Start/Complete Date : 4-3-01 / 4-5-01
Boring/Well Location : BK drive thru
Approx. Surface Elev. : 3181 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3181	DESCRIPTION	USCS	Samples	PID (ppm)	% Fine	% Med.	% Coarse	REMARKS
36	3145	SANDY GRAVEL, light reddish brown (2.5YR 6/3), gravel up to 2.5-inch size, increase in pea gravel, very fine to medium sand, some coarse sand, minor coarse sand, no "caliche" fragments, dry to slightly moist.		15		5.6	49.5	44.9	
37	3144	Gradual increase in sand, fine to medium sand, few coarse sand, few silt, one cobble up to 3-inch size, few "caliche" fragments present.			1.0				
38	3143	SAND, brown (7.5YR 5/3), fine to medium sand, very few coarse sand, some small pieces of mud (silt and clay), minor gravel up to 1/2-inch size, slightly moist.		16					
39	3142	As above. Slight increase in gravel up to 1-inch size.	SP						
40	3141	GRAVELLY SAND, brown (7.5YR 5/4), fine to medium sand, minor coarse sand, gravel up to 2-inch size, very slightly moist.			1.0				
41	3140			17		2.7	97.3	0	
42	3139	SANDY GRAVEL, brown (7.5YR 5/4), gravel up to 2-inch size, cobbles up to 4-inch size, fine to coarse sand, minor fine sand, slightly moist.			2.3	6.3	54.5	40.2	
43	3138	Gradual increase in gravel. Gravel up to 2.5-inch size, cobbles up to 5-inch size, sand grades from fine to coarse sand to coarse to very coarse sand, some medium sand, minor fine sand, some clay and silt.		18		2.1	16	81.9	
44	3137								
45	3136	As above. Dark reddish gray (2.5YR Y/1), grades to medium to coarse sand, minor fine sand, some very coarse sand, minor clay and silt.			91.4				Slight hydrocarbon odor.
46	3135			19		1.8	15.5	82.7	
47	3134	SANDY GRAVEL, reddish gray (2.5YR 5/1), gravel up to 2-inch size, cobbles to 4.5-inch size, coarse sand, some medium sand, minor fine and coarse sand, minor clay and silt, moist.	GW		723				Strong hydrocarbon odor.
48	3133					1.8	18.7	79.5	
49	3132			20					
50	3131	As above. Brown (7.5YR 5/4), cobbles up to 4-inch size, fine to medium sand, few coarse sand, few silt and clay.			1089				Very strong hydrocarbon odor. Collected subsurface sample MFG-B3(50')
51	3130			21					
52	3129				283				Strong hydrocarbon odor to 60 feet bgs.
53	3128	As above.		22					
54									

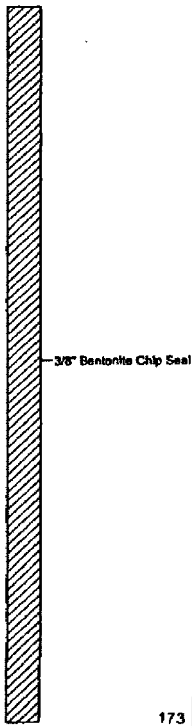
GRAPHIC



Qualitative % Gravel



Well: MFG-B3
Elev.:



LOG OF BORING MFG-B3

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Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2196

Characterization of the Lithostratigraphic Factors Controlling Petroleum
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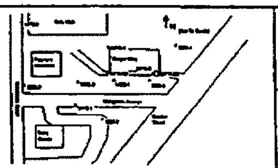
Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002

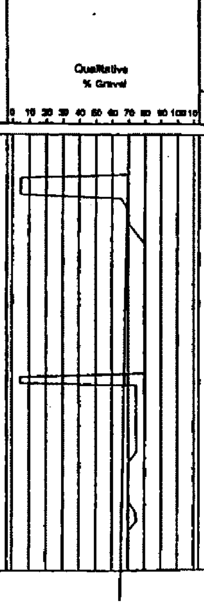


LOG OF BORING MFG-B3

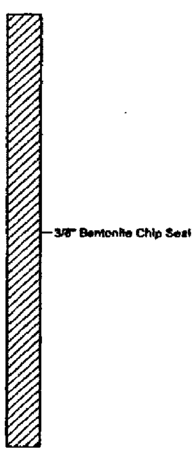
(Page 4 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 66.5 feet bgs
Start/Complete Date : 4-4-01 / 4-5-01
Boring/Well Location : BK drive thru
Approx. Surface Elev. : 3181 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3181	DESCRIPTION	USCS	Samples	PID (ppm)	SIEVE ANALYSIS CUTTINGS % Fine	% Med.	% Coarse	REMARKS
54	3127	"Caliche" fragments. As above at 47.5 feet bgs. Fine to medium sand, few coarse sand, gravel up to 2-inch size.	GW	22					
55	3126	GRAVELLY CLAY, brown (10YR 5/3) and reddish brown (2.5YR 6/3), few silt, gravel up to 1/2-inch size, wet to saturated.	CL		580				Collected subsurface sample MFGB3-(55').
56	3125	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1-inch size, broken cobbles up to 3.5-inch size, medium to coarse sand, some very coarse sand, minor fine sand, some silt and clay, saturated.	GW	23		3	37.9	[illegible]	No water level collected, hole caved. Water level encountered at approx. 56 feet bgs.
57	3124	Above grades to gravel up to 1.5-inch size, cobbles up to 3-inch size, coarse to very coarse sand, some medium sand, few silt and clay.							
58	3123	As above. Lots of pea gravel, few medium to fine.			239				
59	3122	As above.		24					
60	3121	CLAY, brown (10YR 5/3), few silt, some gravel up to 1/2-inch size, wet to saturated.	CL		188				
61	3120	SANDY GRAVEL, brown (7.5YR 4/3), gravel as above at 56.5 feet bgs, fine to medium sand, some coarse sand, some silt and clay, saturated.	GW	25					
62	3119	As above. Gravel up to 2-inch size, cobbles up to 4.5-inch size, medium to coarse sand, few very coarse sand, minor fine sand, few silt, saturated.			130				
63	3118			26		1.7	24.4	73.9	
64	3117	As above.			8.5				
65	3116								
66	3115	Total depth of borehole = 66 feet below ground surface.							
67	3114								
68	3113								
69	3112								
70	3111								
71	3110								
72									



Well: MFG-B3
Elev.:



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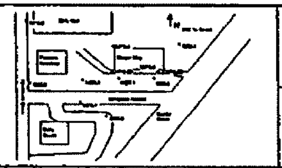
LOG OF BORING MFG-B4

(Page 1 of 4)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2186

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002



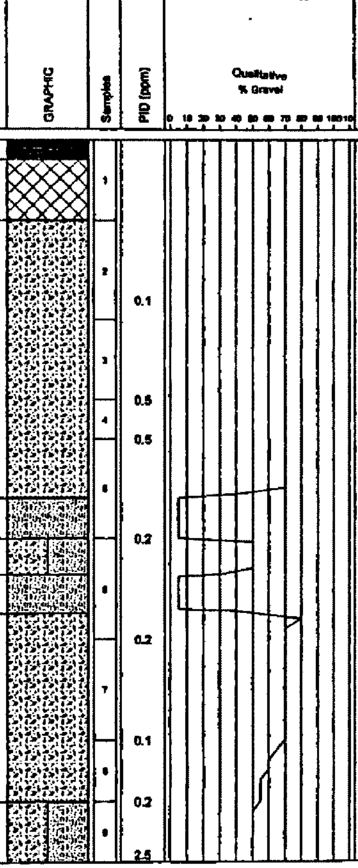
LOG OF BORING MFG-B4

(Page 1 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 76 feet bgs

Start/Complete Date : 4-6-01 / 4-6-01
Boring/Well Location : NW corner of B.K. building
Approx. Surface Elev. : 3181.32 Feet AMSL
Measuring Point Elev. : 3181.8 Feet AMSL
Logged By : Natalie Morrow

Depth In Feet	Surf. Elev. 3181.8	DESCRIPTION	USCS	Samples	PID (ppm)
0		Asphalt.			
1	3181	SANDY GRAVEL, grayish brown (10YR 5/3), gravel up to 3/4-inch size, fine to medium sand, few coarse sand, slightly moist to moist. Fill.		1	
2	3180	SANDY GRAVEL, brown (7.5YR 4/2), gravel up to 2.5-inch size, cobbles up to 3.75-inch size, fine to medium sand, few coarse sand, moist.			
3	3179			2	
4	3178				0.1
5	3177	As above. Gravel and cobbles up to 3.5-inch size, fine to coarse sand, few pea gravel, some very fine sand and silt, few silt size mica.	GW	3	
6	3176	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 2-inch size, cobbles up to 3.5-inch size, some pea gravel, medium to coarse sand, some fine sand, few very coarse sand and silt, some silt size mica, minor clay, very wet.			0.5
7	3175	As above. Gravel and cobbles up to 2.5-inch size, one cobble 4-inch size, pea gravel, very moist to wet.		4	0.5
8	3174			5	
9	3173	SAND, reddish brown (7.5YR 5/3), fine to very fine sand, minor medium sand, some silt, gravel up to 1-inch size present in top 3 inches, very moist to moist.	SP		
10	3172	SANDY GRAVEL to GRAVELLY SAND, reddish brown (7.5YR 4/3), fine to medium sand, some very fine sand and silt, gravel up to 1.5-inch size, minor mica.	GW/SP		0.2
11	3171	SAND, as above 9-10 feet bgs, gravel up to 1-inch throughout, moist. Grades to include few coarse sand at 11.25 feet bgs. GRAVELLY SAND, reddish brown (7.5YR 4/3), fine to medium sand, some coarse sand, pea gravel, some silt, moist.	SP	6	
12	3170	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, lots of pea gravel, few cobbles to fine to medium sand, some silt, minor mica, moist.			0.2
13	3169			7	
14	3168	As above.	GW		
15	3167	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, cobbles to 3.5-inch size, very fine to medium sand, some silt, minor clay, very moist.			0.1
16	3166	Grades to 40 to 45 percent sand, gravel up to 1-inch size, cobbles up to 3.5-inch size, medium to coarse sand, few fine sand, minor silt, minor mica, slightly moist.		8	0.2
17	3165	SANDY GRAVEL TO GRAVELLY SAND, brown (7.5YR 4/3), gravel up to 1.5-inch size, one broken cobble 3.5-inch size, fine to coarse sand, slightly moist to moist.	GW/SP	9	
18	3164	As above. Cobbles up to 3-inch size, medium sand, some fine and coarse sand, few very fine sand and silt.			2.5



REMARKS

No Recovery (0-2.6 bgs)

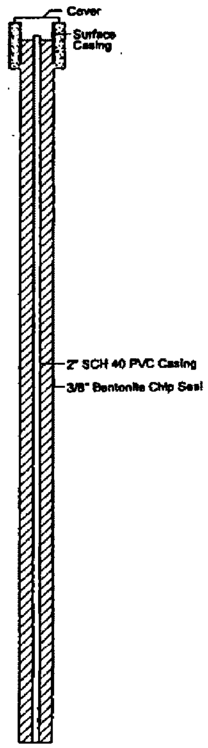
PID readings were collected with a Photovac Photoionization Detector calibrated with 100 ppm Isobutylene gas.

PID readings were collected at the bottom of each core interval.

GW = Gravel and cobbles.
GP = Gravel up to 2-inch size and no cobbles.

Throughout core gravel is rounded to occasionally subrounded; sand ranges from rounded to slightly subangular.

Well: MFG-4
Elev.: 3181.32 Feet AMSL



LOG OF BORING MFG-B4

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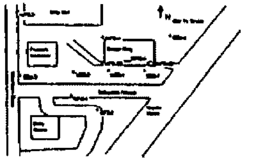
Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002

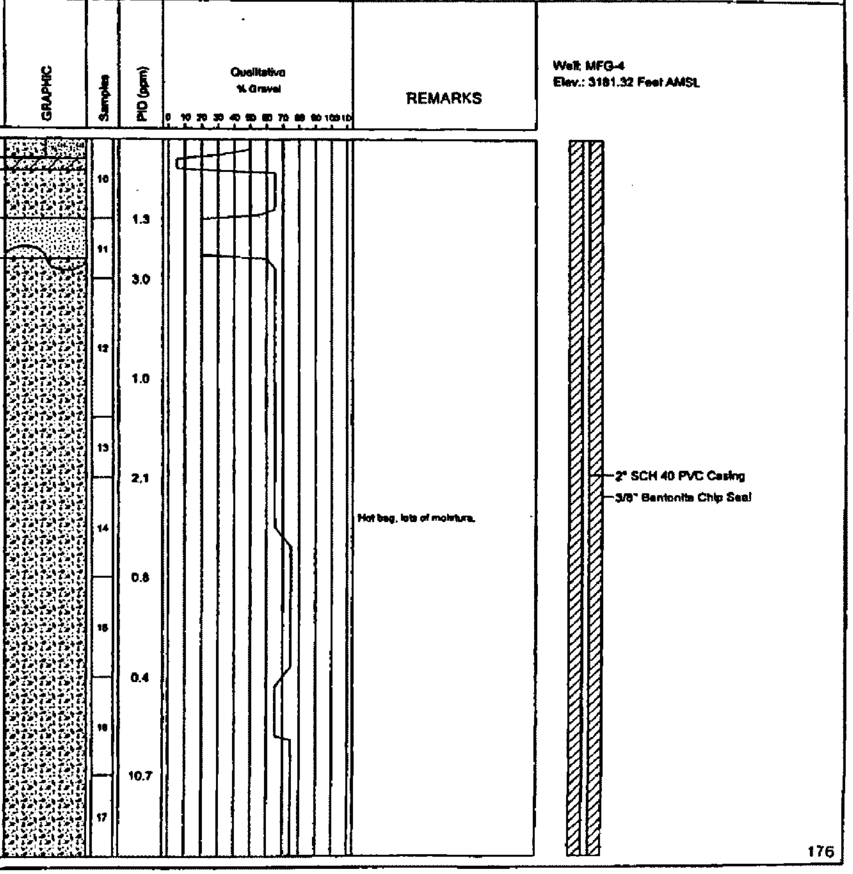


LOG OF BORING MFG-B4

(Page 2 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 70 feet bgs
Start/Complete Date : 4-8-01 / 4-8-01
Boring/Well Location : NW corner of B.K. building
Approx. Surface Elev. : 3181.32 Feet AMSL
Measuring Point Elev. : 3181.8 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3181.8	DESCRIPTION	USCS	Samples	PID (ppm)
18	3163	SANDY GRAVEL TO GRAVELLY SAND, brown (7.5YR 4/3), gravel up to 1.5-inch size, one broken cobble 3.5-inch size, fine to coarse sand, slightly moist to moist.	GW/SP GC		
19	3162	CLAYEY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, minor silt, moist. As above 17.75 feet bgs. Very fine to medium sand, few very fine and coarse sand, few silt.	GW	10	
20	3161	GRAVELLY SAND, pale brown (10YR 6/3), very fine sand and silt, few fine and medium sand, 15 to 20 percent gravel, gravel up to 0.5-inch size.	SW	11	1.3
21	3160	SANDY GRAVEL, brown (7.5YR 4/3), broken cobble fragments and gravel up to 2.75-inch size, fine to medium sand, few coarse sand, some silt, minor mica, slightly moist.	GW		3.0
22		As above. Gravel up to 2.5-inch size, some very fine and coarse sand, some silt.			
23	3159			12	
24	3158	As above at 21 feet bgs. Gravel up to 3.5-inch size, some broken rock fragments.			1.0
25	3157				
26	3156	As above. Grades to gravel up to 2.5-inch size, broken cobbles up to 3.5-inch size, medium sand, few coarse to very coarse sand, minor fine sand, slightly moist.		13	2.1
27	3155				
28	3154	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.5-inch size, cobbles up to 3.5-inch size, medium sand, few coarse to very coarse sand, minor fine sand, some silt, few clay, slightly moist.		14	
29	3153	As above. Gravel up to 2.75-inch size, lots of pea gravel, cobbles up to 3.5-inch size, fine to medium sand, some coarse sand, minor silt, slightly moist.			0.8
30	3152			15	
31	3151	SANDY GRAVEL, light brown (7.5YR 6/4), gravel up to 1.5-inch size, very fine to fine sand, few medium sand, some to lots of silt.			0.4
32	3150				
33	3149	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 2.5-inch size, some to few pea gravel, cobbles to 4.5-inch size, medium sand few fine sand, minor coarse to very coarse sand, slightly moist.		16	
34	3148	As above. Gravel up to 2.25-inch size, cobble core from 36-36.5 feet bgs, broken rock fragments up to 3.5-inch size, lots of rock flour.			10.7
35	3147			17	
36	3146				



LOG OF BORING MFG-B4

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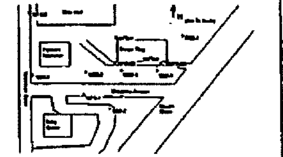
Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002



LOG OF BORING MFG-B4

(Page 3 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 70 feet bgs

Start/Complete Date : 4-9-01 / 4-9-01
Boring/Well Location : NW corner of B.K. building
Approx. Surface Elev. : 3181.32 Feet AMSL
Measuring Point Elev. : 3181.8 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3181.8
36	
37	3145
38	3144
39	3143
40	3142
41	3141
42	3140
43	3139
44	3138
45	3137
46	3136
47	3135
48	3134
49	3133
50	3132
51	3131
52	3130
53	3129
54	3128

DESCRIPTION

SANDY GRAVEL, brown (7.5YR 4/3), gravel and cobbles up to 3.8-inch size, fine to medium sand, some very fine sand, few silt, few pea gravel.

As above. Medium sand, minor fine and coarse sand.

As above. Lots of rock flour, light gray (7.5YR 7/1), broken cobbles up to 4-inch size, few gravel up to 1.5-inch size, dry to very slightly moist.

As above at 39 feet bgs. Broken rock fragments up to 1-inch size, gravel up to 2.75-inch size, fine to very fine sand, minor medium sand, some silt.

As above at 40 feet bgs. Broken cobble 3.75-inch size, gravel up to 1.5-inch size, fine to medium sand.

SANDY GRAVEL, brown (7.5YR 4/3), gravel and cobbles up to 3-inch size, broken rock fragments up to 1.5-inch size, some pea gravel, very fine to medium sand, very few coarse sand, minor mica, slightly moist.

As above. Gravel and cobbles up to 3.75-inch size, fine to medium sand, few coarse sand, minor very fine and coarse sand and silt, moist.

Above grades, medium sand, some fine and coarse sand, minor fine sand and silt, gravel as above.

SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 1.75-inch size, broken rock fragments up to 1.8-inch size, fine to medium sand, some very fine sand, minor coarse sand, few silt.

As above. Yellowish brown (10YR 5/4), lots of rock flour, rock fragments up to 3-inch size, fine to very fine sand, minor medium sand, slightly moist.

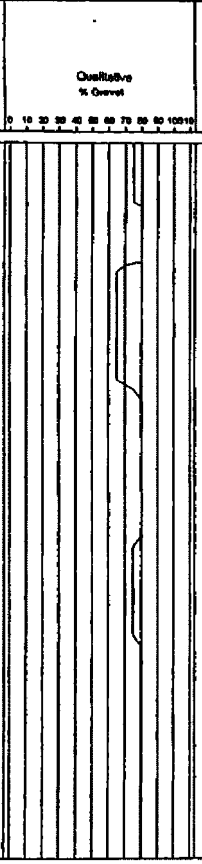
SANDY GRAVEL, brown (7.5YR 4/4), gravel and broken cobbles up to 3-inch size, very fine sand to medium sand, some to few coarse to very coarse sand, some clay and silt, moist to very moist.

As above. Very fine to fine sand, few medium sand, some silt, few clay, minor mica.

USCS: GW

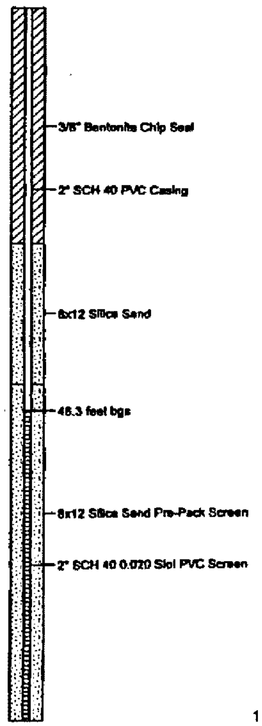
GRAPHIC

Samples	PID (ppm)
17	4.8
18	27.5
19	10.1
20	18.0
21	6.0
22	10.3
23	4.2
24	6.7



REMARKS

Well: MFG-4
Elev.: 3181.32 Feet AMSL



LOG OF BORING MFG-B4

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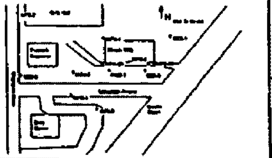
Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002



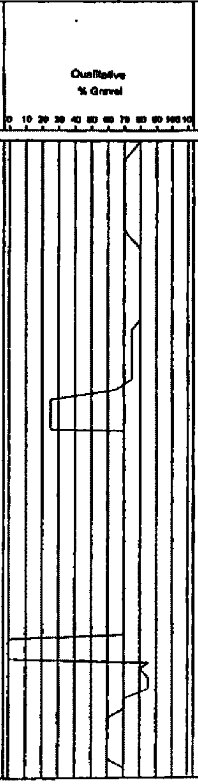
LOG OF BORING MFG-B4

(Page 4 of 4)

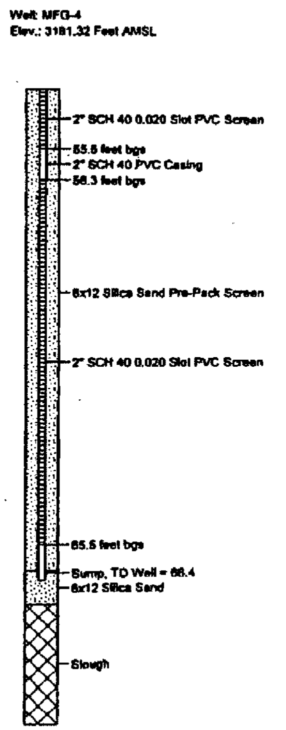
Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.6" Cores
Total Depth of Borehole 70 feet bgs

Start/Complete Date : 4-9-01 / 4-9-01
Boring/Well Location : NW corner of B.K. building
Approx. Surface Elev. : 3181.32 Feet AMSL
Measuring Point Elev. : 3181.8 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3181.8	DESCRIPTION	USCS	Samples	PID (ppm)	REMARKS
54		As above. Gravel and broken rock fragments up to 2.75-inch size, lots of gravel up to 1-inch size, some silt, minor clay.				
55	3127	Above grades to very fine sand, few to some fine sand, minor medium sand, some silt, minor clay, gravel as above.		25		
56	3126					
57	3125	SANDY GRAVEL, brown (7.5YR 4/4), gravel and cobble fragments up to 3.5-inch size, very fine to medium sand, minor coarse sand, some silt, wet to saturated.	GW	26	23.4	First encountered water at approximately 56.8 feet bgs.
58	3124	As above. Gravel up to 2.5-inch size, very fine to fine sand, few medium sand, some silt and clay.			3.2	Collected subsurface sample MFG-B2(58').
59	3123	Above grades to gravel up to 2-inch size, lots of pea gravel, fine to coarse sand, few very coarse sand, few silt, relatively clean.		27		
60	3122					
61	3121	GRAVELLY SAND, brown (7.5YR 4/3), medium sand, minor coarse sand, few fine to very fine sand, minor silt, gravel up to 2-inch size, few pea gravel, clean, saturated.	SP	28	4.3	
62	3120	SANDY GRAVEL, brown (7.5YR 4/3), most gravel up to 1-inch size, few gravel up to 2-inch size, medium to coarse sand, minor fine to very fine sand, very few silt, clean, saturated. Grades to medium to very coarse sand, few fine sand, minor silt.				
63	3119	Above grades to fine to coarse sand, few very coarse sand, lots of gravel up to 1-inch size, gravel up to 3-inch size.				
64	3118		GW	29		
65	3117	Above grades to gravel up to 2-inch size, lots of pea gravel, very fine to medium sand, few coarse sand, some silt.				
66	3116	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 3-inch size, one cobble 4.5-inch size, very fine to medium sand, lots of silt, minor clay, saturated.				
67	3115	SAND, brown (7.5YR 4/3), medium to very coarse sand, very minor silt, clean, saturated.	SP	30		
68	3114	SANDY GRAVEL, brown (7.5YR 4/3), most gravel up to 1-inch size, cobbles up to 4-inch size, medium to coarse sand, few fine sand, minor silt, clean, saturated. As above. Gravel up to 3-inch size, fine to medium sand, some coarse sand, some to few very fine sand and silt, minor clay.	GW			
69	3113	As above at 67.5 feet bgs. Gravel up to 2-inch size, lots of pea gravel, sand as above, few silt.		31		
70	3112					
71	3111	Total depth of borehole = 70 feet below ground surface.				
72	3110					



Well: MFG-4
Elev.: 3181.32 Feet AMSL



LOG OF BORING MFG-B5

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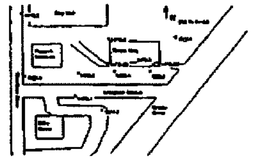
Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10577
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002



LOG OF BORING MFG-B5

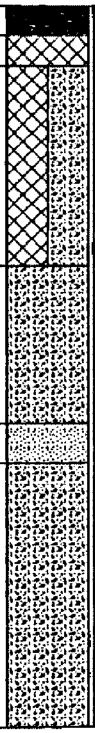
(Page 1 of 4)

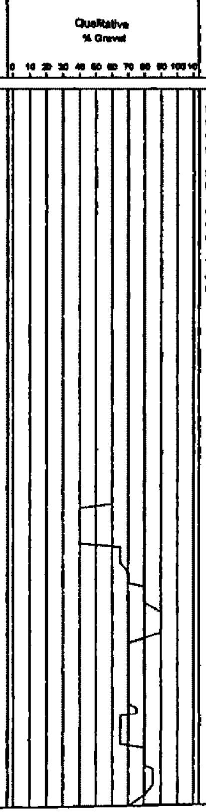
Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 70 feet bgs

Start/Complete Date : 4-9-01 / 4-9-01
Boring/Well Location : BK drive thru
Approx. Surface Elev. : 3182.5 Feet AMSL
Measuring Point Elev. : 3182.07 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3182.5	DESCRIPTION	USCS	Samples	PID (ppm)
0	3182	Asphalt and Concrete.		1	0
1	3181	SANDY GRAVEL, brown (7.5YR 4/2), gravel up to 2-inch size, fine to medium sand, some dark staining on rocks and gravel, very slightly moist. Fill.			
2	3180	SANDY GRAVEL, brown (7.4YR 4/2), gravel and broken cobbles up to 3.5-inch size, fine to medium sand, few coarse sand. Possibly fill.			
3	3179			2	
4	3178				
5	3177				
6	3176	SANDY GRAVEL, brown (7.5YR 4/3), gravel and broken cobbles up to 3.5-inch size, fine to medium sand, few very fine sand, few roots, slightly moist.			4.0
7	3175			3	
8	3174		GW		1.0
9	3173				
10	3172	GRAVELLY SAND, brown (7.5YR 4/3), gravel up to 2.75-inch size, cobble up to 4.5-inch size, coarse to very coarse sand, some medium sand, minor fine sand, few mica, sand and very small gravel has some granitic composition, slightly moist.	SW	4	
11	3171	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 2-inch size, fine-sand, some medium and very fine sand.			
12	3170	As above. Brown (7.5YR 4/4), gravel up to 2.75-inch size, medium sand, few fine sand. As above. Gravel and cobbles up to 3.25-inch size, medium to very coarse sand, few fine sand, some silt and clay.		5	0.8
13	3169	As above. Brown (7.5YR 4.3), Gravel up to 2-inch size, one cobble 3.5-inch size, very fine to fine sand, few medium sand, few silt, minor clay, moist.			
14	3168	As above. Gravel and cobbles up to 3-inch size, fine to medium sand, few coarse sand, minor very fine sand and silt.	GW	6	
15	3167	As above. Brown (7.5YR 4/2), gravel and cobble up to 3-inch size, broken cobbles up to 4-inch size, most gravel up to 1-inch size, very fine to medium sand, very slightly moist.		7	1.1
16	3166	As above. Brown (7.5YR 4/3), gravel up to 1-inch size, few gravel up to 2-inch size, medium sand, some fine sand.		8	5.0
17	3165	As above. Brown (7.5YR 4/2), gravel and cobbles up to 4-inch size, most gravel up to 1-inch size, fine to medium sand, some very fine sand, some silt, few to minor clay, few mica.		9	8.8
18					

GRAPHIC





REMARKS

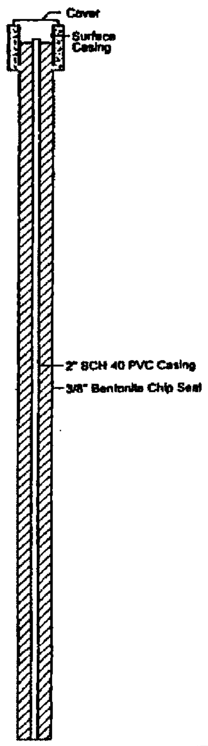
PID readings were collected with a Photovac Photoionization Detector calibrated with 100 ppm Isobutylene gas.

