Groundwater Quality in the O'Keefe Creek/Wye Area: 1997/1998

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March 1999

Executive Summary

Residential and commercial development of the O'Keefe Creek/Wye area has led to concerns about potential water quality impacts. Nitrate-N in groundwater is a particular concern due to its association with on-site septic systems, which are used to manage waste water in the study area due to the absence of municipal sewer service.

The geology of the upper several hundred feet within the study area is complex and is characterized by alternating and discontinuous layers of clay, silt, sand, and gravel, as well as beds of consolidated and semi-consolidated sedimentary materials (e.g. conglomerate and coal). Groundwater occurs under confined, semi-confined, and unconfined conditions. Groundwater flow was measured to be generally to the southwest, with a hydraulic gradient ranging from nearly flat in the Cartage Road area to 0.01 in the Missoula Industrial Park area.

Groundwater samples were collected from 38 drinking water wells within the study area in 1997 and 1998. Samples were analyzed at the Murdock Environmental Laboratory at the University of Montana for fluoride, chloride, sulfate, nitrite-N, nitrate-N, ammonia-N, barium, calcium, iron, potassium, sodium, magnesium, and total dissolved inorganic carbon.

Three likely sources of nitrate-N were identified for wells with average concentrations exceeding 2.0 mg/L: 1) the individual on-site septic drainfield; 2) proximity to a large commercial or community septic drainfield; 3) livestock waste, generally from horses and other livestock allowed near the wellhead.

Four actual or potential problem areas were identified:

1) The Cartage Road Area - Data collected from wells in the Cartage Road area north of the I-90/US 93 intersection show the highest degree of anthropogenic impacts within the study area. Nitrate-N in particular is significantly elevated above background concentrations. One commercial well contained nitrate-N concentrations approaching the 10 mg/L standard during the last sampling event in 1998. Degradation in this area appears to result from large volumes of sewage (estimated at 21,000 gal/day) discharged from commercial facilities to a portion of the aquifer which has inadequate dilution potential due to a flat hydraulic gradient.

2) The High Density Residential Area Northeast of the I-90/US 93 Intersection - Up to 459 single family homes may be built in this area and meet county zoning and Health Code requirements. Groundwater beneath the adjacent Cartage Road Area has already demonstrated susceptibility to contamination from large drainfields and/or seepage pits, so there is concern that groundwater may be similarly impacted by these residential densities, particularly if large community drainfields are used. More work needs to be done to assess the potential impacts in this area.

3) The Missoula Livestock Auction - This facility has the potential to significantly impact local groundwater resources. According to building plans available at the time this report was written, the facility has taken steps to minimize impacts, including a liquid waste collection/treatment system. However, there is a considerable volume of solid manure

stockpiled on site, and additional holding pens appear to have been constructed which are not part of the waste collection/treatment system. This site should be inspected, and BMPs implemented, as necessary.

4) The Apparent CAFO on Waldo Road - Impacts to O'Keefe Creek are likely from an apparent confined animal feeding operation (CAFO) located adjacent to the creek, south of its Waldo Road crossing. Sheep and horses are kept in pens adjacent to the stream, and a significant volume of manure is stockpiled on the site and immediately adjacent to the stream. This site is likely to contribute significant quantities of organic and inorganic pollutants to the stream, particularly during wet periods.

Recommendations include:

1) Inventory public water supplies within the study area and ensure compliance with state sampling requirements;

2) Identify existing systems applying >600 gal/acre/day and evaluate alternatives for corrective action. Priority should be given to those where excessive impacts to groundwater are known to exist;

3) Adhere to housing densities stipulated by the Missoula Urban Area Comprehensive Plan. Densities for the high density residential area should be evaluated for potential impacts to groundwater. Evaluation efforts may involve modeling, if feasible;

4) Residential wells are poor monitoring points. Install additional monitoring wells at strategic locations to obtain an accurate measure of water quality in the upper mixing zone;

5) Restrict future groundwater monitoring efforts to identified problem areas;

6) Collect surface water samples from O'Keefe Creek above and below the apparent CAFO during high and low flow conditions. Analyze for nitrate-N, nitrite-N, TKN, BOD, phosphorous, and major cations/anions;

7) Evaluate Missoula Livestock Auction for potential impacts to groundwater. Implement BMPs, if necessary.

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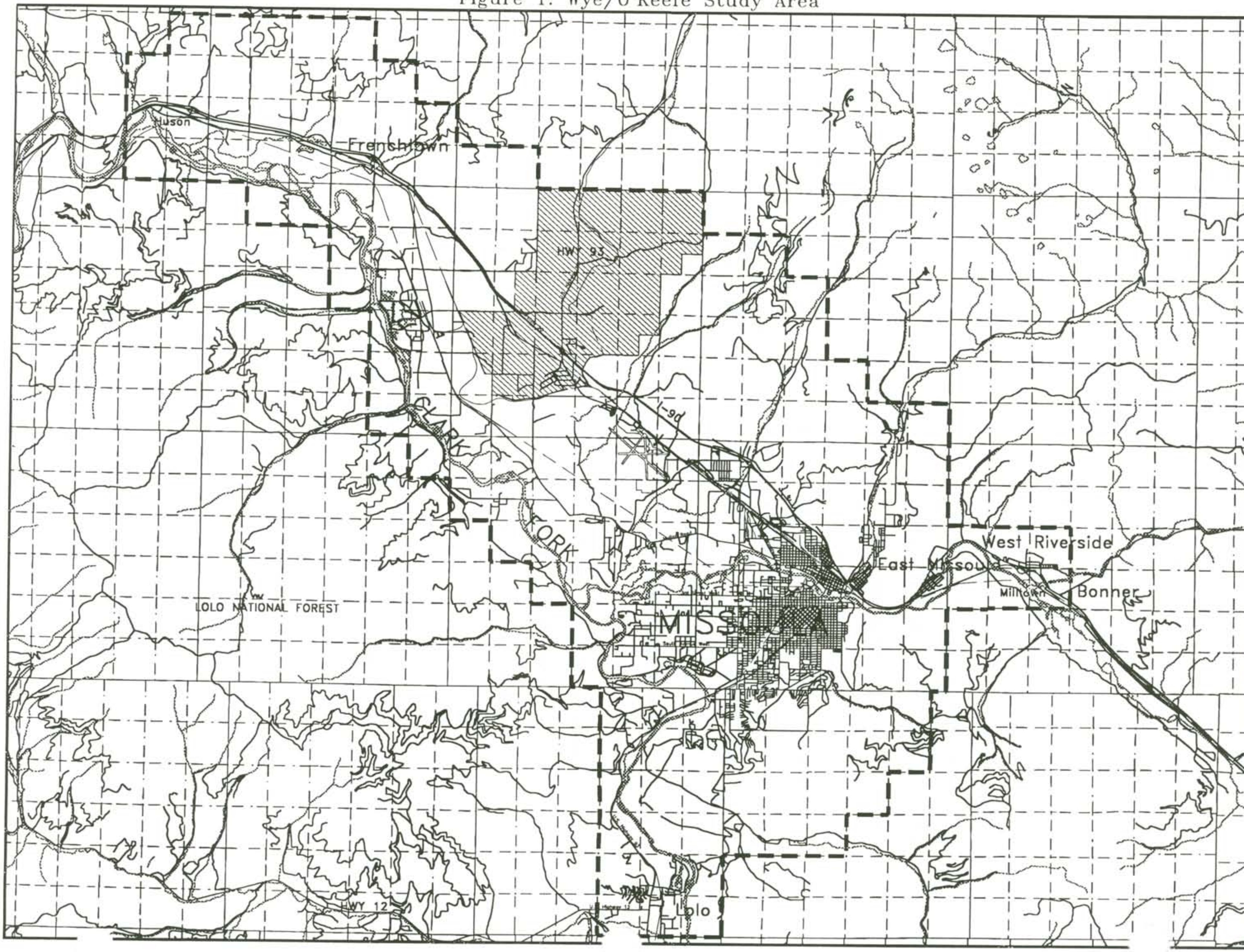
I. Introduction and Problem Statement

O'Keefe Creek enters the Missoula Basin from the north approximately 9 miles northwest of the City of Missoula. It originates on Forest Service land near the Reservation Divide northwest of Evaro. It enters the US 93 corridor near Evaro, and flows south parallel to the highway. At the base of Evaro Hill, the valley widens. The creek occupies the western portion of this lowland valley, which stretches to the floor of the Missoula Valley near Stone Container. Several intermittant streams enter O'Keefe Creek from the east. The creek eventually enters the Clark Fork River about 12 miles northwest of Missoula. Land use in the main drainage is generally residential development, with some irrigated horse pasture, and limited cultivation of dryland grains in the upper reaches of the drainage.

"The Wye" refers to the area around the intersection of I-90 and US 93. The Wye area straddles the drainage boundary between O'Keefe and LaValle Creeks. Businesses related primarily to the trucking industry are located in this area. Missoula Industrial Park is located south of the Wye area. This area is largely occupied by businesses related to the trucking industry. Other businesses in the Park include vehicle salvage operations, building supplies, heavy equipment sales and repair, and water well drilling.

The study area includes the O'Keefe Creek Drainage from approximately the base of Evaro Hill to the Montana Rail Link right-of-way, the Wye area, and the Missoula Industrial Park (Figure 1). Ongoing commercial and industrial development of the Wye area and Missoula Industrial Park, and the relatively recent residential development within the O'Keefe Creek drainage is cause for concern from a water quality standpoint. Community wastewater management facilities are not available in this area, and residents and businesses alike depend on individual on-site sewage disposal systems to discharge their waste to the subsurface. These same residents and businesses rely exclusively on groundwater as their source of drinking water. Because subsurface disposal of wastewater has the potential to degrade water quality, it is necessary to gather information on the existing water quality of the area. This data may be used to detect trends in water quality, and predict future impacts to water quality as development continues.

Figure 1: Wye/O'Keefe Study Area



The overall objective of this study is to determine the impact that development has had on water quality, particularly with regard to nitrate in groundwater, and to make recommendations for managing these impacts. The purpose of this report is to present and discuss the results of fieldwork which was performed in 1997 and 1998, to make recommendations for future study, and to explore potential solutions to identified problems.

II. Regulatory Implications

Nitrate is the most common groundwater contaminant in the United States. It is associated with methemoglobinemia, or "blue baby syndrome", a disease in which nitrate interferes with the oxygen-carrying capacity of blood. Infants are most susceptible, and may develop a characteristic blue tint to the skin denoting oxygen starvation. There are also some studies which suggest that nitrates are related to certain cancers, miscarriages, and other diseases. The current maximum contaminant level (MCL) established by the United States Environmental Protection Agency (USEPA) for nitrate is 10 milligrams per liter (mg/L) measured as nitrogen, and was established by direct observations of cause and effect relationships made during human case studies of methemoglobinemia (Canter, 1997). The World Health Organization (WHO) also uses 10 mg/L nitrate-nitrogen as a guideline. However, it should be noted that there are some who think that the 10 mg/L standard does not provide an adequate margin of safety, and that some countries use stricter standards.

The most common sources of nitrate in groundwater include fertilizers, subsurface disposal of human waste, and animal waste. Drinking water supplies in many rural farm communities across the United States contain levels greater than 10 mg/L due to runoff from livestock operations and overuse of nitrogen-based fertilizers. Documented nitrate problems in the Missoula area (e.g. lower Linda Vista subdivisions) are most commonly associated with the subsurface disposal of human waste through individual, on-site septic systems. Nitrogen exiting a septic tank is primarily in the form of ammonia or ammonium. In a properly operating septic drain field, the ammonia is converted to nitrate as the wastewater percolates downward through the unsaturated soil column. Nitrate is relatively non-reactive and will migrate in the direction of groundwater flow once it reaches the water table. Denitrification (i.e. microbe-facilitated conversion of nitrate to nitrogen gas) can occur provided that anaerobic conditions, denitrifying bacteria, and a source of organic carbon are present in the subsurface.

On-site sewage systems are regulated at both the local and state levels. The objective of this regulation is to ensure that the density, design, and operation of these systems will protect public health and the environment. Local regulations for on-site systems are contained in Regulation 1 of the Missoula City-County Health Code. Soil texture, percolation rates, depth to groundwater and/or bedrock, slope, and floodplain designation are limiting conditions which determine the suitability of a particular site for an on-site sewage system. These site-specific factors also control the design of the septic system. Other constraints include lot size and the required separation distances between the individual components of the septic system and wells, surface water, and floodplains. Review of new subdivisions where on-site wastewater systems are proposed is conducted under the provisions of Title 76, Chapters 3 and 4 Montana Code Annotated (MCA), as well as the nondegradation provisions of Title 75 MCA. Title 76, Chapter 3 MCA is the Subdivision and Platting Act and Chapter 4 MCA is the Sanitation in Subdivisions Act. Title 75 MCA is the Montana Water Quality Act.

Local planning review, surveying and filing requirements, subdivision definitions, as well as exclusions to subdivision review are contained in Title 76, Chapter 3, MCA. State and local review of water and wastewater systems in subdivisions is provided for in Title 76, Chapter 4, MCA. Major subdivisions of more than 5 lots are reviewed locally and by the Department of Environmental Quality (DEQ). Minor subdivisions of 5 or fewer lots are reviewed locally under a contract with the DEQ for drinking water and wastewater system design. Administrative Rules governing on-site subsurface wastewater treatment, together with Water Quality Circular 6, define siting standards and lot size requirements for approval of on-site systems.

Other than the previously mentioned potentially limiting conditions for a particular site, the minimum lot size required for an on-site system is one acre (43,560 ft^2) if an individual well is the water supply. If community water or sewer is proposed the minimum lot size may be decreased to 21,780 ft^2. Within the O'Keefe Creek study area, the Spring Meadows subdivision is an example of smaller lots with on-site sewage systems and a community water supply. Local regulations also define maximum land application rates, limiting rates to less than or equal to 600 gallons/acre/day for lots one acre or larger in size; 300 gal/day for existing lots smaller than 1/2 acre; and a pro-rated effluent application rate between 300 and 600 gal/day for lots between 1/2 and one acre in size. For the purposes of determining maximum application rates, Regulation 1 defines effluent flows for a variety of structures. For example, a single family residence is defined to have a minimum flow of 300 gallons per day, resulting in an effective minimum lot size of 1/2 acre. This minimum lot size is slightly larger than the State requirement where a public water supply is used. On-site wastewater systems in commercial subdivisions must be designed based on estimated flows and the nature of the effluent. The 600 gallons per acre per day local rule is still applicable.

