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Cumulative effects of septic system disposal on groundwater quality in selected portions of Missoula County Montana

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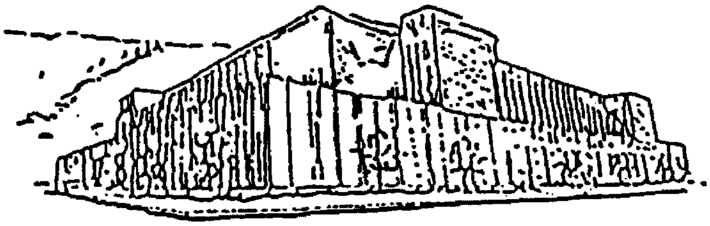

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The Cumulative Effects of Septic System Disposal on Groundwater Quality in Selected Portions of Missoula County, Montana

by

Jeffrey John King

B.S. University of Wisconsin-Madison

Presented in partial fulfillment of requirements

for the degree of Master of Science in Geology

University of Montana

August, 1996

Approved By:

Chairperson, Board of Examiners

Dean, Graduate School

7-19-96

Date

Jeffrey John King, M.S., August 1996 Geology

The Cumulative Effects of Septic System Disposal on Groundwater Quality in Selected Portions of Missoula County, Montana
(185 pp.)

Director: Dr. William W. Woessner 7/17/96

Recent trends of locating higher density residential developments within the urban fringe of towns and cities has spurred concern when household waste is disposed of on-site. The goal of this project was to characterize the cumulative impacts to groundwater quality in selected areas of Missoula County, Montana, that resulted from septic system disposal of household waste. Methods to assess the cumulative impacts included: selection of subdivision scale residential areas which utilize septic systems and exhibited distinct geologic environments and residential densities, establishment of groundwater level and quality monitoring networks within these communities, creation of solute transport groundwater models calibrated to field-measured individual septic plumes, and the extrapolation of the individual septic plumes to simulate multiple septic systems within the selected subdivisions.

Two study sites were chosen within the fluvial Missoula Valley (East and West sites) and one within the fluvial-lacustrine geologic environment of Frenchtown. The East site consists of 63 homes with a housing density of approximately one home per acre, while the West site has 29 homes and a housing density of about two homes per acre. The Frenchtown cumulative site consists of approximately 79 homes and a housing density of 0.2 homes per acre.

Individual nitrate-N and chloride septic derived plumes emitted from a single home in both Missoula and Frenchtown were numerically simulated. The individual simulations were extrapolated to represent emission from the homes within the cumulative impact sites. The configuration of the cumulative plumes showed the highest chloride and nitrate-N concentrations to occur when septic systems are situated consecutively along the same groundwater flowpath. The less dense East site had higher simulated chloride and nitrate-N concentrations than the West site. The greatest potential of cumulative impacts to groundwater, caused by septic system disposal, was predicted to occur in areas where septic systems are aligned within the same general flowpath. The degree of cumulative impacts were not necessarily dependent on housing densities.

Up and down-gradient multi-level monitoring wells emplaced adjacent to the East and West sites measured a 1-10 mg/l increase of chloride concentrations down-gradient of the developed area, while nitrate-N concentrations showed no measurable change.

ACKNOWLEDGMENTS

This thesis was possible because of the efforts, advice, and patience of many extraordinary people. First, and foremost I would like to thank the members of my thesis committee: Dr. Nancy Hinman, Dr. Garon Smith, and Dr. Bill Woessner. Your suggestions, advice, resources, and support made this research project possible. Very special thanks needs to go to thesis committee chairperson, Dr. Woessner. Not only did you provide me with the academic knowledge required to tackle a research project of this magnitude, but also, and maybe more importantly, the organizational and communication skills and the confidence to move into the next stage of my life, moving out into "the real world". Your continued efforts to see that I had funding throughout my research at the University of Montana did not go unnoticed or unappreciated.

The funding for this project was provided by the Missoula County Commissioners, and I thank you. Your financial support directly provided Missoula County with valuable information in terms of septic systems and their effects to groundwater quality in the county, but also indirectly to the education of many individuals. I hope the county will continue to seek the vast available resources at the University of Montana for their research needs in the future.

I also need to thank the Missoula County residents who participated in this project by providing access to your wells. Thanks also goes to my fellow septic researchers: Sean Lambert, Tom McCamant, and Tom Michalek. Our numerous "bull sessions" were truly helpful.

Finally, I need to thank my parents, Tom and Chris King, and my wife, Lisa, whose patience and understanding were remarkable.

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CHAPTER 1

INTRODUCTION

On-site sewage disposal systems have been regarded historically as an economical and effective means of handling household wastes in a non-urban setting (Canter and Knox, 1984; Rajagopal et al., 1975). It is traditionally assumed in settings with sparse developments, that sufficient open space exists such as septic system effluent is treated and diluted to a non-hazardous level by the time it becomes accessible to adjacent wells. However, there is an increasing trend to use individual on-site sewage disposal systems for waste disposal in higher density developments in the urban fringe of cities. Recent work by researchers evaluating the transport of sewage effluent components in sand-rich aquifers warn that dilution of nitrate-nitrogen concentrations and other contaminants is much less than has been assumed for decades (Wilhelm et al., 1994; Shutter et al., 1994).

Today, concern is also being voiced over the perceived impact of multiple septic systems on associated groundwater and surface water systems. Densities of two systems per acre have been found to cause a degradation of the groundwater in some settings (Tinker, 1991; Hantzsche and Finnemore, 1992; Ford et al., 1980; and Walker et al., 1973). Perkins (1989) and Ford et al. (1980) noted that the number and orientation of septic systems relative to the groundwater flow and physical aquifer size, influence the degree and extent of groundwater impact.

Households served by septic systems often obtain potable water from wells penetrating the same groundwater system being used for domestic sewage disposal.

Septic system effluent degrades the quality of soil water below drainfield lines and the underlying groundwater by elevating the concentration of dissolved constituents (Canter and Knox, 1984), acts as a source for human pathogens (Hagedorn, 1984) and introduces trace quantities of toxic organic chemicals from household products (Kalega et al., 1987). Groundwater immediately below the disposal field and within a plume of groundwater extending down-gradient from the effluent source area, often exceeds drinking water standards for nitrate [Maximum Contaminant Level (MCL) of 10 mg/l nitrate-N] and fecal coliform bacteria (1 per 100 ml) (Wilhelm et al., 1994). Over 70% of the disease outbreaks traced to the consumption of untreated groundwater are attributed to septic system waste contaminated with bacteria and viruses (Keswick and Gerba, 1980; Yates and Yates, 1989). An outbreak of hepatitis A in Arkansas was attributed to septic effluent contamination of a groundwater water supply (Craun, 1979). Septic system effluent has also been documented to contribute to eutrophication of lakes and streams (Alhajjar et al., 1989).

In unsewered portions of the United States over one trillion gallons of domestic sewage leaves septic systems and enters the groundwater each year (Prins and Lustig, 1988; Moody, 1990). Domestic waste disposal via septic systems constitutes the largest volumetric source of sewage effluent to the subsurface (U.S. EPA, 1977). Forty-one states describe individual septic systems as a major source of groundwater contamination (Moody, 1994). The widespread use of septic systems to dispose of household sewage and gray water accounts for approximately 20 million point sources of groundwater contamination (Wilhelm et al., 1994).

Urban fringe and rural communities found within Montana depend on septic systems for on-site effluent disposal. The 2,625 mi^2 Missoula County contains about 10% of Montana's population, 85,669, of which about 45% are served by community sewer systems (English, per. com., 1995). Growth rates of 11% in the last few years have increased the demand on the county's sole source aquifers to supply high quality water to existing and new residents. Much of the growth is occurring in the unsewered portions of the Missoula and Swan Valleys. It is estimated over 30,600 septic systems are currently in use in Missoula County. Subdivisions and rural property development often allow two septic systems per acre today. Older regulations have allowed portions of the county to contain six to seven systems per acre.

Evaluation of impacts of septic system waste disposal in Montana include work by Peavy et al. (1980) who monitored five subdivisions that represent varying housing densities in western Montana. Their work concluded there was little to no groundwater impact as a result of septic system disposal. Ver Hey (1987) conducted detailed instrumentation of two septic systems within the coarse sand and gravels of the Missoula Valley. She found the septic systems impacted groundwater directly beneath and adjacent to the septic drainfield. Nitrate-nitrogen concentrations were elevated approximately 75 feet down-gradient of the drainfield. Work by Bayuk (1986) showed elevated nitrate-nitrogen levels and other dissolved constituents, as a result of on-site disposal systems, in the fractured rock aquifers in the Hayes Creek area southwest of the Missoula Valley. Woessner (1988) conducted a regional groundwater quality survey of a portion of the Missoula Valley surrounding the City of Missoula. He found as the groundwater traveled through the western portion of the valley, which is presently using on-site subsurface disposal systems, nitrate-nitrogen and chloride concentrations in domestic wells increased in the direction of groundwater flow. In addition, 20% of the wells sampled in the unsewered area tested positive for bacteria. A comprehensive evaluation of additional groundwater impacts from septic systems in Missoula County, of which this work is part, has recently been completed by Woessner et al. (1996).

As population growth continues, protection of the county's groundwater systems is of paramount importance. It is logical as additional adjacent unsewered lots are developed, concentrations of constituents originating from septic systems will increase in the underlying aquifers. The cumulative impact of waste disposal from individual systems can result in a compounded degradation of portions of a groundwater system. The degree of aquifer impact is dependent on the number of waste sources, their constituent concentrations and loading rates, and the ability of the groundwater system to mix, react and dilute contaminant streams. The residents of the Missoula Valley already have taken steps to assess groundwater conditions by establishing the 208 mi^2 Missoula Water Quality District. County-wide efforts to evaluate the current groundwater conditions within the county are, in part, addressed by this work. The project attempts to document the effects of septic system disposal on the county's groundwater resources. Results of this work will provide an assessment of the individual and cumulative impacts to the county's underlying groundwater systems. The funding for this project was provided by the Missoula County Commissioners.

Goals and Objectives

The goal of this project is to characterize the cumulative impacts to the quality of groundwater resources in selected areas of Missoula County that result from the use of septic tank and drainfield systems for household sewage disposal. This goal will be achieved by field study and numerical simulation.

Specific objectives include:

1. Determination of the groundwater flow system, on a regional scale, in the selected study areas within Missoula County;
2. Characterization of the nitrate-nitrogen and chloride concentrations as a result of septic system disposal within and adjacent to the study areas;
3. Development of solute transport models of septic plumes that are calibrated to individual field plumes;
4. Application of the single plume models to a subdivision scale setting; and
5. Comparison of the theoretical chloride and nitrate-nitrogen concentration distribution to the measured field distribution.

Thesis Organization

The thesis is organized in six chapters. Chapter Two discusses septic system operation and the effects to groundwater quality, as described by previous groundwater researchers. Chapter Three reviews the site conditions within two study sites, that are associated with this study, originally described by Woessner et al. (1996). Chapter Four explains the methodology used in this investigation. Chapter Five is a discussion of the results, including the solute transport simulations of the individual and cumulative septic plumes. Chapter Six presents the conclusion and recommends additional information that could be used to further define the effects of septic system disposal on groundwater quality in Missoula County.

CHAPTER 2

SEPTIC SYSTEM OPERATION AND EFFECTS TO GROUNDWATER

A typical septic system consists of four treatment stages that are designed to reduce contaminant concentrations to acceptable levels: 1) a septic tank; 2) a drainfield; 3) a soil zone; and 4) a groundwater system below the drainfield (Figure 2.1). Effluent is treated within the septic tank; biochemical reactions decompose organic material and solids are removed by settling. Liquid waste is treated as it overflows the tank into the soil surrounding the drainfield. The drainfield insures the effluent is released into the adjacent soil zone within a relatively wide area. The soil filters the effluent and slows its downward movement, reducing dissolved nutrients and particulates. Soil bacteria also act on nutrients in the waste. The underlying groundwater system receives treated effluent and disperses it in the direction of groundwater flow. However, if the vadose zone is thin, has high permeability and/or effluent loading rates are high, concentrations of some effluent constituents may contaminate underlying groundwater systems.

Composition of Effluent

All liquid derived household wastes are treated by the septic system. This averages about 50 gallons per person per day (Ver Hey, 1987). Components of septic effluent that affect water quality include inorganic and organic contaminants, and bacteria and viruses (Table 2.1). The effluent is composed of 0.2 g/l to 0.6 g/l of organic matter by weight which includes anthropogenic organic chemicals and microbial pathogens (Wilhelm

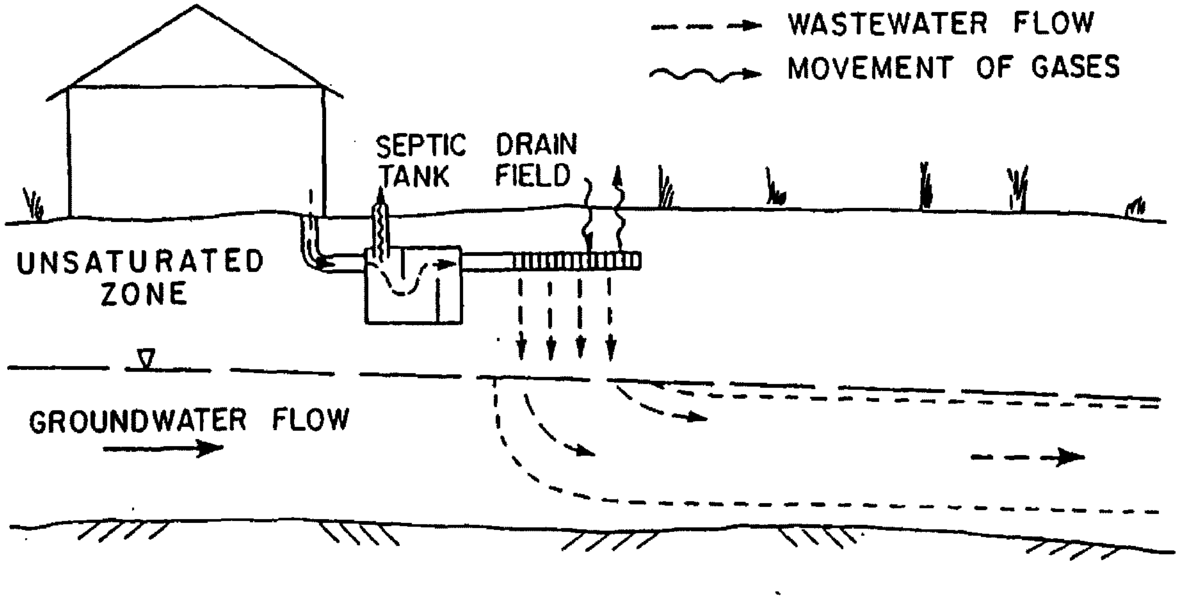


Figure 2.1: Components of a typical septic system (Welhelm et al., 1994).

	Mean (mg/L)	95% Confidence Interval	Range (mg/L)	Ref.
Total Dissolved Solids			350–1200	a
Total Organic Carbon			100–300	a
Total Nitrogen, N	45	41–49	<x.9–125	b
Nitrate, N	.4	<.1–.9	<.1–.9	b
Ammonia, N	31	28–34	.1–91	b
Total Phosphorus, P	13	12–14	.7–99	b
Orthophosphorus, P	11	10–12	3–20	b
Chloride			37–100	c
Boron			.1–.4	d
Sodium			40–70	d
Potassium			7–15	d
Magnesium			3–6	d
Calcium			6–16	d
Sulfate			15–30	d
Carbonate Alkalinity			100–150	d
Sodium	75		71–78	e
Zinc	.45		.35–.53	e
Lead	.03		.02–.04	e
Copper	.17		.14–.20	e
Iron	.46		.19–.64	e
Fecal Coliform	#/100mL 5.0×10^6	#/100mL 2.5×10^6– 1×10^7		a
Enteric Viruses (PFU/L)			32–7000	f

References:

a) Metcalf and Eddy Inc., 1972
b) from seven septic tanks (Univ. of Wisconsin, 1978)
c) Peavey, 1978
d) normal range of mineral pickup in sewage (EPA, 1975)
e) Winneberger, 1975
f) Siegrest, 1977

Table 2.1: Summary of Effluent Quality (Ver Hey, 1987).

et al., 1994). Waste water also typically has elevated concentrations of total dissolved solids, including chloride and alkalinity (Wilhelm et al., 1994). Extremely high values of chloride are often found in effluent originating from households generating brines during the back-flushing of water softeners. The pH typically ranges between 6.5 and 8.0 (Canter and Knox, 1985).

Septic Tank Treatment

Household wastes drain into a collection tank where dense particulates settle to the bottom, and grease and other light constituents form a scum layer on the liquid surface (Figure 2.2). The anaerobic conditions within the tank allow some decomposition of the sludge and scum, decreasing the solid volume. Microorganisms oxidize organic matter using hydrogen, carbon dioxide, organic carbon and sulfate as electron acceptors (Wilhelm et al., 1994). About 90% of the incoming nitrogen is released from the organic molecules and forms ammonium (NH_4^+). Hydrogen gas, methane, hydrogen sulfide and carbon dioxide are also generated as by-products (Figure 2.3). The remaining accumulation of solids collects in the tank and should be removed by pumping every three to five years. Baffles in the tank serve to prevent the outflow of solid matter to the drainfield.

Drainfield

The partially clarified and treated liquid is discharged from the tank to a subsurface drainfield. This fluid is composed of large humic-like organic molecules, microbes and inorganic compounds (Wilhelm et al., 1994). The drainfield consists of a network of

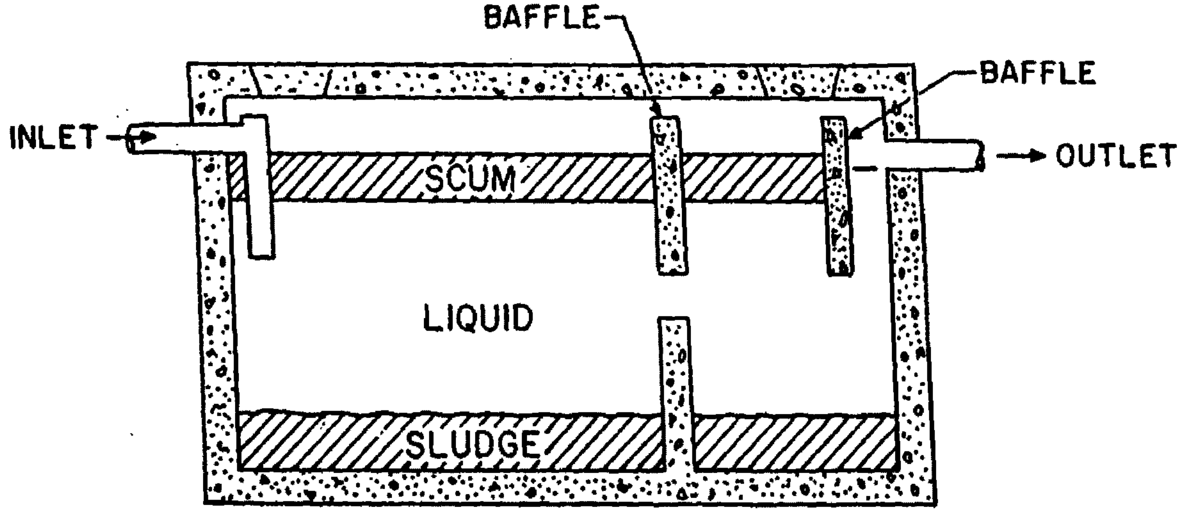


Figure 2.2: Cross section of a standard septic tank (modified from Canter and Knox, 1985).

Figure 2.3: Important reactions in septic systems (Wilhelm et al., 1994).

Anaerobic zone (septic tank and biological mat):

Organic molecule hydrolysis:

Proteins + $H_2O \rightarrow$ Amino acids

Carbohydrates + $H_2O \rightarrow$ Simple sugars

Fats + $H_2O \rightarrow$ Fatty acids and glycerol

Ammonium release:

Urea $[CO(NH_3^+)_2] + H_2O \rightarrow 2\ NH_4^+ + CO_2$

Amino acids + $H_2O \rightarrow NH_4^+$ + Organic compounds

Fermentation:

Amino acids, simple sugars $\rightarrow H_2$, acetate (CH_3OO^-), other organic acids

Anaerobic oxidation:

Fatty acids + $H_2O \rightarrow H_2, CH_3OO^-$

Sulfate reduction:

$SO_4^{2-} + 2\ CH_2O^a + 2\ H^+ \rightarrow H_2S + 2\ CO_2 + 2\ H_2O$

Methanogenesis:

CH_3OO^- (acetate) + $H^+ \rightarrow CH_4 + CO_2$

$CO_2 + 4\ H_2 \rightarrow CH_4 + 2\ H_2O$

Aerobic zone (unsaturated zone, and saturated zone to lesser extent):

Organic matter oxidation:

$CH_2O + O_2 \rightarrow CO_2 + H_2O$

Nitrification:

$NH_4^+ + 2\ O_2 \rightarrow NO_3^- + 2\ H^+ + H_2O$

Sulfide oxidation:

H_2S (or organic sulfide) $+ 2\ O_2 \rightarrow SO_4^{2-} + 2\ H^+$

Carbonate buffering:

$H^+ + HCO_3^- \rightarrow H_2CO_3$

$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$

$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2\ HCO_3^-$

Second anaerobic zone (saturated or near-saturated conditions)[b]:

Denitrification:

$4\ NO_3^- + 5\ CH_2O + 4\ H^+ \rightarrow 2\ N_2 + 5\ CO_2 + 7\ H_2O$

---

[a] Organic matter is simplified as CH_2O throughout. Actual organic matter contains C of various oxidation states and other elements such as N, P, and S, and therefore actual reaction products vary.

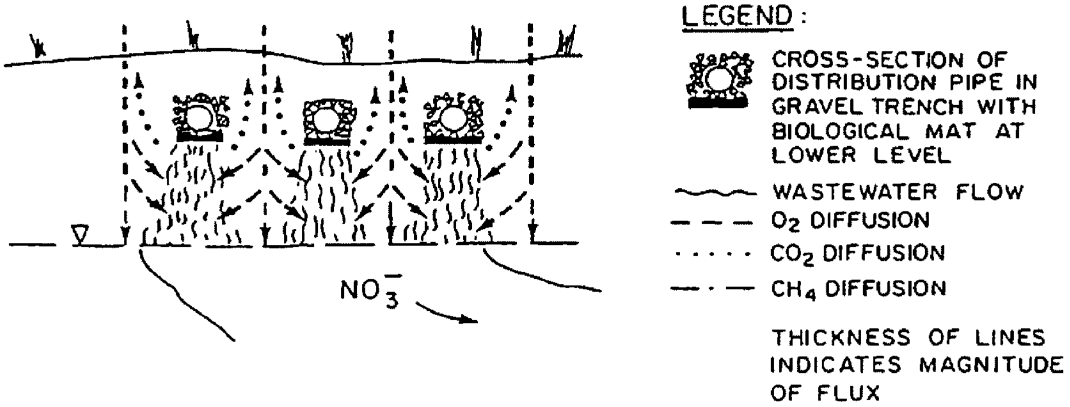
[b] Nitrate reduction can also be accomplished via oxidation of reduced sulfur compounds (Howarth and Stewart, 1992).

perforated pipe or porous tile laid in individual trenches or in a single bed lined with one-half to two inch diameter gravel. The purpose of the distribution pipes is to insure the unimpeded flow of effluent from the tank, and create an area over which effluent can percolate into the underlying soil. If the native soil is finer grained than the gravel fill, a biological mat forms which continues anaerobic treatment of the effluent (Figure 2.4). The two to five cm. thick mat forms as organic matter and particulates are retained at the trench fill-soil interface. This black slime layer also includes soil microorganisms such as fungi, bacteria, protozoans, and microscopic insects. The mat reduces the hydraulic conductivity of the underlying soil, limiting percolation rates (Jones and Taylor, 1965).

The soil underlying the drainfield is intended to mechanically and chemically treat percolating effluent (Figure 2.5). Under proper operation, aerobic conditions exist in the soil zone. Research has shown that complete oxidation of ammonia requires only a few hours within one meter below the biologic mat, if the concentration of oxygen is not limited (Wilhelm et al., 1994). When oxygen is limited and/or infiltration rates are high, ammonia is often found within the vadose zone and the underlying groundwater system (Wilhelm et al, 1994). Hydrogen ions released during oxidation of ammonia are generally neutralized by the alkalinity of the effluent. However, in poorly buffered systems the effluent pH may decrease (Wilhelm et al., 1994).

The vadose zone soil may also act to adsorb ammonia, phosphates, metals, organic matter, and viruses present in the waste stream. Ortho-phosphates are often present in the effluent at concentrations of 10 to 20 mg/l. Ortho-phosphate is usually immobilized within six to seven feet of the drainline in acidic soil settings. However, in low cation exchange

(a) WELL-AERATED DRAIN FIELD



(b) POORLY-AERATED DRAIN FIELD

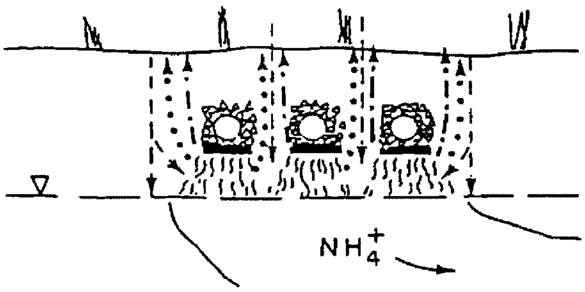


Figure 2.4: Gas and water movement in the drainfield of septic systems. Black bar beneath the drainfield represents the location of the biologic mat. a) Well-aerated system, in which adequate oxygen enters the drainfield and carbon dioxide and nitrate are produced. b) Poorly aerated system, in which adequate oxygen does not enter the soil zone and carbon dioxide and methane are produced (Wilhelm et al., 1994).

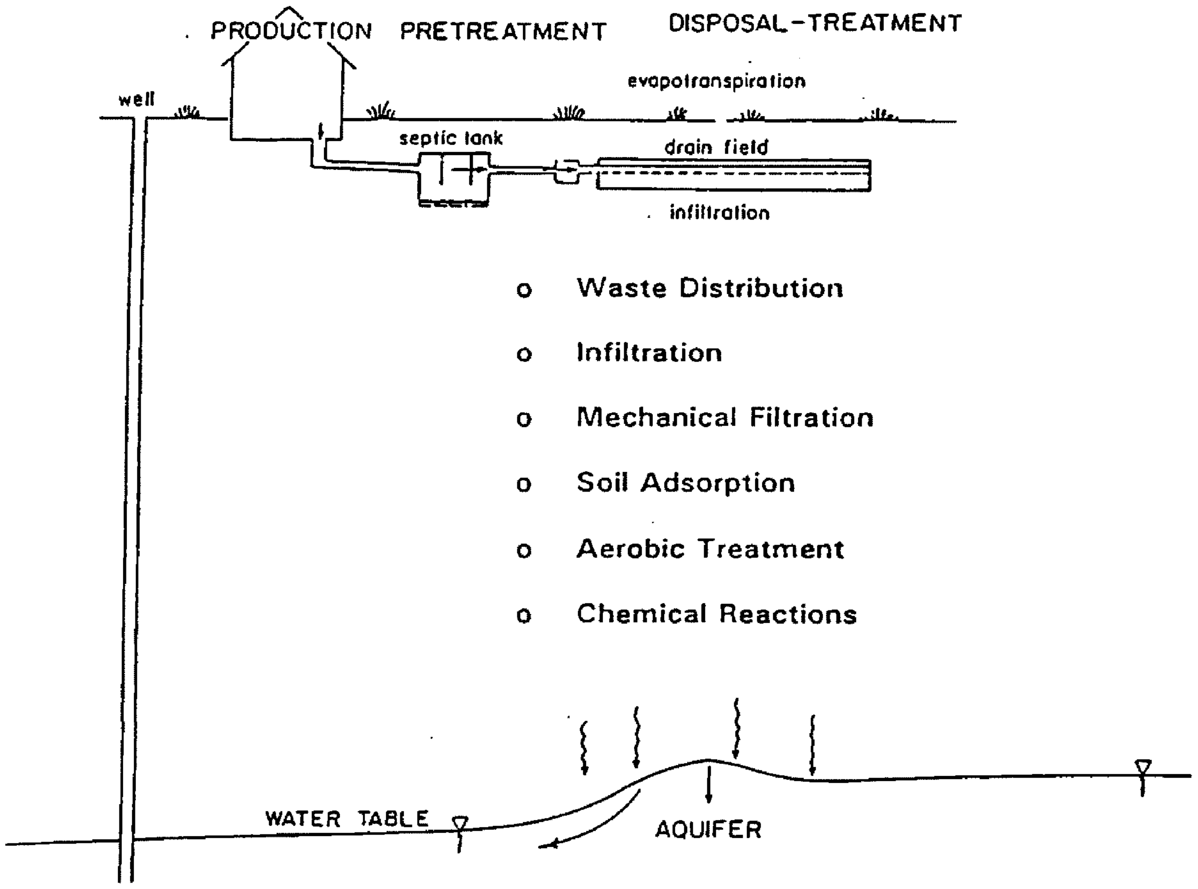


Figure 2.5: Processes occurring in the unsaturated soil zone below the drainfield (after Canter and Knox, 1985).

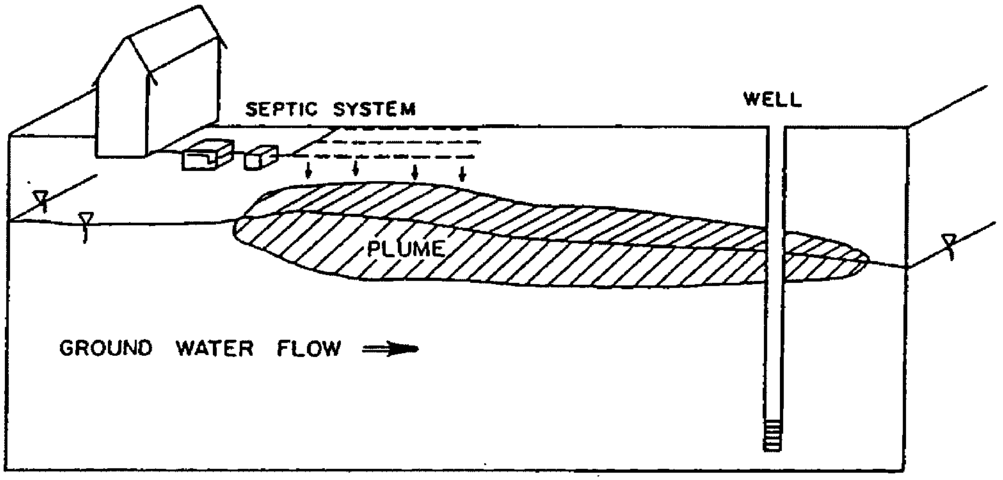
capacity (CEC) soils, adsorption decreases rapidly after available exchange sites are filled.

An additional function of the soil zone is to mechanically sieve the effluent. As the dispersed waste passes downward through pore spaces, bacteria and virus are filtered from the effluent, either partially or completely.

Groundwater

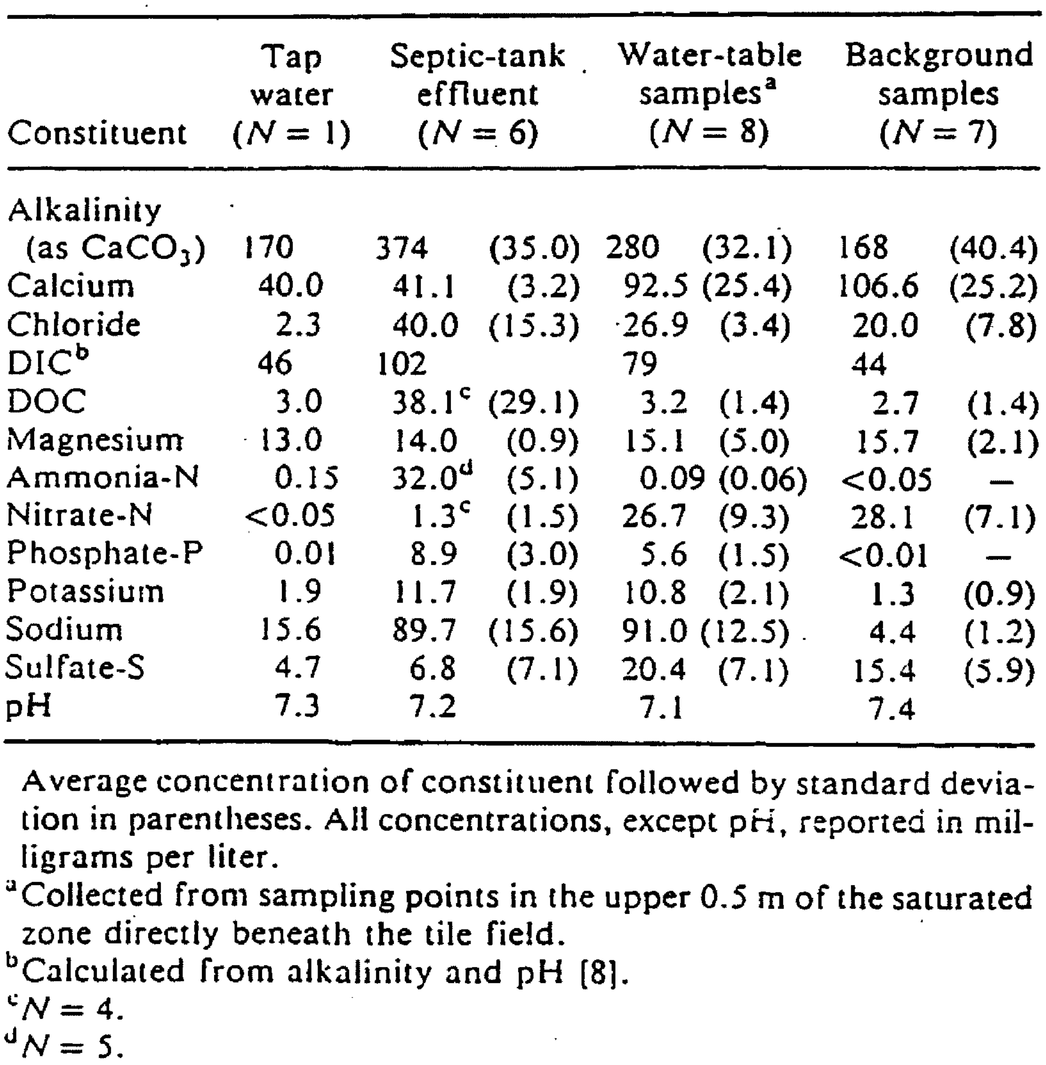
The fourth component of the disposal system is the physical transport of the effluent reaching the water table under the drainfield. Aquifer transportation of effluent containing inorganic, organic and biologic materials occurs when it enters the groundwater flow system (Figure 2.6). This process spreads the effluent into progressively larger volumes of aquifer. The result of the spreading is a lowering of contaminant concentrations by dilution. Though dilution is often the dominant process occurring in the groundwater system, adsorption, die off of bacteria and viruses and other chemical reactions can occur that reduce effluent impacts.

Groundwater immediately beneath drainfields is typically elevated in inorganic constituents (Table 2.2). Nitrate-N concentrations often exceed drinking water standards. Nitrates in sufficient concentrations have been shown to be hazardous to livestock and to also interfere with the ability of young children to metabolize oxygen, methemoglobinemia. Diarrhea is another possible side effect of high concentrations of nitrates. In a sandy aquifer, nitrate-N concentrations beneath a drainfield were 20 and 35 mg/l-N above background (Robertson et al., 1991). Plumes contained elevated concentrations of sodium and nitrate-N at distances exceeding 490 ft down-gradient of the drainfield



- o Advection (carried with ground water flow)
- o Dispersion (spreading in the direction of and at right angles to flow)
- o Biotransformation (plume decay and alteration)
- o Chemical Reactions (retardation of plume development)

Figure 2.6 : Development of a groundwater plume containing constituents of septic system effluent and processes operating within the groundwater system that effect the fate of these wastes.



Constituent	Tap water ($N = 1$)	Septic-tank effluent ($N = 6$)		Water-table samples[a] ($N = 8$)		Background samples ($N = 7$)	
Alkalinity (as $CaCO_3$)	170	374	(35.0)	280	(32.1)	168	(40.4)
Calcium	40.0	41.1	(3.2)	92.5	(25.4)	106.6	(25.2)
Chloride	2.3	40.0	(15.3)	26.9	(3.4)	20.0	(7.8)
DIC[b]	46	102		79		44	
DOC	3.0	38.1[c]	(29.1)	3.2	(1.4)	2.7	(1.4)
Magnesium	13.0	14.0	(0.9)	15.1	(5.0)	15.7	(2.1)
Ammonia-N	0.15	32.0[d]	(5.1)	0.09	(0.06)	<0.05	—
Nitrate-N	<0.05	1.3[c]	(1.5)	26.7	(9.3)	28.1	(7.1)
Phosphate-P	0.01	8.9	(3.0)	5.6	(1.5)	<0.01	—
Potassium	1.9	11.7	(1.9)	10.8	(2.1)	1.3	(0.9)
Sodium	15.6	89.7	(15.6)	91.0	(12.5)	4.4	(1.2)
Sulfate-S	4.7	6.8	(7.1)	20.4	(7.1)	15.4	(5.9)
pH	7.3	7.2		7.1		7.4	

Average concentration of constituent followed by standard deviation in parentheses. All concentrations, except pH, reported in milligrams per liter.

[a] Collected from sampling points in the upper 0.5 m of the saturated zone directly beneath the tile field.

[b] Calculated from alkalinity and pH [8].

[c] $N = 4$.

[d] $N = 5$.

Table 2.2 : Comparison of Various Waters Related to Cambridge Septic System (Wilhelm et al., 1994b).

(Robertson et al., 1991) (Figure 2.7). Research by Ver Hey (1987) in the Missoula Valley found elevated total nitrogen and chloride concentrations directly beneath two septic systems. As nitrate and chloride are negatively charged ions, they are not subject to adsorption to soil particles. These factors and their high solubility make these compounds extremely mobile in the subsurface.

If the percolating waste water is enriched in oxygen within the soil zone above the water table, oxidation reactions can continue in the groundwater system. However, little additional aerobic oxidation typically occurs as the rate of oxygen diffusion into the saturated system is slow. Therefore, the availability of oxygen in the groundwater system is limited (Wilhelm et al., 1994). Under these conditions, concentrations of nitrate usually decrease only by mechanical dispersion. However, in some groundwater settings anoxic conditions prevail and groundwater undergoes reduction and denitrification (Figure 2.3). This requires an electron donor, often labile organic carbon and microorganisms. Nitrogen, carbon dioxide and water are produced as the end products of this process (Wilhelm et al., 1994). De-nitrification is reported to be observed in only a few settings by Wilhelm et al. (1994), commonly in soil containing organic matter. In addition to mechanical effluent spreading, consumption of nitrate in both aerobic and oxygen depleted groundwater system may occur by the process of nitrate assimilation. In this process, bacteria in the aquifer sediments utilize nitrate as a source of nitrogen. The nitrogen is removed from the system and incorporated in the cell mass. Table 2.3 summarizes the possible mechanisms of nitrate mass loss within a groundwater system.

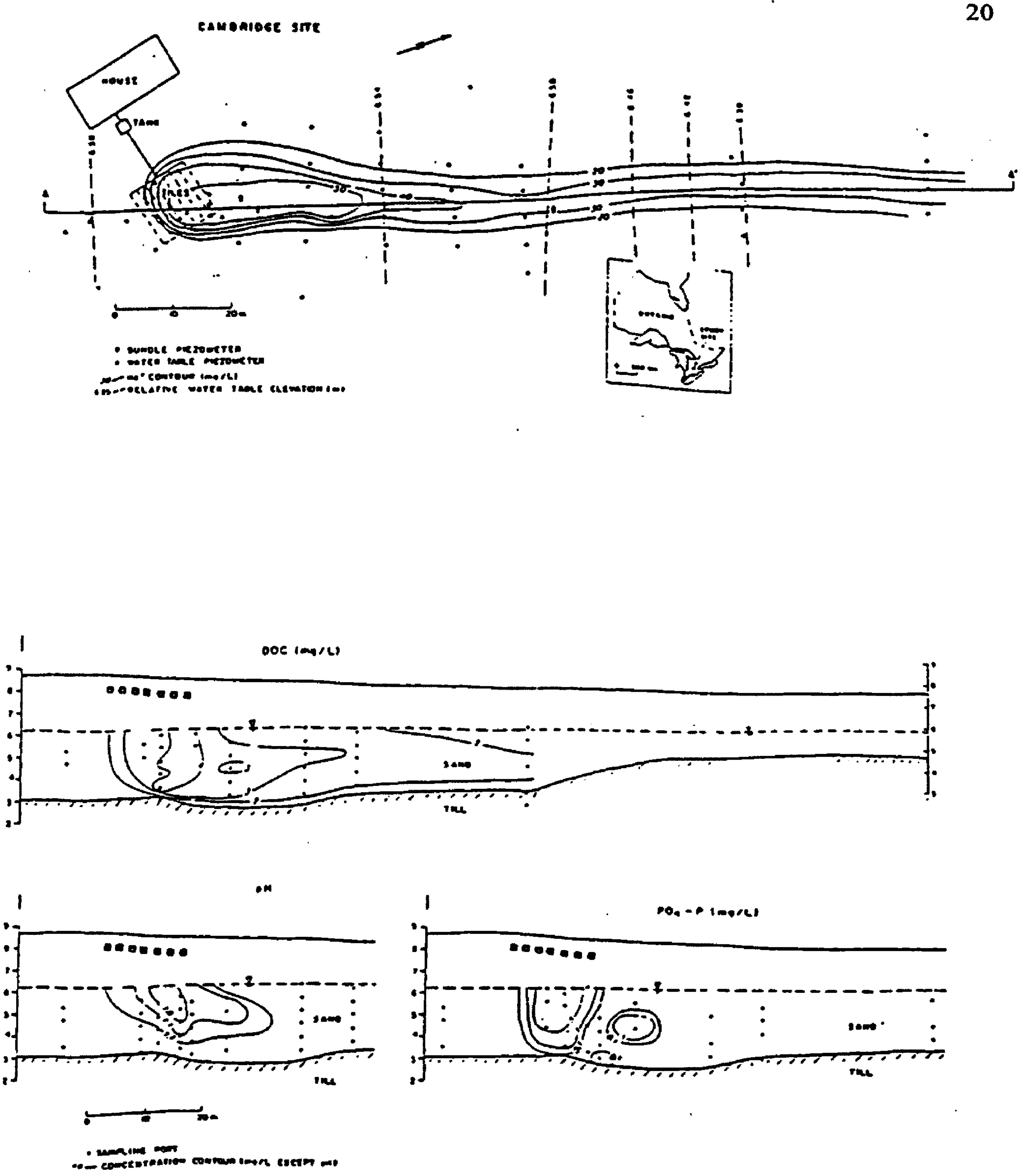
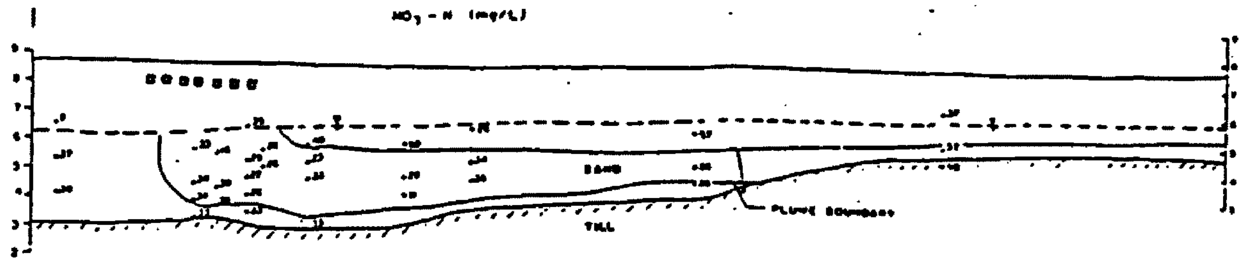
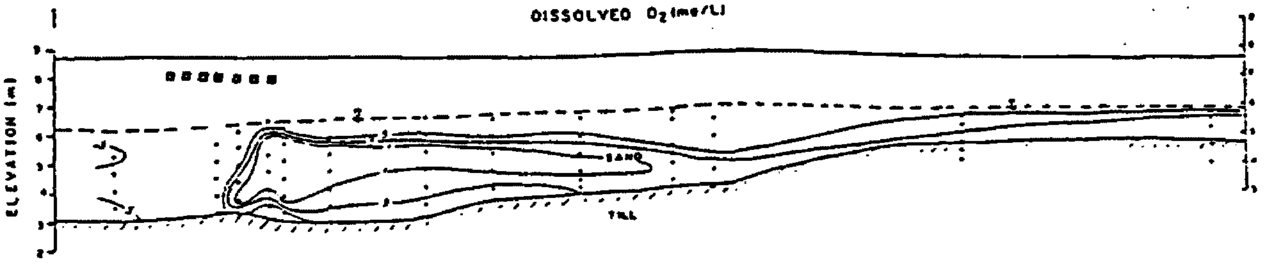


Figure 2.7 : Map view of vertically averaged sodium concentrations and vertical A-A' cross sections of water quality data for other constituents found in groundwater impacted by a drainfield serving a household of four. The aquifer is composed of a fine to medium sand with an average hydraulic conductivity of 85 ft/d (Robertson et al., 1991).


NO3 - N (mg/L)
SAND
TILL
PLUME BOUNDARY


DISSOLVED O2 (mg/L)
ELEVATION (m)
SAND
TILL

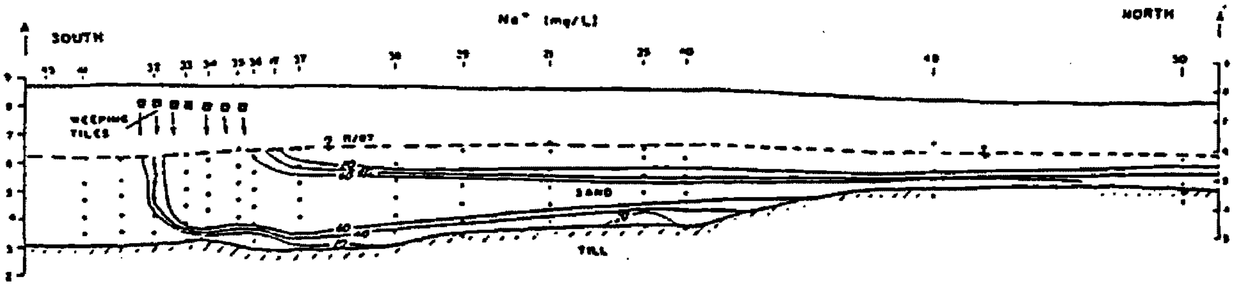

A
SOUTH
Na+ (mg/L)
NORTH
A'
WEEPING TILES
SAND
TILL

Table 2.3 Mechanisms of Nitrate-N Mass Loss within the Groundwater

Method	**Process**	**Method to Test for Occurrence**	**Required Environmental Factors**	**Reference**
Assimilatory Reduction	Nitrogen from the nitrate is incorporated into the biomass of bacteria.	An increase of bacterial biomass would be expected within the septic plume. Loss of nitrate.	Nitrate assimilatory bacteria, anoxic or oxic conditions, nitrogen source.	Robertson and Kuenen, 1984.
Dissimilatory Reduction	Nitrate is converted by bacteria, through respiration, into ammonium. Ammonium can be converted back to nitrate, in oxygenated environments	Presence of ammonium, loss of nitrate, and dissimilatory bacteria.	Nitrogen source, bacteria, anoxic or oxic conditions.	Robertson and Kuenen, 1984.
Denitrification	Nitrate is reduced through a sequence of nitrogen oxides to nitrogen gas.	Loss of nitrate mass.	Nitrate, oxic or anoxic conditions, organic carbon or reduced inorganic compounds.	Tiedje et al., 1982.
Plant Uptake	Plants consuming nitrate as a nutrient source.	Relative abundance of plant life near known source of nitrogen. Loss of nitrate mass.	Plants with a root zone capable of nitrogen uptake.	Tiedje et al., 1982.

Groundwater directly below the drainfield can contain fecal coliform bacteria, salmonellae bacteria, and viruses. The bacteria *E. coli* is easily detected and is used as an indicator of contamination by sewage waste.

CHAPTER 3

SITE CONDITIONS

In the following paragraphs, I will discuss the chloride and nitrate-N plumes originating from two septic systems in Missoula County as investigated by Woessner et al. (1995). The sites (figure 3.1) include one system in the Missoula Valley (South site) and another near Frenchtown (Quarter Mile Road site). The individual site monitoring network, source character and loading rates, site hydrogeology, septic tank characteristics, and the distribution of the chloride and nitrate-N septic plumes are discussed below.

South Site

The site is located south of Sundown Road in the southwest corner of the Missoula Valley near McCauley Butte (figure 3.2). It consists of two dwelling units connected to a conventional septic system. The site is bordered to the east, north, and south by very low housing density residential land (0.1 homes per acre), and to the west by approximately 1.1 million square feet of pasture land which extends west to the Bitterroot River. It is located on a fluvial terrace above the pasture land to the west. There are presently four adults and two school aged children as residents.

The septic system consists of a 1000-gallon concrete tank with three 66-foot long laterals, that are orientated perpendicular to groundwater flow. Video inspection of the outlet main from the tank shows that the openings of the first two laterals are essentially

Figure 3.1: Site location map

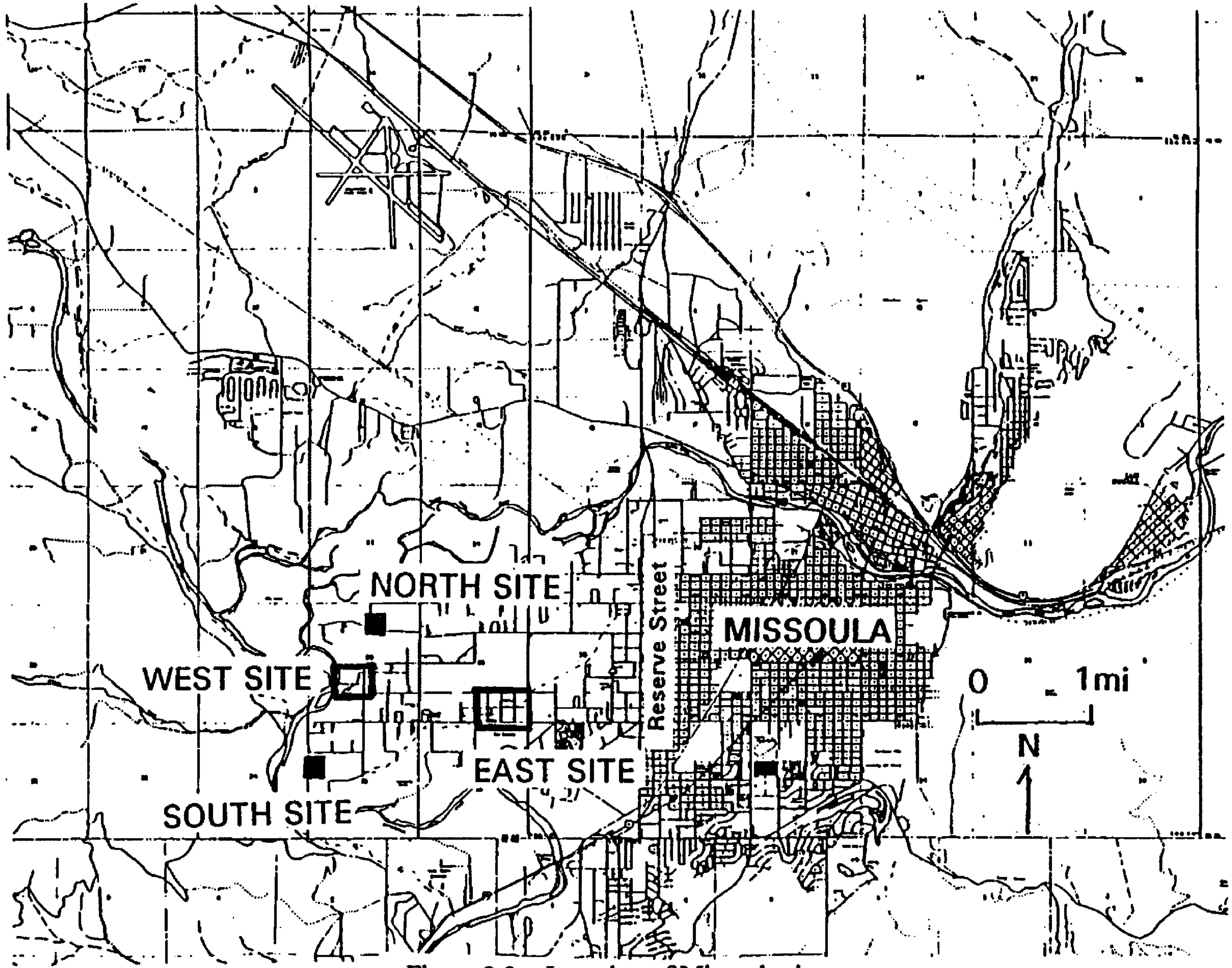


Figure 3.2: Location of Missoula sites

plugged, directing the discharge to the eastern most lateral. Due to the right angle connection, internal video inspection of the laterals was not possible.

The geologic setting at the South Site consists of a two foot soil zone overlying coarse sand, gravel, and cobbles. Clast composition is dominated by granitic material. Though cores were not collected at this site, some silty, organic-rich soil was observed at the surface. Evidence of silty clay and saturated clay material mixed with the gravel were also observed. Driller's reports for local domestic wells show mixed sand, gravel, and some sandy-clay at depths greater than 25 feet from the surface. Bedrock is estimated to be found 116 ft. below the surface (Miller, 1990). The aquifer here is unconfined (Woessner, 1988). The geology and hydrogeology of the Missoula Valley is described in greater detail in Appendix A.

An array of multi-level monitoring wells and piezometers was installed by Woessner et al. (1996) to characterize the groundwater flow and the septic plume concentration configuration (figure 3.3). The water table is approximately five to eight ft. below the ground surface in the late spring and summer, and 10-13 ft. below ground surface in the winter (Woessner et al., 1996).