PID readings were collected at the bottom of each core interval.

GW = Gravel and cobbles.
GP = Gravel up to 2-inch size and no cobbles.

Throughout core gravel is rounded to occasionally subrounded; sand ranges from rounded to slightly subangular.

Well: MFG-5
Elev.: 3182.07 Feet AMSL



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LOG OF BORING MFG-B5

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Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2196

Characterization of the Lithostratigraphic Factors Controlling Petroleum
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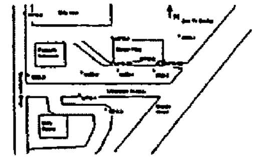
Natalie J. Morrow
Geology, M.S. Thesis   University of Montana, Missoula   Spring 2002



LOG OF BORING MFG-B5

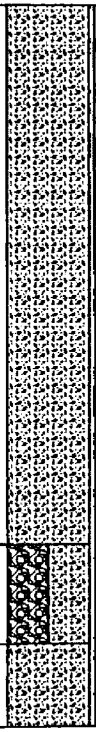
(Page 2 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 70 feet bgs

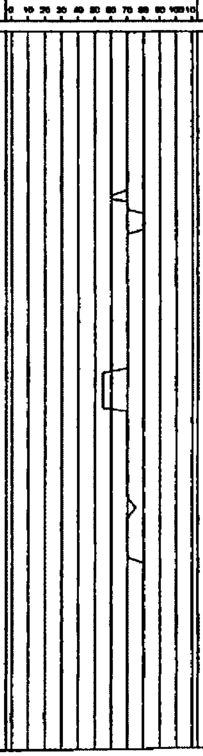
Start/Complete Date : 4-9-01 / 4-9-01
Boring/Well Location : BK drive thru
Approx. Surface Elev. : 3182.5 Feet AMSL
Measuring Point Elev. : 3182.07 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3182.5	DESCRIPTION	USCS	Samples	PID (ppm)	REMARKS
18	3184	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 2-inch size, fine sand, some medium and very fine sand.	GW			
19	3183			9		
20	3182	SANDY GRAVEL, brown (7.5YR 5/4), gravel and cobbles up to 3-inch size, most gravel up to 1-inch size, medium to coarse sand few fine, very fine and very coarse sand, minor silt and clay, very slightly moist.			5.4	
21	3181			10		
22	3180	SANDY SILTY GRAVEL, dark reddish brown (5YR 3/3), gravel and cobbles as above, silt with very fine sand, slightly moist. Some yellowish red (5YR 4/6) cementing material, possibly limonite.			9.2	Coloring indicates possible hydrocarbon contamination. No odor.
23	3159	SANDY GRAVEL, weak red (10YR 5/2), cobbles up to 4.5-inch size, gravel up to 1-inch size, fine to medium sand, some silt, some silt, lots of broken rock fragments, very slightly moist.		11		
24	3158					
25	3157	As above, Gravel up to 2.75-inch size, medium sand, few fine and coarse sand.		12	2.5	
26	3156	As above. One 5-inch size cobble, gravel up to 1-inch size, very fine to fine sand, minor medium sand, some rock flour and broken rock fragments.		13	10.3	
27	3155				3.8	
28	3154	As above. Gravel up to 2.5-inch size, most gravel up to 1.5-inch size, fine to medium sand, few silt and clay.		14	4.1	
29	3153	As above. Cobbles up to 4-inch size, gravel up to 2.5-inch size, fine sand, some medium and very fine sand, few coarse sand, minor silt and clay.				
30	3152			15		
31	3151	SANDY GRAVEL, as above at 29 feet bgs, decrease in sand. "Caliche" fragments.			3.5	
32	3150			16		
33	3149				5.8	
34	3148	SANDY GRAVEL, brown (7.5YR 4/3), as above at 29 feet bgs, slightly moist.	GW	17		
35	3147					
36						

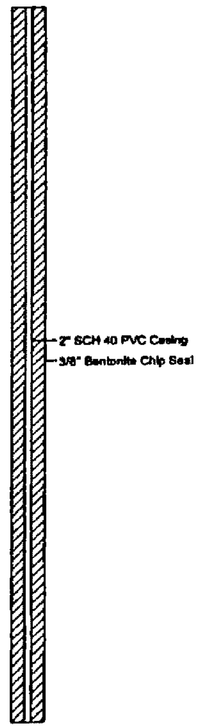
GRAPHIC



Qualitative % Gravel



Well: MFG-5
Elev.: 3182.07 Feet AMSL



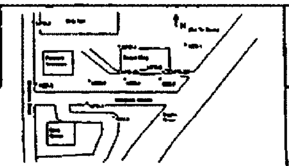
LOG OF BORING MFG-B5

(Page 3 of 4)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002



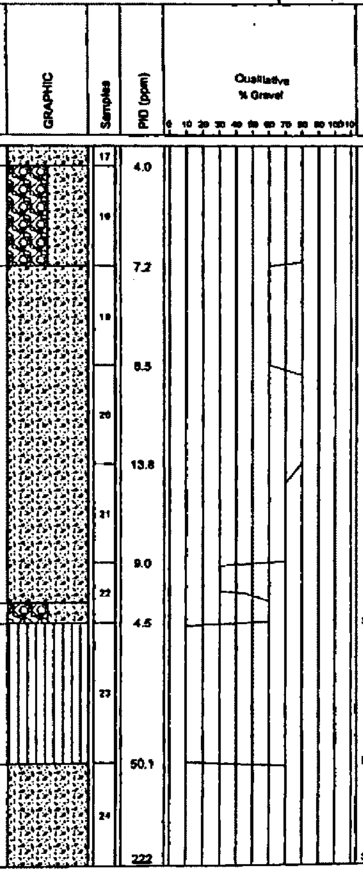
LOG OF BORING MFG-B5

(Page 3 of 4)

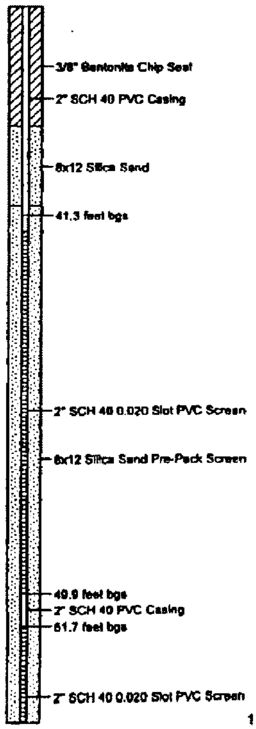
Drilling Agency : Boart Longyear
Drilling Method & SS : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 70 feet bgs

Start/Complete Date : 4-9-01 / 4-9-01
Boring/Well Location : BK drive thru
Approx. Surface Elev. : 3182.5 Feet AMSL
Measuring Point Elev. : 3182.07 Feet AMSL
Logged By : Natalie Morrow

Depth In Feet	Surf. Elev. 3182.5	DESCRIPTION	USCS	Samples	PID (ppm)	REMARKS
36						
	3146	SANDY GRAVEL, brown (7.5YR 4/3), as above at 29 feet bgs, slightly moist.	GW	17	4.0	
37		SANDY GRAVEL, as above at 36.5 feet bgs, increase in broken rock fragments, gravel up to 3-inch size, "caliche" fragments.		18		
	3145					
38						
	3144					
39		SANDY GRAVEL, brown (7.5YR 4/3), as above at 29 feet bgs, grades to very fine to fine sand, some silt, very slightly moist to slightly moist.			7.2	
	3143			19		
40						
	3142					
41						
	3141	SANDY GRAVEL, broken rock fragments up to 1-inch size, lots of rock flour (white 7.5YR 8/1), fine to medium sand.			8.5	
42				20		
	3140					
43			GW			
	3139	As above. Gravel up to 2.75-inch size, most gravel up to 1/2-inch size, fines as above.				
44		As above. Broken cobbles up to 5-inch size, broken rock fragments up to 1.5-inch size, lots of rock flour, fine to medium sand.			13.8	
	3138					
45				21		
	3137					
46					9.0	
	3136	As above. Brown (10YR 5/3), gravel up to 2.5-inch size, very fine sand, few medium sand, some silt, rock flour.				
47				22		
	3135	Above grades to very fine to fine sand and silt, some medium sand, few coarse sand, lots of broken rock fragments up to 1.5-inch size. "Caliche" fragments.			4.5	Slight hydrocarbon odor
48						
	3134	GRAVELLY SILT, light yellowish brown (10YR 4/4), silt, minor fine and medium sand, gravel up to 1-inch size, most gravel up to 1/4-inch size, dry.				
49						
	3133		ML	23		
50						
	3132					
51					50.1	Hydrocarbon odor.
	3131	SANDY GRAVEL, brown (7.5YR 4/3), gravel and cobbles up to 4-inch size, most gravel up to 1-inch size, very fine to medium sand, some coarse sand, slightly moist.				
52						
	3130	Above grades coarser, most gravel up to 2-inch size.	GW	24		
53		SANDY GRAVEL, brown (7.5YR 4/3), gravel and cobbles up to 4.75-inch size, most gravel up to 1.5-inch size, very fine to medium sand, few silt, few coarse sand, some silt and clay, moist.			222	Strong hydrocarbon odor.
	3129					
54						



Well: MFG-5
Elev.: 3182.07 Feet AMSL



LOG OF BORING MFG-B5

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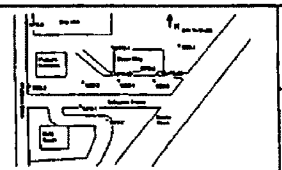
Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis   University of Montana, Missoula   Spring 2002



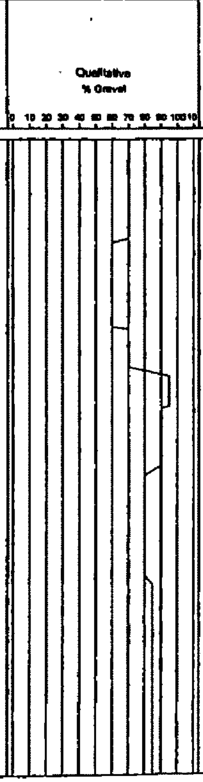
LOG OF BORING MFG-B5

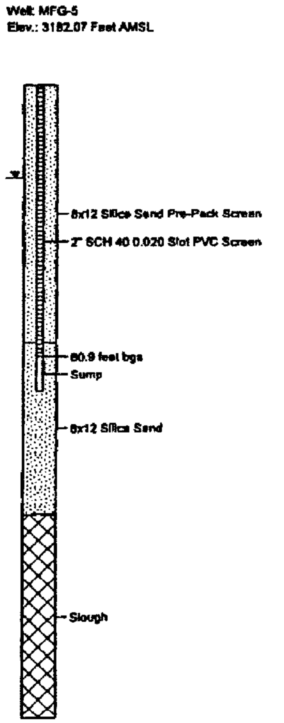
(Page 4 of 4)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 8" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Cores
Total Depth of Borehole 70 feet bgs

Start/Complete Date : 4-9-01 / 4-9-01
Boring/Well Location : BK drive thru
Approx. Surface Elev. : 3182.6 Feet AMSL
Measuring Point Elev. : 3182.07 Feet AMSL
Logged By : Natalie Morrow

Depth in Feet	Surf. Elev. 3182.5	DESCRIPTION	USCS	Samples	PID (ppm)	REMARKS
54	3128	SANDY GRAVEL, brown (7.5YR 4/3), gravel and cobbles up to 4-inch size, most gravel up to 1-inch size, very fine to medium sand, some coarse sand, slightly moist.	GW			
55	3127	As above. Saturated.		25		
56	3126	SILTY SANDY GRAVEL, brown (7.5YR 4/3), some gray staining, one cobble up to 4-inch size, gravel up to 3-inch size, fine to medium sand, some very fine and coarse sand, somewhat compact saturated.			901	First encountered water at approx. 56 ft bgs. Very strong hydrocarbon odor, gray hydrocarbon staining. Subsurface sample collected: MFG-B5(56.5 ft).
57	3125			26	1265	Strong hydrocarbon odor. Subsurface sample collected: MFG-B5(57.5 ft).
58–59	3124	As above. Increase in gravel content and up to 2.5-inch size.		27		
60	3123–3122	As above. Gravel and cobbles up to 3-inch size, most gravel up to 1-inch size, fine to medium sand, some coarse to very coarse sand, minor silt, clean, approximately 5 percent sand/fines.			776	Diminishing hydrocarbon odor.
61	3121	As above. Gravel as above, increase in sand/fines to approximately 10 percent, fine to coarse sand, few silt.		28		
62	3120	As above. Cobbles up to 3.5-inch size, increase in sand and fines to approximately 20 percent.			45.4	
63–64	3119–3118			29		
65	3117	As above. One cobble 5-inch size, fine to medium sand, some silt, few to minor clay. Grades to fine to coarse sand, few silt, minor clay.			48.9	
66–67	3116–3115	As above.		30	48	
68–69	3114–3113	As above.		31	24.0	
70–72	3112–3111	Total depth of borehole = 70 feet below ground surface.				





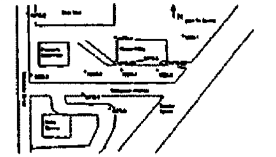
LOG OF BORING MFG-B6

(Page 1 of 2)

Hi-Noon Petroleum
Burger King Petroleum Release Site
Facility ID# 32-10677
Release# 2198

Characterization of the Lithostratigraphic Factors Controlling Petroleum
Hydrocarbon Migration in a Portion of the Missoula Valley Aquifer, Missoula, Montana.

Natalie J. Morrow
Geology, M.S. Thesis University of Montana, Missoula Spring 2002



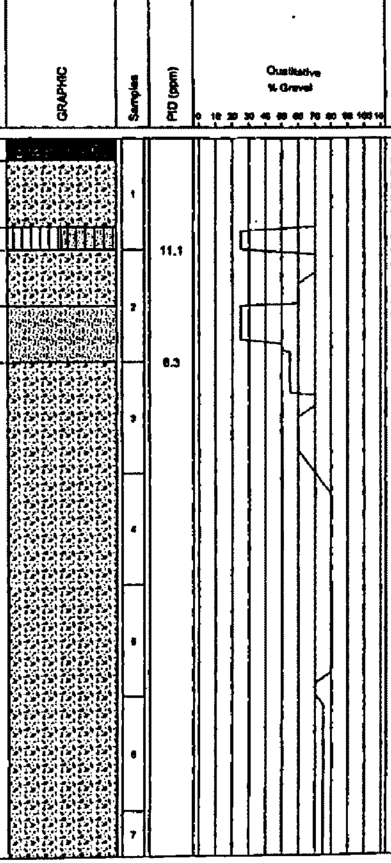
LOG OF BORING MFG-B6

(Page 1 of 2)

Drilling Agency : Boart Longyear
Drilling Method & Bit : Rotosonic, 6" diam. borehole
Drill Rig : Boart Longyear Rotosonic
Sample Type : Continuous 4.5" Core
45 deg angled borehole 28 ft long, 20 ft vert dist. bgs

Start/Complete Date : 4-9-01 / 4-9-01
Boring/Well Location : BK drive thru
Approx. Surface Elev. : 3182
Logged By : Natalie Morrow

Depth in Feet	DESCRIPTION	USCS	Samples	PID (ppm)
0	Asphalt.			
1	SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 3/4-inch size, fine sand, few coarse and medium sand, some silt, slightly moist. Fill. SANDY GRAVEL, brown (7.5YR 4/3), gravel up to 2.5-inch size, cobbles up to 4-inch size, fine to coarse sand, some silt, slightly moist.	GW	1	
2	SILT, very dark brown (7.5YR, 2.5/2), some very fine to fine sand, few mediume sand, gravel up to 1.5-inch size, slightly moist. Fill.	ML/SM		11.1
3	SANDY GRAVEL, dark brown (7.5YR 3/2) to strong brown (7.5YR 5/6), gravel up to 2.5-inch size, very fine to fine sand, few medium sand, slightly moist.	GW	2	
4	GRAVELLY SAND, strong brown (7.5YR 5/6), fine to medium sand, gravel up to 3/4-inch size, slightly moist. As above. Black (7.5YR 2.5/1), moist. As above at 3.75 feet bgs.	SP		
5	SANDY GRAVEL, black (2.5YR, 2.5/1), gravel up to 1.5-inch size, lots of pea gravel, fine to medium sand, few coarse sand, slightly moist. As above. Brown (7.5YR 5/4), gravel up to 2.75-inch size, broken cobble 5.5-inch size, medium sand, some fine sand, roots.	GW	3	6.3
7	SANDY GRAVEL, brown (7.5YR 5/4), gravel up to 3-inch size, most gravel up to 2-inch size, very fine to medium sand, few coarse and very coarse sand, very slightly moist.	GW	4	
11	As above.	GW	5	
13		GW	6	
15	As above.	GW	7	
16				



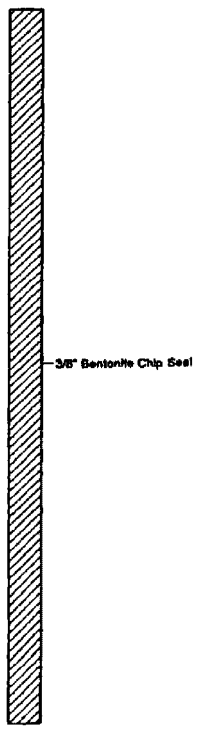
REMARKS

PID was inoperable after 8 feet bgs. No PID readings were collected beyond this depth. There was no hydrocarbon odors observed during drilling or logging.

GW = Gravel and cobbles.
GP = Gravel up to 2-inch size and no cobbles.

Throughout core gravel is rounded to occasionally subrounded; sand ranges from rounded to slightly subangular.

Well: MFG-B6
Elev.:



LOG OF BORING MFG-B6

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Hi-Noon Petroleum
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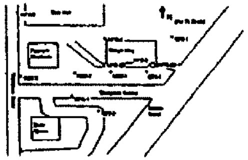


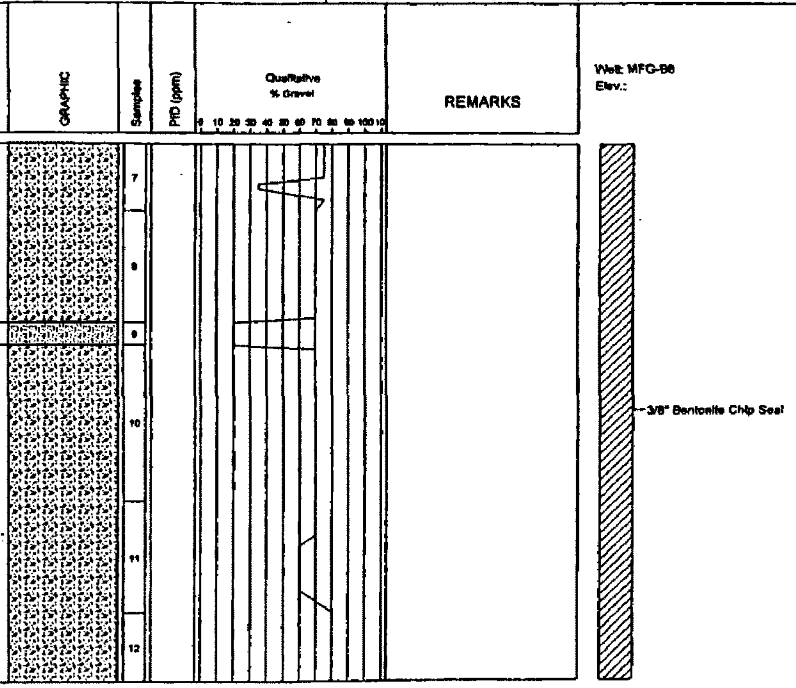
LOG OF BORING MFG-B6

(Page 2 of 2)

Drilling Agency	: Boart Longyear	Start/Complete Date	: 4-9-01 / 4-9-01
Drilling Method & Bit	: Rotosonic, 6" diam. borehole	Boring/Well Location	: BK drive thru
Drill Rig	: Boart Longyear Rotosonic	Approx. Surface Elev.	: 3182
Sample Type	: Continuous 4.5" Cores	Logged By	: Natalie Morrow

45 deg angled borehole 28 ft long, 20 ft vert dist. bgs

Depth in Feet	DESCRIPTION	USCS	Samples
16	SANDY GRAVEL, (7.5YR 4/3), gravel up to 3-inch size, most gravel up to 1.5-inch size, fine to medium sand, few silt, minor mica, very slightly moist.	GW	
17	0.25 inch SILT layer. As above at 4.6 to 4.7 feet bgs.		7
	As above.		
18	SANDY GRAVEL, brown (7.5YR 4/4), gravel up to 1.5-inch size, cobbles up to 4.5-inch size, very fine sand and silt, lots of rock flour, very slightly moist.		
19			8
	As above. Gravel up to 1-inch size, fine to medium sand, few coarse to very coarse sand.		
20	GRAVELLY SAND, brown (7.5YR 4/4), fine to medium sand, few coarse and very coarse sand, gravel up to 1-inch size, very slightly moist.	SP	9
21	SANDY GRAVEL, brown (7.5YR 4/4), gravel up to 3-inch size, cobbles up to 6-inch size, fine to medium sand, few coarse sand, very slightly moist	GW	
22			10
23			
24	SANDY GRAVEL, brown (10YR 5/3), gravel up to 1.5-inch size, very fine to medium sand, minor coarse sand, very slightly moist.		
25			11
26	As above. Very pale brown (10YR 7/3), lots of rock flour, gravel up to 3.5-inch size, mostly broken rock fragments.		
27			12
28	Total length of borehole = 28 feet. Total vertical depth bgs = 20 feet.		
29			
30			
31			
32			



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APPENDIX D

WATER TABLE MODEL RESULTS

Water Table Model Setup

Initially, the potentiometric surface was drawn by hand to determine the flow direction at the Site using water table elevation data collected on April 14, 2001. The approximate direction of flow at the Site was determined to be to the southwest, approximately paralleling Brooks Street. This information was then used to align the model grid in the approximate direction of flow.

A two-layer steady state model was designed to simulate groundwater flow conditions at the Site and produce a water table map of the Site and surrounding area. Two layers were chosen after review of the lithostratigraphic logs, cross sections, and water table elevation data.

Layer 1 is defined as the subsurface zone between the ground surface and bottom of the Upper Unit (top of the Lower Unit; see Section 4). Within the modeled area, Layer 1 extends from the ground surface of 3,200 feet AMSL (northeastern boundary of the modeled area) to 3,110 feet AMSL. Layer 1 at the Site extends from approximately 3,182 feet AMSL to 3,110 feet AMSL. Layer 2 of the model extends from 3,110 feet AMSL to an estimated depth of 3,050 feet AMSL. Figure D1 in Appendix D shows the approximate divisions between Layer 1 and Layer 2 at the Site.

Constant head boundary conditions were set according to the MVA gradient calculated from water level elevation data obtained from the Missoula Water Quality district well located at the intersection of Blaine and Crosby streets and Mountain Water Company MWC-26 on Benton Avenue. The gradient over the modeled area is approximately 0.0014 ft/ft. No-flow boundaries were placed on each side of the model. The groundwater gradient for the MVA was calculated using data from Missoula Water Quality District and Mountain Water Company wells in the vicinity of the Site. The groundwater gradient calculated from these two wells producted a groundwater gradient of approximately 0.0014 ft/ft. In addition, the groundwater gradient for the Site was calculated between wells MFG-4 and MFG-1. Constant head boundaries were placed at the northeastern and southwestern boundaries of the model grid such that the gradient over the modeled area was approximately 0.0014 ft/ft. The wells at the Site were placed on the model grid as observation wells and the water table elevation data collected on April 14, 2001 was entered as calibration values.

No aquifer testing has been performed at the Site. Therefore, no site-specific hydraulic conductivity data exists for the Site. Hydraulic conductivity values, previously estimated for the MVA in the vicinity of the Site, were initially used in the model. The hydraulic conductivity values were based on simulations by Pracht (2001) in a numerical model of the MVA were used as inputs in this model. Pracht's study estimated hydraulic conductivity along a flow tube generally following Brooks Street. Three hydraulic conductivity values from Pracht's study were initially used in the model and include 36,000 ft/day, 25,000 ft/day and 21,700 ft/day. In addition, porosity, specific yield, and specific storage were estimated after reviewing the lithostratigraphic logs, grain size analyses, and cross sections. Porosity (0.20) and specific yield (0.12) values used in the model are consistent with those described by others.

MODEL INPUT VALUES

Parameter	Layer 1	Layer 2
Hydraulic Conductivity (ft/day)	$K_{x,y}$ = 4,000; K_z = 400	$K_{x,y}$ = 36,000; K_z = 3,600 $K_{x,y}$ = 19,000; K_z = 1,900 $K_{x,y}$ = 25,000; K_z = 2,500
Specific Storage (S_s: 1/ft)	0.00001	0.00001
Specific Yield (Sy)	0.12	0.15
Effective Porosity	0.20	0.20
Total Porosity	0.20	0.20
Constant Head Values: Top (Northeast boundary) = 3128.77 ft AMSL Bottom (Southwest boundary) = 3127.67 ft AMSL		

OBSERVATION WELL INPUT VALUES

Well Number	Observation Point (ft AMSL)	Observed Head (ft AMSL)
MSE-1	3130.22	3128.19
MSE-2	3129.16	3127.92
SES-1	3135.63	3128.35
SES-2	3137.04	3128.01
SES-3	3135.45	3128.15
SES-5	3134.94	3128.33
MFG-1	3130.22	3128.19
MFG-2	3125.51	3128.30
MFG-4	3125.42	3128.36
MFG-5	3129.77	3127.73

SITE STATIC WATER LEVEL ELEVATIONS
BURGER KING PETROLEUM RELEASE SITE
Page 1 of 2

Well SES-1
Measuring Point Elevation (ft AMSL) = 3181.38

Date	Depth to Water from PVC MP (ft)	Static Water Level Elevation (ft AMSL)
11/22/94	51.92	3129.46
8/30/95	47.99	3133.39
3/6/96	49.90	3131.48
6/13/96	41.76	3139.62
10/3/96	48.03	3133.35
6/4/97	40.20	3141.18
12/18/98	50.14	3131.24
5/14/99	49.30	3132.08
7/6/99	43.85	3137.53
3/22/00	52.61	3128.77
9/12/00	50.34	3131.04
12/22/00	51.63	3129.75
1/4/01	51.77	3129.61
1/10/01	52.03	3129.35
1/18/01	52.27	3129.11
2/1/01	52.74	3128.64
2/15/01	53.11	3128.27
3/3/01	53.48	3127.9
3/17/01	53.48	3127.9
4/1/01	53.26	3128.12
4/14/01	53.03	3128.35
6/1/01	49.25	3132.13

Well SES-3
Measuring Point Elevation (ft AMSL) = 3181.53

Date	Depth to Water from PVC MP (ft)	Static Water Level Elevation (ft AMSL)
11/22/94	52.28	3129.25
8/30/95	48.36	3133.17
3/6/96	50.28	3131.25
6/13/96	42.16	3139.37
10/3/96	48.50	3133.03
6/4/97	40.63	3140.9
12/18/98	50.51	3131.02
5/14/99	49.60	3131.93
7/6/99	44.20	3137.33
3/22/00	52.98	3128.55
9/12/00	50.73	3130.8
12/22/00	52.04	3129.49
1/4/01	52.17	3129.36
1/10/01	52.44	3129.09
1/18/01	52.66	3128.87
2/1/01	53.11	3128.42
2/15/01	53.46	3128.07
3/3/01	53.83	3127.7
3/17/01	53.84	3127.69
4/1/01	53.62	3127.91
4/14/01	53.38	3128.15
5/31/01	49.66	3131.87

Well SES-2
Measuring Point Elevation (ft AMSL) = 3182.58

Date	Depth to Water from PVC MP (ft)	Static Water Level Elevation (ft AMSL)
11/22/94	53.46	3129.12
8/30/95	49.63	3132.95
3/6/96	51.44	3131.14
6/13/96	43.33	3139.25
10/3/96	49.70	3132.88
6/4/97	41.85	3140.73
12/18/98	51.60	3130.98
5/14/99	50.90	3131.68
7/6/99	45.35	3137.23
3/22/00	54.10	3128.48
9/12/00	51.86	3130.72
12/22/00	53.18	3129.4
1/4/01	53.33	3129.25
1/10/01	53.61	3128.97
1/18/01	53.79	3128.79
2/1/01	54.26	3128.32
2/15/01	54.61	3127.97
3/3/01	54.98	3127.6
3/17/01	54.92	3127.66
4/1/01	54.79	3127.79
4/14/01	54.57	3128.01
5/31/01	50.92	3131.66

Well SES-5
Measuring Point Elevation (ft AMSL) = 3182.64

Date	Depth to Water from PVC MP (ft)	Static Water Level Elevation (ft AMSL)
8/30/95	49.31	3133.33
3/6/96	51.25	3131.39
6/13/96	43.18	3139.46
10/3/96	49.45	3133.19
6/4/97	41.60	3141.04
12/18/98	51.40	3131.24
5/14/99	50.70	3131.94
7/6/99	45.15	3137.49
3/22/00	53.91	3128.73
9/12/00	51.70	3130.94
12/22/00	52.98	3129.66
1/4/01	53.13	3129.51
1/11/01	53.41	3129.23
1/18/01	53.63	3129.01
2/1/01	54.10	3128.54
2/15/01	54.46	3128.18
3/3/01	54.81	3127.83
3/17/01	54.86	3127.78
4/1/01	54.63	3128.01
4/14/01	54.41	3128.23
6/1/01	52.56	3130.08