New on-site wastewater systems must also be reviewed by the DEQ for nondegradation of State waters under the provisions of 75-5-303 MCA. The Montana Legislature in 1995 amended the Montana Water Quality Act and modified nondegradation requirements for subdivisions using septic systems. The amendments changed the non-significance level for nitrate-N from 2.5 mg/l to 5.0 mg/l within a ground water mixing zone at the lot boundary down-gradient from the proposed drain field (75-5-304 MCA). A dilution equation (Bauman & Shafer, 1984) is used to predict the impact of a proposed on-site wastewater system on groundwater. If existing nitrate-N levels are below 5.0 mg/l in groundwater and the predicted levels resulting from the proposed subdivision and on-site wastewater systems are also below 5.0 mg/l nitrate-N, a determination of "non-significance" is granted by the DEQ and the proposed subdivision may use conventional septic tanks and drainfields. If the predicted nitrate-N levels within the proposed subdivision would exceed 5.0 mg/l, "level II" treatment of effluent would be required. Level II systems are approved by the DEQ for nitrogen removal that reduce levels of nitrogen in the discharged effluent by a least 60%. If these systems are used, predicted nitrate concentrations in groundwater are allowed to reach 7.5 mg/l as nitrogen (75-5-301 (iii), MCA). Regulation 1 of the Missoula City-County Health Code does not currently permit the use of these systems for the purpose of nitrate removal, specifically because the State allows additional degradation of groundwater if the level two systems are used, and due to concerns over maintenance issues, and inadequate documentation of nitrogen removal.

Based on these current regulations, an existing nitrate-N level of 5.0 mg/l in ground water would preclude further subdivision immediately downgradient from that sample location, unless authorized by a variance fro the Missoula City-County Health Department. A proposed subdivision of a parcel of land located immediately northwest of the I-90/US 93 intersection was denied for this reason. Background nitrate-N levels measured at the well located at Missoula Freightliner were above 5.0 mg/l. A determination of non-significance was granted by the DEQ for a hypothetical development and subdivision based on "level II treatment," but a variance to local rules which do not permit a recirculating sand filter for nitrogen removal was denied.

The regulatory issues related to on-site sewage systems in the Wye/O'Keefe area can be summarized as follows:

* An on-site wastewater system may not contaminate any existing or potential drinking water supply (Missoula City-County Health Code).

* Application rates are limited to 600 gallons per acre per day (Missoula City-County Health Code)

* Minimum lot sizes for on-site wastewater systems may be 1/2 acre if community water or sewer is used (State Administrative Rules/Missoula City-County health Code).

* The minimum lot size is one acre if on-site sewer and individual wells are used (State Administrative Rules/Missoula City-County Health Code).

* Nondegradation rules apply to new subdivisions using on-site wastewater disposal systems (Water Quality Act/State Administrative Rules).

* If the existing nitrate-N level in groundwater is 5.0 mg/l or greater, level II treatment septic systems may only be approved through a variance to the Missoula City-County Health Code (Missoula City-County Health Code/State Non-Degradation Rules)

* The Wye/O'Keefe Area Plan adopted by the Board of County Commissioners in 1979 recommends rural residential densities of one dwelling unit per 5 acres in all of Sections 15 and 16, T14N, R20W.

* The Wye/O'Keefe Area Plan also recommends densities from 2 to 25 dwelling units per acre in portions of Sections 20, 21 and 22, T14N, R20W, with the highest densities recommended adjacent to I-90 and Hwy. 93. These densities

cannot be achieved with the use of conventional, alternative, or experimental on-site wastewater disposal systems.

* Other areas on the Wye/O'Keefe area are designated "open and resource land" and have a recommended density of 1 dwelling unit per 40 acres.

III. Literature Review

Although groundwater resources in the Wye/O'Keefe area are not the specific focus of previous studies, some information has been reported in various documents reporting on the greater Missoula Valley. McMurtrey et al (1965) described the geology and hydrogeology of the entire Missoula Basin, including the study area. Groundwater chemistry data is reported for one well located within the present study area. Konizeski and Alt (1972) estimated the age of groundwater from 300 wells located in the Missoula Valley, five of which are located in or near the present study area. The results for 40 samples are reported. Groundwater chemistry was determined for two wells located in the present study area as part of the Missoula Valley Water Study (Juday and Keller, 1978). Geldon (1979) described the geology, hydrogeology, groundwater chemistry, and groundwater usage for the entire Missoula Valley. Groundwater chemistry is reported for three wells located in the airport area. Smith (1992) reported on the geology, hydrogeology, and groundwater chemistry for the northwestern portion of the Missoula Basin, including a portion of the study area. Land & Water Consulting, Inc. (1996) developed a predictive model for nitrate concentrations in groundwater for Missoula County, including the Wye/O'Keefe area, based on hydrogeology and various septic density scenarios.

Public water supply owners are required to submit water sample results to the Montana Department of Environmental Quality annually. Specific analytical parameters vary depending on how the public water supply is categorized, but always include microbiological quality, nitrate as nitrogen, and nitrite as nitrogen. Data is available for fifteen (15) public water supplies located within the study area, some of which date back to 1979.

Permits have been required by the Missoula City-County Health Department for on-site septic systems since 1967. Although the amount of information contained in individual permits is highly variable, the permits generally describe the drain field location, and in the case of commercial facilities sometimes estimate the amount of effluent discharged on a daily basis.

IV. Hydrogeology

The general stratigraphy of the Missoula Basin, adapted from McMurtry (1969), is illustrated in Table 1. An examination of the available well logs indicates that wells within the O'Keefe Creek valley bottom typically penetrate 50 to 80 feet of unconsolidated clay, sand, and gravel which are probably Lake Missoula sediments interfingered with a mixture of colluvial, alluvial, deltaic and debris flow deposits derived from sources to the north (Qgl and Toa in Table 1). Some wells are completed in these shallow, water bearing units. Deeper wells are finished in alternating beds of gravel, sand, clay, coal, sandstone, and shale below a depth of approximately 80 feet. Wells in the Wye area, including Missoula Industrial Park, generally penetrate 125 to 200 feet of unconsolidated clay, sand, and cobbles, and are completed in underlying water bearing sands and gravels. Both unconfined and confined aquifer conditions are indicated by the well log data.

Table 1: General Stratigraphy of the Missoula Basin, after McMurtry (1969)

Stratigraphic Division	Description
Qa	Recent Alluvium: silt, sand, and gravel
Qoa	Older Alluvium: reworked Lake Missoula sediments
Qgl	Glaciolacustrine Deposits (Lake Missoula sediments) Upper: unconsolidated varved clay and silt Middle: sand interbedded w/ clay, silt, and gravel Lower: gravel
Ts	Tertiary Alluvium: sand and gravel, well sorted & bedded
Toa	Tertiary Consolidated and Semi-consolidated Alluvium: well-consolidated conglomerate interstratified w/ shale, coal, and volcanic ash
Basement Rocks	undifferentiated sedimentary, metamorphic, and igneous rocks

Figures 2, 3, and 4 (see Figure 1 for x-section locations) are geologic cross sections constructed using data from available well logs submitted to the Montana Department of Natural Resources and Conservation and/or the Montana Bureau of Mines and Geology. The lithology is

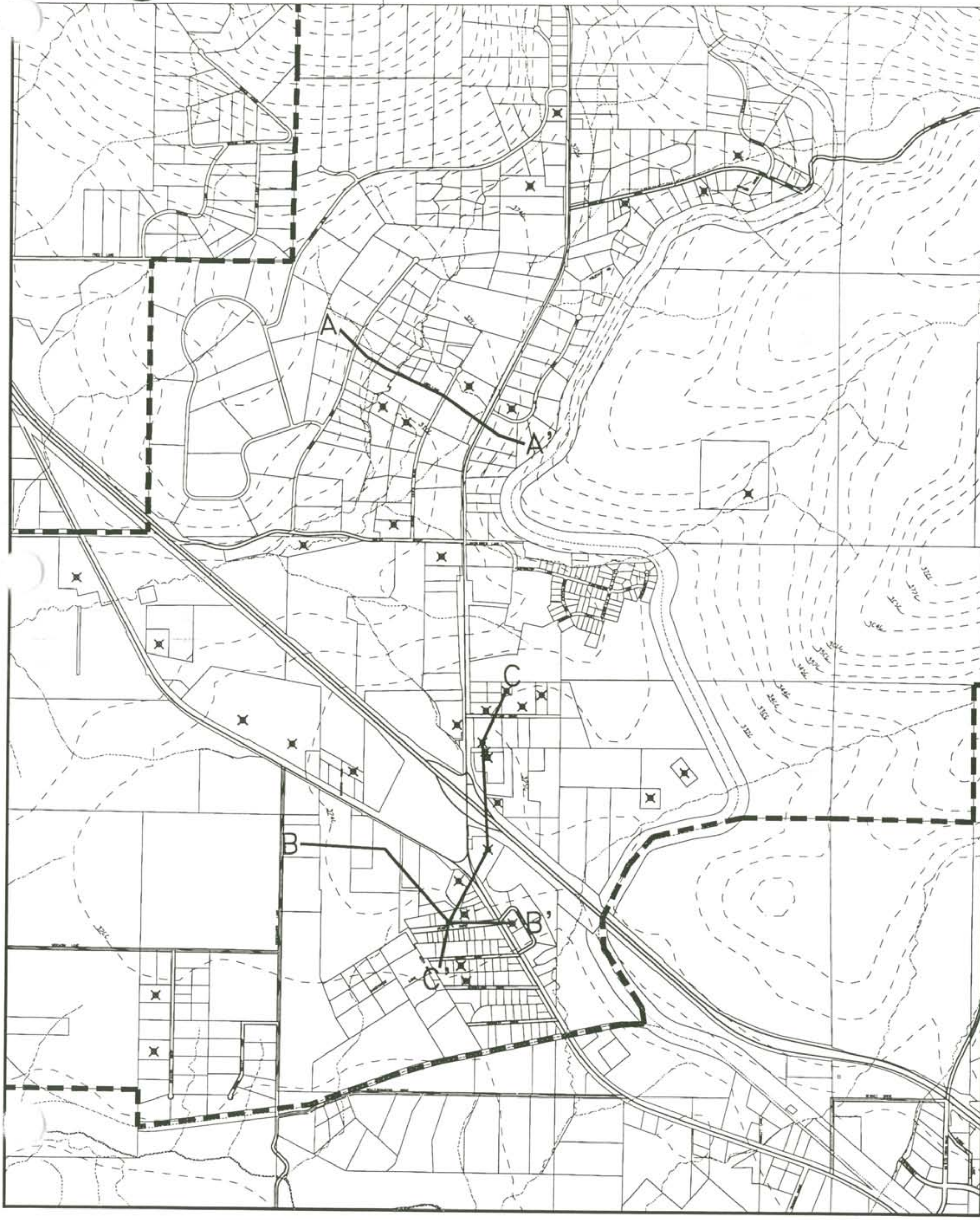
MISSOULA COUNTY

CITY-COUNTY HEALTH DEPARTMENT
MISSOULA, MONTANA
MISSOULA VALLEY WATER QUALITY DISTRICT
March 29, 1999

0 1250 ft 2500 ft
SCALE

N E S W

WYE/O'KEEFE STUDY
GEOLOGIC CROSS SECTIONS



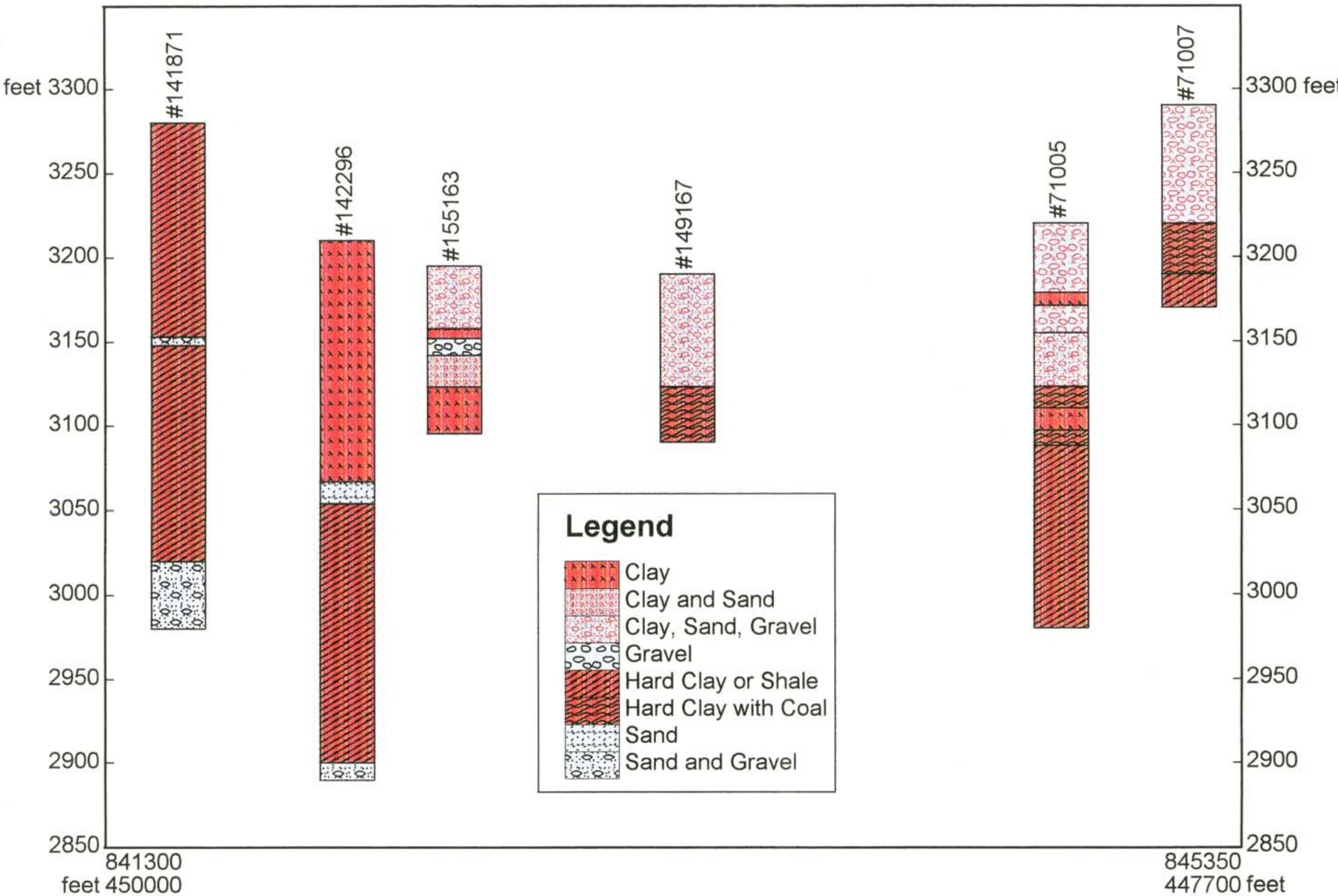


Figure 2: Cross Section A-A'