Groundwater flow is generally from the east to west across the site (figure 3.4); the hydraulic gradient is approximately 0.003. Miller (1990) assigned a hydraulic conductivity of 1000 feet per day (7480 gpd/ft^2) to the sediments in the western portion of the valley. Woessner (1988) reports an aquifer specific yield and porosity to be 0.12 and 0.20, respectively. Woessner et al. (1996) estimated a groundwater velocity of nine feet per day.

West Missoula Study Area
South Site
Monitoring Network

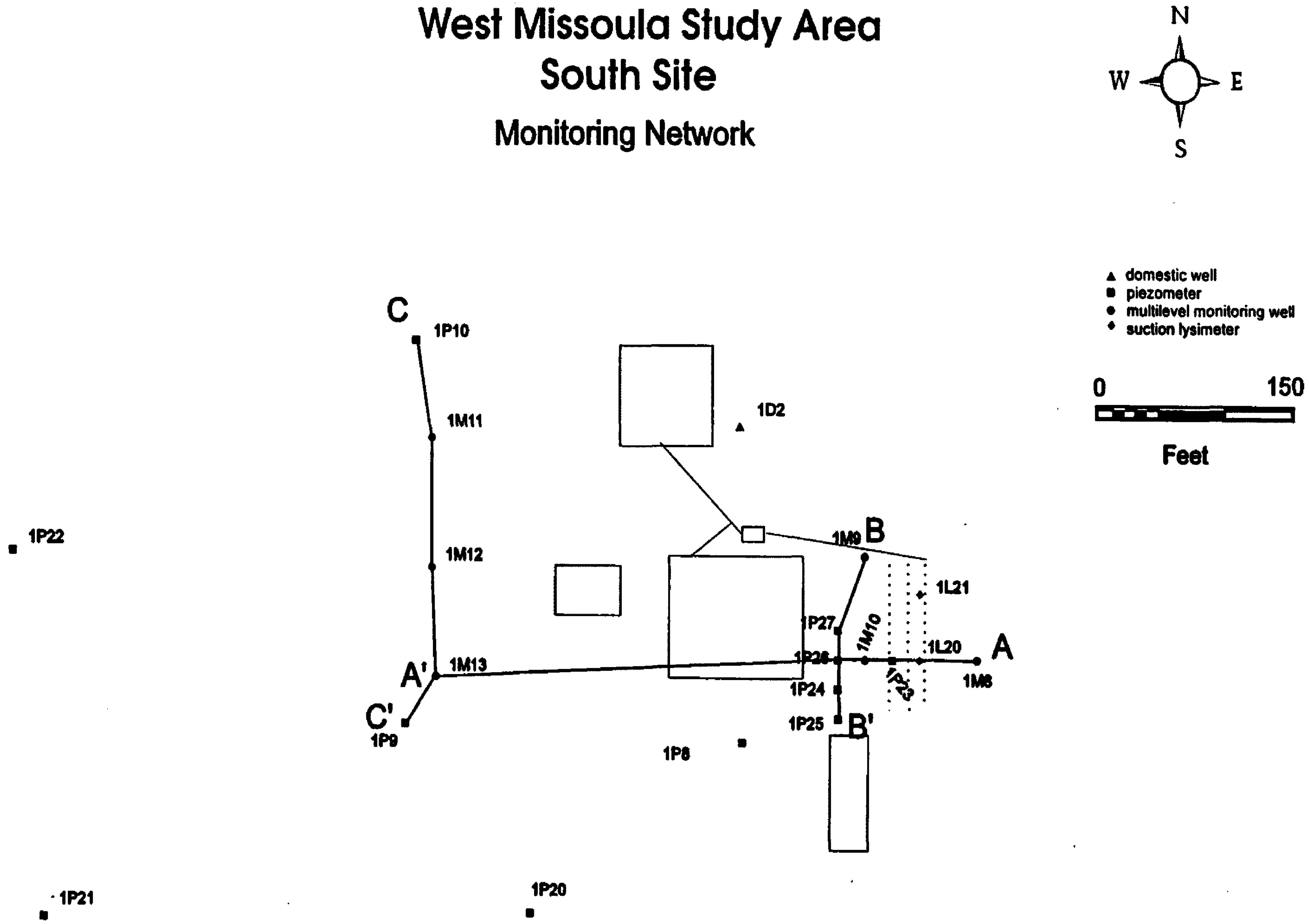


Figure 3.3

West Missoula Study Area
South Site

Potentiometric Surface June 1994
Elevation + 3100 ft. above sea level

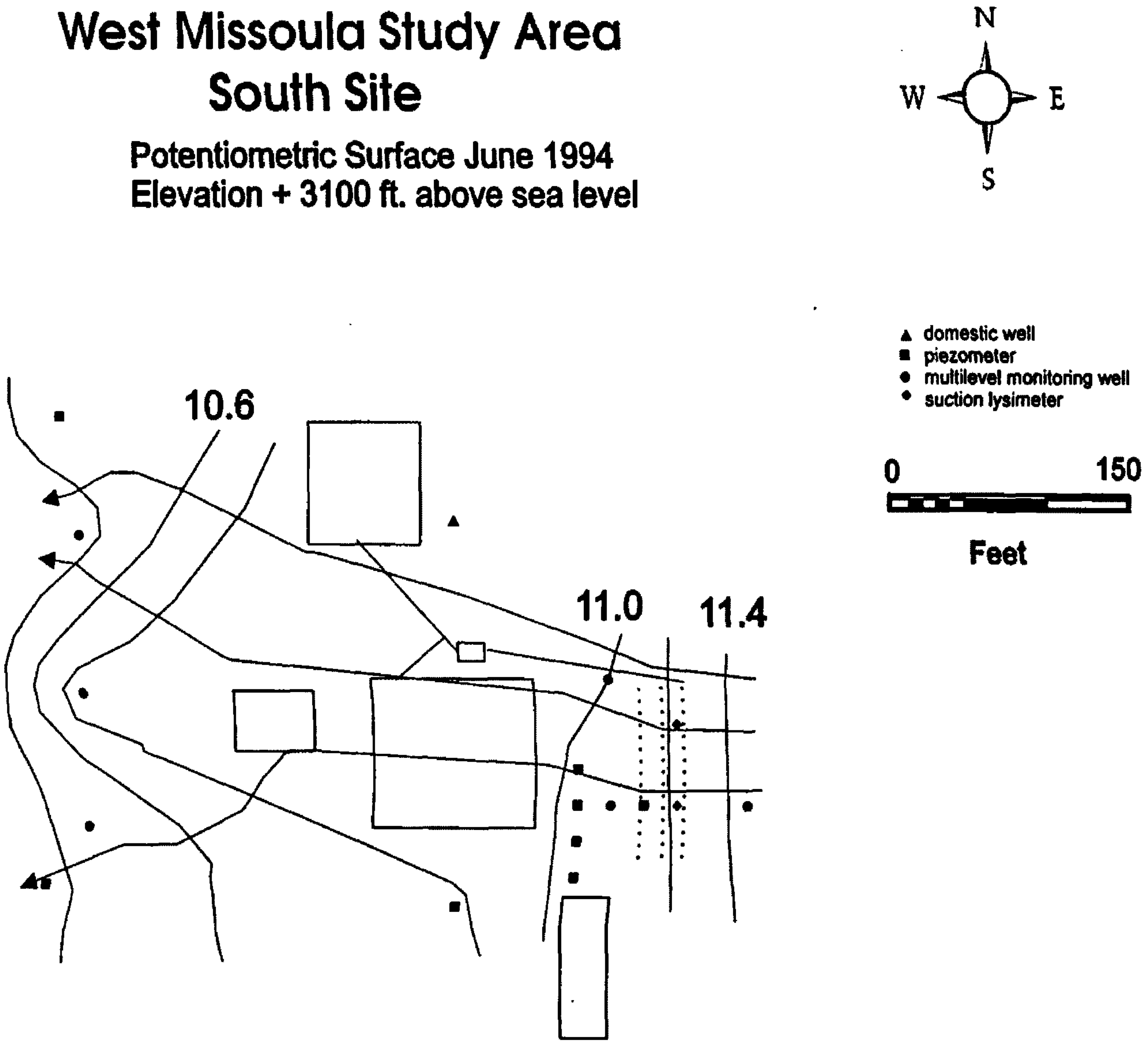


Figure 3.4

The aerial and cross-sectional nitrate-N and chloride concentration distribution, originating from the South site, was interpolated from water quality data derived from the monitoring well network (Woessner et al., 1996). Representative plume constituent concentrations were obtained by averaging water quality data, found within 7.5 feet below the water table (the identified vertical mixing zone at the site), from multi-level sampling points. The mixing zone, as illustrated by figures 3.5 and 3.6, is recognized as the interval over which nitrate-N and chloride concentrations decrease to background levels (Woessner et al., 1996). Background groundwater nitrate and chloride concentrations are assumed to be approximately 0.8 mg/l and 3.2 mg/l, respectively, which was based on groundwater quality measured below the impacted groundwater at monitoring well 1M81.

June, 1994, was selected as the representative sampling period for the following discussion of chemical distribution. The source data is given in Woessner et al. (1996).

The single-field chloride plume within the upper 7.5 feet of groundwater is interpreted to be divided into two lobes within approximately 120 feet downgradient from the source (figure 3.7) (Woessner et al., 1996). The two lobes merged into one plume after 120 feet. Concentrations as high as 9 mg/l were measured approximately 30 ft. downgradient. The monitoring wells 1M11 and 1M13, approximately 170 ft. downgradient, had an average value of six to seven mg/l and five to six mg/l above background (a.b.), respectively. An average value of 3-4 mg/l a.b. was measured within the upper 7.5 feet of groundwater at about 40 feet upgradient from the effluent source (well 1M8). This well is probably influenced by an up-gradient source.

Cross-Section of Phosphate-P, Chloride, and Nitrate-N Concentrations for June 1994 Along A-A' South Site Missoula, MT

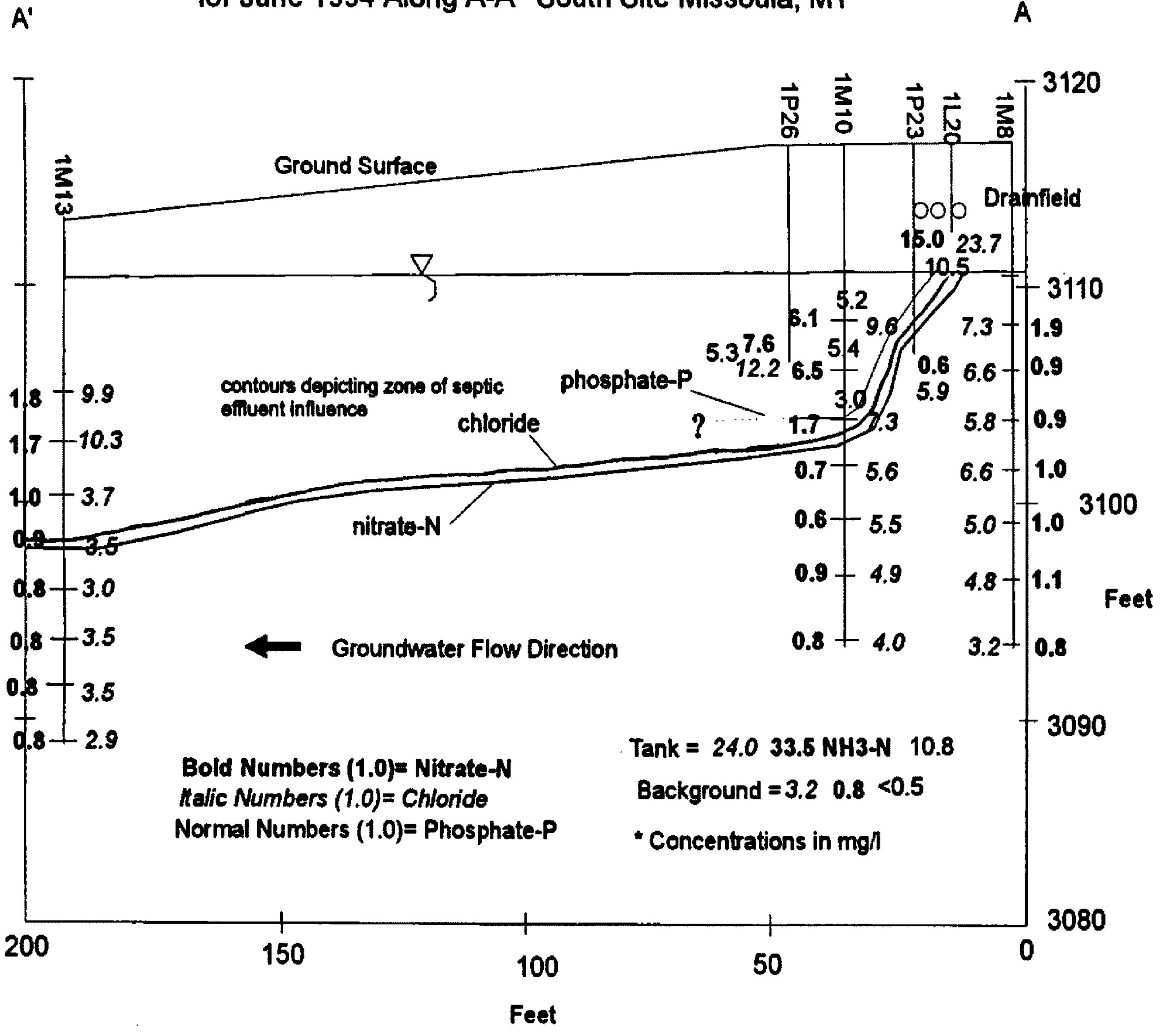
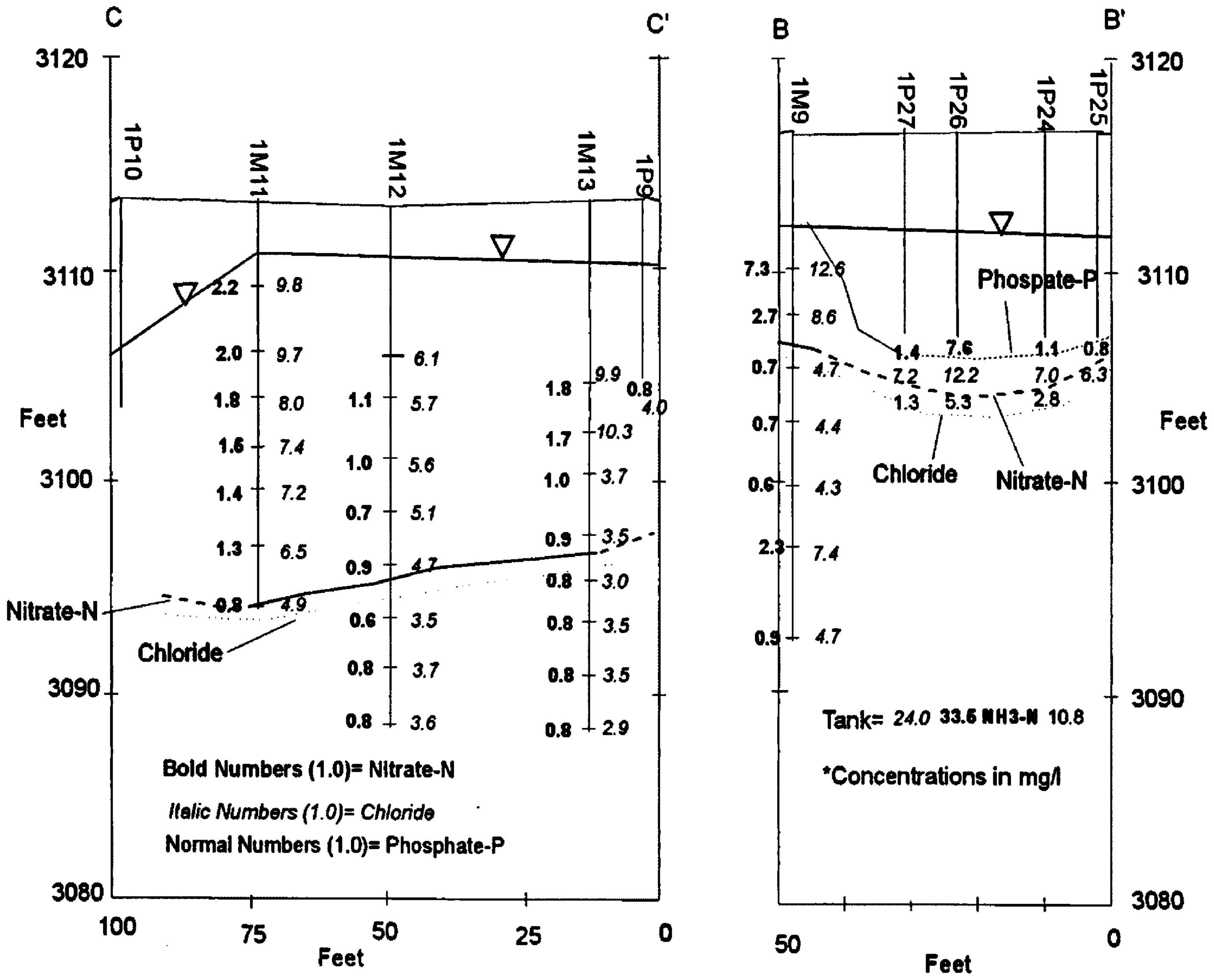


Figure 3.5



Cross-Section of Phosphate-P, Chloride, and Nitrate-N Concentrations for June 1994 Along B-B' and C-C' South Site Missoula, MT

Bold Numbers (1.0)= Nitrate-N

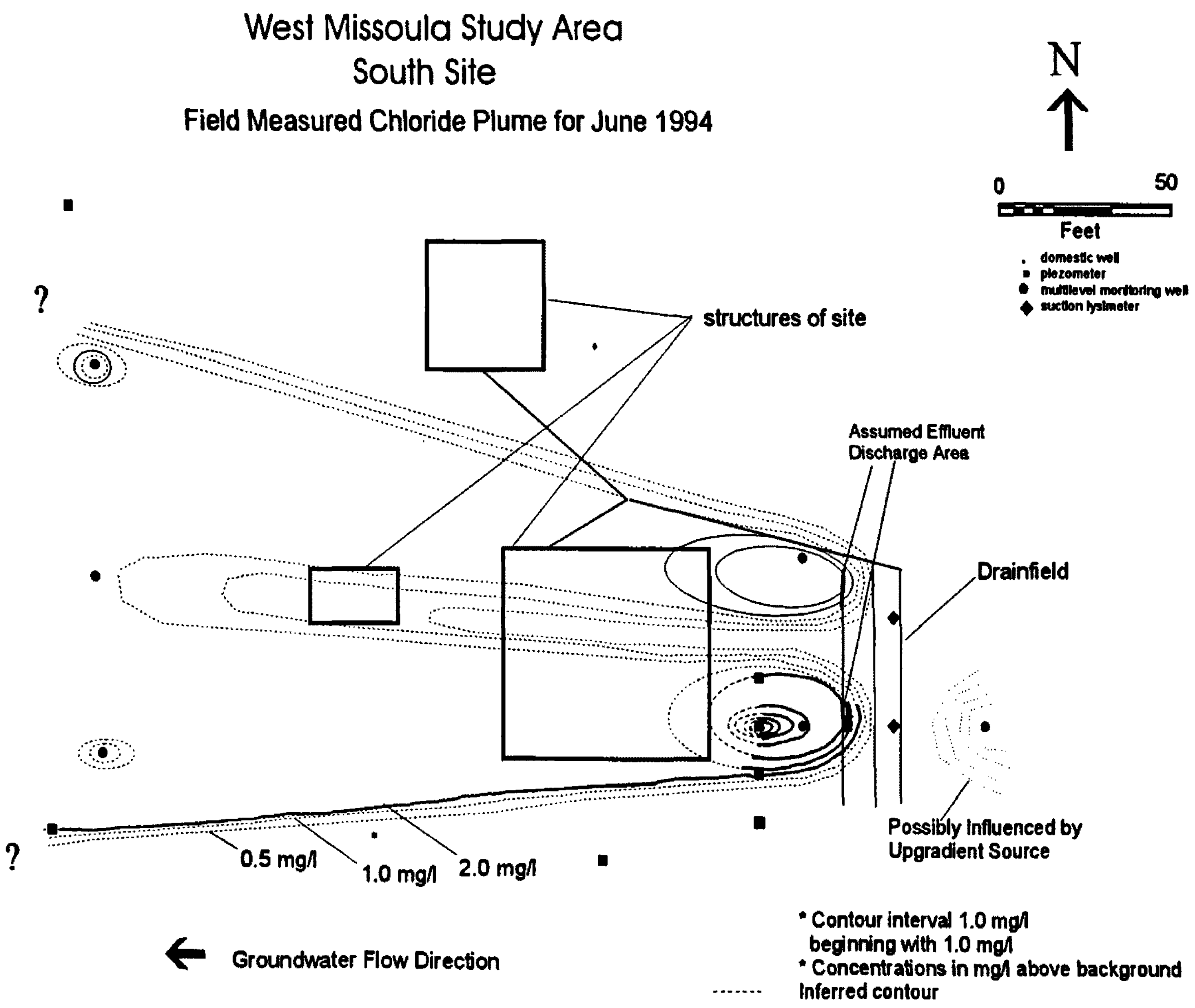
Italic Numbers (1.0)= Chloride

Normal Numbers (1.0)= Phosphate-P

Tank= *24.0* **33.6 NH3-N** 10.8

*Concentrations in mg/l

Figure 3.6


West Missoula Study Area
South Site
Field Measured Chloride Plume for June 1994

* Contour interval 1.0 mg/l beginning with 1.0 mg/l
* Concentrations in mg/l above background
------- Inferred contour

Figure 3.7

The nitrate-N concentration configuration is similar in shape to the chloride configuration (figure 3.8). Nitrate-N concentrations created a two lobed shape plume within about 150 feet downgradient from the effluent source. The two lobes merged into one plume after 150 feet. Wells 1M11 and 1M13 had average concentrations of 0.5-1 mg/l and 1-1.5 mg/l a.b. within the mixing zone. An average value of 0.2-0.5 mg/l a.b. was measured in 1M8.

The lateral extent (N-S) of the plumes were assumed to be from 60 to 150 feet within the monitoring network. The longitudinal extent of the plume is unknown outside the monitoring network. The monitoring wells 1M11 and 1M13, which form the downgradient edge of the monitoring network, exceeded background concentrations.

Frenchtown-Quarter Mile Road Site

The Quarter Mile Road site, in the Frenchtown area, is located on Quarter Mile Road off Roman Creek Road about a mile north of Frenchtown Pond (figure 3.9). The 1000 gallon tank and 300 ft of drainline making up the household septic system were used by two to four residents during the study (Woessner et al., 1996). The drainfield is made up of three parallel 100 ft. sections of perforated PVC pipe lying seven feet apart which are perpendicular to the main discharge line. The drainfield lies two feet below ground surface. Inspection of the system using a remote video camera revealed that only the northern-most 100 feet drainline of the drainfield was actively receiving and discharging septic tank wastes. The actual length of drainline actively discharging wastes could not be determined.

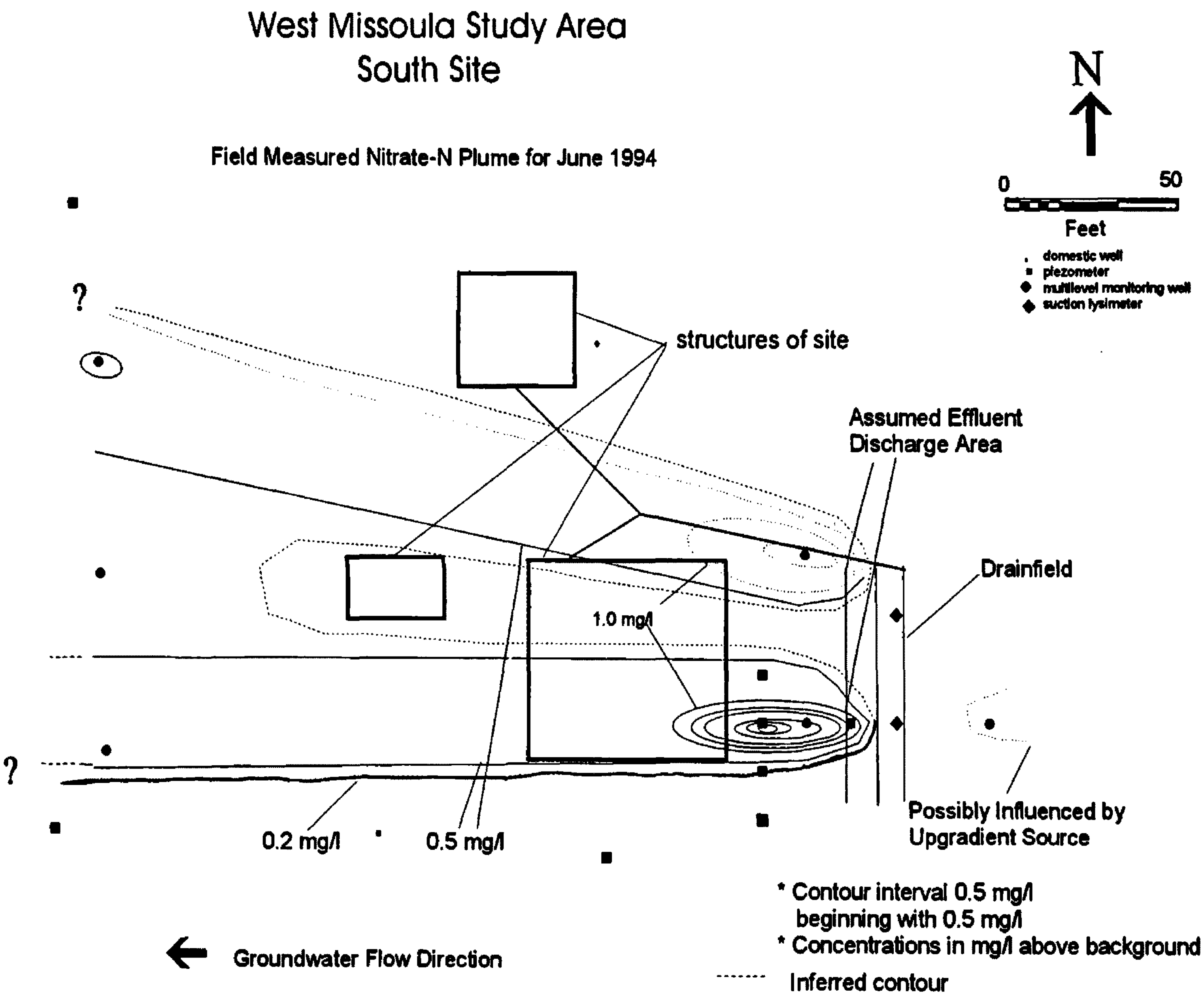

West Missoula Study Area
South Site
Field Measured Nitrate-N Plume for June 1994
N
0
50
Feet
domestic well
piezometer
multilevel monitoring well
suction lysimeter
?
structures of site
Assumed Effluent
Discharge Area
Drainfield
1.0 mg/l
?
0.2 mg/l
0.5 mg/l
Possibly Influenced by
Upgradient Source
* Contour interval 0.5 mg/l
beginning with 0.5 mg/l
* Concentrations in mg/l above background
Groundwater Flow Direction
Inferred contour

Figure 3.8

LOCATION OF FRENCHTOWN STUDY SITES

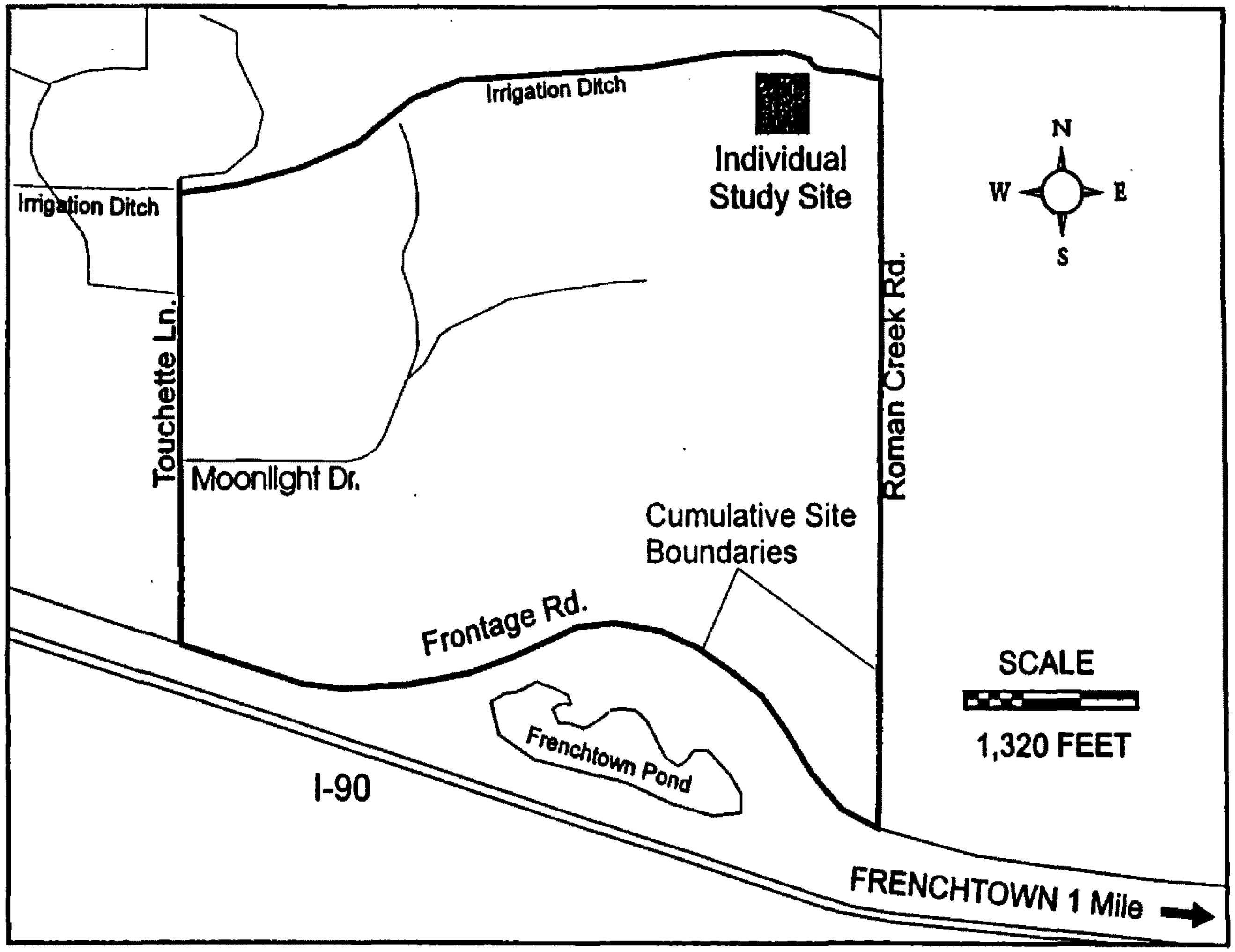


Figure 3.9

The land surface slopes gently to the south and west in the site. In general, below two feet of soil is approximately ten feet of interbedded clay, silty sand, and gravel characteristic of a fining upwards sequence of fluvial deposits. These sequences dominate the geology within the area and extend to 25 to 60 feet below the surface. A 100 to 150 ft thick layer of finer grain sediments underlies the higher energy fluvial sequence. These sediments consist of silty sand with clay and gravel interbeds. Below this lies 30 to 50 feet of gravel with sand and some clay. This sequence is underlain by what are believed to be fine-grained Renova Formation Tertiary sediments. A more detailed description of the area's geology and hydrogeology is included in Appendix A.

The study area has two aquifers, both sand and gravel with varying amounts of clay. The upper aquifer is unconfined and is found between 20 to 50 feet below land surface. The lower aquifer is confined by the sequence of fine-grained sediments. The monitoring wells and piezometers sample water within the upper aquifer. The domestic well at this site is finished in this aquifer.

This site was instrumented with hand-augered and power-augered wells to determine the direction of groundwater flow and the distribution of septic system wastes (figure 3.10) (Woessner et al., 1996). A total of 12 piezometers and 14 multi-level monitoring wells were constructed and inserted.

The water table at the study site is 10 to 14 feet below land surface and groundwater flows from north to south with a hydraulic gradient of approximately 0.003-0.004 (figure 3.11). The water table varied about five to six feet during the year with the lowest elevation in March and the highest elevations during the summer and early fall. A

FRENCHTOWN SITE INSTRUMENTATION

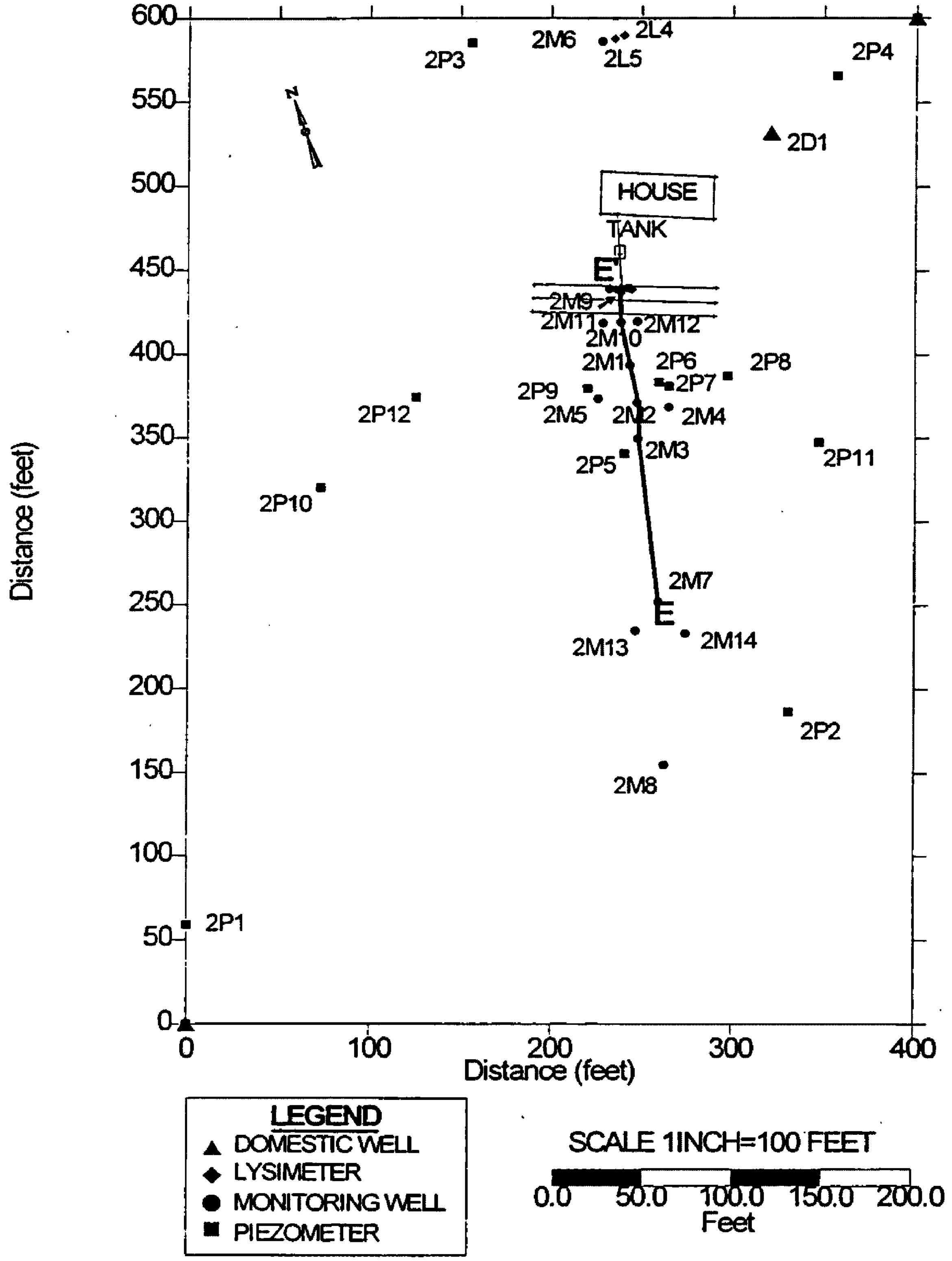


Figure 3.10

Potentiometric Surface for 6/94 at the Frenchtown Site

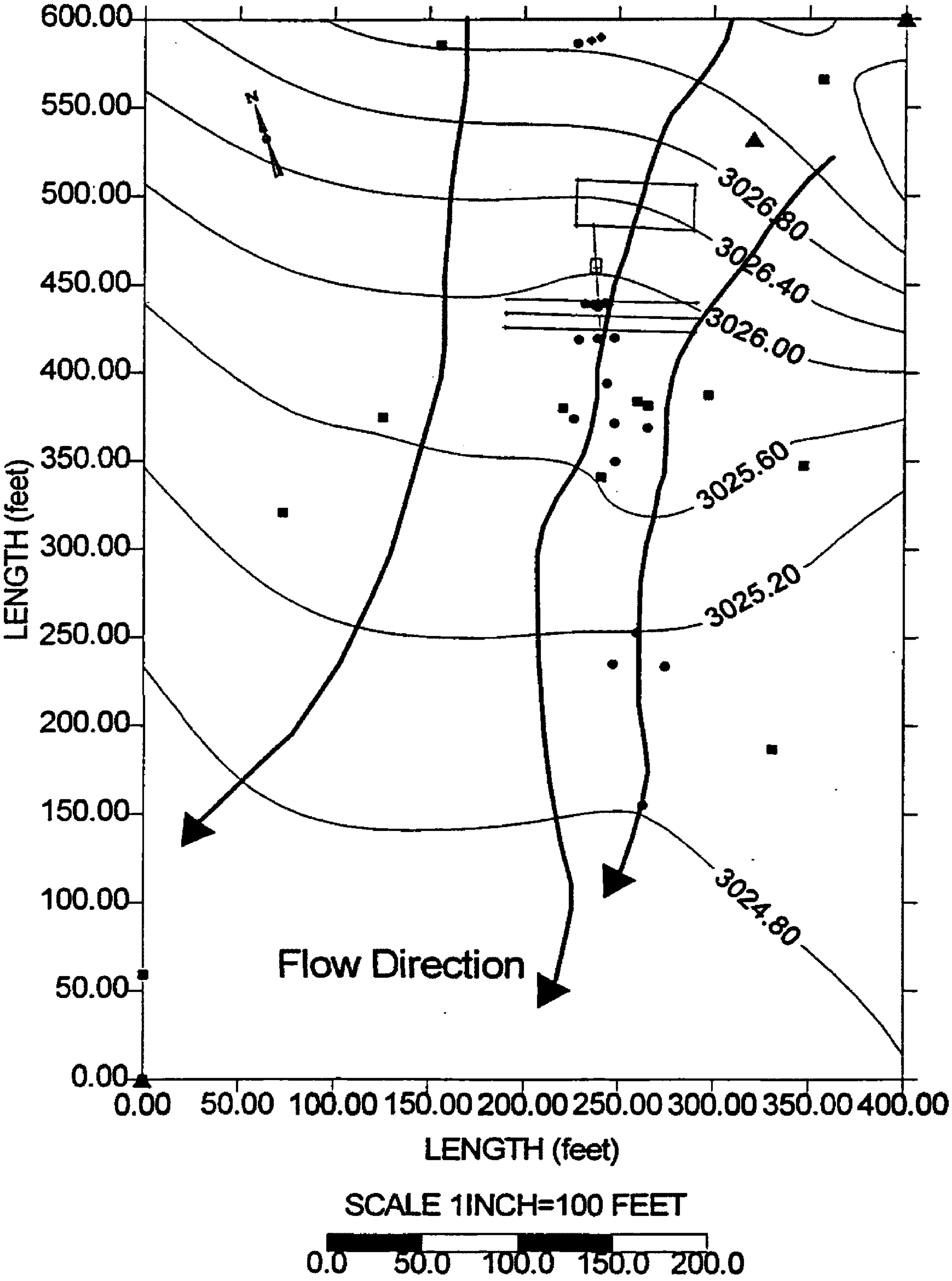


Figure 3.11

hydraulic conductivity of 350 feet per day and a groundwater velocity of 7.5 ft/d was estimated from a bromide tracer test (Woessner et al., 1996). Woessner et al. (1996) report a specific yield of 0.1 and a porosity of 0.25 for the study area.

The aerial extent of the groundwater nitrate-N and chloride plume for the Quarter Mile Road (Frenchtown) site for June, 1994, is shown in figures 3.12 and 3.13. Average chloride and nitrate-N concentrations from June, 1994, in wells penetrating the eight foot thick mixing zone were used to represent general plume symmetry (Woessner et al., 1996) (figure 3.14). Background was assumed to be approximately 0.1 mg/l for nitrate-N and 2.0 mg/l for chloride, as measured in 2D1 and 2M6. The average plume values were derived from the sampling wells 2M6, 2M9, 2M11, 2M10, 2M5, 2M2, 2M4, 2M3, and 2M7 (figure 3.10).

The highest chloride and nitrate-N concentrations were measured in wells 2M9, 2M11, and 2M10, approximately 5-30 feet downgradient from the assumed drainline discharge area. Field-measured chemical concentrations decline rapidly away from this relatively enriched zone. Wells 2M1, 2M2, 2M3, 2M4, and 2M5 (figure 3.10) had concentrations close to background for both nitrate-N and chloride. Interestingly, the wells further downgradient (2M7, 2M13, and 2M14) had slightly higher concentrations than wells in the intermediate downgradient zone. The plume width is approximately 20 to 30 feet within the monitoring network. The length and width of the plume is unknown outside the monitoring network.

Field Measured Chloride Plume for June 1994
Frenchtown Site, Frenchtown, MT

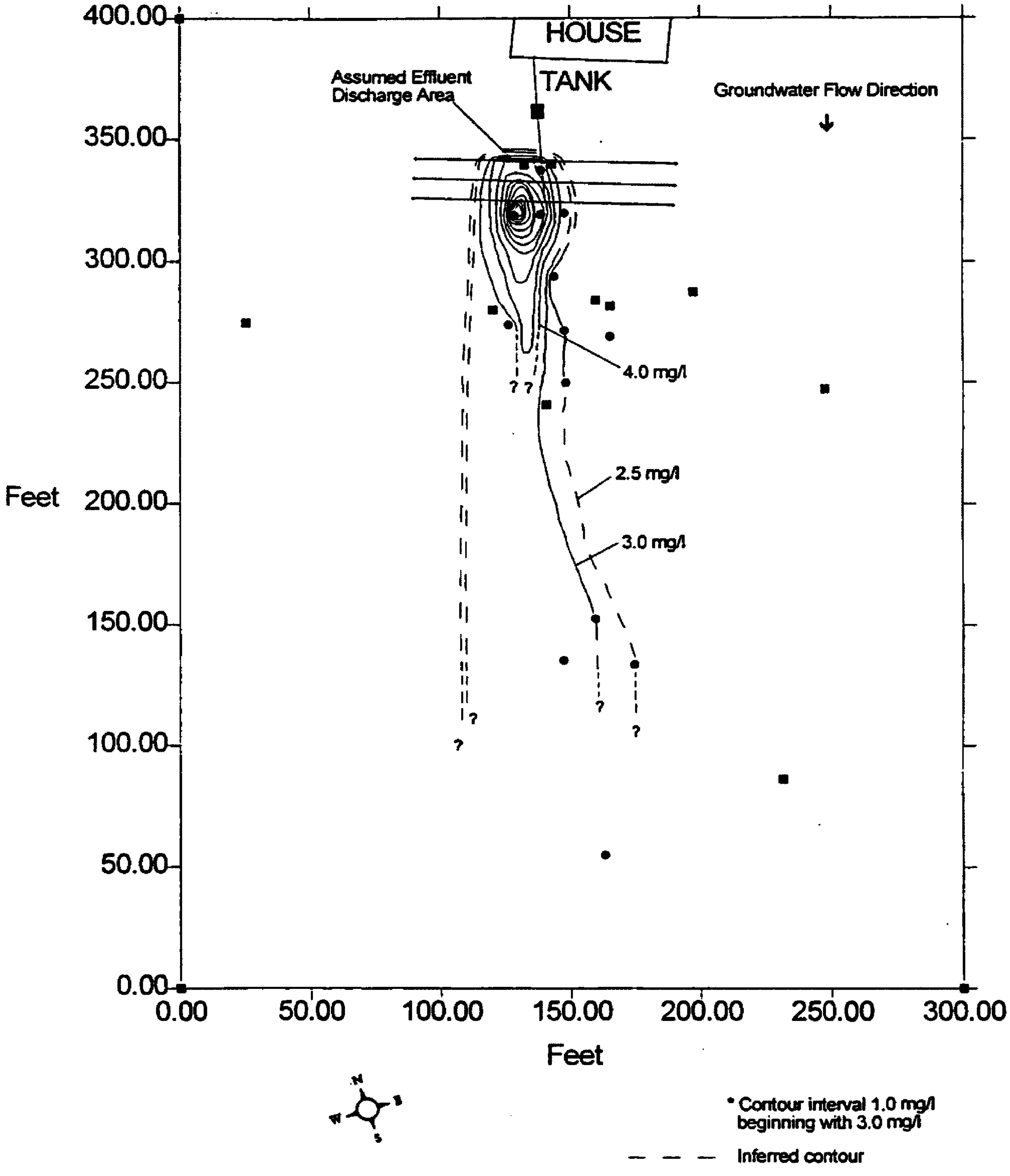


Figure 3.12

Field Measured Nitrate-N Plume for June 1994
Frenchtown Site Frenchtown, MT

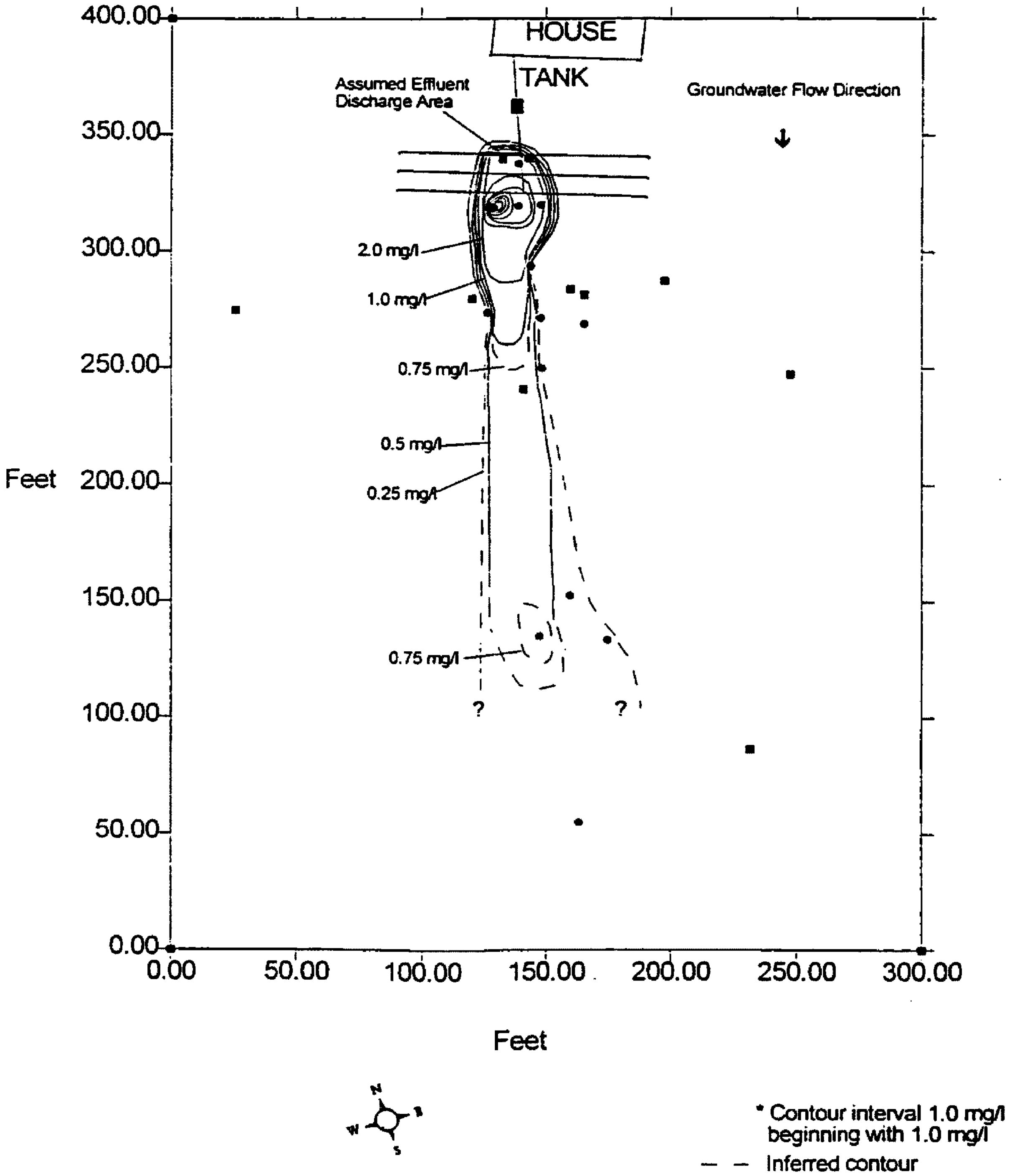


Figure 3.13

Cross-Section of Chloride and Nitrate-N Concentrations for June 1994 along E-E' at Frenchtown Site

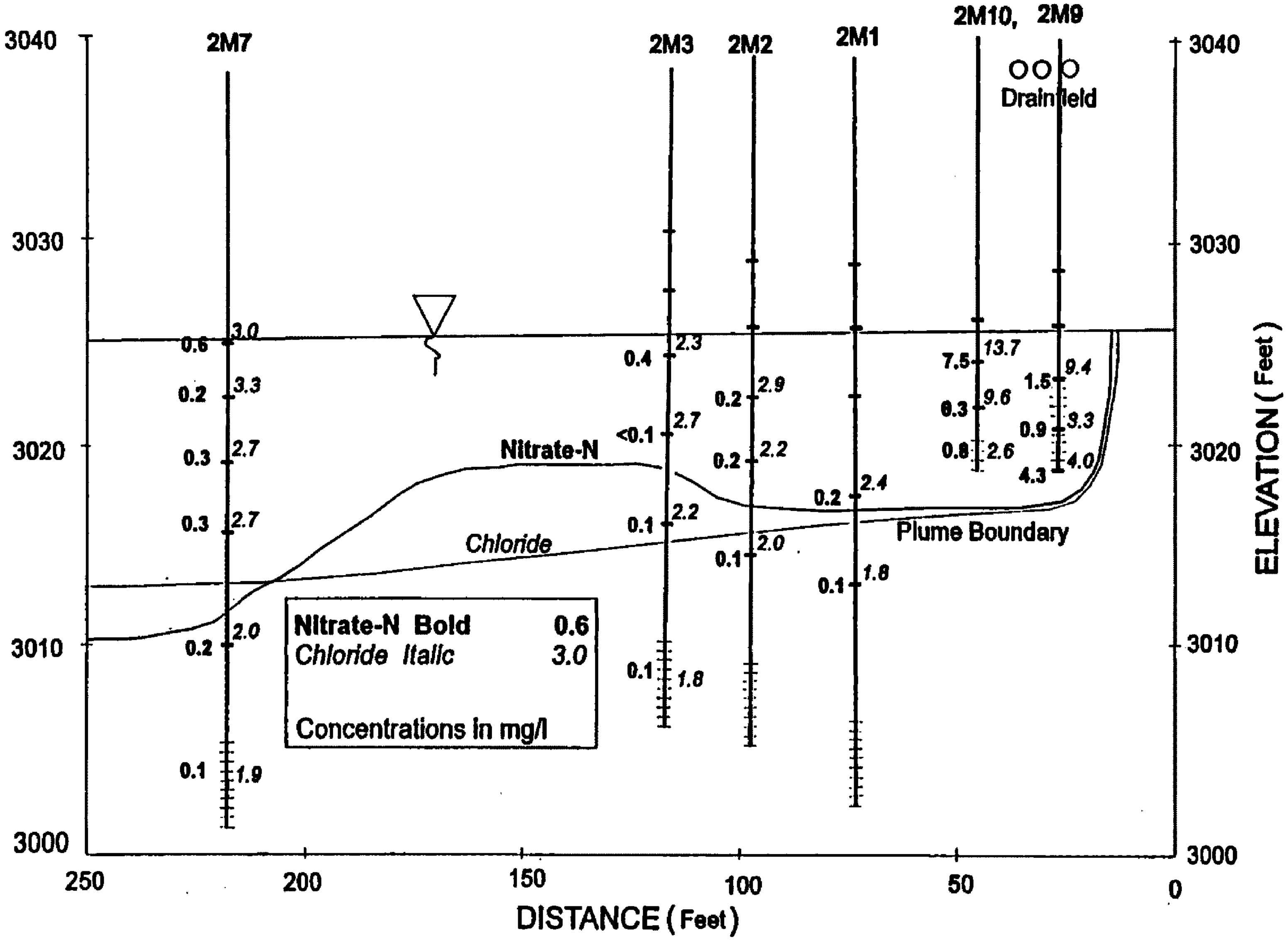


Figure 3.14

CHAPTER 4

METHODS

A solute transport simulation was used to model the nitrate-N and chloride field plumes reported by Woessner et al. (1995) at the South and Frenchtown sites. The following section describes the solute transport model used to represent the septic plumes and the methodology used to parameterize the model. The model was then used to predict the cumulative effects of multiple septic plumes at different subdivision densities.

Model Used for Simulation

The computer-driven, two-dimensional, analytical, particle-transport model, RANDWALK (Prickett, 1994), was chosen to simulate the plumes. The random-walk process involves representing the mass of a single constituent by many individual particles, each representing a portion of the total source mass. Particles are transported by advection and then dispersed longitudinally and transversely using a statistical function. Groundwater concentrations are derived by placing a modeler-chosen grid over the aquifer and counting the number of particles in each grid block, determining the volume of water in each block, and calculating the concentration of the constituent in the cell (Prickett, 1994). The model does not allow vertical mixing. A predicted chemical concentration is an average value within the entire simulated aquifer.