SITE STATIC WATER LEVEL ELEVATIONS
BURGER KING PETROLEUM RELEASE SITE
Page 2 of 2

Well MSE-1
Static Water Level Data
Measuring Point Elevation (ft AMSL) = 3182.82

Date	Depth to Water from PVC (ft)	Static Water Level Elevation (ft AMSL)
9/8/94	53.59	3129.23
11/22/94	51.78	3131.04
8/30/95	49.56	3133.26
3/6/96	51.50	3131.32
6/13/96	43.32	3139.50
10/3/96	49.64	3133.18
6/4/97	41.80	3141.02
12/18/98	51.68	3131.14
5/14/99	50.90	3131.92
7/6/99	45.45	3137.37
3/22/00	54.12	3128.70
9/12/00	51.94	3130.88
12/22/00	53.22	3129.60
1/4/01	53.38	3129.44
1/11/01	53.70	3129.12
1/18/01	53.88	3128.94
2/1/01	54.34	3128.48
2/15/01	54.70	3128.12
3/3/01	55.07	3127.75
3/17/01	55.08	3127.74
4/1/01	54.86	3127.96
4/14/01	54.63	3128.19
5/31/01	50.92	3131.90

Well MSE-2
Measuring Point Elevation (ft AMSL) = 3181.66

Date	Depth to Water from PVC MP (ft)	Static Water Level Elevation (ft AMSL)
9/8/94	52.64	3129.02
11/22/94	50.88	3130.78
8/30/95	48.74	3132.92
3/6/96	50.6	3131.06
6/13/96	42.67	3138.99
10/3/96	49.8	3131.86
6/4/97	40.92	3140.74
12/18/98	50.85	3130.81
5/14/99	50	3131.66
7/6/99	44.55	3137.11
3/22/00	53.34	3128.32
9/12/00	51.03	3130.63
12/22/00	52.38	3129.28
1/4/01	52.5	3129.16
1/10/01	52.8	3128.86
1/18/01	53	3128.66
2/1/01	53.46	3128.2
2/15/01	53.81	3127.85
3/3/01	54.2	3127.46
3/17/01	54.2	3127.46
4/1/01	53.97	3127.69
4/14/01	53.74	3127.92
5/31/01	50.04	3131.62

Well MFG-1
Static Water Level Data
Measuring Point Elevation (ft AMSL) = 3181.86

Date	Depth to Water from PVC (ft)	Static Water Level Elevation (ft AMSL)
4/14/01	53.64	3128.22
5/31/2001	49.98	3131.88

Well MFG-2
Static Water Level Data
Measuring Point Elevation (ft AMSL) = 3180.01

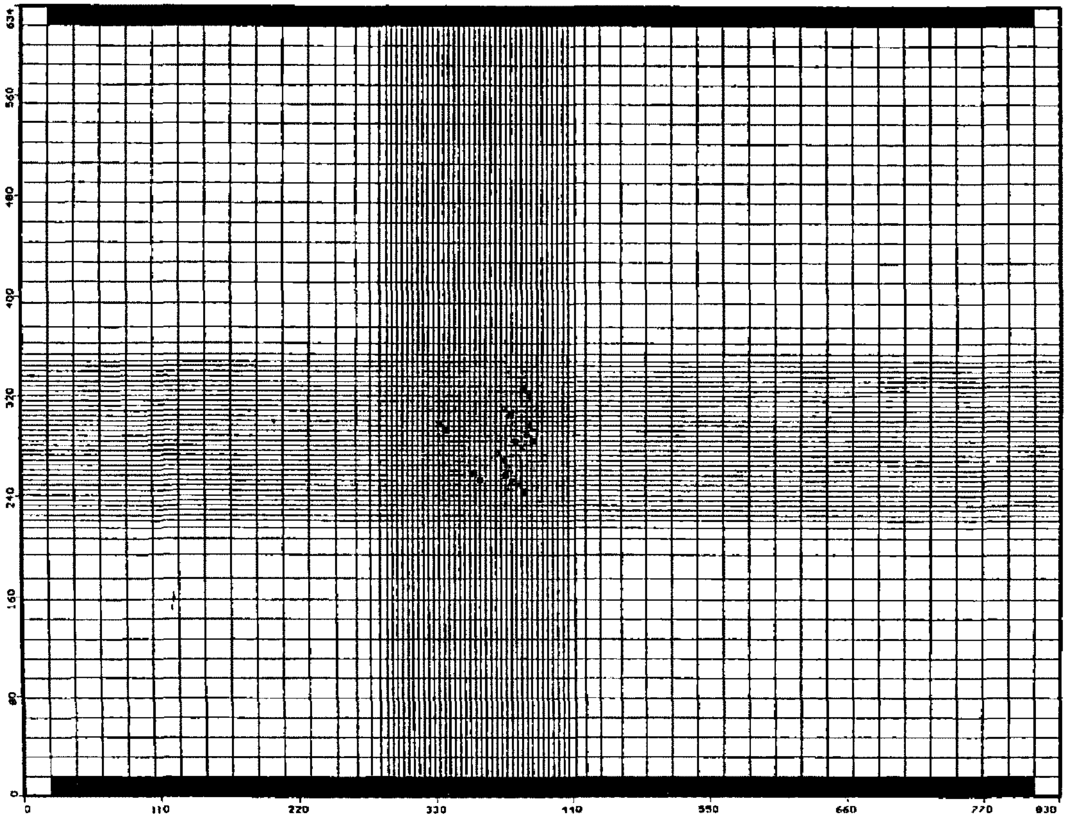
Date	Depth to Water from PVC (ft)	Static Water Level Elevation (ft AMSL)
4/14/01	51.71	3128.30
5/31/2001	47.98	3132.03

Well MFG-4
Static Water Level Data
Measuring Point Elevation (ft AMSL) = 3181.32

Date	Depth to Water from PVC (ft)	Static Water Level Elevation (ft AMSL)
4/14/01	52.96	3128.36
6/1/2001	49.20	3132.12

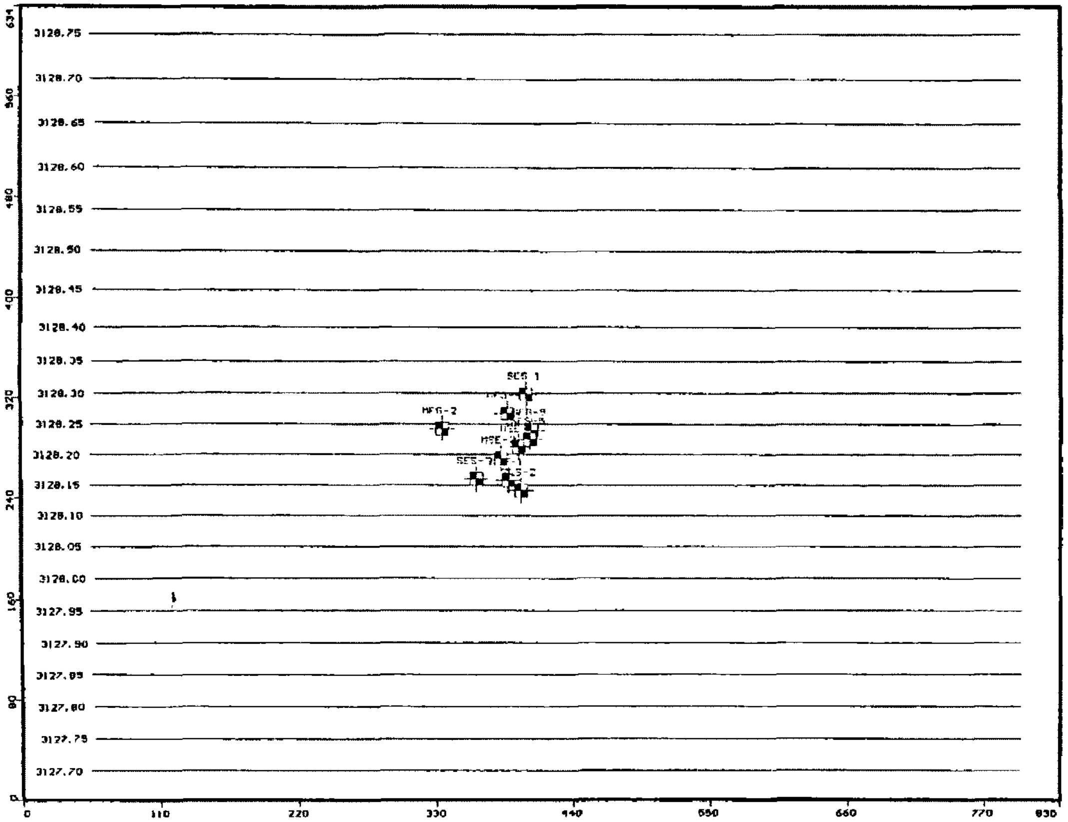
Well MFG-5
Static Water Level Data
Measuring Point Elevation (ft AMSL) = 3182.07

Date	Depth to Water from PVC (ft)	Static Water Level Elevation (ft AMSL)
4/14/01	—	—
6/1/2001	50.06	3132.01



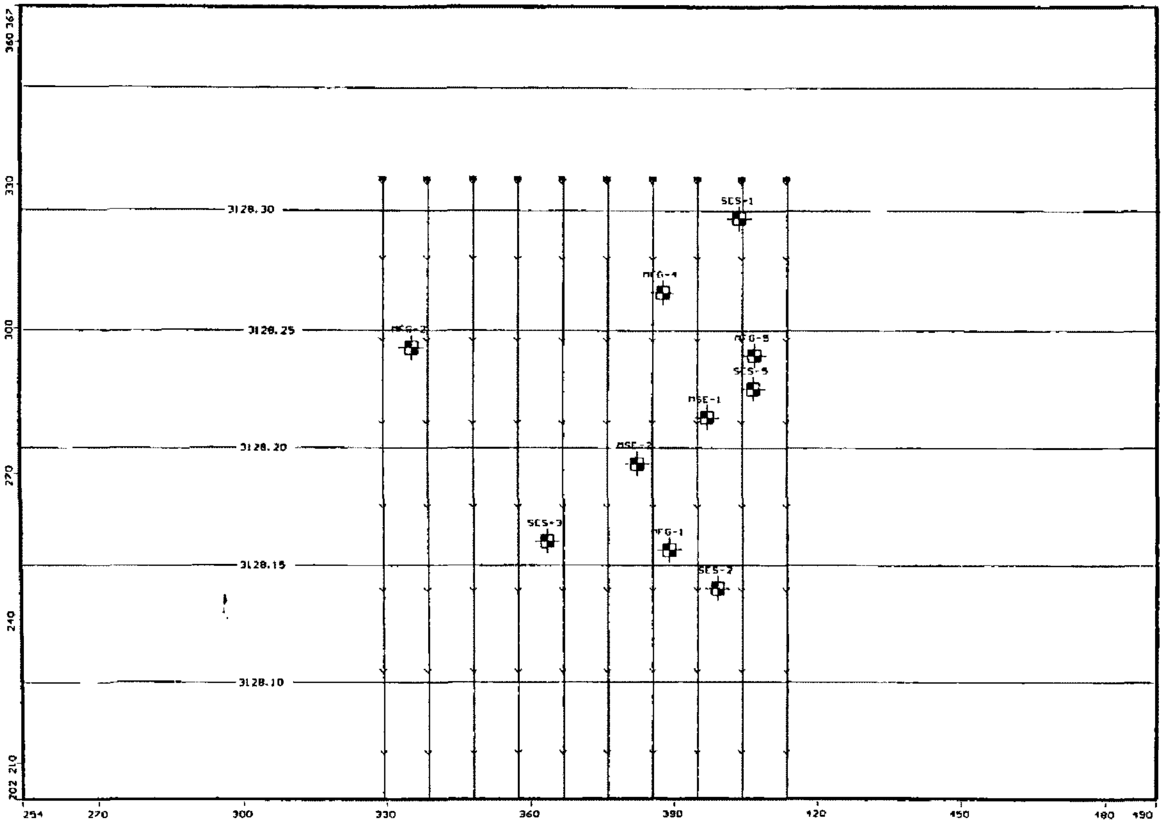
MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: Buger King Site
Modeller: Natalie Morrow
9 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 2



MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: Buger King Site
Modeller: Natalie Morrow
10 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1

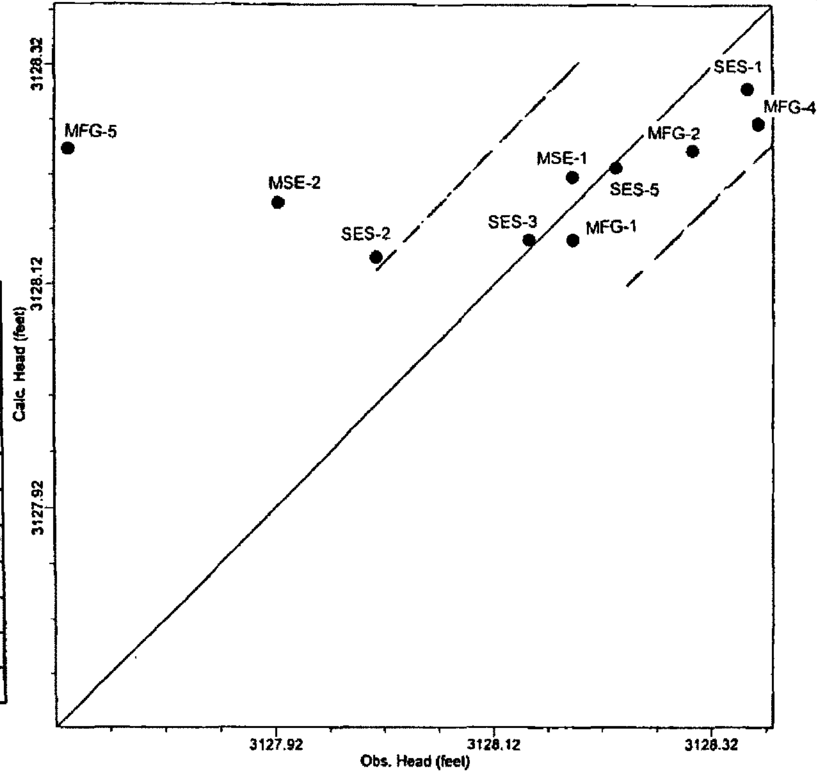


MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: Buger King Site
Modeller: Natalie Morrow
9 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1

Calculated vs. Observed Head : Steady state

Well #	Observed (ft AMSL)	Calculated (ft AMSL)
MSE-1	3128.19	3128.22
MSE-2	3127.92	3128.19
SES-1	3128.35	3128.30
SES-2	3128.01	3128.14
SES-3	3128.15	3128.16
SES-5	3128.23	3128.22
MFG-1	3128.19	3128.16
MFG-2	3128.30	3128.24
MFG-4	3128.36	3128.26
MFG-5	3127.73	3128.24



Num.Points : 10
Mean Error : 0.07042773 (feet)
Mean Absolute : 0.119416 (feet)
Standard Error of the Estimate : 0.05958162 (feet)
Root mean squared : 0.1921192 (feet)
Normalized RMS : 30.49511 (%)

N. Morrow
M.S. Thesis - U of Montana, Missoula
Burger King Site

APPENDIX E

WATER LINE RUPTURE DATA AND WATER LINE RUPTURE MODEL RESULTS

Water Line Rupture Data

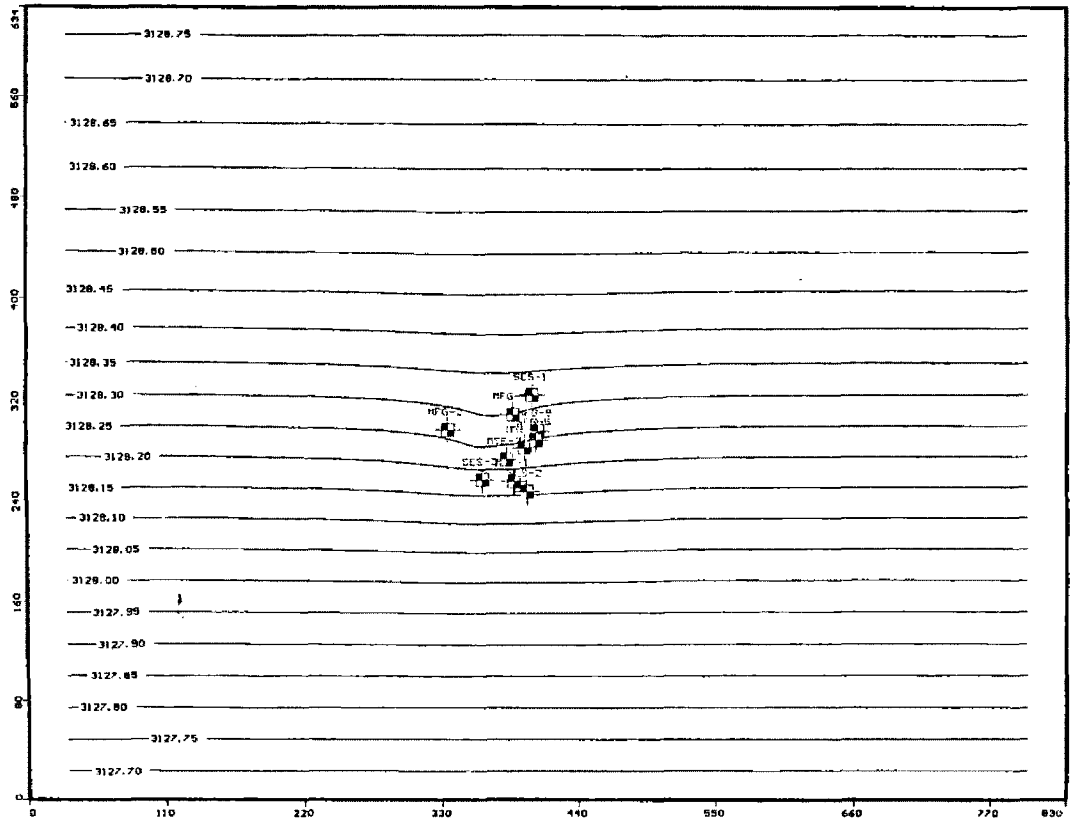
After contacting Mountain Water Company in May 2001, a copy of Service Order Number 35585 (the "Service Order"), dated April 14, 1990 was obtained via facsimile. The first Mountain Water Company service call pertaining to potential water line leaks at Burger King was made on April 15, 1990. At that time, the customer requested that Mountain Water Company locate a suspected water line break. The work was delayed at the time of the service call due to high wind conditions; locating the break(s) was not completed until April 19, 1990.

According to a sketch provided with the Service Order, the water line was(is) located near the northwest corner of the Burger King building and ran approximately northwest until connecting to the main service line in the alley (see Figure 38). In the sketch, the main service line appeared to run parallel with the alley until it connected to the water main under Washburn Street. In addition, the sketch also showed that 1503 Livingston (the Farmer's Insurance building) connected to the main service line in the alley. The sketch showed that the 1503 Livingston service connection ran north, perpendicular to the building.

The results of Mountain Water Company's investigation revealed several potential breaks in the line. One potential break was located near the northwest corner of the Burger King building; a second was located north of the Burger King drive-through entrance; and a third was located east of the connection between the service line for 1503 Livingston and the water line in the alley, also near the Burger King drive-through (Figure 38). According to the Service Order, Burger King was informed that replacement of their service line was necessary from the main water line under Washburn Street to the connection at the Burger King building. The date the water was shut off to the line and replacement of the service line is unknown.

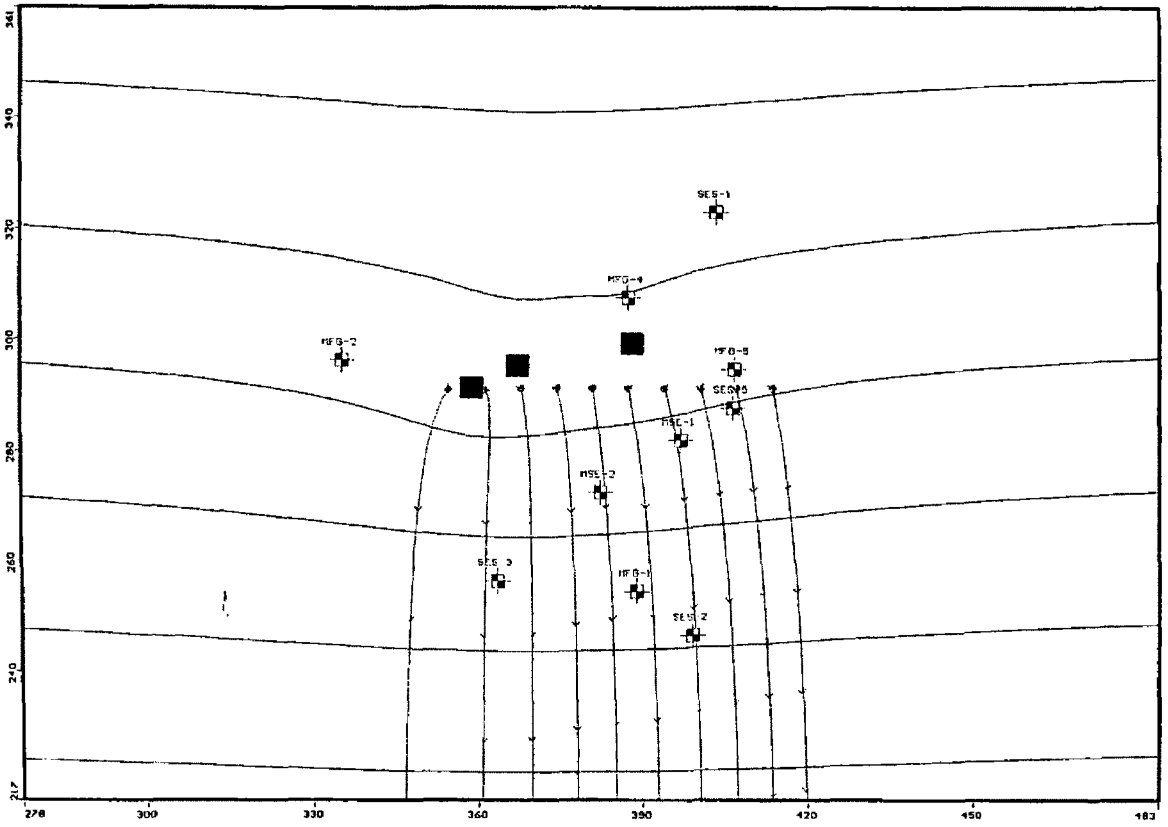
According to Mountain Water Company records, the water line servicing Burger King, at that time and currently, is two inches in diameter. Mountain Water Company personnel stated this line would supply a maximum of 170 gallons per minute (gpm). Therefore, during a complete water line rupture, approximately 170 gpm would be lost to the subsurface. The total volume of water lost to the subsurface at the Site during the rupture is unknown; however, the maximum total volume can be estimated using the above information. Approximately five days lapsed between the reporting of the service line problems until Mountain Water Company located the line breaks. The additional amount of time required to repair the water line is unknown. In addition, the line may have been leaking prior to the final line rupture.

Estimating the of volume lost in five days at a rate of 170 gpm would provide an estimate of the "worst-case senario" of the volume of water discharged into the subsurface at the Site. Under this scenario, the volume of water lost over the 5-day period would have been approximately 1.2 million gallons. Probably a more ideal scenario would be half that volume at approximately 600,000 gallons. After the discovery of the ruptured water line, an additional amount of water would have been leaking into the subsurface until the water line was repaired. The date of the water line repair is unknown. Additionally, prior to the water line rupture, the water line had probably been leaking at an unknown rate and for unknown period of time and would have also been discharging water to the subsurface. The water line rupture event is believed to be one important control on contaminant migration at the Site.



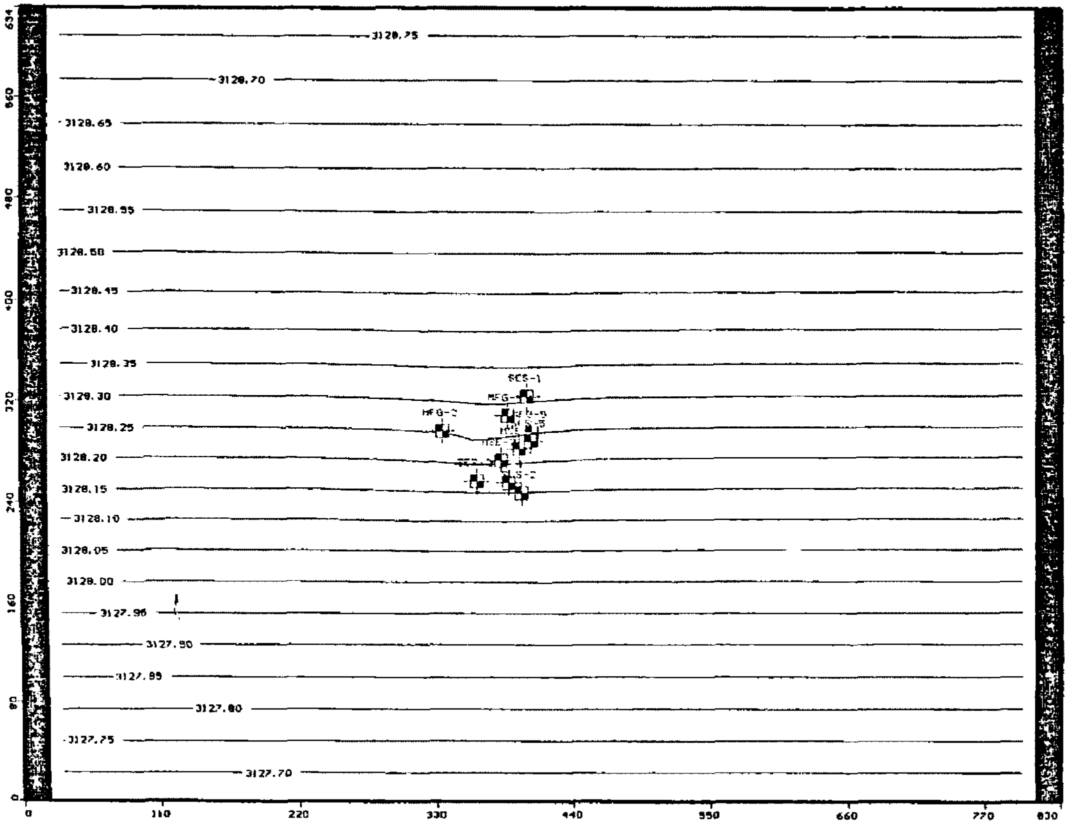
MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: WL Rupture – Worst Case
Modeller: Natalie Morrow
10 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1



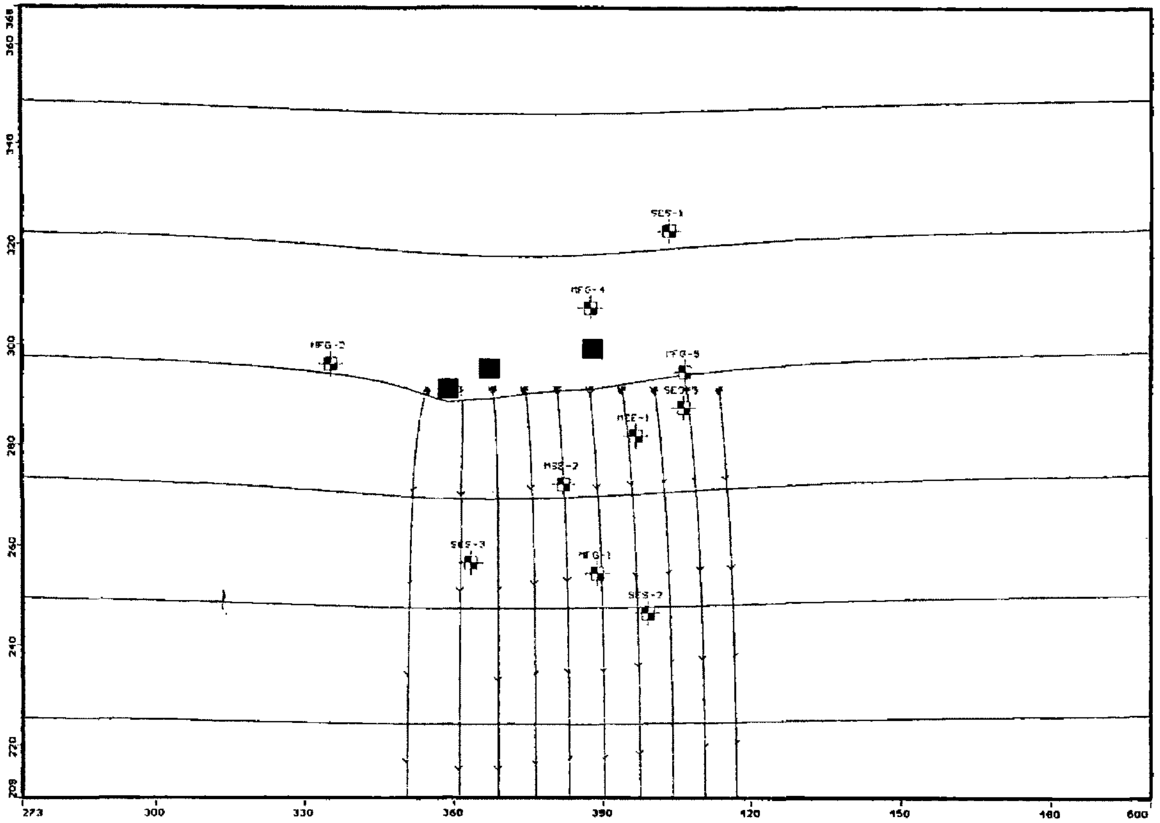
MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: WL Rupture – Worst Case
Modeller: Natalie Morrow
10 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1