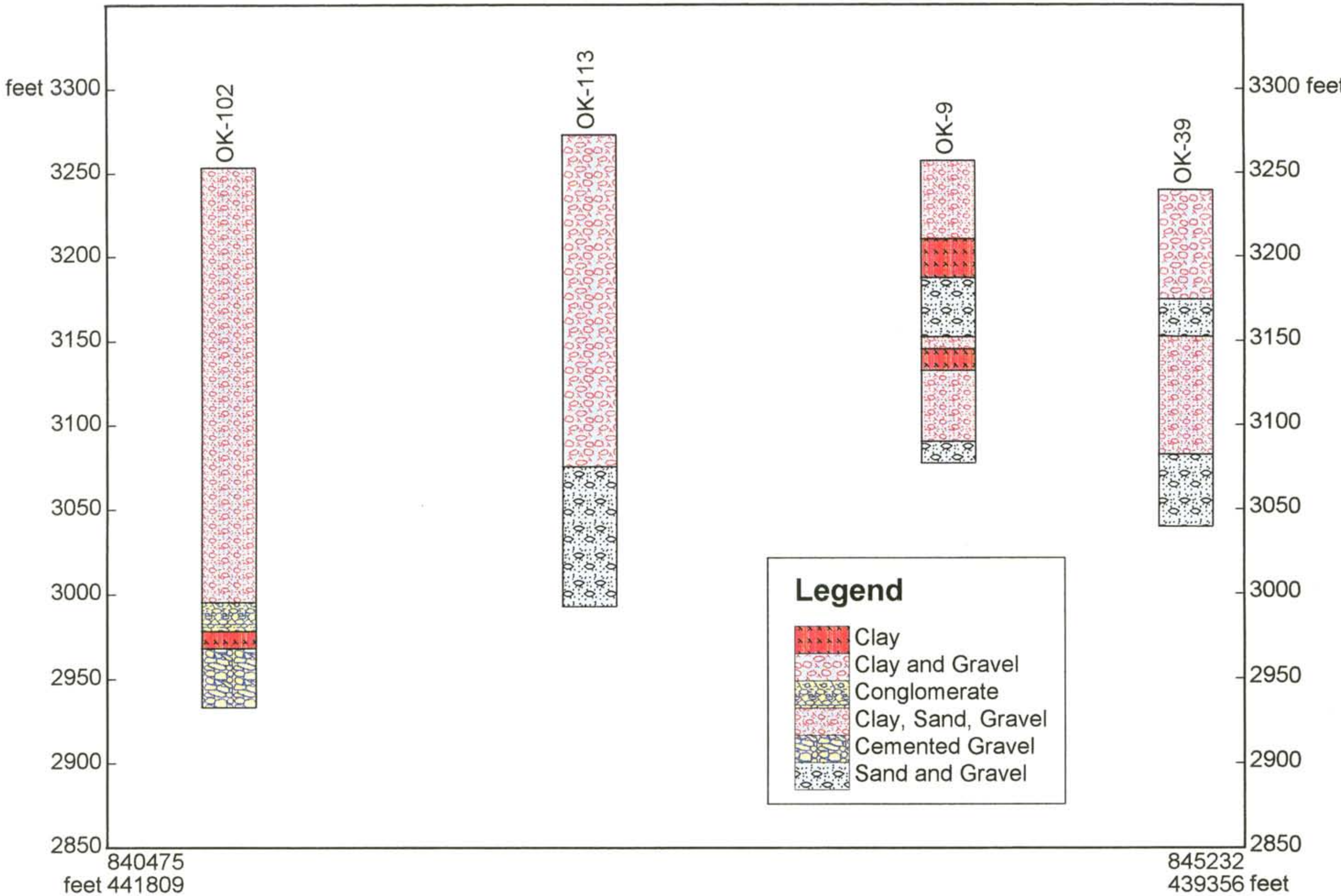


Figure 3: Cross Section B-B'

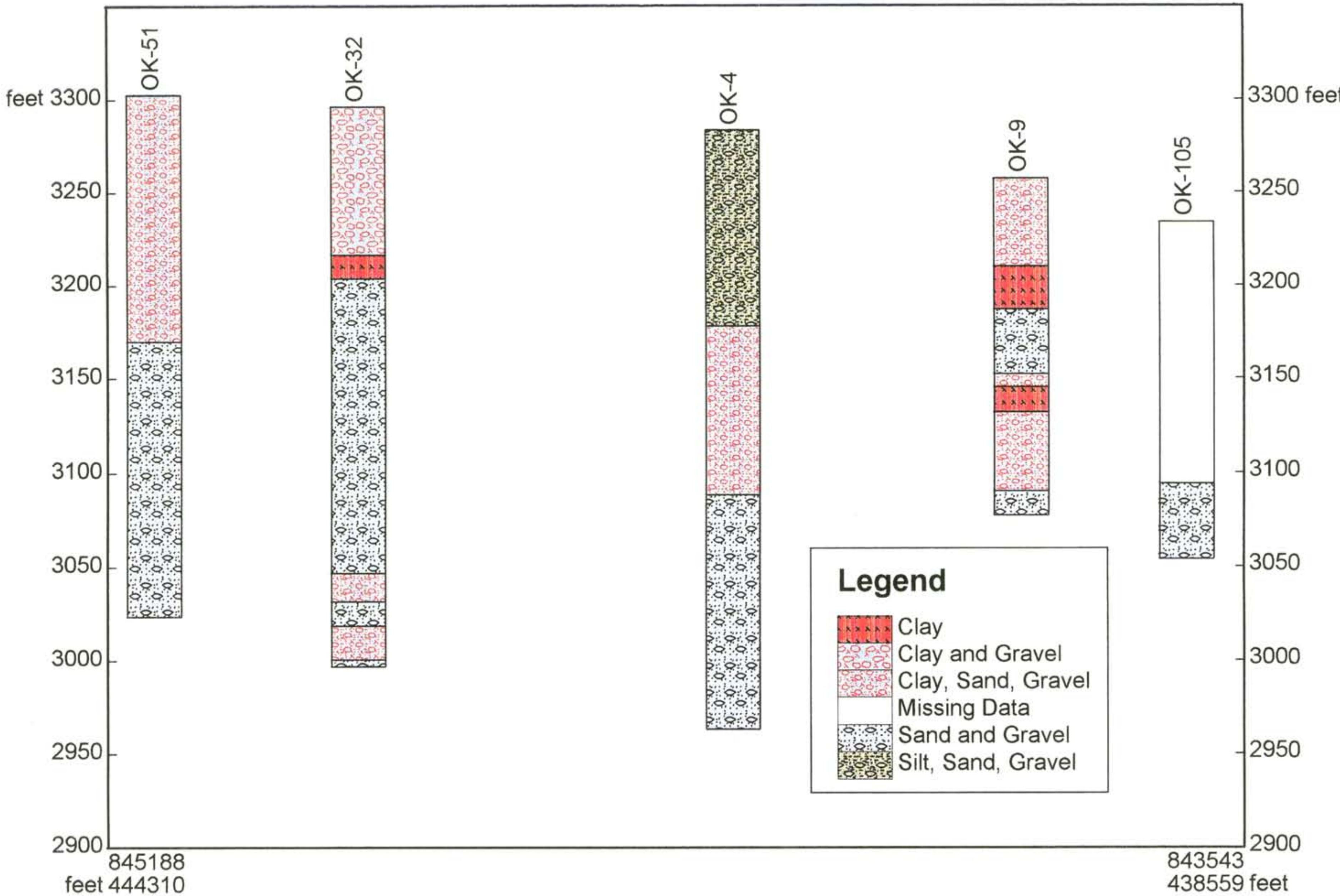


Figure 4: Cross Section C-C'

characterized by alternating and discontinuous layers of clay, silt, sand, and gravel, with some consolidated and semi-consolidated beds of shale, coal, and conglomerate. The lithology corresponds most closely with Tertiary alluvial sediments (Toa in Table 1) described by McMurtrey et al (1965).

Generalized groundwater flow maps created by McMurtrey et al (1965) and Smith (1992) indicate southwesterly flow in the Wye/O'Keefe areas. More detailed published potentiometric maps for this area do not exist.

V. Methods

A. Groundwater and Surface Water Sampling

A total of 122 groundwater samples were collected from 38 production wells located at residential and commercial establishments in 1997 and 1998. A listing of sample points can be found in Appendix A. Groundwater samples were collected from outlets which were connected directly to the well being sampled (i.e. water did not pass through a softener or other treatment device). Each well was purged for at least 15 minutes prior to sampling. During purging, electrical conductivity, pH, and temperature were measured in the field using a Corning Checkmate field meter, which was calibrated using known standards prior to each sampling day. Dissolved oxygen and oxidation-reduction potential (ORP or Eh) were measured in the field during the 3rd quarter of 1997. Samples were collected in laboratory-supplied containers and placed on ice. Field data are included in Appendix B.

Samples were analyzed by the Murdock Environmental Laboratory at the University of Montana for fluoride, chloride, sulfate, nitrite-N, and nitrate-N by EPA Method 300.0; ammonia-N by EPA Method 350.2; barium, calcium, iron, potassium, and sodium by EPA Method 200.15; magnesium by EPA Method 200.7; and total dissolved inorganic carbon. A summary of methods is included in Table 2. Analytical results are included in Appendix C.

B. Groundwater Elevation Measurements

Groundwater elevations were measured at 24 wells in the study area in June 1998 (Table 3). Most of the wells which were measured are located in the Missoula Industrial Park area, and the commercial area north of the I-90/US 93 intersection. Measurements were made using an electric water level indicator. Measurements were made over a period of approximately five minutes in order to ensure that the measured water level was stable and representative of the static water level.

Table 2: Summary of Analytical Methods

Analyte	EPA Method	PQL (mg/L)		Analyte	EPA Method	PQL (mg/L)
Fluoride	300.0	0.01		Barium	200.15	0.001
Chloride	300.0	0.01		Calcium	200.15	0.005
Nitrite-N	300.0	0.01		Iron	200.15	0.002
Nitrate-N	300.0	0.01		Magnesium	200.15	0.005
Sulfate	300.0	0.015		Potassium	200.15	0.035
TIC		1.00		Sodium	200.15	0.005
				Ammonia-N	200.15	0.10

TIC = total inorganic carbon

PQL = Practical Quantitation Limit

VI. Results

A. Groundwater Flow

Based on water level measurements made during June 1998, groundwater flow for the Wye/O'Keefe area is generally to the southwest (Figure 5). A southwesterly flow direction is consistent with previous studies, including McMurtry (1969) and Smith (1992). Local or site-specific (i.e. small scale) groundwater flow patterns may differ from the regional flow. For example, the water table in the area just north of the I-90/US 93 intersection is very flat, with no discernable localized flow direction. Static water level elevations in most groundwater production wells in this area are right around 3,118 feet above mean sea level (ams). Groundwater flow beneath Missoula Industrial Park appears to have a northwesterly flow component.

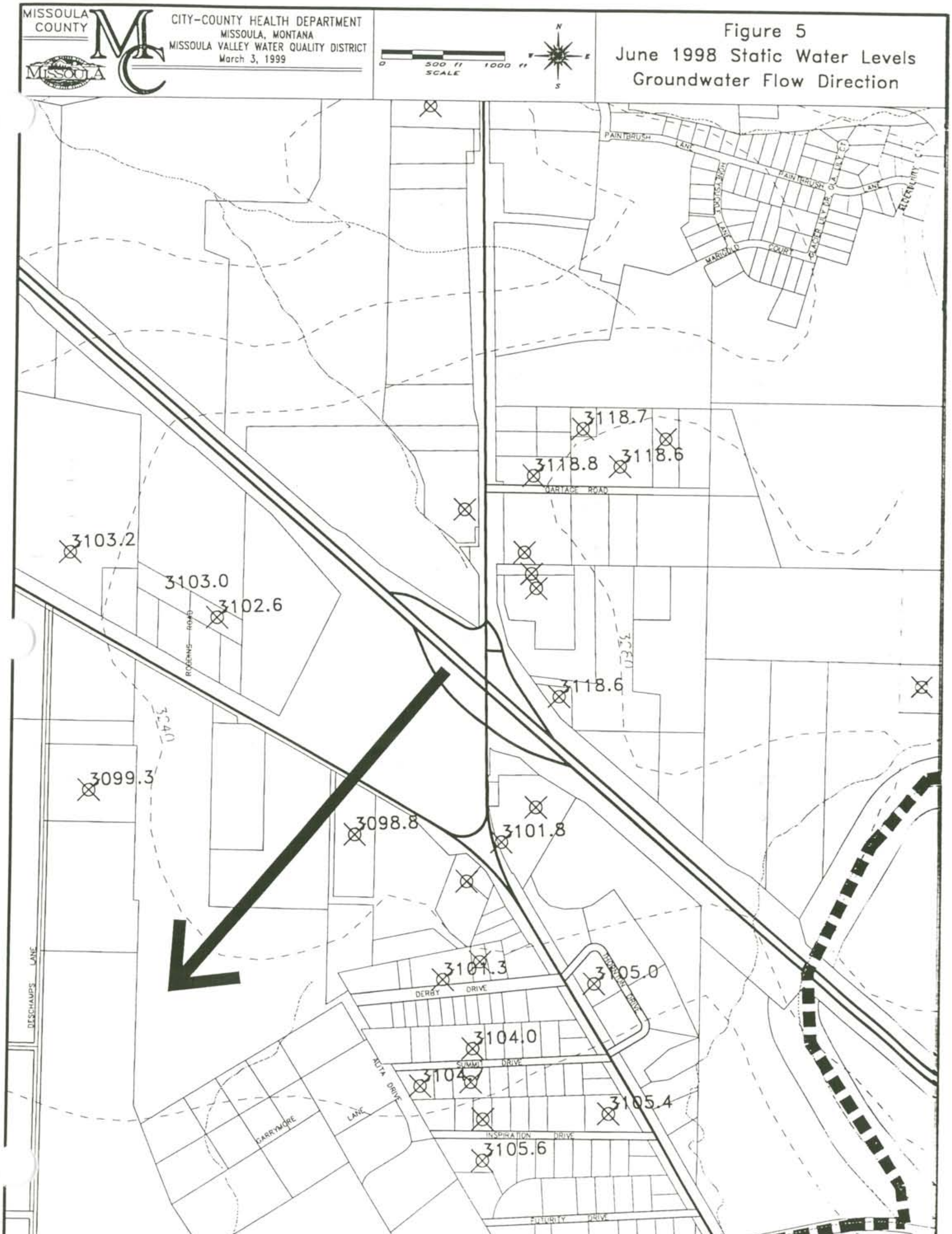

MISSOULA COUNTY
CITY-COUNTY HEALTH DEPARTMENT
MISSOULA, MONTANA
MISSOULA VALLEY WATER QUALITY DISTRICT
March 3, 1999
0
500 ft
1000 ft
SCALE
N
S
E
W
Figure 5
June 1998 Static Water Levels
Groundwater Flow Direction
PAINTBRUSH LANE
MARIGOLD COURT
3118.7
3118.8
3118.6
CARTAGE ROAD
3103.2
3103.0
3102.6
ROBBINS ROAD
3118.6
3099.3
3098.8
3101.8
3101.3
DERBY DRIVE
3105.0
3104.0
SUMMIT DRIVE
ALTA DRIVE
3105.4
GARRYMORE LANE
INSPIRATION DRIVE
3105.6
FUTURITY DRIVE
DESCHAMPS LANE