Model Input Parameters

The modeler needs to have a conceptual understanding of the hydrogeologic processes, and a number of hydrogeologic and physical parameters to use RANDWALK. The more confident the hydrogeologic estimation, the more valid the model prediction. For this reason, an extensive literature search was undertaken to determine representative model input parameters. Conceptualization and hydrogeologic parameters were based on the work by Woessner et al. (1996) and an extensive literature search.

A trial and error approach was used to calibrate single plume models to field-monitored chloride and nitrate-N plumes at the South and Frenchtown research sites. Simulated concentrations were compared to the field data, at sampled locations, and the degree of similarity was used to judge acceptability. Because of uncertainties as a result of the limited monitoring network and aquifer heterogeneities, a simulated plume was considered calibrated when the simulated concentration represented approximately ±50% of the field measured concentration. A second calibration criteria was qualitatively simulating the shape and constituent distribution of the field measured plume. Plume lengths of 170 feet at the South site and 200 feet at the Frenchtown site were assessed for acceptable simulations.

Selection and Instrumentation of Cumulative-Effect Sites

The cumulative sites were selected according to the following criteria:

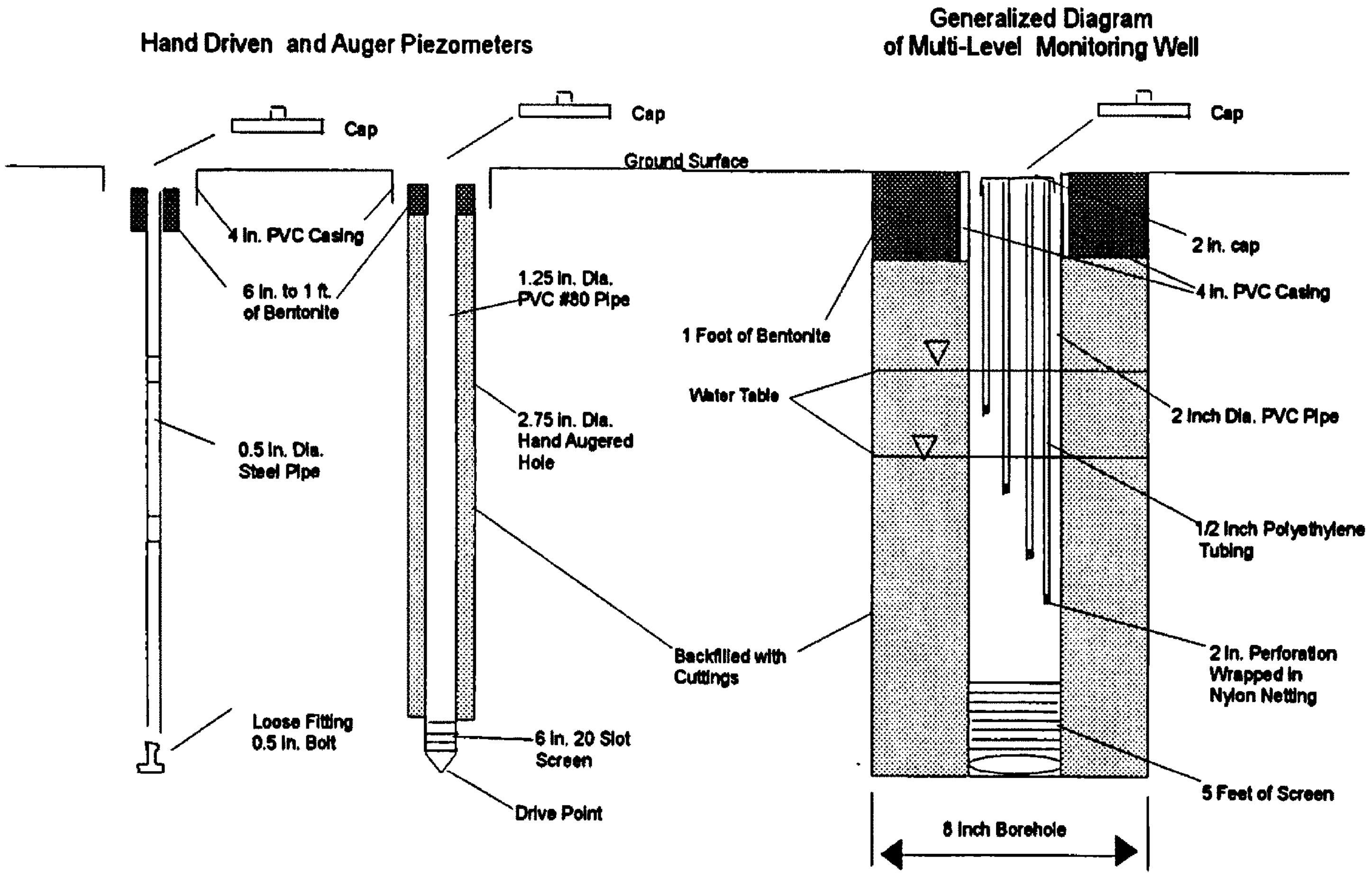
1. Homes which dispose of household waste into a conventional septic system,

2. Homes that have individual domestic wells,
3. Established homes (preferably 3-10 years old),
4. A housing density representative of other adjacent neighborhoods,
5. A geologic environment representative of the adjacent neighborhoods,
6. A relatively shallow water table (< 30 ft),
7. A number of cooperating landowners, and
8. Locations to complete up and down-groundwater gradient monitoring wells.

A site was considered for study if all site conditions were met.

Monitoring networks for the cumulative-effect sites consisted of pre-existing domestic wells and installed multi-level monitoring wells and piezometers (figure 4.1). The monitoring networks were used to determine the groundwater flow system and general water quality. The domestic wells were used to determine the groundwater flow system. The multi-level monitoring wells were installed up and down-groundwater gradient to each cumulative-effect site. If the installation of multi-level monitoring wells were not possible, then piezometers were installed. Water level and water quality were conducted within the sites using methods described by Woessner et al. (1996).

Groundwater Monitoring and Sampling Devices



Hand Driven and Auger Piezometers

Generalized Diagram of Multi-Level Monitoring Well

* Drawing Not to Scale

Figure 4.1

Simulation of Cumulative Effects

The simulated individual nitrate-N and chloride plumes were used to simulate the impacts of individual subdivision septic systems. The cumulative-effect simulations were evaluated by comparing simulated chemical distribution to field measured groundwater chemistry data at the water table.

CHAPTER 5

RESULTS

Results of this study are discussed in the following sections starting with the model input parameters. Results of the simulation of the single plumes measured by Woessner et al. (1995) are examined. This is followed by a description of conditions at the cumulative-effect sites, and the section concludes with the presentation of the cumulative impact simulations.

Model Input Parameters

Final calibrated model input parameters are summarized in Table 5.1.

Table 5.1 Summary of Variables used in RANDWALK Simulations

Parameter	Missoula South Site	Frenchtown
Hydraulic Conductivity	750 ft/day	350 ft/day
Aquifer Thickness	7.5 ft	8 ft
Hydraulic Gradient	0.003	0.004
Groundwater Velocity	9 ft/day	7 ft/day

Parameter	**Missoula South Site**	**Frenchtown**
Porosity	0.25	0.2
Septic Loading Rate	1135 liters/day	380 liters/day
Effluent Total Nitrogen Concentration	40 mg/l	34 mg/l
Conc. of Nitrate-N Reaching Groundwater	20 mg/l	17 mg/l
Effluent Chloride Conc.	24 mg/l	20 mg/l
Conc. Chloride Reaching Groundwater	24 mg/l	20 mg/l
Longitudinal Dispersivity	Asymptotic value which reaches limit at 200 feet and has maximum value of 10 feet	Same as Missoula
Transverse Dispersivity	1/30 the value of longitudinal dispersivity	Same as Missoula

Parameter	**Missoula South Site**	**Frenchtown**
Chloride Half-Life	1000000 years	1000000 years
Nitrate-N Half-Life	4 days	5 days
Retardation Factor	1	1

The values of hydraulic conductivity, aquifer thickness, hydraulic gradient (for June 1994), groundwater velocity, porosity, specific yield, effluent nitrate-N and chloride concentration, and the concentration of nitrate-N and chloride reaching the groundwater were all taken from Woessner et al. (1996). The values used for aquifer thickness were the observed mixing zone of septic effluent within the South and Frenchtown sites. No vertical mixing was permitted between the plume and the underlying unimpacted groundwater. The remaining input parameters were based on values from the literature and parameter fitting during model calibration (Domenico and Schwartz, 1990).

Based on data presented by Woessner et al. (1996) and by Ver Hey (1987), the concentration of nitrate-N reaching the groundwater was assumed to be one-half the nitrate-N concentration measured in the septic effluent. Groundwater samples collected by these authors in monitoring points directly beneath and adjacent to Missoula Valley septic drainfields showed that the nitrate-N concentrations were approximately 50% of the nitrate-N concentration measured in the septic effluent. This 50 % reduction in nitrate-N mass was assumed to occur in the modeled sites.

The most difficult model parameter to determine proved to be the longitudinal and transverse dispersivities. During calibration of the chloride models, a function allowing for an asymptotic increase in longitudinal dispersivity (α_L) was used to represent the behavior of effluent plumes (figure 5.1). The following paragraph discusses the rational for using an asymptotic dispersivity value.

Using field tracer test data, Molz et al. (1983) and Pickens and Grisak (1981a) independently concluded that plume spreading in the direction of groundwater flow was not best described by a constant value of dispersivity. Much better was a function that allowed the value to be small at short distances from the source and linearly increase over some distance at which point it becomes constant. This relation was best described by using an asymptotic function for longitudinal dispersivity. Dagan (1988) and Anderson (1979) also concluded that the dispersion of solutes by groundwater is scale dependent and grows with travel time and distance but eventually reaches an asymptotic value. These conclusions were based upon a detailed understanding of the distribution of hydraulic conductivity within a particular study site. Molz et al. (1983) calculated an asymptotic dispersivity value that ranged from 160-3250 feet. These values are site-aquifer dependent and are not directly transferable to other groundwater systems. However, they do illustrate a high upper limit of asymptotic dispersivity. More recent work by Domenico and Schwartz (1990) showed that a scale-dependent representation of dispersivity is not necessary if the variations in the aquifer velocity fields, caused by small

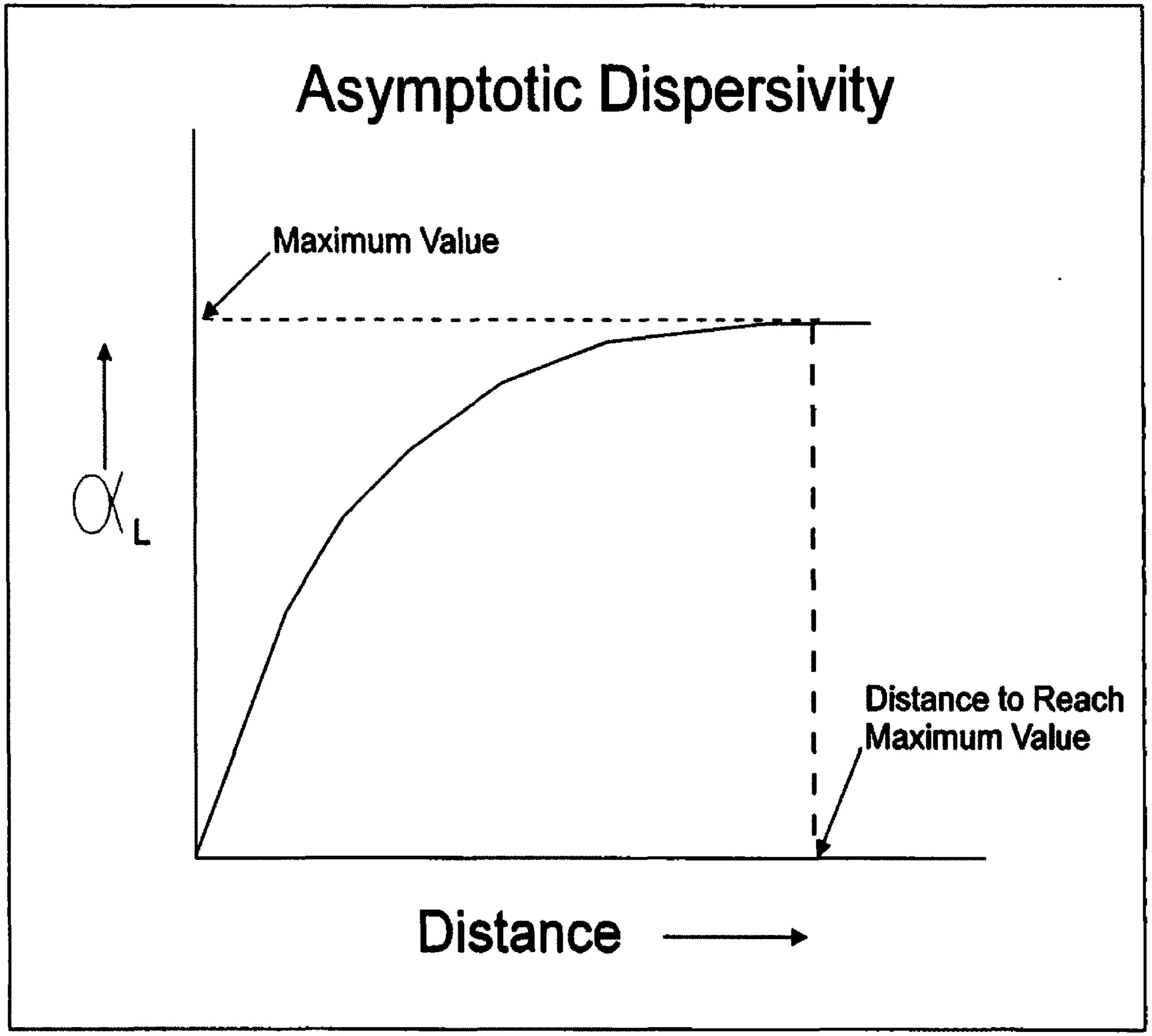


Figure 5.1: Longitudinal dispersivity vs. distance for an asymptotic dispersivity value

scale heterogeneities in the aquifer hydraulic conductivity, are well defined. When the magnitude and distribution of these variations are not well defined, describing the plume behavior using an asymptotic function for aquifer dispersion is more representative than applying a constant value.

Transverse dispersivity is commonly taken to be a percentage of longitudinal dispersivity. Shutter et al. (1994) report a transverse dispersivity value that is 1/100 of the longitudinal dispersivity value. Transverse dispersivity for this modeling effort was assumed to be 1/30 of the longitudinal value.

The final variable required by RANDWALK was the characterization of the modeled chemical constituent, as conservative or not. Nitrate-N is usually assumed to act as a conservative species (Walker et al., 1973a; Perkins, 1984; Tolman et al., 1989; Hebson and Brainard, 1991). To determine if nitrate-N was acting conservatively in the studied groundwater systems, nitrate-N/chloride ratios were calculated. Conservative behavior would be indicated by a constant ratio in the plume region.

Nitrate-N/chloride ratios vary throughout the South site (figure 5.2). Values are approximately 0.7-0.8 directly downgradient from the drainfield, but drop to approximately 0.2 at the wells located 170 feet downgradient. Nitrate appears to behave non-conservatively. Possible mechanisms of nitrate-N mass loss is described in Table 2.3. It was beyond the scope of this project to determine the specific mechanism(s). Based on the field distribution of chloride and nitrate-N a mechanism to remove nitrate mass was developed and included in the simulation. A discussion of this mechanism is given in Appendix B.

West Missoula Study Area
South Site

Nitrate-N : Chloride Ratio within the Groundwater, June 1994

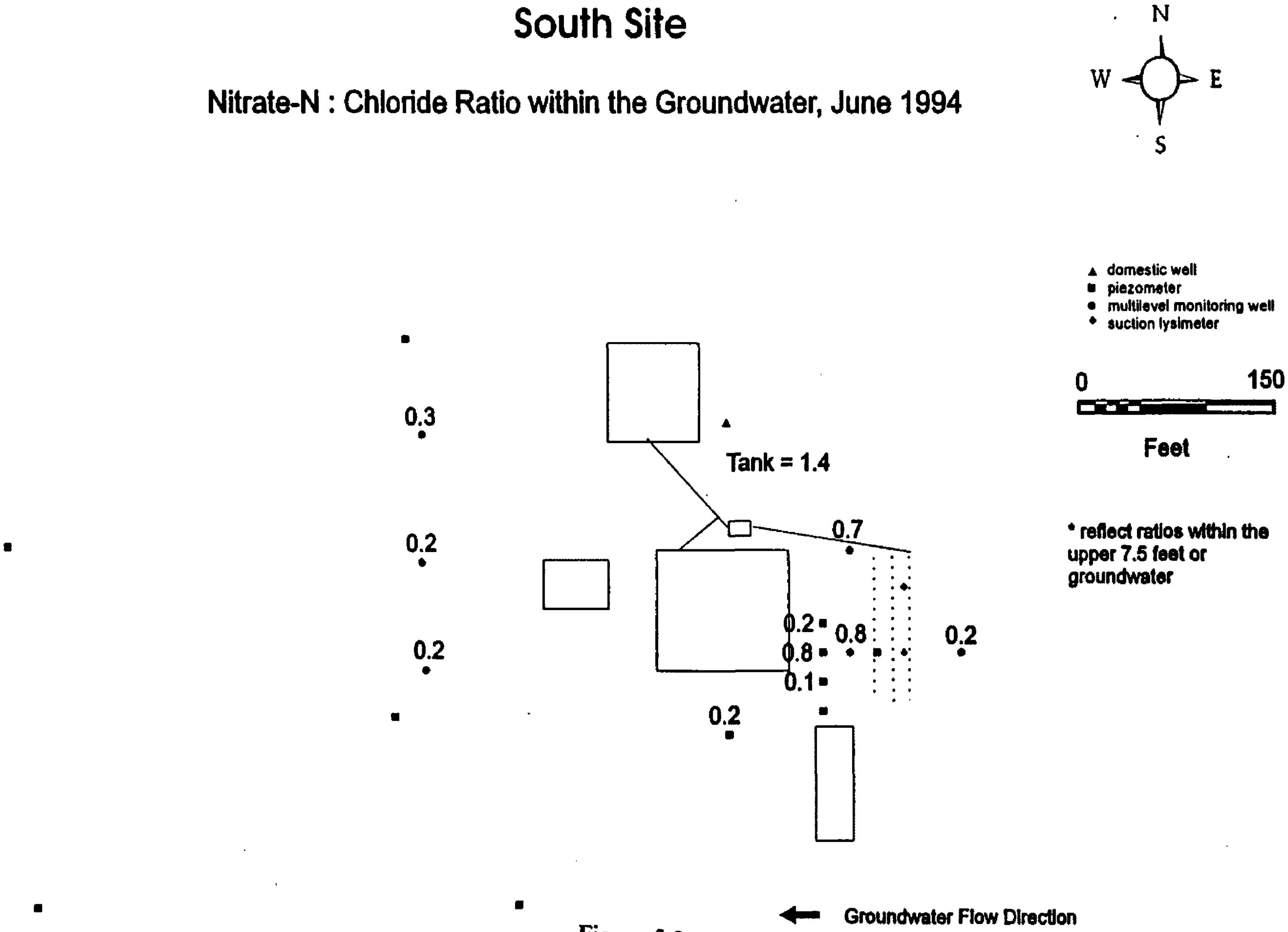


Figure 5.2

Simulation

The chloride plume behavior in both the South and Quarter Mile Road sites was modeled using RANDWALK. Aquifer parameters required by RANDWALK: hydraulic conductivity, aquifer thickness, specific yield, porosity, hydraulic gradient, velocity, half-life, retardation factor, loading rate and loading volume were held constant during the modeling process. Values and functions of dispersivity were determined by fitting during the calibration process. Approaches used to calibrate the chloride plume are summarized in Table 5.2.

TABLE 5.2 Chloride Groundwater Model Calibration Process

Trial Approach	Result	Resulting Modification
1. Treated the input of septic effluent to the aquifer as a continuous source. Effluent emitted from a 50-foot line source. Constant dispersivity.	Generated an unrealistically long and narrow plume that had elevated chloride concentrations too far away from the source compared to the field data.	Treated the effluent source as a 5 foot line source.
2. Input septic effluent to the aquifer as a continuous source. Effluent emitted from a 5-foot line source. Constant dispersivity.	Generated a plume that was much too concentrated according to the field data.	Considered the input of effluent to the aquifer as a slug source.
3. Input effluent to the aquifer as a slug source twice a day. Slug added from a 5-foot source twice per day. Constant dispersivity.	Limitations of RANDWALK resulted in only being able to run the model for times up to 250 days.	Needed to add slug less than twice per day to be able to run the model for longer periods of time.
4. Input effluent to the aquifer as a slug source once a day. Slug added from a 5-foot source twice per day. Constant dispersivity.	Generated plume continued to have unrealistically elevated chloride concentrations compared to field data.	Altered the value of dispersivity.
5. Input effluent to the aquifer as a slug source twice a day. Slug added from a 5-foot source twice per day. Linear dispersivity.	Generated plume continued to have unrealistically elevated chloride concentrations compared to field data.	Altered the value of dispersivity.

Trial Approach	**Result**	**Resulting Modification**
6. Input effluent to the aquifer once per day as a slug source. Slug added from a 5-foot source once per day. Asymptotic dispersivity. Maximum longitudinal dispersivity value is 100 feet and it reaches this value 600 feet from the source. Transverse dispersivity is 10% of the longitudinal value.	Generated plume had the highest concentrations too far downgradient from the source compared to the field data.	Continue to assume an asymptotic dispersivity, but alter the maximum longitudinal dispersivity value.
7. Inputted effluent to the aquifer once per day as a slug source. Slug added from a 5-foot source once per day. Asymptotic dispersivity. Maximum longitudinal dispersivity value is 200 feet and it reaches this value 600 feet from the source. Transverse dispersivity is 10% of the longitudinal value.	Generated plume continued to have incorrect simulated chloride concentration distribution based on field data.	Altered source dimensions and dispersivity value. Close inspection of chemical data reveled consistent elevated concentrations within 1P26 & 1M9 (South site).
8. Assumed elevated concentrations in 1P26 & 1M9 was caused by two five feet segments of one lateral to be actively inputting effluent. Maximum longitudinal dispersivity is 10 feet and reaches limit 200 feet from source. Transverse dispersivity is 1/30 of longitudinal value.	Generated chloride plume was considered calibrated to the field measured chloride plume.	

Representing the source for the model involved treating the loading of the groundwater system both continuously and discontinuously. Research at sites, such as the Cambridge site in Ontario, found the effluent source behaved as if effluent is placed continuously into the aquifer (Robertson et al., 1991). However, use of a continuous source to represent waste input was found to be inadequate. A second approach, the use of pulses of effluent entering the underlying groundwater was assessed. Source conditions were further complicated by not knowing the exact length and location at which effluent was leaving the drainfield. Based on video camera investigations of the main discharge lines and on the measured chemical distribution, two discharge segments of five feet each were used to represent the source of effluent within the South site, while 15 feet of drainfield was used to represent the Frenchtown source.

An additional challenge was to generate a representative plume that would appropriately represent the operation of a single septic system over many years. Theoretically, a continuous or slug source would create a plume that would continually expand in the downgradient longitudinal direction. Modeling was used to assess if pseudo-steady-state conditions would occur after a definable time period of operation. It was found that representing input as slugs generated plumes in which the width and position of the highest concentration zones appeared to stabilized after simulating about 400 days of operation.

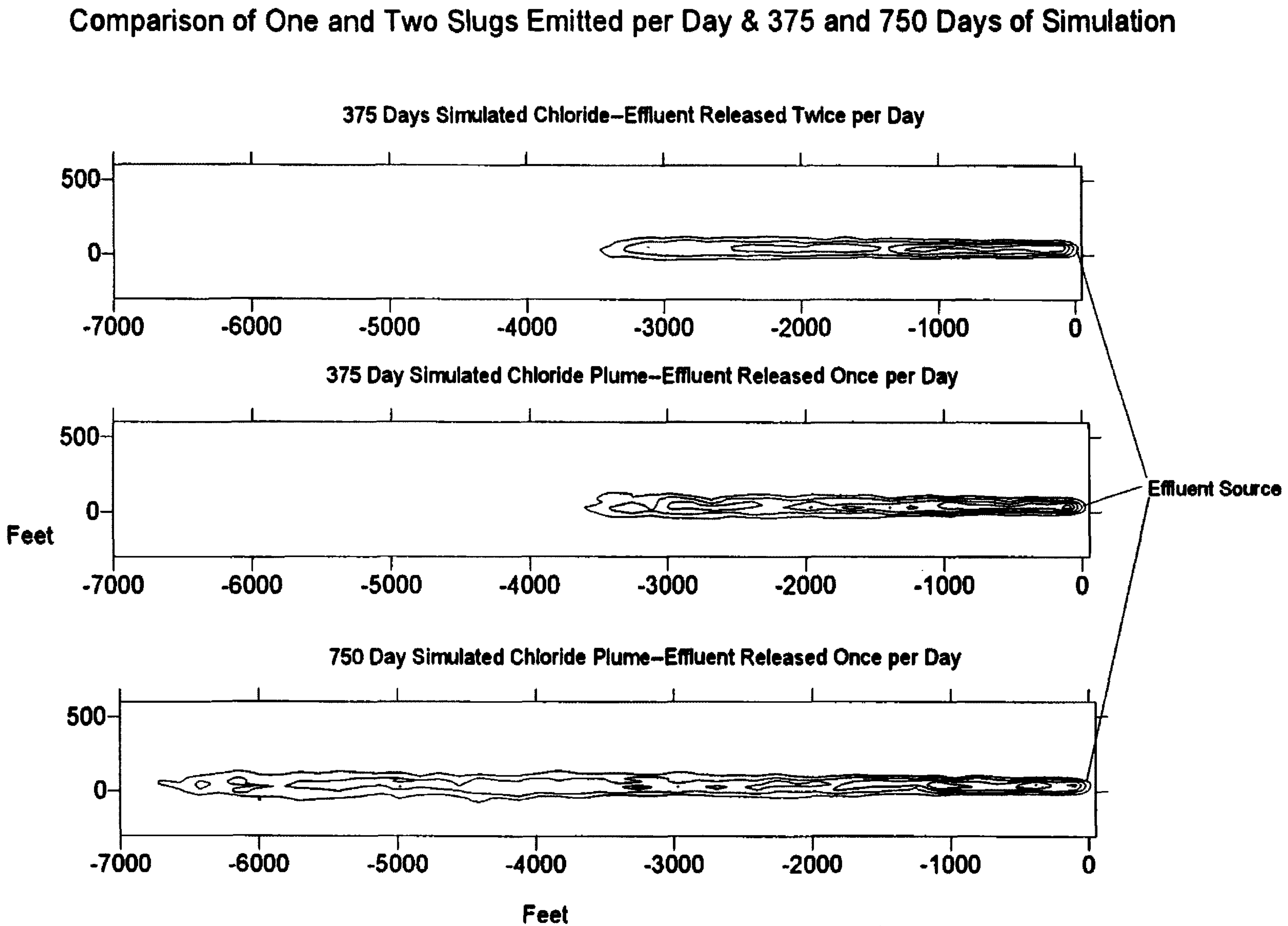
The pulse input was believed to best represent actual septic system loading. An average household typically uses their washing machines, toilets, and faucets most in the morning while the household is getting ready for work and/or school, and in the evening when the residents get home. This translates into a slug of liquids entering a septic tank, and leaving, in both the morning and evening. Initial source representation used two slug inputs per day. RANDWALK, as originally available, could only account for two daily source inputs (20 particles each) for 250 days. After modification of the code by the model author to track 15,000 particles, the input of twice per day could be extended to 375 days. The use of a single slug to simulate daily input was tested and compared against the two daily slug plumes. Dimensions and mass distribution of plumes were sufficiently similar to allow the use of a single daily slug input to represent effluent loading (figure 5.3). This allowed modeling of plumes over longer periods of time.

A comparison of the 375 and 700 day plumes for a slug source at the South site shows the similar, general distributions of chloride, with the exception of the 0.2 mg/l concentration line which continued to expand over 6,500 ft. from the source after 750 days (figure 5.3). The 750 day plume was chosen to represent the effect of septic systems on the underlying groundwater. Though septic systems have actually been used in the study areas for many years, the septic plume appears to stabilize after about 400 days of operation in the groundwater system. It was assumed a similar relationship was present at the Frenchtown site.

Individual Plume Behavior

South Site

The simulated chloride plume for the Missoula South site best met the calibration standards (figure 5.4 and 5.5). The configuration of the simulated chloride plume is

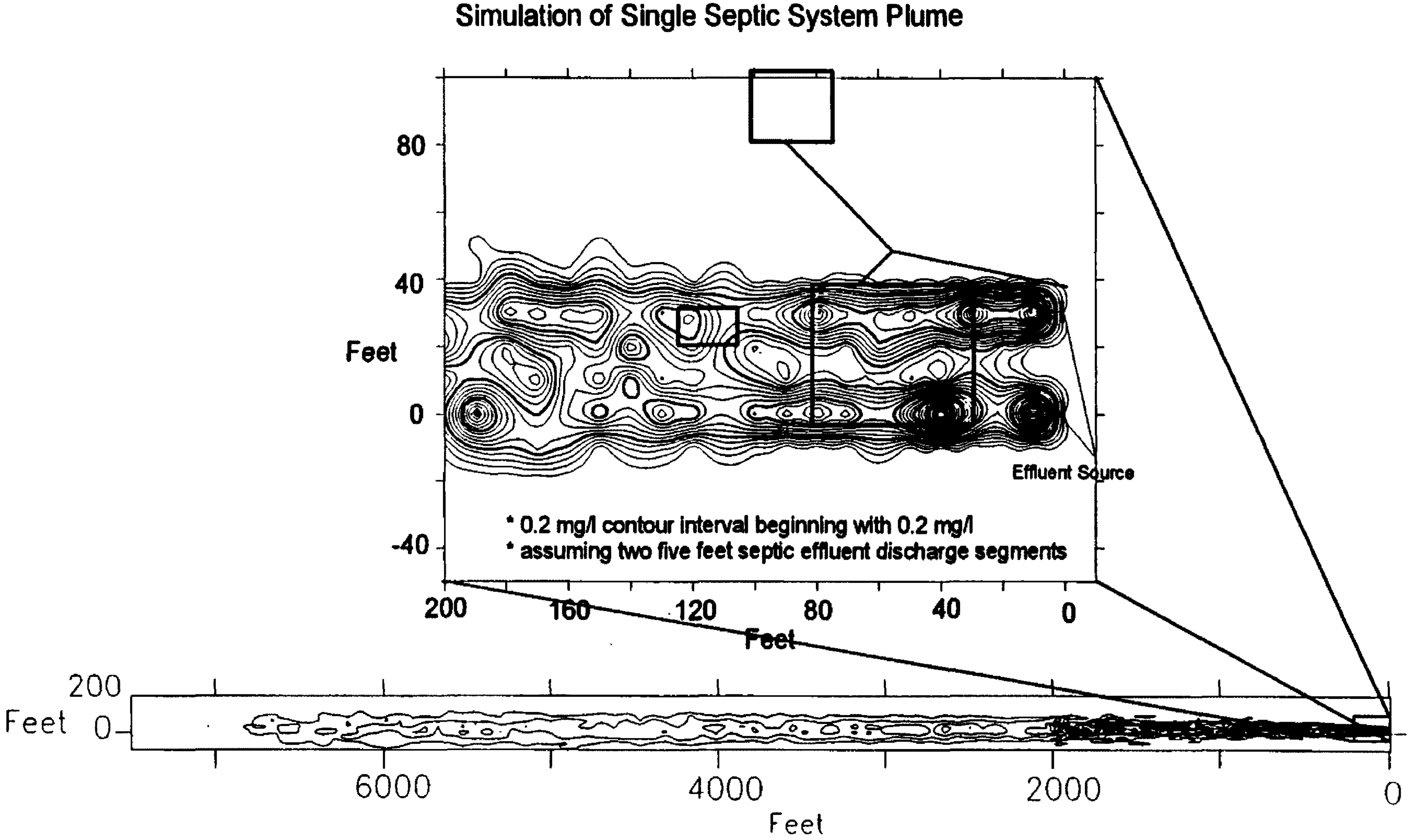


* effluent released from a single 80 foot length of drainline

* 0.1 mg/l contour interval
beginning with 0.1 mg/l

Figure 5.3

Simulation of Chloride Concentrations in the Upper 7.5 Feet of Groundwater After 750 Days-South Site Missoula, MT



← Groundwater Flow Direction

* 0.2 mg/l contour interval beginning with 0.2 mg/l
* assuming two five feet input segments

Figure 5.4

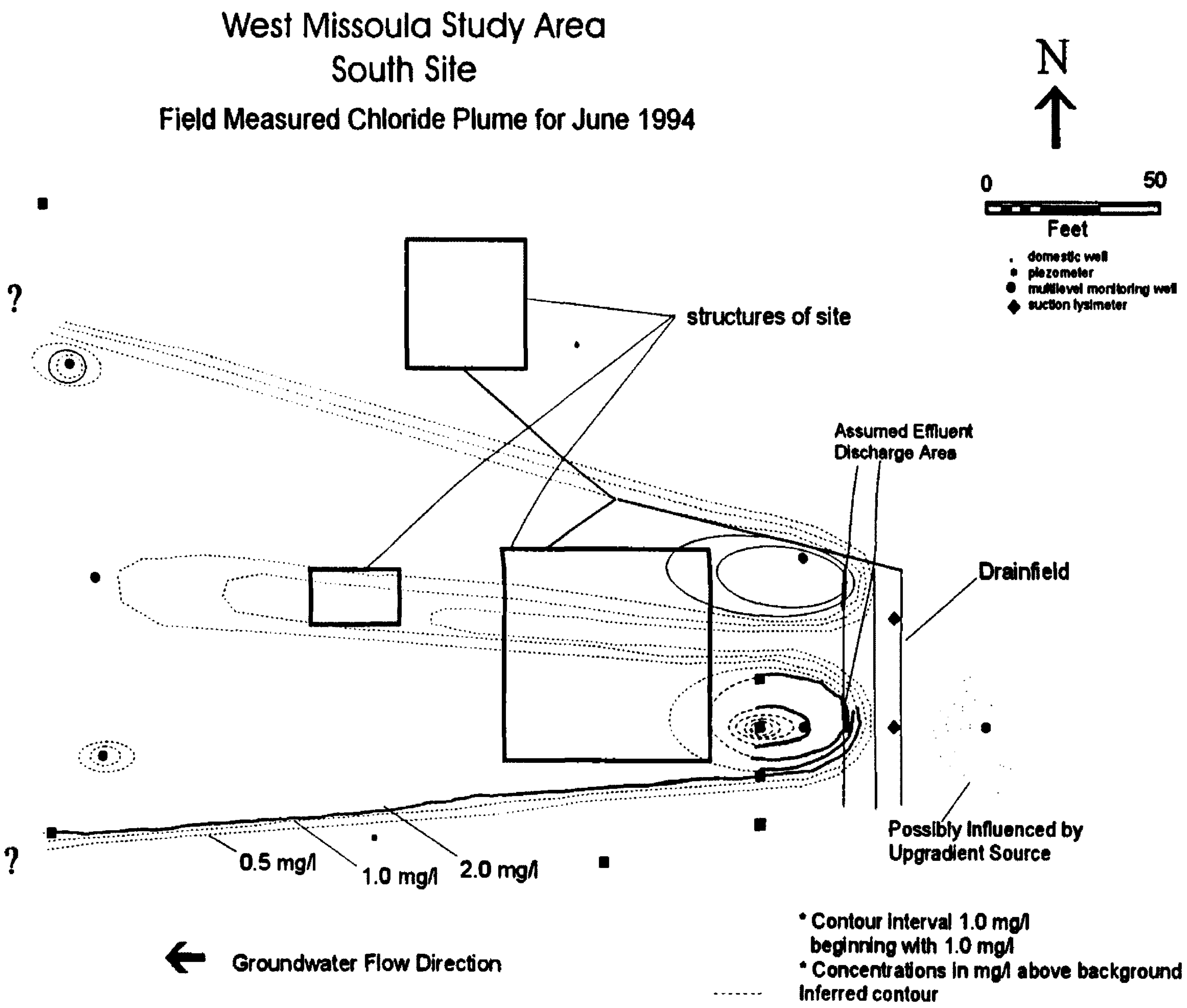
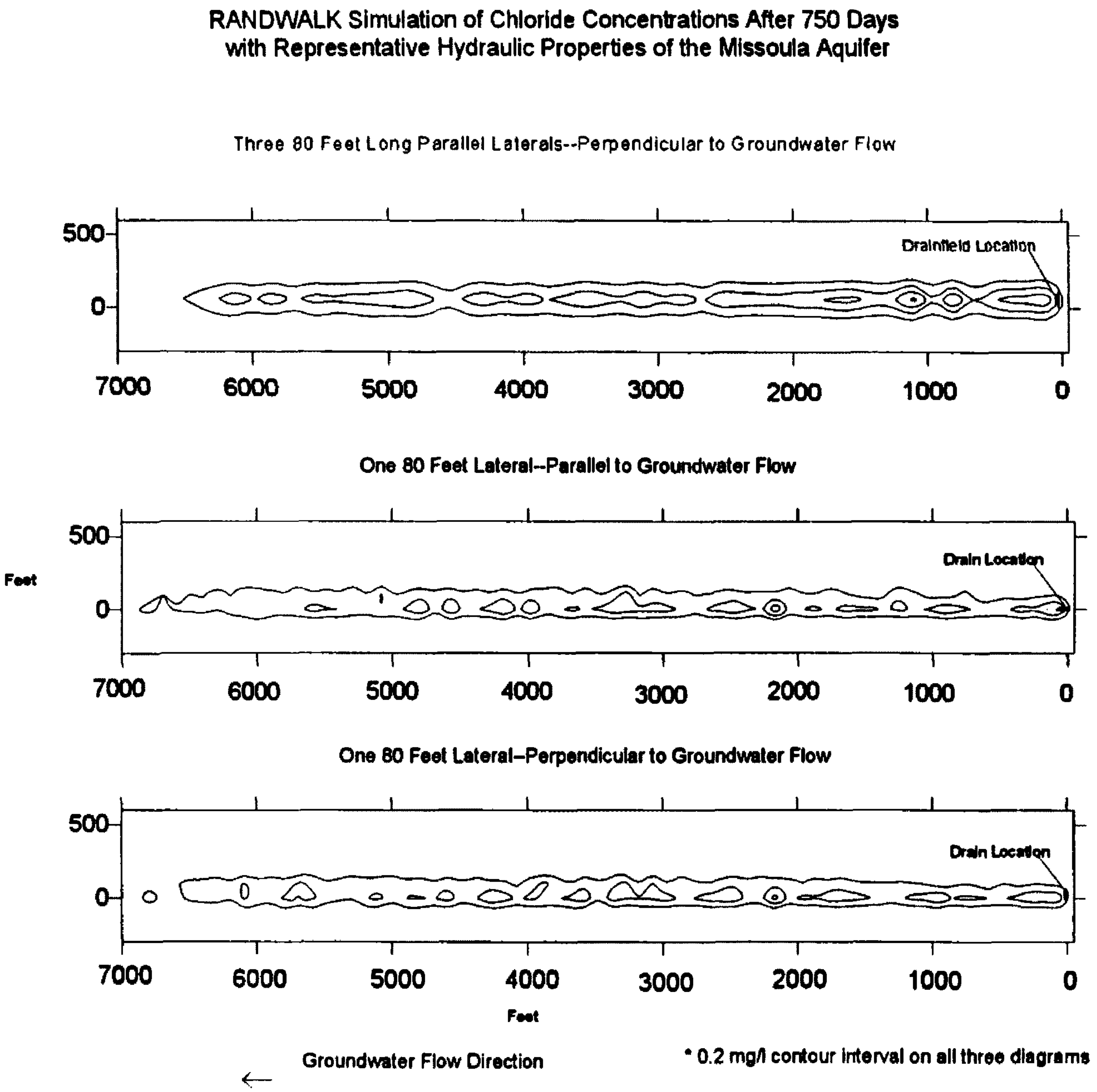

West Missoula Study Area
South Site
Field Measured Chloride Plume for June 1994
N
0
50
Feet
domestic well
piezometer
multilevel monitoring well
suction lysimeter
structures of site
?
?
Assumed Effluent Discharge Area
Drainfield
Possibly Influenced by Upgradient Source
0.5 mg/l
1.0 mg/l
2.0 mg/l
Groundwater Flow Direction
* Contour interval 1.0 mg/l beginning with 1.0 mg/l
* Concentrations in mg/l above background
Inferred contour

Figure 5.5

similar to the measured plume within approximately 170 feet downgradient of the drainfield. The simulated plume continues at distances greater than the lateral limit of the measured plume; low concentrations, but above background, were simulated to persist at distances up to 6000-7000 feet downgradient of the source. The simulated plume appears discontinuous at distances downgradient. Such a distribution of chloride may actually occur and may be a result of representing the source as a slug input and also accounting for the heterogeneities in aquifer hydraulic conductivity by using an asymptotic spreading function. This pattern may be also be somewhat artificial, an artifact of the grid system and number of particles used in the RANDWALK model and/or the interpolation functions selected to contour the data. The low concentrations in this portion of the plume background chloride levels and the absence of monitoring points make conformation difficult.

Simulations were conducted to evaluate possible chloride concentration distributions as a result of different drainfield configurations within the Missoula Valley (figure 5.6). The first is when the entire drainfield is evenly releasing effluent into the underlying groundwater. The simulated drainfield is three parallel 80-foot laterals, the regulated drainfield distribution for these sediments (Barger, 1995 per. comm.), which were situated perpendicular to groundwater flow. The second shows the chloride distribution simulated to occur from one 80-foot length of pipe parallel to groundwater flow. The third is the chloride distribution simulated to occur from one 80 foot length of pipe that is perpendicular to groundwater flow. The figure depicts minimal chloride concentration variation as a result of each different scenario. These scenarios did not


RANDWALK Simulation of Chloride Concentrations After 750 Days
with Representative Hydraulic Properties of the Missoula Aquifer

Three 80 Feet Long Parallel Laterals--Perpendicular to Groundwater Flow

One 80 Feet Lateral--Parallel to Groundwater Flow

One 80 Feet Lateral--Perpendicular to Groundwater Flow

* 0.2 mg/l contour interval on all three diagrams

Figure 5.6: simulated chloride concentrations which resulted from different drainfield configurations

appear to be occurring at the site as simulated chloride concentrations were much lower than field values. They do provide an illustration of the consequences of distributing the effluent over a larger area.

A simulation of the nitrate-N plume configuration was also conducted. This was accomplished by assigning a half-life, within RANDWALK, to the observed loss of nitrate-N mass. Table 5.3 summarizes the various approaches used to calibrate the simulated nitrate-N concentration distribution to the field measured distribution.

Table 5.3 Nitrate-N Groundwater Model Calibration Process

Trial Approach	**Result**	**Resulting Modification**
1. Used the resultant hydrogeologic properties of the chloride plume calibration. Used four day half-life. Assumed there was a 50% reduction of nitrogen mass within the vadose zone, and used this mass as a starting concentration. Used the same two input sources.	Simulated plume would only persist, at concentrations of 0.2 mg/l and greater, 100-200 feet downgradient. Did not seem conceptually correct since background nitrate-N concentrations are about 1.0 mg/l.	Re-evaluate the simulated non-conservative behavior of nitrate-N.
2. Treated the behavior of nitrate-N to be non-conservative within the first 100 feet downgradient from the source, and to be conservative at greater distances (see discussion below for detail).	Simulation met calibration standards.	

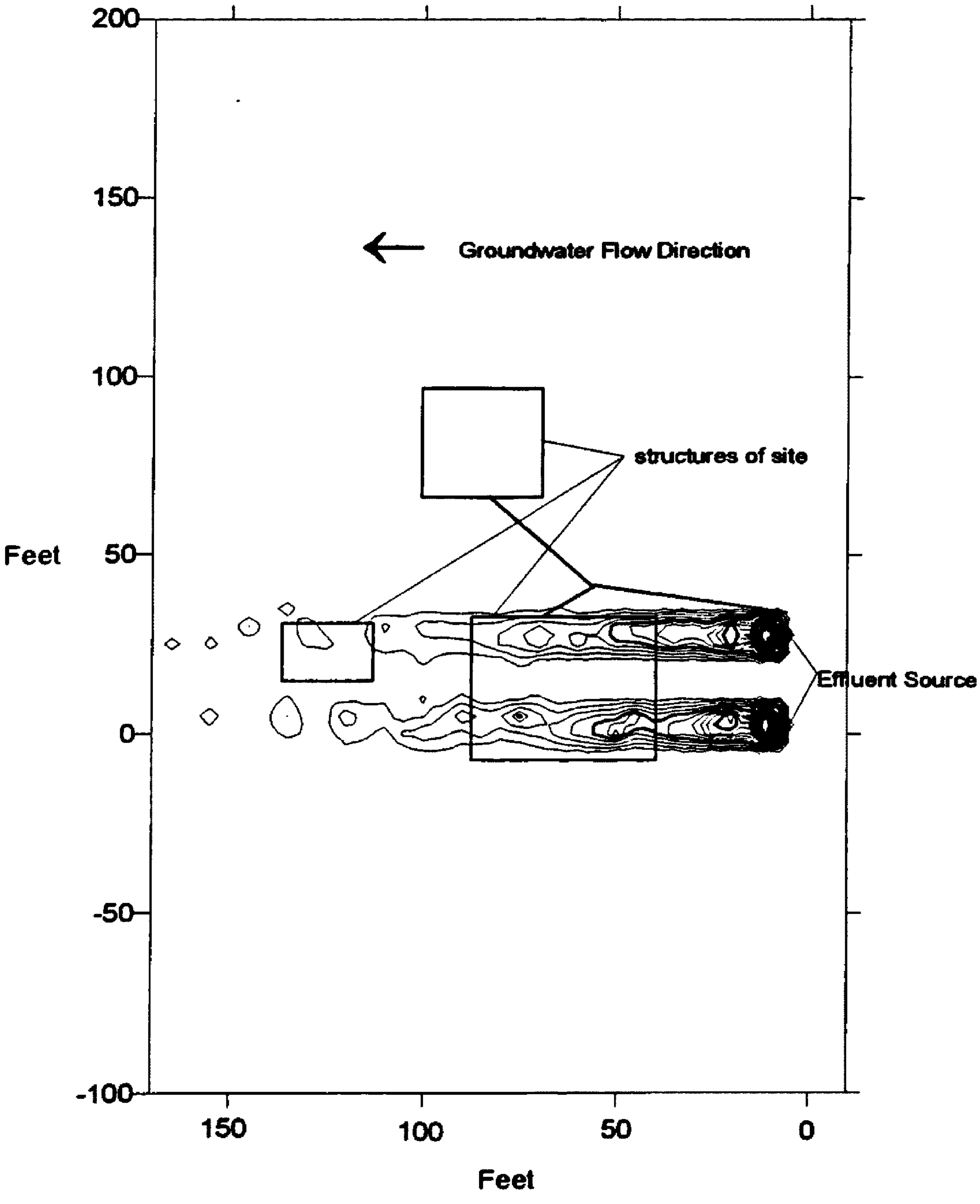
There were two general simulations of nitrate-N concentrations: one which considered its behavior to be totally non-conservative and one which considered its behavior to be partially non-conservative. Initially, a totally non-conservative simulation was conducted. Based upon the field data at the South site, it appeared nitrate-N was undergoing some form of continual degradation from the time it was released from the septic drainfield until it reached the lateral extent of the monitoring network. The simulation attempted to reproduce the field-measured concentrations.

The totally non-conservative simulation reproduced the field measured concentrations, within the monitoring network relatively well. But the simulation did not conceptually reproduce the nitrate-N concentrations beyond the monitoring network adequately (figure 5.7). The predicted nitrate-N concentrations would drop below the detection limit (0.1 mg/l) approximately 100-200 feet downgradient from the source. If this was in fact occurring in the Missoula Aquifer, nitrate-N concentrations would be expected to be close to or below detection limits throughout the entire aquifer. Groundwater samples taken as part of this study, and by many other researchers, have confirmed measurable concentrations of nitrate-N within the groundwater throughout the Missoula Valley (Woessner, 1988). Thus, considering the behavior of nitrate-N to be totally non-conservative was considered to be incorrect.

Another attempt to simulate nitrate-N behavior in the Missoula Aquifer was conducted. This simulation considered nitrate-N to behave non-conservatively within the first 100 ft from the source, and to behave conservatively further out. Evidence for this relationship came from the observation of nitrate-N : chloride ratios measured throughout

Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of Groundwater After 750 Days-South site Missoula, MT

Totally Non-Conservative Simulation of a Single Septic System



* 0.2 mg/l contour interval beginning with 0.2 mg/l
* assuming two five feet segments of working drainfield

Figure 5.7

the Missoula Valley conducted by this study and by Woessner (1988). Measurements of total nitrogen : chloride ratios within the South site's septic tank were approximately 2:1 (Woessner et al., 1996). Water collected directly beneath two Missoula Valley septic systems had total nitrogen : chloride ratios of approximately 0.8-1 (Woessner et al., 1996 and Ver Hey, 1987), thus the vadose zone reduced the nitrogen mass by approximately 50%, assuming no other source of chloride. Monitoring wells and piezometers measured at the South site and by Ver Hey (1987) revealed nitrate-N : chloride ratios to be approximately 0.6-0.8 about 20 feet downgradient. Monitoring wells, measured roughly 170 feet downgradient within the South site, displayed ratios of nearly 0.2 (figure 5.2). It was originally assumed the ratio continued to become smaller at larger distances from the source, which was the basis for the totally non-conservative model. Observing ratios measured, through domestic wells, by Woessner (1988) showed a ratio of 0.2 ± 0.1 within the groundwater. Interestingly, the ratio is consistently about 0.2 regardless of whether the sample was taken within the on-site disposal portion of the valley (roughly west of Reserve Street within the City of Missoula) or within the City of Missoula, where most homes are connected to the city sewer system, thus an area not directly influenced by on-site waste disposal. Woessner (1988) illustrated groundwater concentrations of both nitrate-N and chloride to increase downgradient from the sewered portion of the Missoula Valley through the unsewered portion, but the nitrate-N : chloride ratio was consistently about 0.2. Figure 5.8 represents the chloride versus nitrate-N concentrations within the groundwater sampled in the South site. The figure depicts an approximate 0.2 nitrate-N : chloride ratio at 20-170 ft from the source. Samples which had 5-8 mg/l of nitrate-N,

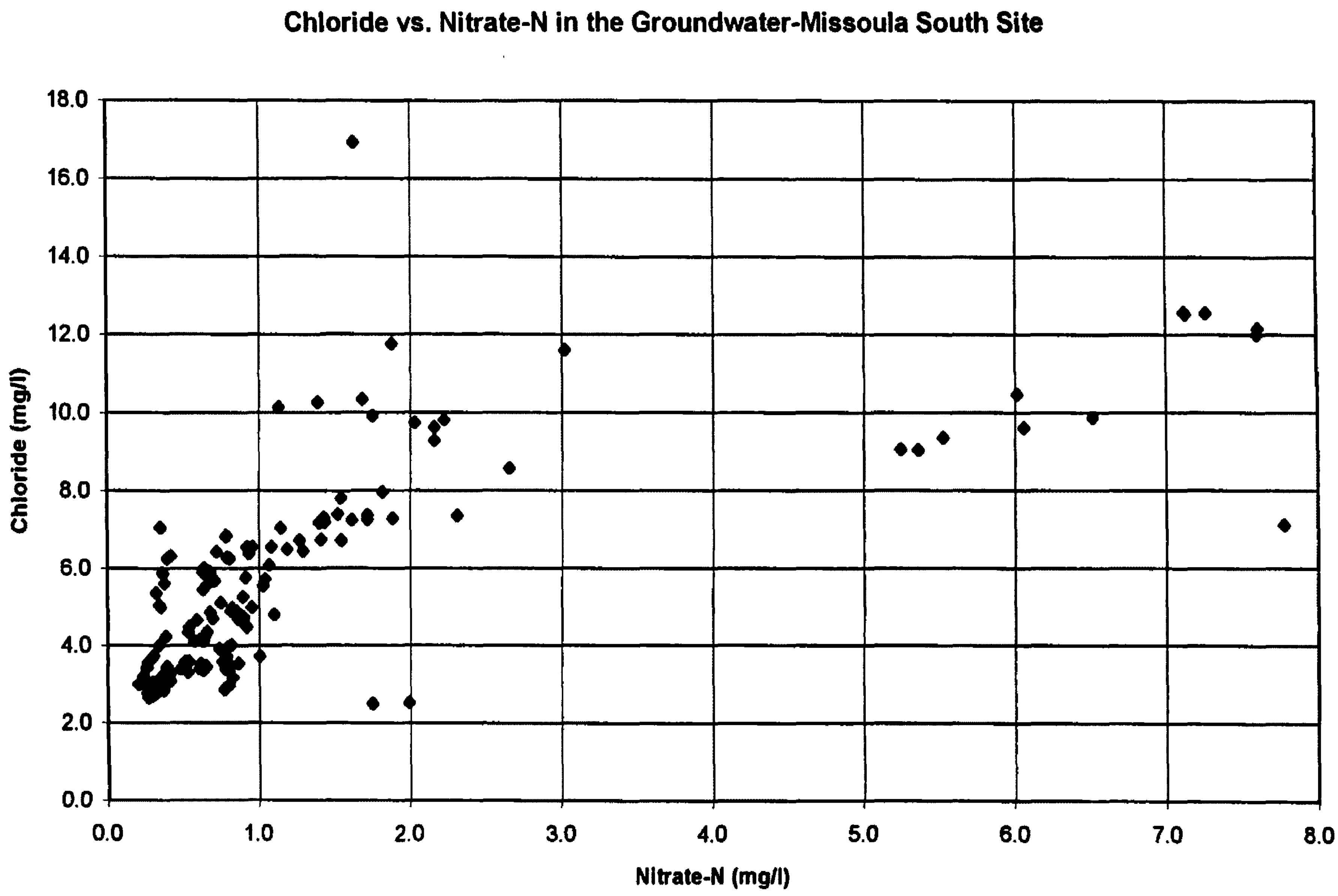

Chloride vs. Nitrate-N in the Groundwater-Missoula South Site
Chloride (mg/l)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Nitrate-N (mg/l)

Figure 5.8

were ones collected from wells found within roughly 20 feet downgradient of the drainfield, or the area of the site where nitrate-N was assumed to behave non-conservatively.