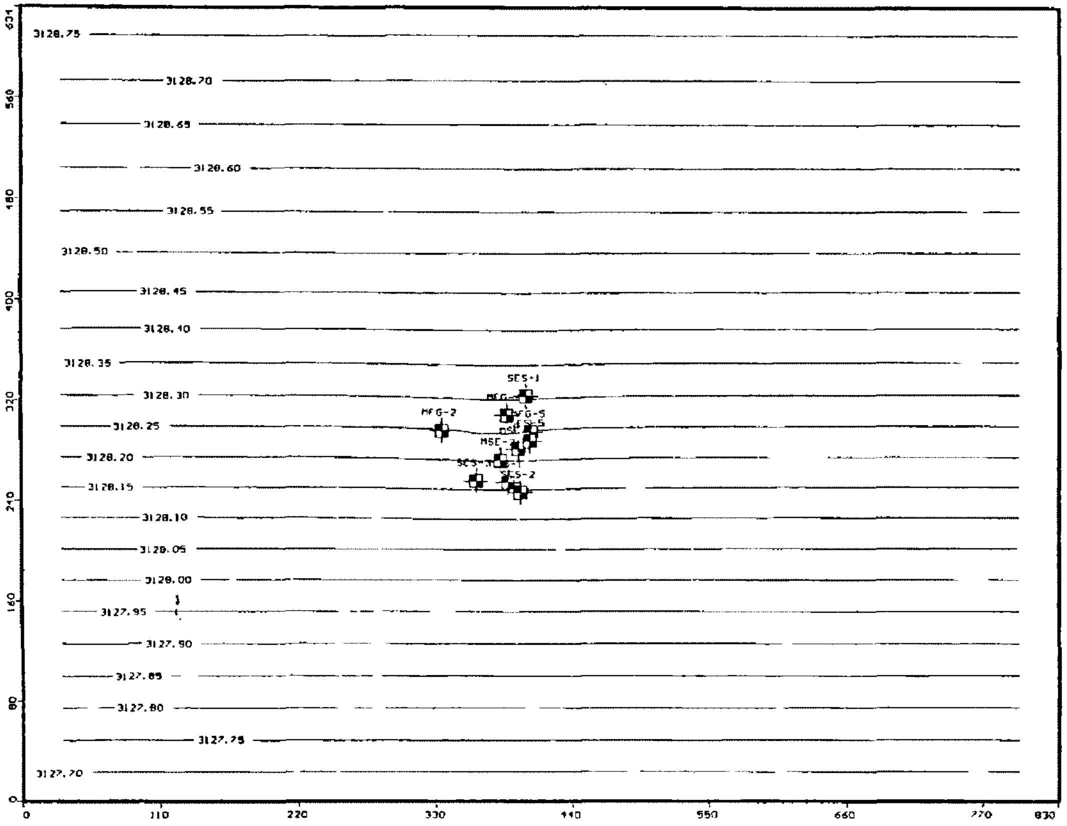
MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: WL Rupture – Half Case
Modeller: Natalie Morrow
10 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1



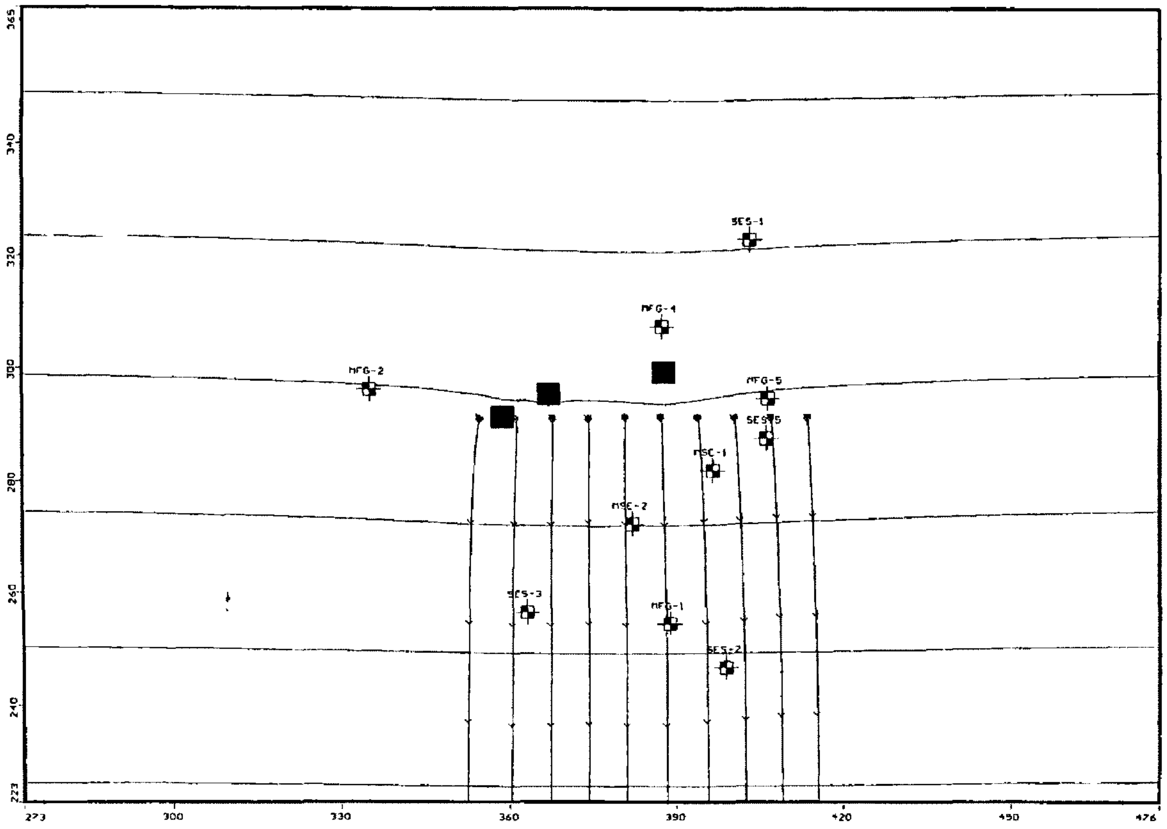
MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: WL Rupture – Half Case
Modeller: Natalie Morrow
10 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1



MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: WL Rupture – Weighted
Modeller: Natalie Morrow
9 Mar 02

Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1



MFG, Inc.
Project: M.S. Thesis –U of Montana
Description: WL Rupture – Weighted
Modeller: Natalie Morrow
9 Mar 02

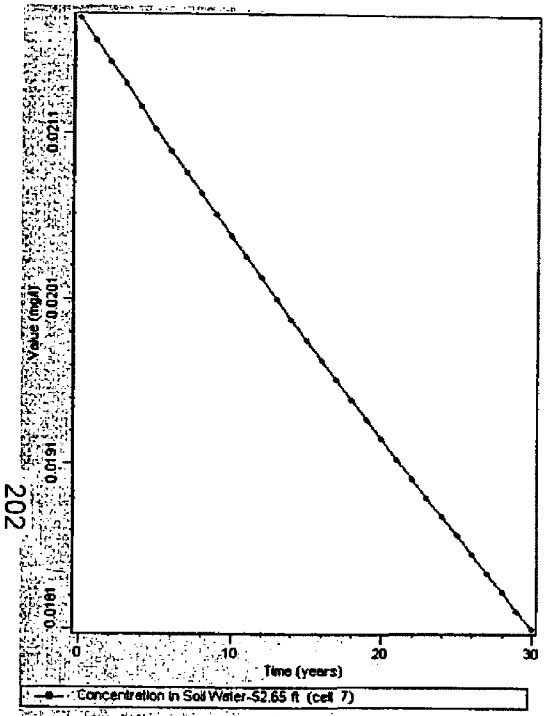
Visual MODFLOW v.2.8.2, (C) 1995–1999
Waterloo Hydrogeologic, Inc.
NC: 72 NR: 66 NL: 2
Current Layer: 1

APPENDIX F

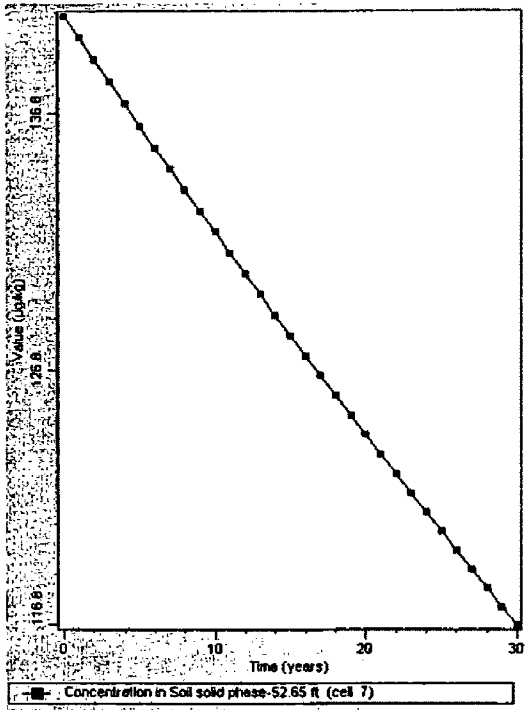
VADOSE ZONE MODEL RESULTS

VADOSE ZONE MODEL INPUT PARAMETERS

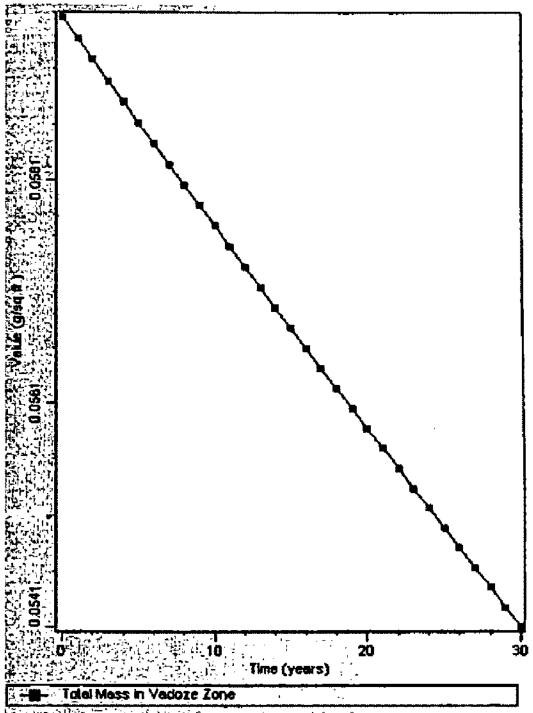
PARAMETER	VALUE
Ethylbenzene Soil Concentration	0.18 mg/kg at 50 feet bgs 0.06 mg/kg at 55 feet bgs
Percent Moisture	6% at 50 feet bgs
Organic Carbon	0.1
Soil Matrix/Profile	Sand Profile
Model Run Time	30 Years
Remaining Parameter	Model Defaults



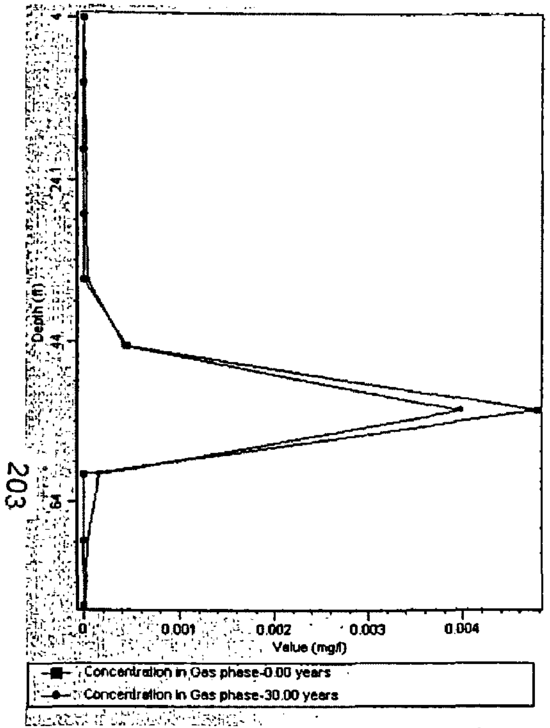
MFG-B3 Ethylbenzene concentration in Soil Water at 52.65 feet bgs



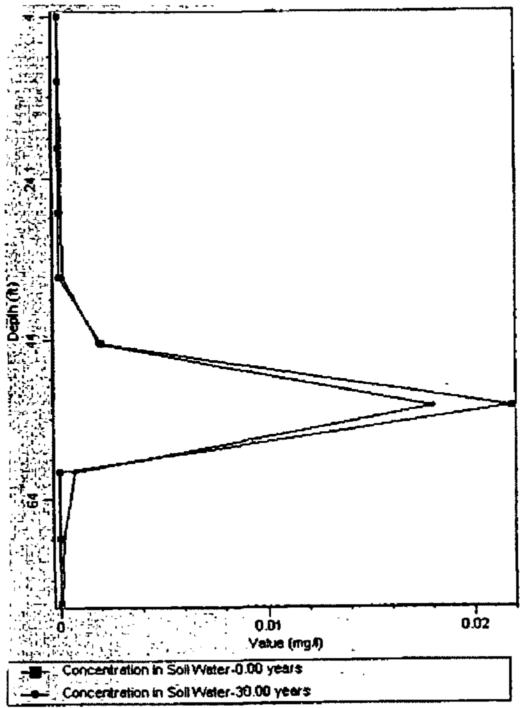
MFG-B3 Ethylbenzene concentration in the solid phase at 52.65 feet bgs



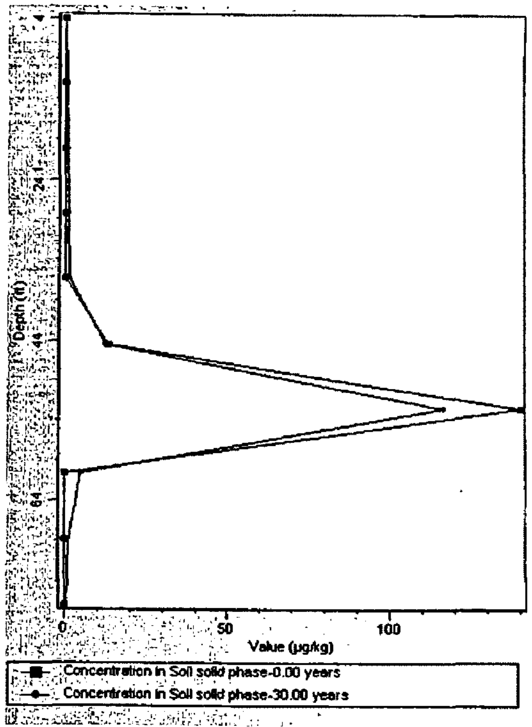
MFG-B3 Ethylbenzene total change in mass in vadose zone from 0 to 30 years



MFG-B3 Ethylbenzene concentration change in gas phase from 0 to 30 years



MFG-3 Ethylbenzene concentration change in pore water from 0 to 30 years



MFG-B3 Ethylbenzene concentration change in solid phase from 0 to 30 years

APPENDIX G

GRAIN SIZE ANALYSIS RESULTS

GRAIN SIZE ANALYSIS

Sample Preparation

At the laboratory, all samples were transferred from the quart-size plastic bags into stainless steel trays for drying. Sample identification tags were placed immediately into each drying tray. The tray was then placed into the drying oven. Samples were dried at 200°F (93°C) for approximately seven hours, and allowed to cool in the drying oven overnight. The samples were removed from the oven on an as needed basis during the analysis procedure.

Selection of Sieves

The number and type of sieves used in the analysis, were chosen to facilitate the capture of the largest range of grain sizes present in the samples. Therefore, nine coarse mesh soil test sieves (3, 2, 1½, 1, ¾, ½, ⅜, #4, and #8) were chosen for analysis of cobble to granule size gravel. In addition, a total of five finer mesh soil test sieves (#16, #30, #50, #100, #200) were chosen for the analysis of sand and silt and clay size fractions. Silt and clay grain sizes were captured in the bottom collection pan and were not analyzed further into their respective grain sizes. Table 3 provides a grain size classification table for general reference to sieve and grain sizes including classification according to Wentworth Classification and the Unified Soil Classification System.

All sieves used in the analyses were 12-inch diameter ASTME-11 Soil Test Sieves, with the exception of the soil test sieves used for the 3-inch and 2-inch size fractions. These two sieves were six inches in diameter. Table 4 provides information about the specifications of the soil test sieves used in the analyses.

Grain Size Analysis

Standard grain size analysis logs, provided by the Lolo National Forest Materials Testing Laboratory, were used for each sample analyzed. Prior to analysis, each sample was weighed and the weight recorded on the sample log. The purpose was to document the beginning and ending weights of the sample to evaluate the amount of material that may have been lost during the analysis procedure. After the beginning weight was recorded, each sample was transferred to the first stack of test sieves. A capture pan was placed on the bottom of the stack to retain material passing the finest sieve in the stack. Next, a cover pan was placed on the top of the stack to contain the sample. Samples were analyzed by using a Ro-Tap machine. The Ro-Tap operates by shaking the stack of sieves while tapping the top cover pan of the sieve stack to facilitate both horizontal and vertical movement of the stack.

Analyzing for a total of 15 possible grain sizes required two rounds of analyses per sample. The first set of sieves included the 3, 2, 1½, 1, ¾, ½, and ⅜ size test sieves. The first stack of test sieves was placed on the Ro-Tap. The Ro-Tap was then programmed to shake and tap the first set of sieves for a total of seven minutes. Once the seven minutes had passed, the Ro-Tap would stop. The stack of sieves was removed from the Ro-Tap and taken to the weighing scale. A weiging pan was placed on the scale and the scale tared (reset to zero). The weight retained on each sieve was weighed by transferring all material retained on the top of the sieve to the weighing pan on the scale. The weight retained was recorded on the analysis log. The scale was tared prior to the addition of the material from each consecutive sieve size. After the weights were recorded for the first set of sieves, the material remaining in the capture pan at the bottom of the first sieve stack was then transferred to the second stack of test sieves.

The second stack of test sieves consisted of the #4, #8, #16, #30, #50, #100, and #200 size sieves. This second stack of sieves was placed on the Ro-Tap for a total of 12 minutes. The adjustment in analysis time was to try to provide additional time for the very fine sand and silt and clay size fractions to pass through the smaller sieve sizes. Once analysis on the Ro-Tap was completed, the weight retained on each sieve and the silt and clay size material retained in the capture pan was recorded on the analysis log, as described above. The results of the grain size analysis are discussed in Section 4.

The average gravel content in the Upper Unit was 55.2 percent and 59.6 percent in the Lower Unit. The average sand content in the Upper Unit was 41.3 percent and 38.5 in the Lower Unit. In the Upper Unit, the average silt and clay content was 3.6 percent and 1.9 percent in the Lower Unit. The average d_{40} value (where 40 percent of the sample is coarser and 60 percent finer) for the Upper Unit was 10.9 millimeters and 12.0 millimeters for the Lower Unit. The average Effective Grain Size (d_{90}) value (where 10 percent is finer and 90 percent coarser) for the Upper Unit was 0.2 millimeters and 0.3 millimeters for the Lower Unit. The mean grain size (d_{50}) for the Upper Unit was 5.6 millimeters and 9.1 millimeters for the Lower Unit. The average Uniformity Coefficient was 40.6 and 40.5 for the Upper and Lower Units, respectively.

Grain Size Analyses and Hydraulic Conductivity Estimates

No aquifer testing was performed during this remedial investigation. While grain size analyses were performed on samples from two boreholes, there is no accurate way to calculate hydraulic conductivity directly from grain size analyses and grain size distribution curves (Driscoll, 1995). One method commonly used to estimate hydraulic conductivity is the Hazen Method. It uses the effective grain size and uniformity coefficient to estimate hydraulic conductivity on sandy sediment and sediments with uniformity coefficients under five, meaning well sorted (poorly graded). This method was not used to estimate hydraulic conductivity on the sediments at the Site because most of the sediments were sandy gravel with uniformity coefficients well above five. A second method developed by Shepherd (Fetter, 1994), uses the mean (median) grain size (d_{50}) to estimate hydraulic conductivity. Shepherd developed formulas to estimate the hydraulic conductivity on several categories of well-sorted, texturally mature sediments with high roundness and sphericity (Fetter, 1994). This method could also not be used because most of the subsurface material at the Site was shown to be poorly sorted (well graded) through the grain size analyses and logging effort.

ASTME - 11 SOIL TEST SIEVES

Sieve / Mesh Size	Sieve Diameter (inches)	Aperture		Frame Composition	Mesh Composition
		Millimeter	Inches		
3	6	76.2	3	Brass	Brass
2	6	50.8	2	Brass	Brass
1 1/2	12	38.1	1.5	Stainless Steel	Stainless Steel
1	12	25.4	1	Stainless Steel	Stainless Steel
3/4	12	19.0	0.75	Stainless Steel	Stainless Steel
1/2	12	12.5	0.5	Stainless Steel	Stainless Steel
3/8	12	9.5	0.375	Stainless Steel	Stainless Steel
#4	12	4.75	0.19	Stainless Steel	Stainless Steel
#8	12	2.36	0.09	Stainless Steel	Stainless Steel
#16	12	1.18	0.05	Stainless Steel	Stainless Steel
#30	12	0.600	0.02	Stainless Steel	Stainless Steel
#50	12	0.300	0.01	Stainless Steel	Stainless Steel
#100	12	0.150	0.006	Stainless Steel	Stainless Steel
#200	12	0.075	0.003	Stainless Steel	Stainless Steel
- #200	12	-0.075	-0.003	Stainless Steel	Stainless Steel

GRAIN SIZE CLASSIFICATION TABLE

[1]Sieve / Mesh Size	Sieve Aperture / Grain Size			[2]Size Classifications					
	Millimeters (mm)	Microns (um)	Inches (in)	General	Wentworth Classification	Wentworth Size Range Inches	Milimeters	USCS Classification	USCS Size Range
3	76.2	76,200	3.0	Gravel	Cobble	2.52 to 10.08	64 to 256		
2	50.8	50,800	2.0		Pebble	0.16 to 2.52	4 to 64	Very Coarse Gravel	1.26 to 2.52 in (32 to 64 mm)
1 1/2	37.5	37,500	1.5		Pebble	0.16 to 2.52	4 to 64	Very Coarse Gravel	1.26 to 2.52 in (32 to 64 mm)
1	25.0	25,000	1.0		Pebble	0.16 to 2.52	4 to 64	Coarse Gravel	0.63 to 1.26 in (16 to 32 mm)
3/4	19.0	19,000	0.75		Pebble	0.16 to 2.52	4 to 64	Coarse Gravel	0.63 to 1.26 in (16 to 32 mm)
1/2	12.7	12,700	0.50		Pebble	0.16 to 2.52	4 to 64	Medium Gravel	0.31 to 0.63 in (8 to 16 mm)
3/8	9.5	9,500	0.38		Pebble	0.16 to 2.52	4 to 64	Medium Gravel	0.31 to 0.63 in (8 to 16 mm)
#4	4.75	4,750	0.19		Pebble	0.16 to 2.52	4 to 64	Fine Gravel	0.16 to 0.31 in (4 to 8 mm)
#8	2.36	2,360	0.09		Granule	0.08 to 0.16	2 to 4		
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	0.04 to 0.08	1 to 2		
#30	0.6	600	0.02		Coarse Sand	0.02 to 0.04	0.5 to 1		
#50	0.3	300	0.01		Medium Sand	0.01 to 0.02	0.1 to 0.02		
#100	0.15	150	0.006		Fine Sand	0.005 to 0.01	0.125 to 0.25		
#200	0.075	75	0.003		Very Fine Sand	0.002 to 0.005	0.063 to 0.125		
-#200	-0.075	-75	-0.003	Silt & Clay	Silt & Clay	Silt: 0.0002 to 0.002; Clay: <0.0002	Silt: 0.004 to 0.063 Clay: <0.004		

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[1] Screen / Mesh Size information obtained from screens used in grain size analysis.

[2] Classifications and values obtained from Groundwater and Wells, Second Edition, 1986. Fletcher G. Driscoll. Published by Johnson Screens, St. Paul, Minnesota.

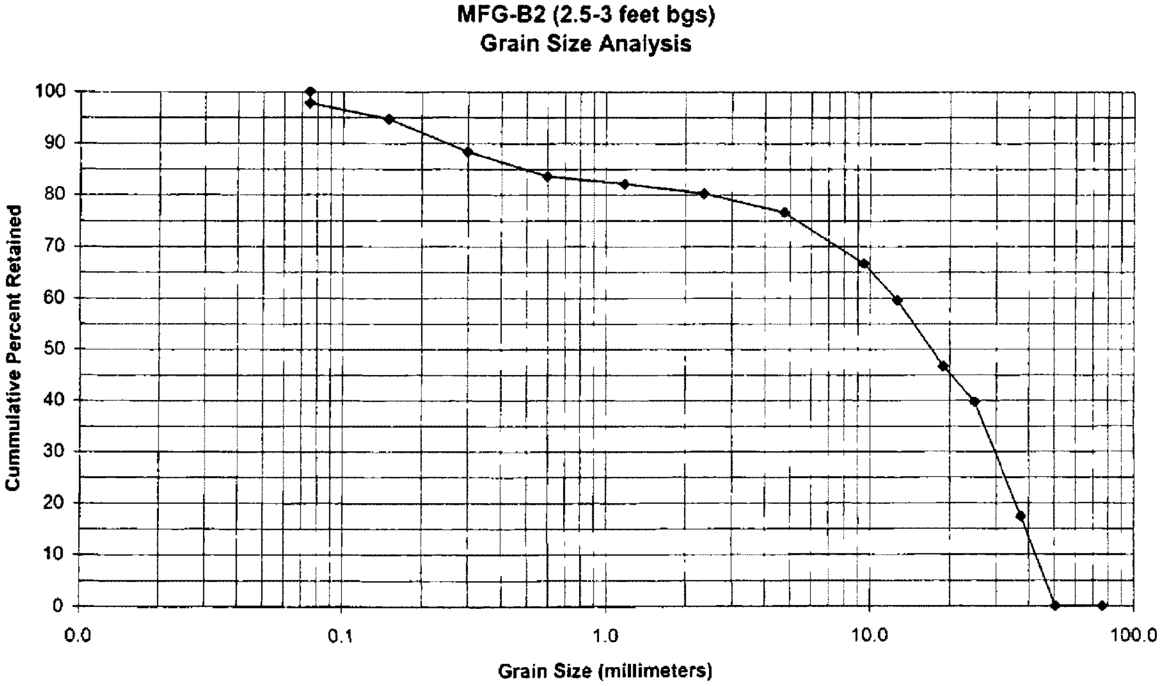
GRAIN SIZE ANALYSIS SUMMARY TABLE

Borehole & Depth Interval (feet bgs)	Percent Gravel	Percent Sand	Percent Silt & Clay	d_{40} (mm)	d_{40} (inch.)	Effective Grain Size d_{80} (mm)	Effective Grain Size d_{80} (inch.)	Mean Grain Size d_{50} (mm)	Mean Grain Size d_{50} (inch.)	Uniformity Coefficient (C_u)
MFG-B2										
2.5 - 3	80.2	17.5	2.3	25	1.0	0.25	0.01	7.8	0.31	100
5 - 5.5	70.7	26.2	3.1	8.4	0.33	0.3	0.01	6.3	0.25	28
11 - 11.5	53.4	42.9	3.7	8.5	0.34	0.17	0.01	4	0.16	50
17.5 - 18	28.3	66.1	5.6	0.55	0.02	0.11	0.00	0.44	0.02	5
28 - 29	2.0	95.0	3.0	0.39	0.02	0.16	0.01	0.35	0.01	2.4
38 - 39	42.4	52.4	5.2	3	0.12	0.13	0.01	0.95	0.04	23
51 - 52	69.3	26.6	4.1	16.4	0.65	0.2	0.01	10.1	0.40	82
75 - 76	34.9	60.8	4.3	1.1	0.04	0.16	0.01	0.54	0.02	6.9
77 - 77.5	25.2	72.4	2.5	0.9	0.04	0.19	0.01	0.65	0.03	4.7
77.5 - 78	11.7	86.3	2.0	1.4	0.06	0.27	0.01	1	0.04	5.2
79 - 80	86.1	12.6	1.2	22	0.87	1.5	0.06	18.4	0.73	15
89 - 90	21.8	75.9	2.3	0.52	0.02	0.18	0.01	0.44	0.02	2.9
90 - 91	69.6	28.9	1.5	6.7	0.27	0.44	0.02	5	0.20	15
94 - 95	3.0	94.2	2.8	0.43	0.02	0.14	0.01	0.38	0.02	3.1
98.5 - 99	78.4	18.8	2.8	17.8	0.71	0.27	0.01	15	0.60	66
104 - 105	83.4	14.5	2.1	28	1.11	0.5	0.02	23	0.91	56
105 - 105.5	4.9	93.3	1.7	0.82	0.03	0.24	0.01	0.7	0.03	3.4
107 - 107.5	14.7	83.8	1.5	1.6	0.06	0.32	0.01	1.3	0.05	5
109 - 110	79.3	17.8	2.9	25	0.99	0.25	0.01	19	0.75	100
111 - 111.5	74.7	24.5	0.9	12	0.48	0.28	0.01	8.5	0.34	43
Overall Average:	46.7	50.5	2.8	9.0	0.36	0.3	0.01	6.2	0.25	30.8
Avg Upper Unit (0 to ~60 feet bgs):	49.5	46.7	3.9	8.9	0.35	0.2	0.01	4.3	0.17	41.5
Avg Lower Unit (~60+ feet bgs):	45.2	52.6	2.2	9.1	0.36	0.4	0.01	7.2	0.29	25.1
MFG-B3										
12 - 13	79.8	18.7	1.5	21	0.83	0.3	0.01	3.3	0.13	70
18 - 19	80.1	17.8	2.1	7.8	0.31	0.3	0.01	4.5	0.18	26
32 - 32.5	50.3	42.9	6.8	4.3	0.17	0.1	0.00	2.4	0.10	43
36 - 37	44.9	49.5	5.6	3.5	0.14	0.14	0.01	1.6	0.06	25
40.5 - 41.5	0.0	97.3	2.7	0.37	0.01	0.16	0.01	0.3	0.01	2.3
41.5 - 42	40.2	54.6	5.3	0.24	0.01	0.14	0.01	0.8	0.03	1.7
43 - 44	81.9	16.0	2.1	28	1.11	0.53	0.02	21	0.83	53
46 - 47	82.7	15.5	1.8	23	0.91	0.6	0.02	19	0.75	38
48 - 49	79.5	18.7	1.8	27	1.07	0.4	0.02	8.4	0.33	68
55.5 - 56.5	69.1	27.9	3.0	13.4	0.53	0.19	0.01	8	0.32	71
63 - 64	73.9	24.4	1.7	15	0.60	0.27	0.01	11	0.44	56
Overall Average:	62.0	34.8	3.1	13.1	0.52	0.3	0.01	7.3	0.29	41.3
Avg Upper Unit (0 to ~60 feet bgs):	60.9	35.9	3.3	12.9	0.51	0.3	0.01	6.9	0.28	39.8
Avg Lower Unit (~60+ feet bgs):	73.9	24.4	1.7	15	0.60	0.27	0.01	11	0.44	56
Averages for MFG-B2 and MFG-B3										
Overall Average:	54.4	42.7	3.0	11.0	0.44	0.3	0.01	6.7	0.27	36.1
Avg Upper Unit (0 to ~60 feet bgs):	55.2	41.3	3.6	10.9	0.43	0.2	0.01	5.6	0.22	40.6
Avg Lower Unit (~60+ feet bgs):	59.6	38.5	1.9	12.0	0.48	0.3	0.01	9.1	0.36	40.5