Table 3: Water Level Elevations

ID	Location	Top of Casing	Depth to Water	Water Elevation
OK-2	Northwest Peterbilt	3293.54	174.75	3118.79
OK-3	Missoula Cartage	3308.26	189.65	3118.61
OK-4	Crossroads Truck Stop	3283.04	181.30	3101.74
OK-9	Jim Palmer Trucking	3257.23	155.95	3101.74
WQD-16	Waldo Rd.	3152.81	3.04	3149.77
OK-19	Missoula Freightliner	3287.56	169.20	3118.36
OK-24	Moen residence	3182.12	26.68	3155.44
OK-31	Stockman's Feed	3267.76	165.17	3102.59
OK-34	Missoula Trap & Skeet	3252.57	149.37	3103.20
OK-39	Mel's Electric	3239.73	134.70	3105.03
OK-50	Big Sky T & A	3286.75	168.13	3118.62
OK-51	Northern Specialty	3302.04	183.35	3118.69
OK-102	Ross Electric	3253.35	154.10	3099.25
OK-103	Williams Equipment	3264.03	164.00	3100.03
OK-104	Jones Equipment	3272.46	173.63	3098.83
OK-105	Montana Salvage Pool	3233.94	129.20	3104.74
OK-106	Iroquois Industrial	3234.43	130.50	3103.93
OK-107	Transport Equipment	3198.37	93.00	3105.37
OK-108	Jerome's Drilling	3215.66	110.95	3104.71
OK-109	Missoula Auto Salvage	3211.85	106.22	3105.63
OK-110	Sunset West PWS	3194.06	33.10	3160.96
OK-112	Fletcher Excavation	3265.42	162.40	3103.20
OK-113	B'root Int'l #2 (@ shop)	3272.56	171.27	3101.29
OK-114	B'root Int'l #1 (in lot)	3271.17	170.32	3100.85

B. Potential Sources of Water Quality Impacts

Man's activities can impact groundwater quality in vulnerable areas. Potential sources of contamination which exist within the study area include petroleum fuels in underground storage tanks, application of highway deicers, cultivation of agricultural crops, livestock waste, and subsurface disposal of wastewater.

1. Underground Storage Tanks

Currently, there are regulated, state-permitted, underground fuel storage tanks located at Muralts Travel Plaza, Crossroads Truck Center, Jim Palmer Trucking, and Missoula Cartage. Other, non-regulated or non-permitted tanks may exist. There is potential for groundwater degradation by petroleum hydrocarbons if these tanks or associated piping and equipment leak due to corrosion, loose fittings, spills, and overfills. Documented soil contamination due to leakage from USTs exists at Muralts Travel Plaza, Crossroads Truck Center, and Missoula Cartage. However, site investigations at each location found that contamination was limited to soils, and groundwater was not affected.

2. Highway Deicers

Two types of materials are used to aid wintertime driving on county and State roads in the Wye-O'Keefe area: magnesium chloride (MgCl) as an anti-icing agent, and sanding material for traction control. Approximately 10% sodium chloride (NaCl) is added to sanding material to prevent the stockpiled material from freezing, thus facilitating handling. Magnesium and chloride ions associated with these materials may migrate to groundwater in the vicinity of roads where they are used. In particular, chloride is very mobile in the subsurface due to its low affinity for adsorption to soil particles and organics. Sodium ions are generally less mobile in soils due to their size and positive charge. Sodium ions may become adsorbed to clay and organic particles in soil, liberating calcium and magnesium ions in the process. Therefore, chloride concentrations in groundwater near roadways is the best indicator of impacts due to de-icing. Increases in sodium, magnesium, calcium, metals, and nitrate concentrations may also indicate impacts.

3. Agricultural Crops

There is little agricultural activity in the study area. There is some irrigated horse pasture adjacent to O'Keefe Creek, and limited cultivation of dryland grains in the upper reaches of the drainage. There is one small alfalfa field located adjacent to Waldo Road where O'Keefe Creek crosses the road. Potential water quality impacts from cultivation of crops are due to the use of pesticides and fertilizers. In particular, nitrogen-based fertilizers have caused widespread nitrate groundwater contamination in many farming communities throughout the country. Due to the minor amounts of agricultural activity within the study area, the potential for impacts to groundwater resources are considered negligible.

4. Livestock Waste

Livestock waste can be a source of total dissolved solids, nitrogen, phosphorous, and organic loading to surface and groundwater. The potential for water quality impacts from livestock generally comes from two sources within the study area: 1) livestock owned by residents on 5 to 10 acre "ranchettes" in the main O'Keefe Creek drainage; and 2) the cattle auction yard located in the SW 1/4 of Section 21, T14N R20W.

There is potential for surface water and shallow groundwater impacts from livestock, particularly horses, within the study area. Horses produce approximately 11.3 times as much waste per capita per day as an adult human (Nemerow, 1971). Although this waste is deposited on the ground surface, the tendency of the animals to congregate in small areas, thereby destroying vegetative cover, most likely eliminates plant uptake of nitrogen in the heavily used areas.

Impact to O'Keefe Creek from these sources due to storm water runoff is also likely. The greatest threat to surface water quality within the main O'Keefe Creek drainage is from animals which are allowed access to the creek's riparian zone. There is one facility located just south of the Waldo Road crossing of O'Keefe Creek where horses and sheep are concentrated within the creek's riparian area. Manure has been placed on the banks of the stream in large piles, and the entire area is completed denuded. There is little doubt that this facility is significantly impacting O'Keefe Creek.

One noteworthy potential threat to groundwater quality from livestock waste is the cattle auction yard located on Highway 10 west of US 93. This facility has been in existence at this location since about 1988. A review of the building plans for the facility indicate that the pens are designed to manage the liquid portion of the cattle waste. The floor of the cattle pens are concrete and slope to a catchment trough. The trough catches the liquid draining from the pens and transfers it to a clay-lined lagoon via an underground PVC pipe. Additional pens appear to have been constructed which are apparently not on a concrete slab, and do not drain to any catchment basin. Large quantities of solids from the pens are stockpiled on site. Based on known contamination of groundwater by concentrated animal feeding operations, this facility has the potential to significantly impact local groundwater quality.

5. Subsurface Wastewater Disposal Systems

Areas impacted by septic systems are expected to exhibit elevated concentrations of nitrogen, chloride, and/or total dissolved solids. Microbiological contamination of groundwater is also possible. Nitrate is a contaminant of particular concern due to its mobility in the subsurface, and its documented association with septic systems. Because all residents and businesses within the study area depend on individual onsite wastewater disposal systems, they are considered the greatest existing threat to groundwater quality.

C. Water Quality

Natural groundwater chemistry is largely determined by the makeup of the aquifer. As groundwater flows through the aquifer matrix, it dissolves the aquifer material. Groundwater can be generally classified according to the relative concentrations of dissolved material. Geldon (1979) reports that water within the Missoula Basin generally classifies as calcium or calcium-magnesium bicarbonate type water. Smith (1992) reports that water from a well located in the lower O'Keefe drainage (west of the I-90/US 93) classifies as sodium-bicarbonate type. The analyses done over the course of this study indicate that, in general, groundwater within the study area is bicarbonate type with no dominant cationic composition (i.e. neither calcium, sodium, nor potassium dominate). Appendix C contains all laboratory analytical data for the project.

Average background concentrations for each parameter measured during the study were calculated using data collected from wells least likely to be impacted by human activity. These background concentrations are summarized in Table 4.

Water quality within the study area is due to both natural conditions and human activities. The lowest concentrations for individual constituents are found in areas which are relatively undeveloped. The highest concentrations for individual constituents, particularly specific conductance, nitrate-nitrogen, and chloride, are associated with areas which are more extensively developed.

Table 4: Average Background Concentrations in Groundwater

Analyte	**Average Concentration**
Potassium	1.4
Sodium	13.7
Calcium	21
Magnesium	13
Sulfate	12
Chloride	2.7
Bicarbonate	86
Nitrate	0.6
Specific Conductance	244

In general, the commercial wells in the Wye Area produce the poorest quality water measured in the study area. Table 5 summarizes the water quality data collected from the Wye area. A comparison of the values in Table 5 with background concentrations (Table 4) indicates that average dissolved concentrations for each measured parameter are elevated above background concentrations. In particular, average chloride and nitrate-nitrogen concentrations are elevated by an order of magnitude above background concentrations. Although nitrate concentrations greater that the 10 mg/L standard were not measured during the course of this study , concentrations greater than 5 mg/L were routinely measured at Northwest Peterbilt (OK-2), Big Sky Tent & Awning (OK-50), and Missoula Freightliner (OK-19), and Wye West

Casino (OK-6), which had average concentrations of 8.1, 5.9, 6.0, and 4.4 mg/L, respectively.

Nitrate and chloride concentrations in the Northwest Peterbilt well were the highest detected in the study area. Nitrate concentrations ranged from 5.96 mg/L in February 1997 to 9.80 in November 1998, which is just below the regulatory limit of 10 mg/L. Chloride concentrations increased from 12.6 to 63.9 mg/L over the same time period. It is not known whether this is a seasonal, short term, or long term water quality trend controlled by water table position, sewage loading rate, or other factor(s).

Table 5: Water Quality in the Wye Area - Commercial Wells

Analyte	Highest	Lowest	Median	Average	Standard Deviation
Potassium	3.0	0.8	1.7	1.8	0.6
Sodium	41.1	11.1	21.1	22.1	8.0
Calcium	80.7	20.3	28.6	36.3	18.9
Magnesium	37.1	7.5	11.7	14.4	8.7
Sulfate	24.5	3.7	10.7	10.6	5.9
Chloride	98.5	2.0	4.1	21.9	31.6
Bicarbonate	289	100	144	167	57
Nitrate	8.1	0.4	2.3	3.0	2.4
Specific Conductance	938	241	309	407	221

Water quality in the Missoula Industrial Park is generally good (Table 6). As a group, wells located in this area produce the highest quality water within the study area. Dissolved constituents are elevated only slightly above average background concentrations, and in some instances are lower than background concentrations.

Table 7 is a summary of water quality data for residential wells located within the study area. The data indicate that dissolved solids are generally elevated with respect to background, with nitrate and chloride concentrations being the most significantly elevated. The highest nitrate concentrations are found in OK-33, OK-34, and OK-40 (2.5, 4.2, and 4.8 mg/L nitrate as nitrogen, respectively).

Table 6: Water Quality in Missoula Industrial Park - Commercial Wells

Analyte	Highest	Lowest	Median	Average	Standard Deviation
Potassium	1.0	0.7	0.8	0.9	0.1
Sodium	18.7	14.6	15.6	15.8	1.5
Calcium	45.7	23.0	24.5	28.7	8.6
Magnesium	16.6	7.8	8.7	10.2	3.2
Sulfate	5.9	4.3	5.2	5.0	0.6
Chloride	26.1	2.0	2.3	7.0	9.5
Bicarbonate	145	104	131	129	15
Nitrate	3.4	0.7	1.9	1.8	0.9
Specific Conductance	455	230	260	294	82

Table 7: Water Quality in Residential Wells

Analyte	Highest	Lowest	Median	Average	Standard Deviation
Potassium	7.7	0.8	1.2	2.0	1.7
Sodium	79.2	8.4	14.7	22.9	19.3
Calcium	80.7	20.3	24.6	24.5	8.5
Magnesium	41.0	7.2	11.5	14.5	8.4
Sulfate	69.0	5.1	12.0	17.6	16.4
Chloride	56.2	2.1	7.5	12.5	13.7
Bicarbonate	267	59	107	125	54
Nitrate	4.8	ND	0.9	1.2	1.2
Specific Conductance	641	130	301	335	141

An apparent correlation exists between the sewage loading rate and elevated nitrate concentrations in groundwater. Figure 6 illustrates average nitrate concentrations in wells sampled during the course of this study, and the sewage loading rate in gallons per acre per day for all land ownership parcels located within the study area. With a few exceptions, high nitrate concentrations correspond to proximity to large septic drainfields.

Based on design criteria recorded in Missoula City-County Health Department septic permit files and/or estimated volume based on number of employees, 21,000 gallons of sewage per day (gpd) is potentially discharged to the subsurface from businesses located north of the I-90/US 93 intersection alone. This is roughly equivalent to the volume of sewage discharged by 117 four-person households, assuming 45 gal/capita/day (EPA, 1980). The majority of the effluent, an estimated 18,800 gallons per day, is discharged by Muralt's Travel Plaza (13,000 gpd) and Days Inn (5,850 gpd). Table 8 lists drainfield measurements and the design sewage effluent rate for each commercial facility located north of the I-90/US 93 intersection.