The nitrate-N concentration distribution was simulated by the non-conservative/conservative model. The first 100 feet of plume was assumed to be behaving in a non-conservative manner. It was assumed nitrate-N was undergoing some form of mass reduction within this zone. Sampling points 170 feet downgradient measured ratios about 0.2. It was assumed nitrate-N mass reduction was not occurring at this distance. Since there were no sampling points at distances between 20 and 170 feet, 100 feet was chosen as the distance where the non-conservative behavior ceased and the conservative behavior began. The behavior at the Quarter Mile site was assumed to behave similarly. Appendix C describes the calibration procedure executed to simulate the nitrate-N plume.

Figures 5.9 and 5.10 present a comparison of the simulated and field-measured plume. The contours shown on both the field-measured and simulated plumes illustrations portray average concentrations, above background, within the nitrate-N mixing zone. The simulated plume is shown in two different scales: one which is on the same scale as the field plume and a second that characterizes the total length and width of the simulated plume. Both the simulated and the field plumes depict a two lobed plume shape. This was attributed to suspected release of effluent at two locations within the western-most drainline. The upgradient monitoring well, 1M8, consistently had slightly elevated concentrations, which was speculated to be influenced by an upgradient source. Minor

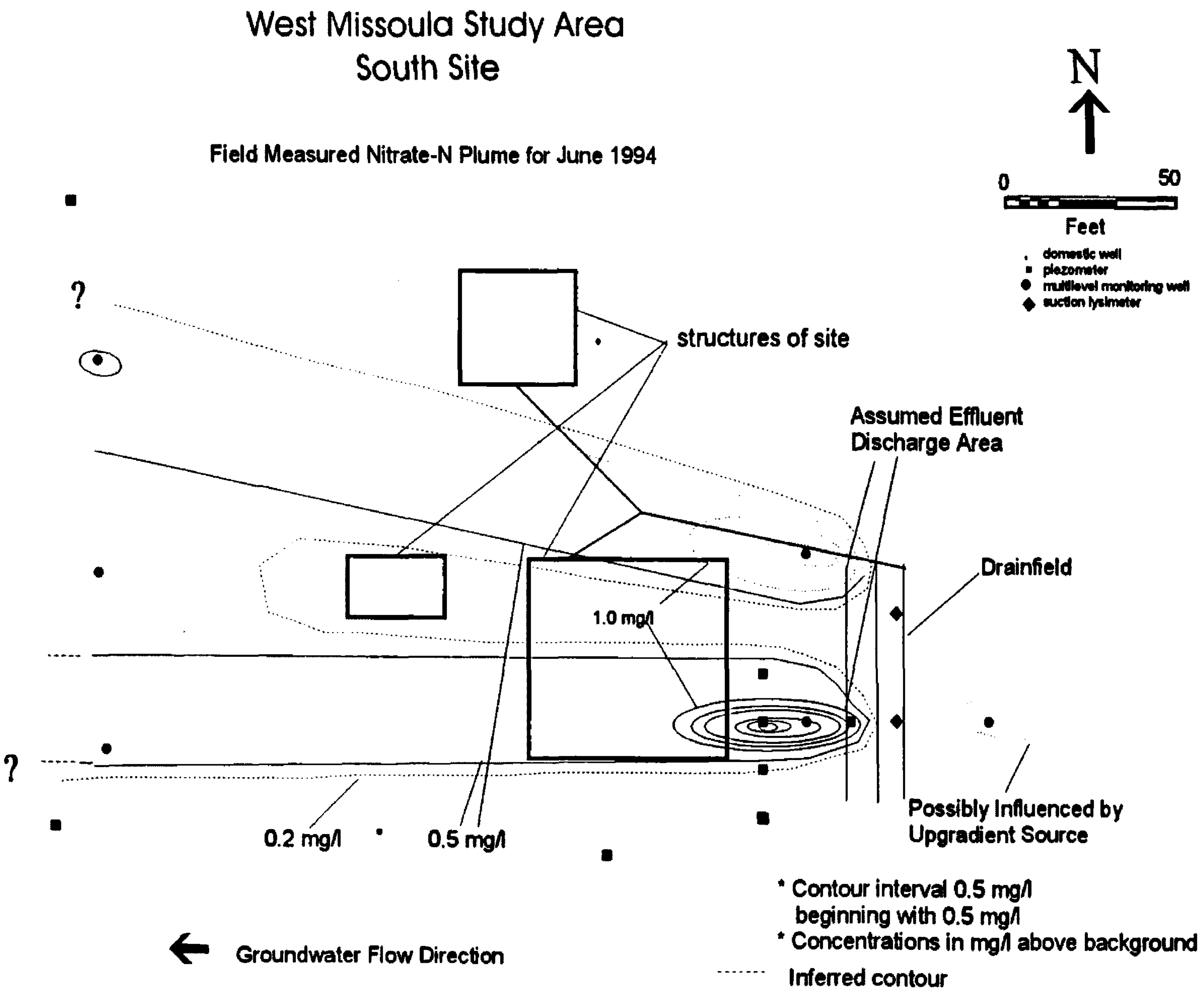

West Missoula Study Area
South Site
Field Measured Nitrate-N Plume for June 1994
N
0
50
Feet
domestic well
piezometer
multilevel monitoring well
suction lysimeter
?
structures of site
Assumed Effluent Discharge Area
Drainfield
1.0 mg/l
?
0.2 mg/l
0.5 mg/l
Possibly Influenced by Upgradient Source
* Contour interval 0.5 mg/l beginning with 0.5 mg/l
* Concentrations in mg/l above background
Groundwater Flow Direction
Inferred contour

Figure 5.9

Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of Groundwater After 750 Days-South Site Missoula, MT

Simulation of a Single Septic System Plume

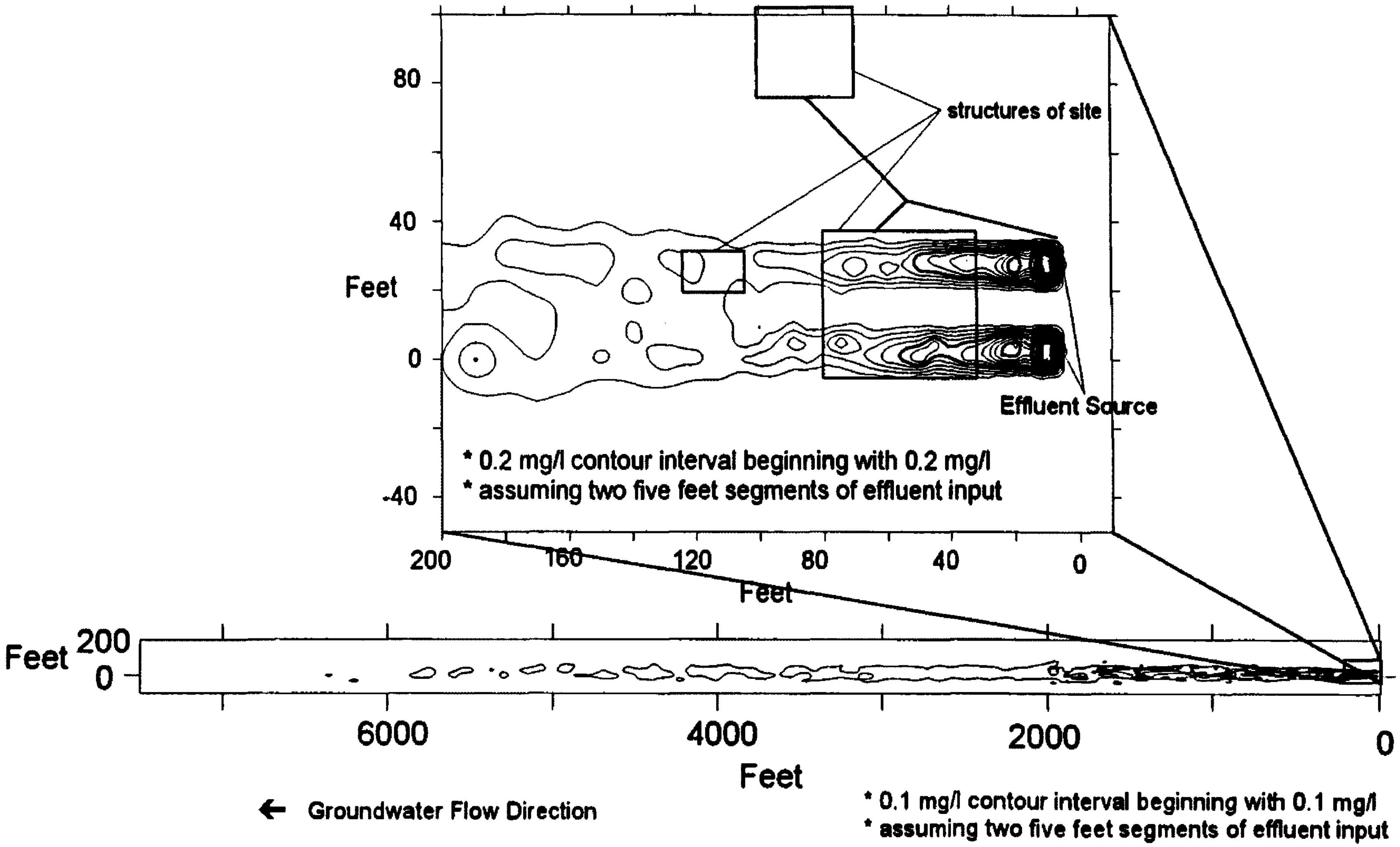


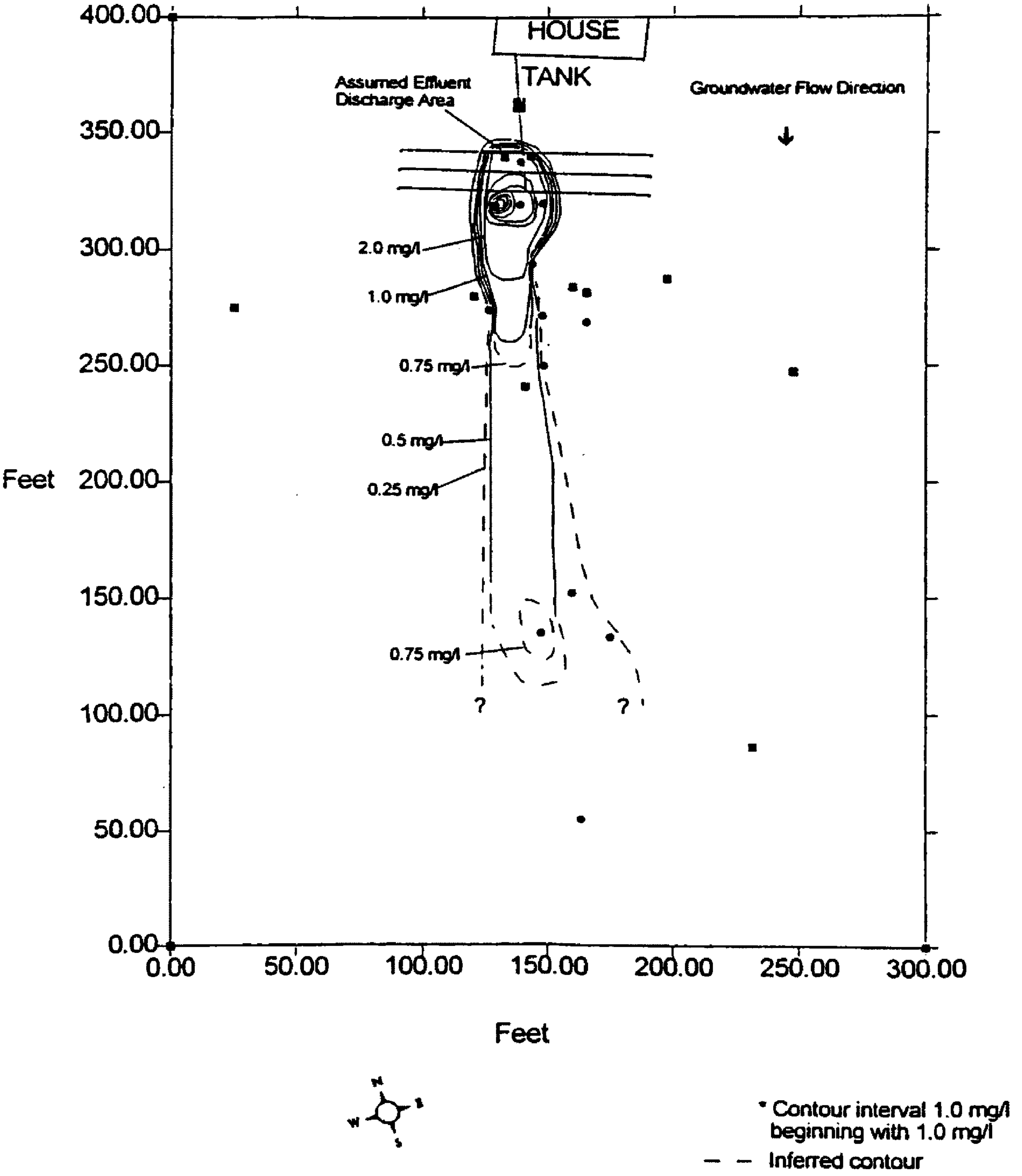
Figure 5.10

variations between the two plumes was attributed to aquifer heterogeneities, which were not considered by the model, and the limitations exhibited by the monitoring network.

Quarter Mile Road Site, Frenchtown

Figures 5.11, 5.12, 5.13, and 5.14 present a comparison of the simulated, at two different scales, and field-measured plumes. Each plot represents the concentrations within the upper eight feet of the aquifer, the assumed mixing zone. The distribution of the monitoring network set limits on the interpolation of the field concentration values.

The chloride simulation predicted concentrations to be elevated as much as 7 mg/l above background. This was less than the highest field measurement but may have been caused by the model's inability to consider aquifer heterogeneities. The simulated chloride plume was quite lumpy in shape, which can be attributed to the slug input of septic effluent to the groundwater. Other downgradient wells measured chloride concentrations in the groundwater to be at or slightly above background values. The simulation predicted values to be greater at the locations of these monitoring wells. This may be caused by the configuration of the monitoring network and by the modeled nature of effluent input. Intermediate downgradient monitoring wells (2M1, 2M2, 2M3, 2M4, and 2M5) quite possibly may have sampled groundwater which was between effluent slugs. Interestingly, the monitoring wells further downgradient (2M7, 2M13, and 2M14) observed slightly higher concentrations than those found in the intermediate downgradient zone, which could be the remnant of a septic slug. Both the simulated and the field plume had a width of approximately 20-30 feet.

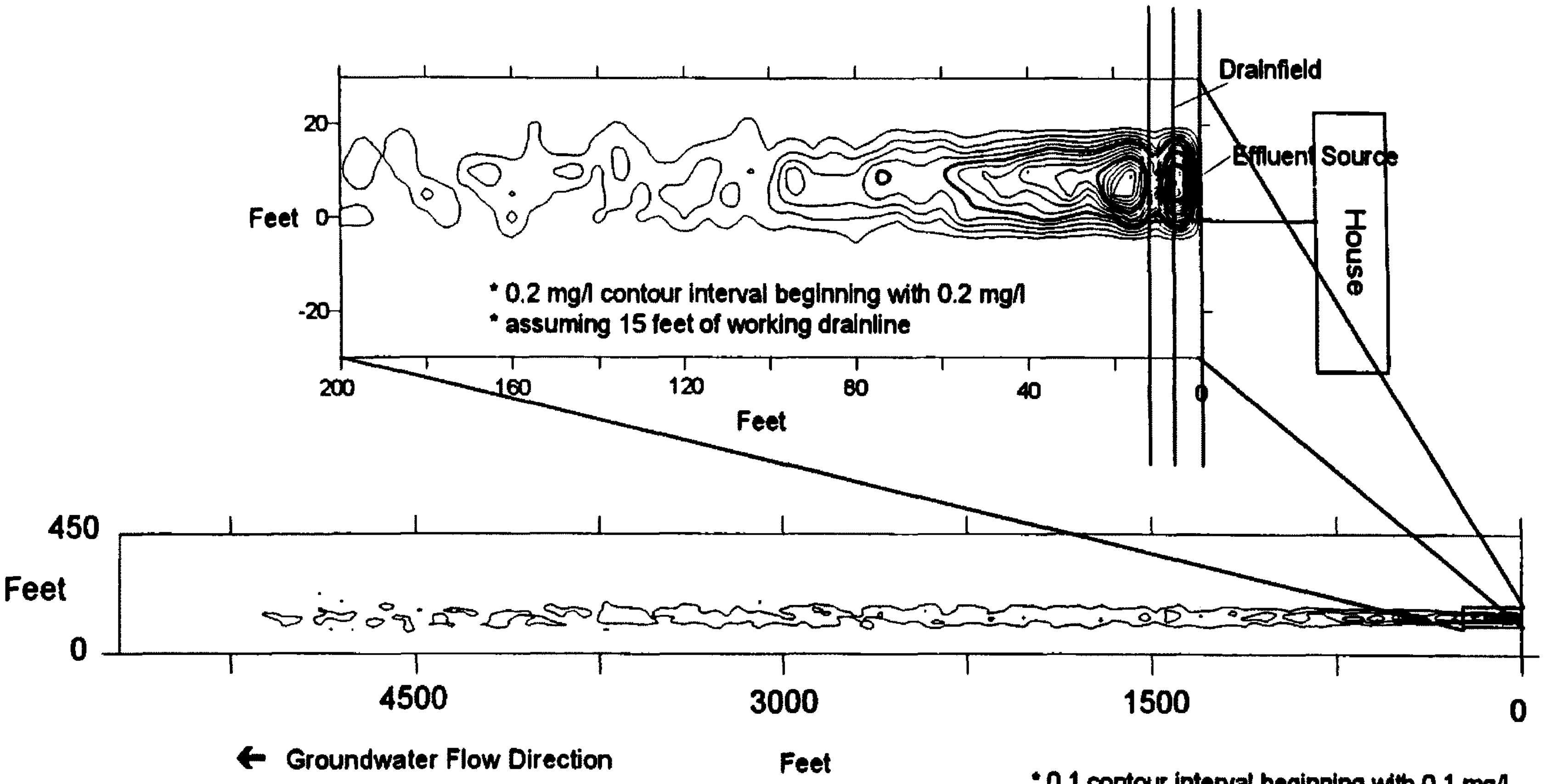


Field Measured Nitrate-N Plume for June 1994
Frenchtown Site Frenchtown, MT

Figure 5.11

Simulation of Nitrate-N Concentrations within the Upper Eight Feet of Groundwater After 750 Days-Frenchtown, MT Individual Site

Simulation of a Single Septic System Plume



* 0.2 mg/l contour interval beginning with 0.2 mg/l
* assuming 15 feet of working drainline

* 0.1 contour interval beginning with 0.1 mg/l
* assuming 15 feet of working drainfield

Figure 5.12

Field Measured Chloride Plume for June 1994
Frenchtown Site, Frenchtown, MT

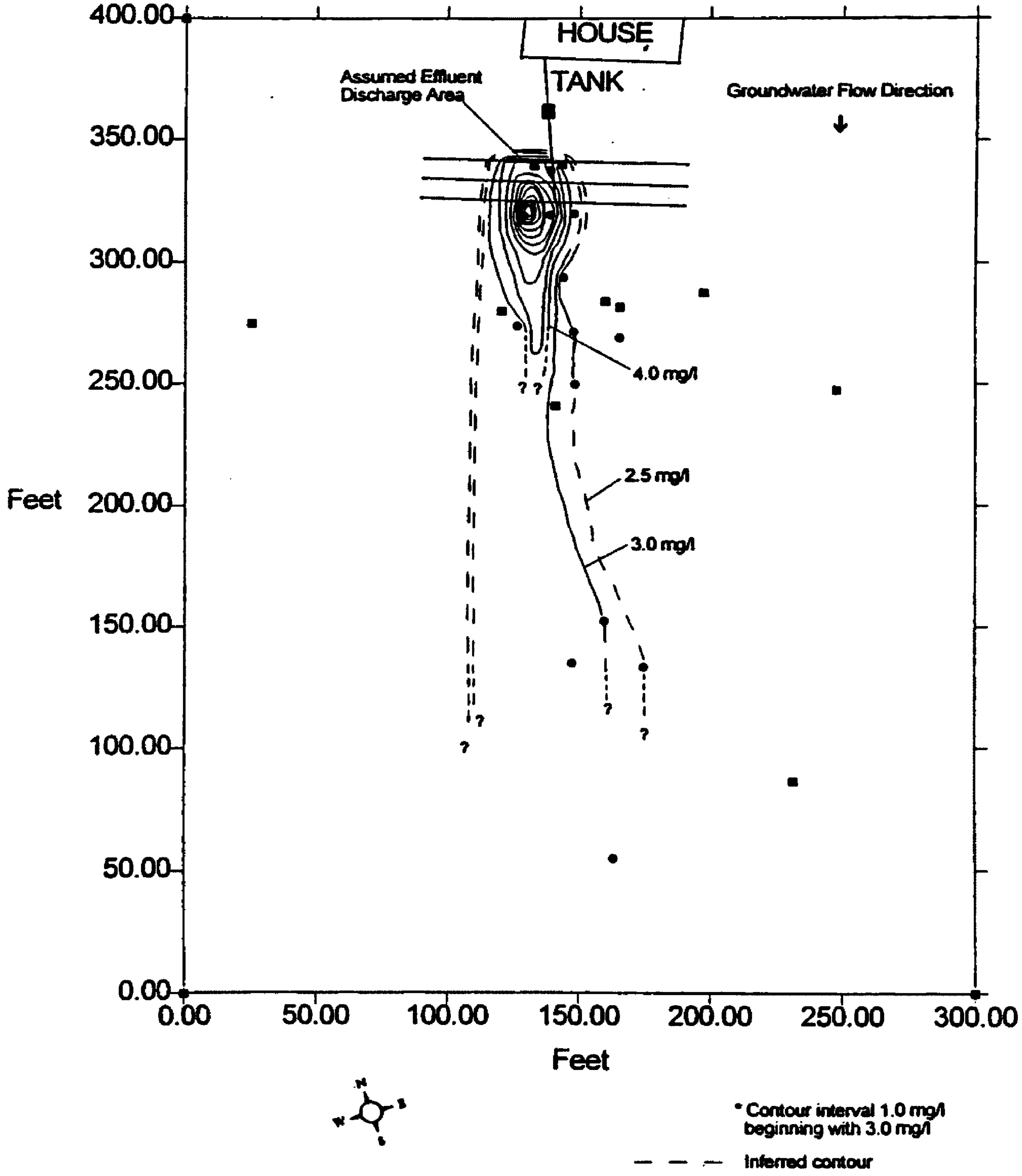


Figure 5.13

Simulation of Chloride Concentrations within the Upper Eight Feet of Groundwater After 750 Days-Frenchtown, MT Individual Site

Simulation of a Single Septic System plume

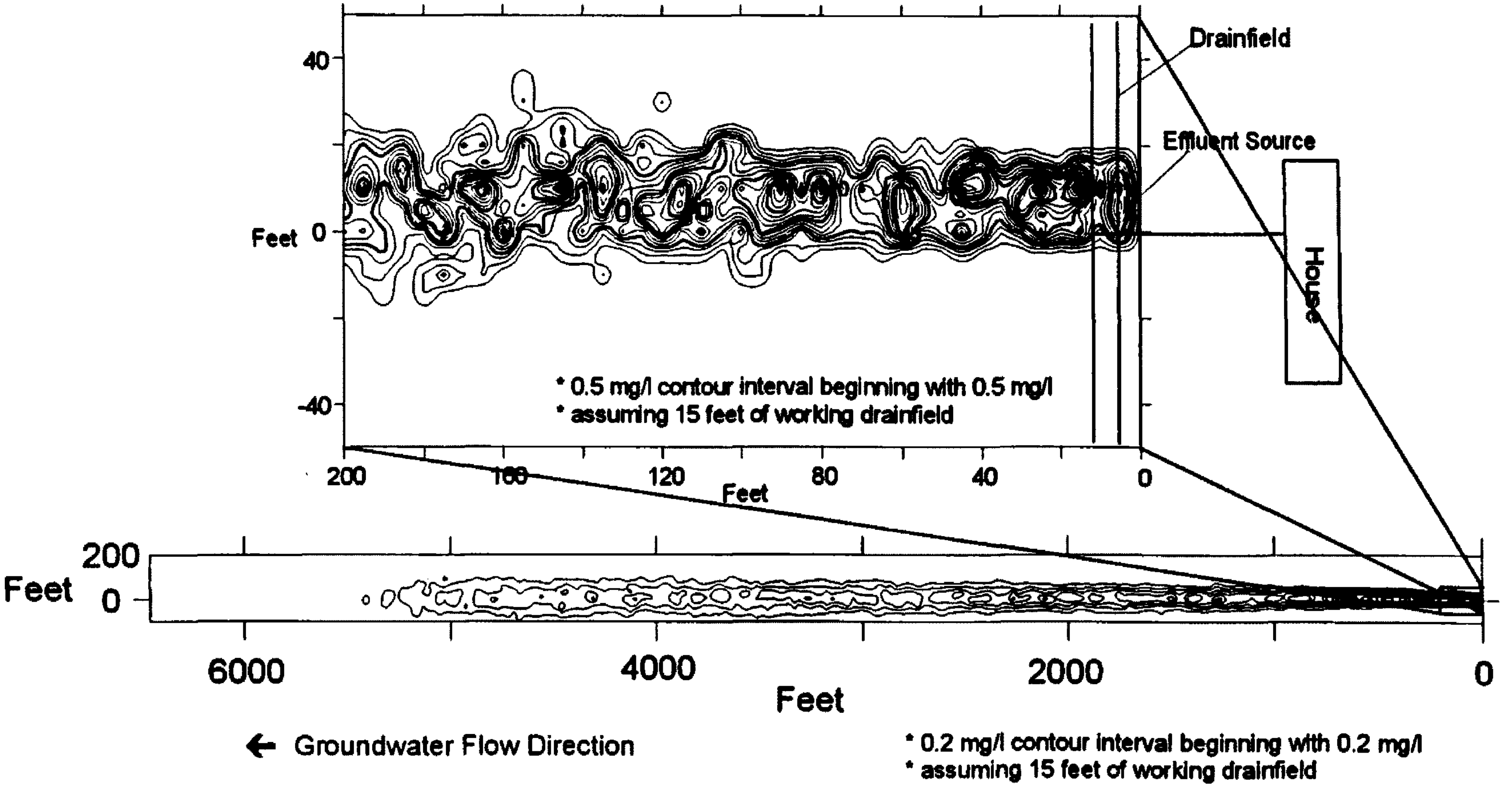


Figure 5.14

A similar chemical distribution was apparent with nitrate-N concentrations. The model predicted the most elevated concentrations to be within 30 feet downgradient of the source, with concentrations as high as 3.2 mg/l. Both the simulated and the field plume had a width of approximately 20-30 feet.

Evaluation of Cumulative Impacts

Two subdivision scale sites within the Missoula Valley (East and West sites) and one within Frenchtown were used to simulate the cumulative effects of septic system disposal on shallow groundwater quality. The simulation attempted to reproduce the chloride and nitrate-N concentrations measured within the field. Calibrated plumes for each area were used to represent a large number of septic system sources in portions of the Missoula Valley with different densities of development. Simulated plumes for both an 80-foot linear source and a 10-foot linear source, perpendicular to groundwater flow were produced. A 10-foot linear source was chosen because it is an approximate average value of the working portion of a septic drainfield recognized Woessner et al. (1996) and by Ver Hey (1987). An 80-foot source was chosen to represent the simulated impact of a fully operational drainline.

East Site

The location of the East site is shown in figure 3.2. It is a residential area bound by North Avenue to the north, South Avenue to the south, 37th Avenue to the west, and

Tower to the east. The study site's eastern boundary is located one block west of Big Sky High School.

The land to the north and south of the study site is open and undeveloped. The land to the east comprises Big Sky High School and to the west is a residential neighborhood. The topography of the site is flat.

Approximately 60 acres, or 2,600,000 square feet, comprised the East Site. The site has 63 homes. Presently there is one half block that is undeveloped grassland, otherwise all other lots are developed. On average, there is approximately one home per acre (figure 5.15).

The potentiometric surface, for the monitoring network (figure 5.16), for September, 1994 is shown on figure 5.17. Direction of groundwater flow was from the east-northeast to the west-southwest. A hydraulic gradient of 0.001 was measured for this month. Water level measurement methodology is given in Woessner et al. (1996). Complete groundwater level measurements are given in Appendix G. The water table is approximately 23 ft below land surface.

The multi-level monitoring wells for this site sampled groundwater approximately 1-14 ft. below the water table, while domestic wells sampled 40-60 ft. below the water table. The well inventory is given in Appendix F.

The chloride concentration configuration is shown in figure 5.18. Concentrations in the shallow groundwater, measured by the multi-level monitoring wells (construction details and well depths are given in Appendix F), are slightly higher than the deeper water sampled by the domestic wells. The high concentrations measured in 1M103 are

Location of Homes within East site Missoula, MT

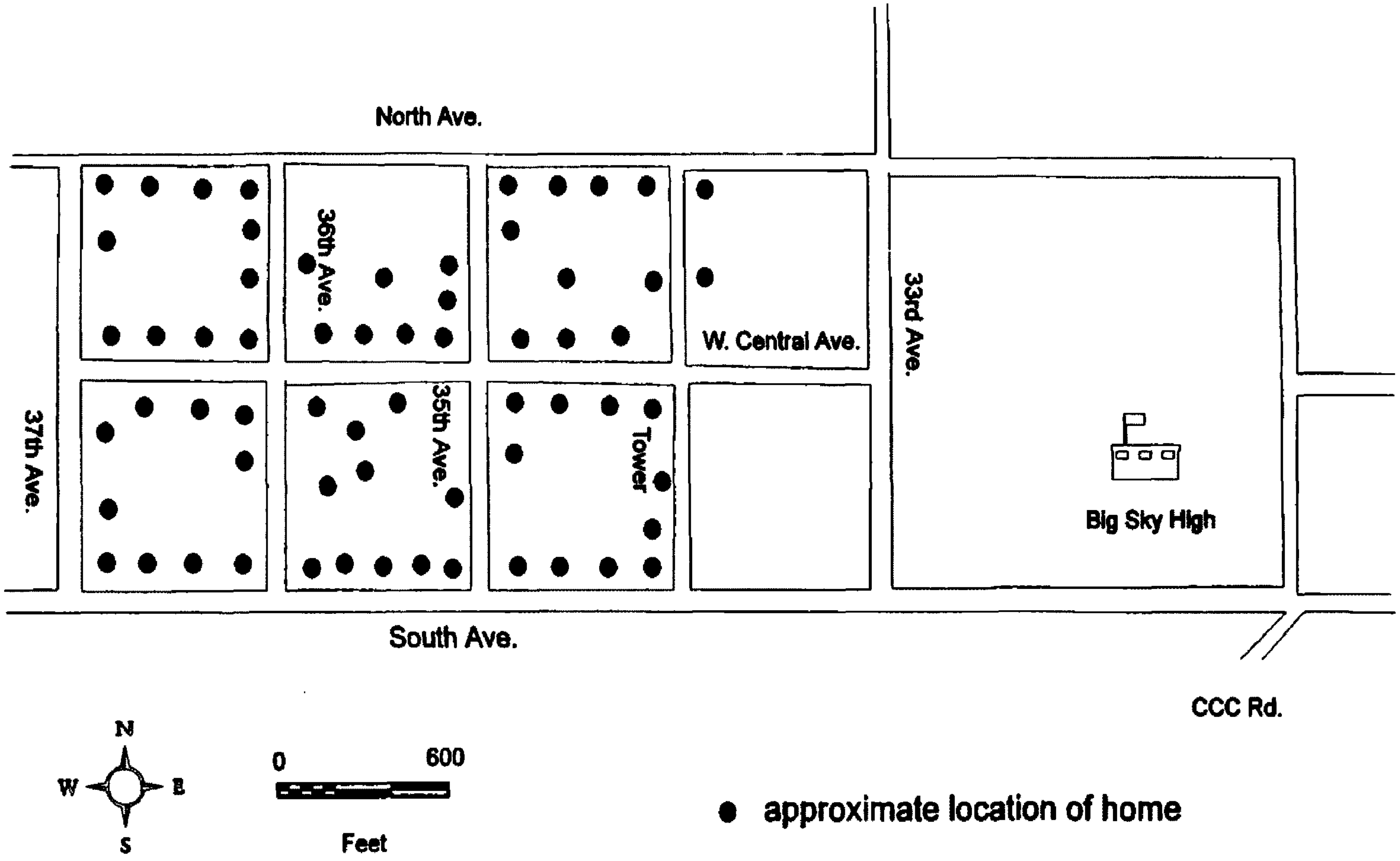


Figure 5.15

Monitoring Network, East Site, Missoula, MT

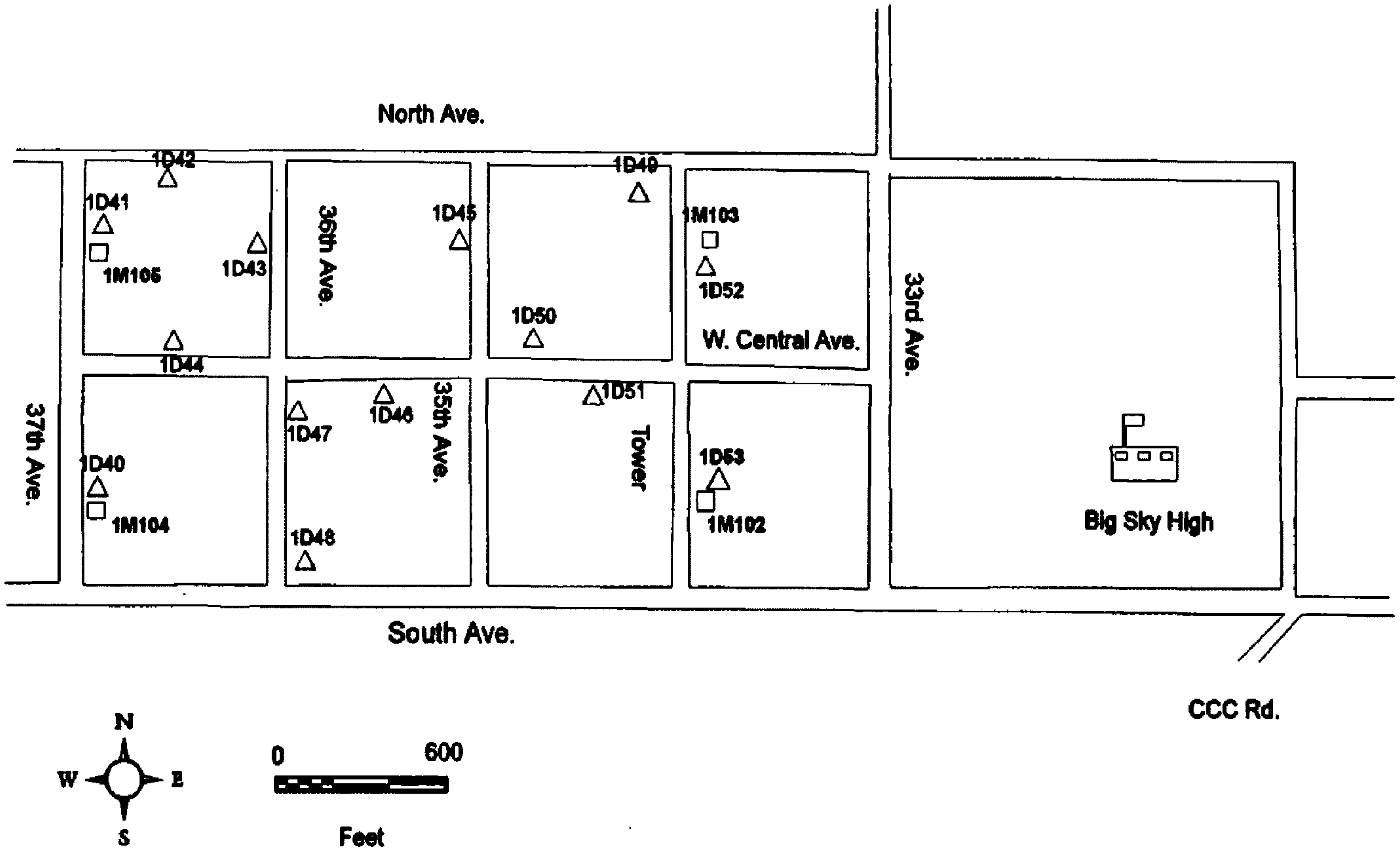


Figure 5.16

Potentiometric Surface for September 1994, East Site, Missoula, MT

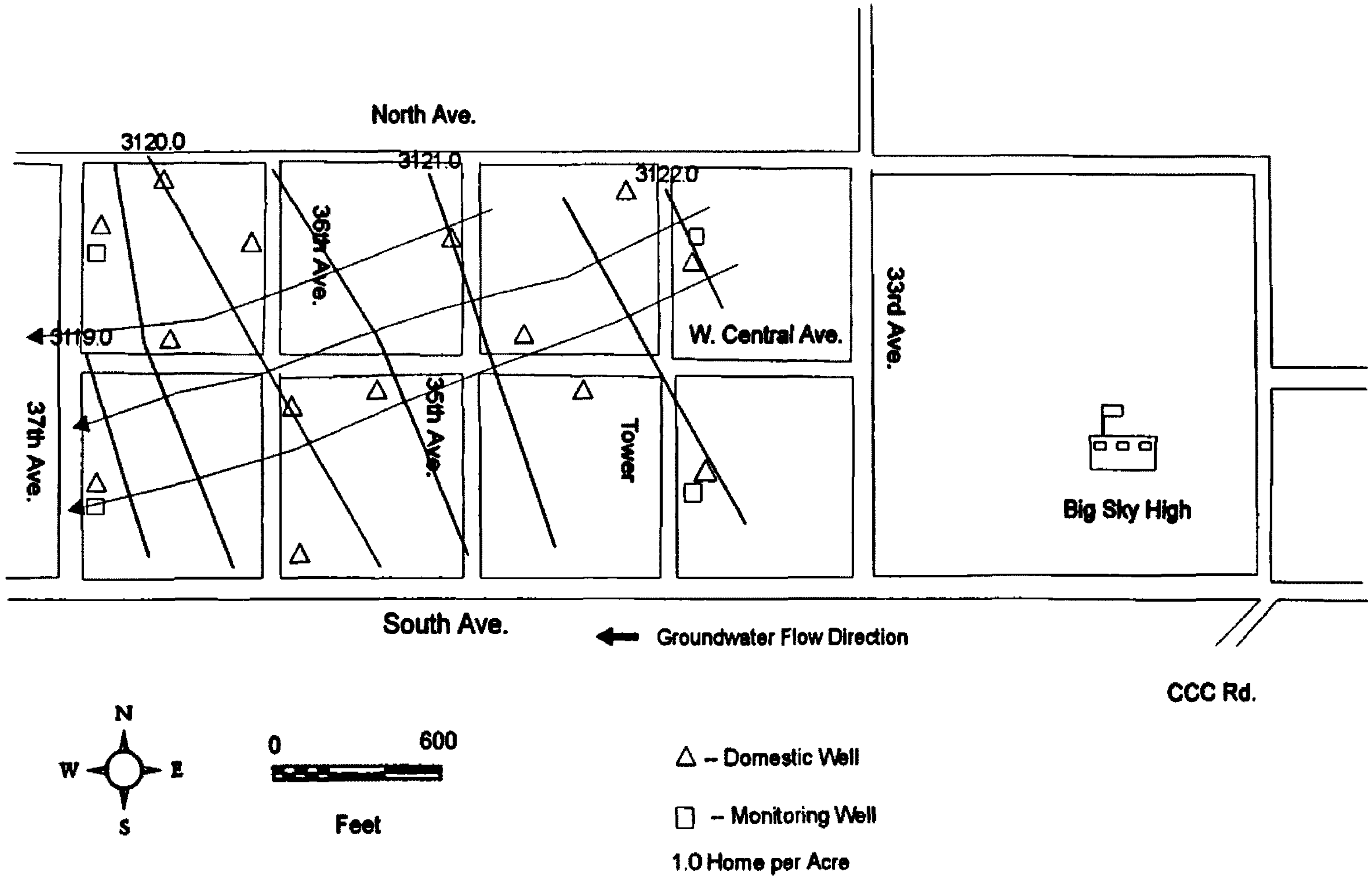


Figure 5.17

Chloride Concentrations in the Groundwater for September 1994 East Site, Missoula, Montana

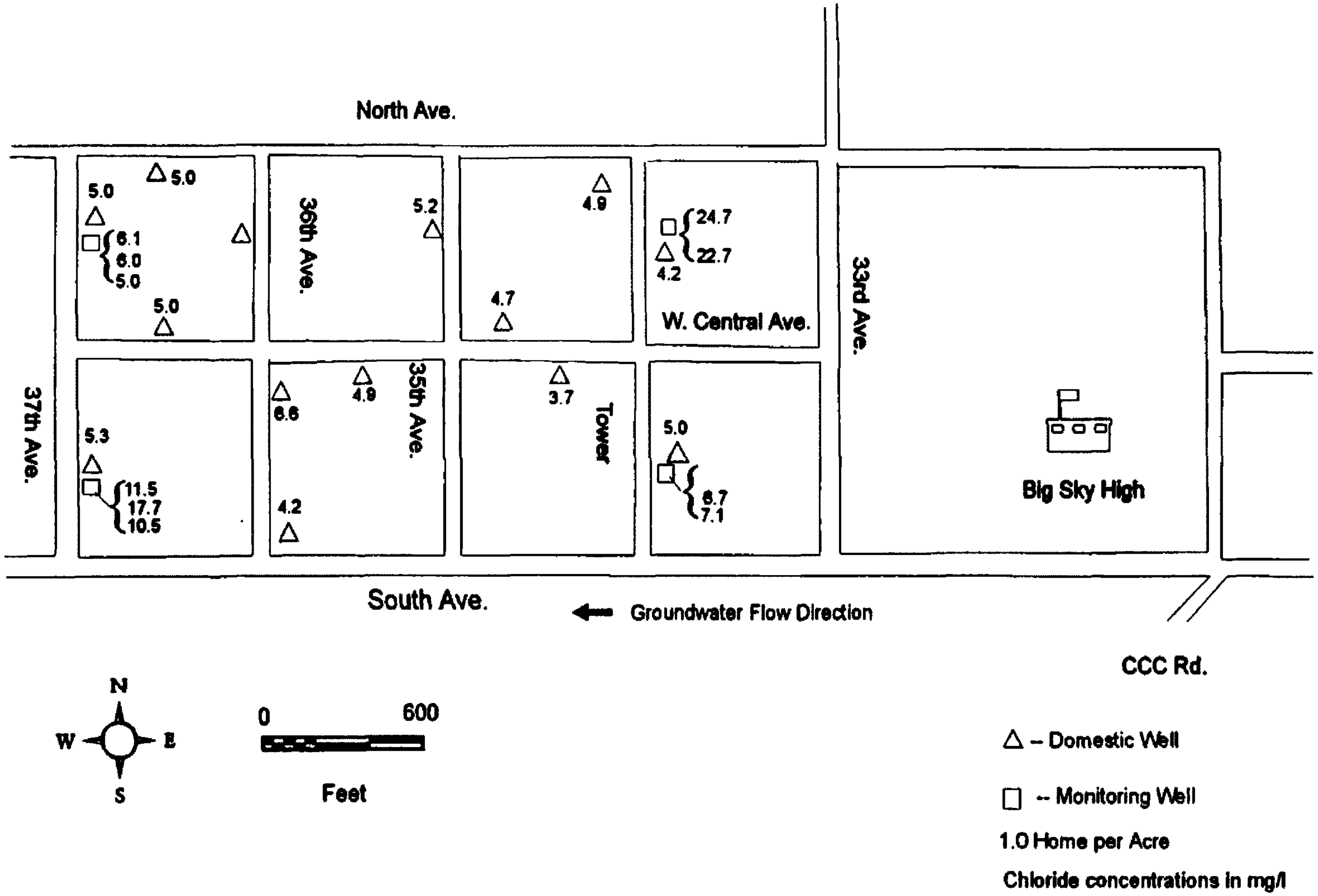


Figure 5.18

suspected to be influenced by an upgradient drainfield releasing water softener salts. It was assumed that chloride concentrations increased by approximately 5-6 mg/l as water traveled through the site (comparing concentrations measured in 1M102 to 1M104). Concentrations did not appear to vary downgradient within the domestic wells, which can most likely be attributed to the limited mixing of the groundwater near the water table with the deeper groundwater.

The nitrate-N concentration configuration is shown in figure 5.19. Concentrations did not appear to vary downgradient within either the shallow monitoring wells or the deeper domestic wells. General groundwater chemistry, for this site, is included in Appendix H.

West Site

The location of the West Site is shown in figure 3.2. It is a residential area bounded by North, Humble, and Edward Avenues. It is located immediately east of the Bitterroot River and immediately northeast of the Maclay Bridge.

The West Site is located on a fluvial bench that rises approximately 15-20 feet above the adjacent Bitterroot floodplain, which is located to the west and north of the site. This portion of the floodplain is presently used as alfalfa cropland in the spring and summer, and as cattle grazing land in the fall and winter. The land immediately east and south of the site is also residential neighborhood located on the same fluvial bench. The topography of the bench is relatively flat.

Nitrate-Nitrogen Concentrations in the Groundwater for September 1994 East Site, Missoula, Montana

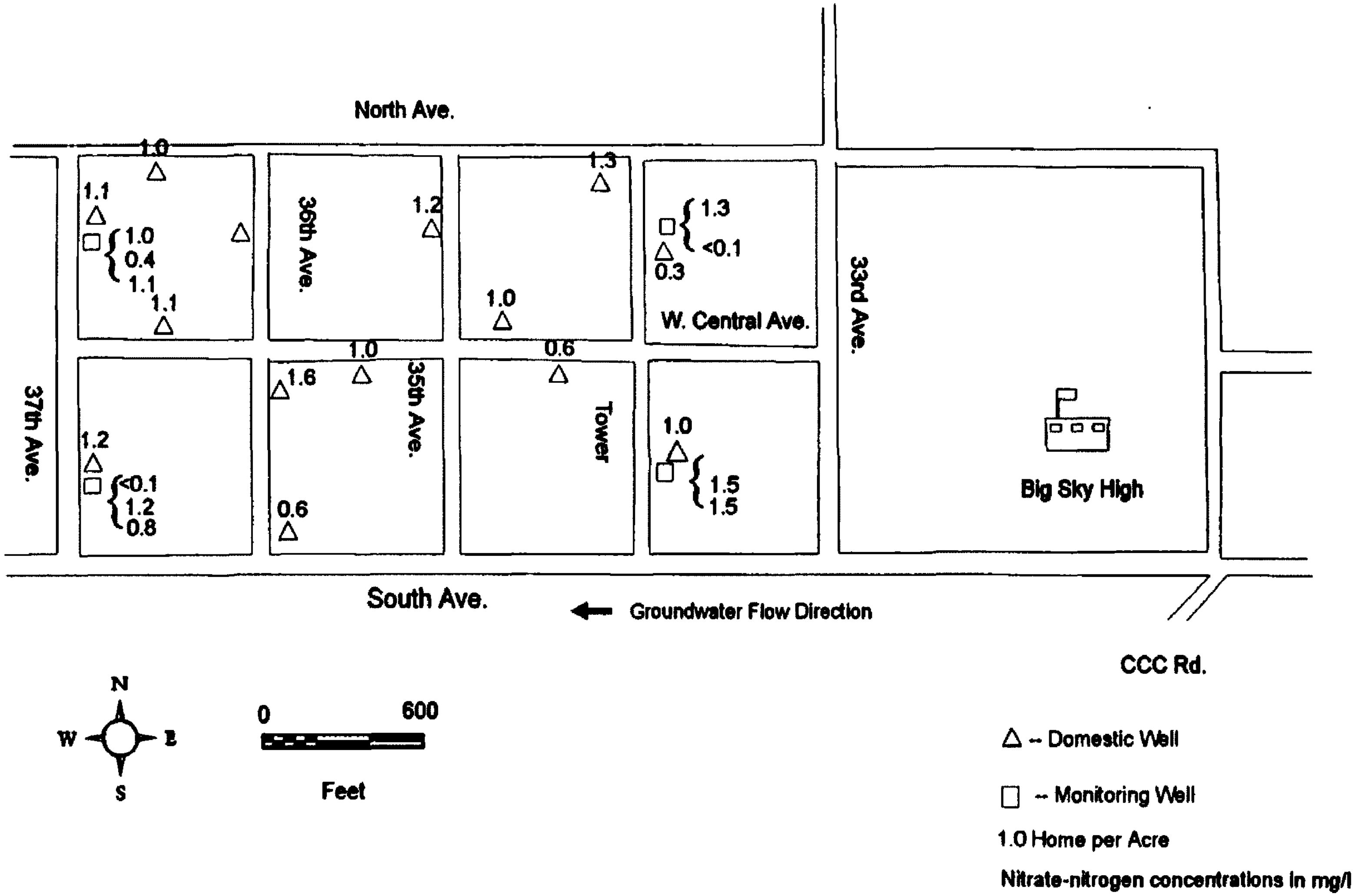


Figure 5.19

The West Site comprises an area of approximately 550,000 square feet. It has 31 lots and each lot is approximately 0.45 acres. There is presently one home per lot. The housing density is approximately 1.9 homes per acre (figure 5.20).

The potentiometric surface, for the monitoring network (figure 5.21), for August, 1994 is shown in figure 5.22. Groundwater flowed downgradient from the east to west. The site had a hydraulic gradient of 0.006. Water level measurement methodology is given in Woessner et al. (1996). Additional groundwater level measurements are given in Appendix G. The water table is approximately 20 ft below land surface.

The multi-level monitoring wells for this site sampled groundwater approximately 3-18 ft. below the water table, while domestic wells sampled 40-100 ft. below the water table. The well inventory is given in Appendix F.

The chloride configuration is given in figure 5.23. Concentrations in the shallow groundwater are slightly higher than the deeper groundwater, 4-6 mg/l for the shallow groundwater compared to 4-5 mg/l for the deeper groundwater. Chloride concentrations increase slightly downgradient through the site. The monitoring well 1M100 had concentrations 3.4-4.1 mg/l, while 1P100 had a value of 6.4 mg/l. There was no apparent increase in concentrations within the deeper domestic wells as was observed in the East site.

The nitrate-N configuration is given in figure 5.24. Concentrations in the shallow groundwater do not appear to be different from the concentrations measured in the deeper groundwater. Nitrate-N concentrations do not appear to differ downgradient through the site. General groundwater chemistry, for this site, is included in Appendix H.