Boring: **MFG-B2**
Depth Interval (feet bgs): **2.5-3**
Date Analyzed: **5/25/01**
Analyzed By: **Natalie Morrow**

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	342	342	17.3	17.3	82.7
1	25.0	25,000	1.0		Pebble	441	783	22.4	39.7	60.3
3/4	19.0	19,000	0.75		Pebble	138	921	7.0	46.7	53.3
1/2	12.7	12,700	0.50		Pebble	253	1174	12.8	59.5	40.5
3/8	9.5	9,500	0.38		Pebble	142	1316	7.2	66.7	33.3
#4	4.75	4,750	0.19		Pebble	195	1511	9.9	76.6	23.4
#8	2.36	2,360	0.09		Granule	72	1583	3.6	80.2	19.8
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	36	1619	1.8	82.1	17.9
#30	0.6	600	0.02		Coarse Sand	29	1648	1.5	83.5	16.5
#50	0.3	300	0.01		Medium Sand	94	1742	4.8	88.3	11.7
#100	0.15	150	0.006		Fine Sand	125	1867	6.3	94.6	5.4
#200	0.075	75	0.003		Very Fine Sand	61	1928	3.1	97.7	2.3
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	45	1973	2.3	100.0	0.0
Total Weight (g)						1973	d_{40} (mm)=	25	d_{50} (mm)=	7.8
% Gravel						80.2	d_{90} (mm)=	0.25	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
% Sand						17.5	$C_u=d_{40}/d_{90}=$	100	K (ft/d)=	13,340
% Silt & Clay						2.3				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

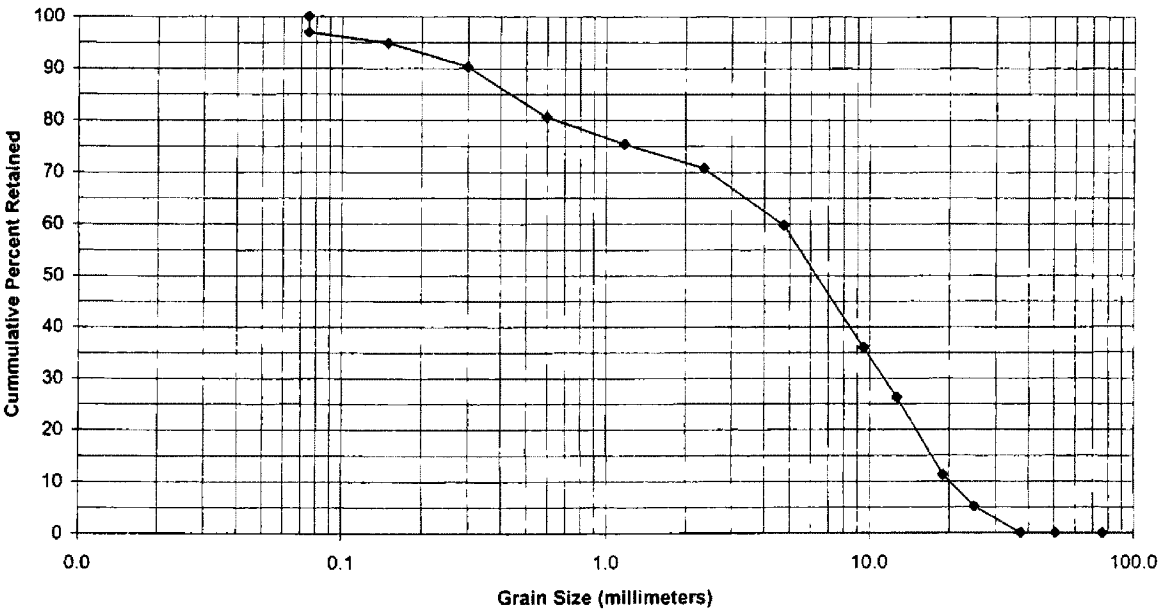


Boring: **MFG-B2**
Depth Interval (feet bgs): **5-5.5**
Date Analyzed: **5/25/01**
Analyzed By: **Natalie Morrow**

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	95	95	5.1	5.1	94.9
3/4	19.0	19,000	0.75		Pebble	114	209	6.1	11.2	88.8
1/2	12.7	12,700	0.50		Pebble	281	490	15.0	26.2	73.8
3/8	9.5	9,500	0.38		Pebble	181	671	9.7	35.9	64.1
#4	4.75	4,750	0.19		Pebble	445	1116	23.8	59.7	40.3
#8	2.36	2,360	0.09		Granule	204	1320	10.9	70.7	29.3
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	87	1407	4.7	75.3	24.7
#30	0.6	600	0.02		Coarse Sand	97	1504	5.2	80.5	19.5
#50	0.3	300	0.01		Medium Sand	182	1686	9.7	90.3	9.7
#100	0.15	150	0.006		Fine Sand	84	1770	4.5	94.8	5.2
#200	0.075	75	0.003		Very Fine Sand	40	1810	2.1	96.9	3.1
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	58	1868	3.1	100.0	0.0
					Total Weight (g)	1868	d_{40} (mm)=	8.4	d_{50} (mm)=	6.3
					% Gravel	70.7	d_{90} (mm)=	0.30	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
					% Sand	26.2	$C_u=d_{40}/d_{90}=$	28	K (ft/d)=	9,378
					% Silt & Clay	3.1				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (5-5.5 feet bgs)
Grain Size Analysis

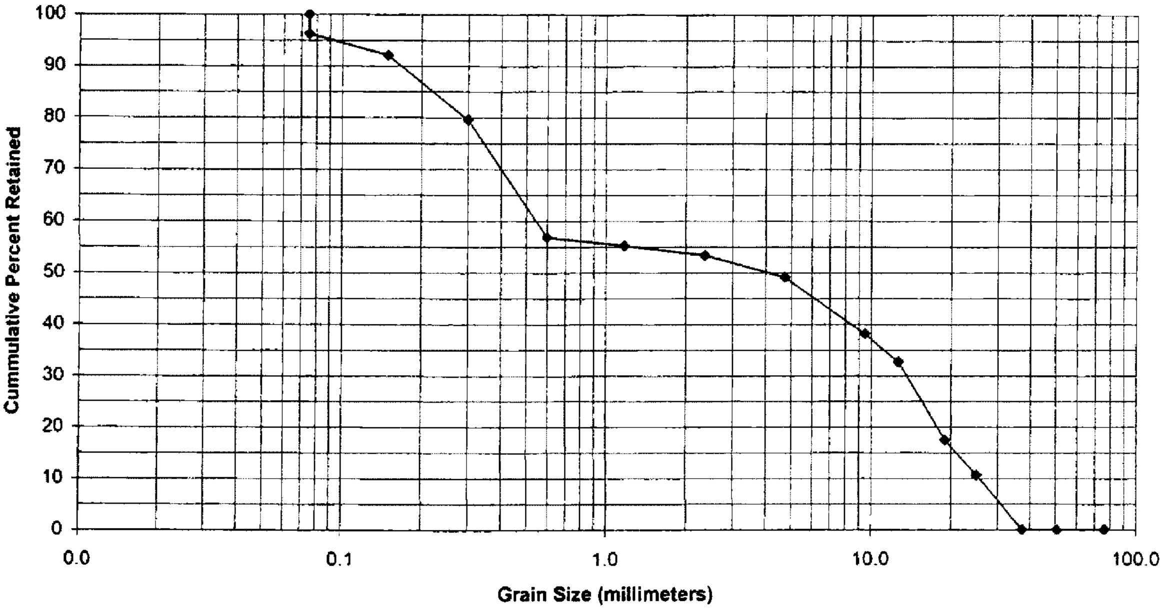


Boring: MFG-B2
Depth Interval (feet bgs): 11-11.5
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	189	189	10.6	10.6	89.4
3/4	19.0	19,000	0.75		Pebble	122	311	6.8	17.4	82.6
1/2	12.7	12,700	0.50		Pebble	273	584	15.3	32.7	67.3
3/8	9.5	9,500	0.38		Pebble	98	682	5.5	38.1	61.9
#4	4.75	4,750	0.19		Pebble	196	878	11.0	49.1	50.9
#8	2.36	2,360	0.09		Granule	76	954	4.3	53.4	46.6
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	33	987	1.8	55.2	44.8
#30	0.6	600	0.02		Coarse Sand	28	1015	1.6	56.8	43.2
#50	0.3	300	0.01		Medium Sand	406	1421	22.7	79.5	20.5
#100	0.15	150	0.006		Fine Sand	224	1645	12.5	92.0	8.0
#200	0.075	75	0.003		Very Fine Sand	76	1721	4.3	96.3	3.7
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	67	1788	3.7	100.0	0.0
					Total Weight (g)	1788	d_{40} (mm)=	8.5	d_{50} (mm)=	4.0
					% Gravel	53.4	d_{90} (mm)=	0.17	$K=Cd_{50}^{J}=450d_{50}^{1.65}=$	
					% Sand	42.9	$C_u=d_{40}/d_{90}=$	50	K (ft/d)=	4,432
					% Silt & Clay	3.7				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (11-11.5 feet bgs)
Grain Size Analysis

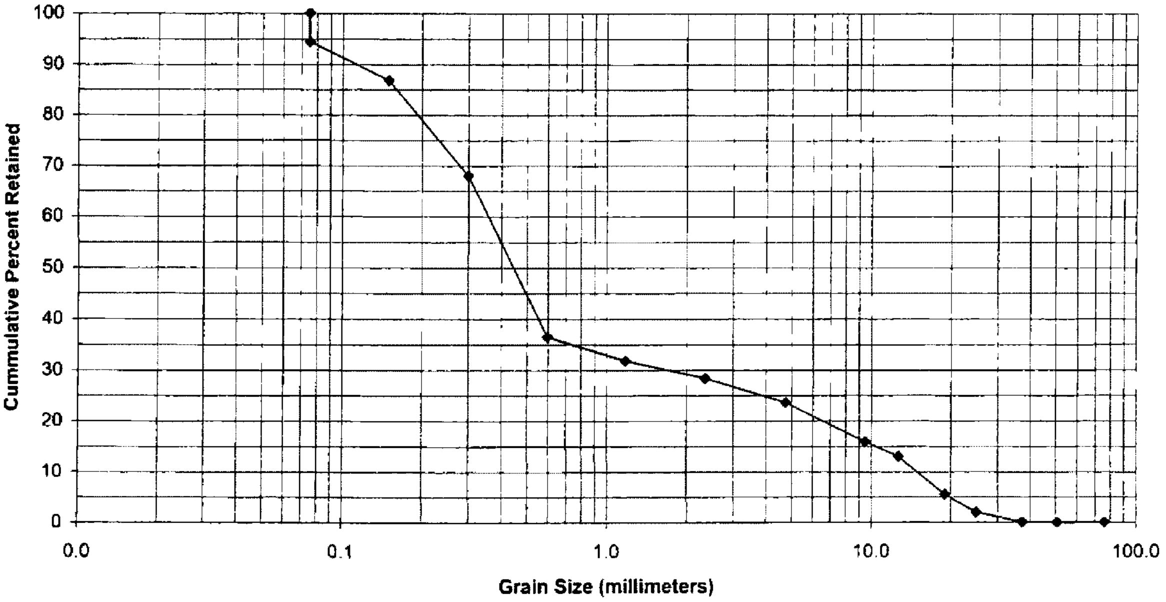


Boring: **MFG-B2**
Depth Interval (feet bgs): **17.5-18**
Date Analyzed: **5/25/01**
Analyzed By: **Natalie Morrow**

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	28	28	2.0	2.0	98.0
3/4	19.0	19,000	0.75		Pebble	50	78	3.5	5.5	94.5
1/2	12.7	12,700	0.50		Pebble	107	185	7.5	13.0	87.0
3/8	9.5	9,500	0.38		Pebble	41	226	2.9	15.8	84.2
#4	4.75	4,750	0.19		Pebble	111	337	7.8	23.6	76.4
#8	2.36	2,360	0.09		Granule	67	404	4.7	28.3	71.7
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	49	453	3.4	31.8	68.2
#30	0.6	600	0.02		Coarse Sand	67	520	4.7	36.5	63.5
#50	0.3	300	0.01		Medium Sand	449	969	31.5	68.0	32.0
#100	0.15	150	0.006		Fine Sand	268	1237	18.8	86.7	13.3
#200	0.075	75	0.003		Very Fine Sand	109	1346	7.6	94.4	5.6
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	80	1426	5.6	100.0	0.0
					Total Weight (g)	1426	d_{40} (mm)=	0.55	d_{50} (mm)=	0.4
					% Gravel	28.3	d_{90} (mm)=	0.11	$K=Cd_{50}^{J} = 450d_{50}^{1.65}$=	
					% Sand	66.1	$C_u=d_{40}/d_{90}$=	5	K (ft/d)=	116
					% Silt & Clay	5.6				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (17.5-18 feet bgs)
Grain Size Analysis

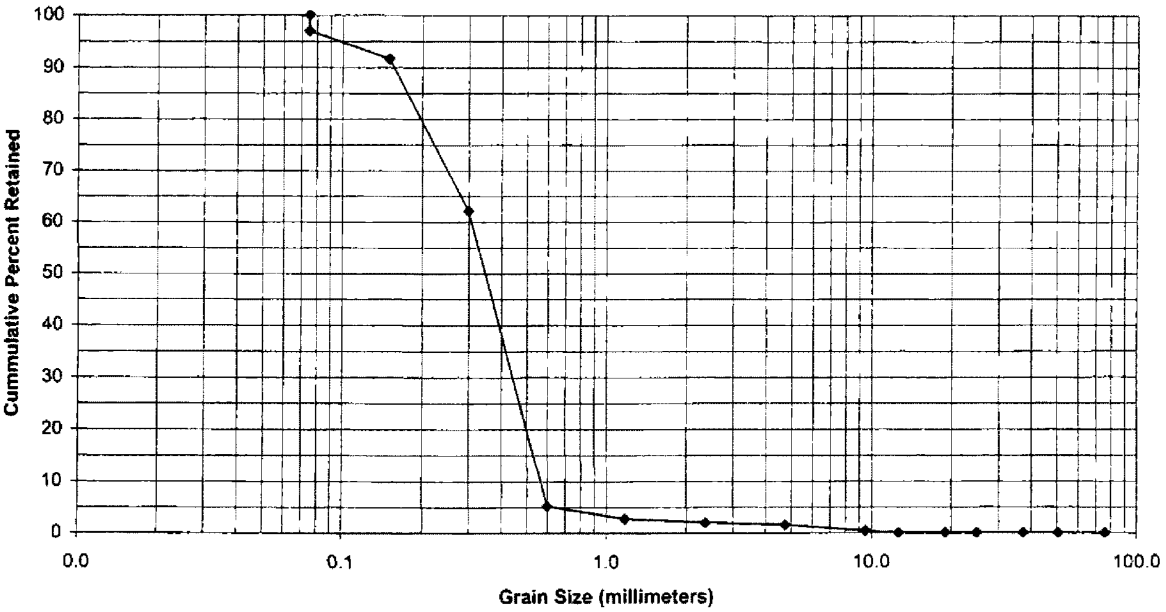


Boring: MFG-B2
Depth Interval (feet bgs): 28-29
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	0	0	0.0	0.0	100.0
3/4	19.0	19,000	0.75		Pebble	0	0	0.0	0.0	100.0
1/2	12.7	12,700	0.50		Pebble	0	0	0.0	0.0	100.0
3/8	9.5	9,500	0.38		Pebble	6	6	0.4	0.4	99.6
#4	4.75	4,750	0.19		Pebble	16	22	1.1	1.5	98.5
#8	2.36	2,360	0.09		Granule	7	29	0.5	2.0	98.0
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	10	39	0.7	2.7	97.3
#30	0.6	600	0.02		Coarse Sand	37	76	2.5	5.2	94.8
#50	0.3	300	0.01		Medium Sand	828	904	56.9	62.1	37.9
#100	0.15	150	0.006		Fine Sand	429	1333	29.5	91.6	8.4
#200	0.075	75	0.003		Very Fine Sand	78	1411	5.4	97.0	3.0
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	44	1455	3.0	100.0	0.0
					Total Weight (g)	1455	d_{40} (mm)=	0.39	d_{50} (mm)=	0.4
					% Gravel	2.0	d_{90} (mm)=	0.16	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
					% Sand	95.0	$C_u=d_{40}/d_{90}=$	2.4	K (ft/d)=	80
					% Silt & Clay	3.0				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (28-29 feet bgs)
Grain Size Analysis

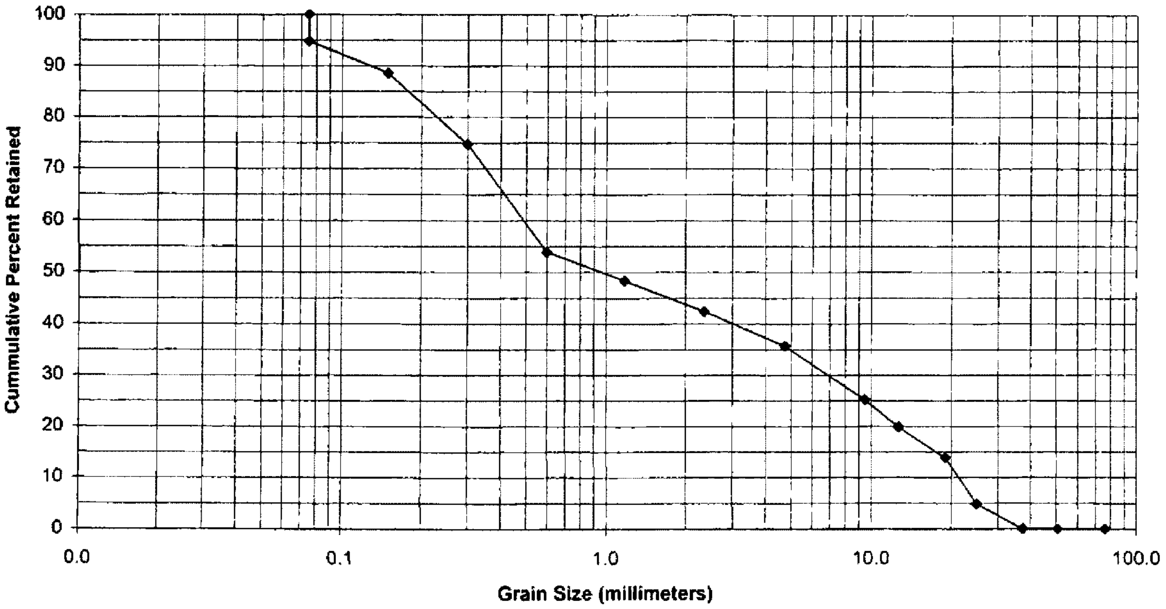


Boring: MFG-B2
Depth Interval (feet bgs): 38-39
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	85	85	4.8	4.8	95.2
3/4	19.0	19,000	0.75		Pebble	160	245	9.0	13.8	86.2
1/2	12.7	12,700	0.50		Pebble	108	353	6.1	19.9	80.1
3/8	9.5	9,500	0.38		Pebble	95	448	5.3	25.2	74.8
#4	4.75	4,750	0.19		Pebble	185	633	10.4	35.6	64.4
#8	2.36	2,360	0.09		Granule	120	753	6.8	42.4	57.6
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	105	858	5.9	48.3	51.7
#30	0.6	600	0.02		Coarse Sand	99	957	5.6	53.9	46.1
#50	0.3	300	0.01		Medium Sand	369	1326	20.8	74.6	25.4
#100	0.15	150	0.006		Fine Sand	247	1573	13.9	88.5	11.5
#200	0.075	75	0.003		Very Fine Sand	111	1684	6.2	94.8	5.2
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	93	1777	5.2	100.0	0.0
Total Weight (g)						1777	d_{40} (mm)=	3	d_{50} (mm)=	1.0
% Gravel						42.4	d_{90} (mm)=	0.13	$K=Cd_{50}^{J}=450d_{50}^{1.65}=$	
% Sand						52.4	$C_u=d_{40}/d_{90}=$	23	K (ft/d)=	413
% Silt & Clay						5.2				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (38-39 feet bgs)
Grain Size Analysis

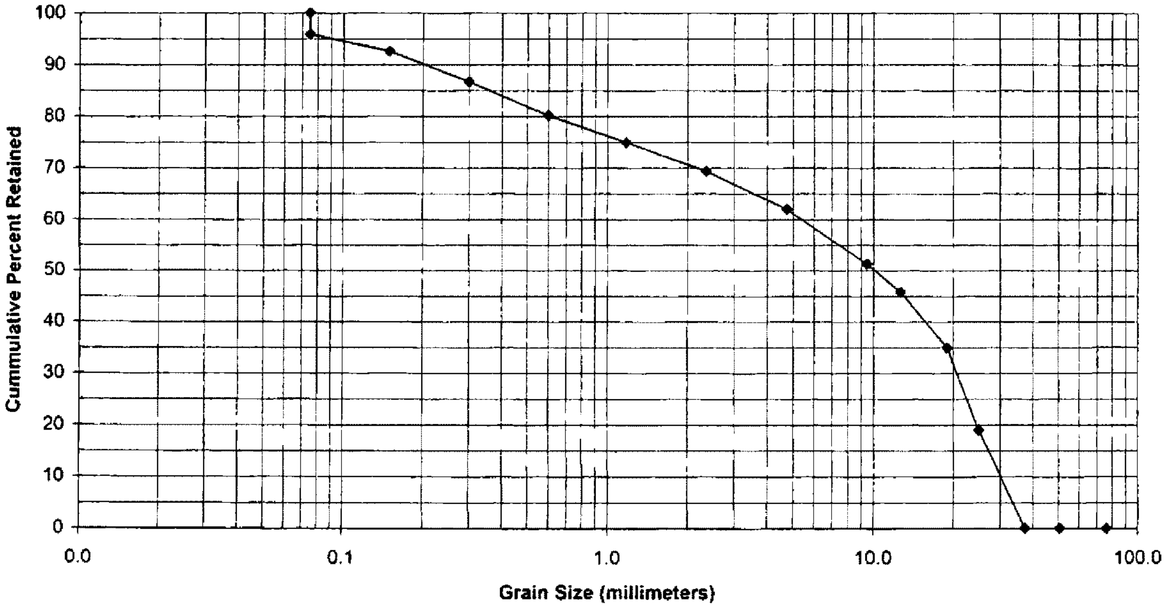


Boring: MFG-B2
Depth Interval (feet bgs): 51-52
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	296	296	19.0	19.0	81.0
3/4	19.0	19,000	0.75		Pebble	249	545	15.9	34.9	65.1
1/2	12.7	12,700	0.50		Pebble	170	715	10.9	45.8	54.2
3/8	9.5	9,500	0.38		Pebble	86	801	5.5	51.3	48.7
#4	4.75	4,750	0.19		Pebble	167	968	10.7	62.0	38.0
#8	2.36	2,360	0.09		Granule	115	1083	7.4	69.3	30.7
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	87	1170	5.6	74.9	25.1
#30	0.6	600	0.02		Coarse Sand	82	1252	5.2	80.2	19.8
#50	0.3	300	0.01		Medium Sand	102	1354	6.5	86.7	13.3
#100	0.15	150	0.006		Fine Sand	92	1446	5.9	92.6	7.4
#200	0.075	75	0.003		Very Fine Sand	52	1498	3.3	95.9	4.1
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	64	1562	4.1	100.0	0.0
					Total Weight (g)	1562	d_{40} (mm)=	16.4	d_{50} (mm)=	10.1
					% Gravel	69.3	d_{90} (mm)=	0.2	$K=Cd_{50}^{J} = 450d_{50}^{1.85}=$	
					% Sand	26.6	$C_u=d_{40}/d_{90}=$	82	K (ft/d)=	20,434
					% Silt & Clay	4.1				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (51-52 feet bgs)
Grain Size Analysis

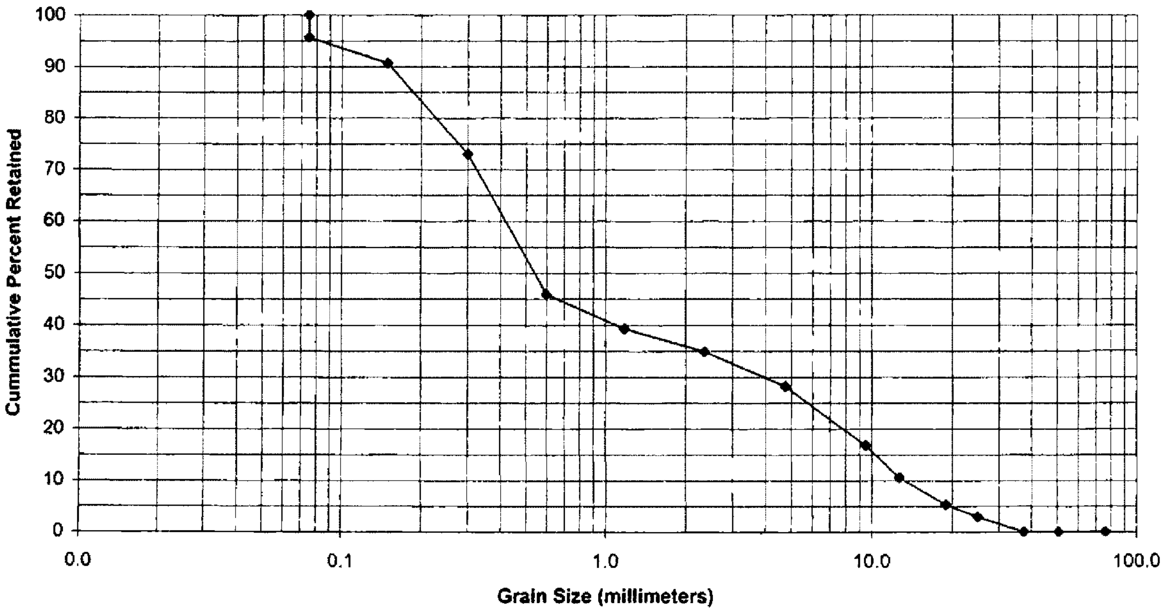


Boring: MFG-B2
Depth Interval (feet bgs): 75-76
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	37	37	2.9	2.9	97.1
3/4	19.0	19,000	0.75		Pebble	30	67	2.4	5.3	94.7
1/2	12.7	12,700	0.50		Pebble	67	134	5.3	10.6	89.4
3/8	9.5	9,500	0.38		Pebble	79	213	6.2	16.8	83.2
#4	4.75	4,750	0.19		Pebble	144	357	11.4	28.2	71.8
#8	2.36	2,360	0.09		Granule	85	442	6.7	34.9	65.1
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	56	498	4.4	39.3	60.7
#30	0.6	600	0.02		Coarse Sand	84	582	6.6	45.9	54.1
#50	0.3	300	0.01		Medium Sand	343	925	27.1	72.9	27.1
#100	0.15	150	0.006		Fine Sand	224	1149	17.7	90.6	9.4
#200	0.075	75	0.003		Very Fine Sand	64	1213	5.0	95.7	4.3
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	55	1268	4.3	100.0	0.0
					Total Weight (g)	1268	d_{40} (mm)=	1.1	d_{50} (mm)=	0.54
					% Gravel	34.9	d_{90} (mm)=	0.16	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
					% Sand	60.8	$C_u=d_{40}/d_{90}=$	6.9	K (ft/d)=	163
					% Silt & Clay	4.3				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