Table 8: Drainfield Area and Estimated Sewage Discharge from Businesses North of Wye

Location	**Drain field Area (l.f.)**	**Estimated Discharge (gpd)**
Bee Line Transportation	200	75
Washworks	140	75
Nelcon, Inc.	240	100
Northern Specialty Supply, Inc.	100	100
Hagan Welding	200	130
Big Sky Tent & Awning	100	145
Sacs Trucking	60	100
Northwest Peterbilt Co.	160 + 3 seepage pits	290
Missoula Freightliner	500	300
Missoula Cartage	200	565
Days Inn Westgate	3,200	5,850*
Muralt's/Wye West Casino	1,000 + 1,000 ET + lagoon**	13,000***

* assumes motel operates at full capacity
** ET = evapotranspiration system
*** calculated by engineer in 1978; current discharge may be greater

Figure 7 is a graphical representation of groundwater chemistry at individual sampling points. In general, the shape of the diagram (Stiff diagrams) is controlled by the relative proportions of individual chemical constituents to each other. Waters with similar chemical makeup will have similarly shaped diagrams. The overall size of the diagram is controlled by the amount of dissolved material in the sample: higher total dissolved solids result in a larger diagram. In general, stiff patterns indicate that for wells which contain nitrate concentrations greater that 3 mg/L, there is a corresponding increase in total dissolved solids. Wells with high total dissolved solids are located proximal to large sources of septic effluent (see Figure 6).

The most likely source of nitrate and other elevated dissolved constituents in groundwater in the Wye area commercial wells are individual and non-community public wastewater treatment and disposal system located at these same commercial facilities. During the November 1998 sampling event, nitrate-N concentrations in the Northwest Peterbilt well (OK-2) were just below the 10 mg/L maximum contaminant level established by the USEPA. Historic nitrate data for this well collected by Juday and Keller (1978) indicate that concentrations were significantly lower at 0.83 and 0.65 mg/L in May and August of 1978, respectively. Water quality data from Northern Specialties, Inc. (OK-51), Missoula Cartage (OK-3), and Hagan Welding (OK-1) are similar to background data. These wells are located hydraulically upgradient based on the calculated regional flow direction. It is uncertain to what degree individual wells at NW Peterbilt (OK-2) Days Inn Westgate (OK-5), Wye West Casino (OK-6), Missoula Freightliner (OK-19), and Muralt's Travel Plaza (OK-32) are affected by their own or their neighbor's septic system. However, there is no doubt that the elevated nitrate-N concentrations in this area reflect impacts from subsurface disposal of the large quantities of sewage discussed above.

The Jim Palmer Trucking (OK-9) well contains the highest average nitrate concentration within the Missoula Industrial Park. This well is located adjacent to Missoula Village West trailer park, whose septic system was designed for 7,500 gallons/day (see Figure 6). Effluent originating from this source may be impacting the Jim Palmer Trucking well. However, a review of septic system permits indicates that this well is located approximately downgradient from two on-site drainfields: one which is currently in use, and one whose use was discontinued about 1992. It is more likely, based on June 1998 water levels, that the facility is impacting its own well.

Nitrate-N concentrations in residential wells are most likely due to a combination of sources, including upgradient septic systems at individual homes. The well OK-25 is likely impacted by effluent originating from the large septic drainfield at Jim & Mary' RV Park, which was designed for 4,120 gallons/day. Wells OK-31 and OK-34 are located near and probably hydraulically downgradient from the Missoula Livestock Auction on Highway 10 West. As discussed above, this facility has concrete holding pen floors and a collection system for liquid waste. However, there appear to be additional pens which do not have concrete floors or liquid waste collection facilities. Additionally, large quantities of solid waste from the holding pens is stockpiled on site. This is a potential source for elevated nitrate-N in these wells.

Several parcels on the O'Keefe Valley floor are horse properties. In particular, the land to the north, south, and surrounding well OK-33 is used to raise/keep horses. Horses are allowed within close proximity to the OK-33 wellhead. Infiltration of nitrogen rich water from these fields is likely partially responsible for the observed Nitrate-N concentrations. Elevated nitrate-N concentrations in OK-11 and OK-24 are also likely due in part to these horse properties.

Nitrate-N concentrations in well OK-40 are considerably elevated. The only identified source of nitrogen on this site is nearby or onsite septic systems. A review of the septic permit for this property indicates that the well is located west of the drainfield, and is in violation of the 100 foot separation rule in the State and local regulations. This well is most likely impacted by the onsite septic system.

Historic data for fifteen public water supplies (PWS) located within the study area are included in Appendix D. Nitrate-N concentrations as high as 6.3 and 3.8 mg/L have been measured in Wye West Casino's (OK-6) and Muralt's Travel Plaza (OK-2) wells, respectively, as early as August, 1980. The highest nitrate concentration reported for the Days Inn Westgate well (OK-5) is 3.0 mg/L in November, 1988. The high degree of variability observed in these historic data is not observed in the current data, and may be due to a combination of factors, including relative time intervals between sampling events, poor sampling procedures, and/or non-uniform sampling procedures. No definitive trend is observed in this data, although the latest reported results are generally comparable to the average concentrations measured during this study. This data indicates that elevated nitrate concentrations in this area is an ongoing situation which pre-dates about 1980.

A Water Quality District monitoring well is located on the north side of Waldo Road in the southwest corner of Section 16. This well is screened across the water table, which is generally 3 to 4 feet below ground surface. Data for this well (Table 9) indicates that nitrate concentrations have steadily increased from non-detectable concentrations in May 1996 to greater than 2 mg/L in November 1998. The significance of these observations is uncertain. However, it is unlikely that nitrate concentrations are indicative of cumulative impacts of residential development in Section 16. This well appears to be hydraulically isolated from groundwater north of O'Keefe Creek. It is more likely that nitrate concentrations are associated with the cultivation of the alfalfa field located immediately adjacent to the monitoring well to the north.

Table 9: Nitrate Data for Waldo Williams Monitoring Well

Sample Date	Nitrate Concentration (mg/L)
5/30/96	ND
8/15/96	ND
12/2/96	0.06
3/6/97	0.19
5/20/97	0.48
8/26/97	1.47
11/17/97	1.05
11/12/98	2.30

VII. Conclusions

1. Nitrate poses the greatest threat to groundwater quality within the study area.

2. Background nitrate-N concentrations are estimated to be about 0.6 mg/L, based on wells which have no obvious sources of nitrogen other than the on-site septic system. On-site septic systems may be the cause of detectable nitrate-N in these wells.

3. Commercial wells in the Wye area produce the lowest quality water in the study area,

with all measured constituents elevated above background, and an average nitrate-N concentration of 3.0 mg/L. The Northwest Peterbilt well shows a trend of increasing nitrate-N concentration, with a measured nitrate-N concentration of 9.8 mg/L during the last sampling event in November 1998. This concentration is just below the maximum contaminant level of 10 mg/L.

5. Residential wells within the study area averaged 1.8 mg/L nitrate, with a range from <0.01 to 4.8 mg/L. Individual dissolved constituents were generally elevated. A progressive increase in overall water quality occurs with distance up the main O'Keefe Creek drainages and side drainages.

6. As a group, commercial wells in Missoula Industrial Park produce the overall highest quality water in the study area. Average nitrate concentration is elevated at 1.8 mg/L, with a range from 0.7 to 3.4 mg/L.

7. In addition to cumulative effects of upgradient nitrogen sources, nitrate-N concentrations greater than 2.0 mg/L appear to result from proximity to large septic drainfields, impacts from individual on-site septic systems, and impacts from livestock wastes. Table 10 is a listing of sample locations with nitrate-N concentrations greater than 2.0 mg/L and likely contributing sources to contamination.

Table 10: Probable Sources of Elevated Nitrate-N in Wells with Concentrations > 2 mg/L

ID	Probable Cause		ID	Probable Cause
OK-2	OSWT, lrg. d.f.		OK-31	livestock
OK-5	lrg. d.f.		OK-32	lrg. d.f.
OK-6	lrg. d.f.		OK-33	livestock
OK-9	OSWT, lrg. d.f.		OK-34	livestock
OK-11	livestock		OK-38	?
OK-19	OSWT, lrg. d.f.		OK-40	OSWT
OK-25	lrg. d.f.		OK-50	lrg. d.f.

OSWT = on-site wastewater treatment device probably impacting well
lrg. d.f. = proximity to a large drainfield
livestock = on-site or nearby cattle, sheep, or horse waste source

8. Nitrate-N concentrations <2 mg/L appear to be the result of background concentrations and upgradient sources including livestock, and/or the individual on-site septic system.

The fact that wells OK-14 and OK-26 have measurable nitrate concentrations may be an indication that on-site groundwater quality will be degraded by even one septic system.

VIII. Discussion

It should be noted that nitrate concentrations measured during the course of this study are probably not representative of concentrations in the upper portion of the aquifer. Groundwater production wells are not well suited for use as compliance monitoring points, or as indicators of shallow groundwater pollution from subsurface sewage disposal systems. Production wells are typically open to the aquifer well below the water table. For example, the Muralt's Travel Plaza well is an open-ended well completed at 299 ft. below ground surface, while the static water level in the well is approximately 170 ft. below ground surface. However, the State considers the upper 16.4 ft. of the aquifer as the vertical mixing zone where nondegradation standards apply during subdivision review. In aquifers of sedimentary origin, vertical hydraulic conductivity is usually orders of magnitude less than horizontal hydraulic conductivity. The result is that groundwater flow to wells is predominantly horizontal. Therefore, the quality of the upper 16.4 feet of the aquifer is rarely measured. Samples from a monitoring well completed across the water table (where a water table exists) would most likely measure significantly greater impacts to groundwater due to subsurface sewage disposal, particularly in the Wye area.

Additionally, with the exception of subdivisions with public drainfields, each groundwater well has an associated septic system. It is difficult in most situations to separate the impacts due to the on-site septic system or nearby off-site septic systems from non-sewage sources such as livestock waste, and widespread cumulative impacts from upgradient development. At each sampling point where the nitrate-N concentration exceeds approximately 2 mg/L, there are definable nearby potential sources which are probably impacting the well.

Perhaps the greatest potential for significant groundwater quality degradation is within the area bounded on the southwest by I-90, on the east by the railroad tracks, and on the north by the section line for Sections 21 and 22. The Missoula Urban Area Comprehensive Plan (1998) provides for commercial and high density residential development (2 to 25 dwelling units/acre) in this area, which has also received zoning designations (Figures 8 & 9). Although restricted to

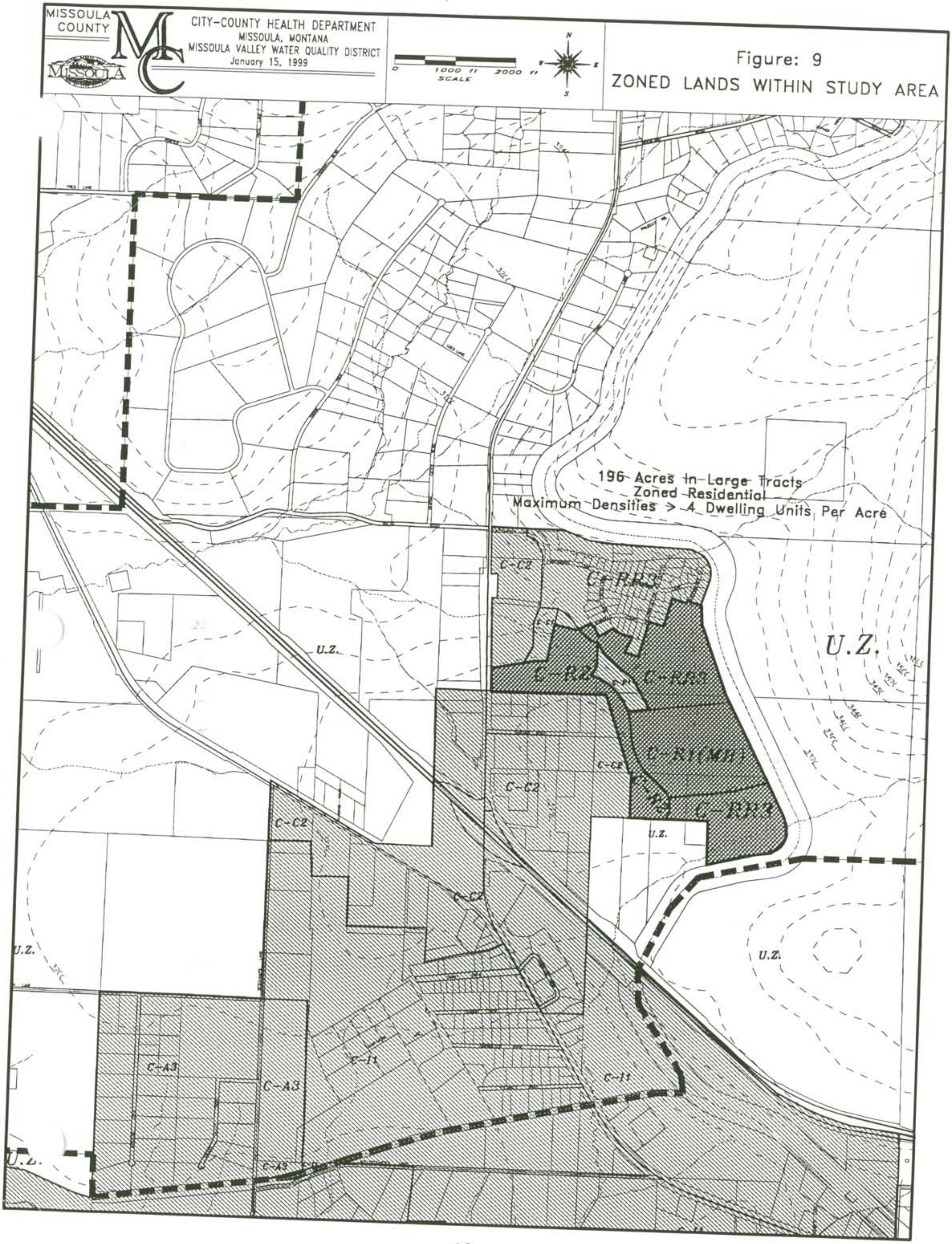


Figure: 9
ZONED LANDS WITHIN STUDY AREA

two lots per acre by local health regulations, up to 392 additional 1/2 acre lots can be created within the designated residential subareas. Including the 67 lots in the existing Spring Meadows subdivision, the first major subdivision in this area, a total of 459 single family homes can potentially be built within the combined designated residential areas. Assuming an average family of 3 per household, approximately 62,000 gallons per day (45 gpd/capita) of sewage could potentially be discharged to the subsurface. The Missoula County Carrying Capacity Study (Land & Water, 1996) suggests a septic density of 1 per 2-5 acres for this area. However, the potential effects on water quality within the drainage is uncertain, but should be estimated using site-specific data.

Each subdivision is subject to State review for nondegradation of groundwater. However, there is a flaw in the State review process with regard to existing lots, which may result in water quality problems as these residential areas are developed. When a new major subdivision is proposed upgradient from an existing lot or lots, the background nitrate-N concentration will obviously increase. However, the State has no mechanism to consider these cumulative impacts, and they will not affect the outcome of the nondegradation review unless calculations predict that nitrate-N concentrations will exceed the 10 mg/L drinking water standard beneath the existing lots (Eric Regensberger, personal communication). A mechanism to address these cummulative impacts should be developed and, if the proposed subdivision is predicted to cause violations of the nondegradation standard of 5 mg/L, the subdivision should be denied until measures are proposed to mitigate these impacts. Similarly, upgradient lots which have been approved but remain undeveloped should also be taken into consideration during the review process.