Location of Homes within West Site, Missoula, MT

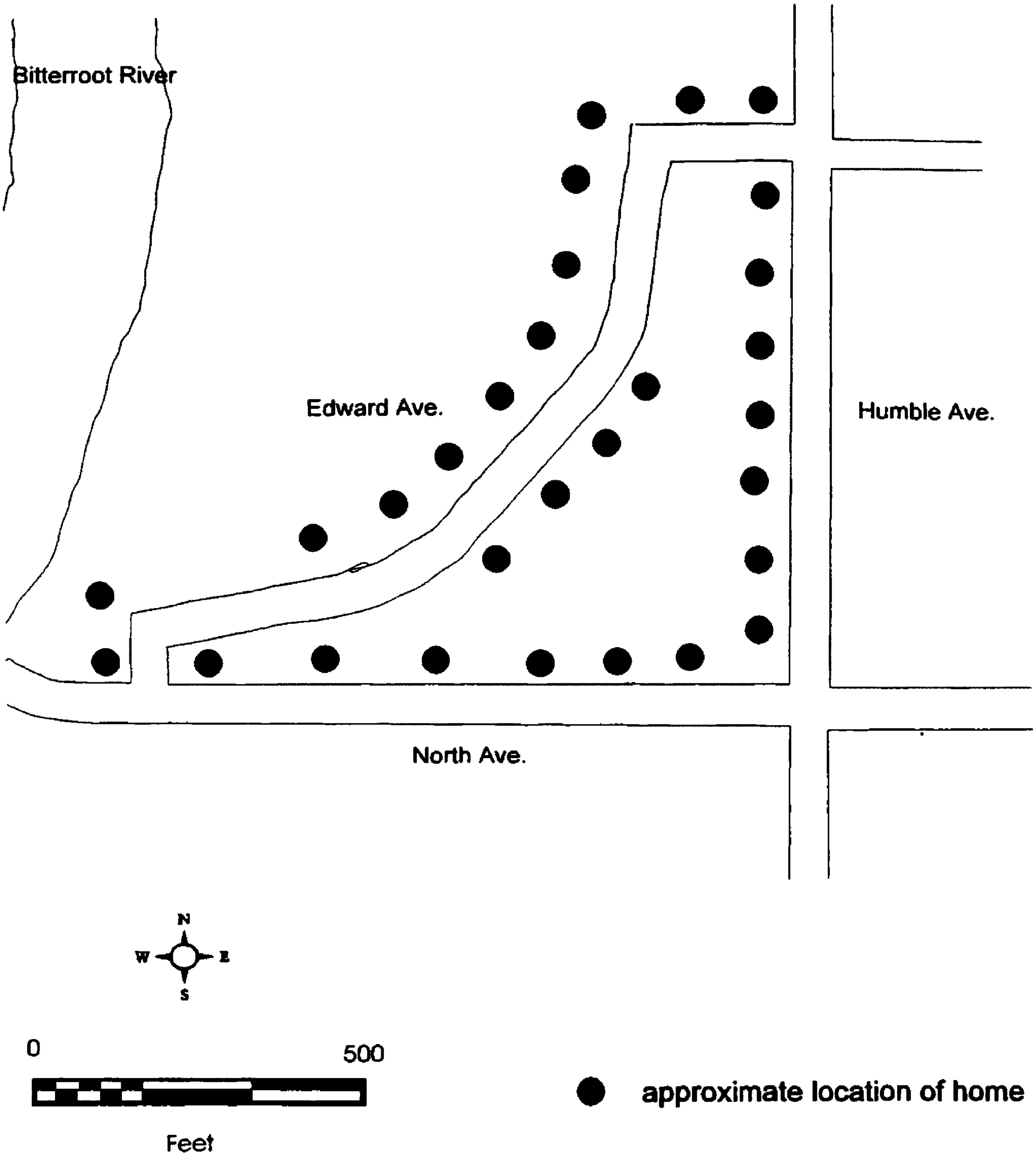


Figure 5.20

Monitoring Network West Site, Missoula, MT

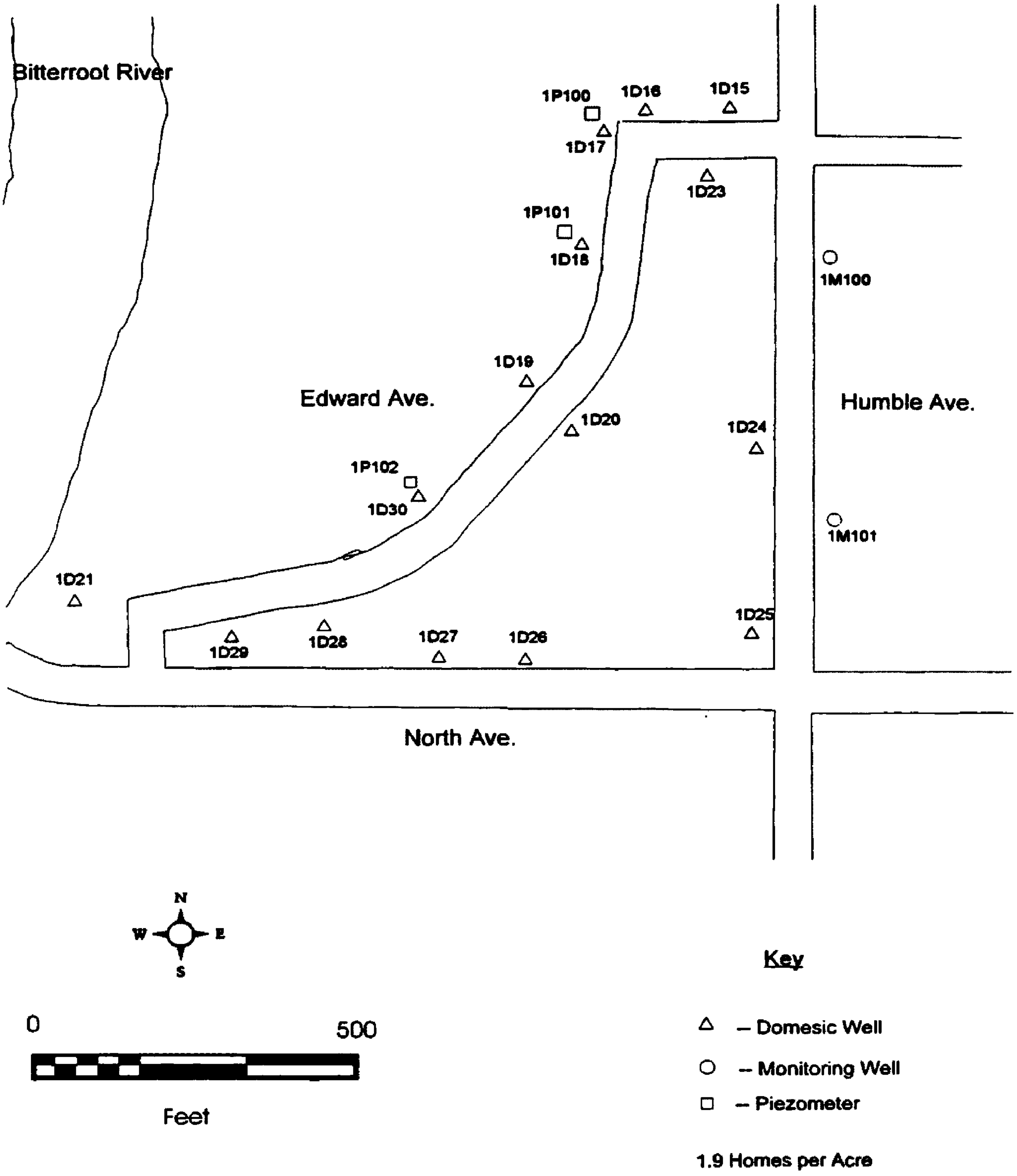


Figure 5.21

Potentiometric Surface for August 1994
West Site, Missoula, MT

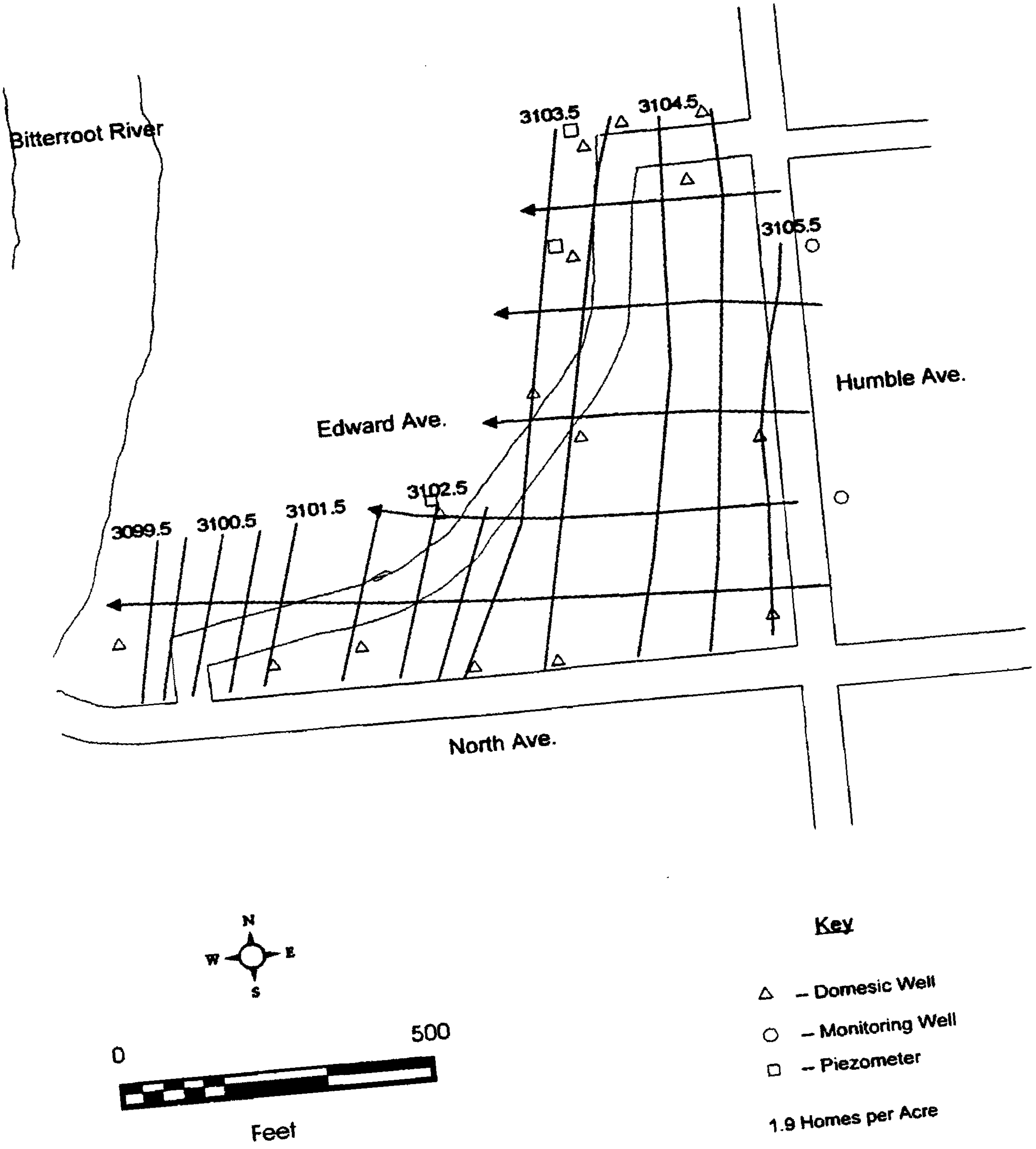


Figure 5.22

Chloride Concentrations in the Groundwater for September 1994 West Site, Missoula, Montana

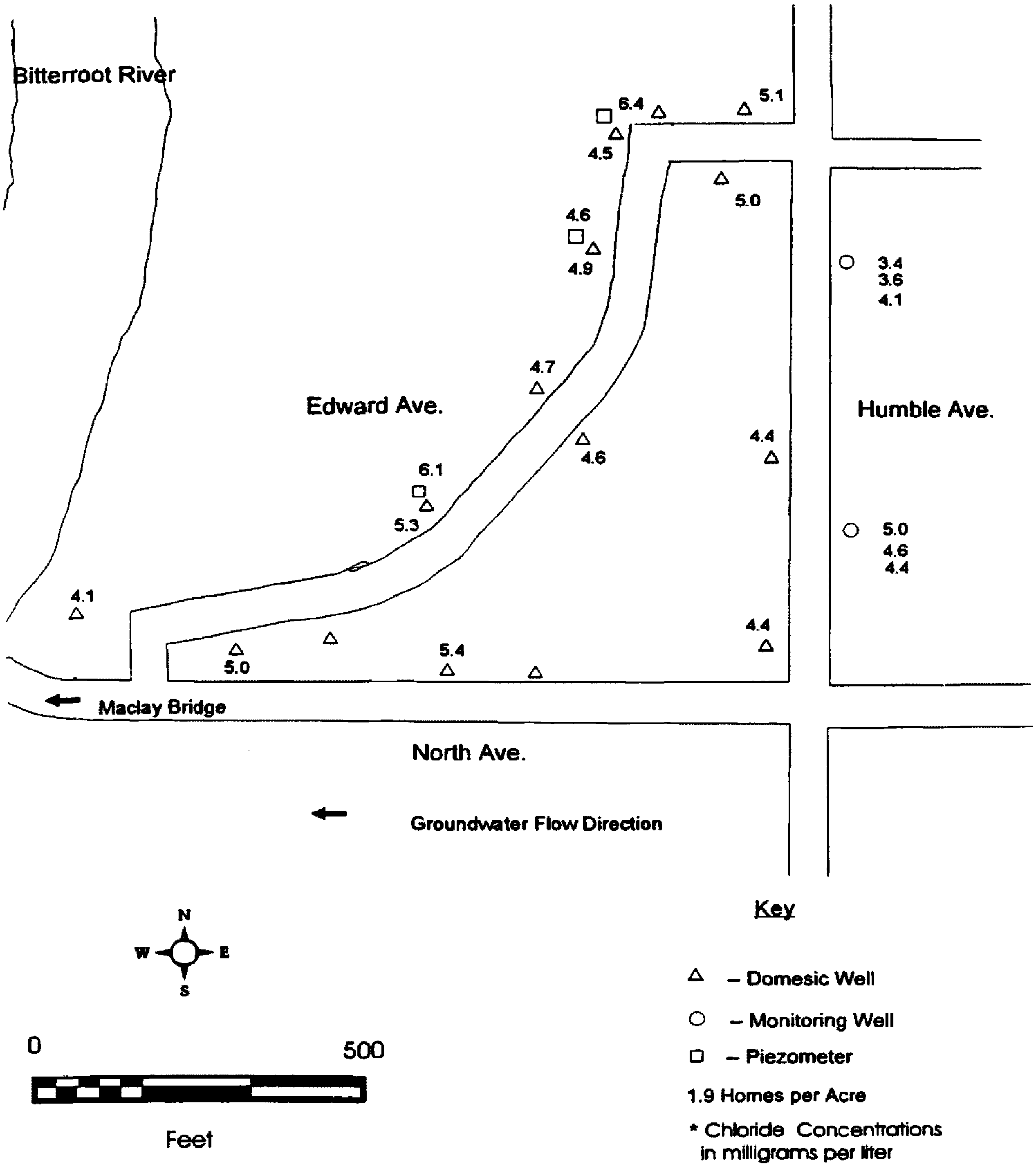


Figure 5.23

Nitrate-Nitrogen Concentrations in the Groundwater for September 1994 West Site, Missoula, Montana

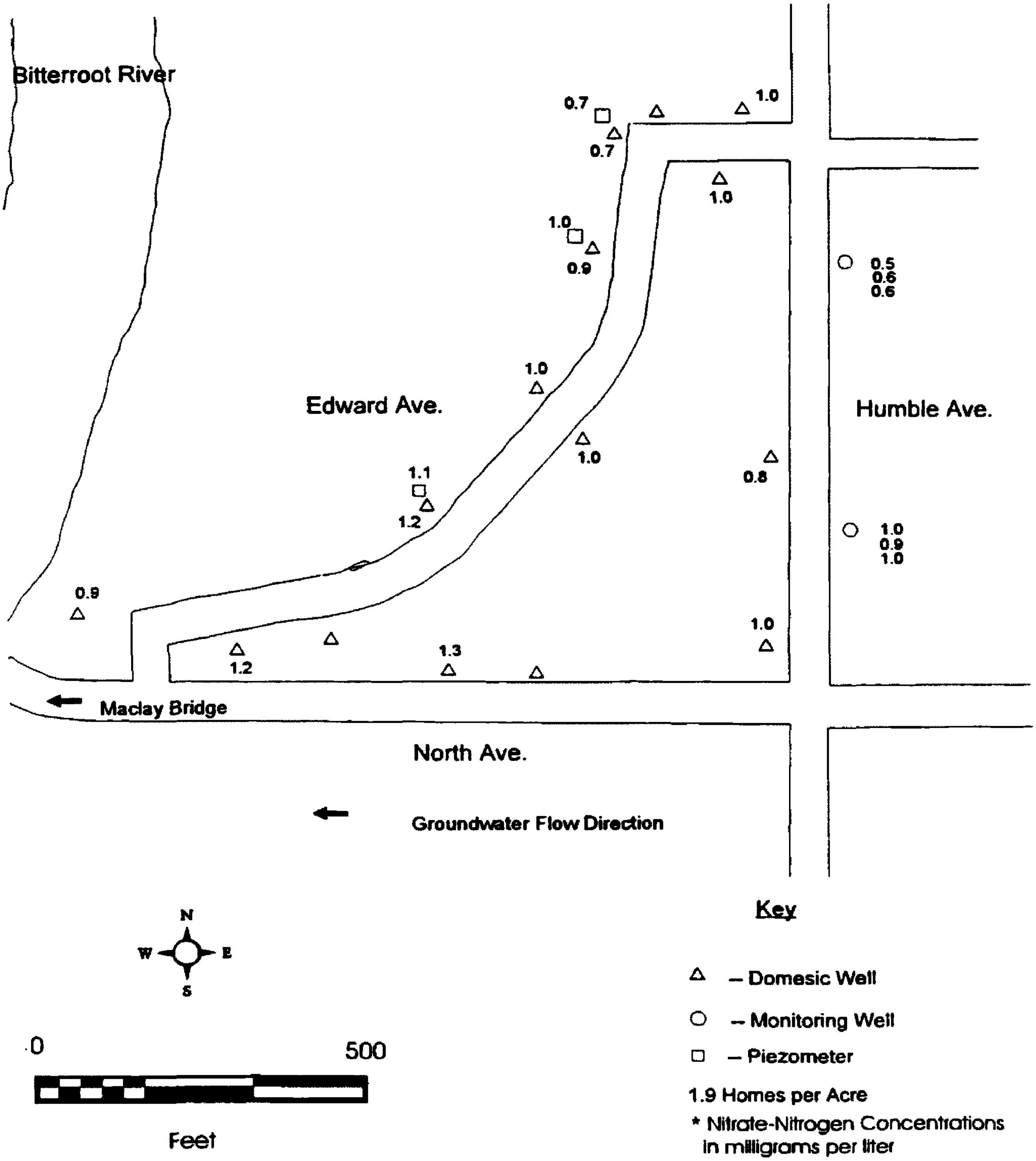


Figure 5.24

Individual chloride and nitrate-N plumes found within the East and West Sites were assumed to resemble the simulated chloride and nitrate-N plume of the South Site. It was presumed an average plume emitted in the cumulative sites would have one-half the chloride and nitrate-N concentration of the individual home plume. This was based on waste generation of an average household of 3 instead of the 6 found at the South Site. An identical three-person derived chloride and nitrate-N plume were assumed to be released by each home within the two sites.

The cumulative effects of multiple septic system operation on the shallow water table aquifer was evaluated by superimposing plumes generated for each source into a cumulative plume. Output files of a 750 day plume, assumed to be generated from a single 3 person household, were set within a grid created for the study area. Plumes were created at each septic system location within the study sites. The East Site has a total of 63 septic systems, while the West Site has 29. The West Site has a larger septic density than the East Site, 1.9 septic systems per acre compared to 1.0 per acre. Details of the cumulative simulation process are found in Appendix D.

Cumulative Results

Modeling results were compared to water quality sampling of domestic wells and monitoring wells located within the cumulative sites. Domestic wells extract groundwater significantly below the water table and may not produce representative samples of water quality in the shallow mixing zone.

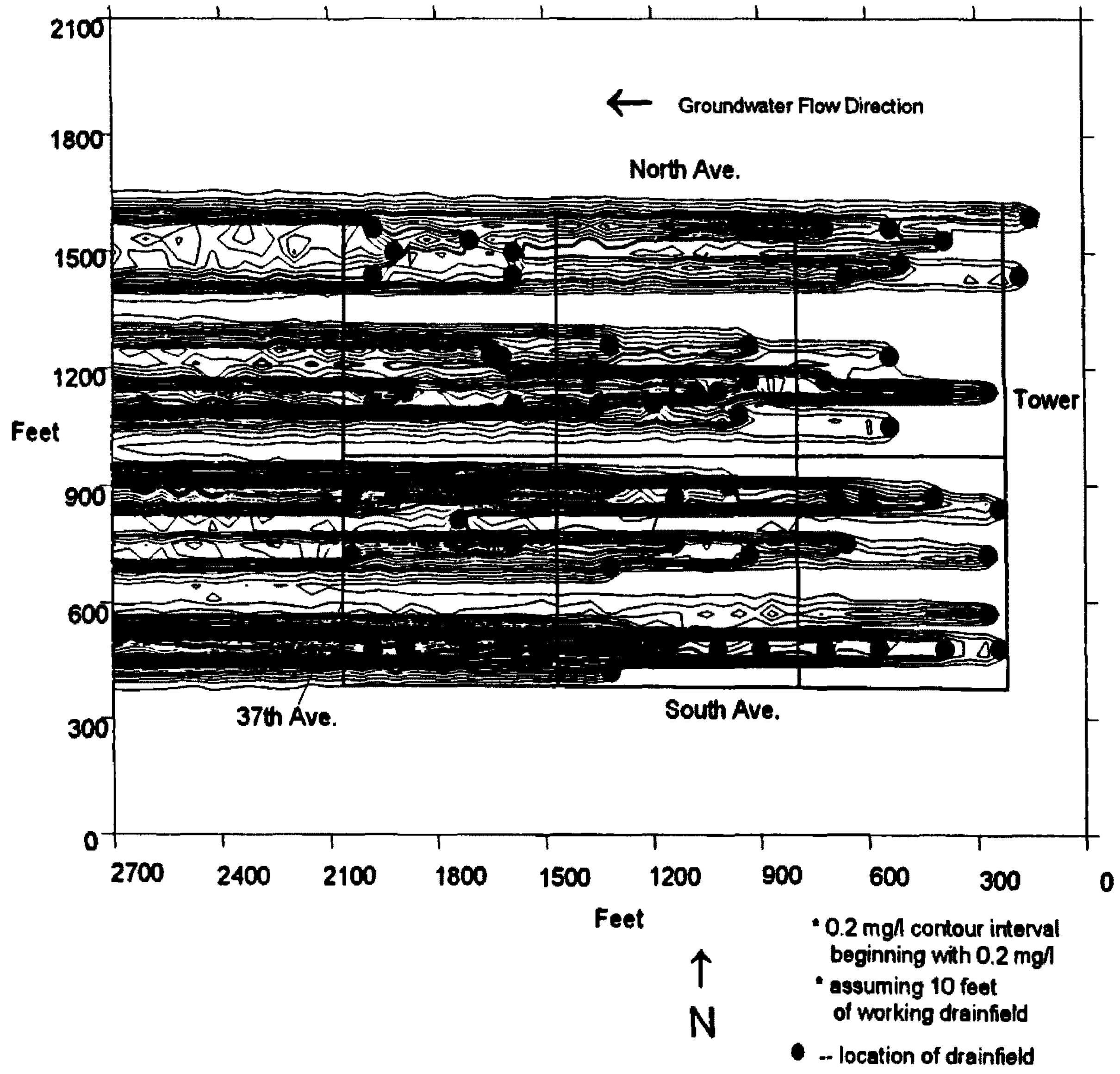
Missoula Sites

Approach #1

The multi-chloride plume configuration for the Missoula cumulative study areas for 10 feet of working drainfield is shown in figures 5.25, 5.26, 5.27, and 5.28. The contours represent chloride concentrations in the mixing zones just below the water table, 7.5 feet within the Missoula sites.

The two Missoula sites have identical simulated hydraulic properties and run time but dissimilar simulated cumulative chloride plumes. The differences, on a large scale, result from the position and number of septic systems. A larger number of septic systems within an area seems to have a greater effect on chloride concentrations in the groundwater, on a large scale (neighborhood), than septic system density within this particular environment and these septic densities. Simulated high concentrations dissipated down-gradient away from the sources but, in general, concentrations increase as the groundwater is transmitted through the underlying aquifer beneath the sites.

The smaller scale plots depict the most elevated chloride concentrations for both sites to be located in areas where a number of septic systems are consecutively aligned within the same groundwater flowpath. This resulted from the overlap of multiple individual plumes. At these locations concentrations were simulated to be up to 4.2 mg/l above background in the West site, and 6 mg/l above background in the East site. Concentrations were modeled to persist, 0.5 mg/l above background, approximately 8500 feet downgradient from the source within the East site, and approximately 8000 feet for



Cumulative Simulation of Chloride Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--East Site Missoula, MT

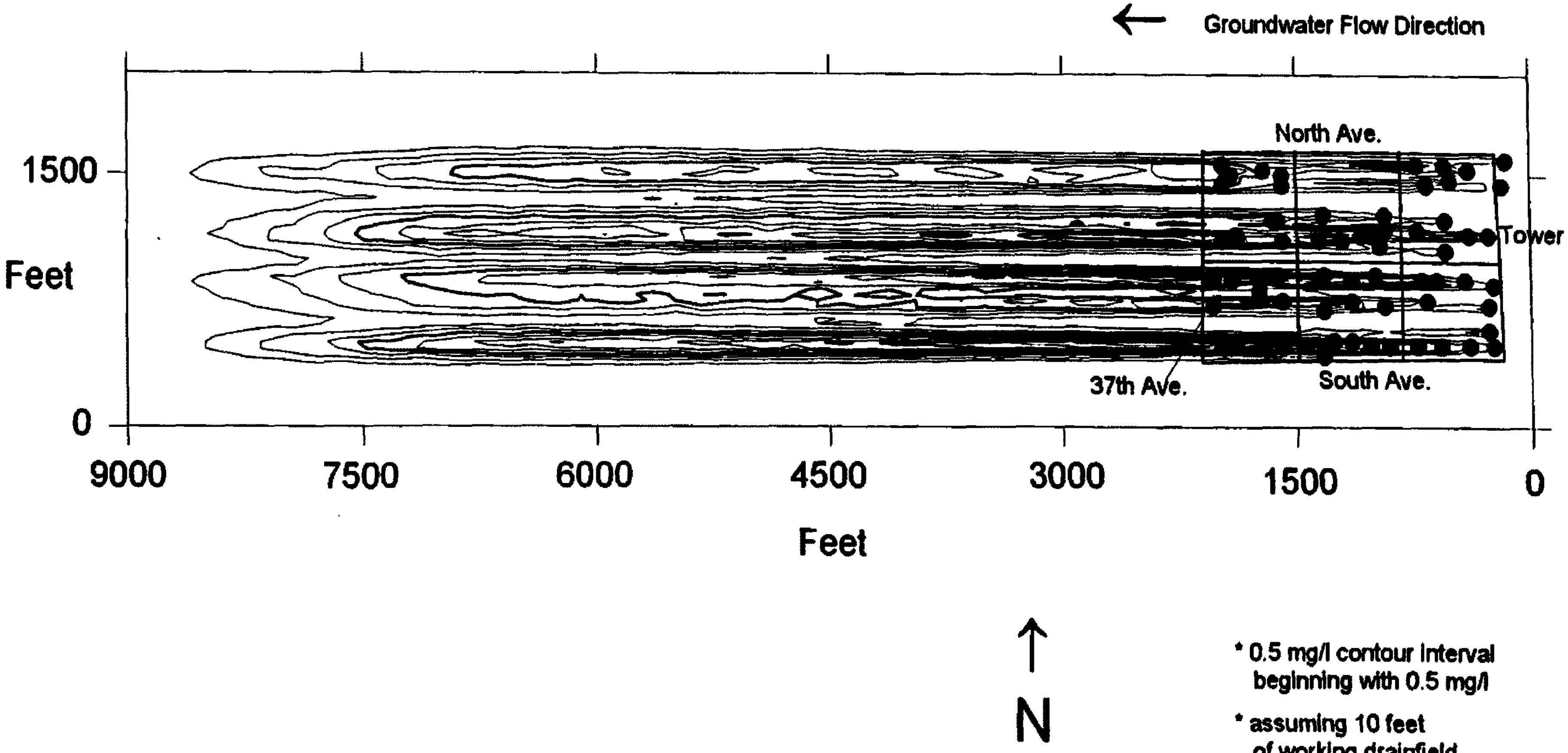
* 0.2 mg/l contour interval beginning with 0.2 mg/l

* assuming 10 feet of working drainfield

● -- location of drainfield

Figure 5.25

Cumulative Simulation of Chloride Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--East Site Missoula, MT



* 0.5 mg/l contour interval beginning with 0.5 mg/l

* assuming 10 feet of working drainfield

● -- location of drainfield

Figure 5.26

Cumulative Simulation of Chloride Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--West Site Missoula, MT

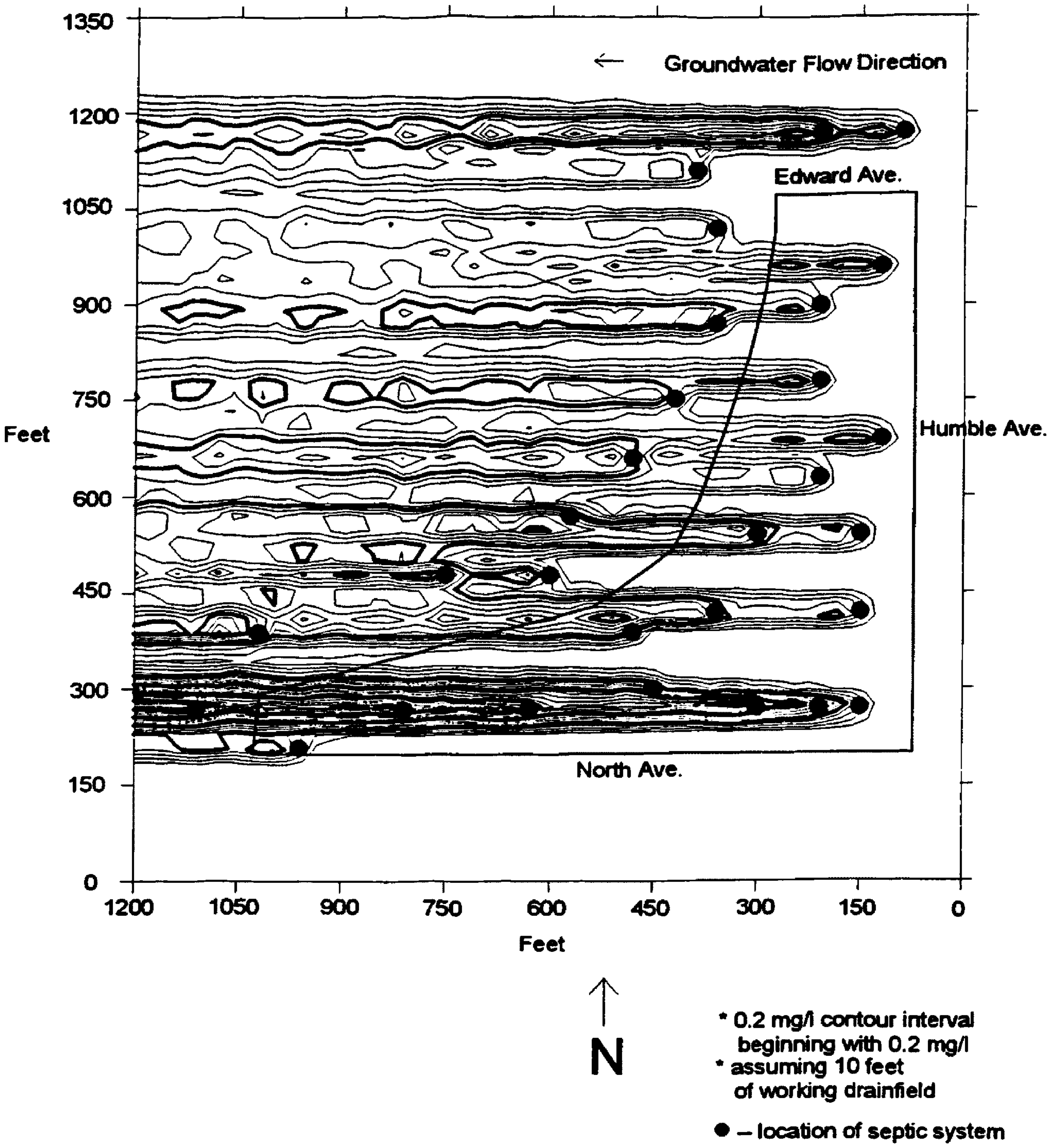
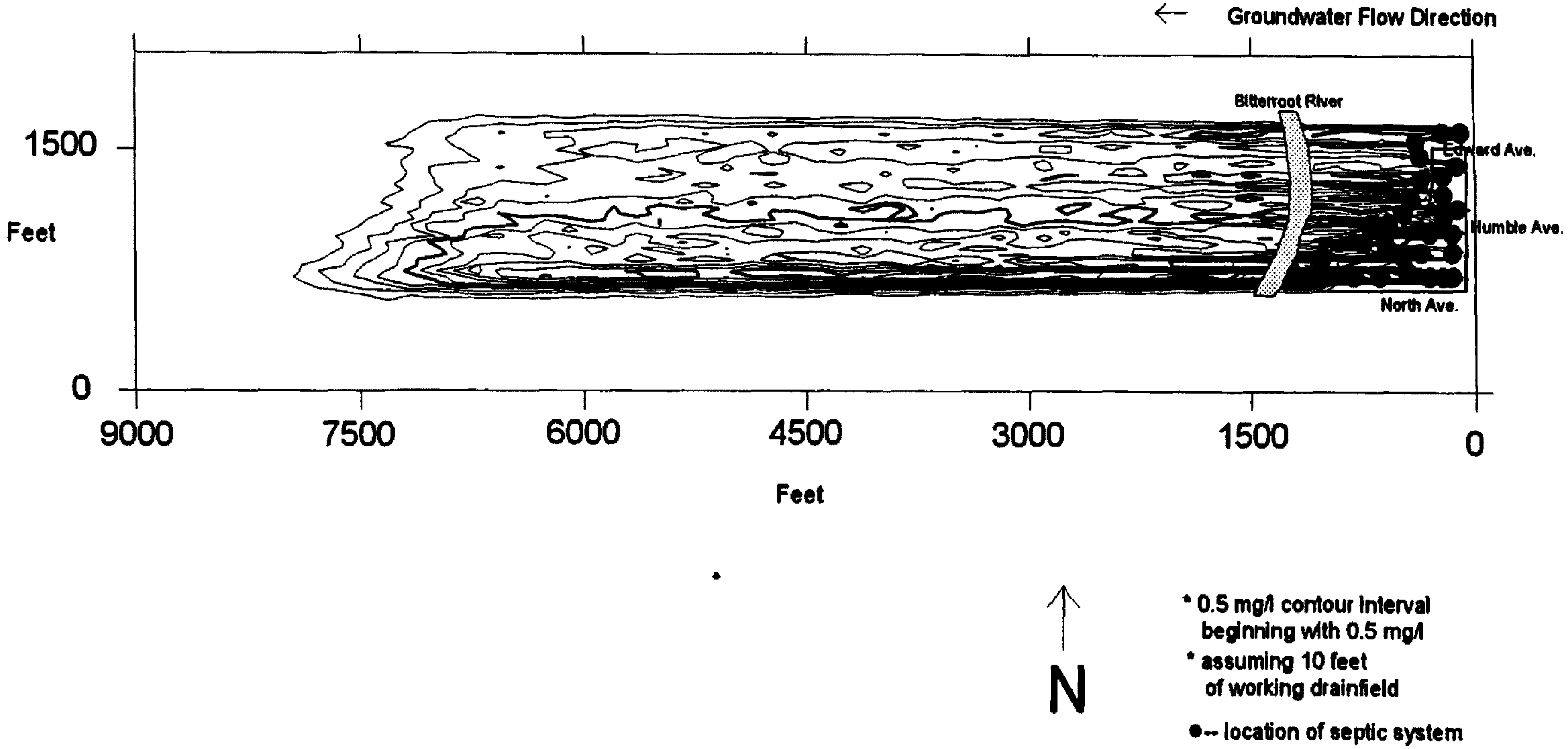


Figure 5.27

Cumulative Simulation of Chloride Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--West Site, Missoula, MT



* 0.5 mg/l contour interval beginning with 0.5 mg/l

* assuming 10 feet of working drainfield

●-- location of septic system

Figure 5.28

the West site. The width of the cumulative plume was the approximate width of the cumulative site.

The simulated chloride concentrations do resemble the field measured concentrations. According to the simulated concentration for the East Site, the groundwater should have a concentration of approximately 0 mg/l and 2 mg/l above background in the vicinity of the downgradient monitoring wells, 1M104 and 1M105, respectively. Field measurements of these wells yielded concentrations that were approximately background in 1M105 and 4-9 mg/l for 1M104, for both sampling events (figure 5.18). Background was assumed to be the concentrations measured in the mixing zone of monitoring well 1M102, approximately 7 mg/l. The simulation predicts the chloride concentration within 1M105 very well, but not as well for 1M104. This may be caused by unaccounted heterogeneities and/or homes serviced by water softeners not considered by the model and may have resulted in the higher concentrations measured within the well during these sampling events.

The chloride concentrations simulated in the West Site are approximately 1.4, 0.6, and 1.4 mg/l for the downgradient piezometers, 1P100, 1P101, and 1P102, respectively. Field measurements yielded values of 2.4, 0.4, and 2.6 mg/l above background in 1P100, 1P101, and 1P102, respectively. Background was assumed to be the concentrations measured in the up-gradient monitoring wells, 1M100 and 1M101. The simulated concentrations predicted the field measured concentrations relatively well.

The multi-nitrate-N plume configuration for the Missoula cumulative-effects study areas for 10 feet of working drainfield is shown in figure 5.29, 5.30, 5.31, and 5.32. The

Cumulative Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--East Site Missoula, MT

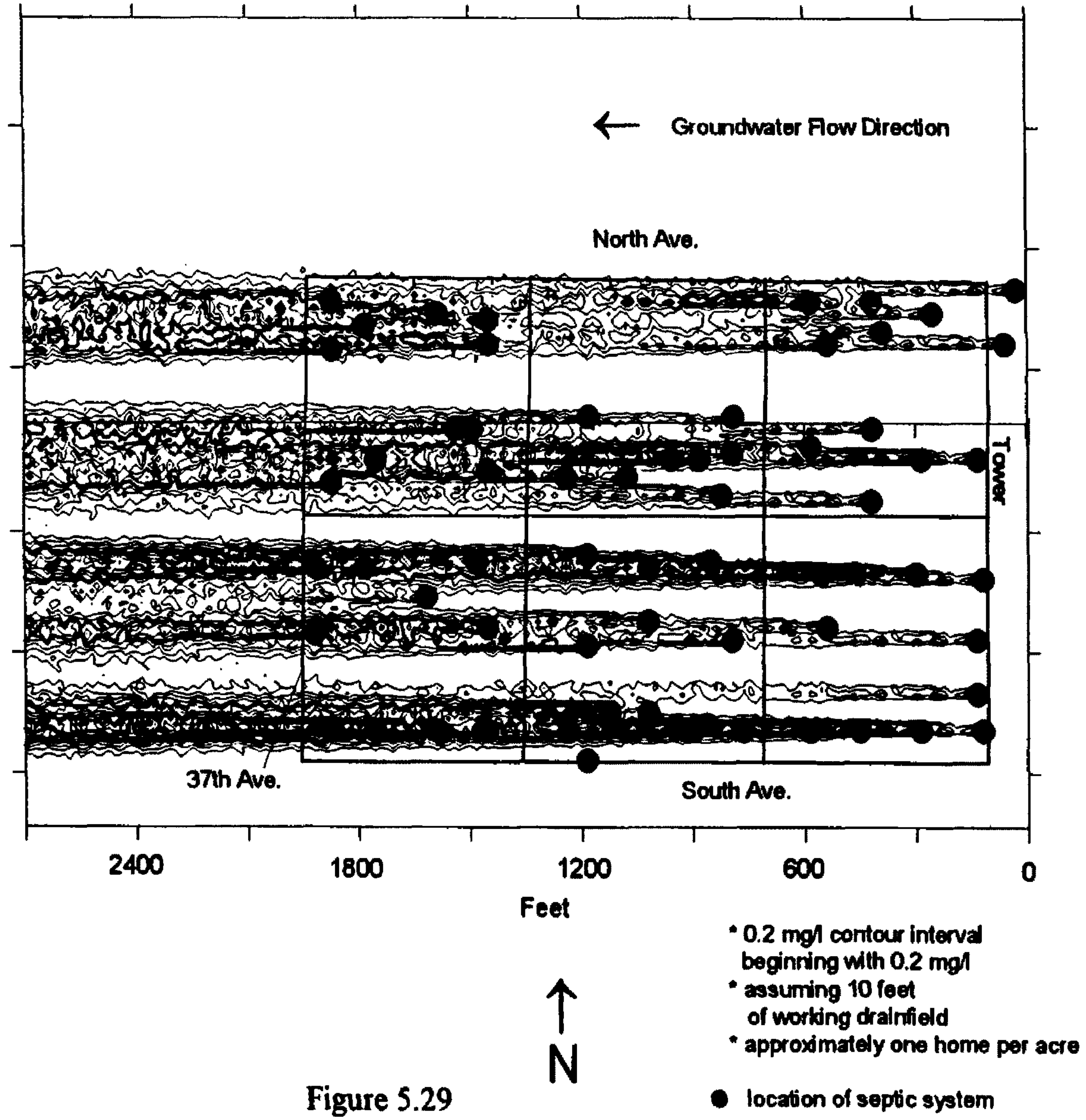


Figure 5.29

Cumulative Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--East Site Missoula, MT

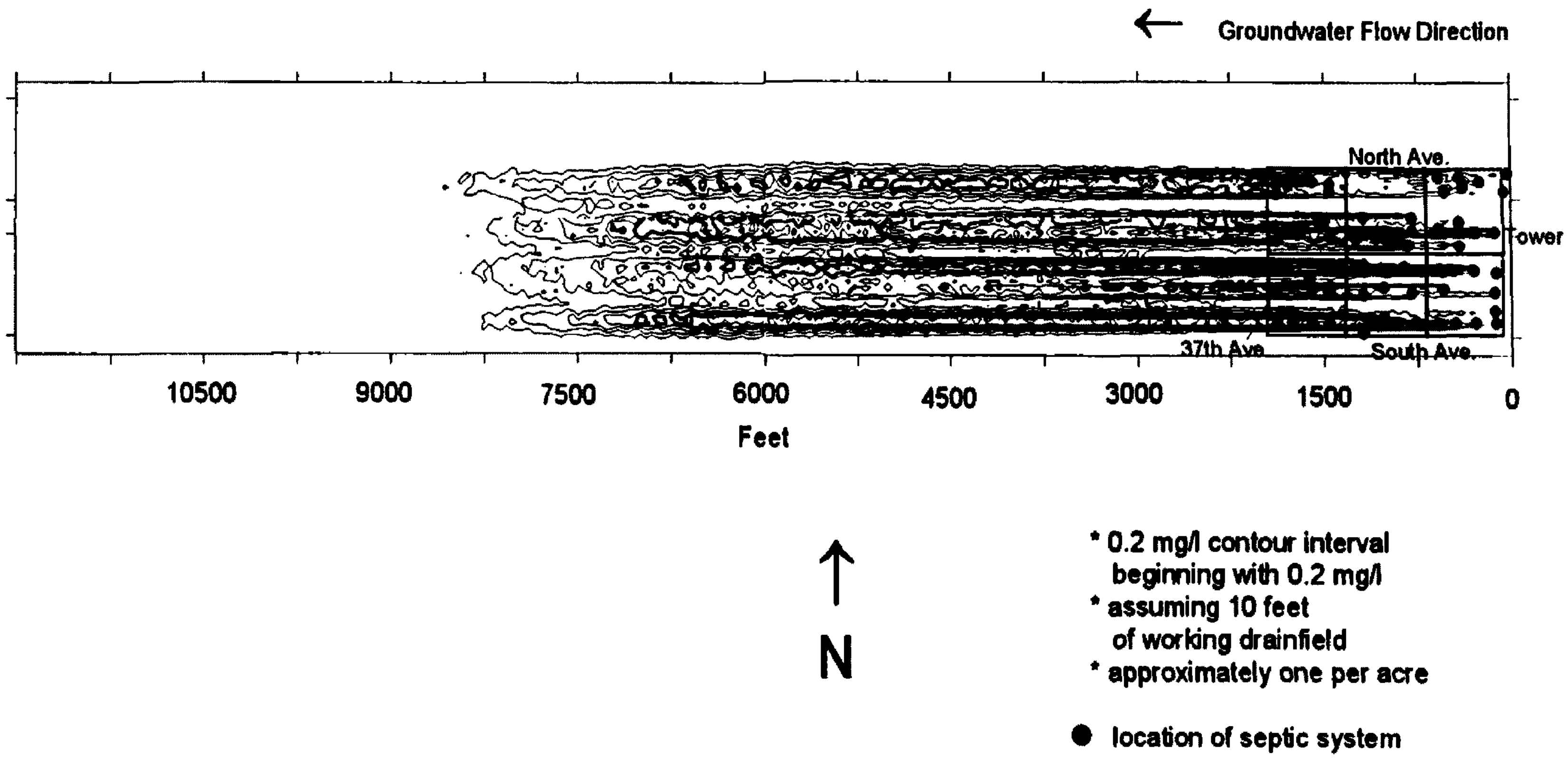
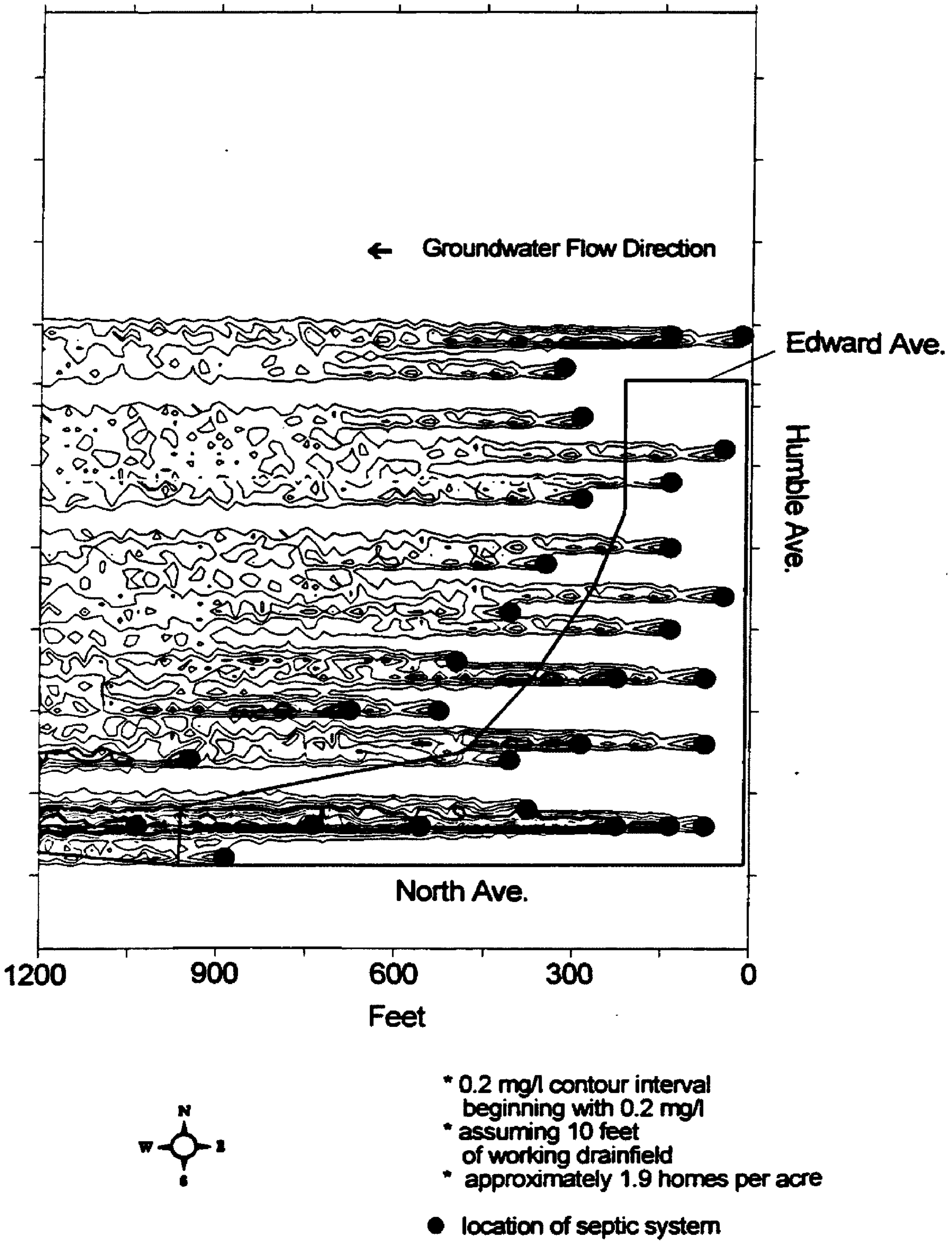


Figure 5.30

Cumulative Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of Groundwater After 750 Days–West Site Missoula, MT

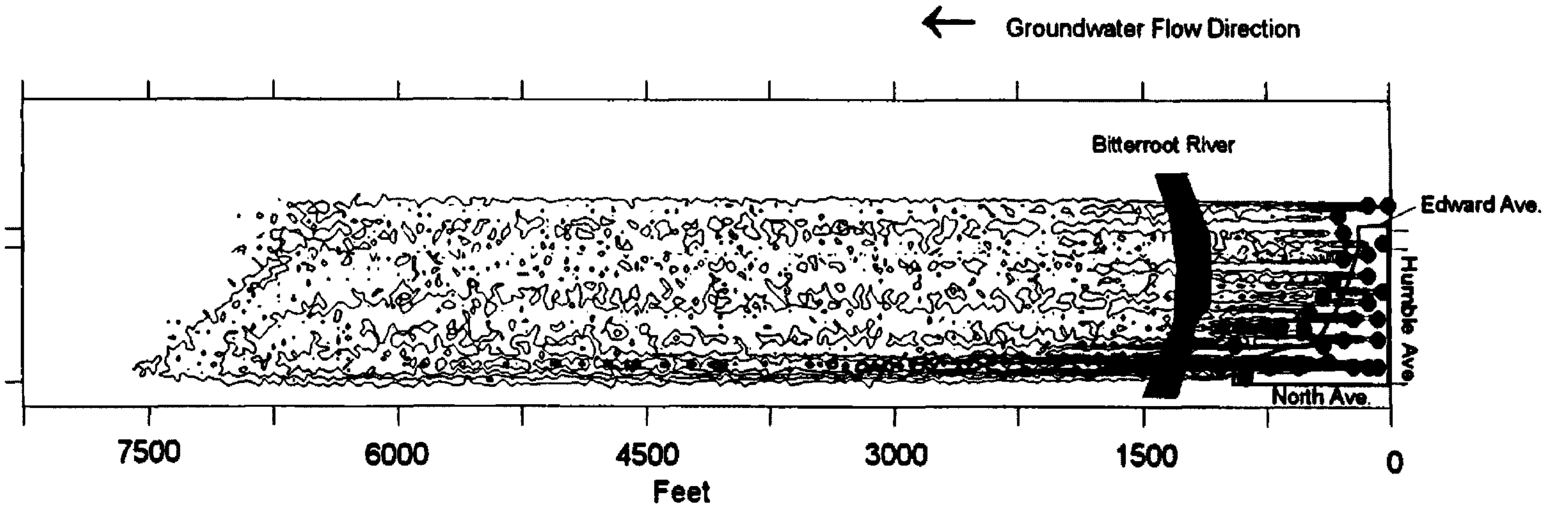


* 0.2 mg/l contour interval
  beginning with 0.2 mg/l
* assuming 10 feet
  of working drainfield
* approximately 1.9 homes per acre

● location of septic system

Figure 5.31

Cumulative Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--West Site Missoula, MT



*** 0.2 mg/l contour interval beginning with 0.2 mg/l**
*** assuming 10 feet of working drainfield**
*** approximately 1.9 homes per acre**

● location of septic system

Figure 5.32

contours represent nitrate-N concentrations in the mixing zones just below the water table, 7.5 feet within the Missoula sites.

The concentration configuration for nitrate-N resembles the configuration depicted by chloride. The most elevated concentrations are located where septic systems are aligned consecutively in the same general flowpath. Within these areas, concentrations as high as 3 mg/l for the East site and 2.6 mg/l for the West site were modeled. In general, the simulated nitrate-N concentrations were approximately 20-40% of the modeled chloride values. Larger scale plots depict concentrations 0.5 mg/l above background to persist approximately 7000 feet downgradient from the source within the West site, and 7500 feet for the East site. The width of the cumulative plume was the approximate width of the cumulative-effects sites.

Nitrate-N field measured concentrations did not vary from the upgradient wells to the downgradient wells within either of the Missoula sites. Modeled nitrate-N concentrations were simulated to increase through the site. This may be explained by the location of the downgradient monitoring wells. The wells may be located in unimpacted areas of the sites, or possibly nitrate is continuing to act non-conservatively at distances greater than 100 ft downgradient from the septic drainfield.

Approach #2

The second cumulative simulation was to model the cumulative impacts associated when each septic system has 80 feet of working drainline. An 80-foot source was chosen to represent the simulated impact of a fully operational septic system.

The multi-chloride plume configuration for the Missoula cumulative-effects study areas for 80 feet of working drainfield is shown in figures 5.33, 5.34, 5.35, and 5.36. The figures depict the same relative concentration pattern seen when the simulated drainline was 10 feet, that is the most elevated concentrations associated in areas where there are a number of septic systems consecutively aligned within the same groundwater flowpath. The differences between the 10 and 80-foot simulations is the 80-foot simulations depict an approximate 50% decrease in chloride concentrations, roughly 40% increase in plume width, and a slight (500 feet) decrease in plume length. An identical pattern is apparent for nitrate-N behavior (figures 5.37, 5.38, 5.39, and 5.40).

Approach #3

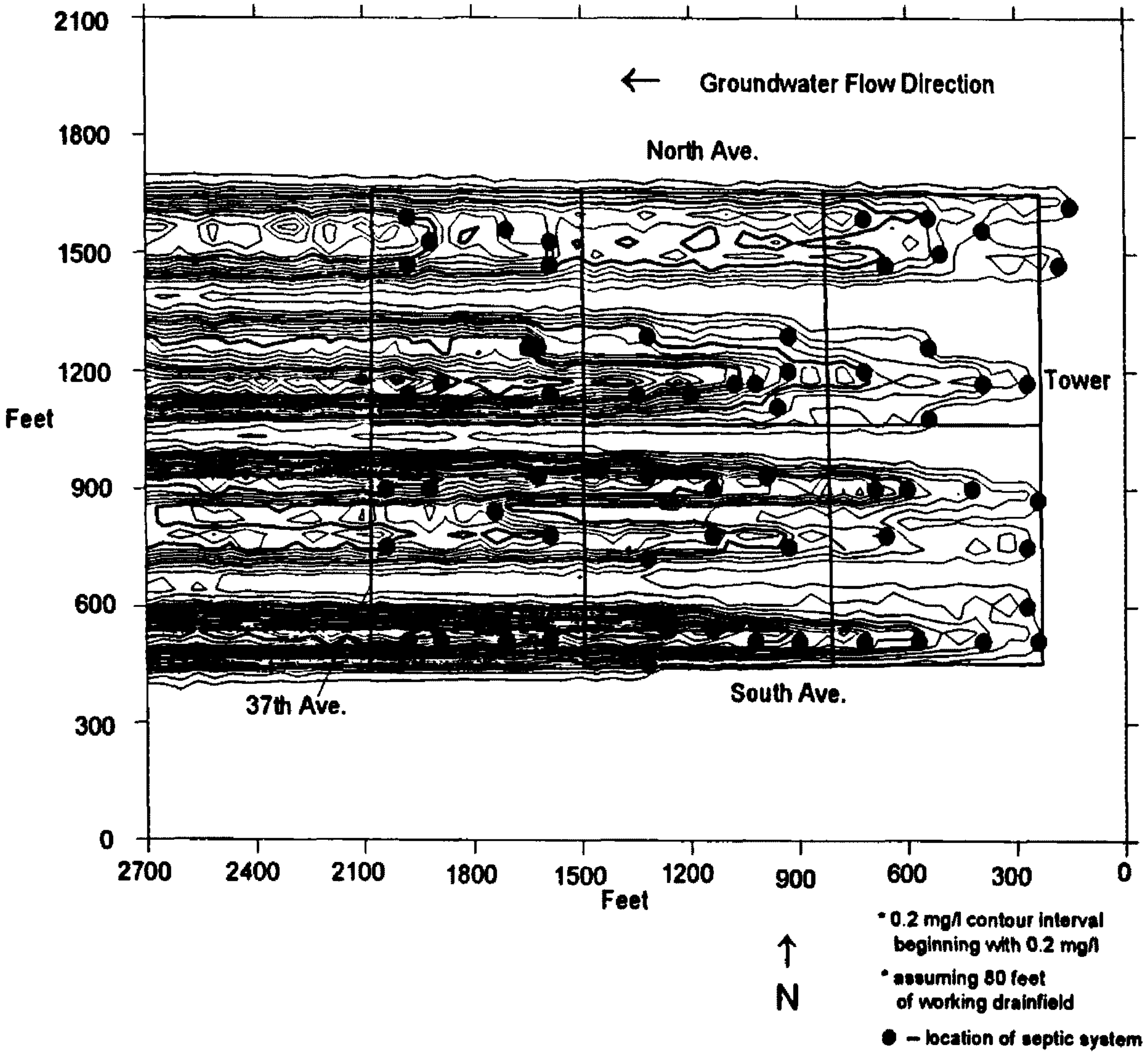
A simulation was conducted within the East and West sites to model the nitrate-N impacts when nitrate-N was assumed to behave totally non-conservatively. Figures 5.41 and 5.42 depict the results. Concentrations are simulated to be reduced below 0.2 mg/l 100-200 feet away from the source.