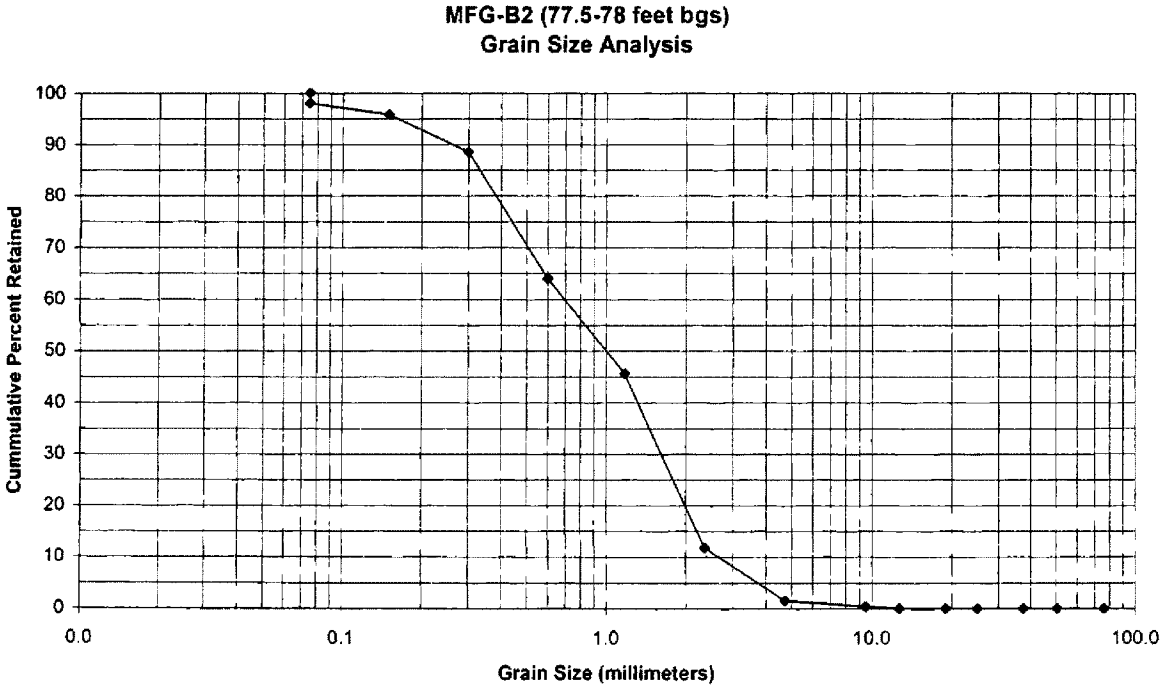
MFG-B2 (75-76 feet bgs)
Grain Size Analysis



Boring: MFG-B2
Depth Interval (feet bgs): 77.5-78
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	0	0	0.0	0.0	100.0
3/4	19.0	19,000	0.75		Pebble	0	0	0.0	0.0	100.0
1/2	12.7	12,700	0.50		Pebble	0	0	0.0	0.0	100.0
3/8	9.5	9,500	0.38		Pebble	5	5	0.4	0.4	99.6
#4	4.75	4,750	0.19		Pebble	14	19	1.1	1.5	98.5
#8	2.36	2,360	0.09		Granule	128	147	10.2	11.7	88.3
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	424	571	33.9	45.6	54.4
#30	0.6	600	0.02		Coarse Sand	230	801	18.4	64.0	36.0
#50	0.3	300	0.01		Medium Sand	307	1108	24.5	88.5	11.5
#100	0.15	150	0.006		Fine Sand	92	1200	7.3	95.8	4.2
#200	0.075	75	0.003		Very Fine Sand	27	1227	2.2	98.0	2.0
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	25	1252	2.0	100.0	0.0
					Total Weight (g)	1252	d_{40} (mm)=	1.4	d_{50} (mm)=	1
					% Gravel	11.7	d_{90} (mm)=	0.27	$K=Cd_{50}^{J} = 450d_{50}^{1.65}$=	
					% Sand	86.3	$C_u=d_{40}/d_{90}$=	5.2	K (ft/d)=	450
					% Silt & Clay	2.0				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

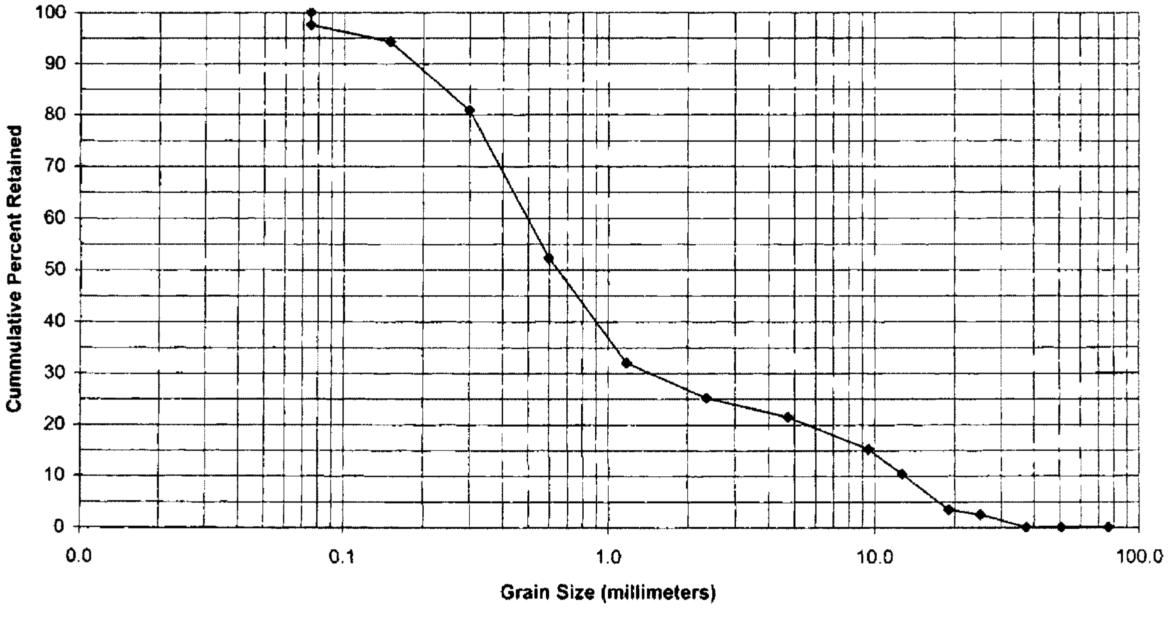


Boring: MFG-B2
Depth Interval (feet bgs): 77-77.5
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	32	32	2.5	2.5	97.5
3/4	19.0	19,000	0.75		Pebble	13	45	1.0	3.5	96.5
1/2	12.7	12,700	0.50		Pebble	89	134	6.9	10.4	89.6
3/8	9.5	9,500	0.38		Pebble	62	196	4.8	15.2	84.8
#4	4.75	4,750	0.19		Pebble	81	277	6.3	21.4	78.6
#8	2.36	2,360	0.09		Granule	48	325	3.7	25.2	74.8
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	88	413	6.8	32.0	68.0
#30	0.6	600	0.02		Coarse Sand	263	676	20.4	52.3	47.7
#50	0.3	300	0.01		Medium Sand	368	1044	28.5	80.8	19.2
#100	0.15	150	0.006		Fine Sand	173	1217	13.4	94.2	5.8
#200	0.075	75	0.003		Very Fine Sand	43	1260	3.3	97.5	2.5
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	32	1292	2.5	100.0	0.0
					Total Weight (g)	1292	d_{40}(mm)=	0.9	d_{50}(mm)=	0.65
					% Gravel	25.2	d_{90}(mm)=	0.19	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
					% Sand	72.4	$C_u=d_{40}/d_{90}=$	4.7	K (ft/d)=	221
					% Silt & Clay	2.5				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (77-77.5 feet bgs)
Grain Size Analysis

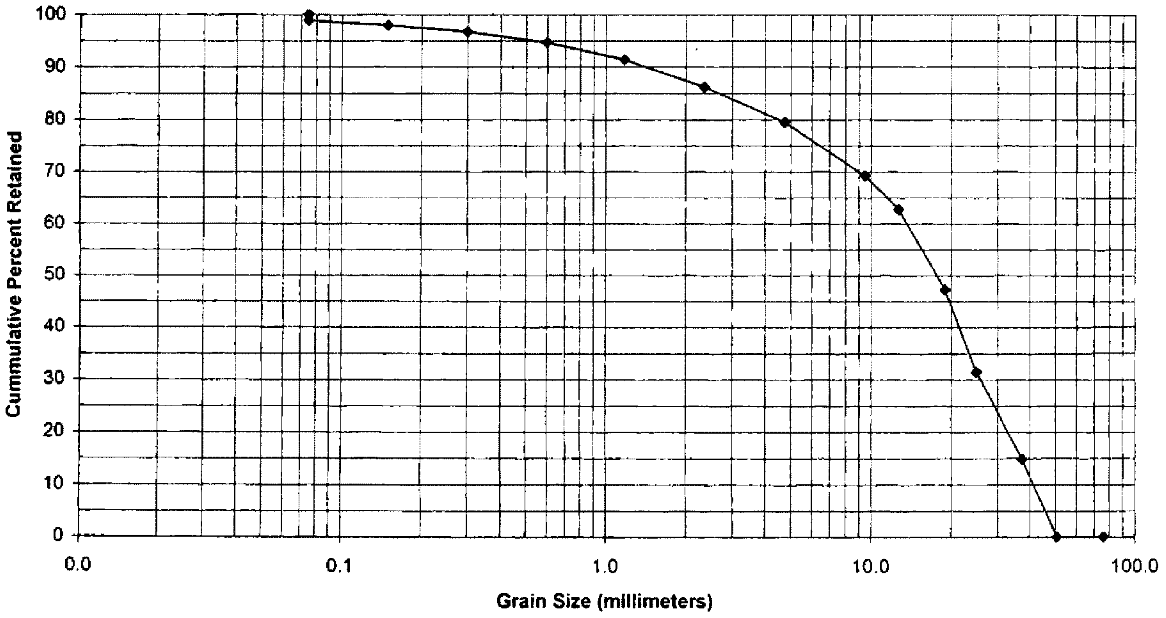


Boring: MFG-B2
Depth Interval (feet bgs): 79-80
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	221	221	14.9	14.9	85.1
1	25.0	25,000	1.0		Pebble	246	467	16.5	31.4	68.6
3/4	19.0	19,000	0.75		Pebble	236	703	15.9	47.3	52.7
1/2	12.7	12,700	0.50		Pebble	230	933	15.5	62.7	37.3
3/8	9.5	9,500	0.38		Pebble	96	1029	6.5	69.2	30.8
#4	4.75	4,750	0.19		Pebble	153	1182	10.3	79.5	20.5
#8	2.36	2,360	0.09		Granule	99	1281	6.7	86.1	13.9
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	77	1358	5.2	91.3	8.7
#30	0.6	600	0.02		Coarse Sand	49	1407	3.3	94.6	5.4
#50	0.3	300	0.01		Medium Sand	30	1437	2.0	96.6	3.4
#100	0.15	150	0.006		Fine Sand	19	1456	1.3	97.9	2.1
#200	0.075	75	0.003		Very Fine Sand	13	1469	0.9	98.8	1.2
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	18	1487	1.2	100.0	0.0
					Total Weight (g)	1487	d_{40} (mm)=	22	d_{50} (mm)=	18.4
					% Gravel	86.1	d_{90} (mm)=	1.5	$K=Cd_{50}^{j} = 450d_{50}^{1.85}=$	
					% Sand	12.6	$C_u=d_{40}/d_{90}=$	14.7	K (ft/d)=	54,975
					% Silt & Clay	1.2				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (79-80 feet bgs)
Grain Size Analysis

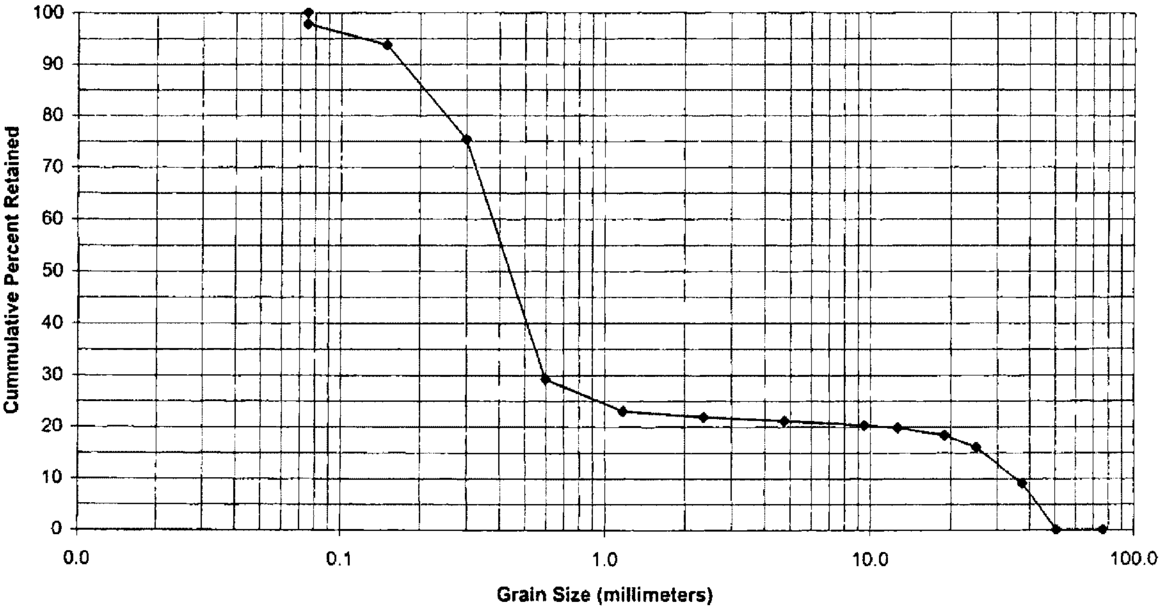


Boring: **MFG-B2**
Depth Interval (feet bgs): **89-90**
Date Analyzed: **5/25/01**
Analyzed By: **Natalie Morrow**

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	120	120	9.0	9.0	91.0
1	25.0	25,000	1.0		Pebble	94	214	7.1	16.1	83.9
3/4	19.0	19,000	0.75		Pebble	30	244	2.3	18.3	81.7
1/2	12.7	12,700	0.50		Pebble	20	264	1.5	19.8	80.2
3/8	9.5	9,500	0.38		Pebble	6	270	0.5	20.3	79.7
#4	4.75	4,750	0.19		Pebble	11	281	0.8	21.1	78.9
#8	2.36	2,360	0.09		Granule	10	291	0.8	21.8	78.2
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	15	306	1.1	23.0	77.0
#30	0.6	600	0.02		Coarse Sand	83	389	6.2	29.2	70.8
#50	0.3	300	0.01		Medium Sand	614	1003	46.1	75.3	24.7
#100	0.15	150	0.006		Fine Sand	245	1248	18.4	93.7	6.3
#200	0.075	75	0.003		Very Fine Sand	54	1302	4.1	97.7	2.3
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	30	1332	2.3	100.0	0.0
					Total Weight (g)	1332	d_{40} (mm)=	0.52	d_{50} (mm)=	0.44
					% Gravel	21.8	d_{90} (mm)=	0.18	$K=Cd_{50}^{J} = 450d_{50}^{1\ 65}$=	
					% Sand	75.9	$C_u=d_{40}/d_{90}$=	2.9	K (ft/d)=	**116**
					% Silt & Clay	2.3				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (89-90 feet bgs)
Grain Size Analysis

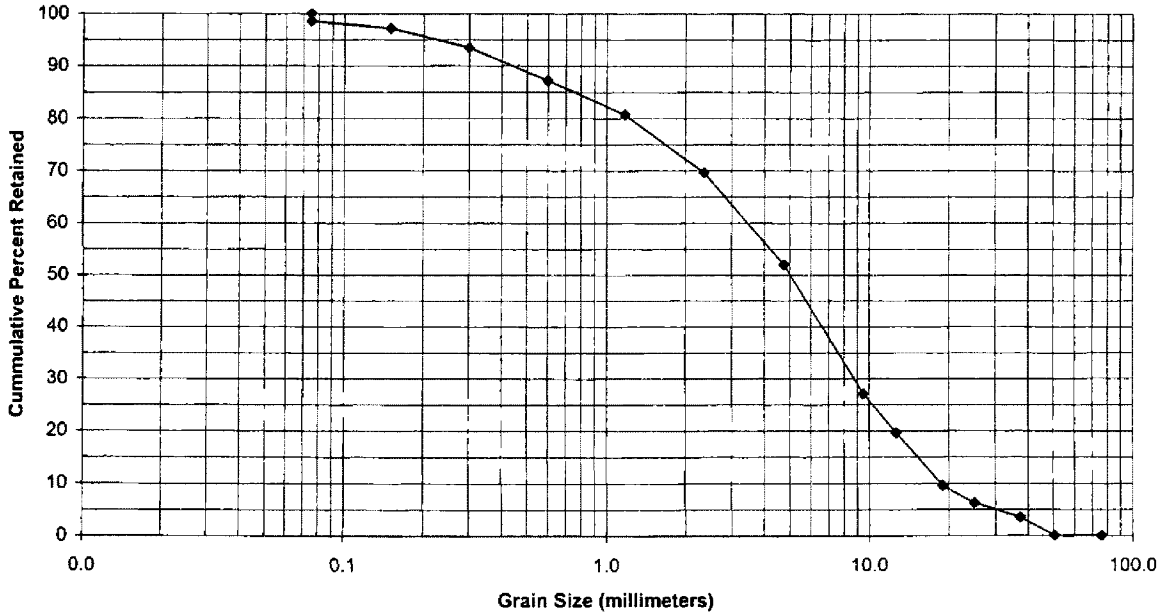


Boring: MFG-B2
Depth Interval (feet bgs): 90-91
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	70	70	3.5	3.5	96.5
1	25.0	25,000	1.0		Pebble	56	126	2.8	6.2	93.8
3/4	19.0	19,000	0.75		Pebble	66	192	3.3	9.5	90.5
1/2	12.7	12,700	0.50		Pebble	203	395	10.0	19.5	80.5
3/8	9.5	9,500	0.38		Pebble	152	547	7.5	27.1	72.9
#4	4.75	4,750	0.19		Pebble	504	1051	24.9	52.0	48.0
#8	2.36	2,360	0.09		Granule	357	1408	17.7	69.6	30.4
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	223	1631	11.0	80.7	19.3
#30	0.6	600	0.02		Coarse Sand	131	1762	6.5	87.1	12.9
#50	0.3	300	0.01		Medium Sand	127	1889	6.3	93.4	6.6
#100	0.15	150	0.006		Fine Sand	75	1964	3.7	97.1	2.9
#200	0.075	75	0.003		Very Fine Sand	28	1992	1.4	98.5	1.5
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	30	2022	1.5	100.0	0.0
					Total Weight (g)	2022	d_{40} (mm)=	6.7	d_{50} (mm)=	5
					% Gravel	69.6	d_{90} (mm)=	0.44	$K=Cd_{50}^{J} = 450d_{50}^{1.65}$=	
					% Sand	28.9	$C_u=d_{40}/d_{90}$=	15	K (ft/d)=	6,405
					% Silt & Clay	1.5				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (90-91 feet bgs)
Grain Size Analysis

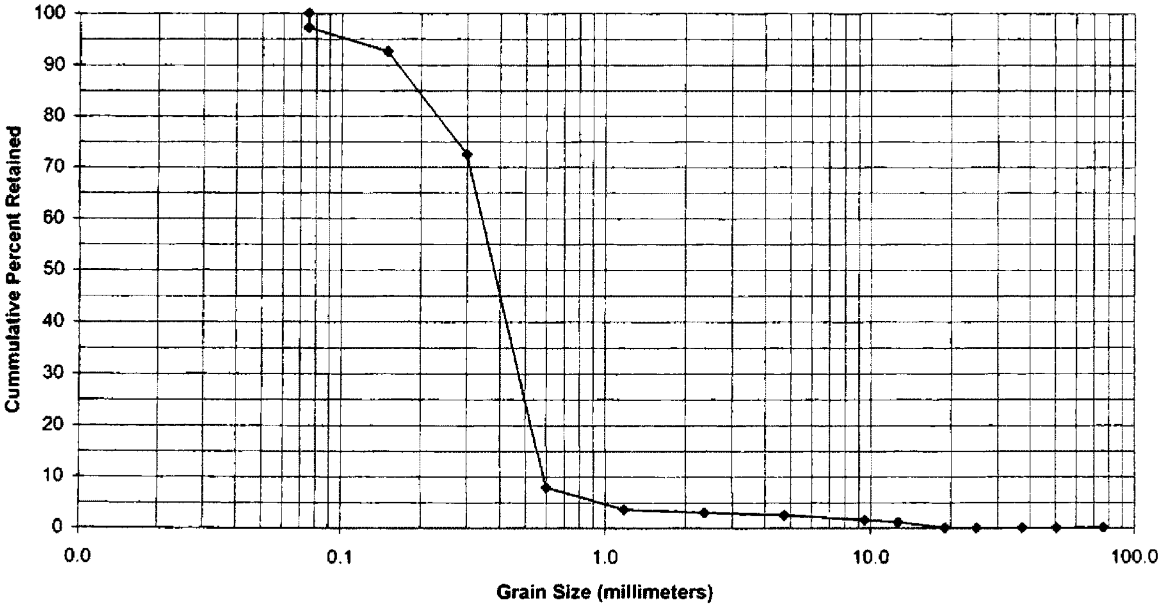


Boring: **MFG-B2**
Depth Interval (feet bgs): **94-95**
Date Analyzed: **5/25/01**
Analyzed By: **Natalie Morrow**

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	0	0	0.0	0.0	100.0
3/4	19.0	19,000	0.75		Pebble	0	0	0.0	0.0	100.0
1/2	12.7	12,700	0.50		Pebble	15	15	1.1	1.1	98.9
3/8	9.5	9,500	0.38		Pebble	6	21	0.4	1.5	98.5
#4	4.75	4,750	0.19		Pebble	13	34	1.0	2.5	97.5
#8	2.36	2,360	0.09		Granule	7	41	0.5	3.0	97.0
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	8	49	0.6	3.6	96.4
#30	0.6	600	0.02		Coarse Sand	59	108	4.3	7.9	92.1
#50	0.3	300	0.01		Medium Sand	879	987	64.5	72.5	27.5
#100	0.15	150	0.006		Fine Sand	274	1261	20.1	92.6	7.4
#200	0.075	75	0.003		Very Fine Sand	63	1324	4.6	97.2	2.8
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	38	1362	2.8	100.0	0.0
Total Weight (g)						1362	d_{40} (mm)=	0.43	d_{50} (mm)=	0.38
% Gravel						3.0	d_{90} (mm)=	0.14	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
% Sand						94.2	$C_u=d_{40}/d_{90}=$	3.1	K (ft/d)=	91
% Silt & Clay						2.8				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (94-95 feet bgs)
Grain Size Analysis

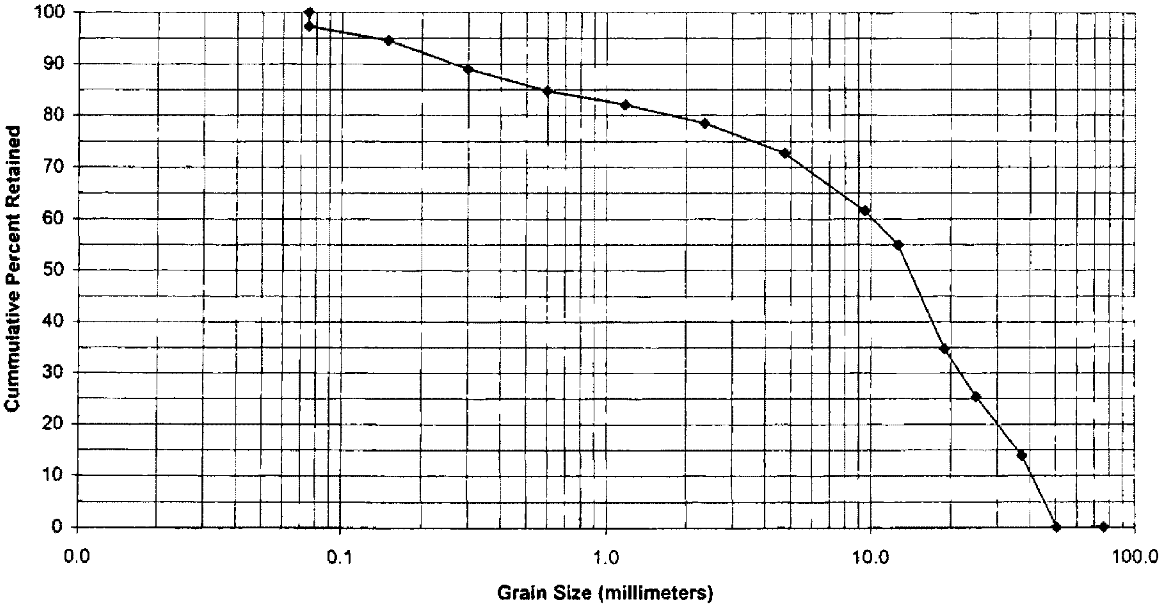


Boring: MFG-B2
Depth Interval (feet bgs): 98.5-99
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	205	205	13.8	13.8	86.2
1	25.0	25,000	1.0		Pebble	171	376	11.5	25.3	74.7
3/4	19.0	19,000	0.75		Pebble	140	516	9.4	34.7	65.3
1/2	12.7	12,700	0.50		Pebble	301	817	20.2	54.9	45.1
3/8	9.5	9,500	0.38		Pebble	98	915	6.6	61.5	38.5
#4	4.75	4,750	0.19		Pebble	166	1081	11.2	72.6	27.4
#8	2.36	2,360	0.09		Granule	86	1167	5.8	78.4	21.6
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	53	1220	3.6	82.0	18.0
#30	0.6	600	0.02		Coarse Sand	40	1260	2.7	84.7	15.3
#50	0.3	300	0.01		Medium Sand	63	1323	4.2	88.9	11.1
#100	0.15	150	0.006		Fine Sand	83	1406	5.6	94.5	5.5
#200	0.075	75	0.003		Very Fine Sand	41	1447	2.8	97.2	2.8
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	41	1488	2.8	100.0	0.0
					Total Weight (g)	1488	d_{40} (mm)=	17.8	d_{50} (mm)=	15.00
					% Gravel	78.4	d_{90} (mm)=	0.27	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
					% Sand	18.8	$C_u=d_{40}/d_{90}=$	66	K (ft/d)=	39,243
					% Silt & Clay	2.8				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

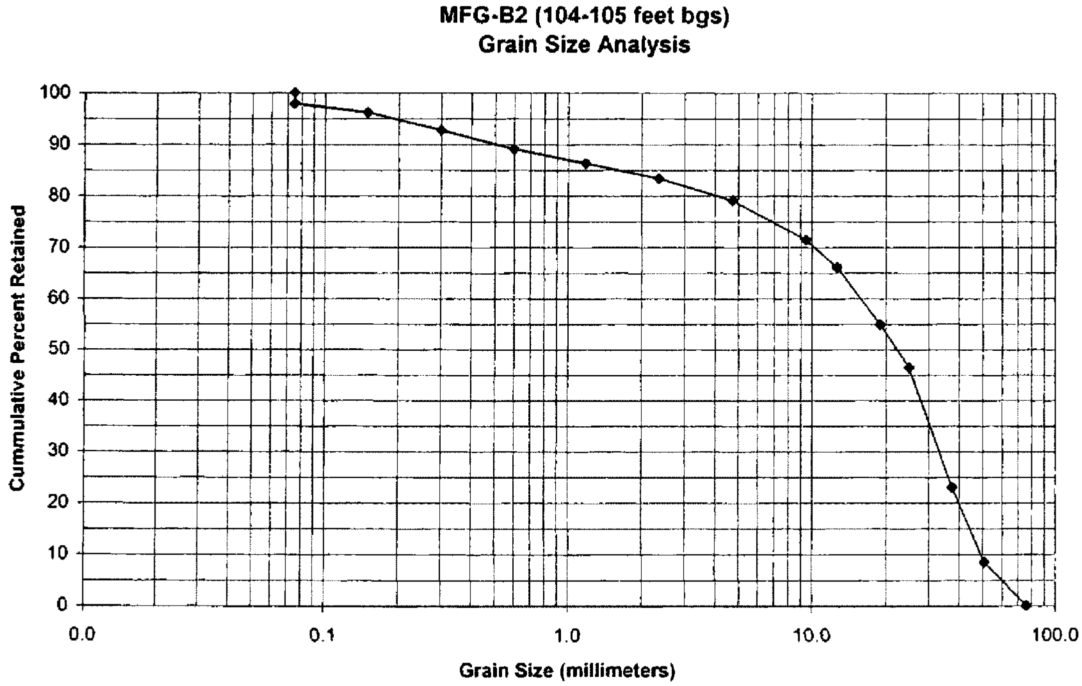
MFG-B2 (98.5-99 feet bgs)
Grain Size Analysis