The nitrate-N concentrations measured in the Wye area commercial wells indicate that groundwater resources in this area are being adversely affected by the discharge of large volumes of sewage to the subsurface. Based on current State nondegradation review methodology, if the existing commercial facilities right around the US93/I-90 intersection were proposed today, they would not be approved for conventional septic systems, and current conditions should prevent future subdivision of land if conventional septic systems are proposed. A Bauman & Schafer analysis based on a hypothetical, newly proposed, 35-employee, truck repair facility located on a lot upgradient from existing developed lots would result in nitrate-N concentrations of 10 to 20 mg/L at the 500 ft. mixing zone boundary. The model was run by holding the all variables constant and varying the hydraulic conductivity and hydraulic gradient values. The range of hydraulic conductivity values was determined using specific capacity data and an analysis of drawdown data submitted for the proposed Williams Addition subdivision. The variables used in the analyses are included in Appendix E. Results are summarized in Table 11.

Table 11: Bauman & Schafer Analyses Results for a Hypothetical Septic Drainfield

Effluent Rate (gpd)	Drainfield Width (ft)	Hydraulic Conductivity (ft/d)	Hydraulic Gradient (ft/ft)	Nitrate-N Concentration (mg/L)
322	77	25	0.0002	20.4
322	77	250	0.0002	10.4
322	77	25	0.002	10.4
322	77	250	0.002	2.9

Based on this analysis, the hydraulic gradient on top of the hill is too flat to result in adequate nitrate dilution. Only by combining the upper end of the probable hydraulic conductivity range with a hydraulic gradient value which is an order of magnitude greater than that which was measured in the field will this hypothetical drainfield pass nondegradation review and not result in a violation of the nitrate-N standard. This illustrates the importance of using site-specific data, or data collected from as close to the proposed subdivision as possible, to perform the nondegradation analysis. Otherwise, the results of the nondegradation analysis may be based on data which is not representative of site conditions. This could lead to subdivisions erroneously passing or failing review. If water level data from Missoula Industrial Park and hydraulic conductivity data from the proposed Williams Addition were used in the analysis, the hypothetical drainfield discussed above would most likely pass State review.

Commercial and industrial development is encouraged in the Wye area by zoning and the Missoula Urban Area Comprehensive Plan (1998). However, the data suggests that large conventional drainfields associated with commercial service facilities such as Muralts Travel

Plaza, Crossroads Truck Stop, and Days Inn may not be appropriate for this area. It may be necessary to develop special management strategies for this area which include packaged sewage treatment plants, community wastewater management facilities (e.g. lined lagoon and spray irrigation), denitrifying septic systems, or extension of municipal sewer service.

The Missoula Urban Area Comprehensive Plan (1998) land use designations for the remainder of the O'Keefe Creek drainage are one dwelling unit per five acres (Sections 15 and 16) and rural densities of 1 dwelling unit per 40 acres. There is no evidence to suggest that development of the O'Keefe Creek drainage at these densities will result in significant water quality impacts.

Finally, several businesses within the study area are appear to qualify as public water supplies. As such, they are required to submit microbiological and inorganic chemistry data from their wells to the State. Northwest Peterbilt Company, Missoula Freightliner, Missoula Cartage, and Missoula Livestock Auction are all possible public water supplies which have apparently failed to submit this information to the State. These businesses should be required by the State to submit these data, particularly since each is located in an area known to have elevated concentrations of nitrate-N.

IX. Recommendations

1. All public water supplies within the study area should be identified and required to report on the microbiological and chemical quality of their water.

2. Drainfields, particularly those which are new or expanded, within the study area should be reviewed for compliance with the 600 gallons per acre per day requirement of Regulation 1 of the Missoula City-County Health Code. Expansion of use, usually due to addition of employees, appears to be a problem at some commercial facilities.

3. Identify existing septic systems applying >600 gal/acre/day in areas where nitrate-N concentrations in groundwater could violate the 10 mg/L standard. Investigate alternatives for corrective action, including land application, denitrifying septic systems, municipal sewering, etc.

4. Housing densities stipulated in the Missoula Urban Area Comprehensive Plan should be adhered to in the majority of the study area. Zones designated for high density development should be evaluated for appropriate allowable housing densities based on

site specific information.

5. Monitoring wells should be installed at strategic locations in order to obtain a true measure of water quality within the study area. In particular, monitoring well pairs should be installed north of the I-90/US 93 intersection in the commercial area where significantly elevated nitrate concentrations are known to exist. In the residential section of the main O'Keefe Creek drainage, groundwater flow direction should be determined and shallow and deep monitoring well pair(s) should be installed downgradient from the area(s) with the highest potential for development.

6. Future groundwater monitoring efforts should focus on areas north of the Wye designated for commercial and high density residential housing by zoning and the Missoula Urban Area Comprehensive Plan. Access to all wells in this area should be obtained to the extent possible for the purpose of obtaining water level measurements. Quarterly sampling of wells at Northwest Peterbilt, Missoula Freightliner, and Big Sky Tent and Awning should continue in 1999.

7. Impacts to groundwater quality in the commercial and high density residential areas north of I-90 should be calculated/modeled to the extent possible. An estimation of allowable density should be made to the extent possible. An evaluation of need for additional regulatory measures should be made following the modeling effort.

8. Surface water samples should be collected from O'Keefe Creek both above and below the livestock operation located south of where the creek crosses Waldo Road. Samples should be analyzed for nitrate-N, nitrite-N, ammonia-N, total Kjeldahl nitrogen (TKN), biochemical oxygen demand (BOD), phosphorus, and major cations & anions. If sampling indicates water quality degradation, the owner should be required to implement best management practices to mitigate impacts to the creek from this operation.

9. The Missoula Livestock Auction should be evaluated for potential to impact groundwater quality. If necessary, BMPs should be implemented to minimize any ongoing or potential impacts.

Appendix A

Description of Well Locations

I.D.	Name	Well Location
OK-1	SACS Trucking (Hagan Welding)	9200 Cartage Rd.
OK-2	NW Peterbuilt Co.	9550 Cartage Rd.
OK-3	Missoula Cartage	9300 Cartage Rd.
OK-4	Crossroads	I90 & 93 N
OK-5	Days Inn	8600 Truck Stop
OK-6	Wye West Casino	8700 Truck Stop
OK-7	C.B.'s Clip Joint	8005 Hwy 10 W
OK-8	R.H. Grover Inc.	9550 Derby Dr.
OK-9	Jim Palmer Trucking	9730 Derby Dr.
OK-10	Industrial Services	9665 Summit
OK-11	Brown, Mark & Jeanne	10080 Equestrian Way
OK-13	Coty, Brook	12190 Okeefe Cr
OK-14	Peterson, John	8585 Cartag Rd-home
OK-15	Malach, Elsie	11505 Polecat Ln
OK-16	Hennes, Al	11665 Hwy 93 N
OK-17	Bagly, Shelby	8303 Indreland Rd
OK-18	Fuller, Jerry	11985 Buff. Spwy
OK-19	Freightliner	8745 Hwy 93 N
OK-22	Miss Trap/Skeet Clb.	Hwy 10 W
OK-23	Kammerer, Mick	10450 El Toro
OK-24	Moen, Cameron	10425 George Cates
OK-25	Manley, Jeanette	9755 Waldo Rd.
OK-26	Tucker, Wally & Ruth	8100 Tucker Ln.
OK-26	Tucker, Ruth & Wally	8100 Tucker Ln.
OK-28	Giffin, Brian	9080 Hwy 10 W
OK-29	Birgenheier,Stephanie	10505 Waldo Rd
OK-30	Keane, Don	9955 George Cates Blvd.
OK-31	Stockman's Feed	Hwy 10 W (Robbins Rd.)

I.D.	Name	Well Location
OK-32	Muralt's	Truck Stop Rd.
OK-33	Nooney, Bill & Wanda	W&W Ranch-93N
OK-34	Trap/Skeet (caretaker's)	Hwy 10 W
OK-35	John Peterson (2nd well)	Cartage Rd-Trailer House
OK-36	Fife, Andrew	9555 Hwy 10 W
OK-37	Nicholson, Chad	7355 Medow Dr.
OK-38	Renneberg Hardwoods	9600 Inspiration
OK-39	Mel's Electric	7885 Thorton Dr
OK-40	Steinbach, Jim	7005 Medow Dr.
OK-50	Big Sky Tent & Awning	8385 Truck Stop Rd.
OK-51	Northern Specialty Supply	9400 Cartage Rd.
OK-101	Starfire Center	9819 Waldo Rd.
OK-102	Ross Electric	Deschamps Ln.
OK-103	Williams' Equipment	8295 Hwy 10 W
OK-104	Jones Equipment	8155 Hwy 10 W
OK-105	Montana Salvage	9775 Summit Dr.
OK-106	Iroquois	9660 Summit Dr.
OK-107	Transport Equipment	9300 Inspiration Dr.
OK-108	Jerome's Drilling	Inspiration Dr.
OK-109	Msla Auto Salvage	9905 Inspiration Dr.
OK-110	Nooney Prop. PWS well	George Cates Blvd.
OK-111	Properties 2000 lot	O'Keefe Cr Blvd.
OK-112	Fletcher Excavation	Robbins Rd.
OK-113	Bitteroot International (near shop)	8275 Hwy 10 W
OK-114	Bitteroot Int'l (away from shop)	8275 Hwy 10 W
n/a	Washworks	Cartage Rd.
WQD-16	Waldo Rd.	Waldo Rd.
n/a	Equestrian Wy.&George Cates Blvd.	Equestrian Wy. & George Cates Blvd.

Appendix B

Field Sampling Parameters

Location	Date	pH s.u.	T C	EC uS	DO mg/L	Eh mV
OK-01	02/12/97	7.55	8.4	279	nm	nm
	05/06/97	7.32	9.0	269	nm	nm
	08/07/97	7.47	12.2	308	8.6	161
	10/20/97	7.41	11.2	285	nm	nm
OK-02	02/13/97	7.80	9.4	416	nm	nm
	05/06/97	7.70	10.7	419	nm	nm
	08/06/97	7.32	12.9	650	7.7	143
	10/22/97	7.65	12.9	704	7.5	nm
	11/12/98	7.25	12.9	887	nm	nm
OK-03	02/13/97	7.71	10.7	258	nm	nm
	05/06/97	7.63	9.9	277	nm	nm
	08/11/97	7.16	11.4	269	9.2	5
	10/22/97	7.69	9.5	267	8.9	nm
OK-04	02/13/97	7.88	11.0	256	nm	nm
	05/07/97	7.02	12.5	249	nm	nm
	08/07/97	7.42	12.6	247	7.4	156
	10/20/97	7.24	12.0	238	6.9	nm
OK-05	02/13/97	7.57	9.9	380	nm	nm
	05/06/97	7.72	10.7	346	nm	nm
	08/07/97	7.19	11.6	326	5.0	136
OK-06	02/13/97	7.73	8.9	416	nm	nm
	05/06/97	7.62	9.5	438	nm	nm
	08/06/97	7.03	11.8	501	8.5	106
	10/20/97	7.30	11.0	490	6.3	nm
	11/12/98	7.16	13.0	589	nm	nm
OK-07	02/13/97	7.97	7.5	256	nm	nm
	05/13/97	7.00	15.7	248	nm	nm
	08/11/97	7.50	13.1	263	8.0	5
	10/29/97	7.63	12.3	253	7.6	nm
OK-08	02/18/97	7.49	10.2	268	nm	nm
	05/07/97	6.85	12.8	255	nm	nm
	08/14/97	7.32	12.2	273	9.3	nm
	10/22/97	7.23	9.3	289	7.2	nm
OK-09	02/18/97	7.44	10.7	463	nm	nm
	05/07/97	6.83	12.1	447	nm	nm
OK-10	02/18/97	7.49	8.9	281	nm	nm
	05/13/97	6.98	13.1	255	nm	nm
	08/14/97	7.50	11.0	238	9.2	nm
	10/29/97	7.43	12.3	265	8.8	nm
OK-11	02/24/97	7.20	10.1	272	nm	nm
	05/08/97	6.87	10.0	272	nm	nm
	08/12/97	6.96	11.3	280	7.4	159
	10/27/97	6.85	10.8	260	7.1	nm
OK-13	02/10/97	7.45	4.3	248	nm	nm
	05/08/97	7.02	15.8	202	nm	nm
	08/12/97	6.92	7.5	218	4.9	156
	10/22/97	6.98	10.0	212	6.8	nm
OK-14	02/13/97	7.75	9.5	198	nm	nm
	05/08/97	7.08	15.6	197	nm	nm
	08/06/97	7.03	11.1	198	8.0	85
	10/20/97	7.03	11.0	197	7.9	nm
OK-15	02/10/97	7.42	6.2	380	nm	nm
	08/12/97	7.24	10.4	618	0.1	110
	10/27/97	7.40	11.9	308	6.0	nm