Frenchtown

Approach #1

The Frenchtown cumulative-effects site consisted of approximately 79 homes within an area of approximately 400 acres. The housing density for the entire site is approximately 0.2 homes per acre. The large size of the site presented modeling difficulties, so a smaller area, located in the upper northwest corner of the site, was chosen

Cumulative Simulation of Chloride Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--East Site Missoula, MT



* 0.2 mg/l contour interval beginning with 0.2 mg/l

* assuming 80 feet of working drainfield

● – location of septic system

Figure 5.33

Cumulative Simulation of Chloride Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--East Site Missoula, MT

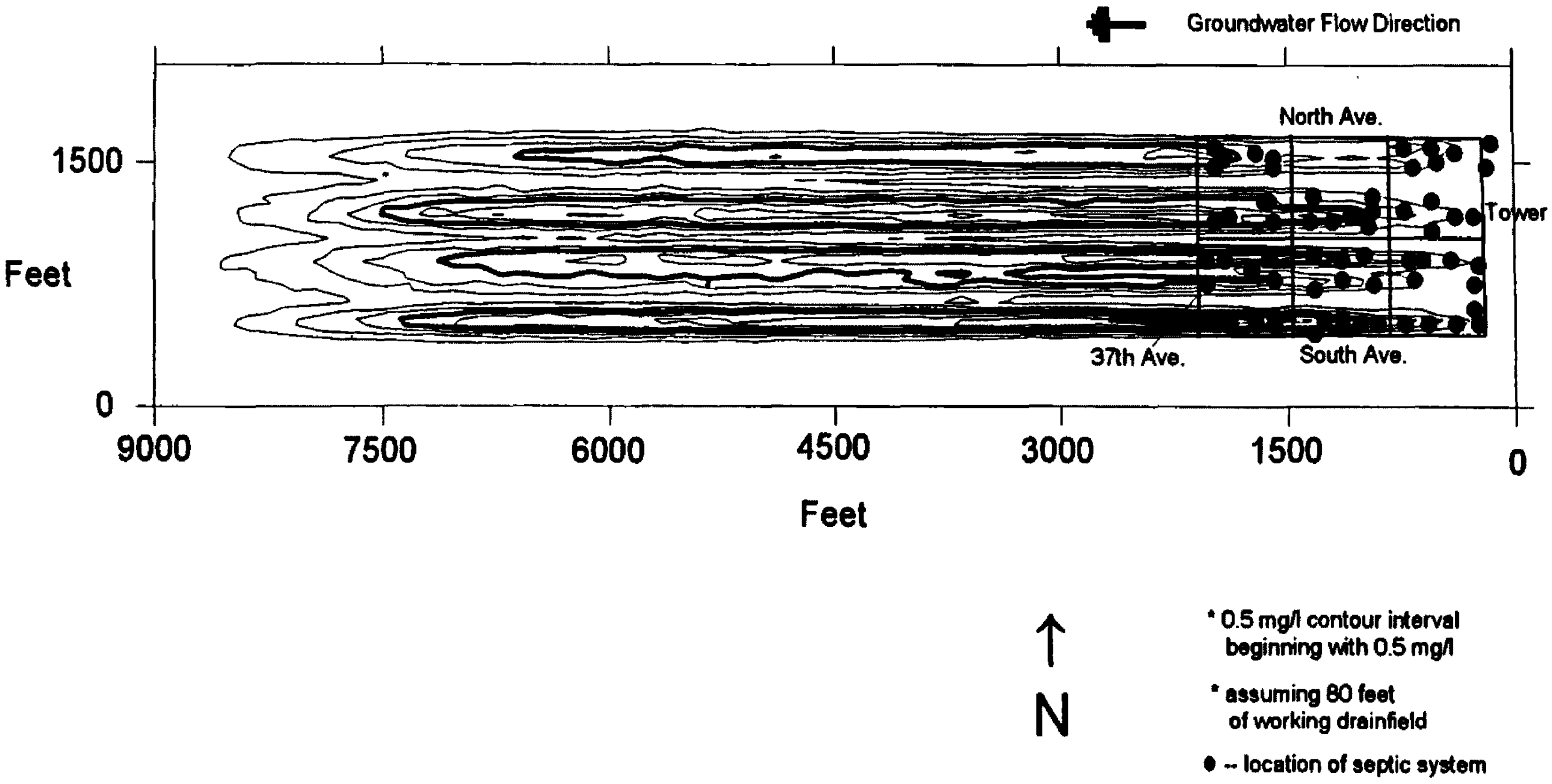
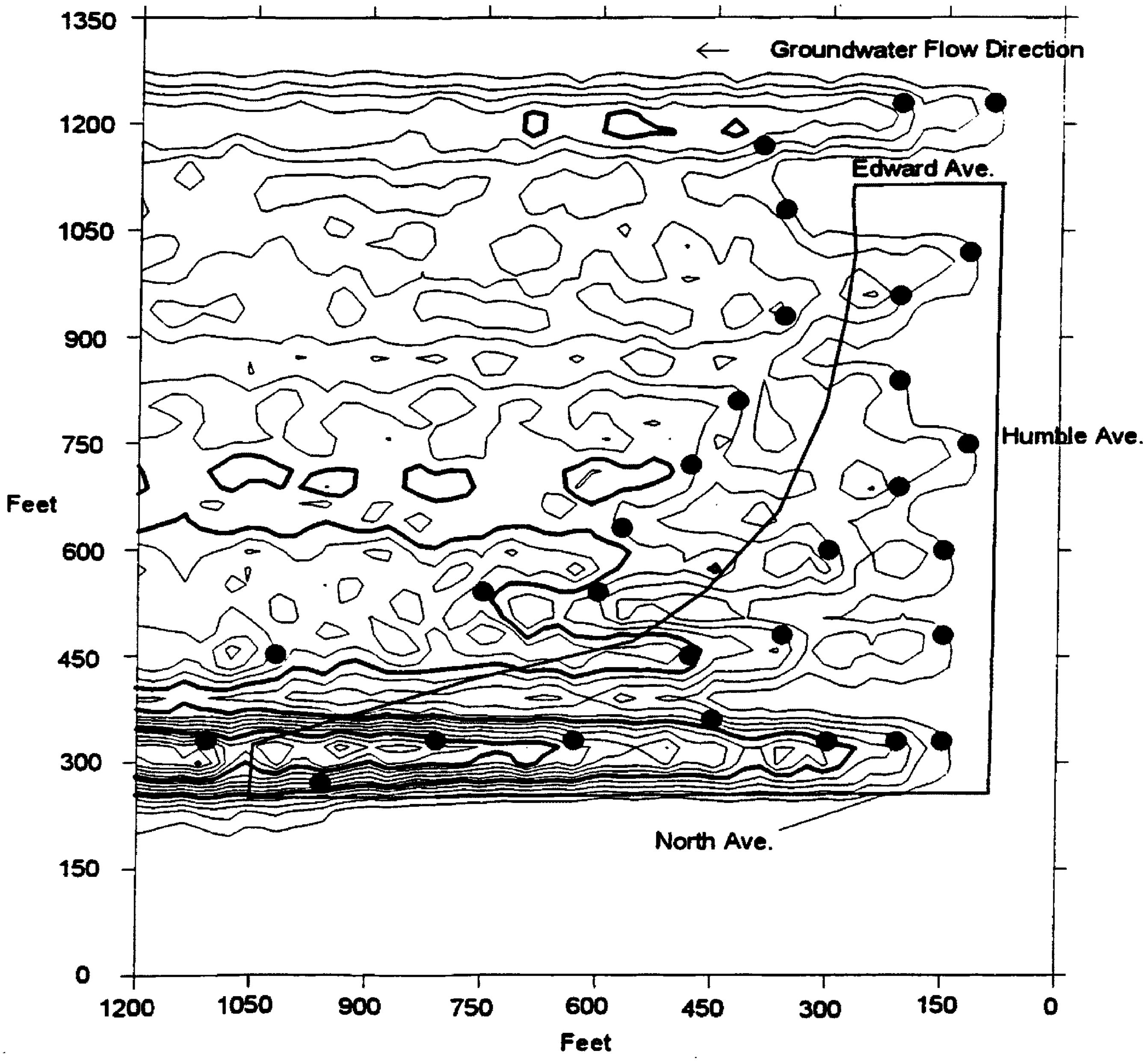


Figure 5.34

Cumulative Simulation of Chloride Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--West Site Missoula, MT



* 0.2 mg/l contour interval beginning with 0.2 mg/l
* assuming 80 feet of working drainfield
● – location of septic system

Figure 5.35

Cumulative Simulation of Chloride Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--West Site Missoula, MT

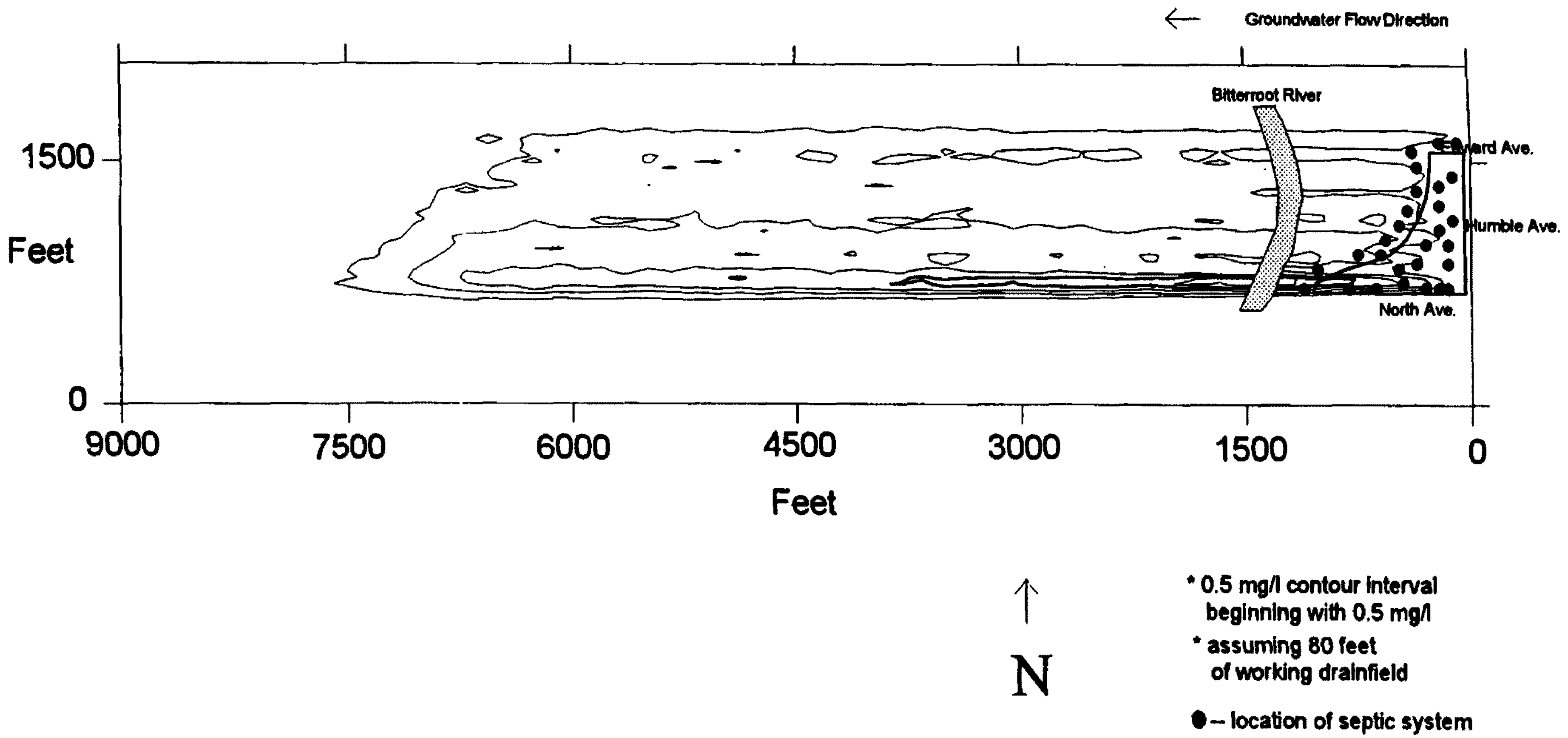


Figure 5.36

Cumulative Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--East Site Missoula, MT

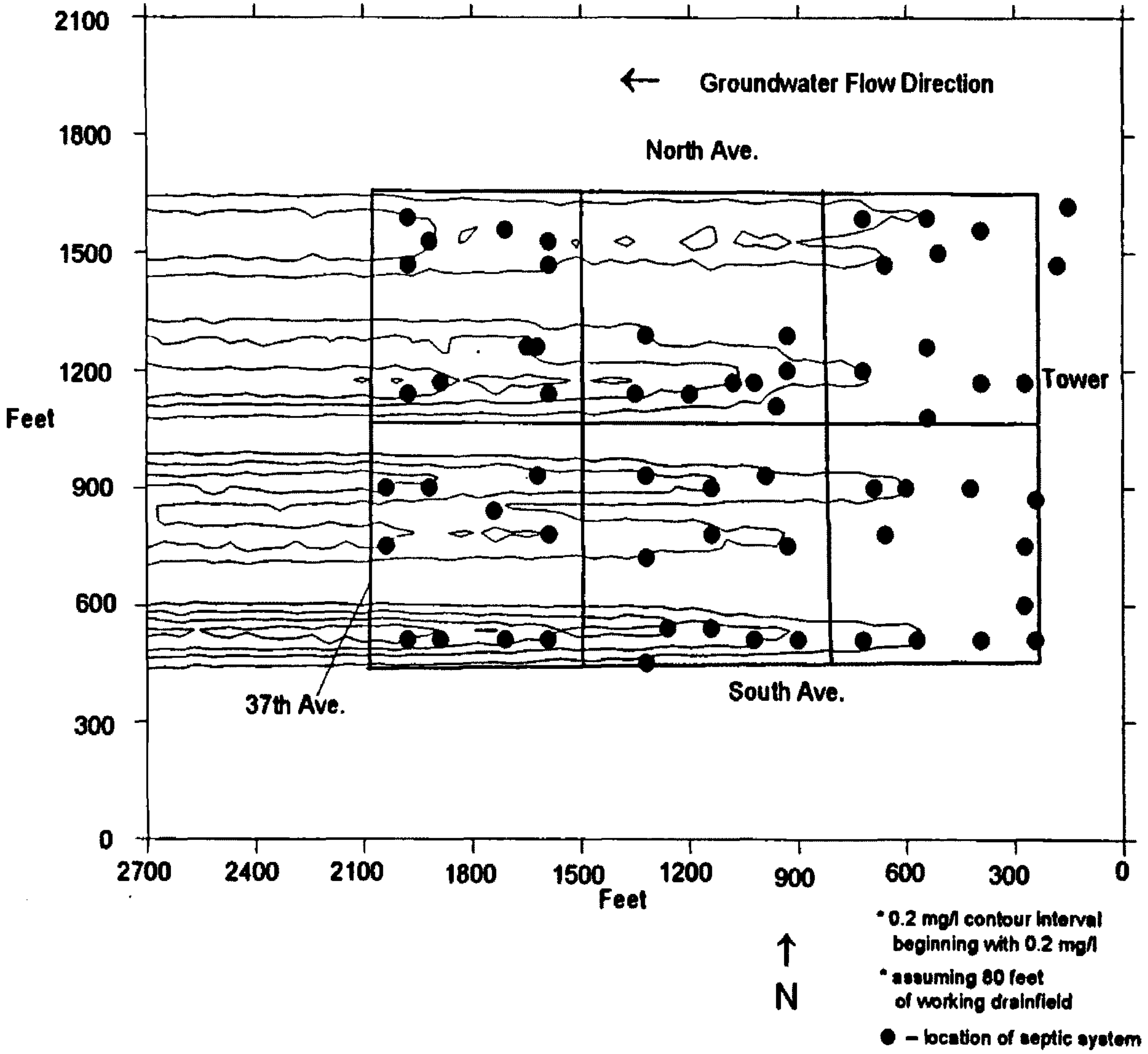
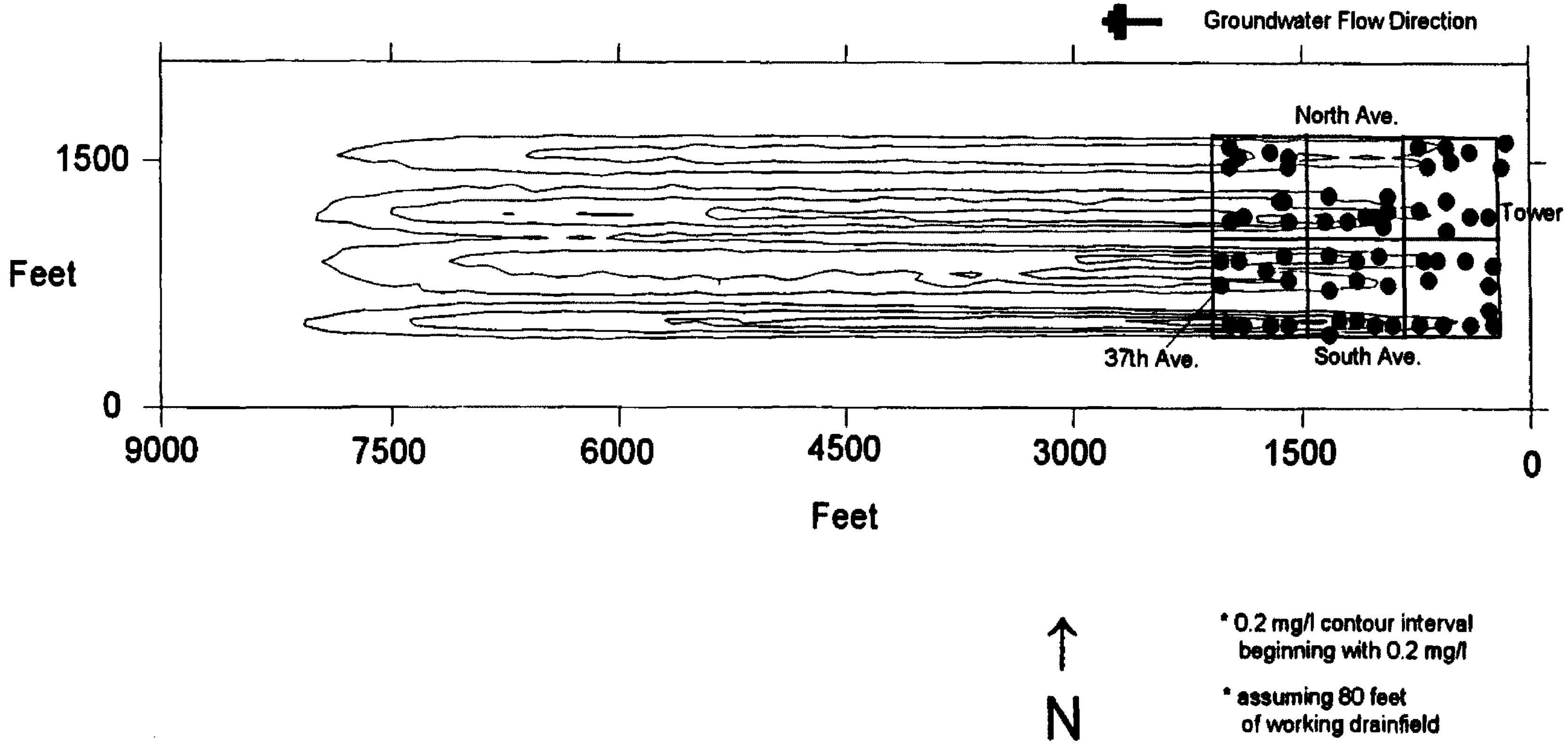


Figure 5.37

Cumulative Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--East Site Missoula, MT



* 0.2 mg/l contour interval beginning with 0.2 mg/l

* assuming 80 feet of working drainfield

● -- location of septic system

Figure 5.38

Cumulative Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--West Site Missoula, MT

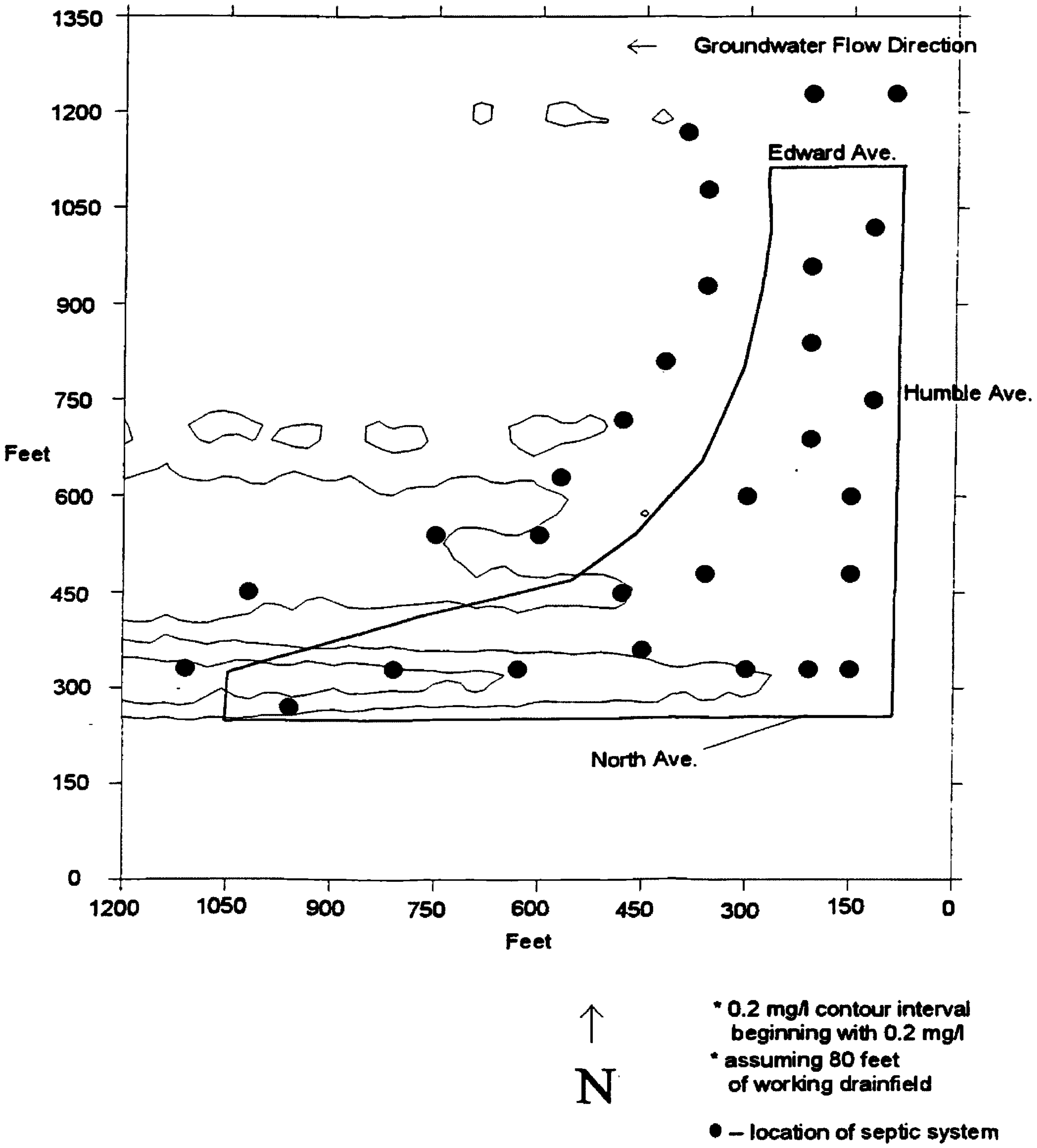
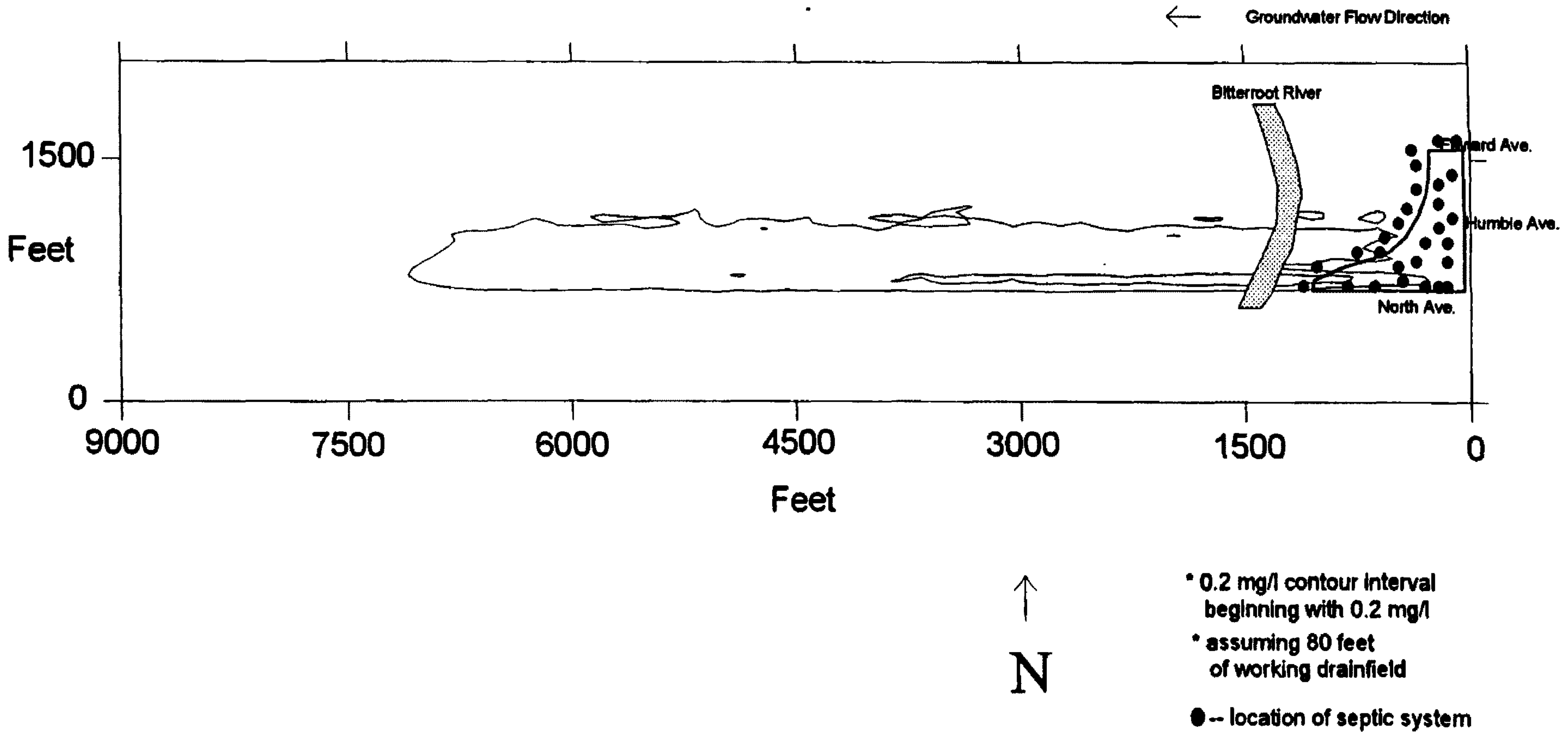


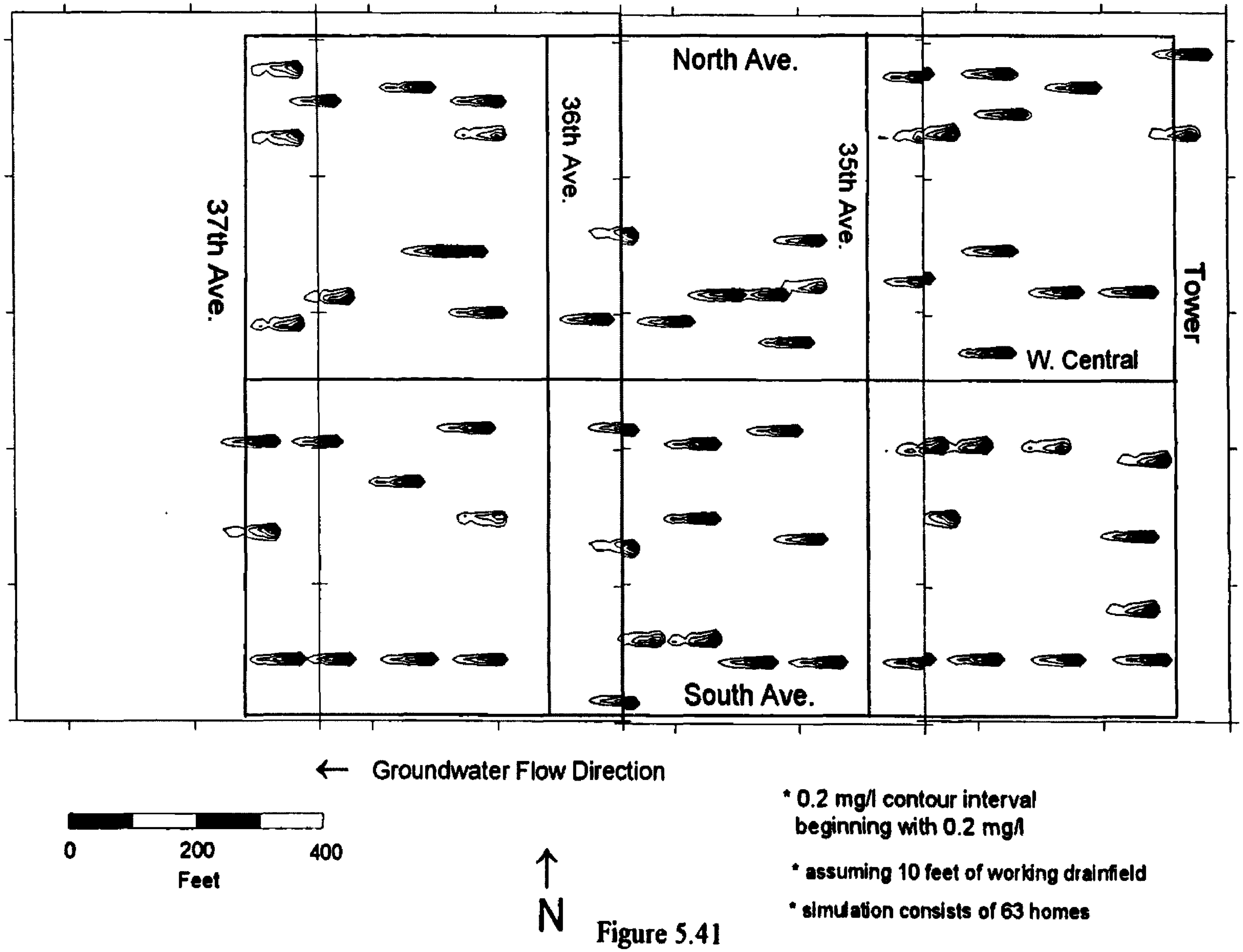
Figure 5.39



Cumulative Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of the Groundwater After 750 Days--West Site Missoula, MT

Figure 5.40

Cumulative Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet of Groundwater After 750 Days East Site Missoula, MT Assuming Totally Non-Conservative Nitrate-N Behavior



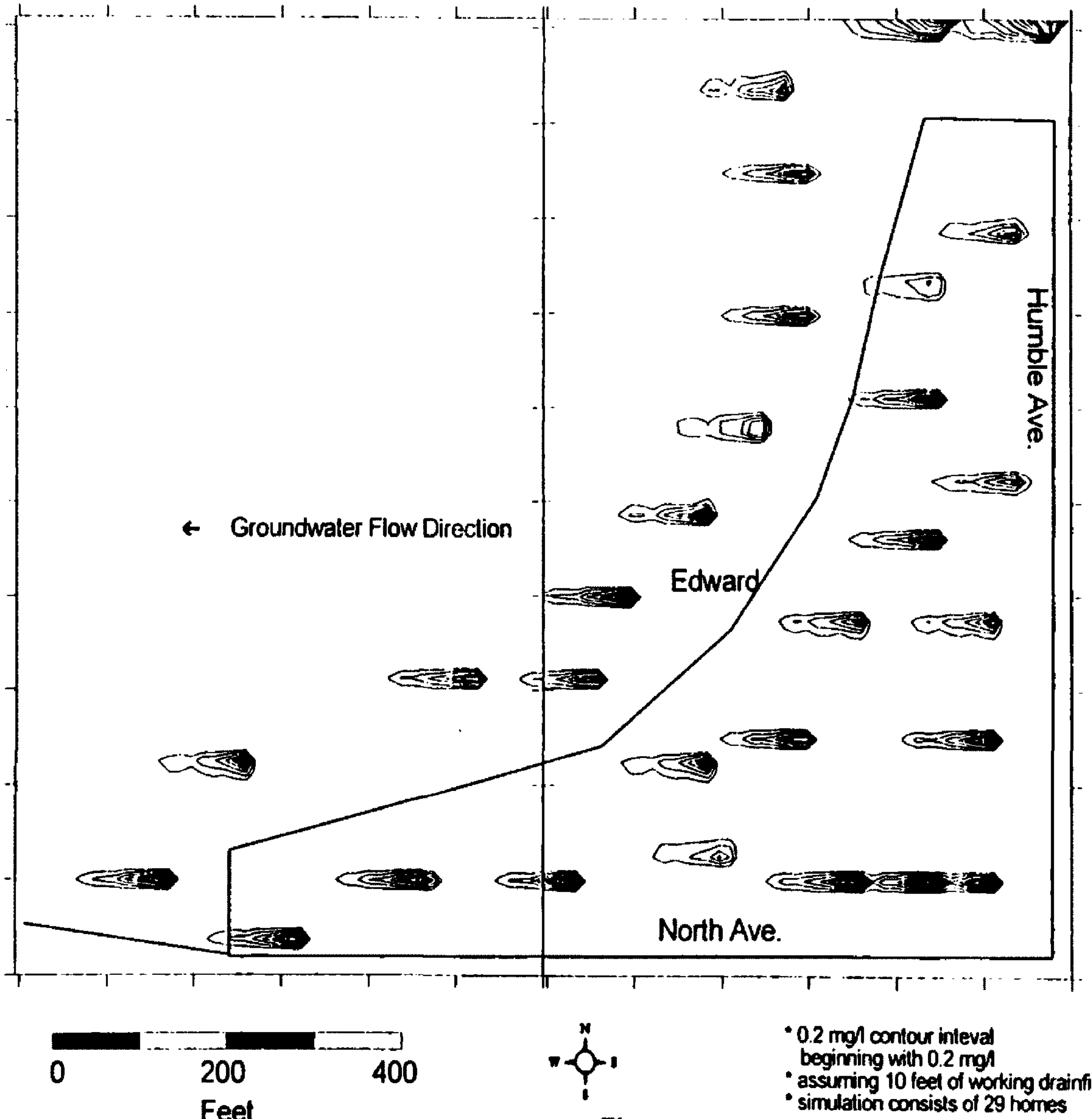
* 0.2 mg/l contour interval beginning with 0.2 mg/l

* assuming 10 feet of working drainfield

* simulation consists of 63 homes

Figure 5.41

Cumulative Simulation of Nitrate-N Concentrations within the Upper 7.5 Feet
of Groundwater After 750 Days West Site Missoula, MT



- 0.2 mg/l contour inteval beginning with 0.2 mg/l
- assuming 10 feet of working drainfield
- simulation consists of 29 homes

Figure 5.42

for representation. This area exhibited a larger housing density, approximately one home per acre, and presented the cumulative effects on groundwater quality of eight homes in a hydrogeologic environment similar to the Frenchtown cumulative-effects site. Each of these homes were simulated to have 15 feet of working drainline, the observed working length in the individual Frenchtown site. Neither monitoring wells nor piezometers were placed within the Frenchtown cumulative-effects site, so field verification of modeled concentrations were not possible.

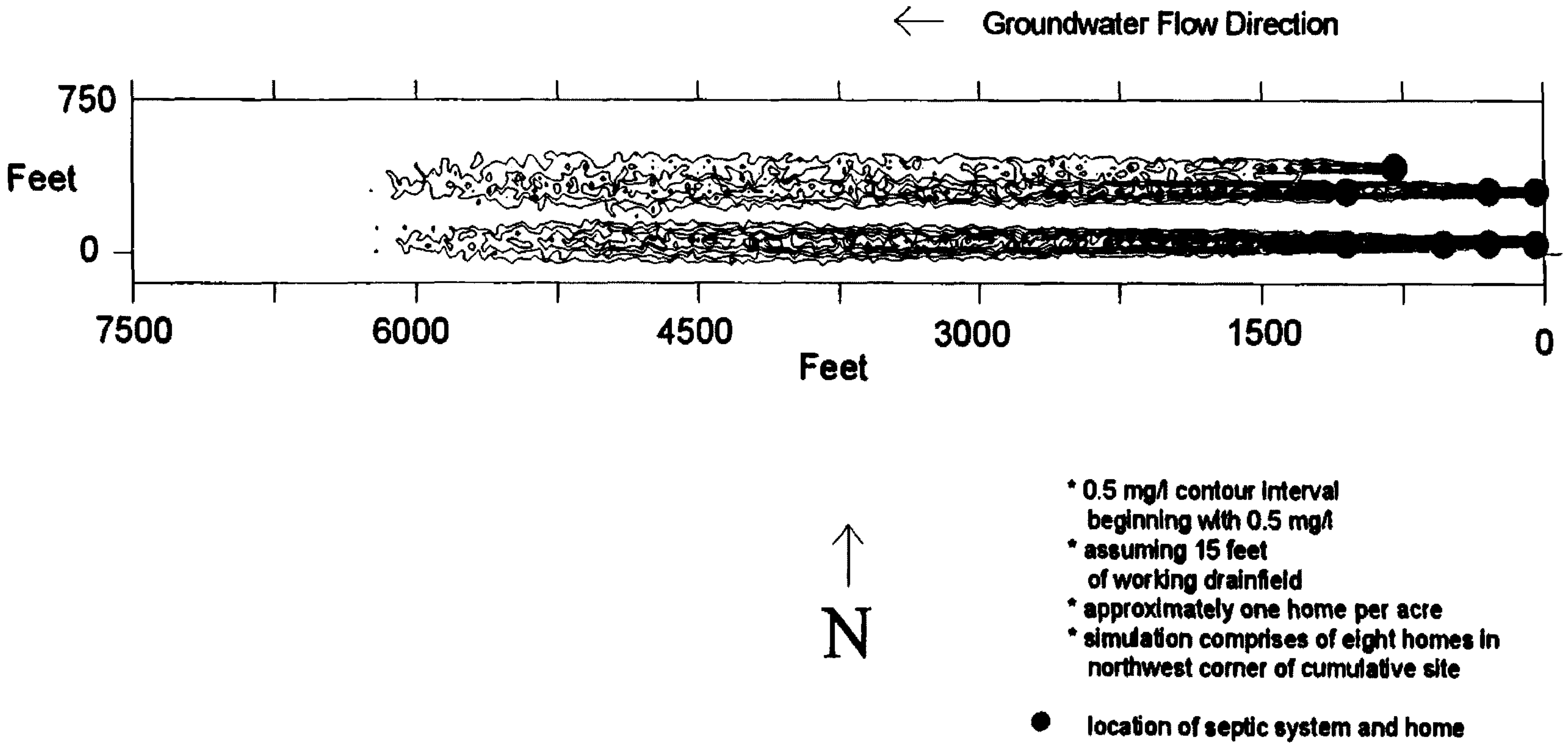
The chloride and nitrate-N cumulative impact of eight homes on the upper eight feet of the shallow aquifer is shown on figures 5.43 and 5.44. Relatively high concentrations of chloride and nitrate-N are predicted to occur when septic systems are located consecutively downgradient from each other along the same groundwater flowpath. Concentrations as high as approximately 5 mg/l and 1.2 mg/l of chloride and nitrate-N, respectively, were simulated to occur. Elevated chloride concentrations persisted 6000-7000 feet and nitrate-N concentrations 5000-6000 feet downgradient from the eight homes.

It should be noted that these are simulated concentrations in the upper eight feet of the water table aquifer. Most wells are finished over 120 feet below the water table and separated from the water table aquifer by over 100 feet of silty-sand.

Approach #2

A simulation was conducted within the Frenchtown cumulative-effects site to model the nitrate-N impacts when nitrate-N was assumed to behave totally non-

Cumulative Simulation of Chloride Concentrations within the Upper Eight Feet of Groundwater After 750 Days-Frenchtown, MT Cumulative Site



* 0.5 mg/l contour interval beginning with 0.5 mg/l

* assuming 15 feet of working drainfield

* approximately one home per acre

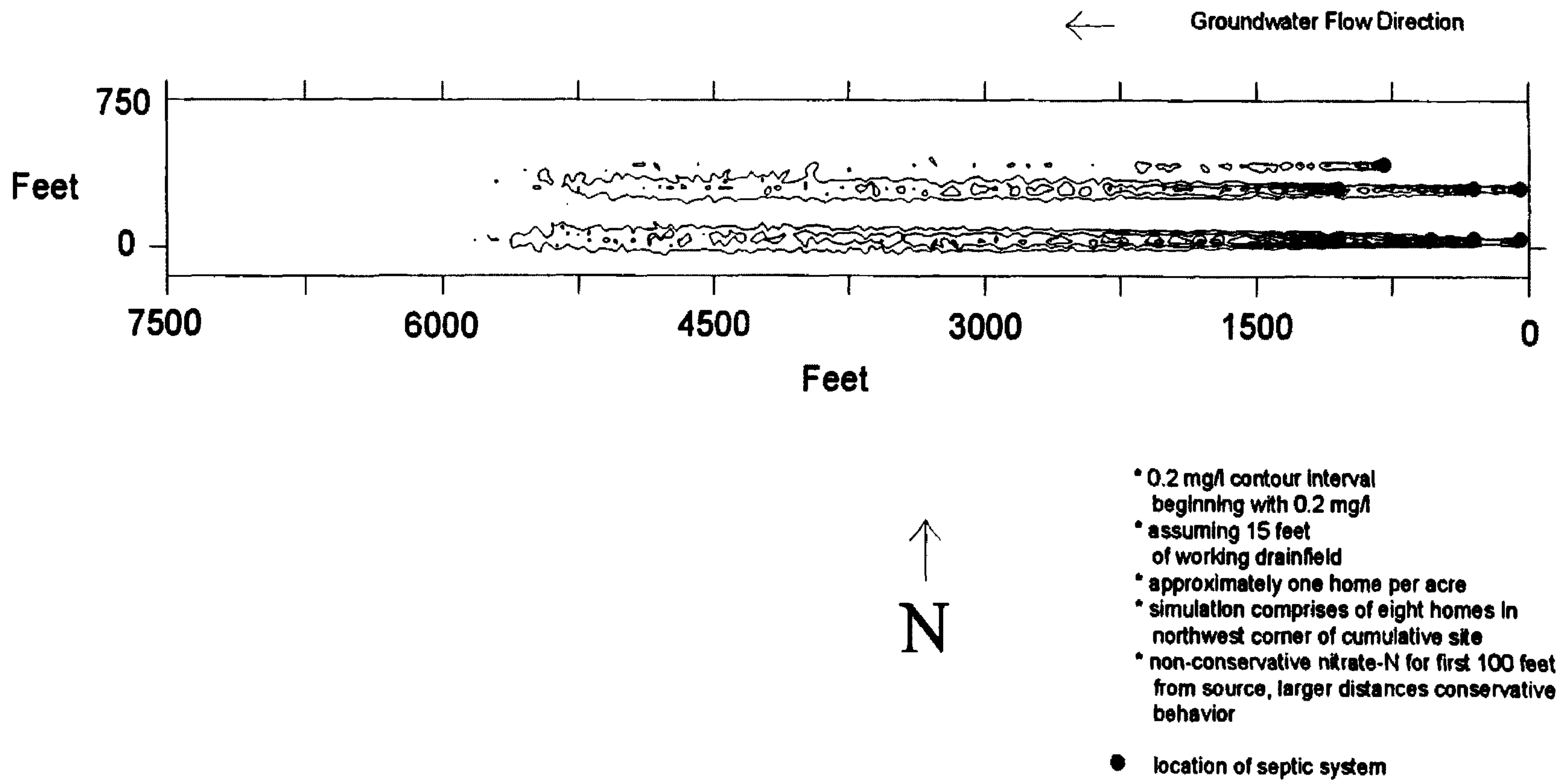
* simulation comprises of eight homes in northwest corner of cumulative site

● location of septic system and home

Figure 5.43

Cumulative Simulation of Nitrate-N Concentrations within the Upper Eight Feet of Groundwater After 750 Days-Frenchtown, MT Cumulative Site

Simulation Depicts Partial Non-conservative and Conservative Nitrate-N



- * 0.2 mg/l contour interval beginning with 0.2 mg/l
- * assuming 15 feet of working drainfield
- * approximately one home per acre
- * simulation comprises of eight homes in northwest corner of cumulative site
- * non-conservative nitrate-N for first 100 feet from source, larger distances conservative behavior

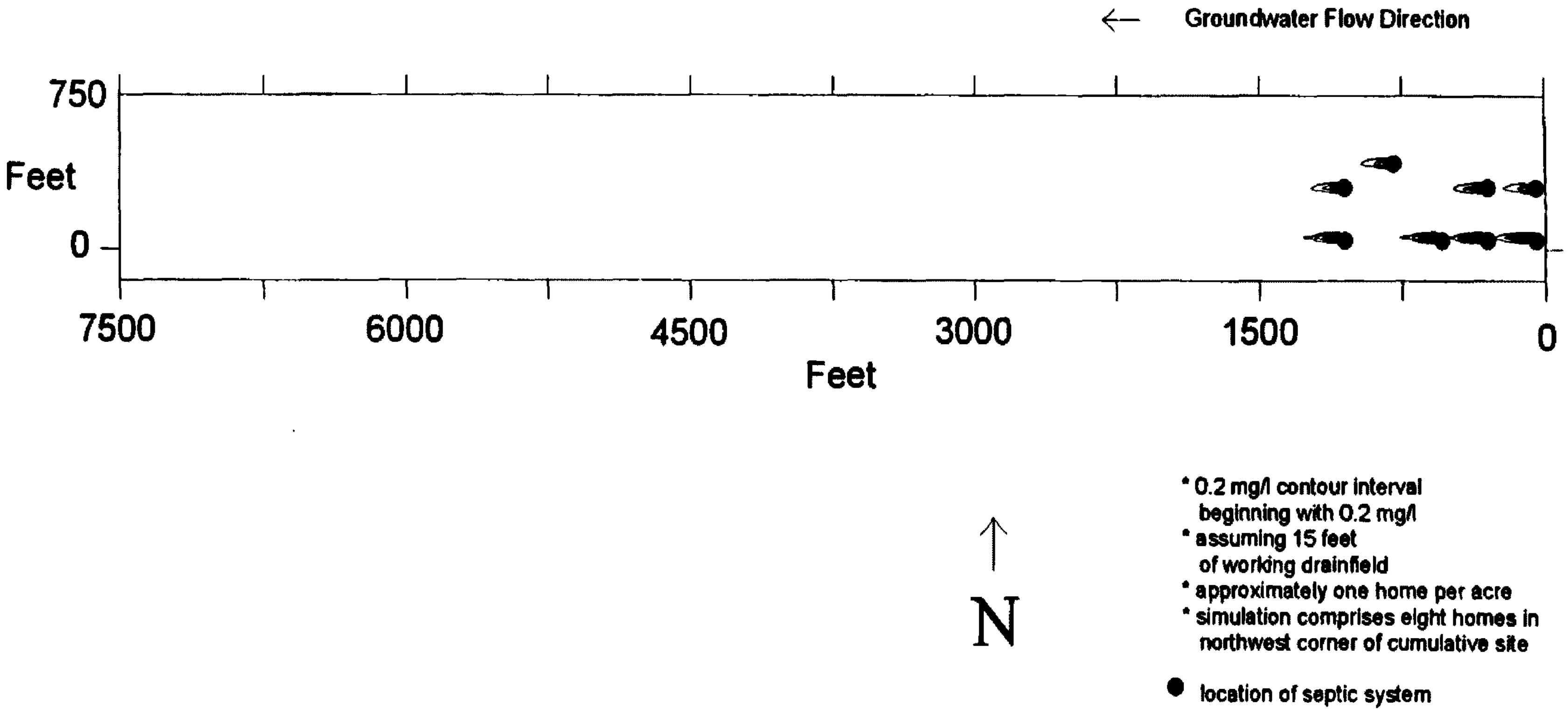
● location of septic system

Figure 5.44

conservatively. Figure 5.45 depicts the results. Concentrations are simulated to be reduced below detection limits (0.1 mg/l) approximately 200 feet downgradient from the source.

Cumulative Simulation of Nitrate-N Concentrations within the Upper Eight Feet of Groundwater After 750 Days-Frenchtown, MT Cumulative Site

Simulation Depicts Totally Non-conservative Nitrate-N Species



- 0.2 mg/l contour interval beginning with 0.2 mg/l
- assuming 15 feet of working drainfield
- approximately one home per acre
- simulation comprises eight homes in northwest corner of cumulative site

● location of septic system

Figure 5.45

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to conceptualize and approximate the cumulative effects of septic system disposal on groundwater quality in selected portions of Missoula County. This was accomplished by identifying the spatial extent of chloride and nitrate-N plumes within two different hydrogeologic environments, calibrating a solute transport model to the individual septic plumes, and identifying the degree of impact subdivisions of two different housing densities would have on the associated groundwater quality. The following discussion will summarize the information gained through the completion of this research effort.

Evaluation of an individual septic system within the Missoula Valley fluvial aquifer and one within the fluvial-lacustrine aquifer of Frenchtown revealed the most concentrated portion of the chloride plume was found within approximately 30 feet downgradient from the effluent discharging drainline for both sites. Average chloride concentrations found within the upper 8 feet of the aquifer were as high as 9 mg/l and 12 mg/l within the South and Frenchtown sites, respectively. The high chloride concentrations were isolated. Concentrations were 3-4 mg/l above background at the downgradient edge of the monitoring network used to sample the South site, and 1-2 mg/l for the Frenchtown site. The width of the South site plume was 60-150 feet, while the Frenchtown plume was approximately 50 feet wide. The total length of both plumes were unknown.

Nitrate-N concentrations were found to be most concentrated within 30 feet downgradient from the working drainlines. Average concentrations found in the upper 7.5 feet of the aquifer were as elevated as 3.5 mg/l above background within the South site, and 8 mg/l within the Frenchtown site. Nitrate-N concentrations were approximately 0.5 mg/l above background at the downgradient edge of the monitoring network for both sites. The plume shape was very similar to the chloride concentration distribution.

An interesting relationship was recognized through the comparison of nitrate-N : chloride ratios throughout each site. The septic tank for each site had a ratio of roughly 1.2, where nitrogen was totally in the form of ammonia. By the time the effluent intercepted the water table, the ratio was reduced to 0.7-0.8, with nitrogen being in the oxidized nitrate form. Unaccounted nitrate mass loss was assumed to have occurred, considering chloride was behaving conservatively. Ratios further downgradient were 0.1-0.3 within both sites. Nitrate mass was interpreted to have been continuously removed from the effluent until a ratio of approximately 0.2 was reached. This same ratio was identified in other groundwater samples taken throughout the Missoula Valley, in both the shallow and deep groundwater. It appears nitrate mass was lost within a short distance downgradient from the septic drainfield until a threshold value was reached. The cause of nitrate degradation and why the degradation stops was not determined. Nitrate was believed to have undergone non-conservative behavior within the first 100 feet downgradient from the effluent source within both sites, and conservative behavior at distances greater than 100 feet.

Numerically simulated plumes were used to generate cumulative impact scenarios of septic system disposal within two sites in the Missoula Valley (East and West sites) and one in Frenchtown. The configuration of the cumulative plumes showed the highest chloride and nitrate-N concentrations to occur when septic systems are situated consecutively along the same groundwater flowpath. The less dense East site (one home per acre) had higher chloride and nitrate-N simulated concentrations than the West site (1.9 homes per acre). The greatest potential of cumulative impacts to groundwater quality, caused by septic system disposal, was predicted to occur in areas where septic systems are aligned within the same general flowpath. The degree of cumulative impacts are not necessarily dependent on housing densities, at least at the densities represented by the East and West sites. A similar pattern was seen in the cumulative-effects Frenchtown site. Less impact to groundwater quality was observed when the effluent source was 80 feet rather than 10 feet.

Multi-level monitoring wells were placed both groundwater upgradient and downgradient from the Missoula cumulative-effects sites. The chloride concentrations increased by 1-2 mg/l within the West site, and by 1-10 mg/l in the East site. Little to no nitrate-N impact was recognized in either site. There were no shallow groundwater monitoring devices placed in the Frenchtown cumulative-effects site. Groundwater chemistry varied little in terms of depth below the water table within the wells monitored in the East and West sites.

Recommendations

Through the course of the study, several unaddressed or unresolved issues became apparent. The following section will suggest topics which require further attention.

1. The amount and location of the sampling and monitoring points within both individually monitored septic systems was not sufficient to characterize the total dimensions of the septic plume. Attention needs to be paid to the present monitoring network and the degree of plume depiction, and the monitoring network should be expanded accordingly. Specifically, more sampling points are needed within the first 100 feet downgradient from the effluent source to test the validity of depicting nitrate-N behavior as a non-conservative/conservative combination. Also, sampling devices are necessary at larger distances downgradient from the drainfield. Modeling predicts the plumes to extend 5000-7000 feet downgradient, but this was untestable. The use of multi-level monitoring wells should continue. These allowed the interpretation of a groundwater-effluent mixing zone associated with septic systems.
2. Nitrate-N : chloride ratios presented strong evidence that one or more processes are responsible for a nitrate mass loss within the groundwater in close proximity to septic drainfields in both the Missoula Valley and Frenchtown. The cause should be determined. Additional data collection should include measurements of organic carbon, a detailed understanding of dissolved oxygen content within the groundwater, and a microbiological

study which would identify the resident bacteria in the area of the drainfield.