Boring: MFG-B2
Depth Interval (feet bgs): 104-105
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	139	139	8.4	8.4	91.6
1 1/2	37.5	37,500	1.5		Pebble	240	379	14.6	23.0	77.0
1	25.0	25,000	1.0		Pebble	385	764	23.4	46.4	53.6
3/4	19.0	19,000	0.75		Pebble	139	903	8.4	54.9	45.1
1/2	12.7	12,700	0.50		Pebble	184	1087	11.2	66.0	34.0
3/8	9.5	9,500	0.38		Pebble	89	1176	5.4	71.4	28.6
#4	4.75	4,750	0.19		Pebble	125	1301	7.6	79.0	21.0
#8	2.36	2,360	0.09		Granule	71	1372	4.3	83.4	16.6
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	48	1420	2.9	86.3	13.7
#30	0.6	600	0.02		Coarse Sand	46	1466	2.8	89.1	10.9
#50	0.3	300	0.01		Medium Sand	60	1526	3.6	92.7	7.3
#100	0.15	150	0.006		Fine Sand	56	1582	3.4	96.1	3.9
#200	0.075	75	0.003		Very Fine Sand	29	1611	1.8	97.9	2.1
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	35	1646	2.1	100.0	0.0
Total Weight (g)						1646	d_{40} (mm)=	28	d_{50} (mm)=	23
% Gravel						83.4	d_{90} (mm)=	0.50	$K=Cd_{50}^{J} = 450d_{50}^{1.65}$=	
% Sand						14.5	$C_u=d_{40}/d_{90}$=	56	K (ft/d)=	79,444
% Silt & Clay						2.1				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

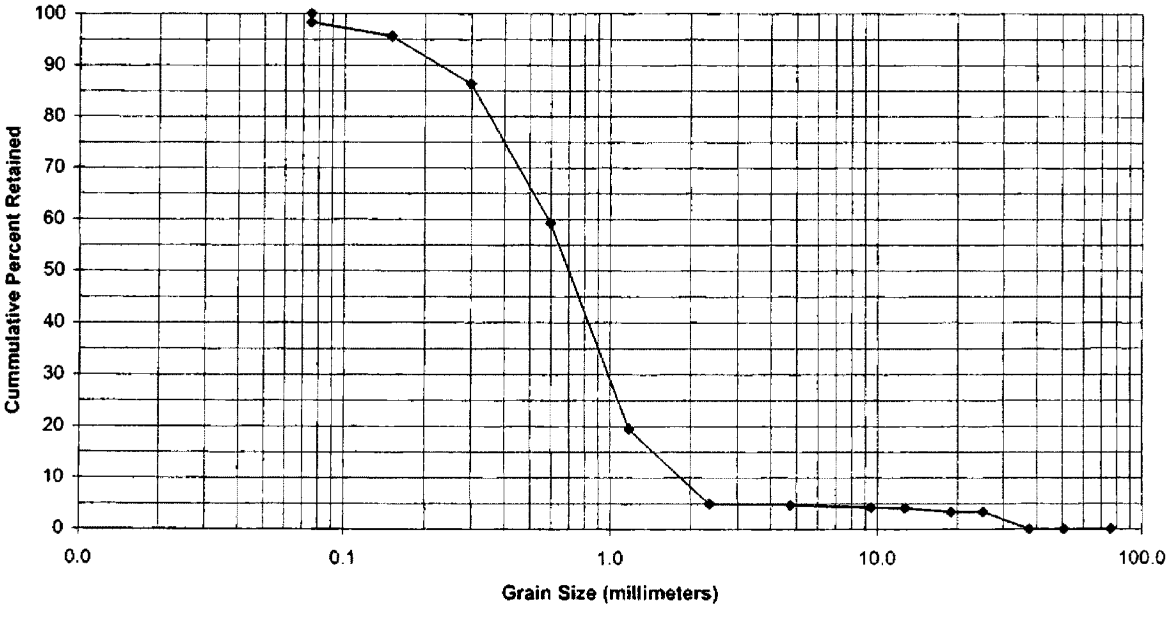

MFG-B2 (104-105 feet bgs)
Grain Size Analysis

Boring: MFG-B2
Depth Interval (feet bgs): 105-105.5
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	44	44	3.3	3.3	96.7
3/4	19.0	19,000	0.75		Pebble	0	44	0.0	3.3	96.7
1/2	12.7	12,700	0.50		Pebble	9	53	0.7	4.0	96.0
3/8	9.5	9,500	0.38		Pebble	2	55	0.2	4.2	95.8
#4	4.75	4,750	0.19		Pebble	6	61	0.5	4.6	95.4
#8	2.36	2,360	0.09		Granule	4	65	0.3	4.9	95.1
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	192	257	14.5	19.5	80.5
#30	0.6	600	0.02		Coarse Sand	524	781	39.7	59.2	40.8
#50	0.3	300	0.01		Medium Sand	358	1139	27.1	86.3	13.7
#100	0.15	150	0.006		Fine Sand	122	1261	9.2	95.5	4.5
#200	0.075	75	0.003		Very Fine Sand	36	1297	2.7	98.3	1.7
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	23	1320	1.7	100.0	0.0
					Total Weight (g)	1320	d_{40} (mm)=	0.82	d_{50} (mm)=	0.7
					% Gravel	4.9	d_{90} (mm)=	0.24	$K=Cd_{50}^{J}=450d_{50}^{1.65}=$	
					% Sand	93.3	$C_u=d_{40}/d_{90}=$	3.4	K (ft/d)=	250
					% Silt & Clay	1.7				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (105-105.5 feet bgs)
Grain Size Analysis

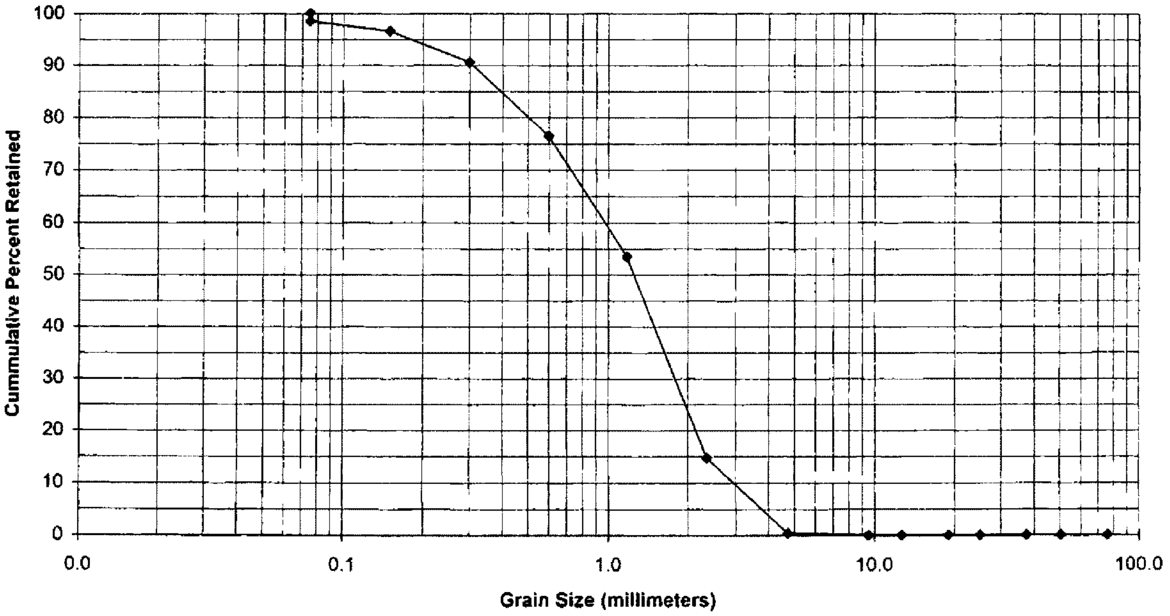


Boring: MFG-B2
Depth Interval (feet bgs): 107-107.5
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	0	0	0.0	0.0	100.0
3/4	19.0	19,000	0.75		Pebble	0	0	0.0	0.0	100.0
1/2	12.7	12,700	0.50		Pebble	0	0	0.0	0.0	100.0
3/8	9.5	9,500	0.38		Pebble	0	0	0.0	0.0	100.0
#4	4.75	4,750	0.19		Pebble	6	6	0.4	0.4	99.6
#8	2.36	2,360	0.09		Granule	204	210	14.3	14.7	85.3
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	553	763	38.7	53.4	46.6
#30	0.6	600	0.02		Coarse Sand	329	1092	23.0	76.4	23.6
#50	0.3	300	0.01		Medium Sand	202	1294	14.1	90.6	9.4
#100	0.15	150	0.006		Fine Sand	85	1379	5.9	96.5	3.5
#200	0.075	75	0.003		Very Fine Sand	28	1407	2.0	98.5	1.5
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	22	1429	1.5	100.0	0.0
					Total Weight (g)	1429	d_{40} (mm)=	1.6	d_{50} (mm)=	1.3
					% Gravel	14.7	d_{90} (mm)=	0.32	$K=Cd_{50}^{J} = 450d_{50}^{1.65}$=	
					% Sand	83.8	$C_u=d_{40}/d_{90}$=	5	K (ft/d)=	694
					% Silt & Clay	1.5				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (107-107.5 feet bgs)
Grain Size Analysis

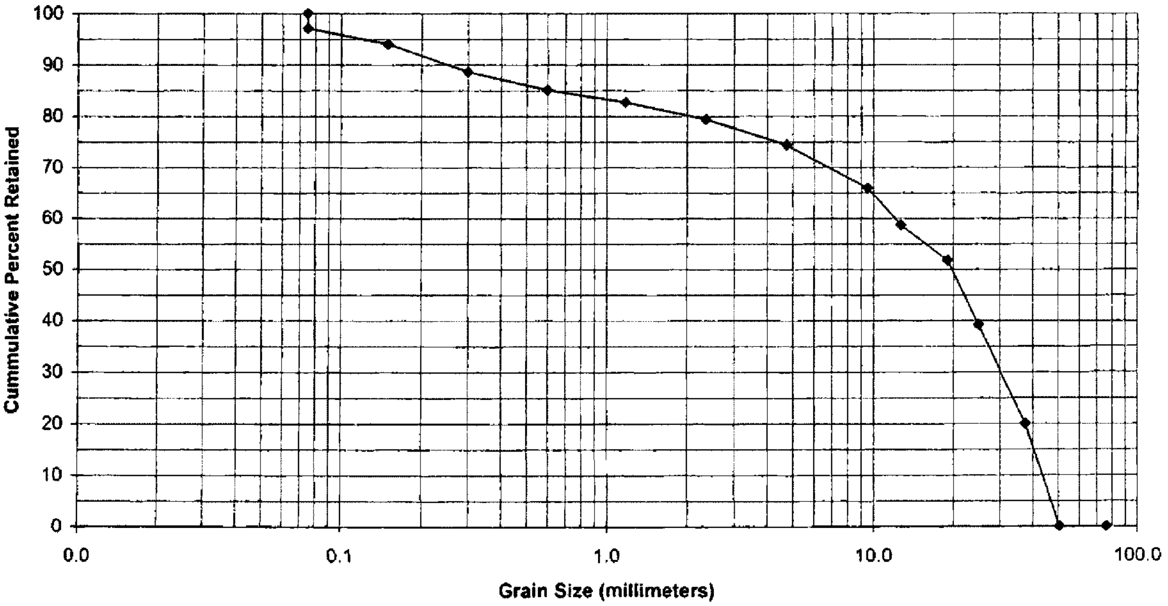


Boring: MFG-B2
Depth Interval (feet bgs): 109-110
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	355	355	20.0	20.0	80.0
1	25.0	25,000	1.0		Pebble	341	696	19.2	39.1	60.9
3/4	19.0	19,000	0.75		Pebble	224	920	12.6	51.7	48.3
1/2	12.7	12,700	0.50		Pebble	123	1043	6.9	58.7	41.3
3/8	9.5	9,500	0.38		Pebble	129	1172	7.3	65.9	34.1
#4	4.75	4,750	0.19		Pebble	150	1322	8.4	74.4	25.6
#8	2.36	2,360	0.09		Granule	88	1410	4.9	79.3	20.7
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	60	1470	3.4	82.7	17.3
#30	0.6	600	0.02		Coarse Sand	42	1512	2.4	85.0	15.0
#50	0.3	300	0.01		Medium Sand	63	1575	3.5	88.6	11.4
#100	0.15	150	0.006		Fine Sand	96	1671	5.4	94.0	6.0
#200	0.075	75	0.003		Very Fine Sand	55	1726	3.1	97.1	2.9
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	52	1778	2.9	100.0	0.0
					Total Weight (g)	1778	d_{40}(mm)=	25	d_{50}(mm)=	19
					% Gravel	79.3	d_{90}(mm)=	0.25	$K=Cd_{50}^{J}=450d_{50}^{1.65}=$	
					% Sand	17.8	$C_u=d_{40}/d_{90}=$	100	K (ft/d)=	57,964
					% Silt & Clay	2.9				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (109-110 feet bgs)
Grain Size Analysis

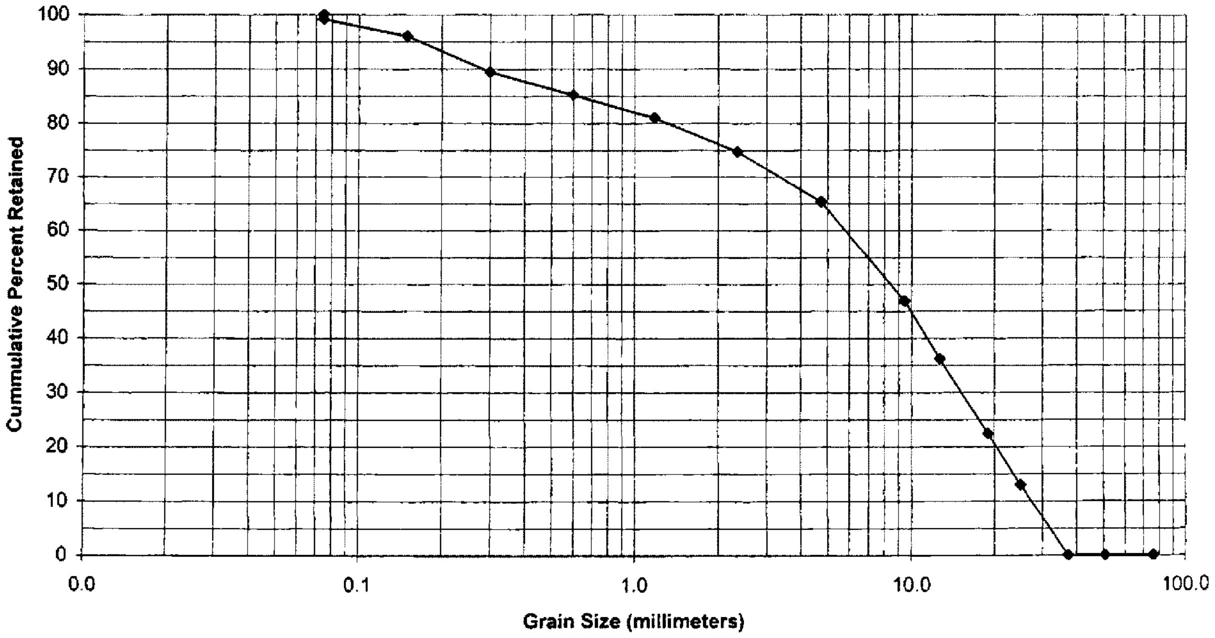


Boring: MFG-B2
Depth Interval (feet bgs): 111-111.5
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	208	208	12.9	12.9	87.1
3/4	19.0	19,000	0.75		Pebble	151	359	9.4	22.3	77.7
1/2	12.7	12,700	0.50		Pebble	221	580	13.8	36.1	63.9
3/8	9.5	9,500	0.38		Pebble	173	753	10.8	46.9	53.1
#4	4.75	4,750	0.19		Pebble	297	1050	18.5	65.3	34.7
#8	2.36	2,360	0.09		Granule	150	1200	9.3	74.7	25.3
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	100	1300	6.2	80.9	19.1
#30	0.6	600	0.02		Coarse Sand	69	1369	4.3	85.2	14.8
#50	0.3	300	0.01		Medium Sand	68	1437	4.2	89.4	10.6
#100	0.15	150	0.006		Fine Sand	106	1543	6.6	96.0	4.0
#200	0.075	75	0.003		Very Fine Sand	50	1593	3.1	99.1	0.9
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	14	1607	0.9	100.0	0.0
					Total Weight (g)	1607	d_{40} (mm)=	12	d_{50} (mm)=	8.5
					% Gravel	74.7	d_{90} (mm)=	0.28	$K=Cd_{50}^{J} = 450d_{50}^{1.65}$=	
					% Sand	24.5	$C_u=d_{40}/d_{90}$=	43	K (ft/d)=	15,373
					% Silt & Clay	0.9				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B2 (111-111.5 feet bgs)
Grain Size Analysis

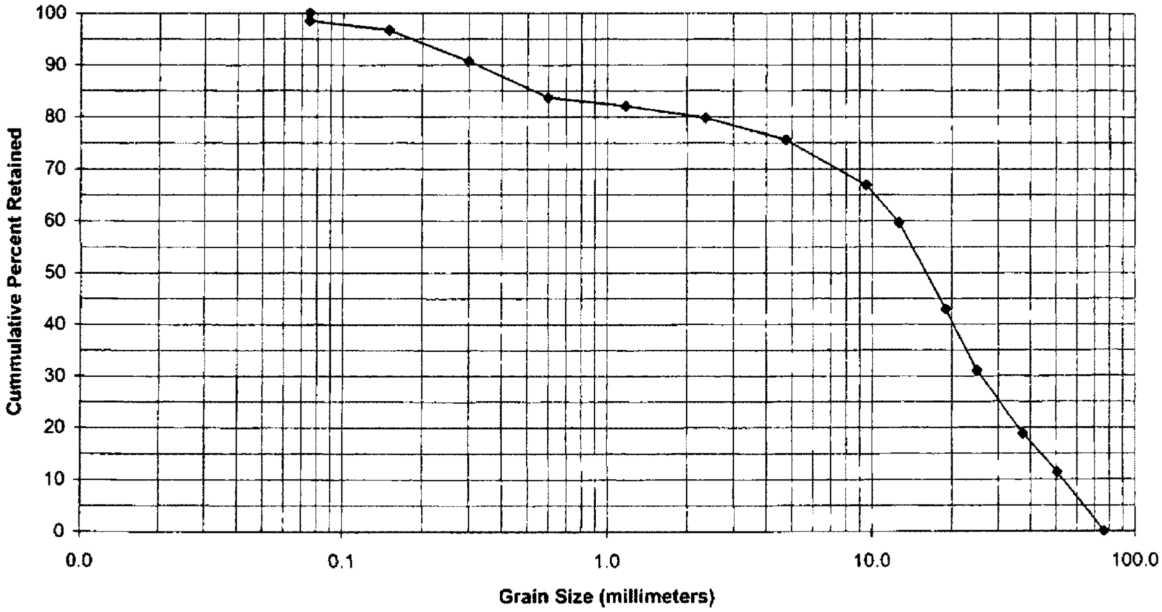


Boring: MFG-B3
Depth Interval (feet bgs): 12-13
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	240	240	11.3	11.3	88.7
1 1/2	37.5	37,500	1.5		Pebble	159	399	7.5	18.7	81.3
1	25.0	25,000	1.0		Pebble	260	659	12.2	31.0	69.0
3/4	19.0	19,000	0.75		Pebble	255	914	12.0	42.9	57.1
1/2	12.7	12,700	0.50		Pebble	355	1269	16.7	59.6	40.4
3/8	9.5	9,500	0.38		Pebble	155	1424	7.3	66.9	33.1
#4	4.75	4,750	0.19		Pebble	184	1608	8.6	75.5	24.5
#8	2.36	2,360	0.09		Granule	90	1698	4.2	79.8	20.2
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	47	1745	2.2	82.0	18.0
#30	0.6	600	0.02		Coarse Sand	36	1781	1.7	83.7	16.3
#50	0.3	300	0.01		Medium Sand	148	1929	7.0	90.6	9.4
#100	0.15	150	0.006		Fine Sand	129	2058	6.1	96.7	3.3
#200	0.075	75	0.003		Very Fine Sand	39	2097	1.8	98.5	1.5
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	32	2129	1.5	100.0	0.0
					Total Weight (g)	2129	d_{40} (mm)=	21	d_{50} (mm)=	3.3
					% Gravel	79.8	d_{90} (mm)=	0.30	$K=Cd_{50}^{J} = 450d_{50}^{1.65}$=	
					% Sand	18.7	$C_u=d_{40}/d_{90}$=	70	K (ft/d)=	3,227
					% Silt & Clay	1.5				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B3 (12-13 feet bgs)
Grain Size Analysis

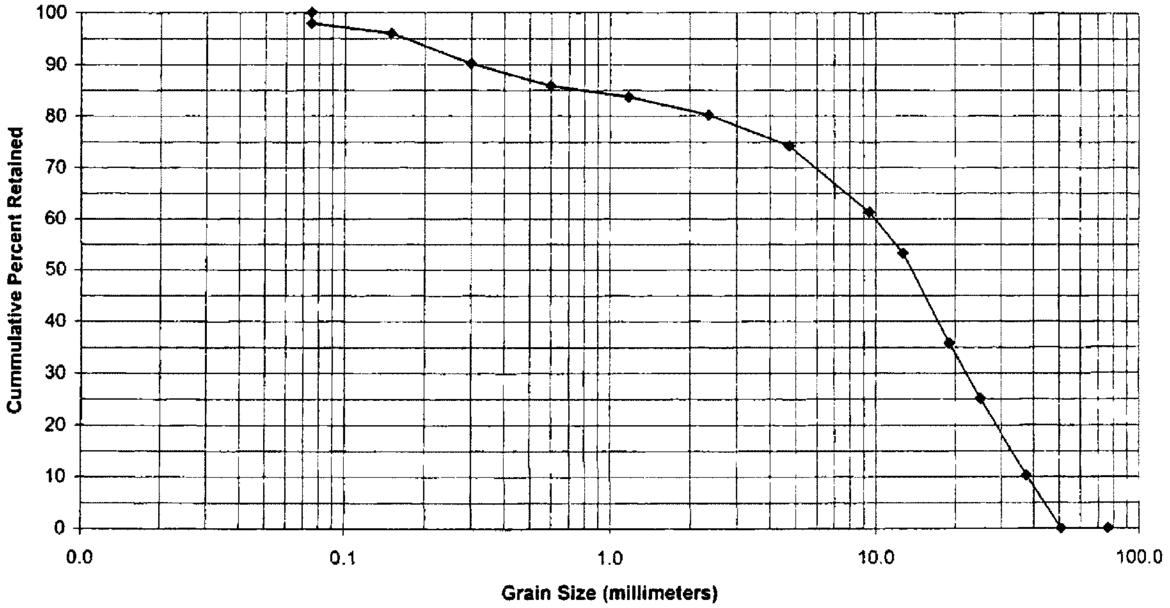


Boring: **MFG-B3**
Depth Interval (feet bgs): **18-19**
Date Analyzed: **5/25/01**
Analyzed By: **Natalie Morrow**

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	169	169	10.2	10.2	89.8
1	25.0	25,000	1.0		Pebble	245	414	14.8	25.0	75.0
3/4	19.0	19,000	0.75		Pebble	177	591	10.7	35.7	64.3
1/2	12.7	12,700	0.50		Pebble	290	881	17.5	53.2	46.8
3/8	9.5	9,500	0.38		Pebble	133	1014	8.0	61.2	38.8
#4	4.75	4,750	0.19		Pebble	214	1228	12.9	74.2	25.8
#8	2.36	2,360	0.09		Granule	99	1327	6.0	80.1	19.9
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	59	1386	3.6	83.7	16.3
#30	0.6	600	0.02		Coarse Sand	35	1421	2.1	85.8	14.2
#50	0.3	300	0.01		Medium Sand	71	1492	4.3	90.1	9.9
#100	0.15	150	0.006		Fine Sand	97	1589	5.9	96.0	4.0
#200	0.075	75	0.003		Very Fine Sand	32	1621	1.9	97.9	2.1
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	35	1656	2.1	100.0	0.0
					Total Weight (g)	1656	d_{40} (mm)=	7.8	d_{50} (mm)=	4.5
					% Gravel	80.1	d_{90} (mm)=	0.30	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
					% Sand	17.8	$C_u=d_{40}/d_{90}=$	26	K (ft/d)=	5,383
					% Silt & Clay	2.1				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B3 (18-19 feet bgs)
Grain Size Analysis

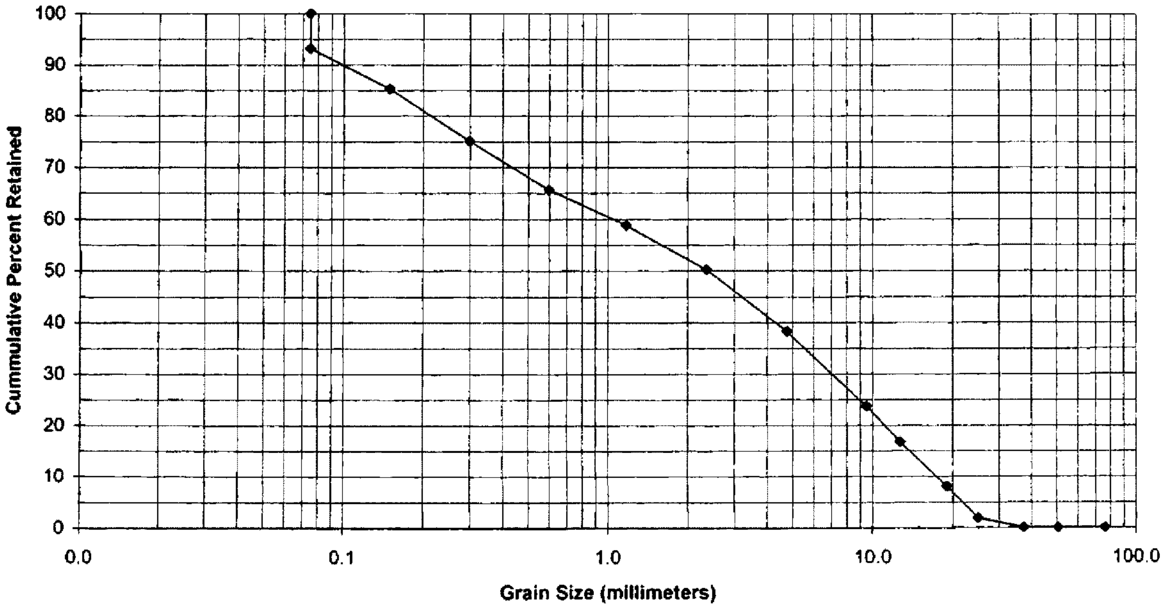


Boring: MFG-B3
Depth Interval (feet bgs): 32-32.5
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	30	30	1.9	1.9	98.1
3/4	19.0	19,000	0.75		Pebble	98	128	6.1	8.0	92.0
1/2	12.7	12,700	0.50		Pebble	139	267	8.7	16.7	83.3
3/8	9.5	9,500	0.38		Pebble	111	378	7.0	23.7	76.3
#4	4.75	4,750	0.19		Pebble	233	611	14.6	38.3	61.7
#8	2.36	2,360	0.09		Granule	191	802	12.0	50.3	49.7
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	136	938	8.5	58.8	41.2
#30	0.6	600	0.02		Coarse Sand	109	1047	6.8	65.6	34.4
#50	0.3	300	0.01		Medium Sand	151	1198	9.5	75.1	24.9
#100	0.15	150	0.006		Fine Sand	163	1361	10.2	85.3	14.7
#200	0.075	75	0.003		Very Fine Sand	126	1487	7.9	93.2	6.8
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	109	1596	6.8	100.0	0.0
					Total Weight (g)	1596	d_{40} (mm)=	4.3	d_{50} (mm)=	2.4
					% Gravel	50.3	d_{90} (mm)=	0.10	$K=Cd_{50}^{j}=450d_{50}^{1.65}=$	
					% Sand	42.9	$C_u=d_{40}/d_{90}=$	43	K (ft/d)=	1,908
					% Silt & Clay	6.8				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B3 (32-32.5 feet bgs)
Grain Size Analysis