Location	Date	pH s.u.	T C	EC uS	DO mg/L	Eh mV
OK-16	02/10/97	7.62	5.0	308	nm	nm
OK-17	02/10/97	7.41	7.9	641	nm	nm
OK-18	02/10/97	7.49	5.9	291	nm	nm
OK-19	02/19/97	6.86	11.8	920	nm	nm
	05/07/97	6.75	11.9	899	nm	nm
	08/11/97	6.83	11.6	974	6.8	4
	10/22/97	6.85	11.6	941	7.0	nm
	11/12/98	7.01	11.0	957	nm	nm
OK-22	02/12/97	7.40	8.0	293	nm	nm
	05/07/97	6.90	11.8	249	nm	nm
	08/11/97	7.00	11.2	273	5.2	155
OK-23	02/11/97	7.28	9.5	378	nm	nm
	05/08/97	6.86	13.2	372	nm	nm
	08/13/97	6.88	10.9	409	0.1	-80
	10/22/97	7.01	10.5	381	nm	nm
OK-24	02/24/97	7.12	8.8	225	nm	nm
	05/08/97	6.89	12.0	218	nm	nm
	08/12/97	6.86	8.7	264	7.6	155
	10/27/97	6.87	10.7	257	6.9	nm
OK-25	02/12/97	7.09	8.5	309	nm	nm
	05/08/97	7.02	17.4	275	nm	nm
	08/13/97	7.00	11.1	311	8.6	132
	10/27/97	6.98	11.1	310	8.2	nm
OK-26	02/11/97	7.34	8.4	240	nm	nm
	05/08/97	6.99	11.9	238	nm	nm
	08/11/97	7.19	11.7	251	4.4	125
	10/29/97	7.11	11.8	247	5.1	nm
OK-28	02/18/97	7.13	10.0	338	nm	nm
	05/13/97	7.15	15.8	294	nm	nm
OK-29	02/11/97	7.50	8.2	226	nm	nm
	05/08/97	7.08	10.0	220	nm	nm
	08/13/97	6.82	9.0	208	8.3	144
	10/20/97	7.20	10.9	240	7.9	nm
OK-30	02/11/97	7.40	7.3	311	nm	nm
	05/08/97	6.98	13.0	341	nm	nm
	08/13/97	6.85	11.5	360	5.5	140
	10/27/97	6.95	11.7	347	6.1	nm
OK-31	02/12/97	7.39	8.8	262	nm	nm
	05/07/97	6.81	11.2	309	nm	nm
	08/11/97	7.07	10.0	294	8.7	154
	10/29/97	7.18	11.8	303	8.3	nm
OK-32	02/13/97	7.55	8.9	419	nm	nm
	05/06/97	7.62	9.9	430	nm	nm
	08/06/97	6.90	11.5	463	5.0	152
	10/27/97	7.10	12.3	423	5.3	nm
OK-33	02/11/97	7.41	8.1	289	nm	nm
	05/08/97	7.00	14.8	280	nm	nm
	08/11/97	7.00	9.8	298	7.2	143
	10/29/97	7.08	11.1	273	7.0	nm
OK-34	02/18/97	7.58	9.3	359	nm	nm
	05/07/97	6.94	12.5	258	nm	nm
	08/11/97	6.91	18.9	278	5.3	174
	10/20/97	6.97	11.2	354	6.0	nm
	11/12/98	7.39	9.4	380	nm	nm

Location	Date	pH s.u.	T C	EC uS	DO mg/L	Eh mV
OK-35	02/13/97	7.70	9.5	281	nm	nm
	05/08/97	7.01	14.9	305	nm	nm
	08/06/97	6.98	11.0	326	7.7	75
OK-36	08/14/97	7.02	9.1	130	4.9	148
OK-37	05/07/97	6.84	9.1	552	nm	nm
	08/13/97	7.54	13.1	617	5.0	134
	10/27/97	7.58	9.0	621	5.6	nm
OK-38	05/13/97	7.00	14.0	230	nm	nm
OK-39	05/13/97	7.10	18.6	254	nm	nm
	08/14/97	7.20	10.0	252	9.4	nm
	10/22/97	7.21	9.3	252	nm	nm

Location	Date	pH s.u.	T C	EC uS	DO mg/L	Eh mV
OK-40	08/13/97	6.18	11.4	624	2.6	97
	10/27/97	6.96	9.9	628	4.0	nm
OK-41	08/27/97	8.38	15.7	148	8.5	nm
OK-42	08/27/97	7.81	16.8	201	8.8	nm
OK-43	08/27/97	7.77	16.0	259	6.0	nm
OK-50	10/20/97	7.03	10.6	682	6.2	nm
OK-51	10/22/97	7.12	11.0	241	8.2	nm

Key:
- pH = Hydrogen Ion Concentration
- T = Temperature in Degrees Celcius
- EC = Electrical Conductivity
- DO = Dissolved Oxygen
- Eh = Oxidation-Reduction Potential

Appendix C

Laboratory Analytical Results

Location	Date	K	Na	Ca	Mg	SO4	Cl	TIC	HCO3	NO3-N	NH4-N	Ba	Fe
OK-01	02/12/97	0.7	17.5	27.7	10.1	9.7	3.8	30	144	1.56	ns	0.095	0.018
	05/06/97	1.1	18.2	27.7	10.1	9.3	4.0	21	95	1.55	ns	0.115	0.020
	08/07/97	1.1	17.4	26.8	9.9	9.6	4.1	34	160	1.61	ns	0.105	0.023
	10/20/97	1.1	18.6	28.2	10.3	9.4	3.9	33	152	1.51	<0.01	0.106	0.021
OK-02	02/13/97	2.0	22.8	38.9	13.9	8.6	12.6	39	189	5.96	ns	0.177	0.015
	05/06/97	2.7	25.9	44.4	16.6	9.2	17.4	46	220	7.53	ns	0.234	0.016
	08/06/97	2.9	28.5	58.3	22.1	11.6	24.3	62	283	8.36	ns	0.290	0.023
	10/22/97	3.2	31.6	67.7	25.6	11.6	42.1	67	320	8.76	<0.01	0.318	0.019
	11/12/98	ns	ns	ns	ns	13.7	63.9	ns	ns	9.80	ns	ns	ns
OK-03	02/13/97	1.7	16.5	24.4	8.5	6.2	2.9	29	143	1.37	ns	0.142	0.021
	05/06/97	1.6	18.1	25.0	8.8	5.8	3.4	30	143	1.35	ns	0.141	0.018
	08/11/97	1.6	17.1	24.0	8.6	5.5	3.0	33	144	1.40	ns	0.132	0.019
	10/22/97	1.6	18.2	25.2	9.0	5.4	2.8	33	157	1.30	<0.01	0.124	0.017
OK-04	02/13/97	0.8	10.8	26.2	9.1	4.5	2.7	27	135	1.04	ns	0.125	0.013
	05/07/97	0.8	11.2	26.6	9.3	4.3	2.9	28	116	1.11	ns	0.128	0.013
	08/07/97	0.8	10.9	25.0	9.1	4.2	2.9	31	142	1.06	ns	0.118	0.015
	10/20/97	0.8	11.3	26.9	9.6	4.3	2.8	29	128	1.03	<0.01	0.113	0.013
OK-05	02/13/97	1.6	19.5	29.7	12.0	11.0	20.0	31	147	2.47	ns	0.148	0.024
	05/06/97	1.6	20.4	30.0	12.1	10.9	18.8	32	154	2.57	ns	0.157	0.028
	08/07/97	1.7	20.6	32.4	12.7	11.5	17.0	35	154	2.38	ns	0.147	0.032
OK-06	02/13/97	1.9	23.8	38.6	15.9	10.7	31.4	37	178	4.32	ns	0.201	0.015
	05/06/97	1.9	25.1	38.6	16.3	10.4	27.3	38	180	4.45	ns	0.205	0.014
	08/06/97	2.1	26.4	45.2	19.0	11.3	28.8	45	188	3.95	ns	0.206	0.018
	10/20/97	2.1	26.9	47.9	21.2	12.0	35.4	51	232	4.77	<0.01	0.227	0.015
	11/12/98	ns	ns	ns	ns	12.7	44.8	ns	ns	4.40	ns	ns	ns
OK-07	02/13/97	0.7	13.6	25.7	8.4	6.6	1.7	28	138	0.48	ns	0.098	0.013
	05/13/97	0.7	15.2	26.2	8.8	6.3	2.1	30	120	0.48	ns	0.104	0.012
	08/11/97	0.8	15.3	27.8	9.1	6.3	2.0	31	148	0.48	ns	0.096	0.016
	10/29/97	1.1	16.7	26.3	9.2	8.7	2.0	33	159	0.42	<0.01	0.114	0.013
OK-08	02/18/97	1.0	14.4	26.8	9.2	4.2	2.2	31	147	1.04	ns	0.114	0.018
	05/07/97	1.0	15.9	27.3	9.5	4.4	2.4	32	122	1.00	ns	0.124	0.018
	08/14/97	1.1	15.9	28.6	9.8	4.4	2.4	34	153	1.04	ns	0.112	0.023
	10/22/97	1.0	16.0	26.5	9.7	4.3	2.2	33	148	1.01	<0.01	0.105	0.014
OK-09	02/18/97	0.7	18.6	45.9	16.5	5.9	52.1	34	160	3.36	ns	0.176	0.015
	05/07/97	0.7	18.9	45.5	16.7	5.9	0.0	35	130	3.39	ns	0.177	0.014
OK-10	02/18/97	0.7	14.2	22.8	7.6	4.3	2.2	26	123	2.00	ns	0.066	0.012
	05/13/97	0.8	15.2	23.6	7.9	4.3	2.3	26	105	1.93	ns	0.074	0.012
	08/14/97	0.8	14.3	22.4	7.6	4.4	2.4	27	128	1.95	ns	0.068	0.014
	10/29/97	0.9	15.1	23.9	8.1	4.3	2.2	28	131	1.91	<0.01	0.067	0.013
OK-11	02/24/97	1.1	11.1	24.8	13.3	7.4	9.0	33	143	0.69	ns	0.188	0.011
	05/08/97	1.1	10.9	22.9	12.6	6.1	9.6	30	114	0.65	ns	0.182	0.013
	08/12/97	1.2	10.7	23.7	13.1	9.8	13.1	28	111	3.64	ns	0.175	0.012
	10/27/97	1.2	10.9	27.0	14.9	11.6	14.7	35	133	3.45	<0.01	0.185	0.011
OK-13	02/10/97	0.7	8.0	18.8	8.5	5.3	16.1	22	105	0.27	ns	0.171	0.012
	05/08/97	0.8	8.7	19.2	9.0	4.9	15.0	20	83	0.33	ns	0.182	0.015
	08/12/97	0.8	8.3	18.8	8.9	5.1	15.0	22	88	0.43	ns	0.165	0.011
	10/22/97	0.8	8.5	19.8	9.3	5.3	12.8	23	94	0.56	<0.01	0.168	0.010
OK-14	02/13/97	0.9	12.7	14.6	6.8	5.9	2.4	20	95	0.69	ns	0.082	0.033
	05/08/97	1.2	14.0	15.8	7.3	6.7	2.8	21	87	0.94	ns	0.099	0.022
	08/06/97	1.3	13.3	14.7	7.2	7.0	2.8	21	87	0.67	ns	0.095	0.024
	10/20/97	1.3	13.9	15.8	7.6	7.0	2.7	23	95	0.84	<0.01	0.091	0.022
OK-15	02/10/97	1.7	14.5	53.9	31.4	19.9	28.8	64	295	0.00	ns	0.153	0.017
	08/12/97	*	*	*	*	20.7	27.0	64	283	0.00	ns	0.023	0.068
	10/27/97	*	*	*	*	20.8	29.7	65	302	0.00	<0.01	0.025	0.051

Location	Date	K	Na	Ca	Mg	SO4	Cl	TIC	HCO3	NO3-N	NH4-N	Ba	Fe
OK-16	02/10/97	1.0	79.2	14.7	13.5	7.5	5.1	63	303	<0.01	ns	0.037	0.086
OK-17	02/10/97	2.1	14.8	51.0	30.9	26.9	38.9	59	275	<0.01	ns	0.125	0.017
OK-18	02/10/97	2.0	14.7	32.6	24.1	22.3	2.7	50	235	0.59	ns	0.133	0.014
OK-19	03/25/97	2.6	39.6	84.3	36.7	17.8	106.0	64	243	5.91	ns	0.485	0.019
	05/07/97	3.1	42.7	80.9	37.7	18.1	102.0	84	297	5.84	ns	0.572	0.020
	08/11/97	2.9	39.9	76.8	35.8	18.5	96.9	85	315	5.96	ns	0.511	0.023
	10/22/97	3.1	42.3	80.9	38.0	17.7	97.6	80	301	5.98	<0.01	0.509	0.021
	11/12/98	ns	ns	ns	ns	17.7	90.0	ns	ns	6.00	ns	ns	ns
OK-22	02/12/97	1.5	18.2	20.3	10.8	10.6	2.1	29	135	0.93	ns	0.070	0.016
	05/07/97	1.8	19.9	20.7	11.4	10.7	2.5	31	122	1.21	ns	0.095	0.017
	08/11/97	1.7	18.7	20.1	11.1	11.3	2.4	35	143	1.20	ns	0.086	0.015
OK-23	02/11/97	1.5	60.9	13.1	8.2	18.7	1.8	46	206	0.00	ns	0.048	0.939
	05/08/97	1.8	71.2	12.1	7.6	18.5	2.7	50	189	0.00	ns	0.048	0.664
	08/13/97	1.8	63.4	13.5	8.4	18.2	2.5	51	196	0.03	ns	0.048	0.170
	10/22/97	1.9	67.2	13.8	8.6	18.3	2.3	52	211	0.00	0.38	0.045	0.633
OK-24	02/24/97	0.9	9.9	20.5	10.7	5.8	8.6	28	120	0.44	ns	0.156	0.014
	05/08/97	1.0	9.6	19.2	10.4	5.4	10.0	24	91	0.91	ns	0.165	0.014
	08/12/97	1.1	9.9	21.5	11.6	8.7	14.5	25	96	3.23	ns	0.171	0.012
	10/27/97	1.1	9.9	24.6	13.3	9.7	15.2	28	107	2.54	<0.01	0.182	0.012
OK-25	02/12/97	3.5	20.3	29.0	11.6	13.9	6.5	34	143	2.96	ns	0.197	0.028
	05/08/97	3.6	21.2	23.8	10.0	11.6	4.3	31	128	2.33	ns	0.190	0.020
	08/13/97	3.4	19.5	23.7	9.9	11.9	5.6	32	132	2.58	ns	0.174	0.023
	10/27/97	3.6	20.8	25.4	10.6	11.8	7.5	33	134	2.68	<0.01	0.171	0.022
OK-26	02/11/97	0.9	14.4	15.0	8.0	7.0	1.4	24	108	0.00	ns	0.046	1.941
	05/08/97	1.3	17.1	19.1	10.4	7.0	1.2	28	114	0.00	ns	0.045	0.233
	08/11/97	1.2	16.0	17.9	9.8	7.6	1.1	31	136	0.00	ns	0.041	0.151
	10/29/97	*	*	*	*	5.0	4.6	16	70	1.12	<0.01	0.045	0.003
OK-28	02/18/97	1.5	16.6	28.5	14.8	11.4	6.2	38	164	0.90	ns	0.196	0.015
	05/13/97	1.5	16.4	27.9	15.2	12.6	4.7	38	163	0.90	ns	0.183	0.015
OK-29	02/11/97	0.9	9.2	17.9	9.0	6.3	10.5	20	92	1.32	ns	0.147	0.010
	05/08/97	1.0	9.6	19.0	9.6	5.9	8.9	22	94	0.81	ns	0.149	0.010
	08/13/97	0.9	9.2	17.8	9.1	5.7	9.4	23	87	1.21	ns	0.139	0.011
	10/20/97	1.0	9.5	19.4	9.9	6.3	11.3	22	98	1.87	<0.01	0.133	0.010
OK-30	02/11/97	2.2	22.3	25.0	15.1	13.0	9.0	36	168	1.77	ns	0.133	0.013
	05/08/97	2.3	23.2	26.4	16.2	15.0	10.7	38	155	1.86	ns	0.139	0.014
	08/13/97	2.2	23.1	24.4	15.4	14.5	9.7	41	153	1.65	ns	0.120	0.015
	10/27/97	2.3	23.4	26.0	16.2	14.3	9.9	40	160	1.69	<0.01	0.119	0.014
OK-31	02/12/97	2.4	21.3	21.7	9.0	7.4	2.9	30	137	2.05	ns	0.167	0.019
	05/07/97	2.4	22.5	22.1	9.2	7.2	3.2	30	112	1.99	ns	0.151	0.017
	08/11/97	2.3	22.1	22.6	9.5	7.9	3.6	35	145	2.58	ns	0.155	0.019
	10/29/97	2.3	22.6	23.6	9.4	7.9	3.4	33	146	1.89	<0.01	0.154	0.018
OK-32	02/13/97	1.8	23.4	39.1	14.2	13.1	26.2	38	183	2.05	ns	0.171	0.017
	05/06/97	1.8	25.0	41.3	15.2	12.9	26.7	43	204	2.17	ns	0.183	0.016
	08/06/97	1.8	24.9	41.3	15.5	13.9	30.5	48	185	4.60	ns	0.173	0.019
	10/27/97	2.0	28.1	48.7	18.2	14.0	33.7	50	210	2.39	<0.01	0.200	0.017
OK-33	02/11/97	1.3	11.2	26.8	14.2	8.3	9.6	33	152	0.64	ns	0.197	0.012
	05/08/97	1.2	11.4	24.5	13.6	8.1	9.6	29	117	2.35	ns	0.185	0.011
	08/11/97	1.2	11.4	26.0	14.7	12.0	14.2	31	127	4.12	ns	0.183	0.012
	10/29/97	1.3	12.1	29.2	16.3	13.0	12.9	34	145	3.00	<0.01	0.193	0.011
OK-34	02/18/97	1.2	15.4	37.3	14.0	10.2	5.7	36	172	5.91	ns	0.191	0.022
	05/07/97	1.7	18.9	22.2	11.0	11.2	2.2	33	130	1.22	ns	0.100	0.015
	08/11/97	1.7	18.5	19.9	11.0	11.1	2.4	34	131	1.18	ns	0.083	0.015
	10/20/97	1.2	16.6	38.6	14.8	10.9	5.7	38	154	6.30	<0.01	0.173	0.017
	11/12/98	ns	ns	ns	ns	9.7	5.4	ns	ns	6.40	ns	ns	ns