3. Data presented by Woessner et al. (1996) and other researchers have recognized a nitrate mixing zone in the shallow groundwater associated with septic system disposal. Nitrate was found to reside in the upper 7.5 feet of groundwater within the South site, and the upper eight feet within the Frenchtown site. Interestingly, nitrate-N concentrations were measured in domestic wells in the East and West sites to be 1-1.5 mg/l. Information how the nitrate-N reached the deeper groundwater is unavailable. Possible mechanisms may be: 1) an increased mixing zone as a result of well pumping , or 2) well casing-sediment interfaces are providing a downward conduit for septic effluent. The effect of well pumping is currently being addressed, but the well casing conduit theory is not.
4. The particle transport modeling efforts simulated cumulative effects to occur in the upper eight feet of groundwater within the Frenchtown cumulative site, but monitoring devices were not inserted to test the validity of the simulation. Sampling points are needed to further test the groundwater models.
5. Input of septic waste to the underlying aquifer was modeled assuming an effluent slug reached the groundwater once per day. This was an original method to represent the input of septic effluent. A study should be conducted to test the validity of this assumption. One way this could be

accomplished would be to monitor water quality and loading rates of individual septic systems over a 24 hour period.

6. The modeling of septic system derived solutes relied on estimated values of dispersivity. Knowledge of dispersivity values within the Missoula Valley and Frenchtown is limited. A better estimation of dispersivity is needed to get an improved understanding of solute behavior in these environments. Additional tracer tests should be conducted within these aquifers.

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Appendix A

General Geology and Hydrogeology

Missoula General Geology

The Missoula Valley is believed to have formed from horizontal extension after the Laramide thrusting, which occurred between the late Createaceous and middle Eocene, 97.5 to 52 million years ago (Fields et al., 1985). The horizontal extension is also believed to have formed the normal faults found on the northern and eastern boundaries of the valley (figure A.1).

The mountains surrounding the valley are composed of Precambrian metasediments of the Belt Supergroup, 0.8 to 1.6 billion years old. The base of the Missoula Valley is composed of Belt Supergroup rocks. They can be found approximately 1000 to 3500 feet below the surface of the valley floor (figure A.2) and are possibly over 10,000 feet in thickness. Renova Formation equivalent, deposited within the Tertiary, overlies, unconformly, the Belt rocks. These sediments can be found 0 to 150 feet below the valley surface. They are composed of clay with interbedded sand and gravel and range from 2500 to 3500 feet in thickness. The sediments of the valley floor are Quarternary sands, gravels, and boulders with minor amounts of silt and clay. They can be up to 150 feet thick.

General Hydrogeology

The physical and hydrogeologic properties of the Missoula Aquifer are described in great detail by Woessner (1988). The following hydrogeologic description is taken from this report.

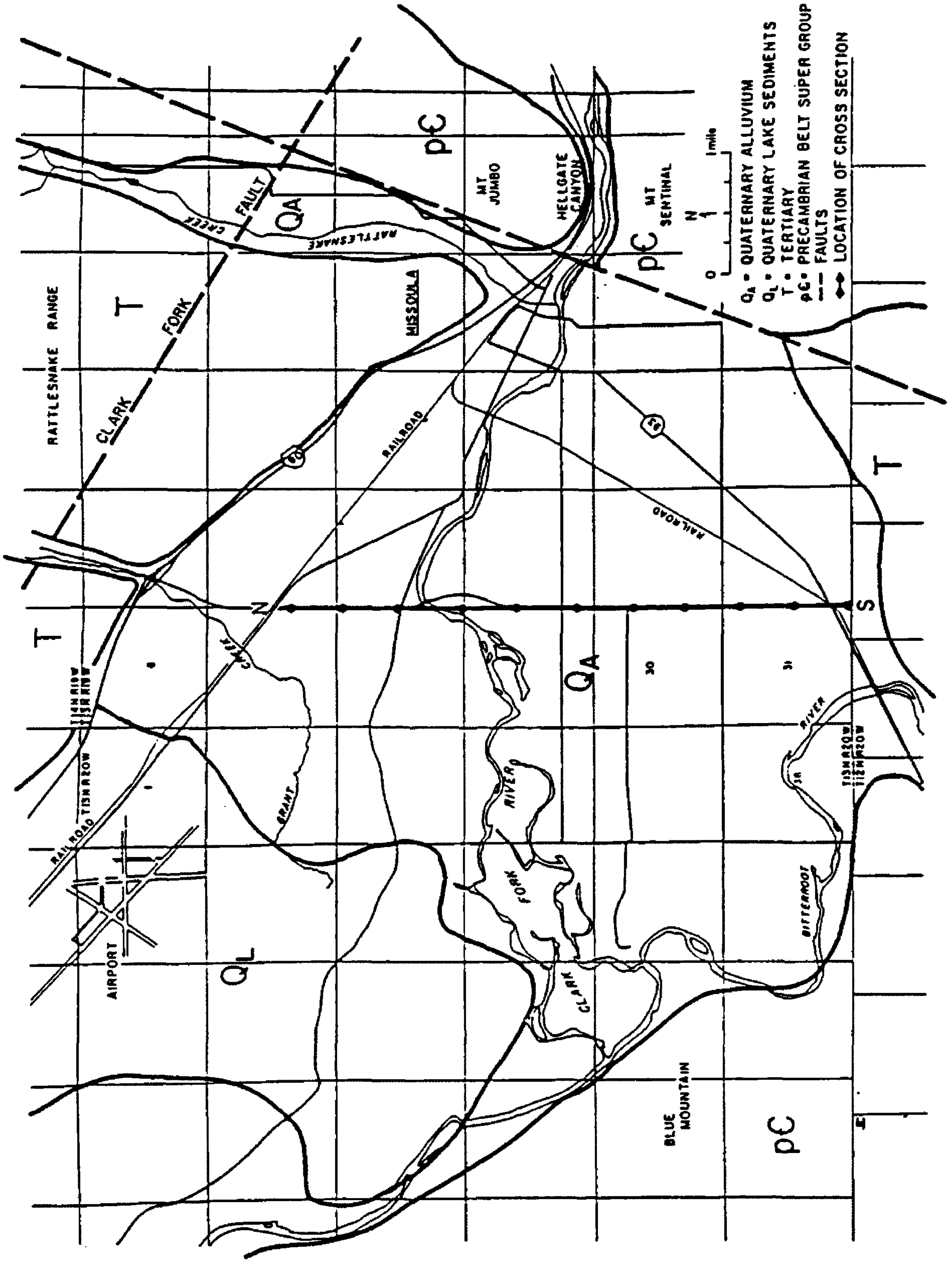


Figure A.1: Geologic map of Missoula Valley (Clark, 1986)

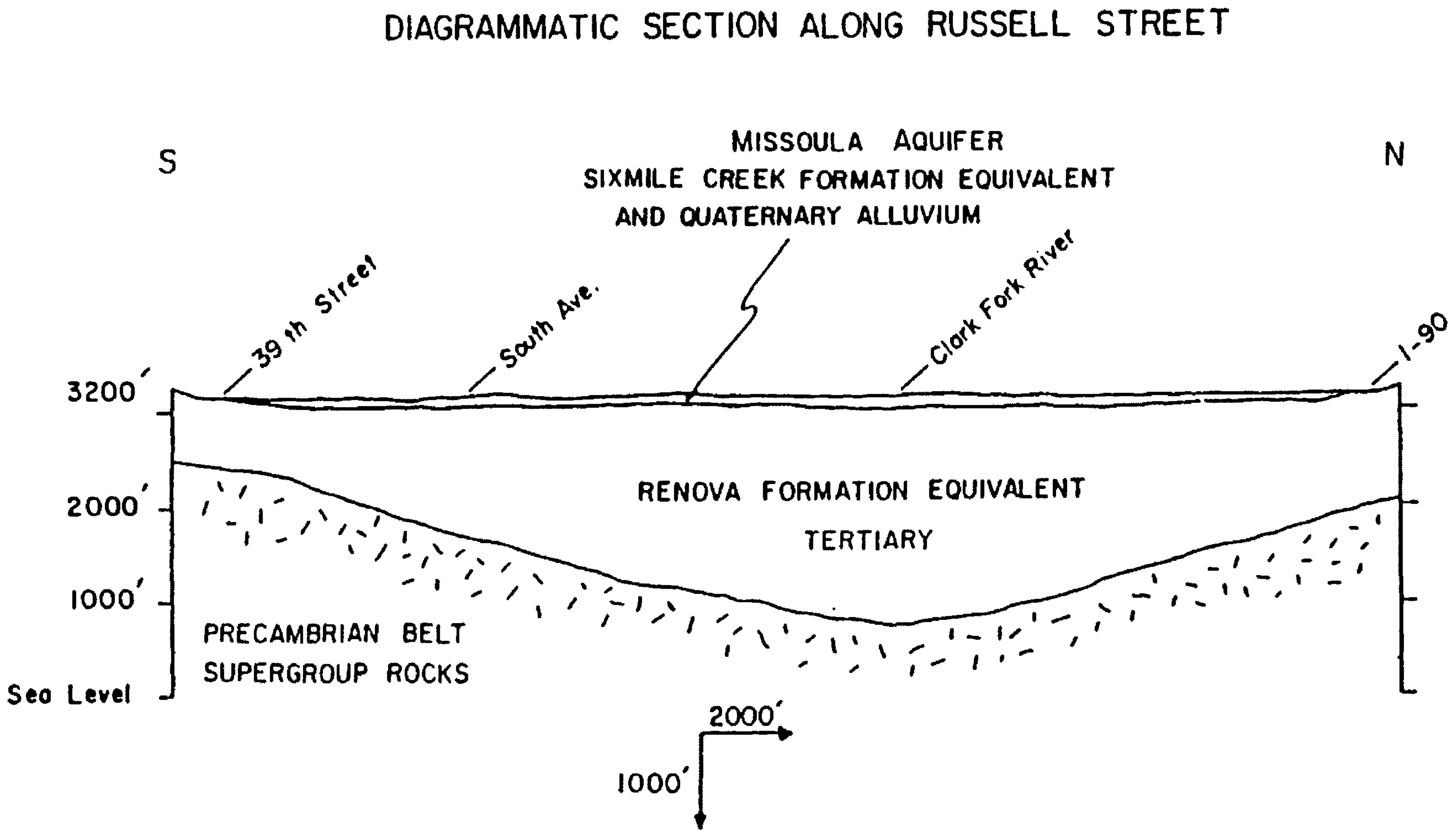


Figure A.2: Schematic north-south cross-section of the Missoula Valley (Clark, 1986)

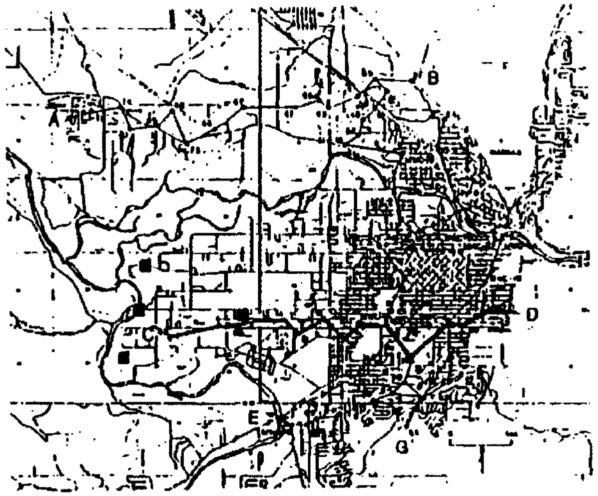
The primary water yielding unit in the Missoula Valley is the Quaternary sediments. The sediments were deposited in an alluvial environment within the Pleistocene and Recent. They consist of sands, gravels, and boulders with minor amounts of silt and clay. Figure A.3 illustrates these sediments within a cross-sectional view through the middle of the Missoula Valley.

The hydrogeologic properties of the aquifer vary both horizontally and vertically. The hydrogeologic properties of the entire aquifer based on a weighted average, yield a hydraulic conductivity of 18,200 gpd/sq. ft., a thickness of 90 feet, a porosity of 0.2, and a specific yield of 0.12. Miller (1990) constructed a model calibrated hydraulic zone map to the Missoula Valley.

Frenchtown General Geology and Hydrogeology

The hydrogeologic description comes from Woessner et al. (1996). Their description of the regional hydrogeology is based upon drillers' well logs. The individual site hydrogeology is based upon the interpretation of cuttings that were produced through the installation of piezometers and monitoring wells within the site.

The uppermost sediments are a 5 to 10 foot deposit of a dark brown silty loam, which is illustrated in Woessner et al. (1996) . Underlying the silty loam deposit is an interbedded clay, silty sand, and gravel layer which tends to fine upwards. This interbedded sequence of sediments extend about 10 to 30 feet below the surface. The clay sediments tend to thicken in the eastern and northern direction.



CROSS SECTION BASED ON WELL LOGS

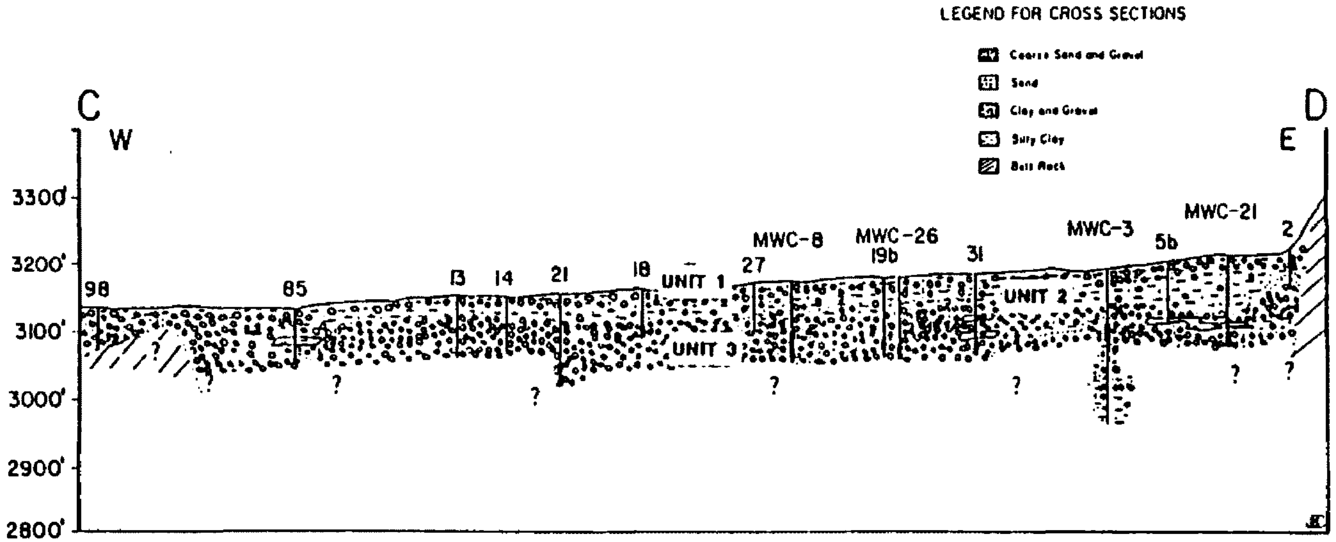


Figure A.3: Schematic east-west cross-section of the upper 150 feet of sediments in the Missoula Valley (Woessner, 1988)

A 100 to 150-foot thick layer of silty sand with clay and gravel interbeds underlies the overlying interbedded sediments. Below this lies 30 to 50 feet of gravel with sand and clay. This sequence is believed to be Renova Formation sediments, which were deposited in the Tertiary.

The region has two primary aquifers. The upper most is a 20 to 50 foot thick sand and gravel unconfined aquifer. The water table lies approximately 5 to 15 feet below the ground surface. The hydraulic gradient for the upper aquifer is only known within the individually monitored site, where it has been measured to range from 0.001 to 0.005 depending upon the time of the year. The groundwater flow is from the north to the south (figure A.4). Hydraulic conductivity has been measured, through a bromide tracer test to be from 100 to 360 feet per day in the upper aquifer.

The lower aquifer is confined. It is separated from the upper aquifer by the 100 to 150 feet of silty sand and clay. The lower aquifer is composed of 20 to 50 feet of sand, gravel, and sporadic clay lenses. The hydraulic gradient is 0.004 to 0.005. Groundwater flow is from the northeast to the southwest within most of the regional study site, except along the western portion of Touchette Lane where flow is to the west. The hydraulic conductivity for the lower aquifer is unknown. This aquifer is the primary source of drinking water for the residents in the area.

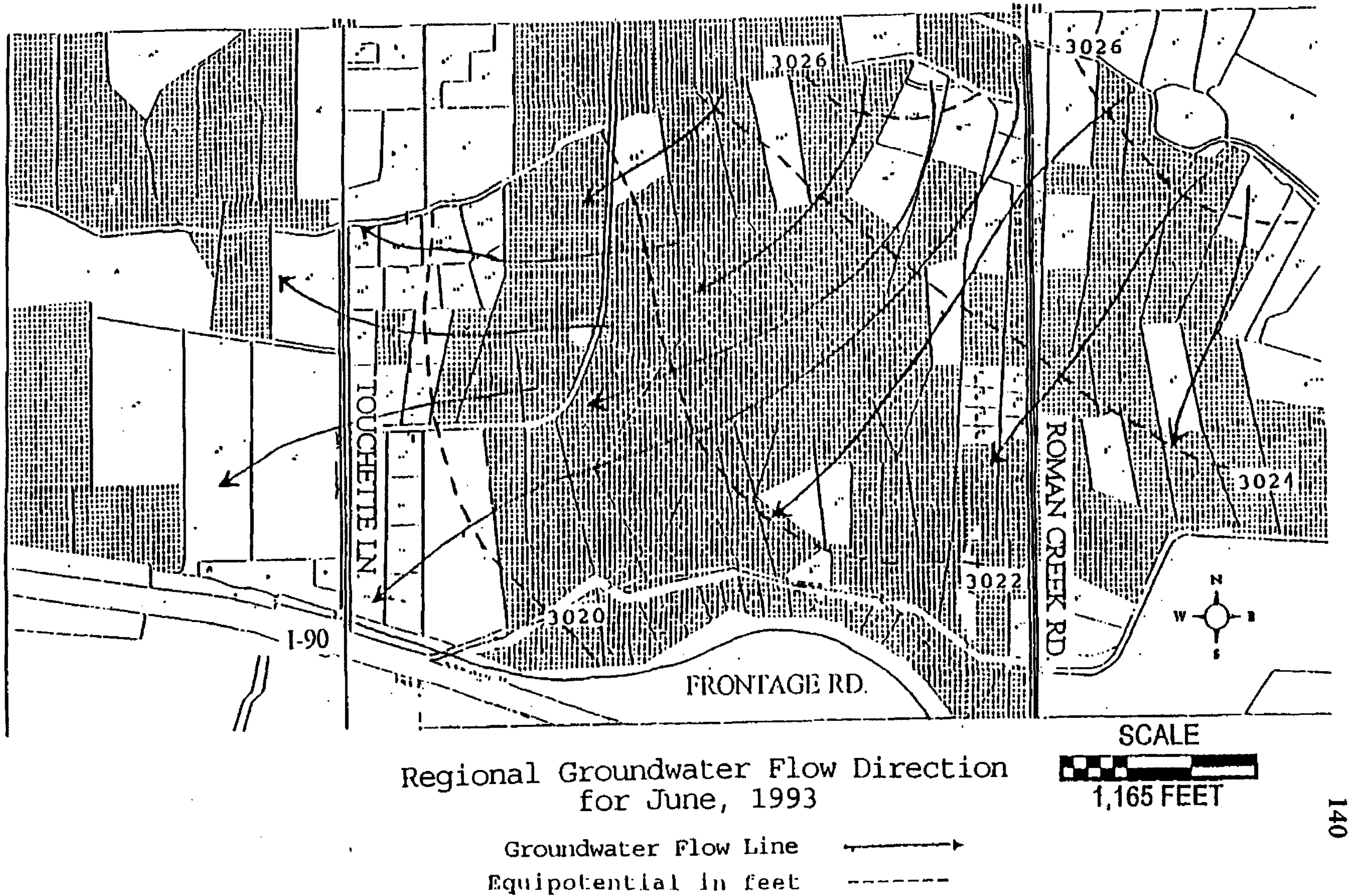


Figure A.4: **Regional groundwater flow direction for June 1994-Frenchtown**

Appendix B

Nitrate-N Half-Life Determination

To simulate the suspected non-conservative behavior of nitrate-N within the Missoula South and the Frenchtown sites, it was necessary to calculate a half-life based upon each site's calibrated hydraulic properties. The following discussion will explain how a half-life was chosen for each site.

Data presented by Woessner et al. (1996) and Ver Hey (1987) indicate total nitrogen concentrations within the Missoula Valley, which were derived from a single septic system, were reduced by approximately 50% within the vadose zone. For example, the South site had on average 40 mg/l total nitrogen in the septic tank; therefore 20 mg/l would reach the groundwater in a nitrate-N form. This is supported by data given in Woessner et al. (1996) where monitoring wells and lysimeters directly beneath the South site's drainfield were shown to contain only nitrate-N; no detectable ammonia was measured.

A first-order kinetic rate law for decay was used to determine the half-life (Domenico and Schwartz, 1990):

$$t = (t_{1/2}/\ln 2)\ \ln(A_O/A_{Obs}) \quad \text{or} \quad t_{1/2} = \ln 2[t/\ln\ (A_O/A_{Obs})]$$

where:
$t =$ residence time of mass in system,
$t_{1/2} =$ half-life,
$A_O =$ the activity assuming no decay (in this case the starting concentration),
$A_{Obs} =$ the observed or measured activity of the sample (in this case the observed concentration).

For the South site, the values used were:

$A_O =$ 20 mg/l,

A_{Obs} = 0.7 mg/l (the average mixing zone concentration above background within 1M13 for June 1994),

t = 18 days (the approximate time it would take groundwater to flow from the drainfield to 1M13, assuming a groundwater velocity of 9 ft/day and not considering dispersivity).

The calculated half-life for the South site was:

$t_{1/2}$ = 4 days.

The same equation was applied to the Frenchtown data. The chosen variables were:

A_O = 17 mg/l (50% of the average total tank nitrogen concentration),

A_{Obs} = 0.4 mg/l (the average mixing zone concentration above background within 2M7 for June 1994),

t = 26 days (the approximate time it would take groundwater to flow from the drainfield to 2M7, assuming a groundwater velocity of 7 ft./day, and not considering dispersivity).

The calculated half-life for the Frenchtown site was:

$t_{1/2}$ = 5 days.

Appendix C
Nitrate-N Non-Conservative/Conservative Plume Construction Methodology

Since the behavior of nitrate-N was assumed to operate both in a non-conservative and conservative manner, the calibration of a simulated nitrate-N plume required a combination of both types of behaviors. The initial 100 feet downgradient from the source was considered to function in a non-conservative manner, while distances greater than 100 feet were believed to act conservatively. The following section will discuss how this multi-behavior nitrate-N plume was constructed.

A 750 day RANDWALK model was run for both sites which used a half-life of four days for the Missoula sites and five days for the Frenchtown sites. Since it was assumed the non-conservative behavior continued roughly 100 feet downgradient from the effluent source, only the first 100 feet were considered for the composite plume. The simulated non-conservative plumes were generated using the appropriate input data for each site. The RANDWALK output data file was altered so it consisted of 100 feet of x, y, and z data. The data file was originally saved in a five feet by five feet grid, so a concentration value existed every five feet in the y and x direction. Concentrations which were calculated by the model to exist 100 feet downgradient from the source were considered to be the starting concentration of the conservative portion of the plume.

The simulated non-conservative nitrate-N plume from the South site consisted of a two lobed shaped plume 100 feet downgradient from the source. Nitrate-N concentrations were averaged over the width of each lobe, within one row of five feet by five feet blocks. The concentration of nitrate-N required to mix within the volume of water represented within the row of blocks (the blocks used to calculate the average nitrate-N concentration) was determined. Since each lobe was similar in shape and concentration configuration, it was assumed an identical concentration of nitrate-N was required to mix within each row of blocks. The width of each lobe was considered to be the length of a line source. The mixing nitrate-N concentration was considered to be evenly discharged from this line source.

A conservative nitrate-N RANDWALK model for the South site was simulated using the mixing nitrate-N concentration as a source concentration. The size and location of the row of nodes used to calculate the average mixing nitrate-N concentration were used as input locations for the conservative model. A conservative simulation was executed, and the resultant output file was compared to the non-conservative output file. It was necessary for the concentrations present 100 feet downgradient, within the non-conservative model, and the concentrations found at the source, for the conservative representation, to be similar. The conservative output file was altered until the concentrations were similar. Once this occurred, the data sets (0-100 feet of the non-conservative data set and 100+ feet for the conservative data set) were combined and re-contoured within SURFER.

Since the conservative nitrate-N simulation was run using an effluent input location 100 feet downgradient from the actual drainline location (the different input location was used to represent the switch from non-conservative to conservative behavior), it was necessary to alter the RANDWALK code. This was because RANDWALK assumes the dispersivity value begins at the solute input location. A new source of nitrate-N was not input at the non-conservative/conservative behavior interface but rather a change in nitrate-N behavior. This means the aquifer's dispersive properties, which were affecting nitrate-N within the non-conservative zone, were continuing in the conservative area within the shallow aquifer. For this study, dispersivity was simulated by an asymptotic value which reached its limit 200 feet downgradient from the source. The code needed to be altered so the dispersivity value used at the beginning of the non-conservative simulation was preserved through the conservative simulation. This was done by altering line 3810 of the RANDWALK code from: IF D$ = "A" OR D$ = "a" THEN DL = AD * (1 - BA / (DIST(K) + BA)) to IF D$ = "A" OR D$ = "a" THEN DL = AD * (1 - BA / (DIST(K) + BA + 100)).

A similar procedure was conducted for Frenchtown, except the input area for the conservative model was considered to be a single line source. This was because the non-conservative nitrate-N plume did not have the two lobed shape of the South site plume.

The same procedure was conducted for the simulation of the cumulative effects of septic system disposal on groundwater nitrate-N concentrations within the East and West sites, except the non-conservative and conservative output files created by a 10 and 80-foot source were used.

Appendix D

Cumulative Impact of Septic Disposal-Explanation

The cumulative effects of the operation of multiple septic systems on the shallow groundwater was evaluated by superimposing plumes generated for each source into a cumulative plume. Each source within the Missoula and Frenchtown cumulative-effects sites assumed the 750 day calibrated individual plume from the South site (for Missoula) and the individual Frenchtown site (for the cumulative Quarter Mile Road, Frenchtown site) was emitted from each drainfield. Cumulative-effects sites were assumed to have, on average, three people within each home. It was necessary to alter the South site plume to reflect emission from three people, rather than six, which was the number of people living at the residence during the sampling events. This consisted of using half the concentrations depicted by the calibrated South site plume for both chloride and nitrate-N, since three people were assumed to release half the volume of effluent as a home of six. The calibrated Frenchtown plumes were not altered since they were calibrated assuming emission from a home of three. Simulated plumes for both an 80-foot linear source and a 10-foot linear source, which are both perpendicular to groundwater flow, were used in the representation of the cumulative impacts of septic disposal. A 10-foot linear source was chosen because it is an approximate average value of the working portion of a septic drainfield recognized Woessner et al. (1996) and by Ver Hey (1987). An 80-foot source was chosen to represent the simulated impact of a fully operational septic system.

RANDWALK created ASCII output files for the calibrated individual chloride and nitrate-N plumes. The output files could be saved in two different formats: SURFER and TAPDOT (Prickett, 1994). Each of these are means to contour the concentration data file created within RANDWALK. This study chose to use the SURFER data output format.

The size of each SURFER output file was limited by RANDWALK to consist of a 31x31 sized grid. This means if one chooses to view the resultant model particle distribution every five feet in both the x and y direction, then a saved RANDWALK SURFER output file would be limited to data from 0-155 feet (31 x 5 = 155) in both the y and x direction, assuming the origin was 0,0. If the particle distribution was viewed every ten feet within RANDWALK, then an output file would only consist of data from 0-310 feet (31 x 10 = 310) in the x and y direction, again assuming the origin was 0,0. In order to create an output file which represented the entire plume, which for chloride was up to approximately 7000 feet in length, a number of output files were needed. For the East and West sites, the individual plume was saved according to a 30-foot by 30-foot viewed particle distribution, so each output file contained data which represented 930 feet in both the x and y direction. The multiple output files were combined in EXCEL (Microsoft Corp., 1992) and saved in an ASCII format. This new file was now ready to be opened within SURFER and contoured.

The total individual plume output file needed simulated release from each septic system within the cumulative-effects sites. This required knowledge of the location of each septic system. The approximate location of each septic system was estimated by asking homeowners, obtaining septic permits from the Missoula County Health Department, and by estimation. Once the approximate septic system location was known, the single plume file was altered, dimensionally, to depict emission from each septic system. This was done by creating a BASIC program which moved the simulated individual plume to the appropriate septic system location within the cumulative-effects study areas (Appendix H). The program moved the simulated plume to depict emission from the particular selected septic system location . A final ASCII file was created by the program to characterize the chloride and nitrate-N concentration configuration which resulted from the number of simulated septic systems. The new ASCII file was exported into SURFER for contouring. The files were contoured by kriging.

Appendix E

Cumulative Septic Impact Program

A BASIC program was created to perform the apparent release of the calibrated individual chloride and nitrate-N plumes from each septic system within the cumulative Missoula and Frenchtown sites. The program code is shown in Table E.1.

The program begins by prompting for the x and y dimensions of the model, which represent the total area over which the cumulative plume will be viewed. Limitations of BASIC require the area to not exceed 32 kilobytes in size. Each dimension unit demands one byte of memory. For this reason, it was necessary to convert the RANDWALK output files and the septic system input locations into terms of a relatively large unit of length. Converting the x and y dimensions to be in terms of 30-foot units (i.e. 60 feet equals two 30-foot units) was chosen because this was the unit of length, in which the RANDWALK output file was saved, and this also allowed for a large enough area in which to depict the entire length and width of the cumulative plumes. The program next asks for the name of the file assigned to the x,y, and z (z equalled concentration) data of the individual calibrated chloride or nitrate-N plume. This file was converted into 30 feet units within the SURFER spreadsheet. The file also needed to be altered to eliminate any negative numbers. This BASIC program did not tolerate negative numbers. A positive offset was added to entries in the x and y columns to convert negative values into positive ones within the SURFER spreadsheet. The value(s) added to the x and/or y data were subtracted from the cumulative data set after the completion of the plume transformation. This was done within the program on line 330. The data sets used for the East, West, and Frenchtown cumulative-effects sites needed an offset value of +2.0 for all x values, while an offset value of 10 was added to all y values to eliminate negatives. These values were subtracted by line 330. Memory limitations of BASIC required all z values, which were reported in milligrams per liter, to be converted into whole numbers. This was done in line 100 where all z values were multiplied by 1000 to eliminate decimals. The z values were converted back into decimal values in line 330 after the completion of the plume transformation. Lines 190 and 200 prompted for the displacement in both the x and y directions. The values represent the location of the input source or septic system within the cumulative sites. This study placed an arbitrary grid over the cumulative sites, and recorded the location of each septic system in terms of distance away from the user defined origin. The distances were input in terms of 30-foot units. After the completion of the model, a cumulative ASCII file was saved and brought into SURFER for contouring. Additional model functions are given by remark statements within the code.

Table E.1 Cumulative Impact BASIC Program

```
1  REM Model called CUMUL2
2  REM Model to predict cumulative impacts of septic system disposal on groundwater
3  REM quality
5  REM X and Y dimensions of cumulative area, area must not exceed 32K where
6  REM each dimension unit is one byte, but the X and Y dimensions must be greater
7  REM than the largest X and Y value within the individual plume data set.
10 INPUT "X DIMENSION"; XX%
20 INPUT "Y DIMENSION"; YY%
30 DIM ZM%(XX%, YY%)
40 DIM ZC%(XX%, YY%)
50 N = 1
55 REM Read the filename of X, Y, and Z individual plume data file, must not contain
```

```
56 REM negative numbers, present version of program requires the data file to be altered
57 REM within a spreadsheet
60 INPUT "FILENAME WITH X,Y,Z DATA"; FILE$
70 OPEN FILE$ FOR INPUT AS #1
80 WHILE NOT EOF(1)
90 INPUT #1, X%, Y%, Z
95 PRINT X%, Y%, Z
96 REM Z values multiplied by 1000 to eliminate all decimals, memory limitations
97 REM required whole numbers rather than decimals
100 ZM%(X%, Y%) = INT(Z * 1000)
110 WEND
120 CLOSE #1
130 FOR X% = 1 TO XX%
140 FOR Y% = 1 TO YY%
150 ZC%(X%, Y%) = 0
160 NEXT Y%
170 NEXT X%
180 PRINT "PLUME #"; N
181 REM Input coordinates of septic plume source, coordinates based on distance from a
182 REM site specific arbitrary origin
190 INPUT "ENTER DISPLACEMENT IN X DIRECTION FROM MASTER
PLUME";XD%
200 INPUT "ENTER DISPLACEMENT IN Y DIRECTION FROM MASTER
PLUME";YD%
210 FOR X% = 1 TO XX%
220 FOR Y% = 1 TO YY%
221 REM Equation calculates the new X and Y coordinates of input individual
222 REM septic plume and calculates the new cumulative concentration as a result
223 REM of the input of this specific plume
```

```
230 IF (X% + XD% >= 1) AND (X% + XD% <= XX%) AND (Y% + YD% >= 1)
AND (Y% + YD% <= YY%) THEN ZC%(X% + XD%, Y% + YD%) = ZC%(X%
+ XD%, Y% + YD%) + ZM%(X%, Y%)
240 NEXT Y%
250 NEXT X%
260 N = N + 1
270 INPUT "ANOTHER RUN"; A$
275 B$ = LEFT$(A$, 1)
280 IF B$ = "Y" OR B$ = "y" THEN GOTO 180
285 INPUT "ARE YOU REALLY DONE"; A$
286 IF LEFT$(A$, 1) = "n" OR LEFT$(A$, 1) = "N" THEN GOTO 180
290 INPUT "OUTPUT FILENAME"; OUTP$
300 OPEN OUTP$ FOR OUTPUT AS #1
310 FOR X% = 1 TO XX%
320 FOR Y% = 1 TO YY%
321 REM Output file is saved correcting for the X and Y offsets made within
322 REM spreadsheet needed for the elimination of the negative numbers, also
323 REM converted Z values back into decimals
330 WRITE #1, X% - 2, Y% - 10, ZC%(X%, Y%) / 1000
340 NEXT Y%
350 NEXT X%
360 CLOSE #1
370 END
```

Appendix F

Well Inventory

Well Inventory for Missoula Cumulative Sites

Well	Address	Name	Top of Casing Elevation (feet)	Depth (feet)	Screened Interval (feet)	Drill Method	Site
1M102	Tower		3147.75	36	31-36	Auger	East
1M1022	Tower		3147.75	27.3	27.13-27.3	Auger	East
1M1022	Tower		3147.75	32.2	32.03-32.2	Auger	East
1M1023	Tower		3147.75	36	35.8-36	Auger	East
1M103	Tower		3148.16	40	35-40	Auger	East
1M1031	Tower		3148.16	29	28.8-29	Auger	East
1M1032	Tower		3148.16	34	33.8-34	Auger	East
1M1033	Tower		3148.16	40	39.8-40	Auger	East
1M104	37th		3141.95	31.9	26.9-31.9	Auger	East
1M1041	37th		3141.95	23.8	23.6-23.8	Auger	East
1M1042	37th		3141.95	26.8	26.6-26.8	Auger	East
1M1043	37th		3141.95	31.9	31.7-31.9	Auger	East
1M105	37th		3141.3	33.5	28.5-33.5	Auger	East
1M1051	37th		3141.3	24	23.8-24	Auger	East
1M1052	37th		3141.3	29	28.8-29	Auger	East
1M1053	37th		3141.3	33.5	33.3-35	Auger	East
1D40	2214 37th Ave.	Clevenger	UK	UK	UK	UK	East
1D41	2008 37th Ave.	Dahlgren	UK	UK	UK	UK	East
1D42	3625 North	Neidt	3145.59	80	UK	UK	East
1D43	2007 36th Ave.	Smith	3144.65	77	UK	UK	East
1D44	3616 W. Central	Braach	3144.8	82	UK	UK	East
1D45	2117 35th Ave.	Norick	3141.33	70	UK	UK	East
1D46	3515 W. Central	Gilfillian	3148.21	77	UK	UK	East
1D47	3529 W. Central	Popham	3145.4	56	UK	UK	East
1D48	2336 36th Ave.	Ash	3144.64	61	UK	UK	East
1D49	3405 North	Mitchell	3143.54	UK	UK	UK	East
1D50	2130 35th Ave.	Hartford	3147.2	60	UK	UK	East
1D51	3415 W. Central	Hereford	3143.63	76	UK	UK	East
1D52	2120 Tower	Collins	3152	68	UK	UK	East
1D53	2300 Tower	Elliott	3149.91	75	UK	UK	East
1M100	Humble		3125.15	38	33-38	Auger	West
1M1001	Humble		3125.15	28	27.8-28	Auger	West
1M1002	Humble		3125.15	33	32.8-33	Auger	West
1M1003	Humble		3125.15	38	37.8-38	Auger	West
1M101	Humble		3128.55	38	33-38	Auger	West
1M1011	Humble		3128.55	28	27.8-28	Auger	West
1M1012	Humble		3128.55	33	32.8-33	Auger	West
1M1013	Humble		3128.55	38	37.8-38	Auger	West
1D15	4504 Edward Ave.	Boltzman	3126.19	108	UK	UK	West
1D16	4510 Edward Ave.	Wheeler	3125.31	65	UK	UK	West
1D17	4516 Edward Ave.	Lillebo	3124.77	60	UK	UK	West
1D18	4528 Edward Ave.	Stevenson	3128.42	60	UK	UK	West
1D19	4544 Edward Ave.	Zimmerman	3128.56	62	UK	UK	West
1D20	4547 Edward Ave.	Palmer	3127.1	60	UK	UK	West
1D21	4640 Edward Ave.	Delany	3114.87	UK	UK	UK	West
1D23	1721 Humble	Johnston	3126.11	105	UK	UK	West
1D24	1821 Humble	Kahler	UK	60	UK	UK	West
1D25	1925 Humble	Brambo	3128.88	62	UK	UK	West
1D26	4518 North	Spangler	3128.01	UK	UK	UK	West
1D27	4528 North	Sayles	3127.92	60	UK	UK	West
1D28	4604 North	Batt	3126.52	60	UK	UK	West

Well Inventory for Missoula Cumulative Sites

Well	Address	Name	Top of Casing Elevation (feet)	Depth (feet)	Screened Interval (feet)	Drill Method	Site
1D29	4612 North	Smith	3129.82	60	UK	UK	West
1D30	4610 Edward Ave.	Burnside	3123.91	56	UK	UK	West
1P100	4516 Edward Ave.	Lillebo	3111.05	10	open ended	Hand	West
1P101	4528 Edward Ave.	Stevenson	3111.92	12.5	open ended	Hand	West
1P102	4610 Edward Ave.	Burnside	3108.48	8	open ended	Hand	West

UK= Unknown
D= Domestic Well
M= Monitoring Well
P= Piezometer
Auger= Hollow Stem Auger
Hand= Hand Augered and Driven

Appendix G

Groundwater Level Measurements

Missoula Valley Groundwater Level Measurements--East Site

Well #	Top of Casing	June 30, '94	Aug. 23, '94	Sept. 7, '94	Oct. 4, '94
1D42	3145.59	3121.79		3120.09	3119.02
1D43	3144.65	3122.16		3120.35	3119.32
1D44	3144.80	3121.54		3119.77	3118.76
1D45	3141.33	3123.08			3120.26
1D46	3148.21	3122.34		3120.42	3119.50
1D47	3145.40	3121.80		3119.98	3119.02
1D48	3144.64	3121.31			3118.74
1D49	3143.54	3124.55			
1D50	3147.20			3121.25	
1D52	3152.00	3124.12	3121.87	3121.99	3120.96
1D53	3149.91		3121.37	3121.40	3120.55
1M102	3147.75		3121.30	3121.34	3120.49
1M103	3148.16		3122.41	3122.44	3121.44
1M104	3141.95		3118.71	3118.71	3117.93
1M105	3141.30		3119.30	3119.36	3118.33

Measurements in feet above sea level

Missoula Valley Groundwater Level Measurements--West Site

Well #	Top of Casing	May 5, '94	June 30, '94	Aug. 22, '94
1D15	3126.19	3105.46	3106.18	3105.19
1D16	3125.31	3104.81	3105.63	3104.56
1D17	3124.77	3104.22	3105.27	3104.21
1D18	3128.42	3104.32	3105.61	3104.30
1D19	3128.56	3104.28	3104.61	3104.01
1D20	3127.10	3104.28	3105.12	3104.10
1D21	3114.87	3100.49	3100.47	3099.32
1D23	3126.11	3105.17	3106.01	3104.96
1D25	3128.88	3105.61		3105.74
1D27	3127.92	3104.47	3105.52	3103.93
1D28	3126.52	3103.01	3103.93	*3094.95
1D29	3129.82	3106.71	3107.44	3106.32
1D30	3123.91		3103.77	3102.71
1M100	3125.15			3105.85
1M101	3128.55			3105.86
1P100	3111.05		3105.10	3103.88
1P101	3111.92		3105.12	3103.90
1P102	3108.48		3103.00	

* Pump on during measurement
Measurements in feet above sea level

Appendix H

Selected Groundwater Chemistry

Total Water Quality Data
for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	pH	Temp (C)	Cond. (mV)	D. O. (mg/l)	Alk. (mg/l)	Cl (mg/l)
Detection Limit								0.5
1D15	08/22/94	10/04/94	7.8	12.2	-44	5.3	170	4.7
1D15LD	08/22/94	10/04/94	NA	NA	NA	NA	NA	NA
1D16	08/22/94	10/04/94	7.7	17.3	-40	6.0	190	6.5
1D17	08/22/94	10/04/94	7.7	14.9	-37	7.0	181	5.4
1D18	08/22/94	10/04/94	7.5	12.5	-31	7.1	182	4.7
1D19	08/22/94	10/04/94	7.5	15.3	-28	6.3	185	6.2
1D19LD	08/22/94	10/04/94	NA	NA	NA	6.3	185	4.9
1D20	08/22/94	10/04/94	7.8	15.4	-43	5.6	182	5.1
1D21	08/22/94	10/04/94	7.8	15.5	-45	4.7	172	4.3
1D21FD	08/22/94	10/04/94	7.8	15.5	-45	4.7	176	4.2
1D21FDLD	08/22/94	10/04/94	NA	NA	NA	NA	NA	NA
1D23	08/22/94	10/04/94	7.7	14.0	-42	5.6	185	4.8
1D24	08/22/94	10/04/94	7.8	12.8	-46	4.8	176	5.0
1D25	08/22/94	10/04/94	7.8	14.1	-45	4.7	180	4.1
1D26	08/22/94	10/04/94	7.7	16.9	-37	5.4	186	6.1
1D27	08/22/94	10/04/94	7.7	14.6	-40	5.1	189	5.6
1D28	08/22/94	10/04/94	7.7	12.5	-39	4.4	181	4.2
1D29	08/22/94	10/04/94	7.8	15.1	-42	5.2	184	5.1
1D30	08/22/94	10/04/94	7.6	13.5	-36	5.6	188	5.7
1M1001	08/22/94	10/04/94	7.6	12.5	-38	8.0	187	4.7
1M1002	08/22/94	10/04/94	7.7	12.2	-40	7.1	186	4.8
1M1003	08/22/94	10/04/94	7.7	12.5	-42	5.1	175	4.5
1M1003FD	08/22/94	10/04/94	7.7	12.5	-42	5.1	180	3.8
1M1003LD	08/22/94	10/04/94	NA	NA	NA	NA	NA	NA
1M1011	08/22/94	10/04/94	7.5	15.6	-29	5.8	198	5.8
1M1012	08/22/94	10/04/94	7.6	15.4	-35	7.2	190	5.6
1M1013	08/22/94	10/04/94	7.8	14.7	-47	5.0	197	5.5
1P100	08/22/94	10/04/94	NA	NA	NA	NA	NA	7.4
1P101	08/22/94	10/04/94	7.6	13.5	-32	7.5	189	5.1
1P102	08/22/94	10/04/94	NA	NA	NA	NA	NA	7.6
1DD2	08/22/94	10/04/94	NA	NA	NA	NA	NA	2.2
1DD2LD	08/22/94	10/04/94	NA	NA	NA	NA	NA	2.1
1DFB	08/22/94	10/04/94	NA	NA	NA	NA	10	<0.1
1D15	09/27/94	10/04/94	7.3	12.8	-39	4.6	192	5.1
1D17	09/27/94	10/04/94	7.2	16.7	-33	6.0	194	4.5
1D18	09/27/94	10/04/94	7.4	13	-42	6.2	179	4.9
1D18FD	09/27/94	10/04/94	7.4	13	-42	6.2	196	4.8
1D19	09/27/94	10/04/94	NA	NA	NA	NA	210	4.7
1D20	09/27/94	10/04/94	7.3	15.7	-41	6.3	197	4.6
1D21	09/27/94	10/04/94	7.5	12.8	-47	5.8	187	4.1
1D23	09/27/94	10/04/94	7.4	13.2	-42	6.2	193	5.0
1D24	09/27/94	10/04/94	7.4	13.4	-42	6.3	185	4.4
1D25	09/27/94	10/04/94	7.4	11.7	-43	6.0	187	4.4
1D27	09/27/94	10/04/94	7.3	16.5	-40	7.1	196	5.4
1D29	09/27/94	10/04/94	7.4	13.1	-43	6.2	202	5.0
1D30	09/27/94	10/04/94	7.2	16.7	-29	7.3	192	5.3
1M1001	09/27/94	10/04/94	7.2	13.3	-34	9.0	198	3.4
1M1002	09/27/94	10/04/94	7.3	12.8	-40	9.3	194	3.6
1M1003	09/27/94	10/04/94	7.2	12.9	-35	9.0	180	4.1
1M1003LD	09/27/94	10/04/94	NA	NA	NA	9.0	180	3.8

Total Water Quality Data for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	pH	Temp (C)	Cond. (mV)	D. O. (mg/l)	Alk. (mg/l)	Cl (mg/l)
1M1011	09/27/94	10/04/94	7.2	14.5	-30	8.4	188	5.0
1M1012	09/27/94	10/04/94	7.2	14.4	-33	8.8	200	4.6
1M1012LD	09/27/94	10/04/94	NA	NA	NA	NA	NA	NA
1M1013	09/27/94	10/04/94	7.3	14.6	-38	8.1	207	4.4
1P100	09/27/94	10/04/94	NA	NA	NA	NA	NA	6.4
1P101	09/27/94	10/04/94	7	15.5	-26	9.8	192	4.6
1P102	09/27/94	10/04/94	NA	NA	NA	NA	NA	6.0
1P102LD	09/27/94	10/04/94	NA	NA	NA	NA	NA	6.1
1DD2	09/27/94	10/04/94	NA	NA	NA	NA	166	2.1
1DFB	09/27/94	10/04/94	NA	NA	NA	NA	0	<0.1

Total Water Quality Data
for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	NO3-N (mg/l)	PO4-P (mg/l)	SO4 (mg/l)	NH3-N (mg/l)	Al (mg/l)
Detection Limit			0.1	0.5	0.6	0.01	0.07
1D15	08/22/94	10/04/94	1.0	<0.5	20.7	<0.01	<0.07
1D15LD	08/22/94	10/04/94	NA	NA	NA	<0.01	<0.07
1D16	08/22/94	10/04/94	1.1	<0.5	21.0	<0.01	<0.07
1D17	08/22/94	10/04/94	0.9	<0.5	20.7	<0.01	<0.07
1D18	08/22/94	10/04/94	1.0	<0.5	20.2	<0.01	<0.07
1D19	08/22/94	10/04/94	1.1	<0.5	20.7	<0.01	<0.07
1D19LD	08/22/94	10/04/94	1.1	<0.5	21.0	<0.01	NA
1D20	08/22/94	10/04/94	1.0	0.6	20.1	<0.01	<0.07
1D21	08/22/94	10/04/94	0.9	<0.5	19.7	<0.01	<0.07
1D21FD	08/22/94	10/04/94	0.9	<0.5	19.6	<0.01	<0.07
1D21FDLD	08/22/94	10/04/94	NA	NA	NA	<0.01	<0.07
1D23	08/22/94	10/04/94	1.0	<0.5	20.3	<0.01	<0.07
1D24	08/22/94	10/04/94	0.9	<0.5	20.1	<0.01	<0.07
1D25	08/22/94	10/04/94	1.0	<0.5	19.8	<0.01	<0.07
1D26	08/22/94	10/04/94	1.5	<0.5	20.5	<0.01	<0.07
1D27	08/22/94	10/04/94	1.3	<0.5	20.4	<0.01	<0.07
1D28	08/22/94	10/04/94	1.0	<0.5	19.8	<0.01	<0.07
1D29	08/22/94	10/04/94	1.1	<0.5	20.0	<0.01	<0.07
1D30	08/22/94	10/04/94	1.2	<0.5	20.5	<0.01	<0.07
1M1001	08/22/94	10/04/94	0.7	<0.5	20.7	<0.01	<0.07
1M1002	08/22/94	10/04/94	0.8	<0.5	20.5	<0.01	<0.07
1M1003	08/22/94	10/04/94	0.7	<0.5	20.7	<0.01	<0.07
1M1003FD	08/22/94	10/04/94	0.7	<0.5	20.7	<0.01	<0.07
1M1003LD	08/22/94	10/04/94	NA	NA	NA	<0.01	<0.07
1M1011	08/22/94	10/04/94	1.5	<0.5	22.6	<0.01	0.56
1M1012	08/22/94	10/04/94	1.7	<0.5	23.6	<0.01	0.33
1M1013	08/22/94	10/04/94	1.0	<0.5	21.2	<0.01	<0.07
1P100	08/22/94	10/04/94	0.7	<0.5	20.0	<0.01	<0.07
1P101	08/22/94	10/04/94	1.7	<0.5	22.7	<0.01	<0.07
1P102	08/22/94	10/04/94	1.0	<0.5	20.4	<0.01	<0.07
1DD2	08/22/94	10/04/94	<0.1	<0.5	27.5	<0.01	<0.07
1DD2LD	08/22/94	10/04/94	<0.1	<0.5	27.6	<0.01	NA
1DFB	08/22/94	10/04/94	<0.1	<0.5	<0.6	<0.01	<0.07
1D15	09/27/94	10/04/94	1.0	<0.5	20.4	<0.01	<0.07
1D17	09/27/94	10/04/94	0.7	<0.5	22.3	<0.01	<0.07
1D18	09/27/94	10/04/94	0.9	<0.5	20.5	<0.01	<0.07
1D18FD	09/27/94	10/04/94	0.9	<0.5	20.5	<0.01	<0.07
1D19	09/27/94	10/04/94	1.0	<0.5	21.8	<0.01	<0.07
1D20	09/27/94	10/04/94	1.0	<0.5	20.8	<0.01	<0.07
1D21	09/27/94	10/04/94	0.9	<0.5	19.5	<0.01	<0.07
1D23	09/27/94	10/04/94	1.0	<0.5	20.1	<0.01	<0.07
1D24	09/27/94	10/04/94	0.8	<0.5	20.5	<0.01	<0.07
1D25	09/27/94	10/04/94	1.0	<0.5	19.7	<0.01	<0.07
1D27	09/27/94	10/04/94	1.3	<0.5	20.3	<0.01	<0.07
1D29	09/27/94	10/04/94	1.2	<0.5	19.8	<0.01	<0.07
1D30	09/27/94	10/04/94	1.2	<0.5	21.0	<0.01	<0.07
1M1001	09/27/94	10/04/94	0.5	<0.5	23.3	<0.01	<0.07
1M1002	09/27/94	10/04/94	0.6	<0.5	22.2	<0.01	<0.07
1M1003	09/27/94	10/04/94	0.6	<0.5	23.1	<0.01	<0.07
1M1003LD	09/27/94	10/04/94	0.6	<0.5	23.0	<0.01	NA

Total Water Quality Data for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	NO3-N (mg/l)	PO4-P (mg/l)	SO4 (mg/l)	NH3-N (mg/l)	Al (mg/l)
1M1011	09/27/94	10/04/94	1.0	<0.5	23.3	<0.01	<0.07
1M1012	09/27/94	10/04/94	0.9	<0.5	24.9	<0.01	<0.07
1M1012LD	09/27/94	10/04/94	NA	NA	NA	<0.01	<0.07
1M1013	09/27/94	10/04/94	1.0	<0.5	23.4	<0.01	<0.07
1P100	09/27/94	10/04/94	0.7	<0.5	24.1	<0.01	<0.07
1P101	09/27/94	10/04/94	1.0	<0.5	23.9	<0.01	<0.07
1P102	09/27/94	10/04/94	1.1	<0.5	20.9	<0.01	<0.07
1P102LD	09/27/94	10/04/94	1.1	<0.5	21.0	<0.01	NA
1DD2	09/27/94	10/04/94	<0.1	<0.5	35.3	<0.01	<0.07
1DFB	09/27/94	10/04/94	<0.1	<0.5	<0.6	<0.01	<0.07