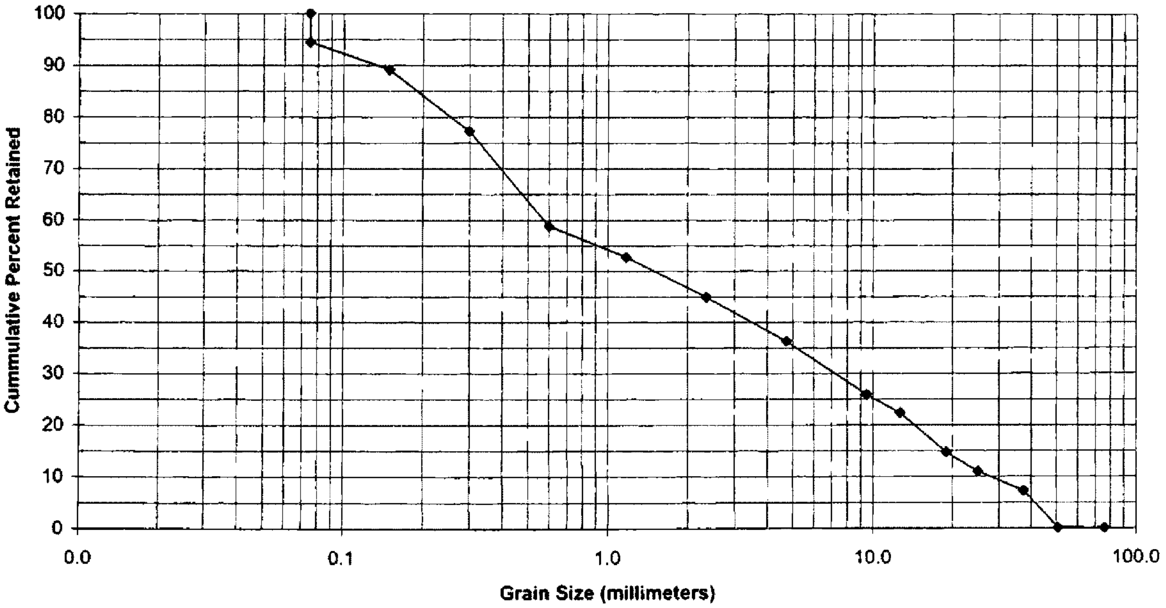


Boring: MFG-B3
Depth Interval (feet bgs): 36-37
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	122	122	7.2	7.2	92.8
1	25.0	25,000	1.0		Pebble	64	186	3.8	10.9	89.1
3/4	19.0	19,000	0.75		Pebble	64	250	3.8	14.7	85.3
1/2	12.7	12,700	0.50		Pebble	129	379	7.6	22.3	77.7
3/8	9.5	9,500	0.38		Pebble	61	440	3.6	25.9	74.1
#4	4.75	4,750	0.19		Pebble	177	617	10.4	36.3	63.7
#8	2.36	2,360	0.09		Granule	147	764	8.6	44.9	55.1
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	133	897	7.8	52.7	47.3
#30	0.6	600	0.02		Coarse Sand	104	1001	6.1	58.8	41.2
#50	0.3	300	0.01		Medium Sand	314	1315	18.4	77.3	22.7
#100	0.15	150	0.006		Fine Sand	202	1517	11.9	89.1	10.9
#200	0.075	75	0.003		Very Fine Sand	90	1607	5.3	94.4	5.6
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	95	1702	5.6	100.0	0.0
					Total Weight (g)	1702	d_{40} (mm)=	3.5	d_{50} (mm)=	1.6
					% Gravel	44.9	d_{90} (mm)=	0.14	$K=Cd_{50}^{J}=450d_{50}^{1.65}=$	
					% Sand	49.5	$C_u=d_{40}/d_{90}=$	25	K (ft/d)=	977
					% Silt & Clay	5.6				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

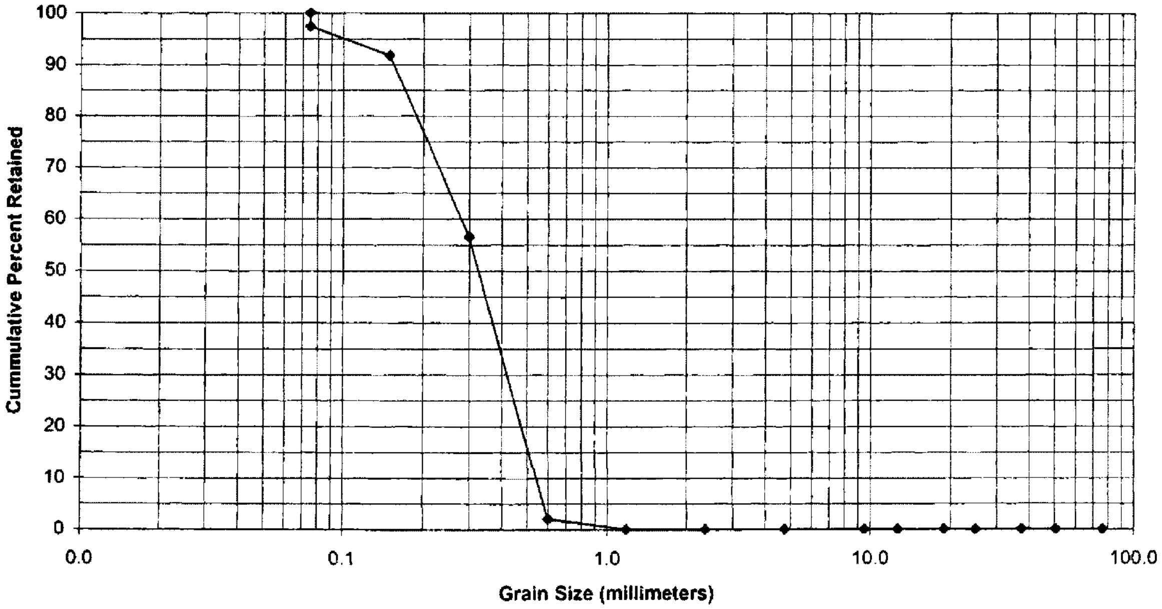
MFG-B3 (36-37 feet bgs)
Grain Size Analysis



Boring: MFG-B3
Depth Interval (feet bgs): 40.5-41.5
Date Analyzed: 5/25/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	0	0	0.0	0.0	100.0
3/4	19.0	19,000	0.75		Pebble	0	0	0.0	0.0	100.0
1/2	12.7	12,700	0.50		Pebble	0	0	0.0	0.0	100.0
3/8	9.5	9,500	0.38		Pebble	0	0	0.0	0.0	100.0
#4	4.75	4,750	0.19		Pebble	0	0	0.0	0.0	100.0
#8	2.36	2,360	0.09		Granule	0	0	0.0	0.0	100.0
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	0	0	0.0	0.0	100.0
#30	0.6	600	0.02		Coarse Sand	23	23	2.0	2.0	98.0
#50	0.3	300	0.01		Medium Sand	614	637	54.5	56.5	43.5
#100	0.15	150	0.006		Fine Sand	397	1034	35.2	91.7	8.3
#200	0.075	75	0.003		Very Fine Sand	63	1097	5.6	97.3	2.7
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	30	1127	2.7	100.0	0.0
					Total Weight (g)	1127	d_{40}(mm)=	0.37	d_{60}(mm)=	0.3
					% Gravel	0.0	d_{90}(mm)=	0.16	$K=Cd_{50}^{j} = 450d_{50}^{1.65}$=	
					% Sand	97.3	$C_u=d_{40}/d_{90}$=	2.3	K (ft/d)=	72
					% Silt & Clay	2.7				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)



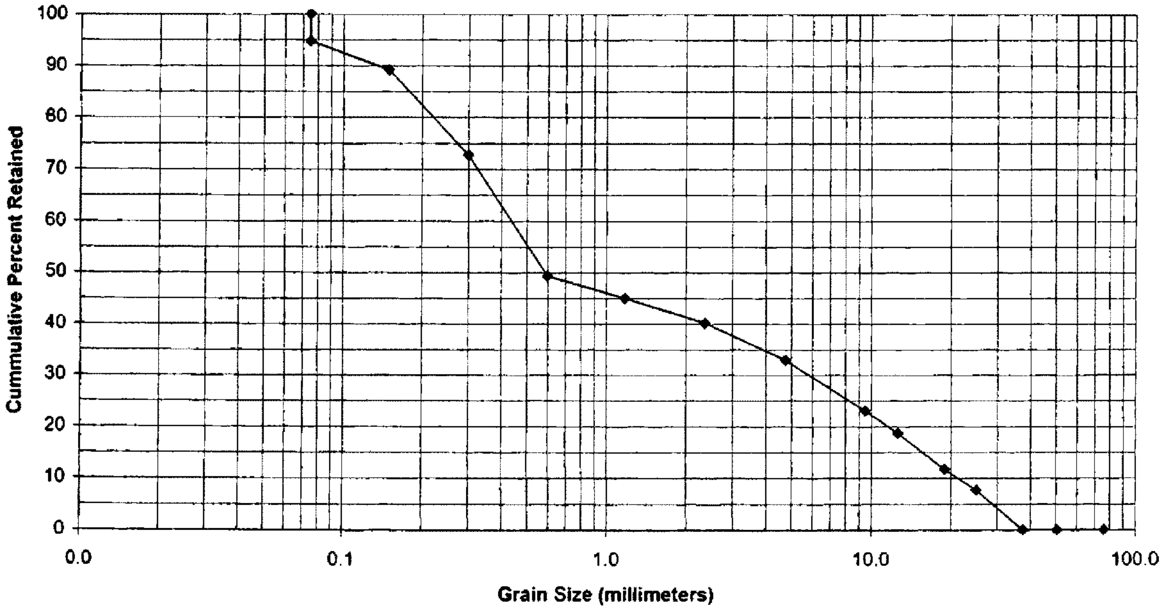
MFG-B3 (40.5-41.5 feet bgs)
Grain Size Analysis

Boring: **MFG-B3**
Depth Interval (feet bgs): **41.5-42**
Date Analyzed: **5/25/01**
Analyzed By: **Natalie Morrow**

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	0	0	0.0	0.0	100.0
1	25.0	25,000	1.0		Pebble	120	120	7.7	7.7	92.3
3/4	19.0	19,000	0.75		Pebble	62	182	4.0	11.7	88.3
1/2	12.7	12,700	0.50		Pebble	108	290	6.9	18.6	81.4
3/8	9.5	9,500	0.38		Pebble	68	358	4.4	23.0	77.0
#4	4.75	4,750	0.19		Pebble	154	512	9.9	32.9	67.1
#8	2.36	2,360	0.09		Granule	113	625	7.3	40.2	59.8
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	75	700	4.8	45.0	55.0
#30	0.6	600	0.02		Coarse Sand	67	767	4.3	49.3	50.7
#50	0.3	300	0.01		Medium Sand	365	1132	23.5	72.8	27.2
#100	0.15	150	0.006		Fine Sand	255	1387	16.4	89.1	10.9
#200	0.075	75	0.003		Very Fine Sand	87	1474	5.6	94.7	5.3
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	82	1556	5.3	100.0	0.0
					Total Weight (g)	1556	d_{40}=	0.24	d_{50}=	0.8
					% Gravel	40.2	d_{90}=	0.14	$K=Cd_{50}^{J} = 450d_{50}^{1.65}$=	
					% Sand	54.6	$C_u=d_{40}/d_{90}$=	1.7	K (ft/d)=	311
					% Silt & Clay	5.3				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B3 (41.5-42 feet bgs)
Grain Size Analysis

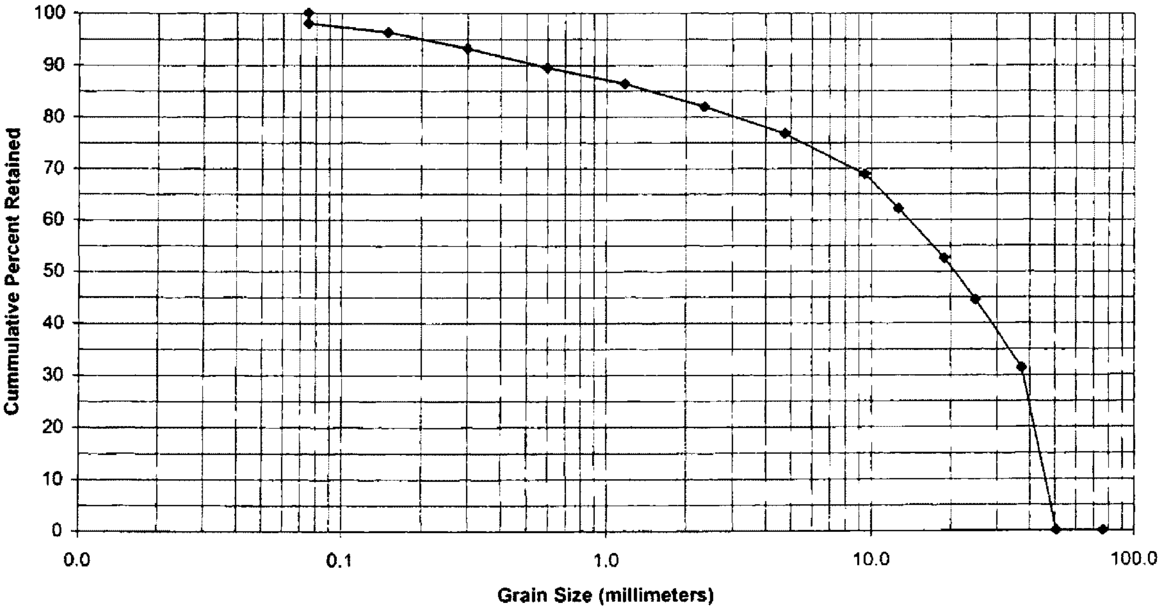


Boring: **MFG-B3**
Depth Interval (feet bgs): **43-44**
Date Analyzed: **5/25/01**
Analyzed By: **Natalie Morrow**

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	618	618	31.3	31.3	68.7
1	25.0	25,000	1.0		Pebble	260	878	13.2	44.4	55.6
3/4	19.0	19,000	0.75		Pebble	159	1037	8.0	52.5	47.5
1/2	12.7	12,700	0.50		Pebble	190	1227	9.6	62.1	37.9
3/8	9.5	9,500	0.38		Pebble	134	1361	6.8	68.9	31.1
#4	4.75	4,750	0.19		Pebble	155	1516	7.8	76.7	23.3
#8	2.36	2,360	0.09		Granule	103	1619	5.2	81.9	18.1
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	87	1706	4.4	86.3	13.7
#30	0.6	600	0.02		Coarse Sand	61	1767	3.1	89.4	10.6
#50	0.3	300	0.01		Medium Sand	74	1841	3.7	93.2	6.8
#100	0.15	150	0.006		Fine Sand	61	1902	3.1	96.3	3.7
#200	0.075	75	0.003		Very Fine Sand	33	1935	1.7	97.9	2.1
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	41	1976	2.1	100.0	0.0
					Total Weight (g)	1976	d_{40}(mm)=	28	d_{50}(mm)=	21
					% Gravel	81.9	d_{90}(mm)=	0.53	$K=Cd_{50}^{J} = 450d_{50}^{1.55}=$	
					% Sand	16.0	$C_u=d_{40}/d_{90}=$	53	K (ft/d)=	68,371
					% Silt & Clay	2.1				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B3 (43-44 feet bgs)
Grain Size Analysis

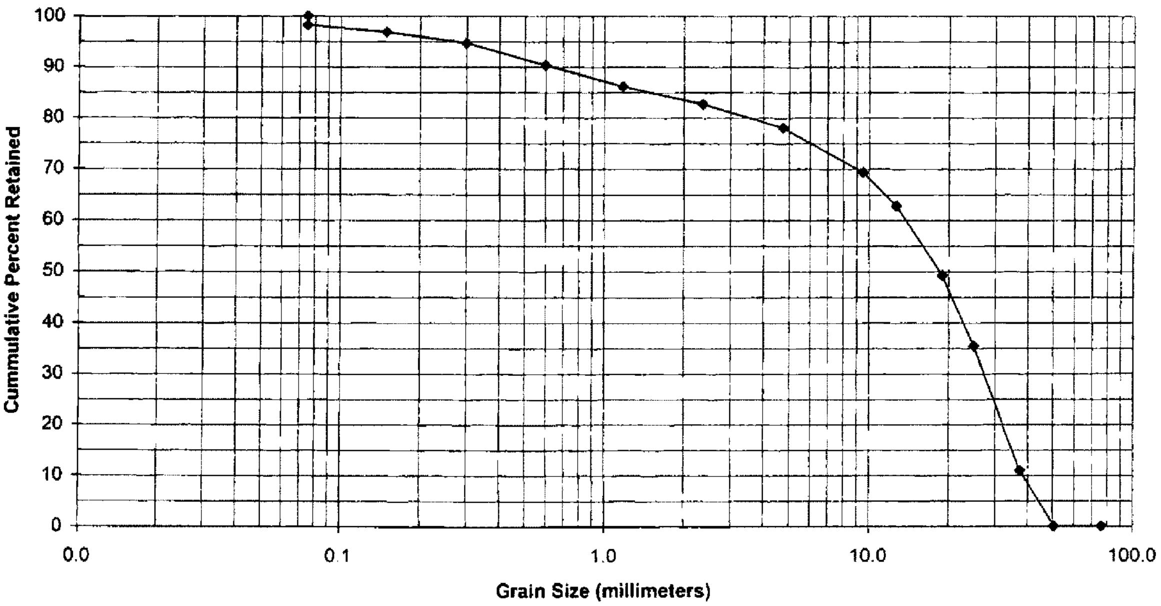


Boring: **MFG-B3**
Depth Interval (feet bgs): **46-47**
Date Analyzed: **5/25/01**
Analyzed By: **Natalie Morrow**

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	204	204	11.0	11.0	89.0
1	25.0	25,000	1.0		Pebble	455	659	24.4	35.4	64.6
3/4	19.0	19,000	0.75		Pebble	257	916	13.8	49.2	50.8
1/2	12.7	12,700	0.50		Pebble	252	1168	13.5	62.7	37.3
3/8	9.5	9,500	0.38		Pebble	123	1291	6.6	69.3	30.7
#4	4.75	4,750	0.19		Pebble	161	1452	8.6	78.0	22.0
#8	2.36	2,360	0.09		Granule	87	1539	4.7	82.7	17.3
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	65	1604	3.5	86.1	13.9
#30	0.6	600	0.02		Coarse Sand	78	1682	4.2	90.3	9.7
#50	0.3	300	0.01		Medium Sand	81	1763	4.4	94.7	5.3
#100	0.15	150	0.006		Fine Sand	40	1803	2.1	96.8	3.2
#200	0.075	75	0.003		Very Fine Sand	25	1828	1.3	98.2	1.8
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	34	1862	1.8	100.0	0.0
					Total Weight (g)	1862	d_{40} (mm)=	23	d_{50} (mm)=	19
					% Gravel	82.7	d_{90} (mm)=	0.60	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
					% Sand	15.5	$C_u=d_{40}/d_{90}=$	38	K (ft/d)=	57,964
					% Silt & Clay	1.8				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B3 (46-47 feet bgs)
Grain Size Analysis

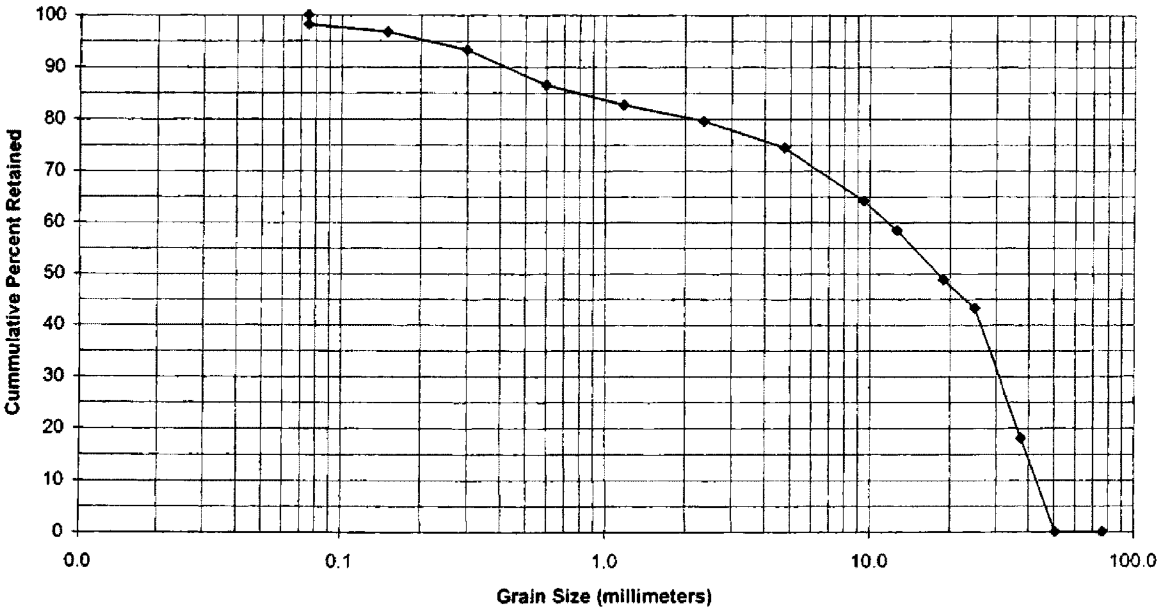


Boring: MFG-B3
Depth Interval (feet bgs): 48-49
Date Analyzed: 5/24/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size			Size Classifications		Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
	Millimeters (mm)	Microns (um)	Inches	General Classification	Wentworth Classification					
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	344	344	18.1	18.1	81.9
1	25.0	25,000	1.0		Pebble	479	823	25.2	43.2	56.8
3/4	19.0	19,000	0.75		Pebble	105	928	5.5	48.8	51.2
1/2	12.7	12,700	0.50		Pebble	184	1112	9.7	58.4	41.6
3/8	9.5	9,500	0.38		Pebble	109	1221	5.7	64.2	35.8
#4	4.75	4,750	0.19		Pebble	196	1417	10.3	74.5	25.5
#8	2.36	2,360	0.09		Granule	96	1513	5.0	79.5	20.5
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	60	1573	3.2	82.7	17.3
#30	0.6	600	0.02		Coarse Sand	73	1646	3.8	86.5	13.5
#50	0.3	300	0.01		Medium Sand	128	1774	6.7	93.2	6.8
#100	0.15	150	0.006		Fine Sand	66	1840	3.5	96.7	3.3
#200	0.075	75	0.003		Very Fine Sand	28	1868	1.5	98.2	1.8
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	35	1903	1.8	100.0	0.0
					Total Weight (g)	1903	d_{40} (mm)=	27	d_{50} (mm)=	8.4
					% Gravel	79.5	d_{90} (mm)=	0.40	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
					% Sand	18.7	$C_u=d_{40}/d_{90}=$	68	K (ft/d)=	15,076
					% Silt & Clay	1.8				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B3 (48-49 feet bgs)
Grain Size Analysis

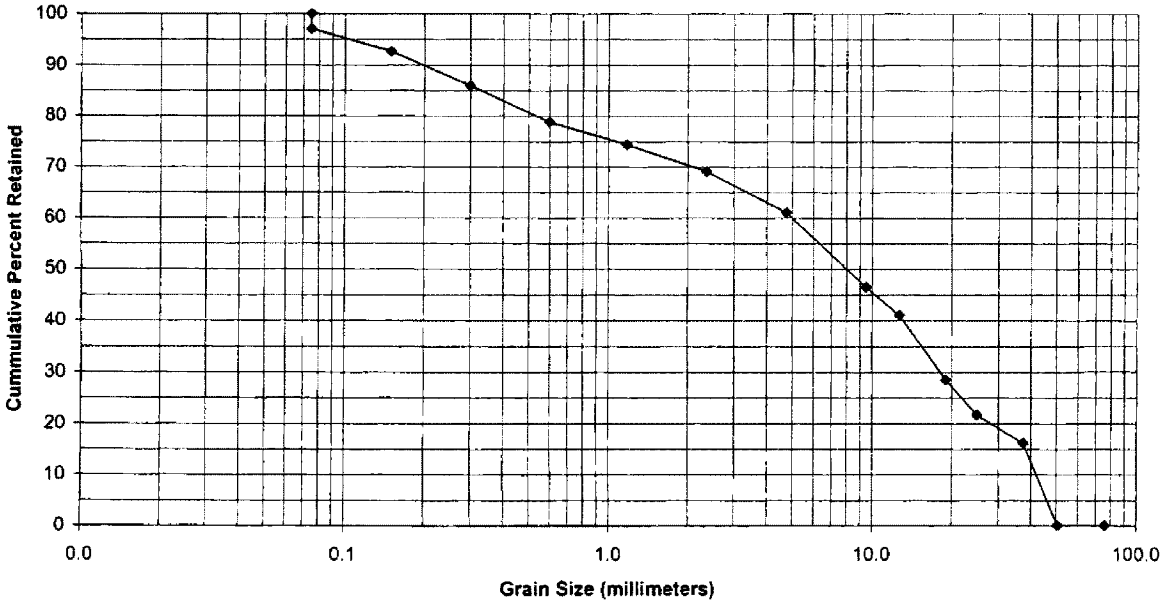


Boring: MFG-B3
Depth Interval (feet bgs): 55.5-56
Date Analyzed: 5/24/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	215	215	16.1	16.1	83.9
1	25.0	25,000	1.0		Pebble	73	288	5.5	21.6	78.4
3/4	19.0	19,000	0.75		Pebble	91	379	6.8	28.5	71.5
1/2	12.7	12,700	0.50		Pebble	167	546	12.5	41.0	59.0
3/8	9.5	9,500	0.38		Pebble	73	619	5.5	46.5	53.5
#4	4.75	4,750	0.19		Pebble	194	813	14.6	61.0	39.0
#8	2.36	2,360	0.09		Granule	107	920	8.0	69.1	30.9
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	70	990	5.3	74.3	25.7
#30	0.6	600	0.02		Coarse Sand	59	1049	4.4	78.8	21.2
#50	0.3	300	0.01		Medium Sand	96	1145	7.2	86.0	14.0
#100	0.15	150	0.006		Fine Sand	89	1234	6.7	92.6	7.4
#200	0.075	75	0.003		Very Fine Sand	58	1292	4.4	97.0	3.0
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	40	1332	3.0	100.0	0.0
					Total Weight (g)	1332	d_{40} (mm)=	13.4	d_{50} (mm)=	8.0
					% Gravel	69.1	d_{90} (mm)=	0.19	$K=Cd_{50}^{J} = 450d_{50}^{1.65}=$	
					% Sand	27.9	$C_u=d_{40}/d_{90}=$	71	K (ft/d)=	13,909
					% Silt & Clay	3.0				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)

MFG-B3 (55.5-56 feet bgs)
Grain Size Analysis



Boring: MFG-B3
Depth Interval (feet bgs): 63-64
Date Analyzed: 5/24/01
Analyzed By: Natalie Morrow

Sieve / Mesh Size	Sieve Aperture / Grain Size Millimeters (mm)	Microns (um)	Inches	Size Classifications General Classification	Wentworth Classification	Total Weight Retained (g)	Cummulative Weight Retained (g)	Percent Retained	Cummulative Percent Retained	Percent Passing
3	76.2	76,200	3.0	Gravel	Cobble	0	0	0.0	0.0	100.0
2	50.8	50,800	2.0		Pebble	0	0	0.0	0.0	100.0
1 1/2	37.5	37,500	1.5		Pebble	143	143	7.9	7.9	92.1
1	25.0	25,000	1.0		Pebble	201	344	11.0	18.9	81.1
3/4	19.0	19,000	0.75		Pebble	197	541	10.8	29.7	70.3
1/2	12.7	12,700	0.50		Pebble	253	794	13.9	43.6	56.4
3/8	9.5	9,500	0.38		Pebble	174	968	9.6	53.2	46.8
#4	4.75	4,750	0.19		Pebble	246	1214	13.5	66.7	33.3
#8	2.36	2,360	0.09		Granule	131	1345	7.2	73.9	26.1
#16	1.18	1,180	0.05	Sand	Very Coarse Sand	86	1431	4.7	78.6	21.4
#30	0.6	600	0.02		Coarse Sand	85	1516	4.7	83.3	16.7
#50	0.3	300	0.01		Medium Sand	173	1689	9.5	92.8	7.2
#100	0.15	150	0.006		Fine Sand	76	1765	4.2	96.9	3.1
#200	0.075	75	0.003		Very Fine Sand	25	1790	1.4	98.3	1.7
-#200	0.075	75	0.003	Silt & Clay	Silt & Clay	31	1821	1.7	100.0	0.0
					Total Weight (g)	1821	d_{40} (mm)=	15	d_{50} (mm)=	11
					% Gravel	73.9	d_{90} (mm)=	0.27	$K=Cd_{50}^{J} = 450d_{50}^{1.65}$=	
					% Sand	24.4	$C_u=d_{40}/d_{90}$=	56	K (ft/d)=	23,524
					% Silt & Clay	1.7				

Hydraulic conductivity (K) equation obtained from Shepard's relationship of hydraulic conductivity to grain size for channel deposits (Fetter, 1994)