Location	Date	K	Na	Ca	Mg	SO4	Cl	TIC	HCO3	NO3-N	NH4-N	Ba	Fe
OK-35	02/13/97	1.2	20.1	29.7	11.2	15.4	4.2	34	163	1.01	ns	0.155	0.024
	05/08/97	1.3	21.2	30.3	11.4	15.4	4.5	35	144	1.06	ns	0.160	0.025
	08/06/97	1.2	20.3	30.1	11.5	16.6	4.8	40	162	1.07	ns	0.152	0.021
OK-36	08/14/97	1.1	10.1	22.9	10.6	9.3	5.4	29	121	0.42	ns	0.157	0.015
OK-37	05/07/97	5.5	34.5	26.4	40.7	53.6	7.8	59	222	1.93	ns	0.010	0.016
	08/13/97	5.4	33.1	25.1	39.7	54.9	7.4	61	289	1.85	ns	0.010	0.010
	10/27/97	5.6	36.0	27.2	42.7	55.4	7.4	61	289	1.74	<0.01	0.009	0.008
OK-38	05/13/97	0.8	14.6	23.0	8.4	5.2	2.3	25	104	2.06	ns	0.152	0.016
OK-39	05/13/97	1.0	15.7	24.5	8.6	5.1	2.2	29	124	0.74	ns	0.109	0.015
	08/14/97	1.0	15.1	23.3	8.4	5.3	1.8	31	136	0.71	ns	0.102	0.019
	10/22/97	1.0	16.1	25.5	9.0	5.4	2.1	33	132	0.69	<0.01	0.102	0.014
OK-40	08/13/97	7.7	45.5	32.9	16.2	75.3	64.5	26	50	4.79	ns	0.146	0.024
	10/27/97	*	*	*	*	62.6	47.9	27	107	*	*	*	*
OK-41	08/27/97	0.9	7.7	17.1	7.9	3.9	5.8	22	109	0.04	ns	0.131	0.020
OK-42	08/27/97	1.2	9.2	19.6	8.9	6.8	7.3	21	101	0.26	ns	0.143	0.036
OK-43	08/27/97	3.5	14.2	21.9	15.4	13.0	3.1	37	181	0.01	ns	0.101	0.036
OK-50	10/20/97	1.9	26.9	61.8	21.9	24.5	71.0	51	212	5.96	<0.01	0.27	0.02
OK-51	10/22/97	1.8	22.8	20.3	7.5	3.7	2.4	30	128	0.42	ns	0.039	0.072

Key:

K = Potassium
Na = Sodium
Ca = Calcium
Mg = Magnesium
Ba = Barium
Fe = Iron
SO4 = Sulfate

Cl = Chloride
TIC = Total Inorganic Carbon
HCO3 = Bicarbonate
NO3-N = Nitrate as nitrogen
NH4-N = Ammonia as nitrogen
ns = not sampled
* = error, not reported

Appendix D

Historic Public Water Supply Data

Public Water Supply	**Sample Date**	**Nitrate-N (mg/L)**
Bitterroot Int'l Systems	2/24/95	0.03
"	2/11/97	0.4
Crossroads Truck Center	8/4/81	1.0
"	5/12/87	1.5
"	4/6/92	0.1
"	11/8/94	1.0
"	3/30/95	1.15
"	7/15/97	1.07
"	8/12/98	1.05
Days Inn Westgate	11/28/88	3.0
"	11/8/93	1.89
"	11/14/94	1.94
"	10/1/96	2.42
"	7/14/97	2.6
"	10/7/98	2.3
Go West Drive In Theater	6/22/88	1.2
"	10/5/93	1.86
"	11/8/94	1.66
"	11/20/97	1.85
Jellystone RV Park	10/1/96	1.11
"	7/15/97	1.12
"	5/11/98	0.55
Jim & Mary's RV Park	11/28/88	1.1
"	11/15/94	1.91
"	8/4/97	1.01
"	10/19/98	1.35

Public Water Supply	Sample Date	Nitrate-N (mg/L)
Marvin's Bar	5/5/80	0.5
"	2/6/87	0.5
"	3/25/92	0.5
"	2/21/95	0.66
"	10/8/96	0.8
"	10/17/97	1.02
"	11/20/98	0.93
Missoula Village West Trlr. Ct.	3/20/87	0.54
"	5/4/90	0.51
"	2/7/94	0.41
"	12/27/95	0.52
Muralts Travel Plaza	8/25/80	3.8
"	11/5/85	0.1
"	2/5/91	2.3
"	11/7/94	1.69
"	10/1/96	1.83
"	7/14/97	2.43
"	10/7/98	3.02
Out Post Campground	9/1/81	0.4
"	3/5/87	0.3
"	5/12/92	0.4
"	11/13/94	0.35
"	9/15/97	0.94
"	7/14/98	0.55

Public Water Supply	Sample Date	Nitrate-N (mg/L)
Redwood Lodge	12/20/94	2.12
"	3/6/95	0.01
"	12/4/95	1.88
"	9/30/96	2.01
"	11/6/97	2.07
"	12/1/98	2.09
Spring Meadows Subdivision	9/25/93	0.22
"	4/10/94	0.31
"	9/26/95	0.18
"	10/6/97	0.04
"	8/17/98	0.76
Transport Equipment	6/6/97	1.91
Williams Equipment	12/22/97	0.04
Wye West Lounge and Casino	8/25/80	6.3
"	3/5/87	5.4
"	2/13/92	1.8
"	11/7/94	3.14
"	10/1/96	4.58
"	8/14/97	2.61
"	10/7/98	4.54

Appendix E

Non-Degradation Anlyses for a Hypothetical Drainfield

Hypothetical Drainfield: 43 cu.ft./d, K=25 ft/d, i=0.2/1000

K=	Hydraulic Conductivity (from chart)	25	ft/dy
i=	Hydraulic Gradient (from engineer)	0.0002	ft/ft
d=	Depth of Aquifer (constant)	16.405	ft
l =	Downgradient Mixing Zone Boundary Distance	500	ft
	= 100 ft for sngl fam & lots < 2 acres		
	= 200 ft for sngl, mutpl fam & lots 2 acres		
	= downgradient length of adj undeveloped land if central water		
	= 500 ft for public systems		
y =	Width of drainfield perpendicular to shallow gw flow	77	ft
w=	Width of mixing zone perpendicular to flow direction	164.5	ft
Am=	Cross sectional area of aquifer mixing zone	2698.6	ft2
As=	Surface area of mixing zone	82250	ft2
Ng=	Background Nitrates from Report	1.5	ppm
Nr=	Naturally Occuring Nitrates in Rainwater	1	ppm
Ne=	Nitrates in Effluent (constant)	50	ppm
#l=	Number of Lots in Subdivision	1	ea
Ql=	Quantity of Effluent per Dwelling Unit	43	ft3/dy
pi	precipitation in inches per year	14	in/yr
p=	Precipitation for Area	0.0032	ft/dy
I=	Recharge Percentage (constant)	0.2	na
Qg=	Groundwater or Aquifer = K*i*Am	13.493	
Qr=	Recharge = As*p*I	52.58	
Qe=	Effluent = #l*Ql	43	
Nt=	Total Measureable Nitrates After Development	20.4	

Hypothetical Drainfield: 43 cu.ft./d, K=250 ft/d, i=0.2/1000

K=	Hydraulic Conductivity (from chart)	250	ft/dy
i=	Hydraulic Gradient (from engineer)	0.0002	ft/ft
d=	Depth of Aquifer (constant)	16.405	ft
l = Downgradient Mixing Zone Boundary Distance		500	ft
= 100 ft for sngl fam & lots < 2 acres			
= 200 ft for sngl, mutpl fam & lots 2 acres			
= downgradient length of adj undeveloped land if central water			
= 500 ft for public systems			
y = Width of drainfield perpendicular to shallow gw flow		77	ft
w=	Width of mixing zone perpendicular to flow direction	164.5	ft
Am=	Cross sectional area of aquifer mixing zone	2698.623	ft2
As=	Surface area of mixing zone	82250	ft2
Ng=	Background Nitrates from Report	1.5	ppm
Nr=	Naturally Occuring Nitrates in Rainwater	1	ppm
Ne=	Nitrates in Effluent (constant)	50	ppm
#l=	Number of Lots in Subdivision	1	ea
Ql=	Quantity of Effluent per Dwelling Unit	43	ft3/dy
pi	precipitation in inches per year	14	in/yr
p=	Precipitation for Area	0.003196	ft/dy
I=	Recharge Percentage (constant)	0.2	na
Qg=	Groundwater or Aquifer = K*i*Am	134.9311	
Qr=	Recharge = As*p*I	52.57991	
Qe=	Effluent = #l*Ql	43	
Nt=	Total Measureable Nitrates After Development	10.4	

Hypothetical Drainfield: 43 cu.ft./d, K=25 ft/d, i=2/1000

K=	Hydraulic Conductivity (from chart)	25	ft/dy
i=	Hydraulic Gradient (from engineer)	0.002	ft/ft
d=	Depth of Aquifer (constant)	16.405	ft
l = Downgradient Mixing Zone Boundary Distance		500	ft
= 100 ft for sngl fam & lots < 2 acres			
= 200 ft for sngl, mutpl fam & lots 2 acres			
= downgradient length of adj undeveloped land if central water			
= 500 ft for public systems			
y = Width of drainfield perpendicular to shallow gw flow		77	ft
w=	Width of mixing zone perpendicular to flow direction	164.5	ft
Am=	Cross sectional area of aquifer mixing zone	2698.623	ft2
As=	Surface area of mixing zone	82250	ft2
Ng=	Background Nitrates from Report	1.5	ppm
Nr=	Naturally Occuring Nitrates in Rainwater	1	ppm
Ne=	Nitrates in Effluent (constant)	50	ppm
#l=	Number of Lots in Subdivision	1	ea
Ql=	Quantity of Effluent per Dwelling Unit	43	ft3/dy
pi	precipitation in inches per year	14	in/yr
p=	Precipitation for Area	0.003196	ft/dy
I=	Recharge Percentage (constant)	0.2	na
Qg=	Groundwater or Aquifer = K*i*Am	134.9311	
Qr=	Recharge = As*p*I	52.57991	
Qe=	Effluent = #l*Ql	43	
Nt=	Total Measureable Nitrates After Development	10.4	

Hypothetical Drainfield: 43 cu.ft./d, K=250 ft/d, i=2/1000

K=	Hydraulic Conductivity (from chart)	250	ft/dy
i=	Hydraulic Gradient (from engineer)	0.002	ft/ft
d=	Depth of Aquifer (constant)	16.405	ft
l = Downgradient Mixing Zone Boundary Distance		500	ft
= 100 ft for sngl fam & lots < 2 acres			
= 200 ft for sngl, mutpl fam & lots 2 acres			
= downgradient length of adj undeveloped land if central water			
= 500 ft for public systems			
y = Width of drainfield perpendicular to shallow gw flow		77	ft
w=	Width of mixing zone perpendicular to flow direction	164.5	ft
Am=	Cross sectional area of aquifer mixing zone	2698.623	ft2
As=	Surface area of mixing zone	82250	ft2
Ng=	Background Nitrates from Report	1.5	ppm
Nr=	Naturally Occuring Nitrates in Rainwater	1	ppm
Ne=	Nitrates in Effluent (constant)	50	ppm
#l=	Number of Lots in Subdivision	1	ea
Ql=	Quantity of Effluent per Dwelling Unit	43	ft3/dy
pi	precipitation in inches per year	14	in/yr
p=	Precipitation for Area	0.003196	ft/dy
I=	Recharge Percentage (constant)	0.2	na
Qg=	Groundwater or Aquifer = K*i*Am	1349.311	
Qr=	Recharge = As*p*I	52.57991	
Qe=	Effluent = #l*Ql	43	
Nt=	Total Measureable Nitrates After Development	2.9	