Total Water Quality Data for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	As (mg/l)	B (mg/l)	Ca (mg/l)	Cd (mg/l)	Co (mg/l)
Detection Limit			0.07	0.04	0.1	0.01	0.03
1D15	08/22/94	10/04/94	<0.07	<0.04	53.6	<0.01	<0.03
1D15LD	08/22/94	10/04/94	<0.07	<0.04	50.2	<0.01	<0.03
1D16	08/22/94	10/04/94	<0.07	<0.04	52.2	<0.01	<0.03
1D17	08/22/94	10/04/94	<0.07	<0.04	53.2	<0.01	<0.03
1D18	08/22/94	10/04/94	<0.07	<0.04	53.2	<0.01	<0.03
1D19	08/22/94	10/04/94	<0.07	<0.04	53.7	<0.01	<0.03
1D19LD	08/22/94	10/04/94	NA	NA	NA	NA	NA
1D20	08/22/94	10/04/94	<0.07	<0.04	52.5	<0.01	<0.03
1D21	08/22/94	10/04/94	<0.07	<0.04	50.6	<0.01	<0.03
1D21FD	08/22/94	10/04/94	<0.07	<0.04	50.2	<0.01	<0.03
1D21FDLD	08/22/94	10/04/94	<0.07	<0.04	50.6	<0.01	<0.03
1D23	08/22/94	10/04/94	<0.07	<0.04	52.1	<0.01	<0.03
1D24	08/22/94	10/04/94	<0.07	<0.04	52.2	<0.01	<0.03
1D25	08/22/94	10/04/94	<0.07	<0.04	51.8	<0.01	<0.03
1D26	08/22/94	10/04/94	<0.07	<0.04	54.5	<0.01	<0.03
1D27	08/22/94	10/04/94	<0.07	<0.04	53.8	<0.01	<0.03
1D28	08/22/94	10/04/94	<0.07	<0.04	52.6	<0.01	<0.03
1D29	08/22/94	10/04/94	<0.07	<0.04	52.2	<0.01	<0.03
1D30	08/22/94	10/04/94	<0.07	<0.04	54.8	<0.01	<0.03
1M1001	08/22/94	10/04/94	<0.07	<0.04	52.9	<0.01	<0.03
1M1002	08/22/94	10/04/94	<0.07	<0.04	54.3	<0.01	<0.03
1M1003	08/22/94	10/04/94	<0.07	<0.04	51.9	<0.01	<0.03
1M1003FD	08/22/94	10/04/94	<0.07	<0.04	52.6	<0.01	<0.03
1M1003LD	08/22/94	10/04/94	<0.07	<0.04	50.3	<0.01	<0.03
1M1011	08/22/94	10/04/94	<0.07	<0.04	57.8	<0.01	<0.03
1M1012	08/22/94	10/04/94	<0.07	<0.04	55.8	<0.01	<0.03
1M1013	08/22/94	10/04/94	<0.07	<0.04	54.1	<0.01	<0.03
1P100	08/22/94	10/04/94	<0.07	<0.04	39.8	<0.01	<0.03
1P101	08/22/94	10/04/94	<0.07	<0.04	55.6	<0.01	<0.03
1P102	08/22/94	10/04/94	<0.07	0.08	37.1	<0.01	<0.03
1DD2	08/22/94	10/04/94	<0.07	<0.04	39.5	<0.01	<0.03
1DD2LD	08/22/94	10/04/94	NA	NA	NA	NA	NA
1DFB	08/22/94	10/04/94	<0.07	<0.04	<0.1	<0.01	<0.03
1D15	09/27/94	10/04/94	<0.07	<0.04	51.5	<0.01	<0.03
1D17	09/27/94	10/04/94	<0.07	<0.04	52.6	<0.01	<0.03
1D18	09/27/94	10/04/94	<0.07	<0.04	50.9	<0.01	<0.03
1D18FD	09/27/94	10/04/94	<0.07	<0.04	51.8	<0.01	<0.03
1D19	09/27/94	10/04/94	<0.07	<0.04	53.7	<0.01	<0.03
1D20	09/27/94	10/04/94	<0.07	<0.04	52.0	<0.01	<0.03
1D21	09/27/94	10/04/94	<0.07	<0.04	50.1	<0.01	<0.03
1D23	09/27/94	10/04/94	<0.07	<0.04	51.7	<0.01	<0.03
1D24	09/27/94	10/04/94	<0.07	<0.04	51.8	<0.01	<0.03
1D25	09/27/94	10/04/94	<0.07	<0.04	52.1	<0.01	<0.03
1D27	09/27/94	10/04/94	<0.07	<0.04	56.1	<0.01	<0.03
1D29	09/27/94	10/04/94	<0.07	<0.04	51.2	<0.01	<0.03
1D30	09/27/94	10/04/94	<0.07	<0.04	53.9	<0.01	<0.03
1M1001	09/27/94	10/04/94	<0.07	<0.04	52.6	<0.01	<0.03
1M1002	09/27/94	10/04/94	<0.07	<0.04	56.4	<0.01	<0.03
1M1003	09/27/94	10/04/94	<0.07	<0.04	53.6	<0.01	<0.03
1M1003LD	09/27/94	10/04/94	NA	NA	NA	NA	NA

Total Water Quality Data for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	As (mg/l)	B (mg/l)	Ca (mg/l)	Cd (mg/l)	Co (mg/l)
1M1011	09/27/94	10/04/94	<0.07	<0.04	56.3	<0.01	<0.03
1M1012	09/27/94	10/04/94	<0.07	<0.04	56.0	<0.01	<0.03
1M1012LD	09/27/94	10/04/94	<0.07	<0.04	55.2	<0.01	<0.03
1M1013	09/27/94	10/04/94	<0.07	<0.04	57.2	<0.01	<0.03
1P100	09/27/94	10/04/94	<0.07	<0.04	47.7	<0.01	<0.03
1P101	09/27/94	10/04/94	<0.07	<0.04	53.8	<0.01	<0.03
1P102	09/27/94	10/04/94	<0.07	<0.04	49.6	<0.01	<0.03
1P102LD	09/27/94	10/04/94	NA	NA	NA	NA	NA
1DD2	09/27/94	10/04/94	<0.07	<0.04	44.9	<0.01	<0.03
1DFB	09/27/94	10/04/94	<0.07	<0.04	<0.1	<0.01	<0.03

Total Water Quality Data
for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	Cu (mg/l)	Fe (mg/l)	Mg (mg/l)	Mn (mg/l)	Mo (mg/l)
Detection Limit			0.01	0.03	0.1	0.005	0.01
1D15	08/22/94	10/04/94	<0.01	<0.03	15.0	<0.005	<0.01
1D15LD	08/22/94	10/04/94	<0.01	<0.03	14.1	<0.005	<0.01
1D16	08/22/94	10/04/94	0.02	<0.03	14.8	<0.005	<0.01
1D17	08/22/94	10/04/94	0.02	<0.03	14.6	<0.005	<0.01
1D18	08/22/94	10/04/94	<0.01	<0.03	15.0	<0.005	<0.01
1D19	08/22/94	10/04/94	0.04	<0.03	15.0	<0.005	<0.01
1D19LD	08/22/94	10/04/94	NA	NA	NA	NA	NA
1D20	08/22/94	10/04/94	0.01	<0.03	15.2	<0.005	<0.01
1D21	08/22/94	10/04/94	<0.01	<0.03	15.0	0.007	<0.01
1D21FD	08/22/94	10/04/94	<0.01	<0.03	15.2	0.007	<0.01
1D21FDLD	08/22/94	10/04/94	<0.01	<0.03	14.7	0.007	<0.01
1D23	08/22/94	10/04/94	0.01	<0.03	15.1	<0.005	<0.01
1D24	08/22/94	10/04/94	<0.01	<0.03	14.9	<0.005	<0.01
1D25	08/22/94	10/04/94	<0.01	<0.03	15.1	<0.005	<0.01
1D26	08/22/94	10/04/94	0.02	<0.03	15.5	<0.005	<0.01
1D27	08/22/94	10/04/94	0.01	<0.03	15.2	<0.005	<0.01
1D28	08/22/94	10/04/94	<0.01	<0.03	15.3	<0.005	<0.01
1D29	08/22/94	10/04/94	0.01	<0.03	15.1	<0.005	<0.01
1D30	08/22/94	10/04/94	0.02	<0.03	15.6	<0.005	<0.01
1M1001	08/22/94	10/04/94	<0.01	<0.03	14.4	0.022	<0.01
1M1002	08/22/94	10/04/94	<0.01	<0.03	14.7	0.015	<0.01
1M1003	08/22/94	10/04/94	<0.01	<0.03	14.3	<0.005	<0.01
1M1003FD	08/22/94	10/04/94	<0.01	<0.03	14.4	0.007	<0.01
1M1003LD	08/22/94	10/04/94	<0.01	<0.03	13.6	0.007	<0.01
1M1011	08/22/94	10/04/94	0.01	0.71	16.0	0.080	<0.01
1M1012	08/22/94	10/04/94	0.01	0.30	15.7	0.099	<0.01
1M1013	08/22/94	10/04/94	<0.01	<0.03	15.0	0.075	<0.01
1P100	08/22/94	10/04/94	<0.01	<0.03	13.5	0.507	<0.01
1P101	08/22/94	10/04/94	<0.01	<0.03	15.4	0.021	<0.01
1P102	08/22/94	10/04/94	0.01	<0.03	13.5	0.159	<0.01
1DD2	08/22/94	10/04/94	<0.01	<0.03	13.3	<0.005	<0.01
1DD2LD	08/22/94	10/04/94	NA	NA	NA	NA	NA
1DFB	08/22/94	10/04/94	<0.01	<0.03	<0.1	<0.005	<0.01
1D15	09/27/94	10/04/94	<0.01	<0.03	14.3	<0.005	<0.01
1D17	09/27/94	10/04/94	0.04	<0.03	14.3	<0.005	<0.01
1D18	09/27/94	10/04/94	<0.01	<0.03	14.2	<0.005	<0.01
1D18FD	09/27/94	10/04/94	<0.01	<0.03	14.3	<0.005	<0.01
1D19	09/27/94	10/04/94	0.09	<0.03	14.7	<0.005	<0.01
1D20	09/27/94	10/04/94	0.01	<0.03	14.6	<0.005	<0.01
1D21	09/27/94	10/04/94	0.01	<0.03	14.5	<0.005	<0.01
1D23	09/27/94	10/04/94	<0.01	<0.03	14.6	<0.005	<0.01
1D24	09/27/94	10/04/94	<0.01	<0.03	14.3	<0.005	<0.01
1D25	09/27/94	10/04/94	<0.01	<0.03	14.8	<0.005	<0.01
1D27	09/27/94	10/04/94	0.01	<0.03	15.5	<0.005	<0.01
1D29	09/27/94	10/04/94	0.01	<0.03	14.5	<0.005	<0.01
1D30	09/27/94	10/04/94	0.05	<0.03	15.1	<0.005	<0.01
1M1001	09/27/94	10/04/94	<0.01	<0.03	14.1	0.007	<0.01
1M1002	09/27/94	10/04/94	<0.01	<0.03	15.2	<0.005	<0.01
1M1003	09/27/94	10/04/94	<0.01	<0.03	14.5	<0.005	<0.01
1M1003LD	09/27/94	10/04/94	NA	NA	NA	NA	NA

Total Water Quality Data
for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	Cu (mg/l)	Fe (mg/l)	Mg (mg/l)	Mn (mg/l)	Mo (mg/l)
1M1011	09/27/94	10/04/94	<0.01	<0.03	15.0	0.016	<0.01
1M1012	09/27/94	10/04/94	<0.01	<0.03	14.8	0.032	<0.01
1M1012LD	09/27/94	10/04/94	<0.01	<0.03	14.7	0.032	<0.01
1M1013	09/27/94	10/04/94	<0.01	<0.03	15.4	0.025	<0.01
1P100	09/27/94	10/04/94	0.01	<0.03	14.1	0.354	<0.01
1P101	09/27/94	10/04/94	<0.01	<0.03	14.4	<0.005	<0.01
1P102	09/27/94	10/04/94	<0.01	<0.03	14.3	0.110	<0.01
1P102LD	09/27/94	10/04/94	NA	NA	NA	NA	NA
1DD2	09/27/94	10/04/94	<0.01	<0.03	13.7	<0.005	<0.01
1DFB	09/27/94	10/04/94	<0.01	<0.03	<0.1	<0.005	<0.01

Total Water Quality Data
for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	Na (mg/l)	Ni (mg/l)	P (mg/l)	Pb (mg/l)	Si (mg/l)
Detection Limit			0.1	0.02	0.2	0.1	0.1
1D15	08/22/94	10/04/94	8.4	<0.02	<0.2	<0.1	7.2
1D15LD	08/22/94	10/04/94	8.2	<0.02	<0.2	<0.1	6.9
1D16	08/22/94	10/04/94	9.6	<0.02	<0.2	<0.1	6.9
1D17	08/22/94	10/04/94	9.5	<0.02	<0.2	<0.1	7.0
1D18	08/22/94	10/04/94	8.6	<0.02	<0.2	<0.1	7.1
1D19	08/22/94	10/04/94	8.7	<0.02	<0.2	<0.1	7.1
1D19LD	08/22/94	10/04/94	NA	NA	NA	NA	NA
1D20	08/22/94	10/04/94	8.3	<0.02	<0.2	<0.1	7.0
1D21	08/22/94	10/04/94	7.6	<0.02	<0.2	<0.1	7.0
1D21FD	08/22/94	10/04/94	7.6	<0.02	<0.2	<0.1	7.0
1D21FDLD	08/22/94	10/04/94	7.6	<0.02	<0.2	<0.1	7.0
1D23	08/22/94	10/04/94	8.6	<0.02	<0.2	<0.1	7.1
1D24	08/22/94	10/04/94	8.4	<0.02	<0.2	<0.1	7.0
1D25	08/22/94	10/04/94	7.8	<0.02	<0.2	<0.1	7.1
1D26	08/22/94	10/04/94	9.3	<0.02	<0.2	<0.1	7.1
1D27	08/22/94	10/04/94	8.7	<0.02	<0.2	<0.1	7.1
1D28	08/22/94	10/04/94	8.0	<0.02	<0.2	<0.1	7.2
1D29	08/22/94	10/04/94	8.2	<0.02	<0.2	<0.1	7.0
1D30	08/22/94	10/04/94	9.1	<0.02	<0.2	<0.1	7.2
1M1001	08/22/94	10/04/94	9.0	<0.02	<0.2	<0.1	7.1
1M1002	08/22/94	10/04/94	9.1	<0.02	<0.2	<0.1	6.9
1M1003	08/22/94	10/04/94	8.8	<0.02	<0.2	<0.1	6.9
1M1003FD	08/22/94	10/04/94	8.7	<0.02	<0.2	<0.1	6.9
1M1003LD	08/22/94	10/04/94	8.6	<0.02	<0.2	<0.1	6.6
1M1011	08/22/94	10/04/94	9.0	<0.02	<0.2	<0.1	8.6
1M1012	08/22/94	10/04/94	8.9	<0.02	<0.2	<0.1	8.2
1M1013	08/22/94	10/04/94	8.7	<0.02	<0.2	<0.1	7.3
1P100	08/22/94	10/04/94	11.0	<0.02	<0.2	<0.1	3.9
1P101	08/22/94	10/04/94	9.0	<0.02	<0.2	<0.1	7.3
1P102	08/22/94	10/04/94	12.7	<0.02	<0.2	<0.1	4.2
1DD2	08/22/94	10/04/94	6.5	<0.02	<0.2	<0.1	4.9
1DD2LD	08/22/94	10/04/94	NA	NA	NA	NA	NA
1DFB	08/22/94	10/04/94	<0.1	<0.02	<0.2	<0.1	<0.1
1D15	09/27/94	10/04/94	8.4	<0.02	<0.2	<0.1	6.9
1D17	09/27/94	10/04/94	9.1	<0.02	<0.2	<0.1	6.9
1D18	09/27/94	10/04/94	8.3	<0.02	<0.2	<0.1	6.8
1D18FD	09/27/94	10/04/94	8.3	<0.02	<0.2	<0.1	6.8
1D19	09/27/94	10/04/94	8.6	<0.02	<0.2	<0.1	7.0
1D20	09/27/94	10/04/94	8.1	<0.02	<0.2	<0.1	6.9
1D21	09/27/94	10/04/94	7.5	<0.02	<0.2	<0.1	6.9
1D23	09/27/94	10/04/94	8.3	<0.02	<0.2	<0.1	7.0
1D24	09/27/94	10/04/94	8.2	<0.02	<0.2	<0.1	6.8
1D25	09/27/94	10/04/94	7.8	<0.02	<0.2	<0.1	7.0
1D27	09/27/94	10/04/94	9.0	<0.02	<0.2	<0.1	7.2
1D29	09/27/94	10/04/94	8.1	<0.02	<0.2	<0.1	6.8
1D30	09/27/94	10/04/94	8.8	<0.02	<0.2	<0.1	6.9
1M1001	09/27/94	10/04/94	8.5	<0.02	<0.2	<0.1	7.0
1M1002	09/27/94	10/04/94	9.0	<0.02	<0.2	<0.1	7.2
1M1003	09/27/94	10/04/94	8.6	<0.02	<0.2	<0.1	7.1
1M1003LD	09/27/94	10/04/94	NA	NA	NA	NA	NA

Total Water Quality Data for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	Na (mg/l)	Ni (mg/l)	P (mg/l)	Pb (mg/l)	Si (mg/l)
1M1011	09/27/94	10/04/94	8.5	<0.02	<0.2	<0.1	7.2
1M1012	09/27/94	10/04/94	8.3	<0.02	<0.2	<0.1	7.3
1M1012LD	09/27/94	10/04/94	8.4	<0.02	<0.2	<0.1	7.2
1M1013	09/27/94	10/04/94	8.5	<0.02	<0.2	<0.1	7.8
1P100	09/27/94	10/04/94	10.0	<0.02	<0.2	<0.1	6.3
1P101	09/27/94	10/04/94	8.8	<0.02	<0.2	<0.1	7.1
1P102	09/27/94	10/04/94	9.3	<0.02	0.4	<0.1	6.3
1P102LD	09/27/94	10/04/94	NA	NA	NA	NA	NA
1DD2	09/27/94	10/04/94	8.1	<0.02	<0.2	<0.1	5.6
1DFB	09/27/94	10/04/94	<0.1	<0.02	<0.2	<0.1	<0.1

Total Water Quality Data
for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	Sr (mg/l)	Ti (mg/l)	Zn (mg/l)	K (mg/l)
Detection Limit			0.05	0.05	0.005	1.5
1D15	08/22/94	10/04/94	0.15	<0.05	0.060	2.3
1D15LD	08/22/94	10/04/94	0.14	<0.05	0.057	1.5
1D16	08/22/94	10/04/94	0.15	<0.05	0.100	2.1
1D17	08/22/94	10/04/94	0.15	<0.05	0.038	2.2
1D18	08/22/94	10/04/94	0.15	<0.05	0.060	2.2
1D19	08/22/94	10/04/94	0.15	<0.05	0.060	2.0
1D19LD	08/22/94	10/04/94	NA	NA	NA	NA
1D20	08/22/94	10/04/94	0.15	<0.05	0.051	2.0
1D21	08/22/94	10/04/94	0.15	<0.05	0.036	1.6
1D21FD	08/22/94	10/04/94	0.15	<0.05	0.037	1.8
1D21FDLD	08/22/94	10/04/94	0.14	<0.05	0.037	1.7
1D23	08/22/94	10/04/94	0.15	<0.05	0.058	1.7
1D24	08/22/94	10/04/94	0.15	<0.05	0.024	2.2
1D25	08/22/94	10/04/94	0.15	<0.05	0.013	1.8
1D26	08/22/94	10/04/94	0.15	<0.05	0.038	2.0
1D27	08/22/94	10/04/94	0.15	<0.05	0.021	2.1
1D28	08/22/94	10/04/94	0.15	<0.05	0.016	2.1
1D29	08/22/94	10/04/94	0.15	<0.05	0.220	1.9
1D30	08/22/94	10/04/94	0.15	<0.05	0.028	2.1
1M1001	08/22/94	10/04/94	0.15	<0.05	0.020	3.1
1M1002	08/22/94	10/04/94	0.15	<0.05	0.019	2.7
1M1003	08/22/94	10/04/94	0.15	<0.05	0.021	2.2
1M1003FD	08/22/94	10/04/94	0.15	<0.05	0.015	2.3
1M1003LD	08/22/94	10/04/94	0.14	<0.05	0.015	1.8
1M1011	08/22/94	10/04/94	0.16	<0.05	0.045	3.7
1M1012	08/22/94	10/04/94	0.16	<0.05	0.027	3.0
1M1013	08/22/94	10/04/94	0.15	<0.05	0.006	4.1
1P100	08/22/94	10/04/94	0.13	<0.05	0.554	3.8
1P101	08/22/94	10/04/94	0.16	<0.05	0.169	2.3
1P102	08/22/94	10/04/94	0.12	<0.05	1.157	5.4
1DD2	08/22/94	10/04/94	0.15	<0.05	0.010	2.0
1DD2LD	08/22/94	10/04/94	NA	NA	NA	NA
1DFB	08/22/94	10/04/94	<0.05	<0.05	<0.005	<1.5
1D15	09/27/94	10/04/94	0.14	<0.05	0.109	1.6
1D17	09/27/94	10/04/94	0.15	<0.05	0.054	1.8
1D18	09/27/94	10/04/94	0.14	<0.05	0.057	1.6
1D18FD	09/27/94	10/04/94	0.14	<0.05	0.063	1.9
1D19	09/27/94	10/04/94	0.15	<0.05	0.148	1.7
1D20	09/27/94	10/04/94	0.15	<0.05	0.058	1.6
1D21	09/27/94	10/04/94	0.14	<0.05	0.008	1.5
1D23	09/27/94	10/04/94	0.15	<0.05	0.054	1.6
1D24	09/27/94	10/04/94	0.14	<0.05	0.025	1.9
1D25	09/27/94	10/04/94	0.15	<0.05	0.007	1.5
1D27	09/27/94	10/04/94	0.15	<0.05	0.040	2.1
1D29	09/27/94	10/04/94	0.14	<0.05	0.076	1.5
1D30	09/27/94	10/04/94	0.15	<0.05	0.109	1.6
1M1001	09/27/94	10/04/94	0.15	<0.05	0.006	2.1
1M1002	09/27/94	10/04/94	0.16	<0.05	<0.005	2.4
1M1003	09/27/94	10/04/94	0.15	<0.05	<0.005	2.1
1M1003LD	09/27/94	10/04/94	NA	NA	NA	NA

Total Water Quality Data for the West Site, Missoula, MT

Well	Sample Date	Analysis Date	Sr (mg/l)	Ti (mg/l)	Zn (mg/l)	K (mg/l)
1M1011	09/27/94	10/04/94	0.16	<0.05	0.005	2.0
1M1012	09/27/94	10/04/94	0.15	<0.05	<0.005	2.2
1M1012LD	09/27/94	10/04/94	0.15	<0.05	0.005	1.9
1M1013	09/27/94	10/04/94	0.16	<0.05	0.005	3.1
1P100	09/27/94	10/04/94	0.14	<0.05	5.037	3.7
1P101	09/27/94	10/04/94	0.15	<0.05	0.154	1.9
1P102	09/27/94	10/04/94	0.14	<0.05	2.752	3.0
1P102LD	09/27/94	10/04/94	NA	NA	NA	NA
1DD2	09/27/94	10/04/94	0.18	<0.05	0.010	2.2
1DFB	09/27/94	10/04/94	<0.05	<0.05	<0.005	<1.5

FD= Field Duplicate
LD= Lab Duplicate
FB= Field Blank
D= Domestic Well
M= Monitoring Well
P= Piezometer
NA= Not Analyzed
DD= Irrigation Ditch

Total Water Quality Data for the East Site, Missoula, MT

Well	Sample Date	Analysis Date	pH	Temp (C)	Cond. (mV)	D. O. (mg/l)	Alk. (mg/l)	Cl (mg/l)
Detection Limit								0.5
1D40	08/23/94	10/04/94	NA	NA	NA	NA	NA	5.3
1D41	08/23/94	10/04/94	7.6	13.0	-44	5.0	NA	5.0
1D42	08/23/94	10/04/94	7.6	13.8	-45	4.9	NA	4.7
1D43	08/23/94	10/04/94	7.5	14.7	-42	4.7	NA	4.4
1D44	08/23/94	10/04/94	7.6	12.4	-43	4.6	NA	4.3
1D45	08/23/94	10/04/94	7.4	12.1	-38	4.7	181	4.7
1D46	08/23/94	10/04/94	7.6	15.8	-45	5.4	NA	4.7
1D47	08/23/94	10/04/94	7.5	11.8	-42	6.0	NA	7.2
1D48	08/23/94	10/04/94	7.6	13.6	-45	5.5	NA	4.5
1D49	08/23/94	10/04/94	7.5	11.5	-40	4.8	158	4.2
1D49LD	08/23/94	10/04/94	7.5	11.5	-40	4.8	178	NA
1D50	08/23/94	10/04/94	7.6	12.1	-45	5.5	184	4.4
1D51	08/23/94	10/04/94	7.6	13.8	-46	5.8	130	3.5
1D52	08/23/94	10/04/94	7.5	14.9	-37	5.0	168	2.9
1D53	08/23/94	10/04/94	7.3	15.1	-32	3.7	180	4.1
1M1022	08/23/94	10/04/94	7.7	13.7	-53	7.0	202	7.5
1M1022LD	08/23/94	10/04/94	NA	NA	NA	7.0	202	7.6
1M1023	08/23/94	10/04/94	7.5	15	-43	5.6	202	7.0
1M1031	08/23/94	10/04/94	7.5	16.2	-45	6.5	176	22.5
1M103	08/23/94	10/04/94	7.7	15.6	-52	3.8	197	21.1
1M1042	08/23/94	10/04/94	7.8	19.4	-58	6.0	190	17.3
1M1043	08/23/94	10/04/94	7.8	16.3	-58	2.3	187	10.6
1M1051	08/23/94	10/04/94	7.6	16.4	-51	4.5	179	4.9
1M1052	08/23/94	10/04/94	7.9	16.7	-64	3.0	179	5.9
1M1053	08/23/94	10/04/94	7.7	15.8	-51	7.0	182	4.4
1DD1	08/23/94	10/04/94	NA	NA	-92	8.4	NA	2.3
1DFB	08/23/94	10/04/94	NA	NA	NA	NA	0	<0.1
1D40	09/26/94	10/04/94	NA	NA	NA	NA	176	5.3
1D41	09/26/94	10/04/94	7.5	13.3	-41	6.4	186	5.0
1D42	09/26/94	10/04/94	7.5	15	-42	6.0	186	5.0
1D44	09/26/94	10/04/94	7.5	12.6	-42	6.4	188	5.0
1D45	09/26/94	10/04/94	7.6	12.3	-44	7.0	177	5.2
1D46	09/26/94	10/04/94	7.6	17	-46	5.8	178	4.9
1D47	09/26/94	10/04/94	7.5	15.5	-42	6.5	194	6.6
1D48	09/26/94	10/04/94	7.5	16	-42	6.8	197	4.2
1D49	09/26/94	10/04/94	7.5	14.4	-42	7.0	181	4.9
1D50	09/26/94	10/04/94	7.6	12.4	-44	7.1	206	4.7
1D51	09/26/94	10/04/94	7.7	13.8	-48	6.9	168	3.7
1D52	09/26/94	10/04/94	7.6	13	-43	7.0	192	4.2
1D52FD	09/26/94	10/04/94	7.6	13	-43	7.0	180	3.9
1D53	09/26/94	10/04/94	7.4	16.6	-34	6.5	192	5.0
1D54	09/26/94	10/04/94	NA	NA	NA	NA	NA	5.9
1M1022	09/26/94	10/04/94	7.4	13.5	-32	7.0	206	6.7
1M1023	09/26/94	10/04/94	7.3	12.6	-31	7.5	200	7.1
1M1031	09/26/94	10/04/94	7.4	13.6	-38	7.6	198	24.7
1M1031LD	09/26/94	10/04/94	NA	NA	NA	7.6	198	27.2
1M103	09/26/94	10/04/94	7.5	13.8	-44	5.8	192	22.7
1M1041	09/26/94	10/04/94	8.1	18.7	-76	NA	NA	11.5
1M1042	09/26/94	10/04/94	7.7	14.6	-53	5.5	192	17.7
1M1043	09/26/94	10/04/94	7.9	13.6	-63	4.3	200	10.5
1M1051	09/26/94	10/04/94	7.5	13.7	-42	6.1	190	6.1

Total Water Quality Data
for the East Site, Missoula, MT

Well	Sample Date	Analysis Date	pH	Temp (C)	Cond. (mV)	D. O. (mg/l)	Alk. (mg/l)	Cl (mg/l)
Detection Limit								0.5
1M1052	09/26/94	10/04/94	7.7	13.1	-52	3.3	190	6.0
1M1053	09/26/94	10/04/94	7.6	13.4	-44	7.0	191	5.0
1DD1	09/26/94	10/04/94	NA	NA	NA	NA	174	2.5
1DFB	09/26/94	10/04/94	NA	NA	NA	NA	0	<0.1

Total Water Quality Data
for the East Site, Missoula, MT

Well	Sample Date	Analysis Date	NO3-N (mg/l)	NH3-N (mg/l)	PO4-P (mg/l)	SO4 (mg/l)	Al (mg/l)	As (mg/l)
Detection Limit			0.1	0.01	0.5	0.6	0.07	0.07
1D40	08/23/94	10/04/94	1.2	<0.01	<0.5	20.7	<0.07	<0.07
1D41	08/23/94	10/04/94	1.0	<0.01	<0.5	20.1	<0.07	<0.07
1D42	08/23/94	10/04/94	0.9	<0.01	<0.5	20.9	<0.07	<0.07
1D43	08/23/94	10/04/94	1.0	<0.01	<0.5	19.8	<0.07	<0.07
1D44	08/23/94	10/04/94	1.1	<0.01	<0.5	20.1	<0.07	<0.07
1D45	08/23/94	10/04/94	1.1	<0.01	<0.5	20.5	<0.07	<0.07
1D46	08/23/94	10/04/94	1.0	<0.01	<0.5	21.3	<0.07	<0.07
1D47	08/23/94	10/04/94	1.7	<0.01	<0.5	22.9	<0.07	<0.07
1D48	08/23/94	10/04/94	0.6	<0.01	<0.5	21.4	<0.07	<0.07
1D49	08/23/94	10/04/94	1.2	<0.01	<0.5	20.1	<0.07	<0.07
1D49LD	08/23/94	10/04/94	NA	<0.01	NA	NA	<0.07	<0.07
1D50	08/23/94	10/04/94	0.9	<0.01	<0.5	20.1	<0.07	<0.07
1D51	08/23/94	10/04/94	0.6	<0.01	<0.5	19.6	<0.07	<0.07
1D52	08/23/94	10/04/94	0.5	<0.01	<0.5	19.0	<0.07	<0.07
1D53	08/23/94	10/04/94	0.9	<0.01	<0.5	20.7	<0.07	<0.07
1M1022	08/23/94	10/04/94	1.3	<0.01	<0.5	21.7	<0.07	<0.07
1M1022LD	08/23/94	10/04/94	1.3	<0.01	<0.5	22.2	NA	NA
1M1023	08/23/94	10/04/94	1.4	<0.01	<0.5	21.3	<0.07	<0.07
1M1031	08/23/94	10/04/94	1.3	<0.01	<0.5	21.4	<0.07	<0.07
1M103	08/23/94	10/04/94	0.2	<0.01	<0.5	22.3	<0.07	<0.07
1M1042	08/23/94	10/04/94	1.2	<0.01	<0.5	23.8	0.07	<0.07
1M1043	08/23/94	10/04/94	<0.1	<0.01	<0.5	22.8	<0.07	<0.07
1M1051	08/23/94	10/04/94	0.9	<0.01	<0.5	20.6	<0.07	<0.07
1M1052	08/23/94	10/04/94	0.3	<0.01	<0.5	20.8	<0.07	<0.07
1M1053	08/23/94	10/04/94	1.0	<0.01	<0.5	20.3	<0.07	<0.07
1DD1	08/23/94	10/04/94	<0.1	<0.01	<0.5	28.0	<0.07	<0.07
1DFB	08/23/94	10/04/94	<0.1	<0.01	<0.5	<0.6	<0.07	<0.07
1D40	09/26/94	10/04/94	1.2	<0.01	<0.5	21.3	<0.07	<0.07
1D41	09/26/94	10/04/94	1.1	<0.01	<0.5	21.2	<0.07	<0.07
1D42	09/26/94	10/04/94	1.0	<0.01	<0.5	21.5	<0.07	<0.07
1D44	09/26/94	10/04/94	1.1	<0.01	<0.5	21.0	<0.07	<0.07
1D45	09/26/94	10/04/94	1.2	<0.01	<0.5	21.1	<0.07	<0.07
1D46	09/26/94	10/04/94	1.0	<0.01	<0.5	21.4	<0.07	<0.07
1D47	09/26/94	10/04/94	1.6	<0.01	<0.5	2.3	<0.07	<0.07
1D48	09/26/94	10/04/94	0.6	<0.01	<0.5	22.7	<0.07	<0.07
1D49	09/26/94	10/04/94	1.3	<0.01	<0.5	21.1	<0.07	<0.07
1D50	09/26/94	10/04/94	1.0	<0.01	<0.5	21.1	<0.07	<0.07
1D51	09/26/94	10/04/94	0.6	<0.01	<0.5	20.8	<0.07	<0.07
1D52	09/26/94	10/04/94	0.3	<0.01	<0.5	22.3	<0.07	<0.07
1D52FD	09/26/94	10/04/94	0.5	<0.01	<0.5	22.2	<0.07	<0.07
1D53	09/26/94	10/04/94	1.0	<0.01	<0.5	21.5	<0.07	<0.07
1D54	09/26/94	10/04/94	1.3	<0.01	<0.5	21.6	<0.07	<0.07
1M1022	09/26/94	10/04/94	1.5	<0.01	<0.5	22.0	<0.07	<0.07
1M1023	09/26/94	10/04/94	1.5	<0.01	<0.5	22.0	<0.07	<0.07
1M1031	09/26/94	10/04/94	1.3	<0.01	<0.5	23.8	<0.07	<0.07
1M1031LD	09/26/94	10/04/94	1.3	<0.01	<0.5	22.2	NA	NA
1M103	09/26/94	10/04/94	<0.1	<0.01	<0.5	22.1	<0.07	<0.07
1M1041	09/26/94	10/04/94	<0.1	<0.01	<0.5	8.6	<0.07	<0.07
1M1042	09/26/94	10/04/94	1.2	<0.01	<0.5	12.6	<0.07	<0.07
1M1043	09/26/94	10/04/94	0.8	<0.01	<0.5	23.5	<0.07	<0.07
1M1051	09/26/94	10/04/94	1.0	<0.01	<0.5	21.6	<0.07	<0.07

Total Water Quality Data
for the East Site, Missoula, MT

Well	Sample Date	Analysis Date	NO3-N (mg/l)	NH3-N (mg/l)	PO4-P (mg/l)	SO4 (mg/l)	Al (mg/l)	As (mg/l)
Detection Limit			0.1	0.01	0.5	0.6	0.07	0.07
1M1052	09/26/94	10/04/94	0.4	<0.01	<0.5	22.1	NA	NA
1M1053	09/26/94	10/04/94	1.1	<0.01	<0.5	21.5	<0.07	<0.07
1DD1	09/26/94	10/04/94	<0.1	<0.01	<0.5	35.6	<0.07	<0.07
1DFB	09/26/94	10/04/94	<0.1	<0.01	<0.5	<0.6	<0.07	<0.07

Total Water Quality Data for the East Site, Missoula, MT

Well	Sample Date	Analysis Date	B (mg/l)	Ca (mg/l)	Cd (mg/l)	Co (mg/l)	Cu (mg/l)	Fe (mg/l)
Detection Limit			0.04	0.1	0.01	0.03	0.01	0.03
1D40	08/23/94	10/04/94	<0.04	54.4	<0.01	<0.03	<0.01	<0.03
1D41	08/23/94	10/04/94	<0.04	51.6	<0.01	<0.03	0.01	<0.03
1D42	08/23/94	10/04/94	<0.04	51.2	<0.01	<0.03	0.02	<0.03
1D43	08/23/94	10/04/94	<0.04	51.9	<0.01	<0.03	0.01	<0.03
1D44	08/23/94	10/04/94	<0.04	51.9	<0.01	<0.03	<0.01	<0.03
1D45	08/23/94	10/04/94	<0.04	51.7	<0.01	<0.03	<0.01	<0.03
1D46	08/23/94	10/04/94	<0.04	54.2	<0.01	<0.03	<0.01	<0.03
1D47	08/23/94	10/04/94	<0.04	57.1	<0.01	<0.03	0.01	<0.03
1D48	08/23/94	10/04/94	<0.04	51.7	<0.01	<0.03	<0.01	<0.03
1D49	08/23/94	10/04/94	<0.04	51.7	<0.01	<0.03	<0.01	<0.03
1D49LD	08/23/94	10/04/94	<0.04	51.2	<0.01	<0.03	<0.01	<0.03
1D50	08/23/94	10/04/94	<0.04	50.0	<0.01	<0.03	<0.01	<0.03
1D51	08/23/94	10/04/94	<0.04	48.0	<0.01	<0.03	0.01	<0.03
1D52	08/23/94	10/04/94	<0.04	47.1	<0.01	<0.03	0.01	<0.03
1D53	08/23/94	10/04/94	<0.04	53.4	<0.01	<0.03	0.04	<0.03
1M1022	08/23/94	10/04/94	<0.04	60.4	<0.01	<0.03	<0.01	<0.03
1M1022LD	08/23/94	10/04/94	NA	NA	NA	NA	NA	NA
1M1023	08/23/94	10/04/94	<0.04	61.3	<0.01	<0.03	<0.01	<0.03
1M1031	08/23/94	10/04/94	<0.04	54.5	<0.01	<0.03	<0.01	0.03
1M103	08/23/94	10/04/94	<0.04	55.3	<0.01	<0.03	<0.01	<0.03
1M1042	08/23/94	10/04/94	<0.04	51.2	<0.01	<0.03	<0.01	0.05
1M1043	08/23/94	10/04/94	<0.04	51.9	<0.01	<0.03	<0.01	<0.03
1M1051	08/23/94	10/04/94	<0.04	51.1	<0.01	<0.03	<0.01	<0.03
1M1052	08/23/94	10/04/94	<0.04	49.2	<0.01	<0.03	<0.01	0.03
1M1053	08/23/94	10/04/94	<0.04	51.6	<0.01	<0.03	<0.01	<0.03
1DD1	08/23/94	10/04/94	<0.04	39.1	<0.01	<0.03	<0.01	<0.03
1DFB	08/23/94	10/04/94	<0.04	<0.1	<0.01	<0.03	<0.01	<0.03
1D40	09/26/94	10/04/94	<0.04	49.6	<0.01	<0.03	0.01	<0.03
1D41	09/26/94	10/04/94	<0.04	48.1	<0.01	<0.03	0.01	<0.03
1D42	09/26/94	10/04/94	<0.04	49.7	<0.01	<0.03	0.03	<0.03
1D44	09/26/94	10/04/94	<0.04	50.9	<0.01	<0.03	0.01	<0.03
1D45	09/26/94	10/04/94	<0.04	48.5	<0.01	<0.03	<0.01	<0.03
1D46	09/26/94	10/04/94	<0.04	49.1	<0.01	<0.03	0.01	<0.03
1D47	09/26/94	10/04/94	<0.04	53.3	<0.01	<0.03	0.06	<0.03
1D48	09/26/94	10/04/94	<0.04	48.9	<0.01	<0.03	<0.01	<0.03
1D49	09/26/94	10/04/94	<0.04	49.5	<0.01	<0.03	0.01	<0.03
1D50	09/26/94	10/04/94	<0.04	47.9	<0.01	<0.03	<0.01	<0.03
1D51	09/26/94	10/04/94	<0.04	47.0	<0.01	<0.03	0.02	<0.03
1D52	09/26/94	10/04/94	<0.04	48.8	<0.01	<0.03	0.01	<0.03
1D52FD	09/26/94	10/04/94	<0.04	47.6	<0.01	<0.03	0.01	<0.03
1D53	09/26/94	10/04/94	<0.04	52.9	<0.01	<0.03	0.07	<0.03
1D54	09/26/94	10/04/94	<0.04	49.9	<0.01	<0.03	0.01	<0.03
1M1022	09/26/94	10/04/94	<0.04	57.1	<0.01	<0.03	<0.01	<0.03
1M1023	09/26/94	10/04/94	<0.04	58.5	<0.01	<0.03	<0.01	<0.03
1M1031	09/26/94	10/04/94	<0.04	51.9	<0.01	<0.03	<0.01	<0.03
1M1031LD	09/26/94	10/04/94	NA	NA	NA	NA	NA	NA
1M103	09/26/94	10/04/94	<0.04	50.0	<0.01	<0.03	<0.01	0.04
1M1041	09/26/94	10/04/94	<0.04	59.7	<0.01	<0.03	<0.01	0.03
1M1042	09/26/94	10/04/94	0.04	43.2	<0.01	<0.03	<0.01	<0.03
1M1043	09/26/94	10/04/94	<0.04	53.7	<0.01	<0.03	<0.01	<0.03
1M1051	09/26/94	10/04/94	<0.04	49.9	<0.01	<0.03	<0.01	<0.03

Total Water Quality Data
for the East Site, Missoula, MT

Well	Sample Date	Analysis Date	B (mg/l)	Ca (mg/l)	Cd (mg/l)	Co (mg/l)	Cu (mg/l)	Fe (mg/l)
Detection Limit			0.04	0.1	0.01	0.03	0.01	0.03
1M1052	09/26/94	10/04/94	NA	NA	NA	NA	NA	NA
1M1053	09/26/94	10/04/94	<0.04	48.8	<0.01	<0.03	<0.01	<0.03
1DD1	09/26/94	10/04/94	<0.04	43.5	<0.01	<0.03	<0.01	<0.03
1DFB	09/26/94	10/04/94	<0.04	<0.1	<0.01	<0.03	<0.01	<0.03

Total Water Quality Data for the East Site, Missoula, MT

Well	Sample Date	Analysis Date	Mg (mg/l)	Mn (mg/l)	Mo (mg/l)	Na (mg/l)	Ni (mg/l)	P (mg/l)
Detection Limit			0.1	0.005	0.01	0.1	0.02	0.2
1D40	08/23/94	10/04/94	15.1	<0.005	<0.01	8.4	<0.02	<0.2
1D41	08/23/94	10/04/94	14.3	<0.005	<0.01	7.9	<0.02	<0.2
1D42	08/23/94	10/04/94	14.4	<0.005	<0.01	7.7	<0.02	<0.2
1D43	08/23/94	10/04/94	14.4	<0.005	<0.01	7.8	<0.02	<0.2
1D44	08/23/94	10/04/94	14.4	<0.005	<0.01	7.7	<0.02	<0.2
1D45	08/23/94	10/04/94	14.2	<0.005	<0.01	7.5	<0.02	<0.2
1D46	08/23/94	10/04/94	14.4	<0.005	<0.01	7.5	<0.02	<0.2
1D47	08/23/94	10/04/94	15.5	<0.005	<0.01	9.8	<0.02	<0.2
1D48	08/23/94	10/04/94	13.7	<0.005	<0.01	8.6	<0.02	<0.2
1D49	08/23/94	10/04/94	14.3	<0.005	<0.01	7.6	<0.02	<0.2
1D49LD	08/23/94	10/04/94	14.0	<0.005	<0.01	7.5	<0.02	<0.2
1D50	08/23/94	10/04/94	13.5	<0.005	<0.01	7.5	<0.02	<0.2
1D51	08/23/94	10/04/94	12.8	<0.005	<0.01	6.8	<0.02	<0.2
1D52	08/23/94	10/04/94	12.3	<0.005	<0.01	6.7	<0.02	<0.2
1D53	08/23/94	10/04/94	14.3	<0.005	<0.01	7.4	<0.02	<0.2
1M1022	08/23/94	10/04/94	15.8	0.114	<0.01	9.5	<0.02	<0.2
1M1022LD	08/23/94	10/04/94	NA	NA	NA	NA	NA	NA
1M1023	08/23/94	10/04/94	16.3	0.025	<0.01	9.0	<0.02	<0.2
1M1031	08/23/94	10/04/94	14.3	0.057	<0.01	22.2	<0.02	0.2
1M103	08/23/94	10/04/94	16.1	0.732	0.01	19.6	<0.02	<0.2
1M1042	08/23/94	10/04/94	15.0	0.672	<0.01	22.8	<0.02	0.2
1M1043	08/23/94	10/04/94	15.1	0.261	0.01	14.9	<0.02	<0.2
1M1051	08/23/94	10/04/94	14.3	0.106	<0.01	8.9	<0.02	<0.2
1M1052	08/23/94	10/04/94	14.4	0.316	<0.01	9.8	<0.02	<0.2
1M1053	08/23/94	10/04/94	14.6	0.027	<0.01	8.1	<0.02	<0.2
1DD1	08/23/94	10/04/94	12.9	<0.005	<0.01	6.5	<0.02	<0.2
1DFB	08/23/94	10/04/94	<0.1	<0.005	<0.01	<0.1	<0.02	<0.2
1D40	09/26/94	10/04/94	14.2	<0.005	<0.01	7.9	<0.02	<0.2
1D41	09/26/94	10/04/94	13.9	<0.005	<0.01	7.6	<0.02	<0.2
1D42	09/26/94	10/04/94	14.4	<0.005	<0.01	7.8	<0.02	<0.2
1D44	09/26/94	10/04/94	14.3	<0.005	<0.01	7.8	<0.02	<0.2
1D45	09/26/94	10/04/94	13.9	<0.005	<0.01	7.5	<0.02	<0.2
1D46	09/26/94	10/04/94	14.0	<0.005	<0.01	7.3	<0.02	<0.2
1D47	09/26/94	10/04/94	15.2	<0.005	<0.01	9.6	<0.02	<0.2
1D48	09/26/94	10/04/94	13.7	<0.005	<0.01	8.1	<0.02	<0.2
1D49	09/26/94	10/04/94	14.0	<0.005	<0.01	7.5	<0.02	<0.2
1D50	09/26/94	10/04/94	13.4	<0.005	<0.01	7.4	<0.02	<0.2
1D51	09/26/94	10/04/94	13.0	<0.005	<0.01	6.8	<0.02	<0.2
1D52	09/26/94	10/04/94	13.2	<0.005	<0.01	7.0	<0.02	<0.2
1D52FD	09/26/94	10/04/94	13.1	<0.005	<0.01	6.9	<0.02	<0.2
1D53	09/26/94	10/04/94	14.7	<0.005	<0.01	7.5	<0.02	<0.2
1D54	09/26/94	10/04/94	14.4	<0.005	<0.01	8.9	<0.02	<0.2
1M1022	09/26/94	10/04/94	15.6	0.048	<0.01	8.8	<0.02	<0.2
1M1023	09/26/94	10/04/94	15.8	0.009	<0.01	8.8	<0.02	<0.2
1M1031	09/26/94	10/04/94	14.4	0.010	<0.01	22.7	<0.02	<0.2
1M1031LD	09/26/94	10/04/94	NA	NA	NA	NA	NA	NA
1M103	09/26/94	10/04/94	15.2	1.261	<0.01	18.9	<0.02	<0.2
1M1041	09/26/94	10/04/94	20.3	1.259	0.02	15.5	<0.02	<0.2
1M1042	09/26/94	10/04/94	12.9	0.727	0.01	22.2	<0.02	0.2
1M1043	09/26/94	10/04/94	16.3	0.542	0.01	12.2	<0.02	<0.2
1M1051	09/26/94	10/04/94	14.6	0.078	<0.01	9.0	<0.02	<0.2

Total Water Quality Data
for the East Site, Missoula, MT

Well	Sample Date	Analysis Date	Mg (mg/l)	Mn (mg/l)	Mo (mg/l)	Na (mg/l)	Ni (mg/l)	P (mg/l)
Detection Limit			0.1	0.005	0.01	0.1	0.02	0.2
1M1052	09/26/94	10/04/94	NA	NA	NA	NA	NA	NA
1M1053	09/26/94	10/04/94	14.3	0.029	<0.01	7.9	<0.02	<0.2
1DD1	09/26/94	10/04/94	14.0	<0.005	<0.01	7.8	<0.02	<0.2
1DFB	09/26/94	10/04/94	<0.1	<0.005	<0.01	0.1	<0.02	<0.2

Total Water Quality Data
for the East Site, Missoula, MT

Well	Sample Date	Analysis Date	Pb (mg/l)	Si (mg/l)	Sr (mg/l)	Ti (mg/l)	Zn (mg/l)	K (mg/l)
Detection Limit			0.1	0.1	0.05	0.05	0.005	1.5
1D40	08/23/94	10/04/94	<0.1	7.2	0.15	<0.05	0.036	2.2
1D41	08/23/94	10/04/94	<0.1	7.0	0.14	<0.05	0.008	2.1
1D42	08/23/94	10/04/94	<0.1	6.9	0.14	<0.05	0.107	1.8
1D43	08/23/94	10/04/94	<0.1	7.0	0.14	<0.05	0.074	1.9
1D44	08/23/94	10/04/94	<0.1	6.9	0.14	<0.05	0.025	1.9
1D45	08/23/94	10/04/94	<0.1	6.9	0.14	<0.05	0.030	2.1
1D46	08/23/94	10/04/94	<0.1	7.1	0.15	<0.05	0.095	2.2
1D47	08/23/94	10/04/94	<0.1	7.2	0.15	<0.05	0.008	2.1
1D48	08/23/94	10/04/94	<0.1	7.3	0.14	<0.05	0.052	2.3
1D49	08/23/94	10/04/94	<0.1	7.0	0.14	<0.05	0.037	2.1
1D49LD	08/23/94	10/04/94	<0.1	6.9	0.14	<0.05	0.037	2.0
1D50	08/23/94	10/04/94	<0.1	6.9	0.14	<0.05	0.022	2.0
1D51	08/23/94	10/04/94	<0.1	6.8	0.13	<0.05	0.036	1.8
1D52	08/23/94	10/04/94	<0.1	6.7	0.13	<0.05	0.042	1.7
1D53	08/23/94	10/04/94	<0.1	7.0	0.14	<0.05	0.074	1.9
1M1022	08/23/94	10/04/94	<0.1	7.2	0.16	<0.05	0.042	3.3
1M1022LD	08/23/94	10/04/94	NA	NA	NA	NA	NA	NA
1M1023	08/23/94	10/04/94	<0.1	7.6	0.16	<0.05	0.170	3.7
1M1031	08/23/94	10/04/94	<0.1	7.0	0.15	<0.05	0.066	2.9
1M103	08/23/94	10/04/94	<0.1	5.5	0.16	<0.05	0.062	5.5
1M1042	08/23/94	10/04/94	<0.1	6.3	0.14	<0.05	0.026	4.8
1M1043	08/23/94	10/04/94	<0.1	6.0	0.14	<0.05	0.020	4.6
1M1051	08/23/94	10/04/94	<0.1	6.6	0.14	<0.05	0.015	2.4
1M1052	08/23/94	10/04/94	<0.1	5.6	0.13	<0.05	0.018	3.8
1M1053	08/23/94	10/04/94	<0.1	7.0	0.14	<0.05	0.022	2.4
1DD1	08/23/94	10/04/94	<0.1	5.1	0.15	<0.05	0.007	1.8
1DFB	08/23/94	10/04/94	<0.1	<0.1	<0.05	<0.05	<0.005	<1.5
1D40	09/26/94	10/04/94	<0.1	6.9	0.14	<0.05	0.182	2.3
1D41	09/26/94	10/04/94	<0.1	6.7	0.13	<0.05	0.008	2.3
1D42	09/26/94	10/04/94	<0.1	7.0	0.14	<0.05	0.155	2.2
1D44	09/26/94	10/04/94	<0.1	7.0	0.14	<0.05	0.027	2.4
1D45	09/26/94	10/04/94	<0.1	6.8	0.14	<0.05	0.058	2.2
1D46	09/26/94	10/04/94	<0.1	6.8	0.14	<0.05	0.144	2.2
1D47	09/26/94	10/04/94	<0.1	7.1	0.15	<0.05	0.068	2.4
1D48	09/26/94	10/04/94	<0.1	7.2	0.14	<0.05	0.051	2.5
1D49	09/26/94	10/04/94	<0.1	6.9	0.14	<0.05	0.166	2.6
1D50	09/26/94	10/04/94	<0.1	6.8	0.13	<0.05	0.080	2.0
1D51	09/26/94	10/04/94	<0.1	6.8	0.13	<0.05	0.039	2.2
1D52	09/26/94	10/04/94	<0.1	6.9	0.13	<0.05	0.046	2.2
1D52FD	09/26/94	10/04/94	<0.1	6.8	0.13	<0.05	0.048	2.2
1D53	09/26/94	10/04/94	<0.1	7.1	0.15	<0.05	0.042	2.4
1D54	09/26/94	10/04/94	<0.1	6.9	0.14	<0.05	0.026	2.2
1M1022	09/26/94	10/04/94	<0.1	7.3	0.15	<0.05	0.007	3.0
1M1023	09/26/94	10/04/94	<0.1	7.3	0.16	<0.05	0.009	2.8
1M1031	09/26/94	10/04/94	<0.1	7.0	0.15	<0.05	0.027	3.3
1M1031LD	09/26/94	10/04/94	NA	NA	NA	NA	NA	NA
1M103	09/26/94	10/04/94	<0.1	4.9	0.15	<0.05	0.014	5.1
1M1041	09/26/94	10/04/94	<0.1	6.4	0.19	<0.05	0.014	8.0
1M1042	09/26/94	10/04/94	<0.1	6.1	0.12	<0.05	<0.005	4.4
1M1043	09/26/94	10/04/94	<0.1	5.7	0.15	<0.05	0.016	4.9
1M1051	09/26/94	10/04/94	<0.1	6.7	0.14	<0.05	0.016	3.3

Total Water Quality Data
for the East Site, Missoula, MT

Well	Sample Date	Analysis Date	Pb (mg/l)	Si (mg/l)	Sr (mg/l)	Ti (mg/l)	Zn (mg/l)	K (mg/l)
Detection Limit			0.1	0.1	0.05	0.05	0.005	1.5
1M1052	09/26/94	10/04/94	NA	NA	NA	NA	NA	NA
1M1053	09/26/94	10/04/94	<0.1	6.9	0.14	<0.05	0.007	2.5
1DD1	09/26/94	10/04/94	<0.1	5.8	0.18	<0.05	0.013	3.3
1DFB	09/26/94	10/04/94	<0.1	<0.1	<0.05	<0.05	<0.005	<1.5

FD= Field Duplicate
LD= Lab Duplicate
FB= Field Blank
D= Domestic Well
M= Monitoring Well
P= Piezometer
NA= Not Analyzed
DD= Irrigation Ditch